Pronounced anomalies of air, water, ice conditions in the Barents and Kara Seas, and the Sea of Azov

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Abstract

This paper analyses the anomalous hydrometeorological situation that occurred at the beginning of 2012 in the seas of the Russian Arctic and Russian South. Atmospheric blocking in the temperate zone and the extension of the Siberian High to the Iberian Peninsula (known as the Voeikov et al. axis) led to a positive anomaly of air and water temperatures and a decrease in the ice extent in the Barents and Kara Seas. At the same time a prolonged negative air temperature anomaly was recorded in central and southern Europe and led to anomalously severe ice conditions in the Sea of Azov. Winter hydrographic conditions in the Barents and Kara Seas are illustrated by a unique set of observations made using expendable bathythermosalinographs (XCTD).

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

1. Introduction

Problems relating to thermal regimes and sea ice extent changes at the global and local scale have been discussed at length in the recent scientific literature (Matishov & Dzhenyuk 2012, Levermann et al. 2012, Matishov et al. 2012a,b). Usually, it is the deviations of climatic norms and long-term hydrometeorological trends, which often do not go beyond the bounds of statistical errors, that are analysed. Meanwhile, economic activities in seas and coastal areas as well as the stability of terrestrial and marine ecosystems depend first of all on large and prolonged oceanological anomalies, which do not always coincide with the sign of long-term trends (Matishov 2008).

Strong warming has been recorded in the Arctic Ocean and its shelf seas since the beginning of the 21st century (Matishov et al. 2009, Alekseev et al. 2010, Kattsov & Porfiryev 2011). The positive water temperature anomaly in Atlantic water masses has remained in the Barents Sea for no less than ten years (Matishov et al. 2009, 2012).

The Arctic ice area in summer and autumn has decreased significantly in recent years; as a result, navigation on the Northern Sea Route has taken place without icebreaker support. Parts of the Pechora and Kara Seas were ice-free in the winter of 2011/12, whereas the probability of that condition based on long-term data is close to zero. Meanwhile, at the beginning of 2012 (January and February) the air temperature on Franz Josef Land reached values that were close to the absolute maximum (+ 1–2°C). The position of the ice edge in the Barents Sea was close to its climatic minimum with 1% probability. In the Kara Sea significant areas of water remained open until February. No such climatic data had previously been recorded (*Atlas of the oceans* . . . 1980).

Some researchers believe that the decrease in the ice extent in the Arctic basin in summer and autumn is caused by a change in the large-scale atmospheric circulation (Overland & Wang 2010), which results in an increase of blocking situations and precipitation in Europe in winter (Liu et al. 2012).

At the same time anomalously cold weather in the second half of winter has become a typical phenomenon in central and southern Europe and the adjacent seas (the Sea of Azov, the north-eastern Black Sea, the northern Caspian Sea) (Matishov et al. 2012a, Moore & Renfrew 2012, Tourpali & Zanis 2013). The anomalies in January and February of 2006 and 2012 were especially pronounced. The air temperature in the south of European Russia decreased in January 2006 to −32–33°C; the average monthly values were about −15°C, that is, 12–15°C below the climatic norms. Similar conditions were recorded in January and February 2012. At that period the influence of the Siberian High reached as far as the English Channel and

Portugal. It was the first time in 30 years that the northern part of the Black Sea was frozen, the first time in 80 years when the canals of Venice were iced over, and that piers at harbours on Lake Geneva were covered by ice.

On the Sea of Azov and the Caspian Sea, navigation, which typically does not encounter any obstacles all the year round, was seriously complicated by the ice cover. The duration of the ice period was as long as 50–80 days on the Caspian Sea and the Sea of Azov. About 100 vessels were locked in the ice in offshore areas and in ports of the Sea of Azov and the Kerch Strait in February and March 2012 (Matishov et al. 2012a). On the Caspian Sea the drifting ice spread along the west coast to the Apsheron Peninsula.

