MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESSA STATE ENVIRONMENTAL UNIVERSITY

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THE IMPACT OF CLIMATE CHANGE ON THE ECONOMIC SECTORS OF UKRAINE (MARINE ENVIRONMENTAL)

Lecture notes

Odesa
Odesa State Environmental University
2022

UDC 504.04
B26

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B 26 The impact of climate change on the economic sectors of Ukraine (Marine Environmental): Lecture notes.
Odesa : Odessa State Environmental University, 2022. 70 p.
ISBN 978-966-186-195-3

The lecture notes cover some components of environmental changes caused by climatic factors, as well as acquaintance with the current state and prospects of research of current and projected climate change in Ukraine, intended for masters of the Educational Program Oceanology and Hydrography.

Берлінський М.А., П'ятакова В.Ф.
Вплив кліматичних змін на галузі економіки України (Морське середовище): конспект лекцій. Одеса : Одеський державний екологічний університет, 2022. 70 с.

У конспекті лекцій висвітлюються окремі складові екологічних змін, спричинених кліматичними факторами, а також ознайомлення із сучасним станом та перспективами досліджень поточних та прогнозованих змін клімату в Україні, призначені для магістрів Освітньої програми «Океанологія та гідрографія».

UDC 504.04

Recommended by the Methodological Council of Odessa State Environmental University of the Ministry of Education and Science of Ukraine as a lecture notes (Minutes No.8 of 28.04.2022)

ISBN 978-966-186-195-3

CONTENT

INTRODUCTION

Over the past 50-100 years, the impact of the expansion of human activities on natural climate-forming factors has led to potentially dangerous changes in the climate system. These changes have radically affected the ocean and the Earth's atmosphere, which are inextricably linked with each other.

The time scales of changes occurring in the ocean are much larger than the time scales of changes in the atmosphere. Despite this, the impact of the ocean on climate is no less significant than the anthropogenic impact, although the ocean itself cannot be isolated from it.

There are two main types of causes of climate change – external and internal. External changes include cosmic factors (changes in the solar constant and tidal changes), changes in the optical properties of the atmosphere caused by volcanic eruptions and the greenhouse effect of anthropogenic origin. Internal ones are caused by changes within the climate system as a result of the interaction of the ocean, atmosphere, lithosphere and biota.

The textbook provides an introduction to the current state and prospects of research on current and projected climate change and related threats to sustainable development of society. The main attention is paid to the analysis of models and interpretation of observations on regional level, namely on the territory of Ukraine.

1 CLIMATE AND ITS IMPACT ON ECONOMIC ACTIVITY

1.1 Climate and its natural variability

Man has an "innate" idea of the climate due to historical experience - the climate has always directly affected human health and economic activity. There is enough many formal definitions of climate. We will not dwell on them here, because of them comparative analysis is not our business. Here is just an explanatory statement Intergovernmental Panel on Climate Change (IPCC), which is sufficient to address applied tasks (Climate Change 2001, 2001b, pp. 982-996).

Climate is usually defined as "average weather", and more strictly - as it statistical description in terms of average values and variability of the corresponding hydrometeorological values within a certain period of time - from months to millennium. According to the recommendations of the World Meteorological Organization (WMO), classical period - thirty years. As such values most often appear parameters of temperature, precipitation and wind in the near-surface layer of the atmosphere.

In the "pre-industrial" era (conditionally - until 1750), when man did not have a "technological" opportunities to significantly influence global processes, global climate formed during the interaction of external factors (mainly solar radiation) and orbital factors (the position of the Earth relative to the Sun and the orientation of the Earth 's axis relative to plane of its orbit) with the Earth's climatic system. The latter, according to the definition of the UNFCCC (The UN Framework Convention on Climate Change (Article 1) is "a set of atmosphere, hydrosphere, biosphere and geosphere and their interaction ". Interaction of the mentioned natural factors with the Earth's climate system shaped its climate.

The Earth's climate has never been constant. Even in the absence of anthropogenic influences, he markedly changed (Mokhov et al., 2005). These natural changes were also very noticeable in last 2000 years. In fig. 1 shows the temperature change at Vostok station in Antarctica (anomaly regarding the average temperature of the late twentieth century).

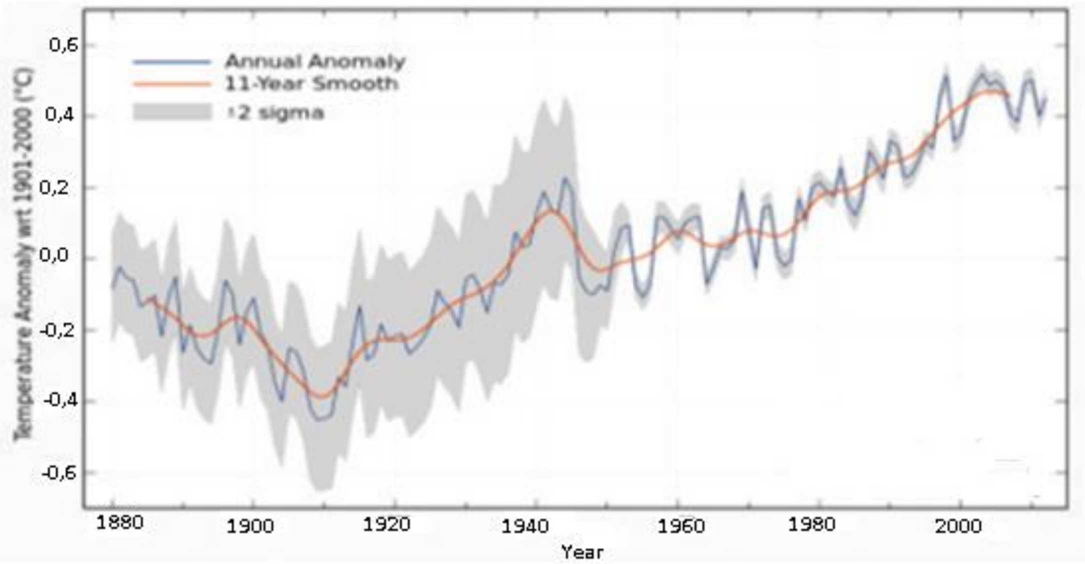

Fig. 1 – Change in global surface air temperature over the period 1880–2011 in deviations from the average for the period 1901–2000. for the ocean, including 11-year moving averages and interval

1.2 Anthropogenic influence on the global climate

The greenhouse effect, which was discovered in the works of Tyndall (Tyndall, 1861) and Arrhenius (Arrhenius, 1896), was later seriously studied by scientists in connection with the possibility its intensification due to anthropogenic greenhouse gas emissions (for example, Budiko, 1972; Budiko, Israel, 1987).

Presence of preconditions for anthropogenic global warming (strengthening of the natural greenhouse effect due to anthropogenic greenhouse gas emissions), global warming occurred (as evidenced by climate monitoring data) and its possible negative effects have heightened attention to this problem in the world scientific community, including from domestic scientific schools (Lyalko, 2010, Shestopalov, etc., 2011).

Issues of regulation of anthropogenic impact on the climate are also being intensively developed. This investigates not only the critical limits of greenhouse gas content in the atmosphere and possible programs (scenarios) to limit their emissions, but also other active effects on the global climate, in particular, the introduction of sulfate aerosols to increase the albedo atmosphere. (Israel, 2005; Crutzen, 2006; Wigley, 2006).

At the international level, the Intergovernmental Panel on Climate Change has prepared several evaluation reports on climate change, its effects and opportunities for mitigating anthropogenic impacts on the global climate.

At this time, the Fifth Evaluation Report (Climate Change 2013) has already been published - see also http://www.ipcc.ch. These reports contain a fairly complete and objective summary of the results of scientific publications (monographs, articles, reports) for the relevant period of time, as well as the results of "non-politicized synthesis" of the information obtained.

1.3 Climate change and its possible consequences: causes for concern

Any climate parameters - the average temperature or the amount of precipitation, the scatter of current values relative to these averages, the frequency of extreme values (i.e., greater than the specified upper limits or lower than the specified lower limits), temperature and precipitation trends, etc. - for this area of physical space in different periods of time may differ for natural and anthropogenic reasons.

Among the natural causes of global climate change over time, external to the Earth's climate system, are variations in the flow of solar energy entering the Earth's atmosphere and variations in the flow of solar energy reflected by the earth's surface and flowing back into space (associated with cyclic changes in the inclination of the ecliptic and differences in the values of the albedo of the earth's surface at different latitudes).

Among the anthropogenic causes of global climate change are additional climate emissions active substances - greenhouse gases (the most important of which - carbon dioxide CO2, methane CH4, nitrous oxide N2O) and some aerosols. An increase in their concentration in the atmosphere leads to change the ability of the horizontal layers of the atmosphere to transmit radiant energy on different frequencies. As a result, the energy budget specific to different changes altitudes, causing a change in the vertical temperature distribution, in particular warming or cooling in the near-surface layer of the atmosphere, as well as changes in its other parameters. Increasing the concentration of greenhouse gases in the atmosphere leads to warming; this is anthropogenic enhancement of the greenhouse effect.

With the beginning of the industrial era to the natural causes of climate change that cause it natural variability, added anthropogenic causes - anthropogenic greenhouse gas emissions gases and aerosols, as well as the change of the albedo of the earth's surface when changing land use.

Climate change is any change in climate over time due to its natural variability or human activity. This is a different definition of the IPCC

UNFCCC - UN Framework Convention on Climate Change. UNFCCC defines "climate change" as "caused directly or indirectly by human activities that change the composition of the atmosphere in globally. This change is in addition to the natural variability of the climate, observed for appropriate periods of time ".

According to IPCC estimates, by the end of the XX century the average global temperature near the surface layer increased by 0.6 °C relative to the level of the middle - end of the XIX century (Climate Change 2001, 2001a).

Climate change is also noticeable in Ukraine. So, for example, for the last 100 - 120 years the average annual surface temperature increased by approximately 0.6 ± 0.1 °C on average territory of Ukraine, and in the northern and south-eastern regions - by 1.0 ± 0.2 °C, and in southern and southwestern regions - by 0.5 ± 0.1 °C.

The general equalization of the climatic field of annual precipitation amounts was revealed. In the north-western regions of Ukraine, where the annual rainfall was quite high (650-750 mm / year), it decreased by about 10-15%, and in the south-eastern regions, where the annual rainfall was relatively low (350-450 mm / year) - increased by about 10%. An increase was detected rainfall in some months of the summer in the south-western regions, and, conversely, their decrease for these months in the southern and south-eastern regions. Also installed a sharp decrease of precipitation in the spring months, especially in May and autumn, mainly in September.

It should be noted that when talking about the climate of the XXI century and future centuries, we are in principle we cannot have exact information about him. After all, the Earth's climate is changing natural and for anthropogenic reasons, and in the near future long-term an accurate forecast of both components is impossible. If natural changes are related mainly with orbital factors and variations in the intensity of solar radiation, so there is reasons to hope for an improved understanding of their ever-anthropogenic impact the component depends on socio-economic factors. Predict them accurately for the period more than 100 years is hardly possible in principle. Therefore, for appropriate analysis involve the concept of "scenario" of the world socio-economic system.

Scenario - a plausible and often simplified description of future developments, based on a consistent and internally consistent set of assumptions about the driving force forces and basic interdependencies.

Each scenario of the world socio-economic system corresponds to its own the trajectory of global anthropogenic greenhouse gas emissions into the atmosphere and, as a consequence, - specific nature of anthropogenic disturbance of natural change of their concentrations in atmosphere and climate of the Earth.

Impossibility of long-term forecast (for 100 years and more) socio-economic development and, as a consequence, the trajectories of emissions of climatically active substances led to the introduction in the scientific life of the term "prospective assessment" or "projection" (in English literature - projection). In essence, this is a conditional forecast, that is a forecast under certain conditions, when a certain scenario of future anthropogenic impact on the climate system, within which is a change in the studied value.

However, climate is a physical phenomenon. Therefore, its changes in themselves cannot be favorable, unfavorable, dangerous, etc. These and similar categories reflect assessment of climate change by man, based on his values, that is are valuable judgments. In addition, such perceptions are usually subjective and differ for different regions, countries and population groups. They depend in particular on the level of economic development, way of life and cultural traditions.

What are the reasons for the global community's concern about climate change? In Fig.2 historical data on changes in the concentration of carbon dioxide in the pre - industrial era for the last 400,000 years according to the station East (Antarctica) and its changes from 1850 to 2000 according to the station Mauna Loa (Hawaii). Because CO2 is a gas that mixes well (ie its long-term levels are approximately the same everywhere), these two series of data can be compared.

Figure 2a clearly shows that the concentration fluctuated in the range of 180-300 million^{-1} in the latter 400,000 years before the onset of significant anthropogenic emissions, and since the early 1900s, on the contrary, has always been greater than 300 million^{-1}, growing by the end of the XX century to about 370 million^{-1} - see fig.2b. Fluctuations in concentration, shown in Fig.2a, are natural. The original the leading factor in these fluctuations is the temperature, the cyclic fluctuations of which were associated with orbital factors. An increase in temperature causes a shift in the balance between atmospheric and oceanic CO2 in favor of atmospheric. The reason for the change in CO2 concentration, shown in Fig.2 b, is completely different. This is a consequence of anthropogenic emissions, during which the total amount of

CO_2 circulating in the climate system increases. Due to this increasing the greenhouse effect leads to warming, which is superimposed on natural fluctuation. If we keep in mind the last 400,000 years, the Earth's climate is now in warm phase. That is why additional anthropogenic warming is perceived as "potentially dangerous ".

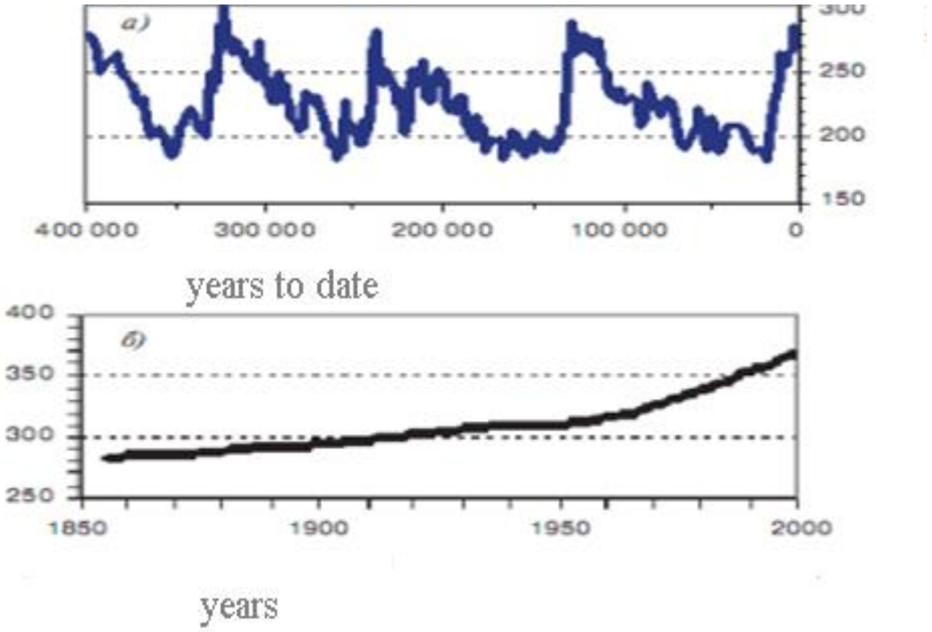

Fig. 2 – CO_2 concentration, mln[1]: a) Historical data from Vostok station, Antarctica (Barnola et al., 2003); b) average annual values in the subsurface layer at the station Mauna Loa: for 1959-2000 - data of instrumental measurements, and by 1959 - correlation reconstruction for the results of measurements of the concentration in the ice cores at the Low Dome station according to the data (Etheridge et al., 1998) (Semenov SM et al., 2008)

IPCC in its Synthesis Report to the Third Assessment Report (Climate Change 2001, 2001, p. 68) lists five main reasons for concern about climate change (these five categories of IPCC have been retained in the following evaluation reports):

- unique systems and systems that are in a threatening situation;
- extreme weather events;
- distribution of influences;
- global aggregate impacts;
- large-scale violations.

Climate change in the 21st century and in the longer term is expected preservation and (or) increase of the current volume of anthropogenic greenhouse gas emissions in atmosphere, can lead to unacceptable risks and dangers associated with objects or processes of these five categories.

1.4 System responses to climate change: sensitivity, adaptability, vulnerability and risk

This section explains a number of basic concepts and terms related to the impact on climate change on natural systems and renewable resources.

Sensitivity is the degree to which the system can be compromised (favorable or unfavorable way) influence associated with climate change. The effect can be direct (for example, a change in yield agricultural plants due to changes in the average or range values of temperature, or its variability) or indirect (for example, change damage due to an increase in the frequency of floods due to rising sea levels).

Adaptability - the ability of systems to adapt to change climate (including its variability and extreme phenomena), leading to reduction of potential damage, use of favorable opportunities or to overcome the consequences.

In the literature there are the following terms associated with adaptation:

- preventive adaptations (those that occur before the impact begins to manifest itself);
- reactive adaptations (those that occur after the effect was detected);
- autonomous adaptations (those that are not the result of conscious appropriate action of people, but only natural response systems);
- planned adaptations (the result of people taking conscious appropriate measures);
- shares of adaptation (those that use at the individual level and respond private purposes);
- social adaptations (those that are used at the level of society and correspond to public ones goals).

The vulnerability characterizes the degree to which the system is sensitive to climate change and not able to cope with the adverse effects of changing climate (including it variability and extreme phenomena). The vulnerability of the system depends on the type, magnitude and the rate of climate change in which the system, its sensitivity and adaptability.

The relationship between the categories of sensitivity, adaptability and vulnerability is possible expressed by such a symbolic formula

$$\text{Vulnerability} = \frac{\text{sensibility}}{adaptability}$$

The vulnerability is greater the greater the sensibility at a given adaptability, and increasing the latter at a given sensibility reduces the vulnerability.

Risk is a category that has always been used in the analysis of economic and political decisions in the following sense: if the probabilities (fXn) of events X1, X2, ..., X N are known (complete system of events - the sum of the probabilities is equal to 1), as well as monetary estimates of damage D (Xn) that occur when each event (negative damage values correspond to a win!), the risk R (Xn) for each event X is measured by the product R (Xn) = D (Xn) f (X). This approach to risk assessment is risk assessment (Morgan and Henrion, 1990) - has long gone beyond the economy and widely used in applied sections of other sciences, including climatology and ecology. At this loss is rarely measured in monetary units, and more often - in kind or conditional. Fig.3 illustrates the definition of risk for an example of rising water in a river: the loss (in conventional units) increases linearly, but the probabilities of different levels are such that the risk maximum when the water rises by 4 m.

