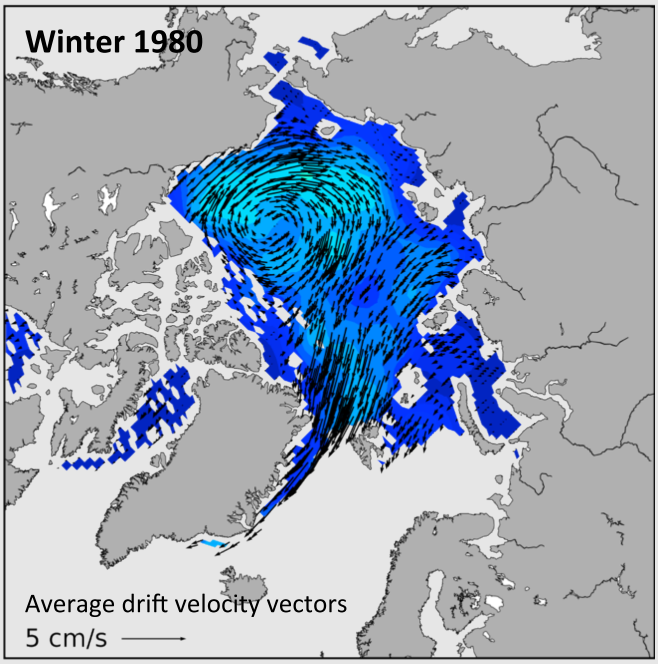
Annual Report 2013

Nansen International Environmental and Remote Sensing Centre

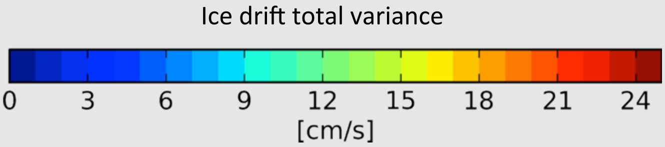
St. Petersburg, Russia

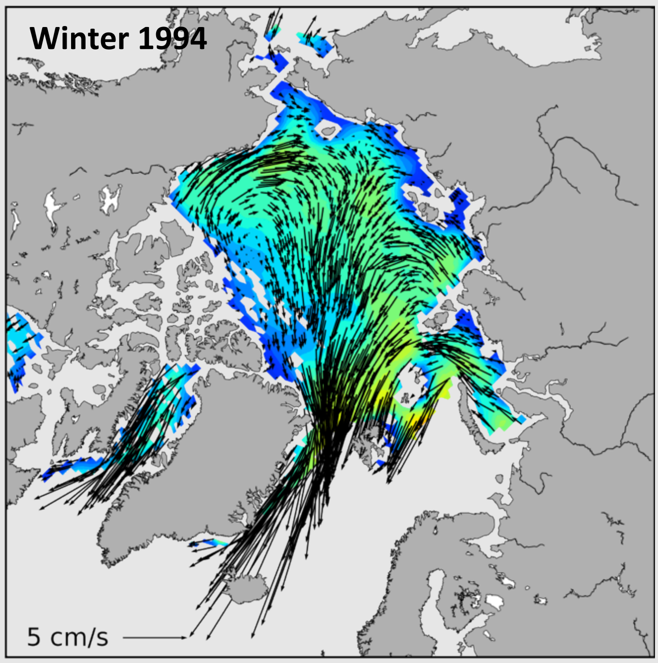
Non-profit international research institute for environmental and climate research

Founded in 1992



Two different types of sea ice drift in the Arctic Ocean as revealed from space





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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
- 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 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 2013 NIERSC staff incorporated 22 employees comprising core scientists, including 1 full Doctor of Science and 4 with a PhD degree, part-time researchers, and administrative personnel. 9 Nansen Fellowship PhD-students are supervised and supported financially, 7 of them holding also part-time positions of Junior Researchers at NIERSC.

Production

In 2013 totally 32 publications were published, 10 papers in peer reviewed journals, 4 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

Cover page: *Distribution of two main invariant characteristics of ice drift fields in the Arctic for winter seasons 1980 and 1994 calculated by vector-algebraic technique from IFREMER satellite data set. Colors and arrows show total variance and average drift velocity vectors correspondingly.*

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 modeling 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 Centre and the Nansen Scientific Society 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.

24 young Russian PhD-students have since 1994 got their doctoral degrees under the NFP. In 2013, one NFP participant, Evgeny Morozov, defended PhD-thesis on 6 June 2013 at the Russian State Hydrometeorological University. The title of his PhD thesis was: *Algorithms for determination of chlorophyll-a and total suspended matter and for identification of micro algae Lepidodinium chlorophorum and Emiliania huxleyi with the use of satellite remote sensing data in the Bay of Biscay. Supervisors: D.V Pozdnyakov, V.I. Sychev, H. Grassl, L.H. Pettersson.*

Research Projects

Below is the list of the research projects implemented at NIERSC in 2013. Most of them were implemented in close cooperation with other national and international scientific institutions.

- Monitoring and Assessing Regional Climate Change in High Latitudes and the Arctic (MONARCH-A, EU FP7, 2010-2013)
- Processing Russian satellite measurements (NTSOMZ/Roscosmos, 2011-2013)
- Sea Ice Downstream Services for Arctic and Antarctic Users and Stakeholders (SIDARUS, EU FP7, 2011-2013)
- Investigation of factors driving changes in phytoplankton surficial fields as an aftermath of passage of hurricanes in tropical and polar regions (RFBR-China, 2012-2013)
- CPA Algorithm (Michigan Tech, 2012-2013)
- CryoSat validation (NERSC s/c, 2013)
- Great Lakes (Michigan Tech, 2013)
- Monitoring Arctic Land and Sea Ice using Russian and European Satellites (MAIRES, EU FP7, 2011-2014)
- COCONET (EU-FP7/NERSC s/c, 2012-2015)
- Prototype Operational Continuity for the GMES Ocean Monitoring and Forecasting Service (MyOcean-2, EU FP7, 2012-2014)
- Nordic seas climatology (NERSC, 2012-2014)
- Sea ice ECV (ESA, with additional NERSC s/c, 2012-2014)
- Extreme scenarios of climate change and their impacts on Russian and world economy (RFBR, 2013-2015)
- Knowledge Based Climate Mitigation Systems for a Low Carbon Economy (COMPLEX, EU-FP7, 2012-2016)
- Arctic climate change (RFBR-NORRUS, 2012-2014)
- Optimization and system-dynamic approaches in models of economics of climate change (RFBR, 2012-2014)

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 major NIERSC projects funded within 2010 EU FP7 INCO-LAB call “Strengthening European research facilities in third countries”. 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 (see back cover page).

