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Proceedings of
Scientific Conference on Climate Change in the Caspian Sea Region

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The cover page features a satellite image of the Caspian Sea. A modified photo of the desiccated Gomishan Lagoon, a Ramsar Site, can be seen on the south-east corner; in the lower panel the eroded rims of the mudcracks and articulated bivalves are visible (Photo by Hamid Alizadeh Ketek Lahijani, October 2021).

Proceedings of

Scientific conference on climate change in the Caspian Sea region

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I would like to take the opportunity to extend a hearted welcome to all the attendees of the Scientific Conference on Climate change in the Caspian Sea Region held by the CASPCOM and the Tehran Convention interim Secretariat (TCIS). Also, allow me to thank the organizers of this important Conference for having brought us together in this platform to discuss one of the main current challenges worldwide which is without doubt climate change. Climate change is a major crisis of our time, and its impact is happening even faster than expected. Climate change has taken unprecedent prominence today due to the sharp increase of global temperature in recent decade. Certainly, no corner of the globe is untouched by the destructive consequences of this phenomena, and here the Caspian Sea is no exception. Climate change has caused a major threat to the ecosystem and biodiversity of the Caspian Sea. The Caspian Sea literally stayed affected by severe climate change effects, including sea level variation, intensified floods, severe droughts, reduction of biodiversity and aggravation of the desertification.

This have led to unavoidable socio-economic consequences in these States. Therefore, there is an inevitable need for holding scientific and technical discussion on different facets of this existing topic to come up with recommendation that will led to the better protection of the Caspian Sea. In this connection, this Conference intent to cover wider spectrum of topics including climate change in the Caspian Sea, modeling and long-term prediction of sea level changes, climate change impacts on its ecosystem and biodiversity and also adaptation to climate change in the Caspian Sea Region. I sincerely hope that this Conference along with the 25th session of the Coordination Committee of Hydrometeorology of the Caspian Sea, which was held on the 25th of October, will be an effectively positive asset in tackling the high-priority problem of the Caspian Sea arising from climate change. Moreover, I hope that this Conference will serve as a strong platform to enhance the cooperation in technical and scientific fields. Thank you very much for your active participation in this session and again I welcome you to this Conference and look forward to your participation. Thank you.

Sahar Tajbakhsh
Conference Chair

Dear participants of the Scientific Conference!

I am pleased and honored to address this Conference with an opening remark, on behalf of the Secretariat of the Framework Convention for the Protection of the Marine Environment of the Caspian Sea (which is called in short – the Tehran Convention).

Pleased, because we have been discussing the idea of holding a scientific conference for the Caspian Sea region for quite some time, and today we see the realization of our ideas and ambition. Honored, because together with our co-organizing partner CASPCOM we are helping to bring together the region's knowledge on the modern environmental challenges which affect lives in our current generation and, what is more important, will affect lives of the generations of our children and grandchildren.

Today, the Caspian region is known mainly for its hydrocarbon resources and the important transport routes connecting the East and West. At the same time, the Caspian Sea is home to a unique cultural diversity of peoples inhabiting its shores; collection of endemic flora and fauna which enriches our global wildlife heritage; and geoclimatic variety which demands its due place in the global repository of scientific data and research.

We are convening in uneasy times, when COVID-19 continues to claim lives and challenge our social and economic wellbeing. Just like the virus finds the weakest spot in our body and attacks it the most, the pandemic has revealed the weakest spots in our economy, social set-up and outlook on the future. The economic crisis triggered by the pandemic, results from many earlier decades of putting economic growth and exploitation of natural resources above the sustainability of those resources and the health of our ecosystems. As a result, the impacts of this planetary-scale pandemic are severely conditioned by three planetary-scale crises: climate change; loss of biodiversity; and pollution and waste.

All three of these planetary crises are relevant for the Caspian Sea region, however the focus of this Conference is climate change. And this is not by chance. In just a few days, the 26th session of the Conference of the Parties (COP 26) to the UNFCCC will start its work in Glasgow, UK. It is our hope that this Conference will, among others, be perceived as an input of the Caspian Sea region to the global debate on the effects of climate change and ways forward.

We will hear many presentations and discussions during these two days about the devastating effects of climate change and the ways of its mitigation and adaptation in the Caspian Sea region. So, it is not my place nor intention to dwell on the technical side of the matter.

I would like to speak however about the opportunities I see in this Conference.

The knowledge that mankind has accumulated throughout its history allows us to believe in our collective capacity to come out of a crisis building a better life, stronger economy, more equal society, and a more resilient environment to overcome the challenges we are yet to confront.

The Caspian Sea region is a vivid example of the wealth and care nature gives us to cope with our daily needs and build a better future for our children. The century-long industrial exploitation in the Caspian Sea is of course responsible to a large extent for the environmental degradation we face in the region today. At the same time, the human potential that developed in the region over this period, modern technologies and the understanding of long-term benefits of investing in nature allow us to draw a bright picture for this region. A region actively promoting its bleu economy, building its physical infrastructures on nature-based solutions, and developing a climate resilient and sustainable society.

What we expect from this Conference is the synthesis of the existing scientific knowledge on the impact of climate change in the region, which would help us boost a true basin-wide cooperation on the Caspian and mobilize resources to jointly combat the negative effects of clime change.

This Conference is the first in its kind in the Caspian region, as it aims to build a firm scientific foundation for the basin-wide five-lateral cooperation of the Caspian states on the climate change mitigation and adaptation.

The Tehran Convention was the first and for a long time the only legally binding agreement among the five sovereign states of the Caspian region. It was concluded soon after the break-up of the Soviet Union, at the time of many existing differences among the littoral states on the legal status of the Caspian and the ensuing access to its natural resources. The fact that the five neighbor states found political will to start building common governing frameworks from the environmental cooperation shows the vital role of the environment for the development and prosperity of the region.

Today, when the legal status of the Caspian is regulated by a dedicated Convention, and the hydrocarbon industry has put the Caspian region on the modern geopolitical map of the world, more than ever we need to be concerned and conscientious about investing into the preservation and enrichment of the natural ecosystem of the Caspian Sea to ensure sustainable and prosperous future for the region.

The Framework Convention and its Protocols create mechanisms for engagement among the parties. The will demonstrated by all Caspian states to work together for a healthier and prosperous Caspian region is a driving engine towards achieving our common goals. The wealth of scientific knowledge and rich diversity of people and cultures around the Caspian Sea is the key to success.

I wish this Conference successful and productive two days and thank you for your attention!

Mahir Aliyev
Coordinator, Tehran Convention Interim Secretariat

Dear ladies and gentlemen!

It is a great honor for me to welcome the participants of the International Scientific Conference on Climate Change in the Caspian Region on behalf of the Coordinating Committee for Hydrometeorology of the Caspian Sea (CASPCOM).

Climate change is one of the most pressing global problems of our time. Taking into account the geographical location of the Caspian region, its vast territory and remoteness from the ocean, these changes may be more noticeable.

Let me give you an example: for the period 1976-2020 the coefficient of the linear trend of the average annual air temperature for the Globe was +0.18°C / 10 years, and for the Caspian region – (+ 0.460°C / 10 years).

Consideration of climatic conditions and assessment of their changes are necessary to determine the potential consequences and take timely and adequate adaptation measures, ultimately, to ensure the sustainable development of the region. That is why, at the 24th session of CASPCOM in 2019, it was decided to prepare and hold a regional scientific conference dedicated to this issue.

As follows from the conference programme, the participants will discuss not only climate change in the Caspian Sea region, but also the problems associated with it.

This is, first of all, the impact of climate on the change in the Caspian Sea level. The effects of level fluctuations are most pronounced in the northeastern, shallow part, which belongs to the territory of Kazakhstan. It is also necessary to discuss equally important issues of the impact of climate change on the ecosystem and biodiversity of the Caspian Sea, as well as the economic consequences of climate change and adaptation measures.

We are confident that this conference, organized under the auspices of the Coordinating Committee for Hydrometeorology of the Caspian Sea and the interim Secretariat of the Framework Convention for the Protection of the Marine Environment of the Caspian Sea, will become a significant international event and once again emphasize that without attracting information from hydrometeorological services, many of the urgent tasks facing the world community cannot be addressed.

The representative circle of the conference participants confirms once again the importance of these studies for the conservation of the unique ecosystem of the world's largest closed water body – the Caspian Sea. I wish you all successful and constructive work.

I am confident that the outcomes of the conference will be useful not only to the governments of the Caspian littoral countries, but also to the world community for making informed decisions on the problems of climate change and adaptation to them in the Caspian region.

Thank you for your attention!

Danara Alimbaeva
Director General of RSE the "Kazhydromet"

Thank you for the invitation to provide a brief message from UNEP for this Scientific Conference on Climate Change in the Caspian Sea region. It is a privilege to be amongst such an esteemed group of scientists for this important conference.

My congratulations go to the organizers: the Coordinating Committee on Hydrometeorology and Pollution Monitoring of the Caspian Sea (CASPCOM) and the Tehran Convention interim Secretariat (TCIS) through the Organizing Committee consisting of representatives of the two organizations and of the five Caspian States.

We have already heard about the significance of this event in terms of the Caspian Sea Region and the environmental issues faced. I am going to address my remarks on science and the benefits of science informed policy, something that UNEP has always and continues to promote and which we need to keep in sight as we shift our focus from understanding the problems to effective and evidence based solutions. More than ever we need to ensure the science of the issues we are dealing with are communicated effectively. That we address the climate change challenges and mitigate and adapt to the effects in this sensitive region of the world. UNEP is actively engaged in promoting early adoption of net zero with accelerated action in the next 10 years. Indeed, we are asking all sectors and governments to listen to the science and not to delay early action to enable a transition to renewable futures and circular economies.

This Scientific Conference is a first step towards more institutionally established scientific collaboration in the Caspian Sea region and I wish you well in your meeting and exchange of the science of the region.

Andrea Hinwood
UNEP Chief Scientist

Thank you for the invitation the IPCC to address the participants of the Conference on the climate change in the Caspian Sea region.

As the Chair of the UN body for assessing the science related to the climate change, I welcome the initiative of the Parties to the Tehran Convention and CASPCOM to bring together the scientists from five riparian countries of the Caspian Sea to exchange knowledge and create a better understanding of the evolving climatic conditions of the largest inland water body on Earth.

The Caspian Sea with its unique and isolated ecosystem, its abundant oil and gas resources, and its long history of water level fluctuations deserves special attention in the science of assessing and addressing the impact of climate change.

We know that as the consequences of the global warming the shallow parts of this closed water body risk to disappear, while coastal zones may lose their viability as engines of economic development and posts and feathers of endemic biodiversity.

Understanding how climate change may affect the living conditions and future development potential of the region seems more urgent then ever in life of projections made by IPCC.

This Conference may compliment and enrich the work and understanding of the climate risks and consequences pertaining to this important area covered by IPCC assessment.

May I encourage you to not only review but also build upon the impressive amount of scientific research brought to this Conference.

The IPCC will be happy to assess the science and recommendations presented to and emerging from this Conference.

May I further encourage the organizers to sustain the network of scientists created, facilitating also the IPCC to collaborate with and benefit from the science community of the Caspian Sea region

I wish you a very successful Conference! Thank you!

Hoesung Lee
IPCC Chair

RECOMMENDATIONS

Participants of the International Scientific Conference "Climate Change in the Caspian Sea Region", held on October 27-28, 2021 under the auspices of the Co-ordinating Committee for Hydrometeorology of the Caspian Sea and the Tehran Convention interim Secretariat,

Taking into account the climate changes occurring in the Caspian Sea region and expressed in:

- Increase in air temperature,
- Decline in water flow of rivers,
- Increased evaporation from the surface of water bodies in the sea basin,
- Decrease in the sea level,
- Changes of ice regime;

Recognizing the need to strengthen international cooperation between the Caspian littoral states in addressing climate variability and change;

Supporting the implementation of the Sustainable Development Goal (SDG) – 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development;

Recognizing the growing need to study and address the interrelated implications of urbanization and climate change related to sea level fluctuations, drought and water scarcity to ensure long-term economically sustainable and environmentally sound management of the Caspian Sea coastal zones;

Realizing that the Caspian Sea is a unique body of water with many inherent features; the most famous is the fluctuation of its level under the impact of changes in natural and anthropogenic processes;

Recognizing the need to exchange operational and regime information on the state of the environment to ensure the security and sustainable development of the Caspian region in a changing climate;

Considering that the change in the interrelations that make up the water balance, especially river runoff and evaporation, has the greatest impact on long-term sea level fluctuations;

Noting that under the impact of climate change, the life cycles and distribution of unique endemic species of the Caspian Sea are altering, trophic networks will be affected and the functioning of ecosystems will be disrupted, what in the worst case will result in the extinction of many species,

Recommend:

Aimed at adequate assessment and development of a forecast of climate change in the Caspian Sea region

1. To the Caspian littoral states:

- To develop climate services in the region on the basis of the Global Framework for Climate Services (GFCS), to facilitate the exchange of data on climate and the state of the environment within the framework of WMO, CASPCOM, Tehran Convention, and other interstate agreements;

- To promote regular international complex field studies of the current state and pollution of the marine environment and river deltas, state of biological communities of the Caspian Sea, including the assessment of their dynamics under the impact of climate changes;

- To promote the exchange of information and results of scientific climate research among scientists inside and outside the region, to form and maintain a network of interested researchers.

2. To academia:

- To contribute to the development and improvement of the quality of global and regional climate models, including the study and modeling of paleoclimate and individual climatic characteristics, modeling and forecasting of dangerous hydrometeorological phenomena;

- To facilitate the study of impact of hydrometeorological conditions and climate changes in the Caspian region on the state of the marine environment, hydrophysics, hydrogeology, hydrochemistry, hydrology of rivers flow into it, and ecology of the sea,;

- To develop remote monitoring methods and GIS applications for the study of regional climate, hydrological and ice regime of the sea and their changes;

- To continue research on long-term changes in the runoff of rivers flowing into the Caspian Sea, including long-term periods of increased/decreased water content, as well as flow of heat, sediment, chemicals runoff, and natural and anthropogenic factors affecting them.

Aimed at increase the quality of monitoring, modeling and forecasting of the Caspian Sea level

1. To the Caspian littoral states:

- To monitor changes in the main components of the water balance and hydrometeorological characteristics of the Caspian Sea within the framework of the intergovernmental Agreement on Cooperation in the Field of Hydrometeorology of the Caspian Sea;

- To develop scientific co-operation in the region within the framework of the intergovernmental Agreement on Cooperation in the Field of Scientific Research in the Caspian Sea being developed;

- To promote regular updating of the General Catalogue of the Caspian Sea Level, Catalogues of water and air temperature, surface runoff into the Caspian Sea and salinity, established under the auspices of CASPCOM to assess the dynamics of these parameters under the impact of climate change;

- To develop monitoring networks, especially on the east coast, in coastal and open areas of the Caspian Sea, as well as to encourage shipowners to voluntarily register hydrometeorological parameters in the open part of the Caspian Sea;

- To facilitate the exchange of hydrometeorological and prognostic information to ensure safety at sea in accordance with the international obligations of the Caspian littoral states and the agreements among them.

2. To academia:

- To contribute to the study of impact of fluctuations in the Caspian Sea level on its ecological state and changes in morphometric characteristics;

- To develop remote sensing methods for the study of the sea level regime;

- To develop a scientific project on the diagnosis and long-term forecast of changes in the Caspian Sea level based on the new CMIP results from AR-6, establishing a targeted scientific fund and combining the efforts of the national scientific foundations of the Caspian littoral countries;

- To develop a new generation of interactively linked regional models "atmosphere – land surface – lake" to refine estimates of evaporation and obtain more reliable forecasts.

Aimed at the conservation and protection of the ecosystem and biodiversity of the Caspian Sea

1. To the Caspian littoral states:

- To promote ecosystem-based management of biological resources of the Caspian Sea as a strategic tool for marine planning to overcome the social and economic consequences of climate change and sea level decline, the cumulative human impact, and to strengthen efforts on the conservation and restoration of the marine environment on the border between land and sea;

- To reduce, to the extent possible the anthropogenic load on marine and coastal ecosystems, including the reduction of land-based and marine-based pollution, overgrazing, cutting of shrub vegetation, discharge of collector and drainage waters, construction of various structures;

- To ensure the protection of marine and coastal ecosystems, cessation of illegal fishing, as well as support the exchange of experience and lessons learned on their implementation in the Caspian region;

- To support the development and implementation of a regional projects on the impact of climate change and adaptation to it on the marine environment and coastal zones of the Caspian Sea under the auspices of the Tehran Convention in close cooperation with international donor organizations (the Green Climate Fund, Adaptation Fund and the GEF);

- To promote regional cooperation of the Caspian littoral countries aimed at the conservation, reproduction, rational use and sustainable management of joint biological resources of the Caspian Sea, such as sturgeon, sprat and Caspian seals, for a better understanding and overcoming the consequences of global warming and climate change in the Caspian Sea;

- To establish a regular (quarterly) meeting of the Working Group on Biodiversity in the Caspian Region, possibly with the involvement of the Tehran Convention interim Secretariat;

- To implement the provisions of the Article 6 of the Part II of the Ashgabat Protocol and, above all, provision (A): provide comprehensive inventories of threatened species of flora and fauna; to develop the Caspian Red Book of the Tehran Convention on the basis of the inventories for its adoption at the Conference of the Contracting Parties;

- To carry out systematic monitoring of the natural flora, regular assessment of the condition of rare species, reproduction in natural conditions and possibility of cultivation in experimental sites;

- To take into account the assessment of environmental and climate risks in all projects for the use of natural resources;

- To provide training for young researchers and to support existing researchers with experience in taxonomy and biodiversity to provide a good scientific basis for addressing the Caspian biodiversity crisis now and in the future by regional scientists;

- To raise public awareness of the local communities of the Caspian region about how to protect the biodiversity of the Caspian Sea in the conditions of climate change.

2. To academia:

- To strengthen collective efforts in the framework of regional cooperation among the littoral countries to carry out a large meta-studies covering biodiversity, the temporal and spatial scales of variability, modeling of ecosystems, as well as standardization of future research (taxonomic groups, methods, time horizon, scale, and so on);

- To contribute to the development of information systems on biodiversity of the Caspian Sea through the platform IOC/IODE/OBIS;

- To jointly plan a Coastal Marine Ecological Classification Standard based on the CMECS model for the countries of the Caspian basin to monitor changes in sensitive and vulnerable habitats due to the likely harm from climate change, taking into account the experience of Iranian Fisheries Science Research Institute (IFSRI);

- To use the seabed habitat maps developed with the support of the European Marine Observations and Data Network (EMODnet) to address gaps in research and knowledge about the current and future projected impacts of climate change on the ecosystem and biodiversity and the Caspian Sea, as well as to make informed decisions on climate change issues in the Caspian Sea region;

- To promote cooperation with the portal of the European Marine Observation and Data Network (EMODnet) on seabed habitats in the field of comparison, development and compilation of EUSeaMap in the Caspian Basin, including in the development of a large-scale map of the Caspian Sea habitats (EUSeaMap), being developed for information monitoring of the impact of climate change on the ecosystem and biodiversity of the Caspian Sea;

- To create a centralized library of detailed local maps of communities, biocenoses, biotopes and habitats for the entire Caspian Sea, with the assistance of the EMODnet portal on seabed habitats;

- To establish a catalogue of data on the Caspian basin biodiversity (including wetlands), a catalogue of environmental data, that would facilitate centralized access to data on biodiversity in the Caspian region, as well as the comparison and aggregation of existing environmental aspects of ecological importance for the Caspian Sea;

- To establish a modern and updated library of Caspian species, accessible to everyone, since the correct identification of species is the basis for environmental and biodiversity monitoring;

- To support the study of impact of the new invasive species Beroe ovata, which is a natural enemy of Mnemiopsis leidyi, on pelagic and benthic communities and fish stocks in the changing environmental conditions of the Caspian Sea;

- To develop indicators of the climate change impact on the Caspian Sea biodiversity, which would summarize empirical data from monitoring programmes for the analysis of relevant loads, conditions, impacts or measures related to biodiversity;

- To develop regional models to assess the impact of climate change on the Caspian Sea biodiversity, primarily the impact of sea level changes.

Aimed at the conservation of the unique population of the Caspian seal

1. To the Caspian littoral states:

- To give priority attention to the elimination of existing threats, in particular, to reduce the mass mortality of seals during illegal fishing and the development of protected areas, as this will increase the resilience of the population to climatic impacts;

- To promote the establishment of a network of protected areas of the Caspian Sea, such as the Ramsar wetlands under the Tehran Convention, for the conservation and restoration of the Caspian seal population, and to strengthen international co-operation;

- To exclude the Caspian seal from the Agreement on the Conservation and Rational Use of Aquatic Biological Resources of the Caspian Sea, which implies commercial fishing of joint aquatic biological resources, which, according to this document, currently includes the Caspian seal.

2. To academia:

- To study the adaptive responses of the Caspian seal to rapidly changing environmental conditions to predict the future situation, given that global climate warming and sea regression may adversely affect its numbers and distribution;

- To facilitate the modeling of the Caspian seal population to obtain quantitative forecasts of the consequences for its demography under various scenarios and of how climatic processes may interact with other anthropogenic stress factors, such as the mortality of seals associated with fishing;

- To explore the prospects for expanding alternative habitats for breeding, including the establishment of artificial marine substrates for breeding and protected areas on land.

Aimed at the conservation of the unique avifauna

1. To the Caspian littoral states:

- To ensure the maximum possible conservation of wetlands that provide a food base for the resources of wetland birds and biodiversity;

- To facilitate the systematic development of Special Protected Areas (SPA) network, including wetlands of international, regional and national importance;

- To restore degraded wetlands, river floodplains and rivers flowing into the Caspian Sea;

- To initiate the establishment of an international working group of ornithologists from the Caspian region countries to combine efforts to study the wintering of waterfowl in the Caspian and the long-term dynamics of their numbers.

2. To academia:

- To continue accounting and monitoring of waterfowl with the involvement of all countries of the region;

- To assess the contribution of climatic factors to the degradation of habitats of waterbirds in the Caspian region;

- To prepare a collective monograph: "The dynamics of biodiversity (on the example of waterbirds) against the background of climate change in the Caspian region".

Aimed at minimizing the adverse effects of and adaptation to the climate change in the Caspian Sea region

1. To the Caspian littoral states:

- To develop national and regional climate change adaptation plans;

- To ensure close interaction of the hydrometeorological services specialists, academic and departmental science and users of climate information in the sectors of economic, nature use, social sphere, including decision-makers, in the development and implementation of all stages of the adaptation process;

- To strengthen transboundary co-operation within the framework of existing agreements (CBD, Tehran Convention, Ramsar, CMS and other conventions, AEWA, and funds, initiatives);

- To adopt at the regional level the Environmental Monitoring Programme based on generally accepted goals and water quality standards and supported by a well-developed network of marine observations, as a means and tool for policy development and decision-making in relevant regional bodies, in particular at the Conference of the Contracting Parties to the Tehran Convention and CASPCOM;

- To include the impact of climate change on vulnerable ecosystems and biodiversity of the Caspian Sea region in international and national disaster risk reduction plans and programmes such as Global Network of Civil Society Organisations for Disaster Reduction (GNDR);

- To promote the expansion of the network of protected areas and establishment of new marine SPAs;

- To facilitate the strengthening of conservation measures and sustainable management of the nominated EBSA areas (ecologically and/or biologically significant areas) in the Caspian Sea;

- To promote the establishment of spatially dynamic protected areas taking into account changes in important habitats due to climate change and sea level regression;

- To develop appropriate coordinated measures and procedures to mitigate the effects of fluctuations in the Caspian Sea level;

- To assess vulnerability of coastal areas to the instability of the Caspian Sea level to plan adequate adaptation, protective and restoration actions;

- To promote the integrated coastal zone management in the Caspian Sea as a tool for addressing increased environmental risks in the conditions of the Caspian Sea level fluctuations on the basis of regional co-operation of the countries of the region;

- To provide, within the framework of the implementation of the main provisions of the Tehran Convention, work on maritime spatial planning – the development and implementation of the state and transboundary Marine Plans (as an example, Directive 2014/89/EU "On establishing a framework for maritime spatial planning" of July 23, 2014);

- To ensure that oil and gas producers in the Caspian Sea region develop low-emission development strategies, using new and innovative measures and technologies to reduce emissions at all stages of the oil and gas production cycle, including with the support of appropriate agreed legislation;

- To reduce dependence on fossil fuels in the oil and gas producing regions of the Caspian Sea and its coastal zones through coordinated research and operation of suitable renewable energy sources and measures to adapt and introduce fully cost-effective industrial and domestic equipment;

- To strengthen regional and international co-operation of the Caspian littoral countries, including the implementation of international projects, joint scientific research in the field of assessing the impact of the Caspian Sea level fluctuations on marine and coastal ecosystems, as well as to mitigate the effects of sea level fluctuations;

- To raise awareness of the coastal population, starting from preschool age, about the Caspian Sea, its wildlife, history, environmental conditions, challenges and threats to the health of the sea and its coastal zones to develop a respectful attitude towards nature, develop household habits that do not harm the Caspian Sea and its coast.

2. To academia:

- To conduct studies on the dependence of the efficiency of fishing and agriculture on the hydrographs of the catchment basins of rivers flowing into the Caspian Sea to ensure optimal regulation of their operation modes for sustainable development;

- To encourage the updating and introduction of new research and subjects into the curricula of universities, to maximize the human potential in littoral states to eliminate the economic, social and environmental consequences of climate change; to this end, an interstate academic exchange programme and a database could be developed;

- To establish a network of concerned scientists and experts on various aspects of biodiversity, hydrology and climatology of the Caspian Sea (a database of regional experts under the auspices of the Tehran Convention interim Secretariat) to participate in future regional projects.

Preface to the Collection of the Conference on

Section 1

Climate of the Caspian Sea region and its changes in the 21st century

Scientific conference on climate change in the Caspian Sea region

(27 - 28 October 2021 online)

Preface to the Collection of the Conference on Section 1

Introductory Speech – Svetlana Dolgikh

The work of the first section of the Scientific Conference on Climate Change in the Caspian Sea Region was devoted to the study of various aspects of the region's climate and its changes.

In total, 11 reports were presented by representatives of all countries of the Caspian region, the audience was about 50 participants.

According to WMO, 2020 was one of the three warmest years in the history of observations – the global average temperature was approximately 14.9 °C, which is 1.2 °C higher than the pre-industrial (1850-1900) level. The last 10 and 5 years have been the warmest in the entire history of observations. As it has been shown in many reports, the current climate of the Caspian region, as well as the global one, is undergoing significant changes.

The main features of climate change in the region over the past 45 years are an increase in surface air temperature and a multidirectional and, as a rule, insignificant change in precipitation quantity. Thus, the rate of change in the average annual temperature and the temperature of the winter season is 0.4-0.6°C/10 years, the temperature of the spring season increases by 0.4-0.7°C/10 years, the summer season – by 0.5 -0.7°C/10 years, and in the autumn season – by 0.2-0.5°C/10 years. The range of changes in the amount of precipitation in the region in the winter and autumn seasons and as a whole for the year is from -5 to + 5% over 10 years (percentage of the norm for 1961-1990), from -5% to + 10% in the spring season. In the summer season, the amount of precipitation either does not change or decreases, sometimes up to 15% over 10 years.

In addition to an increase in the average annual and seasonal temperatures, the following most noticeable changes also occurred in the temperature regime of the region:

- Increase in the number of days with temperatures above the 90th percentile, hot days with air temperatures above 30 ºC, the number and duration of heat waves;

- Reduction in the number of days when the daily minimum air temperature dropped below 0 ˚C and below -2 ˚C, what affects ice conditions on the Caspian Sea surface;

- Increase in repeatability of so-called tropical nights, when night temperatures do not drop below 20 ˚C, as a result of which the human body does not have time to rest from the heat of the day;

- Increase in the duration of the growing season with an average daily temperature above 10 ˚C and the sum of temperatures for this period.

The effects of climate change are already noticeable.

In most parts of the region, an increase in aridity is noticeable. In some regions, an increase in the number of days with heavy precipitation was recorded, what evidances the intensification of convective processes, including due to an increase in the temperature of the sea surface and changes in the nature of atmospheric circulation. Intense precipitation has already led to a number of problems, especially in Baku, including flooding of streets and tunnels, and a rise in the level of groundwater. The level of the Caspian Sea has dropped significantly. The area of the water surface of the sea decreased by 22.3 th. km^2, mainly due to the shallow northeastern part.

The water area of the Northern Caspian is characterized by the occurrence of surges, especially November through March, and mainly with two types of circulation – with the establishment of the Siberian anticyclone and with the invasion of cyclones, when baric contrasts and, accordingly, the wind above the sea surface increase.

The combined effect of climatic changes and anthropogenic factors on the hydrological regime of the Volga Delta is observed. The winter runoff of the river has increased, the runoff in high water has decreased, the total duration of ice phenomena and the duration of ice formation is decreasing. The change in the ice regime of the Volga Delta cannot but affect the ecological systems of the Delta.

According to the IPCC Sixth Assessment Report (IPCC AR6), global warming of 1.5 °C and 2 °C will be exceeded in the 21st century, unless significant reductions in carbon dioxide (CO_2) and other greenhouse gas emissions would take place in the coming decades.

Climate projections for a period of up to several decades indicate further significant warming in the near Caspian region. With an increase in global temperature by 2 °C in accordance with the SSP5-8.5 scenario, the following changes in climate characteristics can be expected in the region:

- Increase in the average annual temperature by 2.5-3.5 °C, an increase in the number of days with a maximum temperature above 35 °C by 5-37 days;

- Change in annual precipitation from minus 5 to plus 10%, precipitation in the winter season – from minus 2 to plus 13%, while a decrease in precipitation in the summer season is possible by 10-25%;

- With an increase in the level of warming, the intensity and frequency of heavy precipitation will increase;

- Average surface wind speed has decreased (high degree of reliability) and will continue to decline (medium degree of reliability);

- Seasonal snow cover duration will be further reduced by the mid-21st century (high degree of reliability).

According to the reports presented at the section, an increase in the frequency of dust storms due to dust from the exposed bottom of the Caspian Sea is likely in the region. The thickness of the sea ice will decrease, and the likelihood of ice-free conditions will increase. At the same time, there is a great uncertainty in the estimates of the future runoff of the Volga River, which provide a significant inflow of water into the Caspian Sea.

Evidences of the so-called climate event 4.2 observed in cores collected in the Southern Caspian basin indicate that dramatic climate change may have caused the collapse of many civilizations in the past. The unprecedented climate change now being observed could also lead to significant social changes in many regions of the globe, including the Caspian region.

As a result of the work of the section, a number of recommendations were proposed for the scientific community on the intensification of comprehensive studies of the Caspian region climate and the development of climate services in the region based on the Global Framework for Climate Services (GFCS).

Translated from Russian

Hydrochemistry and ecology of the aquatic environment of the Turkmen coast of the Caspian Sea

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Combating the global climate warming, protecting and improving the environment have become a global problem. The Caspian Sea environmental problems are among it. Studies on the ecology of the hydrochemical composition of the Caspian water environment stem from the constantly growing social, economic, cultural and ecological role of the sea.

The Caspian Sea washes the western part of the territory of Turkmenistan. As a result of the use of the sea stream near the Turkmen coast for the production of salt, salt deposits were formed in the places of Guvlyduz and Garabogaz. Waste from these industrial facilities has an impact on the water-salt balance of the Caspian Sea.

On the basis of our research, changes in the hydrochemical composition of the Caspian waters that occurred in the corresponding calendar quarters of the period of 2016-2018 in such water points of the Turkmen coast as Garabogaz, Gyanli, Avaza, Turkmenbashi, Khazar, Esenguly were studied. In this study general methods for analyzing the hydrochemical composition of the aquatic environment were used. Based on the results obtained, the favorable levels of the mineral composition of the waters for the habitation of fish of the Turkmen Caspian coast are characterized.

During the years of the research, the average salinity of the sea was observed as 13.8 g/l. This indicator is gradually increasing towards the eastern direction and reaches up to 14.1 g/l. In summer, the salinity level increases on the water surface and in shallow coastal waters. A significant increase in the salinity level of the Caspian water brings it closer to the Black Sea. This phenomenon creates a danger of parasites living in the Black Sea entering the Caspian Sea (for example, Ctenophora).

Under the influence of river waters invasion into the sea, the quantity of chloride ions decreases. The amount of calcium (370 mg/l), carbonate (22 mg/l) and sulfate ions (3,500 mg/l) increases, while the amount of sodium + potassium (3,460 mg/l), magnesium (750 mg/l) and bicarbonate (210 mg/l) changes slightly. At the eastern coast of the Caspian Sea, the excess of chromium (1.9 micrograms/l), lead (26.1 micrograms/l), arsenic ions (44 micrograms/l) compared with the average level across the sea is observed, as well as exceeding the accepted norms of calcium, sulfates and strontium (18.36 micrograms/l).

The geological location of the Caspian Sea on a highly mineral "red" thermocline leads to the invasion to the sea of salt flows water from the outside and complication of its hydrochemical composition. The consistent decrease in river flow into the Caspian Sea due to global warming of the climate is the reason for the decrease in the water level in it. With a decrease in the level, the salinity of sea waters increases, and the penetration of highly mineralized underground thermal waters into the sea increases. This significantly affects the ecology of the aquatic environment, creates threats to biological communities, therefore, it must be taken into account when developing measures for the conservation of the biodiversity of the Caspian Sea.

Reconstruction climate change in the southeastern part of the Caspian Sea

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Reconstruction of past climate change can provide us valuable information about the time, scale, and details of climate changes. For reconstruction of late quaternary climatic conditions, various methods are used, paleomagnetism, paleontology etc. One of these methods is to use stable isotopes of carbon and oxygen, which is particularly valuable information on the temperature of the depositional environment, digenesis temperature, the temperature changes in different digenesis environments, separating different areas with various content of carbonates. Considering the importance of Gorgan Bay from different aspects and the fact that many studies have not been done in this region regarding long-term climate change, in this research we have tried to use different data obtained from sedimentary cores harvested from the southeastern part of the Caspian Sea (Gorgan Bay). Temperature changes and environmental conditions of the region in the late Quaternary to be studied and reconstructed.

Gorgan Bay with an area of more than 400 km is located in the southeastern part of the Caspian Sea (36°48'N, 53°35'E and 36°55'N, 54°03'E, 60 km ×12 km, maximum depth of 4 m). Gorgan Bay formed during the Holocene period by a sandy spit which is named Miankaleh coastal barrier system. It is connected to the Caspian Sea through the inlet of Ashoradeh-Bandar Torkaman (Chapaghli) which is located in the northeastern part of the Bay. This bay is mainly influenced by processes that are operating within the basin. Water balance in the Gorgan Bay is influenced by freshwater inflow from a number of small rivers and streams, including Gorgan-roud from the north and QarehSu from the east. These two rivers drain runoffs from residential and agricultural areas into the bay.

In this for reconstruction of late Quaternary climatic conditions a sedimentary core (N1) was collected from Gorgan Bay using a gravity corer. The core was first examined for magnetic susceptibility (MS). After slicing the core and subsampling with certain distances, Laser particle size analyzer (Horbia LA-950) was used for grain size analysis. Also, to specify total organic matter content (TOM), loss of ignition method (L.O.I) was used. For these purposes, a portion of each sample (about 3 gr) was placed inside a crucible and heated at 550 °C for 5 hours and after that the weighing percentage of the organic material was reported. For measurement of carbonate content ($CaCO_3$%), coarser grain particles were manually removed and remaining sediments were placed in a muffle furnace

(Excitation, EX.1200-12L) for 1 hour at 950°C. For ^{14}C dating, totally 3 organic matter samples were sent to the Poznan Laboratory, Poland, the oxygen and carbon stable isotope analysis was carried out on the non-digenetic and negligible digenetic benthic foraminifera (*Ammonia Beccari*) by mass spectrometer in the Winsor Laboratory, Canada. Paleotempreture of the seawater estimated based on $\delta^{18}O$ values for seawater and its counterpart in aragonite.

Grain size was very variable – from sand to clay. N1 core consists of 39 sandy silt facies, 28 silty facies, 9 silty sand facies, 9 facies of gravelly sandy mud, 3 facies gravelly muddy sand and 1 facies gravelly sand. The maximum and minimum of sand were abstained at 617 and 690 cm (80.27% and 0%), respectively, while the highest content of silt and clay were at depth 138 and 416 cm (99.45% and 8.95%), respectively. The lowest amount of silt content was observed at 626 cm (7.23%). The average of sand, silt and clay in this core was 25.13%, 72.52% and 1.56%, respectively.

Result of magnetic susceptibility showed a close relationship between particle size distribution and MS magnitude due to variation in terrestrial influx, which is caused by sea-level fluctuations in different times. This process increases with particle size and ranges of MS simultaneously with sea level fall and decreases during sea-level rise.

The range of oxygen ($\delta^{18}O$) and carbon isotope ($\delta^{13}C$) was between -4.22 to -1.17‰ and 2.66 to -0.94‰ with a mean of 3.34 and -2.11 ‰ correspondingly. According to the results of carbon dating (14C Dating), age of sediment in the N1 achieved 22,070 cal. The rate of sedimentation in the cores varied from 0.57 to 3 mm. Reconstruction of paleotemperature with stable isotopes showed that the maximum temperature recorded in the core was acquired at 144 and 686 cm (27.4 and 27.1°C), and the minimum temperature was 450 cm (13.7°C). The mean temperature in this core was 22.2°C. Based on the results of 14C age and stable isotopes 15 centigrade changes in temperature have occurred during about 22,000 years, accordingly, seven warm and cold periods were identified, of which the coldest period being the last glacial maximum (Wurm) with a temperature of 13.7°C. The highest temperatures related to the pre-glacial and the present periods (about 27°C). Moreover, the sedimentology and magnetic susceptibility data confirmed the above results.

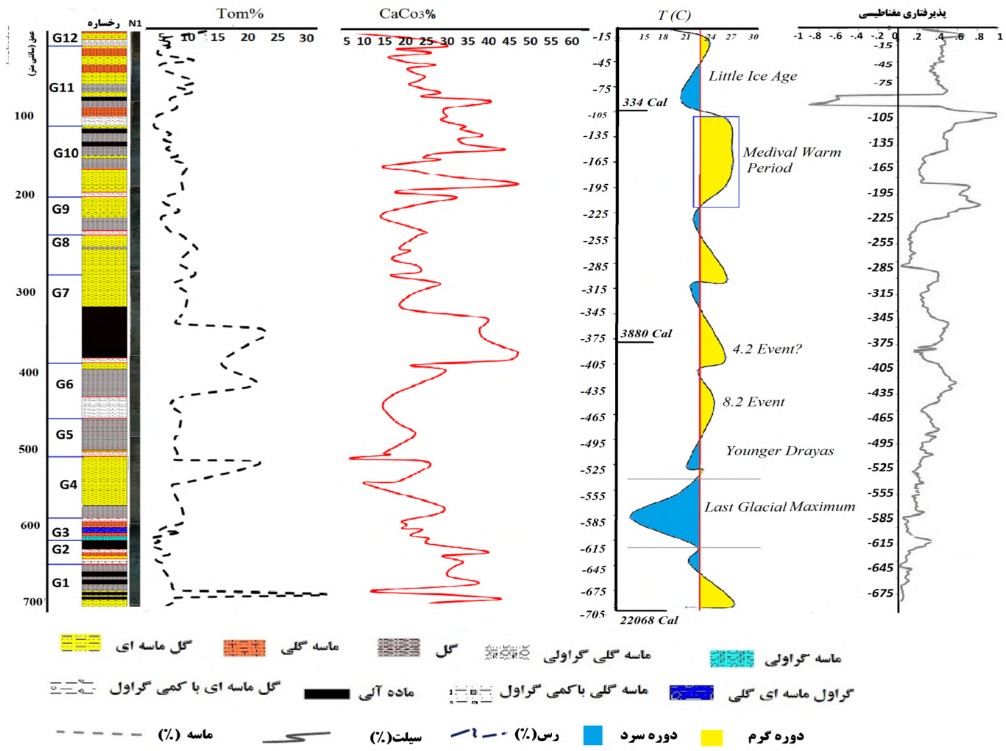

Fig. 1. Reconstruction warm and cold periods using sedimentary facies, temperature and magnetic susceptibility over the past 22 000 years.

Translated from Russian

Climatic conditions of the lower Volga and the northern part of the Caspian Sea over the past 24th cycle of solar activity and most likely changes in the beginning of the 25th and following 26th cycles

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Solar activity cycles

Solar activity is the regular occurrence of distinctive formations in the solar atmosphere: sunspots, faculae in the photosphere, plages and flashes in the chromosphere, prominences in the corona. The areas where these phenomena are observed together are called centers of solar activity. Regarding the solar activity (the growth and decline of the number of solar activity centers, as well as their energy), there is an approximately 11-year periodicity (the cycle of solar activity). Solar activity effects many terrestrial processes, including the climate.

The influence of the cyclical processes of solar activity on the Earth's climate was identified more than two centuries ago and is now not denied by anyone.

In 1849, Rudolf Wolf, Director of the Zurich Observatory, proposed a conditional unit to characterize solar activity – the number of sunspots, which is now called a Wolf number. In the optical region, the average number of spots is an indicator of solar activity.

The connection of 11-year cycles of solar activity with hydrometeorological phenomena on Earth was identified. Thus, the most severe floods in St. Petersburg pertained to the beginning of the ascending branch of the solar cycle with a delay of one year after its minimum (1824, 1924, 1955).

In addition, the longer cycles were identified as well:

22-year cycles (Hale cycles). In the transition from one 11-year cycle to another, the polarity of the lead and follow sunspots in each hemisphere changes. This allowed Hale to identify 22-year cycles, each of which consists of an even and odd 11-year-old cycle.

“Secular” cycles. A. Gansky identified 80-year cycles of solar activity, which were called “secular”. In 1939, Gleissberg calculated the duration of secular cycles at about 78 years. In 1956, he specified them at 78.8 years. The existence of "secular" cycles was confirmed by M. Gnevyshev [1].

190-year cycles ("Indiction"). In 1948, L. Predtechensky identified a cycle of solar activity lasting 190 years, which was called "Indiction" – the recurrent. According to Anderson's calculations, the Indiction consists of two half-periods: of 88 and 81 years, which gives 169 in total. According to the calculations of D. Bonov, considering the magnetic characteristics of 11-year cycles, the Indiction consists of eight 22-year cycles and lasts 176 years [2]. In the second half of the 17th century, a general cooling was observed on Earth (the Little Ice Age) (Fig. 1).

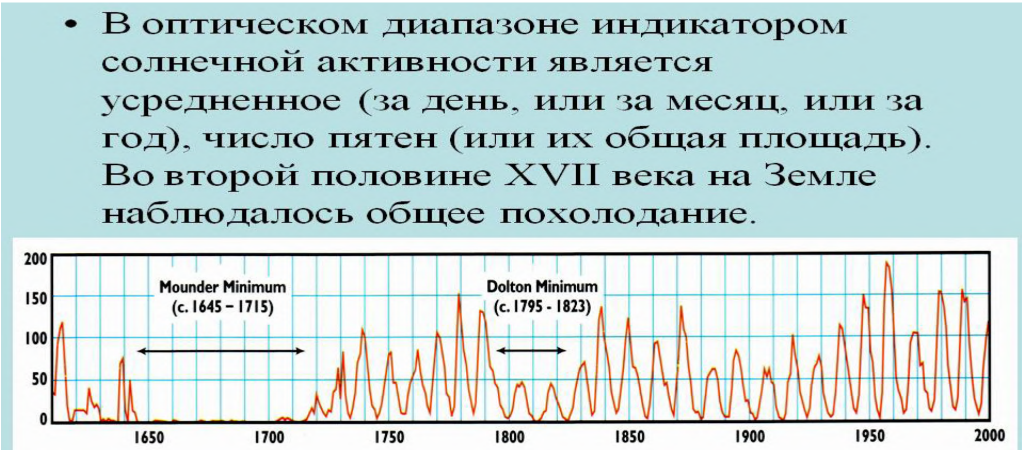

Fig. 1. The average number of sunspots is an indicator of solar activity in the optical region. The graph clearly shows quasi-11-year cycles and periods of a sharp decline in solar activity, when the Sun seems to "fall asleep".

The analysis of the temperature regime in Astrakhan for the period of time from 1836 to 2016 is very much in line with the calculations of D. Bonov [2]. The impact of solar activity on climatic characteristics is of a regional nature, and manifests itself in the amplification of atmospheric processes in some regions and their weakening in others. Climate change along the coast and the water area of the Northern Caspian Sea is unidirectional. Thus, the temperature regime according to the meteorological stations Astrakhan, Tyuleniy, Kulaly, Ganyushkino, Atyrau, Peshnaya, Fort Shevchenko for 1938-2003 changes synchronously and in-phase. Periods of drastic changes in the air temperature ensue simultaneously and follow one trend – either increase or decrease [3].

Having the data of observations of the air temperature from the Astrakhan meteorological station since 1836, made it possible to identify the temperature regime specificities from the 8th to the 23rd eleven-year cycle of solar activity and to extend them to the entire North Caspian region.

The analysis of the temperature regime shows:

The past 23rd 11-year solar cycle (1996-2009) became the warmest in the North Caspian region in the entire history of observations – the average annual air temperature reached +10.8°C (with a norm of +9.6°C) and the average temperature of the cold season reached -0.2°C (with a norm of -2.3°C). Probably, the peak of the next increase in air temperature connected with changes of solar activity has already been passed. This is also confirmed by changes in the wetting regime. A sharp increase in the annual amount of precipitation which had been observed in 1990-2000, was replaced in turn by its decrease.

The following 24th even cycle of solar activity had begun in December 2008 and lasted until about the middle of 2020. The total duration of the cycle amounted to 11.8±0.7 years. The main maximum of solar activity occurred in the first half of 2011. The decrease in atmospheric pressure in the polar regions, which is typical for even 11-year cycles during the periods of increased solar activity, usually leads to a shift of the center of the Arctic anticyclone to the northeast. Atlantic cyclones that are formed in moist marine air and pass northward than usual, which, in general, leads to a decrease in precipitation in the Volga and Kama basins and subsequently to a decrease in the annual flow of the Volga River in the Caspian Sea.

Such significant projected changes in climatic and hydrological conditions, of course, should have had a negative impact on the activities of all, without exception, branches of the national economy, not only in Astrakhan and the Astrakhan region, but in the entire North Caspian region. This led to considerable additional material costs both during the warm and cold seasons of the period under review.

In the North Caspian region, the anticyclonicity of the climate has increased under the influence of the ridge of the Azores and Siberian highs. The weather has become drier and the precipitation amount has decreased. The continental Arctic air mass, in which the Siberian High is formed, determined sharp drops in the air temperature as a result of intensive radiative cooling during the winter season of the year.

The strengthening of the meridional form of atmospheric circulation during the periods of maximum solar activity led to an even greater decrease in air temperature in the winter season due to the invasion of Arctic air along the normal polar and ultrapolar axis. To a greater extent, this affected the eastern part of the Northern Caspian Sea.

The average annual air temperature in the 24th cycle reached about 9°C, which is 0.6°C lower than the long-term average and 0.8°C lower than the 23rd cycle average (1996-2007). The decrease in the average annual temperature is attributable to the sharp decrease in the air temperature during the cold season of the year to -3.0-3.5°C (in November-March), which is 0.7-1.2°C lower than the average and 3.0-3.5°C lower than in 1996-2007.

Hence, the 24th even eleven-year cycle of solar activity in the Astrakhan region and entire Northern Caspian region was characterized by dry summers with lower precipitation level, the recurrence of rather cold winters and strong easterly winds. The general decrease in the amount of precipitation in the Volga-Kama basin led to a decrease in the annual flow of the Volga River, to lower high waters in the spring, a decrease to critical level of the river depths during the summer and winter low water seasons, and a general decrease of the Caspian Sea level.

The intensification of the climate continentality in the region affected agriculture, water transport and also the fishing industry. During the summer months, the intense water blooming in the reservoirs of the Volga-Akhtubinsk floodplain and the Volga delta could be observed. The water deficit led to the massive drying up of small and medium-sized watercourses in the Volga delta and in the floodplain. Water bodies of the western steppe ilmen area were especially susceptible to this.

Additional scope of dredging and reclamation works as well as reconstruction of many existing coastal marine and river hydraulic structures and facilities were necessitated. The expenses of housing and public utilities on providing water to the population, especially during the summer and autumn law water periods, as well as for the heating supply of private, office and industrial premises during the cold seasons have risen. The consumption of electric and thermal energy along with various types of fuel has significantly increased [1].

The lowering of the Caspian Sea level primarily affected its shallow northern part. During the hot summer seasons, this led to intensive heating and water evaporation from the vast shallow waters of the Northern Caspian Sea, to the dangerous level of sea water salinity along with the emergence of extensive hypoxia zone. The frequency and intensity of dangerous water downsurge increased, which caused the massive ship demurrage in the marine part of the Volga-Caspian Sea navigable channel, especially during the winter periods, in the presence of drift ice [5].

Analysis of the long-term temperature regime (1836-2016) and a preliminary climate projection for the 25th-26th solar cycles

The international community of climatologists has divided into two groups.

Certain believe that a global warming regime has been established on the planet. The trend of global warming is irreversible and determined by anthropogenic factors. They appeal to take urgent measures to sharply reduce emissions of industrial gases into the atmosphere in order to avoid a pronounced climate warming and a catastrophic increase in the World Ocean level.

Others believe that the changes in the temperature regime are cyclical by their nature and are determined by the cyclical processes of solar activity and the connected change in the Earth angular velocity. It is assumed that solar activity has entered a phase of the sharp decline. A projection was made, that since about 2030, the Maunder phase is going to start with it's almost complete absence of sunspots along with the resulting new little ice age.

Analyzing the Astrakhan temperature regime, we conclude the cyclical nature of its changes related to the natural causes. The cold and warm periods detected by observations in Europe are in close connection with the 11-year cycles of solar activity and are confirmed by the data of Astrakhan observations (Tab. 1).

Tab. 1 Average air temperature during the cold and warm periods in Astrakhan

Period	Duration in years	11-year-cycle number	Average cycle temperature
Cold	1746-1756	0	-
	1833-1843	8	8.8
	1923-1933	16	9.0
Moderately cold	1766-1775	2	-
	1855-1867	10	9.0
	1944-1954	18	9.2
Warm	1823-1833	7	-
	1913-1923	15	10.0
	1996-2007	23	10.8
Moderately warm	1810-1823	6	-
	1902-1913	14	9.5
	1986-1996	22	10.2

The coldest are the even 11-year cycles, the warmest are the odd ones. The cyclicity is of 89 years for the cold periods, and of 88 years for the warm ones.

In this way, the cyclicity of cold and warm periods, both in Europe and in the Astrakhan region, in particular, corresponds to the "secular" cycles of solar activity calculated by D. Bonov [2].

Characteristics of the temperature regime of solar cycles

Based on the data of the air temperature observations from the Astrakhan meteorological station since 1836, the temperature regime was analyzed during the 13th-24th eleven-year solar cycles.

