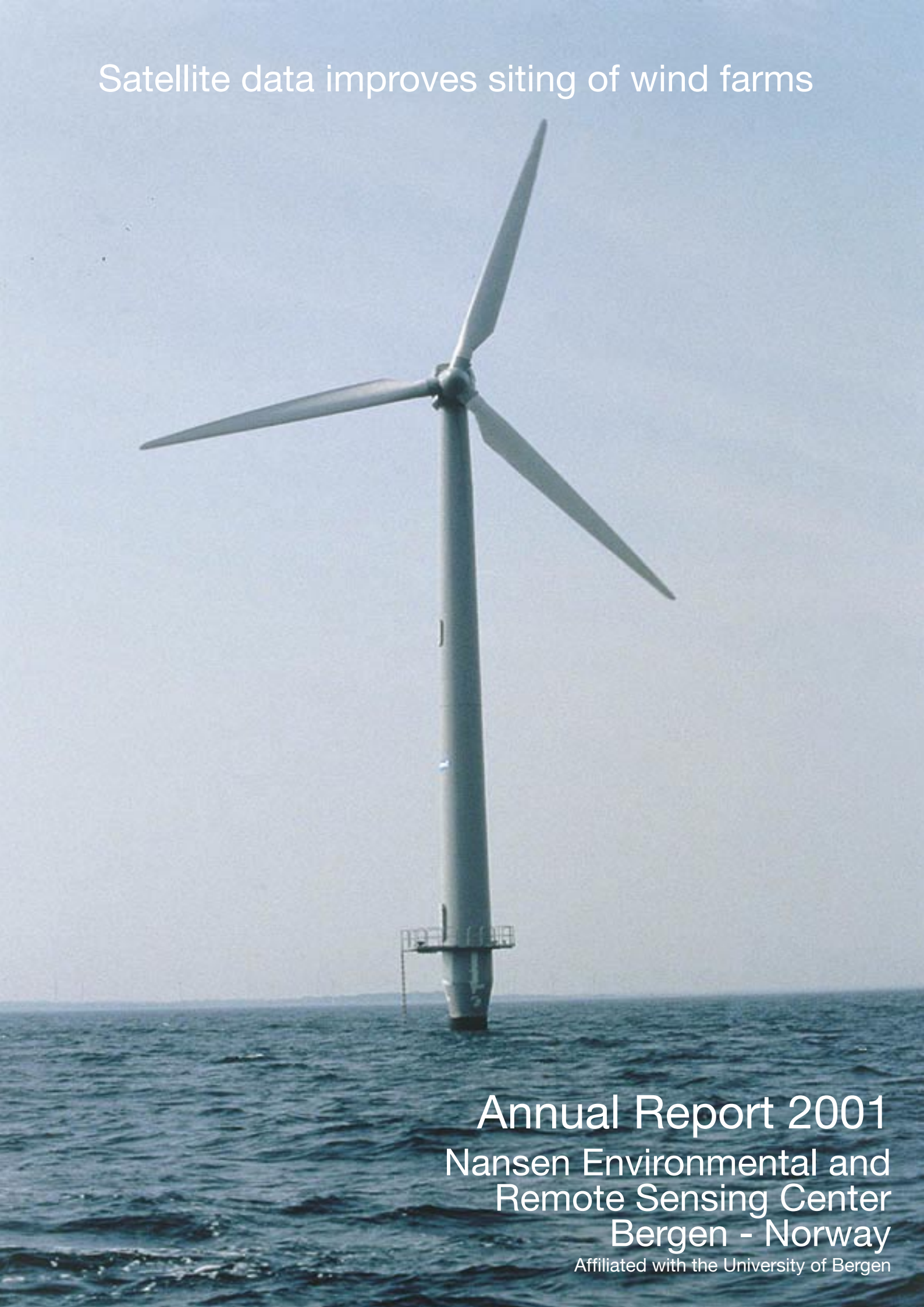
Satellite data improves siting of wind farms



Annual Report 2001

Nansen Environmental and Remote Sensing Center
Bergen - Norway

Affiliated with the University of Bergen

Report from the board

Vision

The Nansen Center´s vision is to make a significant contribution to the understanding of the world's environment and climate on regional and global scales.