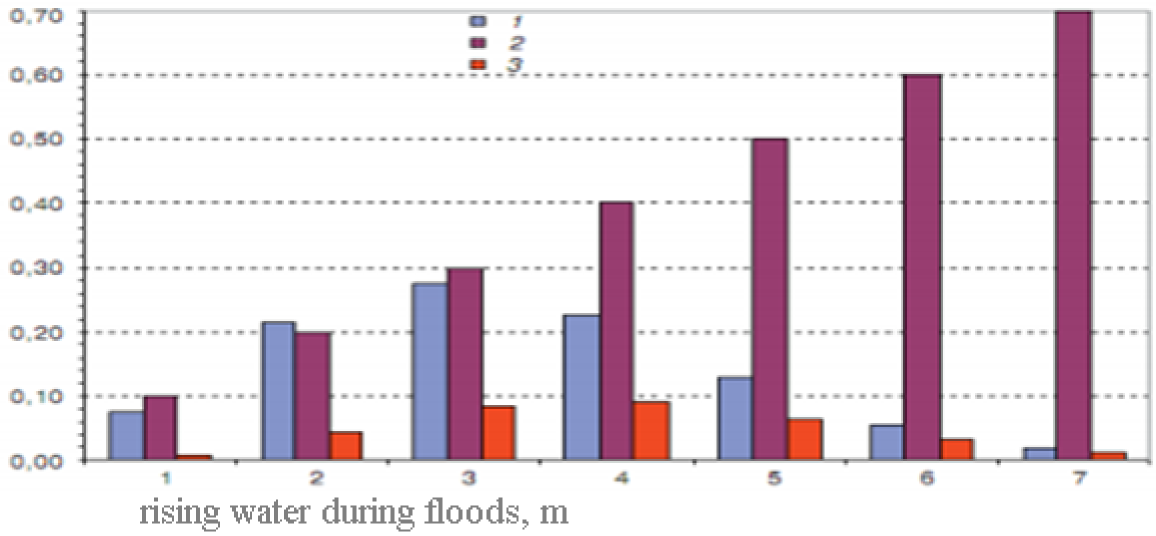

Fig. 3 –Illustration of the concepts of probability (1) of adverse event, damage (2) and risk (3)

Often only two results are considered in the simplest case: X1 is undesirable the event did not take place and X2 did. In the first case D (X1) = 0, and in the second f (X2) - the probability of an undesirable event, D (X2) -

the resulting damage, and R (X2) = D (X2) · f (X2) - the risk associated with the occurrence of an adverse event. If the damage is measured in conventional units, then, if we take as a unit the damage that occurs during the implementation of an undesirable event, the numerical value of risk in this example with two results coincides with the probability this unwanted event.

The probability turn can be represented as the product of the probability the occurrence of an adverse event H and the probability P of its occurrence on the recipient for conditions that an event (such as a flood) has occurred. The latter can be explained as follows drawing (Fig. 4).

For the case of floods and floods of the river H is the probability of this event, and P is the share of the population, living in this area on flooded lands.

The values of both H and P may depend on adaptation measures. Yes, in the example of the flood

H to some extent depends on the condition of local protective hydraulic structures, and P – from the degree of individual protection of people, in particular from the choice of site for construction housing.

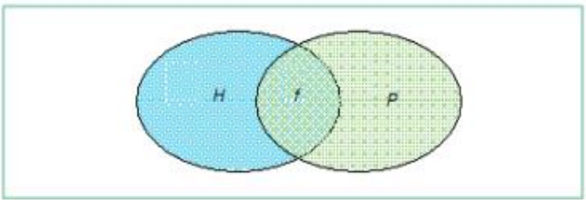

Fig. 4 –Damage occurs (probability f) when an undesirable event occurred (probability H) and the recipient was exposed (probability P): f = HP

The use of monetary expression of loss in risk assessments is inappropriate in cases where when it comes to the loss of human lives, the damage done by the unique natural systems and global climate-forming systems.

It is methodically expedient to distinguish between primary and secondary risks. For example, as a result persistent summer drought poses a primary risk to crop yields, as well as the secondary risk associated with fire hazards.

It should be noted that the concept of risk is not yet fully established in applied research and sometimes used in different senses.

The basic concept of maximum allowable levels of climate change for the Earth's biosphere was put forward and developed in the work (Israel, 1979). Performing applied assessments of the consequences of change climate in terms of their acceptability was proposed to be based on the reactions of key vulnerable elements (key vulnerabilities) of climatic and socio-economic systems (Patwardhan et al., 2003). Such elements have the following properties: high sensitivity to climate change, limited adaptability and importance to the decision-making process areas of regulation of anthropogenic impact on climate.

Climate change is affecting everyone aspects of human life, including his health, economic activity and quality environment - for all that constitutes human well-being (HWB – Human Well Being). Because the implementation of assessments requires extensive research and networking monitoring, which requires appropriate resources, raises the question of the priority of those systems for which such assessments will be performed. If globally it should to pay attention first of all to the consequences of climate change for the climate system itself - ocean currents, polar ice sheets, global biogeochemical cycles, then in the analysis at the national level, this is only a certain, albeit significant, part of the problem.

Here the priorities are shifted closer to the aspects of human well-being, to the tasks of sustainability development of countries. In this regard, it is advisable to focus more at the national level note that they are widely recognized as important in the "measurable" components of HWB. They are WEHAB - Water, Energy, Health, Agriculture, Biodiversity, i.e. water, energy, health (human), agriculture and biodiversity. The WEHAB concept was presented at World Summit on Sustainable Development in Johannesburg in 2002, where it received a wide support.

A set of specific ones was further selected to consider and assess climatogenic changes natural and socio-economic systems - components of WEHAB, which have already taken place in XX century or able to be exposed in the XXI century to the significant effects of climate change. When choosing as criteria the realized or potential possibility of climatogenic was used changes to these systems affect the following:

1) hydro meteorological safety;
2) living conditions and health of the population;
3) economic infrastructure;
4) resources;
5) functioning and biodiversity of natural ecosystems;
6) climate-forming and biosphere functions of natural systems.

If criteria 1-5 are directly associated with WEHAB components, then criterion 6 contributes to the identification of significant feedback - for example: climate change that has occurred or able to take place in the country, able to influence the global climate system Earth (for example, a change in the albedo of the earth's surface due to a shift in the boundaries of plant zones or change in the flow of carbon dioxide and methane from areas where change occurs or is expected thermal regime of permafrost).

Functioning of technical economic objects (technical constructions, transport and etc.) can be supported by man in a changing climate, even at a significant costs. However, we will not be able to completely eliminate even at significant costs opportunities for climate-dependent infectious diseases, to guarantee high yields agriculture and the abundance of water resources, easy management conditions coastal areas of the seas. In these processes there are not absolutely controlled by the person physical and biological components and therefore adaptability is assessed as average. Regarding natural systems, the typically ecological have an average adaptability (there are processes that compensate for undesirable consequences - the replacement of some species by others in the conditions changing climate, for example), and physical systems - low.

1.5 Questions for self-control

1. Define the terms "climate", "climate change", "scenario"
2. Identify the natural and anthropogenic causes of climate change.
3. What means to reduce the anthropogenic load on the Earth's climate system do you consider appropriate?
4. How has the concentration of greenhouse gases in the atmosphere changed in recent years?

2 THE ROLE OF THE OCEAN IN CLIMAT CHANGE

The problem of climate change is one of the most pressing global problems. Changes climate affect the development of any civilization. At the present stage of development civilization conditions for the functioning of the climate system are very different from the conditions previous geological epochs. It is the last 50 - 100 years due to expansion human economic activity on natural climatic factors is superimposed anthropogenic impact, which leads to potentially dangerous changes in climate system. In light of the above, the identification and identification of such factors that determine observed evolution of the climate system, important not only for research in some narrow areas of geophysical science, but also for many practical applications.

The ocean plays a key role in shaping climate change. No wonder that during the last 25-30 years several of the largest oceanographic ones have been realized programs to study the role of the ocean in climate change.

The term "climate" at this time is usually understood as averaged over time 30 years of characteristics of the ocean-atmosphere-lithosphere- cryosphere -biosphere system. Conditionally there are two main types of causes of climate change - external and internal. To external put space factors (change of solar constant and tidal changes), changes optical properties of the atmosphere caused by volcanic eruptions, and greenhouse effect of anthropogenic origin. Internal causes are due to changes inside the climatic system itself as a result of the interaction of the ocean, atmosphere, lithosphere and biota.

On a scale of several years to several decades, the change of the solar constant is (according to satellite data) about 0.1% (Hoffert et al., 1999) and, apparently, little affects climatic variations. In the meteorological literature is quite common assertions about the direct impact of solar activity on atmospheric processes, resulting in the terrestrial spectra there are supposedly distinct components with periods of 5.5, 11 and 22 years. However generalized data analysis conducted by A.S. Monin (1999), shows that the 11-year cycle and its components are recorded only in a small (not more than 20%) number of cases. Most often this is due to the inaccuracy of the spectral density estimate when compared small sample size.

The impact of tidal fluctuations on climate change, according to some experts, is enough great (Sidorenkov, 2004). However, most experts do not share this view (Monin, 1999).

Eruptions of large volcanoes (such as Krakatoa, Pinatubo, El Ichon) lead to decrease in global temperature by 0.1 - 0.2 ° C for about 1 year (Makhotkina and et al., 2005). Thus, they are quite effective in influencing the climate system. Such large eruptions occur infrequently (the time interval between them is from ten to several tens - a hundred years). Therefore, their impact on interannual climate change systems is usually small.

Anthropogenic due to the greenhouse effect, most pronounced in the industrial period, especially during the last 150 years, is estimated at 0.6 °C for 100 years (for the latest data - at 0.74 °C / 100 years) on average throughout the globe. However convincing evidence of its impact on climate change internally - ten years scales have not yet been obtained. Some researchers, for example (Corti et al., 1999), believe that such an impact can be quite large, others doubt its effectiveness. Exactly therefore it is necessary to consider internal mechanisms of climatic variability, and first of all interaction of the ocean, atmosphere and lithosphere.

Thermal effects of the ocean on the atmosphere (especially due to high thermal inertia ocean and the realization of latent heat during evaporation) transform the circulation atmosphere, and it, in turn, controls the circulation of the ocean. The brightest an example of related oscillations in the ocean-atmosphere system is the El Niño phenomenon: weakening trade winds in the tropical Pacific lead to a weakening of upwelling and formation of large-scale anomalies of temperature fields and zonal currents in equatorial zone of the Pacific Ocean. This determines the global atmospheric response and accompanied by climate change in different regions of the globe.

Decrease (increase) of planetary albedo (A) directly causes increase (decrease) of the assimilated amount of solar heat Q (1 - A) and as a result - warming (cooling) of the climate. At the same time positive feedback is realized of the following type: at warming (cooling) the area of a snow and ice cover and the corresponding albedo decreases (increases), which leads to an increase in the primary anomalies until negative feedback is activated. One of them is manifested in increase (decrease) of evaporation, cloudiness and albedo of the atmosphere with growth (fall) lower troposphere temperature, which reduces the initial anomaly.

In addition to the above mechanisms, it plays an important role in low-frequency climate fluctuations can play a greenhouse effect of natural origin. Indeed, it is created in as a result of the presence in the atmosphere of gases that absorb long-wave heat radiation from the Earth's surface, but transmit short-wave solar radiation. To these include water vapor and carbon dioxide, as well as methane, nitrous oxide (1), CFCs, ozone, ammonia, etc. The lower atmosphere is heated and the upper is cooled. IN this time due to the greenhouse effect is the average global surface temperature air on Earth is about 15 °C - 2 °C higher than it would be (at a fixed albedo) radiant equilibrium temperature without greenhouse gases (17 °C). Only close 1/4 of the greenhouse effect is due to the presence of CO2. The main greenhouse gas on Earth there is water vapor, the concentration of which in the atmosphere is determined by the rate of evaporation from the surface ehe world's oceans and the amount of precipitation that falls, as well as clouds. However, (in as a result of human economic activity) increasing emissions of carbon dioxide causes the greenhouse effect of anthropogenic origin. From 1980 to 2005 the average the concentration of CO2 in the Earth's atmosphere increased from 0.033 to 0,037%.

Most published estimates of changes in temperature, cloudiness, humidity, wind speed and other hydro meteorological characteristics in the modern climatic era indicates significant influence of anthropogenic factors on the processes occurring in the global climate system, and regional climate change (IPCC, 1996). Appropriate practical recommendations for limiting the level of thermal pollution of the atmosphere are formulated in Kyoto Protocol, adopted in December 1997, which entered into force in February 2005 (Kyoto Protocol, 1997). At the same time, the question of relative remains unclear the role of anthropogenic and natural climate change. In other words, it is unclear how much the observed climatic tendencies are caused by anthropogenic influence, but are not (at least in part) by the superposition of natural changes in the climate system of different spatio-temporal scales. Some authors point out that existing observations insufficient for reliable isolation of anthropogenic changes against the background of natural variability climatic system (Polonsky, 2001; Kondratiev, 2002). Admittedly, from one on the one hand, the problem of global and regional climate change is very complex, and on the other hand, it affects interests of various social, financial-industrial and political structures. So get an unambiguous answer to the question of the relative role of anthropogenic and natural influences on the climate system and their probable consequences at this time virtually impossible (Schneider, 1998; Science, 2005).

The problem of climate change with characteristic time scales is especially important from a year to several decades, associated with large-scale ocean interaction and atmospheres. It is most likely that ocean processes are responsible for generation and / or maintenance of low-frequency oscillations in the climate system at the specified time scales.

It is known (Zilitenkevich et al., 1978; Polonsky, 2001) that the ocean, in principle, affects climate as follows:

1. Relatively slowly heats up and cools down because of much more heat capacity in comparison with the atmosphere, damping climatic contrasts and reducing the amplitude of seasonal fluctuations of hydro meteorological parameters.

2. Serves as the main source of steam for the atmosphere, regulating cloudiness and radiation balance of the Earth's surface.

3. Provides at least half of the total meridional heat transfer (MPT) in ocean-atmosphere system at low latitudes, thus reducing interlatitude climatic contrasts and continental climate.

4. Imposes on the climate system natural frequencies due to the typical time baroque adaptation of large-scale oceanic and global rotations thermohaline circulation to changing atmospheric conditions.

Ocean parameters vary over a wide range of time scales (from seconds to many millennia) as a result of both internal variability and under the action of forces that force them to change. One of the main physical regulatory mechanisms the most interesting from a practical point of view and climatically significant fluctuations in the ocean with typical periods from several months to decades, there are advective processes in the active layer ocean (100-200 m thick) and the main thermocline (1-2 km thick). No less important changes in the rate of formation of deep North Atlantic waters.

The exceptional importance of the problem of the impact of oceanic variability on the climate system confirms the huge number of international programs and projects in its various aspects, and as well as numerous seminars and conferences held around the world. The earliest of they were devoted to the substantiation of the observation strategy and the first results, obtained under the international programs CUTS (1980-1990) and TOGA (1985-1995). The WOCE experiment (1990-1997), being a natural development of the CUTS program, culminated in two exceptionally fruitful conferences held in Canada and the United States and stimulated the study of climatically significant large- and mesoscale oceanic processes. The first results summarizing decades of research from the program CLIVAR (1995-2010), discussed in detail in 2004 in Baltimore (USA). Development Global Observatory on the Role of the Ocean in

Climate Change (GOOS) significantly increased the number of experts involved in the discussion of this problem was clearly demonstrated at an international forum in France (San Rafael, 1999), which justified the use of ARGO technology as a basic element GOOS. The initiative of American experts on creation turned out to be extremely fruitful working group on the study of 10-year climate change (DECVAR), which regularly going (since the late 1990s). A significant (if not most) part of the participants these discussions are made by experts in the field of ocean research. Here named only the most representative meeting of experts who played a major role in formation of modern ideas about the subject discussed in this course. However, they demonstrate the growing interest of the world scientific community in this subject.

At this time, a comprehensive study of the internal variability of the oceans is necessary for achieving the following goals:

- Scientifically sound decision-making on further measures control of global greenhouse gas emissions;
- Clarification of forecasts of El Niño events and other quasi-periodic fluctuations in ocean-atmosphere system;
- Assessments of 10-year climate change trends and their forecast;
- Estimates of the probability of thermohaline catastrophe development in modern climate epoch taking into account the greenhouse effect of anthropogenic origin.

2.1 Questions for self-control

1. How does the ocean affect the Earth's climate system?
2. What role does the general circulation of the ocean play in the balance of the climate system?
3. What are the priorities for clarifying the role of the ocean in climate change?
4. What ocean parameters have changed in recent years?

3 OBSERVED CHANGES IN THE CLIMATE SYSTEM

Observations of the climate system are based on direct measurements and remote sounding from satellites and other platforms. Observation of temperature and other variables on a global scale began in the mid-nineteenth century with the advent of the era of instrumental methods, and since 1950 have become more available comprehensive and diverse series of observations. Paleoclimatic reconstructions are prolonged some series for periods from hundreds to millions of years ago. Together, they give comprehensive view of variability and long-term changes in the atmosphere, ocean, cryosphere and on the land surface.

The data presented in this lecture are obtained on the site (http://climate2013.org/images/report/WG1AR5_SPM_brochure_ru.pdf) International group on Climate Change (IPCC) in the 2013 Synthesis Report.

3.1 Atmosphere

Each of the last three decades has been characterized by a higher one temperature near the Earth's surface compared to any previous one decade since 1850 (see Fig. 5). In the Northern Hemisphere 1983-2012 were probably the warmest 30-year period in the last 1,400 years.

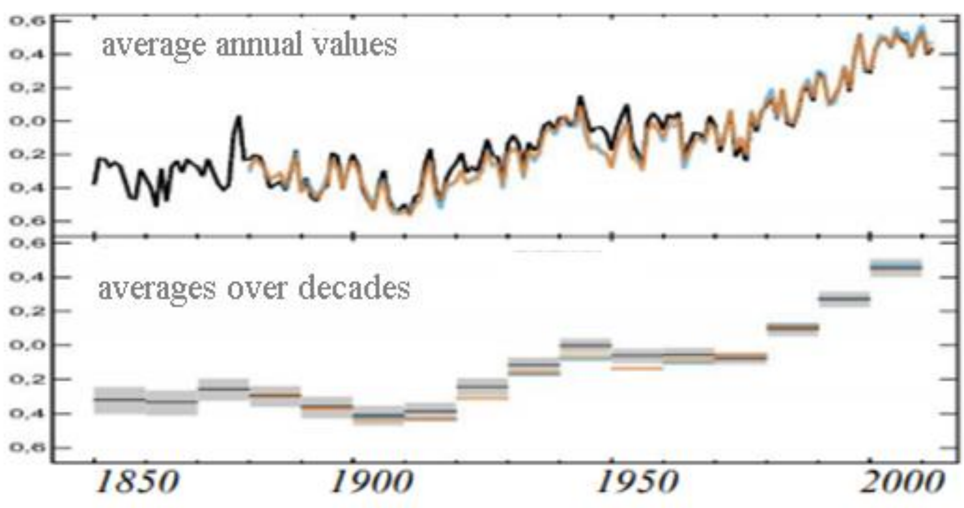

Fig.5 – Observed in the period 1850-2012, the average global total anomaly land surface and ocean surface temperatures, (Shestopalov et al. 2011)

Globally averaged aggregate data on land and ocean surface temperatures, calculated on the basis of a linear trend, indicate a warming of 0.85 [0.65-

1.06]°C by period 1880-2012, for which there are numerous, independently obtained, data sets. General increase in the average for the period 2003-2012 in comparison with 1850-1900 is 0.78 [0.72-0.85] °C, as evidenced by one, the longest series of data.

