Biennial Report 2011-2012

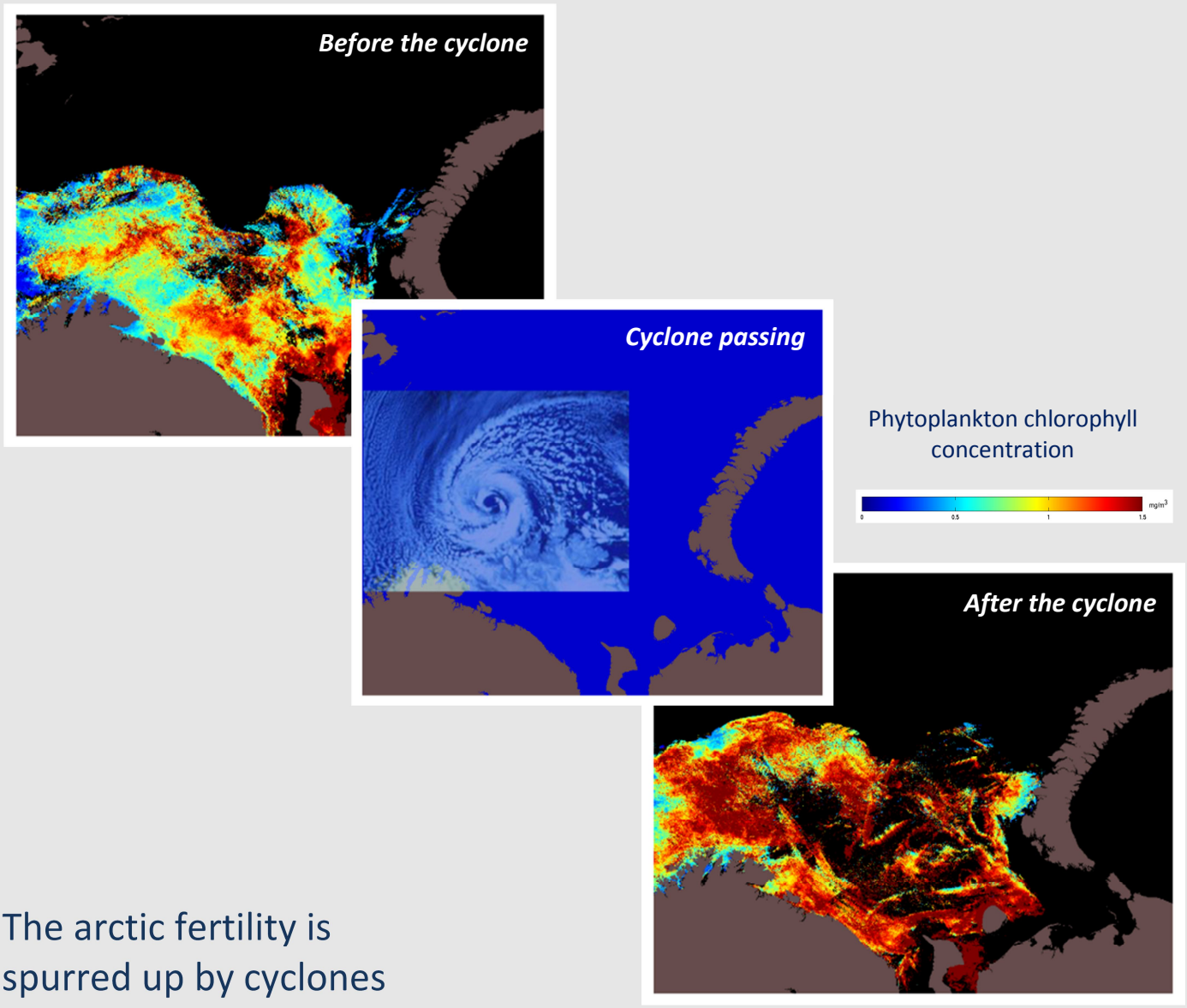
Nansen International Environmental and Remote Sensing Centre

St. Petersburg, Russia

a non-profit international research institute for environmental and climate research

Founded in 1992

1992-2012
20 years in science



The arctic fertility is spurred up by cyclones

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Bergen, Norway

Max Planck Society
Munich, Germany

Nansen Environmental and Remote Sensing Centre
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Saint-Petersburg State University
Saint-Petersburg, Russia

Scientific Research Centre for Ecological Safety of Russian Academy of Science
Saint-Petersburg, Russia

With the initial support of
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Dr. Dmitry V. Kovalevsky, Research Director,
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Report from the General Meeting of Founders

Vision

The Scientific Foundation "Nansen International Environmental and Remote Sensing Centre" (Nansen Centre, NIERSC) vision is to understand, monitor and predict climate and environmental changes in the high northern latitudes for serving the Society.

Major Research Areas

- Climate Variability and Change in High Northern Latitudes
- Atmosphere-Ocean Interaction
- Aquatic Ecosystems in Response to Global Change
- Applied Meteorological and Oceanographic Research for Industrial Activities
- Socioeconomic Impact of Climate Change

Organization

NIERSC is an independent non-profit international research foundation established by Russian, Norwegian, German and US research organizations. NIERSC conducts basic and applied environmental and climate research funded by the national and international governmental agencies, research councils, space agencies and industry. Additionally, NIERSC receives basic funding from its Founder – Nansen Environmental and Remote Sensing centre.

NIERSC was founded in 1992 and re-registered at the St. Petersburg Administration Registration Chamber into a non-profit scientific foundation in 2001. The Centre got accreditation at the Ministry of Industry, Science and Technology of the Russian Federation as a scientific institution in 2002 and was re-registered in 2006 according to a new legislation on Non-Commercial Organizations of the Russian Federation.

NIERSC got a license for conducting meteorological and oceanographic observations from Roshydromet in 2006.

In 2008 NIERSC received also a license from Roscosmos for conducting the space-related research activities.

Staff

At the end of 2012 the NIERSC staff incorporated 29 employees comprising core scientists, including 3 full Doctors of Science and 4 with a PhD degree, part-time researchers, and administrative personnel. 9 Nansen Fellowship PhD-students are supervised, 5 of them holding also part-time positions of Junior Scientist at NIERSC. In December 2012 NIERSC lost Dr. Vitaly Alexandrov, famous scientist and excellent expert in the Arctic sea ice research.

Production

In 2011-2012 totally 80 publications were published including two books, nine chapters in books, 16 papers in peer reviewed journals, 8 papers in other journals and 55 conference proceedings (see the Reference list).

National and International Activities

NIERSC has a long-lasting cooperation with Russian organisations such as St. Petersburg State University, institutions of the Russian Academy of Science, Federal Space Agency, Federal Service for Hydrometeorology and Environmental Monitoring including the Northern Water Problems Institute, Scientific Research Centre for Ecological Safety, Arctic and Antarctic Research Institute, Russian State Hydrometeorological University, Voeikov Main Geophysical Observatory, Murmansk Marine Biological Institute, Research Centre of Operational Earth Monitoring and other, totally about 40 institutions.

Fruitful relations are established also with a number of foreign and international organizations, universities and institutions including Max-Planck Institute for Meteorology, GKSS Research Centre, Friedrich-Schiller-University in Jena, Germany, Finnish Meteorological Institute, Institut Français de recherche pour l'exploitation de la mer (IFREMER) in Brest, France, Global Climate Forum, and especially with the NIERSC founders. Close cooperation is established with the Nansen Centre in Bergen. Most of scientific results described below are achieved within the joint research activities of both Nansen Centres, in St. Petersburg and Bergen.

Cover: *From top left to bottom right: field of phytoplankton biomass prior to cyclone passage, cyclone arrival in the southern Barents Sea, field of phytoplankton enhanced biomass after the cyclone passage*

Nansen Fellowship Programme

The main objective of the Nansen Fellowship Program (NFP) at NIERSC is to support PhD-students at Russian educational and research institutions, including Russian State Hydrometeorological University, St. Petersburg State University, Arctic and Antarctic Research Institute, and others. The research areas are climate and environmental change and satellite remote sensing, including integrated use of satellite Earth observation techniques in combination with supporting *in situ* observations and numerical modeling for studies of the Earth system.

NFP provides the PhD-students with:

- Russian and international scientific supervision
- financial fellowship
- efficient working conditions at NIERSC
- training and research visits to international research institutions within the Nansen Group and beyond
- involvement into international research projects.

The postgraduate student activity is supervised by at least one Russian and one international senior scientist. All NFP PhD-students have to publish their scientific results in the international refereed journals and make presentations at the international scientific symposia and conferences.

23 young Russian PhD-students have since 1997 got their doctoral degree under the NFP.

NFP is sponsored by core funding from the Nansen Center in Bergen, Norway (NERSC) and the Nansen Scientific Society.

In 2011-2012, three NFP participants defended their PhD theses:

- **Alexander Smirnov.** Defended at the Arctic and Antarctic Research Institute on 14 April 2011. Title of PhD thesis: *Evolution of the ocean upper layer in the North-European basin*. Supervisors: G. Alekseev, Ola M. Johannessen.
- **Sergey Semakin.** Defended at the St. Petersburg State University on 20 June 2011. Title of PhD thesis: *Satellite retrieval of stratospheric aerosol parameters from measurements of scattered solar radiation at the Earth horizon*. Supervisors: Yury Timofeev and Hartmut Grassl
- **Ivan Sudakov.** Defended at the Novgorod State University on 26 January 2012. Title of PhD thesis: *Mathematical modelling of cryolithozone–atmosphere interaction.* Supervisors: Tamara Sukacheva, Sergey Vakulenko, Leonid Bobylev, Gennady Menzhulin.

Research Projects

Below is the list of the research projects implemented at NIERSC in 2011-2012. Most of them were implemented in close cooperation with other national and international scientific institutions.