Organisation

The Nansen Center is an independent non-profit research foundation affiliated with the University of Bergen, Norway. The Nansen Center conducts basic and applied environmental research funded by research councils, space agencies, national and international governmental agencies and industry.

The Nansen Center celebrated its 15 years anniversary on November 15, 2001 by organizing "*The Nansen Centers 15 years Colloquium*". Dr. Christian Patermann, Director General, European Commission Research Directorate opened the Colloquium giving a lecture on the "Perspectives of European climate research". Professors Klaus Hasselmann, Lennart Bengtsson, Werner Alpers, Jean-Paul Malingreau, Hui-Jun Wang and Dr. Leonid Bobylev gave the other international lectures. The "*Polar Bear Award 2001*" was granted to Professors Alpers and Malingreau for their outstanding scientific efforts within satellite earth observations.

Staff

At the end of 2001 the Nansen Center employed a staff of 46 persons, including four scientists in adjunct positions. Professor Jarle Berntsen, Institute of Mathematics, University of Bergen, is employed in an adjunct position since July 1. 2001. The staff includes 12 Ph.D. Candidates. Many foreign students and visiting scientists from especially Russia, France, China and India have worked at the Nansen Center for periods from months up to one year.

Office situation and environment

The office environment is satisfactory. The board feels that there is no activity at the Nansen Center that pollutes or otherwise harms the environment.

Production

During the year of 2001, 19 papers were published in international refereed journals or books and 14 conference proceedings. Furthermore 16 technical reports, three special reports and nine popular scientific articles were published. The publication "*Ocean Release of fossil fuel CO_2: A case study*" by Helge Drange, Guttorm Alendal and Ola M. Johannessen received a wide attention in the international media because of its relevance to the global warming problem.

Public outreach has been done through newspapers at national and international level and TV. Popular scientific lectures have been given in the Nansen Center´s small adventure centre "*Arctica*".

Doctoral thesis

Three Ph. D. students, Lars Jørgen Natvik, Vibeke Haugen and Birgitte R. Furevik defended their thesis in 2001. They worked at the Nansen Center, and defended their thesis respectively at the Mathematical Institute and Geophysical Institute at the University of Bergen.

International Activities

By the end of 2001, the Nansen Center participated in 20 EU projects and co-ordinated 12 of these projects. The Nansen Center also co-ordinated five INTAS (International Association for the promotion of co-operation with scientists from the New Independent State of the former Soviet Union) projects with participation from Russia and Ukraine.

The Nansen International Center in St. Petersburg (NIERSC) was founded in 1992 as a "non-profit" research company. On July 2. 2001 NIERSC was reorganized as a research foundation with the following seven partners; The State University of St. Petersburg, Russia, St. Petersburg Scientific Research Center of Ecological Safety of Russian Academy of Science, Russia, Northern Water Problems Institute of Russian Academy of Science, Petrozavodsk, Karelia, Russia, Nansen Environmental and Remote Sensing Center, Norway, Bergen University Research Foundation, Norway, Altarum Institute, USA, Max-Planck Society with Max Planck Institute for Meteorology in Hamburg, Germany.

Professor Ola M. Johannessen was elected President and Lasse H. Pettersson Secretary General. The Director at the Nansen International Foundation in St. Petersburg is Dr. Leonid Bobylev, who also holds an adjunct position at the Nansen Center in Bergen.

The co-operation with the Institute of Atmospheric Physics at the Chinese Academy of Science, Beijing has expanded with exchange of scientists and Ph. D. students – both ways. A Memorandum of Understanding was signed in June 2001.

The co-operation with the Nansen Center in India continues, but it has been difficult to get funding for project activities.

Several Announcement of Opportunity (AO) projects from the European Space Agency (ESA) including preparations for the new ENVISAT satellite, which was launched on February 28. 2002, were carried out. The Nansen Center is also involved in several AO projects from NASA and the Canadian Space Agency. Stein Sandven is a member of the ESA CRYOSAT Science Advisory Group, Professor Johnny A. Johannessen is a member of the ESA GOCE Mission Advisory Group and Lasse H. Pettersson is a member of MERIS Science Advisory Group for ENVISAT.