During the longest period for which regional trends are calculated quite adequate (1901-2012), warming was observed almost all over the world (see Fig. 6).

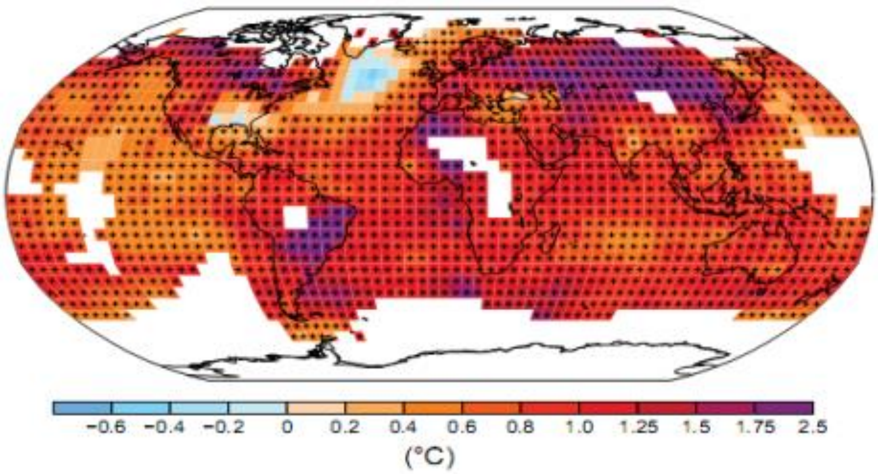

Fig. 6 –The observed change in surface temperature in the period 1901-2012

In addition to a clear increase over several decades, the average global surface the temperature shows significant ten-year and inter-annual variability (see Fig. 5). Due to natural climate variability, trends are calculated on the basis of short series observations, largely depend on the start and end dates of the period and in general do not reflect long-term climate trends. One example is the fact that the rate of warming over the last 15 years (1998-2012; 0.05 [from -0.05 to 0.15]° C for a decade), which begins with the powerful El Niño phenomenon, below rates calculated from 1951 (1951-2012; 0.12 [0.08-0.14]°C for the decade).

Reconstructions of surface temperature values on a continental scale show with a high degree of probability the presence of decades covering many periods during the medieval climatic anomaly (950-1250 gg.), which were in some regions as warm as in the late twentieth century. These are regionally warm periods were not as consistent in different regions as in warming at the end of the twentieth century.

It is almost true that on a global scale for the period from the middle in the twentieth century, the troposphere warmed. More complete observations allow greater than anywhere else, the degree of probability in estimating temperature changes troposphere in extratropical zone of the Northern Hemisphere. There is an average degree of probability regarding the pace warming and its vertical structure in the extratropical troposphere of the North hemispheres, and low probability - in other areas.

The degree of probability regarding the change in precipitation, averaged over all areas land on a global scale since 1901, is low for the period up to 1951 and medium – for next period. On average, in the middle latitudes in the Northern Hemisphere, the number precipitation has increased since 1901 (average probability to 1951 and high degree - after). For other latitudes long-term positive and are averaged over the area negative trends are characterized by a low degree of probability (see Fig.7).

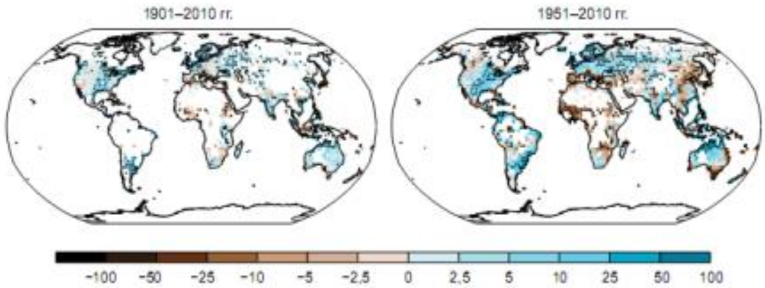

Fig.7 – Observed changes in the annual amount of precipitation over land 1901-2010

Changes in many extreme meteorological and climatic phenomena observed since about 1950. It is likely that on a global scale the number of cold days and nights decreased, and the number of warm days and nights increased. It is likely that the frequency of heat waves has increased over much of Europe, Asia and Australia. Probably, there are more areas of land where it has increased the number of cases of heavy rainfall than the areas where the number of such cases decreased. The frequency and intensity of heavy rainfall is likely to have increased North America and Europe. On other continents, the degree of probability of change that concerning the phenomena of heavy precipitations, at best, average.

3.2 Ocean

Rising ocean temperatures are a major contributing factor increasing the energy contained in the climate system; on his share accounted for more than 90% of the energy accumulated from 1971 to 2010 (high degree of probability). It is practically determined that the temperature of the upper layer ocean (0-700 m) increased in the period from 1971 to 2010 (see Fig.8), and, probably increased from the 1870s to 1971.

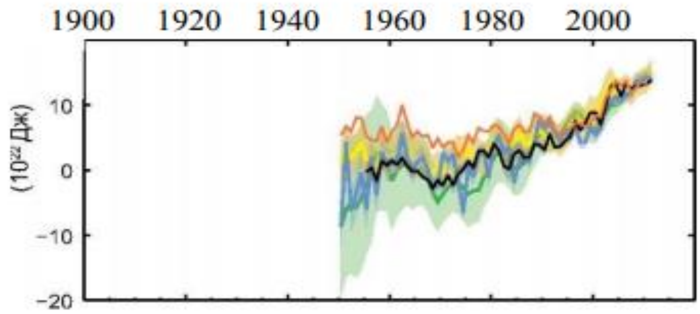

Fig. 8 –Change in the average heat capacity of the upper layer of the oceans

Globally, the rise in ocean temperature was the most significant nearby surface, the temperature in the upper 75 m increased by 0.11 [0,09 - 0,13]°C decades in the period 1971-2010.

It is probable that from 1957 to 2009 there was an increase in ocean temperature by depth from 700 to 2,000 m. There are enough observational data for the period 1992-2005 for global estimate of ocean temperature changes below 2,000 m. Probably not during this period there were no significant temperature trends at depths from 2,000 to 3,000 m.

It is likely that during this period the ocean temperature rose to a depth of 3,000 m to its bottom, with the largest increase in temperature was observed in the South the ocean.

More than 60% of the net increase in energy in the climate system is observed in the upper layer of the ocean (0-700 m) during the 40-year period from 1971 to 2010, which characterized by a relatively large number of observations, and about 30% - on depth of more than 700 m. The growth of heat in the upper ocean during this period, estimated on the basis of a linear trend, is probably 17 [15-19] x 10 22 J (see Fig. 8).

It is relatively probable that the heat capacity of the ocean at a depth of 0-700 m increased more slowly in 2003-2010, than in 1993-2002 (see Fig.8). Heat absorption by the ocean at a depth of 700-2000 m, where the year-on-year variability is less significant, lasted probably continuously from 1993 to 2009.

It is likely that in regions with high salinity, where there is active evaporation, water became even more salty, while in regions with low salinity, where heavy rainfall falls, it became even fresher after the 1950s. These are regional trends in changes in the salinity of the ocean are indirect evidence of changes in evaporation and precipitation over the oceans (medium probability).

According to decades of observations across the Atlantic meridian circulation (AMC) and longer observations of its individual components, c AMC significant trend is not detected.

3.3 Cryosphere

For the past two decades, the Greenland and Antarctic glaciers covers lost weight, glaciers continued to shrink almost in worldwide, the area of sea ice in the Arctic and spring snow cover in the Northern Hemisphere continued to decline (high degree probability) (see Fig.9).

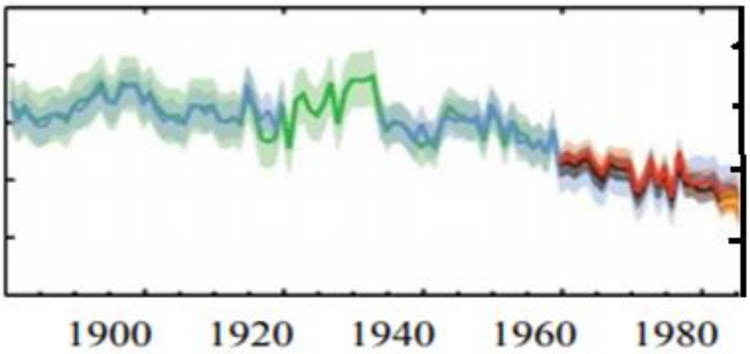

Fig. 9 –The area of sea ice in the summer in the Arctic

The average rate of glacier shrinkage worldwide, except glaciers on the periphery of the ice sheets, was probably 226 [91-361] GtRik-1 for the period 1971-2009, and, presumably, 275 [140-410] Gt-Year-1 for the period 1993-2009.

The average rate of reduction of the ice mass of the Greenland ice sheet, quite likely increased significantly from 34 [-6 to 74] Gt-Year-1 for the period 1992-2001 years to 215 [157-274] Gt-Year-1 for the period 2002-2011.

The average rate of reduction of the ice mass of the Antarctic ice sheet increased, probably from 30 [from -37 to 97] Gt-Year-1 in 1992-2001 to 147 [72-221] Gt-Year-1 in 2002-2011. With a fairly high degree of probability, these losses occur mainly in the northern part of the Antarctic Peninsula and in the sea sector Amundsen in West Antarctica.

The average annual value of the area of Arctic sea ice decreased during 1979-2012 at a rate that is likely to be in the range of 3.5-4.1% decade (range

0.45-0.51 million km2 for decades), and the summer minimum area Arctic sea ice is likely to have decreased by 9.4-13.6% decade (range 0.73-1.07 million km2 for decades) (perennial sea ice).

The average reduction in the area of Arctic sea ice over ten years was the fastest summer (high probability); the flow of ice was reduced in all seasons and in each subsequent decade since 1979 (high degree probability) (see Fig.9). According to updated data, there is a medium probability that the Arctic ice cover has shrunk over the past three decades. Summer sea ice was unprecedented, and sea surface temperatures were abnormally high for at least the last 1,450 years.

It is quite probable that from 1979 to 2012 the average annual value of the Antarctic area sea ice increased at a rate of 1.2 to 1.8% over the decade (within 0.13-0.20 million km2 for decades). There is a high degree of probability that they exist significant regional differences in these average annual rates, with some in regions this area increases, and in others it decreases.

Numerous scientific data indicate a fairly significant warming in the Arctic since the middle of the twentieth century.

3.4 Sea level

The rate of sea level rise since the middle of the 19th century has exceeded the average rates for the previous two millennia (high probability). For the period 1901-2010 the average global sea level rose by 0.19 [0.17-0.21] m (see Fig. 10). Indirect data and sea level measurements indicate a transition in the late nineteenth - early twentieth century from the relatively low average rate of increase that observed in the last two millennia, to higher (high level probability). It is likely that the rate of increase of the average global sea level continued to increase since the early twentieth century. It is likely that the average the rate of increase of the global average sea level was 1.7 [1.5 1.9] mm-year-1 in 1901-2010, 2.0 [1.7-2.3] mm/year in 1971-2010 and 3.2 [2.8-3.6] mm/year in 1993-2010. Data from tide gauges and satellite altimeters confirm more high rates of increase in the last period. It is likely that similar high rates observed in 1920-1950.

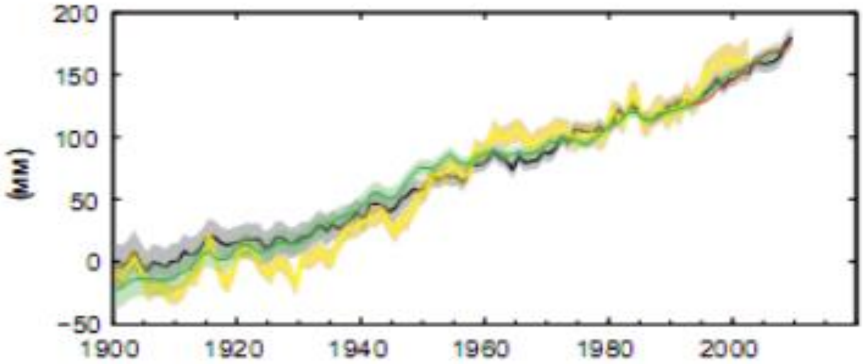

Fig. 10 – Change in the average global sea level

Since the early 1970s, the mass of glaciers has been shrinking and the ocean has been expanding thermally the results of warming, taken together, explain almost 75% of the observed rising average global sea level (high probability). Rising average global sea level during 1993-2010 with a high degree of probability due to a set of observed factors: thermal expansion of the ocean as a result of warming (1.1 [0.8-1.4] mm/year), changes in glaciers (0.76 [0.39-1.13] mm/year), the ice sheet of Greenland (0,33 [0,25-0,41] mm/year), Antarctic ice sheet (0.27 [0.16-0.38] mm/year), land water reserves (0.38 [0,26-0.49] mm/year). The total value of the contribution of these factors is 2.8 [2,3-3,4] mm/year.

There is a fairly high degree of probability as to what is maximum the value of the average global sea level in the last interglacial period (from 129,000 to 116,000 years ago) for several thousand years was at least 5 m higher than today, and with a high degree of probability it is exceeded the current level by no more than 10 m. In the last interglacial Greenland's ice sheet period probably contributed to the rise World Ocean at 1.4-4.3 m, with an additional increase with the average the degree of probability contributed to the ice sheet of Antarctica. This is a change in sea level occurred against the background of various influences of fluctuations in the orbital characteristics of the Earth and beyond due to the fact that the surface temperature at high latitudes is averaged over several thousand years, was at least 2 °C above its current value (a high degree probability).

3.5 Carbon and other biogeochemical cycles (observed)

Concentrations of carbon dioxide, methane and nitrogen oxides in the atmosphere increased to levels unprecedented for at least the last 800,000 years. Carbon dioxide concentrations increased by 40% from pre-industrial levels period, primarily due to emissions from the combustion of fossil fuels, and, secondly, due to net emissions as a result of changes in land use. On absorption by the ocean accounts for about 30% of anthropogenic emissions of dioxide carbon, which leads to acidification of the ocean (see Fig.11).

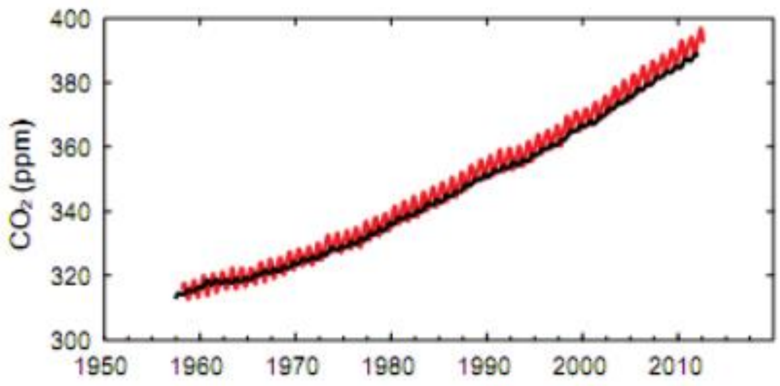

Fig. 11 –The content of CO2 in the atmosphere. Atmospheric concentration of carbon dioxide (CO2) according to the Mauna Loa Observatory (19 ° 32 'N, 155 ° 34' W - red) and South Pole (89 ° 59'S, 24 ° 48'W - Black) since 1958

Atmospheric concentrations of greenhouse gases such as carbon dioxide (CO2), methane (CH4) and nitric oxide (N2O), increased since 1750 as a result of human activity. In 2011, the concentrations of these greenhouse gases were 391 ppm4, 1803 ppb and 324 ppb and exceeded pre-industrial levels by about 40, 150 and 20%, respectively.

At this time, the concentrations of CO2, CH4 and N2O significantly exceed the highest concentrations found in ice cores over the past 800,000 years. Average growth rates atmospheric concentrations over the last century are, with a fairly high degree probabilities unprecedented over the last 22,000 years.

Net annual CO2 emissions as a result of changes in anthropogenic land use amounted to on average 0.9 [0.1-1.7] GtU/Year in the period 2002-2011 (average degree probability).

From 1750 to 2011 as a result of burning fossil fuels and cement production 375 [345-405] gigatons of carbon (GtC) were released into the atmosphere, with emissions associated with deforestation and other land use changes are estimated at 180 [100-260] GtC. Thus, the total anthropogenic emission was 555 [470-640] GtC.

From this total anthropogenic CO2 emissions 240 [230-250] GtU is accumulated in the atmosphere, 155 [125-185] GtC absorbed by the ocean and 160 [70-250] GtC accumulated in natural land ecosystems (ie total residual soil uptake).

A quantitative indicator of ocean acidification is a decrease in pH6. Since the beginning of industrial era, the pH of the surface layer of the ocean decreased by 0.1 (high probability), which corresponds to an increase in the concentration of hydrogen ions by 26% (see Fig.12).

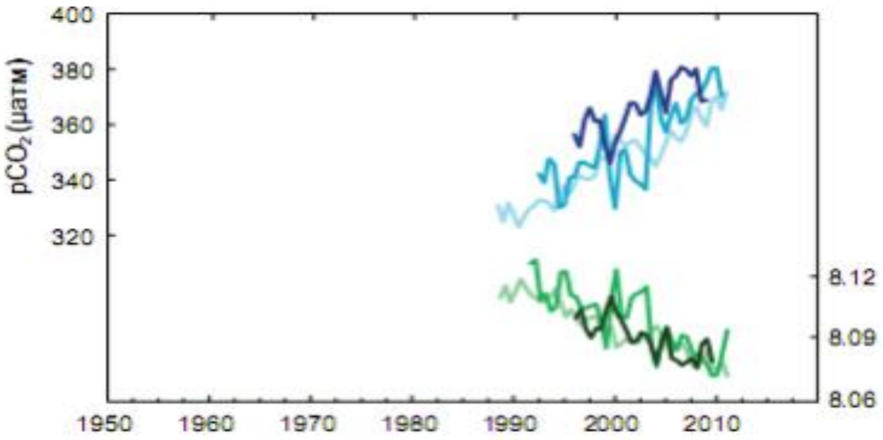

Fig. 12 – CO2 and pH on the ocean surface. Partial pressure of dissolved CO2 on the surface ocean (blue curves) and pH at the location (green curves) – a measure of acidification ocean water. Measurement data from three stations in the Atlantic (29 ° 10 'N, 15 ° 30' W - dark blue / dark green color; 31 ° 40 'N W, 64 ° 10 'W - blue / green) and Pacific (22 ° 45 'N, 158 ° 00' W - light blue / light green) oceans

3.6 Questions for self-control

1. What climate changes are predicted in the Earth's atmosphere?
2. What climate change is forecast in the ocean?
3. How will the Earth's ice shield change?
4. What are the threats to rising ocean levels?
5. What will be the feedback between the climate and the carbon cycle?

