Arctic Security

Annual Report 2007
Nansen Environmental and Remote Sensing Center
Bergen - Norway
affiliated with the University of Bergen
2007-report from the board

VISION
The Nansen Center’s vision is to make a significant contribution to the understanding, monitoring and forecasting of the world’s environment and climate on local, regional and global scales.

Main research focus areas are:
- Climate understanding - its variability and change
- Global ocean studies and ocean forecasting
- Development and use of satellite based methods for marine studies
- Satellite monitoring of global environment and climate
- Wind energy mapping in coastal areas
- Socioeconomic impact of global change

ORGANIZATION
The Nansen Center is an independent nonprofit research foundation affiliated with the University of Bergen, Norway. The Nansen Center conducts basic and applied research funded by research councils, space agencies, national and international governmental agencies, industry and private donations. The Nansen Center receives no basic funding – neither from the Government nor from the Research Council of Norway.

STAFF
At the end of 2007 the Nansen Center employed a staff of 62 persons from 14 nations, - including nine in adjunct positions. The staff includes four Post Docs and 15 Ph.D. candidates. Foreign students and visiting scientists from France, France, Italy, China, Portugal, Russia, U.K., Sweden, South Africa, Germany, Ukraine and USA, have been visiting the Nansen Center for periods from weeks to several months during 2007.

The Nansen Center's goal is to be an equal opportunity employer. 27% of the employees were female in 2007.

OFFICE AND ENVIRONMENT
The working environment is very satisfying – both in the premises in Bergen and in our office in Svalbard Research Park in Longyearbyen. The board concludes that the Center does not pollute or in other ways harm the environment.

PRODUCTION
During 2007, 33 papers were published in international refereed journals, one book, one book article, 22 articles in conference proceedings, 26 technical and special reports and 15 popular science articles – totally 98 publications. Public outreach has been done through newspaper interviews at national and international level - including TV and radio. Popular scientific lectures have been given at the Nansen Center's adventure center "Arctica" and "VilVite" in Bergen.

MASTER AND DOCTORAL THESIS
The following four master and two doctor theses were completed in 2007:

MASTER EXAMS:

Johan Wåhlin: Sea ice monitoring in the Arctic using satellite SAR images. NERSC/Luleå University of Technology, Department of Applied Physics and Mechanical Engineering, Division of Physics. Supervisor: Prof. S. Sandven.


DOCTORAL DISSERTATIONS:
Dorotea Iovino: On the role of the Nordic Seas in the Atlantic Meridional Overturning Circulation, NERSC/Geophysical Inst., Univ. of Bergen. Supervisors: Dr. T. Eldevik, Prof. H. Drange and Dr. F. Straneo.

Knut Arild Liserø: A coupled ice-ocean data assimilation system for the Arctic monitoring and prediction. NERSC/Dept. of Mathematics, Univ. of Bergen. Supervisors: Dr. G. Evensen, Prof. J. Berntsen.

AWARDS
The board of "Fridtjof Nansen’s Fund" decided to give Professor Ola M. Johannessen the Fridtjof Nansen’s Award for outstanding research in Science for 2007 for his "path-breaking studies of dynamic oceanographic processes in the Arctic marginal ice zone". The Medal is an official Norwegian decoration. Former physical oceanographers that were awarded this medal are Professor H. Mohn in 1914, Professor B. Helland-Hansen in 1915 and Professor J. E. Fjeldstad in 1945.

Helge Drange was one of many "Contributing Authors" to "The fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)", an organization which was awarded the Nobel's Peace Price for 2007. The Nansen Center “Polar Bear Award” for 2007 was given to Dr. Leonid P. Bobylev and the staff of the Nansen International Center in St. Petersburg during their 15th years anniversary in September “for their outstanding scientific achievements in Arctic research”.

INTERNATIONAL ACTIVITIES
By the end of 2007 the Nansen Center participated in 17 EC projects and co-ordinated five of these projects. The Nansen Center also co-ordinated two INTAS (International Association for the promotion of co-operation with scientist from the New Independent State of the former Soviet Union) projects with participation from Russia and the Ukraine – and the Nansen Center is also partner in a third INTAS project.

