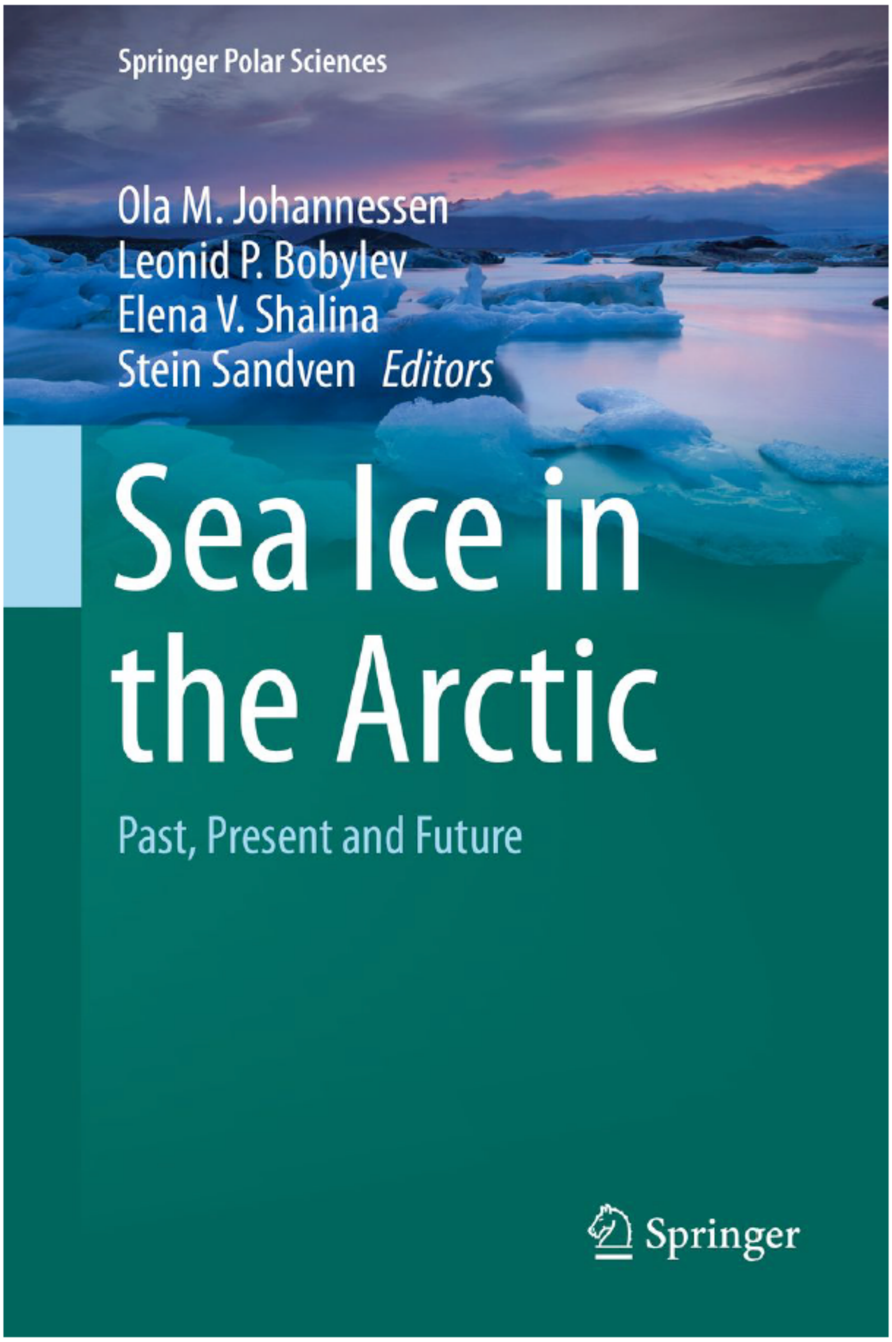
Annual Report 2020

Nansen International Environmental and Remote Sensing Centre

St. Petersburg, Russia

Non-profit international centre for environmental and climate research
Founded in 1992

In-depth insight into Arctic sea ice



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Cover page: *Cover page of the book: Johannessen, O.M., Bobylev, L.P., Shalina, E.V., Sandven, S. (Editors). Sea Ice in the Arctic: Past, Present and Future. Springer, 2020, 575 p.*

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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.

Scientific Research Groups

- Climate of High Northern Latitudes (*Head Dr. Leonid Bobylev)*
- Aquatic Ecosystems Under Global Warming (*Head Prof. Dmitry Pozdnyakov)*
- Applied Meteorological and Oceanographic Research (*Head Dr. Vladimir Volkov*)

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.

NIERSC was established 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 license from Roscosmos for conducting space-related research activities.

Staff

At the end of 2020 NIERSC staff incorporated 26 employees, 14 full-time and 12 part-time, comprising research and administrative personnel. Research personnel included one full Doctor of Science and 12 PhDs. Four PhD-students were supervised and supported financially through the Nansen Fellowship Programme, all holding also part-time positions of Junior Scientists at NIERSC.

Scientific Production

In 2020, totally 30 publications were published including one book, 15 papers in peer reviewed journals, 1 paper in other journals and 13 abstracts and brief papers in conference proceedings (see the list of main publications at the end of the report).

National and International Cooperation

NIERSC has a long-lasting cooperation with Russian organisations including St. Petersburg State University and institutions of the Russian Academy of Sciences, Federal Space Agency, Federal Service for Hydrometeorology and Environmental Monitoring, among which are the Northern Water Problems Institute, Murmansk Marine Biological Institute, Scientific Research Centre for Ecological Safety, Obukhov Institute of Atmospheric Physics, Arctic and Antarctic Research Institute, Russian State Hydrometeorological University, Voeikov Main Geophysical Observatory and other.