The Nansen Center is a major partner in the EuroGOOS activities. Ola M. Johannessen is a member of the Board, Stein Sandven is the chairman of the Arctic task team, Johnny A. Johannessen is a member of the Space Panel, and Lasse H. Pettersson is the co-chairman of the Product Group.

The Nansen Center participated, as one of the founders, at the opening of the "European Climate Forum (ECF)" in Potsdam in Germany in October 2001. Ola M. Johannessen is co-chairman in ECF`s Technological Group and also member of the scientific council.

The Nansen Center is involved in several ocean modelling projects for international consortiums of oil companies. One of these projects, "North Western Approaches Group (NWAG)", is dealing with modelling of ocean currents in the region north west of UK under leadership of Professor Geir Evensen.

G. C. Rieber Climate Institute

The G. C. Rieber Climate Institute is a part of the Nansen Center, and is led by Dr. Helge Drange. The main

activity of the institute is devoted to the stability 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 between the University of Bergen, the Institute of Marine Research in Bergen and the Nansen Center. Helge Drange is a member of the leader-team of the Bjerknes Co-operation and Ola M. Johannessen is a member of the board. Helge Drange is also a member of the Joint Global Ocean Fluxes Study (JGOFS) of the World Climate Research Program.

Other important topics, of the institute program, are modelling of natural cycling of carbon and plant nutrient in ocean, and the ocean storage of greenhouse gas CO_2. Dr. Guttorm Alendal heads the CO_2 ocean storage program. He is also a member of the technical committee in the international "*CO_2 ocean sequestration field experiment*" under the Climate Technology Initiative (CTI) program, with partners from Japan, USA, Norway, Australia, Canada and ABB Switzerland.

The G. C. Rieber trusts support the institute with NOK 0,45 mill. on an annual basis for recruiting Master students to climate research in Norway.

Terra Orbit AS / COTO AS

The Nansen Center is the owner of these companies. The purpose is to commercialize some of the research products, which are developed by the Nansen Centers in Bergen, in St. Petersburg and in Kochin, India. Terra Orbit is focusing on environmental IT products and COTO on CO_2 mitigation from industrial sources.

These companies are also "know-how" companies giving advice and consultant services to industry and governmental agencies.

Ocean Numerics Ltd

The Nansen Center and Fugro GEOS Ltd. in UK have formed a joint company, Ocean Numerics Ltd. Its main aim is to provide regional met-ocean services throughout the world´s oceans. The services use advanced numerical models and forecasting techniques, validated and tested with oceanographic field measurement that have been designed and collected specifically for this purpose. The equal share joint company combines the commercial oceanographic measurements capabilities of Fugro GEOS and the modelling and analytical expertise of the Nansen Center. Ocean Numerics Ltd. is registered in UK and the chairman of the board is Professor Ola M. Johannessen with Professor Geir Evensen as a member of the board.

Arctica

"*Arctica*" is a small public adventure centre at the Nansen Center. Among the attractions are a wide-screen movie "*Svalbard – Arctic Seasons*", a slide show about Fridtjof Nansens life and an exhibition in the "*Science Room*".

Financial situation

The Nansen Center is an independent non-profit research institute without basic public funding. The income in 2001 amounted to NOK 27.210.471 – an increase of NOK 1.791.078 compared to 2000. The 2001 project income has mainly come from the European Commission (EU), The Research Council of Norway, oil companies, European Space Agency, the Norwegian Space Center and INTAS. Financial support has also been received from G. C. Rieber trusts.

The annual net income for 2001 totalled NOK 2.048.912 of which NOK 822.388 came from financial income. This is a slight improvement compared to 2000 – where these numbers were NOK 1.291.866 and NOK 894.989 respectively. The equity capital amounts to NOK 19.670.670 out of a total balance of NOK 27.210.471.

Prospect for 2002

We are expecting a slight expansion of our research activities in 2002, primarily due to an increase in the funding level in Norway, and a limited numbers of new EU project.

