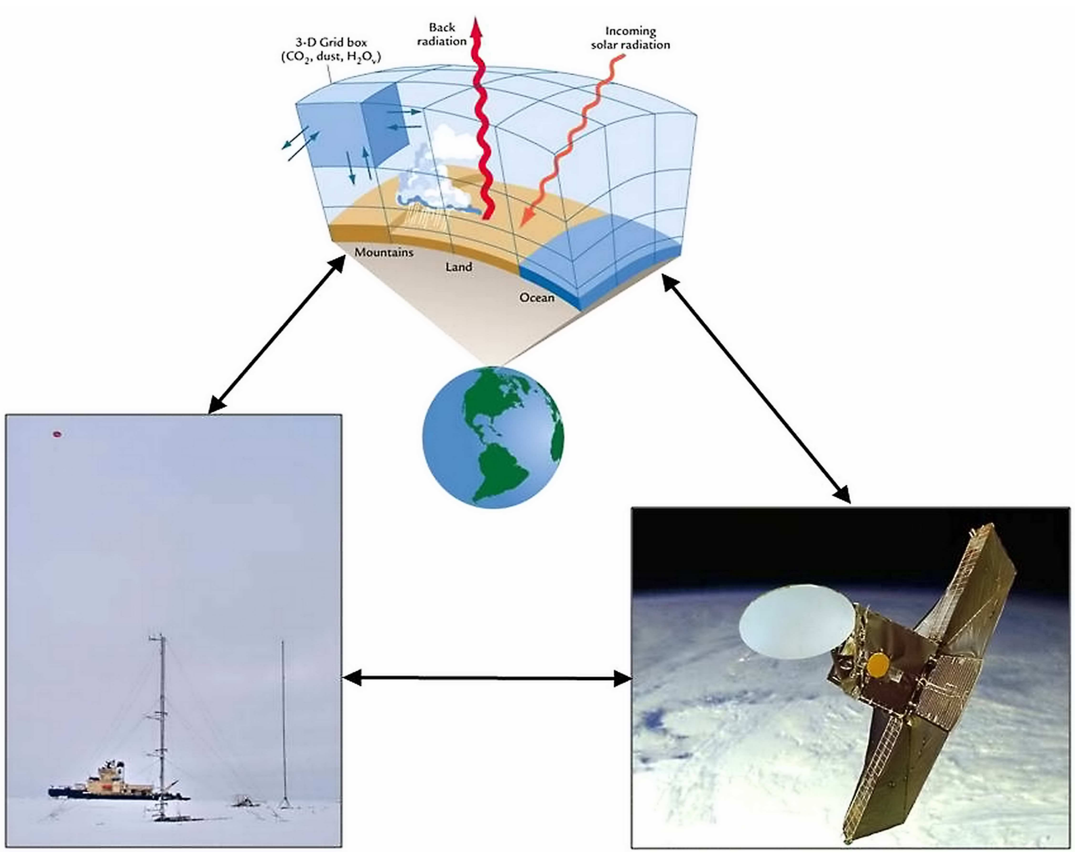
Stockholm University

INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

DEPARTMENT OF METEOROLOGY, STOCKHOLM UNIVERSITY



BIENNIAL REPORT 2009 – 2010

FRONT COVER | Illustrating the interactivity between climate modeling (top graphics courtesy of SMHI), process studies (lower left, the icebreaker Oden and the ice camp during ASCOS, photo: Michael Tjernström) and climate monitoring (picture of Odin satellite, courtesy of Swedish Space Corporation).

INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM (IMI) AND DEPARTMENT OF METEOROLOGY, STOCKHOLM UNIVERSITY (MISU)

BIENNIAL REPORT 1 JANUARY 2009 – 31 DECEMBER 2010

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ISSN 0349-0068
Printed at US-AB (PrintCenter), Stockholm University 2011

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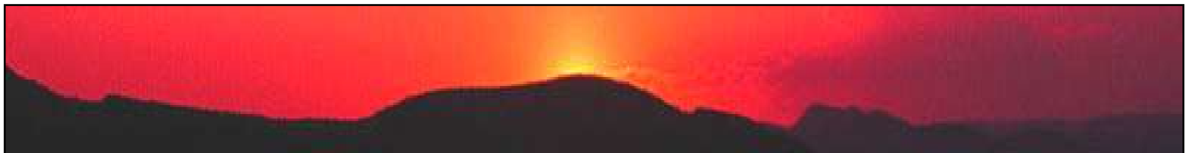

THE INSTITUTE

THE INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

The International Meteorological Institute in Stockholm (IMI) was created in 1955 by a decision of the Swedish Parliament with the objective "to conduct research in meteorology and associated fields and to promote international scientific co-operation within meteorology". This decision was a result of initiatives taken by Professor Carl-Gustaf Rossby, strongly supported by the former Minister for Foreign Affairs of Sweden, Richard Sandler.

The most important function of the institute is to provide opportunities for foreign scientists to work in Sweden for varying periods of time in close collaboration with their Swedish colleagues. The institute also publishes the scientific journal Tellus.

The institute was an independent institute financed by a direct contribution from the Swedish Government until the end of 2009. Since 1 January 2010, IMI is an idependent institute at the Department of Meteorology, of which it is an integral part, funded by Stockholm University through the Faculty of Science.

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THE DEPARTMENT OF METEOROLOGY AT STOCKHOLM UNIVERSITY

The Department of Meteorology at Stockholm University (MISU) was established in 1947 when Carl-Gustaf Rossby assumed the duties of the chair which was created for him by Stockholm's Högskola (later Stockholm University). Among many other things, Rossby spearheaded the development of numerical weather forecasting while at MISU. At Rossby's death in 1957 Bert Bolin took over the leadership of the department, a role that he maintained for almost three decades.

The Department of Meteorology is organizationally tied to the Physics and Mathematics Section of the Faculty of Science at Stockholm University. The International Meteorological Institute is an integral part of the department, but with a separate economy. The small research group that Rossby created soon developed into a successful department now consisting of more than 60 people, including some 20 graduate students. The research emphasis at MISU today can be divided into the four main specialties: Dynamical Meteorology, Chemical Meteorology, Atmospheric Physics and Physical Oceanography.

Since 2006 the department is also part of an integrated centre for climate research, in collaboration with three other departments at the university through a so called "Linnaeus Grant", funding the Bert Bolin Centre for Climate Research. The centre promotes studies of climate, climate change and variability as well as processes of importance for the climate and involves scientists at the departments of Meteorology (MISU), Physical Geography and Quaternary Geology (INK), Geological Sciences (IGV) and Applied Environmental Sciences (ITM); a Climate Research School is also attached to the research centre. The centre cuts across several disciplines on climate research and has transformed how this type of research is conducted at Stockholm University. Since 2010 the Bolin Centre is augmented by a special strategic government grant for climate modelling, and partly because of this MISU is in now a very expansive phase.

HEAD OF THE DEPARTMENT

Peter Lundberg, Professor of Physical Oceanography.

INTRODUCTION

INTRODUCTION

The extensive international network in the field of atmospheric science and oceanography established at the institute has provided an excellent platform for cooperative research. This cooperation is directed to fundamental research as well as to providing important scientific knowledge in the development of society on national and international levels. The specific scientific research projects are dealt with in some detail in the following chapters. This introduction outlines a few ongoing major international collaborative activities.

A broad spectrum of international activities has characterized the work at the institute during the past two years, including participation in the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) and several international research projects funded through the European Union Framework Programme (e.g. DAMOCLES and EUCLIPSE), and by the European Commission and the European Space Agency (ESA).

Some large projects are of common interest for dynamic meteorology, physical oceanography and chemical meteorology. One is the active participation in the development and use of a new global climate model, EC-Earth. This work is conducted in a European consortium with leadership at KNMI, also including the European Centre for Medium Range Weather Forecasts (ECMWF) and the Rossby Centre at Swedish Meteorological and Hydrological Institute (SMHI). EC-Earth aims at developing a new Earth System model based on the ECMWF seasonal forecast system. In addition to the development of the atmospheric component, this includes coupling to the NEMO ocean model and components for interactive atmospheric chemistry, aerosols and aerosol/cloud interactions. Another international interdisciplinary project cutting across dynamical meteorology, chemical meteorology and physical oceanography is the Arctic Summer Cloud-Ocean Study (ASCOS), lead from MISU since several years. ASCOS aims at understanding the formation and lifetime of Arctic summer low clouds and started with a research expedition to the central Arctic Ocean summer 2008 as a part of the International Polar Year.

International cooperation in the area of dynamic meteorology takes place both within several international programs and with individual universities or laboratories. Several collaboration projects besides the EC-Earth program mentioned above concern model development. The Arctic Model Intercomparison Project (ARCMIP) aims at improving modelling of Arctic processes in climate models and the GEWEX Atmospheric Boundary Layer Study (GABLS) at improving boundary-layer descriptions in general. In these projects, there is an active collaboration with several research groups in Europe and USA. Moreover, there is a long-standing collaboration with the Naval Research Laboratory on the COAMPS™ atmospheric model and collaborations with the National Center for Atmospheric Research (NCAR), USA, on evaluating and developing the Community Earth System Model.

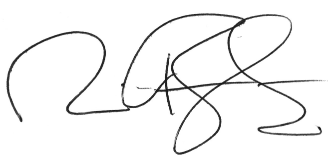
MISU's physical oceanographers are actively engaged in international collaboration in the Baltic Way programme, aimed at improving the physical and ecological state of this inland sea. All nations bordering the Baltic Sea are represented in the programme by their marine agencies and oceanographically orientated university departments. The Esonet programme represents a concerted European effort to establish permanent sea-bed observatories in the Atlantic proper as well as in marginal seas for long-term monitoring purposes. Additionally, numerous ongoing collaborations on an individual basis with scientists abroad serve to rejuvenate MISU's research in physical oceanography.

The chemical meteorology group has continued its involvement in the international Atmospheric Brown Cloud (ABC) project with focus on measurements in The Maldives and in Nepal. The main MISU/IMI contribution to ABC is to seek a better understanding of the atmospheric life cycle of soot. The group is also actively involved in examining and developing model tools for understanding aerosol-cloud interaction on a global scale (in addition to collaboration within EC-Earth community, also with UiO/MetNo using the Oslo-CAM model), and on a regional scale over the Arctic (GRACE project), Amazon (AVIAC project) and Europe (MACCII project).

The Atmospheric Physics group is involved in a number of international satellite, rocket and ground-based projects as well as modelling studies concerning the middle atmosphere. Members of the group contribute to the mission preparation of the ESA Earth Explorer Atmospheric Dynamics Mission Aeolus, to provide global line-of-sight wind profiles using a Doppler-wind lidar. The launch is expected late 2013. The group has also been deeply involved in collaboration with several international partners concerning the Odin satellite mission; launched in 2001 Odin continues to provide a wealth of atmospheric data. Beyond Odin, new middle atmosphere satellite collaborations concern ESA's plans for PREMIER, NASA's AIM satellite mission, the European ENVISAT community, and the ACE mission on the Canadian SciSat.

The Atmospheric Physics group has also continued to collaborate in international rocket programmes with instruments deployed in rocket launches led by several collaborators. The group also participated in two rocket projects within the extended ALOMAR Research Initiative (eARI), an opportunity funded by the European Commission, and now lead the preparations for the comprehensive international rocket project PHOCUS from Esrange, Sweden, in summer 2011.

Michael Tjernström is a member of the Science Advisory Committee (SAC) of the ECMWF, a member of the WCRP Observation and Analysis Panel (WOAP), vice Chair in the Atmospheric Working Group (AWG) of the International Arctic Science Committee (IASC) and member of the board for the Swedish Secretariat for Environmental Earth System Science (SSEESS). Michael Tjernström has also been the chair of the Science Steering Group of the International study of Arctic Change (ISAC) and a member of the Coastal Environment Committee for the American Meteorological Society. Caroline Leck is a member of Surface Ocean Lower Atmosphere Study (SOLAS) implementation committee and is the Chair of the Swedish National Committee on Geophysics (IUGG and SCOR). Gunilla Svensson is the co-chair of the GEWEX Atmospheric Boundary Layer (GABLS) Science Panel, Heiner Körnich is member of the Mission Advisory Group of the ESA Earth Explorer Atmospheric Dynamics Mission Aeolus and Annica Ekman is a member of the International Commission on Clouds and Precipitation (ICCP). Henning Rodhe has been the vice chair of the Atmospheric Brown Cloud (ABC) Science Team.



Michael Tjernström, Director

RESEARCH ACTIVITIES

RESEARCH ACTIVITIES

The different research activities in this section have been divided as follows:

- DYNAMIC METEOROLOGY
- PHYSICAL OCEANOGRAPHY
- CHEMICAL METEOROLOGY
- ATMOSPHERIC PHYSICS
- ARCTIC STUDIES

DYNAMIC METEOROLOGY

LARGE SCALE DYNAMICS

In the area of large scale dynamics research mainly concern the general circulation of today, the past and the future. Tools used in this research are numerical weather prediction models and climate models on both regional and global scales together with observational products. Within the area of numerical weather prediction the predictability problem is studied by investigating new techniques for ensemble prediction. Effects of subgrid-scale organization on the larger scale is studied in a simplified framework and new techniques of estimating errors in trajectory analysis and analysing the general circulation are investigated. Regional studies include projects of the monsoon circulation and of cold climates in the European history. Other paleo-climate studies concern the climate during the Holocene.

Estimating trajectory uncertainties due to flow dependent errors in the atmospheric analysis

Anders Engström, Linus Magnusson (ECMWF, UK)

Trajectory calculation is a widely used method to determine the origin or fate of air parcels in the atmosphere. For example, the use of back trajectories is common in atmospheric chemistry to determine source regions of sampled air at a particular site. The uncertainty of a calculated trajectory is dependent on the uncertainty in the atmospheric analysis. The errors in meteorological analyses are partly due to observation errors and the fact that observations can include local phenomena that are not representative for an entire grid box. In order to produce a best estimate of the atmospheric state, numerical weather prediction centers use advanced data assimilation systems. In data assimilation, the information from observations combined with a background (usually a short forecast valid at the time of the analysis) is used to obtain an analysis. However, both of these components contain uncertainties. Thus the resulting analysis will not perfectly match the current atmosphere and will therefore impact on the calculated trajectory path.

Using the Ensemble Transform method (originally adapted for ensemble forecasting) we sample the analysis uncertainty in order to create an ensemble of analyses where a trajectory is started from each perturbed analysis. This method, called the Ensemble analysis method (EA), is compared to the Initial spread method (IS), where the trajectory receptor point is perturbed in the horizontal and vertical direction to create a set of trajectories used to estimate the trajectory uncertainty. The deviation growth is examined for one summer and one winter month and for 15 different geographical locations. We find up to a 40% increase in trajectory deviation in the mid-latitudes using the EA method. A simple model for trajectory deviation growth speed is set up and validated. It is shown that the EA method result in a faster error growth compared to the IS method. In addition, we examine case studies to qualitatively illustrate how the flow dependent analysis uncertainty can impact the trajectory calculations. We find a more irregular behavior for the EA trajectories compared to the IS trajectories and a significantly increased uncertainty in the trajectory origin. By perturbing the analysis in consistency with the analysis uncertainties the error in backward trajectory calculations can be more consistently estimated.

Publications

Engström, A. and Magnusson L. (2009), Estimating trajectory uncertainties due to flow dependent errors in the atmospheric analysis, Atmospheric Chemistry and Physics, 9, 8857-8867, 2009.

Flow-dependent versus flow-independent initial perturbations for ensemble prediction

Anders Engström, Linus Magnusson (ECMWF, UK)

An essential problem in ensemble prediction is how to construct the initial perturbations that define the different ensemble members. Two popular methods that are used in operational forecasting are singular vectors and the ensemble transform method. Both these initialisation methods are flow-dependent, the aim being to concentrate the initial perturbations to features that are particularly crucial for the future evolution.

In this project, these methods are compared to a much simpler flow-independent method, called random field perturbations. The initial perturbations are in this case based on the difference between two randomly chosen previous atmospheric states (i.e. analyses), which yields perturbations in approximate flow balance. The skill scores indicate a statistically significant advantage for the RF method for the first 2–3 days for the most of the evaluated parameters. For the medium range (3–8 days), the differences are very small.

Publications

Magnusson L., J. Nycander and E. Källén, 2009: Flow-dependent versus flow-independent initial perturbations for ensemble prediction, Tellus, 61A,194-209.

Large-scale dynamical response to sub-grid scale organization using a cellular automaton

Lisa Bengtsson-Sedlar Heiner Körnich, Gunilla Svensson and Erland Källén (ECMWF, Reading)

Due to the limited resolution of numerical weather prediction (NWP) models, sub-grid scale physical processes are parameterized, and represented by grid-box means. However, some physical processes are better represented by a mean and its variance, a typical example being deep convection, with scales varying from individual updraughts to organized meso-scale systems. In this study, we investigate, in an idealized setting, whether a cellular automaton (CA) can be used in order to enhance sub-grid scale organization by forming clusters representative of the convective scales, and yield a stochastic representation of sub-grid scale variability. We study the transfer of energy from the convective to the larger atmospheric scales through wave interaction. This is done using a shallow water (SW) model initialized with equatorial wave modes. By letting a CA act on a finer resolution than that of the SW model, it can be expected to mimic the effect of, for instance, gravity wave propagation on convective organization. Employing the CA-scheme allows to reproduce the observed behaviour of slowing down equatorial Kelvin modes in convectively active regions, while random stochastic perturbations fail to feed back on the large-scale flow. The analysis of kinetic energy spectra demonstrates that the CA sub-grid scheme introduces energy back-scatter from the smallest model scales to medium scales. However, the amount of energy back-scattered depends almost solely on the memory time scale introduced to the sub-grid scheme, whereas any variation in spatial scales generated does not influence the energy spectra markedly.

Publications

Bengtsson-Sedlar, L., H. Körnich, E. Källén, and G. Svensson, 2011: Large-scale dynamical response to sub-grid scale organization using a cellular automaton. Submitted to J. Atmos. Sci.

Moist Effects on Orographically Forced Stationary Waves

Marcus Löfverström, Heiner Körnich and Johan Nilsson

The present study examines orographically forced stationary waves in a moist atmosphere. The waves induce zonal asymmetries in the diabatic heat fields that interact with the orographically forced stationary waves and altering their amplitude. Model simulations were carried out with the Planet Simulator, an Earth System Model of Intermediate Complexity including a slab-ocean with prescribed heat-flux and a simple radiative scheme. The model code allows external control over the eddy components of the diabatic terms. In the different experiments, stationary waves were forced either solely by an idealized orography or by the orography in combination with different diabatic terms. Furthermore, a linear stationary wave model was used to analyse separate responses from the orography and induced diabatic heating terms, received in the non-linear model. The results show that the far field response in the fully coupled case has a higher amplitude than in the purely orographic case. A plausible explanation is that northward advection of warm moist air enhances latent heat release and reduces outgoing longwave radiation, which amplifies the stationary waves. The impact of different diabatic terms and transient eddies is also analyzed.

Radiative effects of atmospheric aerosols and their impact on large-scale circulation and precipitation patterns

Anna Lewinschal, Annica Ekman, Heiner Körnich, Chien Wang (MIT, Cambridge, USA), Dongchul Kim (MIT, Cambridge, USA)

Aerosol particles with their large abundances in industrialized areas have a considerable impact on the radiation balance in the atmosphere in that they can both scatter and absorb incoming radiation. Due to the short residence time of aerosol particles in the atmosphere, the radiative forcing pattern is largely dependent on the local emissions of aerosols. This also means that a change in aerosol emissions leads to a relatively quick response in the radiative forcing both in terms of magnitude and spatial distribution.

The response in the planetary stationary wave pattern induced by aerosol radiative forcing is currently investigated by using EC-Earth, a coupled climate model based on ECMWF operational forecast model. To do this, the aerosol description in the model has been modified to allow different aerosol distributions, and now consists of climatologi-cal monthly mean mass fields of sulphate, black carbon, organic carbon, sea salt and dust as provided for the CMIP5 experiments. The aerosols are treated as external mixtures, where the optical depth is calculated individually for each type of aerosol, and for hygroscopic aerosols the relative humidity dependency on the optical depth is taken into account. By comparing simulations with mass fields representing pre-industrial and present day conditions the possible changes in the stationary wave pattern caused by anthropogenic aerosol emissions can be determined. In addition to EC-Earth a linearised model is used to investigate if linear theory of thermally forced planetary waves applies to aerosol radiative forcing. If so, the wave response to changes in the aerosol forcing field can easily be assessed.

Publications

Kim, D., Wang, C., Ekman, A. M. L., Barth, M. C. and Rasch, P. J., 2008. Distribution and Direct Radiative Forcing of Anthropogenic Aerosols in an Interactive Size-Resolving Aerosol-Climate Model. J. Geophys. Res., 113, D16309, doi:10.1029/2007JD009756

Wang, C., Kim, D., Ekman, A. M. L., Barth, M. C., Rasch, P. J., 2009. Modeling the impact of absorbing aerosols on Indian summer monsoon. Geophysical Research Letters, 36, L21704, doi:10.1029/2009GL040114.

Intraseasonal and interannual variability of the South-Asian monsoon

Faisal S. Syed, Heiner Körnich, Jin Ho Yoo (APEC Climate Center, Busan,Korea), Fred Kucharski (ICTP, Trieste, Italy)

Intraseasonal and interannual variability of the South-Asian monsoon (SAM) are examined. For intraseasonal SAM variability, it was investigated how active phases for the western edge of SAM are developing based on daily reanalysis and observational data. These active phases seem to have significant contribution in the mean seasonal rainfall in the region. The proposed mechansism relies on an upper level warm anomaly over the north Hindu Kush-Himalaya region which is reinforced by surface heating. The low-level anticyclone causes the moisture convergence at the western edge of the SAM region. The proposed mechanism has some resemblance with large scale south Asian monsoon onset, whereas conventional south Asian monsoon intraseasonal oscillations do not show clear relationship with active phases at the western edge of SAM.

For the interannual variability, the focus lies on the effects of extratropical dynamics on the interannual monsoon variations. Using a conditional maximum covariance analysis on NCEP/NCAR reanalysis and CRU precipitation data, it is found that two modes provide a strong connection between the upper-level circulation in the Atlantic/European region and SAM rainfall: the Circumglobal Teleconnection (CGT) and the Summer North Atlantic Oscillation (SNAO). Both modes display a distinctive influence on the SAM rainfall. The physical mechanisms for the influence of CGT and SNAO on SAM are related to the upper-level geopotential anomaly which affects the amplitude and position of the low-level convergence. The small displacements of the centers of these responses and the low level cold advection from the north east of SA in case of SNAO explain the differences in the corresponding SAM rainfall distributions. These findings are confirmed with the relatively high-resolution coupled climate model EC-Earth.

Publications

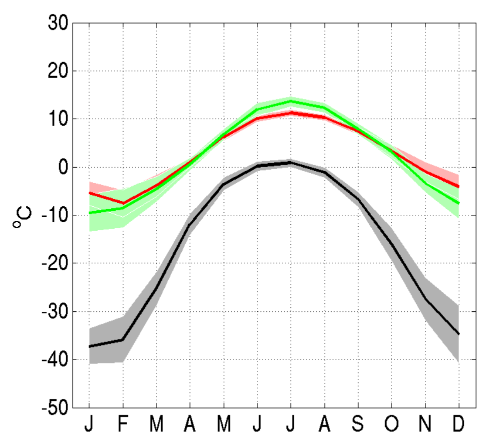
Syed, F.S., J.H. Yoo, H. Körnich, F. Kucharski, 2010: Are intraseasonal summer rainfall events micro monsoon onsets over the western edge of the South-Asian monsoon? Atmospheric Research, 98, 341-346.

Syed, F.S., J.H. Yoo, H. Körnich, F. Kucharski, 2011: Extratropical Influences on the Inter-Annual Variability of South-Asian Monsoon. Submitted to Clim. Dyn.

Regional climate model paleo-simulations for cold climates in Europe

Erik Kjellström, Barbara Wohlfart (Stockholm University), Gustav Strandberg (SMHI), Jenny Brandefelt (KTH), Ben Smith (Lund University, Sweden) Jens-Ove Näslund (SKB, Sweden)

The Rossby Centre regional climate model (RCA3) has been used in simulations of past cold climates. One period during Marine Isotope Stage 3 (at 44 ka BP) and one during LGM (at 21 ka BP) has been simulated. Documentation of these can be found in Kjellström et al. (2010) and Strandberg et al. (2011). 50-year long periods from multi-centennial simulations with a global climate model have been downscaled to 50km horizontal resolution over Europe. A dynamic vegetation model has been used to produce vegetation consistent with the simulated climate. Results from the global and regional climate models have been compared with proxy data for temperature and precipitation in Europe and sea-surface data for the global oceans. Implications for permafrost growth and ice-sheet extent are discussed.



Seasonal cycle of temperature as an areal average over Sweden according to CRU observations (green) and to RCA3 forced with reanalysis data for 1961-1990. In black are corresponding temperatures from RCA3 forced by a global climate model for a cold period in MIS3 (44 ka BP). Shaded areas indicate the ±1 standard deviation range of individual monthly averages in each data set.

Publications

Kjellström, E., Brandefelt, J., Näslund, J.-O., Smith, B., Strandberg, G., Voelker, A. H. L. & Wohlfarth, B. 2010: Simulated climate conditions in Europe during the Marine Isotope Stage 3 stadial. Boreas, 436-456. 10.1111/j.1502-3885.2010.00143.x. ISSN 0300-9483.

Strandberg, G., Brandefelt, J., Kjellström E., Smith, B., 2011. High resolution regional simulation of Last Glacial Maximum climate in Europe. Tellus, 63A(1), 107-125. DOI: 10.1111/j.1600-0870.2010.00485.x

Northern high-Latitudes climate response to mid-Holocene insolation

Qiong Zhang, Heiner Körnich, Johan Nilsson in collaboration with Hanna Sundqvist, Anders Moberg, and Karin Holmgren (Department of Physical Geography and Quaternary Geology, Stockholm University)

The project aims to study the climate evolution and variability within the last 6000 years over the northern high latitudes, through integrating proxy data analysis and global climate modeling. The climate response over northern high latitudes to the mid-Holocene orbital forcing has been investigated in three types of PMIP simulations with different complexity of the modeled climate system as well as in the published proxy reconstructions. Here, an objective selection method is applied in the model-data comparison to evaluate the capability of the climate model to reproduce the spatial response pattern seen in proxy data. The possible feedback mechanisms behind the climate response have been explored based on the selected model simulations. Model-model comparisons indicate the importance of including the different physical feedbacks in the climate model. The comparisons between the reconstructions and the best-fit selected simulations show that over the northern high latitudes, summer temperature change follows closely the insolation change and shows a common feature with strong warming over land and relatively weak warming over ocean at 6 ka compared to 0 ka. The sea-ice-albedo positive feedback enhances this response furthermore. The reconstructions show a stronger response in the annual mean temperature than winter and summer temperature, which is verified in the model simulations and the reason is attributed to the larger contribution from autumn. Despite a smaller insolation during winter at 6 ka, a pronounced warming centre is found over Barents Sea in winter in the simulations, which is also supported by the nearby northern Eurasian continental and Fennoscandia reconstructions. It indicates that in the Arctic region, the response of the ocean and the sea ice to the enhanced summer insolation is more important for the winter temperature than the synchronous decrease of the insolation.

Publications

Sundqvist, H. S., Zhang, Q., Moberg, A., Holmgren, K., Körnich, H., Nilsson, J., and Brattström, G., 2010: Climate change between the mid and late Holocene in northern high latitudes – Part 1: Survey of temperature and precipitation proxy data, Clim. Past, 6, 591-608, doi:10.5194/cp-6-591-2010.

Zhang, Q., Sundqvist, H. S., Moberg, A., Körnich, H., Nilsson, J., and Holmgren, K., 2010: Climate change between the mid and late Holocene in northern high latitudes – Part 2: Model-data comparisons, Clim. Past, 6, 609-626, doi:10.5194/cp-6-609-2010.

CAM3 isotope modeling over northern high latitudes

Qiong Zhang, Christophe Sturm (Department of Geological Sciences, Stockholm University) and David Noone (University of Colorado, USA)

We applied NCAR Community Atmosphere Model (CAM3.0) with embedded stable water isotopes in paleoclimate cases. The impact of radiation forcing on the simulated isotopic composition of precipitation is illustrated in the isotope modeling review paper. Our three time-slice sensitivity experiments (present day, pre-industrial and mid-Holocene) highlight the risks of using local O18-temperature calibration for climate reconstructions and enable the quantification of the biases. Beyond their role as a virtual laboratory, isotope-enabled climate models can shed new light by providing physically based "transfer functions" between the isotopic signal and climate, in order to exploit most of the information enclosed in isotopic climate archives. A particular advantage compared to conventional paleoclimatic methods is the ability to make a spatial synthesis of multiple proxies, leading to the assimilation of multiple isotopic proxy data.

Publications

Sturm, C., Zhang, Q., and Noone, D., 2010: An introduction to stable water isotopes in climate models: benefits of forward proxy modelling for paleoclimatology, Clim. Past, 6, 115-129, doi:10.5194/cp-6-115-2010, 2010.

Holocene climate variability over Southern Africa

Qiong Zhang, Heiner Körnich in collaboration with Karin Holmgren and Hanna Sundqvist (Department of Physical Geography and Quaternary Geology, Stockholm University)

This project aims to improve the knowledge of patterns and drivers behind climate variability in southern Africa through increasing the accuracy and precision in the interpretation of regional climate proxy signals and through confronting the climate proxy observations with climate models. In a first step we examined the climate variability over southern Africa during the recent 100 years. A stalagmite record from cold-air cave at Makapansgat, South Africa suggests that at the millennium time scale, the wet conditions are corresponding to warm states and dry conditions are to cool states over the region. An inverse correlation between southern Africa and eastern Africa is found from the independent proxy records during the last millennium. In order to understand and interpret the above two hypotheses suggested from the proxy records, we here use the station-based meteorological observation data to investigate (1) the association between wet/dry conditions and warm/cool states and (2) the 'see-saw' phenomenon between southern and eastern Africa.

The examination from Global Network of Isotopes in Precipitation (GNIP) from 1958-2001 shows that at interannual time scale, over the southern Africa, the oxygen isotope in precipitation is mostly related to the amount of precipitation and the water vapour in atmosphere, but no correlation with the temperature. Climate Research Unit (CRU) data from 1901-2006 shows that at decadal time scale, there is no straightforward correspondence between wet/dry conditions and warm/cool states, all combinations are possible. The wet/dry conditions are mainly determined by the moisture transfer, which is related to the atmospheric circulation and the ocean condition. One-point correlation between the stalagmite location and the entire southern Africa does show the inverse correlation pattern between the southern and eastern Africa, which indicating that the proxy data can well represent the variability over the southern Africa. However, the inverse correlation between the two regions did not persistent during the whole century, particularly after 1980, the precipitation over southern Africa and eastern Africa shows in-phase behaviour. This change might be related to the rapid warming over the region since 1980 and needs further dynamical explanation by stable water isotope modelling.

Arctic regional climate modeling of the AOE-2001 data

Michael Tjernström, Per Axelsson, Gunilla Svensson, Stefan Söderberg (WeatherTech, Sweden), Cathryn Birch (University of Leeds, UK), Sean Milton and Paul Earnshaw (UK MetOffice).

See Arctic Studies

Water-vapour feedback and Arctic amplification

Rune Grand Graversen, Peter Langen (Copenhagen University, Denmark) and Thorsten Mauritsen (Max Planck Institute, Germany)

See Arctic Studies

Recent Arctic sea-ice retreat

Rune Grand Graversen, Michael Tjernström, Thorsten Mauritsen (Max Planck Institute, Germany) and Marta Zygmuntowska (Nansen Center, Norway)

See Arctic Studies

The role of meridional energy transport for the 2007 Arctic sea-ice retreat

Rune Graversen, Thorsten Mauritsen, Michael Tjernström, Sebastian Mårtensson , Sybren Drijfhout (KNMI, The Netherlands)

See Arctic Studies

Is recent Arctic summer sea-ice melt driven by warming from aloft?

Rune Grand Graversen and Thorsten Mauritsen (Max Planck Institute, Germany)

See Arctic Studies

BOUNDARY LAYER AND MESOSCALE DYNAMICS

This field of research concerns small-scales atmospheric motions, typically not resolved in climate or operational NWP models. The work at the institute revolves either around using and developing high-resolution mesoscale models or organizing and participating in, as well as using data from field campaigns. While mesoscale motions can be resolved in high-resolution models, boundary-layer turbulence is not directly resolvable in models, nor is it deterministic in its details. The statistics of turbulent flows is, however, to some degree deterministic. Much of the work in this field is directed at determining the effects of turbulence on the mean flow, to improve larger-scale numerical models. Conversely, this means that one must also understand the effect on the turbulence from the mean flow.