At the end of the 19th century the climatologist A. I. Voeikov was analysing the connection between wind and pressure and came to basic conclusions about the development of 'big axis of the European-Asian continent' (Voeikov 1884). The Siberian High with its extension to southwest Europe is known as the axis of Voeikov. This climatic axis manifests itself as a wind divide, which separates winds with a southerly component (to the north of the axis) from winds with a northerly component (to the south of the axis). As a result the anomalous advection of the Siberian High circulation reaches the Pyrenees and at the same time Atlantic waters flow into the Arctic towards Franz Josef Land during winter (Figure 1).

As a consequence, the atmospheric circulation conditions above the northern hemisphere were studied in detail by Vangengeim (1940), Dzerdzeyevskiy et al. (1946), Girs (1971) and Kononova (2009). Several sets of macrosynoptic process types were developed on a similar methodological basis (zonal and meridional transfers with subtypes). The persistence of the blocking anticyclone leads to a cooling of the surface layer of the atmosphere above the continent, and this easterly transfer impairs the warming effect of southern seas.

In our opinion the intensification of these processes in the atmosphere favours the development of weather anomalies, as well as anomalies of hydrological and ice conditions, which are of different signs depending on the season and geographical location of atmospheric transfers. To estimate such anomalies we used a database of climatic and biological parameters of the Arctic and southern seas, which was created as a result of many years' cooperation with NOAA and the World Ocean Data Center of the USA (Moiseev et al. 2012). Furthermore, the anomalous situation in January-March 2012, which is elucidated by a unique set of meteorological and oceanological data, will be considered.

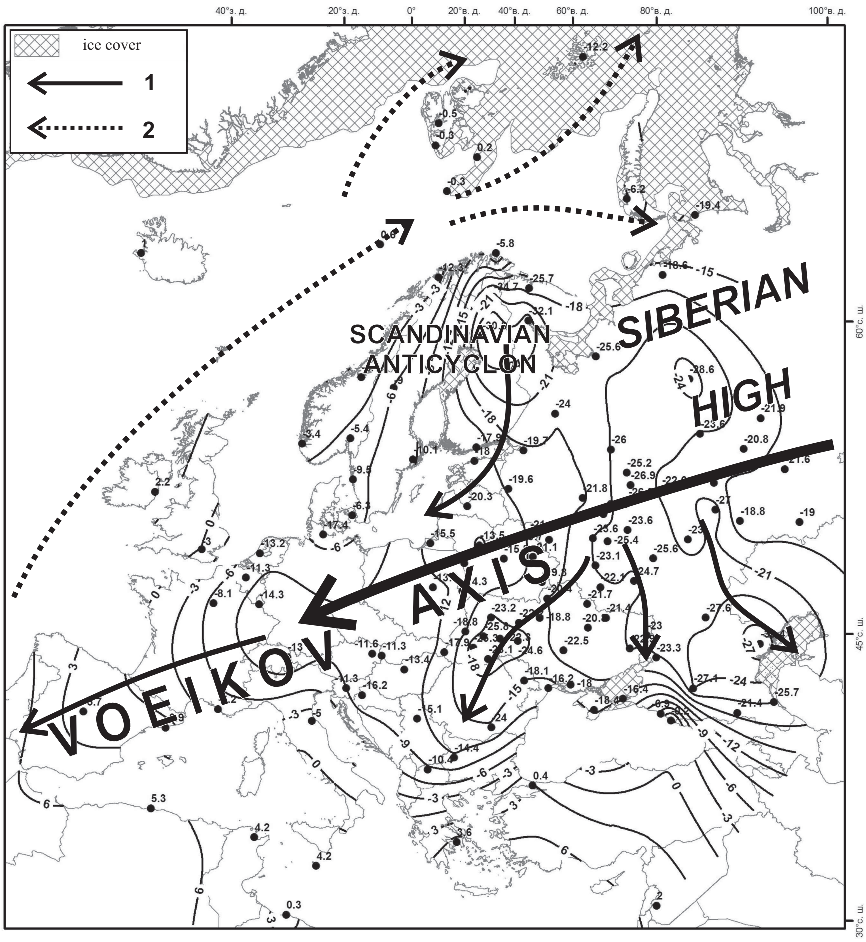

Figure 1. Anomalous spreading of the Siberian High branch: 1 – cold atmospheric inflow; 2 – warm air and water inflows. Isotherms are drawn according to the mean air temperatures for the coldest period of 1–4 February 2012. Minimum air temperatures are shown by digits near every point of observation

2. Material and methods

The schematic map of average surface temperature was drawn using data from the Internet resource 'The weather of Russia' (http://meteo.infospace.ru). The final schematic map based on data from more than 130 weather stations was drawn in ESRI ArcGIS. The isotherms are drawn according to the average surface air temperatures in the coldest period 1–4 February. The minimum temperatures for the same period are also shown (Figure 1).