St. Petersburg, 1 April 2014

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Climate Variability and Change in High Northern Latitudes

Climatology of polar lows over the Nordic and Barents seas for 1995-2008 created from satellite passive microwave data

PhD-student Julia E. Smirnova (Russian State Hydrometeorlogical University (RSHU)/Nansen Centre (NIERSC), St. Petersburg, Russia)

Dr. Elizaveta V. Zabolotskikh (RSHU/NIERSC)

Dr. Leonid P. Bobylev (NIERSC/Nansen Centre (NERSC), Bergen, Norway)

Prof. Bertrand Chapron (IFREMER, Brest, France/RSHU)

Polar lows are intense mesoscale maritime cyclones, characterized by short life-time (several hours-1 day), small sizes (<1,000 km) and surface wind speed ≥ 15 m/s. These cyclones develop during wintertime in high latitudes over marine areas in both hemispheres, but in the Arctic they are most vigorous and dangerous. Polar lows possess by high destructive power and, therefore, present threats for ships, oil and gas platforms and coastal infrastructure in the Arctic and Sub-Arctic. The same time polar lows are much less studied than the tropical cyclones. Therefore, the polar low climatological data are of critical importance.

There are several existing polar low climatologies, but most of them are based on modelling and reanalysis data, weather maps and partly on infrared imagery. However, polar lows are often not detected at the weather maps and are under-represented in the current reanalysis datasets. Therefore, the most informative polar low studies should base on the comprehensive joint analysis of different satellite data from various instruments. Among the satellite sensors, microwave radiometers have important advantages for detecting and tracking polar lows. This is independence on day and night time and clouds, and regularity and high temporal resolution in polar regions provided by past and current satellite radiometers.

Thus, we created new 14-year (1995-2008, September-April) climatology of polar lows for the Nordic (Norwegian, Greenland, Iceland) and the Barents seas using new approach for detecting and tracking polar lows based on satellite passive microwave data (see *Bobylev et al.*, IEEE, 2011). Totally 637 polar lows were detected above these seas over the considered period with average frequency 45.5 cyclones/year. A 14-year period is insufficient for trend estimation, however we can sea some tendency for increasing of polar low number over this period (Fig. 1b). Overwhelming majority of polar lows in this climatology has diameter from 100 to 400 km (Fig. 1c) and life-time from 3 to 18 hours (Fig. 1d).

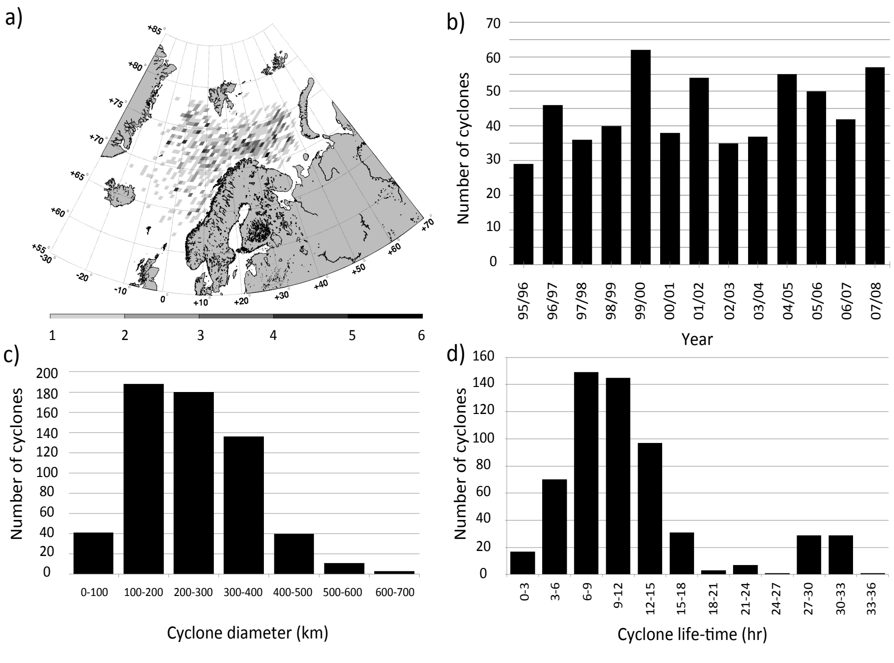

***Figure 1**. Characteristics of polar lows observed in the Nordic and Barents seas over the period 1995-2008: **a)** spatial distribution of polar low occurrence; **b)** interannual variability of polar occurrence; **c)** size distribution of observed polar lows; **d)** life-time distribution of polar lows*

Spatial distribution of detected polar lows is shown in Fig. 1a. Maximum of polar low occurrence is observed in the south-western Barents Sea, north-eastern Norwegian Sea and in the Greenland Sea south-west of Svalbard.

Snow on the Arctic sea ice from historical data

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

Stein Sandven (NERSC, Bergen, Norway)

In the frame of the ESA-CCI Sea-Ice-ECV project, the NIERSC/NERSC team has worked on describing snow on sea ice that is an essential parameter in retrieving sea ice thickness from satellite measurements.

The study included analysis of data collected during the Soviet Union's high-latitude airborne expeditions Sever that were carried out in 1937, 1941, 1948-1952, and 1954-1993. The landings generally took place from mid-March to early May, when there was enough light to operate, but before summer melt made safe landings impossible. As to the ice types where the landings took place, they were quite different. The most thorough examination of the ice and snow characteristics was provided for the marginal seas.