The collaboration with the Nansen-Zhu Center at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Science (CAS) in Beijing has expanded through mutual exchange of Ph.D. candidates and scientists. The Nansen-Zhu Center now employees 58 persons – including 22 Ph.D. candidates and 11 Master students. Prof. Hui-Jun Wang, Director of IAP, is the co-director for the Nansen-Zhu Center together with Helge Drange. Ola M. Johannessen and Prof. Wang are the co-chairmen of the Board. Ola M. Johannessen and Helge Drange are formally appointed "Visiting Professors" at the Institute of Atmospheric Physics of CAS.

The Nansen International Center in St. Petersburg celebrated its 15 years anniversary in September 2007. Ola M. Johannessen resigned his "President" position and Jean-Pierre Contzen was elected to be the new President. Lasse H. Pettersson is still Secretary General for the Center, which now has 31 employees including 9 Ph.D. candidates. During 2007 the Center hosted together with the St. Petersburg State University the...
summer school on “High Northern Latitude Climate” with 34 student participants from seven countries. The summer school was sponsored by St. Petersburg State University, the Nansen Centers in Bergen and St. Petersburg, the University of Bergen and the Nansen Scientific Society in Bergen. The co-operation with the Nansen Center in Cochin is expanding with several new Ph.D. candidates, focusing their studies on the Indian Ocean.

INTERNATIONAL COMMITTEES

Johnny A. Johannessen is appoint-ed chairman of the Earth Science Advisory Committee (ESAC) in ESA for the next three year period. He is also member of “the ESA GOCE Mission Advisory Group” and “the ESA Terra SAR Science Advisory Group”. Lasse H. Pettersson has been a member since 1994 of the Satellite Missions” and of “European Science Foundation Marine Board”. Lasse H. Pettersson has been a member of the ESF Marine Board working group on “Remote Sensing of Shelf Seas” launching its positioning paper in February 2008. The Nansen Center is one of the founders of the “European Climate Forum (ECF)” and Ola M. Johannessen is a member of the Council. ECF is a multi-disciplinary forum gathering research, industry, governmental authorities, NGOs and stakeholders to meetings and projects dealing with climate change issues. Ola M. Johannessen is also a member of the Science and Technology Council of the International Risk Governance Council in Geneva, Switzerland. He is also one of four advisors of the “High-Level Science Advisory Committee” to the General Director of ESA.

THE G.C. RIEBER CLIMATE INSTITUTE

The G.C. Rieber Climate Institute is a part of the Nansen Center, and is led by Prof. Helge Drange with Dr. Tor Eldevik as deputy leader. Helge Drange’s Professorship II at the Geophysical Institute, University of Bergen is a donation from the G.C. Rieber Funds. The institute has a staff of 18 scientists and Ph.D. candidates. The main activity of the institute is devoted to the variability and the dynamic properties of the North Atlantic and Arctic climate system. The Nansen Center is a major partner in the Bjerknes co-operation in Climate Research established in Bergen between the University of Bergen, the Institute of Marine Research and the Nansen Center.

The G.C. Rieber Climate Institute, in particular Mats Bentsen and Ingo Bethke, contributed with climate modelling and future simulations using the Bergen Climate Model for the IPCC “Fourth Assessment Report”. Helge Drange is a member of CLIVAR ‘Working Group for Ocean Model Development’ under the World Climate Research Program and is a member of the board of CICERO at the University of Oslo.

The G. C. Rieber Funds support the institute with NOK 0.4 mill a year for recruitment of Master students to climate research in Norway. The board sincerely thanks the G.C. Rieber Funds for this important support through many years.