Information on salinity and water temperature was obtained in the course of observations of the MMBI team on board the diesel-electric ship

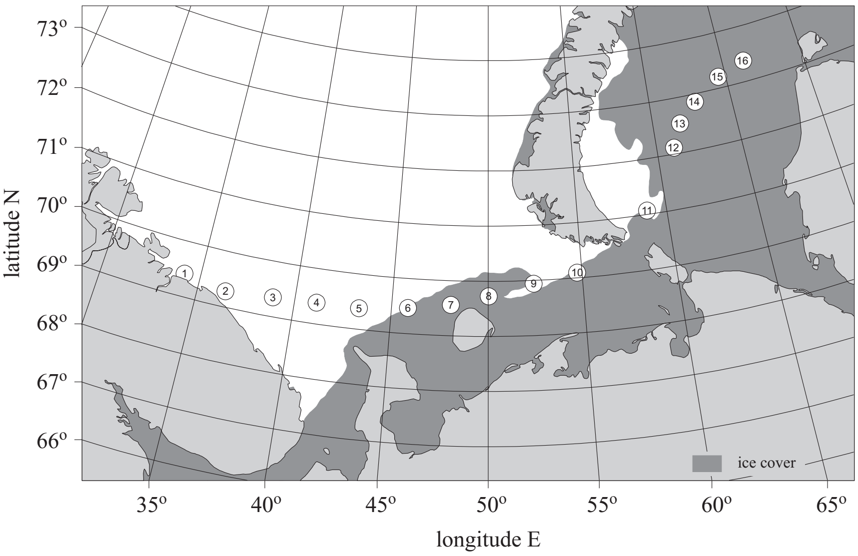

Figure 2. Position of XCTD stations on 11–13 March 2012; ice cover (according to ice analysis of AARI on 11–13 March)

'Talnakh' in March 2012. Two transects were done in the Barents (st. 1–10) and Kara (st. 11–16) Seas (Figure 2). Expendable bathythermosalinographs XCTD-3 (Tsurumi Seiki, Japan) were used for the TS profiling. This method was first tested on board a non-specialised ship along the Northern Sea Route during the ice period. The results of measurements were interpolated and marked on bottom profiles, which were drawn according to bathymetric data from Matishov (1997).

Sea ice data downloaded from the AARI site (http://www.aari.ru) and integrated into the MMBI database were used for calculating the ice anomalies. The ice anomalies of the Sea of Azov were estimated using SSC RAS data collected during winter expeditions in 2005–2012 on board the research vessels 'Professor Panov', 'Deneb', the icebreaker 'Captain Demidov' and other vessels.

3. Results and discussion

3.1. Meteorological situation

The anomalous situation in January–February 2012 was caused by the Siberian High spreading to central and southern Europe (as far as the English Channel and Portugal) and the anomalous advection of Atlantic waters on to the Siberian shelf (Figure 1). The trajectories of Atlantic cyclones deviated northwards, forming a warm air anomaly in the Nordic, Barents and Kara Seas. The intensification of the westerly atmospheric transfer to high latitudes caused the air and sea surface temperatures to increase, ice formation processes to slow down and the ice edge to retreat towards the north-east. Cold air masses from Siberia and central Asia extended to southern Europe and the Mediterranean far to the south of the Voeikov axis in the anticyclonic pressure field.