There were several types of snow depth measurements obtained during landings: runway snow depth, snow depth on prevailing landing area ice, depth measured at mid-length of snow dunes extending out from ridges, depth of snow on hummocks, on both windward and lee sides, and height of sastrugi. The main goal of our study was to produce a reliable map of snow depth on the marginal sea ice in the end of winter season that could be used in ice thickness retrievals form satellite altimeter measurements. Therefore, the main attention was paid to the processing of snow depth measurements done on prevailing landing area ice. However data collected on hummocks, ridges and sastrugi were also analysed.

Snow depth observations on prevailing landing area ice are illustrated by Fig. 2. In the central Arctic snow depth observations were quite sparse and measured values were unexpectedly low (in most cases lower and in some cases much lower than in the widely used Warren climatology). In the marginal seas observations were densely packed making a good base for snow depth

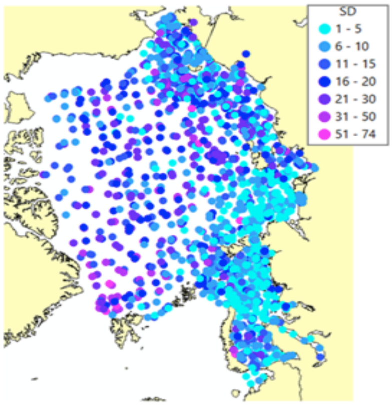

Figure 2. *Spatial distribution of measured snow depth (in cm) on the prevailing landing area ice from Sever expeditions made in March and April, 1959-1988*

analysis. Basing on those observations we have produced a map of the average snow depth in the marginal seas. The highest values were observed in the East Siberian Sea and the lowest values – in the Barents and Kara seas. Since there were very little measurements in the Barents Sea, all results for this area should be treated as not having an adequate level of data provision. Two main causes of dissimilarity in snow climatology for different seas are most likely (i) differences in life-time of ice cover and as a result not concurrent start of snow accumulation, and (ii) differences in meteorological effects like snow precipitation and winds in different parts of the Arctic Ocean. Average snow depth for the Arctic seas where observations were conducted in the course of Sever expeditions is presented in Table 1.

Table 1. *Average snow depth in different seas calculated from Sever measurements*

Sea	Snow thickness (cm)
Barents Sea	8.4±2.2
Kara Sea	8.6±2.1
Laptev Sea	9.4±3.2
East Siberian Sea	14.7±3.0
Chukchi Sea	13.7±3.4

Projections of the Arctic summer sea ice for the 21st century from CMIP5 climate models

Dr. Svetlana Kuzmina (NIERSC)

Dr. Leonid Bobylev (NIERSC/NERSC)

Prof. Ola M. Johannessen (NERSC)

As one of the most dramatic consequences of the on-going global warming is the shrinking Arctic sea ice, especially summer ice which is decreasing by 13.7 % per decade and can disappear already in the 21st century. The fate of the summer sea ice in the Arctic is of a great interest and critical importance from scientific, economic and geopolitical point of view. It is not realistic to get absolutely ice-free conditions in the Arctic Ocean even in summer therefore the scientific community uses the term “nearly sea ice-free Arctic”. As a threshold for a nearly sea ice-free conditions it is suggested to use the minimal ice extent of one million square kilometres.

To estimate the timing of nearly sea ice-free summer in the Arctic one should use future projections of sea ice by modern climate models, such as CMIP5. But, as it was shown by several researches, CMIP5 ensemble projections of summer sea ice are still not enough reliable. The most widely used approach to make future projections of the Arctic sea ice more reliable is selection from CMIP5 ensemble those models which adequately reproduce the real-life past sea ice. Such selection was done by several researches using different techniques. We also selected the best models from CMIP5 ensemble for projections of the Arctic sea ice using several criteria for model’s reproducing annual cycles of sea ice extent and surface air temperature as well as their average values and trends for the past climate. Thus, for estimation of the timing of nearly sea ice-free summer Arctic we selected two models: CCSM4 and HADGEM-CC. The graph in Fig. 3a shows projections of the summer Arctic sea ice over the 21st century by each of these models and their model mean. We see that our selected models give the timing of the nearly sea ice-free summer Arctic about 2060.

Fig. 3b gives the summary of existing estimations of the timing of nearly sea ice-free summer Arctic based on different approaches. According to Overland & Wang, there are three such approaches: 1) extrapolation of observational data for sea ice extent and volume; 2) assuming several more rapid ice loss events such as 2007 and 2012; and 3) climate model projections. Correspondingly, researches applying these approaches are called trendsetters, stochasters and modellers. We added here the fourth approach suggested by Ola M. Johannessen (OMJ), based on the relation between CO^2 concentration in the atmosphere and sea ice extent. The synthesis graph (Fig. 3b) shows projections of summer sea ice for the 21st century provided by CMIP5 ensemble mean, 7 selected by Wang and Overland CMIP5 models and model mean of two selected by us models. Both our and Wang & Overland selected models give the timing of nearly sea ice-free summer Arctic about 2060. Projections provided by trendsetters, stochasters and OMJ give timing of nearly sea ice-free Arctic in summer about 2020, 2030 and 2045 accordingly. Light blue dotted lines indicate the range of said timing, provided by modellers: from 2040 to 2060 (IPCC 2013 and our estimations). Concluding, we can summarize that the nearly sea ice-free conditions in the Arctic in summer can emerge from 2020-2060, but more realistically from 2030-2060.

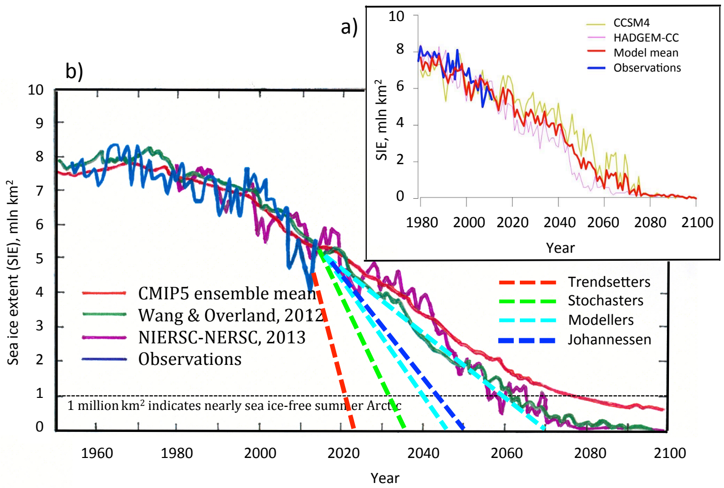

Figure 3. *Projections of summer sea ice in the Arctic in the 21st century:* ***a)*** *projections by CMIP5 ensemble model mean and two CMIP5 selected models; and* ***b)*** *projections of beginning of nearly sea ice-free summer Arctic Ocean based on CMIP5 climate models and alternative approaches*