- The data analysis of these tables allows to draw the following conclusions:
- A binary system is clearly seen in the solar cycles' structure from 11-year-olds to the "Indiction":
- the 11-year cycle consists of two 5.5-6.0-year-cycles;
- the 22-year cycle consists of two 11-year-cycles.;
- two 22-year cycles make up the half-period of the "secular" cycle;
- the "secular" cycle consists of two half-periods;
- the "Indiction" consists of two "secular" cycles etc.
- Preliminary projection of the 25th solar cycle

Scientists tasked with projecting the solar activity during the following 25th 11-year solar cycle say that it is likely to be weak, very similar to the past 24th cycle (Fig. 2).

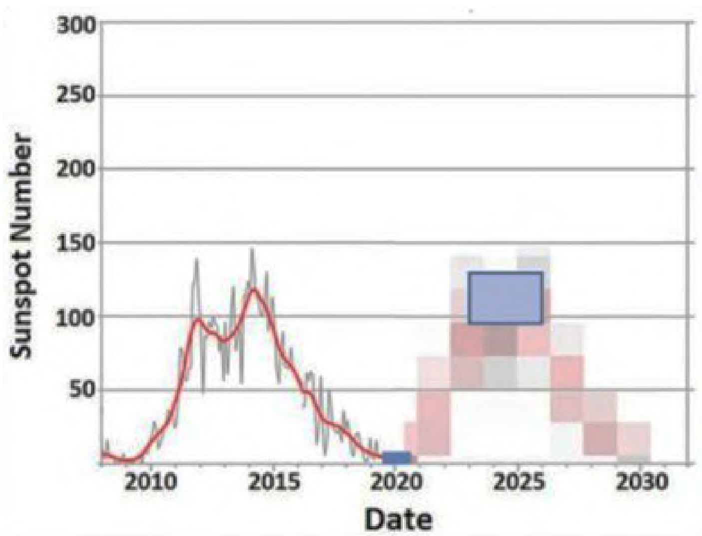

Fig. 2. 25th solar cycle projection. The Earth is approaching another little ice age.

Experts of the Solar Cycle 25 Prediction Panel consider that the new solar cycle pursues a slow start. The period of the greatest solar activity (solar maximum) is expected between 2023 and 2026 with a range of sunspots from 95 to 130. This is significantly lower than the average number of sunspots, which normally ranges from 140 to 220 per solar cycle. Experts are confident that the beginning of the 25th cycle should break the trend of weakening solar activity observed during the last four cycles. “We expect that the 25th solar cycle will be very similar to the 24th: another rather weak cycle, preceded by a long, deep minimum”, says Dr. Lisa Upton, Co-Chair of the Panel and a solar physicist from the Space Systems Research Corporation.

Expected climatic conditions for the 25th solar cycle (from 2021-22 to 2032-33). The first two years are colder than average. The sum of the average temperatures of the calendar winter is below -20°C. Further, closer to the peak of the cycle activity, an increase in the average annual temperature above the average (10.5-11.0°C) and by the end of the cycle, a steady decrease in temperature again. Fluctuations in average temperatures will be determined by their fluctuations in the period of November-March. At the beginning and in the end of the cycle, early establishment of ice cover in the Volga Delta and the Northern Caspian Sea would be observed [4].

Projection for the 26th solar cycle (2023-33 to 2043-44)

The beginning of the Maunder phase and the onset of another little ice age.

The prevailing synoptic process: the Asian (Siberian) High or its ridge. Extremely low precipitation is expected along with the prolonged and strong winds of the eastern quarter. During the warm season of the year, dust storms and dry winds are awaited, as well as the severe ice conditions in the Northern Caspian Sea for the period of December-March.

The effect of solar activity on climatic characteristics is of a regional nature, strengthening atmospheric processes in some regions and weakening them in others. Climate change along the coast and the water area of the Northern Caspian Sea is unidirectional. Thus, the temperature regime according to the Astrakhan, Tyuleniy, Kulaly, Ganyushkino, Atyrau, Peshnaya, Fort Shevchenko meteorological stations for 1938-2003 changes synchronously and in-phase. Periods of drastic changes in the air temperature ensue simultaneously and follow one trend – either increase or decrease. Taking into account the correlation coefficient, the weather forecast compiled for Astrakhan can be extended to the entire region of the Northern Caspian Sea.

Sustainable and continuous work of the Volga-Caspian Sea navigable channel during this period would require a significant increase in the capacity of the ice-breaking fleet in the Northern Caspian. Without a specialized system of hydrometeorological support for marine activities on the Lower Volga and in the freezing northern part of the Caspian Sea, it will be impossible to ensure the uninterrupted service of the Volga-Caspian Sea navigable channel and navigation in the Northern Caspian Sea [4].

Conclusion

All of the above is scientific assumptions based on actual long-term hydrometeorological data and the projections made by colleagues in the field of research of solar-active connections. But the technologies are not perfect; there are many unexplored and unidentified factors and dependencies. However, there is no other alternative for today, since today the hydrometeorological service cannot make projections for such long periods using traditional methods. It should be noted that the previously projected consequences of the influence of the past 24th cycle of solar activity on the climatic conditions in the North Caspian region for the period from 2006 to 2017 were almost completely credible.

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Translated from Russian

Modern climate change in the Kazakhstan territory of the Caspian region

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Global warming continues to break records. According to WMO, 2020 entered the three warmest years with an average global temperature anomaly of 1,2 ± 0,1°C relative to temperatures for the period 1850-1900, the last five years, as well as the last decade, were the warmest for the period of industrial observations [2]. The rate of climate change is not the same across the globe. In Kazakhstan, the Caspian region is distinguished by the highest rate of increase in the average annual and seasonal air temperature [1].

Initial data. The data of the Republican Hydrometeorological Fund of the RSE “Kazhydromet” for 8 meteorological stations of the region were used: 1) series of average monthly air temperatures and monthly precipitation amounts; 2) series of daily maximum and minimum air temperatures and daily precipitation.

Assessment methods. To assess changes in climate characteristics over a certain time interval, the coefficients of linear trends determined by the least squares method were used. When analyzing trends, the threshold level of statistical significance P value <0.05 was used. As a measure of the significance of the trend, the coefficient of determination (R2) was calculated, which characterizes the contribution of the trend component to the total variance of the climatic variable for the period under consideration and expressed as a percentage of the total dispersion.

The climatic indices recommended by the World Meteorological Organization and calculated using the ClimPACT software package [3] were used to assess changes and extremes in the temperature and precipitation regimes. These indices make it possible to assess many aspects of climate change, such as changes in the intensity, frequency and duration of the manifestation of extremes in air temperature and precipitation.

Results. The rate of increase in average annual air temperatures ranges from 0,24°C/10 years (MS Tushchibek) to 0.43°C/10 years (MS Aktau, Fig. 1).

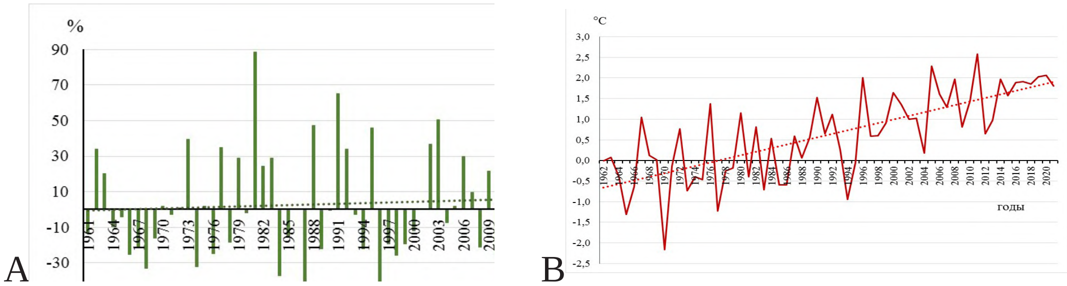

Fig. 1. Time series and linear trend of anomalies: a) air temperature (in °C) and b) precipitation amount (in% of the norm) according to the data of the Aktau meteorological station. Anomalies are calculated relative to the period 1961-1991.

All trends are statistically significant, and the proportion of variance explained by the trend is from 23 to 45%. It should be noted that over the last 20-year period, at all stations of the Caspian region, only positive deviations from the mean multiyear value for the period from 1961 to 1990 were noted. At stations located on the coast, or close to it, the maximum increase in air temperature was noted in the winter-spring period (up to 0.43°C/10 years at MS Atyrau and MS Peshnaya). On the mainland, the maximum warming occurs in the summer season (up to 0.42°C/10 years at the Kyzan MS). Temperatures rise to a minimum, mainly in the autumn season.

In addition to the increase in the average annual and seasonal temperatures, the following most noticeable changes also occurred in the temperature regime of the region:

- at almost all stations, there is a statistically significant increase in the number of days with a temperature above the 90th percentile (by 1-3 days every 10 years, tx90p index), hot days with an air temperature above 30°C (by 1-8 days/10 years, SU30 index), the number and duration of heat waves (by 1-7 days/10 years);

- statistically significant reduction in the number of days when the daily minimum air temperature (index FD0) fell below 0°C and lower below -2°C (for 2-5 days/10 years), which affects the conditions of ice formation;

- a widespread decrease in the proportion of cold nights by 1-2 %/10 years (with a minimum air temperature below the 10th percentile, TN10p index) and an increase in the frequency of so-called tropical nights, when night temperatures do not fall below 20°C, as a result of which the human body does not have time to rest from the daytime heat;

- the duration of the growing season with an average daily temperature above

10°C (by 2-4 days/10 years, GSL index) and the sum of temperatures for this period increase.

- There were practically no significant long-period changes in the precipitation regime in the Caspian region. Statistically significant changes were observed only at two weather stations – Peshnaya and Kulaly, the island. Moreover, the changes at these stations are of the opposite nature:

- at the Kulaly station, the island, there is a slight decrease in the annual precipitation, the amount of precipitation for 5 days (Rx5day index), the number of days with precipitation of more than 10 mm (R10mm index), the frequency of days with precipitation of more than the 90th and 99th percentiles (r95p and r99p indices), and, respectively, the average precipitation intensity per day (SDII index);

- at the Peshnaya station, there were changes in the same characteristics of the precipitation regime, only with the opposite sign.

Conclusion. Climate change in the region is characterized by a combination of a significant increase in the average annual and seasonal surface air temperatures, the recurrence of extremely high daily temperatures, the duration of heat waves, and the absence of significant changes in the precipitation regime.

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Assessment of Anzali wetland water surface area in the southwest Caspian Sea by satellite remote sensing

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The Caspian Sea is the Earth's largest water basin with specific physical and chemical characteristics. As in some features, it was classified as a deep seas category, and in other features as a lake [1]. This provided for the unique conditions to grow different fauna and flora in the lake and coastal area. One of the most important protected areas in the south of Caspian Sea is the Anzali Wetland (Fig. 1a). It was registered as an international protected wetland in the Ramsar Convention in 1975 [2]. The Anzali Wetland has the substantive impact on tourism, biodiversity, economy, subterranean waters of the region. Different environmental and anthropogenic factors threaten the Anzali Wetland, so its area is gradually decreasing. These factors are sedimentation due to rainfall, overgrowth and silting, drought, irregular irrigation, aquaculture, agricultural runoff, urban and industrial waste, overfishing and illegal hunting, soil erosion, algal bloom and so on [3].

In this research, the changes in the water surface area of Anzali Wetland have been investigated using satellite images. The Moderate Resolution Imaging Spectroradiometer (MODIS) Surface Reflectance images provide an assessment of the surface spectral reflectance as it would be estimated at ground level in the absence of atmospheric scattering and absorption. For this purpose, MODIS Terra surface reflectance images from 2000 to 2021 have been used (https://earthexplorer.usgs.gov). Then the Normalized Difference Water Index (NDWI) was applied on the collected images to estimate water area of Anzali Wetland.

The results of this study show that in 2021 the area of Anzali Wetland decreased to 20% of the surface area in 2000 (Fig. 1b). This can be related to various factors such as climate change, indiscriminate and wrong use of natural resources in the region. It will be studied in future researches. Also, the results indicate that NDWI algorithm on the satellite images can be used to generate and improve a model to support and management of Anzali international protected wetland.

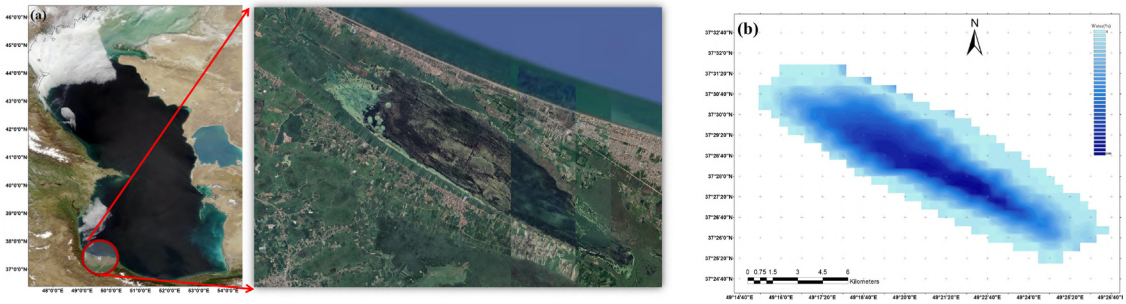

Fig. 1. a) Caspian Sea and Anzali Wetland (Study Area). b) Percentage of water in the study area from 2000 to 2021.

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Translated from Russian

Volga water flow under conditions of Holocene optimum and scenario anthropogenic climate changes in the 21st century

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Changes in the Volga River flow were estimated on the *model of the monthly water balance* [2]. It is based on the equation of the long-term annual average monthly water balance of catchment areas. In the proposed approach, scenario changes in the long-term annual average monthly runoff in the cells of a regular grid of 1x1 degrees in latitude and longitude are estimated. Water balance calculations are carried out within the mentioned cells covering the soil grounds, including the active water exchange groundwater horizon, characteristic of medium-sized river catchment areas. The main components of the water balance are calculated for such cells, including the runoff formed on the surface and in the subsurface layer, and the runoff from the zone of active water exchange, on which basis the total runoff from the cell is determined, which is integrated for the entire Volga basin. River flow, air temperature, and precipitation are set for each of the cells. Calculations are carried out on quasi-days, i.e. the average monthly values of air temperature and precipitation are interpolated by days within each month, based on the use of the developed algorithms, which are set out in [2].

To carry out paleohydrological assessments for *the Holocene optimum conditions*, the data of traditional paleoclimatic reconstructions of air temperature and precipitation deviations from their modern values for January and July were used. They were derived through zonal and information-statistical methods [3, 4]. Model paleoclimatic reconstructions of the average monthly anomalies of the above-mentioned climatic characteristics for each month of the average annual year were derived as well by averaging the results of paleoclimatic reconstruction carried out on 18 global climate models included in the PMIP-II program [7].

Calculations of changes in the Volga River flow *in the conditions of the current century scenario climate* were carried out on the basis of the mid-ensemble model climatic scenarios from the CMIP3 program [8] with the most (A2) and least (B1) intensive growth of the global average annual air temperature. The model anomalies used as input variables (relative to the period of 1960-1990) of the average mont hly amounts of atmospheric precipitation and air temperatures were averaged over the period of the first third (2010-2039) and the middle (2040-2069) of the current century.

Specificities of changes in the Volga River flow near Volgograd. The anomalies assessment of the annual flow of the Volga in the Holocene optimum derived on the model of the monthly water balance and based on the mid-ensemble model paleoclimatic reconstruction of PMIP-II, is 9% of its current value. Whereas the calculations of flow changes performed on the ground of paleoclimatic reconstructions based on the palynological method [5] show that the flow of this period could be lower than the modern one by 3-4%. And this result is qualitatively consistent with the assessments of the paleoflow derived earlier for the Volga River on the basis of zonal dependencies of the annual flow [1]; and with the results of the flow reconstruction from ancient bends [6]. In the first third of current century, the annual flow of the Volga River is likely to increase by 12% (scenario A2) – 2% (scenario B1), and by 12-9% in the middle of the century, respectively. The flood runoff during the Holocene optimum period (on the ground of paleoclimatic reconstructions based on palynological methods) could be 3-4% lower than the current one, whereas in winter and in the summer-autumn period it was higher than the current one by 19-30% and 8-6%, respectively. Based on model reconstructions of the paleoclimate (PMIP-II), the high water runoff could exceed its current values by 23%, and in other seasons of the year the runoff almost did not differ from the modern one. In the scenario conditions of the first third of the current century (scenarios A2 and B1), a less intensive increase in the flow of the Volga is probable for the main seasons of the year: in high water – by 17% (scenario A2) and 4% (scenario B1), in winter – by 6 and 15%, and in the summer-autumn period – by 19 and 12%. At the same time, the high water can start a month earlier without significant changes in its shape. By the middle of the century, the intra-annual flow structure will not change significantly compared to the previous stage of the scenario climate warming.

Conclusions. The conditions of the late Atlantic optimum of the Holocene, reconstructed from palynological data, are the closest to the scenario thermal regime in the Volga River basin, characteristic of the first third of the current century. The annual Volga River flow in these conditions, according to the calculations on the monthly water balance model, has proved to be lower than the modern one. Qualitatively, this result is consistent with the paleoflow assessments derived earlier for the Volga River on the basis of zonal dependencies of the annual flow, and with the results of the reconstruction of the flow from ancient bends. Under scenario climatic conditions and under paleoclimatic reconstructions based on the ensemble of climate models of the PMIP-II program, it proves to be higher than the modern one. In the conditions of the scenario future climate (in the first third and in the middle of this century), the annual flow of the Volga River is likely to increase as the climate warms.

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Evidences of the so-called 4.2 climate event observed in the cores collected from the southern Caspian basin

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Introduction

Studding on past climate events can help us to better understand the undergoing changes in climate. One of the interesting worldwide climatic changes is called "4.2 event" that has been reported in the Mid-Holocene. This climatic event was associated with cultural transformation in the human societies of the old world [3]. The end of the mid – this event happened at around 4200 yr BP, is used as formal boundary between Middle and Late Holocene [5] and has been widely recognized from the Northern Hemisphere [1]. There is an idea that this climatic event played an important role in the "collapse" of major ancient civilizations like China, India, Egypt and etc. and this idea supports by increasing number of data [3, 6]. In spite of many evidences reported of this event within the low latitudes, rarely reports in literature can be fined for the high latitudes and there is no reported evidence in the Caspian Basin. In this paper, the observations on the sediment cores collected in the southern Caspian Basin were discussed that can be considered as evidences for the climatic changes occurred at around 6 th. years ago.

Study area, materials and methods

The study area of the present work is located on the eastern side of the southern Caspian Sea. Three short sediment cores were retrieved from continental slope and deep basin of the eastern part of the south Caspian Sea using a KC gravity corer. The cores are located along a profile which starts from the depth of about 400 m close to the southern coastline (BS400) and continues NW, down to the depth of about 600 m (BS600). Different tests including magnetic susceptibility (MS) with 1 cm increment, continuous XRF measurements and also sedimentary tests to measure the grain size, calcium carbonate, and organic matter (OM) contents for every 2 cm were performed in INIOAS laboratory (Iran) and CEREGE laboratory of Aix-Marseille University (France). In addition, four bulk samples taken from different horizons of cores BS400 and BS600 were dated in Poznan Radiocarbon Laboratory by 14C method.

Results and Discussion

Based on the variation of different sedimentological and geochemical parameters and also considering the calibrated ages, anomalous sedimentary facies and beds in the cores were identified and correlated. An anomalous bed was identified in cores BS400, BS500 and BS600 that characterized mainly by coarser sediments. In spite of identification of this bed in all the cores, the evidences that show this bed probably can be related to the 4.2 climatic event are observed on the log of BS400 due to the thickness of the bed that is much more than it on two other cores. So, here, we discuss only on the observation and evidences of BS400.

According to the radiocarbon dating, non-calibrated ages for the samples taken at the depths of 97 and 136 cm of core BS400 were determined 4950 ± 40 BP and 5110 ± 40 BP, respectively. The radiocarbon ages were calibrated to calendar years using the CALIB Rev 6.1.1 software based on the Marine09 curve with 1R=26±69 14C yr [4]. Core BS400 hardly covers Middle Holocene, while BS600 could go back to Younger Dryas and even older.

Based on age-depth model of core BS400, the anomalous bed shown on fig 1 is deposited between 4430±350 to 4860±350 BP and associates with significantly higher values of Zr and Ti. The discussed event of 4.2 is characterized by dry and cool climatic conditions [3]. The high values of Zr and Ti also represent rather physical weathering and cold climate conditions [2]. Therefore, it seems that the discussed bed may be linked to the climatic event of 4.2.

Conclusion

Three short cores collected from southern Caspian Basin were tested by different sedimentary and geochemically methods and analyzed to identify certain climatic conditions in the past. For the first time in the Caspian Basin, sedimentary and geochemically anomalies were observed on a bed aged between 4430±350 to 4860±350 BP that can be considered as traces of the climatic event so-called "4.2 event". These results show that the high latitudes also were affected by the event. Considering these facts that first, the climatic events like 4.2 have been associated with social and political transformations that affect almost the entire then known world, and second, humankind is facing with a global climate change, it can be claimed that the current changes in climate will probably be followed by social and political changes affecting north latitudes.

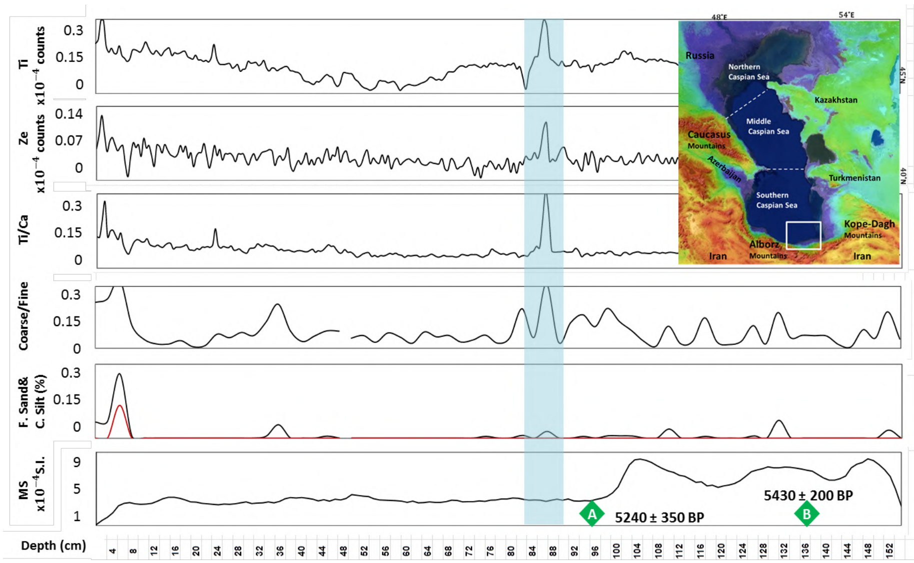

Fig. 1. Core logs of BS400 and the area of study. Anomalous bed showed by shadow can probably be linked to climatic event of 4.2. Green diamonds show the depth where the samples were selected for chronology. The calibrated age of samples is presented close to diamonds.

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Simulation of dust emission in Gorgan Bay area in semi-arid conditions

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Gorgan Bay is located in the Southeast of the Caspian Sea in northern Iran. It covers an area of about 400 km^2 [2] with a maximum length of 70 kilometers and a maximum depth of 5 m, although a big part of this bay has a depth of less than 2 meters. The shallow depth of this bay has made it vulnerable to climate change impacts.

In this research, Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) model version 3.9.1 [3] has been used to simulate the effect of Gorgan Bay drying up on dust emission in the region. WRF-Chem is a chemistry version of WRF that simulates the emission, transport, mixing, and motion of airborne particles [1]. In general, there are 33 options for selecting land vegetation in WRF model. In this research, the input model data was changed, so that the Gorgan Bay area was considered as a dry area with little vegetation. Soil material was considered as a proportion of sand and clay, which is about 80% sand and 20% clay and vegetation cover was selected as low grass. The model was run for 4 days and in different seasons of the year to consider the weather conditions in the region during the year. The dates were selected in such a way that no precipitation had occurred in the study area for the past week, so that soil moisture was low and dust particles could rise from the ground. The first 12 hours of the run were considered as spin-up. Also, a Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model has been used to generate an ensemble forward trajectory in order to trace the trajectory of the dust particles in the Gorgan Bay area.

The results of models WRF-Chem and HYSPLIT are shown in (Fig. 1) and (Fig. 2) for March 5, 2018, respectively. Heavy dust concentration is observed at the beginning of March 5, 2018 in the study area. At the Turkaman port station, the dust concentration reaches about 3500 µg/kg-dry air, and at this time the wind speed is 8 meters per second, which can be considerable. The output results of the model show that on March 5, 2018, there is more convergence and less uncertainty in the results and there is a possibility of dust particles spreading to the northeast of Gorgan Bay.

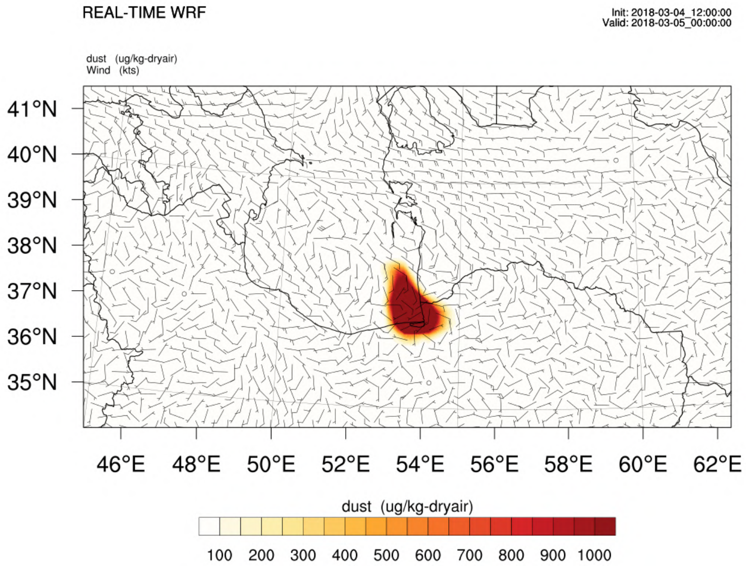

Fig. 1. The WRF-Chem model output for dust concentration (μg/kg-dry air) on 5 March 2018 at 0000 UTC.

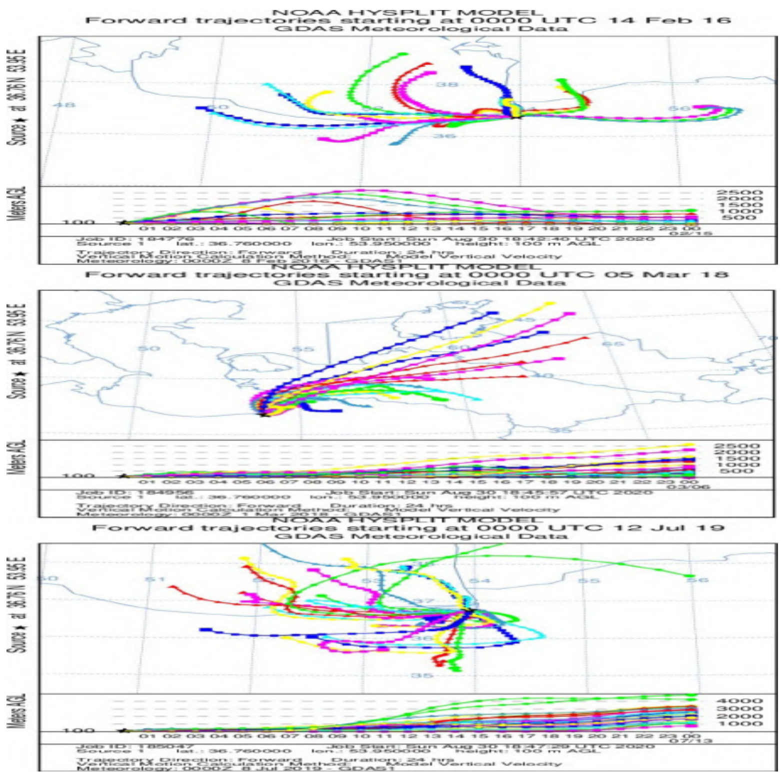

Fig. 2. HYSPLIT model forward 24h trajectory 27 member meteorological ensemble at synoptic weather stations in the Gorgan Bay at 100 m above ground on 5 March 2018 at 0000 UTC.

In general, the results showed that if the Caspian Sea level decreases, which results in the drying of the bay and its cover with grasslands, the Gorgan Bay can be considered as a source of dust. If the land is dry and there is no precipitation in the previous few days, with the wind blowing, sand and soil particles rise from the surface of the bay, then by the movement of atmospheric systems and the direction and speed of the wind, a significant area will be affected by dust. Also, the results showed that the intensity of dust is strongly dependent on the wind speed in the Gorgan Bay area. So that if the wind speed in the study area is more than 7 m/s, the creation of dust cloud with a concentration of more than 2000 μg/kg-dry air is possible. Also, the most intense dust events at Gorgan Bay occur when the atmospheric pattern indicates low-pressure and high-pressure contrast in the study area and the middle levels of the atmosphere are stable. Finally, due to the weather conditions in the region, there is a possibility of transfer of dust particles from the Gorgan Bay to the west, northeast, and south of the region.

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Translated from Russian

Volga delta hydrological regime under conditions of modern climate changes

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The Volga Delta is a classic extension delta formed on the open seacoast. It constitutes an alluvial plain, gently descending towards the Caspian Sea; the slope of the delta surface is 3-5 cm per 1 km. Since 1961, the hydrological regime of the vast Lower Volga region, including the Volga-Akhtuba floodplain and the Volga Delta, has been formed under the influence of the regulation carried out by the Volga Hydroelectric Power Plant (HEPP) – the closing stage of the Volga-Kama cascade. The Lower Volga is a river section without additional inflow; therefore, the long-term variability of the average annual water consumption and annual flow volumes of the Volga River in the Volgograd water abstraction point (the lower reach of the Volga HEPP) also characterizes the long-term changes in the flow at the top of the river delta.

The performed analysis showed that the average flow volumes for the period of the natural and regulated regime are very close – 256 km^3/year and 249 km^3/year, respectively. The average annual flow volume for the 130-year period of instrumental observations is 253 km^3/year. Against this background, there are periods of increased and decreased water content that until the 1950s were caused only by climatic changes in the European territory of Russia, where the reception basins of the Volga and Kama rivers are located. After the flow was regulated, climatic factors along with anthropogenic factors began to exert the most important influence on the hydrological regime of the Volga – the regulation itself with irrevocable water consumption for irrigation, industrial and municipal water supply. The growth of water consumption in the basin continued until the beginning of the 1990s, when, for objective reasons, the development of water-intensive sectors of the national economy significantly slowed down, and in some regions, it practically stopped and has not been restored to the previous volume until now. The regulation had the most significant impact on the parameters of the intra-annual flow distribution and the characteristics of the most important phase of the hydrological regime – the spring high-water season. After the regulation, the runoff of the spring high-water decreased by almost 30% compared to natural conditions, while the low-water flow has increased, in particular, for the winter low-water – more than 2 times compared to the natural period.The hydrological regime of the

Volga Delta is determined by the impact of climatic changes of various spatial and temporal scales. Long-term changes in the annual flow volumes entering the top of the delta are determined by climatic processes developing over the European territory of Russia, while regional climatic changes cause inter-annual and seasonal variability of temperature and ice regimes which are essential for the development and functioning of the delta ecosystem.When considering long-term fluctuations in water temperature values and indicators of the ice regime of the Volga Delta, the air temperature according to the data of the Astrakhan meteorological station (MS) was used as an integral characteristic that allows taking into account the climatic factor. The analysis of long-term fluctuations in air temperature at the Astrakhan MS showed that after the runoff was taken under control in this region the period of ice phenomena warmed compared to the period of the natural regime. The average air temperature of the ice period in the Volga Delta increased from -3.0°C in 1942-1960 to -1.1°C in 1961-2018. The total duration of ice phenomena and the freeze-up duration at the section of measuring station at Verkhnelebyazhye village decreased by 28 days and 29 days, respectively. During the period of the regulated runoff, there is a significant change in the characteristics of the ice regime in recent decades. The dates of the beginning of the ice phenomena, of the ice drift and of the ice formation moved forward to a later date by 11-15 days, while the start of the spring ice drift began to start by 7 days earlier, and the date of clearing from the ice – by 10 days earlier. In this regard, the duration of both the ice formation and the entire period of ice phenomena has been reduced – by 12 and 24 days, respectively. The duration of both the autumn (by 10 days) and spring (by 6 days) ice drift has been reduced as well.

The thermal regime of the Volga Delta is formed under the influence of natural climatic and anthropogenic factors. A common pattern for the Volga Delta is an increase in water temperature from the top of the delta to its marine edge. This pattern is disrupted in the area of the western sub-steppe Ilmen, Astrakhan and some other areas. The seasonal course of water temperature, characterized by periods of water heating and cooling, is common for all delta watercourses. In general, the course of water temperature in a more smoothed form repeats the course of air temperature, which confirms the dominant role of air temperature in the formation of the thermal regime of the Volga Delta watercourses. Nowadays, in the context of increasing extremeness of hydrological events against the background of climate change, systematic hydrological observations on the current observation network of the Astrakhan Center for Hydrometeorology and Environmental Monitoring, as well as systematic specialized works on the runoff accounting, its distribution and redistribution across the largest systems of watercourses, are of particular importance.

Translated from Russian

Impact of hydrometeorological conditions of the Caspian Sea on the Kura River

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To regulate the flow regime of the waterflow during the low-water period, it will be advisable to build hydraulic structures (controlled water regulating locks) at the mouth of the Kura River, which will create a barrier effect to prevent mixing of the salt water of the Caspian Sea with the river. By means of this device, by regulating the flow of the Kura during the low-water period, it is possible to improve the supply of drinking water and the efficient use of irrigation water, preventing the mixing of sea and groundwater, which are the main causes of river salinization. In order to reduce the influence of daily, monthly, seasonal, annual and long-term fluctuations of the Caspian Sea on the flow regime at the mouth of the Kura River, restored in the Kura delta to Goltug Bay in the southwestern channel of the channel (small tributaries) will increase the river flow rate and transport capacity, increase salinity and will prevent the water from mixing with the river.

Catastrophic floods are unlikely due to the fact that the river flow through the Mingachevir, Yenikend, Shamkir and Varvarskoye reservoirs, built for hydropower and irrigation purposes on the Kura River, is regulated on a daily, weekly and seasonal basis. The most urgent problem for the Kura River is the increase in the salinity of the source water within the range of 0.6 ÷ 12.8% (Tab. 1). For the first time, this problem was identified during monitoring observations during the low-water periods of 2020 (July, August, September) and as a result of laboratory analysis of water samples. At present time, the salinity of the Kura River is increasing towards the source of the river (by about 50-60 km). One of the main factors causing this anomaly is the decrease in the level difference between the Caspian Sea and the Kura River, as well as the movement of sea water in the direction opposite to the river flow, as a result of fluctuations (expulsions) on windy days.

Research and analysis related to changes in the physicochemical composition of water at the mouth of the Kura River (increased salinity) have also shown the existence of a correlation between water level, salinity and northeasterly winds at the hydrological station at the mouth of the river (Fig 1). The results of laboratory analysis of water samples taken on the left and right banks of the Kura River in the Neftchala region from wells intended for hydrogeological research and water wells drilled for personal use in the courtyards of private houses show that the effect of groundwater on the Kura River (an increase in salinity) is insignificant.

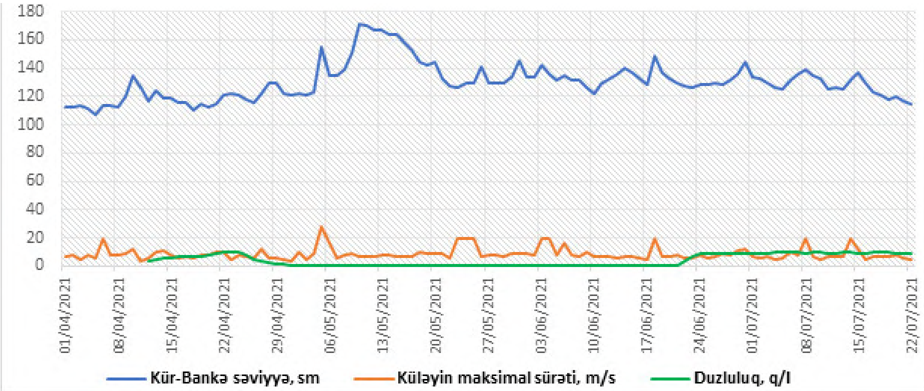

Fig. 1 . Dynamics of changes in water level, Maximum wind speed ad salinity in the Kura River in April 2021

Tab. 1. Results of laboratory analysis of water samples taken from the surface and from the bottom of the river at selected points (g/l)

№	24 July		30 July		4 August		5 August		6 August		7 August		8 August		9 August	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
M-1	-	-	-	-	-	-	0.7	0.7	0.7	0.5	0.7	0.7	0.6	0.7	0.7	0.7
M-2	-	-	-	-	-	-	0.6	0.7	0.7	0.6	0.7	0.7	0.6	0.7	0.7	0.7
M-3	-	-	-	-	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.7
M-4	0.8	0.6	-	-	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.9	0.7	0.8	0.8	0.8
M-5	1.5	0.7	-	-	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8
M-6	2.6	1.7	-	-	1.7	3.5	2.1	2.0	3.5	3.4	2.6	2.4	1.5	2.4	1.7	1.7
M-7	4.8	4.1	6.7	7.3	4.4	4.4	4.8	4.7	7.1	7.8	9.2	9.2	6.6	7.8	7.0	7.0
M-8	9.5	7.0	8.0	9.5	10.2	10.2	11.4	11.5	11.1	11.5	11.2	12.3	11.0	11.9	8.1	8.3
M-9	9.3	9.1	7.8	9.4	11.4	11.9	11.8	11.7	12.3	11.9	12.1	12.8	11.3	12.0	10.1	11.9
M-10	9.4	9.3	8.1	9.7	11.9	11.9	11.5	11.4	12.6	12.2	12.4	12.5	12.2	12.3	11.7	12.3

Our analysis, based on satellite imagery, also shows that the main tributary of the Kura River in the Caspian Sea is Ana Kura and Bala Kura, which flow north-east and east, and strong northeast winds dominating it creation of regular strong waves in the Caspian Sea (during a sharp drop in level). It creates favorable conditions for the movement of sea water in the opposite direction of the river flow.

Investigation of climate change effects on the south Caspian Sea region (physico-chemical characteristics in southern shelf - north of Iran)

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The Caspian Sea with a length of more than 1000 km is a unique low-salinity water body of the Eurasian region. The sea included of three parts: northern shallow area, middle and southern deep basins [1, 5]. According to the extent and dimensions, the Caspian Sea region is affected by various climatic fields (Arctic cold weather, Atlantic wet fields, warm and hot fronts of Mediterranean Sea, and hot and dry fronts from Iran and Kazakhstan) [3]. Different factors such as circulation, riverine discharge, climate change and evaporation are the most important parameters to change natural regime of physic-chemical and biological conditions of the seawater [4]. These characteristics seriously affect the lives of human societies and need to be closely monitored. During recent decades, the Caspian marine environment has been threatened by industrial and urban pollutants, climate change and global warming. The purpose of this study is to present the results of field assessments regarding changes in various seawater parameters and the effect of climate change on their pattern.

One of the most effective study tools in marine environments is continuous field measurements and comprehensive monitoring. In recent years, extensive marine researches and studies using data collection instrument have been conducted on the southern border of the Caspian Sea. Measurement of physical, chemical and biological parameters as well as monitoring of coastal areas in different region of west, east and middle part of the southern coastline is planned and implemented. The hot spots were selected for marine studies near important commercial ports including Anzali port in the west, Amirabad and Babolsar ports in the east and Nowshahr port in the center of the southern coastline. Various physical and chemical components of seawater are measured and recorded by the Idronaut CTD device and current by Acoustic Doppler Current Profiler. Sampling and observations were carried out at several fixed stations along several transects.

The results of studies showed that due to increasing temperature (and global warming) the vertical structure of temperature in the seawater column has changed compared to the previous collected data sets. These fluctuations have even affected the amount of dissolving of oxygen in seawater and the pattern of chlorophyll-a changes. As evidence of the effects of climate change on the marine and coastal phenomenon, the Algal Bloom in the period 2001-2005 in the southern part of the Caspian Sea can be mentioned [2]. One of the phenomena that have been observed during recent years is the decrease in the sea water level of the Caspian due to the decrease in precipitation and high evaporation. Variability in annual average or (in some cases heavy seasonal) rainfall in the southern coastal area has caused flood, for instance floods in Golestan province in 2020.

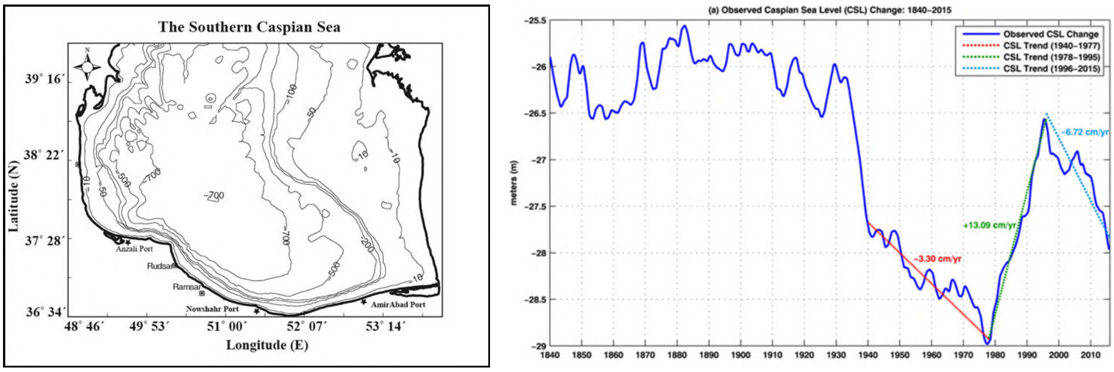

Fig. 1. The southern deep basin and continental shelf of the Caspian Sea, and sea level changes

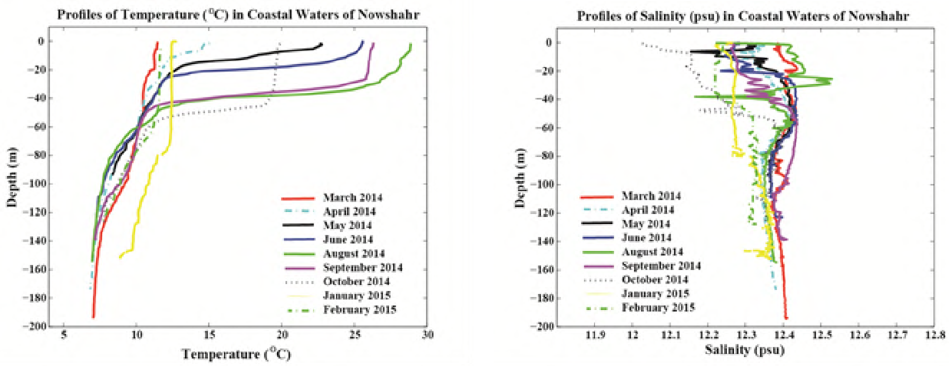

Fig. 2. Vertical structures of temperature and salinity in the southern shelf of the Caspian Sea

On the other hand, the droughts have affected agriculture in the region. Seasonal changes in the vertical structure of water temperature and density in the southern region of the Caspian Sea are shown in Fig. 2. The anomaly of changes in the vertical structure can be due to the impact of climatic field and weather in the region. The results of field studies in the waters over the continental shelf in some cases indicate a considerable chlorophyll-a concentrations at the subsurface layer between depths of 10-30 m. Increasing of the amount of chlorophyll-a (as biodiversity component) can be due to the increasing nutrients and adequate heat in the aquatic environment.

Two other important phenomena are occurring on the southern coastline during these years. One is the reduction of water amount of Anzali wetland, which is one of the protected areas by the Tehran and Ramsar Conventions. Furthermore, the significant decrease in the depth and area of Gorgan Bay in the last decade is another threat to the ecosystem of the South Caspian Sea. The results of our researches showed that the marine environment of the southern basin is under serious threat in terms of the entry of pollutants (industrial and municipal sewage, marine and coastal litter and agricultural pesticides) as well as the effects of climate change and drought.

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Translated from Russian

Satellite monitoring of ice cover and hazardous ice formations of the Caspian Sea

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The Caspian Sea is a unique, closed water body with specific features of hydrometeorological and ice conditions. The ice cover in the northern part of the sea forms annually and is distinguished by a wide variety of ice processes.

At present, work is underway to explore, develop and produce hydrocarbons on the shelf of the North Caspian, which requires serious scientific and technical support. At the same time, the issues of ensuring safety during the operation of oil platforms and transportation of hydrocarbons in difficult ice conditions are of paramount importance. In this regard, it is necessary to conduct permanent monitoring of the ice cover of the Caspian Sea, which is changing under the influence of ongoing climate changes. The necessity and urgency of studying the ice conditions of the Caspian Sea also lie in the fact that the nature and intensity of ice processes change significantly as a result of the sea level fluctuations.

To date, the most effective and fundamental means of surveying the Caspian Sea ice cover are satellite data of the optical, infrared and microwave ranges, which represent the information basis for space ice monitoring. Modern technology for monitoring ice cover is based on a comprehensive analysis of satellite information, ground and climate data on ice conditions, as well as expert knowledge.

To ensure monitoring of ice conditions in the freezing seas of Russia (including the Caspian Sea), the “Planeta” Research Center has created and is developing technologies for processing satellite data. In particular, a specialized technology for constructing ice condition maps has been created [2, 3]. The technology implements automated and interactive processing methods. Preliminary processing of satellite images (geographic referencing, transformation of space images into cartographic bases formed in advance, compilation of survey montages) is carried out in the automated mode. While in the interactive mode, ice parameters (age, concentration, ice shape, generalized characteristics etc.) are decoded on space images and displayed on the map in accordance with national and international symbols. The age composition of ice is assessed during the interactive interpretation of satellite images. This assessment relies on data from measurements of ice thickness at ground-based hydrometeorological stations and posts, as well as the results of calculating the "sum of frost degree days" at the points of location of meteorological stations and hydrological posts on the coast or islands of the North Caspian.

To improve the reliability of mapping in cloudy conditions, the construction of ice maps is carried out on the basis of complex processing of satellite data of different spectral ranges and different spatial resolutions. According to this technology, the "Planeta" Research Center annually produces 17-20 maps of the ice conditions of the North Caspian Sea during the ice season. Ice maps of the North Caspian are issued in graphic and vector formats; ice maps in the Sigrid-3 vector format are published on the server of the World Sea Ice Data Center (FSBI "AARI") [1].

In the future, the maps of the ice conditions of the Caspian Sea are used to assess long-term changes in the main characteristics of the sea ice cover. The analysis of a long-term series of ice maps of the North Caspian, constructed using satellite data, demonstrated that there are no pronounced annual peaks of maximum ice cover during the last 10-year period (2011-2021). This is traced especially well during the 2016-2021 five-year period, during which periods of increase in ice coverage were replaced by its decrease, and this happened several times during the ice season. The maximum areal limits of the ice cover are distributed in the span between the 1st and 3rd ten-day intervals of February (2011-2012), as well as between 3rd ten-day intervals of January and February (2013-2014, 2016-2017). In 2012, 2013, 2014 and 2017, there was a shift in the timing of ice formation to the first-second ten-day interval of December. In other years of the period under review (2011-2021), ice formation began in the second ten-day period of November. The average time of the sea water clearing from ice falls on the 3rd ten days of March, with the exception of the 2011-2012 ice season, when the clearance took place in the last 10 days of April.

The report examines the results of monitoring of dangerous ice phenomena and ice formations using satellite data of high spatial resolution. Most notably, based on the medium and high spatial resolution data from EOS series satellites (Aqua, Terra), "Meteor-M" №2, Landsat-8, Sentinel-1 and Sentinel-2, as well as the "Canopus-V" series spacecrafts, monitoring of stamukhas in the water area of the North Caspian was carried out during the 2016-2021 ice seasons. The position (latitude, longitude) of the stamukhas, its geometric dimensions and the period of existence (for cases when it was possible) were determined. By means of interactive decryption, the contouring of the stamukhas was carried out, followed by recording the results of decryption in vector format (shp-file). Based on the results of this work, a database of grounded hummocks detected from satellites in the Northern Caspian has been formed and is annually updated. Taking into account the shallow depths of the Caspian Sea (in places where stamukhas are concentrated), on some satellite images it was possible to see through the water column the inhomogeneities of the seabed, namely, traces of the impact (exaration) of stamukhas on the bottom soil. It should be noted that dozens of traces of the stamukhas' impact on the seabed were observed on the said satellite images, while according to the currently used data, the instances of detecting them are much lower.

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Translated from Russian

Climate research in the Turkmen part of the Caspian Sea

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The Caspian Sea is the largest inland body of water on the planet. The state of its ecosystem depends on climate change, and meteorological conditions effect human activity in the open part of the sea and the coastal zone. Human activity, in turn, also has an impact on the ecosystem of the sea.

According to scientists, the level of closed reservoirs, such as the Caspian Sea, is determined by a delicate balance between precipitation and runoff on the one hand, and evaporation from the surface on the other. In the case of the Caspian Sea, the water level decrease is explained by increased evaporation and loss of the sea ice in winter.

The Atrek River is the only river of Turkmenistan, which waters flow into the Caspian Sea. The Atrek River is characterized by short-term periods of high water from March to September. Often, the maximum water levels and intensity of water consumption reach critical values and are of destructive character. The intra-annual distribution of runoff within Turkmenistan does not reflect the actual regime of the river due to the water consumption on the territory of Iran. The runoff cessation can be observed during the summer period. In recent years, the Atrek waters rarely reach the Caspian Sea. These processes are associated with general increase in aridity in the Central Asian region.

The Hydrometeorological Service of the Ministry of Agriculture and Environmental Protection of Turkmenistan constantly monitors the state of the climate in the Turkmenistan coastal part of the Caspian.

Due to the vastness and diversity of the geographical location and climatic conditions of Turkmenistan, various extreme natural phenomena are characteristic of different regions. By the totality of hydrometeorological phenomena, almost the entire territory of the country is vulnerable. Insufficient water resources, strong winds, dust storms, frequent mudslides and rain floods on rivers determine the increased sensitivity of the region to climate change.

As for the eastern coast of the Caspian Sea in Turkmenistan, according to the synoptic analysis, there is a change in the atmospheric circulation system. The recurrence of such processes as the western and north-western invasion has become more frequent, and the trajectory of their movement has also changed. If in previous periods these processes mainly took place in the winter, spring, and autumn months, now they are observed during the summer months as well. The reason for this is changes in atmospheric pressure and air temperature, which also lead to the formation of dust storms on the southeastern coast of the Caspian Sea. More often there is an increase in north-westerly winds, with the formation of high waves with storm phenomena at sea. There are manifestations of new synoptic processes during the west-east transfer, in a situation with a blocking ridge, causing an increase in air humidity and fogs in the morning, what is not typical for summer and the climate of Turkmenistan.