Arctic and sub-Arctic climate system and ecological response to the early 20th century warming (ARCWARM, Research Council of Norway, 2008-2011)

Deterministic and stochastic models of economic dynamics (RFBR, 2010-2011)

Logiciel modelisation Matlab (IFREMER, 2011)

Agent-based modeling of climate-socioeconomic system with applications to the sustainability of Russian economy (ECF, 2010-2011)

System-dynamic Integrated Assessment models with endogenous technical change (Nansen Scientific Society, 2011)

Descartes Program (EU Descartes award fund, 2008-2012)

MyOcean (EU FP7, 2009-2012)

MyOcean-2 (EU FP7, 2012-2014)

Monitoring and Assessing Regional Climate Change in High Latitudes and the Arctic (MONARCH-A, 2010-2013)

Economics of climate change in a multiregional Integrated Assessment model for the Russian Federation (RFBR, 2010-2012)

Processing Russian satellite measurements (NTSOMZ/Roscosmos, 2011-2013)

Monitoring Arctic Land and Sea Ice using Russian and European Satellites (MAIRES, EU FP7, 2011-2014)

Sea Ice Downstream Services for Arctic and Antarctic Users and Stakeholders (SIDARUS, EU FP7, 2011-2013)

Foreign direct investment and international trade in multi-region Integrated Assessment models (ECF/NERSC, 2011-2012)

CryoSat postlaunch validation study of sea ice (PRODEX NERSC, 2011-2012)

Impact of global climate change on the processes in the Arctic ocean and atmosphere (AARI, 2011-2012)

Towards Coast to Coast NETworks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential (COCONET, EU-FP7/NERSC s/c, 2012-2015)

European-Russian Centre for cooperation in the Arctic and Sub-Arctic environmental and climate research (EuRuCAS, EU FP7, 2012-2015)

Nordic seas ocean climate (NERSC, 2012)

Assessing the sensitivity of Arctic coastal dynamics to change (RFBR-Helmholtz Gemainschaft, 2009-2012)

Investigation of factors driving changes in phytoplankton surficial fields as an aftermath of passage of hurricanes in tropical and polar regions (RFBR, joint Russian-Chinese call, 2012-2013)

Sea ice ECV (ESA/NERSC s/c, 2012-2014)

Optimization and system-dynamic approaches to models of economics of climate change (RFBR, 2012-2014)

CPA Algorithm (MichiganTech, 2011-2013)

Knowledge Based Climate Mitigation Systems for a Low Carbon Economy (COMPLEX, EU FP7, 2012-2016)

The EuRuCAS Project (EU FP7, 2012-2015)

EuRuCAS (European-Russian Centre for cooperation in the Arctic and Sub-Arctic environmental and climate research) is one of the projects funded within 2010 EU FP7 INCO-LAB call "Strengthening European research facilities in third countries", and the only one in Russia. It uses NIERSC as the joint research facility to extend and consolidate scientific co-operation between European and Russian researchers in the area of climate and environmental changes in the Arctic and sub-Arctic in the 21st century and their socio-economic impact.

1992-2012: 20 Years in Science

On 19th October 2012 NIERSC celebrated its 20th anniversary. The staff of our centre looks into the future with optimism and is ready for conducting the research in the framework of new research projects and for supervising new promising PhD students.

St.Petersburg, 21th November 2012

Jean-Pierre Contzen, UNIFOB, *President*

Valentin Meleshko, VMGO, *Co-President*

Hartmut Grassl, Max-Plank Society, *Co-Vice President*

Lasse H. Pettersson, NERSC, *Co-Vice President*

Valery Astakhov, SPbSU

Vladislav Donchenko, SRCES RAS

Nickolay Filatov, NWPI RAS

Leonid P. Bobylev, *Director*

SCIENTIFIC REPORT

Climate Variability and Change

Temperature dependence of the Northern Hemisphere sea ice extent from observations and models

Dr. Svetlana I. Kuzmina

Prof. Ola M. Johannessen (NERSC, Norway)

Dr. Olga G. Aniskina

Dr. Leonid P. Bobylev

We estimate how well the modern climate models reproduce the interrelated changes of the Northern Hemisphere sea ice extent (SIE) and surface air temperature (SAT) and assess their future changes. The analysis is based on the ensemble of IPCC AR4 global climate models and is performed both for the whole Arctic Ocean and for the different seas. The model ensemble overestimates SIE and underestimates its trend rates. Biases in sea ice concentration derived from observations and models are most pronounced in the Barents, Kara, Laptev and East-Siberian seas exceeding 80%. Model mean underestimates SAT for the Northern Hemisphere. SAT biases are the largest in the Barents Sea and amount more than 8°C. Mean modeled sensitivity of SIE to SAT changes is almost two times smaller than observed. Greenhouse warming reduces the sea ice coverage in the AR4 model simulations, especially during summer and in the coastal Arctic seas, although there is a considerable range among projections. Sea ice retreat projected is not consistent with its trends observed during the past decades. Models, which best match observations in September, show sea ice trends in the 21st century 21% larger than the ensemble mean. They demonstrate also larger SAT and sensitivity of SIE to SAT changes. A new approach is developed for selection of models with the most reliable sea ice projections over the 21st century (Figs. 1-2).

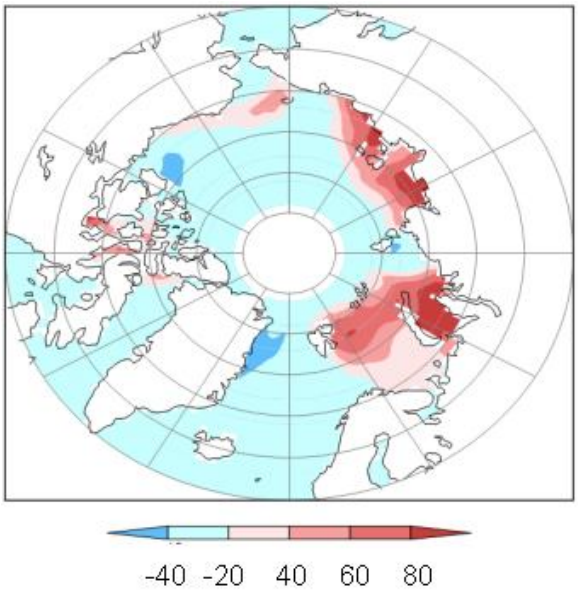

Fig. 1. Mean (1979-1999) difference between models and observed sea ice concentration (Mean model - Satellite Ice) (%)

Polar low study using multi-sensor approach

Dr. Elizaveta V. Zabolotskikh (NIERSC/RSHU)

Dr. Leonid P. Bobylev

PhD-student Julia Ye. Smirnova (NIERSC/RSHU)

Prof. Johnny A. Johannessen (NERSC, Norway)

In 2011 the data of new instrument SSMIS started to be used in research associated with the polar low detection, monitoring and study. Due to the loss of AMSR-E and bad calibration of on-going F15 SSM/I there was an essential need in new calibrated passive microwave data. The work on the calibration of the Special Sensor Microwave Imager/Sounder was started. This work included the modernization of the program for forward calculations and collection of corresponding in-situ data. In future collected data and an upgraded geophysical model will allow calculating brightness temperatures and comparing them with measured ones. Such procedure is necessary for the following algorithm development using new sensor data.

Analysis of different case studies of the polar lows using earlier developed techniques was continued in 2011. Also the climatology of the polar lows over the Nordic Seas for the period 1995-2011, as a first step, based on the usage of passive microwave data started to be created. For this all SSM/I data starting from 1995 were processed and converted to the columnar atmospheric water vapour fields. These fields were analysed and all suspected atmospheric vortexes were checked using other sources of data including NOAA AVHRR cloud images, DMSP SSM/I and QuikSCAT SeaWinds wind speed products. Selected polar low cases constituted the base for the following statistical analysis, which is going to be done in the nearest future with the aim of creating advanced polar low climatology for the Nordic seas. The number of detected polar lows over the Nordic seas for 1995-2009 is shown in Fig. 3.

Accurate estimation of precipitation inside polar lows, quite essential for their study, was started in 2012. New instruments were added for the multi-sensor research: NASA's Tropical Rain Measuring Mission (TRMM) measuring rainfall rate, and CloudSat data advancing our understanding of cloud abundance, distribution and structure accompanying polar low development.

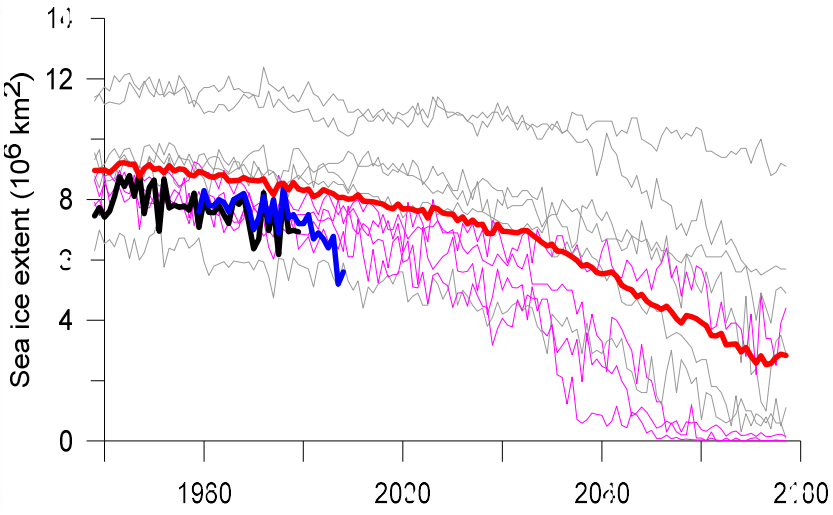

Fig. 2. September sea ice extent from observations (black), satellite data 1979-2008 (blue) and 12 IPCC AR4 models (grey), together with the multi-model ensemble mean (red). Selected models are marked by pink (CGCM 3.1(T47), CNRM-CM 3, MIROC 3.2 (medres), UKMO-HadCM 1)

Permafrost reference map

Dr. Elena V. Shalina

Dr. Leonid P. Bobylev

PhD-student Lyudmila S. Lebedeva

Mr. Kirill E. Zemeszirks

In the frame of the MONARCH-A Project the NIERSC team works on describing permafrost as an Essential Climate Variable. It is important to understand what the state of permafrost was before the present global warming has started, and it is essential to recognize signs of changes in permafrost parameters led by climatic warming.