The blocking situation began to form in the middle of January 2012. An anticyclone centred above the northern Urals had spread to the European part of Russia by 20 January, and to Karelia and Finland by the end of that month. At the same time, the surface pressure in the centre of the anticyclone increased and approached record levels: up to 1055 mb on 27 January and up to 1060 mb from 31 January to 4 February. By this

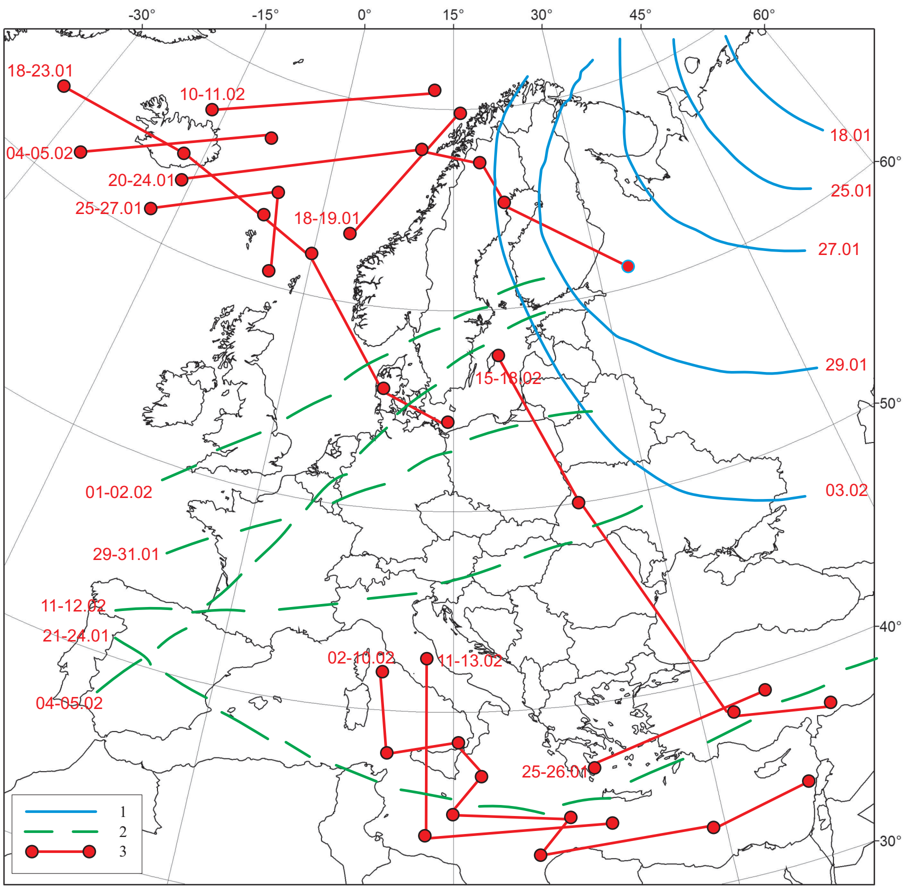

Figure 3. Composite map of atmospheric processes from 18 January to 18 February 2012 (solid line 1 – position of western border of anticyclone, broken line 2 – position of pressure ridge axis, lines with circles 3 – trajectories of cyclones)

time a homogeneous zone of high pressure was covering the whole area of European Russia. The ridge of high pressure above southern and central Europe had stabilised, and the trajectories of cyclones were diverted far to the north and south of the usual directions (Figure 3).

After 5 February the homogeneity of the high pressure zone was broken up by a pressure trough, which spread from central Europe to the White Sea. At the same time the high pressure ridge remained above Scandinavia and the British Isles until 12 February. On 13–14 February it shifted to central Europe, and after 15 February the intrusion of a deep cyclone from the north destroyed the blocking situation completely. Thus, that situation lasted for about 30 days.

In southern Europe during the first days of the above-mentioned period the high pressure ridge spread from the stationary anticyclone along the Mediterranean Sea. The western transfer remained above central Europe. After the passage of the cyclone from Iceland to the south of the Barents Sea and its filling on January 23, the anticyclonic branch occupied eastern and central Europe. Cyclonic activity resumed in this region only on 15 February. Exactly at that time large air temperature anomalies were being recorded: in late January in southern Russia, where the diurnal minimum exceeded -20°, and during the first half of February in the whole of western Europe as far as the British Isles. Temperature records were not exceeded, but the duration and stability of the anomalous frosts had no analogues in the previous two decades, which were generally characterised by warming.