Hydrological regime of the permafrost regions of Eastern Siberia

PhD-student Lyudmila Lebedeva (State Hydrological Institute /NIERSC, St. Petersburg, Russia)

Hydrological consequences of forest fire in permafrost region of Eastern Siberia were studied by means of observational data analysis and flow formation modelling. Fire impact on runoff was

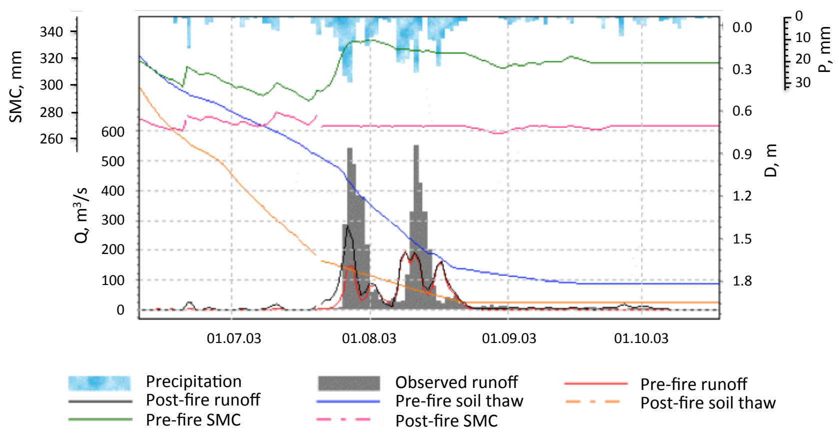

***Figure 4**. Comparison of observed and simulated hydrographs, soil moisture content (SMC) and soil thaw depth with the parameters assessed for pre-fire and post-fire periods. The Vitimkan River basin, 2003*

investigated for two mountainous basins located at the Vitimkan (969 km^2) and Vitim (18,200 km^2) rivers. These basins were affected by fire in 2003 covering 78% and 49% of their area correspondingly. Results of analysis of hydrological and meteorological data suggested that the Vitimkan River basin had quick and profound hydrological response to wildfire in 2003 expressed in increased summer flow by 41 % (133 mm). Larger Vitim River basin has shown no significant changes of runoff after the fire. Modelling of runoff was performed by means of process-based hydrological model Hydrograph. The initial parameters of this model were estimated for pre-fire conditions. Results of runoff simulations conducted for continuous pre-fire periods of 1966-2002 and 1970-2002 for the Vitimkan River and Vitim River basins respectively with daily time step have shown satisfactory agreement with observed flow series. Significant underestimation of precipitation and its poor representativeness for mountainous watersheds was revealed as the main cause of observed and simulated flow discrepancies, especially for high flood events. Such flood peaks exceeding at the Vitimkan River 300-350 m^{3}s^{-1} are systematically undervalued by the model. The challenge of distinguishing between undervalued precipitation and fire impact in formation of two extraordinary flow peaks in 2003 still remains (Fig. 4). The set of post-fire dynamic parameters was developed based on the data analysis and reported in literature post-fire landscape changes. It was applied to investigate the processes in the soil column and their effect on runoff formation in post-fire period. The new set of the model parameters implied intensification of soil thaw, reduction of infiltration rate and evaporation and increase of upper subsurface flow fraction in summer flood events following the fire of 2003. According to modelling results post-fire thaw depth exceeded non-fire depth by 0.4–0.7 m (Fig. 4). Total evaporation reduced by 40 % in summer months, surface flow increased almost 2.5 times during maximum flood events – from 64 mm (25% of total flow) to 148 mm (40% of total flow) during maximum flood events. In post-fire case soil moisture content increased during the period between the fire and extreme flood events and shifted to dryer conditions afterwards. In case of non-fire the behaviour of soil moisture content had the opposite trend. Runoff simulated with post-fire parameters in general shows better agreement with the observed one than simulated with pre-fire parameters. Suggested dynamic approach based on a priori assessment of model parameters showed promising results and has the perspectives for modelling studies in non-stationary conditions for poorly investigated basins. Presented results can be considered as a pilot study on runoff response to fire disturbance in permafrost basins of Russia.

Arctic oceanographic research

Dr. Vladimir A. Volkov (NIERSC)

PhD-student Denis M. Demchev (NIERSC/Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia)

Dr. Natalia Yu. Zakhvatkina (NIERSC/AARI)

Prof. Stein Sandven (NERSC)

Dr. Anton Korosov (NERSC)

Sea ice classification using satellite Synthetic Aperture Radar (SAR)

Sea ice type classification. In 2013 our NIERSC-NERSC team in frame of SIDARUS and MAIRES projects has developed techniques for fast automatic classification of sea ice types from images of Advanced Synthetic Aperture Radar (ASAR) aboard ENVISAT satellite using Neural Network (NN) and Bayesian approaches. Since different sea ice types may have similar backscatter coefficients in C-band on HH-polarization, developed NN approach uses, additionally to backscatter coefficients, also extracted SAR textural features. The optimal topology of the Neural Network for this algorithm was found by means of analysis of classification errors and processing time. The Bayesian algorithm of automated sea ice classification uses pixel-based approach and *a priori* probabilities of level and deformed first-year ice (FYI), and multiyear ice (MYI) appearance in the Central Arctic. These probabilities were estimated from knowledge of the ice conditions. Conditional probabilities of these ice types were derived from calibrated ENVISAT ASAR images. Bayesian algorithm uses only backscatter coefficients, but correctly classifies major sea ice types and leads due to big difference in their *a priori* probabilities.

