Analysis of climate changes of Arctic tundra zone with help of Virtual Globe

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Arctic climatic change

Climatic variations of the beginning of XXI century are especially brightly shown in the Arctic region. During the last nine years the Arctic ice area was reduced very substantially and in 2007 it was minimal during all period of observations [1]. The 2010 minimum ice extent was the third-lowest recorded since 1979. The 2010 minimum ice extent was 470 000 square kilometers above the record minimum in 2007, and 500 000 square kilometers below 2009, previously the third lowest extent since 1979 (Fig.2) [13].

These processes are accompanied by corresponding response of terrestrial landscapes in Northern Polar Region. The Russian Arctic Region is the most industrialized versus the other Arctic states and makes very high contribution to extraction and transportation of the Russian mineral resources. Intensity of mineral resources transportation by sea substantially depends on an ice cover and landscapes condition of the Arctic region. Hence all further changes of landscapes during global climate warming require careful investigation and contiguous monitoring [2].

The present study is aimed to development of the specialized geoinformation system (GIS). With help of this GIS it is possible to visualize the various types of the meteorological, hydrological and sea ice data on the background of Arctic region geographical landscapes [3]. Also GIS allows us to reveal various types of communications between characteristics of an ice cover and the collection of the hydrometeorological datasets in three-dimensional space of Virtual Globe.

Data sources

- Data of microwave radiometers SMMR and SSM/I from dataset of satellite observations NCDIS (United States National Snow and Ice Data Center) were used as base for analysis of the ice fields variability. There were used the sea ice concentration and sea ice extent data from 1978 to 2009. Monthly averaged sea ice concentration data was supplied as 25 x 25 km grid and sea ice extent as vector polygons, both in polar stereographic projection [7].

- The monthly average dataset of sea level pressure for this study is from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The data was supplied as 5° x 5° grid in geographic coordinate system from 1978 to 2009. The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds010.1 [8].

- Surface air temperature anomalies are from the GHCN V2 monthly temperature data sets (National Climatic Data Center). The data was supplied as 5° x 5° grid in geographic coordinate system from 1978 to 2009. Anomalies were calculated on a monthly basis in the 1961-1990 base period [9].

- The Sea Surface Temperature anomalies data was calculated from the Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST). The SSM/I radiometr is used to provide the data for the sea ice analysis [10]. The data was supplied as 1° x 1° grid in geographic coordinate system from 1978 to 2009. Anomalies were calculated on a monthly basis in the 1961-1990 base period.

- The Monthly Mean Wind vector components were derived from the NCEP/NCAR Reanalysis 1 project for 0.995 sigma level. The data was supplied as 2.5° x 2.5° grid in geographic coordinate system from 1978 to 2009 [11].

- Digital elevation model GTOPO30 was created by USGS. The data was supplied as 30" x 30" grid in geographic coordinate system [12].

Figure 1. Arctic Sea Ice Extent (Area of ocean with at least 15% sea ice).

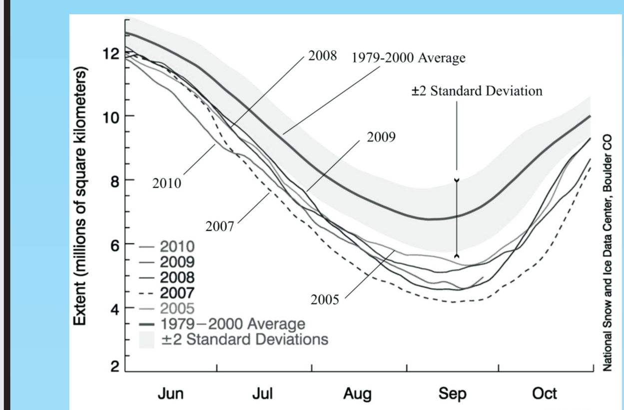


Figure 2. Sea Ice Concentration in the Google Earth.