In 2011 the NIERSC team developed a reference permafrost map based on historical data that represents the state of permafrost in the 1980s. The map was created basing on paper permafrost maps published from 1970 to 1988. Digital data represents permafrost boundary, permafrost depth, temperature of permafrost and active layer thickness. Practically the reference permafrost map is a collection of five different maps (for Russia, Mongolia, China, Canada and Alaska, US) that are difficult to merge because of different approaches to permafrost classification. The main achievement was creation of a very descriptive digital permafrost map for the Russian territory, not widely known yet in the international scientific community.

In 2012 we have been studying permafrost parameters changes over last decades. Data on active layer depth downloaded from the CALM databases and data on permafrost temperature from TSP datasets has been analyzed. Unfortunately records and data for many permafrost regions are incomplete or of short-term duration, and the spatial distribution of the sites where measurements have been conducted is irregular making it impossible to give any substantiated conclusion about permafrost parameters distribution change. Nevertheless, available data shows that an increase tendency in active layer depth has prevailed in Russia, Mongolia and China over the last decades (Fig. 4). Active layer trends are different for different parts of Alaska and Canada being positive in the interior part and unsettled in the areas close to the ocean.

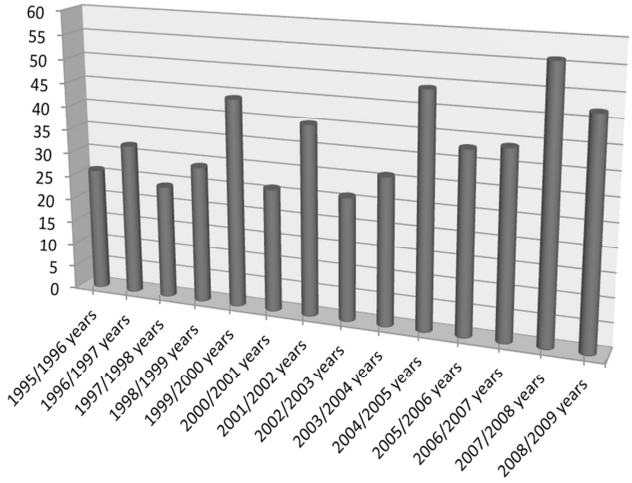

Fig 3. The number of detected polar lows over the Nordic seas

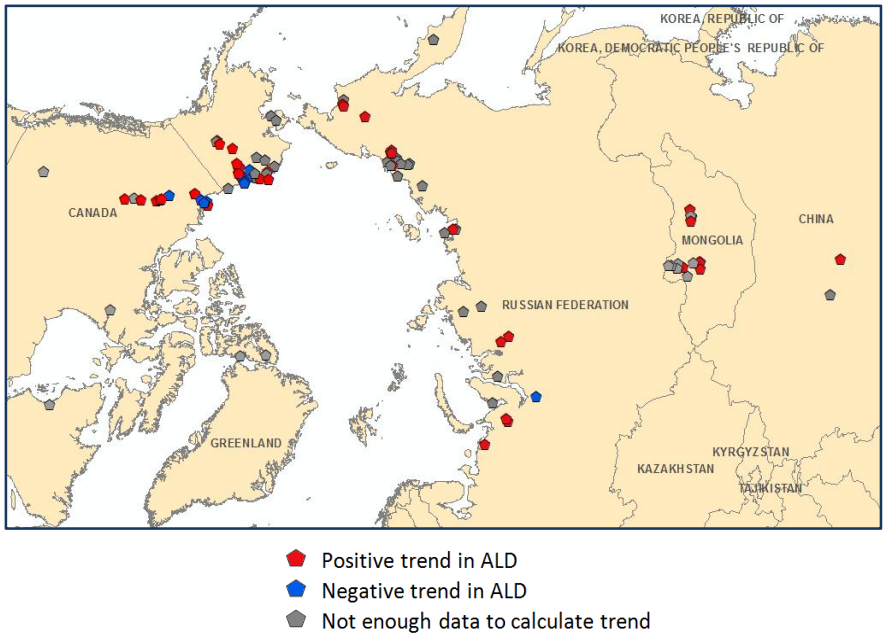

Fig. 4. Sites with active layer depth (ALD) measurements. ALD trends are shown in different colors

Atmosphere-Ocean Interaction Studies

Impact of ocean spray on the dynamics of the marine atmospheric boundary layer

Prof. Vladimir N. Kudryavtsev (NIERSC/RSHU)

Dr. Vladimir Makin (KNMI, The Netherlands)

The impact of ocean spray on the dynamics of the marine near-surface air boundary layer (MABL) in conditions of very high (hurricane) wind speeds is investigated. Toward this end, a model of the MABL in the presence of sea-spume droplets is developed. The model is based on the classical theory of the motion of suspended particles in a turbulent flow, where the mass concentration of droplets is not necessarily small. Description of the spume-droplet generation assumes that, being torn off from breaking waves, they are injected in the form of a jet of spray into the airflow at the altitude of breaking wave crests. The droplets affect the boundary-layer dynamics in two ways: via the direct impact of droplets on the airflow momentum forming the so-called spray force, and via the impact of droplets on the turbulent mixing through stratification. The latter is parameterized applying the Monin–Obukhov similarity theory. It is found that the dominant impact of droplets on the MABL dynamics appears through the action of the 'spray force' originated from the interaction of the 'rain of spray' with the wind velocity shear, while the efficiency of the stratification mechanism is weaker. The effect of spray leads to an increase in the wind velocity and suppression of the turbulent wind stress in the MABL. The key issue of the model is a proper description of the spume-droplet generation. It is shown that, after the spume-droplet generation is fitted to the observations, the MABL model is capable

of reproducing the fundamental experimental finding—the suppression of the surface drag at very high wind speeds. We found that, at very high wind speeds, a thin part of the surface layer adjacent to the surface turns into regime of limited saturation with the spume droplets, resulting in the levelling off of the friction velocity and decrease of the drag coefficient as wind speed in power (-2).

The results of this research are published in: ***Kudryavtsev V.,*** *V. Makin.* Impact of ocean spray on the dynamics of the marine atmospheric boundary layer, *Boundary-Layer Meteorology,* 2011, Vol. 140, Iss. 3, pp. 383-410.

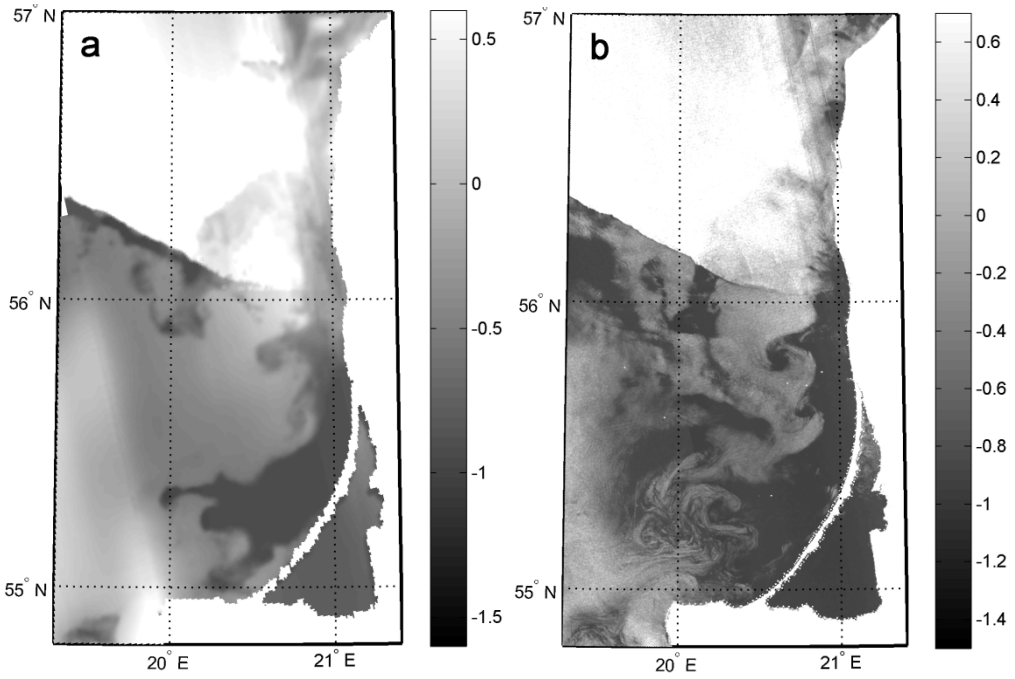

Fig. 5. Modeled (a) and observed (b) radar backscatter of the coastal upwelling area

ASAR imaging for coastal upwelling in the Baltic Sea

Mr. Igor Ye. Kozlov (NIERSC/RSHU)

Prof. Vladimir N. Kudryavtsev (NIERSC/RSHU)

Prof. Johnny A. Johannessen (NERSC, Norway)

Dr. Bertrand Chapron (IFREMER, France/RSHU)

Mr. Alexander G. Myasoedov (NIERSC/RSHU)

Analysis of Envisat Advanced Synthetic Aperture Radar (ASAR) and Aqua/Terra Moderate Imaging Spectrometer (MODIS) infrared (IR) imagery of coastal upwelling in the southeastern Baltic Sea is presented. It is found that upwelling features are well distinct in the SAR images, and the leading imaging mechanism appears to be the change of the marine atmospheric boundary layer (MABL) stratification over the sea surface temperature (SST) front. This finding is supported by model calculations of the MABL transformation supplemented with the SAR backscatter calculations based on the CMOD4 model. In addition an empirical dependence of the SAR contrasts over the upwelling region on the wind speed and the SST drop is suggested. Finally, surface slicks accumulated in the sea surface current convergence zones generate additional distinct features in SAR imagery. This effect is interpreted within the framework of the coastal current circulation model based on analysis of the SST snapshot (Fig. 5).