THE Mohn- Sverdrup Center

The Mohn-Sverdrup Center for Global Ocean Studies and Operational Oceanography (MSC) is part of the Nansen Center. Ola M. Johannessen with Dr. Laurent Bertino as the deputy leader heads the Center. By the end of 2007 the Center employed 19 scientists and Ph.D. candidates. Its main research focus is to develop ocean and marine ecosystem models and data assimilation techniques for the Norwegian Sea, the Barents Sea and the Arctic Ocean Region to the benefit for the society. From 2007, the Center coordinates a large multidisciplinary project under the eVITA program of the Research Council of Norway for applications of the Ensemble Kalman Filter including development of new data assimilation methods in various fields such as oceanography, weather forecasting, oil reservoir modeling, health and bioeconomic management. Furthermore, the TOPAZ ocean forecasting model is also implemented for the Indian Ocean in collaboration with the Nansen Center in Cochin, India.

Trond Mohn through Frank Mohn ASA supports the Mohn-Sverdrup Center annually with NOK 5 mill. Furthermore, Trond Mohn expanded his donation with an additional 25 mill NOK at our annual meeting in 2007. The board sincerely thanks Trond Mohn for his important support that we have received since 2004 and which now is extended until 2014.

POLAR AND MARINE REMOTE SENSING

The Remote Sensing research activities are led by Stein Sandven, who is also a Professor II at the University Centre in Svalbard - UNIS and Johnny A. Johannessen, who is also a Professor II at the Geophysical Institute, University of Bergen. The Group has a scientific staff of 16 persons. The main research focus is development and validation of algorithms for retrieval of ocean-coastal and ice parameters, including detection of icebergs and their drift - from satellite Earth observation data. The information from the satellites is further used in studies of oceanographic processes and climate change for the benefit of the society. Furthermore, ocean colour and infrared satellite data are used in real time monitoring of algae blooms and water quality conditions in the North Sea and Norwegian coastal water (http://HAB.nersc.no). This is part of the NERSC contribution to ESA’s Global Monitoring for Environment and Security (GMES) and it is lead by Lasse H. Pettersson. A dedicated near real time SAR information server is also implemented at NERSC with a focus on wind field and surface current feature retrievals for the marine economic zone of Norway, the Arctic and some other selected regions worldwide.

Sea ice information from satellite Earth observation data is also used in hindcast as well as in near real time to support navigation and operation in ice covered waters. Particularly, for the Northern Sea Route monitoring is done in cooperation with Russian scientists from the Nansen International Center and the Arctic and Antarctic Research Institute, both in St. Petersburg, and the Murmansk Shipping Company.
The research focus of the Group is currently on the development of an integrated ocean and ice monitoring and forecasting system for the Barents Sea by using satellite and in situ data, models and data assimilation techniques. This will become an important activity under ArcticPOOS, and will be to the benefit and use for fisheries, gas and oil exploration and production, as well as management of the Arctic and sub-Arctic regions.

**Arctica**

“Arctica” is a small public adventure centre at the Nansen Center. Among the attractions is a wide-screen movie “Svalbard – Arctic Seasons”, the life of Dr. Fridtjof Nansen in pictures and sound and an exhibition in the “Science Room”. Several school classes and other groups have visited “Arctica” during the year, and it has become a popular meeting place.

**Terra Orbit AS, COTO AS and Ocean Numerics Ltd.**

The Nansen Center is the owner of the companies Terra Orbit AS and COTO AS and a shareholder in Ocean Numerics Ltd. The goal of these companies is to offer services for monitoring of the environment, ocean surveillance and forecasting. The potential revenue of these activities will in turn contribute to the scientific development in the areas where the Nansen Center concentrates its main research and development activities.

**Nansen Scientific Society**

The Nansen Scientific Society, established in 2006, is “the parent organization” for all the Nansen Centers in Norway, Russia, China and India – and possible additional centers in other parts of the world. Its main goal is to expand the existing “Nansen Fellowship Program” supporting young scientists in environmental and climate studies, and furthermore to contribute to the scientific coordination and funding of activities at the Nansen Centers – as well as public outreach on global warming. The vision is that research and education in environmental and climate issues performed by young people from different countries and cultures will help build a foundation for a better understanding and co-existence between people in the world - in the spirit of Fridtjof Nansen.