Developed algorithms were validated by means of comparing classification results with the expert analysis of the

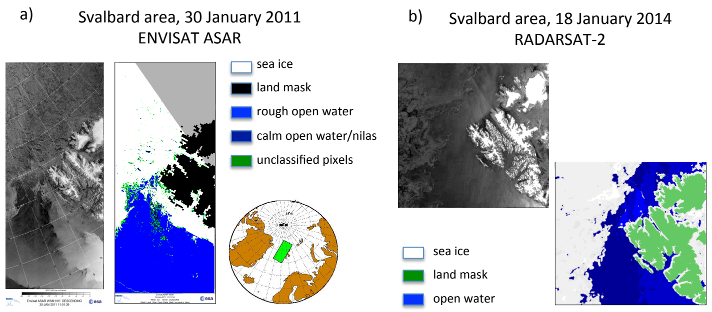

***Figure 5.** SAR sea ice/open water classification products for the Svalbard area: **a)** corrected ENVISAT ASAR WSM image (left) and classification results using trained Neural Networks (right) for 30 January 2011; **b)** RADARSAT-2 SCWA HH image (left top) and SVM (Support Vector Machines) classification results (right down) for 18 January 2014*

images and ice charts for the central part of the Arctic Ocean during winter months.

This study is summarized in *Zakhvatkina et al. Classification of sea ice types in ENVISAT Synthetic Aperture Radar images. IEEE Transactions on Geoscience and Remote Sensing, 2013.*

Open water/ice edge detection in the Fram Strait. NN algorithm for sea ice/open water detection in the Fram Strait in winter is based on ENVISAT ASAR data together with a coarser ice concentration products from SSM/I and AMSR-E microwave radiometers, produced by the University of Bremen. The number of neurons in the input layer of NN corresponds to number of textural characteristics, backscatter coefficient and AMSR-E or SSM/I ice concentration. SAR data are averaged at a grid of 525mx525m, and the AMSR-E product is interpolated for the same grid. There are two outputs of NN: calm open water (OW)/nilas and rough open water. Fig. 5a illustrates one of the results of automated sea ice-open water classification by this algorithm. Validation was made using Norwegian Meteorological Institute (Met.no) ice charts.

Since ENVISAT's mission ended in 2012 it has become very important to develop an automatic ice classification algorithms for other available satellite SARs. Therefore, in 2013 we started the development of a new automatic sea ice classification algorithm for RADARSAT-2 SAR satellite data. However, using NN approach for this algorithm showed that the results of classification were not always satisfactory. Therefore, we tested and used another approach – the Support Vector Machine (SVM) method for OW/ ice edge detection. Based on this approach, a fully automated algorithm to distinguish open water (rough/calm areas) and sea ice using co-polarized RADARSAR-2 SAR images was developed. In this algorithm the extracted SAR image texture features are used as additional information for supervised sea ice image classification based on SVM approach. Validation of the developed algorithm was made using also Met.no ice charts and optical MODIS data. As an example, Fig.5b illustrates the performance this algorithm.

Ice drift in the Arctic Ocean

Activity of MetOcean Group in 2013 on the studying sea ice drift in the Arctic Ocean was organised under MAIRES and MyOcean projects around three major topics:

1. Analysis of ice drift fields variability during two last decades at the turn of the 20th and 21st centuries.
2. Validation of ice drift modelling results.
3. Improvement of algorithms for ice drift calculation.

Analysis of ice drift fields variability in the Arctic Ocean during two last decades was based on datasets presented at regular grid points with a step of about 30 km over the entire Arctic Ocean area. The first dataset, for winter period from 2002 to present, was developed by IFREMER (France), the second dataset, for winter and summer seasons from 1998 to present, was created by NSIDC (USA). Using these datasets a dedicated data archive and special software were developed as a part of the MyOcean Oceanographic Information System.

The vector-algebraic approach developed by Prof. Rozhkov (St. Petersburg State University, Russia) was chosen as a basic method for analysis of seasonal and interannual variability of the ice drift series. This method allows significantly compress the initial information and most adequately describe the vector time series and model data by a set of statistical characteristics in the invariant form. Such statistical analysis make it possible to describe in detail fields variability, to detect some zones with uniform dynamics, to access an intensity of water and ice outflow and variability of state of circulation in the course of time (see figure at the cover page showing total variance and average drift velocity vectors for two types of sea ice drift in the Arctic Ocean).

Joint analysis of drift data and large-scale weather processes during current warming period demonstrates a determinative role of global atmospheric circulation in the formation of ice conditions. Taking it into account, we analysed the correspondence between sea ice drift field's variations and different types of elementary synoptic processes (ESP) in the Arctic. Here we used classification of large-scale weather processes developed at the Arctic and Antarctic Research Institute (AARI) in St. Petersburg, which is a basis of AARI's methodology of the large-scale weather forecast. Classification includes 26 typical ESPs divided into six groups: A, B, V, G, D and K. Our analysis showed that ESPs related to group B possess by the highest degree of influence on the process of ice formation in the Arctic. Processes of this group are characterized by the development of anticyclonic field over the most part of the Arctic basin, the lack of strong advection of warm air masses from mid-latitude zone, and the predominance of eastern air flows and minimal cloud cover. In this case the most favourable conditions for increasing sea ice cover in the Arctic basin are formed. Analysis of synoptic processes for group B from 1939 to 2011 showed that the years with maximum ice coverage were 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 observed, as a rule, on the background of negative anomalies of the group B processes frequency.

However, synoptic processes of others groups were prevailing during the periods of an intensive reduction of the drifting sea ice area. For instance, in October-April 1997-2006 synoptic processes belonging to group V were prevailing. These 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 group V processes the maximum variation of the drift vectors should be observed over the Western Arctic. Our analysis confirmed this conclusion.

The vector-algebraic methodology was adopted for the first time for validation of the modelling results under MyOcean Project aimed at the development and pre-operational validation of upgraded GMES Marine Core Services and capabilities. Using this approach we

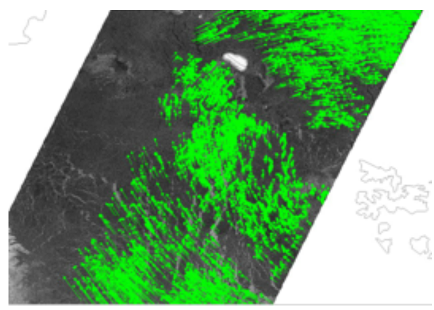

Figure 6. *Example of sea ice drift calculation using new algorithm applied to ENVISAT ASAR data (February 2-5, 2011, Barents Sea)*

validated in 2013 a new version of the TOPAZ modelling and forecasting system and formulate some recommendation for improving this model. The largest differences between fields of ice drift derived from TOPAZ model and satellite data were observed in the Kara Sea.