The results of this research are published in: ***Kozlov I., V. Kudryavtsev***, *J. Johannessen, B. Chapron, I. Dailidiene,* ***A. Myasoedov***. ASAR imaging for coastal upwelling in the Baltic Sea. *Advances in Space Research,* 2012, Vol. 50, Iss. 8, pp. 1125-1137

Imaging meso-scale upper ocean dynamics using SAR and optical data

Prof. Vladimir N. Kudryavtsev (NIERSC/RSHU)

Mr. Alexander G. Myasoedov (NIERSC/RSHU)

Dr. Bertrand Chapron (IFREMER, France/RSHU)

Prof. Johnny A. Johannessen (NERSC, Norway)

Dr. Fabrice Collard (CLS, France/RSHU)

A synergetic approach for quantitative analysis of high resolution ocean SAR and imaging spectrometer data, including the infrared (IR) channels, is suggested. This approach first clearly demonstrates that sea surface roughness anomalies derived from the sun glitter imagery compare very well to SAR-roughness anomalies. As further revealed using these fine resolution (~1 km) observations, the derived roughness anomaly fields are spatially correlated with sharp gradients of the sea surface temperature (SST) field. To quantitatively interpret SAR and optical (in visible and IR ranges) images, equations are derived to relate the "surface roughness" signatures to the upper ocean flow characteristics. As developed, a direct link between surface observations and divergence of the sea surface current field is anticipated. From these satellite observations, intense cross-frontal dynamics and vertical motions are then found to occur near sharp horizontal gradients of the SST field. As a plausible mechanism, it is suggested that interactions of the wind driven upper layer with the quasi-geostrophic current field (via Ekman advective and mixing mechanisms) results in the generation of secondary ageostrophic circulation producing convergence and divergence of the surface currents. The proposed synergetic approach combining SST, sun-glitter brightness and radar backscatter anomalies, possibly augmented by other satellite data (e.g. altimetry, scatterometry, ocean color), can thus provide consistent and quantitative determination of the location and intensity of the surface current convergence/divergence (upwelling/downwelling). This, in turn, establishes an important step towards advances in the quantitative interpretation of the upper ocean dynamics from their 2D satellite surface expressions (Fig. 6). The results of this research are published in: ***Kudryavtsev V.,*** ***A. Myasoedov,*** *B. Chapron, J. Johannessen, F. Collard.* Imaging meso-scale upper ocean dynamics using SAR and optical data. *Journal of Geophysical Research,* 2012, Vol. 117, C04029, doi:10.1029/2011JC007492.

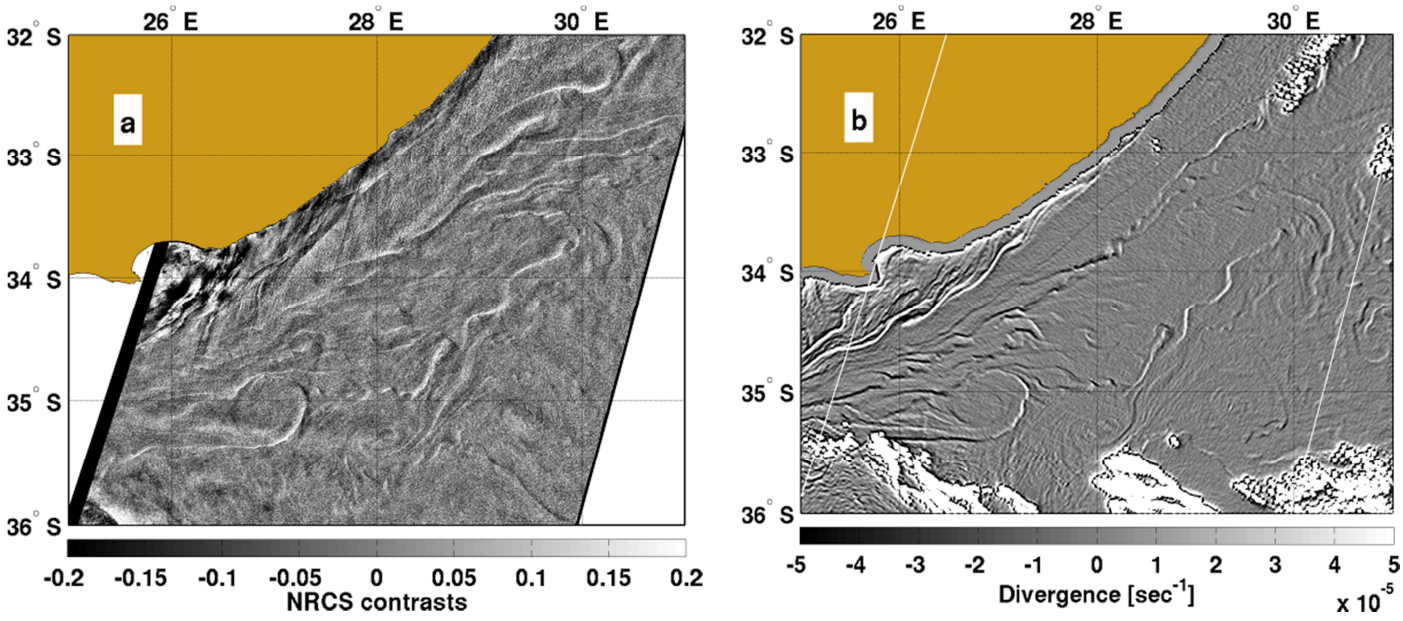

Fig. 6. (a) A fragment of the SAR NRCS contrasts field derived from the ASAR WS image (November 18, 2007, 7:24 GMT), and (b) the corresponding fragment of the surface current divergence field calculated from the MODIS image (November 18, 2007, 12:05 GMT). Bright areas in the (b) plot correspond to the current convergence, and dark – to the current divergence

Aquatic Ecosystems in Response to Global Change

A decadal trend in inorganic carbon production in the Arctic Ocean

PhD-student Dmitry A. Petrenko

Prof. Dmitry V. Pozdnyakov

Dr. Elizaveta V. Zabolotskikh (NIERSC/RSHU)

This work has been performed under the MONARCH-A FP7 project. A coccolithophore *Emiliania huxleyi* (class: Prymnesiophycea) produces $CaCO_3$ in the form of transparent pallets (coccoliths), which become released into the water during the dying-off phase of this alga's living cycle. The release of $CaCO_3$ impacts the carbon cycle in the atmosphere–ocean system. The carbon cycle is one of the most important factors controlling both the functioning of marine ecosystems and the global climate. This alga is also known for its ability to release dimethylsulfade (DMS) – a sulfurous gas produced from breakdown products of phytoplankton through biological interactions. DMS emission into the atmosphere increases the formation of clouds and leads to changes in the planetary albedo, and hence, ultimately results in global climate change.

To investigate the inorganic carbon production by *E. huxleyi* from ocean colour, a dedicated algorithm has been developed called modified BOREALI algorithm. Its application to MODIS-Aqua data permitted to quantify of inorganic carbon release in the Arctic waters during the alga's vegetation period. Three major areas of *E. huxleyi* blooms have been identified, viz. the Barents, Greenland and Northern Norwegian Seas, of which the Barents Sea prevails. It was revealed that inorganic carbon (C) production in the Arctic is maximal in August (Fig. 7).

Satellite data (MODIS-Aqua) obtained indicate that the inorganic carbon production due to *E. huxleyi* in the Arctic over the time interval 2002-2010 has decreased by 61.4 per cent (Fig. 8).

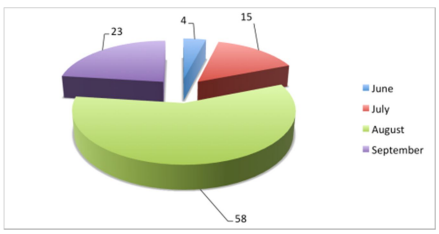

Fig. 7. Averaged over all years studied (2002-2010), the share of each month in the annual E. huxleyi abundance (as assessed via chl concentration): the entire Arctic Ocean

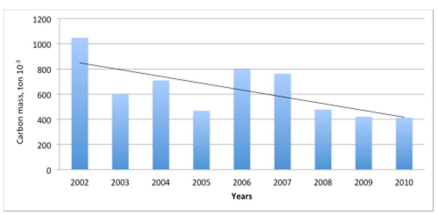

Fig. 8. Interannual variations of and trend in inorganic carbon mass in the E. huxleyi blooms in the Entire Arctic over 2002-2010

Investigation of the dynamics of variations in the factors controlling the inorganic carbon production by *E. huxleyi* blooms shows that all of them (SST, PAR, NAO) have the tendency of decreasing thus supporting the results on C production decline over the above time period.