The main mesoscale research modeling tools used at the institute are the COAMPS® atmospheric model, developed by the US Navy, and the MIT Cloud Resolving Model (CRM). COAMPS® has been applied mainly to Arctic meteorology for example within ARCMIP, an international project to compare and develop Arctic climate models. Work on turbulence dynamics has been directed at three areas: the Arctic boundary layer, interaction between turbulence and clouds and boundary layers in high static-stability conditions. This work is carried out within programs such as GABLS and also involves field experiments in the Arctic, for example SHEBA, AOE-2001 and ASCOS. Scientists at the institute leads several of these efforts.

Comparing turbulence estimates from different near-surface measurements in the stable boundary layer

Michael Tjernström, Gunilla Svensson, Florence Bocquet and Ben Balsley (CIRES, University of Colorado, Boulder, USA)

Estimates of the dissipation rate of turbulent kinetic energy (ε) from hot- and cold-wire turbulence probes on the Tethered Lifting System (TLS) are well correlated with concurrent measurements of vertical velocity variance (σ^2_w) obtained from sonic anemometers on a nearby 60-m tower during the CASES-99 field experiment. Additional results in the first 100m of the nocturnal stable boundary layer confirm our earlier claim that weak but persistent background turbulence exists even during the most stable atmospheric conditions. We measure values of ε as low as 10^{-7} m^2s^{-3}, which is still well above the measurement threshold of our instrument. We also present a set of empirical equations that incorporates TLS measurements of gradients of temperature, horizontal wind speed and ε, all available from the TLS instruments to provide a proxy measurement for σ^2_w at altitudes higher than tower heights but well within reach of the TLS.

Publications

Bocquet, F., B.B. Balsley, M. Tjernström, G. Svensson, 2010: Near-surface measurements of turbulence proxies in nocturnal stable boundary layers. Boundary-Layer Meteorology, 138, 43–60, DOI 10.1007/s10546-010-9542-8.

Regional climate simulations of deforestation in southern Sudan

Abubakr Babiker, Heiner Körnich, Michael Tjernström

We examine the sensitivity of the Sudan climate to the changes in vegetation cover and land use in the southern part of the country. The focus lies on the effect of deforestation on the precipitation and surface temperature during the rainy season. Version three of the Abdu Salam Center for Theoretical Physics Regional Climate Model (RegCM3) is used for this study. As boundary conditions, the ERA-interim reanalysis was applied, and the model experiments were conducted for January 1979 to August 2009, the last almost 20 years.

Sensitivity experiments are performed where the present forest vegetation cover in Sudan south of 10ºN is replaced by grass or, as an extreme case, by desert. The experiments demonstrate that the vegetation changes affect precipitation and surface temperature in both Southern Sudan, where the vegetation changes were implemented, but also in Central Sudan. The precipitation in the perturbed region was significantly reduced, by about 10-60 mm/month in the desert scenario and by 10-30 mm/month in grass scenario, during the rainy season June through September. Surface temperatures display an increase between 1ºC and 2.4ºC in desert and in the grass scenario, respectively. The study demonstrates significant dependency for southern and central Sudan precipitation on the land use in southern Sudan. Such connection indicates that the deforestation has both local and non-local regional climatic effects.

Climatic consequences of water harvesting in southern Sudan

Abubakr Babiker, Heiner Körnich, Michael Tjernström

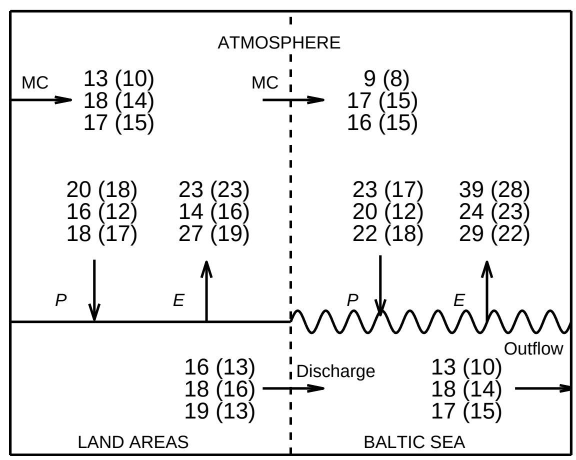
Water harvest is often proposed as a solution for water shortages through increase of rivers and tributary catchments without taking into account the regional climatic feedback due to the changes in surface conditions. This study examines these regional climatic consequences of the Jonglei Canal proposed to be built in Southern Sudan.

The project is designed to change the course of the White Nile in southern Sudan to avoid passing over a large area of swamps and marshland called the Sudd. The Sudd is one of the largest wetlands world-wide, covering an area of about 8000 km2 with dense vegetation providing a high evapotranspiration rate, estimated to be 4.7 billion cubic meters; the equivalent to half of the southwestern annual inflow. The Jonglei Canal is expected to produce a similar amount of water per year, however, severely affecting the vegetation and evapotranspiration of the Sudd. In order to simulate the regional climate consequences in high resolution, we are utilizing a regional climate model with land surface component. We run the model for two land surface scenarios, one with the swamp (control) and another scenario with change in land surface representing the canal conditions. We are investigating the changes in surface hydrology, evaporation, soil moisture and precipitation as well the changes in surface energy balance. The most interesting result is that changes in hydrology are spread to the surrounding regions which indicate non-local effects as well. With the advantage of a high resolution model experiment (about 10 km) this study sheds light on the climatic consequences expected to result from the excavation of the Jonglei canal.

Regional climate model simulations of the water budget in the Baltic Sea catchment

Erik Kjellström, Petter Lind (MISU and SMHI)

The water budget of the Baltic Sea catchment has been investigated by the use of the Rossby Centre regional climate model (RCA3) forced by ERA40 reanalysis data. Evaluation of model performance for precipitation, evaporation and runoff in the recent past (1979-2002) climate has been done by Lind and Kjellström (2009). It is found that the simulated water fluxes were broadly consistent with available observational and reanalysis datasets. Statistically significant differences between different observational data-sets and lack of high-resolution data for evaporation and runoff hamper the possibility to draw any strong conclusions regarding RCA3s ability to correctly simulate precipitation in the area. The study indicates a need for better observations of terms in the water budget in the area. Simulated future changes in the water budget of the Baltic Sea catchment has been documented by Kjellström and Lind (2009). The RCA3 model has been forced by three different climate change scenarios from global climate models. It is shown that the simulated water budget in the control period (1961-1990) have larger errors than in the downscaling of ERA40. To a large degree this is a result of deficiencies in how the global climate models represent the large-scale atmospheric circulation in the area. The climate change signal for the 21st century suggests warmer and wetter conditions in the area (Figure 1). Increased moisture transport into the area via the atmosphere leads to an intensification of the hydrological cycle with more precipitation and evaporation.



Relative (%) changes in annual mean fluxes in the water budget in the Baltic Sea drainage basin in the time period 2071-2100 compared to 1961-1990. Precipitation (P) and evaporation (E) are taken directly as model output. Moisture convergence (MC), discharge and outflow from the Baltic Sea are calculated as residuals. The numbers are from three different simulations with RCA3. Numbers in parenthesis are from the corresponding global model. From Kjellström and Lind (2009).

Publications

Lind, P. & Kjellström, E. 2009: Water budget in the Baltic Sea drainage basin: Evaluation of simulated fluxes in a regional climate model. Boreal Env. Res. 14: 56–67.

Kjellström, E. & Lind, P. 2009: Changes in the water budget in the Baltic Sea drainage basin in future warmer climates as simulated by the regional climate model RCA3. Boreal Env. Res. 14: 114–124.

Evaluations of regional modelling of coastally trapped low-level jets

Raza Rahnja, Michael Tjernström, Gunilla Svensson, Alvaro Smedo (Portugese Naval Academy), Ricardo Tome (Azores University, Portugal)

Coastally trapped low-level jets are climatologically occurring phenomena along mountainous coastlines where the prevailing large scale circulation interacts with the shallow marine boundary layer and the coastal mountains to form an essentially semi-geostrophic system where a high-wind jet is formed near the coast with a wind speed maximum lagging after the maximum inland heating. A classical area for such jets during the northern hemisphere summer is the California coast. As this jet varies in time and interacts with points and capes along the coast, expansion fans and hydraulic jumps appear that may be serious impediments to marine and aviation activities. Using observations taken during a Naval Postgraduate School research cruise out of Monterey we evaluate two regional models, the Weather Research and Forecast model (WRF) and the US Navy COAMPS models at several different resolutions.

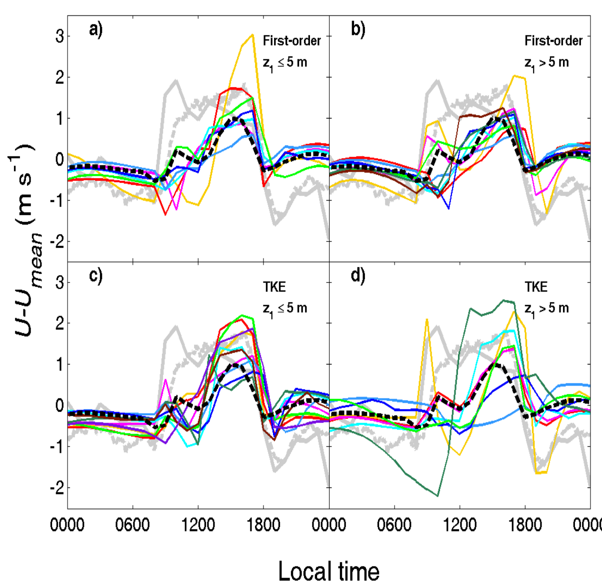
GABLS (GEWEX Atmospheric Boundary Layer Study)

Gunilla Svensson, Michael Tjernström, Bert Holtslag (Wageningen University, The Netherlands) and many others

The GEWEX (Global Energy and Water Experiment) Atmospheric Boundary Layer Study aims to improve representation of boundary layer processes in climate and numerical weather prediction models. So far, three model intercomparison studies have been performed where MISU has participated in all. The first study concerned modeling of a weakly stably stratified case. The main results from the first study is that the operational models generate deeper boundary layers as a consequence of using boundary-layer schemes that enhance turbulent mixing, while the majority of research models show close agreement with results from Large Eddy Simulations of the same case. Further analysis reveals the importance of how the surface boundary condition is formulated. Especially the ones for the components of the turbulent momentum stress are important for the surface angle, i.e. the angle between the surface wind and the free flow. This is in turn important for the integrated mass flux in a low-pressure system that determines the lifetime of cyclones.

The second experiment, chaired by MISU, focused on a diurnal cycle of a dry boundary layer, based on a few selected days during CASES-99, a field campaign that was held in Kansas, US in 1999. The experiment is simplified by using prescribed surface temperature and a constant background forcing. More than twenty model groups with various level of model sophistication are participating, many numerical weather prediction centers as well as climate and research models. The main conclusion is that all models, regardless of closure and vertical resolution, under predict the amplitude of the diurnal variation in low-level wind speed.

The third experiment is based on observational data from Cabauw, the Netherlands and the focus is on the nighttime boundary layer and modeling of the inertial oscillation that gives rise to a low-level jet. Preliminary results show that including dynamical tendencies during the integration has a large impact on the simulations. However, including interaction between the atmosphere and the underlying surface introduces a large variability in the model response.



Time series of observed and modeled wind speed deviation (m s-1) at 10 m a. g. l. For every model (different colors) the mean wind speed is subtracted. The models are shown in different panels depending on their turbulence closure and height to first vertical grid point. Light grey solid line is the selected experiment period, the light grey dashed line shows the average over the entire month of the CASES-99 campaign.

Publications

Svensson, G. and A.A.M. Holtslag, 2009: Analysis of model results for the turning of the wind and the related momentum fluxes and depth of the stable boundary layer. Boundary-Layer Meteorology, 132, 261–277. DOI 10.1007/s10546-009-9395-1

Svensson, G., A.A.M. Holtslag, V. Kumar, T. Mauritsen, G.J. Steeneveld, W. M. Angevine, E. Bazile, A. Beljaars, E.I.F. de Bruijn, A. Cheng, L. Conangla, J. Cuxart, M. Ek, M. J. Falk, F. Freedman, H. Kitagawa, V. E. Larson, A. Lock, J. Mailhot, V. Masson, S. Park, J. Pleim, S. Söderberg, M. Zampieri and W. Weng, 2011: Evaluation of the diurnal cycle in the atmospheric boundary layer over land as represented by a variety of single column models – the second GABLS experiment. Submitted to Boundary-Layer Meteorology.

The impact of resolution on the accurate modeling of coastal climate

Raza Rahnja, Michael Tjernström, Gunilla Svensson, Alvaro Smedo (Portugese Naval Academy)

The coastal zone is probably the most abrupt change in surface conditions one can think of and the consequences are many different phenomena on the mesoscale. Most of these are not resolved by current climate models and some may be important for coupled systems, such as coastal upwelling. Using the regional mesoscale weather forecast model COAMPS developed by the Naval Research Laboratory in Monterey, CA, we study the impact of different resolutions on model performance and on the adequate description of important small scale phenomena. The model is run for a real case using ERA-interim at the lateral boundaries; also SST is taken from from the reanalysis. The model is nested in itself with increasing resolution in four domains, with 54, 18 6 and 2 km horizontal resolution. Although the subjectively judged realism is indeed increasing with increasing resolution, it is difficult to show an objective improvement. Partly this is due to the fact that while the representation fo particular features, such as low-level jets or sea breezes are probably improved, they are also moved around in the model domain and the higher the resolution, the more difficult it gets to have an accurate description of a localized phenomenon both in time and space. At lower resolution, features become less distinct and therefore easier to get “about right”. We also find the 6 km resolution is a descent compromise between detail in the mean flow and computational cost, but also that for some aspects, such as local forcing of the coastal ocean surface, the results in the model does not converge even at 2 km resolution.

Large-Eddy simulation of the diurnal cycle of the atmospheric boundary layer using boundary conditions derived from CASES-99.

Vijayant Kumar (John Hopkins University, USA), Gunilla Svensson , Bert Holtslag (Wageningen University, The Netherlands), Marc Parlange (École Polytechnique Fédérale de Lausanne, Switzerland) and Charles Meneveau (John Hopkins University, USA)

The impact of surface flux boundary conditions and geostrophic forcing on multi-day evolution of flow in the atmospheric boundary layer is in this study assessed using Large-Eddy Simulations. The investigations included several combinations of surface boundary conditions and geostrophic forcing. The setup was based on characteristics observed during a selected period of the CASES-99 campaign, the same as in the GABLS second experiment.

Among the various simulations, the ones driven by a constant geostrophic wind achieve the best agreement with the observations. However, this resulted in significantly over-estimated night-time fluxes. The cases with the surface temperature boundary condition and driven by a “realistic” geostrophic forcing (with height and temporal variability) show good agreement with the nigh-time fluxes on the second simulated day. The runs using time-varying geostrophic forcing show good agreement with the day-time soundings. However, despite the “realistic” geostrophic forcing, the overall agreement with the soundings leaves much to be desired.

The surface temperature boundary condition is better suited for simulations of temporally evolving boundary layer flow. While the cases with either imposed surface temperature or imposed heat fluxes produced similar qualitative trends in time, the heat flux based cases show poor agreement with day-time and night-time fluxes, and day- and night-time mean profiles.

Publications

Kumar, V., G. Svensson, A.A.M. Holtslag, M. B. Parlange, and C. Meneveau, 2010: Impact of surface flux formulations and geostrophic forcing on large-eddy simulations of the diurnal atmospheric boundary layer flow. Journal of Applied Meteorology and Climatology. 49, 1496-1516. DOI: 10.1175/2010JAMC2145.1

Impact of flow dependent horizontal diffusion on resolved convection in AROME

Lisa Bengtsson-Sedlar, Sander Tijm (KNMI), Filip Váňa, CHMI, Czech Republic and Gunilla Svensson

Horizontal diffusion in numerical weather prediction models is in general applied to reduce numerical noise at the smallest atmospheric scales. However in convection-permitting models, with horizontal resolution on the order of 1-3 km, horizontal diffusion can become a compensation to a lacking representation of a physical process. It has been shown in studies with the convection-permitting model AROME that diffusing falling hydrometeors such as rain, snow and graupel lead to an improvement in the model forecast of large precipitation amounts. However, such an application of horizontal diffusion lacks physical motivation.

Within the current AROME, horizontal diffusion is imposed using linear spectral horizontal diffusion on dynamical model fields. This spectral diffusion is complimented by non-linear, flow dependent, horizontal diffusion applied on turbulent kinetic energy, cloud water, cloud ice, rain, snow and graupel. In this study, we apply non-linear flow-dependent diffusion on the dynamical model fields rather than diffusing the already predicted falling hydrometeors.

In particular, we investigate the characteristics of deep convection. Results indicate that for the same amount of diffusive damping, the maximum convective updrafts remain strong for both the current and proposed methods of horizontal diffusion. Diffusing the falling hydrometeors is necessary in order to see a reduction in rain intensity. However, a more physically justified solution can be obtained by increasing the amount of damping on the smallest atmospheric scales using the non-linear, flow-dependent, diffusion scheme. Doing so, a reduction in vertical velocity was found, resulting in a reduction in maximum rain intensity.

Publications

Bengtsson-Sedlar, L., S. Tijm, F. Vanja and G. Svensson, 2011: Impact of flow dependent horizontal diffusion on resolved convection in AROME. Submitted to Journal of Applied Meteorology and Climatology.Mauritsen, T. and G. Svensson, 2007: Observations of stably stratified shear-driven atmospheric turbulence at low and high Richardson numbers. Journal of the Atmospheric Sciences, 64, 645–655.

Representation of the diurnal cycle of near-surface parameters in the CESM1 and CCSM4

Jenny Lindvall, Gunilla Svensson, Cecile Hannay and Sungsu Park (NCAR, Boulder, CO, USA)

As climate models are developing and becoming more complex, there is an increased need for evaluation of their performance in more detail. In this project, we are studying the general behavior of the near-surface variables and the boundary-layer evolution in the present and new version of the National Center for Atmospheric Research (NCAR) Community Atmospheric Model. The current scheme is of first order and with a change to a new shallow-cumulus parameterization a tke-based boundary layer scheme is introduced. The performance of these two schemes are examined and compared with surface based observations of mean and turbulence parameters at about twenty land based locations all over the world. The comparison covers different types of land use and climate zones. The overall performance, sensitivity to parameter choice and differences between the model versions, are also studied.

Residual layer turbulence and gravity wave breaking

Michael Tjernström, Gunilla Svensson, and Ben Balsley and Florence Bocquet (University of Colorado)

The residual layer (RL) forms on top of the stably stratified boundary layer during the night as the remnants of the previous day's deeper well-mixed convective boundary layer is under-cut by the stable nocturnal boundary layer. We have used information from the CIRES Tethered Lifting System (TLS) to analyze RL turbulence using data from the CASES-99 experiment. The TLS is a tethered lifting platform that enables detailed observation through the entire nocturnal boundary layer through the stable boundary layer and the RL into the free troposphere. In addition to detailed mean profiles of temperature, wind and humidity, turbulence is analyzed at high temporal and spatial resolution using power spectra of very high-frequency wind observations from hot- and cold-wire systems are used to estimate the dissipation rate of turbulence, ε, from the inertial sub-range spectra.

The RL is often considered as a quiescent mostly laminar layer developing only by larger-scale dynamics until next day's convective boundary layer is established again. We find this conventional picture of the RL false. The structure of the RL is often highly variable, with values of ε varying orders of magnitude in unexpectedly coherent organized structures. The only logical explanation for such organized turbulence is that it is generated by persistent local instabilities. We illustrate a mechanism whereby momentum deposition from weak gravity waves generated by air flow over even quite modest terrain relief; this occurs as the upward propagating wave encounters a critical layer.

Publications

Tjernström, M., B.B. Balsley, G. Svensson and C.J. Nappo, 2009:: The effects of critical layers on residual layer turbulence. Journal of Atmospheric Sciences, 66, 468–480.

A parameterization with wave saturation adjustment of subgrid-scale average wave stress over three-dimensional topography

Carmen Nappo (CJN Research Meteorology, Knoxville, Tennessee, USA) och Gunilla Svensson

In this study, a parameterization of subgrid-scale wave stress over three-dimensional topography is described and applied to regions of low, moderate, and high-relief terrain is developed. The parameterization explicitly calculates the wave stress using linear theory and the two-dimensional Fourier transform of the subgrid-scale topography. The wave field is maintained convectively stable using the so-called terrain-height adjustment. The method is tested for flows over idealized two- and three-dimensional obstacles. It is shown that in the case of general topography terrain features can be spatially organized such that the magnitude of the wave stress is strongly dependent on the direction of the surface wind. Critical levels will exist whenever the background wind direction changes with height thus giving vertical divergence in the stress profiles. The method is tested on observed profiles in areas with low-relief and moderate terrain with interesting results.

The sub-grid scale wave stress parameterization is presently included in a one-dimensional version of a mesoscale model, the MIUU model. The wave stress divergence is allowed to affect the mean wind which in turn has an impact on the boundary-layer turbulence and surface stress. This in turn affect the wind turning that then may change the diagnosed wind stress. Evaluation of the effect for various sub-grid scale topography and boundary layer structures are on-going.

Analyses of turbulence data for stably stratified conditions

Gunilla Svensson, Larry Mahrt (Oregon State University, Corvallis, OR) and Michael Tjernström

In this project, we focus on analyzing turbulence data for stably stratified conditions with the specific aim to improve parameterizations used in numerical weather prediction models and climate models. We target two specific problems: the turning of the wind in the boundary layer and the variability of the surface drag.

Differences between the surface stress and surface wind direction can be caused by differences between the wind and vertical shear directions. Estimation of the shear direction can be sensitive to choice of levels and the method of fitting of profiles, especially for weak wind conditions. The relevant shear corresponds to the layer over which local mixing occurs; that is, of thickness comparable to the eddy size. Preliminary analysis of several locations indicate a systematic difference between the surface stress and surface wind directions that increase as the mean wind decrease. For very stable conditions, the drag coefficient can assume a wide distribution of values depending on the capture of mixing events within an individual averaging window. The width of the distribution and occurrence of outliers decreases with increasing averaging width. Attempting to estimate the distribution of the drag coefficient for different intervals of the Richardson number requires a large amount of data and this is pursued in this project.

Subtropical cloud regime transitions: boundary layer depth and cloud-top height evolution in observations and models

Johannes Karlsson, Gunilla Svensson, Sambingo Cardoso (University of Lisbon, Lisbon, Portugal and NCAR, USA) and Joao Teixiera (JPL,Caltech, USA)

The mean and variability of boundary layer height (BLH) are analyzed along a transect in the eastern Pacific Ocean for the summer of 2003. BLH estimates based on the height of the main relative humidity (RH) inversion and the height of low cloud tops (CTH) are used. The observations and the regional and global model data have been prepared in the context of the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) Pacific Cross-Section Intercomparison (GPCI). The GPCI transect covers the transition from a stratocumulus-topped marine boundary layer (MBL) off the coast of California to a trade cumulus–topped, less-well-defined, MBL, and finally to the deep-convection regions in the inter-tropical convergence zone (ITCZ). The Atmospheric Infrared Sounder (AIRS) and the Multiangle Imaging Spectroradiometer (MISR) have been used to derive observational records of the two BLH estimates. Analyses from the ECMWF are also used in the study. Both BLH estimates in the models, the ECMWF analysis, and the observations agree on a southward vertical growth of the MBL along the GPCI transect in the stratocumulus region. Away from the region typically associated with extensive cloud cover, the two BLH estimates depict different evolutions of the MBL.

In most models, the height of the main RH inversion decreases southward and reach a minimum at the ITCZ, whereas the height of the RH inversion in the ECMWF analysis and a few of the models is fairly constant all the way to the ITCZ. As a result of insufficient vertical resolution of the gridded dataset, the AIRS data only manage to reproduce the initial growth of the BLH. The median-model CTH increases from the stratocumulus-topped MBL to the ITCZ. In contrast, the observed MISR CTHs decrease southward from 208N to the ITCZ, possibly indicative of the fact that in these regions MISR manages to capture a variety of cloud tops with a mean that is below the subsidence inversion while the models and the ECMWF analysis mainly simulate CTHs corresponding to the height of the subsidence inversion. In most models and in the ECMWF analysis, the height of the main RH inversion and the CTH tend to coincide in the northern part of the GPCI transect. In the regions associated with trade cumuli and deep convection there is a more ambiguous relation between the two BLH estimates. In this region, most of the models place the CTH above the main RH inversion. The ECMWF analysis shows a good agreement between the BLH estimates throughout the transect.

Publications

Karlsson, J., G. Svensson, S. Cardoso, and J. Teixeira, 2010: Subtropical cloud regime transitions: boundary layer depth and cloud-top height evolution in observations and models. Journal of Applied Meteorology and Climatology , 49, 1845-1858.

Snow melt and freeze up in the pan-arctic region analyzed from satellite observations

Jonas Mortin, Gunilla Svensson, Rune Grand Graversen, Thomas Schröder and Aksel Walløe-Hansen (Copenhagen University, Denmark

See Arctic Studies

Simulations of Arctic clouds and their influence on the winter present-day climate in the CMIP3 multi-model dataset

Johannes Karlsson and Gunilla Svensson

See Arctic Studies

ASCOS (The Artic Summer Cloud Ocean Study)

Caroline Leck and Michael Tjernström

See Arctic Studies

Mesoscale variability in the summer Arctic boundary-layer

Michael Tjernström and Thorsten Mauritsen

See Arctic Studies

Arctic clouds and the boundary-layer inversion

Joseph Sedlar and Michael Tjernström

See Arctic Studies

Vertical coupling of clouds and the surface in the summer Arctic

Michael Tjernström, Thorsten Mauritsen, Joseph Sedlar (SMHI), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA), Ian Brooks (Leeds University, UK)

See Arctic Studies

The vertical structure of the lower Arctic atmosphere

Michael Tjernström and Rune Grand Graversen

See Arctic Studies

Evaluation of the UK MetOffice Unified Model operational forecast using ASCOS data

Michael Tjernström, Cathryn Birch and Ian Brooks (Leeds University, UK)

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Vertical coupling of clouds and the surface in the summer Arctic

Michael Tjernström, Thorsten Mauritsen, Joseph Sedlar, Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA), Ian Brooks (Leeds University, UK)

See Arctic Studies

A summer-fall transitioning surface energy balance

Joseph Sedlar, Michael Tjernström, Thorsten Mauritsen, Anders Sirevaag (University of Bergen), Ian Brooks and Cathryn Birch (University of Leeds UK), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA)

See Arctic Studies

Surface layer fluxes in the summer Arctic

Michael Tjernström, Cathryn Birch and Ian Brooks (Leeds University, UK)

See Arctic Studies

Evaluation of the UK MetOffice Unified Model operational forecast using ASCOS data

Michael Tjernström, Cathryn Birch and Ian Brooks (Leeds University, UK)

See Arctic Studies

Multisensor analysis of lower troposphere stability in the summer Arctic

Michael Tjernström, Joseph Sedlar, Thorsten Mauritsen, Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA)

See Arctic Studies

PHYSICAL OCEANOGRAPHY

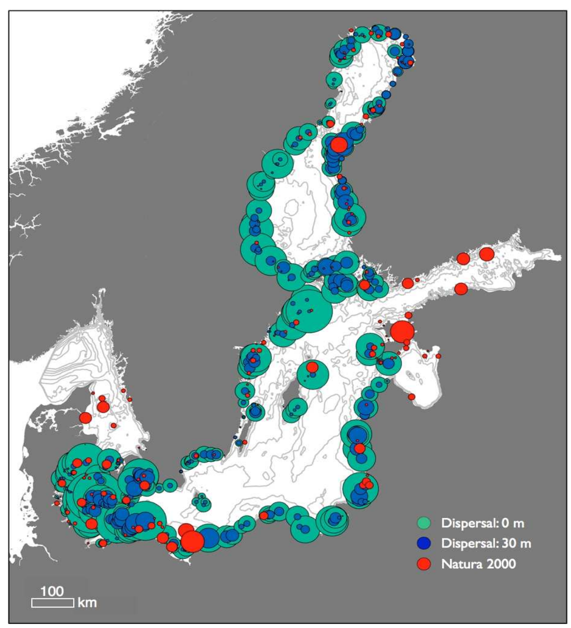
The Oceanography group deals with problems of a global nature as well as with questions related to the Baltic Sea. Additionally some topics in the field of geophysical fluid dynamics are under continuous investigation. To a considerable extent the work is based on numerical modelling, where the NEMO model (linked to EC-Earth) gradually is replacing the various models previously in use. Experimental work focusing on the use of induced voltages for estimating transports is carried on in the Baltic as well as North of the Faroes in the Atlantic. Satellite altimetry is being pursued in the latter region, and recently an ARGO surface-drifter programme has been launched in the Baltic. Collaborative work is carried out with a number of European institutes as well as university departments.

How larval traits and regional oceanography determine dispersal distance and optimum size of marine protected areas

Hanna Corell and Kristofer Döös in external collaboration with Anders Engqvist (KTH) and Per-Olav Moksnes and Per R Jonsson (Department of Marine Ecology, University of Gothenburg)

This is a joint modelling effort between physical oceanography and marine ecology. Marine protected areas (MPAs) are presently set aside at an increasing rate to mitigate loss of habitats and biodiversity and to restore overexploited stocks. Here the effects on dispersal distance and local recruitment within MPAs by life history trait of the larvae, spawning season and spatial and temporal variability in ocean circulation were explored with realistic simulations of larval dispersal. With the Baltic Sea as a testbed a few basic larval traits common to a large group of organisms was tested, to obtain general results. These larval traits were based on empirical larval data from discrete depths obtained in an extensive field sampling program in the study region. A large-scale hydrodynamic 3D ocean model was then used to calculate dispersal trajectories in the study area for all larval trait combinations and we compared the spatial scale of their dispersal with the existing MPA network within the European Union Natura 2000 system.

The strong effects of larval duration and swimming depth on larval dispersal suggest that knowledge about these larval traits is critical for the design of a functional MPA network. The model simulation and empirical data on larvae in the study area suggest that the present size of individual MPAs within the Natura 2000 network of protected areas is considerably below what is required for local recruitment of most sessile invertebrates and sedentary fish. Future designs of MPA networks should be based on spatially explicit biophysical models that consider connectivities for complex circulation patterns and informed larval traits. However, until recently, little attention has considered how larval dispersal capacities of targeted organisms impact the function of MPAs, and how different life-history traits affect the dispersal.



The mean dispersal distance for a larva in summer/autumn with pelagic larval duration of 20 days, swimming at the surface (turquoise) and at 30 metres (dark blue). The figure highlights the regional variation in dispersal pattern. Also shown are the shallow MPAs within the Natura 2000 network of protected areas. The circle diameters indicate dispersal distance and the size of individual MPAs (assumed to be circular) drawn on the same scale as the map

Baltic oceanographic research

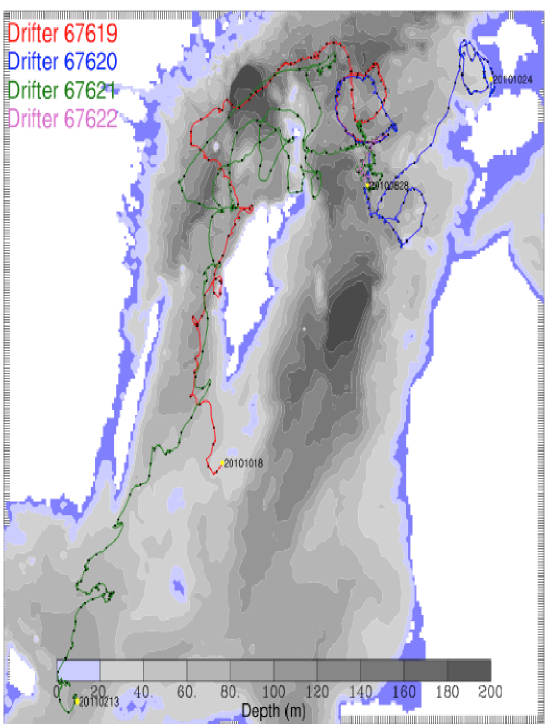
Kristofer Döös, Joakim Kjellsson, Hanna Kling, Peter Lundberg, Markus Meier, Jenny Nilsson, Peter Sigray in external collaboration with Janek Laanearu/Tarmo Soomere (Tallinn Technical University, Estonia), Jari Haapala/Riikka Hietala (Finnish Meteorological Institute, Helsinki), Kai Myrberg (SYKE, Helsinki) Hans Burchard/Thomas Neumann (Baltic Sea Research Institute, Warneműnde), and Bror Jönsson (Princeton University, USA).

This research field encompasses both deep- and surface-water processes in the Baltic.

Investigations concerning the former topic are primarily based on rotating-hydraulic considerations, since the research efforts to a considerable extent have come to deal with the oxygenated saline exchange between the well-defined deep basins of the Baltic, an ecologically very important process.