Bergen 19.04.2002

Bjørn J. Landmark (Chairman)

Bjart Nygaard (Vice-Chairman)

Eirik Sundvor

Anton Kjelaas

Lasse H. Pettersson

Ola M. Johannessen (Director)

The Leader Team

Founding Director
Professor Ola M. Johannessen
Also chair in Remote Sensing/ Oceanography at Geophysical Institute, University of Bergen.

Applied Remote Sensing
Research Director Stein Sandven

Remote Sensing Research
Research Director Dr. Johnny A. Johannessen also Professor II at Geophysical Institute, University of Bergen.

Modelling and Data Assimilation
Research Director Dr. Geir Evensen also Professor II at Department of Mathematics, University of Bergen.

G.C. Rieber Climate Institute
Director Dr. Helge Drange

International Relations & Marketing
Director Lasse H. Pettersson

Administration
Director Bente E. Johannessen

Economy
Manager Lars Gunnar Veland

The Board

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Director Bjart Nygaard, Rieber Eiendom, Vice Chairman

Professor Eirik Sundvor, Dean, University of Bergen

Dr. Anton Kjelaas, representing the Bergen University Research Foundation (Unifob)

Lasse H. Pettersson, representative of employees

Professor Ola M. Johannessen, Director

The Scientific Council

Professor Dr. Arnfinn Graue, University of Bergen, Chairman

Managing Director Arild Blixrud, Norwegian Export Council

Director Harald Dovland, Norwegian Ministry of Environment

Chief Engineer Lars Ingolf Eide, Norsk Hydro A/S

Professor Dr. Hartmut Graßl, Director, Max Planck Institute for Meteorology, Hamburg, Germany

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Director Jan Petter Myklebust, University of Bergen, International Division

Director Sven Rong, Polar Ship Management AS

Vice-President Dr. Robert A. Shuchman, Altarum Institute, Ann Arbor, U.S.A.

Managing Director Rolf Skår, Norwegian Space Centre

Professor Ola M. Johannessen, Director

current research challenges

Will the Atlantic Thermohaline Circulation change over the next 100 years?

Helge Drange

The surface temperature in the North-West Europe, and over the North-East Atlantic Ocean and the Nordic Seas is 5-15ºC above the average surface temperature at similar latitudes. The northward transport of heat by the Atlantic Ocean – known as the Gulf Stream at lower latitudes and the North Atlantic Drift at higher latitudes – is one of the reasons for the anomalous mild climate over our region. Both temperature and salinity play a central role in this ocean circulation system, and it is therefore named the Atlantic Thermohaline Circulation, or the Atlantic THC (thermo for heat and haline for salt).

Time series of air and sea surface temperature proxies from polar ice caps and marine sediments show that the North Atlantic-European region has experienced changes in the surface temperature of 5-10ºC on multi-annual to decadal time scales. The last of these changes took place at the end of the last glacial maximum at about 10.000 years ago. Changes in the Atlantic THC have the potential to change the climate in our region, and these variations are believed to be linked to variations in the Atlantic Ocean circulation. The latter possibility is considered as one of the major challenges in climate research: How stable is the Atlantic THC to the steadily increasing human induced greenhouse warming, and is a weakening or even a (near) collapse of the Atlantic THC likely to occur in the near future? Model results are by no means conclusive regarding this question, although no state-of-the-art climate models show a collapse of the Atlantic THC in the 21st century.

In the simplest description of the system, warm and relatively saline surface waters of tropical and subtropical origin flows northward. During the northward flow, heat is lost to the atmosphere (yielding warm and humid air masses), leading to a gradual increase of the density of these water masses. At some locations, in particular in the Greenland and Labrador Seas, the surface water may become so dense during late winter that it triggers vertical mixing of the water masses to abyssal depths. These newly formed dense and cold water masses, together with subsurface water masses of polar origin flowing southward through the Fram Strait, constitute the source waters of the deep, southward flowing branch of the Atlantic THC.

Direct observations of the strength and variability of the Atlantic THC have not been conducted up to now, mainly caused by the challenge to accurately measure the strength of the circulation all over the Atlantic Basin. However, there is observational-based evidence for a decreasing trend in the southward flow of the dense waters from the Nordic Seas over the last 50 years. A freshening of the overflow waters is also observed over the same period. Since these water masses are part of the Atlantic THC, this may indicate that the strength or the structure of the large scale Atlantic circulation is changing. Ling time series of high-quality measurements are required to give a definite answer to this possibility.