4 FUTURE GLOBAL AND REGIONAL CLIMATE CHANGE

Climate models are used to predict changes in the climate system different levels of complexity, from simple climatic models to intermediate models complexity, complete climate models and Earth system models. These models calculate changes based on a set of scenarios of anthropogenic impacts. For new ones climate calculations performed under Phase 5 of the Joint Comparison Project models (PPSM5) of the World Climate Research Program, a new one was used a set of scenarios, namely Representative Trajectories of Concentrations (RTCs). In all RTC CO2 concentrations in the atmosphere are higher in 2100 compared to today due to continuing in the 21st century increase in total CO2 emissions into the atmosphere. The forecast is given at the end of the 21st century (2081-2100) and is equal to the period 1986-2005, if not specified other. To place these projections in a historical context is necessary consider the observed changes between different periods. Based on the available set data for the longest period of observations of global surface temperature the change between the average value for the period 1850-1900 and the base period is 0.61 [0.55-0.67] °C. However, the warming that occurred exceeded the baseline period. In this regard, this estimate is not an estimate of the magnitude of historical warming to date.

Continued greenhouse gas emissions will cause further warming and change in everyone components of the climate system. Limiting climate change requires significant and continuous reduction of greenhouse gas emissions.

Projections for the next few decades show a spatial picture of change climate, similar to the forecast for the end of the 21st century, but with lower values. Natural intrinsic variability will still be a major factor in that affects the climate, especially in the short term and on a regional scale.

By the middle of the 21st century, the significance of future changes will be large depend on the choice of emission scenario.

4.1 Atmosphere: Temperature

The change in global surface temperature at the end of the 21st century is likely to will exceed 1.5 °C in comparison with the period of 1850-1900 in all scenarios. On in some scenarios it will probably exceed 2 °C. Warming will continue after 2100 according to all scenarios. Warming will continue to show variability at intervals from one year to a decade and on a regional scale does not will be homogeneous (see Figures 13 and 14).

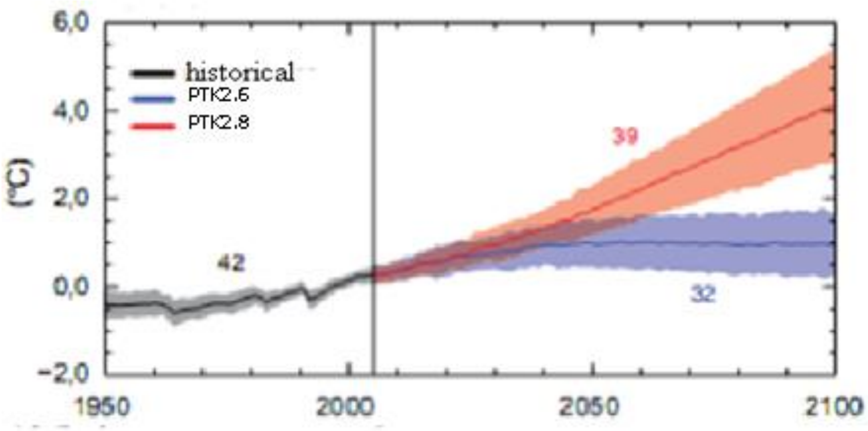

Fig. 13 – Change in the average global surface temperature

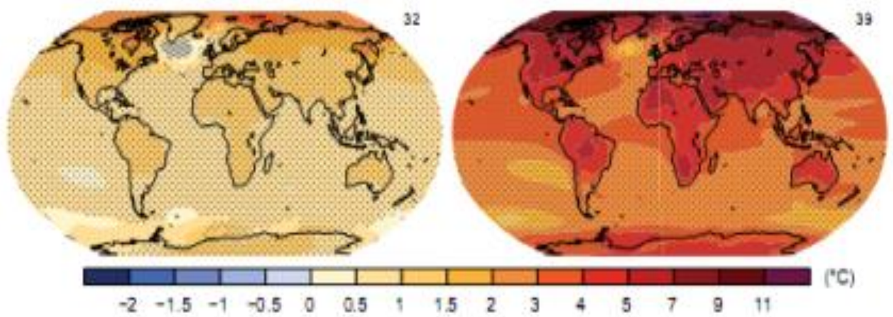

Fig. 14 – Change in average surface temperature (1986-2005 - 2081-2100) scenarios RTK2.6 and RTK8.5 (http://climate2013.org/images/report/WG1AR5_SPM_brochure_ru.pdf)

Change in the average global surface temperature for the period 2016-2035 compared to 1986-2005 will probably be in the range of 0.3-0.7 °C (average degree of probability). This estimate is based on numerous data and assumes no large volcanic eruptions or long-term total changes solar radiation. It is expected that compared to the natural domestic volatility increase in the short term mid-season and average annual temperatures will be more significant in the tropics and subtropics than in mid-latitudes (high probability).

Rising average global surface temperatures in 2081-2100 compared with the period 1986-2005 is projected within the probable limits ranges obtained from scenario calculations on models based on concentration data, ie from 0.3-1.7 °C (RTK2.6) to 2.6-4.8 ° C (RTK8.5). Warming in the Arctic will be faster, than the average on the planet, and above land it will be more significant than above oceans (a fairly high degree of probability) (see Figures 13 and 14).

Compared with the average values for 1850-1900, the change is global surface temperature by the end of the 21st century will probably exceed, according to forecasts, 1.5 °C under the scenarios RTK4.5, RTK6.0 and RTK8.5 (high degree probability). Warming is likely to exceed 2 °C in the RTK6.0 and RTK8.5 (high degree of probability); more likely than not to exceed 2 °C according to RTK4.5 scenarios (high probability); but it is unlikely that it is will exceed 2 °C according to the RTK2.6 scenario (average degree of probability). It is unlikely that warming will exceed 4 °C in scenarios RTK2.6, RTK4.5 and RTK6.0 (high probability), and relatively likely to exceed 4 °C on scenario RTK8.5 (average probability).

It is practically determined that as the average global temperatures increase over most of the land surface on a daily and seasonal time scale will be more often observed extremely high and less often – extremely low temperatures. It is likely that heat waves will occur more often will be longer. Still in the winter sometimes will be extremely low temperatures are noted.

4.2 Atmosphere: Hydrological cycle

Changes in the global hydrological cycle that will occur in the 21st century as a reaction to warming, will not be homogeneous. Differences in quantity precipitation in wet and arid regions, as well as drafts of wet and dry seasons will increase, although there may be exceptions in a number regions (see Fig. 15).

Forecasts of changes in the hydrological cycle over the next few decades show the same trends as at the end of the century, but on a smaller scale. Changes in the short term and on a regional scale are significant degrees are due to natural internal variability, and they can affect anthropogenic emissions of aerosols.

According to the RTK8.5 scenario, by the end of this century in high latitudes and the equatorial Pacific is likely to increase average annual rainfall. In many arid regions in the middle latitudes and in the subtropics, the average rainfall is likely to decrease in that while in many humid regions in the middle latitudes by the end of this century it is likely to increase in the RTK8.5 scenario (see Figure 15).

As the average global surface temperature increases, the intensity and the frequency of extreme rainfall over most of the land in middle latitudes and over humid tropical regions by the end of this century, quite likely to increase.

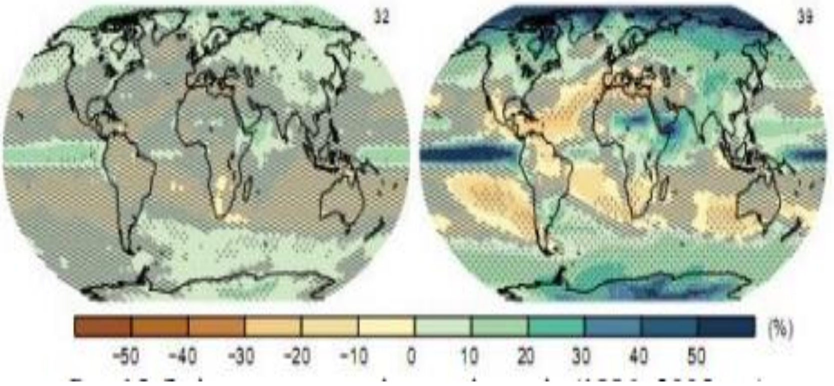

Fig. 15 –Change in the average amount of precipitation (1986 -2005)

Globally, it is likely that the area covered by monsoon systems will increase during the 21st century. Simultaneously with the probable weakening monsoon winds the intensity of monsoon precipitation is likely to increase as a result increasing the moisture content of the atmosphere. The monsoon start dates are likely to shift at an earlier date or will not change significantly. End monsoons, are likely to move to later dates, which will lead to an extension of the season monsoons in many regions.

There is a high probability that the El Niño / Southern phenomenon fluctuations (ENPC) in the 21st century will continue to determine the dominant mode of inter annual variability in the tropical latitudes of the Pacific Ocean, accompanied by global consequences. As a result of increasing humidity the variability of the precipitation regime at the regional level related to the ENPC is likely to be will increase. Natural variability of amplitude and spatial picture of ENPC large, and therefore the degree of probability of specific projected changes in the EPPC and concomitant regional phenomena in the XXI century remains a number.

4.3 Atmosphere: Air quality

Range of projections of air quality (the maintenance of ozone and VCh 2,51 in the near-surface air) is mainly due to emissions (including CH4) and not physical climate change (medium probability). There is a high degree the probability that global warming is declining background ozone content in the surface layer. High levels of CH4 (as in RTK8.5) can compensate for this decrease by increasing the background ozone content surface layer by 2100 on average by about 8 ppb (25% of current levels) compared to scenarios involving slight changes in CH4 levels (as in RTK4.5 and RTK6.0) (high probability).

Observational data and simulation results suggest that in all others equal conditions higher surface temperatures in contaminated regions will cause the strengthening of regional feedback in the chemical atmospheric reactions and local emissions that will lead to increased peaks ozone and RF2.5 levels (average probability). As for HF2.5, then climate change can change and affect natural sources of aerosols their removal with precipitation, however, the total impact of climate change on distribution RF2.5 is not assigned any degree of probability.

4.4 Ocean

The temperature of the oceans will continue to rise during the 21st century. The heat will penetrate from the surface into the deep layers and affect the ocean circulation.

The most significant increase in ocean temperature is projected in it surface layer in the tropics and subtropics of the Northern Hemisphere. On greater depth of warming will be most noticeable in the Southern Ocean (high degree of probability). According to the best estimates, the temperature rises the upper 100-meter layer by the end of the 21st century will be from 0.6 °C (RTK2.6) to 2 ° C (RTK8.5), and at a depth of about 1,000 m - from about 0.3 °C (RTK2.6) to 0.6 °C (RTK8.5).

It is quite likely that a weakening will occur during the 21st century Atlantic meridional circulation (AMC). Best scores and range2 attenuation, according to the PSPM5 models, is 11% (1-24%) for RTK2.6 and 34% (12-54%) for RTK8.5. It is likely that by about 2050 some will be noted weakening of the AMC, but in some decades it may increase as a result significant natural internal variability.

It is quite unlikely that in the considered scenarios in the 21st century AMC will undergo abrupt changes or collapse. The degree of probability of estimating the evolution of the AMC after the 21st century is low due to limited research and ambiguous results. However, its collapse after the 21st century cannot be ruled out century in the case of significant and prolonged warming.

4.5 Cryosphere

It is likely that the length and thickness of sea ice in the Arctic will be continue to shrink and that snow cover in the Northern Hemisphere in the spring the season will decrease in the 21st century as the average increases global surface temperature. The volume of glaciers will continue decrease.

Based on the average values of the multimodel ensemble by the end of the 21st century is projected year-round reduction in the area of Arctic sea ice. This reduction ranges from 43% for RTK2.6 to 94% for RTK8.5 in September and from 8% for RTK2.6 to 34% for RTK8.5 in February (average degree probabilities) (see Figs. 16, 17).

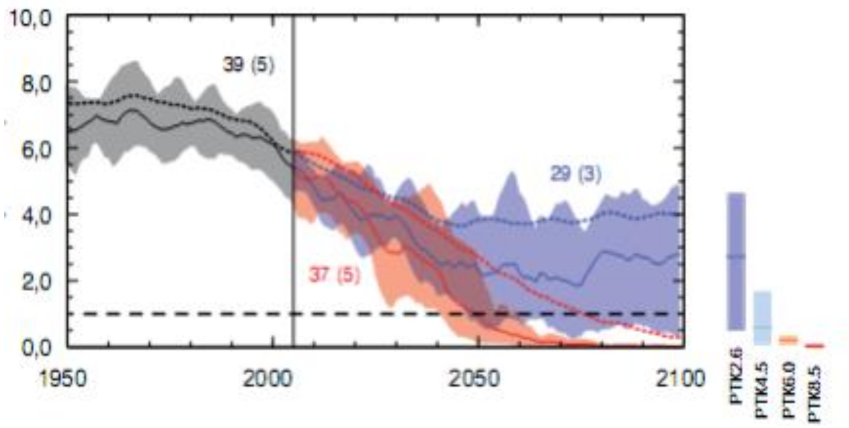

Fig. 16 –The area of sea ice in September in the northern hemisphere

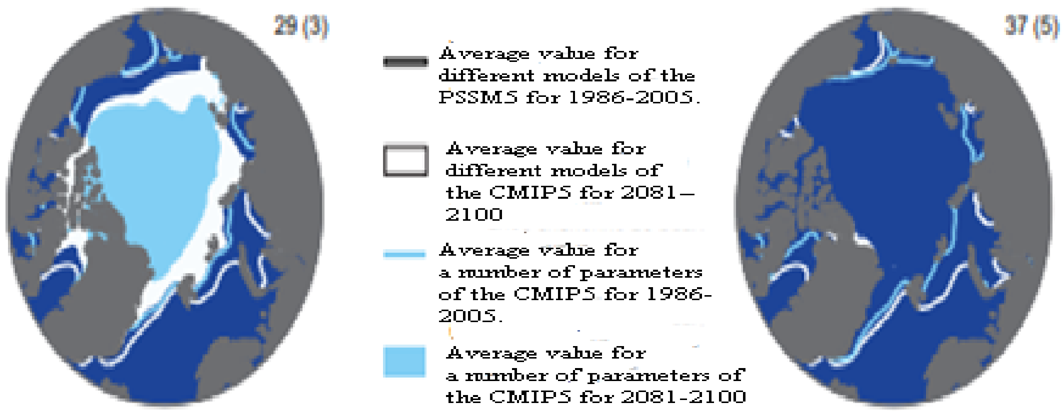

Fig. 17 –The area of sea ice in September in the northern hemisphere (average value in 2081- 2100) (http://climate2013.org/images/report/WG1AR5_SPM_brochure_ru.pdf)

Based on the results of the evaluation made using a subset of models that most accurately reproduce the average climatic condition and trend of the sea area ice in the Arctic in the period 1979-2012, by the middle of the century probably almost complete absence of ice in the Arctic Ocean3 in September according to the script RTK8.5 (average degree of probability) (see Fig. 16, 17). According to other scenarios from it is safe to predict when the Arctic will be in the 21st century in September almost completely free of ice is not possible.

In Antarctica with a low degree of probability, a decrease in the area and volume of sea ice at the end of the 21st century as the average increases global surface temperature.

It is projected that by the end of the 21st century, the reduction of glaciers in the world, except for the marginal glaciers of Antarctica, will be from 15 to 55% in the scenario RTK2.6 and from 35 to 85% according to the scenario RTK8.5 (average degree of probability).

It is projected that by the end of the 21st century, the area of snow cover in the spring the Northern Hemisphere will shrink by an average of 7% on the model ensemble scenario RTK2.6 and 25% according to scenario RTK8.5 (average probability).

It is practically proved that the area of the near-surface layer of permafrost y the high northern latitudes will shrink as the medium increases global surface temperature. According to forecasts, by the end of the 21st century reduction of the permafrost zone (upper 3.5 m) on average model ensemble will range from 37% (RTK2.6) to 81% (RTK8.5) (average degree of probability).

4.6 Sea level

The average global sea level will continue to rise 21st century (see Fig. 14). In all RTK scenarios, speed sea level rise is likely to exceed that value were celebrated in 1971-2010, due to rising ocean temperatures and increasing the reduction in the mass of glaciers and glaciers.

For the period that has elapsed since the release of the previous report, confidence in the results of forecasting an increase in the average global sea level increased due to a clearer understanding of the physical reasons for the increase sea, greater consistency of models describing different processes with the data observations and the inclusion of dynamic changes in ice sheets.

Rising average global sea level in the period 2081-2100 compared to 1986-2005 will probably be in the range of 0.26 to 0.55 m in the scenario RTK2.6, from 0.32 to 0.63 m in the scenario RTK4.5, from 0.33 to 0.63 m in the scenario RTK6.0 and from 0.45 to 0.82 m in the RTK8.5 scenario (average probability). In the script RTK8.5 increase to 2100 will be from 0.52 to 0.98 m, and the rate of increase during 2081-2100 - from 8 to 16 mm-year-1 (average probability). These ranges obtained on the basis of climatic projections PSPM5 in combination with models describing physical processes and estimates described in the literature contributions made by glaciers and ice sheets (see Fig. 18, Table 1).

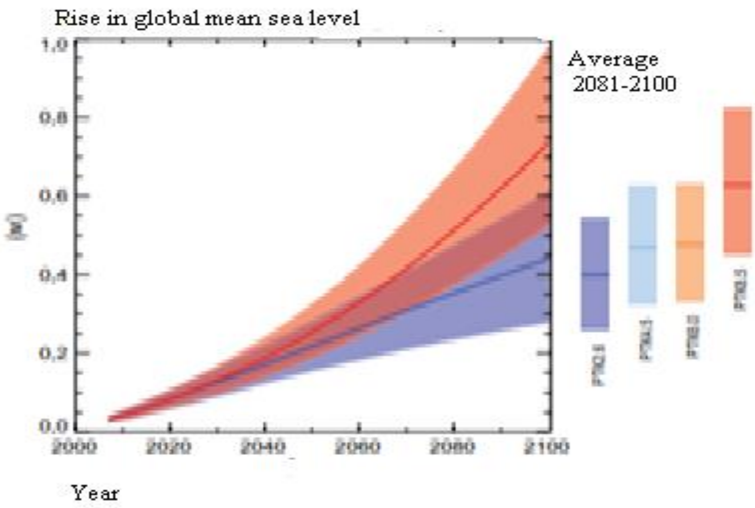

Fig. 18 – Rising average global sea level
(http://climate2013.org/images/report/WG1AR5_SPM_brochure_ru.pdf)

In the projections of RTK the share of thermal expansion is from 30 to 55% rising global average sea level in the twentieth century, and by share glaciers - from 15 to 35%. Increasing the rate of melting of the Greenlandic surface ice sheet will exceed the increase in the amount of snow that falls, which will lead to the positive contribution of changes in the mass balance on the surface of the ice sheet in the increase sea level (high probability). Surface melting in Antarctica will remain insignificant, but an increase in the amount of snow falling is expected (average degree of probability), which will lead to a negative contribution to changes in mass balance by ice sheet surface and sea level rise. Changes in total runoff from both ice shields are likely to contribute in the range of 0.03 to 0.20 m to 2081-2100 years (average probability).

Based on the modern understanding, only the destruction, if it begins, of plots the Antarctic ice sheet, the bases of which are below sea level, could become the cause of a significant increase in the probable range in the 21st century rising global average sea level. At the same time, there is an intermediate degree the probability that this additional contribution will not exceed a few tenths of meters of sea level rise in the 21st century.