A new algorithm for reconstructing sea ice drift vector fields was developed on the basis of the modern achievements in the area of computer image processing. This algorithm is based on the identification and tracking of singular points on successive satellite images. The performance of algorithm has been tested using SAR images obtained from ENVISAT and RADARSAT-2 satellites for the Kara and Barents seas. Example of sea ice drift calculation using new algorithm is presented in Fig. 6.

Long-term changes of extreme levels of the Arctic seas

PhD-student Ivan Ryzhov (AARI/NIERSC)

Prof. Ola M. Johannessen (NERSC)

Dr. Igor Ashik (AARI)

Our study is focused on regularities between surges, the trajectories of the cyclones and the ice regime. We processed data of sea level changes over the past 60 years, recorded by 64 monitoring stations located in four Arctic seas, and analysed extreme fluctuations of sea level together with data on the air pressure and ice conditions. It was found that in the last 20 years maximum annual amplitudes of sea level fluctuations were decreasing by 1 cm/year (Fig. 7) along with increase of average sea level in the Arctic seas. The same time position of the ice edge and the trajectories of cyclones were generally shifted to the north in all seas of Eastern Arctic. The rate of this displacement was about 0.1 degree/year. Such phenomena can be explained by: 1) the relationship between decrease of the maximum annual amplitude of sea-level oscillations in the Arctic Ocean and the global warming; and 2) assuming that the trajectories of cyclone movement follow the sea ice in the Arctic Ocean causing, in turn, pushing ice edge out the shore. This may lead to decrease of atmospheric activity along the shoreline and decrease of the average amplitude of sea-level fluctuations.

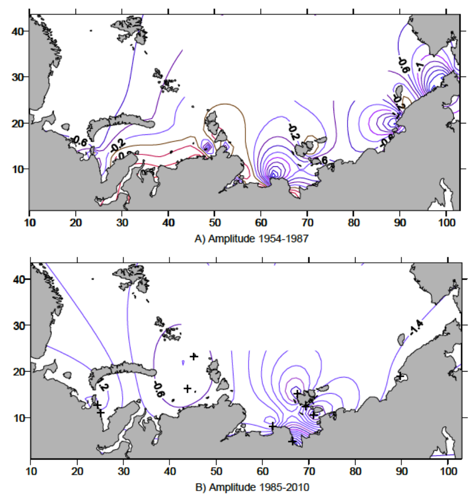

Figure 7. *Contour map showing distribution of trends for maximum annual amplitude of sea level oscillations in the Arctic seas for two periods*

Aquatic Ecosystems in Response to Global Change

Development and embedding of a software package for automatic restoration of ocean biogeochemical properties from satellite data into the ROSCOSMOS portal

Dr. Evgeny A. Morozov (NIERSC)

Prof. Dmitry Pozdnyakov (NIERSC/NERSC)

Dr. Anton A. Korosov (NERSC)

Mr. Lasse H. Pettersson (NERSC)

This work is a continuation of the developments that have been pursued at NIERSC during the last decade in collaboration with the Nansen Centre in Bergen and the Scientific Centre for Operational Earth Monitoring (NTsOMZ/ROSCOSMOS) in Moscow.

The main objective was to realize streamed satellite data processing (SSDT) liable to, firstly, extendability (in terms of the information product nomenclature & acquisition of data from future satellite sensors) and, secondly, compatibility with analogous SSDT Centres in Europe and beyond on both a regional and international scales.

The NIERSC package has a module-based structure of the system and relies on the Nansat program package, which is presently developed at NERSC. This allows to a) quickly update the system to accommodate new satellite sensors such as “Canopus-B”, “Resource-P”, Sentinel-3, etc., 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). Importantly, this approach assures further improvement/perfection of the system without changing both its basic concept and structure. It also possesses necessary facilities of a further data transfer to the common module of data processing at a higher level. 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.

Along with this work, verification of the water quality retrieval algorithm module workability has been performed in collaboration with the Murmansk Marine Biology Institute and the Murmansk Branch of North-western ROSHYDROMET Service. Both institutions successfully employed the developed module and obtained correctly geo-referenced values of phytoplankton chlorophyll concentrations, sea surface temperature and some other parameters that compared well with the available truthing data. Thus it was confirmed that the module is operational and ready for practical employment within the SSDT system.

A comparative study on main factors driving the dynamics of phytoplankton surficial fields in the course of cyclone passage in tropical and polar latitudes (RFBR/China Project)

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Dr. Evgeny Morozov (NIERSC)

Mr. Dmitry Kondrik (NIERSC)

Prof. Dmitry Pozdnyakov (NIERSC)

The present 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. Resorting to a synergetic approach, polar cyclones were first identified from NCEP/NCAR data for the summer time period (April-August) during 2003-2012, and their propagation throughout the Barents Sea was further traced down. The above water wind force was retrieved from QuickSCAT data.

The cyclone’s parameters, bathymetric features and cloud conditions were used to underpin and attain further understanding of the actual processes unfolding along the cyclone track.

During the above time period, nearly 70 cyclones passed cross the Barents Sea throughout the vegetation period (April-

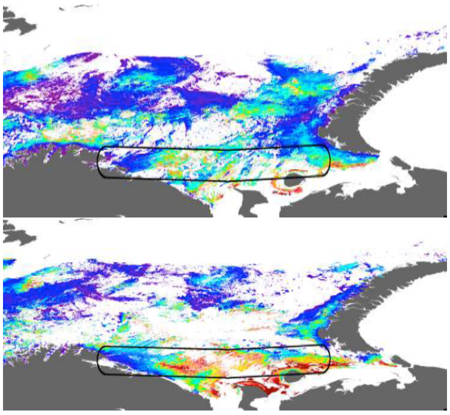

Figure 8. *Impact of cyclone passage on the phytoplankton dynamics in the Barents Sea: upper and lower panels show, respectively, phytoplankton chlorophyll fields averaged over 5 days prior and 5 days after to the cyclone passage (black oval indicates the zone of cyclone passage)*

August). Only cyclones (slightly more than 22) passing over the sea in less than 3 days, and providing enough cloud-free conditions along the track were further analysed to detect the cyclone-driven sea surface temperature (SST) and chlorophyll (chl) concentration space- and time modulations. The chl and SST were collected 5 days prior to the cyclone arrival to the Barents Sea, and then during 5 days following the moment of dissipation of cloud cover over the cyclone's footprint.