According to B. L. Dzerdzeyevskiy's conception, this situation belongs to the winter subtype of the meridional southern circulation. The recurrence of this type increased significantly from 1986 to 1997, and then began to decrease (Matskovskiy & Kononova 2011). Nevertheless, during the last decade the recurrence of this type is well above the norm, calculated for the whole period covered by the meteorological information (from 1899 to the present).

3.2. Hydrographic conditions

The hydrographic conditions in the freezing Arctic seas from January to March are usually stable. As a result of autumn and winter convection the water temperature in shallow areas of the Pechora Sea is homogeneous from surface to bottom and becomes close to freezing point in the surface layer. Depending on the salinity, ice formation starts from 0° (in the Pechora estuary) to -1.9° on the border of the coastal and offshore water masses (close to 70°N). The salinity is about 32–33 ‰ at the maximum of summer freshening in open areas of the Pechora Sea; when river runoff decreases sharply in January-March, salinity increases to 34.0–34.5 ‰. This is close to the typical salinities of Barents Sea waters (*Hydrometeorology* ... 1991, Loeng 1991).

The Kara Sea is remarkable for its significant variability of salinity, because it receives a river runoff vastly exceeding that of the Barents Sea. In summer, the surface water salinities change from values close to 10 ‰ in areas adjoining the Ob and Yenisei estuaries to 32–33 ‰ (*Changeability* ... 1994). In autumn and winter months the runoffs from those rivers remain significant, because they are formed in vast areas covering several latitudinal zones. However, direct measurements of hydrographic characteristics in winter are very scanty, because traditional oceanographic surveys are impossible in the presence of a solid ice cover.

Analysis of XCTD casts, which were carried out during a cruise of an ice-class vessel, offers an opportunity to detect features of anomalous processes of winter 2012 in the Barents and Kara Seas. The distribution

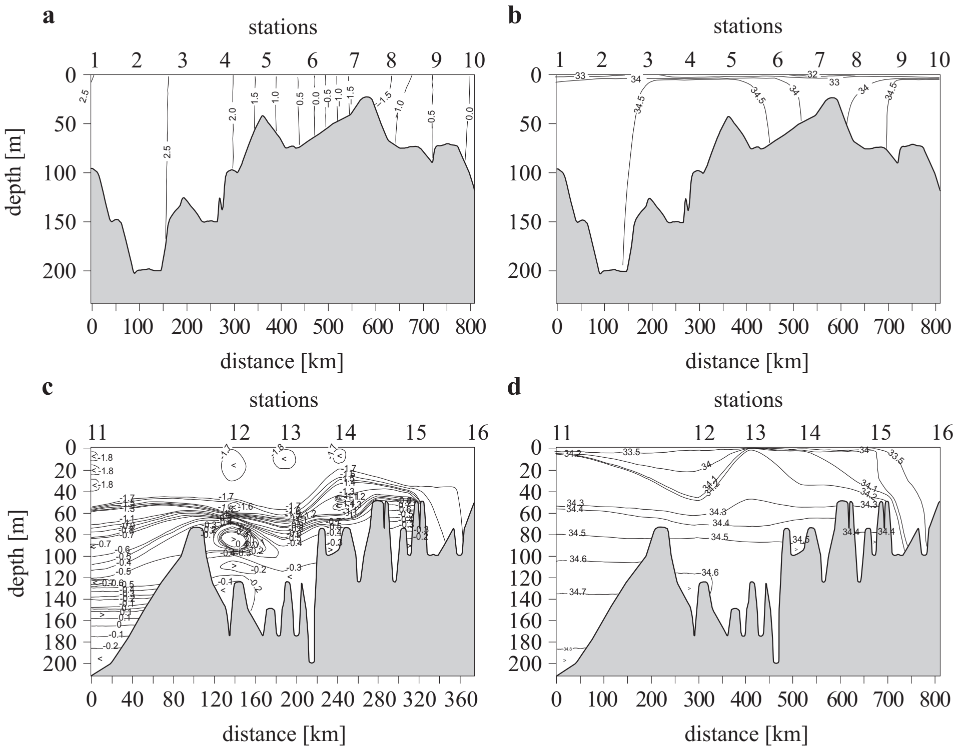

Figure 4. Distribution of temperature (a, c) and salinity (b, d) along transects in the Barents (11–12 March) and Kara (13 March) Seas. The locations of the stations are shown in Figure 2. The bottom profile is drawn according to the bathymetric map of G. Matishov (1997)

of temperature and salinity in this water area is caused by geographical position, bottom topography, ice cover and other factors (Figure 4).