The reasons for the significant increase in the global average were considered sea in the 21st century, but at this time the available data are insufficient for assessment the probability of exceeding the probable range of values. Many projections increase average global sea level, based on semi-empirical models, give greater growth than projections on models describing physical processes (almost two times higher), but the scientific community does not agree on their reliability, and therefore, the probability of these projections is low.

Sea level rise will not be homogeneous. It is likely that by the end of the 21st century sea level rise will occur on more than 95% of the occupied area by the ocean. It is estimated that about 70% of the coastline worldwide will fall under sea level rise within 20% of the change in the average global sea level.

4.7 Carbon and other biogeochemical cycles (future)

Climate change will affect the processes of the carbon cycle, which will lead to increasing the content of CO2 in the atmosphere (high probability). Further carbon sequestration by the ocean will cause an increase in ocean acidity.

Ocean absorption of anthropogenic CO2 will last until 2100 in all four RTK scenarios, with more significant uptake being observed in scenarios with more high concentrations (a fairly high degree of probability). Less clarity relative to the future dynamics of carbon sequestration by land. Most models predict a further increase in land-based carbon sequestration in all RTC scenarios, however some models show carbon losses by land due to the cumulative effect of change climate change and land use change.

Based on the data of global models, with a high degree of probability it is possible believe that in the 21st century, the feedback between climate and the carbon cycle will be positive; that is, climate change will partially prevent the increase in runoff carbon on land and in the ocean caused by increasing concentrations of CO2 in the atmosphere. As a result, a larger amount of anthropogenic CO2 will remain in the atmosphere. Positive feedback between climate and carbon cycle on a time scale from one hundred to one thousand years is confirmed by paleoclimatic observations and simulation results.

Global models predict a global increase in ocean acidity in all RTK scenarios. A corresponding decrease in the pH of the ocean surface by the end of the 21st century is in the range from 0.06 to 0.07 according to the RTK2.6 scenario, from 0.14 to 0.15 according to the scenario RTK4.5, from 0.20 to 0.21 according to the scenario RTK6.0 and from 0.30 to 0.32 according to the scenario RTK8.5 (see Fig.19 and 20).

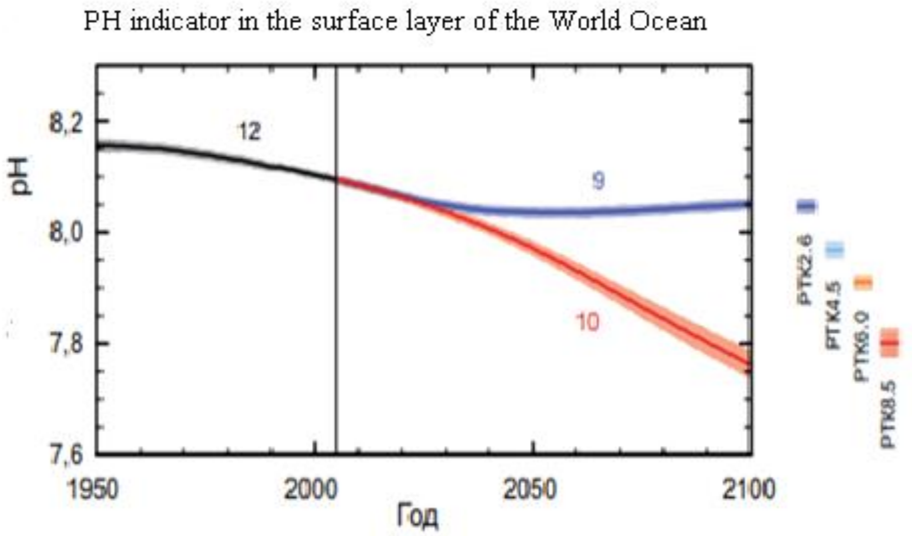

Fig. 19 − pH in the surface layer of the oceans

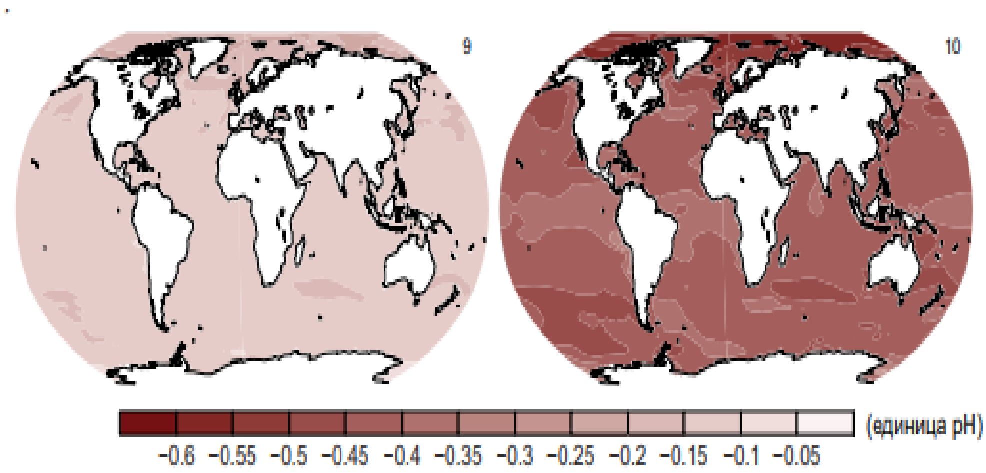

Fig. 20 − pH change on the ocean surface

Total CO2 emissions 4 for the period 2012-2100, compared with CO2 concentrations in atmosphere according to the RTK scenarios obtained in 15 global models are in the range from 140 to 410 GTU according to the RTK2.6 scenario, from 595 to 1 005 GTU according to the scenario RTK4.5, from 840 to 1,250 GTU according to the RTK6.0 scenario and from 1,415 to 1,910 GTU according to the scenario RTK8.5 (see table 2).

By 2050, the annual CO2 emissions obtained in the Earth system models according to the RTK2.6 scenario, less than the issue in 1990 (14-96%). By the end of the XXI century, about half models give emission levels just above zero, while the other half shows clean removal of CO2 from the atmosphere.

Release of CO2 or CH4 into the atmosphere during the melting of permafrost during the 21st century is estimated in the range from 50 to 250 GtU according to the scenario RTK8.5 (low degree probability).

Table 2 - Total CO2 emissions for the period 2012-2100, consistent with atmospheric concentrations under RTK scenarios (http://climate2013.org/images/report/WG1AR5_SPM_ru.pdf)

Scenario	Cumulative CO_2 emissions for 2012-2100			
	GTU		GT CO_2	
	Mean	Range	Mean	Range
PTK2.6	270	140-410	990	510-1505
PTK4.5	780	595-1005	2860	2180-3690
PTK6.0	1060	840-1250	3885	3080-4585
PTK5	1685	1415-1910	6180	5185-7005

4.8 Questions for self-control

1. A group of factors that characterizes the features of the climate system.
2. Gradation of the time range of climatic variability.
3. Causes of global level fluctuations.
4. What is the significance of the temporal trend of surface air temperature on average in Ukraine.

5 CLIMATE CHANGES OF THE HYDROLOGICAL REGIME OF THE BLACK SEA

The Black Sea is the inland sea of the Atlantic Ocean basin. Sea surface area, according to various sources is 400-410 thousand km2, water volume - 535-540 thousand km3. Shelf, or continental shoal, which is a flooded part of the coastal land, occupies about 25% of the seabed. Water exchange with neighboring seas through straits The Bosphorus and Kerch are significantly limited: according to various sources, the profitable part is 180-300 km3/ year, expenditure part -350-600 km^3/year; i.e total water exchange occupies no more than 0.2% of the total sea volume or 2.7% of the upper 100-meter layer.

Long-term fluctuations are one of the main types of variability in the Black Sea. For salinity, they prevail over other time scales, for temperature - yield only to seasonal fluctuations in the upper layer of the sea. Bigger role long-term variability due to the isolation of the Black Sea, small the thickness of the active layer and a sharp density stratification, which leads to rapid reactions of the top layer to large-scale fluctuations of wind influences, thermal and water balance.

On various issues related to the thermohaline structure of the Black Sea and its seasonal variability, published a large number of works. Long-term hydrological variability devoted to a significant but smaller number of publications, in particular (Blatov et al., 1984, Polonsky, Lavenkova, 2004, Ginzburg et al., 2002, Krivosheya et al., 2002).

5.1 Temperature

On a regional scale, the Black Sea is an additional source of heat and moisture for atmosphere and significantly affects the climate of the surrounding land, smoothing sharp fluctuations weather. For the upper 100-meter layer of the Black Sea, the average heat fluctuates in the range of 280-500 kJ / cm2. The heat capacity of the upper layer is significantly seasonal course: it is minimum in March and maximum in August (Fig. 21).

Heat balance and sea circulation form the spatial distribution of heat. The lowest values of heat capacity are 280-300 kJ / cm2 characteristic of the western part of the sea in February-March, where the cooling is most intense. In the second half of the year, starting from June, the minimum heat content is located in the region of the eastern cyclonic cycle. Southeastern part of the sea in the area of Batumi anticyclonic cycle is characterized by the highest heat content (up to 500 kJ / cm2).

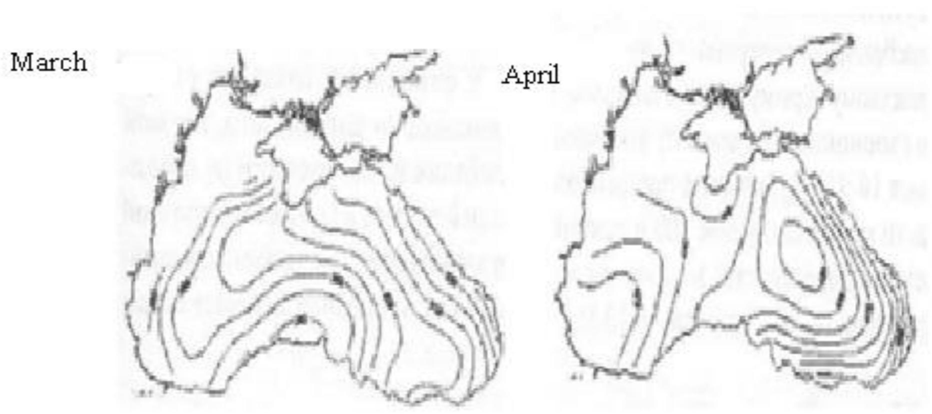

Fig. 21 – Heat capacity in the layer 0-100 m (kJ / cm2)

The rate of change of heat supply during the year in the Black Sea corresponds to the average values in the ocean at the appropriate latitudes (Fig. 22), reaching maximum values 150 W · M -2 in May during intensive heating of the surface layer.

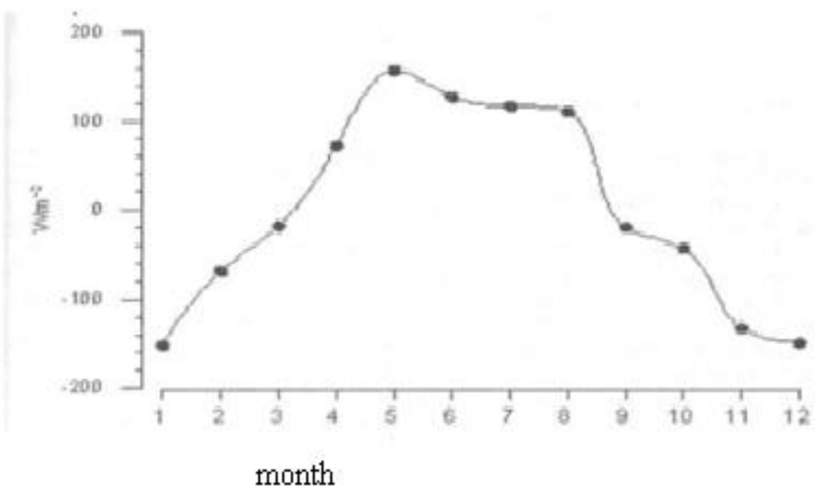

Fig. 22 – Seasonal rate of change of heat capacity in a layer of 0-100 m (W-M-2)

Geographical position of the Black Sea on the border of global climate zones - climate of temperate latitudes and subtropical - determines a significant seasonal course of temperature water. The greatest seasonal variability is observed in the northwestern part of the sea, where the range of seasonal fluctuations on the surface reaches 20 ° C. In the area adjacent to the South-Western Crimea, in the zone of action of the Sevastopol anticyclone the annual course is minimum, the amplitude of seasonal oscillations on the surface does not exceed 16 ° C, which is associated with a constant advection of warm waters from the south-eastern part of the sea. At a depth of 100 m seasonal course significantly reduced, compared with the surface layer, an average of 30 times, western cyclonic cycle - 85 times (Fig. 23).

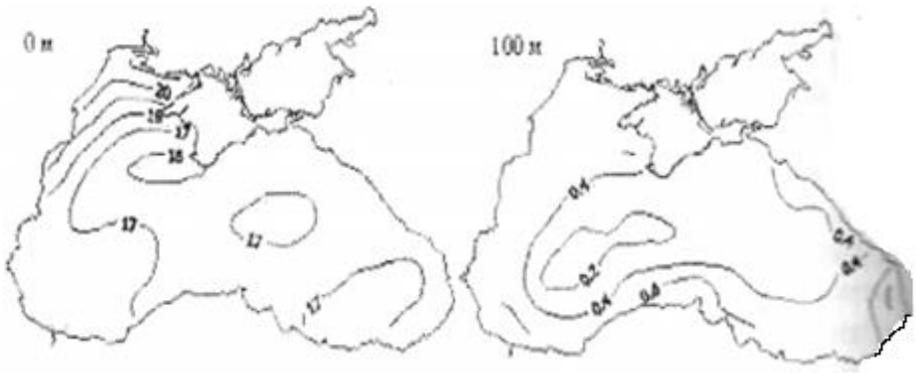

Fig. 23 – The scale of seasonal fluctuations in water temperature is 0 and 100 m

The average annual course of water temperature (Fig. 24) reflects the result of the joint action of different physical processes:

- in the surface layer (0-30 m): seasonal course of heat balance on the surface;
- in the cold intermediate layer (30-80 m): winter convective mixing, adjective redistribution of water, vertical heat transfer:
- in a permanent pycnocline (80-200 m): vertical movements associated with seasonal course of the general circulation of the sea, vertical heat transfer.

Long-term variability of water temperature in the surface layer is more pronounced in summer season. Spatially, the northern part of the sea is more susceptible to year-on-year fluctuations (σ = 1.4-2.0 ° C).

Estimates of long-term fluctuations in water temperature on the Black Sea surface by the last 50 years, obtained from ship observations, satellite data, coastal stations (Fig. 24), indicate that the negative temperature trend has changed on the positive for the summer period of the year in the late 1970s, and for the winter - in the middle 1990s. For annual averages, the change in the trend sign is in the middle 1980s. In general, this nature of long-term fluctuations in the Black Sea is consistent trends for surface water temperatures in the oceans (Rayner N.A. et al, 2006).

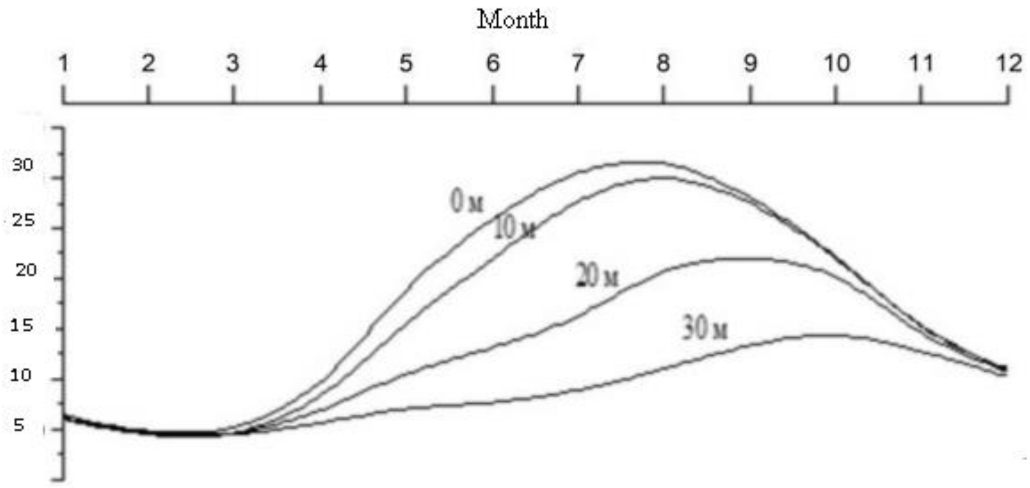

Fig. 24 – Average seasonal course of water temperature

5.2 Salinity

A large number of rivers flow into the Black Sea, the total area of the catchment area is about 2.5 million km^2 , total river runoff - 320-380 km^3/year. About 80% river runoff enters the northwestern part of the sea, causing the most dispersal of this shelf area. River runoff and precipitation in total exceed the evaporation from the sea surface. Therefore, the Black Sea is a typical scattered pool, with a positive fresh balance.

The salinity of the surface layer of the Black Sea (~ 18 ‰) is almost double less than salinity of surface waters of the oceans. Average salinity throughout in volume the Black Sea is equal to 21.96 ‰, in the layer of 0-300 m - 20.26 ‰, in the layer of 400-2000 m - 22.26 ‰.

The low salinity of the surface layer causes a sharp stratification of water. It leads, in addition to limiting turbulent exchange with the underlying layers, also to reduction of depth of winter convection and, accordingly, to falling warming influence sea in winter.

The total salt content in its seasonal cycle follows the annual course of the river runoff with a phase delay of 2-3 months. It reaches its maximum value in March, the minimum - in July (Fig. 25).

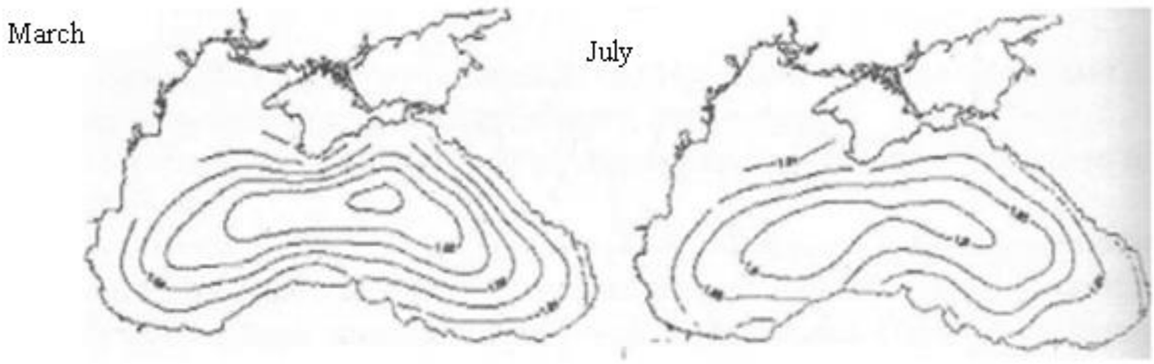

Fig. 25 –Total salt content in the layer 0-100m (T · m-2)
(Lyalko VI (ed.), 2010)

The minimum salt content occurs during the summer season, when the process of redistribution of river water, which occurred during the spring flood, is accompanied by a decrease in intensity general circulation and wind mixing. Maximum salt content observed in winter, when there is an active wind and convective mixing in the surface layer, and the strengthening of the general circulation of the sea provides a rise deep waters of high salinity.