Fruitful relations are established also with a number of foreign and international organizations, universities and institutions including Global Climate Forum, Climate Service Centre Germany (HZG-GERICS), Max-Planck Institute for Meteorology, Friedrich-Schiller-University (all Germany), Finnish Meteorological Institute and University of Helsinki (Finland), University of Sheffield (UK), Stockholm University (Sweden), Johanneum Research (Austria), Iskenderun Technical University, Turkey, Vlaamse Instelling voor Technologisch Onderzoek (VITO) & Royal Meteorological Institute of Belgium, Gent University (Belgium), Latvian Environment, Geology and Meteorology Centre, and especially with the NIERSC founders. Close cooperation is established with the Nansen Centre and the Nansen Scientific Society in Bergen, Norway.

Nansen Fellowship Programme

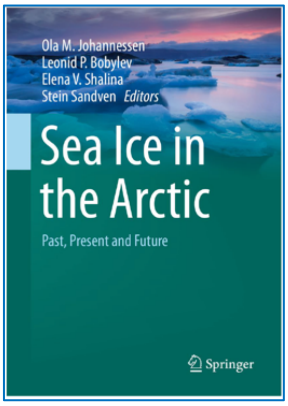
The main goal of the Nansen Fellowship Program (NFP) at NIERSC is to support PhD-students at the Russian educational and research institutions including Russian State Hydrometeorological University, St. Petersburg State University, Arctic and Antarctic Research Institute, and other. The preferred research areas include climate and environmental changes in the Arctic, North Atlantic and Northern Eurasia, as well as methods and techniques of satellite remote sensing with focus on the Arctic and Sub-Arctic. NFP provides PhD-students with the Russian and international scientific supervision, financial fellowship, efficient working conditions at NIERSC, training and research visits to the international research institutions within the Nansen Group and beyond, involvement into international research projects. NFP is sponsored by the NIERSC, Nansen Scientific Society and Nansen Centre in Bergen, Norway. Postgraduate student activity is supervised by at least one Russian and one international senior scientist. All NFP PhD-students obliged to publish their scientific results in the international refereed journals and make presentations at the international scientific symposia and conferences.

NFP participant Dmitry Kondrik has successfully defended his PhD Thesis "Development of a complex of satellite algorithms for estimating changes in the content of inorganic carbon in the *Emiliania huxleyi* bloom areas in the Arctic and Sub-Arctic seas" on 21 September 2020 at the St. Petersburg State University.

Totally 31 Russian PhD-students have got their doctoral degrees under NFP since 1994.

Scientific Report

Main Projects



Sea Ice in the Arctic: Past, Present and Future is the project implemented jointly by the Nansen Centres in St. Petersburg and Bergen and aimed at the publishing book providing in-depth information about sea ice in the Arctic at scales from the paleoenvironmental variability to recent and present changes as well as projections for future changes during the 21st century. It was funded by the European Space Agency (ESA), Earth Observation Programmes with Ola M. Johannessen as the project leader. Additional funding was granted by the Nansen Scientific Society, Bergen, Norway, and the Research Council of Norway. Book was published by Springer in 2020.

The content of the book includes 11 chapters and the Annex. The Preface is written by Josef Aschbacher, Director of ESA Earth Observation Programmes. The Chapter 1 is "Introduction". The Chapter 2 "Sea ice in the Arctic paleoenvironments" summarises knowledge on Arctic sea ice in the distant geologic past, i.e., pre-Quaternary as well as the Pleistocene epoch of the Quaternary, including its glacial and interglacial stages, and more recent geologic past, namely the Holocene epoch since the end of the most recent ice age around 12 000 years ago. Here the focus is on the early- to mid-Holocene, when Arctic temperatures were as warm as or warmer than at present-day. The final part of the chapter presents in more detail Arctic sea-ice variability during the past millennium.

Chapter 3 "Marginal ice zone and ice-air-ocean interactions" presents review of important mesoscale processes, which take place in the marginal ice zone (MIZ) and key processes which govern the thermal and dynamical interaction between the sea ice, ocean, and atmosphere in the Arctic. The future of MIZ is discussed, which may not exist during summertime because of melting ice cover in the 21st century forced by the increasing atmospheric concentrations of CO_2.

Chapter 4 "Changes in Arctic sea ice cover in the 20th and 21st centuries" describes datasets on the spatial and temporal distribution and variability of sea ice available in archives, different organizations' portals that provide ice charts and satellite sea ice databases. Special attention is paid to sea-ice data sets for climate monitoring and model validation, which have the status of climate data records (CDR). The unprecedented Arctic sea ice decline in the recent decades is described, analysed and compared with historical records. Chapter 5 "Arctic sea ice thickness and volume transformation" describes data sets collected by various techniques of ice thickness measurements in different periods of time that can be used for the studies of sea ice thickness change and for validation of new methods of sea ice thickness retrieval and numerical models. The chapter also reviews present knowledge of sea-ice thickness and volume changes including uncertainties.

Chapter 6 "SAR sea ice type classification and drift retrieval in the Arctic" presents the main approaches to the automated sea ice type classification and drift retrieval from SAR images. Application of the Neural Networks and Support Vector Machines for sea ice type classification from SAR images are discussed including a brief description of the methods.

Chapter 7 "Sea ice drift in the Arctic" presents two main observational datasets for sea-ice drift study and analysis – the IFREMER and Pathfinder datasets, and new approach to operate with the information contained there, so-called vectorial-algebraic analysis. The chapter describes the variability of large-scale sea ice circulation in the Arctic Ocean based on the multi-year satellite observational data and its connection with the synoptic atmospheric processes.

Chapter 8 "Sea ice modelling" gives the description of sea ice geophysics, thermodynamics and dynamics as well as different classes of sea ice models: thermodynamic and dynamic models, mesoscale and large-scale sea ice models including main models widely used now - Los Alamos National Laboratory Community Ice Code (CICE) and Louvain-la-Neuve Sea Ice Model (LIM). This chapter describes also coupling of large-scale sea ice models with the ocean and atmosphere for their including in the CMIP climate models. Performance of CMIP5 models in simulation of observed sea ice seasonal cycle, concentration and thickness is analysed.