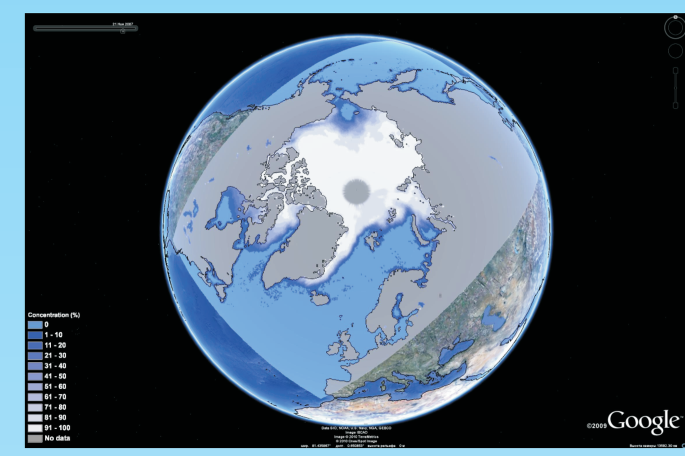


Figure 3. Sea Level Pressure in the Google Earth.

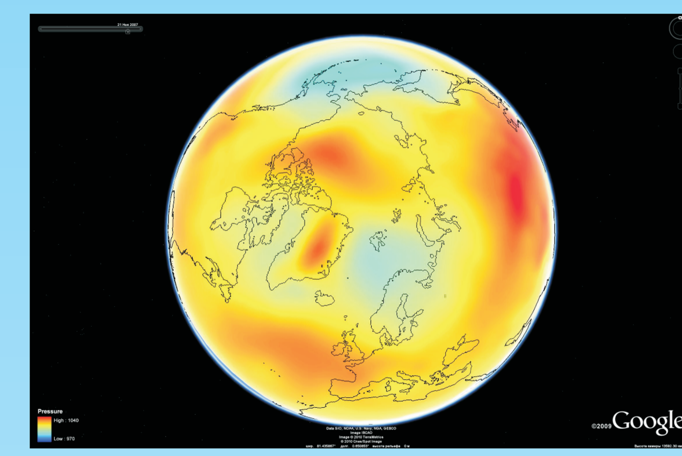


Figure 4. Jointly presentation of Sea Ice Extent and Sea Level Pressure in the Google Earth.

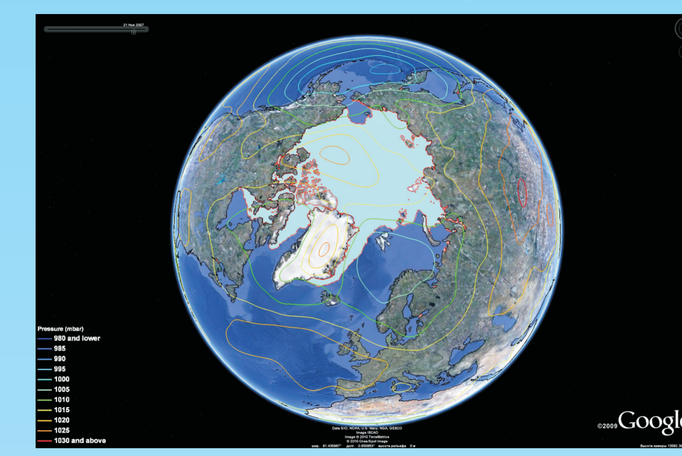


Figure 5. Scheme of the spatial data forming process for presentation in the GIS.