Results of the study are summarized in: ***Petrenko D., E. Zabolotskikh, D. Pozdnyakov,*** *L. Karlin.* Interannual variations of and a trend in inorganic carbon generation by *E. huxleyi* in the Arctic: spaceborne data for 2002-2010 (accepted for publication in *Earth Observations and Remote Sensing,* 2012).

Design solutions for development of automated means for compiling and maintenance of the bank of specialized information products of remote sensing of the Earth

PhD-student Evgeny A. Morozov

Dr. Anton A. Korosov (NERSC, Norway)

Mr. Lasse H. Pettersson (NERSC, Norway)

The aim of the project consists in development of solutions to further improving of the programming-instrumentation means of streamed data processing (PIM SDP) at the Scientific Centre for Operational Monitoring of the Earth (Moscow, Russia).

Developed are solutions providing for complying with the up-to-date

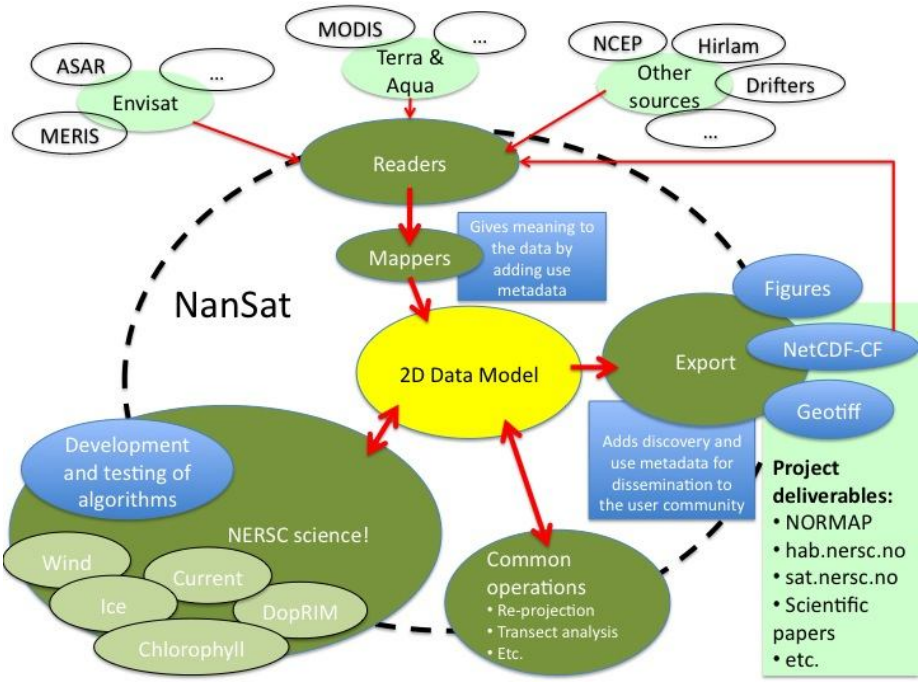

Fig. 9. A general scheme of the Nansat package

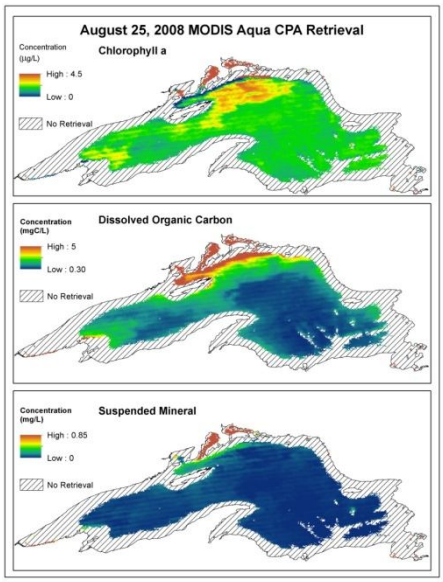

Fig. 10. Lake Superior: results of water quality papameters retrieved from August 25, 2008 MODIS image

requirements to PIM SDP from the perspective of unification, extendability and multiplication of the system (establishment of analogous PIM at regional centers for space data processing).

The solutions developed permit the utilization within PIM SDP of a wide spectrum of spaceborne data as well as assure the possibility of a further diversification of the system composition in order to enable it to acquire data from future sensors. Envisaged is an option of compatibility of PIM SDP information products with various national and foreign systems and data banks. The nomenclature of data products is significantly extended.

The module-based structure of the system relies on the Nansat program package, which is presently developed at NERSC (Fig. 9). This allows to *a*) quickly update the system to accommodate new satellite sensors, and *b*) configure the processing of input data in accordance with the end-user's defined parameters and technical facilities (server's computing power, permissible sizes of stored data). This approach will assure the possibility of a further improvement/perfection of the system without changing both its basic concept and structure. The modulosity is fundamental for attaining the system efficient enlargement while keeping intact the basic scheme of data processing: indeed, required is an addition of necessary new modules of initial processing of data from such sensors as "Canopus-B", Resource-P", MODIS/Aqua and Terra, Sentinel, etc. together with the facilities of a further data transfer to the common module of a higher level data processing. The inclusion of new retrieval algorithms is also practically reduced to a mere addition of modules performing concrete tasks without the necessity of any modification of the already existing modules of the system.

Development of methodology and assessment of the water quality retrieval efficiency of the Levenberg–Marquardt based algorithm when applied to shallow waters of the Great American Lakes

Prof. Dmitry V. Pozdnyakov

Dr. Anton A. Korosov (NERSC, Norway)

Dr. Robert A. Shuchman (MTU, US)

This research has been fulfilled under the bilateral contract between NIERSC and Michigan Tech University. Under the contract the existing Levenberg–Marquardt-based code (CPA-code) has been examined and enriched with new module so that the revised CPA algorithm can estimate phytoplankton chlorophyll, *chl*, dissolved organic carbon, *doc*, and suspended minerals, *sm* in *shallow water* using either MODIS or MERIS data.

Additionally, Nansen-Centre scientists cooperated with the Michigan Tech personnel on the evaluation of the CPA algorithm efficiency. A set of operational algorithms have been developed for the five Great Lakes that utilizes SeaWiFS, MODIS, or MERIS satellite data to estimate chlorophyll (*chl*), dissolved organic carbon (*doc*), and suspended minerals (*sm*), the three primary Color Producing Agents (CPAs). The algorithms utilize a specific hydro-optical (HO) model for each lake. The HO models were generated using simultaneous near surface optical data collected with *in situ* water chemistry measurements of the three primary components collected during research cruises in all the Great Lakes. These new algorithms provided more accurate *chl* values than those obtained using the standard OC3 NASA MODIS retrieval when compared to the EPA and other *in situ* cruise observations, as well as providing the additional information on *doc* and *sm*. The results are exemplified for Lake Superior (Fig. 10).

The above results are summarized in the paper by *Shuchman R., G. Leshkevich, M. Sayers, T. Johengen, C. Brooks,* ***D. Pozdnyakov.*** Generation of an operational algorithm to retrieve chlorophyll, dissolved organic carbon, and suspended minerals from Great Lakes satellite data (submitted to the *Journal of Great Lakes Research*).

A pilot satellite-based investigation of the impact of a deep polar cyclone propagation on the phytoplankton chlorophyll spatial and temporal dynamics in the Arctic Ocean

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Dr. Leonid P. Bobylev

Prof. Dmitry V. Pozdnyakov

PhD-student Evgeny A. Morozov

Dr. Elizaveta V. Zabolotskikh (NIERSC/RSHU)

Among the variety of environmental effects produced by ongoing climate change, significant variations in phytoplankton primary productivity and time- and area-integrated production across the world's oceans are becoming increasingly evident being a reflection of serious alterations occurred to the ecosystems of the hydrosphere. Deep baric formations in the atmosphere are shown to be able to strongly affect PP variations across oceanic/marine tracts. There are reasons to expect that the effect of deep cyclones on the primary production in the Arctic Ocean can also be appreciable regardless of the fact that it is a low production region of the world's oceans. We are unaware, however, of any satellite-based investigations of this phenomenon at these latitudes. A pilot satellite-based investigation of modulations exerted upon mixed-layer phytoplankton fields by deep cyclones is performed for the first time across the northern hemisphere polar region, viz. the Arctic Ocean. The research is performed within the Russian-Chinese bilateral project warded by RBRF. Resorting to a synergistic approach, polar cyclones were first identified from NCEP/NCAR data for the summer time period during 2002-2005, and their propagation throughout the Barents Sea (BS) was further traced down. The above water wind force was retrieved from QuikSCAT data. These data were further accompanied by ocean colour data from SeaWiFS, and MODIS on the spatial and temporal distributions of surficial phytoplankton chlorophyll concentration dynamics along the trajectory of the cyclone's footprint displacement across the sea. The results obtained are exemplified here with an event of the cyclone that passed across the BS on May 15, 2003 with the geopotential height of the isobaric surface of 1000 mbar of -86 m^2s^{-1}. Fig. 11 illustrates the field of above surface winds over the marine area for the moment when the cyclone started moving across the BS.

