Annual Report 2015

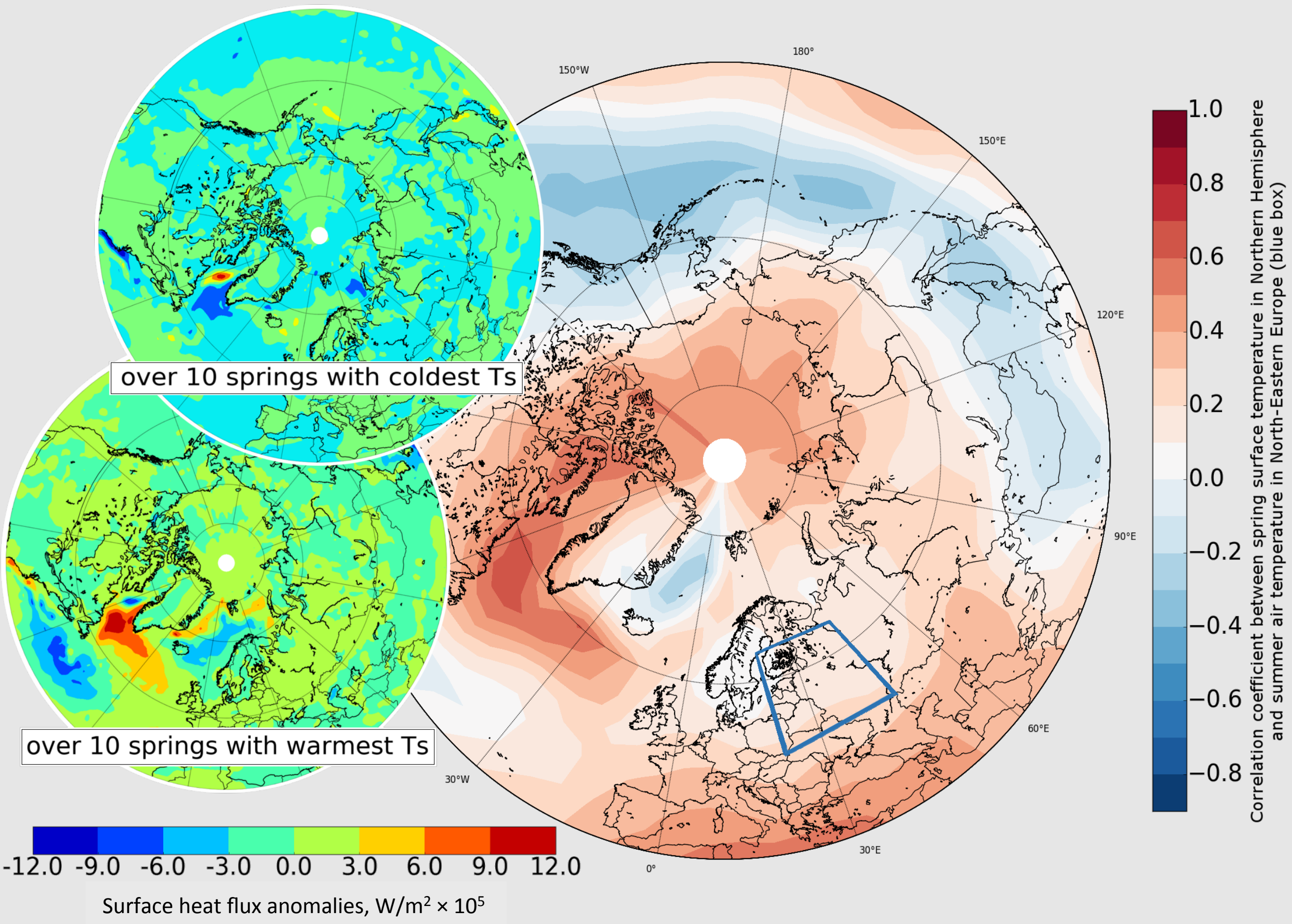
Nansen International Environmental and Remote Sensing Centre

St. Petersburg, Russia

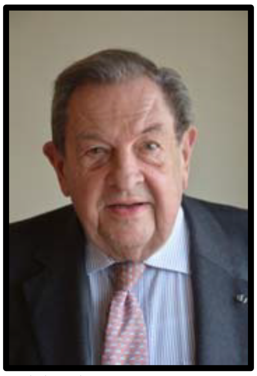
Non-profit international institute for environmental and climate research

Founded in 1992

Spring heat fluxes in Labrador Sea remotely control summer temperatures in the North-Eastern Europe



Tribute to the memory of Prof. Jean-Pierre Contzen



With outmost dismay we announce about the untimely decease of Professor Jean-Pierre Contzen. While on active duty, he suddenly died on Tuesday, October 27, 2015.

Professor Jean-Pierre Contzen studied engineering and nuclear physics at the Université Libre de Bruxelles before working on reactor safety and advanced conversion systems at the Nuclear Research Centre of Mol. He started in 1974 a 25 years' association with the European Commission occupying successively the positions of Director of Programmes of the Joint Research Centre (JRC), Director for Science & Technology Policy, Director General of the JRC and Special Adviser of the Commissioner in charge of External Relations.

In 1993-1997 he was member of the Management Board of the European Environmental Agency. Later he became Special adviser of the Minister of Science and Technology of Portugal.

A veritably noble man, bright scientist, astonishingly skilful organizer of work of scientific institutions, Jean-Pierre in his capacity as the President of NIERSC immensely contributed to further development of our Centre. To achieve this goal, he used his profound vision of the actual situation in both our country and abroad, his extraordinary experience in financial politics of scientific bodies as well as personal wide contacts with the worldwide scientific community.

Invariably friendly responsive, supportive of the NIERSC staff and especially PhD students and young scientists, Jean-Pierre was considered not only as a «high boss» but rather as a friend by all of us. As such he will remain in our hearts for many years to come, and we will always miss him.

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
- 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

Cover page: *(right plot) correlation coefficient between spring surface temperature in the Northern Hemisphere and summer air temperature in North-Eastern Europe (blue box); (left plots) surface heat flux anomalies (sensible + latent heat) averaged over 10 springs with warmest/coldest surface temperature in the Labrador Sea from the period 1979-2014* foundation established by Russian, Norwegian and German 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 2015 NIERSC staff incorporated 30 employees comprising core scientists, including one full Doctor of Science and seven PhDs, part-time researchers, and administrative personnel. 5 Nansen Fellowship PhD-students were supervised and supported financially, all holding also part-time positions of Junior Researchers at NIERSC.