Research focusing on the horizontal circulation of the Baltic is carried out with a wide variety of methods, prominent among these numerical modelling of the two- as well as three-dimensional variety. These studies have examined topics encompassing a wide array of spatial as well temporal scales, ranging from the Baltic seiches and trajectory analyses of the small-scale dispersion of pollutants to the climatologically modified behaviour of the entire Baltic in a hundred-year perspective, the latter research conducted in intimate collaboration with the oceanographic research section of the Swedish Meteorological and Hydrological Agency (SMHI).

As regards field-work, this is presently undertaken within two distinct fields. Since the late 1990s a geo-electric monitoring system has been maintained between the Swedish mainland and the island of Gotland. This installation provides quantitative estimates of the strength of the main circulation gyre of the Baltic, useful information for assimilating into numerical models. More recently an Surface-drifter program has been initiated in collaboration with Estonian colleagues. This has already yielded highly interesting results, not least in view of the trajectory-modelling activities which the MISU-oceanographers have excelled at over the last decade. Most likely this drifter programme will be further augmented in forthcoming years.



Two pairs of surface drifters deployed during the summer 2010 in the Baltic Sea. The 67621 drifter (green) is, as this is written, still working and sending every hour valuable data through the Argos satellite system. It is the longest working surface drifter ever in the Baltic

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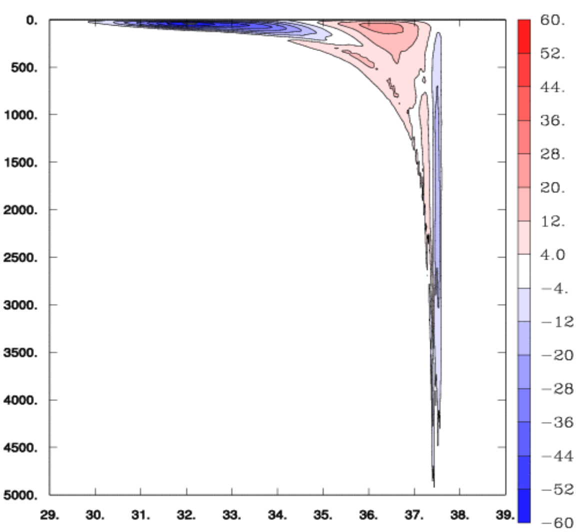
Large-scale ocean and atmosphere modelling and theory

Kristofer Döös, Joakim Kjellsson, Laurent Brodeau, Johan Nilsson, Jonas Nycander, Göran Broström

The large-scale modelling of the ocean and atmosphere at MISU is made with the EC-Earth climate model and its two main components NEMO for the ocean and IFS for the atmosphere. The modelling activities are closely coupled to more theoretical efforts, addressing fundamental dynamical questions and aiming to develop new methods for analysing the general circulation in model data and observations. Specific research questions are tied to the energetics of the ocean circulation, the meridional transports of heat and freshwater by the atmospheric and oceanic circulation, the circulation of the Southern Ocean, and effects of the nonlinear equation of state.



Overturning streamfunction ψ(σ, z) in depth–density coordinates from the OCCAM model as a function of potential density σ2. The transport is given in Sverdrups and ψ(σ, z) is counted positive (red shading) in anticlockwise cells and negative (blue shading) in clockwise cells (Nycander et al. 2007)

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Dynamics of subpolar seas and paleo-oceanography

Jan Backman (Department of Geological Sciences, Stockholm University), Kristofer Döös, Martin Jakobsson (Department of Geological Sciences, Stockholm University), Johan Nilsson, Jonas Nycander, Ole-Anders Nøst (Norwegian Polar Research Institute, Tromsø, Norway) Matthew O'Regan (Cardiff University, Great Britain), Bijoy Thompson (Department of Geological Sciences, Stockholm University), Gösta Walin (Göteborg University, Sweden).

This research project focuses on the dynamics in subpolar seas. These high-latitude oceans experience strong surface heat loss and have weak vertical density stratification, causing their currents to be strongly steered by the bottom topography. Further, a high input of freshwater tends to create a strong salinity stratification that competes with the thermal stratification, a feature that may result in multiple-equilibria states. Fundamental aspects of the circulation in subpolar seas are examined using theory, conceptually-based numerical models, laboratory experiments as well as observations. Some specific research topics are motivated by proxy data of the palo-ocean circulation in the Arctic Ocean. One research focus is the Arctic Ocean circulation during the Miocene at the stage when the Fram Strait opened up, transforming the paleo Arctic Ocean from a landlocked lake to a well-ventilated ocean basin. Another focus is the Arctic Ocean circulation during Marine Isotope Stage 6, when the Arctic Ocean was surrounded by enormous shelf-ice complexes, similar to those found around Antarctica today.

Publications

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Jakobsson, M., J. Nilsson, M. O'Regan, J. Backman, L. Löwemark, J. A. Dowdeswell, L. Mayer, L. Polyak, F. Colleoni, L. G. Anderson, G. Björk, D. Darby, B. Eriksson, D. Hanslik, B. Hell, C. Marcussen, E. Sellen, Å. Wallin, 2010: An Arctic Ocean ice shelf during MIS 6 constrained by new geophysical and geological data. Quaternary Science Reviews, doi:10.1016/j.quascirev.2010.03.015

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Internal tides

Jonas Nycander, Robert Turnewitsch (The Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, UK), Mondheur Zarroug.

The overturning circulation in the ocean is driven by winds and by small-scale mixing. This mixing is caused by breaking internal waves, and in the deep ocean the internal waves are mainly generated by tides over rough topography. In this project, such internal tides are computed for real topography by using linear wave theory. Their importance for sediment dynamics has been studied, opening the possibility that sediments may contain a fingerprint of tides in the past. The effects of various approximations made in the linear computations are also investigated.

Publications

Turnewitsch, R., J.-L. Reyss, J. Nycander, J.J. Waniek and R.S. Lampitt, 2008: Internal tides and sediment dynamics in the deep sea - evidence from radioactive 234Th/238U disequilibria. Deep-Sea Res. I, 55, 1727-1747.

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Oceanographic investigations of the Faroe region

Léon Chafik, Peter Lundberg, Johan Nilsson, Peter Sigray in external collaboration with Thomas Rossby (Graduate School of Oceanography, University of Rhode Island, USA)

The focus of this research is the climatologically important water exchange between the Atlantic Proper and the Nordic seas, a significant part of which takes place in the neighbourhood of the Faroe Islands.

Previously the investigations have mainly been focused on the Atlantic-bound deep-water transports through the Faroe-Bank Channel, a process which has been examined using current-meter records from the passage obtained in the course of a long-term joint Nordic field programme initiated under WOCE auspicies. The modelling of this overflow has primarily been based on the application of rotating hydraulic theory.

Present research is to a large extent devoted to examining and analyzing the inflow of warm and saline Atlantic waters across the Iceland-Scotland Ridge. These investigations are carried out using a variety of different techniques such as satellite altimetry, numerical modelling, and geo-electric monitoring. To conduct the last type of study, an observational system making use of the Faroese branch of the transatlantic CANTAT telecommunications cable is maintained on the Faroes. Work is presently in progress to determine whether similar monitoring can be undertaken from the recently deployed fibre-optical cables between the Faroes and the Shetland Isles as well as Iceland, respectively.

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Mathematical aspects of geophysical fluid dynamics

Peter Lundberg, Jenny Nilsson, Jonas Nycander, Moundheur Zarroug and Qiong Zhang in external collaboration with Fariba Bahrami (Tabriz University, Iran), Janek Laanearu (Tallinn Technical University, Estonia), and J. LaCasce (Oslo University).

Within this project various mathematical questions of an applied geophysical nature are dealt with. Work has hitherto been carried out within such varied fields as existence proofs of vortices, nonlinear oscillators, the improvement of perturbation series, and the resolution of coastal-wave eigenvalue problems using either Frobenius series or perturbative techniques.

Publications

Bahrami, F. and J. Nycander, 2007: Existence of energy minimizing vortices attached to a flat-top seamount. Nonlin. Anal.: Real World Appl., 8, 288-294.

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Lundberg, P., F. Bahrami and M. Zarroug, 2009: A note on the asymptotic analysis of a thermal relaxation oscillator. Z. Angew. Math. Mech. 89, 995-1001.

Measurements of bubble size spectra within leads in the Arctic summer pack ice

Sara Norris, Ian Brooks, Barbara Brooks and Cathryn Birch (Leeds University, UK), Gerrit de Leeuw (Finnish Meteoroloical Institute), Anders Sirevaag (University of Bergen, Norway), Caroline Leck, Michael Tjernström

See Arctic Studies

Mixing, heat fluxes and heat content evolution of the Arctic Ocean mixed layer

Anders Sirevaag, Sara de la Rosa and Ilker Fer (University of Bergen), Marcel Nicolaus2 (Alfred Wegener Institute, Germany), Michael Tjernström, Miles G. McPhee (McPhee Research Company , USA)

See Arctic Studies

CHEMICAL METEOROLOGY

The research in chemical meteorology involves studies of the occurrence and transfer of chemical constituents in the atmosphere as dependent on meteorological conditions: winds, clouds, precipitation etc. This is done by measuring the chemical composition of air, including gases, aerosol particles, cloud water and precipitation and by theoretical modelling of transport, transformation and removal processes. The main focus is on the biogeochemical cycling, on regional and global scales, of constituents containing sulfur (SO_2, DMS, SO_4^{2-}), nitrogen (NOx, HNO_3, NO_3-) and carbon (elemental carbon, hydrocarbons). Special attention is given to exchange processes between the atmosphere and the oceans and between the atmosphere and the soil/vegetation system. Several of the projects are motivated by concern about the effects of anthropogenic changes in the chemical composition of the atmosphere: impact on climate, eco-systems - including acidification – and human health. The specific research areas include:

- REACTIVE TRACE GASES , AEROSOL PARTICLES AND PRECIPITATION CHEMISTRY
- MODELLING OF TROPOSPHERIC CHEMISTRY

REACTIVE TRACE GASES, AEROSOL PARTICLES AND PRECIPITATION CHEMISTRY

The composition of fragments of bubbles bursting at the ocean surface

Caroline Leck and Keith Bigg

Air bubbles bursting on artificial seawater in laboratory experiments have been found to inject numerous particles <200 nm diameter into the atmosphere, some experiments showing copious production of particles as small as 10 nm in diameter. Some reported observations of the real marine aerosol support the presence of a large proportion of sea salt <200 nm diameter, while others suggest that it is absent, or nearly so. However, the observations have shown that its presence in the former case may be based on misinterpretations. Highly surface active exopolymers produced by bacteria and algae, the marine microgels formed by them, and large concentrations of submicrometer particulates are known to be present in the ocean. Their possible influence on bubble formation, bubble bursting and particle injection into the atmosphere have been supported by elctron microscopy of individual particles at a number of sites. As ultraviolet light and acidification cause structural and chemical changes to exopolymers and their gels exposed to the atmosphere the marine aerosol will have properties that change with atmospheric residence time. If this is so, modification of currently accepted theories of particle injection into the atmosphere by bursting bubbles would be required.

Publications

Bigg, E.K., and C. Leck, 2008, The composition of fragments of bubbles bursting at the ocean surface, J. Geophys. Res., 113 (D1) 1209, doi:10.1029/2007JD009078.

Comparison of sources and nature of the tropical aerosol with the summer high Arctic aerosol

Caroline Leck and E. Keith Bigg

Marine aerosol was collected in September 1998 and July 2005 on the upwind coast of an island at latitude 15ºS, about 15km downwind from the outer edge of the Great Barrier Reef, Australia, and examined by electron microscopy. Exopolymer gels, aggregates of organic microcolloids, marine micro-organisms and fragments of marine life formed a sub-stantial part of the accumulation mode aerosol. Differences in transparency, firmness of outlines and shape of gels and the influence of organic vapours on them, suggested progressive physical and chemical changes with atmospheric residence time. The virus-like microcolloid aggregate components had a size distribution remarkably close to that found in similar particles over the central Arctic Ocean peaking at diameters of 30-40nm. Single components or small groups of these aggregates were found within more than 75% of particles resembling ammonium sulfate in appearance indicating that aggregates fragmented in the atmosphere. Sea salt was found to only represent a small part, less than 5%, of the composition of the film drop particles. These findings are not only consistent with those over the Arctic pack ice but also with findings elsewhere. The deduced sequence of changes to particles entering the atmosphere from the ocean is very similar to that found in the Arctic, suggesting that it is a common pattern over the oceans. That conclusion would require modification of the parameterization of the marine aerosol used in climate models and of possible climate feedback effects.

Publications

Bigg, E.K., and C. Leck, 2008, The composition of fragments of bubbles bursting at the ocean surface, J. Geophys. Res., 113 (D1) 1209, doi:10.1029/2007JD009078.

A modified aerosol cloud climate feedback hypothesis

Caroline Leck and E. Keith Bigg

Shaw suggested a biothermostasis mechanism that would operate by altering planetary albedo and thus climate through the creation of at-mospheric particles by oxidation of biospheric organic sulfide gases. This was considered in more detail by Charlson, Lovelock, Andreae and Warren and has become widely known as the “CLAW” hypothesis. It proposed a possible feedback mechanism on the biological influence on cloud formation, radiation and climate and stands on 4 main assumptions: (1) Increased phytoplankton production of dimethyl sulfide (DMS) as a result of global warming leads to (2) an increase in cloud condensation nuclei (CCN) production by its oxidation products (3) Increased CCN concentrations then lead to an increase in cloud albedo and (4) the increased loss of shortwave radiation would result in surface cooling. The DMS link might therefore help climate to be self-regulating.

We have argued that CCN number concentration is not determined by the oxidation products of DMS as has usually been assumed but by the concentration in the air of single components or small groups of colloids derived from the ocean surface by bubble bursting. Fresh aggregates with exoploymer gel on them could act as CCN directly because of the gel’s strong surface-active properties. Those that have lost their gel, given enough time spent in the atmosphere, could still act as sites for condensation of the oxidation products of DMS. This hypothesis has been examined further over the Arctic pack ice and it was found necessary to invoke a highly surface-active Aitken mode, assumed to be exoploymer, externally mixed with a sulfur-containing population in order to explain the observed CCN over the pack ice area. If this is generally so over remote marine areas then a possible climate feedback effect may exist irrespective of a source of DMS in the ocean surface or from interference from the free troposphere aerosols. This by itself weakens the CLAW hypothesis but would also require that a warming would cause an increase in biological productivity that would not be as species-selective as the CLAW hypothesis as bacteria and viruses are probably major players in the colloid generation. The concentration of the latter would depend on total phytoplankton concentrations rather than just on important DMS producers. However, temperature-dependent production of DMS by phytoplankton would still be involved, since the size to which pre-existing aggregates with exoploymer gel grow is determined by DMS oxidation product concentrations and this influences their cloud nucleating properties. This would specify a greater biological control than through DMS alone. The accuracy of predictions of global warming depends amongst other things on a correct representation of climate feedback processes, of which the CLAW hypothesis is potentially one.

Publications

Leck, C. and K. Bigg, 2008, A modified aerosol–cloud–climate feedback hypothesis. Environmental Chemistry, 4, 400–403, doi:10.1071/EN07061,

New Particle Formation of Marine Biological Origin

Caroline Leck and E. Keith Bigg

Large increases in concentration of particles smaller than 20 nm diameter are relatively common over the central Arctic Ocean in summer and have occasionally been observed over lower latitude oceans. These events often do not readily fit theoretical models of homogeneous nucleation from known precursor gases. It is shown that aggregates and gels of marine biological origin are often common over remote oceans and have a partially granular structure. Previous work in the central Arctic Ocean in summer has shown evidence of release of particles of the order of 40 nm diameter in the presence of evaporating fogs. It is suggested here that under some circumstances disintegration of the primary particles may be more complete, releasing particles smaller than 5 nm that would then be mistaken for recently nucleated particles. Examination of particles present during an apparent nucleation event at Cape Grim, Tasmania supports this interpretation. Correlation coefficients of concentrations of particles of different sizes during the period before apparent nucleation events suggests a distinct difference between vigorous true nucleation events and those over the central Arctic Ocean in summer where little subsequent growth is observed.

Publications

Leck, C., and E.K. Bigg, 2010, New particle formation of marine biological origin, Aerosol Science and Technology, 44:570–577.

A new Flexible Multi-component Model for the Study of Aerosol Dynamics in the Marine Boundary Layer

Caroline Leck: Matthias Karl (NILU, Norway), Liisa Pirjola (University of Helsinki, Helsinki, Finland) and Allan Gross (Danish Meteorological Institute, Denmark)

A new sectional aerosol dynamics model, MAFOR, was developed with the main focus to study nucleation in the marine boundary layer. Novel aspects of the coupled gas phase/aerosol dynamics model MAFOR are 1) the full flexibility of gas phase chemistry and the degree of detail specifically in the chemistry of dimethyl sulphide, 2) the detailed treatment of liquid phase chemistry, which can be extended according to needs, and 3) simultaneous calculation of particle number and mass concentration distributions of a multi-component aerosol as functions of time using a sectional approach. Comparison with well-documented aerosol dynamics box models (MONO32 and AEROFOR), a comprehensive dataset on gas phase compounds, aerosol size distribution and chemical composition data obtained during the AOE-96 (Arctic Ocean Expedition, 1996) was used to evaluate the model. Dimethyl sulphide decay during advection of an air parcel over the Arctic pack ice was well captured by the applied models and predicted concentrations of sulphuric acid and methanesulphonic acid in the gas phase range up to 1.0 X 10^6 cm^{-3} and 1.8 X 10^6 cm^{-3}, respectively. Different nucleation schemes were implemented in MAFOR, which allow the simulation of new particle formation. Modelled nucleation rates from sulphuric acid nucleation via cluster activation were up to 0.21 cm^{-3} s^{-1} while those from ion-mediated nucleation were below 10^{-2} cm^{-3} s^{-1}. Classical homogeneous binary and ternary nucleation theories failed to predict nucleation over the central Arctic Ocean.

Publications

Karl, M., A. Gross, L. Pirjola, and C. Leck, 2011, A New Flexible Multicomponent Model for the Study of Aerosol Dynamics in the Marine Boundary Layer, Tellus B. Accepted.

Baseline measurements of airborn particles at Tasmania

Caroline Leck and Jost Heintzenberg (Institute for Tropospheric Research, Leipzig, Germany)

A long-term soot-sampling program in collaboration with the Australian baseline station is in operation at Cape Grim, Tasmania since 1982. A second time series with modified sample substrate was started in 1991, one year before the supply of the first type of substrate was exhausted. On the second substrate, major ions have been analyzed for complementary aerosol chemical information and for systematic corrections of the optical soot measurements. At the Cape Grim station a host of meteorological and trace substance information is available for the interpretation of aerosol data in terms of natural and anthropogenic sources, local regional and long-range influence. The combined ancillary information has been used to harmonize the two parts of this unique time series of an anthropogenic aerosol component. Beyond a previous interpretation that had identified southern African biomass burning as dominating the seasonal soot cycle at Cape Grim, long-term trends in regional pollution and transport patterns are suggested to be of great importance for the temporal evolution of the 25-year long soot record.

Aerosol formation in the Arctic free troposphere

Farahnaz Khosrawi; Johan Ström (ITM, Stockholm University); Andreas Minikin (DLR Oberpfaffenhofen, Germany)

The classical mechanism for the formation of aerosol particles from condensable gases in the atmosphere is the binary homogeneous nucleation of H_2SO_4 and H_2O which is strongly dependent on temperature and relative humidity. The influence of subgrid-scale vertical motion on the binary homogeneous nucleation in the Arctic free troposphere has been investigated. During the ASTAR (Arctic Study of Tropospheric Aerosol and Radiation) campaign nucleation mode particles (4 to 13 nm) were quite frequently observed at altitudes below 4000 m. However, in the upper free troposphere, nucleation mode particles were only observed once, namely during the flight on 24 May 2004 (7000 m). Microphysical box model studies along trajectories that were calculated 6-days backwards based on European Center for Medium-Range Weather Forecasts (ECMWF) meteorological analyses were performed. The simulation results can be divided into three cases: 1. nucleation occurs at the begin of the simulation due to very low temperatures, 2. nucleation occurs at a certain point in the simulation but for higher mixing ratios at the begin of the simulation, 3. nucleation occurs at three different time steps during the simulation. For case 1 the temperature was the only driving mechanism while for case 2 and 3 the sub-grid scale vertical motion could have influenced the formation of new particles.

Publications

Khosrawi, F, J. Ström, A. Minikin, R. Krejci, Particle formation in the Arctic free troposphere during the ASTAR 2004 campaign: a case study on the influence of vertical motion on the binary homogeneous nucleation of H2SO4/H2O, Atm. Chem. Phys., 10, 1105-1120, 2010.

New particle formation in remote Northern American forests under the sulfur plume influence

Vijay Kanawade and Mark E. Erupe (Kent State University, USA), Barry Lefer (University of Houston, USA), Tom Jobson (Washington State University, USA), S. N. Tripath (Indian Institute of Technology, India), Shelley Pressley (Washington State University, USA), Farahnaz Khosrawi, and Shan-Hu Lee (Kent State University, USA)

About 30% of the Earth's land surface is covered by various types of forests. Forest emitted biogenic volatile organic compounds (BVOCs) affect atmospheric photochemistry, aerosol loading, and radiative forcing over forests. Many forests are experiencing rapid changes in environmental conditions as a result of forest succession due to climate change. This also affects local BVOC chemistry and aerosol formation and growth in near canopy environments, thereby altering the climatic effects of forests. We observed aerosol sizes and nucleation precursors during Community Atmosphere-Biosphere Interactions Experiments (CABINEX) collaborative research in the remote Michigan forests in the summer 2009, in order to understand the new particle formation processes in BVOC rich, remote northern American forests. Our observations show that occurrence of ultrafine particles in the remote Michigan forest site was rare, even in the presence of high concentrations of biogenically emitted isoprene and its oxidation products during the summer 2009. NPF was observed on two occasions during 4 weeks of measurements. Analysis based on both the ground- and satellite-based measurements of key trace gas species show that these two events were strongly influenced by anthropogenic SO2 plumes transported from regional power plants. Microphysical box modeling simulations, constrained by the measured SO2, OH, and H2SO4 and other key atmospheric parameters, show that ion nucleation involving high concentrations of SO2 and/or H2SO4 is a likely pathway to explain the observed ultrafine particles, while binary and ternary homogeneous nucleation processes failed to reproduce atmospheric observations. Our results indicate that despite stringent air quality regulations in North America, the threat to remote forests from air pollution are still persist, contributing to formation of aerosol particles over forested areas and must be accounted for in models to accurately predict the impact of new particle formation on climate.

Bi-static lidar studies of cirrus particle properties

Georg Witt, in collaboration with Frans Olofsson, Jan B. C. Pettersson (Göteborg University, Sweden), Ariel Cohen (Hebrew University of Jerusalem, Israel), and M. Frioud (ALOMAR Observatory, Andøya, Norway)

The effect of atmospheric clouds and aerosol is a central topic of climate research. This applies not the least to high latitudes which are most sensitive to climate change. The proper description of the radiative forcing effect of clouds requires knowledge of the microphysical properties of the particles such as composition, phase, size distribution and spatial orientation. Lidar sounding is widely used for assessing the cloud radiative properties. With little exception, current lidar systems restrict themselves to the back-scattering geometry. The singular scattering angle of 180° is a serious limitation to the information that can be obtained from such measurements.

The Co-operative Alomar Bi-static Lidar Experiment (CABLE) extends the range of information of lidar data by combining the back-scatter system with a remote receiver admitting the determination of the polarisation state of the laser return at scattering angles between 130° and 160°, depending on the atmospheric height. While bi-static lidar measurements of tropospheric aerosol have been reported earlier, the CABLE study concentrates on high altitude clouds such as layered cirrus and Polar Stratospheric Clouds. The measurements have been carried out at the ALOMAR facility in Northern Norway (69°N, 16°E)using the ALOMAR tropospheric lidar as light source. CABLE is financed by the enhanced ALOMAR Research Infrastructure (eARI) under the 6th Frame Programme of the European Union.

Publications

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Olofson, K. F. G., Svensson, E. A., Witt, G. and Pettersson, J. B. C., Arctic aerosol and clouds studied by bistatic lidar technique, J. Geophys. Res., 114, doi:10.1029/2008JD011138, 2009.

Surface-Active cis-Pinonic Acid in Atmospheric Droplets: A Molecular Dynamics Study

Caroline Leck Thomas Hede: Xin Li, Yaoquan Tu, Hans Ågren (KTH)

Water vapor in the atmosphere can condensate and form cloud droplets when there is a certain amount of humidity and a presence of cloud condensation nuclei (CCN). In addition organic solutes called surfactants can significantly lower the surface tension of water. We here present a molecular dynamics simulation (MD) of the behavior of cis- pinonic acid, a commonly found organic compound in cloud condensation nuclei, and its effect on the surface tension of water clusters. The advantage of MD simulations is that they could provide us the microscopic details, which are often hard to observe experimentally, such as the structures and aggregation formation of aerosol clusters. The simulations specifically showed that the de-crease in surface tension is found to depend on not only the concentration of the organic compound but also the droplet size due to the spontaneous assembly of the surfactant molecules on the droplet surface. This leads to the conclusion that the partitioning of the surfactant between the bulk and surface plays an important role in the behavior of atmospheric aerosol particles and thus in their availability for cloud formation.

Publications

Xin Li, T. Hede , Y. Tu , C. Leck , and H. Ågren, 2010, Surface Active Cis-pinonic Acid in Atmospheric Droplets: A Molecular Dynamics Study. J. Phys. Chem. Lett., 1 (4), pp 769–773, DOI: 10.1021/jz9004784.

HULIS in nanoaerosol clusters; investigations of surface tension and aggregate formation using molecular dynamics simulations

Thomas Hede, Caroline Leck: Xin Li, Yaoquan Tu, Hans Ågren (KTH)

The most widely used theory that describes a process in which water vapor condenses and forms liquid cloud drops was developed by the Swedish meteorologist Hilding Köhler in the beginning of the 20th century and is based on equilibrium thermodynamics. It combines the change in saturation vapor pressure due to a curved surface (the Kelvin effect), and to the solute (the Raoult's effect). At that time only soluble inorganic particles such as sea salt were thought to act as Cloud Condensation Nuclei (CCN). However, present knowledge concerning the aerosol multiphase system has identified that its organic components contribute and play a crucial role in the formation of cloud droplets in their ability to lower the surface tension for the water uptake.

In this study we use molecular dynamics simulations to show that humic-like substances (HULIS) mimic experimental data well when referring to reduction of surface tension, an ability, which could suppress critical water supersaturaion in cloud droplet activation. The finding that HULIS compounds may aggregate inside nano-aerosol clusters could have implications of various aspects when describing and parameterizing CCN and cloud droplets containing HULIS compounds. Even physical and chemical properties of CCN and cloud droplets could be affected by the ability for HULIS compounds to aggregate. Therefore, aggregation formation in aerosols is probably also a key factor in cloud microphysics

Publications

Hede, T., L. T., Xin , Y. Tu , C. Leck , and H. Ågren, 2011, HULIS in nano aerosol clusters; investigations of surface tension and aggregate formation using Molecular Dynamics simulations. Atmos. Chem. Phys. Discuss., 11, 425–452.

Determination of amino acids, proteins and other organic compounds in aerosol specimens

Bodil Widell and Caroline Leck

The influence of organic components of the atmospheric aerosol on the concentration of cloud condensation nuclei (CCN) has recently demonstrated to make a potentially important contribution to the aerosol-cloud-climate system. To obtain quantitative information of the organic components present in the aerosol, one approach is to use size-segregated bulk-chemical mass detection. The advantage with such an approach is that a quantitative determination of a wide spectrum of organic water-soluble and -insoluble organic com-ponents is made possible. The disadvantages are that the organic constituents could not be determined in individual particles and that the determination is confined to particles in the volume/mass range that is to sizes larger than 100 nm diameters. The method described was specifically designed to determine the aerosol content of amino acids and proteins. Size-segregated (diameter 100nm to 10000nm) aerosol mass was collected on Tedlar film-substrates using a high volume Berner impactor followed by an extraction using repeated applications of methanol. The extract was rinsed through a column packed with a cation exchange phase for further isolation of the amino acids and proteins.

For the analyses of non-volatile and polar substances such as amino acids the compouns have to be chemically and/or physically modified before they can be separated on a GC (Gas Chromatograph) column. In this method they were silylated with N-methyl-N-tert-butyldimethylsilyl-trifluoroacetamide (MTBSTFA). Polar hydrogens,-OH, -SH or –NH, were replaced with tert-butyldimethylsilyl (TBDMS) groups which will decrease the capacity for the compounds to bind irreversible to the column wall. The derivates were deter-mined by a High Resolution GC coupled to a High Resolution Mass detector (HRGC-HRMS), r.p. 10 000. The method be applied to samples collected north of 80° during an icebreaker expedition in the summer of 2001.

Glycine in aerosol water droplets: a critical assessment of Köhler theory by predicting surface tension from molecular dynamics simulations

Caroline Leck, Thomas Hede: Xin Li, Yaoquan Tu, Hans Ågren (KTH)

According to the Köhler theory, which describes the nucleation and the equilibrium growth of cloud droplets, the surface tension of an aerosol droplet is one of the most important factors that determine the critical supersaturation of droplet activation. In this study, with specific interest to remote marine aerosol, we predict the surface tension of aerosol droplets by performing molecular dynamics simulations on two model systems, the pure water droplets and glycine in water droplets. The curvature dependence of the surface tension is interpolated by a quadratic polynomial over the nano-sized droplets and the limiting case of a planar interface, so that the so-called Aitken mode particles, which are critical for droplet formation could be covered and the Köhler equation could be improved by incorporating surface tension corrections.

Publications

Xin Li, T. Hede , Y. Tu , C. Leck , and H. Ågren, 2011, Glycine in aerosol water droplets: a critical assessment of Köhler theory by predicting surface tension from molecular dynamics simulations. Atmos. Chem. Phys., 11, 519-527, 2011www.atmos-chem-phys.net/11/519/2011/doi:10.5194/acp-11-519-2011.

Molecular Dynamics Study on the Surface Tension of Atmospheric Water Droplets Containing Amino Acids

Caroline Leck, Thomas Hede: Xin Li, Yaoquan Tu, Hans Ågren (KTH)

Atmospheric amino acids constitute an important fraction of the water-soluble organic nitrogen compounds in both marine and continental aerosol particles, and have been confirmed as effective cloud condensation nuclei materials in laboratory tests, this through their surfactant properties which could suppress critical water supersaturaion in cloud droplet activation. In order to investigate molecular distributions, orientations and induced changes in surface tension we have performed a molecular dynamics study of six types of amino acids in atmospheric water droplets, These amino acids, including serine, glycine, alanine, valine, methionine and phenylalanine, are categorized into hydrophilic and hydrophobic species according to their affinities to water. Different amino acids show distinct effects on the surface tension; even the same amino acid has different influence on the surface tension of planar and spherical interfaces. To improve the Köhler equation in predicting the critical supersaturation of droplet activation, the curvature dependence of the surface tension was modeled by a quadratic polynomial func-tion of the inverse of droplet radius.

Characterization of exopolysaccharides in marine colloid by capillary electrophoresis

Qiuju Gao, Caroline Leck: Åsa Emmer (KTH)

Surface active extracellular polymeric secretions (EPS) from marine microorganisms are abundant in the oceanic surface layers and are predominantly exopolysaccharides (polymers) with a minor fraction of proteins and lipids bound. These polymers can assemble rapidly into gels through divalent ions such as Ca^{2+} and Mg^{2+} forming bridges between adjacent or different sugar chains. Recent studies have demonstrated that EPS can be transported into atmosphere from air-sea interface by bubble bursting and have a substantial contribution on the concentration of cloud condensation nuclei (CCN) causally related to their highly hydrophilic properties. Their typical sizes in the accumulation mode imply that they could act directly as CCN, with hygroscopic growth factors probably initially as large as that of sea salt. Study of marine exopolysaccharides can provide some further insight on the behaviour of EPS and its atmospheric processing and relevance for climate.

Characterization of polysaccharides at molecular level in marine system is complicated by their structural complexity, high degree of stereoisomeric diversity of their monomers and the difficulties to isolate the trace amount of target compounds from high concentrations of sea salt. A method was established to determine monosaccharides liberated from extracellular polysaccharides by acidic hydrolysis using capillary electrophoresis (CE) with indirect UV detection. Tangential flow filtration was used to isolate and concentrate the colloidal polysaccharides with molecular weight higher than 5kDa from seawater. Isolated sample after dialytic desalting was freeze-dried and hydrolyzed with trifluoroacetic acid (TFA) to cleave the glycosidic bond and yield monosaccharides. The residues are exposed to strong cation exchange (SCX) solide phase extraction (SPE) catridge for further cleanup. The CE method using a background electrolyte (BGE) consisting of 2,6-dimethoxyphenol (DMP) and Cetyltrimethylammonium bromide (CTAB), has been optimized. Electroosmotic flow (EOF) was reversed to improve the separation of the isomeric monosaccharides. Under optimized conditions several neutral monosaccharides commonly existing in marine polysaccharides including 3 aldohexoses (glucose, mannose and galactose), 2 deoxysugars (rhamnose and fucose) and 1 aldopentoses (xylose) are excellently separated in the CE system.