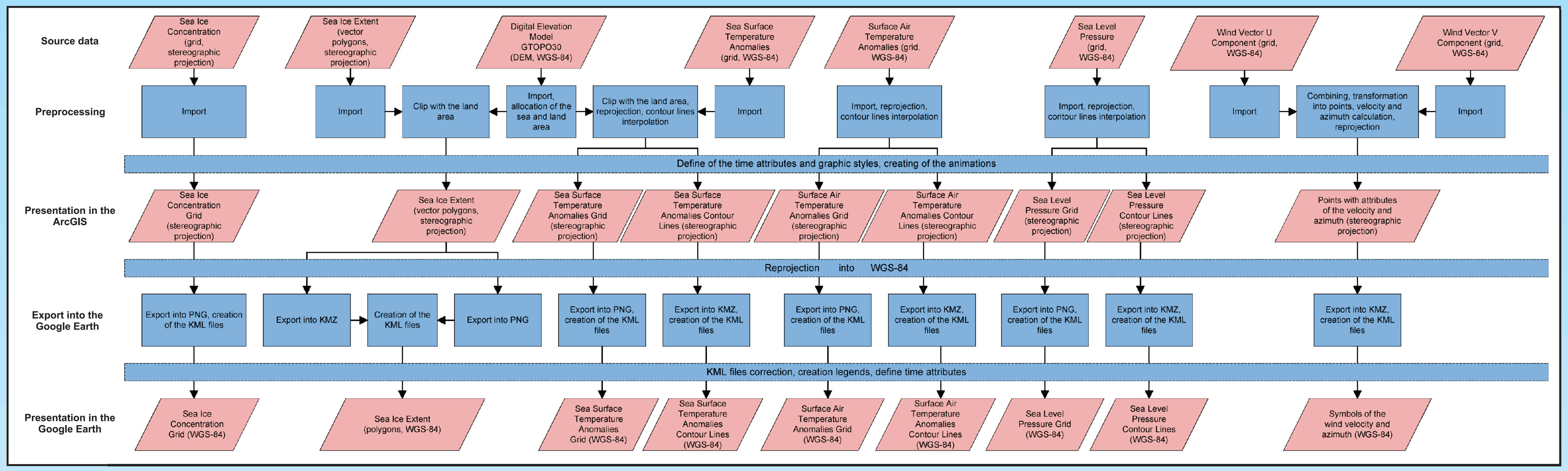
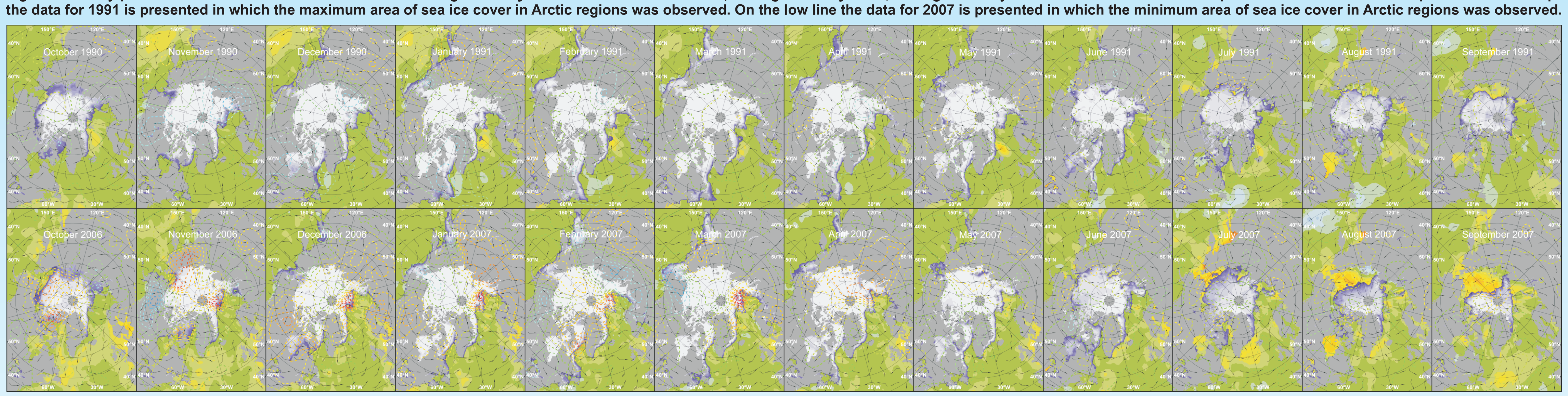


Figure 6. Jointly presentation in the ArcGIS for next fields - Average Monthly Arctic Sea Ice Concentration, Average Monthly Wind, Average Monthly Anomalies of Sea Surface Temperature and Surface Air Temperature. On the top line the data for 1991 is presented in which the maximum area of sea ice cover in Arctic regions was observed. On the low line the data for 2007 is presented in which the minimum area of sea ice cover in Arctic regions was observed.