Production

In 2015 totally 33 publications were published, one book chapter, 12 papers in peer reviewed journals, two papers in other journals and 18 conference proceedings (see the Reference list at the end of Report).

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 European Space Agency, Global Climate Forum, Max-Planck Institute for Meteorology (Germany), Friedrich-Schiller-University (Germany), Finnish Meteorological Institute (Finland), University of Helsinki (Finland), University of Sheffield (UK), Stockholm University (Sweden), Johanneum Research (Austria), 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, and cooperating partners.

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 modelling for studies of the Earth system. NFP provides 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. NFP is sponsored by the Nansen Scientific Society and partly by the Nansen Centre in Bergen, Norway.

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.

25 young Russian PhD-students have since 1994 got their doctoral degrees under the NFP.

Research Projects

Below is the list of the research projects implemented at NIERSC in 2015 in close cooperation with other national and international scientific institutions:

- COCONET (EU-FP7/NERSC s/c, 2012-2015)
- Prototype Operational Continuity for the GMES Ocean Monitoring and Forecasting Service (MyOcean-2, MyOcean-FO, EU FP7, 2012-2015)
- European-Russian Centre for cooperation in the Arctic and Sub-Arctic environmental and climate research (EuRuCAS, EU FP7, 2012-2015)
- Knowledge Based Climate Mitigation Systems for a Low Carbon Economy (COMPLEX, EU-FP7, 2012-2016)
- Ships and Waves Reaching Polar Regions (SWARP, EU-FP7, 2014-2017)
- Extreme scenarios of climate change and their impacts on Russian and world economy (RFBR, 2013-2015)
- Great Lakes 2015-1, 2015-2 (Michigan Tech, 2014-2016)
- Post-fire transformation of permafrost landscapes and its impact on hydrological regime of small and medium rivers in Eastern Siberia (RFBR, 2014-2015)
- Development of software for processing Russian satellite data (ROSCOSMOS, 2015)
- Arctic sea ice book (NERSC s/c (ESA), 2014-2016)
- Meridional heat and moisture transport into Arctic and its role in the Arctic amplification (RFBR, 2015-2017)
- Development of sea ice monitoring and forecasting system to support safe operations and navigation in Arctic seas (SONARC, Russian-Norwegian Project: RFBR-NORRUS, 2015-2017)
- Terrestrial ecosystems and soil carbon accumulation (RFBR, 2015-2017)
- Consumer choice and herding behaviour in microeconomics (RFBR, 2015-2017)
- Sea Ice CCI Phase 2 (ESA/subcontract to NERSC, 2015-2017)
- MON-SWARP (Subsidy from Ministry of Education and Science of RF No.14.618.21.0005 for the project "Ships and Waves Reaching Polar Regions", 2015-2017)

St. Petersburg, 15 March 2016

Nikolay N. Filatov, NWPI RAS, President

Valentin Meleshko, VMGO, Co-President

Hartmut Grassl, Max-Plank Society, Vice President

Stein Sandven, NERSC, Vice President

Sergey V. Aplonov, SPbSU

Vladislav K. Donchenko, SRCES RAS

Leonid P. Bobylev, Director

SCIENTIFIC REPORT

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

In 2015 NIERSC has completed big international EU FP7 project EuRuCAS (Fig. 1) aimed on extension, consolidation and strengthening scientific cooperation between researchers from EU Member States and Associated Countries and Russia using NIERSC as a joint research facility.

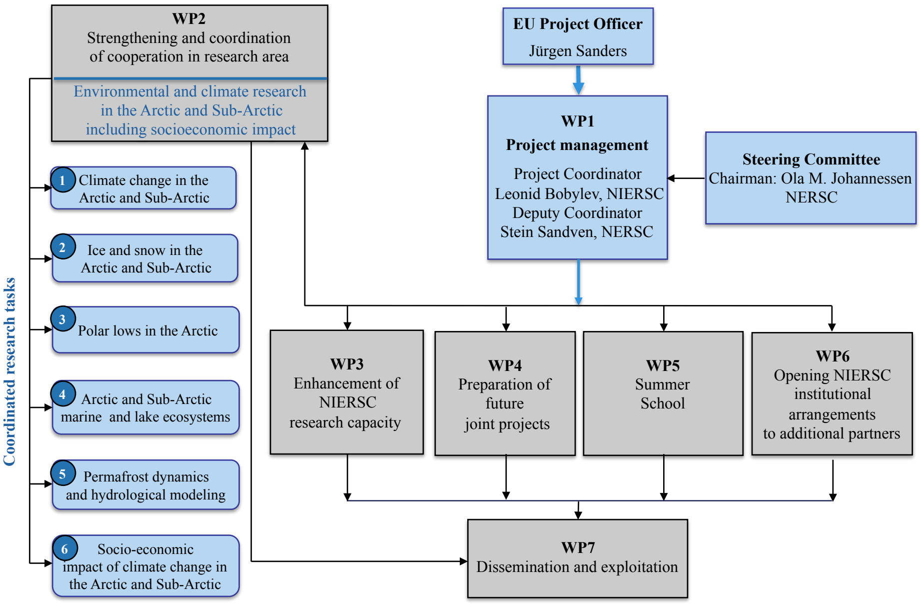


***Figure 1**. Overall strategy and structure of EuRuCAS Project*

EuRuCAS goals have been attained through enhancement of NIERSC research capacities (WP3, Fig. 1), research visits of European scientists from project partner institutions to NIERSC for joint work with Russian scientists (WP2), new future joint projects initiated at the international workshops (WP4), summer school aimed on involvement of young generation of researches into EU-Russian cooperation (WP5), and opening NIERSC institutional arrangements for additional partners from EU (WP6).

Research cooperation was organized around seven tasks (WP2): (i) climate change in the Arctic and Sub-Arctic; (ii) ice and snow in the Arctic and Sub-Arctic; (iii) polar lows in the Arctic; (iv) Arctic and Sub-Arctic marine and lake ecosystems; (v) permafrost dynamics and hydrological modelling; and (vi) socioeconomic impact of climate change in the Arctic and Sub-Arctic. Within this cooperation EU scientists have worked for totally about 112 person-months at NIERSC. The same time, NIERSC researchers have worked for about 16 person-months at EU institutions, mostly at the Nansen Centre in Bergen, Norway, Finnish Meteorological Institute in Helsinki, Finland, Friedrich-Schiller University in Jena and Max-Plank Institute for Meteorology in Hamburg, Germany. This two-way exchange of researches significantly contributed to the achievement of the project objectives.