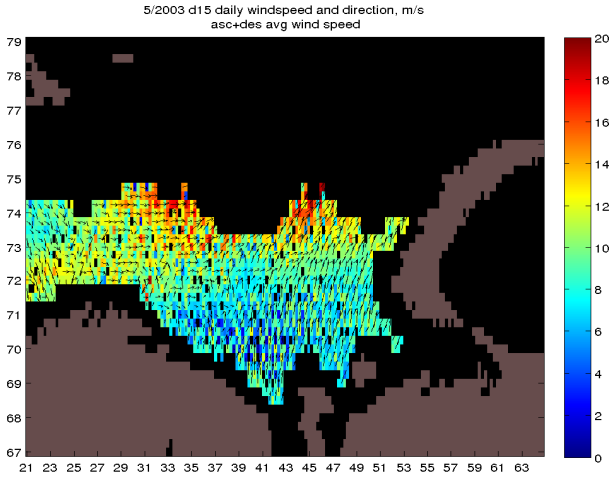

Fig. 11. The wind field on May 15, 2003 in the area of the cyclone coming out in the BS from the main land. The colour bar is in ms^{-1}. Numbers on the horizontal and vertical axes are degrees of latitude and longitude, respectively

Fig. 12 illustrates for the 15 May cyclone the time and space averaged *chl* concentration fields (encompassing the footprint area of this cyclone as it moved from the mainland into the BS) for two time periods, viz. 4 days prior to (*a*) and 3-5 days after (*b*) the cyclone left the sounded area of the water surface. Fig. 12*a*,*b* reveals a notable increase on the *chl* concentration after the cyclone passage. Schematically, the dynamic changes in *chl* and SST are presented in Fig. 13.

Thus, for the first time the impact of cyclones on marine primary production was revealed and documented for the BS in the Arctic Ocean. It was found that (*i*) the cyclone-driven increase in *chl* is far less significant compared to low latitude marine environments, and (*ii*) the typical lag between the cyclone passage over the marine environment and the increase in *chl* is about five days, i.e. longer than that most frequently reported for low-latitude seas. Both specific features can be explained by less favorable conditions for the phytoplankton growth: lower levels of incident light and rather low water temperatures. This leads to lower productivity rates and longer times required for the enhancement of *chl* levels observable from space.

The pattern of SST variations associated with the phenomenon of cyclone passage is unlike that observed in low-latitude seas. Instead of SST lowering with the cyclone passage, we observed an increase in SST. We assume that this

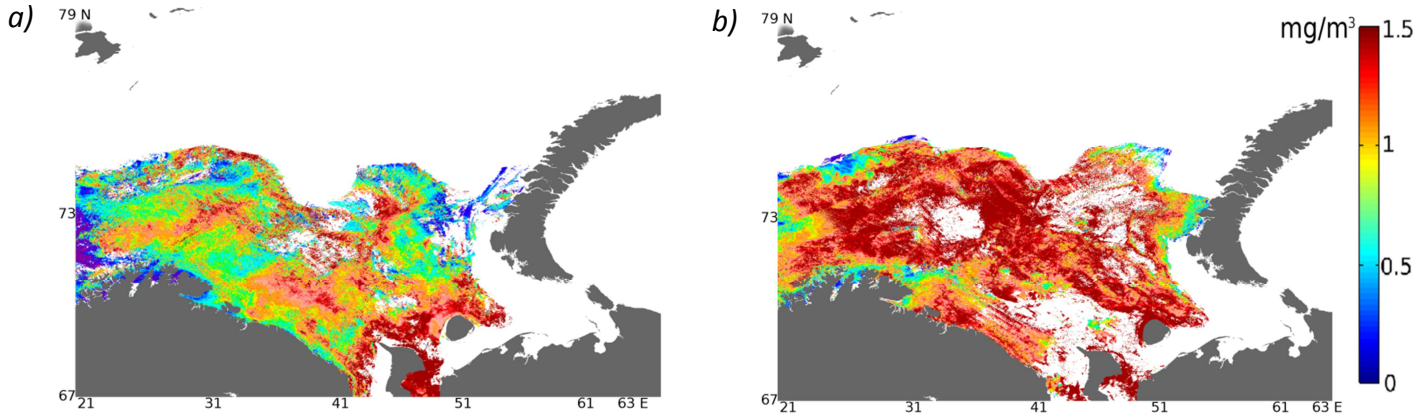

Fig. 12. The chl (mgm^{-3}) field on May 15, 2003 in the area of the cyclone coming out in the BS from the mainland: a) 4 days prior to and b) 5 days after the cyclone passage. Numbers on the horizontal and vertical axes are degrees of latitude and longitude, respectively

increase resulted, at first, from the ascension of submerged warmer and more saline Atlantic waters due to cyclone-driven vertical mixing and further, at a later stage, by the horizontal advection to the target site of North Atlantic surficial waters (also warmer than the Arctic waters) due to the cyclone peripheral winds.

Thus, these pilot studies indicate that cyclonic activity in the Arctic, like that at lower latitudes, is able to appreciably modulate the marine primary productivity and hence alter the marine ecosystem state. These changes are powered by vertical water mixing processes and obviously result in short term alterations of the structure of surface waters. However, unlike the cyclone-driven SST changes at low latitudes, in the BS, due to a very specific interaction of the Arctic and Atlantic waters, the cyclone passage is conducive to a short-term increase in SST.

The present study is in its initial stage. Further research is required through extending the number of cases of cyclone passages across the BS throughout 2003-2012, and establishing the actual meteorological and hydrodynamic mechanisms responsible for the ensuing alterations of primary productivity in the Arctic Seas. The results are summarized in: ***Bobylev L.,*** *D. Tang,* ***D. Pozdnyakov, E. Zabolotskikh, P. Golubkin, D. Petrenko, E. Morozov.*** A pilot satellite-based investigation of the impact of a deep polar cyclone propagation on the phytoplankton chlorophyll spatial and temporal dynamics in the Arctic Ocean. In: *Typhoon Impacts and Crisis Management,* Springer, 2012 *(accepted).*

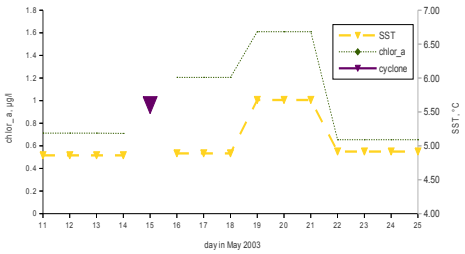

Fig. 13. A schematic presentation of SST and chl variation patterns for the case of the cyclone that passed the BS on May 15, 2003

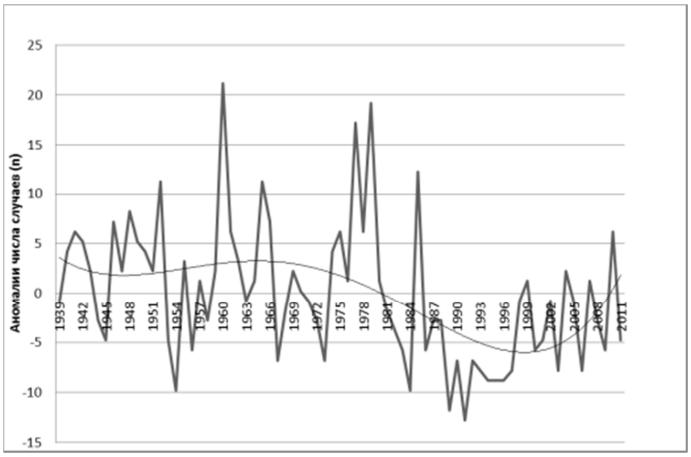

Fig. 14. Annual mean anomalies of the B group synoptic processes frequency, 1939-2011

MetOcean Studies

Ice drift in the Arctic Ocean against the background of macro-synoptic processes

Dr. Vladimir A. Volkov

PhD-student Denis M. Demchev (NIERSC/AARI)

Dr. Alexander Ya. Korzhikov (AARI)

Analysis of the ice drift fields variability in the Arctic Ocean during two last decades at the turn of the 20th and 21st centuries is developing under MAIRES Project (Monitoring Arctic land and sea Ice using Russian and European Satellites – MAIRES, FP7-SPACE-2010-1, 2011-2014). Two daily satellite derived data sets presented at regular grid points with a step of about 30 km over the entire Arctic Ocean area were used as an initial data. One of them (for winter period from 2002 up to now) was prepared by the Center for Satellite Exploitation and Research (CERSAT) at IFREMER (France), the other data set (as well as for winter and summer seasons from 1998 up to now) was prepared by the National Snow and Ice Data Center – NSIDC (USA). On the base of this information a dedicated data archive – as a part of the MyOcean Project oceanographic information system, and some special software, were developed.

The vectorial-algebraic approach developed under the direction of Prof. V. Rozhkov (St. Petersburg State University, Russia) was chosen as a fundamental method for analysis of seasonal and year-to-year variability of the ice drift series. For the first time this methodology was adopted for validation of the modeling results under MyOcean Project (FP7-SPA.2007.1.1.01) associated with development and pre-operational validation of upgraded GMES Marine Core Services and capabilities. The vectorial-algebraic approach allows us to significantly compress the initial information and most adequately describe the vector time series of full-scale and model data restricted by a set of statistical characteristics in the invariant form. The results of such statistical analysis make possible to describe detailed fields variability, to detect some zones with uniform dynamics, to access an intensity of the water and ice outflow and variability of status of circulation systems in the course of time.

Joint analysis of the drift data and large-scale weather processes during current warming epoch demonstrates a determinative role of global atmospheric circulation in forming of ice conditions. At the first steps of our study an analysis of conjugation of the ice fields variations with different types of elementary synoptic processes (ESP) in the Arctic was implemented. The study was developed keeping in mind the classification of large-scale weather processes developed in the Arctic and Antarctic Research Institute (AARI) in St. Petersburg that is a basis of the AARI's methodology of the large-scale weather conditions forecasting. The classification includes 26 typical ESP, divided into six groups: A, B, V, G, D and K. Correspondence between the prevailing type of atmospheric circulation and the specific properties of the drift field was determined. Thus, in the degree of influence on the process of ice formation in the Arctic highlights the ESP related to group B. Processes of this group are characterized by the development of anticyclonic field over most of the Arctic basin, the lack of strong advection of warm air masses from midlatitude zone, the predominance of eastern air flows and minimal cloud cover. In this case the most favorable conditions for increasing of the sea ice cover in the Arctic basin are formed. Analysis of the variability of annual mean anomalies of synoptic processes of the B-group from 1939 to 2011 (Fig. 14) shows that the years with maximum ice coverage are consistent

with major positive anomalies of frequency of anticyclones over the entire water area of the Arctic Basin. At the same time, the reduction of ice cover is going, as a rule, on the background of negative anomalies of the B group processes frequency.