The greatest seasonal variability of salinity is observed in the northwestern part of the sea the mouth of the Danube and the Dnieper-Bug estuary, where the scale of seasonal fluctuations on the surface reaches 4 ‰. In the central part of the sea the annual course is minimal, the amplitude is seasonal oscillations on the surface do not exceed 0.4 ‰.

Seasonal courses of temperature and salinity on different horizons can differ qualitatively among ourselves. In the upper layer of the sea 0-50 m, these characteristics are in antiphase: the minimum values of temperature in the winter correspond to the maximum value of salinity, and, conversely, salinity in the summer is minimal, and the temperature maximum. In a layer of the main halocline of 75-200 m seasonal cycles of temperature and salinities are similar: the minimum values are observed in the spring, the maximum - in the fall.

Long-term variability of salinity is maximum in the surface layer during the period the largest dispersion (May - July) and in the layer of the main halocline in the period winter-spring intensification of sea circulation. The maxima of variability are characteristic of area of the north-western shelf near the mouths of the Danube and Dnieper (σ = 1.5-2 ‰) and coast of the south-eastern part of the sea (σ = 0.5-1 ‰). In the central part of the sea inter annual variability of salinity is minimal (σ = 0.2 ‰).

The long-term course of salinity of water in the surface layer of the sea (Fig. 26) demonstrates it gradual decline over the past 50 years. Long-term fluctuations in salinity waters of inter-decade scale sufficiently correspond to runoff fluctuations Danube, but a positive linear trend for the flow of the Danube, which would explain the general dispersal, absent. Precipitation trends for regions bordering on Black Sea, often divergent. Obviously, to explain the persistent scattering the surface layer of the sea need to be assessed in more detail and other components of the salt balance, such as salt exchange through halocline. However, the negative trend is -0.04 ‰ per decade corresponds to the negative trends in salinity of the Pacific and Atlantic Oceans temperate latitudes (Bayer et al., 2005).

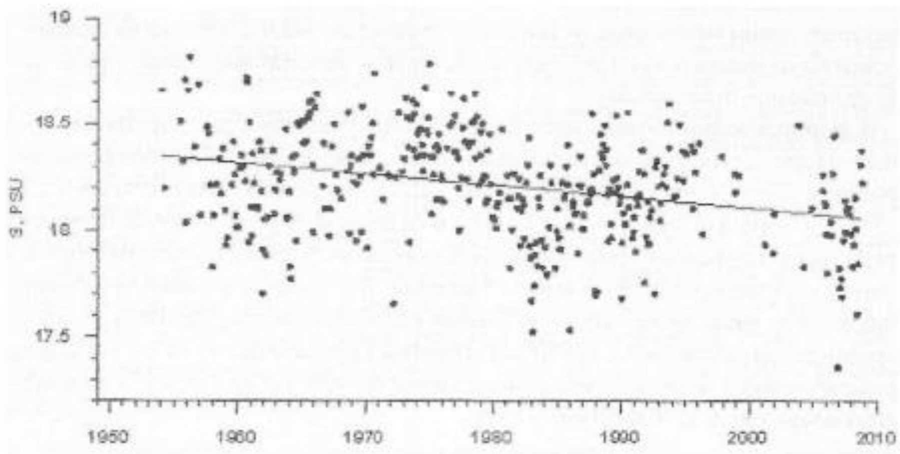

Fig. 26 – Average monthly values of water salinity in the surface layer of the western part Black Sea

5.3 Water masses

Sufficient attention is paid to the assessment of long-term climate change in the world's oceans integral characteristics of water masses, characterizing slow, steady changes ocean, and which also serve as indirect indicators of large-scale variability processes in the system "ocean - atmosphere".

Two primary water masses take part in formation of water masses of the Black Sea: marine water, brought by the Lower Bosporus current (T = 12-16 °C, S = 34-38 ‰, σt = 25-29) and fresh water (T = 0-28 °C, S = 37 ‰) coming from river runoff and precipitation. As a result of their redistribution, processes of exchange and influence atmospheric processes form their own water masses of the basin. Stands out to five Black Sea water masses: coastal Black Sea mass in one mass, Black Sea aquifer, cold intermediate layers (HPSH) and deep Black Sea mass (Fig.27).

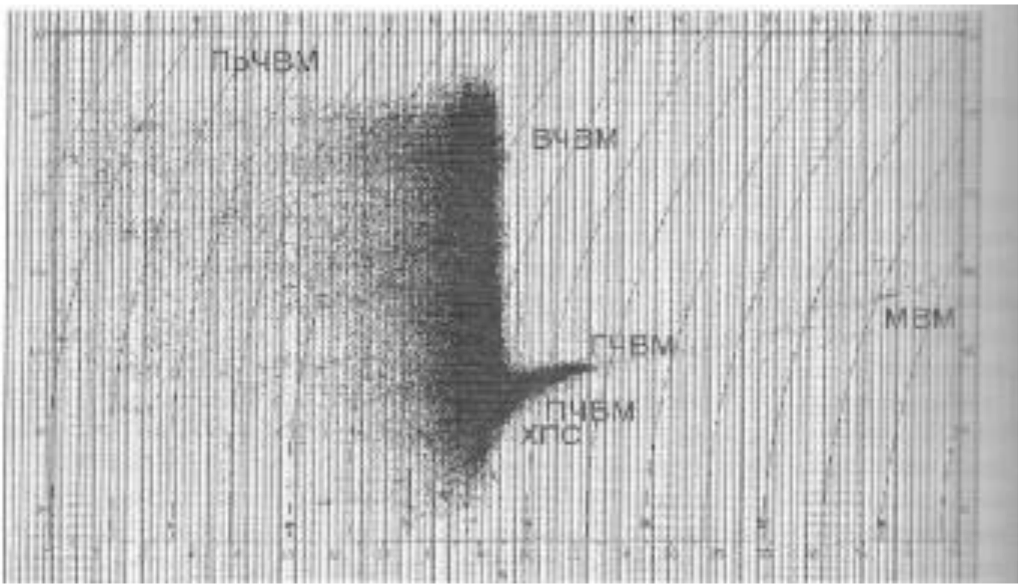

Fig. 27 –T, S-Diagram of the Black Sea waters

Coastal Black Sea water mass formed by river runoff is characterized low salinity and high horizontal salinity gradients. Criterion the allocation of this mass is the salinity S = 17,8-18,0 ‰, below which the volume T, S the diagram sharply increases the scatter of T, S-classes and decreases their percentage. The average volume is 0.5% of the total sea volume. It occupies throughout the year the Caucasus coast, most of the north-western shelf and the coastal a strip along the Romanian and Bulgarian coasts to the mouth of the Sakarya River. Lower limit water mass is at a depth of 10-20 m, sinking at the end of the year in a layer of 20-30 m.

The volume of PrCHVM has a significant seasonal variability - about 50% of its average volume (Fig. 28). The seasonal cycle is directly related to the water balance of the sea. The maximum volume occurs in July, ie it takes about two months after May maximum river runoff for the greatest distribution of river water in open sea.

In long-term fluctuations in the volume of PrCHVM (~ 20% of the average climatic volume) there are two periods: the predominance of negative anomalies in 1964-1980 and dominance positive anomalies in 1981-1992 (Fig. 29). There is a significant statistical relationship the volume of PrCHVM with SAC, because long-term fluctuations of river runoff into the Black Sea directly related to the general circulation of the atmosphere in the region of Europe – North Atlantic.

Cold intermediate layer (X PN), or both layers of the minimum temperature between seasonal thermocline and constant pycnocline, is the result winter convective mixing in cyclonic centers rotations and shelf areas. It happens during the year adjective redistribution of HPSH waters in the sea (Fig. 29), slow salinization and temperature increase under the influence of processes of vertical heat and salt exchange.

The traditional formal criterion for the selection of HPS is isotherm 8 °C, the range of isopicic surfaces from σ t = 1 4, 0 -1 4, 2 in January and to σt = 1 4, 2 -1 4, 8 in August. The average volume of HPS is 2,2% the entire volume of the sea. Seasonal changes in the volume of HPS waters reach about 12% of its average volume (Fig. 28).

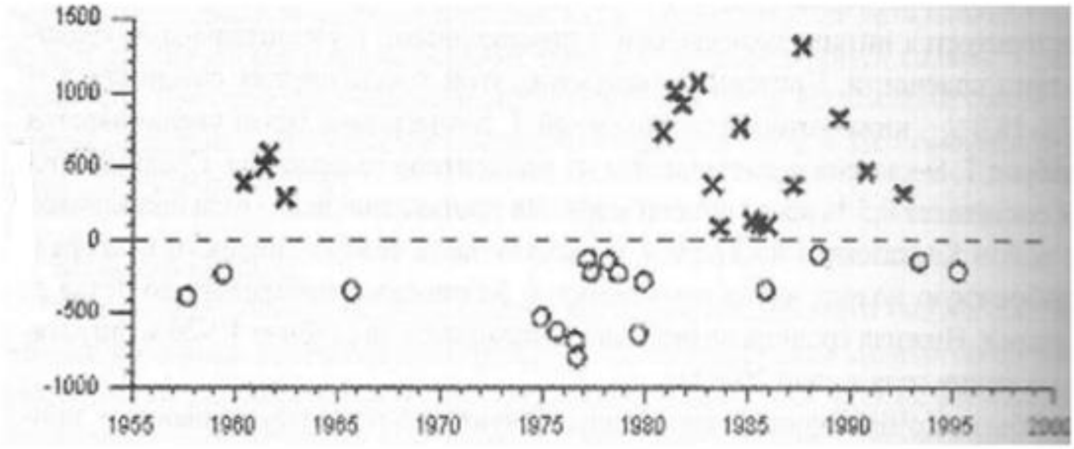

Fig. 28 –Interannual variability of the volume of coastal water mass of the Black Sea symbols: o - negative average monthly anomalies;
x - positive monthly averages anomalies

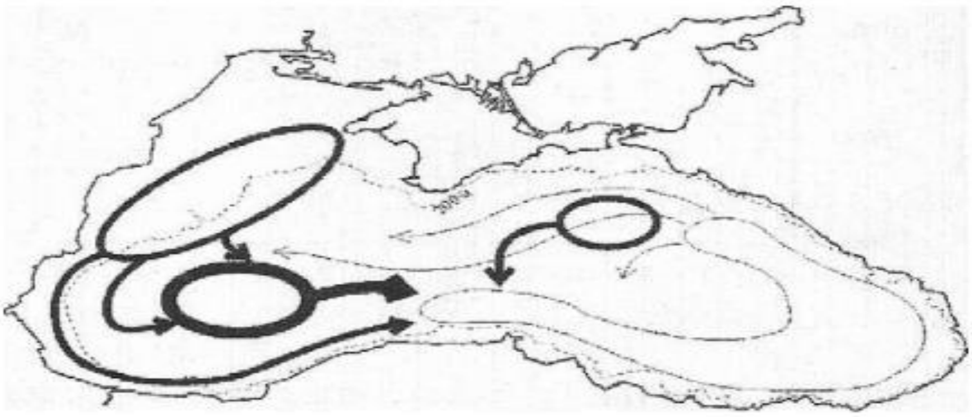

Fig. 29 − Generalized scheme of seasonal redistribution of HPS water

Year-on-year fluctuations in the volume of HPS, as well as other indicators of this water mass, such as the average temperature in the nucleus and the heat content, most closely related to cooling sea surface in the winter (Titov, 2003, Krivoshiya, etc., 2002), which is integral expressed as the sum of negative air temperatures. There are periods for weak recovery of HPSH waters with negative anomalies of water volume and increased temperature - 1961-1984, 1997-2002, periods of intensive water recovery: until 1960, 1985-1996 and 2003-2006, as well as 1964 and 1976 with positive volume anomalies HPSH water and low temperature (Fig. 30)

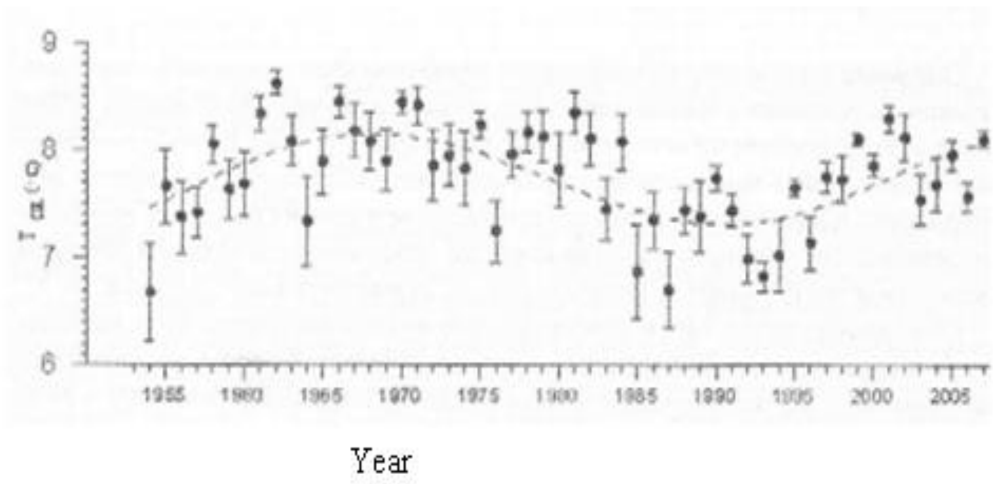

Fig. 30 −Year-on-year course of the average temperature in the HPS core for the period May - November (Lyalko VI (ed.), 2010). The segments show the scatter of values corresponding to ± 1 s.k.v.

During periods of weak water recovery, HPSH is the main source of cold water north-western shelf, in cold winters - the centers of cyclonic cycles, as western and eastern.

Despite the different physical conditions of the formation of water volumes HPSH and PrCHVM, periods anomalies of the same sign for these water masses basically coincide. Negative anomalies prevail in 1960-1980, positive anomalies - in 1980-1990, which may indicate the alternation of periods of interdependent thermal anomalies and water balances of the Black Sea.

PCVM occupies a layer of the basic pycnocline with differences of salinity and density between upper and lower limits ΔS = 3-3.5 ‰ and Δσt = 2.4-2.6. This layer is possible to characterize as a zone of transformation between HPSH and deep waters. The upper limit PCVM is located in a layer of 50-100 m (σt = 14.8, S = 18.9-19.0 (), the lower limit – on depth of 1100-1200 m (σt = 17,195, S = 22,30 ‰, At these limits, it occupies the largest volume among the water masses of the Black Sea (55%).

The main trends of long-term thermohaline changes in the pycnocline layer are expressed in rising temperatures and salinity by the mid-1980s and subsequent declines until 2000 (Fig. 31). Data of modern observations, in particular buoys-profilers of ARGO, indicate a resumption of rising temperatures and salinity, however additional estimates are needed because of the experience of operating these buoys in the oceans it is known about the instability in time of their measuring sensors.

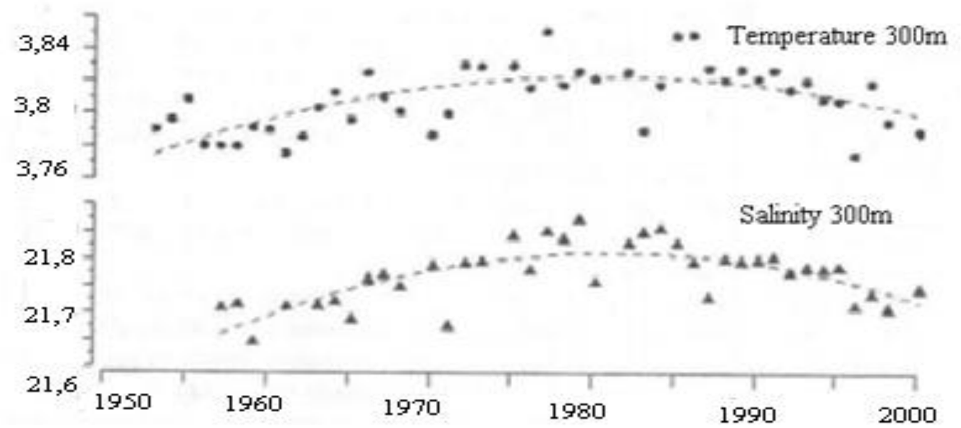

Fig. 31 −Average annual values of temperature and salinity in the main pycnocline layer in the Black Sea (Lyalko VI (ed.), 2010)

These trends in the main pycnocline layer can be caused by different causes: vertical movements of the main pycnocline. related to strengthening / weakening of cyclonic vorticity in the field of currents; changes in intensity heat and salt exchange processes in the main pycnocline; fluctuations in the tide marble waters across the Bosporus.

In the course of many years of temperature changes, a phase shift is observed the onset of the maximum with a depth similar to the phase shift during propagation temperature waves in the seasonal temperature cycle. The maximum is shifted from the period 1961 -1970 on the horizon of 50 m to the period 1981-1990 on the horizon of 300 m.

Many years of change are an important oceanographic and environmental factor vertical stability of waters. A simple but reliable assessment of sustainability can serve the difference in salinity values in the most stratified part of the pycnocline between horizons 50-100 and 50-200 m. This difference has been growing steadily since 1966-1975 to 1981-1990 (Fig. 32a), which may indicate increased stratification and weakening vertical exchange (despite the increase in temperature difference (Fig. 32b)). Stable increasing the difference in temperature and salinity between the layers is also an indicator accumulation of heat and salt in the lower layers of the sea in comparison with the upper layers.

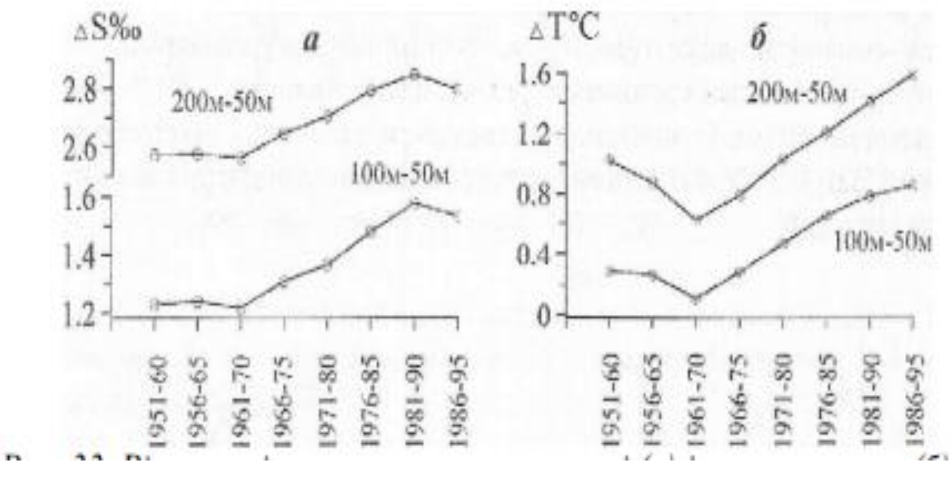

Fig. 32 –The difference between salinity values (a) and temperature (b) per horizons 100 and 50 m, 200 and 50 m (Belokopitov, Shokurova, 2005)

5.4 Water circulation

The circulation of the sea is largely responsible for the spatial redistribution of heat and salt content. The general scheme of ascending movements in the center of the sea and descending on the periphery leads to increased salt content in the central part throughout the sea. For heat content such distribution is characteristic only of the main pycnocline and deep layers. In the upper layer of 0-100 m spatial differences in heat capacity in many respects determined by advection of HPS waters. Changes in the intensity of sea circulation at different time scales directly affect the horizontal and vertical flows heat and salts.