Chapter 9 "Operational forecasting of sea ice in the Arctic using TOPAZ System" describes the Arctic Marine Forecasting Centre (ARC MFC) which provides 10-day forecasts of ocean currents, sea ice, marine biogeochemistry and waves on a daily basis, and a 25-year reanalysis of the Arctic Ocean updated every year. The ARC MFC is powered by the TOPAZ configuration of the HYCOM model, coupled to the sea-ice model CICE, the ecosystem model ECOSMO and assimilates the following data with the Ensemble Kalman Filter: along-track sea level anomalies, sea surface temperatures, sea ice concentrations, drift and thickness, and in-situ temperature and salinity profiles.

Chapter 10 "Current and projected sea ice in the Arctic for the 21st century" describes the internal variability and multi-year trends in sea ice extent for the whole Arctic Ocean and its peripheral seas in the recent past and present derived from satellite records. This chapter presents also results of the validation of CMIP5 climate model performance to reproduce sea ice in the Arctic in the historical period and selection of best models for projecting future sea ice parameters in the 21st century. Projections of the future sea ice extent, its annual cycle and time of occurrence of ice-free conditions in summer in the Arctic shelf seas for the 21st century are presented and analysed. Contribution of sea ice loss into Arctic amplification as well as its impact on atmospheric circulation and weather in mid-latitudes are discussed.

Chapter 11 "Climate change impact on the Arctic economy" describes direct impact of changes in the Arctic on the economy through an assessment of the potential use and exploitation of its natural resources, notably oil-and-gas offshore industry, marine transportation and potential fisheries in the Arctic seas. The economic impact of these three areas of activities is also discussed from an economic modelling perspective. At the end of the chapter, the climate-related risks for the development of the economy in the Arctic are briefly discussed.

Annex "SAR Sea Ice Interpretation Guide" contains a selection of SAR images illustrating various sea-ice conditions and phenomena and demonstrating their characteristic SAR signatures in the Arctic from the east coast of Greenland to the western Laptev Sea. The images were acquired in different seasons with different weather conditions in order to illustrate both short-term and long-term variability in SAR ice characteristics. The images include examples of the most important types of ice, such as multi-year ice, first-year ice and various stages of young and new ice. The interpretation guide also includes examples of phenomena observed near the coast, such as landfast ice, shear zones and polynyas and processes taking place in the interior of the pack ice fields, such as leads, ice motion and break-up of floes.

INTAROS

NTAROS-Russia is the project complemented to the European Union's Horizon 2020 project INTAROS (Integrated Arctic Observation System) carried out by a consortium of 41 institutions and coordinated by the Nansen Centre in Bergen, Norway, with Prof. Stein Sandven as Coordinator. The main goal of INTAROS-Russia is development and application of Russian segment of the Integrated Arctic Observation System for providing Russian authority, organizations, stakeholders and public with the comprehensive and quality hydrometeorological and oceanographic information for the Arctic region. The partners of the INTAROS-Russia are Research Institute for Hydro-meteorological Information (RIHMI), Obninsk; Nansen International Environmental and Remote Sensing Centre (NIERSC) and Arctic and Antarctic Research Institute (AARI), both St. Petersburg. INTAROS-Russia is funded by the Ministry of Science and Higher Education of Russian Federation (Unique Project Identifier RFMEFI61618X0103, 2018-2020).

AFTER

AFTER (Impacts of climate change and climate extremes on the agriculture and forestry in the Europe-Russia-Turkey Region) is the interdisciplinary project established in the framework of «ERA.Net RUS Plus Call 2017» programme and incorporates the scientific groups from Russia, Germany, Belgium, Latvia and Turkey. AFTER aims at bridging the usability gap between state-of-the-art regional climate data and the demands for information at regional scale for climate change impact assessment and adaptation. The main objective of AFTER is to provide state-of-the-art climate information to assess: (i) impact of ongoing and projected global climate change and subsequent changes in climate extremes on the agriculture and forestry in selected regions of Europe, Russia and Turkey; and (ii) the level of contribution, which these changes in agriculture and forestry can provide to climate change mitigation and adaptation due to existing feedbacks. Project partners: NIERSC, St. Petersburg, Russia, coordinator; Ghent University, Gent, Belgium; Climate Service Centre Germany, Hamburg, Germany; Latvian Environment, Geology and Meteorology Centre, Riga, Latvia; Vlaamse Instelling voor Technologisch Onderzoek (VITO), Brussels, Belgium; Iskenderun Technical University, Iskenderun, Turkey. In Russia AFTER is funded by the Russian Fund for Basic Research (RFBR), Grant 18-55-76004, 2018-2020.

ARCONOR (Arctic cooperation between Norway, Russia, India, China and US in satellite Earth observation and education) is the international project aimed at the sustaining long-term international partnership and cooperation between Norway, Russia, India, China and US in the area of satellite Earth observations for monitoring and forecasting the Arctic and support to Arctic shipping through advancing research, higher education and recruitment. ARCONOR is coordinated by the Nansen Environmental and Remote Sensing Centre (NERSC), Bergen, Norway, with partners: Nansen Scientific Society (NSS), Bergen, Norway; NIERSC, St. Petersburg, Russia; Nansen Environmental Research Centre – India (NERCI), Kochin, India; Nansen-Zhu International Research Centre (NZC), Beijing, China; and the University of Connecticut, Storrs, USA. ARCONOR is funded by the Research Council of Norway; NIERSC participation is funded partly by grants from NERSC and NSS, 2017-2021.

Wind speed and wave field dynamics in polar lows and their impact on sea ice is the project devoted to studying distribution of surface wind speed within polar lows in the Arctic, its influence on wind waves and swell generated by polar lows, and their combined impact on sea ice and marginal ice zone. This project is funded by the Russian Science Foundation (RSF), Grant No. 19-77-00092, 2019-2021.