Sea Ice Concentration (%): 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100

Average Monthly Anomalies of Sea Surface Temperature (°C): < -9, -9 - -8, -8 - -7, -7 - -6, -6 - -5, -5 - -4, -4 - -3, -3 - -2, -2 - -1, -1 - 0, 0 - 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, 6 - 7, 7 - 8, 8 - 9, > 9

Average Monthly Surface Air Temperature Anomalies (°C): -14, -12, -10, -8, -6, -4, -2, 0, 2, 4, 6, 8, 10, 12, 14

Average Monthly Wind: Arrow shows wind direction, long switch tongue 5 mps, short switch tongue - 2.5 mps

Tools and methods

Progress of data visualization technologies by means of such software products as Google Earth™ and ArcGIS™ gives the possibility of presentation and the visual analysis of three-dimensional hydrometeorological fields. In this research the two-component Geoinformation System (GIS) has been developed on the base of Google Earth and ArcGIS. ArcGIS was used for gathering, processing and for joint analysis of various datasets of hydrometeorological observations, whereas Google Earth is intended for representation of these data to a wide range of users via Internet.

For data presentation in Google Earth all databases have been transformed to KML files. All presented databases have been structured in the ArcGIS environment and supplied by time attributes. Data processing and conversion have been automated partially with help of the Cartometry® ArcGIS extension [4]. The data transformation process from ArcGIS to Google Earth software became an important part of work because of data processing and results representation were realized in different software.

For storage and data presentation in the ArcGIS was used the stereographic projection that help us to keep spatial similarity of objects in polar regions, but Google Earth demanded the reprojection of data to geodetic system of coordinates WGS-84. Therefore the following scheme for data export to the Google Earth has been chosen:

- Vector layers have been transformed into KML with preservation of graphic design by means of the internal ArcGIS converter.
- In KML format all vector layers have been grouped by years, the time attributes for each layer have been appropriated and legend was added.
- All raster layers has been exported to PNG format. The optimum spatial resolution in geodetic coordinate system has been calculated using "Cartometry" tool [5, 6]. This operation allows to reduce volume of databases without quality loss.
- The KML files with the time attributes, references to corresponding raster layers and legends have been created. Thus, storing raster data in external files gives the possibility to display these layers in Google Earth without lost in images quality.

The ample automation opportunities for almost all processes may be a base for creation of specialized tools set in the near future.

Data processing

There are two main stages of data processing:
- Import, a preliminary processing and visualization in ArcGIS;
- Export, correction and visualization in Google Earth.

The scheme displays general sequence of data processing and data characteristics for the each stage of processing.

It is necessary to note the considerable volume and frequent time discreteness of data involve a large laboriousness of these two stages. Also there is a potential wide opportunities for automation of the data processing. These opportunities could be realized through creation of the special ArcObjects™ based tools. In our project we utilized the models of batch data processing to automate the first stage of processing. But creation of the KML files and animations carried out manually because of insufficient automation means of ArcGIS for these tasks.

The second stage of processing takes a lot of human resources because we need to export into the KML not only datasets but also their graphic styles executed in ArcGIS and time attributes.

The standard export function permits to keep graphic styles of the data but not allow set the time attributes. Also this tool has no options to define spatial resolution for raster data thus quality of the exported raster in the most cases not applicable for the high quality visualization. Instead, if we will use the external converters then we cannot to keep the graphic styles.

As results the vector data was transformed layer by layer into the KML with the help of standard converter with preservation of graphic styles. After that KML files has been manually patched in accordance with time attribute of each dataset. Each layer supplied with the legend. The raster data was exported also layer by layer into the PNG format. Optimal spatial resolution in geographic coordinate system has been calculated with the help of Cartometry. That made it possible to reduce the data volume without worsening of the data quality. Then the KML files were appended with the time attributes and references to the corresponding raster layers and legends.

Applications

Proposed by the authors GIS has a high educational and research potential as the tool for joint analysis of the remote sensing data and hydrometeorological observations in the virtual geographical environment. ArcGIS and Google Earth software used for development of the GIS gives possibility to visualize information in the form of Virtual Globe with ability to change a scale, point of view, and orientation in space of the investigated fields. Using of such additional possibilities as asynchronous representation of different hydrometeorological processes at the time scale give an unquestionable advantage of this GIS over standard techniques of visualization and analysis.