The main elements of the large-scale structure of water circulation in the Black Sea include the following:

- the main Black Sea current is a cyclonic longitudinal coastal stream, localized on the mainland slope near the edge of the shelf;
- two large-scale cyclonic cycles in the eastern and western parts of the sea;
- quasi-stationary anticyclonic vortices.

The maximum intensity of water circulation is observed in February-March, summer circulation weakens. Winter intensification is associated with increased cyclonic wind turbulence over the sea and an increase in density gradients between the shelf and deep-sea areas.

The seasonal cycle of geostrophic circulation can be represented as the following scheme (Fig. 33):

January - March - the only cycle centered in the eastern part of the sea;

April -May: a single cycle centered in the western part of the sea;

June - July: two cycles, the western more intense;

August - September: two cycles, the eastern more intense;

October -December: two cycles of equal intensity.

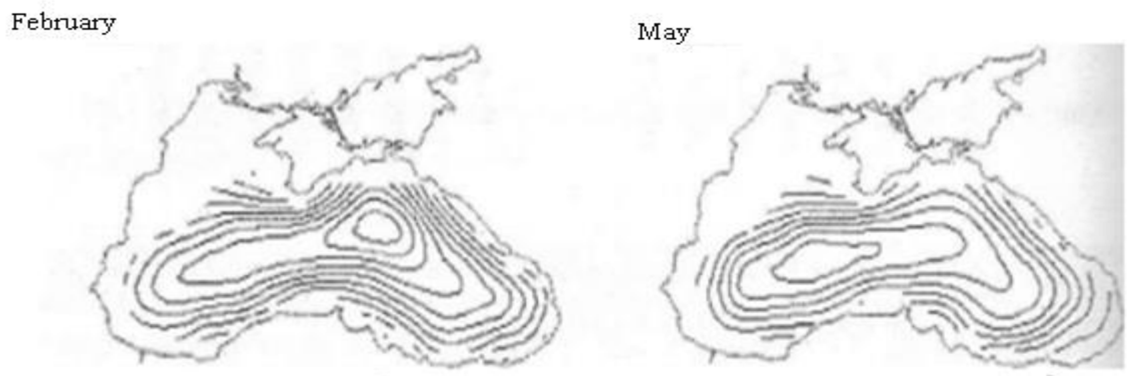

Fig. 33 –Average dynamic topography at the positions of the center of the unit cycle in the eastern and western parts of the basin. Isolines are drawn through 1 mind. din. See (Korotaev GK, 2001)

Quasi-stationary anticyclonic vortices, such as Sevastopol. Sinop, Batumi, intensify in the summer with a weakening of the general circulation.

The seasonal variability of the Black Sea water circulation has been studied in many studies (for example, Korotaev, 2001). Long-term variability of water circulation is much less studied. In the work (Polonsky, Lovenkova, 2006) on the basis of thermohaline changes are made conclusions about the intensification of water circulation in the western cyclonic cycle in the late winter in the 1970s and its weakening in the eastern cyclonic cycle from the mid-1960s to the late 1980s. In the work (Polonsky, Shokurova, 2009) according to the results of geostrophic calculations it is noted that in in the upper layer of the sea in winter there is an intensification of currents, average the value of kinetic energy increased from 1950 to 1995 almost 2 times, moreover the maximum increase occurred in the last decade. The opposite conclusion made in the work (Knysh et al. 2008), where, according to the results of re-analysis of the dynamic and thermohaline structure of the sea, the rate of decrease of kinetic energy is quite small and for 10 years (1985-1995), the average volume of kinetic energy decreased by 1.63 · 10- 4m2/c2 (Fig. 34).

Analysis of long-term changes of the rotor tangential voltage, one of the main reasons fluctuations in the intensity of the general circulation of the sea, complicated by the fact that different realizations of atmospheric fields can be obtained long-term trends of different signs. In the Azov-Black Sea basin over the past 50 years there has been an increase in atmospheric pressure and a decrease in the number of cyclones. Qualitatively, this should lead to a general decline cyclonic wind, at the same time cyclonic wind can to be formed and in the absence of cyclones, especially in the winter.

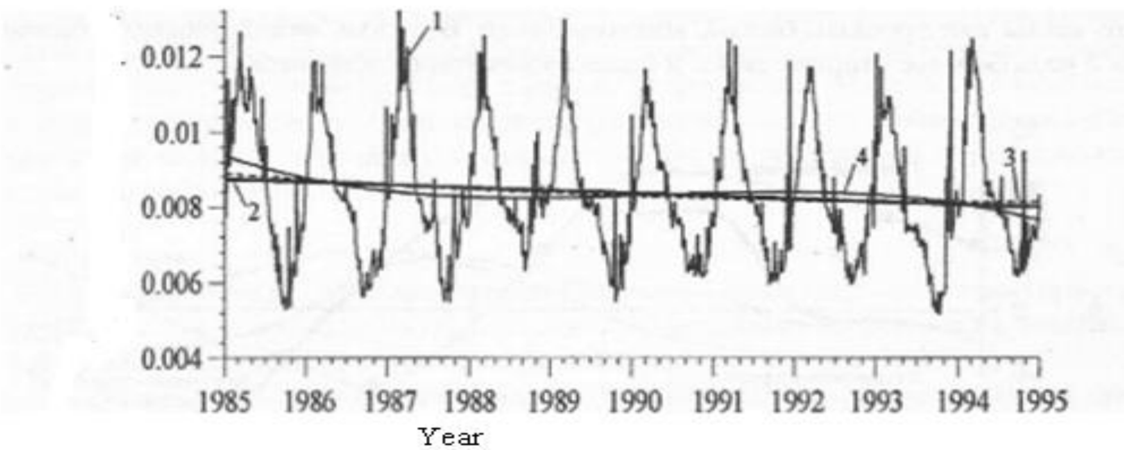

Fig. 34 − Inter annual variability of the average layer kinetic energy of 0–150 m: 1 - kinetic energy; 2 - linear trend; 3, 4 - approximation by polynomials (Polonsky, Shokurova, 2009)

5.5 Sea level

Sea level is an indicator of how global climate change is affecting the level World Ocean (melting of continental glaciers and thermal expansion of water), and variability of the regional climate, the degree of its humidity and thermal regime.

Seasonal and long-term fluctuations of the level in the Black Sea according to coastal materials level posts and alimetric satellite data are analyzed in a number of works (Simonov, Altman (ed.), 1991, Goryachkin, Ivanov, 2007, etc.).

The annual course of the level in the Black Sea is well expressed, the average seasonal amplitude oscillations are 10 cm (Fig. 35). The maximum level is observed in June, minimum - in October and November. The main components of sea level: fresh balance, steric and barometric effects have relative phase shifts in the seasonal course and can mutually compensate each other. Yes, the steric effect is maximum in August, while fresh balance is minimal. In general, the contribution of fresh balance is 2 times greater than the steric and barometric effects.

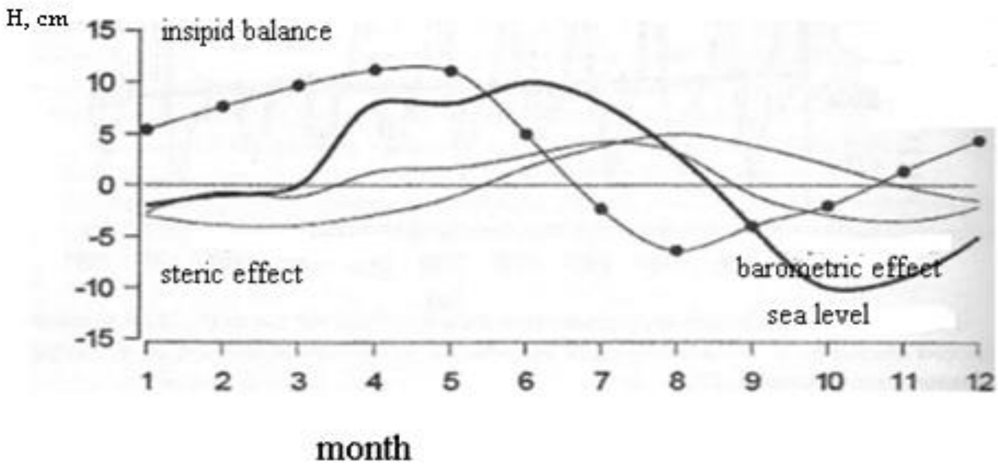

Fig. 35 − Seasonal course of sea level and its individual components in the form monthly deviations from the average annual value (Goryachkin Yu.N., Ivanov VA, 2011)

In the Black Sea there is a eustatic level rise, common to all World Ocean (Fig. 36). The average rate of ascent in 1960-1990 was about 1.3 mm / year, which was slightly below the global sea level trend from the beginning 1990s - about 6 mm / year, which corresponds to the estimates of trends in other basins (Holgate, Woodworth, 2004). The relative stabilization of sea level in 1960-1990 could be caused steric effect associated with a negative water temperature gradient because a direct analogy in the nature of perennial year runoff series is most likely due to the element of water balance of the sea, not identified.

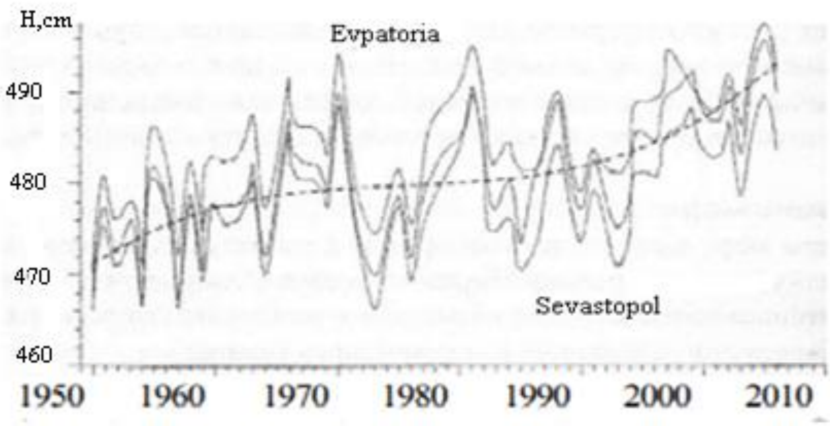

Fig. 36 − Average annual values of sea level at level posts Sevastopol, Yalta and Evpatoria (Goryachkin YN, Ivanov VA)

General conclusions about the variability of hydrological conditions of the Black Sea can be made the following:

Long-term fluctuations of sea level and thermohaline characteristics of the upper layer Black Sea due to climate change in the Euro-Atlantic area and climate system of the Earth as a whole.

Climate change in the main Black Sea pycnocline has its regional features, their connections with external factors are not clarified yet. Quantity and quality of data deep-sea observations do not allow to draw reliable conclusions about long-term trends in the deep layers.

Perennial variability of sea circulation has been studied in a small number of works. So it is not yet possible to identify climate change trends.

5.6 Questions for self-control

1. What factors affect the fluctuations of the Black Sea level?
2. What are the estimates of changes in the level of the Black Sea?
3. What is the sign of the water balance of the Black Sea in recent decades.
4. What threats may arise due to rising sea levels?
5. What parameters are needed to calculate the damage to the aquatic environment and biological resources?

6 CLIMATE CHANGES OF THE HYDROLOGICAL CYCLE OF THE AZOV SEA

One of the main tasks of regional oceanography is to study change hydrological regime of inland seas under the influence of climatic and anthropogenic factors. This task is especially relevant for the Sea of Azov. The isolation and shallowness of the sea, limited water exchange with the oceans, as well as developed industrial infrastructure on the coast significantly increases dependence hydrological regime of the Sea of Azov, thermohaline structure of its waters from anthropogenic impact and regional manifestations of global climate change.

On changes in the hydrological regime of the Sea of Azov, caused by anthropogenic factor (removal of part of the runoff of the year), regional manifestations of climatic are imposed changes that may increase or decrease the negative effects of economic activities. The most noticeable changes in the global climate have occurred in the last 25-30 years, so there is a generalization of the hydrometeorological regime of the Sea of Azov (Goptarev et al. (Ed.), 1991), made on the basis of information obtained by the mid-80's years of 21st, cannot adequately reflect its true regime.

According to estimates presented in the IV report of the Intergovernmental Group of Experts on Climate change (IPCC, 2007), the preferred processes at this time are: rising temperatures air and water, changes in rainfall, rising ocean levels, declining numbers snow and ice. The changes noted in the report have significant regional heterogeneities, especially in the Northern Hemisphere, including for the territory of Ukraine. In this lecture the influence of climate change on the hydrological regime of the Sea of Azov (ice conditions, water balance, thermohaline structure of waters, sea level).

On the coast of the Sea of Azov there is a developed network of stationary hydrometeorological observations (currently 20 stations and posts). For analysis perennial and seasonal variability of hydrological characteristics of the Sea of Azov were the data of coastal hydrometeorological stations of Ukraine and Russia for the whole period of observations are involved (up to and including 2010) (Table 3).

Table 3 - Periods of observations (years) at shore stations used for analysis of the variability of hydrological characteristics

Station	Level	Temperature water	Salinity water	Ice
Dangerous	1944-2009	1945-2009	1952-2009	1944-2010
Kerch port	1873-2009			1924-2010
Mysove	1926-2009	1924-2009	1952-2009	1926-2010
Strilets′ke				1934-2010
Henichesk	1879-2009	1924-2009	1952-2009	1893-2010
Berdyansk	1923-2009	1923-2009	1952-2009	1917-2010
Mariupol	1923-2009	1916-2009	1952-2009	1924-2010
Taganrog	1882-2007	1924-2007	1952-2007	1893-1994
Yeisk	1915-2007	1924-2007	1952-2007	1922-1994
Primorsko Akhtarsk	1916-2007	1924-1992	1952-2007	1924-1994
Temryuk	1910-2007	1924-2007	1952-2007	1924-1994

Time series of observations at coastal points depending on the observed elements have different durations. The longest series of observations of sea level and ice conditions formed for Kerch (since 1873), Genichesk (since 1879) and Taganrog (with 1882). Synchronous observations on almost all hydrological characteristics begin in the mid-20s of XX century. Duration of observations for each item is from 85 to 128-140 years and exceeds the period of natural climatic variability, associated with the Atlantic multi-decade oscillation (Polonsky, 2008).

The history and representativeness of observations at each station for the purpose were considered elucidation of methodological reasons influencing the homogeneity of series. For calculations the severity of winters were taken the sum of negative average daily air temperatures for ice season according to the points Kerch, Genichesk, Taganrog and Primorsko-Akhtarsk (from 1991 - at the points of Dangerous, Genichesk and Mariupol). Winter was considered severe if the sum of negative average daily air temperatures during the ice season (October-April) is below -400 °C, moderate - in the range from -200 to -400 °C and mild - above -200 °C.

Used in the work of an array of expeditionary oceanographic observations in the Sea of Azov contains about 65 thousand hydrological stations built in 1887-2009 years, and is the most provided data at this time (Ilyin et al., 2009). Spatial climatic fields of distribution of average monthly values of temperature and salinity of the Sea of Azov were obtained for the entire period of observations, as well as periods before (1891-1951) and after (1952-2008) regulation of runoff year into the sea, for horizons: surface, bottom, 3 and 5 m.

Hydrological seasons for the Sea of Azov are selected based on features variability of the thermal structure of sea waters: winter season - from December to March, spring - April and May, summer - from June to September, autumn - October and November. Climatic fields are obtained for all hydrological seasons, except winter, as a result a limited number of field observations at this time of year.

Perennial and seasonal characteristics of the components of the water balance of the Sea of Azov were evaluated according to the method (Goptarev et al. (ed.), 1991). In addition, the data were analyzed field observations of salt and water exchange between the Azov and Black Seas through Kerch Strait for 1970-2009 (608 definitions of costs), as well as between the Azov sea and Sivash Bay through the Thin Strait for 1953-2009 (5100 cost definitions).

6.1 Ice regime

Analysis of long-term trends in the number of days with ice in 120-year observation series coastal areas of the Sea of Azov showed that they are negative on almost all points with range of values from 1.3 to 6.9 days in 10 years. For most points of the coast characterized by a decrease in the duration of the ice season (from 0.3 to 5.7 days in 10 years), table 4.

Consideration of winters by types for the last 25 years (1984-2009) in comparison with the previous one period (1893-1983) showed a significant reduction in the frequency of severe winters (in 2, 5 times) with increasing recurrence of mild winters (1, 4 times). Recurrence of moderate winters have not changed significantly. Over the past 25 years, ice conditions have especially softened southern part of the sea. During this period, 14 mild winters were observed, seven of them winter seasons at the stations of the southern sea (Cape, Dangerous) ice did not appear at all.

Table 4 - Angular coefficients of linear trends of annual and seasonal values hydrometeorological characteristics of the coast of the Sea of Azov for many years period

Season	Temryuk	Mysove	Genichesk	Berdyansk	Mariupol	Taganrog	Primorsko Akhtarsk
Water temperature (° C / 10 years)							
Winter	0,174	0,152	0,151	0,106	0,064	0,091	0,092
Spring	0,103	0,163	0,193	0,154	0,093	0,072	0,069
Summer	0,188	0,075	0,046	0,073	0,023	-0,008	0,007
Autumn	0,084	-0,014	-0,072	0,033	0,090	0,041	-0,070
Year	0,126	0,104	0,081	0,085	0,064	0,047	0,025
Sea level (mm / year)							
Year	1,250	2,034	0,433	2,338	1,862	0,425	1,149
Salinity of water (‰ / 10 years)							
Year	-0,13	-0,556	-0,750	-0,294	-0,253		-0,311
Number of days with ice during the ice season (days / 10 years)							
Nov. April	-3,0	-6,9	-1,6	-5,5	-5,3	-1,3	-5,0
Duration of the ice season (days / 10 years)							
Nov. April	-1,1	-5,7	0,4	-4,9	-3,8	-0,3	-2,8

In mild winters (most frequent in recent years) still ice mainly observed in the northern part of the sea and Taganrog Bay. This winter there was a great variety of forms of floating ice, as well as multiple occurrences and the disappearance of ice during the ice season. In such winters the central part of the sea usually remained free of ice; floating ice sometimes appeared in late January - in early February, in small quantities and for a short time. Terms of clearing the sea of ice mild winters on average occurred in the first and second decades of February in the south and southeast and in the first and second decades of March in the north and west of the sea.

6.2 Water balance

Perennial and seasonal variability of water balance components (runoff year, precipitation, evaporation, water exchange through the Kerch and Thin Straits) determines thermohaline structure of the waters of the Sea of Azov (Goptarev et al. (ed.), 1991; Ilyin et al., 2009) and is formed under the influence of climatic variability and human economic activity.