***Figure 2**. Consul General of Norway in St. Petersburg, Ms. Heidi Olufsen, at the opening of the 2nd EuRuCAS Workshop at NIERSC, St. Petersburg, 5 November 2013*

To ensure further EU-Russia cooperation in considered area far beyond the EuRuCAS Project, a number of joint research proposals have been submitted under various calls including EU FP7 and Horizon 2020 Programmes. The ideas and outlines of such proposals have been elaborated during six workshops (Fig. 2) held at NIERSC in St. Petersburg and in Moscow.

The long-term prospects of sustainability of EU-Russian scientific cooperation, being fostered in the EuRuCAS project, crucially depend on how actively young generation of researchers participates in knowledge transfer and implementation of joint research projects. To promote effective scientific communication between world-wide acknowledged scholars and leading experts, on the one hand, and promising young scientists from various research domains, on the other hand, an International Summer School on the land hydrology and cryosphere of the Arctic and Northern Eurasia in the changing climate has been held on 29 June-5 July 2014 in Repino, near St. Petersburg, Russian Federation (Fig. 3).

For maintaining long-term research cooperation between European institutions and NIERSC, Nansen Centre's institutional arrangements were opened to new EU partners using mechanism of Associate Partnership (WP6, Fig. 1). It is assumed that the Associate Partners and NIERSC develop close cooperation in research, implementation of joint projects and supervision of joint PhD-students. The Associate Partners have rights to attend the General Meetings of NIERSC Founders with the consultative vote. As a result of this activity, six institutions have already joined NIERSC as Associate Partners (see list on p.2).

Details on the EuRuCAS Project and project Final report may be found at http://eurucas.niersc.spb.ru

***Figure 3**. Participants of EU-Russia workshop, 29 June-5 July 2014, Repino, St. Petersburg, Russia*

Climate Variability and Change in High Northern Latitudes

Sea ice in the Eurasian Arctic: compilation of a new historical data set

Dr. Leonid Bobylev (Nansen Centre (NIERSC), St. Petersburg, Russia/Nansen Centre (NERSC), Bergen, Norway)

Dr. Elena Shalina (St. Petersburg State University (SPbSU)/NIERSC, St. Petersburg, Russia)

Dr. Svetlana Kuzmina (NIERSC, St. Petersburg, Russia)

Prof. Ola M. Johannessen (NERSC/Nansen Scientific Society (NSS), Bergen, Norway)

A new sea ice extent (SIE) dataset for the Eurasian seas (Barents, Kara, Laptev, East-Siberian, and Chukchi) has been compiled by combining SIE satellite records (1979-2014) and Zakharov historical dataset (1928-2014) based on sea ice chart collection stored at the Arctic and Antarctic Research Institute created a consistent combined 86-year SIE dataset spanning 1928-2014. Since satellite data are produced from consistent sources with consistent processing, we used them unchanged as the foundation of the combined time series. The applied adjustment provided for eliminating biases for each monthly average SIE during the overlap period of both initial datasets 1979-2014.

The created 86-year time series has been used for analysis of sea ice extent trends in the Eurasian seas in the past and present. Since during winter season most of the seas are completely covered by ice, we analysed only summer sea ice variability and trends. Fig. 4 shows time-series of September sea ice extent and its 30-year running linear trends for five Eurasian Arctic seas over the period 1928-2014. In all seas ice extent is characterised by large interannual variability. Yet, there are some periods characterised by average sea ice increase or decrease. Thus, during 1928-1935/40 average SIE was decreasing in all seas.

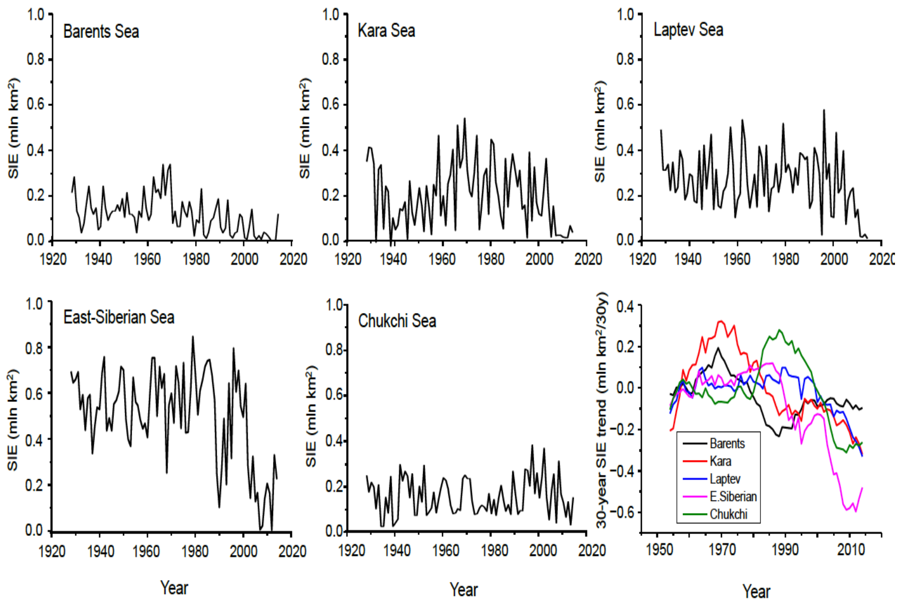


Figure 4. *September sea ice extent (SIE) and 30-year linear SIE trends (right bottom) for five Eurasian Arctic seas. 30-year running trends are computed at one-year increments: X-axis indicates last year of 30-year period, e.g. 1983 indicates 1954-1983, and so on*

(AARI). Observations from passive microwave satellite sensors have provided a continuous and consistent record of sea ice extent since late 1978. While having more confidence in the shorter satellite record, the longer historical record captures more of the internal variability of sea ice extent.

Using sea ice concentrations obtained from passive microwave data applying NORSEX algorithm we calculated sea ice extent for the Eurasian seas for the period 1979-2014. Then we have adjusted Zakharov SIE data to this satellite-derived SIE time-series and

Then, during 1940-1960/70 SIE was increasing on average in Barents and Kara seas, whereas in Laptev, East-Siberian and Chukchi seas average SIE did not show any tendencies from 1940 to late 1990s. Since 1970 to present SIE was decreasing in Barents and Kara seas. On-going decrease in average SIE in Laptev, East-Siberian and Chukchi seas started in late 1990s. Current period of on-going global warming is characterised by decline of summer sea ice in all considered Eurasian Arctic seas. The highest negative September SIE trend over the last 30 years has been observed in the East Siberian Sea: −0.51 mln km^2/30y. All considered seas are now nearly ice-free in September depending on the year.