Publications

Gao, Q. , M. Araia, C. Leck, and Å. Emmer, Characterization of exopolysaccharides in marine colloids by capillary electrophoresis with indirect UV detection, 2010, Analytica Chimica Acta, Vol. 662, Iss. 2, doi:10.1016/j.aca.2010.01.008.

Monosaccharide compositional analysis of marine polysaccharides by hydrophilic interaction liquid chromatography-tandem mass spectrometry

Qiuju Gao, Caroline Leck: Ulrika Nilsson and Leopold L. Ilag (SU)

A simple and sensitive method was developed using hydrophilic interaction liquid chromatography coupled to tandem mass spectrometry for determination of monosaccharides liberated from marine polysaccharides by acidic hydrolysis. Optimal separation of diastereomeric monosaccharides including hexoses, pentoses, and deoxyhexoses was achieved using an aminopropyl bonded column with mobile phase containing ternary solvents (acetonitrile/methanol/water) in conjunction with MS/MS in SRM mode. Mechanisms for fragmentation of deprotonated monosaccharides with regard to cross-ring cleavage were proposed. Matrix effects from coeluting interferences were observed and isotopic-labeled internal standard was used to compensate for the signal suppression. The method demonstrated excellent instrumental limits of detection (LOD), ranging from 0.7 to 4.2 pg. Method LODs range from 0.9 to 5.1 nM. The proposed method was applied to the analysis of polysaccharides in seawater collected from the open leads of the central Arctic Ocean in the summer of 2008.

Publications

Gao, Q. , U. Nilsson, L. L. Ilag, and C. Leck, and Å. Emmer, 2011, Monosaccharide compositional analysis of marine polysaccharides by hydrophilic interaction liquid chromatography-tandem mass spectrometry. Anal. Bioanal. Chem., DOI 10.1007/s00216-010-4638-z.

Atmospheric Brown cloud (ABC) Asia

Caroline Leck, Henning Rodhe, Lennart Granat and Erik Engström (SMHI), J. Heintzenberg (Institute for Tropospheric Research, Leipzig, Germany), U. Kulshrestha (Indian Institute of Chemical Technology, Hyderabad), P.S.P. Rao (Indian Institute of Tropical Meteorology, Pune, India), Bidya Pradhan (ICIMOD, Khatmandu, Nepal), Praveen Siva (Maldives Climate Observatory, Hanimaadhoo)

The international ABC (www-abc-asia.ucsd.edu) project has been launched in response to the dramatic results obtained during the INDOEX project regarding transport of highly polluted air from the Asian continent out over the Indian Ocean during the winter monsoon season. As a first step observatories have been set up in the S and SE Asian region to monitor the concentration of pollutants and their impact on the radiation balance of the atmosphere. The major scientific objectives of the observatories are:

- To establish continuous chemical and microphysical aerosol observations at key locations in the Indo-Asian-Pacific region with a particular emphasis on black carbon, organics and cloud condensation nuclei. A major thrust of these observatories will be characterization of the aerosol sources based on the analysis of aerosol filters for molecular markers and single particle analysis. The identified sources from the molecular markers will include bio-fuels and other forms of biomass burning; coal combustion; diesel and two-stroke engines. The source characterization will be used by UNEP and the regional governments to develop future strategies to mitigate the impact of Asian air pollution on climate, human health, and the environment.
- To use regional scale source-receptor models in conjunction with the data from observatories and validated satellites to identify the relative contribution of the various Asian regions to the observed aerosol loading.
- To determine direct short-wave and long-wave aerosol radiative forcing at the surface and top of the atmosphere based on aerosol data in conjunction with comprehensive in situ and remote radiometric measurements.
- To relate the aerosol forcing to regional sources of aerosol emissions. The ABC project also includes studies of the effects of the pollutants on human health and on agriculture. Capacity building and dialogue with policy makers are important components.

The main MISU/IMI contribution to ABC (http://www.misu.su.se/abc/) is to seek a better understanding of the atmospheric life cycle of soot. Optical and chemical properties of soot particles in air and precipitation are beeing investigated by means of spectral light absorption, Raman scattering, electron microscopy and chemical multicomponent analyses. MISU contributes to the ABC Climate Observation Program by performing measurements at three stations in the South-Asian region (situated in Nepal, India and Maldives). The above measurements are complemented by the determination of various organic and inorganic (sulfate, nitrate and others) components.

Publications

Ramanathan, V. et al. (including Henning Rodhe) 2008. Atmsopheic Brown Clouds – Regional Assessment with Focus on Asia. United Nations Environmental Programme,

Carbon-14 analysis of soot in ABC

Caroline Leck, Henning Rodhe: Örjan Gustafsson (SU/ITM), Rebecca Sheesley (SU/ITM), Erik Engström, Lennart Granat

A fundamental question in the investigations of the Atmospheric Brown Cloud (ABC-Asia) is the origin of the surprisingly high black carbon (soot) component of the aerosol. The strong absorption of solar radiation by the soot and the resulting impact on the atmospheric energy balance and on climate, makes this question particularly important. In this project aerosol particles are sampled at ABC sites in S Asia. After separation of the soot component it is analysed for its C-14 content in collaboration with the National Ocean Science AMS facility in Wood Hole, USA. Results show that during the winter monsoon period about half of the soot carried out over the Indian Ocean is derived from biomass burning rather than from fossil fuel combustion.

Publications

Gustafsson, Ö., Kruså, M., Zencak, Z., Sheesley, R.J., Granat, L., Engström, E., Praveen, P.S., Rao, P.S.P., Leck, C. and Rodhe, H., 2009, Brown clouds over South Asia: biomass or fossil fuel combustion? Science, 323, 495-498 DOI:10.1126/science.1164857.

Reducing uncertainties associated with filter-based optical measurements of soot aerosol particles with chemical information

Caroline Leck and J. Erik Engström (SMHI)

Of the many identified and potential effects of atmospheric aerosol particles on climate, those of soot particles are the most uncertain, in that analytical techniques concerning soot are far from satisfactory. One concern when applying filter-based optical measurements of soot is that they suffer from systematic errors due to the light scattering of non-absorbing particles co-deposited on the filter, such as inorganic salts and mineral dust. In addition to an optical correction of the non-absorbing material this study provides a protocol for correction of light scattering based on the chemical quantification of the material, which is a novelty. A newly designed Particle Soot Absorption Photometer was constructed to measure light transmission on particle accumulating filters, which includes an additional sensor recording backscattered light. The choice of polycarbonate membrane filters avoided high chemical blank values and reduced errors associated with length of the light path through the filter. Two protocols for corrections were applied to aerosol samples collected at the Maldives Climate Observatory Hanimaadhoo during episodes with either continentally influenced air from the Indian/Arabian subcontinents (winter monsoon) or pristine air from the Southern Indian Ocean (summer monsoon). The two ways of correction (optical and chemical) lowered the particle light absorption of soot by 63 to 61 %, respectively, for data from the Arabian Sea sourced group, resulting in median soot absorption coefficients of 4.2 and 3.5 Mm^{-1}. Corresponding values for the South Indian Ocean data were 69 and 97 % (0.38 and 0.02 Mm^{-1}). A comparison with other studies in the area indicated an overestimation of their soot levels, by up to two orders of magnitude. This raises the necessity for chemical correction protocols on optical filter-based determinations of soot, before even the sign on the radiative forcing based on their effects can be assessed.

Publications

Engström, L.E., and C. Leck, 2010, Reducing uncertainties associated with filter-based optical measurement of soot aerosol particles with chemical information, Atmos. Meas. Tech. Discuss., 3, 1197-1227.

Determination of particulate soot in precipitation using Nuclepore filters and photometric detection

Caroline Leck and Erik Engström (SMHI)

Measurement of light absorbing matter at λ = 550 nm (called soot) in air has been performed for some decades and a handful of methods are available but measurements of soot in precipitation are rare. The pore filtration efficiency and the high blank values of the quarts-fiber filters in use were drawbacks of the available methods. Another drawback was the complicated chemical treatment of the sample.

To overcome the shortcomings a more straightforward method for determination of soot has been developed uses polycarbonate membrane filter (PCMB) for collection. The PCMB filter has higher collection efficiency, which will give both a better reproducibility and lower the detection limit of the method. The method does not include any chemical treatment and is therefore less time consuming and the risk of sample loss during repeated treatments is minimized.

Precipitation is collected with glass funnel and glass bottle in a wet-only collector. The sample is then filtrated through a Nuclepore filter with air pressure. The filter is analyzed on a photometric instrument. The photometric instrument is calibrated to achieve a value of the soot concentration on the filter. This value is then used to calculate the soot concentration in precipitation.

The tests showed that the overall loss of soot due to adsorption during collection and filtration was 22 ± 2 %. The detection limit was estimated to 0.025 in optical density, or 2 ng/ml expressed as a concentration assuming a filtration volume of 30 ml. Analysis of environmental samples have been successfully performed with the described method at the Maldives Climate Observatory Hanimaadhoo and Nepal Climate Observatory. At Maldives the average soot concentration in rain was 0.048 µg/ml and at the Nepal observatory 0.086 µg/ml.

This work is performed as a part of MISU/IMI's contribution to the ABC program. This method is now being implemented at the MISU-monitoring stations. During the sampling periods of precipitation synchronous Particle Soot Absorption Photometer (PSAP) filters are taken for evaluation of scavenging ratios.

Publications

Engström, J. E. and Leck, C.2009.: Determination of water-insoluble light absorbing matter in rainwater using polycarbonate membrane filters and photometric detection, Atmos. Meas. Tech. Discuss., 2, 237-264.

Morphology and state of mixture of atmospheric soot aggregates during the winter season over Southern Asia – a quantitative approach

Caroline Leck and Esther Coz

The atmospheric brown cloud phenomena characterized by a high content of soot and a large impact on the solar radiative heating especially affects the tropical Indian Ocean during the winter season. The present study focuses on morphological characteristics and state of mixture of soot aggregates during the winter season over India. Given are quantitative measures of size, morphology and texture on aggregates collected in air at two different sites: Sinhagad near Pune in India and Hanimaadhoo in Maldives. For the latter site two different synoptic patterns prevailed: advection of air from the Arabian region and from the Indian subcontinent, respectively. Aggregates collected at Sinhagad, were associated with open branched structures, characteristic of fresh emission and diameters between 220 and 460 nm. The Hanimaadhoo aggregates were associated with aged closed structures, smaller sizes (130–360 nm) and frequently contained inorganic inclusions. Those arriving from the Indian subcontinent were characterized by the presence of an additional organic layer that covered the aggregate structure. These organic coatings might be a reasonable explanation of the low average wash-out ratios of soot two to seven times lower than that of nss-SO_4^{2-} that have been reported for air flow arriving at Hanimaadhoo from the Indian subcontinent in winter.

Publications

Coz E., and C. Leck, 2011, Morphology and State of Mixture of Atmospheric Soot-like Aggregates during the Winter Season over Southern Asia – a quantitative approach. Tellus B, 63, 107-116.

Chemical composition of rainwater at Maldives Climate Observatory at Hanimaadhoo (MCOH)

Caroline Leck, Henning Rodhe, Lennart Granat, Ruby Das, Siva Praveen (MCOH, Maldives)

Water-soluble inorganic components in rain deposited at the Maldives Climate Observatory Hanimaadhoo (MCOH) were examined to determine seasonality and possible source regions. The study, which is part of the Atmospheric Brown Cloud (ABC) project, covers the period June 2005 to December 2007. Air mass trajectories were used to separate the data into situations with transport of air from India and adjacent parts of the Asian continent during the months December and January (Indian) and those with southerly flow from the Indian Ocean during the summer monsoon season June September (Marine). A third trajectory group was identified with transport from the northern parts of the Arabian Sea and adjacent land areas during the months March, April and October Arabian Sea). The concentrations of nss-SO_4^{2-}, NH_4^+, NO_3^- and H^+ were more than a 10 factor of 4 higher in the Indian group than in the Marine group. This shows a pronounced influence of continental pollutants during December and January. The average rainwater pH was significantly lower in the Indian group (4.7) than in the Marine group (6.0). The origin of the high concentration of nss-Ca^2 in the Marine group – a factor of 4 to 7 higher than in the Indian group – is unclear. We discuss various possibilities including long-range transport from the African or Australian continents, local dust from nearby islands and calcareous plankton debris and exopolymer gels emitted from the ocean surface. The occurrence of NO_3^- and NH_4^+ in the Marine group suggests emissions from the ocean surface. Part of the NO_3^- could also be associated with lightning over the ocean. Despite the fact that the concentrations of nss-SO_4^{2-}, NO_3^- and NH_4^+ were highest in the Indian group their wet deposition was at least as big in the Marine group reflecting the larger amount of rainfall during the monsoon season. The annual wet deposition of NO_3^-, NH_4^+ and nss-SO_4^{2-} at MCOH is about a factor of three lower than observed at rural sites in India.

Publications

Das, R., L. Granat, C. Leck, P. S. Praveen, and H. Rodhe, 2011, Chemical composition of rainwater at Maldives Climate Observatory at Hanimaadhoo (MCOH). Atmos. Chem. Phys., 11, 3743-3755.

Washout ratio of black carbon in the Maldives

Granat, E. Engström, H. Rodhe and, S. Praveen (Maldives Climate Observatory Hanimaadhoo)

A unique set of data has been collected from simultaneous measurements of black carbon (BC) in rain water and in surface air aerosols at the Hanimaadhoo monitoring site in the Maldives in the Indian Ocean. The measurements were initiated during the period 19-24 October 2004 as a part of the Atmospheric Brown Cloud (ABC) APMEX campaign. Additional data were collected during 2005 - 2008.

The washout ratio for BC is compared to that of nss-sulfate and other soluble compounds. The results indicate that the washout ratio for BC is systematically smaller than that of nss-sulfate. The BC washout ratio is also smaller in air masses having passed recently over source areas on the Indian subcontinent compared to cleaner air masses originating from the southern parts of the Indian Ocean. This information has a bearing on the life time of BC in the atmosphere and will provide useful input to those who model the long-range transport of BC.

Publications

Granat, L., Engström, J.E., Praveen, S. and Rodhe, H. 2010, Light absorbing material (soot) in rainwater and in aerosol particles in the Maldives, J. Geophys. Res. 115, D16307, doi: 10.1029/2009JD013768,2010.

Soil sensitivity to acidification in Asia

H. Rodhe, K. Hicks, A. Owen and J.C. Kuylenstierna (Stockholm Environment Institute, York, UK), F. Dentener (Joint Research Institute, Ispra, Italy), A. Owen and H. M. Seip (Oslo University, Norway)

Exceedance of steady-state critical loads for soil acidification is consistently found in southern China and parts of SE Asia, but there is no evidence of impacts outside of China. This study describes a methodology for calculating the time to effects for soils sensitive to acidic deposition in Asia under potential future Sulfur (S), Nitrogen (N), and Calcium (Ca) emission scenarios. The calculations are matched to data availability in Asia to produce regional-scale maps that provide estimates of the time (y) it will take for soil base saturation to reach a critical limit of 20% in response to acidic inputs.

The results show that sensitive soil types in areas of South, Southeast, and East Asia, including parts of southern China, Burma, Hainan, Laos, Thailand, Vietnam, and the West-ern Ghats of India, may acidify to a significant degree on a 0–50 y timescale, depending on individual site management and abiotic and biotic characteristics. To make a clearer as-sessment of risk, site-specific data are required for soil chemistry and deposition (especially base cation deposition); S and N retention in soils and ecosystems; and biomass harvesting and weathering rates from sites across Asia representative of different soil and vegetation types and management regimes. National and regional assessments of soils using the simple methods described in this paper can provide an appreciation of the time dimension of soil acidification–related impacts and should be useful in planning further studies and, possibly, implementing measures to reduce risks of acidification.

Publications

Hicks, W.K., Kuylenstierna, J.C.I., Owen, A., Dentener, F., Seip, H.-M. and Rodhe, H. 2008. Soil sensitivity to acidification in Asia: status and prospects. Ambio 37, 295-303.

MODELLING OF TROPOSPHERIC CHEMISTRY

Sea spray aerosol emission inventory

Annica Ekman, Hamish Struthers (SU/ITM), Paul Glantz (SU/ITM), Monica Mårtensson (SU/ITM), Douglas Nilsson (SU/ITM)

Global and polar sea spray emission inventories have been calculated based on a commonly used sea salt aerosol source parameterization in combination with IPCC model output from the WCRP's CMIP3 multi-model dataset. Model output (sea ice cover, 10 meter wind speed, surface water temperature) from 1870 to 2000 and projections from 2000 to 2100 (SRES A1B) were compiled. This provides the necessary information to estimate sea spray emission changes from 1870 to 2100. Results show that for temperate oceans (55°S-65°N), both changes in wind speed and sea surface temperature play a role in the projected change in sea spray aerosol emissions. In the Arctic, sea ice cover is the main driver of changes in sea spray emissions whereas wind speed is the dominant parameter in the southern polar region.

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Sub-micrometer aerosol particles in the upper troposphere/lowermost stratosphere (UT/LMS) region as measured by CARIBIC and modeled using the MIT-CAM3 Global Climate Model

Annica Ekman, Markus Hermann (IFT-Leipzig, Germany), Peter Groß (IFT-Leipzig, Germany), Jost Heintzenberg (IFT-Leipzig, Germany), Dong-Chul Kim (MIT, Cambridge, USA), Chien Wang (MIT, Cambridge, USA)

Near-global distributions of sub-micrometer aerosol particle concentrations in the UT/LMS region obtained from the CARIBIC project (Civil Aircraft for Regular Investigation of the Atmosphere Based on an Instrument Container) with global model simulations using the MIT-CAM3. The MIT-CAM3 is a state-of-the art global climate model with a two-moment interactive aerosol physics and chemistry module involving seven different aerosol compounds and mixtures. The main aim of the comparison is to learn more about what governs the formation as well as spatial and temporal distribution of the UT/LMS sub-micrometer aerosol. Furthermore, we investigate the performance of a state-of-the-art global climate model in terms of its representation of aerosol processes (and the interaction of aero-sols with clouds) in the UT/LMS, which may indicate where more general model improvement and development is needed.

Developing a module for aerosol physics and chemistry within the global climate model EC-Earth

Annica Ekman, Anna Lewinschal, Twan van Noije (KNMI, the Netherlands), Richard Bintanja (KNMI, the Netherlands), Trude Storelvmo (Yale University, USA), Michael Kahnert (SMHI) and the EC-Earth community.

Aerosols may impact on climate directly through scattering and absorbing sunlight and indirectly by acting as cloud condensation nuclei, thereby altering the physical and radiative properties of clouds. As a first step towards describ-ing aerosol effects on clouds and climate within EC-Earth, time-varying, monthly averaged aerosol mass fields from AEROCOM (Chen and Penner, 2005; Penner et al. 2006) and CMIP5 (http://cmip-pcmdi.llnl.gov/cmip5/) have been introduced to describe the atmospheric aerosol population. The fields include anthropogenic and natural sulfate, black carbon, anthropogenic and natural organic carbon, mineral dust and sea salt. The division into natural and anthropogenic aerosol mass makes it possible to perform simulations for both pre-industrial and present day conditions.

The aerosol mass fields have also been coupled to the radiation scheme within EC-Earth using specified extinction coefficients for the five different aerosol components. This implementation makes it possible to perform simulations of aerosol direct effects on climate using EC-Earth. In Lohmann et al. (2010), estimates of the aerosol direct effect and indirect effect derived using the EC-Earth model have been compared with other state-of-the-art climate model estimates. The results produced by EC-Earth are of comparable magnitude to the other model results, which indicates that the aerosol module introduced in EC-Earth, and its interaction with the model meteorology, is physically sound.

The most recent part of the development of the aerosol-chemistry module within EC-Earth has been to couple a fully interactive chemistry and aerosol model (TM5/M7) with the atmospheric part of EC-Earth. At the moment, it is possible to conduct interactive atmosphere-chemistry-aerosol simulations but the chemical compounds (e.g. greenhouse gases and aerosols) cannot yet impact on clouds and radiative processes in the model. This work is still in progress.

Publications

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Correlation of aerosols with meteorological variables in aerosol-cloud related studies

Anders Engström, Annica Ekman

Studies of the correlation between aerosol optical depth and cloud fraction suggest that variations in cloud fraction can at least to some extent be explained by variations in aerosol optical depth. However, the correlation cannot unequivocally be linked to a microphysical impact of aerosols on clouds. It is likely that the previously observed correlation between aerosols and cloud properties is a combination of many effects, including the microphysical connection. Using meteorological analysis data from the European Center for Medium-Range Weather Forecasts (ECMWF) the correlation between aerosol optical depth and cloud fraction is examined while controlling for variations in a number of meteorological variables that can be assumed to correlate with both cloud fraction and aerosol optical depth. As a consequence of including meteorological information in the analysis the validity of a linear independent relationship between aerosol optical depth and cloud fraction is significantly reduced. The results further highlight the need to examine all possible correlations with meteorological variables in aerosol-cloud related studies.

Publications

Engström, A. and Ekman, A. M. L. (2010), Impact of meteorological factors on the correlation between aerosol optical depth and cloud fraction. Geophysical Research Letters, 37, L18814, doi: 10.1029/2010GL044361

Aerosol-cloud interaction in shallow and deep convective clouds

Annica Ekman, Radovan Krejci (SU/ITM), Anders Engström, Anders Söderberg, Chien Wang (MIT, Cambridge, USA), Johan Ström (SU/ITM), Marian de Reus (Univ. Mainz, Germany), Jonathan Williams (MPI-Mainz, Germany), Meinrat O. Andreae, (MPI-Mainz, Germany)

Convective clouds are important components of the Earth's climate system. They play a significant role in the transfer of heat, energy and chemical constituents between the Earth's surface and the free troposphere. This is particularly true in the tropics, where consistently warm surface temperatures and high surface air humidity result in many deep convective cloud systems. In this research project, a 3-D cloud-resolving non-hydrostatic model is utilized together with in-situ observations to examine aerosol-cloud interactions. The model domain covers approximately 200x200x30 km3 with a spatial resolution of 500-2000 km horizontally and 200-400 m vertically. A two-moment aerosol module (predicting aerosol number concentration and mass) for four different aerosol modes (nucleation, Aitken, accumulation and coarse aerosols) is interactively coupled to the CRM. The CRM is used to study both how aerosols, which are necessary for cloud formation, affect convective cloud properties as well as how the cloud processing affects the aerosol population itself. Clean episodes are put in contrast to polluted events to explore how the climate system works under pristine conditions and under anthropogenic influence. To evaluate the model, measurements from different aircraft campaigns are utilized.

Publications

Ekman, A. M. L., Engström, A., Wang, C., 2007. The effect of aerosol composition and concentration on the devel-opment and anvil properties of a continental deep convective cloud. Q. J. R. Meteorol.. Soc., 133, 1439-1452.

Ekman, A. M. L., Krejci, R., Engström, A., Ström, J., deReus M., Williams, J., Andreae, M. O., 2008. Do organics contribute to small particle formation in the Amazonian upper troposphere? Geophys. Res. Lett., 35, L17810, doi:10.1029/2008GL034970.

Engström, A., Ekman, A. M. L., Krejci, R., DeReus, M., Ström, J., Wang, C., 2008. Observational and Modelling Evidence of Tropical Deep Convective Clouds as a Source of Mid-Tropospheric Accumulation Mode Aerosols. Geophys. Res. Lett., 35, L23813, doi:10.1029/2008GL035817.

Ekman, A. M. L., Engström, A., Söderberg, A. 2011. Impact of two-way aerosol-cloud interaction and changes in aerosol size distribution on simulated aerosol-induced deep convective cloud sensitivity. Journal of the Atmospheric Sciences, in press.

Albedo, clouds, aerosols and global climate

Frida Bender, Henning Rodhe, Annica Ekman and Robert Charlson (University of Washington, Seattle) in collaboration with others

The objectives of this project are to estimate the impact of aerosols and clouds on global climate and to identify feedbacks in the climate system as well as in climate models. The relative stability of global temperature during Holocene strongly suggests that negative feedbacks operate in the climate system. In view of their strong impact on global albedo, it is also very likely that clouds play an important role in such feedback processes. Analysis of output from GCMs (clouds, albedo etc) and of satellite observations is one of the main activities of this project

The atmospheric component of the community climate system model (CCSM3), CAM3.0, was used to conduct a series of experiments to investigate the influence of GCM tuning on climate sensitivity [Bender, 2008]. Cloud parameterizations, that are not well-constrained by observations, are altered in order to achieve agreement with available observations of top of the atmosphere radiative budget. It is found that the tuning does affect the model's climate sensitivity, but that the effect is comparatively small.

The aerosol emissions due to the volcanic eruption of Mount Pinatubo in 1991 caused a large perturbation to the planetary albedo and the climate system, captured by satellite observations, and simulated in many GCMs. It thereby offers an opportunity to evaluate model performance and to study the climatic impact of such a radiative perturbation. Modeles and observations show a general agreement with regard to magnitude and time scale of radiative perturbation and subsequent temperature perturbation. In an ensemble of models, a relationship is found between sensitivity to the volcanic eruption (defined as temperature response scaled by radiative perturbation), and climate sensitivity (measured as temperature response to a CO_2 doubling). If the same relationship is valid for the real climate system, the measurable volcanic sensitivity can be used to estimate climate sensitivity (Bender et al., 2009).

The planetary albedo appears to have remained stable, as seen in satellite observations for the past decades and deduced from temperature records on longer time scales, But in an ensemble of climate models forced by strong CO_2 increase the planetary albedo significantly decreases, in some cases leading to positive feedbacks similar in magnitude to the CO_2 forcing itself (Bender, 2011). The albedo decrease can be ascribed to surface changes, i.e. retreat of snow and ice cover, on which the models agree well, and changes in cloud cover and cloud properties. This cloud contribution to the negative albedo trend is found to vary largely among models, and to be correlated with climate sensitivity. In high-sensitivity models the clouds generally act to enhance the negative surface-albedo trend, whereas in low-sensitivity models the cloud changes rather counteract the surface albedo trend. This illustrates the importance of shortwave cloud response to global warming in determining climate sensitivity in global models.

Publications

Bender, F. A-M. (2008) A note on the effect of GCM tuning on climate sensitivity, Environ. Res. Lett. 3, 1

Bender, F. A-M., Ekman, A. M-L. and Rodhe, H. (2009) Response to the eruption of Mount Pinatubo in relation to climate sensitivity in the CMIP3 models, Clim. Dynam., 35:875-886

Bender, F. A-M. (2011) Planetary albedo in strongly forced climate, as simulated by the CMIP3 models, accepted for publication, Theor. Appl. Climatol.

Global warming and Climate sensitivity

S. Schwartz (Broohaven Ntl. Lab., USA), R.J. Charlson (Univ. of Washington, Seattle, USA), Henning Rodhe and a few others

The observed increase in global mean surface temperature (GMST) over the industrial era is less than 40% of that expected from observed increases in long-lived greenhouse gases together with the best-estimate equilibrium climate sensitivity given by the 2007 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Possible reasons for this warming discrepancy are systematically examined here. The warming discrepancy is found to be due mainly to some combination of two factors: the IPCC best estimate of climate sensitivity being too high and/or the greenhouse gas forcing being partially offset by forcing by increased concentrations of atmospheric aerosols; the increase in global heat content due to thermal disequilibrium accounts for less than 25% of the discrepancy, and cooling by natural temperature variation can account for only about 15%.

Publications

Schwartz, S.E., Charlson, R.J., Kahn, R.A., Ogren, J.A. and Rodhe, H. 2010, Why hasn't Earth warmed as much as expected? J. Climate 23, 2453-2464. DOI 10.1175/2009JCLI3461.1

ASCOS (The Artic Summer Cloud Ocean Study)

Caroline Leck and Michael Tjernström

See Arctic Studies

The horizontal and vertical distribution of atmospheric DMS in the high artic region

Jenny Lundén, Gunilla Svensson, Caroline Leck, Laurent Brodeau, and Michael Tjernström

See Arctic Studies

On the potential contribution of open lead particle emissions to the central Arctic aerosol concentration

Caroline Leck, Michael Tjernström: Andreas Held (University of Bayreuth, Germany), Ian M. Brooks (Leeds University, UK)

See Arctic Studies

Measurements of bubble size spectra within leads in the Arctic summer pack ice

Caroline Leck, Michael Tjernström: Sara Norris, Ian Brooks, Barbara Brooks and Cathryn Birch (Leeds University, UK), Gerrit de Leeuw (Finnish Meteoroloical Institute), Anders Sirevaag (University of Bergen, Norway)

See Arctic Studies

Modeling the greenhouse Arctic Ocean and climate effect of aerosols

Annica Ekman, Douglas Nilsson (SU/ITM), Hamish Struthers (SU/ITM), Monica Mårtensson (SU/ITM), Margareta Hansson (SU/Natgeo), Radovan Krejci (SU/ITM), Johan Ström (SU/ITM), Peter Tunved (SU/ITM), Åke Hagström (Kalmar Högskola)

See Arctic Studies

The properties of the surface microlayer of the open leads and the ocean mixed layer in the central Arctic Basin pack ice area

Caroline Leck, Qiuju Gao, Patricia Matrai (Bigelow Laboratory, USA) and Monica Orellana (University of Washington, Seattle, USA)

See Arctic Studies

Biogenic particles over the central Arctic Ocean

Caroline Leck, Keith Bigg and Rachel Chang (Univerity of Toronto, Canada)

See Arctic Studies

Free amino acids in aerosol samples collected over the Central Arctic Ocean in summer

Bodil Widell and Caroline Leck

See Arctic Studies

The fractal structure of marine nanogels: a new perspective on particle formation

Caroline Leck and Esther Coz

See Arctic Studies

A Study of New Particle Formation in the Marine Boundary Layer Over the Central Arctic Ocean using a New Flexible Multicomponent Aerosol Dynamic Model

Caroline Leck: Matthias Karl (NILU, Norway), Liisa Pirjola (University of Helsinki, Helsinki, Finland) and Allan Gross (Danish Meteorological Institute, Denmark)

See Arctic Studies

Cloud Condensation Nuclei Closure Study on Summer Arctic Aerosol

Caroline Leck: Maria Martin, Berko Sierau, Ulrike Lohman (ETH, Schwitzerland, Rachel Y. –W. Chang, J.P.D. Abbat (University of Toronto, Canada) Staffan Sjögren, Erik Swietlicki (Lund University)

See Arctic Studies

Marine microgels: a source of CCN in the high Arctic

Caroline Leck: Mónica V. Orellana and Allison M. Lee (Institute for Systems Biology, Seattle, USA), Patricia A. Matrai and Carlton D. Rauschenberg (Bigelow Laboratory for Ocean Sciences, Maine, USA), Esther Coz (MISU, CIEMAT, Madrid, Spain)

See Arctic Studies

Tropospheric long range transport of a forest fire plume to the central summer arctic

Michael Tjernström and Caroline Leck: Erik Swietlicki (Lund University), Armin Wisthaler and Armin Hansel (University of Insbruck)

See Arctic Studies

A low-CCN cloud regime in the summer Arctic

Michael Tjernström, Caroline Leck: Thorsten Mauritsen (Max-Planck Institute for Meteorology, Hamburg, Germany), Joseph Sedlar (SMHI), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA), Staffan Sjögren and Erik Swietlicki (Lund University), Berko Sireau (ETH, Zurich, Switzerland), Ian Brooks (Leeds University, UK)

See Arctic Studies

The vertical stratification of submicrometer aerosol particles and their relevance for cloud formation over the Arctic Ocean pack ice during summer - a contribution to the Arctic Summer Cloud Ocean Study (ASCOS)

Caroline Leck, Linda Orr, Joeseph Sedlar (SMHI) Barbara. Brooks, Sarah Norris (University of Leeds, UK), Erik Swietlicki and Staffan Sjögren (Lund University)

See Arctic Studies

Observations of aerosols and optically thin clouds in the Arctic from a space-borne lidar

Abhay Devasthale (SMHI), Michael Tjernström, Joe Sedlar, K.-G. Karlsson and Colin Jones (SMHI), Mannu Anna Thomas (University of East Anglia, UK), Ali Omar (NASA Langley, USA)

See Arctic Studies

ADDITIONAL PUBLICATIONS: CHEMICAL METEOROLOGY

Kim, D., Wang, C., Ekman, A. M. L., Barth, M. C. and Rasch, P. J., 2008. Distribution and Direct Radiative Forcing of Anthropogenic Aerosols in an Interactive Size-Resolving Aerosol-Climate Model. J. Geophys. Res., 113, D16309, doi:10.1029/2007JD009756

Rockström, J. et al. (27 co-authors, including H. Rodhe) 2009, A safe operating space for humanity. Nature 461, 472-475

Rockström, J. et al. (27 co-authors, including H. Rodhe) 2009, Planetary Boundaries: Exploring the safe operating space for humanity. Ecology and Society, 14(2): 32.