The founders are The Nansen Center, Trond Mohn, G.C. Rieber Funds and Sparebanken Vest. The foundation started with an equity capital of NOK 10 millions.

The Society has financed in 2007 two Ph.D. candidates from China and one from Russia. It further contributed to the summer school on “High Northern Latitude Climate” in St. Petersburg and an oceanographic expedition to the West coast of Greenland.

**Merging of the Nansen and Bjerknes Centers**

Negotiations has begun to achieve a merging of the Nansen and Bjerknes Centers and to get a new building next to the Nansen Center for its co-localization.

**Financial Situation**

The Nansen Center is an independent non-profit research institute without any basic public funding. The income in 2007 amounted to NOK 37 188 984 and NOK 1 824 004 in financial income. The 2007 project income has mainly come from the European Commission (EU), The Research Council of Norway, European Space Agency, oil companies, the Norwegian Space Center and INTAS. The Nansen Center has received substantial financial support from G.C. Rieber Funds and Frank Mohn ASA by Trond Mohn. The annual net surplus for 2007 amounts to NOK 4 179 514. NOK 4 179 514 of the annual income is transferred to the equity capital. The equity capital amounts to NOK 32 746 642.

**Prospects for 2009**

We are expecting an expansion of our research activities in the year 2008, primarily due increased activities in the Northern areas – where the Nansen Center has a major expertise and experience developed through the last 21 years. Additionally increased funding for climate research is expected.

**Bergen, April 28th 2008**

Dag L. Aksnes (Chairman)
Bjart Nygaard (co-Chairman)
Hans Petter Seijrup
Anton Kjelaas
Lasse H. Pettersson (Repr. of employees)
Ola M. Johannessen (Director)
Global warming is enhancing in the Arctic regions. The air temperature has increased to double that of the global average over the last 100 years, the ice cover is decreasing at a rate of 3–5% per decade while the thicker multi-year ice is decreasing at a rate of 7–10% per decade, the river discharge from Russia is increasing, and a significant decrease in the ice cover.

The prediction for the Arctic region is a strong increase in the air temperature and a significant decrease in the ice cover. A Blue Arctic Ocean is predicted during the summer time at the end of this century or earlier. However, the many recent IPCC-coupled climate models also indicate a strong widespread in the result. Recent studies also indicate that most of the annual decrease in ice extent can be explained by the increase of CO₂ in the atmosphere and that the ice extent is reduced faster than the IPCC models predict.

If the predictions turn out to be valid, then global warming will have a strong impact on the ecosystem and fisheries, living conditions for humans and animals, offshore and onshore oil and gas production, and ship transportation along the Northern Sea Route and North West Passage, on society, economy and energy supply (25% of the remaining oil and gas reserves is estimated to be in the Arctic region). However, it should be pointed out that the IPCC models have not taken into account the potential impact of the increased melting and discharge of fresh water from the Greenland ice sheet – giving increased uncertainty to the predictions. Another important issue which has not been taken into account is the potential increasing uptake of CO₂ by a "Blue Arctic Ocean".

Global warming in the Arctic region can have both positive and negative effects. It is easy to understand that a retreating ice cover will make offshore oil and gas production easier in the future. On the other hand, the thawing of the tundra and permafrost will cause problems for the onshore gas and oil industry. Furthermore, the thawing permafrost will cause a lot of infrastructure problems for the population living in this region. Another big question is what will happen with the huge methane reservoirs which are present are frozen in the permafrost – also located offshore.

"These climate changes and the projection of future climate change have also significance in the politics of international relations, in regard to security questions in both the narrow sense and in that of wider human security. The shrinking of the ice cover may allow navigation through Arctic waters and will make for easier access to sea bed resources. This, in turn is already leading to competing claims to sovereignty. Environmental change will also have a profound effect of the livelihoods of indigenous peoples, both directly and through its implications for the militarization of the region" quoted from the conference on “Problems of Arctic Security in the 21st Century” April 11-12, Simon Fraser University. Vancouver organized by Jayantha Dhanapala and John Harris, where O.M. Johannessen gave a talk.