Response of air temperature in Europe to anomalies in Northern Hemisphere surface temperature

PhD-student Natalia Gnatiuk (NIERSC, St. Petersburg, Russia)

Dr. Leonid Bobylev (NIERSC, St. Petersburg, Russia/NERSC, Bergen, Norway)

Dr. Timo Vihma (Finnish Meteorological Institute (FMI), Helsinki, Finland)

To examine hypothesised linkages between the Arctic Amplification and mid-latitude weather patterns, atmosphere response on the anomalies in surface temperature of the Northern Hemisphere (NH) has been evaluated. The basic idea we were following when analysing such potential linkages was that from the point of view of the atmosphere it is almost the same whether the thermal forcing originates from the sea ice melt, snowmelt, or changes in sea surface temperature. Most important is to quantify how the atmosphere responds to anomalies in the surface temperature and then affects weather patterns in remote areas.

Based on this idea, we studied the hemispheric-scale relationships between anomalies in the NH surface temperature (T_S) and 2-meter air temperature (T_{2m}) in mid-latitudes (Central and Eastern Europe). We used basic regression analyses and neural networks clustering (Self-Organizing Maps) based on ERA-Interim reanalysis data. We analysed these temperature linkages with focus on seasonal, lagged inter-seasonal (in the following seasons) and neighbouring (following) months.

We have found that the strongest links in the considered kind of relationships took place between spring T_S in the Labrador Sea and summer T_{2m} in the North-Eastern Europe (see cover figure). In order to confirm obtained results, identify thermal forcing factors and assess their relative importance we analysed for the Labrador Sea area the multiyear averages and anomalies of various meteorological parameters (surface pressure, total precipitation, sea-ice and total cloud cover, wind components, surface solar radiation downwards, surface heat fluxes and air trajectories) for selected 10 years with coldest/warmest spring/summer sea surface temperatures over the period 1979-2014.

The results showed that the remote effects are strongest with a time lag from spring to summer. The Labrador Sea T_S variations in spring have a detectable impact on the thermodynamics of the local atmosphere in spring; particularly positive surface heat flux anomalies are larger in years with a high spring T_S (cover figure). Also, there is a detectable effect on anomalies in the atmospheric pressure field and wind components. These springtime anomalies over the Labrador Sea region favour certain planetary wave patterns during summer. Thus, spring cold (warm) conditions over the Labrador Sea are a precursor for summer low pressure and temperatures (high pressure and temperatures) over the Eastern Europe.

Long-term variability of thermohaline water characteristics in the North Atlantic and Greenland Sea in 1950-2012

PhD student Anastasia Fedorova (NIERSC/ SPbSU, St. Petersburg, Russia)

Dr. Andrey Popov (Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia)

Dr Andrey Rubchenia (SPbSU, St. Petersburg, Russia)

The work was dedicated to study of long term variability of water temperature and salinity in the Nordic seas and North Atlantic in 1950-2012. Interest to chosen area is determined by its important role in the climate system and its change. Thus, as one of the main areas of deep water formation, the Greenland Sea is an important part of the global ocean conveyor.

Temporal variability of water thermohaline characteristics and their linear trends for selected areas of the considered region have been obtained to study comprehensively the processes of salinization and water warming occurred in the last two decades. The analysis of the autocorrelation functions and spectral density of observational data allowed identify the main periods of temperature and salinity variability in each study area. Cross-correlation and wavelet analysis revealed the possible relationships at different time shifts and similar variability periods. The area of "dome" of the bottom and deep waters was described in details.

It is suggested that the possible causes of the observed variability of the thermohaline characteristics in the area of bottom water formation are (1) the influence of advection due to connection with the North Atlantic and Norwegian currents, and (2) interrelation with the atmospheric processes.

The main conclusion of this study is that observed since 1991 increase of top layer temperature of the Greenland Sea "dome" of bottom water led to the weakening of convection processes.

Investigating the spatial variability of the carbon storage in tundra and boreal forest soils along ecotones

Dr. Alla Yurova (NIERSC, St. Petersburg, Russia)

Dr Jing Tang (University of Copenhagen, Copenhagen, Sweden)

Prof. Kevin Bishop (SLU, Uppsala, Sweden)

Boris Tupek (LUKE, Helsinki, Finland)

Tatiana Minaeva (Wetlands International/ Russian Forestry Institute, Moscow, Russia)

Soil is among the major terrestrial sinks of carbon and therefore playing a large role in mediating the climate change by removing significant amounts of CO_2 from the atmosphere (through plants litter). The purpose of this study was to investigate the role of ecosystem topographical position (and its place on the slope relative to other ecosystems) and variation in meteorological drivers in the dynamics of soil carbon storage in tundra and boreal forest biomes. Specific objectives were: (1) to develop a process-based model of soil water and temperature regime (including the presence of permafrost) and soil organic matter dynamics for a hill slope with a usage of satellite data on Net Primary Production (NPP); (2) to analyse the results of field studies of soil carbon accumulation for different positions on a hill slope performed for a number of test sites across boreal forest and tundra (Russia, Sweden, Finland); and 3) to analyse the found spatial features with the developed model.

New version of the model was prepared that enables simulations of soil temperature and water content for different soil layers, the thawing and freezing depths, evapotranspiration and runoff on the basis of 2D hydrological hill slope model SUTRA developed at USGS. Application to the permafrost soils is under development. In the current model version the 30x30 m grid cells are coupled laterally trough horizontal water exchange in saturated and unsaturated zones. Based on climatic mean hydrological variables the grid cells were classified in oligotrophic, mesotrophic and riparian zones (accumulative positions) for the test hill slopes in Northern Sweden – Abisko and Kryclan. The dissolved organic carbon (DOC) lateral transport and export to the stream was also calculated for Abisko site, and model sensitivity of model results to the input parameters was studied separately for the riparian and well-drained sites (Tang et al., 2015). Bayesian approach was used for the initialization of the soil pools based on multi-layer field observations of the soil carbon content made in Russia and Sweden. Additional samples were taken on one well-studied hill slope in Finnish boreal forest – peatland transition ecotone (Lakkasuo), and analysed in the laboratory of the University of Helsinki.

It was found that the northern boreal forest (Krycklan, Sweden) has rather typical pattern of the hill slope carbon accumulation with the maximum at the forest-stream transition and minimum (20% of the maximum) near the water divide, while intermediate positions have around 50% of the maximum carbon storage. Most of carbon is accumulated in the organic horizons with proportion being the highest (92%) in the riparian zone. No definite link between the position on the slope and the carbon storage was found for the tundra soils on permafrost (Shapkino, Russia). It is the combination of the deepening of the permafrost thawing depth and the excessive soil moisture that lead to the high accumulation of soil carbon – primarily in organic horizons.