Sharp warming occurs with the release of southern cyclones series with south-westerly flows. Carrying out of tropical air leads to a sharp increase in temperature, the appearance of squally winds that provoke dust storms. They are accompanied by abundant fallout of difficult to predict convective precipitation, with the formation of mudflow floods.

The frequency of the release of South-Caspian and Murgab cyclones has increased, not according to the classical type. For the northwestern plains of Central Asia, the typical synoptic situation favorable for the formation of droughts is the southern, southwestern and western periphery of the anticyclone. The stronger warming up and drying of the air is taking place.

According to long-term data, in the average annual air temperature, there is a tendency of increase. Analysis of changes in maximum temperatures demonstrated the trend for raising in the majority of months. The maximum water temperature over the past 10-20 years has also increased along the entire coast, in some years by 3-4 degrees.

Observations of salinity on the Turkmen coast are made at three sea stations: Turkmenbashi, Guvlymayak and Duzlybogaz. According to long-term observations, salinity values range from 12-14‰, but in 2020, in the Türkmenbaşy Gulf, its increase to 15.72‰ was noted in July, August and September. At the Guvlymayak and Duzlybogaz stations in the summer months, the salinity, although slightly, is also always higher than in the winter months. According to long-term observations at the Duzlybogaz station (Kara-Bogaz-Gol), it was noted that its values reached 37-39‰. Also, the findings of studies in past years show that due to the fact that winds are constantly blowing in the water area of the bay, in some parts its surface runoff flow could be sharply disrupted, what may result in the creation of countercurrents that are of an episodic nature.

Regular measurements of water flow are made in the Duzlybogaz Strait. Seawater flows into the bay through the Strait at an average speed of about 0.60-0.70 m/s and a maximum speed of 1.00 m/s. In the annual seawater runoff, there is a decrease of 360-400 m^3/s in the winter season and an increase in June, July up to 480-540 m^3/s.

The Southern Caspian rarely freezes, only in the cold winters (Krasnovodsk Bay froze in 1969). Over the past 15 years, ice phenomena in the form of fast ice on the Turkmen coast were observed in February 2012 and 2014 at the posts of Turkmenbashi (Krasnovodsk) and Khazar (Cheleken), the fast ice width reached 500 m, the ice thickness ranged from 1 to 5 cm. From 2015 to 2021, no ice phenomena were observed at the sea posts of Turkmenistan.

Thus, an increase in air and water temperature, a change in the atmospheric circulation system, a slight increase in water salinity in some places of the coastal part of the sea is observed at the Turkmen coast of the Caspian Sea.

Translated from Russian

Assessment of changes in the Caspian Sea ice cover by the end of the 21st century according to climate scenarios

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The purpose of this work is to assess the future ice regime of the Caspian Sea by the end of the 21st century on the basis of climate models and their projections. The main data were obtained from 29 stations and posts of the near Caspian region. In the author's previous works [1, 2], the results of research activities were noted, according to which the maximum ice thickness in the 1980s decreased throughout the Northern Caspian Sea. The maximum thickness of the ice is observed in February. When considering the values of the maximum ice thickness for the period 1944-2019, the greatest thickness is observed in the north-eastern sea area (over 40 cm), in the Middle Caspian Sea – does not exceed 15 cm. The thickness of the ice in the last century was significant, often more than 50 cm in the north, in some years over 1 meter.

About 50 physical and mathematical models have been developed, which include not only the atmosphere and the ocean, but also all other components of the climate system, and also take into account the chemical composition of the atmosphere, the interactions between the stratosphere and the atmosphere and many other features, what brings these models to the level of models of the planet Earth system [2, 6]. Through the CMIP5 international project, the results of experiments on climate models have become unified and are freely available on the Internet [3, 4, 5]. The results of experiments on 10 climate models were used: the model of the Beijing Climate Center, China (BCC Model); the model of the Canadian Center for Climate Modeling and Analysis with a resolution of T63 (Canadian Center for Climate Modeling and Analysis, CanESM2, CGCM3, 1 Model, T63 resolution); the model of the National Center for Atmospheric Research CCSM3.0,USA (National Center for Atmospheric Research, CCSM3, 0); the model of the Center for National Meteorological research, France (Meteo-France,Centre National de Recherché Meteorologiques, CNRM, CM3 Model); model of the Center for Atmospheric Research of Australia version Mk3,5 (CSIRO Atmospheric Research, Australia); Hadley Center for Climate Prediction model HadCM3, UK (Hadley Center for Climate Prediction, Met Office, UK, HadCM3 Model); model of the Institute of Computational Mathematics of the Russian Academy of Sciences, Russia (Institute for Numerical Mathematics, Russia, INM CM4,0 Model); model of the Max Planck Institute, Germany (Max Planck Institute for Meteorology, Germany, ECHAM5 / MPI OM); Japanese model MIROC3,2 with high resolution (CCSR/NIES/FRCGC, Japan, MIROC3,2, high resolution), MIROCESM; The French model CM4 V1 of the Laplace Institute (IPSL/LMD/LSCE, France, CM4 V1).

The most suitable models were Hadley, INM and CNRM. The scenario values of the average long-term temperatures of three winter months were calculated for three 30-year periods of the 21st century: 2011-2040, 2041-2070 and 2071-2100, and for the three main scenarios RCP 2.6, RCP 4.5 and RCP 8.5. According to the INM and CNRM models, the ice thickness decreases by 10-15 cm until there is no ice formation by the middle of the century. For northeast stations, the reduction is up to 16 cm (Fig. 1). The frequency of severe winters decreases significantly, and by the end of the century it disappears at all. The ice edge shifts by 150-200 km. The probability of ice-free conditions will increase by 10 times according to the INM model.

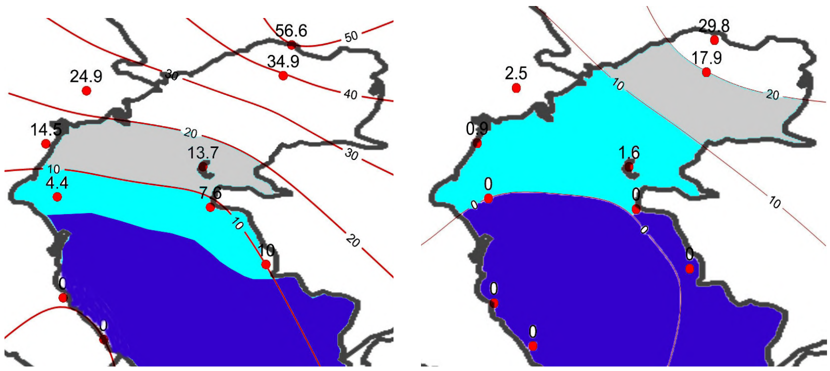

Fig. 1. Spatial distributions of the average maximum ice thickness (cm) for the periods 1981-2010 (left) and 2071-2100 (right).

As a result of the research work, the following conclusions were obtained:

1. Based on the selected most effective climate models (English Hadley, Russian INM and French CNRM), maps of isotherms of future temperatures were corrected and obtained, which show that for the average RCP 4.5 scenario, the area of the region with sums of negative temperatures less than -500°C will decrease by more than 2 times by the end of the 21st century and moderate winters will be observed only in the northeast.

2. The reduction of the scenario maximum ice thicknesses calculated according to empirical dependencies will be 10-15 cm, what leads to the absence of ice formation by the middle of the century according to the INM and CNRM models.

3. The border of the ice edge will shift to the north, will be on the line Isle Tyuleniy – Fort-Shevchenko.

4. The frequency of ice-free winter periods will increase significantly.

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Translated from Russian

Evaluation of the effectiveness of the method of short-term forecasting of ice thickness increase for the northern Caspian Sea

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Objective: To evaluate the effectiveness and reliability of the method of short-term forecasting of ice thickness increase.

Tasks:

- To make a projection on the ice build-up in the Northern Caspian Sea based on a synoptic forecast with a lead time of 1 day.
- To make a projection on the ice build-up in the Northern Caspian Sea based on a synoptic forecast with a lead time of 3 days.
- To make a projection of the ice growth in the Northern Caspian Sea based on the prognostic data of the WRF (Weather Research and Forecasting) model with a lead time of 1 day.
- To develop a forecast form to provide to the consumer.
- To carry out a comparative analysis of the forecasting results using the synoptic forecast and the forecast using the WRF model.
- To evaluate the effectiveness and reliability of the method of the ice thickness increase forecasting.
- To introduce the hydrometeorological parameters forecasting into the operational work.
- To elaborate and adopt the time standards and approve the application of the methodology.

The ice period of the Northern Caspian Sea typically begins in November [2]. The winter of 2020-2021 for the Northern Caspian Sea is classified, according to the generally accepted classification of the severity of winters, as moderate. The first ice phenomena at the Peshnaya station were recorded on November 15, 2020 as the formation of submerged land-fast ice and the coast ice formation, followed by freezing of the water area. Starting with December 2, the ice thickness was measured, ranging from the 9 cm mark. At the Zhanbay station, the first ice phenomena were recorded on November 27, 2020 with the ice thickness of 6 cm.

Since this period, daily records of observation data were kept, as well as predictive air temperatures of the synoptic forecast and the forecast using the WRF model. Whereas the synoptic forecast was carried out for the Atyrau station, the WRF model forecast was performed for the points corresponding to the location of the Peshnaya and Zhanbay stations.

Considering the historical period from 1980 to 2019, the maximum ice thickness in December was observed in 2014 and amounted to 14 and 11 cm at the Peshnaya and Zhanbay stations, respectively. In 2020, the ice thickness in December at the Peshnaya reached 32 cm and at the Zhanbay station – 38 cm, thereby setting a new record for the last 40 years. Also in January, the maximum thickness reached 41 cm at Zhanbay station, surpassing the record mark set in 2008 at 40 cm.

A form of the forecast presentation for consumers has been developed, which includes actual and projection ice thicknesses data in tabular and graphical format, as well as the historical information and satellite images. Concerning the historical information, a time series of data from 1980 to 2019 was analyzed. For the winter period from December 2, 2020 to February 28, 2021, 88 daily forecasts were performed and 25 three-day forecasts were issued.

The reliability of the ice thickness one-day forecast at the Peshnaya station based on the synoptic forecast of air temperature for the Atyrau station was of 98%. Thus, 86 forecasts of 88 were reliable. The reliability of the three-day forecast is slightly less, and amounted to 92%, as 81 forecasts out of 88 were reliable.

For the Zhanbay station 97% of one-day forecasts were reliable (85 forecasts out of 88) as well as 83% of three-day forecasts, which amounted to 73 forecasts out of 88.

Regarding the WRF model data, the results were very high and approaching 100%, namely 99% for the Peshnaya station and 98% for the Zhanbay.

While performing a comparative analysis of the actual air temperature at the stations and the projection temperature using the WRF model, and the comparison between the actual and projection air temperature according to the synoptic forecast for the Atyrau station, it was revealed that both forecasting methods reflect the projected values properly. The reliability of the forecast is sufficient, except the fact that the drastic air temperature drops are not always well predicted, which affects the projection of ice build-up.

Main conclusions:

1. The developed method of short-term forecasting of ice thickness increase in operational work has shown its high reliability.

2. The reliability of one-day forecasts was proved to be of 97-98 % using the synoptic forecast.

3. The reliability of three-day forecasts was proved to be of 92 and 83 %.

4. The using of the WRF model for one-day forecasts has shown a high result and amounted to 98-99%.

5. A form of the forecast presentation for consumers has been developed, which includes actual and projection ice thicknesses data in tabular and graphical format, as well as the historical information and satellite images.

6. A comparative analysis of projection air temperatures by the synoptic method and by using the WRF model was performed.

Conclusion. According to the Manual on the Forecasting Service, Section 3, Part III, issued by the Marine Hydrological Forecasting Service, when forecasting ice phenomena, the short-term forecasting methodology should be considered effective if its reliability is at least 75% [1, 3, 5]. Thus, the proposed methodology fully justifies the decision to introduce forecasting into operational work. More detailed information is given in the work [4].

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Translated from Russian

Changes in the hydro-hydrochemical regime of the northern Caspian Sea in a changing climate

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The purpose of this work is to analyze changes in the main hydrological and hydrochemical characteristics of the marine environment of the northern part of the Caspian Sea under the influence of climatic changes observed since 1996. Modern changes in air temperature, river flow, the level of the Caspian Sea, as well as the main characteristics of its hydrological and hydrochemical regime (temperature and salinity of sea waters, dissolved oxygen content) are considered. The assessment of modern changes is given in comparison with the previous period of the sea level transgression (1978-1995 [1]).

Air temperature

Our research has shown that in the northwestern part of the Caspian Sea, there has been a significant change in air temperature over the past 27 years. This is manifested, first of all, in an abnormal increase in temperatures during the cold season. The average long-term temperature has become higher, especially in January, February, March and October, there is also an increase in the average annual temperature by 1-2°C. According to the materials of the Institute of Global Climate and Ecology named after Yu. Israel, the air temperature in the northern part of the Caspian region is growing on average at a rate of about 0.46°C/10 years; the fastest growth was observed in the period 1991-2000: by more than 1°C. The highest average seasonal warming rate was observed in summer: 0.57°C/10 years. In the spring, since the mid-1980s, an even faster increase in temperature was observed – about 0.77°C/10 years.

Volga runoff

A decrease in moisture content in the last 30 years has been observed throughout the entire territory of the Volga basin, especially in its southern part. In general, an increase in water runoff is noted only in the Kama basin. Since 1996, the mean long-term runoff of the Volga at the apex of the delta has decreased to 236 km^3 in comparison with the previous period (267 km^3). The characteristics of the flood, the most important hydrological event for the sustainability of the Volga-Caspian ecosystems, have also changed. The volume of water runoff has decreased (on average, from 161 to 145 km^3). The duration of the high water decreased to 67 days, which is less than even in the previous dry period (up to 1978), when the high water lasted 74 days on average. The peak of the flood shifted from the last ten days of May to its middle (May 15) [2].

Sea level

The Caspian Sea level is extremely sensitive to changes in climatic conditions in its basin and can serve as an indicator of them. During the period of instrumental observations of the level, the range of its fluctuations reached 4 m, from -25.3 m in the eighties of the XIX century to -29.0 m in 1977. In 1978-1995, there is a sharp increase in the level, which reached 2.5 m by 1995 [1]. Since the late 1990s, the sea level began to decline, and by 2020 it reached the level of -28.23 m BS. This year, the level is expected to fall further by another 15-20 cm.

Sea water temperature

According to the Federal Hydrometeorological Service data, the water temperature in the sea has also increased by an average of 1.5-2.0°C. In comparison with the previous period, there are higher average temperatures of the surface water layer in summer and autumn. And during the high-water period, on the contrary, the water temperature decreased. This is due to the fact that in conditions of low water, the regulatory role of the Volga cascade of reservoirs increases, which, in an effort to save water, reduces the phase of high-water rise. The shortened rise time of the flood wave with a high intensity of level growth leads to the fact that the water masses do not have time to warm up [2]. It is also necessary to note a noticeable increase in water temperature in the autumn low water, on average it increased by 36 % compared to the previous period. At the same time, the difference in average temperatures between the shallow and deep-water areas of the sea has practically disappeared.

Salinity of sea waters

In recent years, the salinity of the waters of the Northern Caspian Sea has increased by an average of 2‰ compared to the previous period due to a decrease in the volume of river runoff. Salinization occurred mainly due to the bottom waters. A statistically significant increase in salinity was observed in the bottom layer for all hydrological seasons and for the entire water area of the northwestern part of the sea. The increase in salinity in the surface layer is mainly characteristic of the shallow water zone during high water and summer autumn, on the contrary, lower salinity values are observed here. In deep-water areas, the increase in salinity (within 1‰) was statistically significant only during the high-water period. The modern period is characterized by a greater spatial heterogeneity of the temperature and salinity fields compared to the previous period of 1978-1995, which is probably due to the weakening of the influence of runoff currents due to a decrease in the volume of fresh river water entering the sea. The decrease in the volume of the Volga runoff at the present time and the lowering of the sea level has led to the fact that local flow systems determined by the orography of the bottom have become more noticeable in the water area.

Oxygen regime of water

The solubility of oxygen depends on the water temperature, so its concentration in the water of the Northern Caspian increases in spring and autumn, decreases in summer. The increase in the temperature of sea water is associated with the decrease in the content of dissolved oxygen observed in it in recent years. Our research shows that, on average, in recent years, compared to the previous period (1978-1995), the average annual indicator of water oxygen saturation has decreased by about 3.5% in the deep-water zone of the Northern Caspian (with depths of more than 5-7 m). There is also a large spatial heterogeneity of the oxygen concentration compared to the high-water period, which is associated with the above-mentioned changes in the thermohaline structure of waters.

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Translated from Russian

Modern changes in atmospheric precipitation on the Absheron Peninsula of Azerbaijan

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As it is known, in recent years, an increase in air temperature has been observed in most regions of the world. Since the air temperature is the most important characteristic of the climate, a change in its statistical characteristics may lead to a restructuring of the processes of heat and moisture exchange in the atmosphere, which in turn affects the processes of precipitation formation.

Against the background of a significant increase in air temperature in bigger part of the Azerbaijan Republic, especially in the lowlands, a significant reduction in precipitation is observed, which leads to drought and creates serious problems in agriculture, ecology, water supply etc. On the contrary, a slight increase in precipitation is observed in some places on the southern slope of the Greater Caucasus. Changes in the precipitation regime are manifested not only in an increase or decrease in their amount, but also in the recurrence of cases with intense precipitation, which in most cases are accompanied by dangerous phenomena such as hail, floods, mudflows etc. [1].

During the cold period of the year, cases of intense precipitation have become more frequent on the Absheron Peninsula, especially in Baku, as a result of which significant damage has been caused to the urban infrastructure, and landslide processes have intensified. For this reason, the study of changes in the precipitation regime on the Absheron Peninsula and the adjacent marine area is of great interest. The location of Baku and the third largest city of Sumgayit in this area increases the relevance of this problem. On the other hand, since precipitation is one of the important elements of the water balance of the Caspian Sea, its changes can affect the fluctuation of the sea level.

Based on the observations of 6 hydrometeorological stations (Sumgayit, Baku, Mashtaga, Chilov, Pirallakhy and Neft Dashlary) in 1961-2017, the nature of changes in the precipitation regime on the Absheron Peninsula is studied in this work.

Data for the period 1961-1990 were used as climatic precipitation norms. The average monthly, seasonal and average annual precipitation amounts, their anomalies and the values of standard deviations for the periods 1961-1990 and 1991-2017 are calculated.

There are various trends in the temporary changes in annual precipitation. Of particular interest is the statistically significant positive linear trend for the Baku station and the negative trend for the Chilov and Neft Dashlary sea stations at the level of 5%.

A characteristic feature of modern climatic changes in the precipitation regime of the studied region is that in all ground stations there is an increase in precipitation in the cold half-year, and a decrease in the warm half-year. The most significant increase in precipitation is observed in the autumn months. In marine stations, a slightly different picture is observed: a decrease in precipitation is observed in both warm and cold half-years, but the amount of precipitation reduction in the warm half-year is much greater (Tab. 1).

Tab. 1. Distribution of precipitation anomalies (mm) by season and half-year in 1991-2017

Stations	Season				Half-year	
	Winter	Spring	Summer	Fall	Cold	Warm
Sumgayit	-0,9(28,0)	-8,7(28,4)	-2,0(21,6)	18,1(47,1)	17,2(57,0)	-10,7(47,3)
Baku	37,5*(51,4)	-8,8(30,0)	0,1(16,7)	48,6*(65,0)	86,1*(79,1)	-8,7(37,6)
Mashtaga	16,7(61,3)	-18,1*(29,5)	-0,5(12,6)	16,2(73,1)	32,9(74,9)	-18,6*(33,6)
Pirallakhy	5,9(36,6)	-13,0(24,9)	-1,2(10,3)	13,9(44,3)	19,8(50,5)	-14,2(31,2)
Chilov	-9,4(29,0)	-19,7*(22,4)	-3,8(6,2)	-1,4(29,9)	-11,3(38,4)	-23,5*(48,4)

Note: 1) standard deviations in brackets;

2) * - statistically significant anomalies at the $p = 0.05$ level.

Along with general changes in the amount of precipitation, study of changes in the frequency of intense precipitation is also of great interest. It was found that for the period 1991-2017, compared with the period 1961-1990, the number of days with precipitation exceeding 10, 15, 20, 25, 30 mm increased by 1.3-1.6 times [2].

In recent years in the autumn months, intense precipitation in most cases is presented by heavy showers with thunderstorms, what indicates the activation of convective processes in the territory under consideration.

As can be seen, changes in the precipitation regime in the Absheron Peninsula are beyond doubt and can be associated with various reasons. These include changes in the hydrometeorological regime of the Caspian Sea, including an increase in sea surface temperature (SST), changes in the nature of atmospheric circulation, changes in land characteristics etc.

A sharp increase in the amount of precipitation and the number of days with intense precipitation in the autumn-winter period on the Absheron Peninsula, especially in Baku, led to a number of problems, including flooding in streets and tunnels, rising ground water levels etc. The activation of landslide processes in various parts of Baku in recent years can also be explained by an increase in the amount and intensity of precipitation in the autumn-winter period. Also of great concern is the reduction of precipitation on the sea surface, which, against the background of an increase in SST and, accordingly, an increase in evaporation, could lead to a further decrease in the level of the Caspian Sea.

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Evaluation of climate model simulations of the Caspian Sea region

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The Caspian Sea is the world's largest inland water body and comprises several climate zones [9, 11]. Its water level varied by several meters in the recent past [1, 2] and underwent multiple phases of regressions and transgressions with an amplitude of more than 100 m since its evolution [10, 11]. Such different water levels lead to large variations in lake area and moisture availability in the atmosphere and thus also affect the regional climate [6, 13, 13].

We analyse the climate in the Caspian Sea region in pre-industrial control (and/or historical) climate model simulations conducted within the Coupled model intercomparison project phase 6 (CMIP6) [8] in comparison with ERA5 reanalysis [7] data. Key climatic features in the Caspian Sea region will be identified and it will be studied how well the climate of the Caspian Sea region is represented in current global climate models. We hypothesise that the complex terrain such as the Caucasus and sharp orographic transition between the Caspian Sea and Elburz Mountains require higher spatial model resolutions in order to represent the regional atmospheric circulation and climate [5, 12, 15]. This can be achieved using regional climate models that will be conducted as a next step.

Our findings will not only be used for present day's conditions, but we will also analyse the climate of the Caspian Sea region for selected time periods, such as the Last Glacial Maximum (LGM, 20,000 years BP) [3] and the Last Interglacial (LIG, 127,000 years BP) [4]. The global climate and boundary conditions during these paleo periods were substantially different than today. During the LGM, for example, large ice sheets covered the northern hemisphere and the greenhouse gas concentrations in the atmosphere were lower than today, leading to a significantly colder and drier global climate [3]. The LIG, on the contrary may serve as a partial analog for future climate change, as global mean temperatures were 1-2°C higher than today [4, 14].

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Translated from Russian

Storm surges in the nothern part of the Caspian Sea and atmospheric circulation

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Introduction

The regime of various components of the climate system and related phenomena, including hazardous hydrometeorological phenomena such as storm surges, are changing against the background of climate change. The study focuses on current changes in the regime of storm surges in the Northern Caspian and related synoptic situations.

Materials and methods

The modelling of the maximum fluctuations of storm surges in the Caspian Sea was conducted using the ADCIRC model. Water level difference serves as the criterion for the detection of storm surges. Cases with the storm surges exceeding one meter were selected for the surge calendar. Based on the results of the modelling, 49 occurrences of negative and positive surges have been identified for the 1990-2015 period. The area flooded as a result of a surge, expressed as a percentage of the maximum possible flooding area, was also estimated.

Information on atmospheric pressure at sea level and geopotential at a height of 500 hPa based on ERA5 reanalysis data was used to study and describe the synoptic factors of storm surge formation. Atmospheric pressure and geopotential anomalies, i.e. their deviation from multiannual averages over the 1990-2015 period, were analyzed for each of the 49 surge incidents.

Results and conclusions

The annual course of monthly storm surges in the northern part of the Caspian Sea is presented in Fig. 1. Beginning in May and ending in September, the number of storm surges was minimal or nonexistent during the selected 1990-2015 period.

The anomalous fields of pressure and geopotential for storm surges were grouped according to their configuration and relative position of the baric formations, resulting in two main groups. The first group (53% of cases) clearly shows a pattern of large high-pressure anomalies – anticyclones to the north and northeast of the region under study. The second group is determined by the intrusion of cyclones in the European part of Russia, the Caucasus and Northern Caspian region, what is indicated by negative pressure anomalies (blue) in the schematic maps. The relative position of cyclones and anticyclones can intensify the existing baric contrasts between the centers of circulation in most cases of this type, thus increasing the indices of the wind fields. Composite field maps for these two types are provided in Fig. 2.

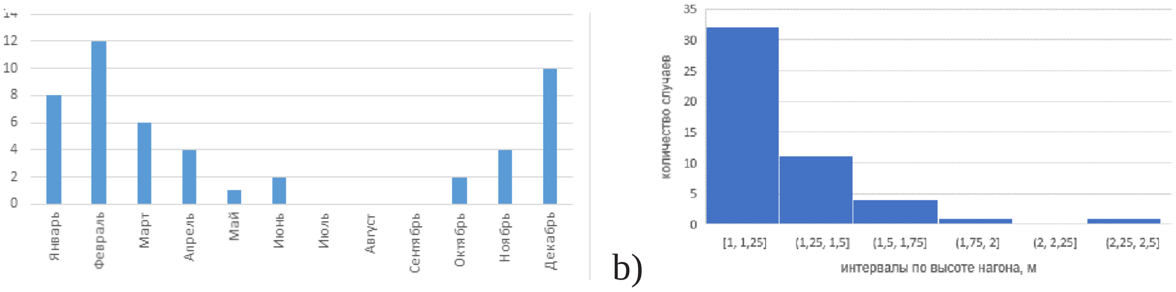

Fig. 2. Main types of surface circulation: left – first type, right – second type.

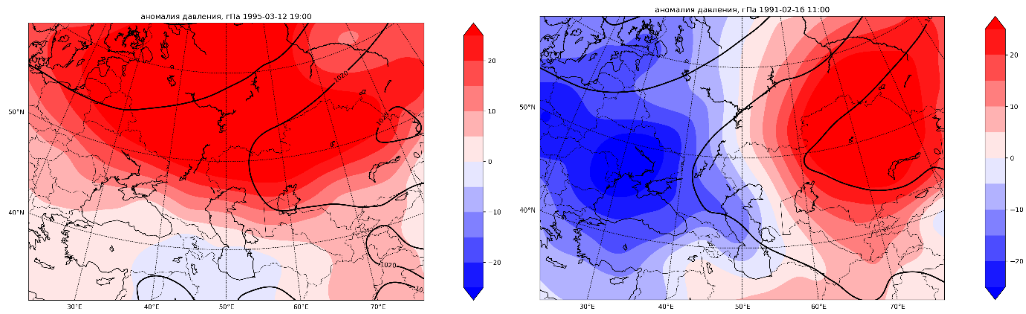

Fig. 1. Annual course of the number of surges per month (a) and frequency of surge heights based on data for the whole period (b)

Based on the obtained results, a storm surge calendar for the northern Caspian Sea was generated, based on which an electronic database of atmospheric pressure and geopotential for surge events was compiled. It is shown that most of the surges (87% of the cases recorded by the model) amount to a height of up to 1.25 m, while the height does not exceed 1.5 m for the greater part of the sample. The area flooded as a result of storm surges, expressed as a percentage of the maximum possible flooded area, is revealed to be 41.5% on average. In view of the fact that the parameter of the maximum possible area of flooding depends on the average annual level of the Caspian Sea, if this phenomenon is considered from the point of view of economic activity in the coastal zone, quantitative estimates of the flooding of the territory will change. Nevertheless, this indicator interprets the qualitative index of flooding of the territory and characterizes the power or potential danger of storm surge formation in this area.

The analysis of the surface pressure fields and H500 made it possible to distinguish two main types of baric fields that accompany storm surges. Both types are characterized by southerly and southeasterly winds. This is the first time that such a long series of model-derived data on storm surges has been used to analyze the temporal variability of surges for 25 years against the background of modern changes of climate.

Translated from Russian

The river flow projection in the Russian part of the Caspian Sea catchment basin

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The increase in the temperature of the surface air layer observed in the last decade will contribute to changes in the functioning of natural systems and human economic activity. For the Caspian Sea region, an important consequence of these changes will be their impact on the volume of river flow. Changes in river runoff volumes, as well as water level across river basins, caused by climate change, depend primarily on changes in the amount and timing of precipitation [1]. Changes in the regime, intensity and extreme values of precipitation can affect the average annual flow of rivers. The aim of the study is to assess future changes in river flow in the Caspian region of Russia (Volga, Terek and Sulak) using global climate models.

The materials of the study were the data on the average annual amount of atmospheric precipitation that are freely available (Internet aggregator of meteorological data "Weather and Climate"), as well as the archived data of the KaspMNITs on the average annual flow of rivers. Projected changes in precipitation over the current century were derived from scenario forecast data based on global simulations of Phase 5 of the International Comparison Models Project (CMIP5). The analysis of the obtained data series was carried out using the capabilities of MS Excel.

The theoretical prerequisite for the study was the assumption of the dependence of the volume of river runoff on the amount of precipitation in the catchment basin of rivers. Comparison of the data series of atmospheric precipitation and river runoff from 1961 to 2019 made it possible to obtain regression dependences of runoff on atmospheric precipitation. We assumed that the resulting dependence will persist throughout the entire study period calculated until the end of the 21st century. Analysis of trends in the amount of precipitation was carried out for the river basins: Volga, Terek, Sulak, Ural showed the relationship of river runoff with the amount of atmospheric precipitation. The connection was especially pronounced for the Volga and the Urals. The linear regression equation for the dependence of runoff and precipitation was obtained as a result of statistical analysis of long-term data. The precipitation data for the catchment basins for the base climatic period (1981-2000) were obtained on the basis of the reference and information portal “Weather and Climate”, the volumes of river runoff for the same period were provided by the structural units of Roshydromet.

The resulting equation was used for an estimated runoff forecast on the territory of the Russian part of the catchment area of the Caspian Sea. Climate changes are considered for the beginning (2011-2030), middle (2041-2060) and end (2080-2099) of the XXI century, in relation to the base climatic period [2]. For this, the expected precipitation values calculated from the scenario forecasts of the Climate Center of Roshydromet based on global models (CMIP5) [2] under the conditions of the RCP family (RCP, Representative Concentration Pathways) [3] were substituted into the equation.

The analysis of the calculated forecasts indicates an increase in precipitation and shows an increase in the flow availability of the catchment basin of the Caspian Sea on the territory of the Russian Federation (Tab. 1), in comparison with the period 1936-2019 (Tab. 2), despite climate warming: according to the same climatic models, the average annual air temperature in the periods 2041-2060 and 2080-2099 in the study area will increase by an average of 3°C.

Tab. 1 – Forecast of the flow volumes of the main waterways of the catchment basin of the Caspian Sea (km^3)

Period	RCP Scenario														
	Volga			Ural			Terek			Sulak			Total		
	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5
2011-2030	258.0	257.3	258.0	9.9	9.9	9.9	7.7	7.7	7.7	4.9	4.9	4.9	280.5	279.8	280.5
2041-2060	258.0	260.2	260.6	9.9	9.9	9.9	7.7	7.7	7.7	4.9	4.9	4.9	280.5	282.7	283.2
2080-2099	258.0	272.3	278.6	9.9	10.2	10.6	7.7	7.7	7.6	4.9	4.9	4.7	280.5	295.1	301.5

Tab. 2 - Average long-term runoff volumes of the main waterways of the Northern Caspian

Water body	Runoff volume, km3	Period of observation
Ural	8.1	1936-2017
Terek	6.4	1965-2019
Sulak	4.8	1976-2019
Volga	242.2	1961-2019
Totally	261.5	

However, according to the forecasts of the State Oceanographic Institute, the level of the Caspian Sea will decrease in the coming decades. An increase in the provision of river runoff will entail an increase in the flow rate in the main watercourses of the channel network of the drainage basin, and, as a consequence, an intensification of erosive processes, which in turn can lead to the death of side streams that provide water to small agricultural enterprises in the estuarine area. The delta cone in such conditions is carried out into the sea, which can lead to drying up of watercourses in villages.

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Translated from Russian

Temporary and spatial change of heat waves in the Caspian region of Russia

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In the face of climate change, the number of hydrometeorological hazards is increasing both globally and in Russia [3], which calls for the need to study extreme weather events that have an impact on various sectors of the economy and the environment, taking into account the specifics of the geographical region. With global climate warming, studying the number, frequency and duration of heat waves is becoming increasingly relevant, especially for agriculture, health and water resources.

The heat wave characteristics for the Russian sector of the Caspian Sea region (Astrakhan Oblast, Republic of Kalmykia and Republic of Dagestan) were investigated. The climate of the Caspian Sea region is mainly arid, with distinct spatial variations in surface air temperature influenced by various climatic features. The mountainous part of the Caspian region of Russia lies entirely within the temperate climate zone of the southern zone [4].

The Climpact software (ETCCDI) [1] was used to calculate climatic indices based on daily maximum and minimum air temperature data. The study materials were based on the set of observations of maximum and minimum daily air temperatures and daily precipitation at Astrakhan, Upper Baskunchak, Elista, Lagan, Yashkul, Makhachkala, Derbent and Buynaksk stations for the period from 1961 to 2020, where 1961-1990 was considered a stable baseline period. Average characteristics of heat waves for the following 30-year periods (1971-2000, 1981-2010, 1991-2021) were calculated.

The Climpact software features allow for the analysis of about 100 different indices. Using a comparison of index variance for the stable baseline period and for the most recent 30-year period, we identified significant differences between the periods. From the obtained indices with significant differences, 4 differences observed at most hydrometeorological stations were selected. Among the selected indices were the HWF index parameters as well as the HWD index, describing various heat wave characteristics.

Two percentile-based temperature indices were used to calculate heat waves: the

90th TX percentile (maximum temperature), when TX> 90th percentile of the TX series and the 90th TN percentile (minimum temperature), where TN> 90th percentile of the TN series [1]. Moreover, the excess heat factor (EHF) as well as a combination of two excess heat indices (EHI) representing acclimatization to heat (EHI (accl.)) and climatological value (EHI (sig.)), were used in the study [2].

To calculate the TX90p and TN90p values, only heat waves observed in the period from May to September were used. We understood a heat wave as a period lasting three or more days in a row, when either EHF is positive, TX> 90th TX percentile of TX, or TN <90th TN percentile [1]. Percentiles are calculated based on a 30-year reference period. The TX90p and TN90p temperature indices were used to analyze the annual values of the following indices:

- The duration (in days) of the longest heatwave (HWD) during the year, defined by either the excess heat factor (EHF) coeffcient, the 90^{th} TX percentile or the 90^{th} TN percentile, defined by the HWN;

- Heat wave frequency (HWF) defined by the excess heat factor (EHF) coefficient, the 90^{th} TX percentile or the 90^{th} TN percentile, the number of days contributing to the generation of heat waves as defined by the HWN;

- Heat wave number (HWN) defined by the excess heat factor (EHF) coefficient, the 90th TX percentile or the 90th TN percentile.

Tab. 1. Changes in the characteristics of heat waves in the Caspian region for the 1961-2020 period

Region	Time period, yrs.	EHF_heatwave (HWF)	_tn90_heatwave (HWF)	tx90_heatwave (HWF)	tx90_heatwave (HWD)
Astrakhan region	1961-1990	5	3	5	5
	1971-2000	5	4	6	5
	1981-2010	10	6	9	6
	1991-2020	16	9	14	7
Republic of Dagestan	1961-1990	2	3	2	4
	1971-2000	3	3	3	5
	1981-2010	6	4	6	5
	1991-2020	15	8	11	6
Republic of Kalmykia	1961-1990	4	2	4	5
	1971-2000	6	4	5	5
	1981-2010	9	6	8	6
	1991-2020	14	9	12	6

All the analyzed indices show an increase in their values in the latest period compared to the baseline climate period. The largest absolute increase in values is seen in HWF. For the Republic of Dagestan, the index has increased by more than 7 times. The HWD index was the most stable; on the whole, its increase in values amounted to 1-2 points. The territory of Kalmykia was the least affected by changes in heat wave characteristics.

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Projected changes in precipitation intensity in the southern coast of the Caspian Sea using a CMIP6 multi-model ensemble

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Introduction

Precipitation is one of the key climate variables and any changes in the characteristics of it (intensity and frequency) is very important. Increasing the frequency of extreme precipitation events may have major impacts on society causing floods, soil erosion, damage to urban infrastructure and water resources, as well as impacts on transportation and public safety [2]. Therefore, analysis of extreme precipitation changes in these areas on one hand provides a more detailed framework of precipitation variability in the region and on the other hand helps to get prepared to deal with the risks caused by them. The purpose of this study is to investigate the anomaly of precipitation by using Simple Daily Intensity Index (SDII) and its projection by the end of the 21th century on the southern coast of the Caspian Sea.

Material and methods

Study area

The study area is the southern coast of the Caspian Sea in Iran. This region includes the three provinces of Golestan, Mazandaran and Gilan. The minimum height of this area is less than 26 meters and the maximum is more than 5600 meters in the Alborz Mountain range. The Caspian coast is the rainiest region of Iran and it is important to study its precipitation changes in the context of climate change.

Observations and CMIP6 Simulations and Scenario Data

We used precipitation data of CMIP6 models from the Inter-Sectoral Impact Model Inter-comparison Project (ISIMIP) archived for the first realization (‘r1i1p1f1’) for 5 GCMs (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL) (Resolution 0.5^{o}). Time series of precipitation (1975-2014) from ground stations was used to evaluate the historical period of CMIP6 models. The ISIMIP project data use WATCH Forcing applied to ERA5 (W5E5) [1] for BC climate data.

This Research examined SDII projection under three Shared Socioeconomic

Pathways (SSP) scenario [3], including SSP1-2.6 (Low for mitigation and adaptation), SSP3-7.0 (High for mitigation and adaptation), and SSP5-8.5 (High for mitigation, low for adaptation). For analyzing the SDII, we divided the time into three 40-year periods including historical period (1975-2014); future periods of 2021-2060 (near future) and 2061-2100 (far future).

The independence weighted mean method was applied to generate the Multi Models Ensemble (MME). We applied the non-parametric extreme climate indices and specifically focused on the SDII which is mean of RR over 10 days; in which RR > 1mm (wet days), where RR is the daily precipitation sum. This indicator provides information on possible runoff losses.

Results and discussion

The study of simple daily intensity index (SDII) in the historical period in the study area shows that in general, the SDII fluctuates between 4.6 to 13.8 mm day in the southern coast of the Caspian Sea and its maximum reaches 13.8 mm/day in the western Caspian Sea. In the southern parts of the study area, the SDII is less than 10 mm/day. In overall, the index is low in the southern Caspian coast despite the very high annual rainfall. This indicates the appropriate distribution of precipitation throughout the year, in other words, the not very high contribution of extreme precipitation in the total annual precipitation on the Southern Caspian coast.

Investigating the projected SDII on the Caspian coast shows that in most areas except Ramsar in the west of Mazandaran province, there would be positive anomaly in other areas. The maximum increase in the SDII is observed in SSP5-8.5 scenario, according to which in most areas, especially in the eastern coast of the Caspian Sea, a positive anomaly is observed with a value of 0.7 mm/day. It is noteworthy that SDII increases the near future (2100-2061) compared to the far future (2060-2021). Accordingly, the contribution of extreme precipitation increases compared to annual precipitation. Projections indicate that the SDII in the east coast of the Caspian Sea is higher than in western regions. Due to the drier climate in the central and western coasts of the Caspian Sea, this increase is a serious threat to surface water management. Moreover, increased precipitation intensity is a serious threat to flooding on the southern coast of the Caspian Sea, according to the results of the CMIP6-MME model.

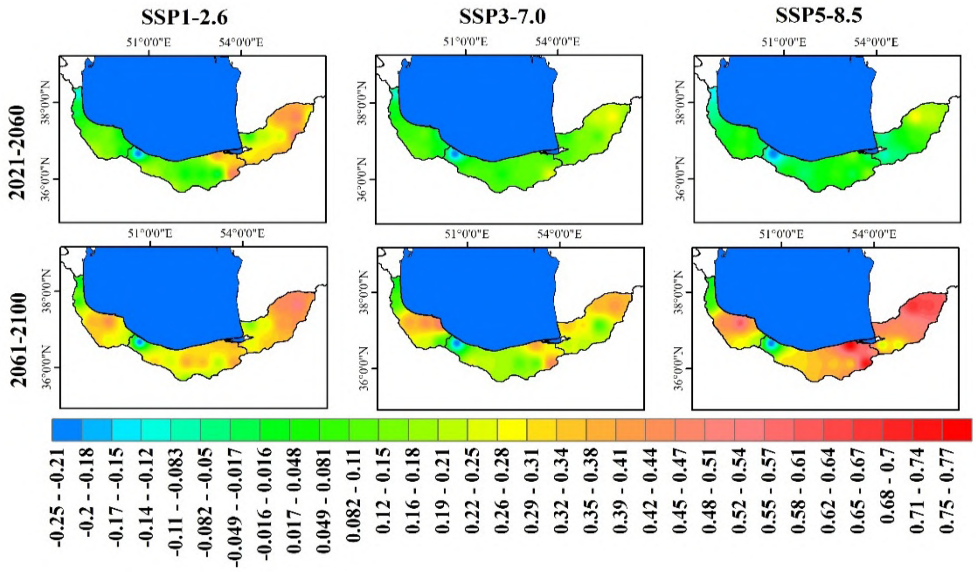

Fig. 1. Projection of intensity of daily precipitation (SDII) based on CMIP6-MME

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Glossary:

CMIP6 – Coupled Model Intercomparison Project Phase 6

GCM – Global Climate Model

ISIMIP – Inter-Sectoral Impact Model Inter-comparison Project

MME – Multi Models Ensemble

RR – Rainfall rate

SDII – Simple Daily Intensity Index

SSP – Shared Socioeconomic Pathways

Translated from Russian

The role of satellite observation systems data while researching the water surface temperature of the Caspian Sea

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As a result of accidents on oil tankers, or ruptures in underwater pipelines, oil is distributed over the water surface of the sea in the thinnest monomolecular layer, contributing to the climate formation with changes in water surface temperature and further deterioration of the state of coastal ecosystems. Thereby, it leads to the necessity of using the remote methods and means of their detection.

Information about the temporal variability of the surface temperature is required to study biological communities, ice regime, evaporation amount, heat balance, climate conditions of the adjacent sea area etc. The temperature change during the month, depending on season and meteorological conditions, in different areas of the sea goes in different ways. This work considers the temporal structures of the surface temperature. This makes it possible to compile maps of temperature fields both on the basis of individual contact measurements, and from satellite remote sensing data [4].

In [2], the distribution of the studied values of water surface temperature (WST) and organic albedo (A_{org}) over the entire water area of the Caspian Sea was analyzed (Fig. 1).

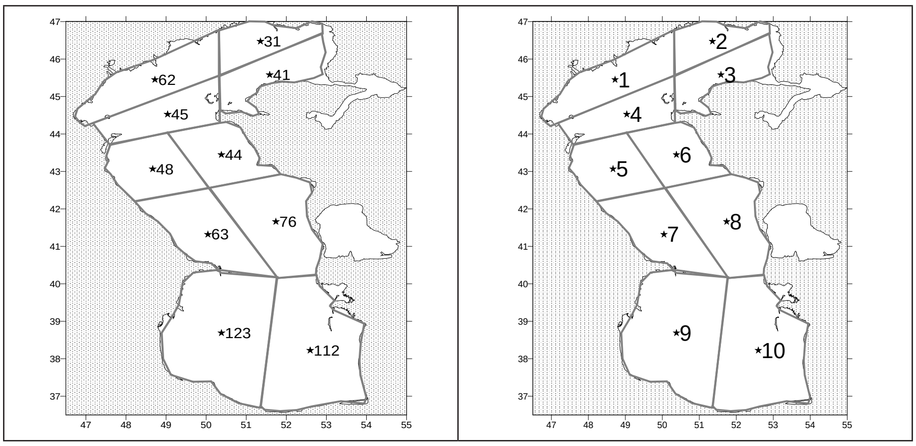

Fig. 1. A diagram of the sections indicating the numbers of nodes that fall into each of them (on the left) and the numbers of the sections with the position of their geographical centers, where the average values are assigned (on the right).

The albedo of the Atmosphere-Ocean System was presented in a linearized form [5]:

A 0.6 = Apost 0.6 + Aatm 0.6 + Aglint wav 0.6 + Aorg 0.6, (1)

A 0.8 = Apost 0.8 + Aatm 0.8 + Aglint wav 0.8 + Aorg 0.8, (2)

where Apost 0.6, Apost 0.8, is albedo of pure water in a transparent atmosphere (horizontal visibility range over 100 km), Aatm 0.6 and Aatm 0.8 – albedo of atmospheric dust, Aglint wav 0.6 and Aglint wav 0.8 – the albedo of the water surface due to solar glint and waves, Aorg 0.6 and Aorg 0.8 – the albedo of the organic suspension at the wavelengths of 0.6 and 0.8 microns.

Based on the identity of the spectral path of the Aatm and Aglint wav values for both wavelengths, that follows from:

the average ratio of changes in the albedo in clear air at wavelengths of 0.8 and 0.6 microns is 0.92±0.08 [6];

the average ratio of changes in the albedo of the water surface due to the waves and solar glint at wavelengths of 0.8 and 0.6 microns is 0.85± 0.15 (the authors' assessment from satellite observations in 5 years);

the average ratio of changes in the albedo of the water surface due to organic suspensions at wavelengths of 0.8 and 0.6 microns is 0.1±0.02.

The values of Aatm and Aglint wav could be combined into Anoise. After that, the system of equations (1) – (2) is represented as (3)-(4):

A 0.6 = Apost 0.6 + Anoise 0.6 + Aorg 0.6, (3)
A 0.8 = Apost 0.8 + Anoise 0.8 + Aorg 0.8, (4)

Further, considering the above spectral contrasts of the albedo of organic suspensions, albedo of atmospheric aerosol and albedo due to solar glint and waves, we can represent expressions (3) and (4) in the form of (5) and (6):

A 0.6 = Apost 0.6 + Anoise 0.6 + Aorg 0.6, (5)
A 0.8 = Apost 0.8 + 0.85 * Anoise 0.6 + 0.1 *Aorg 0.6 (6)

By solving this system of equations, we get the following representations for the albedo of organic suspensions and the total albedo due to the atmosphere and waves [3]:

Aorg 0.6 = (0.85 *(A 0.6 – Apost 0.6) – (A 0.8 – Apost 0.8) / (0.85 – 0.1), (7)
Anoise 0.6 = A 0.6 – Apost 0.6 – Anoise 0.6 (8)

Water albedo values for a transparent atmosphere Apost 0.6 and Apost 0.6 are calculated according to the LOUTRAN–5 procedure [7].

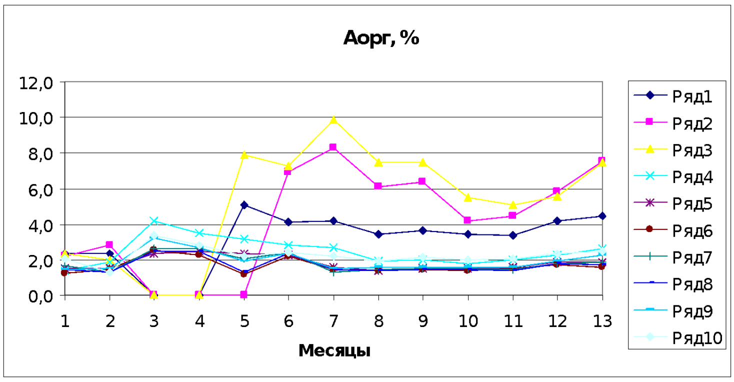

Fig. 2. Graphs of the average monthly Aorg values for ten areas of the Caspian Sea.

The described approach to the albedo of organic suspensions assessment reduces by three times the errors in the estimation of the albedo of organic suspensions; however, it either does not separate the contributions to the total albedo of the ocean-atmosphere system due to the atmosphere and waves, and the errors of calculations in shallow water are not eliminated due to the reflected solar radiation from the bottom and turbid inorganic suspensions [3].

Variations in the radiation temperature of the Earth due to changes in the water vapor content in the atmosphere reach 6-80K. These variations are considered, taking into account the fact that the attenuation of radiation due to water vapor at a wavelength of 12 microns is approximately twice as high as at a wavelength of 11 microns [1, 5]. Therefore, the simplest assessment of the radiation temperature of the water surface is the difference between the doubled radiation temperature at a wavelength of 11 microns and the radiation temperature at a wavelength of 12 microns. This is exactly what the French researchers do, further calibrating the results obtained according to vessel data. The NOAA Agency offers slightly different coefficients for radiation temperatures at wavelengths of 11 and 12 microns, as well as considering the angle of the satellite sensing, such as:

$$RTWS = k1 \cdot T11 - k2 \cdot T12 + k3 \cdot (T11 - T12) \cdot (\sec(\tau) - 1), \quad (9)$$

where RTWS is radiation temperature of the water surface; T11 and T12 – radiation temperatures at wavelengths of 11 and 12 microns, respectively; k1, k2 and k3 - weight coefficients; k1 and k2 are assumed to accepts values from 1 to 4, and the value of the coefficient k1 is taken approximately one plus than k2; k3 - 0.7; τ – the angle of the satellite sensing.

More than ten coefficient values for k1, k2 and k3 are given in the literature. The radiation temperature of the water surface differs when using certain coefficients by 0.5-1.5 K. This is explained by the fact that the distorting effect due to water vapor depends on its temperature, atmospheric pressure and stratification, and the current values of these parameters are known approximately. Therefore, many variations in the values of the coefficients are due to regional, geographical features of the structure of the atmosphere. When numerically analyzing the fields of water temperatures obtained from the fields of radiation temperatures of water, the latter should be pre-calibrated against the test thermodynamic temperatures obtained during contact measurements [8].

Conclusion

Considering a number of ongoing processes during the spill of oil films on the sea surface, it is possible to characterize the latter’s impact on the water surface temperature and, in the future, on climate changes in the selected research area.

This is a kind of form supported by the main parameters for determining the albedo of organic suspension on the water surface, as well as the water surface temperature using modern methods and remote sensing tools.

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Preface to the Collection of the Conference on

Section 2

The Caspian Sea level change: analysis, modeling, and long-term projection

Scientific conference on climate change in the Caspian Sea region

(27 - 28 October 2021 online)

Preface to the Collection of the Conference on Section 2

Introductory Speech – Mikhail Bolgov

The Caspian Sea is the largest inland water body that has no connections with the world ocean. Its regime is characterized by a large amplitude of level fluctuations and is sensitive to the volumes of irreversible withdrawal of runoff in the basins of inflowing rivers, to the ongoing climatic changes.