Along the Barents Sea transect, besides the part to the north of Kolguyev Island, the vertical distribution of water temperature was almost homogeneous. Positive temperatures were recorded in the south-western Barents Sea (the zone affected by the warm Murmansk coastal current). From west to east the temperature of the water column decreased from 2.5–2.9°C to negative values in areas near the ice edge. The lowest water temperature on the Barents Sea transect (−1.61°C) was recorded in shallow water (41 m) to the north of Kolguyev Island. Eastwards, to the south of Novaya Zemlya, the temperature became positive under the impact of warm water advection and reached 0.14°C (Figure 4a).

Water salinity on the Barents Sea transect varied from 31.55 to 34.81 ‰. An upper freshened layer from the surface down to 5 m was noted at all the stations. Below that layer, the vertical salinity distribution was homogeneous. In deep parts of the transect more saline waters of Atlantic origin are delineated by the 34.5 ‰ isohaline (Figure 4b). Maximum salinity values (> 34.70 ‰) were recorded under the freshened layer at station 10.

The water temperature on the transect between Novaya Zemlya and the Yamal Peninsula in the Kara Sea was below zero almost everywhere. Only in the trench area (st. 12) in the 80–100 m layer were positive temperatures from 0 to 0.48°C recorded. Lenses of cold water are characteristic of different layers, especially on the shelf with its rugged relief (Figure 4c).

A freshened surface layer, characteristic of the Kara Sea, was recorded. A horizontal salinity gradient is observed in the northern part of the transect. As a whole, water salinity on the Kara Sea transect varied from 31.79 to 34.82 ‰. The highest salinity values were recorded in surface and bottom layers of the Novozemelskiy trough area close to station 11 (Figure 4d). The atypical temperature of the surface layer in winter prevented ice formation in the Kara Sea (Figure 2).

3.3. Ice conditions

The peculiarities of the atmospheric circulation noted above, the positive anomalies of air and water temperatures impeded ice formation and the growth of ice thickness in the European sector of the Arctic in the winter of 2012. The ice edge in the Greenland and Barents Seas was situated much further to the north and to the east from its average annual position (Figure 5). Ice was not noted in almost all the coastal waters of Svalbard and Novaya Zemlya. Vast expanses of open water were seen in the Kara Sea

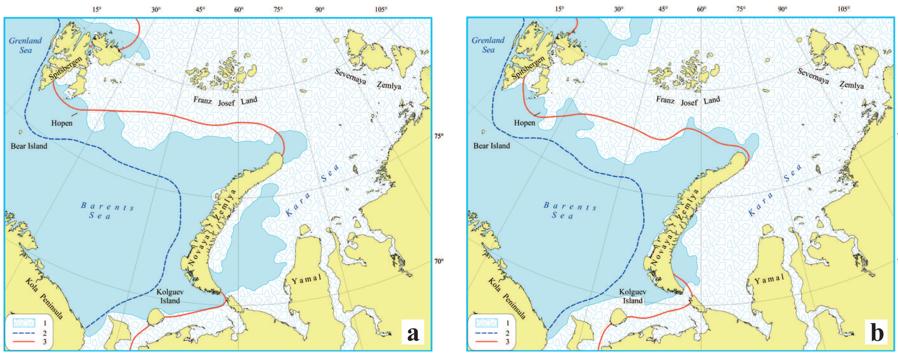

Figure 5. Ice extent in the Barents and Kara Seas in February (a) and March (b) 2012: 1 – ice extent; 2 – median ice extent from 1977 to 2012; 3 – minimum sea ice extent from 1977 to 2012

in winter for the first time in 30 years. In February almost the whole south-western part of the sea was ice-free (Figure 5). The extensive Vostochno-Novozemelskaya polynya remained here in March, which is the month of the maximum ice cover extent in the Arctic according to average annual data (Figure 5b).