The model showed good correspondence between the simulated and observed carbon pools for the boreal forest when the Bayesian method of soil pool initialization was used and historical information about the last disturbance incorporated. The results for the tundra ecotones are more modest, but the model is currently under development.

Impact of forest fires on hydrological regime of small and medium rivers in Eastern Siberia

PhD-student Lyudmila Lebedeva (Melnikov Permafrost Institute, Yakutsk/NIERSC, St. Petersburg, Russia))

Dr. Olga Semenova (State Hydrological Institute, St. Petersburg, Russia)

Dr. Elena Shalina (SPbSU/NIERSC, St. Petersburg, Russia)

Forest fires are regular at large territories of Siberia. Fire occurrence is expected to increase in the future due to climate change and anthropogenic influence Though there are many studies on vegetation and landscapes transformation after fire the analysis of associated hydrological and geomorphologic changes in permafrost environments in Russia are almost absent. Practically nothing is known about post-fire changes of river basins with area >1,000 km^2. The following objectives for the research were set up: (1) to describe changes in stream flow after extensive 2003 forest fire in several middle-size river basins in Trans-Baikal region of Russia; (2) to assess change in sediment flux after the fire in the same catchments; (3) to attribute found responses to dominating landscapes and the level of vegetation disturbance and

higher in the burned areas than in undisturbed landscapes. No changes of snow cover were found due to the post-fire landscape transformation.

Two burned basins (the Vitimkan and Amalat rivers, 78 and 46% burned respectively) out of six showed 35-41% short-term increase of summer streamflow equal to 40 and 140 mm, respectively, as the response to precipitation of low recurrence (Fig. 5).

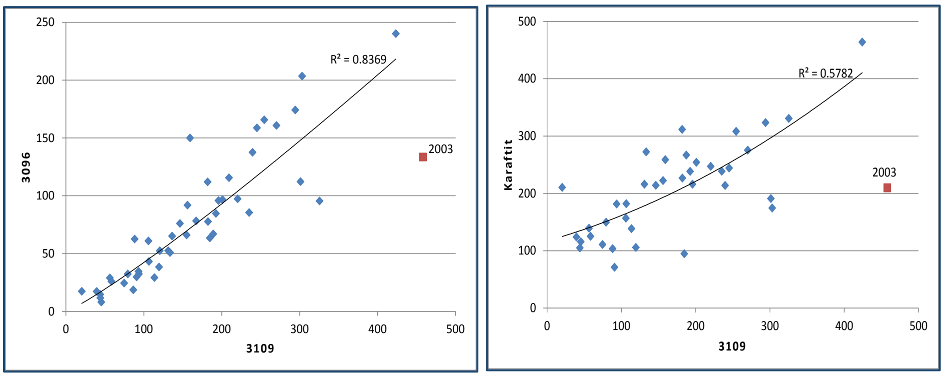


Figure 5. *Dependence of flow depth (mm) in July-August between basins Vitimkan, Ivanovskiy and Vitim, Romanovka (left) and basin 3109 and meteorological station Karaftit (right) with post-fire (2003) outliers marked with red*

other factors; and (4) to analyse the mechanisms of those changes using the analysis of ground and remote sensing data.

Following severe drought 2002-2003 extensive fires occurred in spring and summer of 2003 in the southeast part of Russia when more than 20 million ha were affected by disaster (Siegert et al., 2004). Long-term daily data on river discharge, precipitation and decadal values of suspended sediments from river basins in Trans-Baikal region were analysed to detect any change in water and sediment transport after extensive fire in 2003. The burn watersheds showed significant individuality in their response to fire depending on the particular set of conditions to which they were exposed during the fire.

Total fraction of dead, partially dead and highly disturbed vegetation classes vary between 39.2 and 88.0% of cloud-free basin territory for three burned basins. Estimation of burned area according to MODIS and Landsat imagery do not agree much to each other. In four basins out of six MODIS assessment is in 1.5-2 times higher than Landsat value. For the other two basins Landsat showed larger fraction of burned territory than MODIS. No correlation between fraction of burned area or dead vegetation and water and sediment flow change after the fire was found for the six studied basins. Analysis of the MODIS surface temperature product (MOD11A2) for 2000-2005 showed that spring and summer surface temperature is 2°C

Any changes in the streamflow regime after the fire at the basin of the Karenga River (72% burned) could not be detected.

Thus the proportion of the burnt area could not be considered as the main factor determining the change of water flow regime after fire. The combination of high value of burned area, intense rainfall, significant and simultaneous damage of vegetation by fire is presumably main reason of observed hydrological post-fire changes at the Vitimkan and Amalat Rivers.

Arctic oceanographic research

Automated classification of ice based on satellite Sentinel-1A data

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Dr. Anton Korosov (NERSC, Bergen, Norway)

PhD-student Anna V. Vesman (AARI/NIERSC, St. Petersburg, Russia)

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Dr. Stein Sandven (NERSC, Bergen, Norway)

Development and improvement of automatic sea ice classification algorithms from satellite Synthetic Aperture Radar (SAR) data is being carried out in the framework of SONARC, SWARP and MON-SWARP projects (see list on p.3). In 2015, the work on the ice type classification algorithm for Radarsat-2 data was completed (Fig. 6). Algorithm has been trained for the Barents Sea. It is able to distinguish several classes of underlying surface – first-year ice (FYI) thick, FYI thin, Marginal Ice Zone (MIZ), thin younger ice and some very bright thin ice, and also open water, calm and windy. The multi-year ice was not considered in this area.