Poorly predictable fluctuations of the Caspian Sea level are the main natural factor affecting the economic development of the coastal strip, the state of its ecosystem, and the sectors of the economies of the littoral states that use natural resources of the region.

The complexity of the process of long-term fluctuations of the Caspian Sea level and its poor predictability are the result of insufficient hydrometeorological knowledge of a natural object of such significant size. The series of observations are limited in duration, there are no direct measurements of such components of the water balance as evaporation and precipitation on the water surface of the sea, water exchange with groundwaters is poorly studied. There is no reliable information about irreversible water consumption in river basins. The task of forecasting sea level is significantly complicated by climatic and anthropogenic changes in runoff in the basin and a number of other factors that are difficult to predict.

The task of forecasting sea level for the long term is very relevant, since the risks associated with this problem are very significant. Risk reduction is possible in various ways, among which the ideas of water level management in the Caspian Sea could be mentioned. The study of this issue demonstrated that the management of the sea level regime in modern conditions is possible only on an extremely limited scale, therefore, the main principle of the economic use of coastal areas should be the principle of adaptation to unpredictable changes in its level, including such financial mechanisms as insurance of possible risks.

Nevertheless, numerous applied problems require a scientifically based methodology for forecasting sea level for a period of time that is significant for the development of economy sectors that use water resources. The solution for the task of forecasting the level of a closed reservoir is carried out mainly within the framework of a probabilistic approach involving the balance representations and probabilistic models of "stimulating" processes of varying degrees of complexity.

The reports presented at the section on the Caspian Sea level fluctuations considered various aspects of this problem. At first, a modern assessment of the main components of the water balance was provided. It was demonstrated that if the total inflow to the Caspian Sea over the entire observation period as a stationary random process is considered, then the Markov model could be used for its description. However, the data analysis made it possible to distinguish three periods corresponding to the phases of increased and decreased water content in the sea basin. For simulation modeling of such a piecewise-homogeneous series, it is possible to use more complex models of long-term fluctuations.

Assessments of evaporation from the water surface were the subject of detailed discussion in a number of presentations. Evaporation is the main expenditure component of the water balance of the Caspian Sea; direct measurements of evaporation are not carried out, therefore a calculated approach is used. The actual formulation of the problem of assessing evaporation from the sea surface is the use of meteorological reanalysis data, and for long-term forecasting, the use of the results of calculations based on global climate models. It should be noted that the use of climatic models (models of the earth system) in hydrological tasks is limited today due to the low accuracy of the results of precipitation modeling, and other factors in the formation of runoff, what was the reason for the appearance of forecasts, for example, for a drastic decline in sea level by several meters. The emergence of such forecasts is related to the underestimation of significant factors in the formation of the water balance of the Caspian Sea and a significant "cross-model" spread of scenario estimates.

Another idea that makes it possible to explain the mechanisms of the formation of the Caspian level is the use of the outcomes of paleo-geographical studies (reconstructions). The long reconstructed series, although not particularly accurate, nevertheless allow to discuss scenarios for the possible development of the hydrological situation.

In general, the discussion on the presentations presented at the section demonstrated interest in the problem of all the Caspian littoral states and made it possible to formulate a number of proposals, among which international cooperation of scientists in this field is an indispensable condition for further progress in the problem of the level regime of the Caspian Sea.

Spectrum analysis of the Caspian Sea level changes

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The Caspian Sea (CS) is largest inland water body in the earth with volume of ~78,000 km^3 and a surface area of ~371,000 km^2 extending 1200 km from north to south, and 320 km from west to east. The CS in respect to the physico-geographical and topography conditions divided in three basins; southern, central and northern basins. The mean CS level is currently approximately ~28.0 m below world ocean level [1, 2, 3, 5] and the deepest part of the lake located in southern part.

Without a connection to the ocean, the CS level mainly controlled by rivers inflow, precipitation, evaporation and discharge to Kara-Bogaz Bay. About 130 rivers flow into the CS and the main river inflow is the Volga, which discharges into the northern basin, contributing about 80% of the total river runoff [5, 7]. Due to wide watershed area of the CS, the CS level particularly is sensitive to climatic condition in the catchment area and also inter-decadal climate fluctuations. The ratio between the CS surface area and the catchment basin (1:10) revealed that the processes proceeding in the entire basin on its natural conditions has momentous effects [5, 8].

The mean sea level changes are one of the most descriptive signs of the global climate change. The sea level changeability in each region is influenced by regional and global various factors. Regional and global climate change cause to an increase in air temperature, sea level changes, as well as to a desertification in some areas [8].

In this paper, spectral analysis is used to investigate the CS level changes using historical tide gauge data. Spectral methods decompose and transport a time series from the time domain into the frequency domain, where it is possible to determine both dominant modes of variability and how those modes vary in time [4]. Using Wavelet technics, it is possible to capture localized energies, which indicate the exact signal-occurrence time by translating signals into the time domain.

Historical tide gauge data of the CS level revealed that this basin's level changes were about 3m from 1900 to 2017. From 1900s to 1970s sea level decreased three times with 6.53, 19.86 and 5.45 cm/yr., respectively. Rapid decrease occurred in 1930s. From late 1978 to late 1996, a sharp increase happened with 16.08 cm/yr. gradient and again after that time the CS level is fallen dramatically by 14.02

cm/yr. slope (Fig. 2A). The CS level is affected by regional and global scales in different time scales. Fig. 2B illustrates the spectra of sea level for the CS. The major peak at spectra corresponds to the annual cycle and semiannual (6 months) oscillations peak is located at next vigorous. For long-term oscillations, some peaks are visible at 4 to 7, 14 and around 30 years periods, respectively. The amplitudes of higher seasonal harmonics (except 4 months period) are small and it is difficult to detect them in the background noise at the spectra. Ranges of tidal constituents in the CS are less than 10 cm [6] and their energy in spectra are not detectible from background noise.

Fig. 2C shows wavelet power spectrum for monthly CS level changes from 1900 to 2017, where the strong non-stationary behavior of the spectra is obvious. The results confirm the pick signals of power spectrum analysis by revealing events on the annual, semi-annual scales. High energetic signals are appeared in long periods (more than 128 months) that Fig. 2B reveals, too. In some years, annual signal is absent in wavelet spectrum, e.g., 1969-1970, 1981-1985 and 1996-1998 (vertical line in Fig. 2C). For two first periods, semi-annual signal of evaporation was dominant and for the last one period, the NAO annual period effects on CS level are increased. Generally, local and global parameters affect the CS level changes and recently Siberian High has important role in increase of evaporation and consequently decreases in CS level.

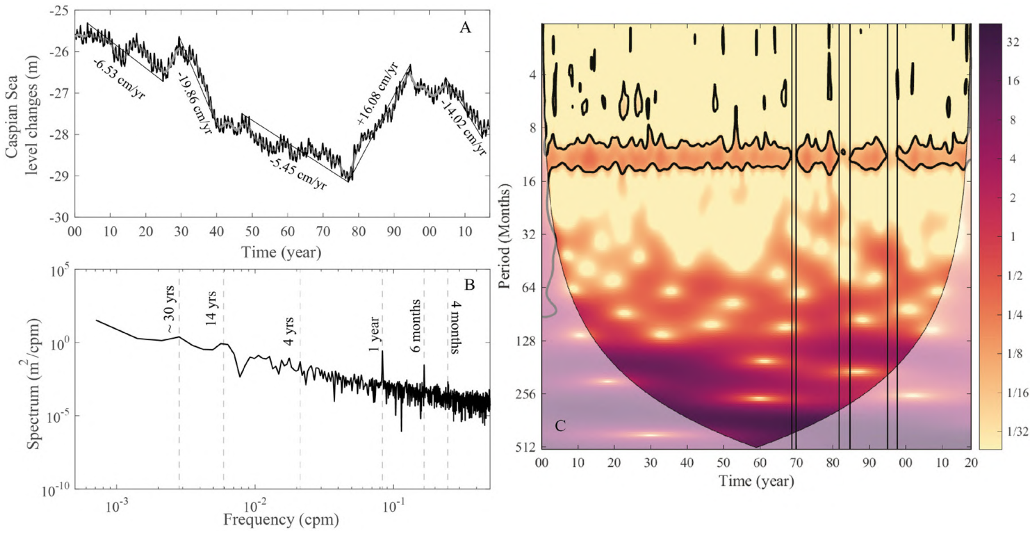

Fig. 1. a) Monthly Caspian Sea level changes recorded by tide gauges and related trends (peak to peak) from 1900 to 2017 behind yearly low-passed data (gray line), b) Morlet wavelet power spectrum of the sea level data, and c) the Caspian Sea level spectra generated by sea level data.

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Translated from Russian

Fluctuations in the Caspian Sea level: history of research and prediction methods

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Introduction

The complexity of the process of long-term fluctuations in the level of the Caspian Sea and its poor predictability are a consequence of insufficient hydrometeorological study of an object of such a significant size, expressed, in particular, in the limited series of observations, in the absence of direct measurements of such components of the water balance as evaporation and precipitation on the water surface, water exchange with underground waters. There is no reliable information on irreversible water consumption in river basins and on a number of other factors. In addition, the task of forecasting is significantly complicated by climatic and anthropogenic changes in runoff in the basin and a number of other factors that are difficult to predict.

The task of forecasting sea level for the long-term perspective is very relevant, since poorly predictable level fluctuations cause significant damage to the economy of coastal areas, create risks for infrastructure facilities for oil production, the existence of aquatic biological resources etc. Repeatedly, in the modern period, various ideas have been expressed about the management of the water level in the Caspian Sea. Among the most ambitious projects are the project to transfer the flow of the Northern rivers to the Volga, the project to cut off the shallow areas of the Caspian by a dam, and others. Only one method was implemented – regulating the outflow of Caspian waters into the Kara-Bogaz-Gol Bay by constructing an overlapping dam, and even that was stopped during the last rise in sea level.

All tasks, both engineering and environmental, require a scientifically based methodology for predicting sea level for the long term. The solution of the problem of forecasting the level of a closed water body is carried out within the framework of a probabilistic approach to the description of hydrometeorological processes. At different stages of the study of this process, balance representations and probabilistic models of varying degrees of complexity were considered, suitable for long-term forecasting of sea level, which are reviewed in [3, 6].

The main components of the sea water balance and approaches to forecasting long-term fluctuations in its level

The total river inflow to the Caspian Sea is four-fifths of the incoming part of the water balance of the Caspian Sea (precipitation is about 20%, underground inflow is not more than 1%). The flow of river water from the Volga basin is about 82% of the total volume of the inflow, about 15% comes from the Kura, Ural, Terek and Sulak rivers, the rest of the inflow is from smaller rivers [3, 8, 11].

The regime of the Volga runoff is well illuminated by observations, and for modern estimates one can use fairly accurate data on water discharges through the turbines and the overflow dam of the Volgograd HPP. Below, the river practically does not receive food, but, on the contrary, loses water for evaporation in the Volga-Akhtuba floodplain, in the delta, in the zone of the West-steppe ilmens. Due to the low variability for the modern period, the average value of the estimated losses (about 10 km^3/year) is used.

The total inflow to the sea for the modern observation period is obtained as the sum of the runoff of the rivers Volga, Ural, Terek, Kura, Sulak, Sefidrud, Polruda, Kharaz, Chalus minus losses in the Volga floodplain and delta. If we consider the total inflow to the Caspian Sea over the entire observation period as a stationary random process, then the Markov model can be used to describe it [1, 4]. However, the analysis of chronological graphs and differential-integral curves of the Caspian Sea level and total inflow to it made it possible to distinguish three periods corresponding to the phases of increased and decreased water content in the sea basin. For simulation modeling of such a piecewise-homogeneous series, it is possible to use a semi-Markov probabilistic model of long-term fluctuations [2].

Evaporation from the water surface is the main expenditure component of the water balance of the Caspian Sea. There is still no reliable method for directly measuring evaporation from the sea surface. To calculate this value, two main approaches are used. The first – balance – is that evaporation is considered as a residual term in the water balance equation, and the remaining terms of the equation are determined from observations or by calculations of various levels of complexity. With this approach, the errors in the estimates of the evaporation rate include all errors arising in the determination of the values of other components of the Caspian water balance.

The second approach to calculating the amount of evaporation is based on the use of the diffusion method, the essence of which is the use of empirical and semi-empirical formulas describing the diffusion of water vapor in the surface layer of the atmosphere. In recent years, calculations of evaporation using reanalysis data, as well as those obtained by calculations using global climate models, have become widespread.

The morphometric characteristics of the Caspian Sea (the relationship between the level, area of the mirror and the volume of water in the sea) were obtained using a digital elevation model without taking into account the water area of the Kara-Bogaz-Gol Bay. Among the characteristic features of the morphometry of the Caspian Sea, it is necessary to note the presence of a feature in the structure of the seabed relief in the range of marks from -32 to -26 m abs., identified in [5] using a digital relief model. Calculations revealed the dependence of the area of shallow waters (areas of the water area with depths of 1, 2 and 3 meters) on the sea level. The maximum areas of shallow water are noted in the range of 26 – -28 m.

Outflow of water to Kara-Bogaz-Gol. The existing ideas about the outflow of sea waters into the Kara-Bogaz-Gol Bay are based on measurements carried out by the Hydrometeorological Service of Turkmenistan. Outflow is mainly determined by the difference in water level in the sea and the bay. Under modern conditions, a new cross-sectional profile of the strait has formed due to its intense erosion. To predict the sea level regime, the relationship between sea level and outflow to Kara-Bogaz-Gol, limited from above by the evaporating capacity of the bay, was accepted.

Irrevocable water consumption in the Caspian basin. The data on water consumption in the basins of the main rivers flowing into the Caspian Sea are summarized in the work of A.P. Demin [7]. The volume of irretrievable water consumption and losses (taking into account evaporation losses from the surface of reservoirs) in the Caspian Sea basin from 1970 to 1980 increased from 32 to 47 km^3 and remained stable until 1991. In the following years of the economic crisis, the volume of irretrievable water consumption began to decline sharply and by 2001 it reached 34 km^3. In recent years, in all CIS states, this indicator has stabilized, and, as a whole for the Caspian Sea basin, in 2003 amounted to 43 km^3, which is close to the estimates obtained in [11].

Groundwater runoff into the sea lends itself only to an approximate estimate based on hydrogeological studies and calculations of the values of submarine groundwater discharge. The sea annually receives from the adjacent areas no more than 3 km^3 of underground runoff, which is about 1% of the river water inflow.

Levels of the Caspian Sea

Inflow and evaporation from the sea water surface play a decisive role in the formation of long-term fluctuations in the level of the Caspian Sea [9]. With the stationary, in general, nature of the temporal variability of these processes, in the hydrological regime of the sea and the Volga River, however, there are several features.

In 1930s, in the series of the Volga runoff, a period of extreme low water stands out, the probability of which, in the Markov stationary approximation, is estimated as 1 time in 900-1,000 years. This low water period directly affects the fluctuations in the Caspian Sea level associated with the Volga runoff – a drop in sea level in the same period, the probability of which, according to V.E. Privalsky estimates, is approximately 1 time in 2,000 years. The sea level decline, which then continued for several decades, ended in 1979 and was replaced by a sharp rise in level by 2.5 m over the next 15 years. The same year corresponds to the change in the majority of rivers in the Volga basin from the low-water period to the high-water one, which lasted until the end of the 1990s. Since 1995, sea level has generally been falling, at varying rates.

During the period of a sharp rise in the level of the Caspian, various hypotheses were put forward regarding the mechanisms of the formation of the water balance, explaining such anomalous behavior of the water level. One of the original proposals was based on the idea of the presence of several levels of gravity of the sea, i.e., the presence of two stable states of this complex hydrological system [10]. The evidence in favor of this hypothesis was a two-modal histogram of the sea level distribution. If two levels of gravitation existed, then the anomalous behavior of the sea could be explained by the rapid transition of the system from one state to another. However, estimates of histograms obtained from short series of observations are unreliable and it is no longer possible to confidently single out two stable states on the basis of a limited series of observations.

Forecast of long-term fluctuations in the level of the Caspian Sea

At the current level of development of hydrometeorology, a long-term forecast of the Caspian Sea level can be presented in the form of a level probability distribution obtained using probabilistic modeling. The modeling of the level as a resultant component of the water balance equation is based on stochastic models of long-term variability of the components of this equation – inflow and visible evaporation, taking into account the amortization mechanism of sea level fluctuations [9].

The stochastic differential water balance equation is solved by the simulation method for a given period at a known sea level at the time of the forecast release. This approach allows solving the probabilistic problem without restrictions on the form of marginal distributions, morphometric dependencies, and other nonlinear relationships. Simulation modeling of fluctuations in the levels of the Caspian Sea is based on the generation of artificial time sequences of average annual values of inflow and visible evaporation (evaporation minus precipitation) of long duration; such series in the Markov case are satisfactorily described by two-dimensional probability distributions. Long-term series of sea levels are obtained by repeatedly solving the water balance equation for a year ahead, taking into account the water surface area at the beginning of the estimated time interval and outflow into the Kara-Bogaz-Gol Bay.

Calculations using a stationary Markov model of inflow and evaporation show that, despite the presence of long series of observations of the components of the water balance, the variance of the predicted sea level fluctuations differs from the variance of the observed series; therefore, it seems appropriate to consider a more complex semi-Markov model. In the time series of the inflow to the Caspian, there are three homogeneous, in terms of statistical parameters, periods with a duration of 40 years. Within the boundaries of each period, the process is considered as a stationary Markov process. The mathematical expectation of a semi-Markov process changes abruptly when passing from one stationary period to another. The change in the states of the process is described in the same way within the framework of the Markov model, but in our case the choice of the state in imitation modeling (the transition from one to another conventionally homogeneous period) is made randomly. The characteristics of the Caspian Sea level obtained using the semi-Markov model with different variants of the inflow modeling parameters are in better agreement with the observational data.

The considered example demonstrates that the sea level regime is sensitive to possible more complex mechanisms of changing the parameters. It is also obvious that the proposed modeling scheme requires further development.

The probabilistic forecast of the Caspian level is obtained as a result of solving the differential equation of the water balance for the lead time period of interest. The forecast can be presented both in the form of conditional distribution parameters (conditional mean, variance, asymmetry, etc.), and in the form of a set of quantiles of conditional probability distributions. For the forecast period with a lead time of 5 to 40 years, the most unfavorable forecast (the level of 0.1% availability) is -25.84 m, and the lowest level (99% of the availability) is -30.67 m.

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Translated from Russian

Towards a long-term forecast of the average annual level of the Caspian Sea

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The problem solution is based on the information provided in numerous scientific publications [1-3, 5, 6]. It was revealed that the average annual level of the Caspian Sea (minus the trend) is formed mainly by four periodicities, whose parameters change in the modern segment of time series are in the ranges of periods of 35-37 years, 65-67 years and of 95-100 years. The parameters of these periodicities were determined by comparing the results of modeling and calculating the average annual level according to observations during the period from 1737 to 2016. Earlier data, mostly irregular, bring large distortions in the spectrum of sea level fluctuations. A variation of the fluctuations periods in some ranges could be observed, whose influence was taken into account by searching for optimal values of the periodicity parameters and digital multipliers in the geometric curve formula approximating the time series, considering the minimization of the variance of deviations of modeled ranks from the observed one by the Prony's method [7]. The variation of the approximation parameters clearly depended on the length of the series used, and the main forming periods of level fluctuations are on average about 65-67 and 97-104 years with amplitudes of about 60 and 95 cm, respectively. The periods on average are "almost" multiples of 11 years, which probably indicates the solar-thermal origin of the fluctuations.

The timing of the forecast is determined by the trend duration, which approximately corresponds to 2060. Next, an increase in the average annual level is formed, which is not described by the current trend. The first projection calculation was performed in 2016, and the calculations were verified during 2017-2020. Herewith, the calculation results matched the observed average annual sea level within 10 cm. The main advantage of the method used is that its application does not involve the need to project river flow, rain, wind and evaporation.

Tab. 1. Projected values of the average annual level of the Caspian Sea for different trend types

	Trend type			Trend type	
Year	harmonic	linear	Year	harmonic	linear
2020	-27.98	-28.01	2041	-29.77	-29.99
2021	-28.08	-28.11	2042	-29.8	-30.04
2022	-28.19	-28.22	2043	-29.83	-30.08
2023	-28.29	-28.33	2044	-29.85	-30.11
2024	-28.4	-28.45	2045	-29.87	-30.14
2025	-28.5	-28.56	2046	-29.88	-30.17
2026	-28.61	-28.67	2047	-29.88	-30.18
2027	-28.71	-28.78	2048	-29.88	-30.19
2028	-28.81	-28.89	2049	-29.87	-30.2
2029	-28.91	-29	2050	-29.86	-30.2
2030	-29.01	-29.11	2051	-29.84	-30.19
2031	-29.1	-29.21	2052	-29.82	-30.18
2032	-29.19	-29.31	2053	-29.79	-30.17
2033	-29.27	-29.4	2054	-29.76	-30.15
2034	-29.36	-29.5	2055	-29.73	-30.12
2035	-29.43	-29.58	2056	-29.69	-30.1
2036	-29.5	-29.66	2057	-29.65	-30.07
2037	-29.57	-29.74	2058	-29.6	-30.03
2038	-29.63	-29.81	2059	-29.55	-30
2039	-29.68	-29.88	2060	-29.51	-29.96
2040	-29.73	-29.94			

A special program based on the DESMOS graphing calculator (https://www.desmos.com) was developed to proceed with these calculations, thereby accelerating the process significantly. The calculations were performed taking into account the linear and harmonic trends, the latter one with a period of 735 years (Tab. 1). It was revealed, that the sea level fluctuations detected in the spectrum of the series with periods of 35 and 37 years, having total amplitude of about 30 cm, do not significantly affect the result, but form beats. This periodicity was noted by Brickner in connection with fluctuations in thermal atmospheric influences and was mentioned in Berg's works [3]. Basically, an annual adjustment of the calculation results considering the observational data is desirable.

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Translated from Russian

Effect of long-term variations in wind regime over Caspian Sea region on the evolution of its level in 1948–2017

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According to the atmospheric reanalysis data of NCEP/NCAR for 1948-2017 (R-1) and NCEP/DOE for 1979-2017 (R-2), it was found that changes in the level of the Caspian Sea are closely related to long-term changes in the near-surface wind field in the sea region as a result of the restructuring of the atmospheric circulation over Eurasia. It is shown that the main significance in the changes in evaporation over the Caspian Sea is the winds of the eastern and northern rhumbs. During the periods of the Caspian Sea level drop (1948-1976 and 1996-2017), easterly winds prevail, which bring dry and warm air from Central Asia to the Caspian Sea and thereby contribute to an increase in the intensity of evaporation of the Caspian Sea waters. During the period of the rising level of the Caspian Sea (1977-1995), northerly winds dominate, which leads to a decrease in the intensity of evaporation. At the same time, the frequency of the north rhumb wind is greatest in the warm period of the year – especially in the summer months, and the east, on the contrary, in the autumn, winter and spring months. The average wind speed over the water area of KM in the annual cycle shows a weakening of the wind in the warm period of the year and, conversely, an increase in the cold period of the year.

The performed calculations of evaporation over the Caspian Sea according to the data of reanalysis R-1 and R-2 fully confirm these conclusions. A close relationship between evaporation and the course of the Caspian Sea level is shown. The correlations between the non-normalized evaporation increments and the Caspian Sea level are -0.86 and -0.75 for R-1 and R-2, respectively. Moreover, according to the refined reanalysis of R-2, the contribution of evaporation to the current lowering of the Caspian Sea level is greater than according to R-1, since the influx of air masses from the neighboring arid region of Central Asia into the Caspian Sea, according to R-2, has been more intense in the last decade. *The work was carried out with the financial support of the RSF (project № 17-17-01295).*

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Variations in Wind Regime over Caspian Sea Region on the Evolution of Its Level in 1948–2017. *Water Resources,* 2, 348-357. In Russ.

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A non-linear model of Caspian Sea level fluctuations in paleotime

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Climate nonstationarity is usually considered to be the cause of significant fluctuations in lake levels in paleotime [1]. Developing the probability-theoretical approach [2-4], we have evaluated the possible role of nonlinear dependence of evaporation from the Caspian Sea on sea level (depth) in significant sea level changes that occurred in the interval of 14-4 thousand years B.C.

An improved dynamic-stochastic model of multiyear fluctuations of the Caspian Sea level has been developed to implement this objective. In this model, evaporation was considered separately for two parts of the sea – shallow water (mainly North Caspian) and deep water (Middle and South Caspian).

It was assumed that evaporation from the deep part of the Caspian Sea consists of two components: the main, constant value and a certain stochastic component acting over the whole water area and reflecting the random nature of evaporation condition changes – changes in air and water temperature, wind speed, etc.

Within the framework of the accepted assumptions, long-term fluctuations of the Caspian Sea level without outflow are described by the sea water balance equation:

$$\frac{dh(t)}{dt} = \frac{\bar{v}^+(t)}{F(h)} - \frac{e_{\det}(h)\, F_s(h) + F_d\, \bar{e}}{F(h)} + \frac{\tilde{v}^+(t)}{F(h)} - e_{\mathrm{stoch}}, \qquad (1)$$

Where:

h is the water level in the Caspian,

$v^+(t) = \bar{v}^+ + \tilde{v}^+(t)\, v^+(t) = \bar{v}^+ + \tilde{v}^+(t)$ is the inflow to the Caspian Sea, representing the sum of river inflow and precipitation per sea area;

$\bar{v}^+ \bar{v}^+$ is the mean inflow, $\tilde{v}^+(t)\tilde{v}^+(t)$ is the fluctuation of inflow relative to mean $\bar{v}^+\bar{v}^+$;

$e_{\det}(h) e_{\det}(h)$ and $e_{\mathrm{stoch}}\, e_{\mathrm{stoch}}$ are level-dependent evaporation and the stochastic component in evaporation from the whole water area, respectively;

$\bar{e}\bar{e}$ is the average evaporation from the deep sea;

$F_d = \text{const}$ $F_d = \text{const}$, $F_s(h)F_s(h)$ - areas of deep and shallow parts of the sea, respectively;

$F(h) = F_d + F_s(h)$ $F(h) = F_d + F_s(h)$,

t - time.

The 1st order autoregressive processes were used as models $\tilde{v}^+(t)\tilde{v}^+(t)$ and e_{stoch} e_{stoch}.

The stationary probability density function (PDF) of the sea level derived from the Fokker-Planck-Kolmogorov (FPK) equation and the histogram derived from the simulation method are in good agreement (Fig. 1).

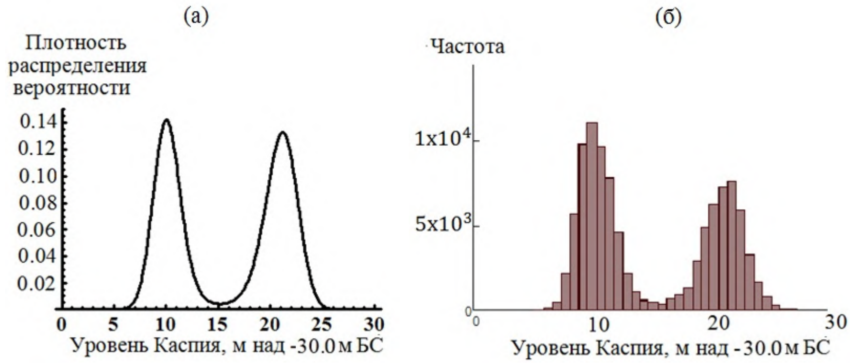

Fig. 1. (a) – the PDF of the Caspian Sea level obtained via the FPK equation; (b) – histogram of the Caspian Sea level derived from the simulation method using the discrete analogue of the differential equation (1).

Fig. 2 illustrates a fragment of the Caspian Sea level realization, obtained by the imitation method, and a graph of the sea level course in paleotime according to [1].

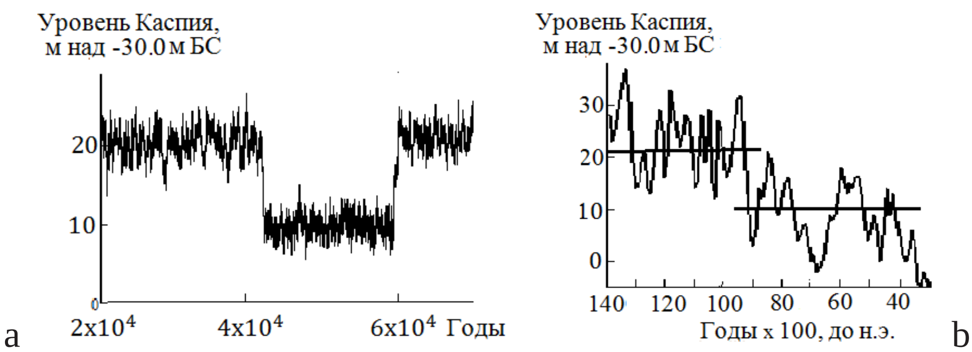

Fig. 2. (a) – fragment of realization of the simulated Caspian Sea level series; (b) – changes in the Caspian Sea level in paleotime according to data from [1].

The graphs in Fig. 2 are alike and represent fragments of realizations of nonstationary processes.

The presented results suggest that a nonlinear dependence of evaporation on sea level and climatic changes in the sea water balance may have a joint impact on the Caspian Sea level regime.

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Translated from Russian

Possible fluctuation of the Caspian Sea level up to the year 2050, considering climate changes

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The Caspian Sea is a unique water body with its own specific characteristics. The most well-known is its level fluctuations under the impact of changes in natural and anthropogenic processes.

Key features of the water balance of the Caspian Sea. The river runoff and evaporation are the most important characteristics for the water balance of the Caspian Sea, whose ratio mainly determines the year-to-year changes in the water volume and the sea level. The input part of the average annual water balance of the Caspian Sea consists of 20% atmospheric precipitation falling on its surface, of 1% – the inflow of groundwater through aquifers and of 79% – the river runoff [1, 2, 3].

Methods for the sea level changes assessment up to the year 2050. When studying the impact of future climate changes on the Caspian Sea level, it is necessary to take into account a number of various factors: meteorological, hydrological and anthropogenic. Studies of the factors that determine the natural fluctuations of the Caspian Sea level indicate that the main ones are river runoff (whose main contribution is made by the Volga River) and visible evaporation. The assessment of possible changes of the Volga River flow was carried out on the basis of the modeling results using the Community Land Model. This model was developed jointly by scientists of the National Center for Atmospheric Research (NCAR) and the CCSM Land Model Working Group [4, 5, 6]. The Community Land Model (CLM) includes a River Transport Model (RTM) designed to route the full water flow to the oceans or seas, enabling to close the hydrological cycle.

Scenarios of greenhouse gas concentrations of the RCP (Representative Concentration Pathways) group were used to assess future changes in air temperature and precipitation in the basin. Data of the river flow projection for the Volga River according to the scenarios RCP4.5 and RCP8.5 up to the year 2100 are available on the website: https://www.earthsystemgrid.org/. Data processing for the Volgograd reservoir site and their visualization was carried out using the IDV software product (Integrated Data Viewer).

To determine the water inflow to the Caspian Sea in future, the dependence of the Volga River flow in the Volgograd reservoir alignment on the river waters inflow to the Caspian Sea for the period of 1978-2019 was constructed (Fig. 1a). This dependence has a correlation coefficient equal to 0.96, which indicates a close connection and the possibility of restoring the inflow of river waters into the sea in the future, using the flow of the Volga River in the Volgograd reservoir alignment. Fig. 1b shows projections of changes in the river waters inflow into the sea in future according to the scenarios RCP 4.5 и RCP 8.5. As the calculations results have shown, the water inflow to the Caspian Sea has no pronounced trend. Calculations of precipitation and evaporation in the Caspian region were also carried out for two selected climate scenarios RCP4.5 and RCP8.5 based on an ensemble of climate models. The calculations results showed that there is a sustained trend, so it follows that evaporation from the Caspian Sea will increase. This is attributable to the projected increase in air temperature.

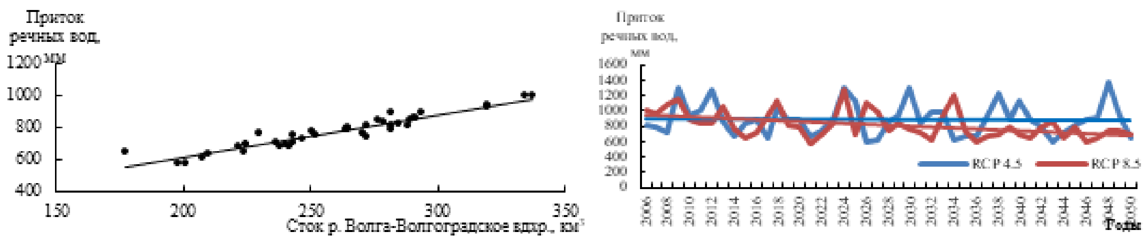

Fig. 1. a) Dependence of the river waters inflow into the Caspian Sea from the flow of the Volga River-Volgograd reservoir on the total river waters inflow into the Caspian Sea for the period of 1978-2019; b) The course of changes in the river waters inflow to the Caspian Sea up to the year 2050 according to the scenarios RCP4.5 and RCP8.5.

Based on the projected data on the river waters inflow into the Caspian Sea, as well as visible evaporation, it was predicted that the level of the Caspian Sea will change until 2050. Fig. 2 shows a visual graph of the course of the predicted Caspian Sea level, considering two climate change scenarios (RCP4. 5 and RCP8. 5), as well as the actual level change (until 2020).

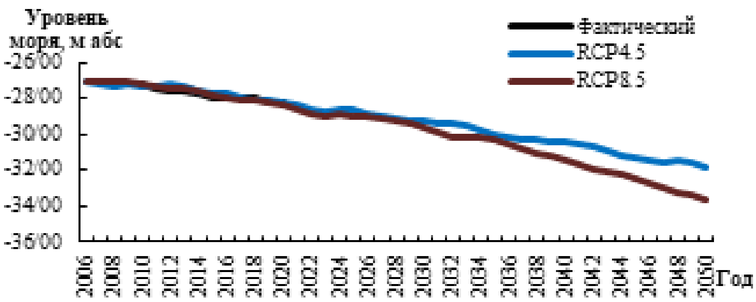

Fig. 2. Projected values of the Caspian Sea level under two climate change scenarios (RCP4.5 и RCP8.5) up to the year 2050.

Calculations have shown that the Caspian Sea level has a steady tendency to decrease. This will be especially clear in the second third of the 21st century. According to our calculations, under the RCP4.5 scenario, the sea level may approach -32 m by 2050, and under the more pessimistic RCP8.5 scenario, the level may even fall below -33 m.

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Translated from Russian

Volga runoff at global warming by 1.5 and 2 degrees

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A model of river runoff formation in the Volga basin, built on the basis of global databases on the underlying surface and monitoring data for air temperature and humidity, precipitation at 306 meteorological stations, with a daily step in time and with a spatial resolution equal to the size of elementary catchments (about 1,800 km^2), describes the main processes of the hydrological cycle of the land [1, 2]. Due to the regulation of the runoff by the Volga-Kama cascade of reservoirs, the model was verified by comparing the actual and calculated average daily water discharges in the outlet sections of the main tributaries of the Volga and Kama. Calibration and verification of the parameters of the runoff formation model was carried out for the periods 2000-2014 and 1986-1999, respectively, using the statistical Nash-Sutcliff tests and the systematic error of the calculation. Satisfactory (NSE> 0.7 and |BIAS| <10%) modeling results were obtained for various sections over a multiyear period. Correlation coefficient between the actual and modeled annual water inflow into the Kuibyshev reservoir for the period 1986-2014 was 0.89 with a systematic error of about 2%.

With the assistance of the developed physical and mathematical model of runoff formation in the Volga basin, the estimation of runoff reproduction was carried out when given as boundary conditions in the hydrological model of these models of the general circulation of the atmosphere and ocean for the base historical period 1970-1999. The hydrological model, based on the data from the models of the general circulation of the atmosphere and the ocean, reproduces the annual runoff of the Volga with an error of 4% relative to the calculation based on the data of meteorological stations. In this case, the largest relative calculation errors are characteristic of the winter runoff (9.5%), and the smallest for the runoff during the spring flood (less than 1%).

To carry out numerical experiments to study the hydrological consequences of global warming in the 21st century by 1.5°C and 2°C relative to pre-industrial values with the model of runoff formation in the Volga basin, the average daily data on the surface fields of meteorological characteristics of the general circulation models of the atmosphere and ocean GFDL-ESM2M and MIROC5 CMIP5 based on the results of the ISIMIP (Inter-Sectoral Impact Model Intercomparison Project) project, taking into account each of the 4 RCP scenarios, were used. Then, 12 possible realizations of global warming were set as boundary conditions in the model of runoff formation in the Volga basin, after which the calculation results were averaged for the threshold values of 1.5°C and 2°C over the corresponding sets. According to the data used, global warming by 1.5°C will be achieved by 2045 and by 2°C by 2064. Runoff anomalies are calculated as the ratio of the calculated value for the conditions of an increase in global air temperature by 1.5°C and 2°C relative to the base period.

With global warming of 1.5°C and 2°C, the decrease in the annual runoff of the Volga amounted to 10-11% under the realization of both warming scenarios relative to the period 1970-1999 (Fig. 1). The increase in the winter runoff of the Volga amounted to 17% and 28% with global warming of 1.5°C and 2°C, respectively, and the negative runoff anomalies for the period of spring flood and summer-autumn were in the range of 21-23%.

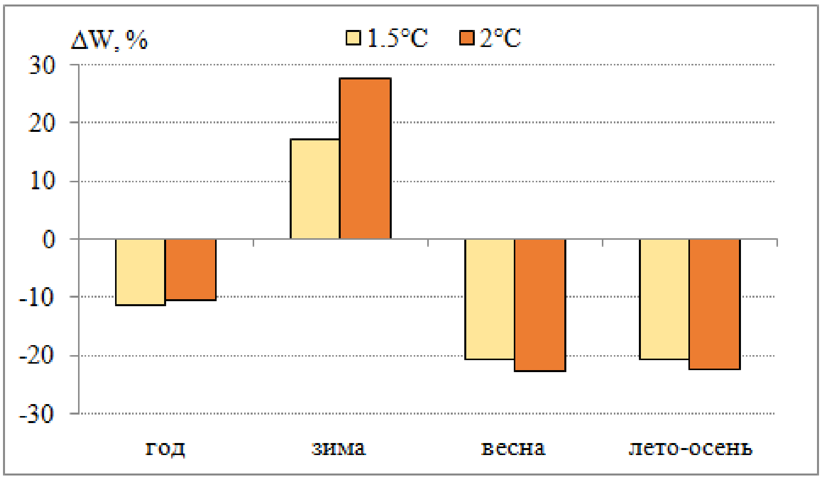

Fig. 1. Anomalies of the annual and seasonal runoff of the Volga during global warming by 1.5°C and 2°C

The research was carried out with the financial support of the grant of the Russian Science Foundation 20-77-00077.

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Caspian rapid Sea level fluctuation impact on the Gorgan Bay environment

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Global warming and rising ocean water levels during the Anthropocene have created the right conditions to increase the physical vulnerability of coastal areas, and large areas of the Earth's coast have been flooded and eroded [1]. The relocation of coastlines has a direct impact on various economic infrastructures such as commercial ports, fishing docks, thermal power plants and coastal tourism facilities. The Caspian Sea coast is no exception to this rule and has undergone serious changes and extensive environmental challenges due to fluctuations in sea level, which is sometimes more than a hundred times faster and sometimes in the opposite direction to the world ocean [2]. Fluctuations in the water level of the Caspian Sea since the twentieth century have caused the deformation of coastal processes and the joint impact of the fluctuating phases of the Caspian Sea and human factors, conditions of sedimentation regime change, shoreline displacement and the development of erosion phenomena on the coast [5]. The economic consequences of a 250 cm increase in the Caspian Sea water level during the period 1978-1995 are estimated at more than US$ 17 billion [4]. The rapid decline of the Caspian Sea water level during the periods 1930-1978 and 1995-2019 has led to major deformation of natural habitats, extinction of coastal wetlands and the impact of centralized economic capacity in coastal areas [3].

The main objective is to assess the severity of changes in the shores of Gorgan Bay and Miankaleh coast as protected environmental areas of wildlife sanctuaries and biosphere reserves during a period coinciding with the decrease of the Caspian Sea water level during the years 1995-2019. The morphological conditions of the coastlines of Gorgan Bay and Miankaleh coast were investigated by field observations and analysis of satellite images. A total of 10 study axes were selected around Gorgan Bay and Miankaleh and the intensity of shoreline movement by processing multi-time satellite images belonging to the years (1995-2019) in the GIS environment and with the help of digital software for coastal line analysis (DSAS), was calculated. Based on the shoreline movement, the study area was classified into three groups with shoreline changes (high, medium and low).

The results show that the northeastern extremities of Miankaleh and the western extremity of Gorgan Bay have the highest coastline displacement and the central areas south of Gorgan Bay and the north-central part to the western part of Miankaleh coast have very little displacement. Comparison of the average rate of shoreline changes over a 24-year period between 1995-2019 shows that the highest shoreline shifts in the westernmost region of Gorgan Bay, northeast coast of Miankaleh and southwest of Gorgan Bay at 1,846, 1,626, and 1,507 meters respectively occurred (Fig. 1). The coastline of Turkmen port (1,058 m) and Gaz port (654 m) has been determined (Fig. 1). The lowest shoreline movement rates are in the west of Miankaleh (127 m), northeast of Gorgan Bay (242 m), northwest of Gorgan Bay (381 m), north-central Miankaleh (476 m) and south-central Gorgan Bay (526 m), respectively (Fig. 1). Reduction of the Caspian Sea water level by 150 cm since 1995 has caused a large part of the western extremity of Gorgan Bay and the northeastern part of Miankaleh Wetland to dry up, resulting in the drying of Miankaleh and Gomishan coastal wetlands and decreased more than 30 percent from the area of the Gorgan Bay [3].

The results of studies have shown that the rate of variability of Gorgan Bay coastal habitats is subject to changes in the water level of the Caspian Sea and sandy shores of the southeastern Caspian Sea along the northeastern part of Miankaleh wetland and shallow lagoons. The western tip of Gorgan Bay had the most changes during 1995-2019 [3]. Changing the aquatic ecosystem to land and changing the cover of coastal wetlands to saline and brackish marshes are the most important ecological events of Gorgan Bay and Miankaleh wetland during the Caspian Sea water retreat during 1995-2019 [3]. The quantitative variability of coastlines in different coastal areas of Gorgan Bay and Miankaleh wetland is very different and the severity of physical vulnerability of coastlines in the study area depends on the geometric structure of the coast [3]. The rate of drought and coastal shifts in the northeastern regions of Miankaleh and the western end of Gorgan Bay is very high (Fig. 1). For comprehensive management of coastlines in the study area, focus on areas with high physical vulnerability is necessary and continuous control of quantitative and qualitative changes in coastal habitats affected by fluctuations in the water level of the Caspian Sea can reduce the existing challenges.

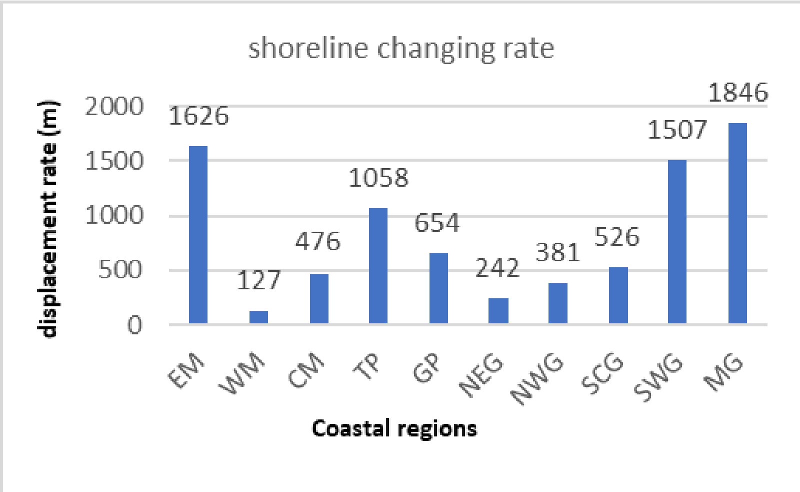

Fig. 1. Comparison of the average amount of changes in the shoreline of Gorgan Bay and Miankaleh during the period 1995-2019

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Assessment of the impact of the Caspian Sea level decline on the geomorphological characteristics of the Caspian Sea coastal zone from the cape bandovan to Astarachay river water basin of Azerbaijan based on satellite image processing

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The coastal zones are environmentally and economically important regions. Monitoring of the coastal zone and, in particular, the precise demarcation of the coastline is important as a fundamental research object in solving problems such as environmental protection in the context of global climate change. Shorelines are important particular qualities for land/water resources management, geographical mapping, safe navigation and coastal monitoring. The most common methods for shoreline extraction involve visual interpretation from conventional ground surveys or aerial photographs [4 ;1]. These methods are, by definition, subjective and depend on the interpreter's individual abilities, often requiring the operator to be familiar with the local environment [1]. Use of tidal datum indicators is a better method to identify the shoreline, but it's limited when determining the historical shoreline [4]. In recent years, there has been an increase in the usage of remote sensing data using optical and synthetic aperture radar (SAR) satellites to extract and map the shoreline automatically or semi-automatically [2]. Several methods have been proposed to accurately locate the position of the shoreline and they are based on the usage of supervised and unsupervised classification or threshold techniques [6 4 ;3]. Regardless of the method, the classification of the pixels in water or land will depend, among other factors, on the resolution of the input data used.

In the study, various semi-automated methods such as Tasseled Cap and DSAS (Digital Shoreline Analysis System) were used to identify and dynamic the coastal zone and coastline. The areas of impact and quantitative indicators of geomorphological processes were determined. For this study, high-resolution Sentinel 2 satellite images for 2016-2021 were used. To extract the shoreline, we used the Tasseled cap transformation method and NDVI (Normalized Difference Vegetation Index). NDVI in this technique uses a composite Red band and Near Infrared (NIR) to determine the level of greenness and classification of vegetation areas. Tasseled Cap process is using composite bands of red, green, blue, NIR, short-wave infrared-1 (SWIR-1) and short-wave infrared-2 (SWIR-2) to find out the level of brightness, greenness and wetness of an object. After this analysis shoreline was extracted (Fig. 1).

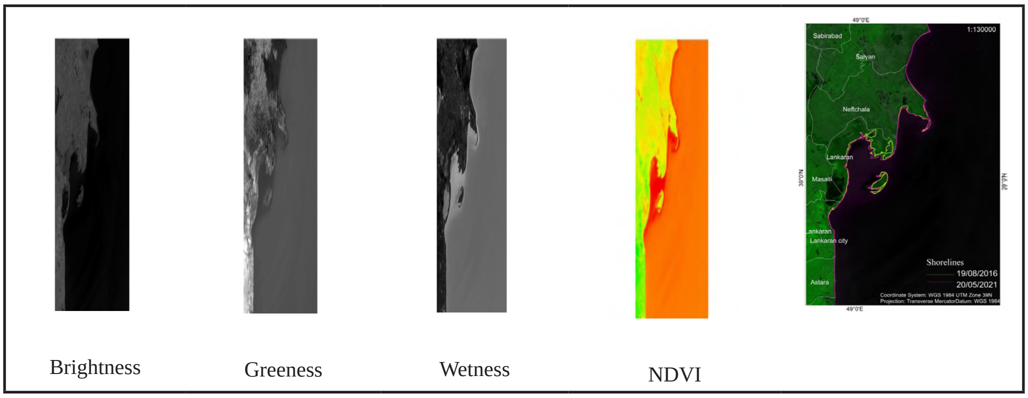

Fig. 1. Shoreline extraction results for 2016 to 2019

In the Caspian Sea, the minimum sea level for the past years was registered in 1977 by a ground station at -29 m. Since 1978, the sea level has risen, and in 1995 it was registered at -26.66 m and whereupon the sea level was almost stable with slight decrease. In 2016-2020, a 0.2 meter descent was observed in the Caspian Sea. The Digital Shoreline Analysis System (DSAS) is a GIS-based system established by the USGS. DSAS5.0 has six statistical methods to measure variations. In this study, Net Shoreline Movement (NSM), End Point Rate (EPR) approaches were used. NSM relates to time criteria and requires only two shorelines, i.e. total distance among the earliest and the latest of coastline in each transect. EPR measures shoreline change by separating the distance of the coastline between its initial and the most current position [5]. EPR and NSM positive and negative value shows seaward and landward movement of the coastline respectively. Areas were identified where the highest rates of abrasion and erosion were observed in the study area and changes in the coastline of Kurdili Island were identified (Fig. 2).

Thus, it was determined that the coastline of the Azerbaijani coast from Cape Bandovan to Asatarachay changed between 1559.6 and -41.7 m / year between 2016 and 2021, and some areas remained unchanged. The results of NSM statistical calculations show that the shoreline was retracted from (-0.01) m to (-197.85) m as a result of the erosion (abrasion) process, and from 0.05 m to 7405 m advanced towards the sea as a result of accumulation (Fig. 2). In the period of 2016-2021, coastal changes are mainly accumulation, and to a lesser extent erosion. The coastline is constantly changing as a result of erosion and accumulation processes. In 2016-2021, 8052 ha of land was gained as a result of accumulation processes, 71.47 ha of land was lost as a result of erosion. On Kurdili Island, 623.66 ha of land area increased on one side, and decreased for 220 ha on the other. The results show that there is a change in the coastline in 2016-2021, and an average of 230 m of coastal movement to the sea and 23.14 m to land.