The Science report from the Nansen Center for 2007 is dealing with examples of different high latitude scientific and applied studies.

**EXPERTISE ON THE NORTHERN SEA ROUTE**
Ola M. Johannessen and Lasse H. Petersson - Johannessen et al. [Book, 2007]

In 1933 the Soviet Union started systematic studies and use of the Northern Sea Route (NSR) as a maritime route of transport. During the last 75 years the NSR has had a major impact on the national ship transportation in Russia and other activities along the Siberian coast. However, secure and efficient activities require great demands to infrastructure, including e.g. ice monitoring and forecasting.

The Nansen Centers in Bergen and St. Petersburg have during the last 15 years contributed with ice monitoring and information in support for ship navigation and other operations in the NSR by using satellite data and numerical ice forecasting models. In co-operation with Arctic and Antarctic Research (Antarctic) and several Russian ice-experts, the Nansen Centers have published the book “Remote Sensing of Sea Ice on the Northern Sea Route” by Springer-Praxis.

The book review the Russian and Norwegian experience and expertise within sea ice monitoring and forecasting in the Northern Sea Route. This information has been used to navigate Russian nuclear icebreakers and other commercial vessels in the NSR during the last 15 years, when the Nansen International Center in St. Petersburg started its activities in 1992. A close cooperation has been developed with the several stake holders including the Murmansk Shipping Company.

The Northern Sea Route has been of great and increasing importance for the Russian ship transportation and other activities throughout the whole year. During the summer ships sail all along the eastern and western parts of the Siberian coast and to the eastward to the Pacific Ocean. During winter the ship traffic is limited to the areas east from Murmansk to the Yenisei River in the Kara Sea. Since 1991 also international ship traffic has been carried out along the NSR, and the NSR are discussed as an alternative shorter ship route between Europe and Asia – during the summer between 10 and 14 days in the Arctic can be saved. Reduced ice-cover in the Arctic will increase the use of the NSR, but still the security of efficient operations in this inhospitable area of the Arctic creates many challenges. Russian experience and expertise in this field is unique. Advanced ice-monitoring assistance from icebreakers and ships designed for this purpose with specialized trained staff are necessary to operate in the extreme ice and weather conditions which are normal in the NSR. Currently reliable sea ice monitoring and forecasting services are essential for the increasing offshore oil and gas activities in the Barents Sea and along the coast of Siberia.

**POLAR AND ENVIRONMENTAL REMOTE SENSING**
Stein Sandven - Sagen et al. [Proc. UAM, 2007]

Monitoring of sea ice thickness, ridges and drift will be an important component of ice management systems for offshore operations in Arctic ice-covered seas. A new method to measure sea ice thickness and ridges on local scale has been studied in the ICESONAR project. A multi-beam sonar, provided by CodaOctopus Omnitech AS, can be operated from
underwater platforms to obtain high-resolution 3-D images of the underside of the ice. These images give detailed measurement of the ridges and ice keels. During field experiments with Lance in the Svalbard area, organised by UNIS, test data have been collected where the sonar has been lowered through a hole in the ice to depths down to 100m. The sonar measurements have been validated by ROV observations and drilling of holes to measure thickness of ridges. It is envisaged that multibeam sonars will be part of future ice management systems used by oil companies operating in ice-covered Arctic waters.

Satellite monitoring of sea ice has been further developed by establishment of an operational SAR server which downloads and presents quicklook images from ENVISAT ASAR every day. In addition, optical and infrared images from MODIS are downloaded every day from NASA satellites covering the Svalbard and Barents Sea area. These images are used in several research projects to produce ice drift, ice types, surface temperature and polynya dynamics, as shown in Figure 1. By combining SAR and infrared data it is easier to distinguish sea ice from open water in polynya areas such as Storfjorden. Passive microwave data are used to retrieve large scale ice concentration for the whole Arctic region to monitor seasonal and interannual changes of the ice cover. The ice concentration data are also assimilated in the TOPAZ ice forecasting system. The satellite ice monitoring system is a contribution to the IPY.