To examine changes in the Atlantic THC in this century, global and fully coupled atmosphere-sea ice-ocean general circulation models are required. To address this key question, the Bergen Climate Model (BCM) has been developed, tested and validated as a joint activity between the staff at the G. C. Rieber Climate Institute at NERSC and Dep. of Geophysics at the Univ. of Bergen. The model is one of a few global climate models that are used in Europe.

Model simulations of the temporal evolution of the strength of the Atlantic THC have been performed for an integration for which the atmospheric concentration of the greenhouse gasses are kept fixed at the present level (named control integration), and an integration for which the atmospheric concentration of CO_2 is increased by 1% per year. It follows that the simulated Atlantic THC exhibits natural variations on decadal time scales, and that the CO_2-integration shows first a reduced Atlantic THC, and then a recovery. This result indicates that the strength of the Atlantic THC will not undergo a dramatic change over the following 100 years. Other groups also find similar results.

Ocean sequestration of CO_2

Guttorm Alendal

Ocean sequestration of CO_2 as an option for reducing the atmospheric burden of anthropogenic CO_2 emission by short cutting the natural carbon cycle has been studied at the Nansen Center since 1991. In 2000 the activities has been to support the technical committee for the international CO_2 ocean sequestration field experiment, also known as the Hawaii experiment (http://www.co2experiment.org) in which the Nansen Center has a member (Guttorm Alendal). This project is an international joint research effort initiated in December 1997 by Japan, Norway and the USA in the framework of the Climate Technology Initiative (CTI). 24 member countries of the OECD and IEA promoted the CTI in 1995. Later Canada, Australia and ABB Switzerland have become partners in the experiment. The main uncertainty for a successful experiment is the permitting issue. To support the required Environmental Assessment the Nansen Center has contributed through studies of the spatial and temporal extent of reduced pH during the experiment.

In a KLIMATEK project, funded by the Research Council of Norway, efforts is made to bridge the modelling tools at different spatial scales that are available at the Nansen Center. The objective is to build a generic model system ranging from small to global scale that can be used for efficiency and impact studies at possible injection sites worldwide.

A strategy plan for strengthening the process studies competence at the Nansen Center has been written and a decision to build a group devoted to process and small-scale studies in the ocean was made. The group will focus on small scale non-hydrostatic modelling and is headed by Guttorm Alendal. The first major task for this group will be to select a suitable core computational fluid dynamics solver, preferably a model with a large user group. The group will, in addition to keep its own portfolio of projects, support other projects at the Nansen Center with knowledge and modelling tools on small-scale processes.

Operational oceanography

Geir Evensen

The operational ocean monitoring and prediction system for the North Atlantic, the Nordic Seas and the Artic Ocean which was established during the EU MAST-III DIADEM project coordinated by G. Evensen at the Nansen Center, has during 2001, been further upgraded and improved. This has been an ongoing activity within the EU FP-V funded project, TOPAZ, which started in December 2000. The system is now using the recently developed state of the art Hybrid Coordinate Ocean Model (HYCOM), and modules for assimilation of additional information such as sea ice concentrations and in situ profiles of temperature and salinity have been developed.

The development of flexible ocean modelling and data assimilation systems is now being exploited by Ocean Numerics Ltd., which was registered Jan 1st 2001. During 2001 Ocean Numerics has won two contracts involving hind-cast current modelling for the offshore oil industry. One contract involved the implementation of a model system for West Africa. This model was run

in a 15 years hind-cast simulation to provide an extensive oceanic data set which is now part of the WANE (West African Normals and Extremes) Met Ocean data base managed by Ocean Weather Inc. on behalf of a large number of oil companies with interests along West Africa. In a continuation of the NWAG project the model system has been applied in a production simulation for the Faeroe Shetland Channel. This model development was motivated by demands for current statistics within the oil industry operating in deep waters along the Atlantic Margin north of Scotland. These commercial contracts are organized through Ocean Numerics, while the actual work has been subcontracted to the Nansen Center and Fugro GEOS. The participation in these two projects has established Ocean Numerics as a reliable provider of ocean model data for the offshore industry.