ATMOSPHERIC PHYSICS

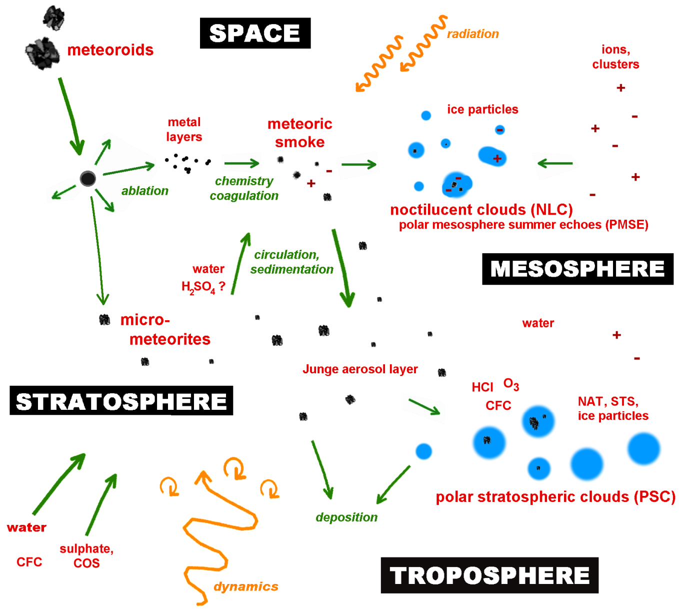
The Atmospheric Physics group (AP) at MISU/IMI continues its research programme on the aeronomy of the middle atmosphere. Focussing on the altitude range 10-100 km, the field of research of our Atmospheric Physics group concerns in particular radiative and chemical interactions of aerosols and trace gases as well as the dynamical and chemical coupling between different regions of the atmosphere. In the middle atmosphere, aerosol particles of interest include ice clouds, particles of meteoric origin, and the background aerosol formed by conversion from various gases.

Noctilucent clouds seen from Stockholm. At an altitude of 82-84 km, these mesospheric clouds are the highest clouds in the Earth's atmosphere.

Our research programme in this field includes a wide range of experimental and theoretical techniques. The experimental component aims at the development, improvement and application of measuring techniques, including sounding rockets, satellites, balloons and ground-based instruments. Spectroscopic techniques and particle microphysics are examples of particular competence. Model studies are essential to put our experimental results in a larger perspective of understanding the middle atmosphere. Our model studies range from the microphysics of particle formation to global dynamics.

The long-term goals for our atmospheric physics programme at IMI/MISU are:

- to establish the distributions and properties of important trace gases, aerosols and clouds in the middle atmosphere,
- to understand underlying transport processes and the dynamical coupling between various parts of the atmosphere,
- to obtain a better understanding of the microphysical, radiative, and chemical interactions that determine the properties and variability of trace gases, aerosols, and clouds.



A schematic of the middle atmospheric aerosol. The properties and distribution of clouds and aerosol particles in the middle atmosphere are closely coupled to dynamical and radiative influences from the lower atmosphere and from space.

MESOSPHERIC CLOUDS, AEROSOLS AND COMPOSITION

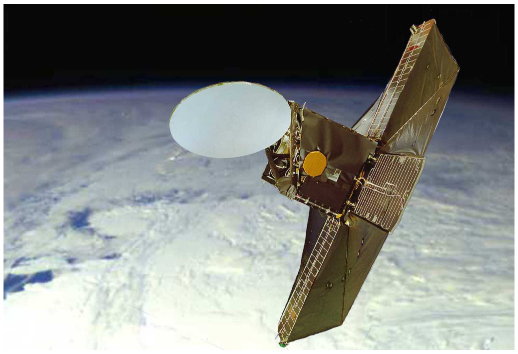
The Swedish Odin satellite has now been in orbit for 10 years, still providing a vast amount of valuable measurements. Odin-related studies continue to take up a major part in MISU/IMI's Atmospheric Physics activities. We are involved in both instruments on the satellite, i.e. the Optical Spectrograph and Infrared Imaging System (OSIRIS) and the Sub-Millimetre Receiver (SMR). During the recent two years, our studies have concerned both the mesospheric and stratospheric mission of Odin.

The interaction of radiative, chemical and dynamic processes in the Earth's mesosphere gives rise to a variety of phenomena like noctilucent clouds (NLC), the ablation and transformation of meteoric material, or the Earth's nightglow. The study of these phenomena and the related chemical and aerosol species is a central research topic for the MISU/IMI Atmospheric Physics group. Rocket-borne in situ measurements are essential tools for the analysis of these complex interactions. Only sounding rockets can provide detailed measurements of the small-scale processes and interactions that govern many of these mesospheric phenomena.

The mesospheric mission of the Odin satellite

Jacek Stegman, Jörg Gumbel, Kristoffer Hultgren, Jonas Hedin, Georg Witt, Bodil Karlsson (currently at Laboratory of Atmosphere and Space Physics, University of Colorado at Boulder, USA), Stefan Lossow (now at Karlsruhe Institute of Technology, Germany)

The main scientific goal of Odin is to explore the middle and upper atmosphere. Since the end of the astronomic part of the Odin mission, the satellite has been fully devoted to atmospheric studies. The two instruments onboard are the submillimetre/millimetre receiver (SMR) and the Optical Spectrograph and InfraRed Imager System (OSIRIS). The Odin mission involves close co-operation with a number of scientific groups from the other participating nations – Canada, France and Finland. Odin is the third scientific satellite in a series of Swedish small satellite projects supported by Swedish National Space Board and other national agencies. It is today operated as an ESA Third Part Mission.



The Swedish-led Odin satellite was launched on February 20, 2001, as a co-operative effort of Sweden, France, Finland and Canada.

Odin provides observations of the Earth's limb during fifteen near-polar orbits each day. In recent years the observation programme for the mesosphere has been significantly expanded with daily measurements up to 110 km during the cold summer mesosphere season. A particular focus of these measurements is on the properties and climatology of mesospheric ice layers (noctilucent clouds, NLC). These data have also given us important new insights into the dynamic coupling between different parts of the atmosphere. The Atmospheric Physics group remains strongly engaged in Odin's entire aeronomy programme and the management of the mission

Studies of noctilucent clouds

Jörg Gumbel, Kristoffer Hultgren, Bodil Karlsson, Heiner Körnich, Jacek Stegman, Georg Witt

Noctilucent clouds (NLC) at about 82 km and their mesospheric environment continue to play a central role in MISU's atmospheric physics research. During the summer months, NLCs are observed as a virtually complete cloud cover at latitudes above 70° and with sporadic occurrence at latitudes down to 50°. The OSIRIS optical spectrometer onboard the Odin satellite provides unique opportunities to study not only the seasonal and geographical NLC climatology, but also NLC particle properties by means of spectral analysis over a broad range of wavelengths.

The spectral analysis has been applied to the study of NLC properties as a function of season and latitude. The long database now available allows us to perform comprehensive studies of year-to-year variability, which in many cases can be related to the dynamical conditions in the middle atmosphere. Many of these efforts are carried out within international collaborations. A network on NLC particle size retrievals has been established in 2008, involving various satellite-borne and ground-based studies.

In 2009, the Atmospheric Physics group organised the 9th International Workshop on Layered Phenomena in the Mesopause Region (LPMR) near Stockholm. A special issue with publications from this workshop is in print in the Journal of Atmospheric and Solar-Terrestrial Physics.

Publications

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Siskind, D. E., M. Hervig, J. Gumbel, M. H. Stevens, Polar mesospheric cloud mass and the ice budget: 3. Application of a coupled ice-chemistry-dynamics model and comparison with observations, J. Geophys. Res., 112, D08303, doi:10.1029/2006JD007499, 2007.

What caused the exceptional mid-latitudinal noctilucent cloud event in July 2009?

Kristoffer Hultgren, Heiner Körnich, Jörg Gumbel, Georg Witt, in collaboration with Michael Gerding and Peter Hoffmann (Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany), Stefan Lossow (Karlsruhe Institute of Technology, Germany), Linda Megner (Canadian Space Agency, Montréal, Canada)

Noctilucent Clouds (NLCs) are rarely observed at mid-latitudes. In July 2009, strong NLCs were recorded from both Paris and Nebraska, located at latitudes 48°N and 41°N, respectively. The main focus of this work is on the atmospheric conditions that have led to NLCs at these latitudes. We investigate to what extent these clouds may be explained by local formation or by transport from higher latitudes. The dynamical situation is analyzed in terms of wind fields created from Aura/MLS temperature data and measured by radar. We discuss possible tidal effects on the transport and examine the general planetary wave activity during these days. The winds do not seem sufficient to transport NLC particles long southward distances. Hence a local formation is rather likely. In order to investigate the possibility of local NLC formation, the CARMA microphysical model has been applied with temperature data from MLS as input. The results from the large-scale datasets are compared to NLC observations by Odin and to local NLC, temperature and wind measurements by lidar and radar. The reason for the exceptional NLC formation is most likely a combination of local temperature variations by diurnal tides, advantageously located large-scale planetary waves, and general mesospheric temperature conditions that were 5–10 K colder than in previous years. The results also point to that NLCs are very unlikely to occur at latitudes below 50°N during daytime. This conclusion can be made from a tidal temperature mode with cold temperatures during nighttime and temperatures above the limit for NLC occurrence during daytime. The best time for observing mid-latitude NLCs is during the early morning hours.

Publications

Hultgren, K., H. Körnich, J. Gumbel, M. Gerding, P. Hoffmann, S. Lossow, and L. Megner, What caused the exceptional mid-latitudinal Noctilucent Cloud event in July 2009, J. Atmos. Terr. Phys., in press, doi:10.1016/j.jastp.2010.12.008, 2010.

Mesospheric measurements of water vapour

Mikhail Khaplanov, Jörg Gumbel, Jacek Stegman, Georg Witt, in collaboration with Stefan Lossow (now at Karlsruhe Institute of Technology, Germany), J. Urban, P. Eriksson and Donal Murtagh (Chalmers University of Technology, Sweden)

The Atmospheric Physics group continues to develop and apply instruments for the measurement of water vapour in the stratosphere and mesosphere. Our sensitive technique utilises the photolysis of water molecules by ultraviolet light and the subsequent fluorescence emission from hydroxyl radicals mainly in the 0-0 vibrational band around 310 nm. For balloon-borne measurements in the stratosphere, a "solar blind" daytime version of the technique has been developed using OH fluorescence in the 1-0 vibrational band near 290 nm. Different versions of compact balloon hygrometers have been developed that are fully self-contained with power supply and data acquisition. This design allows flexible and easy use in balloon campaigns. Both the stratospheric and mesospheric hygrometer developments are closely connected to the water vapour measurements by the Odin satellite, to the MAGIC rocket campaign and to our modelling studies in the middle atmosphere.

Complete measurements of the water vapour distribution from the tropopause to the mesopause have been obtained from simultaneous in-situ rocket and balloon measurements during the Hygrosonde-2 campaign (Esrange, December 16, 2001) and the MAGIC campaign (Esrange, January 10, 2005), complemented by overflights of the Odin satellite. Three rocket campaigns addressing the distribution of middle atmosphere water vapour have now been performed during winter conditions in the vicinity of the polar vortex. The comparison of the *in situ* results to meteorological data has revealed new details on small scale transport throughout the middle atmosphere. In general, these measurements suggest an extension of the polar vortex well into the mesosphere. Horizontal humidity gradients in the vicinity of the vortex boundary were found to be significantly larger than suggested by current 2D model studies.

At the same time, the Atmospheric Physics group continues close collaboration concerning global water vapour measurements by the sub-millimetre radiometer (SMR) onboard the Odin satellite. Water vapour is a tracer of dynamical processes and the studies conducted so far indicate that water vapour variability on different spatial and time scales provide excellent diagnostic tools to investigate the underlying dynamical processes. New exciting results on mesospheric water vapour have also resulted from our involvement in ultraviolet water retrievals based on OH fluorescence spectroscopy. This technique is now being applied to Odin/OSIRIS.

Publications

Lossow, S., M. Khaplanov, J. Gumbel, J. Stegman, G. Witt, P. Dalin, S. Kirkwood, F. J. Schmidlin, K. H. Fricke, and U. Blum: Middle atmospheric water vapour and dynamics in the vicinity of the polar vortex during the Hygrosonde-2 campaign., Atmos. Chem. Phys. Discuss., 8, 12227-12252, 2008.

Lossow, S, Observations of water vapour in the middle atmosphere, Ph.D. thesis, Department of Meteorology, Stockholm University, 2008.

Urban, J., , N. Lautié, D. P. Murtagh, P. Eriksson, Y. Kasai, S. Lossow, E. Dupuy, J.deLaNoë, U. Frisk, M. Olberg, E. Le Flochmoën, P. Ricaud: Global observations of middle atmospheric water vapour by the Odin satellite: An overview. Planet. Space Sci., 55, 9, 1093-1102, 2007.

Lossow, S., J. Urban, P.Eriksson, D. P.Murtagh, and J.Gumbel: Critical parameters for the retrieval of mesospheric water vapour and temperature from Odin/SMR limb measurements at 557 GHz., Adv. Space Res., 40, 6, 835-845, 2007.

Lossow, S., J. Urban, J. Gumbel, P. Eriksson and D. Murtagh: Observations of the semi-annual oscillation (MSAO) in water vapour by Odin/SMR, Atmos. Chem. Phys, 8, 6527 - 6540, 2008.

Lossow, S., J. Urban, H. Schmidt, D. R. Marsh, J. Gumbel, P. Eriksson and D. Murtagh: Wintertime water vapour in the polar upper mesosphere and lower thermosphere – First satellite observations by Odin/SMR., J. Geophys. Res., 114, D10304, doi:10.1029/2008JD011462, 2009.

Stevens, M. H., J. Gumbel, M. Khaplanov, G. Witt, R. L. Gattinger, D. A. Degenstein, and E. J. Llewellyn, First UV satellite observations of mesospheric water vapour, J. Geophys. Res., doi:10.1029/2007JD009513, 2008.

Lossow, S., M. Khaplanov, J. Gumbel, J. Stegman, G. Witt, P. Dalin, S. Kirkwood, F. J. Schmidlin, K. H. Fricke, and U. Blum: Middle atmospheric water vapour and dynamics in the vicinity of the polar vortex during the Hygrosonde-2 campaign., Atmos. Chem. Phys. Discuss., 8, 12227-12252, 2008.

Mesospheric ozone retrievals from the Hartley Band

Jonas Hedin, Jörg Gumbel

The Hartley Band of ozone at ultraviolet wavelengths below 300 nm gives rise to significant absorption in the limb direction up to above 80 km. This is utilised to retrieve global mesospheric ozone concentrations from measurements by the Optical Spectrograph and Infra-Red Imager System (OSIRIS) onboard the Odin satellite. By analyzing the spectral dependence of the limb Rayleigh signal in the Hartley Band, ozone densities can be retrieved in the lower mesosphere between 55 and 75 km. This complements the Canadian OSIRIS standard ozone product from longer wavelengths (up to 60 km) and new OSIRIS ozone retrievals from the O_2 Atmospheric Band (above 70km).

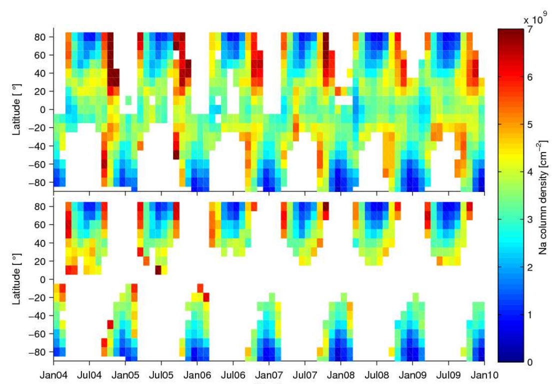
Studies of the mesospheric metal layers

Jonas Hedin, Jörg Gumbel

The source of the metal layers in the upper mesosphere between 80 and 105 km is the ablation of approximately 10-100 tons of interplanetary dust that enter the atmosphere each day. Observations of dayglow spectra by the Optical Spectrograph and InfraRed Imager System (OSIRIS) onboard Odin provide a global database for the climatology of the mesospheric sodium, potassium and iron layers. These atoms are part of a number of chemical cycles involving both ions and neutral species. Our study addresses the relationship between the free sodium density and the dynamic and chemical evolution of the mesopause region. Obviously, sodium and related compounds are also closely connected to the objectives of the PHOCUS rocket project with its focus on metallic condensates in the mesosphere. The following scientific topics are addressed in this study:

- global climatology of sodium layer
- vertical structure of the layer and its relation to NLC
- chemical modelling of the sodium layer

More than eight years of Na D limb observations of the Na D dayglow at 589 nm are now available. A robust retrieval algorithm has been developed based on a detailed radiative transfer model and the Optimal Estimation Method. This provides individual sodium density profiles with a typical accuracy of 20% and altitude resolution of 2 km. Column abundances and density profiles have been validated against the Na lidars at Fort Collins (41°N, 105°W) and at Urbana (40°N, 88°W).



Time-latitude plot showing the monthly mean morning Na column density in zonally averaged 10° latitude bins from January 1,2004 to December 31, 2009. Data are shown för those months and latitude bins where the number retrieved sodium density profiles with solar zenith angles < 92° exceeds 25. The Na D dayglow can not be measured during the dark winter months.

Tomographic studies of noctilucent clouds

Kristoffer Hultgren, Jörg Gumbel, in collaboration with D. A. Degenstein and A. E. Bourassa (University of Saskatchewan, Canada)

Limb-scanning satellites like Odin can provide global information about the vertical structure of polar mesospheric clouds. However, information about horizontal structures usually remains limited. This is due to both a long line of sight and a long scan duration. On six days during the northern hemisphere summer 2010, Odin was operated in a special mesospheric mode with short limb scans limited to altitude range of polar mesospheric clouds. For Odin's Optical Spectrograph and InfraRed Imager System (OSIRIS) this provides multiple views through a given cloud volume and, thus, a basis for tomographic analysis of the vertical/horizontal cloud structure. Algorithms for tomographic analysis of mesospheric clouds are currently being developed based on maximum probability techniques. An important perspective is combined tomographic analysis of common volume measurements by Odin/OSIRIS and the Cloud Imager and Particle Size instrument (CIPS) onboard the AIM satellite.

Global model simulations of mesospheric aerosols

Linda Megner and Jörg Gumbel, in collaboration with M. Rapp (Leibniz Institute of Atmospheric Physics, Germany), and D. E. Siskind (Naval Research Laboratory, USA)

Meteoroids entering the Earth's atmosphere experience strong deceleration and ablate in the mesosphere, whereupon the resulting material is believed to re-condense to nanometre-size 'smoke particles'. Due to the lack of other particles in this region, these particles are thought to be of great importance for many middle atmosphere phenomena, for instance the formation of noctilucent clouds. The properties and distribution of meteoric smoke depend on poorly known or highly variable factors such as the amount, composition and velocity of incoming meteoric material, the efficiency of coagulation, and the state and circulation of the atmosphere. We have developed the first 2-dimensional model which includes both transport and coagulation of meteoric material. For nanometre sized particles the effect of atmospheric circulation is prominent, as it efficiently transports the particles to the winter hemisphere.

At the same time the transport towards the winter pole and down into the polar vortex results in significantly higher concentrations of meteoric material in the winter stratosphere than previously thought. Our modelled number densities of particles are consistent with stratospheric balloon measurements of the so-called CN (Condensation Nuclei) layer. This is particularly interesting since meteoric smoke earlier, on the basis of the low concentrations of meteoric particles suggested by one-dimensional models, has been disregarded as a cause of this layer. The enhanced concentrations of meteoric material in the winter vortex are of potential importance for stratospheric nucleation processes, which in turn affect PSC and ozone destruction.

Publications

Megner, L., Minimal impact of condensation nuclei characteristics on observable mesospheric ice properties, Journal of Atmospheric and Solar-Terrestrial Physics, doi: 10.1016/j.jastp.2010.08.006, in print, 2010.

Megner, L., D. E. Siskind, M. Rapp, and J. Gumbel: Global and temporal distribution of meteoric smoke; a 2D simulation study, J. Geophys. Res., 113, D03202, doi:10.1029/2007JD009054, 2007.

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Particle charging and ice nucleation in the mesosphere

Jörg Gumbel, and Linda Megner, in collaboration with M. Rapp (Leibniz Institute of Atmospheric Physics, Germany)

The properties of mesospheric clouds and their relationship to climate variability are today a major topic of middle atmospheric research. A central question concerns the condensation nuclei for ice particles at these altitudes. The mesopause region coincides both with the ablation altitude of meteoroids and with the ionospheric

D-region. Consequently, both particles of meteoric origin and cluster ions have been suggested as potential condensation nuclei. In a comprehensive model study, we have investigated the feasibility and problems of both candidates. Ablated meteoric material forms a global layer of nanometre-size "smoke" particles in the mesosphere, but the atmospheric circulation is expected to transport these particles away from the polar latitudes before they can grow large enough to become efficient as ice condensation nuclei. Cluster ions, on the other hand, are subject to rapid recombination with free electrons before they can grow large enough to produce stable ice particles.

An important conclusion from this work is that charged meteoric smoke particles can very efficiently act as nuclei for mesospheric ice. It is well established from rocket and radar measurements that charged smoke exists in the D-region plasma. However, neither the fraction of charged particles nor the relative roles of various charging mechanisms are today known. Open questions concern in particular the capture rates for electrons and ions as well as the efficiency of photo ionisation and photo detachment. It is the size of smoke particles that makes these questions so difficult to answer both from a theoretical and a laboratory perspective. As nanometre-size smoke falls into the transition regime between molecular clusters and bulk particles, "conventional" dusty plasma approaches are generally not applicable. Our work on these challenges has resulted in suggestions for both laboratory and sounding rocket experiments that address particle microphysics of charging and nucleation in this size regime.

A continuation of this study concerns the capture of meteoric smoke material by mesospheric ice particles. A detailed coagulation model has been developed that takes into account the charge state of both smoke and ice. For typical mesospheric conditions, an NLC ice particle is predicted to collect thousands of sub-nanometre smoke particles, resulting in typical mass mixing ratios of 0.1% to 1% smoke in the ice. The existence of such "dirty" ice particles is potentially important for both charging properties and optical properties of NLCs. Upon ice particle sublimation, partial conglomeration of the captured smoke into larger smoke grains can be expected. This leads to a scenario of NLCs breeding condensation nuclei for the next generation of NLCs.

Publications

Gumbel, J., and L. Megner, Charged meteoric smoke as ice nuclei in the mesosphere: Part 1 - A review of basic concepts, J. Atmos. Sol. Terr. Phys., 71, 1225-1235, 2009.

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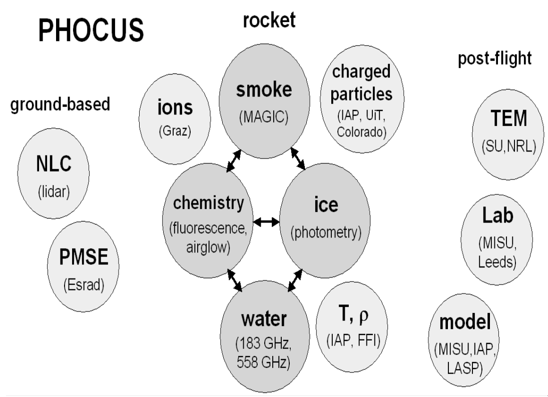
PHOCUS: A rocket study of particle interactions in the mesosphere

Jörg Gumbel, Mikhail Khaplanov, Jonas Hedin, Jacek Stegman, Thomas Waldemarsson

Intensive work has been going on in MISU's Atmospheric Physics group to prepare the PHOCUS rocket project. PHOCUS (Particles, Hydrogen and Oxygen Chemistry in the Upper Summer mesosphere) will study mesospheric particles and their interaction with their neutral and charged environment. Starting out from first ideas in 2005, PHOCUS has developed into a comprehensive venture that connects to a number of new and renewed scientific questions. Interactions of interest comprise the charging and nucleation of particles, the relationship between meteoric smoke and ice, and the influence of these particles on gas-phase chemistry. In particular, the role of meteoric particles as condensation nuclei for mesospheric ice particles has recently been challenged. The possible redistribution of water vapour by mesospheric ice raises questions about local supersaturation and gas-phase Ox/HOx chemistry. A more controversial topic is the idea of heterogeneous surface chemistry on mesospheric particles.

PHOCUS is currently being prepared as a comprehensive summer campaign from Esrange in 2011. Backbone is a major rocket payload carrying 17 instruments from 8 scientific groups in Sweden, Norway, Germany, Austria and the USA. Atmospheric composition and ice particle properties are probed by a set of active and passive optical instruments from the AP group. Exciting new instrument developments concern microwave radiometers for in situ measurements of water vapour at 183 and 558 GHz by Chalmers University of Technology. Charged particles are probed by impact detectors from the University of Colorado (LASP), the University of Tromsø (UiT) and the Leibniz Institute of Atmospheric Physics (IAP), complemented by MAGIC particle sampling from the AP group. The neutral and charged background state of the atmosphere is quantified by the Technical University Graz, IAP, and the Norwegian Defence Research Estab¬lishment (FFI). Important ground-based instrumentation includes the Esrange lidar, the ESRAD MST radar and the SkiYMET meteor radar.

The instrument developments connected to PHOCUS have led to participation of the MISU/IMI Atmospheric Physics group in several other international rocket projects.



Schematic overview of the experiments and collaborations that are part of the upcoming PHOCUS sounding rocket project for the investigation of particle interactions in the mesosphere.

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Rocket-borne photometry of noctilucent clouds

Mikhail Khaplanov, Jonas Hedin, Linda Megner, Jörg Gumbel, Jacek Stegman, Georg Witt

The German/Norwegian ECOMA programme (Existence and Charge state Of Meteoric smoke particles in the middle Atmosphere) featured four rocket launches from Andøya, Norway, into the polar summer mesosphere in both 2007 and 2008. In 2007, this was combined with two rocket launches of the American MASS project (Mesospheric Aerosol Mass Spectrometer). Both these campaigns investigated properties of meteoric smoke particles in the upper mesosphere, their interaction with the ambient ionospheric D-region, and their relation to mesospheric ice particles (i.e., manifest as noctilucent clouds and polar mesosphere summer echoes). The MISU/IMI Atmospheric Physics group contributed to all rocket payloads with ultraviolet photometer for the characterisation of noctilucent clouds (NLC).

NLC photometers have been developed further in preparation of the PHOCUS rocket campaign in 2011. The PHOCUS payload will feature a combination of photometric measurements addressing the spectral dependence, angular dependence and polarisation dependence of NLC scattering of light. A related instrument development concerns the first measurement of NLC scattering at wavelengths as short as Lyman-α (121.6 nm).

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Mesospheric O and NO concentrations from rocket-borne photometry

Jonas Hedin, Jacek Stegman, Mikhail Khaplanov, Jörg Gumbel, Georg Witt

Atomic oxygen (O) and nitric oxide (NO) are two species of major importance for the Earth's middle atmosphere. Produced through O_2 photolysis during the day, O is the major carrier of chemical energy in the mesosphere and lower thermosphere (MLT) and thus a key component of the aeronomy of this region. NO can be formed in the lower thermosphere through dissociation of N_2 by high-energy solar radiation or energetic particles and subsequent reaction with O_2. NO is an important compound in both neutral and ionic atmospheric chemistry as NO^+ is the main ionised species in the lower ionosphere, and transport of NO to lower altitudes and other latitudes leads to ozone destruction which can affect the atmospheric temperature profile.

Nighttime O and NO number densities are retrieved from rocket-borne photometric measurements of the O_2 Atmospheric Band (O_2 A-band) and NO_2 Continuum nightglow emissions. The O_2 A-band emission is the result of O recombination and the NO_2 Continuum emission is produced in the NO + O air-afterglow reaction. This technique has been applied to photometer flights during the sounding rocket campaigns eARI-HotPay-1 and ECOMA from Norway in 2008 and 2010. Ongoing work on ECOMA also includes co-analysis with both satellite measurements and in situ NO ionisation measurements.

Publications

Hedin, J., J. Gumbel, J. Stegman, G. Witt, and D. P. Murtagh, The use of O2 airglow for calibrating direct atomic oxygen measurements from sounding rockets, Atmos. Meas. Tech., 2, 801-812, 2009.

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New methods for accurate measurements of atomic oxygen from sounding rockets

Jonas Hedin, Jörg Gumbel, Mikhail Khaplanov, Jacek Stegman and Georg Witt

Accurate knowledge about the distribution of atomic oxygen is crucial for many studies of the mesosphere and lower thermosphere. Direct measurements of atomic oxygen by the resonance fluorescence technique at 130 nm have been made from several sounding rocket payloads in the past. This measurement technique yields atomic oxygen profiles with good sensitivity and altitude resolution. However, accuracy is a problem as calibration and aerodynamics make the quantitative analysis challenging. In general, accuracies better than a factor of 2 - 3 are not to be expected from direct atomic oxygen measurements. Past measurements using the resonance fluorescence technique show a spread in the measured O profiles by a factor of 50 while there is only a spread by a factor of 3 in the O profiles inverted from simultaneous photometric O_2 nightglow measurements.

Better atomic oxygen number densities can be obtained by combining direct techniques with complimentary O_2 airglow photometer measurements and detailed aerodynamic analysis. Night-time direct O measurements can be complemented by photometric detection of the O_2 ($b^1\Sigma_g^+$-$X^3\Sigma_g^-$) Atmospheric Band at 762 nm, while during daytime the O_2 ($a^1\Delta_g$-$X^3\Sigma_g^-$) Infrared Atmospheric Band at 1.27 µm can be used. The combination of a photometer and a rather simple resonance fluorescence probe can provide both good accuracy and good height resolution. A limitation is that most of our knowledge about the reaction mechanisms underlying the nightglow inversion is based on the results from a single rocket campaign in 1982. It is desirable to verify this with a new study based on complimentary measurement techniques.

Publications

Hedin, J., J. Gumbel, J. Stegman, and G. Witt, Use of O_2 airglow for calibrating direct atomic oxygen measurements from sounding rockets, Atmos. Meas. Tech., 2, 801-812,2009.

Simulations of rocket-borne in situ measurements

Jonas Hedin, Jörg Gumbel

Much effort has been focused on both the development of new instruments and the development of appropriate analysis methods. Aerodynamic influences on rocket-borne measurements play an important role in this respect. We use a Direct Simulation Monte Carlo model, the DS2V model by G. A. Bird, for detailed simulations of rarefied gas flows. During the recent years, our simulations have been applied to the analysis of a number of European and U.S. rocket experiments.

For many in situ probes, interactions with mesospheric particles (ice or smoke), ions and electrons are of particular interest. We have developed two models that trace particles in the air flow about payloads and instruments. The first model, the Continuous motion model, was of central importance both for the design of the MAGIC experiment and for the analysis of the ECOMA project by the Leibniz Institute of Atmospheric Physics, Germany. The second model, the Brownian motion model, includes for the first time the statistical motion of smoke particles due to collisions with thermal air molecules in the air flow. The resulting flow patterns from this model are closer to the real motion of smoke particles, which is especially important for the smallest particles. The Brownian motion model has been used to study the detailed aerodynamic properties of instruments launched from Andøya, Norway, and Esrange, Sweden. We intend to extend this model to include the flow of ions, payload charging and electric fields.

Publications

Hedin, J., J. Gumbel, T. Waldemarsson and F. Giovane, The aerodynamics of the MAGIC meteoric smoke sampler, Advances in Space Research, 40, 818-824, doi:10.1016/j.asr.2007.06.046, 2007.