The Barents Sea is distinguished by the great interannual and seasonal variability of its ice regime (*Hydrometeorology* ... 1990, Vinje 2001, Zhichkin 2010). Analysis of ice anomalies in the Barents Sea in winter (January–March) during the last decade showed that the first decrease of the ice area to minimum values took place in 2008. After that, there was a growth in the ice extent during the next three years, and it became close to the annual average in the winter of 2011. However, in winter 2012 as in 2008, the ice coverage decreased sharply to minimum values (Figure 6).

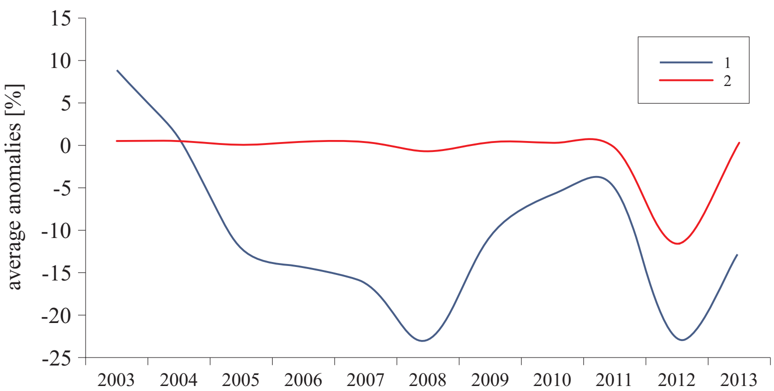

Figure 6. Average anomalies of the ice extent [%] in the Barents (1) and Kara (2) Seas in winter (January–March) from 2003 to 2013

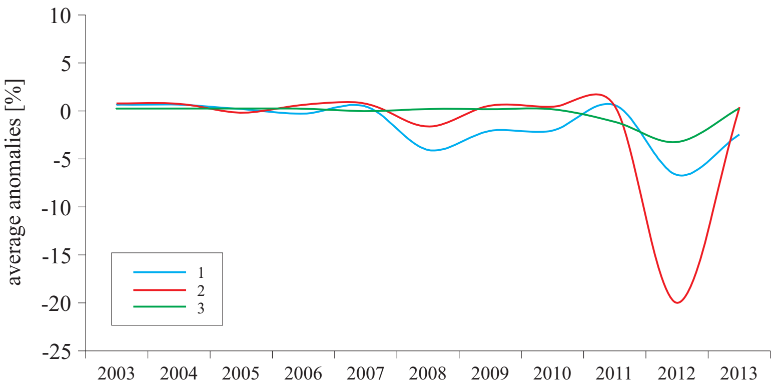

Figure 7. Ice extent anomalies [%] in the Kara Sea in winter from 2003 to 2013 (1 – January, 2 – February, 3 – March)

Figure 8. Ice breaker in the Sea of Azov on 25 March 2012

The ice extent in the Kara Sea in the winter months during the last 10 years was stable, and anomalies of both signs were insignificant. February 2012 was the most anomalous of the winter months in the Kara Sea, when the ice extent anomaly dropped sharply to −20% (Figure 7).

During the winter of 2013 under the changing conditions of the large-scale atmospheric circulation in the northern hemisphere, the ice extent tended to increase in the Barents and Kara Seas (Figure 6). In the Kara Sea in February–March this parameter was close to average values (Figure 7).

At the same time in the southern seas, ice conditions in February–March 2012 were anomalously severe (Figure 8). Thus, there were difficult ice conditions in the Sea of Azov, according to satellite and icebreaker data. The entire area of the sea was covered by ice (this state is observed in $< 50\%$ of winters). The ice was scarcely passable, with marked drifting, pressing and hummocking. Fast ice with a thickness from 20 cm in the Kerch Strait to 50–70 cm in Taganrog Bay formed in the coastal zone. In February–March ice thicknesses of up to 50–80 cm, and in hummocks up to 4 m, were recorded in the Azov-Don Channel in the eastern part of Taganrog Bay.