However, during periods when there was an intensive reduction of the drifting ice area, synoptic processes of others groups repeated more often. For instance, in October-April from 1997 to 2006 standard elementary synoptic processes that belong to the V-group (Fig. 15*a*) have developed. V-group processes are characterized by the development of the cyclonic field over the Western Arctic and anticyclonic field – over the Eastern.

As the cyclonic activity contributes to significant changes in the sea ice drift fields, with the prevalence of the V-group processes the maximum variation of the drift vectors should be observed over the Western Arctic, and that's really going on. Fig. 15*b* shows that, in accordance with the predominance of the V-group processes the maximum of the ice drift vectors variability during the cold period 1997-2006 was observed in the seas of the Western Arctic and the area north of Svalbard.

The gradual increase in frequency of large Arctic anticyclones over the Arctic Basin, observed since 2000, may affect the subsequent growth of ice area in the northern polar region, which may serve as a prelude to the subsequent increase of the polar sea ice area. However, this hypothesis requires more detailed study, which is currently being undertaken within the project MAIRES. It is interesting to analyze the contingency Arctic glaciers variations to changes macrosynoptic conditions, which enables running an ongoing project.

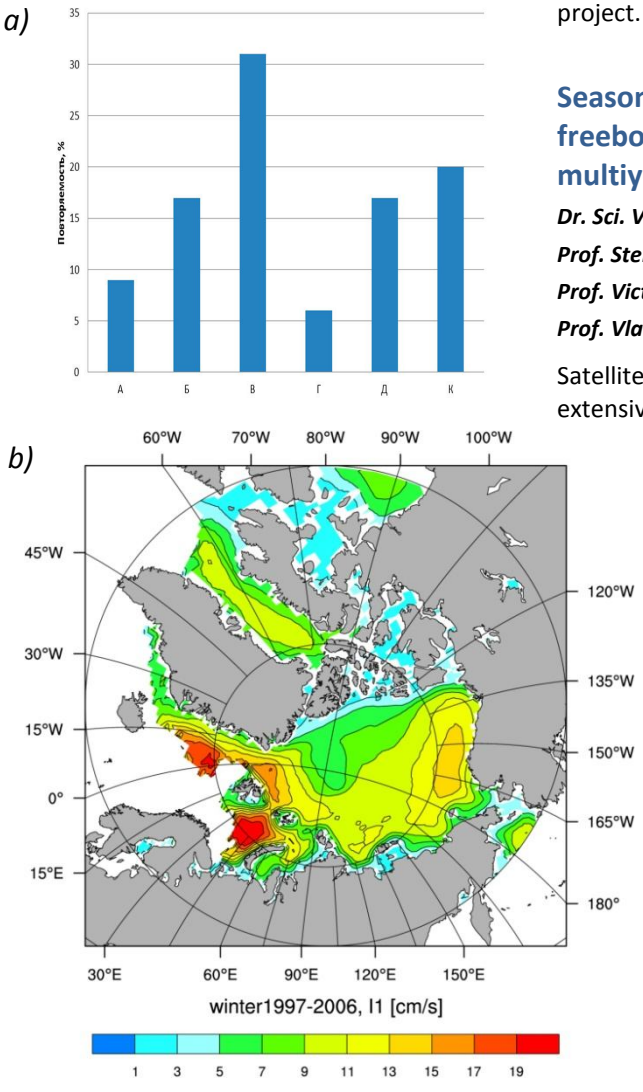

Fig. 15. The frequency of synoptic processes in groups (a) and the variability of ice drift vectors (field of multiyear value of the linear invariant I_1) (b) in October-April from 1997-2006

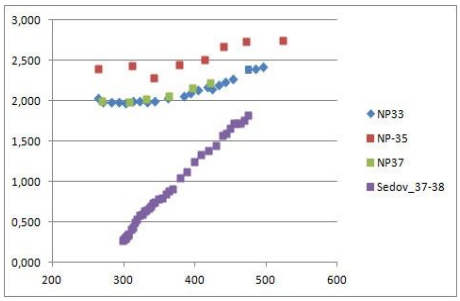

Fig. 16. Seasonal changes of MYI thickness and FYI thickness

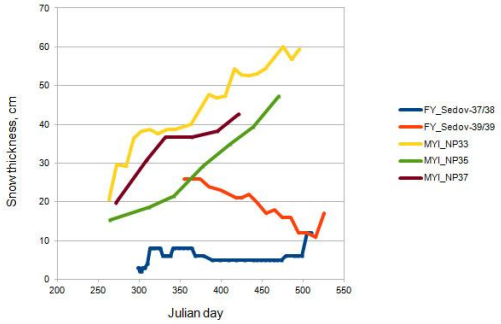

Fig. 17. Seasonal changes of snow depth on MYI and FYI

Seasonal changes of thickness, freeboard and snow depth for multiyear and first-year ice

Dr. Sci. Vitaly Yu. Alexandrov

Prof. Stein. Sandven (NERSC, Norway)

Prof. Victor N. Smirnov (AARI)

Prof. Vladimir T. Sokolov (AARI)

Satellite radar altimeter data can provide extensive spatial and temporal estimates of sea ice thickness through converting ice freeboard measurements to thickness by assuming hydrostatic equilibrium. Seasonal changes of thickness, and freeboard of multiyear ice (MYI), and snow depth on its surface were determined using their measurements at North Pole (NP) drifting stations NP-33 (2004/2005), NP-35 (2007/2008), and NP-37 (2009/2010). Seasonal changes of these parameters for first-year ice (FYI) were determined using their measurements during drift of icebreaker *Sedov* in 1937-1939.

The average increment of ice thickness in the period December-March amounted to 2.3 and 2.5 cm/decade for NP-33 and NP-37 and to 4 cm/decade for NP-35, which is less than typical value of 5 cm/decade for this period (Fig. 16). Snow depth on MYI steadily increased from ice freeze-up until summer melting and reached 60 cm in May 2005, 47 cm in April 2008, and 43 cm in February 2010 (Fig. 17). In all these winters snow depths on MYI exceeded average values from snow climatology. Snow depths on MYI in all cases significantly exceeded that on FYI. Freeboard of FYI steadily increased during 1937/1938 winter due to increase of ice thickness and relatively small variations of snow depth. Measurements from NP-33, NP-35, and NP-37 do not show steady seasonal increase of MYI freeboard, but reveal its significant variations. These measurements also show that during winter thickness to freeboard relation for MYI exceeded that for FYI in almost all cases.

SAR sea ice classification

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Dr. Sci. Vitaly Yu. Alexandrov

Prof. Ola M. Johannessen (NERSC, Norway)

Prof. Stein Sandven (NERSC, Norway)

In 2011-2012 the NIERSC team developed the automatic processing techniques for fast and objective classification of sea ice types from SAR images. In frame of SIDARUS and MAIRES projects the sea ice in the Central Arctic was classified in Advanced Synthetic Aperture Radar

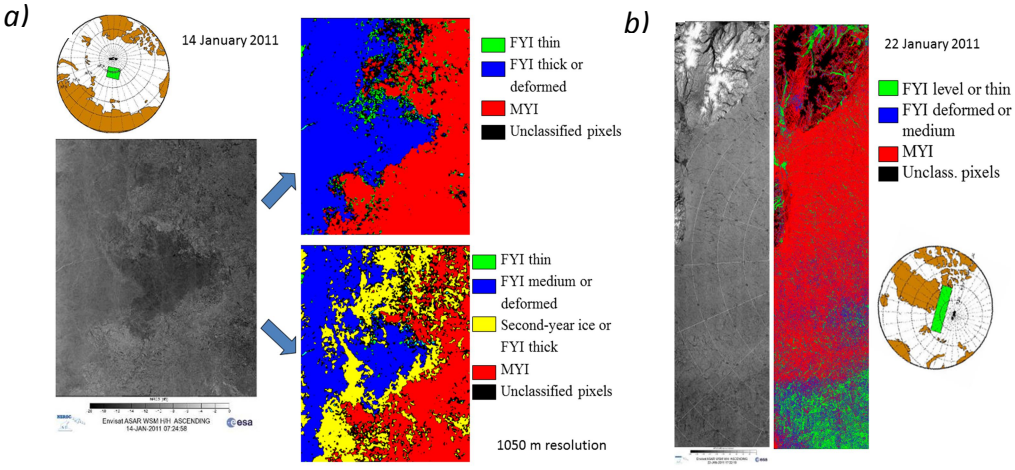

Fig. 18. Sea ice classification of ENVISAT Wideswath SAR image (HH–polarization): a) fragment of SAR image, January 14, 2011 at 07:24 UTC, and result of NN classification for 3 and 4 sea ice types; b) fragment of SAR image, January 22, 2011 at 17:22 UTC, and Bayesian approach classified image

(ASAR) images from ENVISAT using a Neural Network (NN) based algorithm and a Bayesian algorithm.

Since different sea ice types can have similar backscattering coefficients at C-band HH-polarization, we have developed artificial NN approach using textural features in addition to the backscattering coefficients. The NN have been trained with backpropagation learning method. Based on analysis of classification errors and processing time the optimal topology of the NN was found.

The Bayesian algorithm of automated sea ice classification uses pixel-based approach and a priori probabilities of level, deformed first-year ice (FYI) and multiyear ice (MYI) appearance in the Central Arctic. These probabilities were estimated from knowledge of ice conditions, and conditional probabilities of these ice types were derived from calibrated ENVISAT ASAR images. The Bayesian algorithm uses only backscatter, but correctly classifies major sea ice types due to big differences in their a priori probabilities, as well as leads in sea ice (Fig. 18).