Several cases were identified in the data thus obtained: the cyclone passage resulted in (i) SST and chl increase immediately (on the second day) of the cyclone displacement from the area, (ii) SST and chl decrease right after the cyclone passage that further switched to their increase on the fourth-eighth day of the cyclone leaving the area of observation (Fig. 8), and (iii) no recordable changes in SST and chl.

Importantly, the increases in chl concentration were observed not only during the periods of high biological activity of the phytoplankton in the Barents Sea (mid-May-June and mid-August) but even during the periods of low productivity (April-early May and July-late August).

Our analyses of the temporal and spatial modulations of chl and SST fields indicate that they are related to a wealth of factors, first and foremost, the cyclone parameters (baric deepness, wind speed above the water surface, the cyclone translation speed), as well as the Atlantic water circulation pathways across the sea, the bottom relief, and cloudiness conditions. The causal mechanisms of the revealed SST and chl modulations have thus been identified for each specific case, and the general regularities of the entire phenomenon were established.

On balance, our findings imply that with the ongoing amplification of climate warming at high northern latitudes, the increase in chlorophyll discussed above is potentially capable of boosting the primary productivity in the Arctic Ocean.

Development of computer code of water quality retrieval algorithm for optically shallow waters in Lake Michigan (Michigan Tech Institute Project)

Prof. Dmitry Pozdnyakov (NIERSC)

Dr. Anton Korosov (NERSC)

Based on the theoretical investigation performed at NIERSC in the previous year (2012), a computer code has been developed to calculate subsurface remote sensing reflectance, Rrsw(λ) from spectral radiometric data. The algorithm is realized as a Python and C++ software package called Bio-Optical REtrieval AlgorIthm for Optically Shallow Waters (BOREALI-OSW). The Python part consists of one class called Boreali with methods for opening input files, loading spectral values of specific absorption and backscattering coefficients from text files and running the processing in several parallel threads. The C++ part consists of hierarchy of classes Hydrooptics and HydroopticsShallow and several interface functions that communicate with Python and the CMINPACK library. The class Hydrooptics is designed for performing all hydro-optical calculations in deep waters and has separate methods implementing equations relating spectral remote sensing reflectance to the water body inherent properties, viz. spectral coefficients of bulk water absorption (a) and backscattering (bb), both a(λ) and bb(λ), being the sum of products of specific (i.e. normalized to concentration) absorption and backscattering, respectively, and corresponding concentrations of water colour producing agents (CPAs)/water quality parameters. The class HydroopticsShallow inherits from Hydrooptics and overrides methods implementing the parameterization relating Rrsw(λ) to CPA inherent optical properties and their concentrations. The analytic formulas for calculating the elements of Jacobian matrices require more computations than the usage of discreet finite difference derivatives. Therefore the latter was used in the CMINPACK library for performing the Levenberg-Marquardt optimization procedure. The algorithm permits to restore simultaneously the concentrations of phytoplankton chlorophyll, total suspended matter and coloured dissolved organic matter as well as the water depth from radiometric data.

Validation and application of the algorithm for the retrieval water quality in the Great North American lakes (Michigan Tech Institute Project)

Prof. Dmitry Pozdnyakov (NIERSC)

Dr. Anton Korosov (NERSC)

Dr. Robert Shuchman (Michigan Tech Institute, Ann Arbor, US)

Lake Michigan (LM) generally is an oligotrophic clear water body. Predominantly in its littoral areas ecology-relevant processes unfold due to a variety of natural and anthropogenic forcings arising from the watershed. However, the bottom influence there is strong enough to contaminate the at-satellite signal, thus impeding the remote sensing of water quality parameters within the LM coastal zone.

A new algorithm BOREALI-OSW based on a forward radiation transfer model, LM specific hydro-optical model and the multivariate optimization technique was developed to produce a tool for operational retrieval from satellite data of water quality parameters in lake's optically shallow areas. The retrieval output encompasses the concentrations of colour producing agents (CPAs) (phytoplankton chlorophyll, total suspended matter, coloured dissolved organic matter) and either bottom depth or cover type (sand, silt, stands of Chara, Cladophora, and limestone pebble).

The sensitivity of both forward and inverse modules was tested for hydro-optical conditions inherent in LM. Determinations of CPA concentrations were synchronized with *in-situ* radiometric measurements, as well as bottom type and depth. Retrieved were realistic values of spectral signatures of subsurface remote sensing and CPA concentrations within the ranges of depth (<2 m – 15 m depending on the CPA concentration vector and bottom

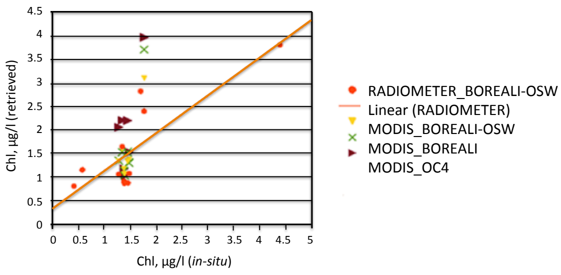

***Figure 9**. A comparison of chl values (µg/l) determined in-situ (on the horizontal) and (on the vertical) their counterparts retrieved from in-situ radiometric measurements and MODIS-Aqua data with and without accounting for bottom optical influence (the determination coefficient $R^2 = 0.68$)*

type), at which the optical impact was detectable.

Application of the developed operational tool to processing MODIS-Aqua data (matching up the location and timing of *in-situ* CPA and radiometric measurements) has convincingly shown its advantage over the OC4 performance in lacustrine optically shallow waters at all control stations (Fig. 9).