These advantages are as follows:
- Multiple datasets simultaneous representation.
- Animation of the data.
- Presentation of the data fields on the various types of underlying surface.
- Asynchronous data analysis.
- Visualization data in the Arctic region occurs without any distortions of map projections.

Use of analytical GIS-tools permits to study the dependences between characteristics of the ice landscapes and a parameters of the atmosphere and hydrosphere in Arctic Region with the help of the mathematical statistics. At present time the connection of analytical tools to the GIS is possible only in the ArcGIS. But authors hope that the swift progress of the Virtual Globe technology will bring such toolkits to the Google Earth too in the nearest future.

This GIS offer exciting and dynamic ways to present data that may enhance data availability, and understanding. It is the authors' opinion that the main users of GIS system could be the students, graduate students and researches interested in the formation of the Arctic ice cover as well as the wide range of the unprofessional users.

Example of ice conditions formation process in Arctic regions with the help of GIS

Let's to conduct analysis of the ice formation process for 1991 and 2007 years with help of our GIS. These years were selected because their ice landscapes characteristics in Arctic regions considerably differed from each other. So in 2007 the minimum ice extent in Arctic regions for all period of observations has been fixed, on the contrary in 1991 the ice extent area was near norm.

With help of our GIS, we have an opportunity of the joint analysis of ice characteristics, sea level pressure (SLP), wind vector components, surface air temperature (SAT) and sea surface temperature (SST).

Two series of maps are represented in Fig 6. Each series of maps includes five calendar months from October 1990 to September 1991 and from October 2006 to September, 2007 accordingly.

The analysis of Fig 6 shows that from October, 2006 to March 2007 in the Arctic and Subarctic regions exist the considerable SAT positive anomalies and negative anomalies of SLP. The area of the negative SLP anomaly support the transfer to the western Arctic regions the Atlantic warm air and support in this area the positive SAT anomaly practically within all winter season. The cyclonic processes prevent to the intensive runoff of sea ice to the Atlantic and on the contrary, intensified of warm waters inflow from North Atlantic Current.

The directions of air streams in Arctic was changed of positive SLP anomaly since June. The anticyclonic type of atmospheric circulation over the Arctic regions from June till September was favorable for incoming solar radiation. Because the solar radiation is a principal reason for melting of the Arctic sea ices hence such favorable combination of all hydrometeorological factors leads to intensive sea ice destruction. The intensive melting of sea ice occurred on a low background of ice cover.

The complex analysis leads us to the conclusion that abnormal small area of sea ice cover in Arctic basin in 2007 was is caused by favorable combination of atmospheric circulation, positive North Atlantic SST anomalies, positive surface temperature anomalies and a low background of ice extent.

In contrast to 2007 - 1991 is year with the normal process formation of sea ice cover. The Western and Central part of Arctic From November to May of the winter of 1990-1991 was under the influence of SAT negative anomalies and SLP positive anomalies. These positive SLP anomalies remained in the Arctic region since November 1990 till March, 1991. These positive SLP anomalies remained in the Arctic region since November 1990 till March, 1991. The anticyclonic type of circulation led to a considerable radiating cooling of the Arctic area during the autumn-winter ice cover formation period. Less considerable than in 2007, SST anomalies in Northern Atlantic, were under the influence of northern winds. These winds were prevented of warm waters flow from Northern Atlantic to Arctic basin. The similar types of processes were observed in the East part of Arctic regions.

From April to August 1991the atmospheric circulating in the Arctic region were changed to cyclonic processes. Hence, during a summer season of 1991 ice melting was weakened. The considered processes of 1990-1991 occurred on the background of more high ice extent, than in 2007. As result the sea ice cover in 1991 was more than in 2007.

Now is possible to draw a next conclusion - ice area in Arctic regions are changed under the influence of a set of hydrometeorological factors and despite the general rise in Arctic air temperature, the area of the Arctic ice cover can fall and grow. Therefore we consider that the factor of "Global Warming" can be completely compensated by atmospheric circulating processes.

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