Ice drift in the Fram Strait has been monitored by SAR since 2004, using ENVISAT Wideswath images (Figure 2). The Fram Strait is the main area for export of sea ice from the Arctic Basin. Satellite data plays a major role in observing the ice area flux, while ice thickness data are obtained from in situ observation. The sea ice remote sensing work is part of the EU projects MERSEA and DAMOCLES.

**Getting Ready for GOCE**

Johnny A. Johannessen - Siegismund et al. [JGR, 2007]

The European Space Agency (ESA) will launch the Gravity Field and Steady State Ocean Circulation Explorer (GOCE) Mission in September 2008. The primary aim of GOCE is to provide unique models of the Earth's gravity field and the geoid, on a global scale with spatial resolution of 100 km and to very high accuracies of 1 mGal and 1-2 cm. Over the ocean the difference between mean sea surface height (MSS) and the geoid height is expressed as the mean dynamic topography (MDT).

A key scientific question is how new and accurate knowledge of the MDT (=MSS-geoid) from the GOCE satellite will improve the understanding of the ocean circulation and its transport of heat and mass. This has been investigated in recent studies (GOCINA, OCTAS and ArcGICE projects) with focus on the Northeast Atlantic, Nordic Seas and the Arctic Ocean. The ocean circulation regime in this area has a profound influence on the water masses leading to a horizontal and vertical density structure unlike any other ocean regions.

Figure 3 displays maps of steric height derived from observed temperature and salinity profiles to 1000 m (upper) and the ocean model MICOM to the same depth (lower) averaged over the period 1950 to 1999. The MICOM map is re-sampled to the same 1 degree resolution grid as for the observed map. These independently derived steric height maps display large scale patterns in good agreement. Both minima in the central Greenland and Iceland Seas and higher values along the coasts of Norway and Greenland.
the upper 1000 m, as only minor changes are encountered for depth-integration of profiles to 1500 m.

Strong barotropic flow causes additional slopes in the MDT, that can be expected along the margins of the basins and over the continental shelf breaks. This, in turn, could imply impact on the shape of the MDT, that would eventually strengthen the general cyclonic circulation structure imposed by the mean steric height. Presently no consensus exist on which ocean models might provide the best estimate of the MDT for the North Atlantic, Nordic Seas and Arctic Ocean. The accuracies of the mean ocean circulation and its transport of heat and mass within and across these ocean basins are consequently uncertain. These uncertainties are expected to be reduced when GOCE delivers its geoid. The more accurate MDT anticipated using this geoid together with MSS will thus provide a very promising method for constraining and validating ocean models.

**The Barents Sea Temperature Variability**

Anne Brit Sandø, Jan Even Øie Nilsen, Yonggi Gao and Katja Lohmann - to be submitted to GRL in 2008

The inflow of warm and saline Atlantic water into the Barents Sea is of great importance to the Arctic climate, as well as for the plankton production and distribution of fish within the Barents Sea region. Much effort has therefore been spent to explore the potential predictability of the system, either based on observations or using ocean only or coupled atmosphere-ocean models.

An isopycnic coordinate ocean model has been used to investigate the role of the poleward flow of warm Atlantic Water and the local air-sea exchange of heat on variations in the Barents Sea temperature.

For evaluation of the model in the Barents Sea, observed and simulated time series from the Kola section, extending northward from the Kola peninsula, are used. As an example, time series of observed and simulated annual mean temperature anomalies from the upper 200 m of the Kola section is shown in Figure 4.

For the period 1948-1997, the ocean transport of heat and the air-sea heat fluxes are about equally important factors for the temperature variability. After 1997, the heat transport becomes the dominating factor as can be seen in Figure 5.

The change in 1997 is likely related to the abrupt increase in the poleward transport of heat and salinity from the northern North Atlantic in 1995/96, caused by a rapid reduction in the strength and extent of the sub-polar gyre. The temperature anomaly is seen to propagate along the Norwegian coast, reaching the Barents Sea about two years later. Anomalies in the ocean transport of heat, in combination with the local air-sea exchange of heat, reveal a potential for predicting climate variations in the Barents Sea in some years in advance.