There are a number of related projects involving post docs and Ph.D. students, which are either applying the model system in various areas, e.g. the Atlantic, Mediterranean, Indian Ocean and the Arctic, or are working on implementation and validation of new modules for the system. This involves projects funded by the Research Council of Norway and the European Space Agency.

Observing the oceans in the 21st century – The role of Earth Observing satellites

Johnny A. Johannessen

Continuous access to calibrated and corrected satellite data is a fundamental element of integrated ocean observing system. Relatively long time series of satellite derived quantities (including sea surface temperature, ocean wave field, near surface wind field, ocean colour, sea surface topography, geostrophic current, mean sea level and sea ice extent, types and concentration) are now available. The challenge is to ensure the continuity of these data while at the same time developing new satellite observation techniques.

The Nansen Center is currently involved in several national and international projects undertaken to develop and demonstrate integrated system for ocean monitoring and prediction both at basin scale and at coastal scale. In studies supported by ESA and EU the relative impact of different Earth Observation data types for operational ocean prediction systems and for seasonal to inter-annual environmental monitoring are assessed and quantified. The impact analyses take into account Earth Observation data from the currently operating satellites including ERS-2, TOPEX/POSEIDON, NOAA TIROS, DMSP, and SeaWiFS. In addition the impact of sea surface salinity data, sea ice thickness retrievals and marine geoid from the future ESA Earth Explorer opportunity and core missions are investigated.

Preliminary conclusions document that synergetic and regular application of satellite altimetry, infrared and passive microwave radiometry and imaging radars are essential for the quality of the products delivered by the integrated system. Assimilation of combined sea surface temperature and sea level anomaly clearly improves the location of major current fronts and sub-surface adjustment in the modelled data. Similarly satellite derived sea ice concentration and extent are highly needed to constrain the model sea ice field, in particular along the marginal ice zones. The positive impact found on chlorophyll concentration and distribution when ocean colour data, with an accuracy of 30-40%, are assimilated is suggesting, on the other hand, that further development is needed for the biochemical model, and its coupling to the physical part. Moreover, if the future satellite salinity measurements can be provided at 0.1 psu accuracy for 200 by 200 km sized region every 10 days in high latitude regions with cold surface temperatures, one can expect very positive impact on ocean circulation modelling including meridional overturning and deep water formation. Finally, in order to obtain more precise sea ice volume and mass estimates of importance to constrain the freshwater flux it is also demonstrated that new observations of sea ice thicknesses to an accuracy of around 10 cm will have a positive impact.

Regarding ongoing study projects (funded by the Research Council of Norway, Norwegian Space Centre, and European Commission) related to coastal ocean monitoring and prediction system, the requirement for satellite imaging observations are very demanding with respect to high-resolution coverage and frequent revisit time. Among the key satellite sensors are imaging spectrometer, radar and infrared radiometer. The main challenges are: - to minimize the limitation associated with cloud cover, - to improve the quantification of chlorophyll versus yellow substance concentration, spreading and distribution; - and to advance the interpretation of imaging radar for surface current feature detection and high-resolution wind field determination. For the latter, ongoing development on radar imaging modelling of surface current features at NIERSC is giving new and promising results, notably to quantify current shear and convergence.

At the Nansen Center the role of Earth Observation satellites is therefore indisputable in the design, implementation and evaluation of global, regional and local ocean observing system.

Aquaculture and harmful algae blooms

Lasse H. Pettersson

During the last decades the expansion of the aquaculture industry along the coast of Norway have been enormous. The harvesting of the marine living resources through fisheries and aquaculture are envisaged to become Norway's prime national export industry after the oil and gas era. Diseases and harmful algae blooms (HAB) are severe threats to the aquaculture industry.