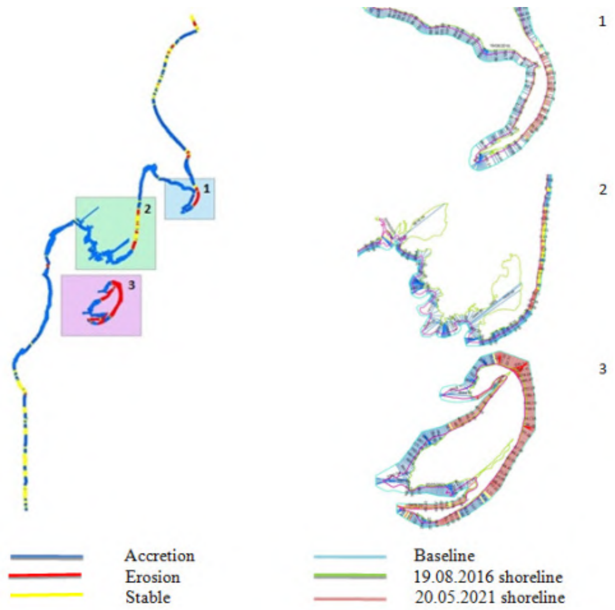

Fig. 2. Areas where the coastline is subject to maximum erosion (1) and accretion (2) and result of Kurdili Island (3)

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Glossary:

DSAS – Digital Shoreline Analysis System

EPR – End Point Rate

NDVI – Normalized Difference Vegetation Index

NIR – Near Infrared

NSM – Net Shoreline Movement

SAR – Synthetic Aperture Radar

SWIR – Short Wave Infrared

Numerical modeling of physical oceanography properties in the southern Caspian Sea

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The Caspian Sea is the greatest lake in the world. This basin is a unique water body due to its bathymetry, volume, and also other features. Scientists categorized this basin into three basins including northern, middle, and southern parts [1]. This area would be very important for all countries which are located in the vicinity of this sea as the Caspian Sea plays a pivotal role in climate change [7]. Now researchers have concentrated on some issues such as global warming and oil contamination. These issues can lead to some problems like the death of marine life and a decrease in ice coverage in the northern part [8]. Although many try to study this area with different approaches, physical oceanographers like to study physical features of this area which includes water properties, thermohaline circulation of this water basin. In the last decade, the number of studies of the circulation of surface and deep-sea waters in the Caspian Sea has been growing. While Gunduz and Özsoy [5] studied the seasonal changes of the surface water, Babagoli et al. [2] and Babagoli and Bidokhti [3] investigated the deep-water flow applying model and laboratory simulations.

Herein, we use ROMS (Regional Ocean Modeling System) model to simulate the surface current and water properties of the southern part. The ROMS model is a free-surface, hydrostatic, and three-dimensional oceanic model that has many capabilities in simulating oceanic and coastal processes. This model solves the Navier-Stokes equations by considering the hydrostatic and Boussinesq approximations [9]. Model apply Arakawa-C grid in the horizontal direction while this model uses inhomogeneous steps in time steps. In this research, we have run this model for the southern part with the horizontal resolution of 2.5 km while we consider 16 layers in vertical grids. The model has been run for 4 years from 2013 to 2016. The GEBCO data are utilized to make the grid file with the resolution 30 seconds. ECMWF data are used to make forcing files for the model. The data were 6-hourly with resolution $0.125^{o} \times 0.125^{o}$. To make initial condition and climatology data, we use COADS and World Ocean Atlas 2013 data respectively. We considered two rivers: Kura and Sepidrud. The river run-off data are extracted from the Global Runoff Data Centre.

The model simulation outputs are validated with observation data and other models. We applied radiation and nudging techniques for our open boundary on Apsheron strait. Fig. 1 shows some results of the model. The results show that ROMS can be an appropriate model to simulate physical phenomena in the Caspian Sea.

The model outputs show that the effects of temperature in the structure of the water body in the southern part can be much more important than salinity. Also, the density is similar to the temperature profile compared to the salinity profile. Generally, the surface circulation is counter-clockwise as the direction of the winds is towards the Iranian coasts. The model indicated that some eddies are formed in the southern part while some of them are dipoles. Most eddies are formed in the deep part of the southern Caspian where the water depth is more than 200 m. The eddies are very strong in fall compared to other seasons.

The model demonstrates surface water changes in the location of eddies formation. These eddies can change thermohaline structure of surface water for roughly 20 cm although the changes (positive or negative) are related to the direction of eddy's vorticity. These eddies have key roles to propagate oil pollution in the vicinity of the southern parts as oil contamination can be one issue of this water basin as a result of human activities.

The eddies' location modelling confirms the previous study which showed that the vicinity of the Sepidrud cape can be the most polluted area [4]. In oceanography, eddies are very important for us as they advect momentum, heat, mass, and also oil pollution [6]. For this reason, we have concentrated on the southern part when boosting our horizontal resolution of the model. This method gives us an opportunity to be able to investigate deeply the behaviors of eddies in this part of the sea.

Based on the studies carried out, it is proposed to regularly monitor, in particular, the Apsheron strait to prevent propagating oil spills. Otherwise, these oil contaminations may reach the eddies. The eddies mix pollution with surrounded water which leads to a more polluted area. Although the authors used numerical models, the observation data to study in-depth the physical phenomena that occurred in the Caspian Sea is needed. In particular, there is a need in some observation data with high resolution on the Apsheron Strait to study the deep water when forming in the northern part of the sea. We suggest that the formation of ice in the northern part can be the best phenomenon to evaluate the effects of climate change on the Caspian Sea, which can be our future goal.

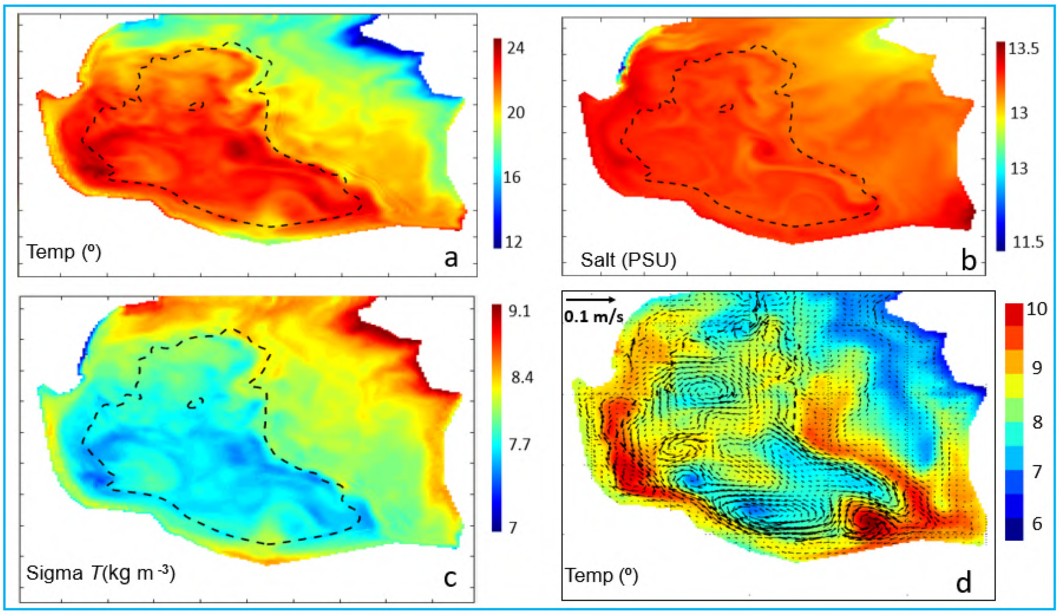

Fig. 1. a) Monthly Sea surface temperature in March, b) Monthly Sea surface salinity in March, c) Monthly Sea surface sigma *T*, d) Monthly mean currents (m s^{-1}) for January in the depth -10 m. The color shows the temperature (please see vector scale). The location of the map is 36-40.5º (latitude) and 49.5-53.5º (longitude).

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The relation of teleconnection phenomena with CSL and SST

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Introduction

Predictions of climate change due to human-induced increases in greenhouse gas and aerosol concentrations have been an ongoing area for debate and discussion. In recent years, the integration of the observation data and modeled data via assimilation techniques has yielded a new generation of datasets for advanced research purposes for a review and comparison of these approaches and for discussion of some related statistical issues. Climate change presents additional obstacles to ending poverty and achieving social justice. Rising temperatures, increasingly erratic rainfall, and more frequent and severe floods, cyclones and droughts all have significant consequences for the livelihood security of poor people; and development professionals are seeing first-hand the effects of a changing climate on their work around the world. Some effects, such as food shortages, may be the result of a combination of hazards, including climate shocks and stresses, declining soil fertility, and insecure access to markets.

Information about temporal and spatial variability in temperature and precipitation time series are extremely important both from a scientific and practical point of view. Meteorological and oceanography studies and predictions benefit from accurate temporal and spatial temperature and precipitation inputs. More uncertain but possible outcomes of an increase in global temperatures include increased risk of drought and increased intensity of storms, including tropical cyclones with higher wind speeds, a wetter Asian monsoon, and, possibly, more intense mid-latitude storms. Changes in climate not only affect average temperatures, but also extreme temperatures, increasing the likelihood of weather-related natural disasters.

Long-term observational data are essential for detecting and understanding local, regional and global climate change. The goal of this work is to consider climate data of Caspian Sea for any trend’s annual means of seas surface temperature and Caspian Sea level for 1979-2020. A link between Caspian Sea level (CSL) and sea surface temperature (SST) was proposed based on idealized model simulations. Some inconsistencies in the data were found. Using such methods as

Man-Kendall correlation and Z-score some statistical considerations were made that are discussed below.

Interpretation and discussion

The Fig. 1 demonstrates the distribution of the mean temperature of the water surface layer in the Caspian Sea in different seasons of the year during the period 1979-2020. The correlation between the annual change of the CSL (DCSL) with ENSO indices shows the statistically significant connection. Moreover, the connection between the Volga River discharge (VRD) and ENSO is observed. The correlations with NAO are low.

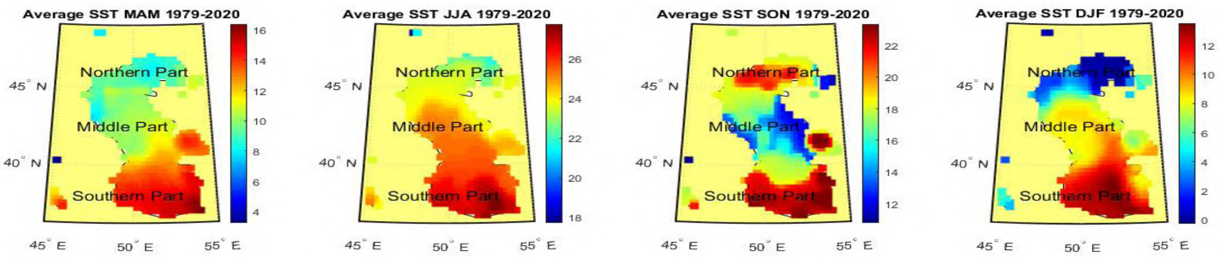

Fig. 1. Position of study area

Tab. 1 shows that after filtering the connection between DCSL and NAO or ENSO have an even stronger connection with ENSO than with NAO though the one with NAO becomes significant after filtering.

Tab. 1. Correlations with and without applying a low pass filter (three point running mean) on all time-series for a selection of variables.

	Without filtering		With filtering	
	DCSL	VRD	DCSL	
SOI	-.468**	-.399**	-.608**	
NAO	.228	.137	.380**	
ONI	.359**	.255	.460**	

*significant at the 0.05 level
**significant at the 0.01 level

Large correlations between DCSL and CSL are surprising. A physical reason may explain this, i.e. with higher CSL the size of the CS will increase [1].

Moreover, one can also use a high pass filter (we use the time derivatives of both series) to remove any impact of trends on the correlation, which improves the correlations for all indices and makes even the NAO values significant but still much below those frm ENSO (Tab. 2).

Tab. 2: Correlations on all time-series for a selection of variables.

parameter	SOI	NAO	ONI	AMO	AAO	TNI	PNA	MEI
CSLDJF	.079	-.141	-.096	.272*	.073	-.085	.005	-.123
CSLJJA	.112	-.136	-.079	.286**	.045	-.120	.023	-.109
SST1	.053	-.065	-.151	.402**	.224*	-.023	-.001	-.225*
SST2	.121	-.150	-.168	.556**	.220*	-.078	.021	-.263*
SST3	.104	-.172	-.141	.572**	.188	-.023	.055	-.243*
SSTDJF1	-.055	.049	-.090	.017	-.056	-.123	-.090	-.164
SSTDJF2	-.022	-.089	-.099	-.013	-.107	-.077	.043	-.146
SSTDJF3	-.069	-.028	.046	-.428**	-.233*	.042	-.017	.097
SSTJJA1	.003	-.128	-.092	.392**	.235*	.095	.169	-.131
SSTJJA2	.064	-.144	-.181	.501**	.351**	.114	.131	-.257*
SSTJJA3	.079	-.115	-.175	.545**	.308**	.124	.158	-.254*

* significant at the 0.05 level
**significant at the 0.01 level

The differences in the SST are not large but obviously large enough to be seen in the evaporation, especially as the larger SST differences are in summer when evaporation is largest.

In our present investigation we wanted to understand the **findings from model simulations by comparing them with observations**. First the decrease of the summer SST in the southern basin of the CS with larger CS sizes during summer for which we look into energy budget terms of the Caspian Sea during years with high CSL and with low CSL.

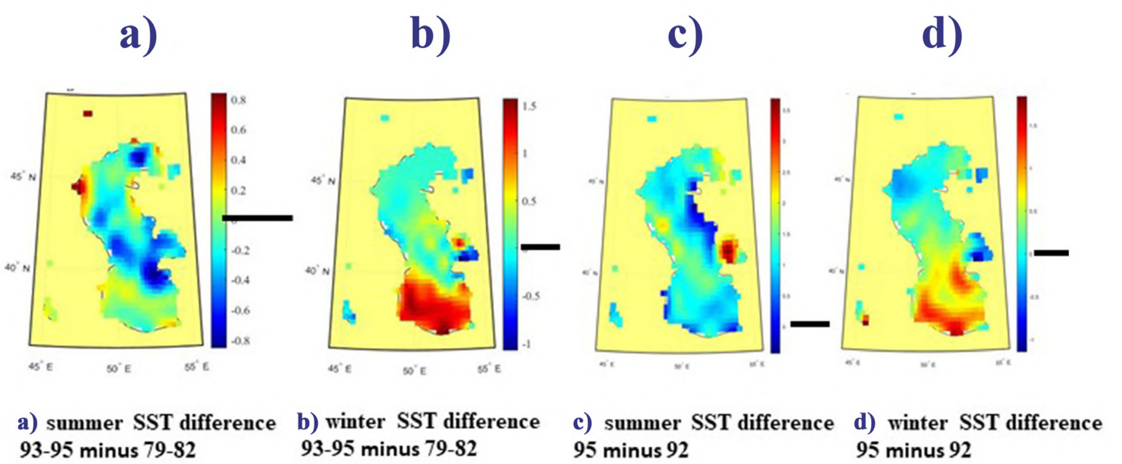

Fig. 2. Sea Surface Temperature difference of the CS between the period 1993 to 1995 (high CSL) and 1979 to 1981 (Low CSL) for JJA (a) and DJF (b) and (c) the differences between 1995 and 1993 for JJA, period of extreme CSL increase C and (d) the differences between 1995 and 1993 for DJF

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Translated from Russian

Modeling of the Caspian Sea level in various climatic conditions using the IVMIO-CICE oceanic model and the INMCM climate model

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In this work, the estimates of changes in evaporation from the surface of the Caspian Sea and the volume of river runoff necessary to maintain the equilibrium state of the lake in different climatic conditions and at different levels of the lake were carried out. The regional configuration of the oceanic vortex-resolving model of the IVMIO, combined with the sea ice model of CICE, was used. As atmospheric boundary conditions in the oceanic model, the results of experiments of the INMCM climate model [5] on reproducing the climate of the last glacial maximum (LGM, LGM experiment, 21 thousand years ago) and the climate of the pre-industrial period (piControl, around 1850) performed within the CMIP6 and PMIP4 project were used [1].

The IVMIO model approximates a system of three-dimensional equations of ocean dynamics and thermodynamics in the Boussinesq approximations, hydrostatics and incompressibility of water by the finite volume method on a B-type grid in vertical z-coordinates. The numerical implementation of the model is described in [4]. In this work, we used a regular horizontal model grid with a resolution of 0.27° in longitude and 0.2° in latitude, 28 vertical levels with a step from 6 m in the upper layer to 125 m in depth. The boundary conditions include the intensity of precipitation, descending fluxes of long-wave and short-wave radiation, air temperature and humidity, and wind speed. The CICE dynamics and thermodynamics model [3] is used on a grid of the same resolution and with the same time step as the ocean model. The construction of a joint IVMIO-CICE model is described in [2].

The calculations were carried out for different levels of the Caspian Sea: -60, -45, -30, -15 mbsl. The experiment was organized as follows: at each level of the lake, an initial approximation was set for the value of the river runoff. After that, over 20 years, a count was carried out using INMCM climate modeling data (piControl, LGM experiments), and the value of water imbalance was calculated, averaged over 6-20 years. Then the volume of the river runoff was corrected for this amount of imbalance, and the counting continued for another 30 years in the conditions of the "balanced" state of the Caspian. As a result, the obtained evaporation fields, averaged over the last 20 years, were analyzed. The obtained values of the river runoff volume required for a balanced state of the Caspian Sea at different levels for the pre-industrial and LGM climate are shown in Fig. 1.

The experiments carried out make it possible to more correctly estimate the volume of evaporation from the surface of the Caspian Sea in different climatic conditions than when using the data of global climatic models; as well as to obtain the dependence of the evaporation volumes on the level of the Caspian Sea, which, due to the morphological features of the lake, is non-linear. This information can be useful both for paleoreconstructions of the lake level and for forecasting the future state of the water body.

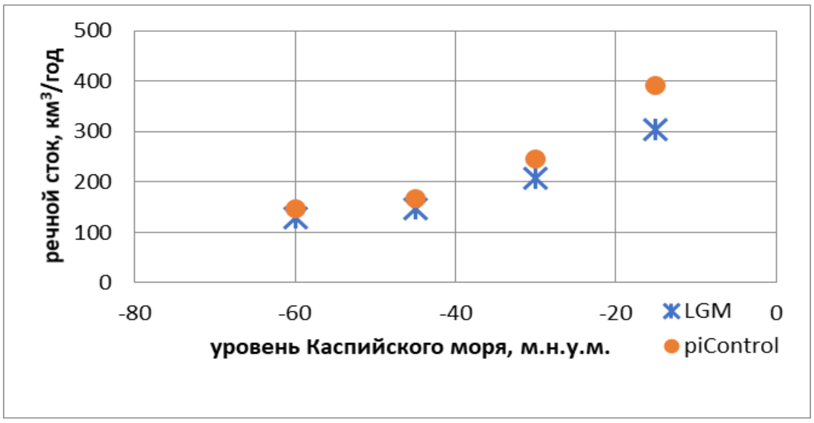

Fig. 1. The volume of river runoff required for the equilibrium state of the Caspian Sea at different levels for the pre-industrial and LGM climate according to IWMIO-CICE and INMCM

Analysis of the data of climatic models that reproduce the preindustrial climate and the climate of the LGM within the framework of the PMIP4 and CMIP6 projects, available on the website [1], showed a large inter-model scatter in the reproduction of the river runoff in the Caspian basin during the LGM epoch. Half of the models reproduced the Volga runoff in the LGM close to the preindustrial one, the other – its decrease by 40-50%. The resulting range of the Volga runoff during the LGM epoch in absolute terms was 100-175 km^3/year. If we consider the change in the flow in the LGM as a deviation in percent from the current observed flow, then the Volga flow into the LGM will be 125-240 km^3/year. If, in addition to the Volga, we also consider the runoff of the Caucasian rivers (Terek, Sulak, Kura), then the relative changes in the region for all models during the LGM epoch do not exceed 20%, i.e. the total runoff of the rivers of the Caucasus fluctuates in the range of 25-35 km^3/year. Thus, the minimum estimates of the river runoff into the Caspian Sea are about 145 km^3/year, the maximum – about 280 km^3/year. According to calculations using the IWMIO model, these volumes of river runoff in the LGM correspond to the Caspian Sea levels of about -45 mbsl and -20 meters above sea level, which excludes deep regression of the Caspian Sea.

This work was supported by the Russian Science Foundation (grant № 19-17-00215, assessment of the results of the PMIP4 project), state assignment IG-RAN 0148-2019-0009 (modeling the LGM climate using the INMCM model) and state assignment IO RAS 0128-2021-0003 (development of a version of the IO-MIO-CICE for Caspian Sea model and INMCM atmospheric data).

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Future decline of the Caspian Sea level: does the north Atlantic oscillation matter?

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The Caspian Sea Level (CSL) has undergone variations of more than 3 m during the past century which drastically affected the lives of coastal people, agriculture activities, fisheries, economies and the ecosystem of the countries which share the Caspian Sea (Azerbaijan, Iran, Kazakhstan, Turkmenistan and Russia). Future CSL is directly affected by changes in its water budget (precipitation minus evaporation over the catchment; P-E) which is linked to the projected impacts from anthropogenic global warming.

Our study examines the annual and seasonal (summer-winter) changes in regional climate and Caspian Sea water budget and potential links to the winter North Atlantic Oscillation (NAO). We use the IPCC-type climate model CESM1.2.2 and its climate projections by 2100 under the Representative Concentration Pathways RCP4.5 (intermediate emissions scenario) and RCP8.5 (high emissions scenario). The model suggests that the NAO remains the key driver of winter variability in the Caspian region, strongly influencing the precipitation pattern over the catchment area.

Under the mid-range RCP4.5 scenario a significant correlation ($r = 0.5$, $p < 0.05$) is found between the NAO and the catchment P-E over the 21st century mainly through a strong impact of the NAO on precipitation over the Volga basin. For the high emissions scenario of RCP8.5, however, this correlation disappears as anomalous net evaporation in the middle and southern catchment basin cancels anomalous precipitation in the northern catchment region in the positive NAO phase and vice versa. This suggests that the North Atlantic Oscillation's effect on the CSL will increase over the 21st century if global warming will be moderate (RCP4.5), but will vanish, if global warming will become too intensive (RCP8.5). In both warming scenarios, increasing evaporation over the lake surface will lead to a gradually declining CSL. Despite increasing precipitation over the northern Volga basin, the increasing evaporation results in a negative water budget and an additional CSL drop of ca. 9 m (RCP4.5) to 18 m (RCP8.5) (or 16 m if we correct for a model evaporation bias).

These values are larger than previous projections of CSL decline shown by other studies. The evaporation increase will take place between the spring and fall seasons. Such a CSL decline will have a significant impact on the Caspian environment, especially over the northern Caspian shelf which presently has a depth of about 5 m. It is necessary to safeguard the livelihood of the coastal communities that rely on a healthy Caspian environment as well as a unique biodiversity with an extraordinary degree of endemism. Hence, our study poses serious concerns and new implications for future risk assessment and developing adaptive strategies for this region.

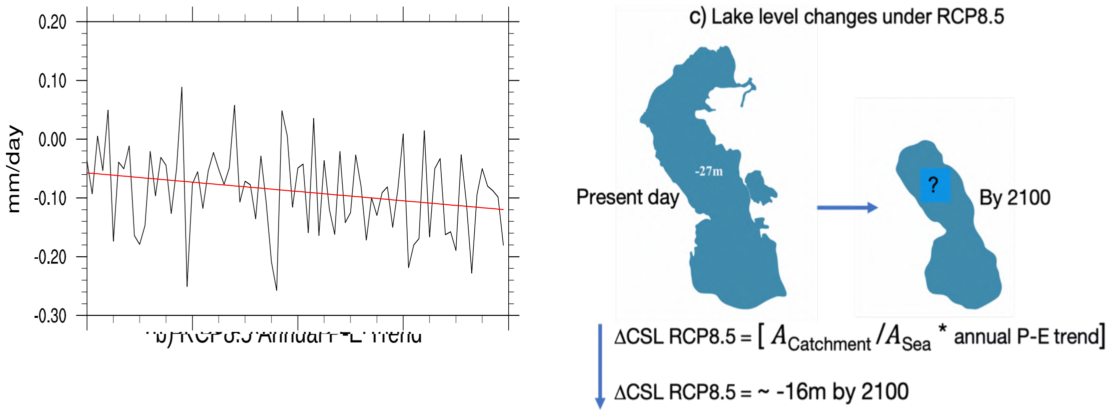

Fig. 1. Trend analysis of P-E timeseries based on annual means integrated over the CS catchment area ($A_{Catchment}$) over 80 years (2020–2100) for (a) RCP4.5 and (b) RCP8.5 as simulated by CESM (CAM5, 1° horizontal resolution). Taking the high emissions scenario RCP8.5 and correcting for a model evaporation bias (c), a 16 m sea level decline is projected by the end of the 21st century.

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Translated from Russian

Main features of the hydrometeorological regime and level of the Caspian Sea in the face of global warming

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The analysis of climate-forming factors, as well as the assessment of their impact on hydrometeorological conditions of the Caspian basin in the XX-XXI centuries, has allowed for the most objective and comprehensive reflection of the dynamics of complex hydrometeorological processes and sea level fluctuations in the face of global climatic variability and anthropogenic effect on the sea regime. Statistically significant causal relationships in the variability of circular processes and sea level fluctuations have been identified. The formation of hydrometeorological processes in the Caspian basin is associated with large-scale ocean-atmosphere interaction processes developing over the North Atlantic. It has been discovered that long-term unidirectional changes in the level of regressions or transgressions occur under the conditions of global climatic variability manifested throughout the whole Atlantic-Eurasian sector. Thus, under conditions of an anomalous development of anticyclonic processes determined by the eastern form of circulation, there has been a drop in sea level (by 1.8, 0.7 and 1.6 m, respectively) in 1930-1941, 1970-1977 as well as since 1996. Under the western circulation form, an abnormal development of cyclonic processes was recorded in 1978-1995, leading to a sharp and intensive rise in sea level (by 2.4 m).

The considerable variability of the Caspian Sea level leads to environmental disasters and very tangible economic losses. From the beginning of instrumental monitoring (1830) until the end of the 19th century, the sea level was high and fluctuated around -25.8 m abs. During the XX-XXI centuries, as a result of the observed tendency towards a secular decline in sea level, one can identify several characteristic periods of the Caspian sea level, corresponding to different water balance conditions: a period of relatively balanced water level – stable and high sea level (around -26.2 m abs) at the beginning of the century (1900-1929); extremely deficit water balance – a period of catastrophic decline (by 1.8 m) from 1930 to 1941; a slight deficit – a slow decline (by 1.2 m) from 1942 to 1977; a period of increase (by 2.4 m) from 1978 to 1995, corresponding to the predominance of inputs over outputs; and a period of decline (by 1.6 m) from 1996 to the present, due to a deficit in the water balance. These periods largely correlate with the variability of climatic processes and are closely associated with epochs of atmospheric circulation, corresponding to their temporal boundaries.

The Caspian Sea level fluctuations are caused by a combination of climatic and anthropogenic factors. The tectonic impact on the sea level fluctuations is insignificant and cannot be compared with the climatic and anthropogenic impact. Modern tectonic processes lead to multidirectional vertical displacements of the floor and shores, not exceeding 2,5÷11 mm/year in most cases, while the modern interannual variability of the sea level is more significant (+36÷40 cm from 1978 to 2018). The annual decrease in sea level influenced by anthropogenic impact, mainly as a result of irretrievable withdrawals of river flow, currently does not exceed the 4-7 cm layer.

The assessment of the effect of climate-forming factors on the moisture character of the sea basin has shown that the main cause of the current Caspian Sea level drop is the development of a combined epoch of the western (W) and eastern (E) forms of atmospheric circulation in the Atlantic-Eurasian sector of the northern hemisphere. The activization of the eastern form of circulation led to a deficit of precipitation in the catchment area of the Volga basin and, as a consequence, shortage of water. All this, together with the intensification of evaporation processes, has led to a drop in sea level.

From 1996 to 2018, 280.5 km^3 of river water (on average) has flowed into the sea; the Volga River flow amounted to 250 km^3 (in 2018 it reduced to 178 km^3). In the previous years of the sea level rise, the volume of the total inflow averaged around 315 km^3/year. The average value of the total surface inflow to the Caspian Sea in the XX-XXI centuries was about 300 km^3/year, varying from 200,0 in 1996 to 459,8 km^3/year in 1926 (a year of extreme Volga inflow). The total volume of flow, taking water surface into account, resulted in an average annual sea level rise of 55÷115 cm.

The average values of the evaporation layer varied from 72.2 to 116.8 cm/year in different periods of the XX-XXI centuries, averaging around 97.0 cm/year. In early XX century, the average annual evaporation was about 97.0 cm (390 km^3/year); in the 1930s it amounted to 100.4 cm (395 km^3/year); in 1940-1960, the average annual evaporation from the decreasing sea area amounted to 96.4 cm (360 km^3/year). In 1970-1977, the evaporation rate increased to 103.9 cm/year, and it decreased to 92.0 cm (344 km^3/year) in 1978-1995. Further, the evaporation rate increased again to 97.6 cm (378.3 km^3/year) during the 1996-2018 time period.

Positive departures of the long-term annual values of air temperature from the mean annual norm have been observed by the Caspian Sea HMS (hydro-meteorological services) since the mid-1980s. The continuation of these trends in the future may lead to an increase in the intensity of evaporation processes, which will affect the drop in sea level.

Thus, the period of the current level drop is caused by a water balance deficit, which led to a -28.2 m BS sea level drop in 2019, with the level dropping by an average of 6 cm annually (in some years the level dropped by 30 cm and rose by 14 cm).

This research allows for the assessment of the current influences of exo- and endogenous processes on hydrometeorological conditions of the Caspian Sea basin and provides an objective characteristic of their long-term variability under the conditions of global and regional climatic variability and anthropogenic impact on the hydrological regime of the sea.

Detection of Caspian Sea coastline changes by applying fuzzy object-based image analysis procedures

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Coastal zone detection is an important task in national development and environmental protection, in which, extraction of shorelines should be regarded as a fundamental climate change research of necessity. Very dynamic coastlines such as the Caspian Sea coasts and islands could pose considerable risk to the littoral countries' future economic-social developments. Due to the rapid advances in remote sensing technology, modern and reliable techniques are required to detect and update the coastline geodatabase of these areas to explore rates of physical and ecological retreats.

Accordingly, the main aim of the present study is to monitor the Caspian Sea coastline swings over a possible maximum period from 1980 to 2021. For this purpose, Landsat TM, ETM+ and OLI, and Sentinel 2 (A & B) imageries were progressively processed to generate most of the thematic models in a tempo-spatial context. All data sets were sampled from the Khazar Islands Port (south of Baku city) to Neftchala Peninsula and precisely preprocessed by ERDAS Imagine software, referenced to the accurate DEM and TOPEX/Jason satellites data.

By introducing Fuzzy Object-Based Image Analysis (F-OBIA) procedures, first, Dynamic Thresholds Classification (DTC) was applied by developing a few spectral several indices. Then, to recognize precise landuse (LU) changes inside the study area, a rule-based Nearest Neighbour Classify (NNC) was considered by accompanying **an advanced supervised classification technique** within the Trimble eCognition 10.1 setting. To improve processing accuracy, all images have been segmented to derive water surfaces and coastlines objects, by applying F-OBIA inside an eCognition software. Revealed models demonstrate several long-term meaningful persuaded fluctuations and considerable periodical changes on the western part of the Caspian Sea coastline, even the emergence of new or enlarging the existing islands and changes in the location of oil rigs mostly observed during the recent years. Implementations of such significant changes signify that at present the majority of Azerbaijan coastal natural components and oil exploration industry are undoubtedly in crucial hazards.

Translated from Russian

Some features of sea level fluctuations in the northern Caspian Sea in the 21st century

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A unique feature of the Caspian Sea is the difficult-to-predict long-term changes in its level. Rapid and significant fluctuations in the level of the Caspian Sea are a normal manifestation of the unstable state of a closed basin with variable conditions on its external borders.

The problems of the Caspian Sea level fluctuations and the forecast of the level for the future have attracted scientific and practical interest in the Caspian countries since the early 30s of the XX century and are reflected in numerous publications. Particularly increased attention to level fluctuations is currently associated with the developing development of oil and gas fields in the shallow Northern Caspian Sea and on coastal areas.

Since 2006, the sea level has been characterized by consistently negative annual increments, and the rate of sea level decline has increased markedly [1, 2]. The maximum annual values of sea level drop during this period reached 19-25 cm per year (maximum: 25 cm in 2011). The intensity of the recorded level drop is also shown by the following figures: the average level for the first 10 years of the XXI century (2000-2010) was -27.10 m, and in the next decade (2011-2020) was -27.88 m (78 cm lower). In 2020 there was a slowdown in the fall of sea level compared to 2019, when it fell by almost 20 cm over the year.

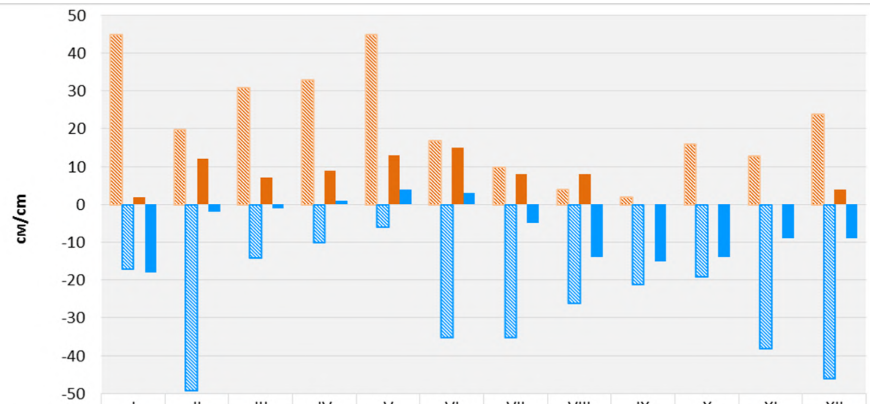
Although the course of the average annual sea level at the posts in the Northern Caspian Sea may differ from the course of the average level of the entire Caspian Sea, however, the transition of the value of -28.00 m at the Peshnaya HMS (hydrometeorological station) and background level occurred in 2018. The maximum annual values of the sea level drop on the Peshnaya HMS were observed in 2018-2019 and amounted to 22 and 29 cm / year, respectively.

Each region of the sea (Northern, Middle and Southern Caspian) has its own characteristics in the hydrometeorological regime and the intra-annual course of the level. In the northern part, where most of the river flow enters, changes in the seasonal course of the level are more pronounced.

More significant values of monthly changes in sea level are reported on Peshnaya HMS, which are under a stronger influence of river flow, than the values of monthly changes in the background (average) sea level. The difference between the average monthly levels reached the values of 35-49 cm at the Peshnaya HMS (Fig. 1).

In 2010, an anomalous seasonal decline in the level of the Caspian Sea was recorded, the value of which was 1.5 times higher than the average value over the past 50 years. From June to October 2010, in the western part of the Northern Caspian (Tyuleniy Island), the seasonal drop in sea level was 32 cm (Roshydromet data) [5]. Analysis of data from hydrological stations of the RSE "Kazhydromet" in the North Caspian also showed that in 2010 the largest seasonal drop in sea level was recorded in the area of the Kulaly Island. In the Peshnoye area, the seasonal decline was also significant, but it was not the largest. The magnitude of the sea level drop from June to October 2010 at the Peshnaya HMS was 34 cm. The maximum seasonal drop in the level (June-October) on the Peshnaya HMS was noted in 2017 and amounted to 59 cm [3, 4, 5].

In general, in the sea, the maximum seasonal decrease in the level in the period 2000-2020 was recorded in 2010 – 32 cm and in 2020 – 34 cm.



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Прирост (Пешной)	45	20	31	33	45	17	10	4	2	16	13	24
Снижение (Пешной)	-17	-49	-14	-10	-6	-35	-35	-26	-21	-19	-38	-46
Прирост (фоновый)	2	12	7	9	13	15	8	8	0	0	0	4
Снижение (фоновый)	-18	-2	-1	1	4	3	-5	-14	-15	-14	-9	-9

Fig. 1. Values of monthly increases and decreases in sea level (background, Peshnaya HMS)

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Translated from Russian

Long-term forecast of the Caspian Sea level in the face of global warming

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Plans for the development of the Caspian region of Russia should be based on long-term forecasts. The establishment of infrastructure ensuring the normal operation of the fuel-energy complex and the transport network should also be carried out with consideration of the hydrological characteristics of the sea. Due to its lack of connection with the World Ocean, the key problem of the Caspian Sea for the long-term planning is long-term forecasting of the sea level variation.

ture climate changes in Russia via an ensemble of global climate models used in the 5th phase of the international coupled model intercomparison project (CMIP5) [7]. Precipitation data for the Volga catchment area were obtained from the AISORI database and the “Pogoda and Klimat” (*Weather and Climate - translator’s note*) website. The archival data of the FSBI CaspMSRC was also used. The calculation of the predicted level of the Caspian Sea was carried out using the water balance approach. The elements constituting the water balance in our calculations were river flow, atmospheric precipitation, evaporation and flow into the Kara-Bogaz-Gol Bay (KBG).

Considering the significant relationship between sea level fluctuations and river flow [3], especially in the case of the Volga River, it can be assumed that changes in the amount of precipitation in the Volga catchment area will determine the sea level dynamics. In fact, there is a fairly consistent relationship between the amount of precipitation in the Volga catchment area and its flow. In the correlation time series analysis from 1966 to 2019, the correlation value was 0.40, which indicates the reliability of the relationship at a significance level of $\alpha = 0.01$. If the soil inertia of the catchment basin, amounting to 2-3 years [5], is taken into account, and the flow range is moved by one step, then the relationship increases to 0.60. Thus, it is permissible to assume that there is a linear dependence of the flow on the total amount of precipitation in the catchment area in the form of $R = 0,3146*P – 4,1755$.

On average, during the 1961-2018 time period, the Volga flow accounted for 88% of the total rivers flows into the sea.

The amount of precipitation falling over the sea was calculated via the method used in the Hydrometeorological Center of Russia [1].The calculation was performed using averaged values for the amount of precipitation as well as the recorded differences between the air and water temperatures at 12 stations. Since the amount of precipitation (according to the modeling results within the framework of CMIP5) in the near Caspian regions of Russia remains practically unchanged, we took the amount of precipitation over the sea to be also constant.

Evaporation was calculated using the method of K.I. Smirnova [6], which requires the average air temperature for the previous 4 months at the stations of Makhachkala, Shevchenko, Baku and Krasnovodsk. From the modeling data, it appears that the amount of evaporation in the Caspian region of Russia has been varying in the range from 0 to 5% over the course of the 21st century [2]. With that in mind, we took the amount of change in evaporation for the Caspian Sea as a whole to be the same, depending on the climatic scenario and time.

The calculation of the water flow into the Kara-Bogaz-Gol bay was carried out using the modeling data from the State Hydrological Institute (SHI) [1]. Therethrough, the level of the bottom of the strait is -30.6 m BS (Baltic system). At this sea level, the flow into the bay stops, and when the sea level rises to -26.8 m BS, the flow into the bay gradually increases to 20 km3/year. To simplify the calculations, we accepted the assumption of a linear dependence of the flow into the KBG on the mean sea level, built from two points (see above) and having the form: D KBG = 5,2632*L + 161,05.

To obtain the predicted values of the sea level, we used the concept of the level of gravity. This level is characterized by an equalization of forces contributing to the decrease and rise in sea level. Thus, the balance sign will indicate the direction of changes in the Caspian Sea level. Considering the dependence of evaporation on the sea area was most convenient for our calculations. A decrease in the amount of evaporation is insured by a decrease in the sea area. The sea area, in turn, is linearly related to its level [4]. The linear dependence of the sea level on a thousand km2 area, obtained from the data for 1961-2018, has the form: L = 0,0716*S – 55,049.

To determine the changes in the sea area from the amount of evaporated moisture, the amount of moisture that entered the sea was subtracted from the sea surface. A positive difference indicated a trend towards a decrease in sea area. The number of ths. km^2 by which the sea area had to decrease in order to compensate for evaporation was calculated as the product of the average evaporation per 1 ths. km^2 by the difference. The resulting area, by which the sea area should have decreased (increased), was subtracted (added) from the initial value of the area. The sea area observed in 2018 was set as the initial area value.

Tab. 1 Elements of the water balance of the Caspian Sea in the XXI century

Scenario	Time period, yrs	Volga flow, km^3	Atmospheric Precipitation, mm	Evaporation, mm	Flow into the KBG, km^3	Sea level, m
1981-2000		260	227	995	13	-27,4
RCP 2.6	2011-2031	258	227	995	14	-29,1
	2041-2060	258	227	1005	14	-29,3
	2080-2099	258	227	1015	14	-29,6
RCP 4.5	2011-2031	258	227	995	8	-29,7
	2041-2060	260	227	1015	7	-30,0
	2080-2099	261	227	1035	5	-30,3
RCP 8.5	2011-2031	258	227	995	5	-30,1
	2041-2060	272	227	1025	3	-29,8
	2080-2099	279	227	1045	1	-29,7

As seen in the obtained results (Tab. 1), the Caspian Sea level will exhibit negative dynamics over the course of our century. Depending on the climatic scenario, the sea level may drop to –30 m BS and below. It is interesting to note that the stabilization of the sea level observed at the end of the century is likely to be due to a decrease in flow into the Kara-Bogaz-Gol Bay.

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Translated from Russian

Climate changes and fluctuations in the Caspian Sea level: a retrospective analysis for the last 10,000 years

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Fluctuations in the level of the Caspian Sea at different stages of its geological history depended on many (both geological and climatic) factors. In the last 10 thousand years, the determining role has belonged to multi-scale and multi-directional climate changes. The task of this work is to reconstruct the level fluctuations under the impact of climate changes based on the analysis of the structure of the sedimentary strata of the Northern Caspian Sea. The material was the results of processing of seismic-acoustic profiles, lithological, faunal and geochronological (radiocarbon analysis) studies of the core of wells and bottom columns. Drilling was performed by Morinzhgeologiya LLC, lithological and faunal analyses were carried out at Moscow State University, and radiocarbon dating was obtained in the laboratories of the State University and the Pedagogical University of St. Petersburg and at the Institute of Geography of the Russian Academy of Sciences. The calibrated age is calculated according to the CalPal program of the University of Cologne [www.calpal.de]. Materials about the Holocene climatic events are taken from literary sources.

The structure of the sedimentary strata of the Northern Caspian Sea reflects the paleogeographic events of the Holocene: the Mangyshlak regression and the New Caspian transgression, which developed in stages. The Mangyshlak regression is dated to a time interval of ~11,500-8,000 years. In climatic terms, this epoch of the early Holocene (Boreal, according to the Blitt-Sernander scheme) was characterized by a relatively high heat supply and dryness [2, 5]. This ratio of climatic indicators led to an increase in the negative component of the Caspian water balance and its regression. The results of the palynological analysis indicate the xerophytization of the vegetation cover in the Caspian region during the Mangyshlak regression [1]. The average annual precipitation is less than the current values reconstructed for the Volga basin in the period up to 9,500 y.a. [4].

Three transgressive stages have been established in the development of the New Caspian transgression. The first one dates from the interval of 8,200-5,600 y.a.

In climatic terms (the Atlantic optimum of the Holocene), most of it belongs to the era of warm and humid climate [4, 5]. The conclusion about the existence of a long stage of warming and humidification of the climate in the Lower Volga region in the range ~8,500-7,600 and from 6,100 to 5,000 y.a. was made by N. Bolikhovskaya [1]. The regressive stage that replaced it has an age range of 5,600-3,700 y.a. The level of the Caspian Sea decreased by 8 m, the near-delta plain came out from under the Caspian waters and was subjected to erosive dismemberment and the influence of subaerial processes. In climatic terms, this is the period of the subboreal thermal maximum of the Holocene (4,700-3,600 y.a.), established for the Eastern European part of Russia [5], and the period of climate drying in the Volga area [1].

The second transgressive stage covered the time interval of 3,600-3,400 y.a. This was the epoch of the late subboreal cooling on the East European Plain [5]. The phase of climate humidification, which began around 3,500 y.a., was reconstructed for the Lower Volga [1]. The second regressive stage dates back to 3,080-2,300 y.a. The level of the basin decreased by 6-8 m, incisions filled with fresh water formed in the near-delta plain. Obviously, this was the response of the Caspian Sea to the stage of warming and reducing the amount of precipitation in the Volga basin [4]. The rise of the Caspian Sea level that followed the regressive event occurred around 2,300 years ago. Two distinct climatic phases correspond to this period of the Late Holocene: the “medieval climatic optimum” (950-1,250), with precipitation on the East European Plain 25-50 mm lower than the modern one [3], and the “little Ice Age” (1,400-1,700) [2]. Transgressive precipitation in the Northern Caspian has dates of 1,700-1,100 and 900-360 y.a. The hiatus between them provides the ground for the assumption that the level of the Caspian Sea decreased during the warm dry period of the Middle Ages, and the second group of dates corresponds to the transgressive rise of the Caspian during the cool and humid climatic episode (the little Ice Age).

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Translated from Russian

Modeling of wind waves at the port of Aktau

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Wind waves are essential for navigation, construction and operation of facilities in the coastal zone, and for marine operations performance. Digital models, in this case the SWAN spectral-wave model, are important tools for wave conditions modeling both in open water and in coastal areas, as they are able to provide information about wave parameters (height, period, length).

The research zone covers the water area of the Aktau port, which functioning is important for the economic stability of the whole region. The Aktau International Commercial Sea Port, founded in 1963, is a modern multipurpose terminal that provides the cargo transportation from East to West, from North to South and back 12 months a year and 24 hours a day. There are 11 docks in the port, 6 of them are oil loading and 3 are dry cargo. There are shipping routes from the port of Aktau to: Makhachkala, Baku, Astara, Anzali, and Amirabad [3].

The waves observations near the port of Aktau are performed visually; waves with a height of 1 m prevail, but the highest ones can reach 4.5 m. About 70 cases of the maximum wave exceeding 2 m were observed in Aktau, 59% of which were directed to the northwest [1].

The modeling of the wave parameters for the area near the port of Aktau in 2017-2018, on the eastern coast of the Caspian Sea, was performed using the SWAN (Simulation Waves Nearshore) spectral wave model [2, 4].

Input parameters used for modeling: triangulation and regular grid, bathymetry, wind, provided by the European Center for Medium Range Weather Forecasts on a grid of 0.25*0.25 degrees.

The modeling result showed that the water area of the Caspian Sea near the coast of the Aktau port is influenced by the waves of various heights. For example, in 2017-2018, the wave height reached 0.25-0.75m in 46.1% of cases; 0.75-1.25m – in 27.2% of cases; 1.25-2.0m – in 13.3%; 2.0-3.5m in 3.4 %; and very rarely in 0.1% of cases it could reach 3.5 meters.

The direction of the waves of the observed and modeled values are of the same course, wherein north-eastern and north-western ones prevail.

Since observations in coastal waters are performed only visually, the possibility of using models in open sea areas enables waves analysis at a higher quality and informative level.

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Preface to the Collection of the Conference on

Section 3

The effects of climate change on the ecosystem and biodiversity of the Caspian Sea

Scientific conference on climate change in the Caspian Sea region

(27 - 28 October 2021 online)

Preface to the Collection of the Conference on Section 3

Introductory Speech – Natalia Ogar

In recent years, there has been a steady warming of the climate. This is especially evident in arid and semiarid regions, on the land-sea border.

Almost 20 years ago, Kazakhstan actually lost the Aral Sea, which is now a small lake in the middle of the desert. The same fate awaits the Caspian Sea, because despite all efforts, it is shallowing at a fairly rapid pace. The rivers flowing into the Caspian Sea are practically waterless. The only waterway is the Volga River. The Zhaiyk River, which was called the Ural not so long ago, is currently waterless on the territory of Kazakhstan and has no flow into the Caspian Sea.

In 2018, the Central Asian Conference on Adaptation to Climate Change was held in Kazakhstan (Almaty), which sparked active discussions on strengthening cooperation between different countries aimed at sustainable development, as well as innovative approaches to mitigating the effects of climate change.

Over the past period, conferences in the countries of the Caspian region have mainly addressed various problems of the Caspian Sea, which has become shallow at a fairly rapid pace. The Caspian region countries began to consolidate and take the necessary measures to save the Caspian Sea.

In October 2021, within the framework of the Tehran Convention with the participation of CASPCOM, UNEP, IPCC, and others the Caspian littoral countries initiated the international conference "Scientific Conference on Climate Change in the Caspian Sea Region".

During the conference, the issue "The impact of climate change on the ecosystem and biodiversity of the Caspian Sea" was considered in Section 3. This topic is extremely relevant, since the rate of drying up of the Caspian is already obvious and possibly irreversible, given the climate forecasts over the past 10 years.

Experts from different countries took part in the conference in the Section 3: Iran – 6 reports, Great Britain – 2 reports, Kazakhstan – 2 reports. In total, 23 reports with co-authors were presented, in which 76 participants took part, mainly scientists with degrees of doctors and candidates of biological sciences, who are officers of research institutes.

This contributed to strengthening of international cooperation among the countries of the Caspian region to address urgent problems related to climate warming and, consequently, the catastrophic decline in the Caspian Sea level.

Speakers provided evidence-based data, in particular maps of seabed habitats, with the support of the European Marine Observation and Data Network (EMODnet), which can be used to address significant gaps in research and knowledge about the current and future impacts of climate change on the ecosystem and biodiversity of the Caspian Sea.

According to scientists and environmentalists, the largest closed water body in the world is on the brink of disaster. If the situation does not change, then the ancient Caspian will no longer be large. Experts have calculated that the sea level is decreasing by 6-7 centimeters annually, at such a pace the Caspian Sea will be reduced by about a third by the end of the century.

Forecast of the level of the Kazakh part of the Caspian Sea as for September 02-07, 2021

Northern Caspian: the average sea level is expected to be around minus 28.20 m, with fluctuations from minus 27.79 m to 28.55 m.

Middle Caspian: the average sea level is expected to be around minus 28.38 m, with fluctuations from minus 28.14 m to 28.82 m. [https://khabar.kz/ru/news/obshchestvo/item/134061-kaspij-na-grani-ekologicheskoj-katastrofy]

Currently, due to climate warming, the risks of loss of some rare species of animals and plants are already being traced. In the Kazakh part, the indicator is the Caspian seal, whose number is catastrophically decreasing. Human intervention is needed in the conservation of this rare species through studying the adaptive responses of the species to rapidly changing environmental conditions.

In the long term, it is necessary to study the natural habitats of seals, as well as the establishment of artificial islands on marine substrates for their reproduction and protected areas on land. In the marine part of the water area, such aboriginal species as Russian sturgeon, Caspian sprat and others that are not found anywhere else will be threatened by climate warming and shallowing of the sea.

For many years and centuries, the population of the Caspian countries has largely lived off the sea, both socially and economically. The sea provided them with the necessary resources, especially important for food and seafood trade.

In the 21st century, it became necessary to manage the Caspian biological resources, as some valuable marine species began to decline rapidly. The population faced the issues of marine planning to address the social and economic consequences of climate change, the cumulative human impact, efforts for conservation and restoration of the marine environment on the border between land and sea.

The need arose to support the Sustainable Development Goal SDG-14: conserve and sustainably use the oceans, seas and marine resources for sustainable development, including reducing pollution of the marine environment, protecting marine and coastal ecosystems, ending illegal fishing, as well as sharing experiences and lessons learned on their implementation in the Caspian region.

In recent years, science has moved towards the Caspian Sea, scientific work has intensified, especially in terms of the accuracy of maps of seabed habitats etc. With the support of the European Marine Observation and Data Network (EMODnet), as well as maps of various types: ecosystems, coastal-aquatic and bottom vegetation, biodiversity in general, which are necessary for decision-making on climate change and especially on the rate of Caspian Sea shallowing.