The classification results for a series of SAR images, acquired in the central part of the Arctic Ocean during winter months were compared to expert analysis of the images and ice charts. This study is summarized in ***Zakhvatkina N.Y., V.Y. Alexandrov,*** *O.M. Johannessen, S. Sandven, I.Y. Frolov.* Classification of sea ice types in ENVISAT Synthetic Aperture Radar images. *IEEE Transactions on Geoscience and Remote Sensing,* doi:10.1109/TGRS.2012.2212445 (in press).

Economic Modelling

Dr. Dmitry V. Kovalevsky

PhD-student Olga Yu. Romanova

Prof. Klaus Hasselmann (MPI-M, Germany/GCF)

A set of economic models for different research areas of economic theory (microeconomics, economic growth theory, economics of climate change) is developed in the framework of three research projects solicited by the Russian Foundation for Basic Research (RFBR Projects No. 10-06-00238, No. 10-06-00369, and No. 12-06-00381).

Price dynamics in PI-controlled Scarf's model

The Scarf's counterexample is a theoretical general equilibrium model of an exchange economy which, unlike traditional models, demonstrates the property of global instability to price vector perturbations. Kumar and Shubik (2004) studied numerically a modified Scarf's counterexample with traditional (Walrasian) price adjustment mechanism (tâtonnement) replaced by proportional-integral (PI) mechanism. As a follow-up of a theoretical analysis of linearized multidimensional PI-controlled Scarf's economy performed by us in 2010, the non-linear stability of the model is studied, and the dependence of stability/instability of motion in price space on initial conditions observed by Kumar and Shubik in their numeric experiments is explained (Fig. 19).

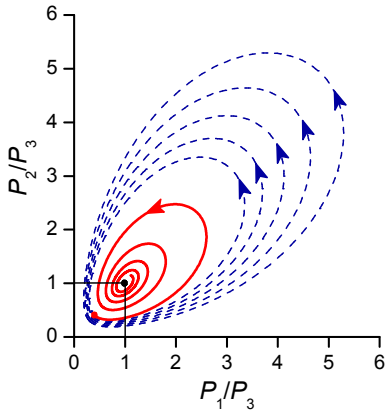

Fig. 19. Global instability of Scarf's model with the Walrasian price adjustment mechanism (tâtonnement; blue dashed trajectories), and convergence to equilibrium of the same model with PI mechanism (red solid trajectory)

An Integrated Assessment model with climate-dependent capital depreciation rate

An Integrated Assessment (IA) model is developed in 2011 on the basis of the neoclassical *AK* model of economic growth in which a negative feedback in the economy–climate system is parameterized by introducing the capital depreciation rate dependent on the state of climate system. Such a feedback distinguishes the proposed model from the majority of IA models in which the climate change impact on the economy is described by introduction of climate damage function reducing the effective output. As a climate module, the model used by Greiner (2005) in IA studies is adopted. Simulations of "business-as-usual" scenario with no explicit mitigation policy are performed. It is shown that the "limits to growth" exist in the developed IA model, and the economy–climate system ultimately converges to the stationary state (Fig. 20). This study is summarized in: ***Kovalevsky D.V.*** An economy–climate model with growing capital depreciation rate. *St. Petersburg State Polytechnical University Journal, Ser. Economics,* 2011, No. 6, pp. 218-221 (in Russian).

In 2012 a regionalized IA model with region-specific physical capital depreciation rates endogenously increasing under effect of global warming is proposed on the basis of the above mentioned model.

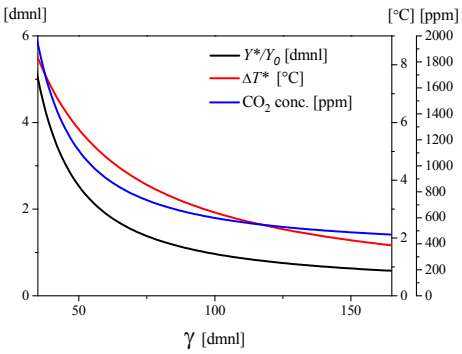

Fig. 20. The dependence of stationary levels of non-dimensional output (black curve), global mean temperature increase (red curve) and CO_2 atmospheric concentration (blue curve) on non-dimensional sensitivity of capital depreciation rate to temperature increase in a single-region Integrated Assessment model

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2011

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Smirnov V.G., **V.Y. Alexandrov.** Methods of ice drift determination from remote sensing data. Chapter 3.5 in: *Satellite Methods of Sea Ice Cover Characteristics Determination,* Smirnov V.G. (Ed.), St. Petersburg: AARI, 2011, pp. 154-158 (in Russian)

Smirnov V.G., I.Eu. Frolov, A.V. Bushuev, I.G. Bychkova, A.V. Grigoryev, **N.Y. Zakhvatkina,** *V.S. Loshchilov, V.V. Stepanov,* **L.P. Bobylev, V.Y. Alexandrov.** Capabilities of Remote Sensing as a source of operative objective information about the polar sea ice cover state. In: *Oceanography and Sea Ice,* Frolov I.Eu. (Ed.), Moscow: Paulsen, 2011, pp. 50-69 (in Russian)

Smirnov V.G., V.S. Loshchilov, **V.Y. Alexandrov.** Ice concentration retrieval from satellite radar images. Chapter 3.3.1 in: *Satellite Methods of Sea Ice Cover Characteristics Determination,* Smirnov V.G. (Ed.), St. Petersburg: AARI, 2011, pp. 131-134 (in Russian)

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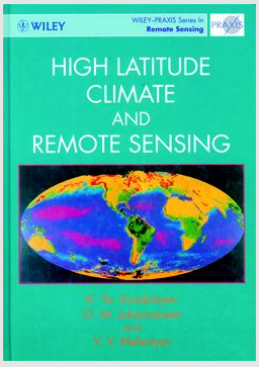

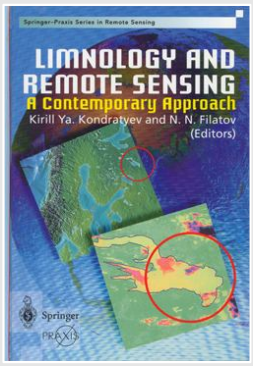

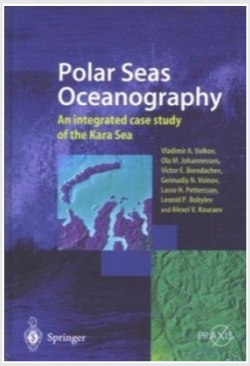

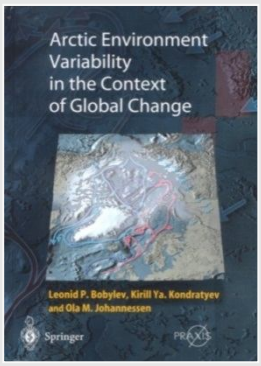

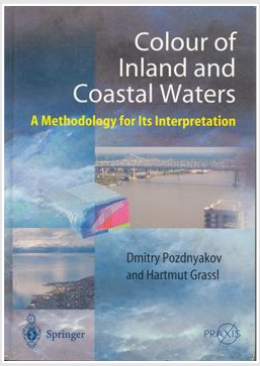

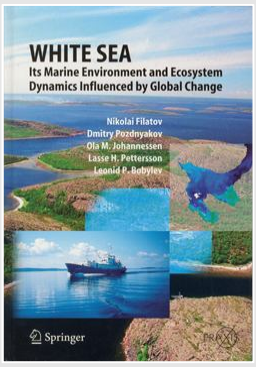

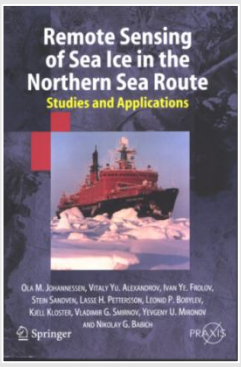

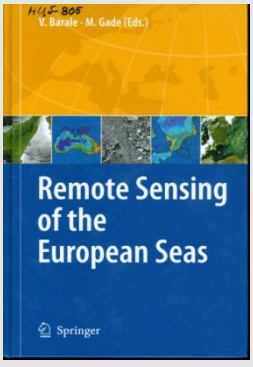

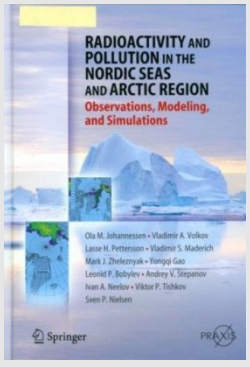

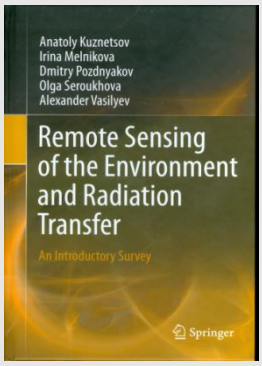

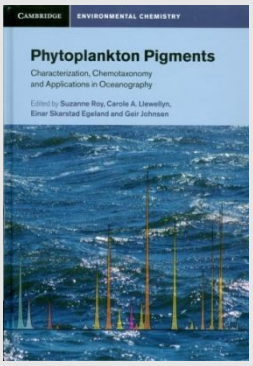

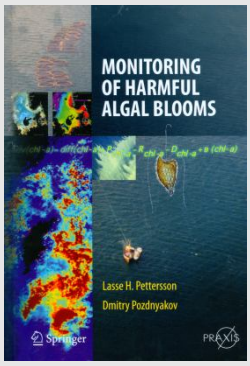

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