Since 1998 the Nansen Center has regularly utilised the US SeaWiFS ocean colour sensor together with other in situ and satellite information to study (harmful) algae blooms in coastal waters of interest to Norway. In March 2001 the entire southern coast of Norway ("Sørlandet") from the western coast of Sweden to the southern part of Jæren were "invaded" by the harmful *Chattonella* algae. Large amounts of fish, mainly farmed salmon, were killed and the economic losses were severe. The future existence of aquaculture in this part of Norway was therefore debated. This bloom was monitored daily using SeaWiFS and AVHRR satellite data in order to provide information of the chlorophyll concentration, phytoplankton biomass and sea surface temperature. The integrated information were used by the authorities and scientists in planning sampling strategy for field data collection as well as providing direct information and advises to the aquaculture owners and the public (http.//www.nersc.no/HAB). Due to favourable wind conditions, this bloom was trapped in two eddies located around Lindesnes and after about two weeks the bloom culminated. The bloom did not move up along the western coast of Norway (Vestlandet) to the region where the major part of the Norwegian aquaculture industry is located.

The MERIS sensor onboard Envisat will significantly improve the quality of the radiation data from the ocean water in the visible part of the spectrum. Such measurements are the basis in monitoring of algae blooms and other water quality parameters. After proper correction of the atmospheric part on the measured signal (about 90 %), bio-optical algorithms for retrieval of information about the phytoplankton concentrations are applied. Improved algorithms used on these new earth observation data will advance our capability to retrieve the water constituents including different algae classes in the optically complex coastal waters.

Satellite data improves siting of wind farms

Heidi Espedal and Birgitte Furevik

Offshore and coastal wind farms are becoming important sources of renewable energy. The energy production of a wind farm is closely connected to its location, and the expected outcome is traditionally calculated from at least one year of accurate wind measurements. Satellite SAR wind mapping may become a useful tool in the process of selecting the optimal site for these measurements, and may therefore increase the cost effectiveness when planning wind farms. The use of satellite SAR data is expected to be particularly valuable in remote coastal areas, where the wind measurements are sparse and there is a need for local production of electric power.

Methods for wind retrieval from ERS SAR (100 × 100 km images) in coastal regions and the marginal ice zone has been developed and tested. High-resolution wind fields from SAR data (400m spatial resolution) show local variability of the wind due to topographic effects such as islands, mountains and fjords. Such local variability is not included in the synoptic weather data. The initial studies have shown a good agreement between SAR retrieved wind, traditional on site measurements and output from high-resolution atmospheric models. For instance investigations of a coastal jet at Spitzbergen revealed good concordance between SAR, in situ and model output over the region influenced by the topography.

A first attempt in deriving useful information from SAR for optimal siting of wind farms has been done for one part of the Norwegian west coast. The results show that it is possible to use SAR to get an overview of the areas with the optimal wind energy potential.

In a global context, the advantage of using SAR in the wind farm industry is expected to lie in combining high spatial resolution retrieved wind with in situ measurements and models. Such applications will benefit from the wide-swath radar satellites, such as Radarsat and ENVISAT, through more frequent coverage.

Sea ice remote sensing

Stein Sandven

Two new ESA satellites, ENVISAT and CryoSAT, will be of particular importance in Polar Regions where sea ice observations from space will be significantly improved. Preparation for use of ENVISAT in ice monitoring has started, where wide-swath images combined with ice retrieval algorithms for ice classification, ice drift, mapping of leads and polynyas will provide better spatial and temporal coverage of key ice parameters.

In a joint project with Norwegian Polar Institute and NORUT IT, the possibility to monitor the migration of polar bears in relation to the sea ice using GPS tags and SAR data have been studied. The first results of this innovative application of satellite EO data suggests that systematic monitoring of key habitat areas for polar bears by SAR, such as Storfjorden at Svalbard, can provide important data in addition to position and behaviour data provided by the GPS tags. The background for this project is the predicted climate change induced reduction of the polar sea ice areas and its consequence for the polar bear populations.

Another polar sea ice project has focussed on the importance of ice thickness measurements from space, which was an ESA – supported study in preparation of CryoSat. The study used simulated CryoSat data in combination with ice-ocean models in order to estimate the importance of a better knowledge of sea ice budget on relevant climate processes such as freshwater budget, thermohaline circulation and deep water formation. CryoSat is scheduled for launch in 2004 and will deliver sea ice thickness data for the whole Polar Regions.

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