The rate of climate warming is especially evident in the transitional coastal-water part of the sea-land. Especially large changes are characteristic of the deltas of the Ural (Zhaiyk) and Volga rivers, where there is a strong regression of the sea. This is determined mainly by the indicator species of flora. For example, in recent years, the areas of wetlands and, accordingly, the places of growth of rare, endangered plant species (sacred lotus, white waterlily etc.) listed in the Red Book of Plants of Kazakhstan have significantly decreased.

For the first time in the Caspian Sea region, all countries have united to avoid the threat of losing this unique water body. At the Scientific Conference on the Climate Change in the Caspian Sea region held on October 27-28, 2021, the countries decided to assist littoral states in eliminating and mitigating the effects of climate change and ensuring sustainable development of coastal zones.

Translated from Russian

Assessment of the state of the Caspian Sea ecosystem due to the impact of climate changes in recent years, based on the results of studies in the coastal waters of Azerbaijan

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Climate change has a significant and diverse impact on the state of water resources, as well as coastal and marine ecosystems in the Caspian Sea basin. There is growing evidence that climate and environmental changes over the past decades have already affected the global hydrological cycle, for example, due to changes in the seasonal flow of rivers in the Caspian Sea basin. It should be noted that during the 2005-2020 period the Caspian Sea level has decreased by 133 cm.

According to CASPCOM (2021), the average level of the Caspian Sea in 2020 compared to the average annual level of 2019 (-28.20 m BS) decreased by about 3 cm over a year and amounted to -28.23 m BS. Thus, due to the low water content of the Volga River, it is predicted that in 2021 the average annual level of the Caspian Sea will be 12-17 cm lower than in 2020.

Anthropogenic activities, including economic ones, lead to an increase in the consequences of climate change. The latter poses an additional danger to the hydrological flow regime, which plays an important role in maintaining the activity of aquatic ecosystems. By the end of the century, in 2071-2100, the mean annual surface temperature in Europe is projected to rise from 1.0°C to 4.5°C compared to 1971-2000 (EEA, 2019). Moreover, estimates indicate that, with global warming of 1.5-2.0°C above pre-industrial levels, water availability will continue to decline, especially in Southern Europe (Bisselink et al., 2020).

Azerbaijan has been facing an acute water deficit in recent years, with an average annual water resources use index (WRUI) exceeding 40%. According to estimates, WRUI amounted to 72.3% in 2017-2019. Due to the new climatic conditions, only a quarter of the total precipitation contributes to the formation of the internal runoff in the country. During the 2000-2020 period, the average long-term flow of the Kura River decreased by more than 50% (Fig. 1). Thus, in recent years, there have been negative trends in the formation of abiotic and biotic factors of natural complexes in the Kura River basin.

Fig. 1. Average annual flow of the Kura River for the 2000-2020 period.

It should be particularly noted that seawater ingress into the Kura (up to 60 km to the city of Salyan) was observed for the first time in Azerbaijan, in 2020-2021, due to a sharp decrease in the river's water level.

In the summer of 2021, during our comprehensive marine environmental studies on the Azerbaijani shelf of the Caspian Sea, due to the abnormally high air temperature, we observed the most significant increase in surface water temperature over the last ten years, to 28-29°C in the Middle Caspian and 30-31°C in the South Caspian. Compared to 2011, the increase in the temperature of the surface layer of the sea was by the order of 4.0-4.5°C (Fig. 2). Moreover, against the background of an abnormal increase in water temperature, there was a decrease in the oxygen content in the water from 7-8 to 6 mg/l, compared to previous ten-year observations. Under conditions of increased sea surface temperature in the upwelling zone in the South Caspian, abnormal blooming of blue-green algae colonies was observed on the traverses from Astara to Kur-Kos, in the depth range of 50-100 m. These algae have a toxic effect on the plankton community and cause a decrease in the dissolved oxygen content in seawater.

Fig. 2. The temperature of the surface water layer in the Middle and South Caspian in the summers of 2011 and 2021 (°C).

For the first time, during the summer marine survey in 2021, a new species of comb jelly, *Beroe ovata*, which is a natural enemy of *Mnemiopsis leidyi*, was discovered in the South and Middle Caspian. It appears that, as a result of climate change in recent years, hydrological conditions that caused an increase in sea water temperature turned out to be favorable for the development of the Beroe ovata population and allowed the new invasive species of ctenophores to successfully acclimatize and reproduce in the waters of both the Southern and Middle Caspian, at isobaths from 10 to 100 m. Moreover, the largest abundance of Beroe ovata was observed at depths from 25 to 75 m; the ratio of the abundance and biomass of the populations of Beroe ovata and Mnemiopsis leidyi amounted to 21% and 79%, respectively.

A significant decrease in trawl research catches of fish as well as the redistribution of fish populations from the Southern Caspian to the water area of the Middle Caspian were observed in the unfavorable climatic and hydrological conditions of the Caspian Sea. The impact of climate change also affected the change in species composition, the decrease in abundance and biomass, as well as the distribution of zooplankton in the South and Middle Caspian Sea.

Thus, as a result of climate changes in recent years and abnormal warming in the Caspian region, a significant decrease in river flow and an increase in sea water temperature caused a significant degradation of the marine ecosystem. With the projected continuation of the scenario of these climate changes in the coming years, the loss of endemic species and a reduction in the biodiversity of the Caspian Sea pose a real possibility.

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Networking management of Ramsar sites in the south of the Caspian Sea, as an important aspect of policy related to climate change

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The Goal2 of the 4th Ramsar (Convention on Wetlands) Strategic Plan states that the Ramsar site network will be effectively conserved and managed by 2024. The report of the Open Working Group on Sustainable Development Goals has anticipated that all wetlands as well as the Ramsar Sites network will have direct relevance for any Sustainable Development Goals related to climate change adaptation, biodiversity and sustainable use of ecosystems, etc. (Ramsar Convention Secretariat, 2016). The key messages of the Millennium Ecosystem Assessment Wetlands and Water Synthesis Report highlight that the degradation and loss of wetlands are more rapid than that of other ecosystems; that global climate change is likely to exacerbate the loss and degradation of many wetlands; that the adverse effects of global climate change will lead to a reduction in the services provided by wetlands; and that the projected continued loss and degradation of wetlands will reduce the capacity of wetlands to mitigate impacts (Millennium Ecosystem Assessment, 2005). In line with the lead implementation role of the Ramsar Convention and CBD for wetlands as well as the terms of the fourth CBD/Ramsar Joint Work Plan, the Ramsar Sites network, the effective management of Ramsar Sites as well as the wise use of other wetlands in the world constitute an essential contribution to the work of not only the Convention on Biological Diversity but also the other Multilateral Environmental Agreements such as the UN Framework Convention on Climate Change.

The Caspian Sea is the largest enclosed body of water on earth, which has about 400 endemic species in its unique and isolated ecosystem. A total of ten Ramsar sites have been designated in the five countries bordering the Caspian Sea. The region's coastal wetlands can be seen as an important part of the Caspian Sea ecosystem, the preservation of which is a matter of priority.

In Iran, there are six Ramsar sites on the southern shoreline of the Caspian Sea (Fig. 1). Development activities have threatened sensitive wetland habitats in this region. In addition, falling water levels in the Caspian Sea have negatively affected coastal wetlands, resulting in shallow and arid areas (Amini et al., 2021).

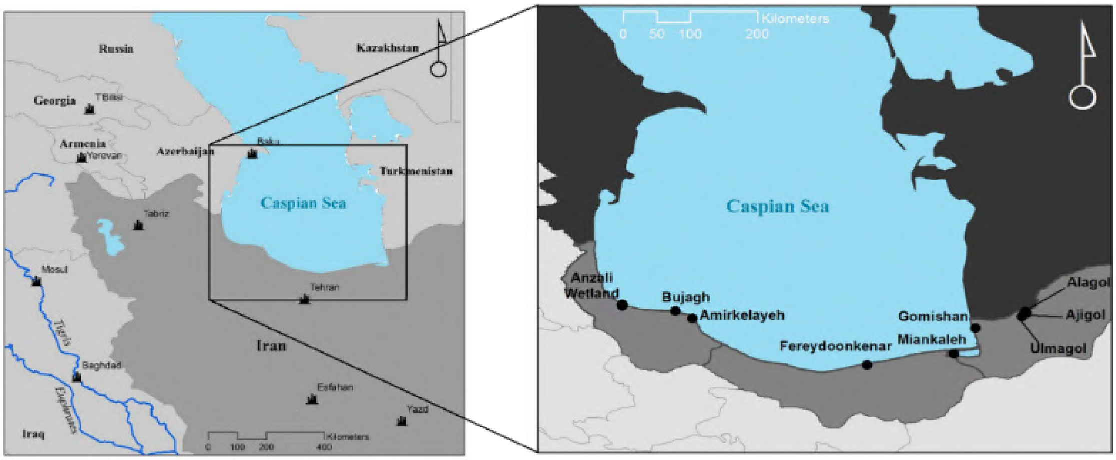

Fig. 1: The Map of Ramsar Sites in the South of Caspian Sea

Paragraph B, Article 38 of the 6th socio-economic development plan stipulates that by the end of the sixth 5-year period, at least 20% of critical and endangered wetlands in Iran, especially the ones registered in Ramsar Convention, shall be restored in cooperation with relevant organizations and local communities. Similarly, and according to the 4th and 5th socio-economic development plans, the Department of Environment (DoE) has been determined as the main responsible party for implementation of ecosystem management. Subsequently, the Marine and Wetlands Deputy of the DoE has commenced their activities in order to establish the ecosystem approach in wetlands management (Fig. 2).

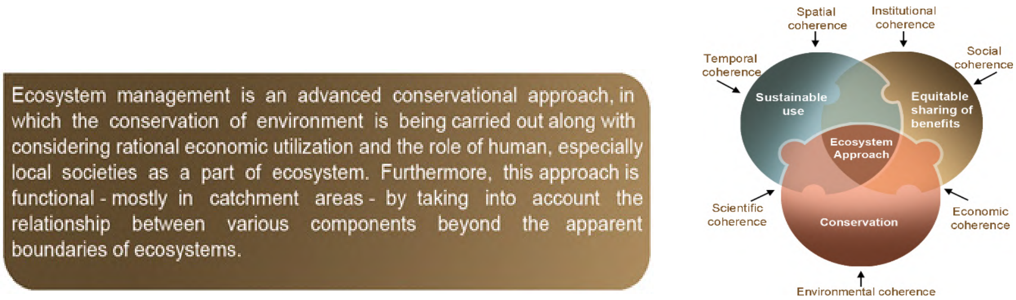

Fig. 2: Overlapping objectives of the Ecosystem Approach (Secretariat of the Convention on Biological Diversity, 2004)

The Caspian Sea has unique regional characteristics, such as the presence of endemic species and long-term fluctuations in water levels. Therefore, it is crucial that the riparian countries of the Caspian Sea region manage coastal wetlands through information sharing and other concerted efforts. For example, as a result of a satellite tracking survey of migratory birds, it was observed that the Dalmatian Pelican (*Pelecanus crispus*) and the Purple Heron (*Ardea purpurea*) move among the Ramsar sites in the littoral countries, such as the Anzali Wetland in Iran, Ghizil-Agaj in Azerbaijan, and the Volga Delta in the Russian Federation (JICA, 2019). This shows that international and transboundary cooperation is effective for the conservation of migratory birds.

In addition, the Framework Convention for the Protection of the Marine Environment of the Caspian Sea (Tehran Convention) envisions the establishment of Protected Areas of the Caspian Sea (PACS), which need international cooperation among riparian countries. Since Ramsar sites can play a key role for the PACS, it is proposed to establish a network of Caspian Sea Ramsar sites.

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The Samur forest: is it a freshwater refuge for brackishwater Pontocaspians?

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Most gastropod species endemic to the Caspian Sea were described based on the empty shells morphology, whereas records of living specimens of these species are extremely scarce (except for *Theodoxus pallasi*, which is quite abundant). This situation characterizes the whole, two century long, history of exploration of the Caspian Sea malacofauna. The genus *Clathrocaspia* Lindholm, 1930 is not an exception, and only a few findings of living snails of this genus are known to date. These were made by B.M. Logvinenko in 1956 off Derbent and near the Mangyshlak Peninsula; the animals were collected at the distance 40–45 km from the coast and from 56–64 m depths. The description of anatomy and radula of *Clathrocaspia gmelinii* and *C. gaillardi* was made on the basis of these samples (Sitnikova & Starobogatov, 1998).

Populations of *Clathrocaspia* species are ecologically confined to the river mouth areas and estuaries (limans) of big rivers in the Azov–Black Sea Basin, where they have been recorded from the moment of discovery (Makarov, 1938) to the present time (Alexenko & Starobogatov, 1987; Anistratenko, 2013; Markovsky, 1953, 1954). Recently, molluscs of this genus were found in the Danube River about 500 km upstream of its delta (Boeters et al., 2015), which suggests that they live not only in brackish water, but also able to withstand freshwater conditions. On the contrary, all known records of living individuals and fresh shells of *Clathrocaspia* in the Caspian Sea were made only in the open sea with local water salinity over 12 ‰(Anistratenko et al., 2021).

In this report we describe the discovery of a unique series of prosperous populations of *Clathrocaspia* in freshwater streams of the Samur Forest reserve on the western coast of the Caspian Sea in Dagestan (Russia). Both shell morphology and anatomy, as well as the radula and protoconch features of snails from Dagestan make it possible to assign them confidently to the genus *Clathrocaspia* as well as to state their close similarity to the known species from the Northern Black Sea region and the Caspian Sea. However, some conchological features and ecological characteristics of the discovered populations suggest the molluscs represent a separate, hitherto undescribed species.

The water-streams of the Samur forest, flowing through the relict liana forest of the Hyrcanian type, are of high biogeographic interest as a putative local refuge for a number of endemic and relict invertebrates. In addition to *Clathrocaspia*, Pontocaspian amphipods *Echinogammarus* and mysids *Limnomysis*, as well as ancient freshwater relict isopods *Proasellus* and amphipods *Niphargus*, *Diasynurella* inhabit small rivers, streams and springs of this vast forest [Palatov & Marin, unpublished data]. Apparently, most of the freshwater species of these genera do not enter the Caspian Sea and live here only in freshwater environments.

We hypothesize that this area may constitute a refuge for populations of several groups of relict invertebrates which survived local unfavorable conditions, e.g. the changes in salinity or sea level of the Caspian Sea. This hypothesis, however, requires a special test using molecular genetic data. The Samur forest phenomenon merits further exploration as it will help to understand the ecological and biological mechanisms of survival of the Pontocaspian fauna under the impact of global change.

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Translated from Russian

Impact of the climate change and the regression of the Caspian Sea on the distribution and abundance of the Caspian seal (*Pusa caspica*)

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Global climate warming leads to a reduction of ice and snow cover, which is explicitly pronounced in the northern hemisphere. This has a negative impact on the state of biodiversity and, ultimately, on the well-being of people (UNEP, 2007).

The Caspian seal is on the top of the trophic pyramid of the Caspian Sea, so it is an indicator of its environmental situation. The seal belongs to the pagophilic group of animals and its reproduction, mating and molting conditions are largely determined by the state of the ice cover in the northern part of the Caspian Sea. Therefore, possible ice regime disturbance in the Northern Caspian Sea due to global climate warming potentially threatens the existence of the species.

Climate warming (during the period from 1941 to 1977, the air temperature over the northern part of the sea increased by 0.6—0.8°C, and the winter temperature by 2°C) affected the ice cover of the Northern Caspian Sea, which decreased by 11% over the period from 1941-1982 (Baydin & Kosarev, 1986. p. 261), and this is a continuing trend. Thus, the analysis for the period from 1941 to 2012 (Kazhydromet, 2014, p. 42) indicates that a widespread increase in surface air temperature was observed on the territory of Kazakhstan, both in each season and throughout the year as a whole.

When considering two regions of Kazakhstan adjacent to the Caspian Sea, the average annual air temperatures in the Mangystau region increased by 0.23...0.25°C/10 years, and in Atyrau region - within 0.27...0.3°C/10 years. In both Atyrau and Mangystau regions, the greatest increase in temperatures occurs in the winter period (0.27...0.38°C/10 years) (Kazhydromet, 2015, p. 53).

In general, the frequency of warm winters is increasing, and the frequency of severe winters is decreasing; the duration of winter periods is decreasing as well (Ивкина и соавт., 2017). The ice regime of the Kazakh part of the Caspian Sea depends on these climatic changes (Bukharitsin, 2019, p. 122).

Thereby, during the 2015-2020 research period, winters that were extreme for the Caspian seal breeding were repeated in 4 years – the winter of 2015-2016 and the winter of 2019-2020. In the winter of 2015-2016, during the multi-year average period, when all female seals were supposed to give birth to pups (on February 15-25), the maximum ice area was a mere 37-20 % of the area of the Northern Caspian Sea. Respectively, the zone of stable ice cover was reduced to a narrow coastal strip of the north-east of the sea (ESIMO). An even more unfavorable ice cover for seal breeding was observed in the winter of 2019-2020. As a result, there may be a decrease of reproduction of this endemic and endangered species, which is especially dangerous for its existence at a time of increasing negative impact of anthropogenic factors.

Seals are semiaquatic animals, so in spring and autumn they spend a significant part of the time crowding on coastal sand-shell islands and sandbanks, creating rookeries (Badamshin, 1966). During the period of stable sea level, these rookeries are fairly constant and consist of hundreds to tens of thousands specimens.

The Caspian Sea is at the stage of regression (Nesterov, 2016, p. 378); its level has been falling in recent decades, and there are forecasts that this trend will continue until the end of the 21st century (Chen et al., 2017). At the moment, the Kaydak and Komsomolets bays have nearly disappeared. As a result, in the Kazakh part of the Northern Caspian Sea, spring and autumn rookeries along the eastern coast of the sea are shifting in a westerly direction and can be found on newly formed islands there (Fig. 1).

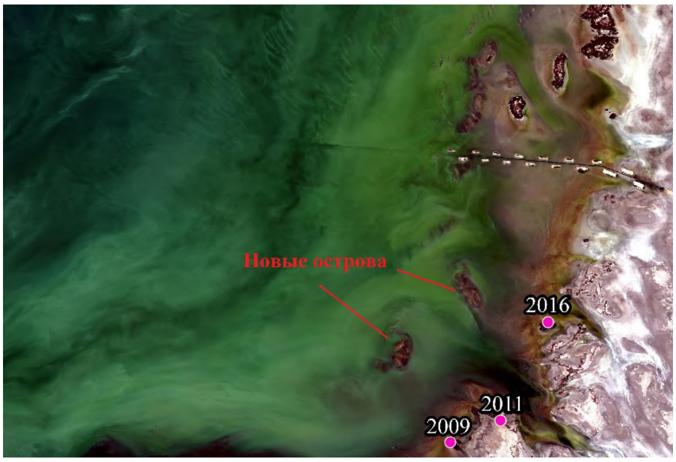

Fig. 1. – Abandoned rookeries of 2009, 2011, 2016 and new islands in the Komsomolets Bay area, where seal rookeries can be found at the moment https://asf.alaska.edu/data-sets/sar-data-sets/sentinel-1/sentinel-1-how-to-cite/).

Thus, climate warming and sea regression affect the distribution of the Caspian seal and may negatively affect its abundance. In order to predict the situation with the Caspian seal, it is necessary to study the adaptive reactions of the species to rapidly changing environmental conditions.

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Biogenic silica and phosphorus pollution in surface sediments of the Anzali wetland, Caspian Sea

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Phosphorus (P), as a renewable source forming on average 0.09% of the earth's crust, is a major element for plants. Different components of phosphorus are added to fertilizers mainly for use in crops, known as phosphorus fertilizers (Pheav et al., 2005). The Anzali wetland, located in the southwest of the Caspian Sea, is a wetland of provincial significance due to specific ecological and socio-economical conditions, aquatic fauna and flora diversity. To measure different forms of phosphorus in surface sediments of the Anzali wetland, 10 stations were selected, and sampling was performed using van veen grab in the autumn of 2020. A sequential extraction method was applied to isolate five different forms of sedimentary P including surface-adsorbed P (Loosely-P), Fe-binding P (Fe-P), Al-binding P (Al-P), Ca-Binding P(Ca-P) and the remaining-P in this trail (Psenner et al., 1984). To measure biogenic SiO_2, 40 ml of 0.1 M sodium carbonate (Na_2CO_3) was added to 30 mg of sediment sample, and then heated on a heater at 85°C. By 3, 4 and 5 hours after heating, 1 ml of the solution was cooled to room temperature and mixed with 9 ml of 0.02 M HCL, and the colorimetric determination for silica was performed. Thereafter, an absorption chart was made, and the resulting intercept is the absorption value used for silica measurement (DeMaster, 1981). Silica, as one of the important nutrients in planktonic communities, is of very low availability due to weak weathering of silica minerals. The highest (3.04%) and the lowest (0.29%) levels of biogenic silica were obtained in stations 4 and 10 (Fig. 1) in the Anzali wetland, respectively. Biogenic silica averaged 1.38±0.83 % at the studied stations.

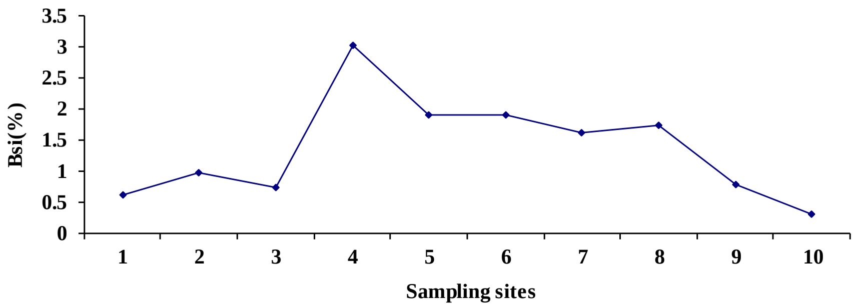

Fig. 1 concentrations of biogenic SiO_2 (Bsi %) at different sampling sites

Several researches (Ran et al., 2015; Wu et al., 2015; Dhame et al., 2016) have studied biogenic silica in sediments of different regions. Some of them had less and the others had more of it than the Anzali wetland, likely because of differences in environmental conditions (hydrological, physical, chemical and biological factors) of each region. Available sediment P is composed of surface adsorbed P, aluminum-binding P (Al-P) and iron-binding P (Fe-P). Among these forms, only surface-adsorbed P or exchangeable P can be directly applied by living marine organisms. Surface adsorbed P ranged from 3.23 up to 32.32 ppm, as its highest and lowest levels were found in stations 6 and 3, respectively, with the average of 15.30. Moreover, the percentage of surface adsorbed P was between 0.47 and 6.56, with the mean of 2.57 in the study area. According to a Caspian Sea study by Bastami et al., (2018), the annually mean percentage of surface adsorbed P was 8.68, which is more than what we observed in the present work. When P increases in the sea water column, it is gradually absorbed by the sediments under aerobic condition and deposited as ferric orthophosphate ($FePO_4$) in the sediment, as long as dissolved oxygen is sufficient. In this investigation, Fe-P was between 96.4 and 172.79 ppm, with the mean of 130.91±24.95 ppm. It was lowest at station 10 and highest at station 5. Based on studies in the Caspian, the average Iron-Binding P (73.50) was less than what we observed in the present work. In this investigation, Al-P ranged from 24.65 to 109.9 ppm with the average of 75.65±29.9 ppm. Al-P averaged 11.60±3.83 % at all stations. In this investigation, Ca-P was from 60.30 to 125.23 ppm with the average of 98.18±21.46 ppm. The lowest and the highest contents of Ca-P were recorded at stations 6 and 2, respectively. The range of bioavailable P in this study was between 141.93 to 267.42 ppm with the lowest level at station 4 and the highest level at station 5. Total P ranged 493-771 ppm with the average of 637.2±79.41 ppm. Inorganic-P ranged from 256.63 to 376.89 ppm with the lowest at station 4 and the highest at station 5. The residual- P consists of both organic P and resistant P. The present residual P was between 203.56 and 413.44 ppm in the study area. Phosphorus pollution index (PPI) ranged from 0.82 to 1.29 with an average of 1.06 in sediment of the Anzali wetland. Stations 6 and 1 showed the lowest and highest PPI, respectively. PPI was > 1 at most sampling sites, indicating that the sediments in the study area were contaminated by phosphorus.

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Translated from Russian

The impact of changes in climatic conditions on the ecosystem of the northern Caspian Sea

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The article presents information on the changes in the climatic conditions of the Northern Caspian Sea in the modern period and its impact on the marine ecosystem. The influence of changes in the temperature regime, salinity and sea level on the reproduction of fish and the vital activity of the Caspian seal is shown.

There has been a significant change in climatic conditions in the Caspian Sea basin. Since the late 1970s, there has been a significant increase in the average annual values of air temperature, mainly as a result of intense winter warming. Thus, the average annual air temperature for the period 2001-2020 exceeded the climatic norm by 0.8°C.

Long-term changes in the temperature regime of the waters of the Northern Caspian in the modern period are characterized by the following features: increased average values of water temperature in early spring (April), due to the predominance of warm winters; a decrease in the water temperature in the summer period in the western part of the North Caspian, which is under the influence of the advection of the Middle Caspian waters with a reduced heat storage; elevated relatively long-term "norm" temperatures in spring and autumn, which determine a longer feeding period for semi-anadromous, sea and sturgeon fish in the North Caspian in the modern period.

For the North Caspian marine ecosystem, under the current climatic conditions, the conditions for natural reproduction of generative freshwater fish have worsened.

A significant part of the Volga water in high-water years as a result of early snow melting in the Volga basin, which occurs even before the onset of spawning temperatures of water in the lower reaches of the Volga, transits into the sea, thereby not providing favorable hydrological conditions during the spawning cycle of semi-anadromous and river fish. In dry years, there is a delay in the timing of water inflow to the spawning grounds of the Volga delta and the Volga-Akhtubinskaya floodplain; as a result, there is an asynchrony between the onset of spawning temperatures and watering of the hollows (Katunin, 2014).

The current climate warming has influenced the ice regime. The increased temperature background of the air led to a slight increase in the water temperature, as well as to an earlier and faster melting of the ice cover. As a result, the ice conditions were weakened: the period with ice phenomena decreased, the ice thickness decreased. The duration of the freeze-up has noticeably decreased, in some years ice-free winters are observed. The processes of ice formation began to occur at a later date, with earlier periods of ice melting.

Climate change (warming) in the modern period did not have a negative impact on the Caspian seal population. The mean long-term (1967-1982, 2005-2020) values of the ice extent of the North Caspian in early February at the assumed moment of mass reproduction of mature females decreased by 10% over 38 years. The frequency of occurrence of moderate winters has increased by 12% and, in recent years, has become 31%. But, despite this, the ice extent of the Northern Caspian in recent years for the breeding period of mature female Caspian seals does not negatively affect the population size and has retained a sufficient area for positive reproduction.

The ecosystem of the northern part of the Caspian Sea has undergone significant changes during the 20th century due to fluctuations in sea level. The deepest transformations took place during periods of a sharp decrease in the level (the sea level dropped most sharply in 1930-1941 and 1971-1977), which affected the state of the ichthyofauna. The periods of sea regression were accompanied by a significant reduction in the area and salinization of the Northern Caspian (correspondingly, a decrease in the feeding areas of semi-anadromous fish), undermining the food supply of commercial benthic-eating fish. So, in connection with the reduction of the feeding area and the deterioration of feeding conditions, the catches of roach in 1939-1941. compared with the previous period, decreased by more than three times (Tanasiychuk, 1948). As a result of the deterioration of breeding and feeding conditions and the entry into the fishery of low-yielding generations, the commercial stocks of roach and bream in 1976-1979. decreased three times in comparison with previous years (Caspian Sea ..., 1989).

In the modern period (2001-2020), the maximum level of the Caspian Sea reached minus 26.91 m abs. (2005), minimum – minus 28.23 m abs. (2020), i.e. the range of fluctuations was 1.32 m, with an average decrease in sea level by 6.6 cm per year.

From 2005 to the present, there has been a steady decrease in sea level, accompanied by a decrease in the volume and area of the reservoir, geomorphological changes at the sea edge of the Volga delta, a weakening of water exchange between individual parts of the sea, and a change in the feeding areas of fish.

Without considering the anthropogenic impact on the ecosystem and aquatic biological resources, the scale of which is increasing more and more, natural factors, especially when they change abruptly, have a significant impact on the habitat, and, through it, on the state and number of hydrobionts of the Volga-Caspian Sea.

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Translated from Russian

Changes in the trophicity and productivity of the northern Caspian Sea under the influence of a changing climate

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Changes in the hydrologic-hydrochemical regime of the Northern Caspian caused by changing climatic conditions, a decrease in water runoff and sea level, led to significant changes in the structure and functioning of biological communities in the northern part of the sea (Kurapov et al., 2020, p. 264). A significant redistribution of the biomass of plankton and benthos (concentration of their main accumulations in the shallow water zone to a depth of 3-5 meters), as well as a decrease in their species diversity compared to the previous period of sea level rise (1978-1995) are observed (Dairova et al., 2020).

The main purpose of this work is to assess changes in trophic indicators and productivity of the Northern Caspian water area in the modern period (since 1996), characterized by a decrease in sea level compared to the previous period of level rise (1978-1995). Trophic indicators and productivity class were calculated based on the average biomass for each period in accordance with the recommendations of S.P. Kitaev (Kitaev, 1986; Kitaev, 2007, p. 395).

The data given in Tables 1 and 2 demonstrate that the biomass of plankton and benthos, and with them the trophicity indices, have decreased compared to the previous period; this is especially typical for the submerged zone of the Northern Caspian (Tab. 2). The only exception is the increased phytoplankton index for the shallow-water zone (Tab. 1): during the sea level transgression, the trophicity level corresponded to the α-mesotrophic type, and it reached the β-mesotrophic level in the modern period (the productivity class also increased from moderate to medium). Most likely, this is due to the regression of the sea since 1996 and is the result of the concentration of algae in shallow waters, while earlier they were more evenly distributed over the water area of the northern part of the sea (Dairova et al., 2020).

Tab. 1. Indicators of trophicity and assessment of productivity for the shallow zone of the Northern Caspian

Indicators	Biomass	Trophic level	Productivity class
1978-1995 (transgression period)			
Phytoplankton, mg/m^3	1,167.6	α-mesotrophic	Moderate
Zooplankton mg/m^3	1,303.1	α-mesotrophic	Moderate
Zoobenthos, g/m^2	54.7	hypertrophic	Very high
1996-2015 (regression period)			
Phytoplankton mg/m^3	2,558.7	β-mesotrophic	Average
Zooplankton mg/m^3	1,092.8	α-mesotrophic	Moderate
Zoobenthos, g/m	19.3	α-eutrophic	Increased

Tab. 2. Indicators of trophicity and assessment of productivity for the deep zone of the Northern Caspian

Indicators	Biomass	Trophic level	Productivity class
1978-1995 (transgression period)			
Phytoplankton, mg/m^3	535.2	β-oligotrophic	Low
Zooplankton mg/m^3	296.7	α-oligotrophic	Very low
Zoobenthos, g/m^2	156.5	hypertrophic	Very high
1996-2015 (regression period)			
Phytoplankton, mg/m^3	347.6	α-oligotrophic	Very low
Zooplankton mg/m^3	107.8	ultra-oligotrophic	The lowest
Zoobenthos, g/m^2	73.3	hypertrophic	The highest

The degree of trophic activity of the shallow-water zone, according to zooplankton indicators, remained at the α-mesotrophic level (productivity class-moderate), while the trophic activity of the deep-water zone decreased from α-oligotrophic to ultra-oligotrophic with a corresponding decrease of the productivity class to the minimum (Tab. 2).

Productivity of benthos in the shallow-water zone decreased by two classes (from very high to elevated), which is most likely due to an increase in the salinity of sea waters in recent years and the replacement of freshwater species with brackish-water ones (Островская и соавт., 2020).

Thus, the climatic changes observed in the Caspian region, along with the anthropogenic impact, resulted in less favorable conditions for the development of plankton and benthos communities in the North Caspian water area compared to the previous period, especially in its shallow zone.

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Emodnet seabed habitats – delivering a habitat map for the Caspian basin

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The European Marine Observation and Data Network (EMODnet) is a network of organisations supported by the EU's integrated maritime policy. These organisations work together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products with the overarching aim of facilitating blue growth. The Seabed Habitats strand of EMODnet (ESH) commences its next phase (Phase 4) in September 2021. The geographical scope will be wider than in the previous phase and aspires to include complete coverage of the Caspian Sea.

Deliverables from this next phase of ESH will include a broad-scale seabed habitat map for Europe and the Caspian Sea. This will require collation and aggregation of existing environmental layers of ecological relevance for the Caspian Sea and development of new ones when necessary. Benthic survey data will be collated and used to find threshold values for classifying the environmental layers into ecologically-relevant classes for the determination of habitat types. The expected delivery of a full-coverage seabed substrate layer for the Caspian from EMODnet Geology, combined with the GEBCO DTM (500m resolution) and other environmental layers will inform the broad-scale seabed habitat map in this region.

In addition, by its conclusion in 2023, ESH Phase 4 will have delivered an expanded library of more detailed, local maps of communities, biocenoses, biotopes and habitats for all of Europe and the Caspian Sea, ingested and converted to a standard format, with metadata available for every map. A dataset of collated point records will also be available. A novel deliverable from ESH Phase 4 will be a combined, harmonized data product showing the best evidence for the extent of wetland type in Europe and the Caspian Sea, with metadata.

These deliverables can be used in addressing significant research and knowledge gaps on current and future predictable climate change effects in the Caspian Sea and its basin. Delivery and access to ESH datasets and models for this region can be used to inform the monitoring of climate change effects on the ecosystem and biodiversity of the Caspian Sea. This will assist policy makers and inform decisions in addressing climate change in the Caspian Sea region.

All deliverables are freely available via the ESH portal, which provides a standardised, centralised and free access point for all spatial information on seabed habitats in Europe: www.emodnet-seabedhabitats.eu/access-data/.

Raising awareness about Caspian Sea biodiversity decline in a changing environment – lessons learned from the Black Sea.

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The Caspian Sea hosts unique endemic flora and fauna, known as Pontocaspian (PC) biota (Gogaladze et al., 2021), that is currently under severe stress (Dumont, 1995; Lattuada et al., 2019; Wesselingh et al., 2019). Projected Caspian Sea level (CSL) drop of 9-18 meters by the end of this century (Prange et al., 2020) will likely trigger ecosystem collapse and a significant loss of biodiversity. Adequate conservation measures and mitigating actions against the devastating consequences of the projected CSL drop require stakeholder engagement and concerted efforts. Increased awareness of the unique nature of the Caspian Sea biodiversity and its likely faith is a precondition for such concerted efforts.

Within the Horizon 2020 ITN-PRIDE program (Drivers of Pontocaspian Biodiversity Rise and Demise: www.pontocaspian.eu), we researched PC stakeholder network structures, governance architectures and public awareness of the PC biota in the Black Sea Basin (Gogaladze et al., 2020a, b). The Caspian Sea and the Black Sea host similar biota and both seas are managed by diverse institutions and governance systems. Therefore, the lessons we learned from the Black Sea stakeholder network analysis can inform and profit conservation planning in the Caspian Sea region.

Initially, relevant institutional stakeholders need to be identified in the Caspian Sea countries, and their collaborative structures need to be outlined. In the Black Sea Basin, the social network analysis (SNA) of stakeholders showed that in Romania and Ukraine conservation networks were largely in place, but the low awareness of PC biodiversity as well as political and financial constraints precluded the full involvement of network members in dealing with PC biodiversity demise (Gogaladze et al., 2020a, b). The SNA studies in Caspian Sea countries are paramount for mapping stakeholder landscapes and informing the conservation decisions.

The effectiveness of stakeholder actions is largely determined by the conservation policy landscape (Gogaladze et al.,). Research into the legal framework of PC biodiversity conservation in Romania and Ukraine showed that PC biota is poorly known by the decision-makers and inadequately incorporated in laws and regulations, with an exception of sturgeon species. Therefore, conservation of PC habitats and biota is mostly incidental. The Caspian Sea hosts flagship species such as the Caspian Seal and sturgeons, which are subject to regulations that are enforced by law, whereas most of the endemic fish and invertebrate groups are likely not (yet) protected.

Next to low political awareness of the PC biota in the Black Sea region, the public awareness is also low. Some flagship species (in this case sturgeons) are used by NGOs to increase public awareness on PC biota. In the Black Sea region we explored the use of outreach materials that target a wider PC taxa, including invertebrates (Gogaladze et al., 2017) to increase awareness of the PC biodiversity. Devising education materials that actively engage school and University students is an effective way of increasing awareness among local communities.

Finally, whether the necessary scientific base for effective conservation of the PC biodiversity is in place shall be explored (Gogaladze et al., 2021). For the Black Sea Basin, we found that scientific evidence is available to outline the PC biodiversity crises and to define their likely drivers, but published studies lack the level of detail to establish policies and develop management plans. This also may be the case for the Caspian Sea, which is shared by five different countries with different laws, institutional compositions and scientific traditions.

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The potential impact of 21st century climate change on Caspian Seals (*Pusa caspica*)

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Caspian seals (*Pusa caspica*), which are endemic to the Caspian Sea, are an iconic species for the region's biodiversity, representing the sea's only marine mammal species. They are a small-bodied species of ice breeding phocid seal, currently listed as 'Endangered' by the International Union for the Conservation of Nature (IUCN), due to population declines exceeding 70% through the 20th Century and ongoing threats arising from human activity (Goodman & Dmitrieva, 2016). The species has been isolated in the Caspian Sea for at least 1 million years (Nyakatura & Bininda-Emonds, 2012) and has evolved a unique set of life-history traits to adapt to the Caspian environment (Wilson et al., 2020). The Caspian Sea sits at the current southern limit for sea ice formation in the northern hemisphere, and Caspian seals breed on the ice-sheet that forms in the shallow northern basin between January and March each year (Wilson et al., 2020). The landlocked nature of the Caspian Sea and the species' ecological and life-history traits mean that it is likely to be one of the most vulnerable marine mammal species to climate change impacts globally (Albouy et al., 2020). Here we suggest climate change impacts on Caspian seals are likely to arise through three main processes.

1) *Declines in winter sea ice extent and duration*: To date, clear declining trends in Caspian winter ice are yet to be observed, but climate models indicate a high likelihood of reduced sea ice extent and duration by 2100 (Tamura-Wicks et al., 2015). One of the most important factors determining Caspian seal breeding success is ice stability through the lactation period (3 to 5 weeks, between late January and early March; Tan, Goodman et al. unpublished data; Wilson et al., 2020). Climate change is likely to increase the frequency of years where the ice melts prior to completion of lactation, resulting in the death of a large proportion of unweaned pups of the year. The increase in frequency of periodic pup mortality catastrophes has potential to feed forwards into population demography and contribute to population declines.

2) *Thermal stress and increased energetic demands due to increased summer sea surface temperatures*: Summer sea surface temperature (SST) in the Caspian can frequently exceed 30°C locally, and the spatial extent, duration and magnitude of such high temperature events are likely to increase under climate change. High

SST has potential to increase the time spent by individuals thermoregulating at the expense of other activities such as foraging, while reductions in dissolved oxygen at elevated water temperatures may influence prey distributions. In combination, these factors could negatively impact the energy balance of individuals. At a population level, even fractional decreases in energy balance could negatively influence population reproductive rates or survival. In extreme cases, increased SST may exceed the capacity of individuals to thermoregulate effectively, which would have the effect of excluding individuals from habitat areas above such temperature thresholds or risk debilitating heat stress. Satellite telemetry data and habitat use modelling can help inform how vulnerable Caspian seals may respond to such processes (Dmitrieva et al., 2016).

3) *Declines in Caspian sea level*: Recent studies have projected declines in Caspian sea level of up to 18 metres by 2100 as a result of increased rates of surface evaporation versus water inflow (Prange et al., 2020). This would cause a near complete drying of the current northern Caspian basin, resulting in the loss of the current Caspian seal breeding grounds, as well as eliminating key areas used for foraging, moulting and resting. It would also lead to the loss of many current or suggested protected areas. It is unclear whether some winter sea ice might persist around the new northern shoreline (Tamura-Wicks et al., 2015), or if it could support seal breeding habitat. New topographical features suitable for seal haul out and resting may emerge as water levels fall, but whether these could replace existing habitat remains to be evaluated.

Collectively these processes suggest a bleak outlook for Caspian seals under climate change during the 21st Century, due to reduced habitat availability and decreased reproductive output. Population modelling studies are needed to generate quantitative predictions of the consequences for population demography under different scenarios, and of how climate processes might interact with other anthropogenic stressors such as fisheries related seal mortality. A key area of uncertainty is to what extent Caspian seals will be able to adapt to terrestrial breeding in the absence of sea ice. Historically, small numbers of neonate pups have been observed on Ogurchinsky (Ogurjali) Island in the southern Caspian (Krylov, 1990), but no data is available on their survival rates. In the Caspian context, terrestrial sites may be unable to replace ice breeding habitat to any significant degree due to increased exposure to land-based predators and human disturbance (Wilson et al., 2020).

Prospects for mitigation of climate impacts on Caspian seals do not appear encouraging due to the projected scale of habitat disruption. Priority should initially be given to addressing current threats, in particular reducing the extensive mortality of seals in illegal fisheries (Dmitrieva et al., 2013) and developing protected areas, since this will increase the resilience of the population to climate impacts as they develop. In the longer term, prospects to increase alternative breeding habitats could be explored, including creating artificial offshore breeding substrates (Kunnasranta et al., 2021) and protected terrestrial sites. Legislation should be adopted that allows for flexible terrestrial and marine protected areas, the boundaries of which are dynamic and can be altered in response to sea level changes. Similarly, planning for offshore industrial infrastructure and activities needs to take into account that the locations of key seal habitat areas may alter over short timescales.

During the approximate 1 million years Caspian seals have been present in the Caspian Sea; the species has survived multiple previous cycles of climate variation. This gives some cause for optimism that the species has the flexibility to adapt to the coming changes, but the question remains whether this is possible in the face of the other anthropogenic stressors that exist in the Caspian.

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Confirmation of heterozygosity in sterlet, acipenser ruthenus and its gynogenic progenies using microsatellite markers

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Sex determination factors are not known in sturgeon, but meiosis gynogenesis has been able to identify the genetic sex determination system in several species. The female homogamety pattern has been reported in some bony fish. In contrast, in sturgeon, this pattern is still female heterogamety. The induction of gynogenesis in female heterogamety system results in different ratios of ZZ males, ZW females, and superior WW females, depending on chromosomal exchange (recombinant effect) between the sex determination gene and centromere during meiosis. Most studies have shown that in fish with a female heterogamety sex determination system, there are often two females and one male, and it is stated that the sex determination gene is assorted independently of the centromere. Molecular markers such as AFLP and microsattelite have the ability to detect heterozygosity and subsequently the sex determination system. The aim of this study was to use molecular markers to confirm or disapprove of heterozygosity in sterlet and its gynogenic progenies. The microsattelite markers used in this study (Afug-9, Afug-63, Afug-112, and Afug-122) showed that sterlet and its gynogenic progenies were heterozygous, and that some of them had shown only one allele while the others had both maternal alleles. This proves that there are two types of zygotes in the sterlet, and that the sex determination system of this species is female heterogamy.

Phenotypic markers: the way to detect hybrids among gynogenic progenies in fish

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In fish, to induce interspecies gynogenesis, some sperm cannot undergo ultra-violet irradiation to destroy sperm DNA. These sperm cells fertilize the eggs and produce hybrid offspring, which in some cases are identified by phenotypic markers. The aim of this study is to determine which parent is more similar to the resulting hybrid (♂ Siberian sturgeon and ♀ sterlet), so that it can be used as a phenotypic marker in the diagnosis of genetic manipulation experiments. A male Siberian sturgeon and a female sterlet were selected for hybrid production. Some phenotypic features were examined in hybrids and their parents. In the head length, there is no significant difference between Siberian sturgeon and hybrids, but there is a significant difference between Siberian sturgeon, sterlet and hybrids. The lowest value of snout length is related to sterlet, and there is a significant difference in mouth width between sterlet and hybrids and Siberian sturgeon. The highest value of lateral scutes is related to sterlet. In terms of the number of abdominal and dorsal scutes, almost the same values are observed in hybrids and their parents. The lowest number of dorsal fin rays is observed in the sterlet, and the hybrids are intermediate. There is no significant difference in the number of anal fin rays between the hybrids and Siberian sturgeon. Analysis of phenotypic markers showed that hybrids inherited most of their paternal characteristics. Due to the similarity of the hybrids with the Siberian sturgeon, the possibility of the presence of hybrids in genetic manipulations, such as gynogenesis, can be well identified and isolated.

Translated from Russian

Application of vegetation indices in remote assessment of vegetation of the Caspian Sea coast

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Climate change will naturally affect the ecosystem and biodiversity of not only the Caspian Sea, but also its coast. Therefore, the most rational and effective measure for monitoring and preventing situations related to climate change would be to conduct multi-level monitoring of the coastal areas of the Caspian Sea, namely vegetation and soils

A characteristic feature of vegetation and its state is spectral reflectivity, characterized by large differences in the reflection of radiation of different wavelengths. Knowledge of the relationship between the structure and state of vegetation with its spectral reflectivity makes it possible to use space images for mapping and identifying vegetation types and their stress state.

The vegetation index (VI) is an indicator calculated as a result of operations with different spectral channels of remote sensing data, and related to the parameters of vegetation in a given pixel of the image. One of the main ways to use these indices is to compare the same object across multiple images over a period of time.

The main advantage of vegetation indices is the ease of obtaining them and a wide range of tasks solved with their help. They are often used as one of the tools for carrying out complex types of analysis, the result of which can be maps of landscapes and natural zones, soil, arid, phenological and other ecological and climatic maps.

In order to make such analysis, in the spring of 2020, spectral characteristics of pasture plants were collected in the Caspian lowland, from which three most common representatives were selecte: *Salsola arbuscula Pall.*, *Artemisia kemrudica*, *Limonium*; the vegetation indices were calculated based on their data (Tab. 1).

Tab. 1. The obtained values of vegetation indices

Index Group	Index	Range of values (for healthy vegetation)	*Salsola arbuscula Pall*	*Artemisia kemrudica*	*Limonium*
Broadband "greenness"	NDVI	-0.2 to 1	0.304	0.507	0.262
Narrowband ("greenness")	MRENDVI	0.2 to 0.7	0.321	0.435	0.195
	MRESR	2 to 8	1.945	2.540	1.485
	VREI2	4 to 8	0.033	0.63	0.012
Light usage efficiency	PRI	-0.2 to 0.2	-0.063	-0.061	-0.080
	SIPI	0.8 to 1.8	1.421	1.257	1.846
	RGRI	0.7 to 3	1.144	1.084	1.110
Carbon content (lignin and cellulose)	PSRI	-0.1 to 0.2	0.149	0.104	0.208
Pigment content	ARI2	0 to 0,2	0.385	0.426	0.218
	CRI2	1 to 11	1.766	3.174	1.848
Moisture content in vegetation	WBI	0.8 to 1.2	0.948	0.994	0.985

Multispectral satellite images of the Sentinel 2 satellite for the springs of 2019, 2020 and 2021 were downloaded for the study area and pre-processed. Based on the image data, the vegetation index NDVI (Normalized difference vegetation index) was calculated. Its values were then used to determine the state of the total vegetation biomass on the test site territory (Tab. 2).

Tab. 2. Values for calculating the NDVI vegetation index for years 2019, 2020 and 2021

2019		2020		2021	
Minimal NDVI	Maximal NDVI	Minimal NDVI	Maximal NDVI	Minimal NDVI	Maximal NDVI
0.047	0.240	0.022	0.180	0.026	0.15

According to the obtained values of the indices, we can trace the dynamics of the state of vegetation and its distribution on the Caspian Sea coast under the influence of climate change.

Translated from Russian

Assessment of the impact of climate change on the quantitative and qualitative state of halophilic vegetation of the eastern coast of the Caspian Sea

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On the eastern coast of the Caspian Sea (Turkmenistan), the coastal alluvial lowland extends from the Gulf of Karabogazgol to the city of Turkmenbashi in the form of a narrow strip. A significant part of this plain is occupied by salt marshes that develop due to the highly mineralized sea waters of the Caspian Sea and Karabogazgol. Most of the studied territory is occupied by the Sochnosolyanka desert, and a small part is occupied by the saltwort desert. The Sochnosolyanka desert is one of the characteristic elements of the vegetation cover of the entire desert region. It is represented mainly by halocnemum communities and rarely encountered climocopterans. Halocnemum plants have a landscape-forming value and are confined to wet salt marshes with a close level of saline groundwater.

In the studied area, halocnemum plants form pure, single-species communities on significant areas. The plants form flat-shaped bushes of a rounded shape, which are scattered from each other by 2-3 m. In these halocnemum communities, saltwort (*Salicornia europaea*) is sometimes found in single individuals or small groups. Sand is often laid under the Halocnemum bushes, which leads to the formation of a kind of small-scale microrelief.

With the groundwater dropping from the surface, as well as the appearance of sand sediment, *Limonium suffruticosum*, *Nitraria Komarovii*, *Halothamnus subaphilla*, *Artemisia kemrudica*, *Zygophyllum ovigerum*, *Naloxylon aphyllum*, and less often *Salsola Richteri* appear on the salt marsh. In addition, annual plants from the goosefoot family are recorded: *Climacoptera lanata*, *Suaeda arcuata*, *Salsola incanescens*. As a rule, they are found in the form of rare specimens, but sometimes they form small sinusias. Occasionally, small, strongly depauperated *Haloxylon Aphyllum* and *Tamarix hispida* individuals are found.

Within the halocnemum formation, in addition to pure halocnemum, we identified *Halocnemum strobilaceum – Climacoptera lanata* and *Halocnemum strobilaceum – Limonium suffruticosum – Nitraria Komarovii* associations. The total projective coverage in the associations is from 5 to 20%. Typical halocnemum plants are usually one-tier or two-tier communities. In winter, after frosts and leaching of tannins, they are well eaten by camels, while by rams – satisfactorily.

Saltwort deserts are groups of formations composed of xerophilic semi-shrubs with strongly reduced leaves. In the studied area, saltwort deserts are represented by limonium formations (*Limonieta suffruticosae*). Within the limonium formation, *Limonio suffruticosi - Climacopteretum lanata* and *Limonio suffruticosi - Nitrarietum Komarovi* associations were identified – two-tiered communities with a projective coverage of 20-30 %.

For remote geobotanical assessment of the impact of climate change on the quantitative and qualitative state of halophilic vegetation on the Caspian coast, the technologies of geoinformation systems were used. Based on the spectral characteristics of the halophilic vegetation type formed in the form of a spectral library in the ENVI software package, the temporal dynamics of changes in their quantitative location were determined when deciphering satellite images of the eastern coast of the Caspian Sea.