**Recent Advances in Understanding of the Arctic Planetary Boundary Layer**

Igor Esau - Mauritsen et al [JAS, 2007] and Zilitinkevich et al, QJRMS in press [2008]

Planetary boundary layer (PBL) is the lowermost layer of the atmosphere where the flow of air has a chaotic, or turbulent, character. The PBL processes seriously affect the earth’s ecosystems and human activity, and constitute a critical component in climate models.

Detailed understanding of the Arctic PBL has been lacking because of...
few observations and insufficient theoretical understanding. A large international collaboration headed by the Marie Curie Professor Sergej Žilitinkevich (University of Helsinki and NERSC) has, however, advanced our understanding of Arctic PBL.

In short, the new understanding addresses the conversion between kinetic and potential energy. Under proper conditions, the potential energy stored in the temperature fluctuations can be converted into the kinetic energy of turbulent eddies and hence force additional mixing with far-reaching consequences. This reversible energy exchange between the wind and temperature fluctuations distinguishes the new theory from the established Kolmogorov theory. In the latter, the kinetic energy is irreversibly lost from the system by dissipation. It is usually difficult to visualize findings from turbulence theory. A. Majda and M. Shefter (USA) have suggested visualization of the reversible energy conversion in a stably stratified flow in a rotated system. Such a flow is observed in the polar PBL. Figure 6 shows the evolution of the turbulent potential to total turbulent energy ratio for the Antarctic summer PBL. The data is obtained from a numerical experiment with the NERSC turbulence-resolving model LESNIC, carried out on the new supercomputer facility CRAY XT4 at the Univ. of Bergen.

During the initial phase (0-10 hours), the wind accelerated and supported enough turbulence for the PBL to grow. In the next phase (10-20 hours), the wind decelerated and the turbulent kinetic energy was partially converted into potential energy of temperature fluctuations at the top of the PBL. During the final stage (20-24 hours), the wind accelerated again creating favourable conditions for the reverse of the energy conversion, leading to growth of the PBL.

The Arctic - Challenges and Opportunities for Oil and Gas Exploration
Stein Sandven
[Offshore, 2007]

The Arctic regions offer vast areas of hydrocarbon resources that have just started to be exploited. The Arctic Ocean is surrounded by continental shelves, where in particular the huge Siberian shelf covering the eastern hemisphere, extending from the Barents Sea to the Chukchi Sea. There is growing political interest for the Arctic Ocean and several countries have started investigations of the continental shelves. Under the UN Convention on the Law of the Sea, a country can claim exclusive economic rights within 200 miles. If a country can prove that its continental shelf extends beyond the 200-mile economic zone, it can claim similar rights over a larger area.

The ongoing changes in Arctic climate with increasing temperatures and decreasing sea ice cover have also stimulated the interest for oil and gas exploration in several Arctic areas. A reduction of the sea ice area opens up the possibility to access new areas of the Arctic Ocean where hydrocarbon resources can be exploited and transported to the markets. The main Arctic areas where large-scale offshore exploration have started are: Sakhalin in Sea of Okhotsk, North Slope of Alaska, Cook Inlet, Grand Banks of Newfoundland, Barents Sea (Snøhvit and the upcoming Shtokman fields) and the Pechora Sea. All these areas have seasonal sea ice cover and some have icebergs that impose severe constraints on design and operation of installations and on the transport solutions. Even if the sea ice cover is decreasing and is expected to diminish further in the coming decades, the sea ice will still remain a dominant factor in most of the exploration areas during the winter season. In the summer months, however, less sea ice will facilitate access to offshore areas in Canada, Greenland and on the eastern Siberian shelf that were previously inaccessible due to sea ice.