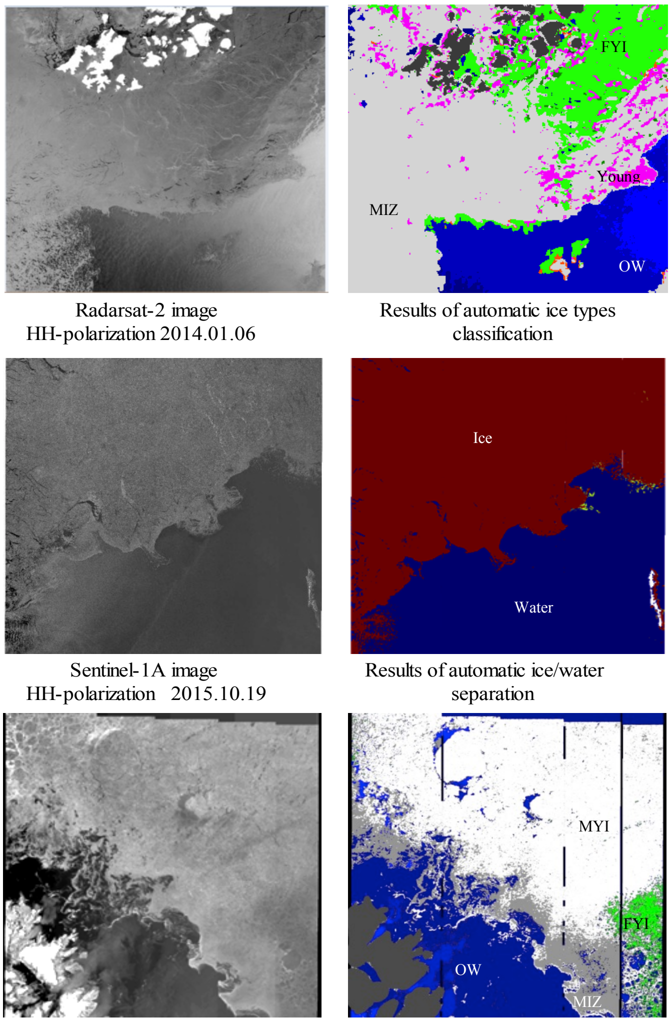
In 2014 a new European radar imaging satellite Sentinel-1A was launched, so there was a challenge to adapt previously developed by the Nansen Centres classification algorithm to the new data type. This has been done in 2015 jointly by the Nansen Centres in St. Petersburg and Bergen: a new algorithm for ice/water discrimination for Sentinel-1A SAR images has been developed.

A distinctive feature of this algorithm is an addition of new, not previously used in Nansen Centre's image classification algorithms, steps. They are: (1) performing Principle Component Analysis (PCA) with extracting only few principal components; (2) applying k-means cluster analysis to split PCs values into several classes; and (3) performing manual re-classification of the automatically generated raster maps.

The addition of these steps allowed to compress the volume of information and, thus, accelerate the calculation process, and to reduce the influence of expert qualification on the analysis results. Earlier, highly qualified expert was required for preparation of a training dataset. Now, the performing preliminary image automatic clustering allows obtain a chart with clusters, which can be analysed by less experienced sea ice expert.

This ice/water discrimination algorithm was trained and tested: in most cases it gave stable satisfactory results. At the received charts (Fig. 6), it is possible not only to highlight a border between ice and water, but also to obtain information about irregularities in ice such as large cracks and leads.

Also the test version of ice type classification algorithm for Sentinel-1A data was trained. It is able to distinguish following classes of underling surface: (1) open water rough; (2) open water calm with nilas or some new ice fractures; (3) MIZ (rather narrow area between open water and ice consisting of, in general, the same ice type as the main closed ice area) and some more younger ice; (4) multi-year ice. The resolution of the classification results is about 300 m



Radarsat-2 image HH-polarization 2014.01.06 — Results of automatic ice types classification

Sentinel-1A image HH-polarization 2015.10.19 — Results of automatic ice/water separation

Sentinel-1A image HH-polarization 2014.10.05 — Results of automatic ice types classification

Figure 6. *Examples of sea ice classification using developed algorithms (FYI – first-year ice; MYI – multi-year ice; MIZ – Marginal Ice Zone; OW – open water)*

Non-Linear Filtering for sea ice drift field retrieval from satellite SAR images

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Viktoriya Khmeleva (NIERSC, St. Petersburg, Russia)

Stefan Muckenhuber (NERSC, Bergen, Norway)

SAR image filtering is needed due to speckle and Gaussian noise, which should be removed as much as possible for successful application of automated algorithms.

In present, linear and non-linear filters for noise reduction are used. Linear filter is determined by function or core of raster filter. It based on convolution function, which averages brightness values by some smoothing mask. Gaussian blurring which is the result of blurring an image by a Gaussian function, is the most widely used. It is very effective against "white" noise of satellite images as well. Gaussian smoothing is also used as a pre-processing stage in computer vision algorithms in order to enhance image structures at the different scales. Mathematically, applying a Gaussian blur to an image is the same as convolving the image with a Gaussian function. This approach is effective when we have Gaussian distribution of noise but this noise smears the edges and fine features together with the speckle noise, thus failing to preserve image structure. The presence of speckle may decrease the utility of SAR imagery by reducing the ability to detect ice features like cracks, leads, ice floe borders etc. Consequently, it is not only complicates visual image interpretation, but also makes automated digital image classification a difficult problem.

Radar speckle noise has a standard deviation linearly related to the mean and is often modelled as a multiplicative process. This means that the higher the signal strength the higher the noise. As a result, more speckle noise is commonly present near brighter pixel areas. Non-linear filters showed the best results for speckle suppression and the edge preservation.

Thus, we used a diffusion non-linear filter for noise suppression in SAR images. The diffusion coefficient is depends on local image intensity for optimal smoothing of noise. If the average intensity around some point is low, then, most probably, it is the noise area and has to be blurred. Otherwise, if the average intensity is high then we have the edge and try to avoid the blurring. So, the diffusion coefficient depends on the local gradient and should vanish when the gradient is endless. In other words, the task to preserve the endless gradients (ice features) and, the same time, to suppress noise was formulated.

The formulated scheme is used for SAR images pre-processing for sea ice drift retrieval.

Fig. 7 shows satellite-derived ice drift vectors retrieved from the Sentinel-1A images. Two initial SAR images were pre-processed using Gaussian and A-Diffusion filters (non-filtered image is also presented). Obtained results clearly indicate the satisfactory degree of

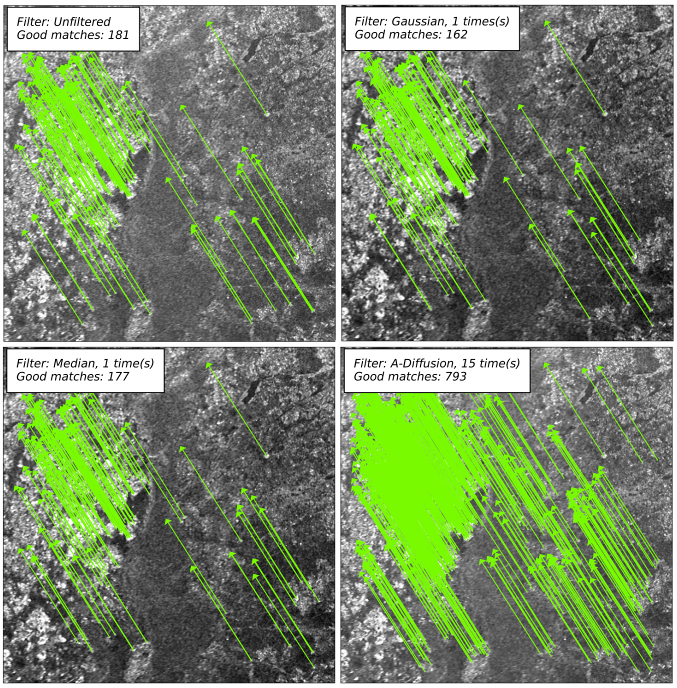

Figure 7. *Application of linear and non-linear filtration algorithms for sea ice drift retrieval from Sentinel-1A SAR images*

blurring small features and sharping areas with strong gradients. Moreover, the maximum number of good ice drift vectors are derived using A-Diffusion filter.