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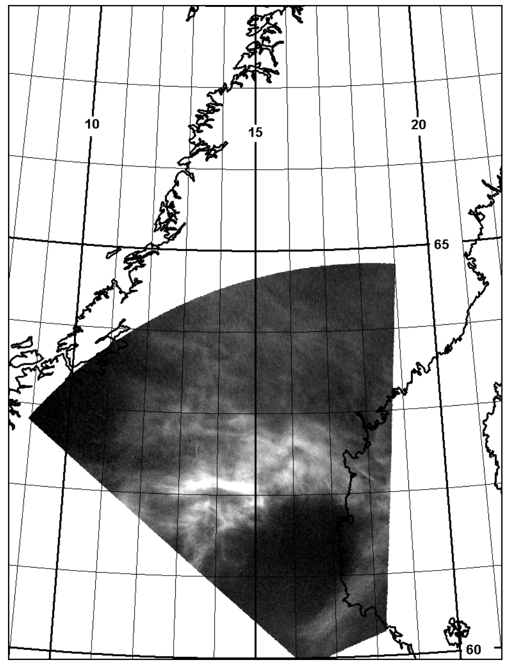
Ground-based studies of "ice voids" in noctilucent clouds

Jacek Stegman, in collaboration with P.-D. Pautet and M. J. Taylor (Utah State University, USA)

Large, "virtually ice-free" regions have been detected in the Polar Mesospheric Cloud fields by the CIPS instrument on the AIM satellite. These regions have been referred to as "ice voids". In the satellite observations, these features appear as oval shape dark spots with diameters varying from tens to more than hundreds of kilometres but typically about 300 km. It has been hypothesized that they could be caused by heating due to energy deposition through breaking of gravity waves from localized, perhaps tropospheric sources. From satellite images only very limited information on the dynamical behaviour on the relevant time scales of these features is, so far, available. Now for the first time, an ice void has been registered by a ground-based camera in a noctilucent cloud display north of Stockholm. The camera takes images every 30 s and the evolution of the void, its growth and its motion could be followed during, at least 1 hour. This project aims at a detailed analysis of the dynamical conditions governing void events.



An "ice void" registered by a ground-based camera in a noctilucent cloud display north of Stockholm on July 4, 2010 at 22:59UT.

Simultaneous observations of NLC from space and from ground

Jacek Stegman, in collaboration with P.-D. Pautet (Utah State University, USA), S. Bailey (Virginia Polytechnical Institute, USA) and D. Rush (University of Colorado, LASP, USA)

Noctilucent Clouds (NLC) have been extensively observed and characterised from the ground since their first identification in 1885. It has been argued that NLC first appeared just around this time and that they are important indicators for atmospheric changes and variability. More recently it has also been demonstrated that NLC properties and occurrence frequency are intimately related to the dynamic coupling processes on global scale. Noctilucent clouds were first detected from space by an instrument on the OGO-6 satellite in 1972. It was also discovered that a permanent scattering layer exists over the polar cup during the summer. NLCs are now considered to be equatorward extensions of this permanent layer, also sometimes called Polar Mesospheric Clouds (PMC).

More recently NLC/PMC have been extensively studied by the Swedish satellite Odin launched in 2001. The AIM satellite mission, launched in 2007, is entirely dedicated to research into noctilucent clouds. The Cloud Imaging and Particle Size (CIPS) experiment on AIM is a wide angle (120° along track by 80° across track) imager consisting of four identical cameras arranged in a cross pattern. CIPS is the first space borne instrument that takes images of PMCs with a high spatial resolution and in the viewing geometry that makes comparison with the ground imagery possible.

Since the summer 2004, photographs of noctilucent clouds (NLC) are taken from the top floor window of the Arrhenius Laboratory at the University Campus in Stockholm, Sweden (59.37ºN, 18.06ºE). A digital camera takes every summer night hundreds of images of twilight sky at the rate of 1 to 2 pictures per minute. When observed and photographed from the ground, noctilucent clouds are distorted by the geometry of the observation. The spherical shape of the atmospheric layer where NLCs reside and the refraction modify the shape, the size and the observed speed of the waves. A technique to re-project these images to a horizontal plane in order to correctly represent movements and actual spatial scales has been developed. Here we use a technique to re-project images to a horizontal plane developed from the method used to un-wrap airglow images. The observed star field is used and here the layer altitude is assumed to be at 82.5 km. In the re-projected images the NLC layer appears as seen from above on a horizontal plane and is represented with a linear scale and thus suitable for a comparison with images obtained from a satellite-borne camera like CIPS.

Lidar measurements in the mesosphere

Mikhail Khaplanov, Jörg Gumbel, Jonas Hedin, Stefan Lossow, in collaboration with Peter Dalin, Peter Voelger (Institute for Space Physics, Kiruna, Sweden), and K. H. Fricke (University of Bonn, Germany)

In 2005, the MISU/IMI Atmospheric Physics group has taken over the responsibility for a powerful lidar system at Esrange. The lidar was originally installed in 1997 by the University of Bonn. In the meantime, a comprehensive technology transfer from Bonn to MISU/IMI has taken place. The Esrange lidar is a central part of the ground-based equipment in the Kiruna region for studies of the mesosphere. In darkness, the Nd:YAG 532 nm system allows the retrieval of temperature profiles up to 80 km. During the summer season, the daylight capability of the system allows the monitoring and study of noctilucent clouds (NLC). The lidar system is thus crucial as part of rocket projects that depend on knowledge of the presence of NLC. In collaboration with Swedish Space Corporation (Esrange), a modernisation of the lidar's data acquisition system is in progress, which in future will provide online access to the lidar data.

The ACE satellite mission

Georg Witt

The ACE experiment onboard the Canadian SciSat satellite performs solar occultation measurements in a polar orbit since 2003. The experiment is dedicated to the study of chemical processes up to the upper stratosphere including the key species involved in the chemistry of Ozone. ACE comprises the two optical experiments MAESTRO, a dual-channel UV/Vis/IR grating spectrograph, and FTS, a BOMEM Fourier spectrometer for the IR. As part of the FTS experiment, the non-structured baseline of the IR spectrum is used to obtain information about the size, shape and composition of aerosol particles. These extinction measurements offer an excellent opportunity of complementing the Odin NLC observations, notably during the Odin Summer Mesosphere Mission. As for measurements of water vapour and temperature, ACE has provided valuable comparisons to the ODIN/SMR observations. Georg Witt is currently adjoint to the ACE Science Team.

Publications

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ADDITIONAL PUBLICATIONS RELATED TO MESOSPHERIC PROCESSES

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DYNAMICAL COUPLING OF THE MIDDLE ATMOSPHERE

Global observations of noctilucent clouds, water vapour and ozone by the Odin satellite have been the basis for comprehensive studies of middle atmosphere dynamics and coupling. The year-to-year variability in both the northern and southern polar summer mesosphere is surprisingly linked to the planetary wave activity in the winter stratosphere in the opposite hemisphere. Various observations and model simulations have confirmed the existence of this interhemispheric coupling and contributed to a better understanding of the mechanism behind it. Comprehensive pre-launch studies for the ESA's ADM/Aeolus mission are another example of ongoing research on middle atmosphere dynamics.

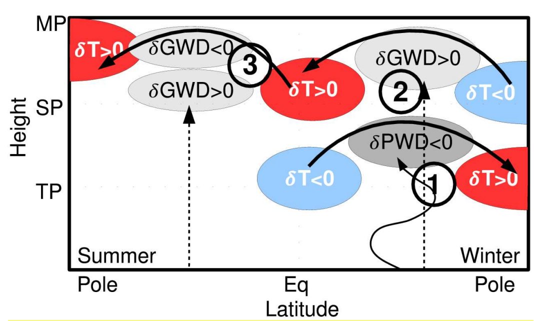
A simple model for the interhemispheric coupling of the middle atmosphere circulation

Heiner Körnich, in collaboration with Erich Becker (Leibniz-Institute of Atmospheric Physics, Germany), Bodil Karlsson (Laboratory for Atmospheric and Space Physics, University of Colorado, USA), Linda Megner (Canadian Space Agency, Montréal, Canada), Theodore G. Shepherd and Charles McLandress (Department of Physics, University of Toronto, Canada), Stefan Lossow (now at Karlsruhe Institute of Technology, Germany), Jörg Gumbel

The interhemispheric coupling of the middle atmosphere general circulation is characterized by a global anomaly pattern of the zonal mean temperature. This pattern reflects an anomalous stratospheric and mesospheric residual circulation, in which a weaker (stronger) stratospheric winter circulation is linked to an upward (downward) shift of its upper mesospheric branch reaching from the summer to the winter pole. This phenomenon is robust in observational data and several middle-atmosphere general circulation models. In the present study, the recently proposed mechanism of the interhemispheric coupling is unequivocally proven within the framework of a zonally symmetric model that excludes any additional effects due to resolved waves and non-zonally propagating gravity waves. Two simulations are conducted that differ in the strength of the polar vortex. A weaker polar vortex results in a downward shift of the winter mesospheric gravity wave drag. This leads to changes also in the summer upper mesosphere via a feedback solely between gravity-wave breaking and the zonal-mean state. The accompanying temperature anomaly reproduces the pattern of the interhemispheric coupling.

Publications

Körnich, H., and E. Becker, A simple model for the interhemispheric coupling of the middle atmosphere circulation. Adv. Space Res., 45, 661-668, doi: 10.1016/j.asr.2009.11.001, 2010.



Schematic of the interhemispheric coupling for a stronger Brewer-Dobson circulation in the winter stratosphere. The expressions T, GWD, and PWD denote the temperature, the gravity wave drag, and the planetary wave drag, respectively. The δ-symbol indicates the variable's anomaly during the stronger Brewer-Dobson circulation in comparison with the mean state. The height regions are marked by the tropopause (TP), stratopause (SP), and mesopause (MP).

Global coupling mechanisms observed in noctilucent clouds

Bodil Karlsson, Jörg Gumbel, Heiner Körnich, Kristoffer Hultgren, in collaboration with Stefan Lossow (Karlsruhe Institute of Technology, Germany)

The occurrence of noctilucent clouds is highly sensitive to the meteorological conditions in the clouds upper mesopheric environment. These conditions are in turn governed to a large extent by dynamical control from other parts of the atmosphere. Hence, noctilucent clouds serve as convenient tracers for these global coupling processes. The database of noctilucent cloud observations by Odin now covers 10 years and, thus, almost the period of a solar cycle. This provides an excellent basis for studies of mesospheric conditions on seasonal and interannual time scales. Related studies are performed in collaboration with the U.S. Aeronomy of Ice in the Mesospere (AIM) mission. Several of these studies have focused on the interhemispheric coupling between the winter stratosphere and the polar summer mesosphere. New studies concern intra-hemispheric coupling between stratospheric and mesospheric conditions. Of particular interest are mechanisms by which the winter polar vortex may control the onset of the subsequent summer noctilucent cloud season in the same hemisphere.

Publications

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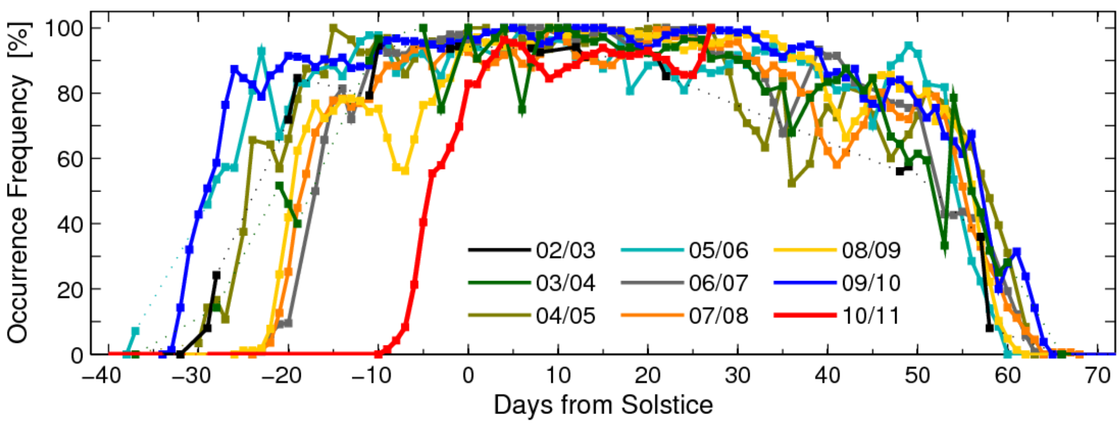


Southern hemispheric occurrence frequencies of noctilucent clouds obtained by Odin/OSIRIS. Data represent the latitude band 70-85□ and are plotted for the southern summer seasons 2002/2003 until 2010/2011. Note the large year-to-year variability in the start of the southern NLC seasons. In contrast, there is little variation at the end of the season. Occurrence frequency is defined as the number of NLC observations devided by the total number of observations performed by OSIRIS. Dashed lines in the plot indicate periods of missing data when Odin was operated in non-mesospheric modes.

Zonal asymmetries in middle atmospheric ozone and water vapour derived from Odin satellite data 2001–2010

Heiner Körnich, in collaboration with Axel Gabriel, Deniz Demirhan Barı and Dieter Peters (Leibniz-Institute of Atmospheric Physics, Germany), Stefan Lossow (Karlsruhe Institute of Technology, Germany)

Based on Odin satellite data 2001–2010 we investigate stationary wave patterns in middle atmospheric ozone (O_3) and water vapour (H_2O) as indicated by their seasonal long-term means of the zonally asymmetric components. At mid- and polar latitudes of northern and Southern Hemisphere, we find a pronounced wave one pattern in both constituents. In the Northern Hemisphere, the wave one patterns increase during autumn, maintain their strength during winter and decay during spring, with maximum amplitudes of about 10–20% of zonal mean values. During winter, the wave one in stratospheric O_3 is characterized by a maximum over North Pacific/Aleutians and a minimum over North Atlantic/Northern Europe and by a double-peak structure with enhanced amplitude in the lower and in the upper stratosphere. The wave one in H_2O extends from lower stratosphere to upper mesosphere with a westward shift in phase with increasing height including a jump in phase at upper stratosphere altitudes. In the Southern Hemisphere, similar wave one patterns occur during southern spring when the polar vortex break down. Based on a simplified tracer transport approach we explain these wave patterns as a first-order result of zonal asymmetries in mean meridional transport by geostrophically balanced winds, which were derived from combined temperature profiles of Odin data and Reanalysis data (ERA Interim) of ECMWF (European Centre of Medium-Range Weather Forecasts), and associated mean geopotential height anomalies. Further influences which may contribute to the stationary wave patterns, e.g. eddy mixing processes or temperature-dependent chemistry, are also examined.

Publications

Gabriel, A., H. Körnich, S. Lossow, D. Peters, J. Urban and D. Murtagh, Zonal asymmetries in middle atmospheric ozone and water vapour derived from Odin satellite data 2001-2010. Atmos. Chem. Phys. Discuss., 11, 2011.

Vertical Aeolus measurement positioning

Heiner Körnich, in collaboration with Ad Stoffelen, Gert-Jan Marseille, Karim Houchi and Jos de Kloe (KNMI), David Tan (ECMWF), Harald Schyberg (Norwegian Meteorological Institute), Anne Grete Straume and Olivier LeRille (ESA)

ESA's Earth Explorer Atmospheric Dynamics Mission Aeolus will provide global line-of-sight wind profiles after its launch planned for 2013. The vertical sampling is limited to 24 range gates both in the receiver channels up to a height of about 30 km. Two aspects are assessed in this study. Firstly, it is examined whether it can be assumed that the line-of-sight wind measurement by the lidar is always dominated by its horizontal component. It is questionable whether this assumption holds for tropical dynamics. The occurrence of tropical convective updrafts and their impact on the Aeolus measurement will be assessed. Furthermore, it is examined how different vertical sampling scenarios for Aeolus affect the forecast quality in the troposphere and stratosphere. To this aim, a new data assimilation ensemble technique was used which allows to estimate the impact of future observing systems. The estimation were carried out with the 4D-variational data assimilation of the ECMWF operational system. It is demonstrated that the impact of Aeolus in the troposphere and stratosphere is comparable to the impact of the radiosonde observations. For the chosen experiment configuration, Aeolus provides tropospheric impact especially over the oceans, in the Tropics and in the Arctic. The Aeolus impact propagates vertically into the stratosphere related to gravity waves on short time-scales and to large-scale Rossby waves on longer time-scales. The strongest impact on the stratospheric analysis is provided by the Aeolus sampling scenario which focuses on the Upper Troposphere/Lower Stratosphere region.

Publications

Stoffelen, A., H. Körnich, G.-J. Marseille, K. Houchi, and J. de Kloe, 2010: Assessment of Optical and Dynamical Atmospheric Heterogeneity. Technical Note, ESTEC, Noordwijk, The Netherlands.

Körnich, H., and H. Schyberg, 2010: Impact of the Vertical Sampling Scenarios on NWP and Stratospheric Wind Analysis. Technical Note, ESTEC, Noordwijk, The Netherlands.

Körnich, H., D. Tan, and G.-J. Marseille, 2011: Impact of different Aeolus sampling scenarios on the stratospheric analysis. In preparation.

Körnich, H., 2011: The impact of strong convective updrafts on line-of-sight wind measurements from a space-borne Doppler-wind lidar. In preparation

ADDITIONAL PUBLICATIONS related to atmospheric dynamics

Graversen, R.G., E. Källén, M. Tjernström, H. Körnich: Atmospheric mass-transport inconsistencies in the ERA-40 reanalysis., Q. J. R. Meteorol. Soc., 133, doi: 10.1002/qj.35, 2007.

Körnich, H., and E. Becker: The influence of the tropospheric annular mode on the polar night jet vacillations in a simple global circulation model, submitted to J. Geophys. Res., 2008.

STRATOSPHERIC CLOUDS, AEROSOLS AND COMPOSITION

Renewed efforts of the Atmospheric Physics group have been focused on the stratosphere and upper troposphere as an important part of our climate system. On the one hand, this concerns cloud formation and exchange processes in the upper troposphere and lower stratosphere (UT/LS). On the other hand, this concerns the physics and chemistry of polar stratospheric clouds, including their dependence on stratospheric dynamics and their influence on the ozone-related chemistry. Our primary experimental tools for these studies are the Odin satellite and the Esrange lidar.

The stratospheric mission of the Odin satellite

Farahnaz Khosrawi, Jacek Stegman, Jörg Gumbel, Georg Witt, Stefan Lossow (now at Karlsruhe Institute of Technology, Germany)

The main scientific goal of Odin is to explore the middle and upper atmosphere. Since the end of the astronomic part of the Odin mission, the satellite has been fully devoted to atmospheric studies. The two instruments onboard are the submillimetre/millimetre receiver (SMR) and the Optical

Spectrograph and InfraRed Imager System (OSIRIS). The Odin mission involves close co-operation with a number of scientific groups from the other participating nations – Canada, France and Finland. Odin is the third scientific satellite in a series of Swedish small satellite projects supported by Swedish National Space Board and other national agencies. It is today operated as an ESA Third Part Mission. Odin provides observations of the Earth's limb during fifteen near-polar orbits each day. In basic stratospheric mode, Odin scans the Earth's atmosphere between 7 and 60 km. A particular focus of these measurements is on the understanding of the chemistry and dynamics of the stratosphere, in particular processes related to stratospheric ozone depletion.

Evaluation of chemical transport model and chemistery-climate model simulations in the lower stratosphere

Farahnaz Khosrawi, Rolf Müller (FZ Jülich), Michael H. Proffitt (Proffitt Instruments, USA), Roland Ruhnke (FZ Karlsruhe, Germany), Ole Kirner (FZ Karlsruhe, Germany), Patrick Jöckel (MPI for Chemistry, Germany), Jens-Uwe Grooβ (FZ Jülich, Germany), Joachim Urban (Chalmers, Göteborg), Donal Murtagh (Chalmers, Göteborg), Hideaki Nakajima (NIES, Japan)

1-year data sets of monthly averaged nitrous oxide (N_2O) and ozone (O_3) derived from satellite measurements were used as a tool for the evaluation of atmospheric photochemical models. Two 1-year data sets, one derived from the Improved Limb Atmospheric Spectrometer (ILAS and ILAS-II) and one from the Odin Sub-Millimetre Radiometer (Odin/SMR) were employed. These data sets are used for the evaluation of two Chemical Transport Models (CTMs), the Karlsruhe Simulation Model of the Middle Atmosphere (KASIMA) and the Chemical Lagrangian Model of the Stratosphere (CLaMS) as well as for one Chemistry-Climate Model (CCM), the atmospheric chemistry general circulation model ECHAM5/MESSy1 (E5M1) in the lower stratosphere with focus on the northern hemisphere. Since the Odin/SMR measurements cover the entire hemisphere, the evaluation is performed for the entire hemisphere as well as for the low latitudes, midlatitudes and high latitudes using the Odin/SMR 1-year data set as reference. To assess the impact of using different data sets for such an evaluation study the evaluation is repeated for the polar lower stratosphere using the ILAS/ILAS-II data set. Only small differences were found using ILAS/ILAS-II instead of Odin/SMR as a reference, thus, showing that the results are not influenced by the particular satellite data set used for the evaluation. The evaluation of CLaMS, KASIMA and E5M1 shows that all models are in good agreement with Odin/SMR and ILAS/ILAS-II. Differences are generally in the range of ±20%. Larger differences (up to -40%) are found in all models at 500±25 K for N2O mixing ratios greater than 200 ppb. Generally, the largest differences were found for the tropics and the lowest for the polar regions. However, an underestimation of polar winter ozone loss was found both in KASIMA and E5M1 both in the northern and southern hemisphere.

Publications

Khosrawi, F., R. Müller, M. H. Proffitt, R. Ruhnke, O.Kirner, P. Jöckel, J.-U. Grooβ, J. Urban, D. Murtagh, H. Nakajima, Evaluation of CLaMS, KASIMA and ECHAM5/MESSy1 simulations in the lower stratosphere using observations of Odin/SMR and ILAS/ILAS-II, 9, 5759-5783, 2009.

Khosrawi, F., R. Müller, M. H. Proffitt, J. Urban, D. Murtagh, R. Ruhnke, J.-U. Grooß, H. Nakajima, Seasonal cycle of averages of nitrous oxide and ozone in the Northern and Southern Hemisphere polar, midlatitude and tropical regions derived from ILAS/ILAS-II and Odin/SMR observations, Journal of Geophysical Research, 113, D18305, doi:10.1029/2007JD009556, 2008.

Can dynamical processes in the tropics cause exceptionally high N_2O mixing ratios in the lower stratosphere?

Farahnaz Khosrawi, Rolf Müller (FZ Juelich, Germany), M. H. Proffitt (Proffitt Instruments, USA) , Jo Urban (Chalmers, Göteborg) and Donal Murtagh (Chalmers, Göteborg)

A modified form of tracer-tracer correlations of N_2O and O_3 has been used as a tool for evaluation atmospheric photochemical models. Thereby, the data is organized monthly for both hemispheres by partitioning the data into altitude (or potential temperature) bins and then average over a fixed interval of N_2O. In our recent model evaluation study where we applied satellite observations from the Odin-Sub Millimeter Radiometer (Odin/SMR) we found large differences between model simulation and Odin/SMR observations in the tropics. The N_2O averages we derived from Odin/SMR observations at potential temperature levels between 500 and 650 K were much higher than the N_2O values we derived from the model simulations. Further, these values are much higher than what up to know has been measured. Validation studies comparing Odin/SMR N_2O data with other data shows that the Odin/SMR N_2O data is of good quality. Further, checking the method we applied did also not reveal any errors. Since our data is averaged over bins of fixed N_2O we found that these bins contain a relatively low number of data points compared to the other bins. Furthermore, these values occur with a seasonal dependence showing a maximum in winter and a minimum in summer. Thus, since we cannot find an error in our analyses or in the Odin/SMR data, a scientific explanation could be that these high values are caused by local dynamical processes in the tropics that are not well represented in the model simulations. To test this hypothesis our method has been applied to other satellite data sets with a high coverage in the tropics as e.g., MLS and CRISTA, however could not find the same behavior in these data sets as in Odin/SMR. Since the cause of these values is still not clear research on this is ongoing.

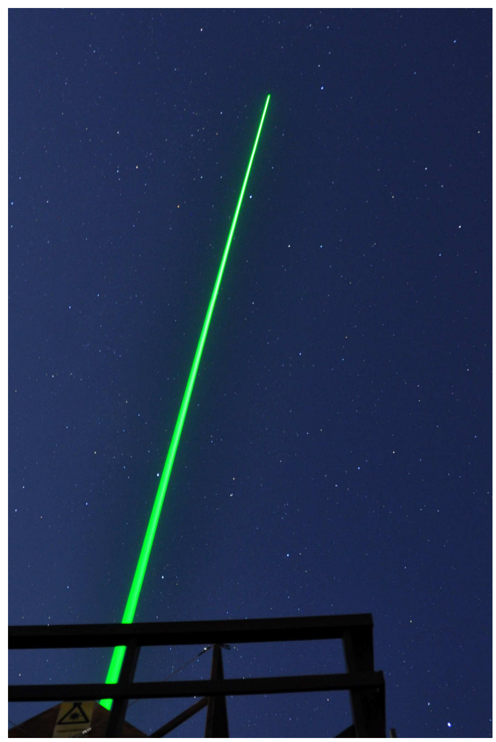
Publications

Khosrawi, F., R. Müller, M. H. Proffitt, R. Ruhnke, O.Kirner, P. Jöckel, J.-U. Grooß, J. Urban, D. Murtagh, H. Nakajima, Evaluation of CLaMS, KASIMA and ECHAM5/MESSy1 simulations in the lower stratosphere using observations of Odin/SMR and ILAS/ILAS-II, 9, 5759-5783, 2009.

Lidar measurements in the stratosphere

Peggy Achtert, Mikhail Khaplanov, Farahnaz Khosrawi, Stefan Lossow, Jonas Hedin, Kristoffer Hultgren, Jörg Gumbel, in collaboration with Peter Voelger (Institute for Space Physics, Kiruna, Sweden), Ulrich Blum, K. H. Fricke (University of Bonn, Germany)

In 2005, the MISU/IMI Atmospheric Physics group has taken over the responsibility for a lidar at Esrange. The lidar was originally installed in 1997 by the University of Bonn. The Kiruna region was chosen as a location mainly to contribute to efforts to unravel the stratospheric ozone problem. The Esrange lidar provides today stratospheric and mesospheric measurements of clouds, aerosols and temperatures. In addition to basic scientific studies, the lidar has thus developed into an important tool for balloon and rocket campaigns. Temperature data are also provided to ESA as part of the MetOp validation programme. The lidar system has recently been extended with Rotational Raman channels for accurate temperature masurements in the presence of aerosols and clouds. Upcoming developments will focus on improved characterisation of clouds and aerosols. A new focus is on the structure of the high-latitude upper troposphere and lower stratosphere (UTLS). These studies will make use of a comprehensive instrumental setup with the Esrange lidar, the ESRAD radar, and a new ozone lidar at the Swedish Institute of Space Physics, in proposed combination with in situ balloon soundings. In collaboration with Swedish Space Corporation (Esrange), a modernisation of the lidar's data acquisition system is in progress, which in future will provide online access to the lidar data.

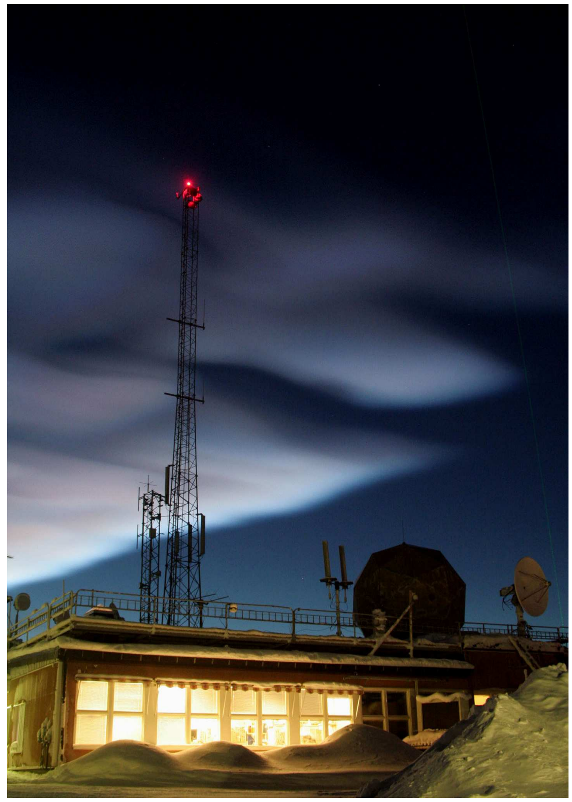


The laser beam of the Esrange lidar. The MISU/IMI Atmospheric Physics group took over the responsibility for this lidar system in 2005. (Photo by Jonas Hedin.)

Occurrence and properties of polar stratospheric clouds

Peggy Achtert, Farahnaz Khosrawi, Jörg Gumbel, Mikhail Khaplanov; Ulrich Blum and K. H. Fricke (University Bonn, Germany); Stefan Lossow (Karlsruhe Institute of Technology, Germany); Peter Völger (IRF Kiruna) and others

Polar stratospheric clouds (PSCs) play a key role in stratospheric ozone depletion. They are also sensitive indicators for the variability of the polar stratosphere where global cooling has become evident. Apart from that the exact formation mechanisms of PSCs are still unclear, especially in the Arctic where dynamic conditions are more complex than in the Antarctic. Local cooling by waves can provide conditions required for PSC formation. Our specific question is to investigate how local stratospheric conditions control the formation and properties of PSCs in the Arctic as well as their interaction with ozone. Our goal is to perform combined analyses of PSCs, atmospheric dynamics, and the local stratospheric environment. A combination of measurements from the space-borne CALIPSO lidar with the two ground-based lidar systems in the Kiruna region and the one in Alomar will be applied for simultaneous analyses of PSC properties and local stratospheric conditions. The lidar located at Esrange will be equipped with additional Rotational-Raman channels for accurate temperature measurements in the stratosphere and in the vicinity of PSCs. Numerical simulations of air parcel history and PSC conditions are an important part of the data analysis. Our combined results on PSC particle properties, temperature structure and dynamics will be investigated using a microphysical box model. Moreover, detailed studies of PSC particle microphysics will be performed using the Community Aerosol and Radiation Model for Atmospheres (CARMA).



Polar Stratospheric Clouds (PSCs) occurring above Esrange on January 27, 2011. PSCs play a decisive role in ozone chemistry and are a central subject of MISU/IMI's satellite and lidar studies. (Photo by Peggy Achtert.)

Publications

Achtert, P., F. Khosrawi, U. Blum, and K. H. Fricke, Investigation of Polar Stratospheric Clouds in January 2008 by means of ground-based and space-borne lidar measurements and microphysical box model simulations, J. Geophys. Res., doi:10.1029/2010JD014803, 2011.

Denitrification, dehydration and formation of polar stratospheric clouds

Farahnaz Khosrawi, Peggy Achtert, Mikhail Khaplanov; Ulrich Blum and K. H. Fricke (University Bonn, Germany); Peter Völger (IRF Kiruna); Joachim Urban and Donal Murtagh (Chalmers, Göteborg) and others

Polar stratospheric clouds (PSC) play a key role in stratospheric ozone depletion since heterogeneous chemical reactions on the surfaces of the cloud particles activate halogen compounds which lead to the observed ozone destruction. PSCs are formed during polar winter when temperatures fall below -83°C. PSCs are either liquid or solid and are composed of water (H_2O), sulphuric acid (H_2SO_4) and nitric acid (HNO_3). Solid PSC particles can grow to larger sizes than liquid PSC particles and finally fall out (sediment) of the stratosphere. The sedimenation of the solid particles can lead either to a dehydration (removal of H_2O) or a denitrification (removal of HNO_3) of the stratosphere. The denitrification limits the deactivation process in springtime allowing the ozone-destroying catalytic cycle to last longer. Though PSC formation has been studied quite well, some processes still remain uncertain. In particular, the exact formation mechanism of the solid particles which cause the denitrification is still under debate. Satellite measurements have a good potential for investigating the chemical composition and physical state of PSCs and dehydration and denitrification processes. Besides their high temporal and spatial resolution they also provide data in both hemispheres. Thus, in this project it is intended to use satellite measurements in combination with model simulations to investigate the formation of solid PSC particles as well as denitrification and dehydration processes in the Arctic and Antarctic. Especially, we will focus on hemispheric differences and on climatological aspects. This research will provide a better understanding of the chemical and dynamical processes in the Arctic and Antarctic which lead to the ozone hole.

Publications

Khosrawi, F, J. Urban (Chalmers, Göteborg), M. C. Pitts (NASA, Langley, USA), P. Völger (IRF, Kiruna), P. Achtert, M. Khaplanov, D. Murtagh (Chalmers, Göteborg), and K. H. Fricke (University Bonn, Germany), Denitrification and polar stratospheric cloud formation during the Arctic winter2009/2010, Atmos.Chem.Phys.Discuss., 11, 11379-11415, 2011.

The STEAM / PREMIER satellite mission

Jörg Gumbel, Jacek Stegman

The Atmospheric Physics group has earlier been involved in the Phase A1 study for the new atmospheric satellite mission STEAM (Stratosphere-Troposphere Exchange And climate Monitor). The Stratosphere-Troposphere Exchange And climate Monitor (STEAM) satellite project is dedicated to the investigation of chemical, dynamical, and radiative processes in the upper troposphere and lower stratosphere (UT/LS). Important questions concern the evolution of Earth's climate in this part of the atmosphere. The concept of STEAM has now become part of the PREMIER project (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation), that has been proposed to ESA as an Explorer mission. PREMIER aims at investigating natural and anthropogenic processes that control the composition of the global atmosphere and their interaction with climate. The MISU/IMI Atmospheric Physics group participated actively in the STEAM phase-A1 study. The group’s main interest was the definition of an optical instrument on STEAM for the detection and characterisation of clouds and aerosols.