Climate of High Northern Latitudes

Differences between present and early twentieth century Arctic warming

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Dr. Richard Davy, Nansen Centre (NERSC), Bergen, Norway

The present warming is accelerated in the Arctic due to phenomenon called Arctic amplification (AA). However, there was also significant warming in the 1920s–1940s known as the early twentieth century warming (ETCW). Uncertainties in our knowledge of two warmings are larger for the ETCW due to the lack of observational data. It is generally accepted that one of the main differences in two warmings is their spatial structure: the ETCW was confined to the high northern latitudes, whereas the present warming is global.

The ability of global climate models CMIP5 and CMIP6 to simulate both Arctic warmings has been investigated in the AA framework. It is shown that the present-day AA is reproduced quite well by the climate models, yet during the winter season there is its statistically significant overestimation by CMIP6 ensemble mean relative to the observations GISTEMP v4 (Fig. 1). The same time, CMIP6 models do not reproduce the observed magnitude and interdecadal time scale of the ETCW in the Arctic. This is the only period, due to which the empirical cumulative distribution functions are negatively biased in the CMIP6 model runs relative to the observations, and the nonparametric Kolmogorov-Smirnov test applied to the mean centred time series of AA confirms that.

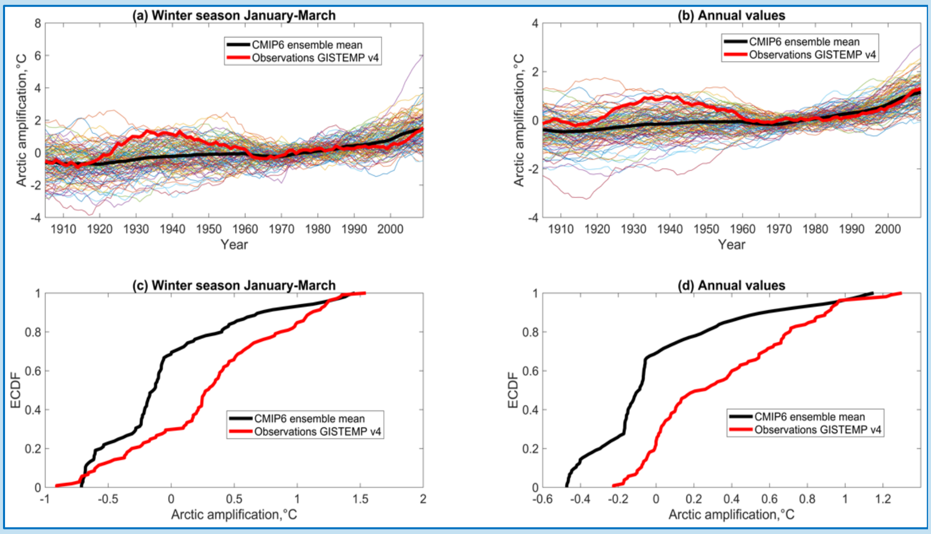

Figure 1. *Arctic amplification time series in the 108 realizations from 32 CMIP6 models in the historical experiment and observations GISTEMP v4 for (**a**) winter season and (**b**) annual values, and the Empirical cumulative distribution functions (ECDFs) for (**c**) winter season and (**d**) annual values. The original horizontal resolution was used in the models and observations.*

Acknowledgements: *This study was funded by the Russian Foundation for Basic Research (RFBR), project number 19-35-90083. Mikhail Latonin is also grateful to the support of the Nansen Scientific Society (Bergen, Norway).*

Relevant publications: *Latonin, M.M., Lobanov, V.A., Bashmachnikov, I.L. (2020). Discontinuities in Wintertime Warming in Northern Europe during 1951–2016. Climate, 8, 80.*

Latonin, M.M., Bashmachnikov, I.L., Bobylev, L.P., Davy, R.. Multi-model ensemble mean of global climate models fails to reproduce early twentieth century Arctic warming. Polar Science (in press).

Latonin M.M., Bashmachnikov I.L., Bobylev L.P. (2020). The Arctic Amplification Phenomenon and Its Driving Mechanisms. Fundamentalnaya i Prikladnaya Gidrofizika (Basic and Applied Hydrophysics), 13, 3, 3–19.

Two warming periods were adjacent to the cooling periods with shorter time scales, namely the 1900s–1910s and 1960s–1970s. In contrast to the warming periods seen in the annual means, these were mostly wintertime anomalies. The statistical modelling of the wintertime time series applied to the surface air temperature observations from weather stations in the Northern Europe has revealed the existence of stationarity during 1872–1950 and non-stationarity during 1951–2016. These results might indicate that warming and cooling periods offset each other at the end of the 19th and the first half of the 20th centuries and that the warming dominates over the cooling in the second half of the 20th and beginning of the 21st centuries. Given the highest spread of CMIP5 and CMIP6 model realizations during the first half of the 20th century for both small and large ensembles, this suggests a higher role of internal and natural climate variability for the ETCW than for the present Arctic amplification driven mostly by the external forcings.

Accuracy in estimating deep convection intensity from a limited number of casts

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Deep convection (DC) is one of the key components of the Atlantic Meridional Overturning Circulation. The intensity of DC is traditionally estimated as the maximum mixed layer depth (MMLD). Based on oceanic reanalysis ARMOR 3D, we developed a criterion of the minimum number of casts needed for obtaining the MMLD in the Greenland Sea with a predefined accuracy. The criterion depends on convection intensity. For gridded datasets, we introduced a complementary measure for the DC intensity: the area of the region with the mixed layer depth over a predefined value (800 m for the Greenland Sea, notated as S800).