The automated study of the seasonal state of halophilic vegetation was carried out using calculated narrow-band vegetation indices:

- to determine the pigment composition of a vegetative plant cell, the following methods were used: Clrededge index = (R750-800/R695-740) - 1, determination of chlorophyll content «a», «b»; mCARY index= [(R700 – R670) - 0.2 (R700 – R550)]/R700/R670, for determination of carotenoid content; mARI index= [(1/R500-570) – (1/R690-700)]x RNIR, for determining the content of anthocyanins;

- to analyze the biochemical composition of a plant cell, the following methods were used: index CAI= 0.5 (R2020 + R2220) – R2100, for determining the content of lignin and cellulose; index NDNI=[log(1/R1510) - log (1/R1680)] / [log(1/R1510) + log (1/R1680)]

- to determine the nitrogen content;

- to determine the moisture content of a plant cell, a narrow-band index NDWI= (R860-R1240)/(R860 +R1240) was used;

- to determine the stress conditions of plant crops, the plant cell moisture index WI= R900/R970 was used.

- to determine the degree of salinity of the soil of the territory of the halophilic vegetation of the eastern coast of the Caspian Sea, the SSSI-1, SSSI-2, SSSI-3 indices were used.

Thus, remote sensing methods make it possible to determine the impact of climate change on the state of halophilic vegetation and soil on the eastern coast of the Caspian Sea.

Translated from Russian

Changes in sea level and its impact on the ecological and geomorphological conditions of the Turkmen coast of the Caspian Sea

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It is known that fluctuations in the water level of the seas and oceans cause the movement of coastlines and lead to changes in geomorphological processes and litho-dynamics of coastal zones. Since the Caspian Sea has developed in an alternating mode throughout its history, a real forecast of geomorphological changes at the transgressive stage is impossible without knowledge of the previous state that emerged after the last drop in sea level. The change from the regressive regime to the transgressive one since 1978 led to a change in the underwater slope of the coast and, accordingly, in geological and geomorphological processes. Denudation and abrasion-accumulative landforms began to form at the site of the accumulative banks.

The Caspian Sea is a unique natural object of great economic and social importance, both for on-farm and interstate relations. Its role is critical because of its climate-forming value. It evens out the amplitudes of temperature fluctuations in the air of the entire Caspian region, which significantly softens the climate.

The Turkmen coast is represented by both abrasive and accumulative landforms. The first are typical for the northern part of the territory – from the Kara-Bogaz-Gol Bay to the Krasnovodskaya Spit, and the second – in the Krasnovodsk Bay itself and south of Cheleken up to the border with Iran. It follows that the rise in sea level stimulates, on the one hand, erosion of steep shores and slopes, and on the other, flooding of sloping ones, contributes to the rise of groundwater and waterlogging of low shores. These are examples of so-called passive land flooding and concern especially the southern part of the region with a low-lying coastal zone and shallow waters. So, during this period, the process of soil desalinization becomes the leading one. It is quite obvious that the transgression of the Caspian will cause changes in the climatic regime of the coast. The depth of such an impact is associated with the most mobile components of the landscape – water and air masses, with a change in which a new local climate can be formed.

To address the existing and newly emerging environmental problems, it is necessary to take a number of urgent and long-term measures: in order to reduce the rise in the level of the Caspian, to carry out the passage of sea waters into the drainless dry basins of the eastern coast; construction of modern treatment facilities and the introduction of environmentally friendly technologies for the complex extraction of useful substances at chemical plants located in the region.

In this regard, there is an urgent need in development of a unified interstate comprehensive scientific programme to make a research on the problems of the Caspian Sea, search for predictive relationships between sea level, climatic, geological and geophysical parameters using modern methods of analysis, instruments and equipment.

The Caspian Sea should be, first of all, an international fishing and economic reservoir (with the predominant development of sturgeon farming) and serve the interests of present and future generations of people living on its coast, and the directions of its economic use should contribute to the preservation of this reservoir as a unique reserve of the planet's biological diversity.

Translated from Russian

Climate and its possible impact on the number of Caspian Seals in 2020-2021

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The Caspian seal belongs to the pagophilic (ice-preferring) group of seals. All of the following activities take place on the ice in the Northern Caspian Sea: whelp, feeding of cubs, mating and molting. Seals gather at the edges of large plates of flat ice, near natural ice holes, gaps between moving ice plates or areas of open water.

In 2020 and 2021, within the framework of the joint Kazakh-Russian Program (2020-2024), scientists of VNIRO and CAAE performed an accounting of the Caspian seal using multispectral video and photography. Modern software devices were used to process video and photo information.

The winter of 2019/2020 belonged to the type of relatively warm early winters, the winter of 2020-2021 to moderately cold ones. Accounting flights were carried out under good weather conditions, with a minimum area of ice. Within the framework of the studies performed, the calculated lower and upper bounds of the estimate of the total population using data from multispectral aerial surveys of seal ice deposits for 2012, 2020 and 2021 were calculated.

Tab. 1. Caspian seal population according to the aerial survey. Survey data from 2012, 2020 and 2021.

Accounting method	Number of puppies, thousand species		Total population, thousand species	
	Min	Max	Min	Max
Multispectral air accounting in 2012	56.00	69.800	268.80	320.000
Multispectral air accounting in 2020	58.24	72.652	282.32	354.421
Multispectral air accounting in 2021	62.261	76.100	302.016	369.149

On one hand, the general warming has contributed to improving the conditions for restoring the food base and increasing the number of non-target fish species, mainly the Caspian sprat. The sufficient fatness of the Caspian seal observed in 2020-2021 has a positive impact on reproduction, there is an increase in the birth rate, and a gradual increase in its number in the last 10 years.

On the other hand, in winter, unstable weather conditions, sudden warming and cooling, storm phenomena lead to the persistent formation of ice. This affects the distribution of mature females on the ice field and possible increased anxiety during periods of minimal ice field, and a high density of mature females during periods of whelp. Earlier ice melting can lead to the death of newborn puppies who are not ready for the permanent stay in the water.

Thus, climate change affects the population of the Caspian seal in winter, further warming may affect the reproduction process, and increase the mortality of cubs.

Possibility of managing of oak forests in Iran using dendroclimatology

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Introduction

The rings width of trees depends on the climate of the tree habitat and is recorded as a series of wide and narrow rings in the trees. The science investigating the effects of climate on the ring width (to study the present and past climates using tree growth rings) is called dendroclimatology (Fritts, 1976; Schweingruber, 1996). Climatic information obtained from annual rings provides an overview of what the weather was like in the past, and what the weather might be like in the future. This study examined the effects of temperature and precipitation on the annual growth of oaks in Zagros forests.

Material and Methods

For this study, two radial cores were collected from each of the 40 trees of *Quercus infectoria* and *Quercus libani* of the Zagros forest, Iran. After preparing the surface of all samples, they were first dated by 10-year periods. We measured the rings width of these species with TsapWin software and the LINTAB table (Rinn, 1996), with an accuracy of 0.01 mm. In addition, cross-dating and standardization were performed by the programs TSAP and ARSTAN programs (Cook, 1987). To determine the effect of climatic factors on chronology, the regression correlation coefficient was calculated using the SPSS software.

Results

Fig. 1 shows the curves of chronologies of the studied species. In *Q. infectoria*, the chronology was 192 years, beginning in 1818 and ending in 2009. The chronology obtained for *Q. libani* was 188 years.

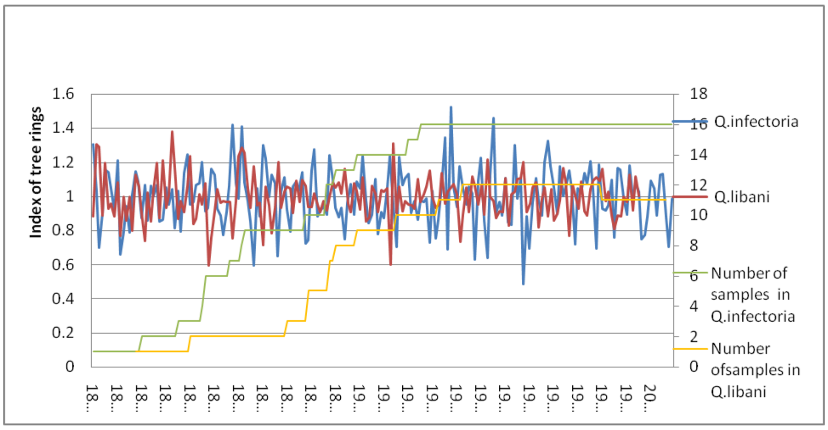

Fig. 1. Chronologies of the studied species

Fig. 2 shows that *Q. infectoria* has a negative correlation between temperature and radial ring width in all months of the current growing season and before the beginning of the growing season. As shown in the figure, *Q. libani* is more susceptible to rainfall than *Q. infectoria*. As seen in the example of *Q. libani*, the effect of precipitation on annual rings in April, May, and November in the year before emergence is direct and significant, while the effect of temperature in April and June is inverse and statistically significant.

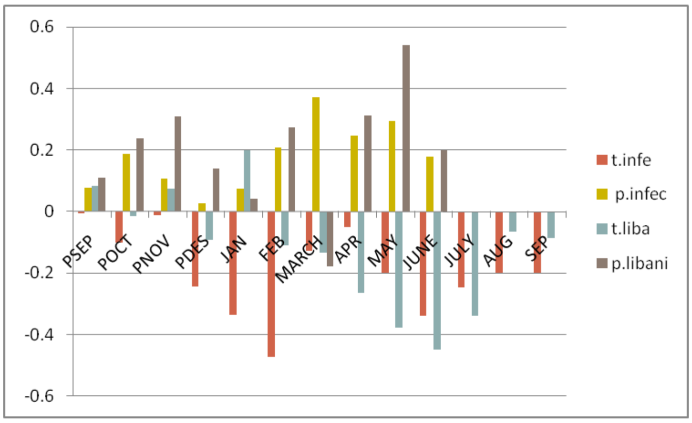

Fig. 2. Correlation between climate and tree chronology

As can be seen in the rings width, rainfall is the most important climatic factor that affects the growth of the trees in warm and dry areas. (Glock and Egter, 1962). The results obtained coincide with the studies of other scientists (Pourtahmasi et al, 2010; Arsalani et al, 2018).

Conclusion

The results showed that in both species, the effect of temperature on annual radial growth rate was negative, and the effect of rainfall was positive. It was also observed that Q. libani is more sensitive to rainfall variation than *Q. infectoria*. On the other hand, rainfall relative to temperature has a more significant effect on the growth of oak trees, and these trees are more sensitive to rainfall than to temperature.

Because of the aridity of the region and the low rainfall in most months of the growing season, both species studied have good stability. Therefore, it is recommended to expand the afforestation of these species.

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Translated from Russian

Productivity potential of jerusalem artichoke (*Helianthus Tuberosus l.*) In the context of climate change in Tajikistan

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Jerusalem artichoke (*Helianthus tuberosus L.*) is a perennial plant. Its homeland is considered to be North America. Jerusalem artichoke was introduced to Europe around the end of the 17th century, and it was brought to Russia at the beginning of the 18th century (Shazzo, 2013).

Jerusalem artichoke is a high-yielding crop. According to the reports of researchers (Pasko, 2003; Funk, 1993), in a number of countries, more than 45.0 t/ha of tubers of this crop are harvested. Jerusalem artichoke tubers contain up to 18-22% sugar, up to 2.5% protein, vitamins B and C, and up to 20-25% dry matter in the green mass. Tubers contain inulin, which is processed in the body of animals into easily digestible fructose. Agroecological factors have a significant impact on the growth and development of Jerusalem artichoke plants. Along with this, a number of researchers (Somda et al., 1999; Partoev et al., 2015) find that the nature of the formation of a number of the plant's polygenic signs have a certain relationship with each other.

In our studies, seed tubers of different varieties of Jerusalem artichoke were used as the starting material. The initial material for the study was obtained from the National Academy of Sciences of Tajikistan (Institute of Botany, Physiology and Plant Genetics of the National Academy of Sciences of Tajikistan), the Maikop Experimental Station and the Kuban Agrarian University (Russian Federation). Field scientific experiments on the study of different varieties of Jerusalem artichoke were conducted in 2016-2019.

The experiments were conducted in the following regions of the republic, located in a vertical zonality above sea level: Vase – 460; Vakhsh – 600; Dushanbe – 840; Muminabad – 1,200; Rasht – 1,800; Lakhsh – 2,000; and Kanask – 2,560 m. Depending on the altitude above sea level, the number of varieties of Jerusalem artichoke was up to 20 pcs. The planting scheme is 70x35 cm, the planting dates are April – May. The repeatability of planting varietal samples is fourfold. All agrotechnological methods for growing samples consisted of the following: fertilizing plants with nitrogen (100 kg/ha), phosphorus (150 kg/ha) and potash (80 kg/ha) fertilizers (in the form of an active substance), loosening between rows, carrying out a single hilling of the soil in the rows of planting. The number of waterings during the growing season was five to seven times. Phenological records and observations were carried out in different phases of the development of Jerusalem artichoke. Mathematical data processing was carried out by (Dospekhov, 1985) and using the Microsoft Excel 2007 program.

The aim of the research was to study the peculiarities of the formation of the biological mass of Jerusalem artichoke depending on the vertical zonality in various agroecological conditions of the Republic of Tajikistan.

The conducted studies demonstrated that the formation of a number of genetic characteristics of Jerusalem artichoke varieties is significantly influenced by such agroecological environmental factors as growing areas and air temperature.

Studies have shown that the total biological mass of plants at an altitude of 2,000-2,560 m above sea level is 3.7 and 4.8 times lower, compared with the cultivation of Jerusalem artichoke in zones located at an altitude of 460 and 600 m above sea level, respectively. When growing Jerusalem artichoke in various agroecological conditions of Tajikistan (at altitudes from 460 m to 2,560 m above sea level), the average yield of tubers is 31.9 t/ha, and the total biomass is 91.8 t/ha. It should be noted that in the conditions of a mountainous country-Tajikistan, the most suitable zones for obtaining a high yield of Jerusalem artichoke are such areas at an altitude of 460, 600, 840 and 1,200 m above sea level. It is determined that in order to obtain the maximum yield of Jerusalem artichoke during the growing season of plants, the sum of effective temperatures should be 2,280-3,760°C. By growing Jerusalem artichoke in various vertical zones of the Republic of Tajikistan, it is possible to obtain a high biological mass, which is very important for food security and strengthening the feed base of animal husbandry in the future.

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The effects of climate change on the Iranian side of the Caspian Sea fish stocks

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Climate change and its effects on changes in various environmental factors have a significant impact on fish stocks (Sumaila, 2011). In this research, we analyzed the relationship between some environmental factors, including sea surface temperature (SST), surface water chlorophyll-a (CH) extracted from data recorded by MODIS satellite, as well as wind speed (WS), air temperature (AT), evaporation (E) and rainfall (R) from the database of the Iran Meteorological Organization data with monthly (1996-2018) fish catch per unit effort (CPUE) collected by gillnetting in three northern provinces, Gilan, Mazandaran and Golestan. To determine the relationship, we used the Generalized Linear Regression Analysis (GLM), the Generalized Additive Model (GAM) as well as step by step regression analysis (R Core Team, 2020). We found that the mean of SST in Iranian waters of the Caspian Sea amounted to 14.14 ± 5.64°C, and the highest amount of SST was recorded in Golestan> Mazandaran> Gilan, respectively. Mean chlorophyll-a was 1.75 ± 3.82 mg/L, and the highest values were Gilan> Mazandaran> Golestan respectively. Mean rainfall was 121±15mm - Gilan> Mazandaran> Golestan; mean evaporation was 45.25±26.4, and the highest values were Golestan> Mazandaran> Gilan respectively. The mean air temperature was 12.38±4.57with the highest values being in Golestan> Mazandaran> Gilan. Finally, the wind speed amounted to 9.03±7.1m/s - Mazandaran> Golestan> Gilan. All factors showed a significant difference (P>0.05) between the three northern provinces (the Caspian Sea). The number of fish stocks during the 1997-2018 period had decreased, and environmental factors have increased (fig. 1,fig. 2), although the trends of provincial ecological changes were not the same, and the studied factors acted differently in marine reserves. Evaporation had the most effect on the CPUE, followed by rainfall and water temperature. In addition to the mentioned factors, the decrease of Kilka, Mullet and Rutilus stocks is also related to changes in the Caspian Sea level (Fazli et al., 2018; Kiabi et al., 1999; Rabbaniha et al., 2014).

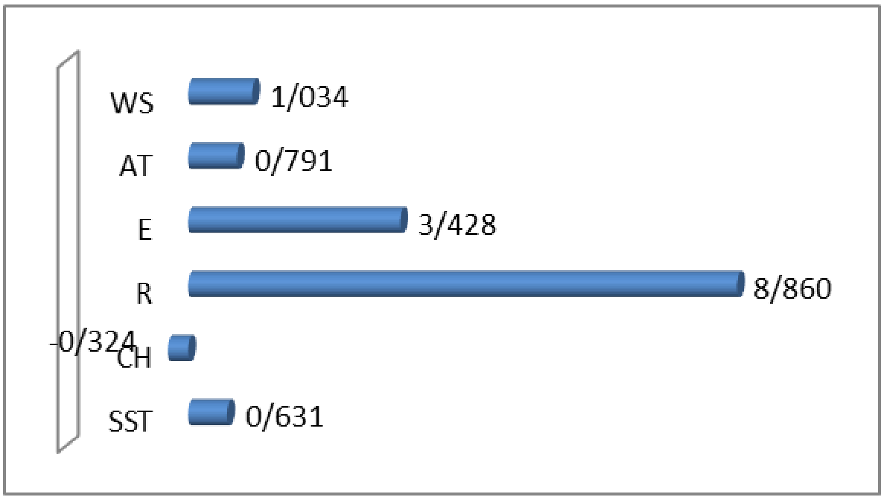

Fig. 1.The difference between the means of environmental factors in the 3-year periods 1996-98 and 2016-2018

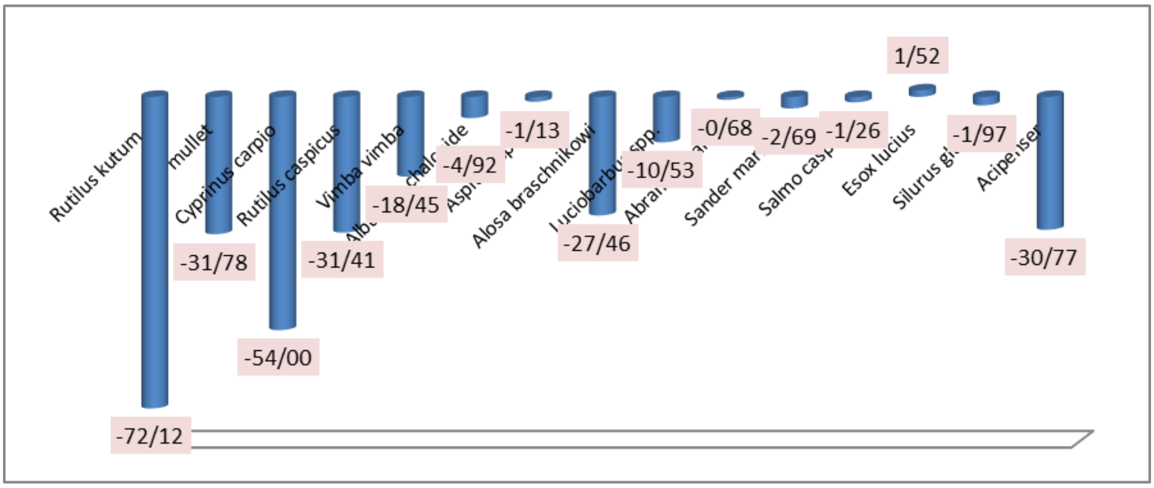

Fig. 2.The difference between the mean fish CPUE in the 3-year periods1996-98 and 2016-2018

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Translated from Russian

Study of the flora of the Caspian desert in the context of climate change

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The Caspian deserts are characterized by a peculiar flora and vegetation. When analyzing the flora, the ecological features of species, various features of life forms, their association with certain types of habitats, landscape belts and plant groupings were studied. During the study, attention was paid to some adaptive characteristics of plants, such as the prickliness of various organs, the forms and methods of flower pollination, as well as their coloration.

The climate of the region is dry, arid and moderately continental. One of the main factors is the location and contiguity of the flat territory of Western Turkmenistan from the west and southwest, the Karakum desert from the north, and the higher ranges of the Southwestern Kopetdag from the southeast.

There are about 440 species of vascular plants belonging to 223 genera and 58 families on the territory of the Caspian desert. In the flora of the region, the dominant families of the desert zone include the families of goosefoot (*Chenopodiaceae*), asteraceae (*Asteraceae*), cereals (*Poaceae*), legumes (*Fabaceae*), cruciferae (*Brassicaceae*) – 40-50% of the flora. The next 20-30% of the flora consist of representatives of the buckwheat family (*Polygonaceae*), borage (*Boraginaceae*), lily (*Liliaceae*), tamarisk (*Tamaricaceae*) and guaiacum (*Zygophyllaceae*).

The vegetation cover of the Caspian desert is characterized by a poor floral composition of plant communities, as well as an exclusively xerophilic set of species. As a result of the analysis of life forms, the following were identified: 258 species of annual grasses; 10 species of biennial grasses; 86 species of perennial grasses; 31 small semi-shrubs, 9 semi-shrubs; 9 small shrubs; 35 shrubs; and 2 species of trees.

The vegetation cover is expressed quite clearly and mainly consists of wormwood-saltwort deserts with fragments of low-grass semi-savannah communities. Groups of *Zygophyllum atriplicoides, Rammus sintenisii, Convolvulus fruticosus, Haloxylon aphyllum, Reamuria fruticosa, Salsola arbuscula, S. orientalis* are widespread here. All species form groupings in most habitat types and occupy dominant positions. Here, on more even, deserted areas, there are also semi-shrub wormwood: *Artemisia deserti, A. diffuza, A. tschernieviana, Mausolea eriocarpa*.

The *Salsola transhyrcanica* is even more common on the saline clay outliers of the Cheleken and Dagada peninsulas, where they form the basis of the saltwort vegetation. On the same peninsulas, there are long-vegetating annual saltwort - *Salicornia europea, Climacoptera czelekenica*. The vegetation of the entire coastal part consists of groups of large halophyton shrubs - *Halostachyz belangerana* (Moq.) Botch., *Reamuria fruticosa* Bunge, *Nitraria schoberi* L., *Tamarix passerinoides* Delile ex Deser.

The following play very important roles in the composition of the vegetation cover of wormwood-saltwort deserts: *Ephedra intermedia*, *E. distachya*, *Salsola dendroides*, *Reamuria tatarica*, *Dendrostellera olgae*, many perennial and annual grasses, as well as *ephemera Agropiron fragile* (Roth) P. Candargy, *Eremopyrum bonaepartis* (Spreng.) Newski, *Anisantha rubens* (L.) Newski, *Trisetaria cavanillesii* (Trin.) Maire, *Cutandia memmphitica* (Spreng) Benth, *Poa bulbosa* L., *Poa sinaica* Stend., *Enneapogon persicus* Boiss., *Eremurus ammophyllus* Vved., *Gagea afghanica* Terr., *Rinopetallum karelinii* Fisch. ex Alexand., *Allium fibrosum* Regel, *Iris longiscapa* Ledeb., *Cressa cretica* L., *Lapula spinocarpos* (Forssk.) Aschers. ex Kuntze, *L. semialata* M. Pop., *Zeziphora tenior* L., *Calendula crasilis* DC., *Acantholepis orientalis* Less., and others.

The aridity of the region is characterized by extremely harsh plant habitat conditions, primarily by high maximum summer temperatures and fairly low winter minima, as well as low annual precipitation amounts. In addition, the vegetation cover of the region experiences a strong anthropogenic impact. Especially in dry years, a number of plants including *Glaucium oxilobum*, *Cleome turkmena*, *Erysimum kerbabaevii* and *Salsola botchantzevii* cannot develop to generative forms and die as a result of desiccation. They, therefore, disappear from certain areas for indefinite periods.

The spore-pollen analysis of the flora of past geological epochs also points to climate change in the region under study. For example, in the Eocene period, the pollen spectrum dominates at 63%, the spore spectrum remains at 37%. During this period, the first representatives of the goosefoot family appear. The flora of the Lower Miocene is characterized by a rich and diverse set of spores (60%) as well as a small participation of evergreens 40%. Such changes in the nature of the spore-pollen spectra can be explained by changes in the vegetation cover, which, in turn, are associated with climate fluctuations.

As it is known, in the territory of Central Asia, during the Quaternary period, vegetation was mainly arid in nature, but there were phases with synchronous periods of glaciation in Europe as a result of the increased role of cyclones passing through the Mediterranean Sea – the Caucasus – Central Asia. The increase in the amount of moisture should have caused changes in the vegetation cover, especially in mountainous areas, due to the entry of representatives of mesophilic woody-shrubby forms of flora from adjacent areas. All these data point to climate change both in the past geological epochs and at present.

Translated from Russian

On the dynamics of the biodiversity of the Turkmen sector of the Caspian Sea depending on climate variability

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On the basis of monitoring materials from the Khazar State Reserve (KSR) and the Work Group on the Ramsar Convention in Turkmenistan, the analysis of wetland birds against the background of interdecadal climate changes was carried out. The monitoring was carried out in the water areas of the KSR and adjacent coastal areas (9 in total), which are included in the network of Key Ornithological Territories (IBAs) of Central Asia (Rustamov et al., 2009, 2010). In 1971-2021, annual autumn-winter surveys were conducted (Vasiliev et al., 2007, 2008; Rustamov et al., 2007), and in the Soymonov Bay, in the north-west of the Turkmenbashi Gulf, the surveys were conducted every decade (Shcherbina, 2015).

During the monitoring phase, we identified 39 sites (coastal segments) in the Eastern Caspian region, based on the similarities and differences of their physiognomic features (the indentation of the coast, the quality of the soil, water and coastal vegetation) together with their bird population; the sites are combined into 4 large areas (Vasiliev et al., 2007). The classification of these sites, which were typologically assigned to one of the 10 types of wetlands as habitats of waterfowl, was carried out (Rustamov et al., 2008).

Since the mid-1970s, global and regional temperatures in Central Asia have been rising similarly to those in the Northern Hemisphere (Novikov & Kelly, 2017). According to the Intergovernmental Panel on Climate Change (IPCC), the warming in Northern Eurasia in 1975-2010 turned out to be more significant compared to the global one; the temperature increased by 1.5^{o}C, and there was a decrease in precipitation during the warm season. Although the warming was blurred by natural temperature variability, during several years, cooling was also observed in some regions. In many regions, there were more days characterized by thawing in winter.

The waterfowl population dynamics on the wintering grounds of the Turkmen coast of the Caspian Sea for the specified period, that is, since the mid-1970s, generally correlated with the change in their breeding range in Northern Eurasia. This can be traced against the background of interdecadal climate variability (Krivenko

& Vinogradov, 2008). According to these authors, **in 1973-1979, the warm-dry period** caused a sharp regression of lake ecosystems in Kazakhstan and Southern Siberia, which, in the second half of the 1970s, led to a reduction in the number of birds nesting there from 1.8 to 0.9 million pairs (Кривенко, 1991). This caused a drop in their abundance in the wintering grounds of the South-Eastern Caspian Sea, where the number, according to our data, on average (1977-1980) did not exceed 300 thousand individuals. The decrease in the number of birds not only wintering, but also nesting in the Caspian Sea, could not but be affected by the shallowing of the bays, for example, Mikhailovsky and Balkhansky, as a result of a drop in sea level which in 1977 reached the lowest possible level (-29 m).

In 1980-2005, during the cool-wet period, against the background of increasing flooding in the breeding areas of Central Asia, there was a noticeable increase in the number of species, for example, gray goose, coot, ruddy shelduck, common shelduck, mute swan, and others. (Krivenko, 1991; Krivenko, 1991; Krivenko & Vinogradov, 2008). However, the increasing impact of the anthropogenic factor suppressed the natural trend of population growth (Auezov, 1984; Auezov & Vinogradov, 1986), and the total abundance of waterfowl continued to decrease not only in the breeding range, but also in wintering grounds. There was a decrease in the total abundance of wintering birds in the 1996-2004 period: from 427.147 to 147.119 individuals (Vasiliev et al., 2007). Even the transgression of the Caspian Sea that began in 1978 and led to the revival of bays and coves by early 1990s, could not contribute to the growth of the population.

The warm-dry period of 2006-2025. The increase in the average annual temperature occurs not only in the inner parts of the Central Asian region, but also in the Caspian region. The total amount of precipitation for the first 10 years has decreased by more than 5%. In the spring, it decreased in the southern desert regions, while increasing in the northern steppe regions. During the summer period, the amount of precipitation decreased in the flat parts, but increased in the mountainous ones. In the southern parts, in Turkmenistan, there was a decrease in the amount of precipitation, which was also recorded in winter. The air temperature indicators in the summer have significantly increased in the Caspian region, as well as throughout Turkmenistan. In autumn, the trend of increasing temperatures was observed throughout Central Asia, including in the Caspian region and in the northern parts of the region (Novikov & Kelly, 2017).

According to the records, in January 2007, there was already a trend of waterfowl population growth (a total maximum of 439,779 specimens) (Rustamov et al., 2007). Environmental conditions for birds in the bays of the KSR improved. Shallow waters and dry areas in the Mikhailovsky, Balkan (Dagada Peninsula became an island) and Turkmen bays were flooded. Despite this, biodiversity, in particular birds, are experiencing depression, because they are under the influence of natural, climatic and anthropogenic factors - primarily hydrocarbon production and poaching. There is a continuing downward trend in the number of birds, including waterfowl (Vasiliev et al., 2007).

In addition to the above, the authors analyzed the trends of changes in the ranges of individual bird species which reacted to the current climate changes in the East Caspian Corridor, by which we mean the territories of the Meshed-Messirian and Transcaspian (N-W Turkmenistan) ecoregions of the Econet network of Central Asia (https://wwf.ru/regions/central-asia/razrabotka-regionalnoy-seti-ekonet/).

Thus, due to long-term monitoring of the most important components of biodiversity on the eastern coast of the Caspian Sea, it was possible to analyze how climate change affected their distribution and abundance. However, we need to find out the true causes of the current climate change in the Caspian Sea region. Without this, we risk making the wrong decisions, which will not only fail to improve the already difficult situation but will also cause irreparable damage.

In 2007, within the framework of the Ramsar Convention and the CBD, a joint program was developed, and innovative standards of cooperation were established, Moreover, the interstate Agreement AEWA (joined by Turkmenistan in 2020) came into force.

After the ratification of the Ramsar Convention by Turkmenistan (03.03.2009) as a result of the nomination of the Turkmenbashi Bay in the KSR as the Ramsar site as well as the inclusion of the South Chelekensky and Turkmen (with lake Ogurdzhaly) bays and the site of the southern branch of the KSR in the shadow list of the convention as wetlands of international importance, the work on monitoring of biological components of the Turkmen sector of the Caspian Sea was intensified, and this was especially true for wetland birds. This was also facilitated by the nomination of three water areas within the EBSA in accordance with the CBD requirements (www.cbd.int).

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Translated from Russian

State of biodiversity in the Caspian

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The Caspian Sea is the largest enclosed body of water on Earth. The biodiversity of the Caspian region is due to history and geographic isolation. More than 300 endemic bird species live here, such as the field sparrow, myna, turtledoves, black-bellied sandgrouse, common and Caspian terns, common and Caspian gulls, flamingo, etc. Coastal wetlands, including temporary and permanent lakes, many of which are saline, attract a variety of bird species. During the year, birds are found in large numbers in and around the Caspian. During migrations their number increases significantly; birds occupy vast deltas, shallow waters and wetlands. Due to the rise in temperature in the Caspian over the past decade, some migratory birds (e.g. flamingo) have become sedentary. here are 101 species of fish in the Caspian Sea, some of which are anadromous and migrate to rivers to spawn. Among them, the most famous are 6 species and subspecies of sturgeon, which have been a valuable economic resource for centuries, as well as roach, carp, mullet, sprat, kutum, bream, salmon, pike and perch.

The vegetation of the Caspian region is represented by 503 species from 59 families, but *Chenopodiaceae, Asteraceae, Poaceae, Cariophyllaceae* dominate. On the desert pastures of the Turkmenbashi district, semi-shrubs are represented by the Kemrud wormwood, saltwort, ephemera - annual or perennial grasses – by carex, harmel.

Caspian seal is an endemic and only species of mammals inhabiting the Caspian Sea. These endemics tend to migrate from the northern part of the sea to the southern one. In the cold season, the main population is in the North Caspian, and in the warm season, seals migrate to the Middle and South Caspian. At the beginning of the 20th century, their number was 1 million specimens, and starting in 1989, the number of individuals began to decline. Currently, employees of the National Institute of Deserts, Flora and Wildlife of the Ministry of Nature Protection of Turkmenistan, based on the results of field expeditions, estimated the number of seals at only 1 thousand specimens.

The main negative factors leading to the decline of the species is sea pollution and climate warming. Increased levels of agricultural chemicals, in particular DDT and endosulfan pesticides, are a major concern for the Caspian, since a high concentration of organochlorine compounds was found in the tissues of many dead individuals. This shows that the use of the banned chemical DDT continues.

Conclusion: some types of biodiversity are threatened with extinction due to excessive reduction of spawning grounds, mainly due to construction of dams on large rivers and accidents during oil transportation in the Caspian Sea. Due to climate warming, most of the migratory birds have now settled in the Gulf of Turkmen.

Proposals: The five states bordering the Caspian Sea should strictly control the use of agricultural chemicals, and DDT should be strictly forbidden. Dams should be built moderately, and oil transportation routes should be regulated and regularly checked for accidents. Since there is no systematic monitoring of biodiversity, it should be included in state programs and published in an environmental journal or website accessible to all.

Projected 2100 Caspian Sea level drop has devastating consequences

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Caspian Sea levels (CSL) in the year 2100 are projected to be 9-18 m lower then today under different RCP scenarios (Nandini-Weiss et al., 2020) due to rising temperatures. This will have severe consequences (Prange et al., 2020). Rapid and profound CSL change is an inherent feature of the Caspian ecosystem and has occurred very often in the past. Yet today the unique Caspian ecosystems and biota are already in severe decline, and the sea as well as its surrounding coastal areas are inhabited by millions of people depending directly and indirectly on the Caspian Sea. We explore implications of CSL projections for ecosystems, biodiversity, economic consequences as well as societal impact in 2100. In this talk we present the result of our ITN-PRIDE program (Drivers of Pontocaspian Biodiversity Rise and Demise) to outline the impact of projected CSL change and identify what critical knowledge we require to understand and mitigate the upcoming Caspian crisis.

Different habitat zones are likely to be very strongly affected by the projected CSL drop, with shallow habitats severely shrinking. Shelf areas will become dry, and the large, very productive northern Caspian Basin and eastern Caspian shelf will disappear (Prange et al., 2020). Important coastal wetland natural reserves (Gorgan Bay, Iran; Kizil Agash, Azerbaijan; Volga Delta, Russia-Kazakhstan) will disappear if they remain in their current shape. The unique Caspian species are already under immense pressure (Lattuada et al., 2019). Species reliant on shallow shelf areas (including the Caspian Seal that has 99% of its breeding grounds on the sea ice of the northern shelf) face extinction. Endemic Caspian Sea hotspots, which today are forced to depths between 30 and 60 m (Lattuada et al., 2020) may become further squeezed between invasive species in shallow zones, and we expect hypoxic zones to expand from the deeper basins. Furthermore, CSL drop will result in a strong decrease of optimum endemic Caspian habitat area due to the bathymetric configuration of the Caspian Sea (Prange et al., 2020). The combination of increased temperatures, disappearance of sea winter ice and rerouting of nutrient load straight into the deeper Middle and South Basins may very well drive strong increase of basin anoxia.

The projected sea level drop will have implications for economic activities on the Caspian Sea, such as fisheries and oil/gas exploration. It will also affect coastal infrastructures. Harbors may become obsolete and in need of constant relocation; shipping lanes need to be deepened, and resorts will become landlocked. The drop will also affect the lowlands surrounding the Caspian Sea. With CSL drops in the order of 9-18 m, we can expect rapid and strong incision of major rivers flowing into the Caspian Sea (e.g. Volga, Ural, Kura). This will lead to dropping groundwater levels in the river basins directly affecting agriculture and water use in a region that is already experiencing severe water stress.

We are currently missing key information to outline CSL trajectories and specific impact required for mitigating action. The awareness of the upcoming crisis in the affected communities is low. Climate and water balance models will need further precision in order to make CSL projection more accurate (Koriche et al., 2021). We need to know the diversity and distribution of (endemic) biodiversity hotspots to know how exactly these will be affected. We need analyses of how different types of ecosystem services will be affected, and what the economic and societal costs will amount to. The Caspian Sea, its unique biota and societies are vulnerable to the adverse consequence of a severe CSL drop. With our work we aim to raise awareness and initiate follow up research and action to deal with the upcoming crises.

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Preface to the Collection of the Conference on

Section 4

Adaptation to climate change in the Caspian Sea region

Scientific conference on climate change in the Caspian Sea region

(27 - 28 October 2021 online)

Preface to the collection of the conference on section 4

Introductory Speech – Murat Atajanov

The fourth section of the Scientific Conference on Climate Change in the Caspian Sea Region is devoted to the topic "Adaptation to climate change in the Caspian Sea region". The reports presented at the section are dedicated to various aspects of this topic.

The Caspian Sea has a number of features, in the light of which global problems are more than relevant for it. These features include the closed nature of the water body, special legal status, sea level fluctuations, the dependence of the water balance on climatic conditions in a territory whose area exceeds the water area by an order of magnitude, high seismicity, active geodynamic processes etc. In addition, three of the five coastal states are intra-continental – Azerbaijan, Kazakhstan and Turkmenistan.

Among the risk factors and threats to the sea, it is possible to distinguish anthropogenic pressure on the sea as a result of shipping, oil operations, use of biological resources, urbanization, agricultural use of coastal land resources. Irrational, unsustainable use of the marine and coast abundance leads to pollution of the sea from land-based sources (rivers, sewage from settlements, agriculture in coastal zones, groundwater), and in the course of the development of the seabed mineral resources. Natural factors also contribute to pollution – an increase in the frequency and intensity of extreme hydrometeorological events, mud volcanoes, fluids and so on, result in the degradation of marine and coastal ecosystems. The listed factors and their consequences cause damage to the population, ecosystems and economy of coastal areas, they are interconnected and interdependent, and climate change, having a global character, exacerbates the existing problems.

It is necessary to note the attention paid to the problems of the Caspian Sea by littoral states. To address the problems of the sea, littoral States are developing scientific cooperation, improving the regional system for assessing the state of the marine environment, organizing regional monitoring and information exchange, training, education and capacity building.

Regional cooperation in the environmental sphere is developing, and its most important condition is the creation of a legal framework for cooperation at sea. Currently, 16 five-party agreements have been signed, a number of which are related to the protection of the natural environment of the Caspian Sea – the Convention on the Legal Status of the Caspian Sea, the Framework Convention for the Protection of the Marine Environment of the Caspian Sea (Tehran Convention) and its four protocols, agreements in the fields of safety, hydrometeorology, conservation and rational use of aquatic biological resources, prevention and elimination of emergencies in the Caspian Sea. The agreement in the field of marine scientific research and the protocol on monitoring, assessment and exchange of information to the Tehran Convention, currently being developed, will undoubtedly serve to deepen Caspian cooperation and conservation of the sea health.

The Caspian littoral states are currently developing and improving national adaptation plans, of which the Caspian region is a part. The purpose of these plans, ultimately, is the health of the sea, its ecosystems, coastal zones and the population, ensuring the sustainability of the economy of littoral states, environmental safety of the sea in the broadest sense.

The existing permanent mechanisms of the Caspian cooperation – the Tehran Convention Secretariat, the Coordinating Committee for Hydrometeorology of the Caspian Sea (CASPCOM), the Commission for the Conservation, Rational Use of Aquatic Biological Resources and Management of their Joint Reserves, the High-level Working Group on the Caspian Sea closely co-operate, and this interaction has a serious potential for growth, as well as interaction with specialized international organizations.

Urbanization and climate change adaptation in coastal area of Caspian Sea; challenges and solutions; with focus on Iran and Azerbaijan[1]

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The Caspian Sea is the world's largest inland body of water. It is a complex system of mutual influence of geological, hydro climatic, anthropogenic and spatial factors [1]. Being an endorheic water body, considerable fluctuations of the water level (Fig. 1) are inherent. Severe climate change hazards, such as sea level variation, intensified floods, and acute droughts, have increasingly adversely affected communities along the Caspian Sea's shores. Simultaneously, urbanization has accelerated, particularly in the Republic of Azerbaijan and the Islamic Republic of Iran, contributing to the loss of biodiversity, the aggravation of desertification, the reduction of agricultural land and water filtration surfaces, and putting additional strain on food and water security. This has an impact on several sectors of countries' economy, including fishing, transportation, and the building industry, as well as those working in these sectors and those living in urban areas. In this article, the trajectories of urbanization and climate change in the Caspian Sea area are studied, with an emphasis on Iran and Azerbaijan, in order to identify some solutions for strengthening adaptation and lessening the adverse effects of climate change. To this end, the trends of climatic factors such as sea level fluctuations, water temperature, extreme weather events, and biodiversity, as well as urbanization expansion (population, economy, and built-up area) over time are examined. The findings revealed a substantial correlation between climatic change effects and the trajectory of urbanization in the Caspian Sea region. First, we established several criteria for highlighting climate changes, such as water temperature, evaporation, precipitation, and evaporation. The findings revealed the amount of precipitation decreased in the Republic of Azerbaijan's whole territory between 1991 and 2010 [1], and projections based on all scenarios of the General Circulation Model (GCM) forecast an increase in monthly average temperature of up to 1.58°. Furthermore, rising temperatures will cause water losses through evaporation and water shortages in the agricultural sector, while increasing irrigation water volume by 10 to 15% [1]. The Caspian Sea was affected by global warming in the

1. This paper is based on the concept note and proposal stage of the project "Urbanization and adaptation to climate change in Caspian Sea region" which is preparing by UN agencies (UN- Habitat, UNEP, and IOM) for Adaptation Fund

last quarter of the twentieth century, with the air temperature over the water rising by 0.7–0.8°C and the surface water layer rising by 0.4–0.5°C [2]. Increasing evaporation owing to elevated warming, as well as the combined effects of precipitation and river discharge changes, all contributed equally to seawater shrinkage.

Fig. 1: Fluctuations of the Caspian Sea level 1900–2017 (source: Tehran Convention (2019), Caspian Sea – State of Environment)

On the other hand, urbanization around the Caspian Sea's shorelines has increased in recent years, putting a growing strain on the land-based and marine environments. The population density along the Caspian Sea shorelines is unequal, with the majority concentrated in major urban centers in the Republic of Azerbaijan, the Russian Federation, and the Islamic Republic of Iran (Fig. 2). Other major implications include cropland loss or degradation, the generation of domestic waste and sewage, the destruction of biodiversity and agricultural land owing to desertification, and the rapid consumption of land resources due to urban sprawl. Unplanned urbanization is also associated to decreasing agricultural acreage, which affects food security, and lower water filtering, which results in increased surface runoff water and subsoil water scarcity. It is estimated that average annual flood damages in the region will amount to 18 - 25 million USD for infrastructure alone. Flash floods pose a significant threat to the population of the Republic of Azerbaijan and the Islamic Republic of Iran.

As a result, it seems there is a significant association between urbanization growth and climate trends, according to an analysis of both. As urbanization increases, the climatic effects become more severe. In other words, the combination of climatic trends with urbanization growth leads to increasingly severe climatic repercussions. To conclude, while current climate change models cannot provide a conclusive answer to the topic of sea level change direction and other components, we can make some recommendations to better the adaptation of the people who live there. These measures are classified into four types: policy/strategy measures, infrastructural measures, biodiversity measures, and livelihood measures. All of the measures have been approved by the national competent agencies and are expected to be executed in the eight selected locations in Iran and Azerbaijan, which were chosen based on the vulnerability of the communities in various dimensions (socio-economic, environmental, physical and infrastructure, and etc.).

Figure 2: Population by number in the Caspian Sea region par cities and administrative units (source: Tehran Convention (2019), Caspian Sea – State of Environment)

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Translated from Russian

Methodological bases of strategies for adaptation to climate change in the regions of Russia

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The ongoing changes in climatic conditions, manifested both in an increase in the frequency and intensity of hazardous hydrometeorological phenomena, and in slow changes in climatic characteristics, affect almost all aspects of human life. Therefore, in the last decade, the world community has been paying increasing attention to methods for developing adaptation measures to climate change and variability together with developing national adaptation plans. National adaptation plans elaborated in many countries are very different from each other depending on country's level of development, priorities of state policy in the field of climate change, the degree of weather and climate risks exposure of economy and social sphere. An analysis of these plans allows us to identify five most common principal stages of the adaptation process:

- identification of adaptation needs (analysis of current and future climate changes and associated weather and climate risks, establishment of acceptable risk values taking into account economic and social factors, assessment of adaptation potential, etc.);
- determination of a set of measures for various adaptation options;
- assessment of these options based on economic estimations;
- planning and implementation of the selected adaptation measures at the federal level and at the level of federal subjects;
- monitoring and evaluating of the implementation progress and the adaptation results, while making the necessary adjustments to the implemented measures [1].

A large number of publications are devoted to the issues of qualitative and quantitative assessment of weather and climate risks for the economy and social sphere on the territory of Russia, methods of managing these risks and developing adaptation measures to climate change. For example, the Second Assessment Report of Roshydromet (2014), a monograph by N.V. Kobysheva et al. on "Climate risks and adaptation to climate changes and variability in the technical sphere" (2015), Report on climate risks at the territory of the Russian Federation (2017), Report on scientific and methodological foundations for elaboration of adaptation strategies to climate change in Russia (within the competence of Roshydromet) (2020), Methodological guidelines for assessing and managing weather and climate risks and elaboration of adaptation measures with an economical justification for their application in the economic and social spheres (2020). In December 2019, the Government of the Russian Federation has adopted a National Action Plan for the first stage of adaptation towards the year 2022. This plan includes 29 activities and consists of 3 large blocks: federal, sectoral and regional. Roshydromet is actively involved in implementation of 21 activities of this plan.

Using the forecast information about the future climate changes obtained on the basis of calculations with the regional climate model of the Main Geophysical Observatory for Central Asia, the impact of future climate changes on the agriculture of arid territories was assessed and recommendations were made on possible adaptation measures in the agricultural sector [2]. The analysis of future changes in agro-climatic indicators by the middle of the to 21st century allowed us to draw fundamental conclusions regarding the regional consequences of global warming for the agro-climatic conditions of growth of key agricultural crops of Central Asia – cotton, spring wheat and spring barley. As calculations have shown, the border of possible cultivation of cotton, for example, will move to the north at a distance of up to 500 km (Fig. 1).

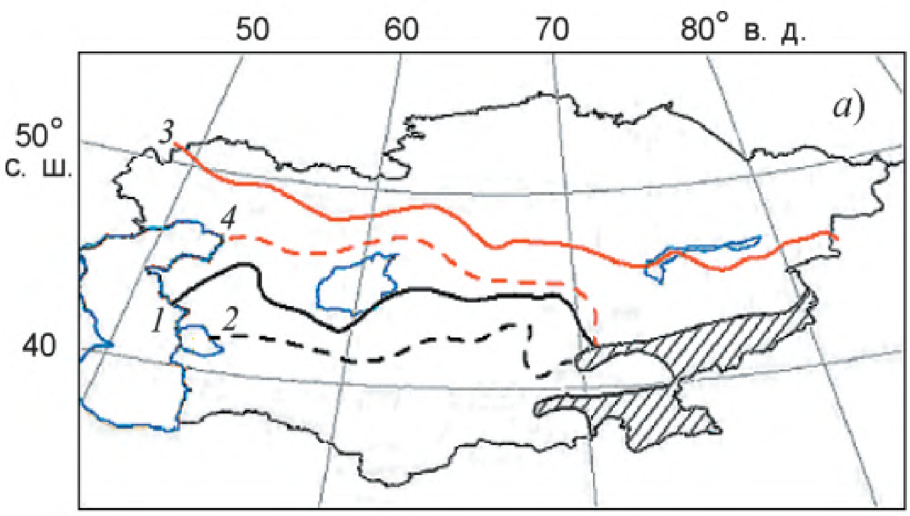

Fig. 1. Availability of thermal resources for cotton for the base period of 1979-2009 (1, 2) and the future period of 2050-2059 (3, 4) on average for the ensemble of calculations.
1 and 3 - for early-maturing varieties, 2 and 4 for late varieties.

The sums of active and effective temperatures for the growing season, the dates of the transition of air temperature through 10°C and the duration of the frost-free period served as a basis for the assessment of thermal resources. The main adaptation measure in this case will be to ensure optimal irrigation rates.

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Contribution of international projects on climate change in the Caspian Sea region to the Tehran convention development and implementation

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The problem of climate change was put on the political agenda of the international community in the mid-80s. In 1988, the World Meteorological Organization (WMO) and UNEP established the International Panel on Climate Change (IPCC). In 1990, the IPCC released its first report confirming the threat of climate change.

In accordance with the Resolution of the UN General Assembly, the Framework Convention on Climate Change was developed. It was adopted and opened for signature at the UN Conference on Environment and Development in Rio de Janeiro, and it entered into force on March 21, 1994.

In May 1994, within the framework of the UNEP Regional Seas Program, the **first meeting of the UNEP Regional Working Group on the Consequences of Climate Change in the Caspian Sea Region (UNEP Working Group on Climate Change, 1994)** was held with the participation of officials from five Caspian Sea littoral states (Moscow, May 20-24, 1994). That event served as a benchmark for elaborating the Framework Convention for the Protection of the Marine Environment of the Caspian Sea - the Tehran Convention [5].

In the course of the meeting of the UNEP Working Group on Climate Change, 1994, it became obvious that consideration of certain aspects of the Caspian Sea environment protection is impossible in isolation from a broader analysis of the ecological situation in the Caspian Sea region. The Final Document of the first meeting of the UNEP Working Group on Climate Change, 1994, noted that the Working Group was established to:

- Address the potential impact of climate change and the Caspian Sea level rise on the Sea and its coastal area environment;

- Develop recommendations for the governments of the Caspian Sea littoral states for the identification of appropriate options and response measures that can mitigate the negative consequences of the expected impacts of climate change.

There were identified the following factors that determine or aggravate emergency situations due to the effects of climate change in the Caspian Sea region as a consequence of the Sea level rise:

- Changes in the water regime (hydrodynamics);
- Changes in the hydrochemical regime of the rivers estuaries and shallow waters;
- Pollution of the Sea;
- Changes in sedimentation processes;
- Changes in the natural and socio-economic conditions of the coastal areas.

Although the name of the UNEP Working Group on Climate Change (1994) is pretty specific and it associates its activities with addressing the “climate” problems of the region, the main tasks of the Working Group were defined as follows:

- Assessment of the situation related to the impact of the Sea level rise and climate change on the environment of the region - shores and water areas, as well as on socio-economic structures;
- Development of recommendations for the government structures of the states of the region for determining the optimal agreed policy and appropriate practical measures to mitigate the revealed negative consequences of climate change.