The most important component of the water balance of the Sea of Azov is the river. His changes affect temperature, salinity, water density and other characteristics. Basic part of the river inflow into the sea is the runoff of the Don - 63.0%. The flow of the Kuban and small the year of the Azov Sea is respectively 31.7% and 5.3% of the total runoff year into the sea. For 85-summer period (1924-2009) year runoff reduction in the Sea of Azov amounted to 9.5 km³ - a value comparable to the volume of irreversible water consumption (Bronfman, 1985). By the last 25 years there has been an increase in river runoff into the sea (mainly due to increased runoff of the Kuban River) - a significant positive trend was 3.53 km³/ 10 years, table. 5, fig. 37. The flow of the Don River in 1984-2009 was close or slightly less long-term average, there was also a decrease in year-on-year variability stock. The increase in runoff of the Kuban is due to both climatic reasons and reducing the value of anthropogenic irreversible removal of runoff. Positive trends in long-term changes in runoff of the Kuban River for the modern period (1984-2009) characteristic of annual and seasonal runoff values.

The amount of **atmospheric precipitation** that falls on the sea surface during the period in 1924-2009, a significant positive trend of 0.569 km3 was revealed for decades. Most a significant amount of precipitation increased after the 1976/1977 climate change period 1976-2007. the average long-term amount of precipitation falling to the surface sea, amounted to 17.6 km³/ year, which is 2.6 km³ / year more than in the previous period (1924-1975 years). Increased precipitation (19.5 km³/ year) was celebrated in 1995-2005.

During the period from 1924-2007 in the amount of evaporation from the surface of the Sea of Azov there is a significant downward trend (-0.320 km³/ 10 years) (Table 5). Reduction evaporation is due to a decrease in average annual and summer values of wind speed in the region of the Sea of Azov (Ilyin et al., 2009). A decrease was also observed in the Black Sea intensity of evaporation from its surface, mainly due to regional climatic changes - reduction of wind speed and deficit of air humidity (Lipchenko et al., 2006).

Table 5 - Angular coefficients of linear trends of annual values hydrometeorological characteristics of the Azov region for different periods duration: 130, 100, 85, 50 and 25 years

Characteristic	1879-2009	1909-2009	1924-2009	1959-2009	1984-2009
Runoff year, km³/ 10 p			-1,147	0,910	3,530
Precipitation, km³/10 years			0,569	0,584	1,150
Evaporation, km³/10 years			-0,320	-0,553	-0,554
Tempo. water, °C / 10 y			0,098	0,186	0,740
Salinity, ‰ / 10 y			0,073	-0,278	-0,713
Level, mm / year	0,814	1,551	1,810	2,153	7,200
Tempo. air, ° C / 10 years	0,086	0,109	0,150	0,187	0,850

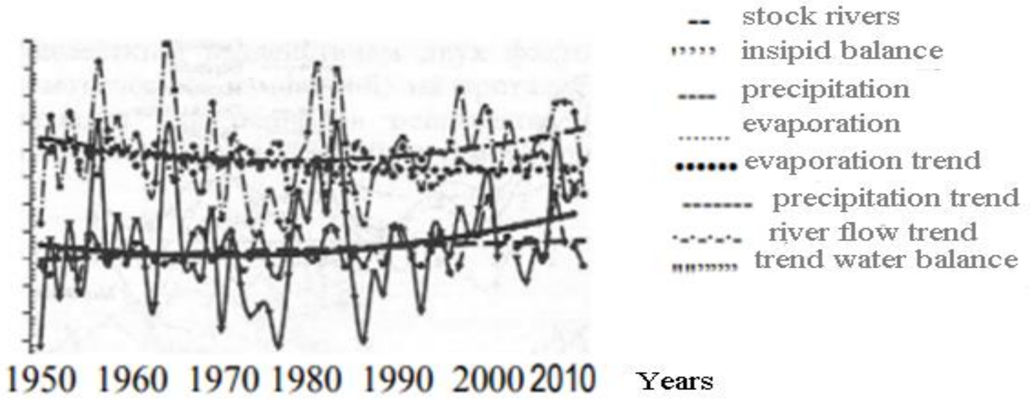

Fig. 37 –Perennial course and trends of Azovsky water balance components seas

Analysis of field observations in the northern narrowness of the Kerch Strait showed a decrease in the intensity of inflows into the Black Sea waters in 1981-2008compared to previous decades. In the values of water exchange between the Gulf of Sivash and the Sea of Azov through the Strait Thin, both in kind and by calculation the data revealed significant changes associated with an increase in the outflow of Siva waters into the sea and reducing the inflow of Azov waters into the Gulf of Sivash.

6.3 Water temperature

This section estimates the long-term variability of water temperature in coastal area of the sea. Positive values of the angular coefficients of linear trends with values of 0.064-0.126 °C / 10 years, significant at the 95% level, found in the average annual values of water temperature in the surface layer for 1924-2009 on the majority coastal points of the Sea of Azov (Table 4, Fig. 38).

Warming of sea waters varies in its areas. In the south (Temryuk, Mysove) the values of positive trends in water temperature are maximum (0.104-0.126 °C / 10 years). On northern coast (Genichevsk, Berdyansk) the magnitude of linear trends slightly less (0.081-0.085 °C / 10 years). In Taganrog Bay, rising temperatures waters are minimal and decrease to the mouth of the Don. If in Mariupol and Yeisk trends 0,064- 0.099 °C / 10 years are still significant, the positive trend in Taganrog is not significant. The maximum linear trends at most points of the coast are observed in winter (December-March) and spring (April-May) hydrological seasons. The most important thing water warming occurred in March. Significant at 95% - m level trends with absolute value of 1.9-3.0 ° C (0.3-0.5 °C / 10 years) for the period 1924-2009 were found at all points coast, except for Berdyansk.

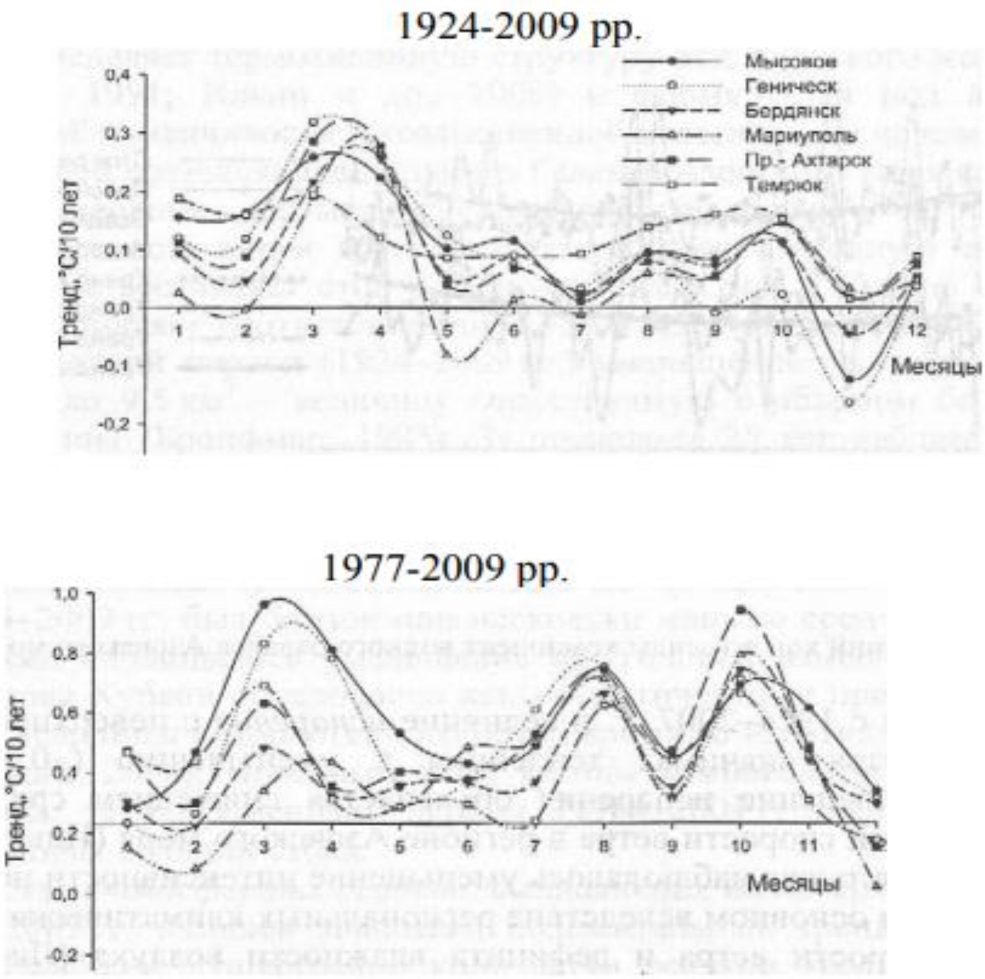

Fig. 38 −Annual course of linear trends of average monthly values of water temperature (°C / 10 years) according to observations on the coast of the Sea of Azov for different periods (Ilyin, YP, Fomin, VV, Dyakov, NN, Gorbach, SB 2009)

The trend towards warming of sea surface waters is typical for the last decades (1977-2009). Maximum significant coefficients of linear trends of the surface layer water temperatures during this period were detected in March, August and October. The average warming of the waters of the surface layer of the Sea of Azov for 85 years (1924-2009) is 0.098 °C / 10 years, and for the last 50 (1959-2009) and 25 (1984-2009) years, respectively, 0.186 and 0.740 °C for 10 years (Table 5).

6.4 Salinity of water

Under the joint influence of two factors (anthropogenic removal of runoff and climate change) during 1952-2009 in the Sea of Azov there were a number of periods salinization (1952-1956, 1970-1978) and crucifixion (1957-1969, 1979-2006) of the sea (Fig. 39).

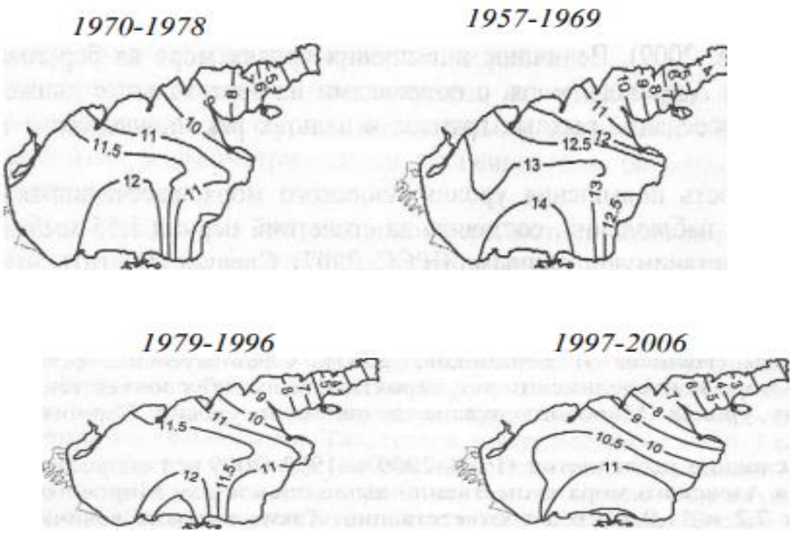

Fig. 39 – Spatial distribution of salinity of sea waters in the surface layer of the Azov sea for different periods

In the long-term course of salinity of the water observed on shore meteorological stations for the period after the regulation of runoff year maximum values salinity occurs in the 70s of last century. Since the early 80's of XX century and on now the salinity of the sea has decreased. The magnitude of the decrease in salinity after climate shift 1976/77 for the period 1977-2009 ranged from -2.28 ‰ for of the southern coast of the sea (Dangerous) to -2,37 ...- 2,67 (for the northern coast and Taganrog Bay (Berdyansk, Mariupol). The maximum reduction in salinity for this period marked in Genichesk (-0.98 ‰) and associated with the dispersal of the Gulf of Sivash in last year’s. In open areas of the sea, according to expeditionary observations, significant negative linear trends for 1977-2009 were found in the western (-0.81 ‰ / 10 years) and central (-1.05 ‰ / 10 years) parts of the sea. In other areas of the sea (Prykerchensky district, Taganrog and Temryuk bays) trends in salinity are not significant (from -0.27 to -0.40 ‰ / 10 years).

The dispersal of the Sea of Azov over the past 25-30 years is due to the complex the influence of a number of factors associated with changes in the components of the water balance of the sea (increase in runoff of the Kuban, decrease in evaporation, increase in the number of atmospheric precipitation falling on the sea surface, reducing the inflow of salts with advection Black Sea and Siva waters) (Fig. 37, Table 5).

6.5 Sea level

According to estimates (IPCC, 2007), the level of the oceans in the XX century. rose from at a rate of 1.7 mm / year, and since 1993 the level increases at a rate of 3.0 mm / year, c mainly due to thermal expansion and melting of continental ice. On most stations on the coast of the Sea of Azov have positive upward trends sea level, with the largest values of the angular coefficients of linear trends are celebrated for the last 60-65 years (Filippov, 2009). The magnitude of sea level rise on the coastal points of the coast of the Sea of Azov, with corrections for vertical movements crust and subsidence of loose soils in the river deltas, are given in Table 5 and in Fig. 40.

The rate of sea level rise in the Sea of Azov, calculated according to coastal data observations, amounted to a period of 1.55 mm / year, ie a value comparable to data (IRSS, 2007). It should be noted that over the age period there are significant trends in the budget fresh sea water (runoff plus precipitation minus evaporation) are absent, and the inflow of sedimentary material the sea decreased. Thus, rising sea levels over the past hundred years are likely to due to rising trends in the level of the oceans as a whole and the level of the Black sea in particular.

In recent decades (1984-2009 and 1993-2009) the rate of increase Sea of Azov is significantly higher than the estimates for the oceans and is 7.2 and 11.9 mm/year in accordance. Such high growth rates of the Sea of Azov are mainly due to changes in the total volume of water in the pool during these years, due to increased values fresh sea budget.

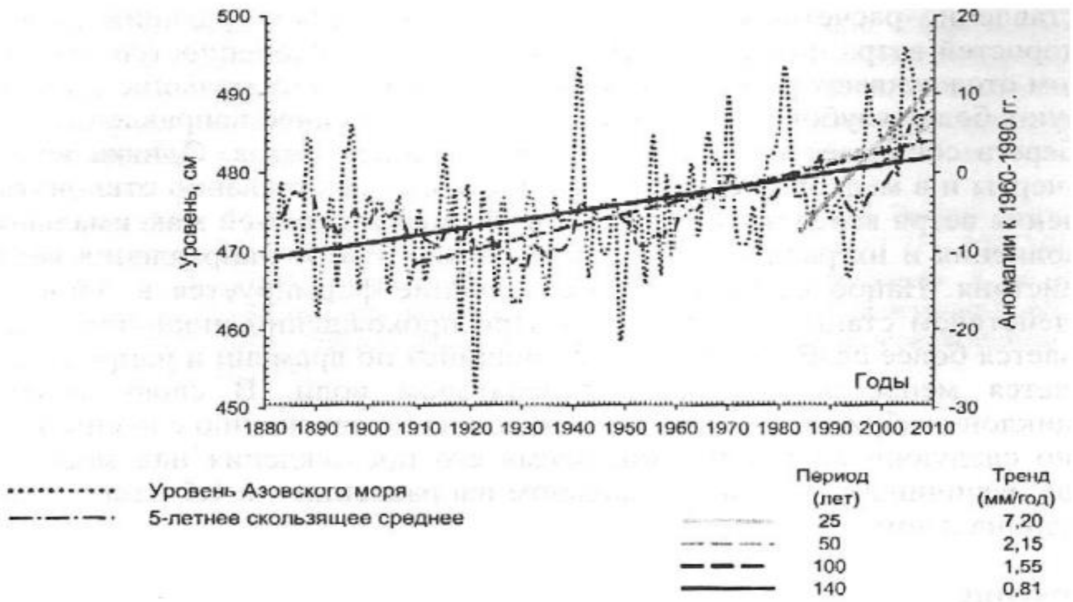

Fig. 40 – Long term route of the Azov Sea. Promoting the size of level growth of the Azov Sea for 25 years (1979-2009), 50 years (1959-2009), 100 years (1909-2009), 130 years (1879-2009)
(Ilyin, Yu.P., Fomin, V.V., Dyakov, N.N., Gorbach, S.B. 2009)

6.6 Dynamics of waters

Numerical simulation data showed that the circulation of the waters of the Sea of Azov characterized by quite pronounced vortex formations due to morphometric features of the basin and the general direction of the wind.

In areas parallel to the wind direction, water flows have the same direction as and the wind. In other areas, the direction of flows depends on local characteristics coastline (the presence of spit, capes and bays). Due to the shallowness and relative isolation Taganrog Bay from the main part of the sea here forms its own system of circulation, which consists in the presence of several vortices of opposite sign. The main feature the field of the Sea of Azov is the existence of compensatory countercurrents in the lower layers. Thus, if in the surface layer of 0-1 m currents are directed mainly by wind (small deviations in the range of 30-45 ° from the wind direction occur in the areas of capes and bays), then starting from depths of 3 m the current can already deviate by 90 ° and more. In a layer of 5-10 m in the central part of the water area there is a well-defined compensatory flow, directed against the wind. The time of formation of the countercurrent in the pool is on average 8-12 hours.

Comparison of calculated excitation fields for different gradations of directions and wind speeds revealed a number of common features. Wave heights in general track the relief of the bottom so that their larger values correspond more deep parts of the water area. The average direction of the waves away from the shore coincides in mainly with the wind direction. However, near the shoreline and in shallow areas of the wave can deviate significantly from the wind direction due to refraction. The size of the areas maximum development of excitement and their location also depend on the direction wind exposure. The most intense unrest is formed in the Sea of Azov under the action of a stationary wind. During the passage of cyclones, the excitement is weaker, because the wind changing in time and direction is a less efficient generator waves. In turn, the western cyclone excites higher waves compared to southern, due to the following reasons: the time of its passage over the sea on 20% more; the magnitude of acceleration in the zonal direction - 1,5 times more than in the meridional.

Thus, climate change in the hydrological regime of the Sea of Azov is possible draw the following conclusions.

The main changes in the hydrological regime of the Sea of Azov are expressed in the increase water temperature, softening of ice conditions, increase of level and decrease in salinity seas.

The largest values of linear trends in hydrological characteristics are characteristic of the last 25-30 years after the 1976/77 climate shift. During this period there were increased values of the budget of fresh sea water (increase in runoff and the amount of precipitation that falls on the sea surface, the reduction of evaporation) and how the consequence is the dispersal of the Sea of Azov.

6.7 Questions for self-control

1. What are the estimates of changes in water temperature in the Sea of Azov?

2. What are the estimates of changes in the level of the Sea of Azov?

3. How is the water balance of the Sea of Azov changing?

4. What are the estimates of changes in the salinity of the Sea of Azov?

5. What is the significance of the trend of water temperature in the Sea of Azov in the surface layer of the period 1924-2009.

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Навчальне електронне видання

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П'ЯТАКОВА Вікторія Францівна

Вплив кліматичних змін на галузі економіки України
(морське середовище)

Конспект лекцій

(англійською мовою)

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ДК № 5242 від 08.11.2016