For a weak or a moderate DC, variations of its intensity is clearer from variations of the MMLD (cluster 1 in the MMLD - S800 parameter space). Then the MMLD can be obtained with the 25% accuracy when at least 40 randomly scattered winter casts are available. For a well-developed DC (cluster 2 in the MMLD - S800 parameter space), variations of

Acknowledgment: *This research has been supported by the Russian Science Foundation (RSF, no. 18-17-00027).*

Relevant publication: *Fedorov, A.M., Bashmachnikov, I.L. (2020). Accuracy of the deep convection intensity from a limited number of casts. Dynamics of Atmospheres and Oceans, 92, 101164.*

the DC intensity are better accessed from variations of S800. For this cluster, the existence of relatively large areas with deep vertical mixing permits relaying on minimum 10 winter casts for obtaining the MMLD with the 25% accuracy. The available number of winter casts in the central Greenland Sea suggests that we can derive the interannual variability of the convection intensity not earlier then 1986 (using 40-casts criterion), except for a few years (Fig. 2). Since 1993, when available gridded ARMOR allows clustering in MMLD - S800 parameter space and allows reducing the critical number of casts for cluster 2, the acceptable accuracy is not reached only for 5 of 24 winters.

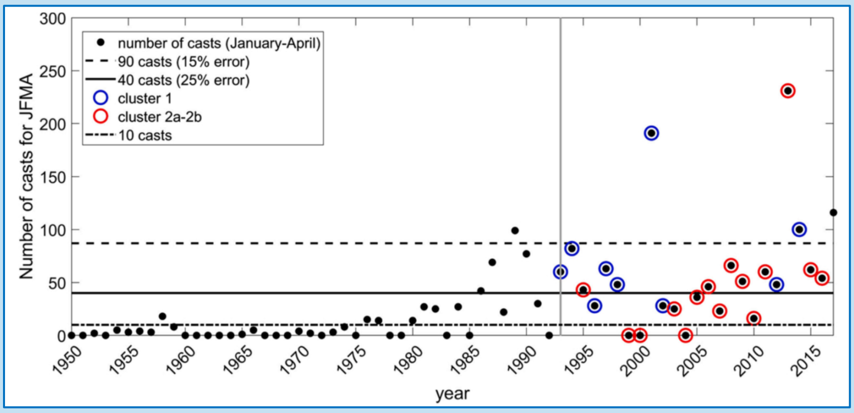

Figure 2. *Number of vertical casts performed in DC region (74-77N, 5E-3W) during DC season (EN4 dataset). The solid and dashed black lines show 40 and 90 casts (cluster 1) and correspond to MMLD estimate with a maximum error of 25 % and 15 %, respectively. Black dash dotted line marks the minimum number of casts required for MMLD detection with 15 % accuracy for cluster 2. Since 1993 (the vertical line), the cluster analysis split the results into clusters 1 (blue) and 2 (red).*

Formation and decay of deep convective chimney

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In this study we further developed an analytical model of an isolated convection chimney. The initial chimney deepening stage is considered to be primarily driven by the buoyancy loss at the sea surface and the modelled parameter is the mixed layer depth. The re-stratification phase is governed by a buoyancy transfer through the lateral surface of the chimney and the modelled parameter is the chimney radius. For the deepening phase with a constant sea-surface buoyancy loss, a rather complex analytical solution for an evolution of the mixed layer depth can be expressed as a combination of two simple asymptotic solutions (Fig. 3a). Solutions for time varying buoyancy flux, including that with synoptic perturbations, are also obtained.

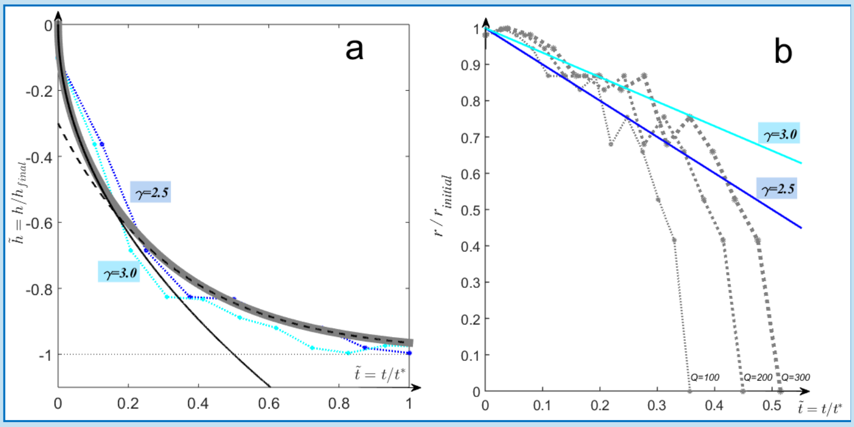

Figure 3. (a) *Variation of chimney depth during the deepening stage of convective chimney driven by a constant sea-surface buoyancy loss. Thick grey solid line is the analytical solution. Black solid line is the asymptotics for the early deepening stage (Eq. 1) and black dashed line is the asymptotics for the late deepening stage (Eq. 2).* ***(b)*** *Variations of chimney radius during the chimney decay stage, given by (Eq. 3), where t=1 is used. Three curves represent results for the sea-surface heat loss of 100, 200 and 300 W m*$^{-2}$*. Blue and cyan dotted lines represent "observed" evolutions from GLORYS reanalysis for* γ *=2.5 and for* γ *=3.0.*

The initial sub-phase of a rapid deepening is:

$$h(t) = \frac{\sqrt{2B_0 t}}{N}, \qquad (1)$$

while the final asymptotic stage is:

$$h(t) = h_{final}\left(1 - 0.7 * \exp\left(-\frac{3t}{\gamma^2}\sqrt[3]{\frac{B_0}{r_0^2}}\right)\right). \qquad (2)$$

Here N is the stratification around the chimney, B_0 is the constant buoyancy flux through the sea-surface, $h_{final} = \gamma\frac{\sqrt[3]{B_0 r_0}}{N}$ is the final depth reached in the chimney, r_0 - is the final chimney radius, γ is a parameter (for the Greenland Sea γ is between 2.5 and 3.0).