Aquatic Ecosystems in Response to Global Change

Multi-year tendencies in E. huxleyi blooms across latitudinally and meridianally distanced marine environments in the Northern Hemisphere

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Among the drivers of global climate change, the dynamics of carbon cycle in the atmosphere-ocean system is considered as a factor of a paramount importance. The industrialization epoch launched in the 20th century manifested itself by a rapid increase of CO_2 partial pressure in the planetary atmosphere. Following the water vapour, CO_2 is the most efficient greenhouse gas. The ability of the World's Oceans to go on uptaking CO_2 from the atmosphere like it was during the pre-industrial epoch is reportedly steadily declining nowadays as the CO_2 dissolution reaction tends to its saturation. This is bound to result in greenhouse effect intensification and global warming. One of the consequences of this process is warming of ocean surface layer, which in turn brings about a shift of the dissociated $CaCO_3$ to solid for, i.e. suspended matter. Thus, the status of the ratio between dissociated and solid forms of $CaCO_3$ in the World's Oceans attains a special importance.

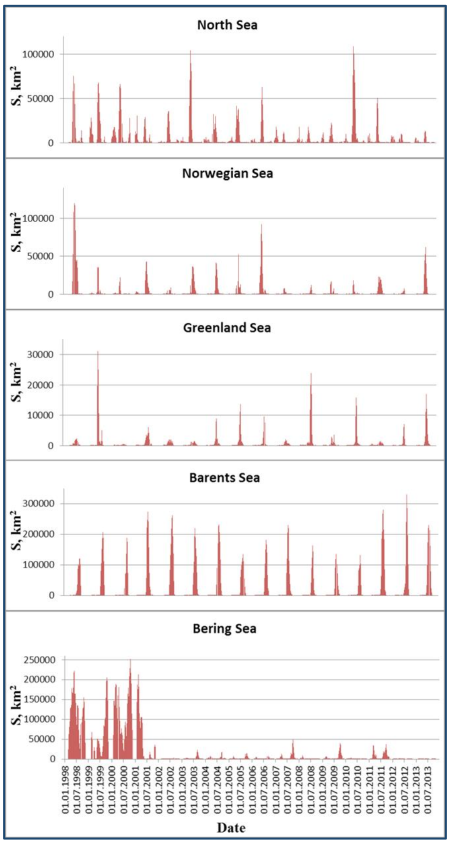

Figure 8. *A spaceborne time series of variations in E. huxleyi bloom occurrence and spatial extent as revealed over the period 1998-2013 for the target seas*

Suspended inorganic carbon is produced in the World's Oceans as calcite in the process of life cycles of reef biosystems macrophytes or planktonic communities such as *Emiliania huxleyi* and *Gephyrocapsa oceanica* – microalgae that are remarkably efficient in calcite production in, respectively, marine open and coastal waters.

It is established *E. huxleyi* and *G. oceanica* account for about 60% of the World's Oceans calcification. That is the overall production of calcite by these two species has a globally relevant importance.

However, a precise assessment of inorganic carbon production by algae is hampered because of gigantic bloom areas, their temporal dynamics and spatial heterogeneity. Understandably, due to logistic limitations, traditional shipborne methods are untenable for providing a *global* coverage of this phenomenon in terms of the calcite quantification. In this sense, satellite remote sensing is the only practical means to reach this goal. These data were obtained from the information product provided by OC CCI (ESA, http://www.esa-oceancolour-cci.org/).

A special procedure was developed to mitigate the cloud masking. As a result, the informative area was increased by 100% and in some cases even significantly more.

The following latitudinally and meridianally distanced marine environments were studied: North, Norwegian, Greenland, Barents, and Bering seas.

Delineation of *E. huxleyi* bloom areas was effected through employing a two-step methodology: firstly, RGB images of marine tracts were generated to reveal the location of *E. huxleyi* bloom areas due to their intrinsic turquoise colour. Secondly, the spectra of remote sensing reflectance, $R_{rs}(\lambda)$ were analysed and statistically typified to determine with the outmost precision the confines of bloom areas. It was established that an *E. huxleyi* bloom can be considered absent if the R_{rs} maximum is localized at ~443 nm, the R_{rs} spectral values (sr^{-1}) in the SeaWiFS standard channels are less than 0.001 (412 nm), 0.008 (443 nm), 0.01 (490 nm), 0.008 (510 nm), 0.008 (555 nm) and ~0 (670 nm). If these thresholds are exceeded, the bloom area was ascribed to *E. huxleyi* bloom.

The results of the study are illustrated in the Fig. 8,9 below for the marine environments specified above.

Our investigations have shown that the bloom occurrence in the target seas in the Atlantic and Arctic oceans on the one hand and on the other hand in the Pacific Ocean differ significantly (Fig. 8): in the latter case there was a period of enhanced blooming that lasted between ~1998 and 2001, which than followed by a drastic drop off of this phenomenon. Conversely, the blooms observed in the north Atlantic and Polar Ocean have a more regular patter, especially so for the Barents Sea.

The intraannual period of *E. huxleyi* blooms has a distinct pattern: the blooms originate only once a year nearly simultaneously in the North and Norwegian seas (but last longer in the latter), but further to the north the setup of blooms in the Barents and Greenland seas occurs later.

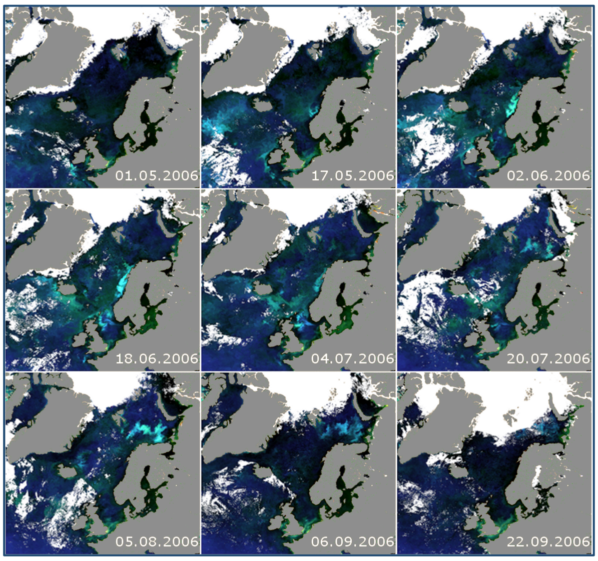

Figure 9. *Example of E. huxleyi bloom successions from the North Sea to the Barents and Greenland seas during 2006*

Fig. 9 exemplifies for 2006 the propagation of bloom areas (designated in black) along the riparian European mainland: firstly, they appear along the west southern coastline of the British Islands to further proliferate into the North and Norwegian seas, which is thought to be driven by the Gulf Stream ramifications. The letter initiate *E. huxleyi* blooms in the northern, central and northeastern parts of the North Sea.