Sea ice concentration, thickness, and pressure are the major direct factors influencing ice forcing on construction and operations in ice-covered areas. For offshore construction, the drift of ice as well as its thickness and mass are key parameters in calculation of ice loading. Maximum ice thickness is mainly determined by ridges and ice keels, formed when ice floes are pushed against the shore and can be piled on top of each other. In shallow waters, where depths are less than 20 m, ice keels can become grounded and ridges can build up to more than 10 m as a result of the drifting ice floes. In addition to the general ice conditions, it is very important to have specific data on these ice parameters in local regions where ice operations are planned. Oil companies usually need to collect region-specific data on sea ice parameters as part of the design phase studies for operations in Arctic areas. For the operations both observations and forecasting of the ice conditions are needed (Figure 7).

For offshore operations, there are two main situations that require different management of the ice. The first situation is in shallow waters (5 – 20 m) where constructions are built on the seafloor and designed to withstand the forces of the drifting sea ice. The sea ice is often attached to the seafloor and can be stationary for a long time. But stationary ice can start to drift due to strong winds and pile up ice blocks forming stamukhas. The other situ-
Iceberg occurrence probability for the Shtokman area was re-calculated and triggered the oil companies to plan an iceberg monitoring and forecasting system for the area. Since the iceberg distribution can vary strongly from year to year, it is important to have good monitoring and tracking systems for the icebergs (Figure 9).

Such systems are not in operation for most parts of the Arctic today. Extreme events can happen from year to year and there is no direct method to predict when and where icebergs occur and how they drift in the ocean.

How can we assess the climate change impact in the various sub-Arctic regions where offshore operations are foreseen? During winter, the central Arctic and all peripheral seas including the Greenland Sea, Bering Sea, and Gulf of St. Lawrence will continue to have significant ice cover. Ice extent and thickness will generally be reduced. The Sea of Okhotsk and Sea of Japan will be ice-free for the entire year. In late summer, the entire Russian coast will be ice-free, allowing navigation through the Barents, Kara, Laptev and East Siberian Seas along the entire Northern Sea Route. This situation has already been observed during the last couple of summers. The Northwest Passage through the Canadian Archipelago and along the coast of Alaska will in general be ice free and navigable in summer by non-icebreaking ships. Ice will be present all year along the eastern and northern coasts of Greenland. Ice will also remain throughout the summer within and adjacent to the northern Canadian Archipelago. However, severe winters with more ice than average may also be expected due to the natural variability of the climate system. The effect of more wind and waves in ice-covered areas will be increased riding and stamukhas in near coastal regions. The iceberg situation in different parts of the Arctic is difficult to assess, but it is likely that more icebergs can occur in some years as a consequence of diminishing Arctic glaciers. Arctic shipping is expected to increase as a consequence of less sea ice and more offshore exploration.

The possible consequences of increased oil and gas exploration in the vulnerable Arctic environment are a controversial issue. The Arctic ecosystems are already today exposed to severe treatments due to the effects of a warmer climate. A growing oil and gas industry operation on land as well as at sea will increase the pressure on the environment with increased risk of accidents that can have severe and long-lasting negative effects on ecosystems. A worst-case scenario is an Exxon-Valdez type of accident that occurred in Alaska. The ecosystems in the area affected by this accident are still marked by this oil pollution disaster, almost 20 years after it happened. The environmental impact of oil and gas exploration will be higher in the Arctic compared to other areas in the world. This calls for new technologies to ensure safe operations as well as legislative norms that regulate the activities. These factors are not in place yet and need to be developed.

In conclusion, offshore operations in the Arctic will be more feasible as a consequence of the climate change, leading to less sea ice and warmer temperatures. The costs of operations, however, will be high due to extreme ice and weather conditions and requirements to operate with minimum risks to harm the vulnerable Arctic environment.
Referee Papers in International Journals

Climate Research


Oceanography and Sea Ice


Marine Information Systems

Boundary Layer Research


Books & Book Contributions


Proceedings


Evening at Ilulissat, Greenland. The photos at pages 1 to 4 and 10 to 12 are from the Jotun Arctic Expedition to west Greenland in July/August 2007. Credit: Helge Drange, NERSC.