Research in Economics of Climate Change

Dr. Dmitry V. Kovalevsky (NIERSC/NERSC)

PhD-student Olga Yu. Romanova ((NIERSC)/ St. Petersburg State University)

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

In 2013 a family of Integrated Assessment (IA) models was developed in the framework of EU FP7 COMPLEX research project (Grant Agreement No. 308601) and two research projects solicited by the Russian Foundation for Basic Research (RFBR Projects No. 12-06-00381 and No. 13-06-00368).

Actor-based system dynamics modelling

A prototype out-of-equilibrium model hierarchy has been developed in MADIAMS (the Multi-Actor Dynamic Integrated Assessment Model System) to explore the insights that can be obtained by abandoning the assumption of market clearing (e.g. supply is no longer assumed to be equal to demand). It is shown that the prototype model hierarchy can yield rich macroeconomic dynamic behaviour including stable growth, business cycles, boom-and-bust events, and pronounced recessions.

The Structural Dynamic Economic Model (SDEM) – an IA model representing a prototype of MADIAMS – has been further developed to incorporate strongly nonlinear climate damage functions (Weitzman, 2012) and potential slowdown of the Atlantic thermohaline circulation (THC) as an example of possible regional climate change. To address the latter effect, a four-box model of the Atlantic THC (Zickfeld et al., 2004) has been incorporated in the climate module of SDEM. Projections were generated for a business-as-usual scenario (BaU) and for several mitigation scenarios assuming different global carbon tax rates.

The results for the 21st and 22nd centuries computed with the SDEM model using the climate module with Atlantic THC module switched off and the strongly nonlinear Weitzman climate damage function indicate that global carbon tax as an economic instrument for reducing GHG emissions is highly efficient, especially in case of very substantial climate damages assumed for high-end scenarios: long-term temperature increases would be much lower for the higher carbon tax rates considered. Furthermore, scenarios with strong mitigation action are economically sustainable in the long term. While the BaU scenario maintains the most rapid economic growth throughout the 21st century, it ultimately leads to global economic collapse in the 22nd century. In contrast, scenarios with stronger mitigation action provide reduced growth rates in the short- and mid-term, but lead to sustainable economic dynamics in the 22nd century.

SDEM simulations until the end of the 23rd century, with the climate module supplemented with the Atlantic THC box model, indicate that the BaU scenario and the scenario with the lowest carbon tax rate considered lead to a slowdown of the THC in the long term, while in scenarios with stronger mitigation action an initial reduction of the THC is reversed, the THC recovering in the long term.

Incorporating high-end CMIP5 climate scenarios in long-term GWP projections

Projections of the gross world product (GWP) for the 21st century are computed on a simple climate-macroeconomic model (based on a standard AK model of economic growth) using different global mean surface air temperature projections provided by CMIP5 models as input data. The basic CMIP5 simulations incorporated in economic growth modelling framework include two representative scenario experiments for the 21st century: medium stabilization scenario RCP4.5 and higher emission scenario RCP8.5. Two alternative specifications of climate damage functions proposed by Nordhaus (2008) and Weitzman (2012) are considered.

High uncertainty of long-term global macroeconomic dynamics with respect to the choice of climate scenarios and climate damage functions is revealed. Strong nonlinearity of the Weitzman function combined with the "worst-case" temperature scenario yields a very dramatic scenario of global economic development. While in the control model run (no climate impacts, zero climate damages) GWP would be substantially higher in 2100 than it was in 2012, in

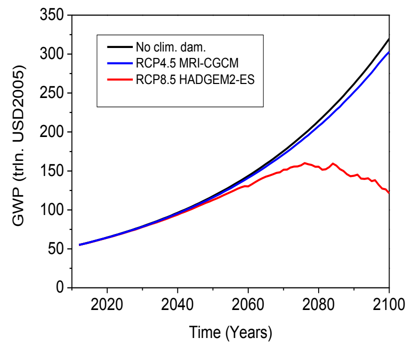

***Figure 10**. Gross World Product (GWP) projections for the 21st century for global mean surface air temperature scenarios provided by different CMIP5 models under specification of climate damage function proposed by Weitzman (2012)*

case of Weitzman function, the situation would be much worse: the effective GWP would be equal to 121 trln USD2005 in 2100, i.e. it would be only 2.2 times higher than in 2012. Moreover, the effective GWP curve would no longer be monotonous in the latter case: the effective GWP would reach its maximum of 160 trln USD2005 in 2076 (2.9 times higher than in 2012), and then it would start rapidly decreasing. Therefore in the "worst-case" scenario a rather slow economic growth (as compared to other model setups considered) is stopped in about 2075 and then the global economy starts decaying (Fig. 10).

A high degree of uncertainty accompanying existing assessments of climate–socioeconomic projections urgently calls for more detailed and better justified estimations of anticipated climate damages at high temperature increases above preindustrial level.

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European-Russian Centre for cooperation in the Arctic and Sub-Arctic environmental and climate research (EuRuCAS)

2012 - 2015

Project Coordinator
Dr. Leonid Bobylev

Project Deputy Coordinator
Prof. Stein Sandven

Steering Commitee Chairman
Prof. Ola M. Johannessen

EuRuCAS project is aimed on the use of Nansen Centre established in St. Petersburg, Russia, as the joint research facility to extend, consolidate and strengthen scientific cooperation between researchers from EU Member States and Associated Countries with those from Russia on the climate and environmental changes in the Arctic and Sub-Arctic in the 21st century and their socio-economic impact

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MPI-M Max Planck Institute for Meteorology (Hamburg, Germany)
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GCF Global Climate Forum (Berlin, Germany)
www.globalclimateforum.org

SU Stockholm University (Stockholm, Sweden)
www.su.se

FSU Friedrich-Schiller University (Jena, Germany)
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IFREMER Institut Francais De Recherche Pour L'exploitation De La Mer (Brest, France)
www.ifremer.fr

CLS Collecte localisation satellites (Toulouse, France)
www.cls.fr/welcome_en.html

JR JOANNEUM RESEARCH Forschungsgesellschaft mbH (Graz, Austria)
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USFD The University of Sheffield (Sheffield, UK)
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UH University of Helsinki (Helsinki, Finland)
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FMI Finnish Meteorological Istitute (Helsinki, Finland)
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