4. Discussion

The large-scale thermal anomaly that spread in the first months of 2012 over the whole of Europe and the adjacent Arctic and southern seas, occurred against the background of diverse climatic tendencies. As we showed in previous papers (Matishov et al. 2009, 2011), since the beginning of the 21st century a prolonged warm anomaly has remained in the western Arctic. Comparable in intensity to 'the Arctic warming' in the first half of the last century, it conforms to the viewpoint of AARI specialists (Frolov et al. 2010) about the presence of a 60-year cycle governing Arctic sea ice fluctuation, and a 200-year cycle of solar radiation arriving at the Earth. The overlap of these cycles gives grounds for considering that temperature decrease and ice growth are more likely than the warming by 2030–2040 predicted by the results of some model calculations (Kattsov & Porfiryev 2011). It is obvious that without taking into account inter-century cycles, it is impossible to analyse the climate and state of the large marine ecosystems of the North Atlantic and the Arctic.

Experience of Arctic navigation has demonstrated the existence of such a 60-year cycle and the warm anomalies it caused in the period not covered by regular observations. As is generally known, in 1878–1879 the expedition on board the 'Vega', a non-icebreaking vessel, under the leadership of A. E. Nordenskiöld sailed all the way along the Northern Sea Route, encountering impassable ice only on the way to the Bering Strait (Nordenskiöld 1887). Nowadays, the possibility of the open passage of vessels along the Northern Sea Route is being interpreted as a feature of irreversible global warming (Stephenson et al. 2013).

Apart from that, many works on climate changeability have singled out cycles of shorter duration, the best known of which is the 11-year cycle caused by changes in solar activity. All cases of Kola Bay freezing were documented over a period of more than 100 years, so it can be regarded as one of the indicators of climatic cycles in the Arctic seas. In the 20th century Kola Bay freezing occurred at intervals close to 30 years (Matishov et al. 2009). These situations were caused by a combination of meteorological and hydrographic factors. The presence of a stable anticyclone above Scandinavia for a long time (no less than ten days) is a significant factor in this.

Certainly, climate cycles do not run like clockwork. An example of their disruption was the situation on the Bering Sea shelf at the beginning of 2012. Ice remained there for a record time, more than 100 days. During the history of satellite observations (since 1979), this happened for just the second time.

The role of macrosynoptic processes in the formation of anomalies in the European climate, as well as hydrographic and ice extent regime of the Arctic seas, requires further research. The warming of 1990–2000 occurred under conditions of intensive western and eastern transfer in middle latitudes. During recent years, the recurrence and especially the duration of anticyclonic blocking above Eurasia has increased, which has led to the forcing of a continental type of climate. At the same time the trajectories of north Atlantic cyclones have shifted to high latitudes, and that is favourable for positive anomalies of water temperatures and ice extent decrease in the Arctic seas in both the warm and cold seasons. In central and southern Europe, the Black and Caspian Seas, and also the Sea of Azov, such situations cause strong positive anomalies of air and water in summer, and sharp falls of temperature and extensive ice formation in winter.

In the opinion of Shakina & Ivanova (2012) the development of a blocking situation can nowadays be successfully forecast only after it has actually come into existence. Given the current level of knowledge is not possible to predict the emergence of such a situation, and especially its duration. Therefore, it is necessary to obtain a probabilistic estimate of such anomalies from both the synoptic meteorology point of view (the frequency and duration of blocking situations, the intensity and location of pressure fields at different levels) and the use of climatological criteria.

5. Conclusion

In the course of research into the global climate and ocean regimes it is important to expedite the development of new technologies and software as well as the improvement of computation algorithms for climate norms and anomalies. Not just oceanological but also hydrobiological data should be used for marine climate assessments. Thus, according to the biomass changes of some species of polychaetes and crustaceans, it appears that fauna react to temperature anomalies with a 3–8 year delay (Matishov et al. 2012b). That is why the warm anomaly in the Barents and Kara Seas, examined above, is expected to affect marine ecosystems until the end of the current decade.

Climate anomaly assessments are especially important in the context of the prospective activities of oil and gas companies on the Barents and Kara Sea shelves. No less important are the ice conditions along the Northern Sea Route. The warming of 2000–2012 has already led to the refusal of ice-breaker support from companies participating in Arctic shipping. The reverse trend may bring about unfavourable consequences for all kinds of economic activity in the Russian Arctic.

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