TROPOSPHERIC AEROSOL STUDIES

MISU/IMI's Atmospheric Physics group has broad experience in studying aerosol and cloud processes. The examples below show how this experience is applied also to tropospheric questions. This includes both experimental and modeling approaches.

Aerosol formation in the Arctic free troposphere

Farahnaz Khosrawi; Johan Ström (ITM, Stockholm University); Andreas Minikin (DLR Oberpfaffenhofen, Germany)

See Chemical Meteorology under “Reactive trace gases, aerosol particles and precipitation chemistry

New particle formation in remote Northern American forests under the sulfur plume influence

Vijay Kanawade and Mark E. Erupe (Kent State University, USA), Barry Lefer (University of Houston, USA), Tom Jobson (Washington State University, USA), S. N. Tripath (Indian Institute of Technology, India), Shelley Pressley (Washington State University, USA), Farahnaz Khosrawi, and Shan-Hu Lee (Kent State University, USA)

See Chemical Meteorology under “Reactive trace gases, aerosol particles and precipitation chemistry

Bi-static lidar studies of cirrus particle properties

Georg Witt, in collaboration with Frans Olofsson, Jan B. C. Pettersson (Göteborg University, Sweden), Ariel Cohen (Hebrew University of Jerusalem, Israel), and M. Frioud (ALOMAR Observatory, Andøya, Norway)

See Chemical Meteorology under “Reactive trace gases, aerosol particles and precipitation chemistry

ARCTIC STUDIES

The Polar Regions are the primary heat sinks for the global atmosphere and the Arctic Ocean with its sea ice is an important component of the global climate system. In recent years, the Arctic climate has experienced a rapid change, with a near-surface temperature increase over the last several decades at about twice that of the Earth on average. Many other climate-change signals also appear, for example, a rapid decline in sea-ice cover and thickness and a reduction of permafrost areas. This trend has attracted a significant scientific interest recently, with the abrupt ice retreat during the summer of 2007 to a new record low since satellite observations started. The loss of ice volume is likely even larger. Climate models suggest that this trend will continue and project an ice-free summer Arctic Ocean within this century. Although many hypotheses have been put forward, there is still inadequate scientific understanding of the underlying mechanisms to explain this apparent climate sensitivity.

The sea ice exerts a strong control of low-level atmospheric conditions and plays a major role in regulating fluxes of energy and matter at the surface, across the ocean/ice/atmosphere interface. In spite of a considerable effort, there is not yet a clear understanding of several important feedback mechanisms within the Arctic climate system, involving for example ice, turbulent fluxes, aerosols, clouds, radiation and marine biology. Consequently, current climate models perform poorly in the Arctic and the uncertainty in scenarios of future climate is larger here than elsewhere. The amount of empirical data on Arctic climate processes is inadequate to allow a proper description of them in climate models. This is in part related to the paucity of process-level in-situ observations in the Arctic. This in turn is explained by the difficulty to make permanent instrumental installation on the perennial drifting sea ice. The hostile conditions make all direct measurements with current technology difficult. Long-term monitoring of Arctic climate from space-borne instruments also suffers from a lack of ground-truth measurements for validation and development of new improved inversion algorithms.

Recent technology advances together with the urgent need for an increased understanding of the processes that regulate the Arctic climate has made the time ripe for a coordinated international initiative to advance the understanding of the climate of the region. The International Council for Science (ICSU) and the World Meteorological Organization (WMO) have jointly taken the lead in the organization of an International Polar Year (IPY) in 2007 and 2008. About 30 countries, including Sweden, both within and outside Europe have planned major involvements during IPY. The Arctic Summer Cloud Ocean Study (ASCOS) stands as one large Swedish initiative to be launched in the summer of 2008. For more details on ASCOS see the section below.

The work on Arctic climate processes at the institute is based on the expertise in boundary layer and mesoscale meteorology and in chemical meteorology. It has strong foci on the interaction between marine biology – aerosol – cloud formation, and between aerosol formation – boundary-layer fluxes – radiation – clouds. A very strong component of this research evolves around the organization of icebreaker-based field experiments to the central Arctic basin, where the institute has an internationally leading role. There are also regional climate-modeling activities, within the ARCMIP program. The importance of larger-scale dynamics is also studied using large-scale model (reanalysis and global modeling) results.

ASCOS (The Arctic Summer Cloud Ocean Study)

Caroline Leck and Michael Tjernström

ASCOS (http://www.misu.su.se/~michaelt/ASCOS/ASCOS.htm) is an interdisciplinary research program evolving from an Arctic field experiment based on the Swedish icebreaker Oden, in the summer of 2008. ASCOS is a direct contribution to the International Polar Year (IPY). The ultimate objective is to understand processes that are poorly described in current climate models. ASCOS will improve our understanding of processes that control the evolution of clouds over the Arctic pack ice area, with an integrated study from the ocean through the sea-ice interface and the cloud-topped boundary layer up into the troposphere. The interdisciplinary approach included marine biochemistry, aerosol and cloud chemistry/physics, and meteorology.

The ASCOS team of 33 scientists from 16 research groups in 10 countries deployed on the icebreaker Oden in Longyearbyen on Svalbard on 31 July, 2008. After a brief start-up and installation phase in the fjord off Longyear-byen, Oden departed in the afternoon of 2 August and headed north for the pack ice. After research stations in the open water south of the ice and a marginal ice zone station, Oden headed north through the ice and arrived to its ice-drift position slightly north of 87˚N on 13 August, after having spent two days scouting for a appropriate ice floe to anchor to. ASCOS remained drifiting in general westward with this same ice floe until the midnight between 1 and 2 September. Oden was back where in Longyearbyen on the morning of 9 September. During the almost three-week long ice-drift period we maintained a suit of meteorological and gas and particulate phase chemistry observations onboard while establishing micrometeorological, oceanographic and marine biogeochemistry observation sites on the ice, both in proximity to Oden and at a remote location 3 km away on the same ice floe.

The ice conditions for deployment of observations on the ice were more difficult than expected. The ice south 87˚N was reasonably thick (2-3 m) but riddled with a multitude of melt ponds and structurally week, and would not hold to anchor an icebreaker. The weather conditions were also unexpectedly severe, with several relatively strong weather systems passing during the first phase, making the deployment of instruments in masts on the ice difficult. After this initial period, the weather settled down but with frequent periods of dense fog making Polar Bear security difficult. The first half of the ice drift was characterized by melting conditions, with a positive net radiation and a reasonably well mixed boundary layer. A cold episode half way through the ice drift, with temperatures down to -6 ˚C caused by cold-air advection (surface temperature higher than air temperature), was followed by a stationary high-pressure period with low clouds and temperatures around -2 ˚C; this can be seen as a preconditioning to the freeze-up that started towards the end of August with temperatures falling below -12 ˚C.

ASCOS was a great success. We monitored the vertical structure of the atmosphere and the ocean below the ice, with both in-situ and remote sensing instruments. We also monitored the structure and phase of precipitation and clouds and the energy fluxes at the surface. We also had comprehensible sampling of chemical and physical properties of aerosols in a specially built laboratory on Oden's 4th deck; atmospheric trace gases were also sampled here. Excitingly, micro-gel precursors to aerosols were abundant both in the so-called ocean micro-layer, the uppermost ocean surface water, and also in the fog water. The bubbles that bring these from the water into the air were also abundant. We brought back large amounts of unique data on such aspects as multi-phase clouds and related aerosol properties, and links between aerosols and the marine biology that will keep us busy for years.

Modeling climate variability of the Arctic Ocean in past and future climates with special focus on changing sea-ice

Sebastian Mårtensson, Markus Meier

This project aims to further improve our understanding of the long-term variability of the Arctic sea ice and its role in future climate. At the project start it was felt that many climate models produce too large errors due to inadequate representation of the sea ice component. Therefore we have improved an established regional coupled ice-ocean circulation model with high grid resolution for climate studies of the Nordic Seas and Arctic Ocean by incorporating an advanced multi-category sea ice model.

Future work includes a fully coupled (ocean and atmosphere) version for producing transient scenario simulations of the Arctic Ocean. The model will be forced with lateral boundary data from available global model simulations and the simulation will span from pre-industrial times until the end of the 21st century. These simulations will be started early 2011.

The model has also been adapted for use in the Baltic by SMHI. There it will be used within the SAFEWIN project to simulate statistics of ridged ice and internal forces within the ice in the Baltic. The aim of the SAFEWIN project is to develop an efficient ice compression and ice dynamics forecasting system – which is precisely aimed in increasing the safety of winter navigation in dynamic ice conditions.

One paper has been submitted to JGR for review with the title: "Simulated long-term variability of ridged sea-ice in the Arctic Ocean using a coupled multi-category sea ice ocean model" written by S. Mårtensson, H.E.M. Meier, P. Pemberton and J. Haapala.

Publications

One paper has been submitted to JGR for review with the title: "Simulated long-term variability of ridged sea-ice in the Arctic Ocean using a coupled multi-category sea ice ocean model" written by S. Mårtensson, H.E.M. Meier, P. Pemberton and J. Haapala.

Arctic Ocean Freshwater Studies

Per Pemberton, Markus Meier

One of the key processes within the Arctic Ocean is the accumulation and redistribution of freshwater. The freshwater maintains a stable stratification of the Arctic Ocean and prevents heat from deeper parts to be transported up-wards. The freshwater reservoir is not only important for the Arctic region itself but also for lower latitudes as freshwater is export to the North Atlantic. This export can vary and several episodes with an increased release of freshwater have been identified. It is still however not exactly known what is controlling the freshwater dynamics inside the Arctic. Also the release of freshwater and how sensitive it is to future changes is not well understood.

Within this project the Arctic Ocean freshwater system is studied mainly with a regional coupled ice-ocean model. The model framework helps us to study the sensitivity of the system and hopefully understand its mechanisms. A part of the work also focus on participating in a number of international model intercomparison experiments within AOMIP (Arctic Ocean Model Intercomparison Project), where the capability of simulating freshwater in the Arctic is investigated among several different models.

Mixing, heat fluxes and heat content evolution of the Arctic Ocean mixed layer

Anders Sirevaag, Sara de la Rosa and Ilker Fer (University of Bergen), Marcel Nicolaus2 (Alfred Wegener Institute, Germany), Michael Tjernström, Miles G. McPhee (McPhee Research Company, USA)

A comprehensive measurement program was conducted during 16 days of a 3 week long ice pack drift, from 15 August to 1 September 2008 in the central Amundsen Basin, Arctic Ocean. The data, sampled as part of the Arctic Summer Cloud Ocean Study (ASCOS), included upper ocean stratification, mixing and heat transfer as well as transmittance solar radiation through the ice. The observations give insight into the evolution of the upper layers of the Arctic Ocean in the transition period from melting to freezing.

The ocean mixed layer was found to be heated from above and, for summer conditions, the net heat flux through the ice accounted for 22 % of the observed change in mixed layer heat content. Heat was mixed downward within the mixed layer and a small, downward heat flux across the pycnocline accounted for the accumulated heat in the upper cold halocline during the melting season. On average, the ocean mixed layer was cooled by an ocean heat flux at the ice/ocean interface (1.2 W m^{-2}) and heated by solar radiation through the ice (-2.6 Wm-2). An abrupt change in surface conditions halfway into the drift due to freezing and snowfall showed distinct signatures in the data set and allowed for inferences and comparisons to be made for cases of contrasting forcing conditions. Transmittance of solar radiation was reduced by 59 % in the latter period. From hydrographic observations obtained earlier in the melting season, in the same region, we infer a total fresh water equivalent of 3.3 m accumulated in the upper ocean, which together with the observed saltier winter mixed layer indicates a transition towards a more seasonal ice cover in the Arctic.

Publications

Sirevaag, A., S. de la Rosa, S, I. Fer, M. Nicolaus and M. Tjernström, 2011: Mixing, heat fluxes and heat content evolution of the Arctic Ocean mixed layer. Ocean Science Discussions, doi:10.5194/osd-8-247-2011.

Measurements of bubble size spectra within leads in the Arctic summer pack ice

Caroline Leck, Michael Tjernström: Sara Norris, Ian Brooks, Barbara Brooks and Cathryn Birch (Leeds University, UK), Gerrit de Leeuw (Finnish Meteoroloical Institute), Anders Sirevaag (University of Bergen, Norway)

Marine bubbles play an important role on direct aerosol emissions from the ocean surface. As a bubble breaks the water surface e, depending on size it will form jet or film droplets. As the water evaporates whatever was dissolved in the sea water will remain airborne.

The first measurements of bubble size spectra within the near-surface waters of open leads in the central Arctic pack ice were obtained during the Arctic Summer Cloud-Ocean Study (ASCOS) in August 2008 at 87–87.6° N, 1–11°W. A significant number of small bubbles (30–100 μm diameter) were present, with concentration decreasing rapidly with size from 100–560 μm; no bubbles larger than 560 μm were observed. The bubbles were present both during periods of low wind speed (U < 6ms−1) and when ice covered the surface of the lead. The low wind and short open-water fetch precludes production of bubbles by wave breaking suggesting that the bubbles are generated by processes below the surface. When the surface water was open to the atmosphere bubble concentrations increased with increasing heat loss to the atmosphere. The presence of sub-stantial numbers of bubbles is significant because the bursting of bubbles at the surface provides a mechanism for the generation of aerosol and the ejection of biological material from the ocean into the atmosphere. Such a transfer has previously been proposed as a potential climate feedback linking marine biology and Arctic cloud properties.

Publications

Norris, S. J., I. M. Brooks, G. de Leeuw, A. Sirevaag, C. Leck, B. J. Brooks, C. E. Birch, and M. Tjernström, 2011, Measurements of bubble size spectra within leads in the Arctic summer pack ice. Ocean Sci., 7, 129–139, 2011www.ocean-sci.net/7/129/2011/doi:10.5194/os-7-129-2011.

On the potential contribution of open lead particle emissions to the central Arctic aerosol concentration

Caroline Leck, Michael Tjernström: Andreas Held (University of Bayreuth, Germany), Ian M. Brooks (Leeds University, UK)

The measurements were made during the icebreaker borne ASCOS (Arctic Summer Cloud Ocean Study) expedition in August 2008 between 2° – 10° W longitude and 87° – 87.5° N latitude. The median aerosol transfer velocities over different surface types (open water leads, ice ridges, snow and ice surfaces) ranged from 0.27 to 0.68 mm $\mathbf{s^{-1}}$ during deposition-dominated episodes. Emission pe-riods were observed more frequently over the open lead, while the snow behaved primarily as a deposition surface. Directly measured aerosol fluxes were compared with particle deposition parameterizations in order to estimate the emission flux from the observed net aerosol flux. Finally, the contribution of the open lead particle source to atmospheric variations in particle number concentration was evaluated and compared with the observed temporal evolution of particle number. The direct emission of aerosol particles from the open lead can explain only 5 - 10 % of the observed particle number variation in the mixing layer close to the surface.

Thus, it remains unclear if open leads are a significant source of aerosol mass to the Arctic boundary layer. It has earlier been proposed that aerosol particles emitted from open leads in the Arctic are enriched in organic compounds from the marine surface microlayer. These gel-like substances found in the aerosol were confirmed to have properties consistent with algal and bacterial exopolymer secretions or marine microgels that could span the whole size spectrum from colloidal-size nanogels containing single macromolecules entangled to form single-chain networks to micrometer-size gels (loose matrix associated with the aggregates or granular structures) that can aggregate to tight capsules reaching several 100 μm in diameter. The assembly and dispersion of macro-molecules can be affected by environmental parameters, such as UV-B radiation (280-320 nm) dispersing or inhibiting microgel formation, and/or pH and temperature inducing microgel volume phase changes. Thus, one can speculate that degradation and break-up is a potential atmospheric fate of the open lead-derived aerosol. This in turn can lead to a large number of smaller daughter particles derived from a small number of large parent particles emitted from the open lead.

Publications

Held A., I. M. Brooks, C. Leck, and M. Tjernström, 2010, On the potential contribution of open lead particle emissions to the central Arctic aerosol concentration. Atmos. Chem. Phys. Discuss., 10, 24961–24992, 2010 www.atmos-chem-phys discuss.net/10/24961/2010/ doi:10.5194/acpd-10-24961-2010.

Modeling the greenhouse Arctic Ocean and climate effect of aerosols

Annica Ekman, Douglas Nilsson (SU/ITM), Hamish Struthers (SU/ITM), Monica Mårtensson (SU/ITM), Margareta Hansson (SU/Natgeo), Radovan Krejci (SU/ITM), Johan Ström (SU/ITM), Peter Tunved (SU/ITM), Åke Hagström (Kalmar Högskola)

This project uses the CAM-Oslo general circulation model with a modified aerosol source scheme that includes interactive sea spray and organic sea spray parameterizations. A set of idealized model simulations were performed to quantify the radiative effects of changes in sea salt aerosol emissions induced by prescribed changes in sea ice extent. The model was forced using present day sea ice concentrations and projections of sea ice extent for 2100. Sea salt aerosol emissions increase in response to a decrease in sea ice, with the annual average increase in number emission over the north polar cap (70–90oN) projected to be 86×106 m^{-2} s^{-1} (mass emission increase of 23 μgm^{-2} s^{-1}). In response, the natural aerosol optical depth increases by approximately 23% leading to a direct aerosol forcing over the Arctic polar cap between −0.2 and −0.4 Wm^{-2} for the summer months. The model predicts that the change in first indirect aerosol effect (cloud albedo effect) is approximately ten times larger than the direct forcing. The overall effect of changes in Arctic sea salt aerosol emissions is a negative climate feedback that is likely to retard but not fully counteract the Arctic amplification of climate change. This study shows that both the direct and first indirect aerosol effects are strongly dependent on the surface albedo, highlighting the strong coupling between sea ice, aerosols, Arctic clouds and their radiative effects. The model is being evaluated against remote marine GAW stations with continuous sea salt aerosol mass measurements and against re-mote marine aerosol size distribution data bases. Tests have also begun on a first organic sea spray source parameterization.

Publications

Struthers, H., Ekman, A. M. L., Glantz, P., Iversen, T., Kir-kevåg, A., Mårtensson, E. M., Seland, Ø., Nilsson, E. D., 2010. The effect of sea ice loss on sea salt aerosol concentrations and the radiative balance of the Arctic. Atmospheric Chemistry and Physics Discussions, 10, 28859–28908. .

The properties of the surface microlayer of the open leads and the ocean mixed layer in the central Arctic Basin pack ice area

Caroline Leck, Qiuju Gao, Patricia Matrai (Bigelow Laboratory, USA) and Monica Orellana (University of Washington, Seattle, USA)

Collection of the surface microlayer, SML, (<100µm thick) of the open leads during the month of August between latitudes 87 and 88□N (ASCOS) was accomplished by hydrophilic teflon rollers ahead of radio-controlled boats. The particulate content of samples of the surface microlayer water was examined by transmission electron microscopy. Concentrations were extremely numerous, ranging from 2 $10^{7} ml^{-1}$ to more than 10^{14} ml^{-1} although bacterial counts made in the same samples varied by only about 50%. Size distributions of the particles were also very variable with modal diameter sizes of 10 nm in some samples and 50 nm in others, the 50 nm particles appearing to be clusters of the 10 nm ones. The particulates were acknowledged to be exopolymer secretions (EPS) of algae and bacteria often referred to as microcolloids or marine gels observed in bulk seawater in lower latitude oceans. EPS gels consist of large, highly surface-active and highly hydrated (99% water) molecules. They are polysaccharides to which other organic compounds such as proteins, peptides and amino acids are readily bound. EPS gels can collapse due to exposure to ultraviolet light, acidification. The surface microlayer also showed, besides particulate matter and bacterias, elevated concentrations of proteins, and dissolved organic substances.

Compositional analysis of EPS from the open leads shows that polysaccharides in particular in colloidal fraction are enriched in SML relative to the underlying surface seawaters. The size-distinguished fractions of EPS differ in monosaccharides composition. Variation of monosaccharide spectra indicates a dynamic physicochemical mechanism occurring during the processes of upwelling accumulation of EPS at sea surface.

The linkage between elevated levels of bulk water chlorophyll a and particulate dimethyl sufonium propionate, DMSP, (both indicators of phytoplankton biomass), proteins, and bacterial abundance is most likely a reflection of the ongoing planktonic production and cycling, as well as the input of ice algae. Most of the phytoplankton was present as small, flagellated forms, while most of the mesozooplankton biomass was composed of copepepods. Production of specific compounds, such as DMSP, was constrained to the surface mixed layer (0-20 m). Nonetheless, carbon export was measured past 50m, staying fairly constant throughout the water column for the duration of the drift. Bulk water primary and bacterial production was measurable but not high, always highest in the upper 5m of the water column.

Publications

Matrai, P.A., L. Tranvik, C. Leck , and J.C. Knulst, 2008, Are high Arctic surface microlayers a potential source of aerosol organic precursors, Marine Chemistry, 108 (1), 109-122, doi:10.1016/j.marchem.2007.11.001

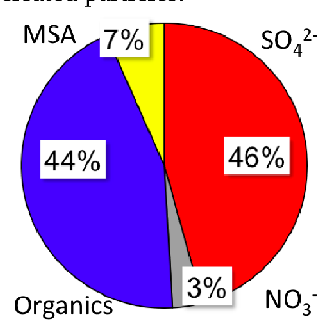
Biogenic particles over the central Arctic Ocean

Caroline Leck, Keith Bigg and Rachel Chang (Univerity of Toronto, Canada)

During the Arctic Summer Cloud Ocean Study (ASCOS) from August to the beginning of September 2008, submicron aerosol particles collected over the in the central Arctic Basin pack ice area were composed of approximately equal amounts of organic and sulpur components (sulphate, SO42-, and methane suphonte, MSA). Although the degree of oxygenation of the organic component of the Marine Biogenic aerosol would normally suggest that it had been processed in the atmosphere, we cannot rule out that local sources emitted primary oxygenated organic aerosols, as suggested by previous findings over the pack ice.

Past findings have shown that airborne particles are compared with those of particles found in the surface microlayer of the open water between ice floes during. The similarity in morphology (closely resembling microcollids or “virus like particles”), physical properties, X-ray spectra and a chemical reaction of the numerous aggregates and their building blocks and of bacteria and other microorganisms found in both, strongly suggests that the airborne particles were ejected from the water by bursting bubbles. On average, surface microlayer-derived particles represented more than one-half of the collected airborne submicrometre particle and more than four-fifths on sunny days when melting of the fringes of the ice floes was observed. On all days surface microlayer-derived particles dominated the population below 70 nm in diameter, the Aitken mode.

The shape of the size distribution of aggregates in the air was very similar to that in the water, each with a well-defined Aitken mode but shifted towards smaller sizes. Diffuse electron-transparent material joining and surrounding the particulates in both the air and water was shown to have properties consistent with the highly surface-active exopolymer secretions, EPS, of microalgae and bacteria in the water. The EPS collapse under the influence of ultraviolet light and acidification. Their lifetime in the atmosphere is therefore limited and is a sufficient reason why the airborne aggregate size distribution shifted to a smaller modal diameter (30nm instead of 50nm). Fresh aggregates with EPS gel on them could act as CCN directly because of the gels strong surface-active properties. Those that have lost their gel (larger degree of hydrophobicity) could still act as sites for condensation of the oxidation products of DMS. Evidence that this happens is the detection of presence of insoluble marine microcolloids in most (50-90% of total number counted) of the predominantly sulphate particles. Their acquistion of sulfuric acid provides a much more direct and faster path to CCN status than having to grow from nucleated particles.



Relative Massdistribution of the biogenic submicron aerosol collected during ASCOS at 88°N during the month of August, 2008.

With this new picture on the evolution of the remote Arctic aerosol, DMS concentration will determine the mass of sulfate produced but will have only a minor influence on the number of CCN and thus cloud droplets, which will be dictated by the number of airborne particles originating in the surface micro-layer of the open leads.

Free amino acids in aerosol samples collected over the Central Arctic Ocean in summer

Bodil Widell and Caroline Leck

Recently an enormously wide range of organic compounds has been found in both polar and remote marine aerosols with particles smaller than 200 nm in diameter considered the main carriers of the organic compounds. Previous literature have found that the production of airborne particles by bubbling in seawater (film and jet drops) discriminated against the more soluble low molecular weight compounds in favor of the more surface active high molecular weight compounds. Past discoveries of proteineous material in Antarctic cloud water samples, had us to start with the assumption that proteins together with bacterial enzymes are present in the film and jet drops which in turn could be relevant to the CCN control of albedo of low clouds in remote marine region.

The central Arctic Ocean summer provides a laboratory with remote marine biogenic sources of particles and limited influences of terrestrial and anthropogenic sources. To search for evidence of a proteninoues aerosol source in the high Arctic summer the present study covers aerosol data on the size-resolved dissolved free amino acid fraction (DFAA) of bubble-derived particles taken during the icebreaker expedition in the summers of 2001 (AOE-2001). The total concentration of DFAAs in the aerosol samples were 25- 50 pg m-3 air and the most abundant amino acids were Alanine, Aspartic acid, Glutamatic acid and Glycine. The composition and total concentration data reported, concert well with earlier published data from remote areas.

The unique determination of DFAAs in the size segregated aerosol samples showed that they were unimodal distributed, with peak mass median levels in the finest fractions (< 0.161 and 0.161- 0.655 mm equivalent aerodynamic diameter, EAD). An exception was however Glycine that showed a bimodal distribution with an additional peak in the larger accumulation mode 0.655 -2.12 µm EAD size range. All DFAAs were however enriched towards the finer fractions (<0.655 mm) with a factor of 2-3. As the DFAA's were found in sizes corresponding to either the film or jet drops or to both the sea surface microlayer was strongly suggested to have been their source.

The vertical distribution of atmospheric DMS in the high Arctic summer

Jenny Lundén, Gunilla Svensson, Michael Tjernström, Caroline Leck and Armin Wisthaler and Armin Hansel (University of Innsbruck, Innsbruck, Austria)

The vertical structure of gas-phase dimethyl sulfide (DMS(g)) in the high Arctic atmosphere is investigated during a summer season using a regional model. The model results show that the near-surface DMS(g) concentration over open ocean is very variable both in time and space, depending on the local atmospheric conditions. Profiles over ocean have typically highest concentration near the surface and decrease exponentially with height. Over the pack-ice, the concentrations are typically lower and the vertical structure changes as the air is advected northward. Modeled DMS(g) maxima above the local boundary layer were present in about 3% of the profiles found over the pack-ice. These maxima were found in association to frontal zones. Our results also show that DMS(g) can be mixed downward by turbulence into the local boundary layer and act as a local near-surface DMS(g) source over the pack-ice and may hence influence the growth of cloud condensation nuclei and cloud formation in the boundary layer. Profile observations are presented in support to the model results. They show that significant DMS(g) concentrations exist in the Arctic atmosphere at altitudes not to be expected when only considering vertical mixing in the boundary layer.

Publications

Lundén J., G. Svensson, A. Wisthaler, M. Tjern-ström, A. Hansel and C. Leck, 2010, The Vertical Distribution of Atmospheric DMS in the High Arctic Summer, Tellus B, Volume 62, 160-171.

A Study of New Particle Formation in the Marine Boundary Layer over the Central Arctic Ocean using a New Flexible Multicomponent Aerosol Dynamic Model

Caroline Leck: Matthias Karl (NILU, Norway), Liisa Pirjola (University of Helsinki, Helsinki, Finland) and Allan Gross (Danish Meteorological Institute, Denmark

Enhancement of number concentrations of particles with sizes less than 20 nm diameter has been observed in many cases over the central Arctic Ocean in summer. New particle formation events in the marine boundary layer occurred over open sea, in the marginal ice zone, and in the pack ice.

A new sectional aerosol dynamics model MAFOR was applied to investigate the nucleation of clusters and their subsequent growth by condensation of vapours. The study evaluated the capability of different nucleation mechanisms to reproduce events observed during three expeditions (1996 (AOE-96), 2001 (AOE-2001), and 2008 (ASCOS)) onboard the Swedish icebreaker Oden to the central Arctic Ocean.

Among the more recent parameterizations, which involve sulphuric acid as the only nucleating agent, the cluster activation (het-erogeneous nucleation) mechanism was found to be the most effective, while ion-mediated nucleation contributed only a few percent to the predicted overall nucleation rates. Predicted nucleation rates ranged on average between 3-8x10^{-4} cm^{-3} s^{-1} for kinetic nucleation of sulphuric acid and between 2-10x10^{-2} cm^{-3} s^{-1} for cluster activation. Several of the event cases could only be reproduced with a newly introduced kinetic-type organic-sulphuric acid nucleation mechanism which resulted in 2-10 times higher nucleation rates than those from the cluster activation mechanism. In most cases, the condensing organic vapour had to be less volatile and/or more surface-active than succinic acid in order to reproduce observed growth of initial clusters into particles of ~10 nm diameter size. Model calculations suggest a value of ~2x10^5 cm^{-3} s^{-1} for the condensable organic vapour source rate in order to reproduce observed particle growth. This estimate, however, involves unrealistically high precursor vapour concentrations and vapour production yields, indicating that the condensable organic vapour was not produced locally but advected to the observation location from a biological active oceanic or coastal source region.

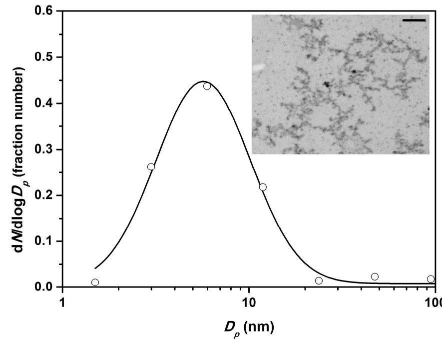
In several events, number concentration enhancement of 10-50 nm sized particles remained unexplained by the current nucleation and growth mechanisms, lending support to alternative theories such as the fragmentation of larger aggregates (about 200 nm diameter) from marine biological origin by physical or chemical processes.

The fractal structure of marine nanogels: a new perspective on particle formation

Caroline Leck and Esther Coz

Large increases in concentration of particles smaller than 20 nm diameter are relatively common in some coastal areas (Mace Head) and over the central Arctic Ocean in summer. These events do often not fit theoretical models of homogeneous nucleation from known precursor gases and do not show growth. Accompanying the Arctic nucleation events was also relative enhanced concentrations of a polymer-gel like substance with granular structures in sizes >100 nm diameter, similar to the exopolymer secre-tions (EPS) or marine microgels described for algae and bacteria, colloidal material. EPS consists of large highly surface-active highly hydrated and water insoluble polysaccharides, with high melting points. Microgels are three-dimensional polymer networks that result from the spontaneous assembly/ dispersion equilibrium of adjacent sugar chains forming hydrated Ca^{2+}-bonded polymer networks to give the gel-like consistency. The assembly and dispersion of macromolecules can be affected by UV dispersing or inhibiting microgel for-mation, and/or pH inducing microgel volume phase changes (swelling and shrinkage) showed that during phytoplankton blooms, the organic aerosol can constitute up to 63% (45% water-insoluble and 18%) of the total aerosol with the surface-active organic matter was sourced from the sea surface.

The goal of this study was to validate the hypothesis that marine gels are associated to a granular structure in the nucleation mode, as well as to determine under which circumstances they are associated to these structural characteristics. To achieve these purposes, samples collected during the ASCOS (Arctic Summer Cloud Ocean Study, www.ascos.se) 2008 from the sea-air interface to the cloud-topped boundary layer have been examined. Preliminary results give the proof of the existence of microgels with granular structures in all the type of samples analyzed down to the nanometer scale. The water insoluble organic marine compounds are associated with a fractal structure partially or totally covered by gels, with size distributions of the primary colloids below 10 nm (Figure 1). The colloid gel mixtures are observed in both externally and internally mixtures as size grow. Microgels (>1 µm) are internal mixtures of the colloids covered by the gel.



Size distribution of marine colloids from a cloud sample (scale bar = 100 nm)

Cloud Condensation Nuclei Closure Study on Summer Arctic Aerosol

Caroline Leck: Maria Martin, Berko Sierau, Ulrike Lohman (ETH, Schwitzerland, Rachel Y. –W. Chang, J.P.D. Abbat (University of Toronto, Canada) Staffan Sjögren, Erik Swietlicki (Lund University)

An aerosol - cloud condensation nuclei (CCN) closure study was performed on measurements that were carried out in summer 2008 during the Arctic Summer Cloud Ocean Study (ASCOS) on board the Swedish icebreaker Oden. The data were collected during a three-week time period in the pack ice (> 85°N) when the icebreaker Oden was moored to an ice floe and drifted passively during the most biological active period into autumn freeze up conditions. CCN number concentrations were obtained using two CCN counters measuring at different supersaturations. The directly measured CCN number concentration was then compared with a CCN number concentration calculated using both bulk aerosol mass composition data from an aerosol mass spectrometer and aerosol number size distributions obtained from a differential mobility particle sizer, assuming _-Köhler theory and an internally mixed aerosol. For the two highest measured supersaturations, 0.73 and 0.41%, closure could not be achieved with the investigated settings concerning hygroscopicity and density. The calculated CCN number concentration was always higher than the measured one. One possible explanation is that the smaller particles that activate at these supersaturations have a relative larger insoluble organic mass fraction and thus are less good CCN than the larger particles. At 0.20, 0.15 and 0.10% supersaturation, the measured CCN number can be represented with different parameters for the hygroscopicity and density of the particles. For the best agreement of the calculated CCN number concentration with the measured one the organic fraction of the aerosol needs to be nearly insoluble.