During the re-stratification phase (Fig. 3b), the chimney radius decreases linearly with time:

$$r(t) = r_0\left(1 - \frac{1}{\gamma^2}\sqrt[3]{\frac{B_0}{r_0^2}}\,t\right) \qquad (3)$$

The theoretical results agree with an evolution of a chimney in the Greenland Sea, derived from GLORYS high-resolution ocean reanalysis (Fig. 4). As the sea-surface buoyancy flux exceeds certain limits, a chimney develops (with in a weak) and then disappears (within two-three days). The "observed" chimney deepening time scale corresponds to the theoretical one,

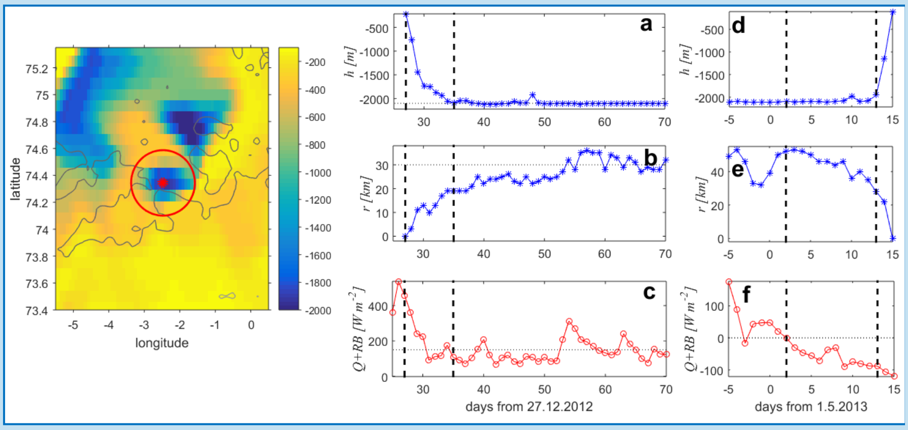

Figure 4. Left *- spatial distribution of the mixed layer depth (m) on 02.01.2013; red circle marks the position of the chimney, evolution of which is shown in the right panels.* ***Right*** *- time series of the chimney parameters during the chimney development phase (**a-c**) and the chimney decay phase (**d-f**): maximum chimney depth (m), radius (km) and heat flux from the sea-surface over the chimney (W m^{-2}). GLORYS and ERA-Interim reanalyses are used.*

while the re-stratification time scale is a half of the theoretical one. The latter is presumably a result a fast chimney collapse at the final stage due to a baroclinic instability, not described by our 1D model.

Acknowledgment: *This research has been supported by the Russian Science Foundation (RSF, no. 17-17-01151).*

Relevant publication: *Kovalevsky D.V., Bashmachnikov, I.L., Alekseev, G.V. 2020. Formation and decay of a deep convective chimney, Ocean Modelling, 148, 101583,*

Satellite-derived spatio-temporal distribution and parameters of North Atlantic polar lows

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Polar low activity is the largest over the North Atlantic. While several satellite-based polar low climatologies exist for the eastern North Atlantic, much less information is available for the western North Atlantic.

We analysed polar lows over the North Atlantic north of 50N and adjacent parts of the Arctic Ocean, i.e., the Baffin Bay and the Greenland and Barents seas, for 2015-2017. This enabled intercomparison of polar low frequency and parameters for different parts of the region. The highest polar low activity was found over the Barents Sea and northern Norwegian Sea. However, the large number of polar lows over this region were dual or multiple systems forming in the same synoptic environment. When considering such systems as a single event, more polar lows were found in 2015 over the Labrador Sea and southern Davis Strait, which is the region with the second highest overall number of polar lows. The main polar low parameters were similar within the region, with the mean values slightly higher in its western part, but all extreme high values were observed in the eastern part.

Fig. 5 shows the composites of 500 hPa geopotential height anomaly and 925 hPa wind vectors highlighting the different large-scale synoptic environments during the formation of western and eastern polar lows. In both cases a strong negative anomaly is present indicative of a strong upper-forcing during formation of identified polar lows while lower-level winds indicate the presence of cold-air outbreaks as intense flows advect the colder air located over the continent or sea ice towards the warmer sea surface. As follows from Fig. 5, the favourable conditions for polar low development in the eastern part of the region generally coincide with unfavourable ones in its western part and vice versa.

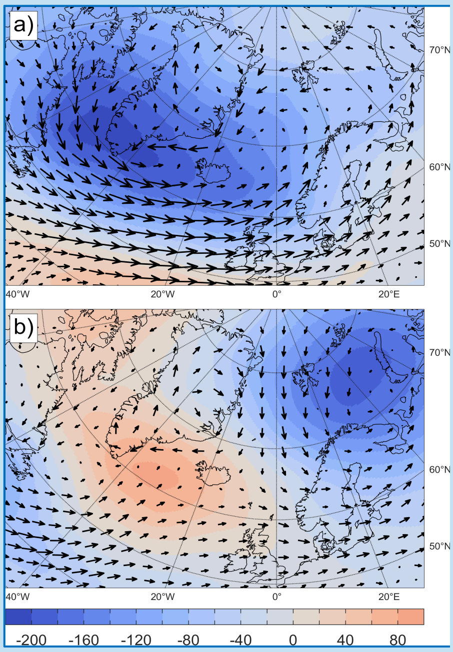

Figure 5. *Composite 500 hPa geopotential height anomaly (m; shaded) and 925 hPa wind vectors (arrows) during formation of polar lows (**a**) west and (**b**) east of 20° W.*

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Relevant publication: *Golubkin, P., Smirnova J., Bobylev, L. (2021) Satellite-Derived Spatio-Temporal Distribution and Parameters of North Atlantic Polar Lows for 2015–2017. Atmosphere 12, 2, 224.*

Aquatic Ecosystems under Global Warming

First results of advanced spectral algorithm usage: spatio-temporal dynamics of coccolithophore blooms

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Coccolithophores are a widespread group of unicellular calcifying phytoplankton that form vast bloom areas in many regions across the World Ocean. In the process of vital activity, this group affect the flows of carbon dioxide in the ocean-atmosphere system in the bloom areas through the production of inorganic carbon. To assess their contribution to the carbon cycle, it is necessary to analyse the spatio-temporal bloom distribution dynamics in the entire World Ocean.