Further on, the blooms emerge in the Barents and Greenland seas. Notably, unlike the European and Barents seas, the blooms in the Bering Sea occur twice a year – in early spring and late fall.

Our investigations have shown that the duration of blooms over the time period 1998-2013 has not undergone significant variations and remained more or less stable, with some rare exceptions, one of which, most notable, occurred in 2002.

Data in Fig. 8 indicate that the most extensive *E. huxleyi* blooms cover immense areas, in some instances reaching several hundreds of thousand square kilometres, thus emphasizing the importance of this phenomenon for the planet climate and ocean ecology.

Spaceborn quantification of primary production in the Baltic Sea

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The absence of an acknowledged pun-Baltic Sea (BS) model of primary productivity (PP) stems from two major impediments: a) significant complexity and heterogeneity of optical properties of the Baltic Sea, and b) notable seasonal variations in the indigenous phytoplankton composition (Beltran-Abauza et al., 2014). These specific features determined the course of task on identification of, firstly, a PP model and, secondly, a biohydrooptical algorithm for the retrieval of phytoplankton chlorophyll (*chl*) that are most adequate for the BS.

Following this pathway, four primary production models developed *specifically* for the Northern Atlantic – Marra et al., 2003; Behrenfeld and Falkowski, 1997; Behrenfeld et al., 2005, and Arrigo and van Dijken, 2011 (see also Pubi et al., 2008) – have been tested for the conditions in the Baltic Sea. For this purpose a BS database of *in-situ* PP measurements was developed. In addition to PP values, it encompassed all presently available data from the Helsinki Commission (HELCOM) and the Swedish Meteorological and Hydrological Institute (SMHI) archives on surface and depth-distributed *chl*, sea surface temperature, and incident photosynthetically active solar radiation. The database included 2,200 and 105 measurements of *chl* and PP respectively for the period 2002-2012. The Behrenfeld and Falkowski (1997) model yielded the best results and became basic for further work.

Among the tested for the BS *chl* retrieval algorithms, viz. OC3 (NASA), GSM (NASA; Maritorena et al., 2003), OC4 (NASA), OC2-modified (Darecki et al., 2005), BOREALI (Korosov et al., 2009), the OC3 algorithm gave better results.

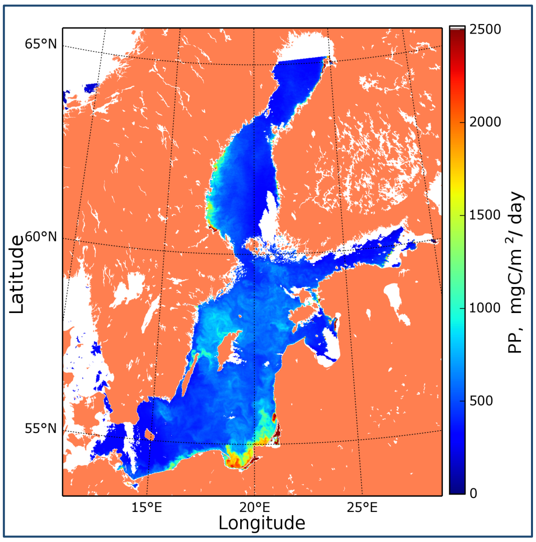

Figure 10. *Spaceborne daily PP fields across the Baltic Sea on 02.07.2014 as restored with the new algorithm*

Two atmospheric correction techniques were comparatively exploited: MUMM (Ruddick et al., 2000) and NASA standard models. The MUMM technique permitted to attain better *chl* retrievals. Thus, that the PP model and *chl* retrieval algorithm most appropriate for the BS have been ascertained and further employed for restoring seasonal PP fields for the period 2002-2012 (Fig. 10 illustrates the restored PP field for 2014).

Research in Economics of Climate Change and Economic Modelling

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Modelling the win-win opportunities of climate mitigation policies

In 2015 Integrated Assessment modelling (IAM) and economic modelling was performed in the framework of EU COMPLEX and EuRuCAS projects and two projects supported by the Russian Foundation for Basic Research (No.13-06-00368 and No. 15-06-05625) (see list on p. 3).

The limited success achieved so far in the area of global climate agreements has been extensively discussed by many authors in the 'free-rider problem' framework. According to this framework, climate mitigation can be achieved only through joint actions of all countries. Any single country – even a large greenhouse gases emitter – would not significantly mitigate the climate change if it acts alone. According to the mainstream viewpoint, such a country would bear net economic losses, while countries not participating in climate agreements ('free-riders') would benefit for free from climate mitigation actions of participating countries. This free-riding in climate negotiations leaves little incentive for climate mitigation policies.

As recently suggested by Klaus Hasselmann jointly with a group of other EU FP7 COMPLEX project participants (including NIERSC), climate mitigation policies at the regional level, if well designed, could be beneficial for the countries initiating them, therefore eliminating the free-rider motivation for inaction, creating instead incentives to forerunning. This reframing of climate mitigation problem from a free-rider to a forerunner perspective is supported by innovative actor-based system dynamics economic models which go beyond measuring the well-being of a country solely in GDP terms and incorporate also other measures of well-being (notably the employment level) in the modelling framework.

As example, the North-South Euro crisis model was developed along these lines, suggesting that properly designed climate mitigation actions might help the resolution of the euro crisis. Modelling results suggest that purpose-oriented green investment (e.g. in renewable energy production) from North to South (the latter experiencing the budget deficit) might help resolve the euro crisis with substantially smaller decrease in the employment level in the South (as compared with the traditional – and actually adopted – austerity scenarios).

The results of this research are reported in: *Hasselmann K., Cremades R., Filatova T., Hewitt R., Jaeger C.,* ***Kovalevsky D.,*** *Voinov A., Winder N. (2015):* Free-riders to forerunners. *Nature Geoscience,* **8,** 895-898.

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