The adopted at the meeting recommendations proposed to consider within the framework of UNEP the possibility of developing a legal mechanism for regional cooperation among the Caspian Sea littoral states to protect the Caspian Sea marine environment. That was the starting point to launch the development of the Tehran Convention.

To this end, the preparation of a **Regional Review on Consequences of Climate Change in the Caspian Sea region (Regional Climate Review -1977**) [6] was recognized as one of the main tasks of the UNEP Working Group on Climate Change, 1994. The document was to be based on national reports of the countries of the region.

The Regional Climate Review-1977 presented historical information related to changes in the Caspian Sea level, which was based on archaeological data, historical documents and instrumental observations. The Review identified the most vulnerable ecosystems and sites, and formulated the major ecological problems and socio-economic consequences arising from changes in the level of the Caspian Sea.

The priority directions of interstate and international cooperation in the Caspian Sea region included:

- Organization of the integrated management of the Sea coastal zone as a greater ecological risk area under the conditions of the Caspian Sea level fluctuations, and a long-term forecast of such fluctuations;

- Conducting joint scientific research to mitigate the consequences of the Caspian Sea level fluctuations;

- Organization of the environmental monitoring system in the region on the basis of a common methodology,

- Harmonization of regulations for the rational use, protection and reproduction of natural resources in the region, first of all, water and biological resources of the Caspian Sea, and biodiversity conservation;

- Combating desertification, preventing degradation of lands and ecosystems of the region.

- Within the framework of the Regional Climate Review-1977, there were formulated the following ideological and methodological approaches, which later formed the basis for the development of the provisions of the Tehran Convention articles:

- The Caspian Sea is a single, geographically and ecologically holistic object. Significant fluctuations of its level, being a characteristic peculiarity of this closed reservoir, contribute to the formation of its unique biological and landscape diversity, and especially valuable biological resources [2];

- Changes in the water balance and level of the Caspian Sea are mainly determined by climate changes in its basin [1];

- The Caspian Sea level reflects the result of a large number of natural and technogenic processes and includes fluctuations in the inflow of river water, evaporation from the surface of the water area and precipitation on it, withdrawal of water from the inflow, sediment inflow from river, tectonic movements of the

Earth's crust, seawater density changes, etc.;

- Due to the recognition of the ecological integrity of the Caspian Sea, any impact on the marine environment of the Sea, wherever it occurs, can be considered as transboundary;

- Effective management of the complex ecological system of the Caspian Sea can only be an integrated management based on regional cooperation of the countries of the region.

In compliance with the recommendations of the UNEP Working Group on Climate Change, 1994, and the Regional Climate Survey, the first meeting of experts, officially appointed by the governments of the Caspian Sea littoral states (Geneva, December, 1995), launched developing a fundamental legal regional instrument under the auspices of UNEP - the Tehran convention. The document established general principles and an institutional mechanism for cooperation of the Caspian littoral states in the field of the Caspian Sea marine environment protection with account of the specific features of the region, legal precedents, models and experience accumulated at the global and regional levels, especially the UNEP experience. Moreover, it was proposed to agree on specific issues within the framework of separate protocols that could be concluded at a later stage.

Organizational and financial support to the Tehran convention development was provided within the framework of international projects realized under UNEP, UNDP, GEF and other international organizations.

Since 1998, the basis for international environmental cooperation in the Caspian Sea region has been the **Caspian Environmental Program (CEP).** CEP embraces international projects implemented under UNEP, UNDP, EU-TACIS in cooperation with all five Caspian littoral states and international organizations related to the Caspian Sea sustainable development and environmental management.

CEP is actually a system of organizational measures that allow the Caspian Sea littoral countries to set out specific terms for joint actions in order to address the ecological problems of the Caspian Sea.

CEP was managed through the Steering Committee (SC) comprised of National coordinators, the Program Coordination Unit (PCU) and national intersectoral coordination structures (ICS) in the countries.

It was in 2000 when the SC made a decision to create an institutional mechanism in the Caspian Sea littoral states - Administrative Advisory Group (AAG). It was comprised of representatives of the Caspian Sea littoral countries and aimed at improving the CEP activity effectiveness. Later, within the framework of the Tehran convention, it was transformed into the National Convention Liaison Office (NCLO).

The main activities of CEP were carried out by experts and consultants of the Caspian Regional Thematic Centers (CRTCs) located in Caspian Sea littoral states.

The problem of climate change in the Caspian Sea region, associated with its impact on the coastal habitats and landscape degradation, the damage to the coastal infrastructure as a result of the Sea level fluctuations, etc., was one of the important thematic areas of the CEP activities within the framework of the relevant CRTC located in the following countries of the region:

- The Republic of Kazakhstan, Almaty – *CRTC for the Sea Level Fluctuation*. The priority activities of this CRTC were to assist relevant national institutions in the Caspian Sea littoral countries in restoring and upgrading the network of hydrometeorological observations; developing adaptation measures in the context of level fluctuations, and assessing the impact of such fluctuations on the socio-economic conditions of coastal territories;

- The Republic of Kazakhstan, Atyrau – *CRTC for the Protection of Biodiversity*. The objectives of the CRTC were to study existing threats to biodiversity, including the Caspian Sea level fluctuations, to develop the Caspian Sea biodiversity in general, as well as species inhabiting the Caspian Sea, and rare and endangered species;

- Turkmenistan, Ashgabat – *CRTC for Combating Desertification and Degradation of the Coastal Areas.* The CRTC`s work aims, mainly, at assessing impacts of desertification processes on the socio-economic development of coastal territories;

- Islamic Republic of Iran, Tehran – *CRTC for Integrated Coastal Zone Management.* The major tasks of this CRTC are spatial planning and management of coastal and marine zones taking into account the Caspian Sea level fluctuations and preparation of countries coastal profiles.

- The development and approval of the Tehran convention became one of the main outcomes of the large-scale CEP implementation on the basis of the CRTC activities. The prepared materials were the basis for the formulation of a number of articles of the Convention and its protocols.

The first phase of CEP activities (1998-2002), carried out within the framework of projects under UNEP, UNDP/GEF, TACIS, the European Commission and the World Bank, included:

- Creation the necessary institutional mechanisms for interaction;
- Conducting **Transboundary Diagnostic Analysis (TDA);**
- Development of the regional **Strategic action Plan (SAP)**, and preparation of a number of pilot projects.
- An important final document within the framework of the implementation of the CEP first phase was TDA, which included a review of the Caspian Sea environment status, the main revealed problems and issues, a list of Environmental Quality Objectives and an analysis of cause-and-effect relationships.
- That document, prepared with the participation of experts from all Caspian Sea littoral highlighted priority problems that are related, *inter alia*, to climate change:
- Degradation of coastal landscapes and destruction of coastal habitats: *a transboundary problem.*

Formulation of the problem: a number of natural and anthropogenic factors lead to the destruction of the coastal landscape and habitats. Among natural factors, there are climate change, the Sea level fluctuation (storm surges and long-term changes).

Analysis: stakeholders consider this problem as being of *medium or low priority*. The problem has both natural causes (the Sea level fluctuations and earthquakes) and anthropogenic (desertification). There is a link with biodiversity and the loss of habitats caused by human intervention. The lack of regional and integrated planning is the main cause of the problem; a multisectoral approach is required to improve the situation.

Damage to coastal infrastructure, cultural and household facilities: *the problem is less a transboundary one.*

Formulation of the problem: the Sea level fluctuation affects coastal infrastructure, cultural and household facilities. When the Sea level lowers, marine infrastructures become unusable (berths, docks, etc.). With the Sea level rise, previously dry areas may be flooded, various types of infrastructure are destroyed, and it causes pollution of flooded land. Wind or storm surges cause both significant flooding and impacts on coastal regions. The coastal zone planning is inefficient without taking into account the Sea level fluctuations. Desertification can push urbanization processes closer to water, and thus increase the burden on the coastal infrastructure.

Analysis: Damage to coastal infrastructure, cultural and household facilities are mainly connected with long-term changes in the Sea level, surges and desertification. Stakeholders consider this issue *as having a low or medium priority*. To solve such problems, improved coastal planning and intersectoral exchange on the corresponding information are needed. Planning for adaptation to the Sea level fluctuations is of great importance.

Simultaneously with the TDA, **the Caspian Sea Strategic Action Plan** was developed. It set out the principles of coordinated environmental management; the problems of integrated environmental management of the Caspian Sea were noted; Environmental Quality Objectives (EQO) agreed at the regional level was established for priority ecological problems in a transboundary context.

The completion of the CEP initial phase realization coincided with the Tehran Convention-2003 signing. Assistance in its elaboration was provided at the first CEP phase through organizational support for a number of meetings on the harmonization of the provisions of the Tehran convention articles. The representatives of the Caspian Sea littoral states contributed to those events.

The second CEP phase (2003-2007) in the form of the GEF/UNDP project **"Implementation of the Tehran Convention and a Strategic Action Plan for the Protection of the Caspian Sea Environment, Phase II (CEP-SAP)"** was of particular interest in the context of the climate change problem in the Caspian Sea region. It was an important component of the activities under the Project, including the process of the development of the Protocol for the Conservation of Biological Diversity to the Tehran Convention (Ashgabat Protocol) [4]. Representatives of the Caspian Sea littoral states agreed to include in the Protocol a number of provisions related to assessing the impact of the Caspian Sea level fluctuations on marine and coastal ecosystems and to accounting the natural dynamics of coastal ecosystems associated with the Sea level fluctuations (paragraph (a), Article 12 of the Ashgabat Protocol), etc.

Within the framework of the GEF/UNDP project second phase, in the **national report of Russia on "State and Conservation of Biological and Landscape Diversity of the Caspian Sea Region" 2002 (Dr. Yu. Puzachenko, et al.) [3],** there were presented a detailed analysis of factors determining the biological and landscape diversity of the region, a series of paleogeographic data on the Caspian Sea level fluctuations (on the basis of statistical analysis); corresponding patterns for such processes were identified, and it was concluded that such fluctuations significantly determine the nature and the most important characteristic features of biological and landscape diversity.

At the same time, the high dynamics of landscape and ecological systems, which is characteristic of the region, was interpreted as the main factor for the formation of the unique bioresource productivity of the Caspian basin.

The Report contained a number of issues of interest in the context of the issue under consideration.

The Caspian Sea level fluctuations undoubtedly affect the number of various species populations and their spatial distribution, but in itself, both landscape and biological diversity both in the water area and on land are largely supported by these fluctuations. The fluctuations constantly unbalance the local system; contribute to the preservation of suppressed species at a particular time. Any types of habitats do not practically disappear in the event of the Sea level fluctuations, but only moved around. Communities, composed of eurybiont species, are rapidly recovering under new conditions. The Caspian Sea ecosystems are fully adapted to the various-scale changes in the Sea level.

The Caspian Sea level rise negatively affects the population of waterfowl and near-water birds. It causes destruction of their nests, transformation of habitat conditions, deterioration of feeding and nesting quality of habitats. All this leads, in particular, to a decrease in the productivity of the Volga Delta wetlands, including wetlands of international importance as a habitat for waterfowl, as well as to the relocation of some animals to other habitats.

Speaking about the positive impact of the level rise on biodiversity, there should be noted the improvement of fish feeding conditions, an increase in spawning areas in the Caspian Sea, an increase in water exchange among various areas of the Sea, expansion of the desalinated buffer zone and an increase in potential productivity in the northern area of the Caspian Sea.

The Report noted that the Caspian Sea level fluctuations have the greatest impact on the delta and avandelt biotopes, significantly transforming the conditions of the aquatic organisms’ existence.

The report, prepared by Dr. A.Filippov et al. “Inventory of the Coastal Areas of the Caspian Sea and Identification of Sites of Particular Importance and/or Sensitive to Impacts” (2005) [7] contains the results of a quantitative assessment of coastal and marine habitats of the Caspian Sea and a preliminary list of the Caspian Sea habitats which includes information on environmental sensitivity, dominant threats, including the Sea level fluctuations.

In cooperation with the UNEP World Conservation Monitoring Center, accurate quantitative maps of the ecologically vulnerable zones of the Caspian Sea have been created, guidelines for the protection and restoration of ecologically vulnerable zones have been developed, and a management plan for the adaptation of coastal lagoons to the Sea level fluctuations, that are important for biodiversity, have been elaborated.

The third phase of the CEP (2007-2012) was implemented with the support of the GEF/UNDP project “The Caspian Sea: Restoring Depleted Fisheries and Consolidation of a Permanent Regional Environmental Governance Framework “CaspEco”. The Project consisted of two main components: Component 1 – “Ecosystem based management of aquatic bioresources”, and Component 2 – “Strengthened Regional Environmental Governance” after the entry into force of the Tehran Convention.

Within the framework of Component 1, a comprehensive analysis of biodiversity assessments for the entire Caspian Sea region was carried out by the experts **- Dr. R.Khodarevskaya and Dr. B.Morozov prepared the “Regional Review of the Ecosystem and Biodiversity of the Caspian Sea”, 2010 [8]** (**Ecosystem Review**). The goal of the work was to identify the full spectrum of the Caspian Sea biodiversity - species, habitats, ecosystems, their number, status and location. The Ecosystem Review was based on the reviews and assessments of national and regional databases carried out earlier within the framework of CEP, as well as on data on biodiversity and pollutants obtained as a result of research activity by oil companies.

In the Ecosystem Review, the authors continued to analyze information about the impact of climate change on the Caspian Sea biodiversity state and, in particular, on the status of biological resources, presented in the above-mentioned Report (Dr. Yu. Puzachenko “State and Conservation of Biological and Landscape Diversity of the Caspian Sea Region” 2002).

For the formation of biological resources of the Sea, its level and the fluctuation amplitude are of great importance. Such Sea level fluctuations radically change ecological conditions for the biocenoses evolution in the estuaries of rivers because the high fish productivity of the Caspian Sea is connected with the annual influx of river water, from which organic and inorganic nutrients come. Also, the productive properties of the Sea itself change, especially its shallow northern part.

On the basis of the analysis of long-term data, which characterize the ecosystem and bioresources of the Volga-Caspian basin under the conditions of changing water regime of rivers and the Sea, the Ecosystem Review provides information on the fact that the Sea level mark of minus 28.5 m is critical for the ecosystem and bioresources in the northern area of the Caspian Sea, and the lowering of the level to minus 29.0 m or more is considered to be catastrophic.

The above-mentioned Review lists the consequences of the Sea level fluctuations that lead to profound transformations of the coastal zone of the Caspian Sea, changes in the conditions for distribution of numerous species of nesting birds' habitats, feeding areas of many fish species, changes in salinity, as well as in the impact of the groundwater level on adjacent territories, etc.

Also, information is provided on the formation of new islands under the condition of the Sea level decrease, for example, the Zhemchuzhnyy Island, located in the northern area of the Caspian Sea.

Originally, this Island was formed during the last regression of the Caspian Sea in the 50s - 70s of the twentieth century. During the current marine transgression, the Island was preserved due to the activation of lithodynamic processes in relatively deep parts of the water area next to it. Zhemchuzhnyy Island became a favorite nesting place for many waterfowl, and extensive rookeries of Caspian seals also appeared on this Island.

It is noted that accounting potential Caspian Sea level fluctuations is also of great importance in terms of ensuring the normal functioning of some protected areas and preserving the environmental role of the coastal water protection zone. In particular, the definition of the seaward limits of the "Volga Delta" wetlands should take into account the probability of the Caspian Sea level lowering. The repetition and periodicity of these transformations allow us to consider the biota of the Caspian Sea as highly adapted to them.

One of the important activities under the GEF/UNDP "CaspEco" project under the third phase of the CEP was the activity that initiated the process of the elaboration and formation the Caspian Sea Environment Monitoring Program (EMP). Its development was continued within the framework of the Tehran Convention.

These works were based on the TACIS project "Caspian MAP". Under the CEP third phase implementation, a draft EMP was developed in respect to the hydro-meteorological monitoring.

In the result of the CEP third phase activities in the field of climate change in the Caspian Sea region, within the framework of cooperation of the Coordination Committee for Hydrometeorology and Monitoring of Caspian Sea Pollution (CASPCOM) and CEP, the international scientific conference "Climate Change and Water balance in the Caspian Region" was held in Astrakhan on October 19-20, 2010. The Conference confirmed the need for further in-depth scientific research in the sphere of climate change and water balance in order to protect the marine environment of the Caspian Sea. The Conference gave an impetus for further development of cooperation between CASPCOM and CEP.

In addition to the above-mentioned UNEP and CEP projects, a number of international UNEP/GEF, UNDP/GEF projects were implemented at the national level in 2008-2012. The following projects envisaged consideration of consequences of climate change in the Caspian Sea region and its level rise:

- Russia-UNEP/GEF project "**Self-assessment of National Capacity Needs for Global Environment Management - Russian Federation**",

- Russia-UNDP/GEF project "**Strengthening the Marine and Coastal Protected Areas of Russia**".

- The Russia-UNEP/GEF project "Self-assessment of National Capacity Needs for Global Environment Management - Russian Federation" was connected with the development of approaches and mechanisms for synergy of three Rio conventions – the UN Convention on Biological Diversity, the UN Convention to Combat Desertification and the UN Framework Convention on Climate Change. The Project used the example of the Caspian Sea region.

The main Project's outcome was the development of an Action Plan for building national capacity to implement the Rio conventions (hereinafter referred to as the Action Plan).

In the course of the Action Plan preparation, priority activities were identified, such as, for example, assessing the global and regional impact of climate change on the strategy of socio-economic development of the Caspian Sea region.

The Russia-UNDP/GEF project "Strengthening the Marine and Coastal Protected

Areas of Russia" contributed to the effectiveness of marine and coastal protected areas system management in Russia, including protected areas in the Caspian region. The activity took into account the changing climatic conditions, which are observed in conjunction with a variety of anthropogenic factors that modify their impact on marine and coastal ecosystems, often making it even more destructive.

An analytical review of the results of the activities under international projects, that include the problems of climate change in the Caspian Sea region (UNEP projects, UNDP/GEF projects, etc. within the framework of the large-scale Caspian Environmental Program), demonstrated that international projects had made a significant contribution to the development and coordination by the Caspian Sea littoral states of the thematic areas which are covered by the Tehran Convention Articles, including Article 16 of the Convention "Caspian Sea Level Fluctuation".

The materials (reports, reviews, recommendations) prepared within the framework of those projects, including on climate change, were relevant and could be used in the implementation of the Tehran Convention.

The recommendations adopted at the first meeting of the UNEP Regional Working Group on the Consequences of Climate Change in the Caspian Sea Region (Moscow, 1994) became the basis for the development of the Tehran convention as a legal mechanism for regional cooperation among the Caspian Sea littoral states on the Caspian Sea marine environment protection and integrated coastal environment management.

The Tehran Convention provisions provide for the need to further study and obtain up-to-date information on the Caspian Sea level fluctuations and the impact of such fluctuations on marine and coastal ecosystems. Such work should be carried out on the basis of information about the hydrological regime and dynamics of the Caspian Sea ecosystem (paragraph (h) of Article 20 of the Convention).

Assessment of the Caspian Sea level fluctuations impact on marine and coastal ecosystems and taking into account the natural dynamics of coastal ecosystems connected with the Sea level fluctuations (paragraph (a), Article 12 of the Ashgabat Protocol) are necessary to develop effective methods for preventing, reducing and controlling pollution of the marine environment of the Caspian Sea (Article 20 of the Convention).

Long-term Sea level fluctuations and storm-surges, being natural risk factors for the coastal areas of the Caspian Sea, have a negative impact on the population and infrastructure of the coastal areas (item 1, Article 10 of the Moscow Protocol) and require the development by the Caspian Sea littoral states of appropriate agreed measures and procedures to mitigate the effects of the Caspian Sea level fluctuations (Article 16 of the Convention).

Article 15 of the Tehran Convention ("Costal Zone Management") provides for the adoption by the Parties to the Convention of necessary measures to develop and implement national strategies and plans for planning and management of the land affected by proximity to the Sea. They should be based on monitoring data to regulate anthropogenic impacts on the status of coastal ecosystems, take into account the uniqueness of its biodiversity, the commercial importance of biological resources and the need to adapt coastal socio-economic complexes to changes of natural conditions, including level fluctuations.

Consistent accounting the Caspian Sea level fluctuations with the aim to ensure the ecological framework for coastal territories is an important recommendatory measure for the environmentally sustainable development of the coastal territories.

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Translated from Russian

Training of specialists in coastal ecosystems monitoring

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In Turkmenistan, the priority sectors for climate change adaptation are public health, agriculture and water management; the coastal zone of the Caspian Sea and natural ecosystems: flora, fauna, soil and land resources. Turkmenistan, together with other Caspian littoral states, has been actively implementing the Caspian Environmental Program (CEP) for many years as a logical outcome of positive cooperation between the countries of the region. In November 2003, the participants of this program signed the Framework Convention for the Protection of the Marine Environment of the Caspian Sea (the Tehran Convention). The Caspian Sea and the coastal region of Turkmenistan play an important role in the sustainable development of the country. The problem of coastal ecosystems of the Caspian Sea in the context of climate change requires regular and detailed monitoring. Different organizations use geospatial technologies for the assessment and management of information along with the remote sensing, and then for the continuous improvement of the state of the environment of the coastal region. Training of professionals in this area is the main task of national universities.

The Magtymguly Turkmen State University trains specialists who got the skills to research the ecological state of various regions of the country and to regulate the processes of change of the natural ecosystems, inter alia in the Caspian region.

Our university is a member of the GEOCLIC consortium (New Courses in Geospatial Engineering for Climate Change Adaptation of Coastal Ecosystems) of the Erasmus+ program, aimed at developing special training programs at universities for specialists in coastal zone management and engineering.

The project aims to modernize the learning plan on geospatial technologies in order to ensure the environmental safety of the coastal ecosystems of the Caspian Sea in the face of climate change, using new technologies GEONETCast, GIS Software-ILWIS along with the remote sensing and modeling technologies.

Currently, there is a lack of human resources with the competencies and skills to understand, transform and interpret satellite data, as well as to analyze this data and make decisions related to environmental protection.

Information technology specialists, meteorologists, ecologists, biologists, cartographers and other professionals will be trained in methods and tools for improving the ecological state of the region, providing spatial technologies and methods for monitoring coastal and wetlands.

Existing learning plan aimed at ecosystems management and monitoring needs to be adapted and improved in accordance with new changes in the region. Environmental management is pointed at ensuring the protection of ecosystems for future generations. Graduates should acquire sufficient knowledge in the field of digital image processing, big data analysis, process modeling and environmental management, optical and hyperspectral processing of remote sensing data, computer vision algorithms, GIS and other technologies. Universities should be interested in collaborating with organizations related to climate change monitoring in the region to expand the content of educational programs considering the needs of the partners. The solution of these tasks will also effect the regional aspect, opening new opportunities for cooperation between universities and enterprises in the exchange of knowledge and educational resources. In this way, the courses being implemented in the most rapidly developing scientific domains will enable training of specialists who have the skills of research activities in the conditions of climate change.

Is Azerbaijan ready to tackle climate change?

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Existing research and media coverage of international energy politics in Azerbaijan is overwhelmingly dominated by a focus on oil and gas extraction due to its crucial place in traditional hydrocarbon markets. While the strategic aspects of oil and natural gas are well-researched, there still exists a great deal of uncertainty about how renewable energy will reshape Azerbaijan's energy security. This article aims to expand the scope of the literature on energy geopolitics in the South Caucasus to bring more attention to Azerbaijan's renewable energy sector, which is still nascent.

Around the world, the use of renewable energy is growing rapidly because of climate change concerns, diversification strategies and strong economic investment. Although oil continues to hold the largest share of the energy mix (33.1%), the share of both natural gas and renewables rose to record highs of 24.2% and 5.0% in 2019, respectively (BP, 2020). Renewables has now overtaken nuclear, which makes up only 4.3% of the energy mix. Recently, countries with significant oil and natural gas resources such as Nigeria and Qatar also have focused on developing their renewable energy potentials. The tendency is not only caused by concern for the environment, but also by economic demands. This trend is observed in almost all oil-rich countries, including Azerbaijan. For example, the Azerbaijani government has initiated various structural changes in order to facilitate investment in the renewable energy market. These initiatives include several draft pieces of energy efficiency legislation such as "Use of renewable energy sources in power generation" and "Efficient use of energy resources and energy efficiency" (IEA, 2020).

Traditional oil producers such as Saudi Arabia, Iran and Russia, which have historically enjoyed geopolitical influence because they supply fossil fuels, are likely to see a decline in their global reach and impact unless they can reinvent their economies for a new energy era. Azerbaijan may face challenges in adapting to a world increasingly powered by renewables. Azerbaijan's economy is smaller and less diversified than those of some of the Middle Eastern oil producers. Therefore, oil and gas rents are a vital component of the state budget, accounting for around 90% of fiscal revenues; Azerbaijan simply does not have competitive industries beyond fossil fuels. Declining export revenues will adversely affect Azerbaijan's economic growth prospects and the national budget.

In this regard, it appears necessary to develop sustainable energy in Azerbaijan by switching to renewable energy sources. Towards that end it is essential to determine the motivation and incentives which enable a small oil-rich country to seek the development of renewable energy. Who is promoting renewable energy in Azerbaijan, and with what effects? Whether climate change is a major security concern in the Caspian Sea region? How is climate security defined and understood in Azerbaijan? Who is promoting climate change in Azerbaijan and with what effects? How do low oil prices and Covid-19 affect the progress of renewable energy in Azerbaijan? These questions are in the focus of our further research.

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Translated from Russian

Lower Volga region water management under conditions of climate changes

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The Lower Volga is an exceptional natural system, and its hydrological regime is the determining factor of existence in an arid climate. Changes in this regime, including those occurring under the influence of climate change, determine the dynamics of the main elements of this unique ecosystem.

The creation of the Volga-Kama Cascade (VKC) made it possible to solve a number of water management problems in Central Russia, but in the Lower Volga region it led to the certain number of the new ones. The complexity and specificity of water and environmental problems of the Lower Volga stem both from natural conditions of the region and inconsistency between the requests of economic sector and environmental requirements for the multi-purpose use of water bodies.

An analysis of the long-term variability of the main parameters of the Lower Volga hydrological regime in the Volgograd water abstraction point showed that the average values of annual runoff volumes for natural and controlled periods are very close – 256 km^3/year and 249 km^3/year, respectively. The average annual flow volume for the entire 130-year period of instrumental observations is 253 km^3/year. In general, with close average annual values, the annual flow of the Volga River after overregulation is characterized by a smaller amplitude of inter-annual fluctuations.

The most significant changes occurred in the intra-annual distribution of the water runoff. After the river control establishment, the flow of the spring high-water decreased by almost 30% compared to natural conditions. On the contrary, the low-water flow has increased, in particular, during the winter low-water season - by more than 2 times compared to the natural period. In the current context, about 40% of the runoff is accounted for during the spring high-water season, and half of them takes place in May – the most high-water month. Before the river control establishment, the runoff of May and June accounted for up to 50% in total, and the winter low-water period gave not more then 3-4% of the annual runoff. The change in the intra-annual flow distribution led to significant changes in the parameters of the hydrological regime, which largely determine the state of terrestrial and aquatic biocenoses of the Lower Volga.

Water resources management does not have an unambiguous solution for different water-years, and it is therefore necessary to plan for several options, while any of them violates the requirements of certain participants of the water management complex. In nowadays operational practice, such decisions are usually made on the basis of dispatchers' management schedules developed considering long-term hydrological series and the experience of managing the basin's water resources in previous years, but regardless the actual and upcoming water inflow, and without taking into account the ongoing climate changes, which makes an effective management impossible.

For the management of water resources in operational mode, a mathematical model, algorithm and computational technology (CT) of the functioning of the Volga-Kama cascade (VKC) reservoirs has been developed, that implements an optimization approach to solving the problem of operational management of hydroelectric facilities during the spring high-water season. This technology allows searching for compromise solutions in the interests of various water users (water supply, hydropower, transport, ecology, agriculture and fisheries, etc.). The proposed technology is based on the use of methods of multi-criteria analysis (the theory of compromises). CT has been implemented for 9 large reservoirs of the VKC: Rybinsk, Nizhny Novgorod, Cheboksary, Kuibyshev, Saratov and Volgograd on the Volga River and Kama, Votkinsk and Nizhnekamsk on the Kama River. The total useful volume of 9 reservoirs of the Volga-Kama cascade is 78.0 km^3.

The proposed approach to solving the problem of operational management is based on taking into account the conflicting requirements of water users. The optimized variables are the daily discharges of water into the lower reaches of each reservoir of the VKC. The proposed CT is based on the solution of the water balance equations for each reservoir.

The nature of flooding of agricultural lands and spawning grounds of the Lower Volga depends on the configuration of the spring special water release. In the absence of detailed information on the dependence of fishing and agriculture efficiency on the discharge hydrograph, an expert decision is made on a standard schedule of special water release, which allows to flood the areas of agricultural land and spawning grounds as much as possible, as well as to create favorable conditions for fishing.

Based on the solution of a number of optimization problems, a set of non-dominant solutions is formed, from which the "optimal" solution in the Pareto meaning can be selected by the method of achievable goals and the corresponding visualization apparatus [1,2]. The final decision for the current date is made in the process of discussing the entire set of received non-dominant decisions at a meeting of the Interdepartmental Group responsible for making decisions on regulating the operating modes of the VKC reservoirs. The Pareto Front Viewer program developed at the A. A. Dorodnitsyn Computing Center of the Russian Academy of Sciences serves as a tool for visualizing the results and rapidly making a compromise decision.

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Translated from Russian

Modernization of the university learning courses on geospatial technologies in order to ensure the environmental safety of coastal ecosystems of the Caspian Sea

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The learning courses aimed at ecosystems monitoring and management, in particular for the coastal zones, not yet match the proper level, so they need to be adapted and modernized in accordance with new changes in the region. It is necessary to elaborate specialized educational programs to train professionals in the field of ecology and coastal zone management and engineering, that would have competencies and skills to use remote sensing tools and geospatial technologies to assess and manage information in order to improve the state of environment.

In our opinion, the current project of the ERASMUS+ program “New Courses in Geospatial Engineering for Climate Change Adaptation of Coastal Ecosystems” (GEOCLIC), funded by the European Union, for the participants from five EU countries and for two participants from Central Asia and Azerbaijan, will contribute to the solution of the above tasks to the certain extent.

Turkmen Agricultural University named after S. A. Niyazov is also taking part in this project.

The main objective of the project is to modernize the BA/MSc/PhD learning courses on geospatial technologies in order to ensure the environmental safety of coastal ecosystems in the context of climate change using new GeoNETast technologies, the GIS Software (ILWIS) along with the sensing and modeling technologies.

Within the project framework, it is also planned to create GEOLAB laboratories supplied with the new equipment, CVE virtual computer classes and GEOCOF spatiality technology offices in the participating universities.

The long-term goals of the project include:

- training of specialists in regular and detailed monitoring of the coastal and wetland ecosystem using space technologies;
- protection of exploited biological resources;

- conservation and management of coastal and marine biodiversity and habitats in the Caspian Sea;

- ensuring higher quality of water, protecting human health, along with the favorable conditions for recreation and the safety of ecosystems.

After the implementation of modernized and new disciplines, university learning courses should provide graduates with sufficient knowledge in the field of digital image processing, big data analysis, machine learning and deep learning, process modeling and environmental management, optical and hyperspectral processing of remote sensing data, computer vision algorithms, GIS and other technologies. The target universities are also very interested in cooperation with companies related to Earth observation, and it is necessary to integrate their proposals to harmonize and expand the content of training programs considering the needs of partners. The proposed project sets the following goal: to offer an innovative interdisciplinary master's and doctoral degree course to improve the university curricula, adaptability and professional awareness to find solutions for the new challenges in the field of remote sensing for environmental management in the coastal ecosystem, in line with new developments in this scientific area, market demand and in accordance with the Bologna process. Analyzing the current situation in the Caspian Sea region, the consortium of universities participating in the project determined that this situation can be changed and improved with the help of this project due to rapid changes in space and environmental monitoring technologies.

Translated from Russian

SOCAR's proactive steps in combating climate change

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As for today, the most important strategic goal facing an oil and gas company is to minimize the impact of its activities on climate change, to assess climate risks and timely plan the adaptation measures aimed at reducing losses from the consequences of climate change. SOCAR's Low Emissions Development Strategy for the period up to the year 2030 was prepared and approved in accordance with a set of measures to reduce emissions from the oil and gas industry contained in the Azerbaijan's Intended Nationally Determined Contribution (INDC) for the UNFCCC as well as in the state strategies and plans aimed at achieving the Sustainable Development Goals. The strategy is based on specific sets of annual mitigation measures taken in the upstream segments: search and production; midstream segments: transportation; and downstream: processing and implementation. The strategy provides the imposition of low-carbon technologies in production, including the use of alternative and renewable energy sources, optimization of energy-intensive processes, recycling of waste, as well as measures for greening and remediation of oil-polluted lands.

The graph below shows the goals for reducing greenhouse gas (GHG) emissions in the upstream segment for the period of 2021-2030, whose projected reduction will be 37% of the baseline scenario emissions. It should be noted that the baseline scenario was calculated considering direct (Scope 1) and indirect (Scope 2) emissions. Also, additional measures are planned to assess emissions from the consumption of manufactured products (Scope 3).

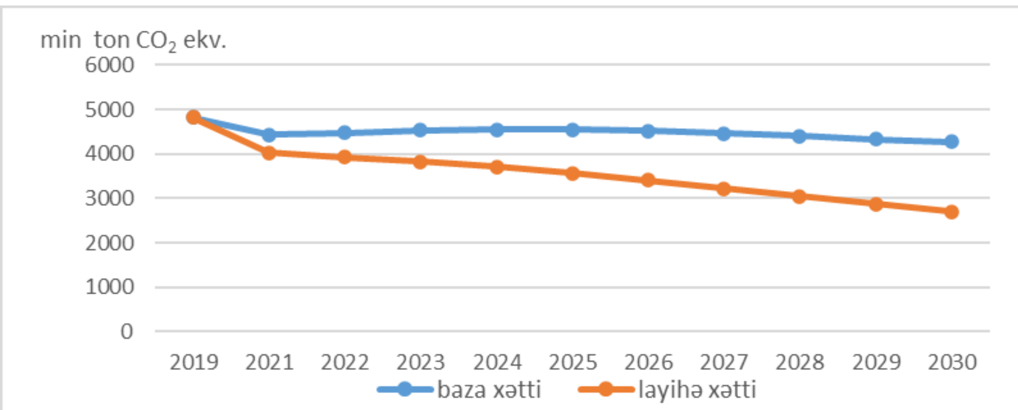

Fig 1. GHG emissions from the Upstream segment of SOCAR.

SOCAR has taken an initiative to create the first independent regional platform “Caspian Environmental Protection Initiative – CEPI” to provide the joint research of international oil companies operating in the region for the environmental protection.

Within the initiative framework, it is planned to jointly develop a set of measures to combat the consequences of climate change, which may threaten sustainable development of the Caspian Basin region.

At this stage, SOCAR is performing research of possible decarbonization of production in order to achieve the so-called “Net Zero” emission in the future. Now, the SOCAR Development Strategy up to the year 2035 is at its approval stage, and it includes specific projects to provide the company’s transition from the rank of oil producers to the energy one. These measures will not only ensure the sustainable development of the economy, but also significantly reduce the level of emissions from the energy sector, which in turn is a significant contribution to the fulfillment of the obligations assumed by the Republic of Azerbaijan under the Paris Agreement.

SOCAR, which is currently a supplier of energy resources on a global scale, develops short -, medium- and long-term development scenarios, and for each of those scenarios it assess climate risks; and special funds are invested in measures aimed at their reducing. To ensure an integrated approach, a commission on “Climate Change and «0» GHG emissions” was established in SOCAR in June 2021 under the leadership of the President of SOCAR. This decision proves once again that the Company has a clear understanding that without the new low-carbon technologies adoption, technological processes improvement and optimization, the widespread use of alternative energy sources and the use of technologies for carbon capture and storage, it is not possible to achieve this goal.

It should be noted that the SOCAR has been performing a GHG inventory at the corporate level since 2007, and in 2020 a methodology for calculating GHG emissions from SOCAR’s activities was prepared and approved. Thanks to the efforts of the Vice-President for Ecology of SOCAR, Ms. Rafira Huseyn-Zadeh, the introduction of a unified corporate system for Monitoring/Measurement, Reporting and Verification (MRV) of atmospheric emissions, including GHG, has been launched since 2021. To ensure control over the implementation, a group of the operating instrumental measurements was established on the base of the SOCAR Ecology Department, experts were certified, and appropriate equipment was purchased. It is planned to introduce an automated system of integrated solutions for building a common information space on the base of the SOCAR as well, which would provide not only the effective resource planning, but also ensure timely reporting, reduce the errors in calculations and identify problem areas/equipment that does not meet the standards for emissions into the atmosphere.

In conclusion, it should be noted that due to the successful implementation of the Plan to Reduce Low-pressure GHG Emissions for the period of 2010-2015, SOCAR managed to collect 656.9 million m^3 of gas, which in turn prevented the release of 8.815 million tons of CO_2 equivalent into the atmosphere. SOCAR and the Representative Office of the United Nations Development Programme (UNDP) in Azerbaijan have successfully launched a project entitled “Nationally Appropriate Mitigation Actions (NAMAs) for low-carbon end-use sectors in Azerbaijan”. The project consisted of three components: ensuring the energy efficiency of buildings, alternative fuel for transport and the collection of low-pressure associated gas.

Translated from Russian

Conservation and effective management of biodiversity in the context of climate change

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In recent years, numerous considerations related to climate change have been included in the programs, decisions and recommendations of various conventions. These environmental conventions address the relationship between climate change and biodiversity. Thus, the Conference of the Parties to the Convention on Biological Diversity (CBD) stressed the importance of integrating the topic of biodiversity into any relevant national policies, programs and plans in order to combat climate change and promptly develop tools for implementing biodiversity conservation measures that promote adaptation to climate change [2]. The Conference of the Parties to the Ramsar Convention on Wetlands called on the Parties to manage wetlands in such a way as to increase their resistance to climate change, encouraging the protection and restoration of wetlands and watersheds to this end.

According to the results of the "Millennium Ecosystem Assessment" report, climate change is likely to become the main direct driving mechanism causing the loss of biodiversity by the end of this century [4]. The impact of climate change on the species component of biodiversity is manifested in changes in the distribution of species, the patterns of their reproduction, the duration of the growing season of plants, the acceleration of the rate of extinction of vulnerable species, especially those already threatened with extinction.

One of the most important features of the Caspian Sea is the change in sea level – the factor that has a significant impact on the biodiversity and management of the coastal zone in the vast shallow waters. The causes of sea level changes can be both natural and anthropogenic, as the result of global climate changes caused by human. Since it is an internal water body, its level depends on changes in the volume of water inflow (mainly river runoff) and loss (mainly evaporation) of water.

In order to implement preventive measures to increase the resilience of ecosystems to climate change, the National Strategy of Turkmenistan on Climate Change (2019) identifies the solution of urgent tasks, including the following related to the Caspian Sea:

- strengthening of state control over the ecological systems protection, prevention of land, surface and underground waters pollution, and the pollution of marine environment of the Turkmen sector of the Caspian Sea and its coastal zone;

- systematic implementation of activities to protect the biodiversity of the marine environment of the Caspian Sea and constant monitoring of compliance with the standards of the activities of coastal production enterprises [3].

The Caspian Sea, located on the border of two large parts of the Eurasian continent, is the largest unique water body that does not have access to the World Ocean. One of the most important features of the Caspian biodiversity is the relatively high endemism. The Caspian Sea is characterized by a small variety of fish species compared to the open ocean. A special status, of course, belongs to sturgeon – relict inhabitants that have existed here for hundreds of millions of years, and whose world gene pool has not been preserved except here, in the Caspian Sea. The only Caspian mammal – the Caspian seal, is supposed to be an alien from the Arctic during the high-level period of the Caspian Sea.

The Caspian region is also known as a mass habitat of waterfowl and near-water birds. About 6 million migratory birds move through the Caspian Sea every year, in this regard, the Turkmenbashi Bay of the Khazar Reserve is officially nominated to the Ramsar List. In 2017, specialists identified and described ecologically and/or biologically significant marine areas (EBSA) in the Turkmen sector of the Caspian Sea: Turkmenbashi Bay, Turkmen Bay and Karabogazgol Strait [5].

Turkmenistan's commitment to international cooperation in the field of biodiversity protection is confirmed by the accession in 2021 to three more new international agreements in the field of biodiversity conservation: the Convention on the Conservation of Migratory Species of Wild Animals (CMS), the Agreement on the Conservation of Wetland Birds Migrating along the Afro-Eurasian Flyway (AEWA) and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization [1, 6]. Thus, the new initiatives will allow Turkmenistan to implement the obligations of a number of international conventions and treaties in the field of conservation and sustainable use of biodiversity, thereby confirming its commitment to international cooperation in the context of global climate change.

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Translated from Russian

Towards the possibilities of achieving the land degradation neutrality in the countries of the Caspian Region (on the example of Russia, Kazakhstan and Turkmenistan)

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The territories of the countries of the Caspian region are known for manifested desertification and land degradation in its various forms. The processes of land degradation and desertification are closely interrelated, and they should be considered in unity, since on the one hand, climate aridization leads to increased land degradation through a reduction in productive water resources, a decrease in soil potential, a decrease in productivity of plant communities and biological diversity; and on the other hand, a change in reflectivity of the land surface and an increase in albedo contributes to the decrease in surface temperature, increase in convection and the appearance of desertification "islands" due to aridization, supported by the 'albedo-precipitation' reverse causality.

The understanding of the need to elaborate more effective strategies aimed at responsible land management in the regions prone to desertification led to the formulation of the Target 15.3 of the Sustainable Development Goals (SDGs) of the UN for the period up to 2030 (Agenda ..., 2015): "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world". The UN Convention to Combat Desertification (UNCCD) (Cowie et al., 2016) has been identified as the "coordinator" of the SDG 15.3 achievement on a global scale on behalf of the UN. The global indicator for the monitoring has been approved and recommended for all countries: the rate of degraded lands to their total area (UNSD, 2016). Further, an agreed international definition of the LDN has been adopted: "Land Degradation Neutrality is a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2016).

Thus, with the emergence and development of the LDN concept, the "classical" paradigm of desertification takes on more formal features, changing from uncertainties like "combating desertification" or "sustainable land use" to specific indicators of achieving the LDN. Therefore, the UNCCD approved a minimum set of three main global indicators for achieving the LDN: changes in land cover, dynamics of land productivity and dynamics of soil carbon reserves. For the purpose of their further monitoring, a "baseline" is established to compare changes. To that end, for the global purposes, it is recommended to take the state of the land conditions in the period around 2000-2005 (depending on the available data).

We have analyzed the state of the lands in several regions of Russia, Kazakhstan and Turkmenistan adjacent to the Caspian Sea applying these indicators (the research method is the calculation module "Trends.Earth", developed for implementation in the Quantum-GIS system. The data set for 2001-2018 was used. The main results are presented in Tab. 1.

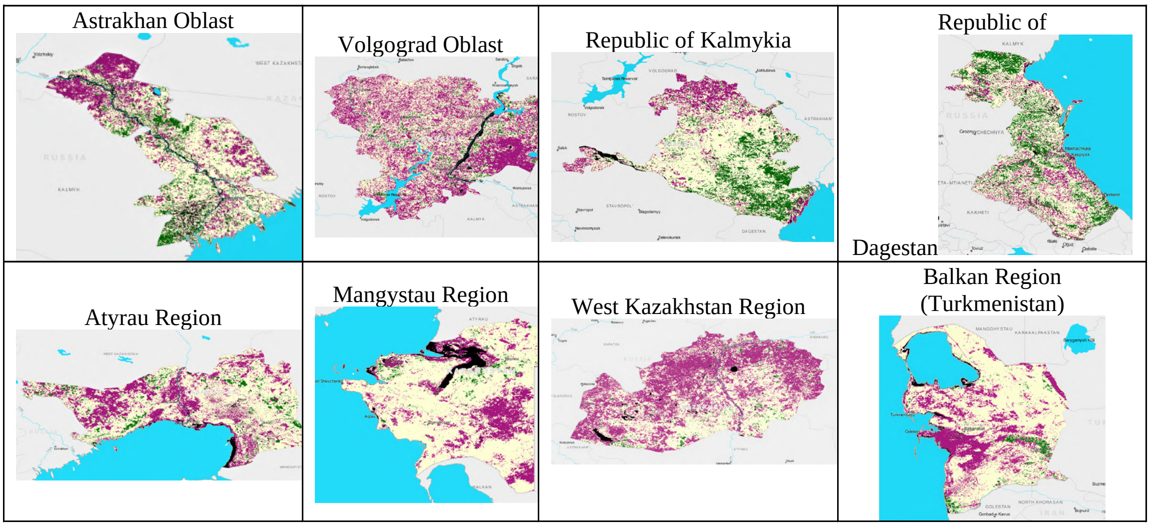
The findings show that the current situation is characterized by the deterioration in most regions. The ongoing measures aimed at reducing the risks of land degradation do not lead to the expected results, although a more in-depth analysis of individual years shows an improvement trend in the last 5-7 years, especially in the Russian part of the Caspian Sea.

Tab. 1. Comparative integral assessment of the regions of Russia, Kazakhstan and Turkmenistan according to the indicators of the Land degradation balance (the LDN index is equal to the difference between improved and degraded lands)

Region	Land degradation balance, % of the area of the region			LDN Index, %
	Meliorated lands	Stable lands	Degraded lands	
Russia				
Volgograd Oblast	4.9	52.5	42.2	-37.3
Astrakhan Oblast	12.2	62.5	23.5	-11.3
Republic of Kalmykia	18.5	65.7	15.5	3.0
Republic of Dagestan	23.0	59.6	17.1	5.9
Kazakhstan				
Atyrau region	6.0	66.6	26.2	-20.3
Mangystau Region	2.3	76.5	20.6	-18.3
West Kazakhstan region	2.2	49.9	47.7	-45.5
Turkmenistan				
Balkan region	2.8	76.0	21.0	-18.2

This assessment method allows not only to get general data on the regions, but also to identify "hot spots" at the studied territory. As can be seen from the presented cartographies (Tab. 2), in most regions there is a clear localization of "spots" of desertification, associated with certain anthropogenic influences, with prevailing of high pasture load, wind and water erosion of soils, salinization during irriga-

tion along with the technogenic effects.



Tab. 2. Cartographic schemes of “hot spots” on the territory of the studied regions

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Translated from Russian

Improving the quality of climate services through automating the marine observation network

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In recent decades, national and international efforts in the development of climate observations, research and modeling have resulted in significant progress in experimental and practical climate prediction and forecasting. The scientific understanding of climate processes, changes and variability of climatic conditions has significantly improved and has become the foundation for the formation of the Global Framework for Climate Services (GFCS) [4]. Climate services are defined by the World Meteorological Organization (WMO) as obtaining climate information, creating information (climate) products and providing them to consumers using various means of communication and presentation. However, the implementation of the GFCS requires a systematic translation of existing knowledge about climate into practical solutions, it is therefore necessary to improve methods and means of producing, storing and transmitting observational data. Observations and monitoring have to be considered for any successful implementation of the GFCS. For effective climate maintenance, observations of the established parameters should be carried out with the required quality, in the required volume, in a certain place and at a given time [5].

One of the priority directions for the development of the national climate service system of the Russian Federation – the national segment of the GFCS – is the modernization of observation networks, including a system for ensuring the quality of hydrometeorological data.

Currently, within the framework of the departmental scientific and technical program of Roshydromet, a Concept for the development of a state observation network using automated hydrometeorological systems is being developed for the Caspian Sea, which would ensure the automatic and uninterrupted receipt, collection, processing, transmission and storage of large volumes of primary data on the optimal set of hydrometeorological parameters.

Identification was carried out on the designation of devices and systems suitable for equipping the marine observation stations of Roshydromet, capable of operating without maintenance for a long time. Also, the selection was carried out according to the following main criteria: mandatory conditions – measurement of water level and temperature; autonomous operation for at least 1 year; transmission of the obtained observation data to the user's server; performance in a protected from the effects of the marine environment way.

To test characteristics and operating modes declared by the manufacturer in real conditions of the marine environment, the scheme has been developed on conducting observations on experimental observation platforms (Fig. 1). The main work on testing measurements by automatic systems in order to determine the accuracy and reliability of the data obtained is carried out in accordance with the guidance document 52.10.892-2020 [2] during the year.

Surveillance on observation platforms should be implemented in accordance with the basic principles of hydrometeorological observations set out in the guidance document 52.04.567-2003 [3]:

- continuity of observations of the state of the environment and its pollution;
- compliance with the established requirements for the collection, processing, quality control, storage and dissemination of information on the state of the environment and its pollution;
- ensuring the spatial and temporal resolution of the measurement results sufficient to determine the characteristics of hydrometeorological quantities with the accuracy required for practical purposes;
- uniform measurements and comparability of their results;
- ensuring the reliability and uniformity of the observation results and the availability of information for users.

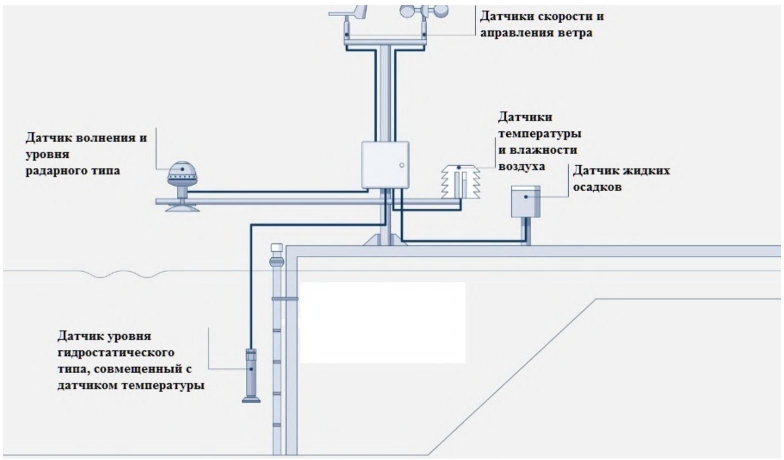

Fig. 1 – Diagram of the organization of the experimental observation platform

According to its type and purpose, the experimental observation platform is equivalent to a standard marine water level station, so the choice of its location is determined by the requirements established in the guidance document 52.10.842-2017 [1].

Automation of the observation network provides creation of a telecommunications infrastructure for high-speed transmission, processing and storage of large volumes of hydrometeorological data, specialized software for the databases building, along with interpretation, visualization and archiving of the received hydrometeorological information.

The advantage of automated platforms is the possibility of their organization not merely on the coast, but also on the islands. Creation of a network of automated posts on the Caspian Sea will expand the coverage area of the observation network, increase the accuracy and reliability of information about the current state of the marine environment in open waters, and, consequently, increase the accuracy and efficiency of developing forecasts of adverse and hazardous phenomena. Over the long term, data obtained from automatic systems will be used for the analysis and forecast of the regional climate.

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