Based on collected spectral statistics of bloom areas, we developed an algorithm for identifying and contouring blooms using ocean colour remote sensing data. At first the algorithm was adapted for Arctic and Subarctic regions, then universalized for all regions of World Ocean. As a result of applying the algorithm, binary masks were obtained, indicating the localization of blooms for more than a 20-year period (1998-2019) with 8-day temporal interval.

The derived masks made it possible to calculate the areas of each persistent coccolithophore bloom. In addition to a quantitative assessment of coccolithophore blooms areas, average annual seasonality of the appearance of blooms was discovered for all the studied regions. In addition to the results of applying the algorithm for individual blooms, the long-term dynamics of the maximum values of the total areas were investigated for north and south hemispheres, as well as for the entire World Ocean (Fig. 6).

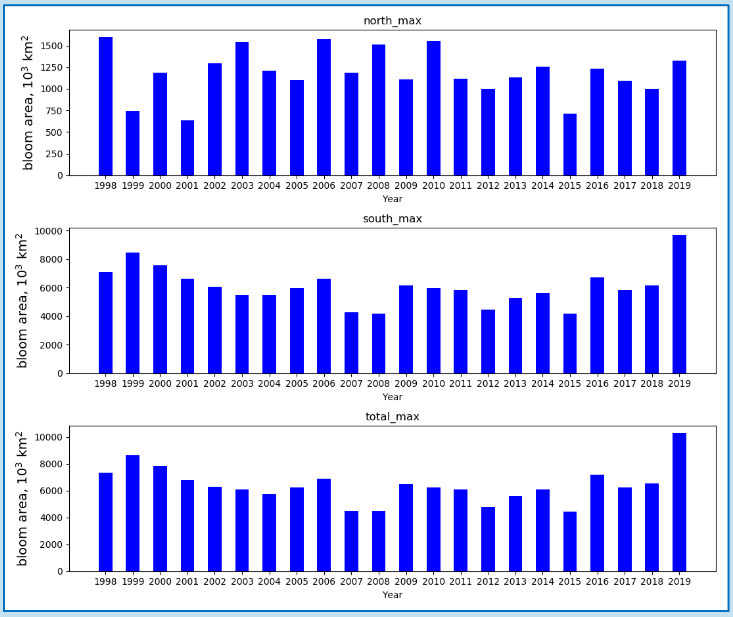

Figure 6. *Maximal coccolithophore bloom dynamics for north and south hemispheres and for the whole World Ocean.*

According to the results obtained, in the Northern Hemisphere the largest blooming areas in the North Pacific Ocean amounted to a total of 988x10^2 km^2 (2003), in the Southern Hemisphere - to a total of 9.5x10^6 km^2 (2019) in six provinces of the Southern Ocean.

Remarkably, that during the entire period of research, both cases of an increase in the total bloom area and cases of its decrease in different time intervals were noted. This is especially noticeable in the dynamics of the maximum areas in the southern hemisphere, where in the period 1998-2008, at first, there was a gradual decrease in area values by year, after which a gradual increase was observed in the period 2008-2019. Though, no significant trends were found over the entire observation period. The opposite and slightly less unambiguous picture can be seen in the Northern Hemisphere: with exception of 1998 and 2019, the smallest areas were observed at the beginning and at the end of the study period, while in 2006, 2008 and 2010, some of the largest total area values were recorded.

Interannual water quality variations in Lake Ladoga in spring during 2016 and 2017: satellite observations

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Results of satellite observations of Lake Ladoga water quality parameters in spring 2016 and 2017 are analysed. These unique results are indicative that even in March, soon after the inception of ice cover melting, the concentration of chlorophyll *a* (Cchl) is non-zero (but yet very low) not only in the lateral but also pelagic waters of the lake (Fig. 7). Arguably, the non-zero *chl* concentrations arise from the phytoplankton that vegetated under ice and then moved up to the surface as the ice began melting. It was revealed for the first time that in springtime the concentrations of inorganic suspended matter (Csm) are year-specific and range between 0.1 and 3.5 mg/l with the elevated values inherent in lateral waters, especially in the vicinity of river outflows. Similar spatial patterns are found for the distributions of coloured dissolved organic matter concentrations (Cdom). The lowest values of Cdom (<4.5 mgC/l) occurred in the pelagic waters, whereas the highest ones (12–15 mgC/l) resided in the lateral zone, in particular, within/adjacent to the Volkhovskaya Gouba. With the beginning of summer, the above concentrations, Cchl, Csm, and Cdom, start growing, remaining however less than they are in July. Such data have never been obtained ever before and is pioneering.

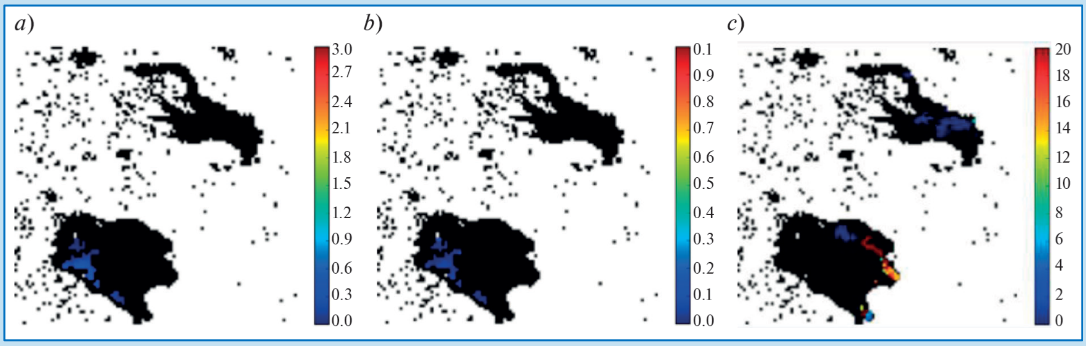

Figure 7. *Retrieved ranges of concentrations of phytoplankton chl (μg/l)* ***(a)****, suspended minerals, sm (mg/l)* ***(b)****, and colored dissolved organic matter* ***(c)****, doc (mgC/l) in Lake Ladoga for March 21, 2017.*

Relevant publication:
Pozdnyakov D.V., Filatov N.N. (2021). Interannual Water Quality Variations in Lake Ladoga in Spring During 2016 and 2017: Satellite Observations. Fundamentalnaya i Prikladnaya Gidrofizikaю 14, 1, 79–85.

Operational ice monitoring in the Arctic seas in 2020

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Techniques for processing satellite radar data developed at the Nansen Centre make it possible to receive online detailed information on the ice cover in the Arctic seas for the benefit of organizations engaged in navigation and drilling operations on the shelf. Information on ice conditions is supplied to users using developed logistic model "System for monitoring and forecasting sea ice cover" (Patent No. 2672531, priority dated May 17, 2017) in the form of specialized ice maps of a new generation based on direct mapping with high spatial resolution (from dozens of meters) and time discreteness of one day or less. This allows ice monitoring on a meso- and synoptic scales and producing datasets for the study of seasonal and interannual regional features of the ice regime of the Arctic seas. In 2020, the monitoring was focused on controlling changes in ice conditions in the Kara Sea during the period from the second decade of June to the middle of the first decade of August, until the sea was completely free of ice. Demonstration monitoring of ice conditions in the Pechora Sea was also carried out during abrupt changes in the synoptic situation in the atmosphere. Radar images from Sentinel 1A/B satellites of wide coverage were used as initial information. The spatial resolution of the maps was about 300 m.

In the Kara Sea in 2020, there were special conditions under which the sea quickly freed from the ice cover and completely cleared. The ice edge in summer was far to the north. During the period of thawing, an unprecedented two-month series of daily ice maps was obtained and the regularities of freeing the water area from ice were determined. It should be noted that in the spring of 2020, detailed daily sea ice monitoring based on high resolution ice maps was carried out for the first time in the history of ice observations. A new unique experience of classification of sea ice during the thawing period and new data on the features of the ice regime of the Kara Sea during the period of seasonal sea ice clearance (Fig. 8) were obtained. For the Pechora Sea, changes in ice conditions after a deep cyclone passed over the region, resulted in forming vast expanses of clean water along the coast, are shown in Fig. 9. Ice conditions changed sharply over a short period. During the passage of the cyclone, the zone of young ice rapidly decreased, and its configuration changed. Changes have also affected areas of first-year thin ice. Similar changes have occurred in the zones of young ice: the area decreased, the zones of open water expanded significantly. The given series of daily ice charts shows their high predictive potential. With daily (and more frequent) monitoring of ice conditions using new type of high-resolution ice charts, an experienced ice analyst can successfully formulate a high-quality analytical ice forecast for the next 2-3 days, even without using an ice model.

It is important to emphasize once again that the monitoring of ice conditions in the interests of companies performing activity in the Arctic should be carried out on the basis of high and medium resolution satellite images of a wide coverage using methods of their automated processing and producing up-to-date high-precision ice maps of a new type. Sea ice classification maps demonstrate the ability to control subtle changes in ice conditions under the influence of atmospheric circulation, which can change significantly during even one day. Maps can be provided in any format convenient for the customer. They can be assimilated into any GIS, on-board navigation and ice management systems.

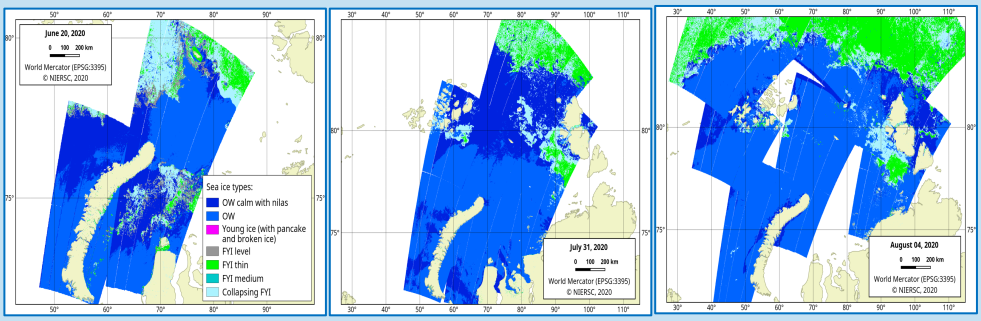

Figure 8. *Examples of ice maps for the final stage of ice cover melting in the Kara Sea in 2020: 20 June, 31 July, and 4 August, respectively.*

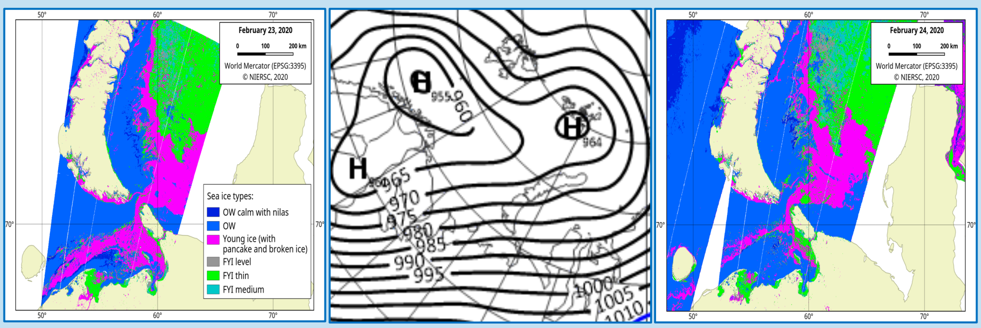

Figure 9. *Changes in ice conditions in the Pechora Sea during the passage of a deep cyclone: 23 and 24 February 2020.*

In 2020, work continued also on the development of automated methods for identifying icebergs. A new approach was developed with the division of objects detected on radar images into ships and icebergs, which, like other objects of artificial origin, are displayed in a similar way in the form of bright dots and areas. For the computer programme of iceberg and vessel identification by radar images using a neural network approach, a Certificate of State Registration No. 2020662722 was received on October 16, 2020.

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Book

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