Publications

Matrai, P.A., L. Tranvik, C. Leck, and J.C. Knulst, 2008, Are high Arctic surface microlayers a potential source of aerosol organic precursors, Marine Chemistry, 108 (1), 109-122, doi:10.1016 /j.marchem.2007.11.001.

Marine microgels: a source of CCN in the high Arctic

Caroline Leck: Mónica V. Orellana and Allison M. Lee (Institute for Systems Biology, Seattle, USA), Patricia A. Matrai and Carlton D. Rauschenberg (Bigelow Laboratory for Ocean Sciences, Maine, USA), Esther Coz (MISU, CIEMAT, Madrid, Spain)

The summer CCN population over the central Arctic Ocean pack ice has been believed to result mostly from homogeneous oxidation of sulfur-containing gases, providing both the newly formed particles and their growth to sizes large enough to become activated into cloud drops, and to contain a large fraction of organic material. Recent results however suggest that for airborne particles north of 80°N, the concentra-tion of the gas dimethylsulfide (DMS) would determine the mass of sulfate, by producing material for growth of the particles, but would have only a minor influence on the number of CCN and thus on the optical properties of the low-level clouds. Instead, the number of cloud drops would be dictated by airborne microgels, or so called exopolymer secretions (EPS; consists of large highly surface-active highly hydrated and water insoluble polysaccharides, with high melting points) emitted from the surface microlayer (SML) of the open leads. Leads, as deformation openings in pack ice, and polynyas couple the atmosphere with the sea ice covered Arctic Ocean, allowing illumination to reach the surface water during the summer melt and promoting ice-bottom algae and phytoplankton growth that takes advantage of the nutrients already present. Such biological activity as well as that found in the receding seasonal ice zone represents a potential steady source of marine microgels (EPS).

For the first time, we demonstrate directly and unambiguously the presence of marine microgels in the clouds, fog, and airborne aerosol particles sampled at 87^{o}N in the summer of 2008 (ASCOS). Microgels were immu-nostained with an antibody specific towards material from surface waters indicating that the source of the gel particles detected in cloud, fog, and aerosols was the surface water and most probably the SML where microgels accumulated; this material, in fact, came from the phytoplankton (M. arctica and other phytoplankton species) and their exocytosed products.

Our results clearly demonstrate that marine microgels, due to their emergent properties, can affect the chemistry and physics of the Earth's atmosphere by being an important source of CCN in the pristine high Arctic summer, and probably elsewhere, thus affecting climate by radiative coupling. The microgel-climate feedback paradigm suggests that biology has an important role in determining the chemistry and the physics of marine aerosol particles such that parameterizations of their source function should include processes pertaining to the source and concentration of marine organic matter and should be included in regional and global aerosol climate models.

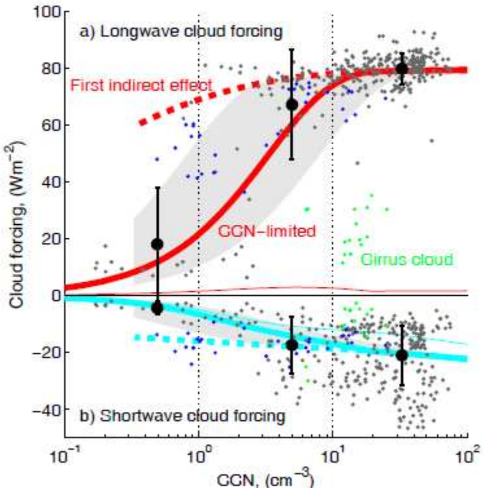
A low-CCN cloud regime in the summer Arctic

Michael Tjernström, Caroline Leck: Thorsten Mauritsen (Max-Planck Institute for Meteorology, Hamburg, Germany), Joseph Sedlar (SMHI), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA), Staffan Sjögren and Erik Swietlicki (Lund University), Berko Sireau (ETH, Zurich, Switzerland), Ian Brooks (Leeds University, UK)

Clouds require clouds condensation nuclei (CCN) to form. Normally nature has an ample supply of CCN and liquid water clouds usually form close to a 100% relative humidity. But during the Arctic Summer Cloud Ocean Study (ASCOS) we observed periods with high relative humidity and very low number concentrations of CCN, and during these periods clouds became tenuous or vanished entirely and consequently the near surface temperature dropped as the greenhouse effect of the clouds approached zero.

Using the observations from ASCOS and calculations with a radiative transfer model we elaborated on these events and propose a hypothesis that is consistent with the observations. We suggest that in conditions with very low CCN concentration only a few droplets can form and with high relative humidity these proceed to grow very rapidly. Eventually they become so large that they will settle to the surface by gravity, thereby limiting both the cloud liquid water and the number of CCN present. The presence of these very large cloud droplets was indicated by the presence of a double fog bow; an optical phenomenon that only appears when the cloud droplets grow larger than 20-25 mm.

Using the radiative transfer model we then illustrate the effects on the surface cloud radiative forcing. These results show under the conditions of very few CCN (< 10 cm^{-1}) small changes in CCN concentration will change the longwave radiative forcing much more than it will change the shortwave surface forcing through an increased cloud albedo; the so-called Twomey effect. Judging by probability density functions of CCN from four different research expeditions to the central Arctic, conditions like these happen an substantial part of the time in summer. This hypothesis therefore provides a new framework in which to consider effects of possible changes in summer Arctic aerosols, anthropogenic or through climate warming feedbacks. Instead of postulating that the aerosol effect is negative, causing a cooling as it is assumed to do at lower latitudes, there is a possibility that an increased aerosol concentration in the Arctic will cause further warming.



Surface cloud radiative forcing in a) longwave- and b) shortwave radiation as a function of CCN. Measurements of CCN are done at a supersaturation of 0.2%. Lines are idealized radiative transfer calculations. Dashed lines represent the first aerosol indirect effect only, while the solid thick lines correspond to cloud liquid content being limited by Re < 15 mm. The grey shaded areas show the range of uncertainly limiting cloud liquid content by 10 mm < Re < 30 mm.

Publications

Mauritsen, T., J. Sedlar, M. Tjernström, C. Leck, M. Martin, M. Shupe, S. Sjögren, B. Sierau, P.O.G. Persson, I.M. Brooks, E. Swietlicki, 2011: An Arctic CCN-limited cloud-aerosol regime, Atmospheric Chemistry and Physics, 11, 165–173, doi:10.5194/acp-11-165-2011.

The vertical stratification of submicrometer aerosol particles and their relevance for cloud formation over the Arctic Ocean pack ice during summer - a contribution to the Arctic Summer Cloud Ocean Study (ASCOS)

Caroline Leck, Linda Orr, Joeseph Sedlar (SMHI) Barbara. Brooks, Sarah Norris (University of Leeds, UK), Erik Swietlicki and Staffan Sjögren (Lund University)

Clouds over the Arctic Ocean regulate the radiative fluxes to the surface, impacting the surface energy budget and melting and freezing of snow and sea ice. Aerosol sources are known to be few in summer while the cloud cover is generally at a maximum during this season. Until now, a large deficiency has been an inability to relate Arctic aerosol and cloud properties because of the difficulties in performing *in situ* measurements within the harsh Arctic environment. During the Arctic Summer Cloud Ocean Study (ASCOS) of 2008, a helicopter was successfully deployed to profile the thermodynamic structure and aerosol particle concentrations in several size ranges across a multitude of surface conditions.

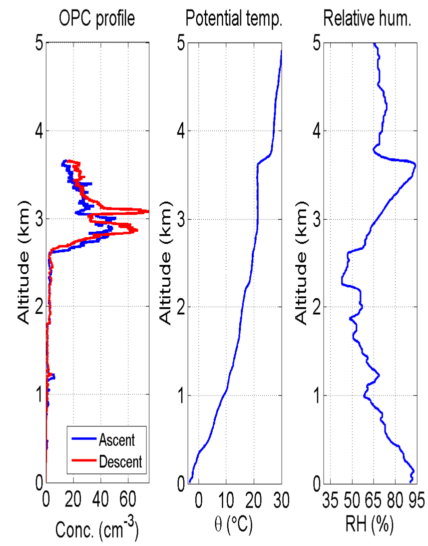
The ultrafine particle (diameters between 3-15 nm) concentrations were typically a few hundred per cm3, but reached as high as 1500 cm^{-3} and were often found within the shallow Arctic boundary layer; occasional elevated concentrations were measured at higher altitudes. However, the accumulation mode particle concentrations were generally less than 1 cm^{-3} within the well-mixed boundary layer. Such low levels can be explained by the presence of a moist boundary layer combined with a general absence of local sources. In addition, and consistent with previous findings in the area largest accumulation mode numbers were found at and above former cloud tops. Stratification of aerosol modes suggests that the application of surface-based measurements of aerosol properties for prediction of cloud properties is critically dependent on atmospheric vertical mixing. This necessitates further understanding before the sign on the radiative forcing due to climate change based on the effects of low-level cloud over the Arctic pack ice area can be assessed.

Tropospheric long range transport of a forest fire plume to the central summer Arctic

Michael Tjernström and Caroline Leck: Erik Swietlicki (Lund University), Armin Wisthaler and Armin Hansel (University of Innsbruck

It is well known that pollution from southerly latitudes reaches far into the central Arctic in winter, among other things giving rise to so called “Arctic haze”, but it has been assumed that the summer Arctic atmosphere is relatively isolated from transport of air from the south. We show the first in-situ evidence of a long-range transported plume from biomass burning, most likely from Siberian forest fires to as far north as near the Pole, at about 88.4 ºN from 8 August 2001. The plume was observed by helicopter-borne instruments at an altitude of about 3 km and was associated with a weak warm front at that height. The plume had a clear maximum of larger than 300 nm aerosol particles, observed with an OPC instrument, coincident with maximums in the gases acetonitrile (CH3CN) and acetone, observed with a proton transfer reaction mass spectrometry (PTR-MS) instrument; acetonitrile is a specific tracer for biomass burning.

These results imply that previous assumptions, that the summer Arctic atmosphere is more or less isolated from lower latitude air masses, are partly incorrect. This has been based primarily on near-surface observations, likely strongly influenced by very effective scavenging of low-level pollutants in fogs and low clouds at the marginal ice zone. This results in a shallow boundary layer with unaffected air, while long-distance transported plumes of pollutants can exist for long times aloft. In the present case the plume was found at an altitude of several kilometers and it is very difficult to envision a process whereby this aerosol could be effec-tively mixed down into the lowest troposphere. Several vertical profiles of longlived gases of continetal origin, such as acetone and acetonitrile, from this and other helicopter flights confirm this; the concentrations were always much higher above the inversion capping the boundary layer than below it.



Profiles of (left) aerosol particles larger than 300 nm, (middle) potential temperature and (right) relative humidity from the evening of 8 August 2001.

A summer-fall transitioning surface energy balance

Michael Tjernström, Caroline Leck: Joseph Sedlar (SMHI) Thorsten Mauritsen (Max-Planck Institute for Meteorology, Hamburg, Germany), Anders Sirevaag (University of Bergen, Norway), Ian Brooks and Cathryn Birch (University of Leeds UK), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA)

An explicit target of the Arctic Summer Cloud Ocean Study (ASCOS) was to measure all terms in the surface energy budget over the central Arctic perennial ice as the melt season ended and the fall freeze-up commenced. This was achieved by having an instrumented tower on the ice with observations of turbulent sensible and latent heat flux, radiation sensors near the surface measuring long- and shortwave radiation and also a mast under the ice with observations of the oceanic boundary layer sensible heat flux and the transmitted radiation through the ice.

At the beginning of the ice drift conditions were still typical for the melt season; short wave radiation dominated the budget and there was a large surplus that went into melting snow and ice. Consequently all melt ponds where still open and the surface albedo was low. This period is followed by the actual “trigger”; during about two days the longwave radiation balance starts to balance the net shortwave radiation and during this time the temperature falls and melt ponds freeze over. This period is ended by a substantial snowfall; snow covered all the frozen melt ponds. Together with substantial riming from frequent fogs during this changed the surface albedo over this episode dramatically. Then follows a period when all the net fluxes are small, temperatures are steady around -2 °C and the presence of a stratocumulus layer in a capping subsidence inversion keeps the surface from freezing further; as these clouds break up towards the end of August the temperature immediately drops. During these last few days of ASCOS the residual heat flux for the first time goes negative and proper freeze-up started.

The important lesson is that the transition from melting to freezing conditions is not a gradual change over several days or weeks as the sun is setting lower in the sky. Instead it is a rapid transition from one state to the other associated with an albedo change provided that the sub is low enough not to start the melt again. The actual chain of events may be even more complicated, as clouds have a significant role; in this case the freeze-up would have started a week earlier if a persistent cloud layer had not been present “protecting” the surface from further freezing. The radiative input from the sun changed somewhat over these three weeks, however, of larger importance was the change in surface albedo and the longwave surface radiative forcing of the clouds; the latter governed the surface temperature.

Publications

Sedlar, J., M. Tjernström, T. Mauritzen, M. Shupe, I. Brooks, P. Persson, C. Birch, C. Leck, A. Sirevaag, and M. Nicolaus, 2010, A transitioning Arctic surface energy budget: the impacts of solar zenith angle, surface albedo and cloud radiative forcing. Climate Dynamics,1-18. doi:10.1007/s00382-010-0937-5

Snow melt and freeze up in the pan-arctic region analyzed from satellite observations

Jonas Mortin, Gunilla Svensson, Rune Grand Graversen, Thomas Schröder and Aksel Walløe-Hansen (Copenhagen University, Denmark)

The impact of snow cover in the pan-arctic region are important. Accurately determining the large scale snow coverage, both by models and measurements, is therefore of significant importance, especially in the light of a potential arctic amplification and global warming. However, *in situ* measurements are spatially and temporally sparse in the arctic region. In this project, satellite based observations, scatterometer data from QuikScat, are used to derive the seasonal snow cycle. Special focus is on the melting and freeze up for which the original algorithms were developed at JPL, USA, and are in this project refined. The dataset is evaluated against in-situ observations both over land and ocean and compared with reanalysis products. The horizontal resolution is about 5x5km2 and data used in the study is from 1999 through 2009.

Mesoscale variability in the summer Arctic boundary-layer

Michael Tjernström and Thorsten Mauritsen

The central Arctic Ocean atmospheric boundary layer is not affected by disturbing terrain features or large horizontal surface temperature gradients, and should therefore be relatively free from mesoscale variability. Still, turbulence power spectra of for example wind speed from AOE-2001 often do not have any spectral gap and wavelet analysis of surface pressure variability show frequent occurrence of variability on hourly time scales, sometimes accompanied by burst of high variability on 5-to-20 minute time scales.

We show that the general variability in surface pressure is directly connected to the vertical structure of the lower troposphere, and changes on a time scale of several days depending on large-scale air mass changes. High-frequency variability events were often related to mesoscale front-like features. These appear only in the boundary layer, with rapid shifts in boundary-layer temperature, enhanced drizzle but no discernible signal aloft, above the top of the low clouds usually < 1 km. Such fronts were very common, appearing on average more than once per day. Turbulence intensity is higher during these events than otherwise, and spectral gaps are, unexpectedly, more pronounced.

We hypothesize that the fronts are induced by small differences in cloud properties or differences in air mass age and sharpens to fronts due to non-linear dynamics. Once formed, the fronts trigger ducted gravity waves when the background structure is favorable. These waves interact with boundary-layer turbulence and enhance boundary-layer variability.

Publications

Tjernström, M., and T. Mauritsen, 2009: Mesoscale variability in the summer Arctic boundary layer. Boundary-layer Meteorology, 130, 383–406, DOI 10.1007/s10546-009-9354-x.

Arctic clouds and the boundary-layer inversion

Joseph Sedlar and Michael Tjernström

The vertical structure of the Arctic summer boundary layer was examined from a suite of remote and in-situ measurements first from the Arctic Ocean Experiment 2001 (AOE-2001). The boundary-layer structure during AOE-2001 has on average a two-layered structure, where the lowest 25% is slightly stable and the upper 75% is nearly moist adiabatic. As the upper layer most often is associated with the cloud, this indicates that cloud-top cooling is maintaining the upper portion of the boundary layer well mixed, while the lowest 25% is more affected by the local surface. The low-level clouds were found to fall in one of two categories: 1) The in-version-capped cloudy boundary layer where the cloud tops was found at the base of the inversion; and 2) Cases where the cloud top penetrated well into the boundary layer. The first type conforms to the proto-typical marine cloud-capped boundary-layer structure found for example over the subtropical oceans, but the second category seems particular to the Arctic. Parti-tioning the data into these two categories and composit-ing the data shows significant differences, for example precipitation is much more common in the 2nd case while the stratification in the upper portion of the boundary layer is higher. This – and other differences – has lead to the conclusion that while the inversion-capped low clouds predominantly consist of liquid wa-ter, the type where clouds penetrate into the inversion are more often mixed-phase, with a significant portion of ice.

This study was extended using data from two field experiments, Surface Heat balance of the Arctic (SHEBA, 1 year) and Arctic Summer Cloud-Ocean Study (ASCOS, 1 month), and from Barrow, Alaska (5 years). Of the profiles available for analysis, clouds with tops penetrating inside the temperature inversion were more frequently observed than the prototypical clouds that are capped by the inversion base over both SHEBA and ASCOS, located over the pack ice, while the situation was reversed at Barrow, located on land, albeit close to the Arctic Ocean. Clouds with tops inside the inversion were typically associated with ~ 3°C stronger and 100-200 m deeper temperature inversion compared to CCI cases. In addition, both cloud-base and cloud-top heights were lower for these cases. Sub-cloud layer stability was unstable nearest the surface, with a stable layer emerging on average approximately midway through the sub-cloud layer and stability weakening slightly below cloud base. Bulk cloud-layer lapse rates were also less stable suggesting a cloud-layer with potentially more buoyant mixing.

Publications

*Sedlar, J., and M. Tjernström, 2009: Stratiform cloud-inversion characterization during the Arctic melt season, Boundary-Layer Meteorology, **132**, 455-474, DOI 10.1007/s10546-009-9407-1.*

Sedlar, J., M. D. Shupe and M. Tjernström, 2011: On the relationship between thermodynamic structure and cloud top, and its climate significance in the Arctic. Journal of Climatology, Accepted.

Arctic regional climate modeling of the AOE-2001 data

Michael Tjernström, Per Axelsson, Gunilla Svensson, Stefan Söderberg (WeatherTech, Sweden), Cathryn Birch (University of Leeds, UK), Sean Milton and Paul Earnshaw (UK MetOffice).

The Arctic Regional Climate Model Intercomparison Project (ARCMIP) aims to improve numerical simulations of Arctic climate, and to improve the description of important Arctic climate processes in global models (see http://curry.eas.gatech.edu/ARCMIP/index.html). Primary ARCMIP activities focus on coordinated simulations with different regional climate models using the same horizontal resolution and lateral boundary conditions. Using regional modeling facilitates controlled simulations of the local and regional climate, providing accurate analyses as lateral boundary conditions. It also makes possible a direct comparison with observations. With a reasonably controlled background climate, imposed by analyzed boundary conditions, remaining errors must be due mostly to regional-model deficiencies.

In a first attempt to simulate data from the Arctic Ocean Experiment 2001 (AOE-2001) we used both the US NAVY model COAMPS® and the UK MetOffice Unified Model at several resolutions. In general the clouds were found to be a problem, while the two models also have their own biases. The problem of using a large (pan-Arctic) outer domain in regional modeling while evaluating the model results with in-situ single point observations was later alleviated using an ensemble of COAMPS® simulations where surface roughness, turbulent mixing in clouds and initial times was varied. The ensemble spread in these results was surprisingly large while the ensemble-average results conformed reasonably well to the observations. COAMPS® was shown to have a cold bias below a few kilometers, likely due to an erroneous cloud/radiation inter action, and to have too weak weather systems. The clouds were too thin and displaced too high with the expected biases in the incoming radiation; however, the turbulent fluxes were similar both within the ensemble and as compared to the observations even when altering the surface roughness orders of magnitude. A possible cause for the cloud problems seems to be that liquid clouds form ice and precipitate out too fast.

Publications

Birch, C. E., I. M. Brooks, M. Tjernström, S. F. Milton, P. Earnshaw and S. Söderberg, 2009: The performance of a global and mesoscale model over the central Arctic Ocean during the summer melt season. Journal of Geophysical Research, 114, D13104, doi:10.1029/2008JD010790.

Axelsson, P., M. Tjernström, S. Söderberg and G. Svensson, 2010: An ensemble of Arctic simulations of the AOE-2001 field experiment. Atmosphere, Accepted.

Simulations of Arctic clouds and their influence on the winter present-day climate in the CMIP3 multi-model dataset

Johannes Karlsson and Gunilla Svensson

Simulations of Arctic clouds and radiation in coupled ocean/atmosphere climate models participating in the fourth assessment report (AR4) of the intergovernmental panel on climate change (IPCC) are analyzed. Satellite observa-tions of cloudiness and radiative fluxes at the top of the atmosphere as well as at the surface are utilized for com-parison. The analysis is performed as seasonal averages over the entire area north of 66.6□N, over the open ocean and over the sea-ice separately. The analyzed model results show large variations over this region in terms of cloudiness, cloud water and ice water content. results indicate that the cloudiness seems to have a week connection to the surface. The fact that six models have the same magnitude of cloud forcing but a spread in surface mean temperature of more than 10K, indicates that non-cloud processes are important for the temperature spread. On the other hand, it is interesting that all but one model which underestimate the surface cloud forcing also underestimate the surface temperature.

Further analysis of the model results show that the wintertime turbulent heat fluxes vary substantially between models and different surfaces. The simulated net longwave radiative flux at the surface is biased high over both surfaces compared to observations, but for different reasons. Over open ocean, most models overestimate the out-going longwave flux while over sea-ice it is rather the downwelling flux that is underestimated. Based on the downwelling longwave flux over sea-ice, two categories of models are found. One group of models which shows reasonable downwelling longwave fluxes, compared with observations and ERA-Interim, is also associated with relatively high amounts of precipitable water as well as surface skin temperatures. This group also shows more uni-form air mass properties over the Arctic region possibly as result of more frequent events of warm-air intrusion from lower latitudes. The second group of models underestimates the downwelling longwave radiation and is associated with relatively low surface skin temperatures as well as low amounts of precipitable water. These models also exhi-bit larger decrease in the moisture and temperature profiles northward in the Arctic region which might be indicative of too stagnant conditions in these models.

Publications

Karlsson, J. and G. Svensson, 2011: The simulation of Arctic clouds and their influence on the winter present-day climate in the CMIP3 multi-model dataset. Climate Dynamics. 36, 623-635.

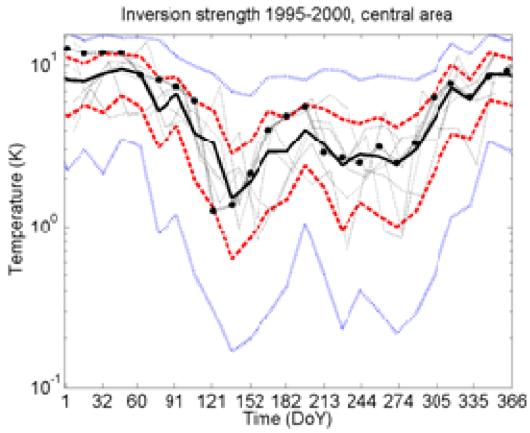
Svensson G. and J. Karlsson, 2011: On the Arctic wintertime climate in global climate models. Submitted to J. Climate.

The vertical structure of the lower Arctic atmosphere

Michael Tjernström and Rune Grand Graversen

We attempt to estimate the vertical structure of the Arctic atmosphere, using the ERA-40 reanalysis data and SHEBA soundings. First we analyze the SHEBA soundings for a full year. Inversions are virtually always present, in summer as a weak elevated inversion and in winter as a mixture of strong surface inversions and elevated inversion each occurring about half the time. There is a pronounced annual cycle in the inversion characteristics with the strongest and lowest, but also most variable, inversions in winter. In summer the conditions are less variable, with weak elevated inversions predominating.

Then we compared the vertical structure of the lower troposphere in ERA-40 with observations from the SHEBA experiment to evaluate if the reanalysis is resolving the observed structure of the Arctic lower troposphere. This analysis reveals a surprising capability of the ERA-40 data to describe the Arctic lower troposphere structure, even in winter with shallow very stable inversions. A special consideration here is that the soundings from the SHEBA experiment were assimilated into ERA-40. We show that: 1) The correspondence between the simulated and observed lower troposphere structure during the SHEBA experiment is good; 2) there is no significant difference in the annual cycle of this structure between the SHEBA year and three years before and three years after the SHEBA experiment. At the same time there is a significant impact of the soundings when analyzing the analysis increment for years with and without the soundings, and also when comparing both first-guess and analysis fields from ERA-40 with the soundings.



An annual cycle of temperature inversion strength for the period 1995-2000 from the ERA-40, showing (black solid) median, (red dashed) 25- & 75- and (blue dashed) 5- & 95-percentiles. The thin dotted lines show the annual cycle for individual years, and the one marked with black dots shows the SHEBA year

Our interpretation is that ERA-40 captures the structure well, but that it has a significant warm bias in the boundary layer and a week cold bias in the free troposphere. Interestingly, when comparing the analysis increment for years with and without assimilation of soundings, the latter draws the model in the opposite direction compared to non-soundings years, when the assimilation presumably relies mainly on satellite data.

Publications

Tjernström, M., and R.G. Graversen, 2009: The vertical structure of the lower Arctic troposphere analysed from observations and ERA-40 reanalysis. Qarterly Journal of the Royal Meteorological Society, ***135****, 431-433.*

Water-vapour feedback and Arctic amplification

Rune Grand Graversen, Peter Langen (Copenhagen University, Denmark) and Thorsten Mauritsen (Max Planck Institute, Germany)

The feedbacks of water vapour, clouds, and surface albedo is investigated. In the radiative code of climate models we lock water vapour, clouds, and albedo one-by-one and in combinations in order to quantify their respective feedback responses associated with a doubling of the atmospheric CO2 content. This is a continuation of a earlier work where we locked the surface albedo in the CCSM3 coupled climate model. We put especial attention to the response of these feedbacks in terms of meridional energy-transport changes and polar amplification and its vertical atmospheric structure.

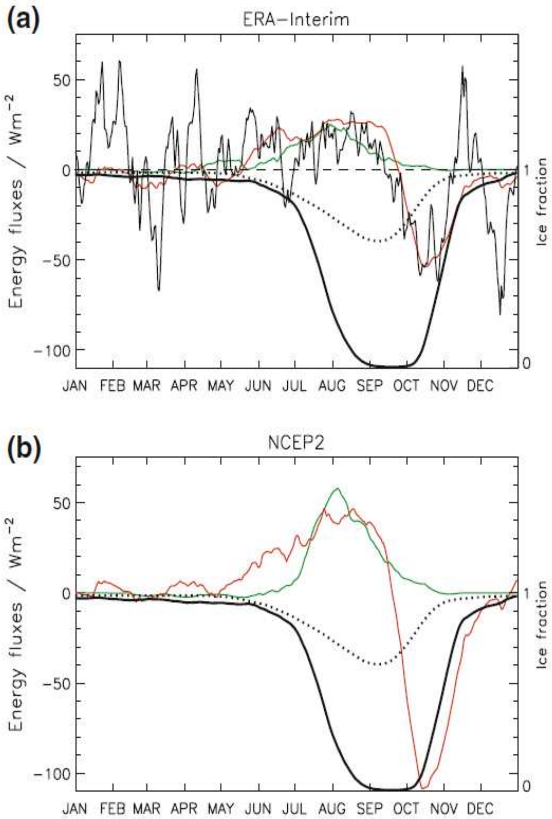
Publications

Graversen R.G. and M. Wang, 2009: Polar amplification in a coupled climate model with locked albedo. Clim Dyn, 33, 629-643.

The role of meridional energy transport for the 2007 Arctic sea-ice retreat

Rune Grand Graversen, Thorsten Mauritsen, Michael Tjernström, Sebastian Mårtensson, Sybren Drijfhout (KNMI, The Netherlands)

The sea-ice cover decrease during the summer of 2007 took scientists by surprise; over one single summer the ice cover Arctic sea-ice shrank by almost 30% to the lowest extent ever observed. The role of the atmospheric energy transport in this extreme melt event was explored using the state-of-the-art ERA-Interim reanalysis data. We find that in summer 2007 there was an anomalous atmospheric flow of warm and humid air into the region that suffered severe melt. This anomaly was larger than during any year in the reanalysis data (1989–2008). Convergence of the atmospheric energy transport over this area led to positive anomalies of the downward longwave radiation and turbulent fluxes. In the region that experienced the largest unusual melt, the net anomaly of the surface fluxes provided enough extra energy to melt roughly one meter of ice over the melting season. When the ocean successively became ice-free, the surface-albedo decreased causing additional absorption of shortwave radiation, despite the fact that the downwelling solar radiation was smaller than average. We argue that the positive anomalies of net downward longwave radiation and turbulent fluxes played a key role in initiating the 2007 extreme ice melt, whereas the shortwave-radiation changes acted as an amplifying feedback mechanism in response to the melt.



Ice coverage, convergence of atmospheric energy transport, and energy fluxes at the surface during 2007 over the region 74°–82 °N and 135° W–165° E. Solid and dotted, thick, black curves indicate ice cover in 2007 and the average during the preceding 18 years, respectively. Green curve shows net shortwave-radiation anomalies at the surface, while the sum of the net longwave radiation, latent, and sensible turbulent flux anomalies is given by the red curve. Thin, solid curve indicates atmospheric energy transport convergence. Anomalies are relative to the climatology with monthly resolution from the years 1989–2003. The daily data are smoothed with a 30 day running-mean filter. Upper panel is based on ERA-Interim data, whereas in the lower panel, the surface fluxes are from NCEP2, and the ice fractions are from the ERA-Interim.

Publications

Graversen, R. G., T. Mauritsen, S. Drijfhout, M. Tjernström, and S. Mårtensson 2010: Warm winds from the Pacific caused extensive Arctic sea-ice melt in summer 2007. Climate Dynamics, DOI 10.1007/s00382-010-0809-z.

Recent Arctic sea-ice retreat

Rune Grand Graversen, Michael Tjernström, Thorsten Mauritsen (Max Planck Institute, Germany) and Marta Zygmuntowska (Nansen Center, Norway)

The linkage between atmospheric circulation variability and the recent years' sea-ice melt is studied. We investigate the changes in radiation and turbulent fluxes at the surface over areas vulnerable to sea-ice melt. We further investi-gate the linkage of these surface fluxes to alterations of the atmospheric sensible heat and moister transport and the cloudiness. Among different issues, it is relevant to know whether a possible increase of the long wave radiation is larger in the Arctic than over the rest of the globe.

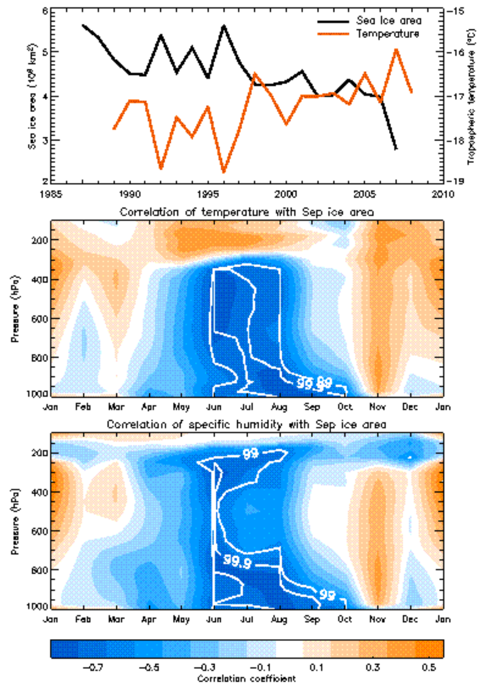
The study is mostly based on reanalysis and satellite data. A large part of this work is comparisons and evaluations of these data against in situ station data. Especially the evaluation of the surface radiative fluxes are needed. For example, we compare both satellite data from the "active" CloudSat and reanalysis data with measurements taken at the Barrow station in north Alaska.

Is recent Arctic summer sea-ice melt driven by warming from aloft?

Rune Grand Graversen and Thorsten Mauritsen (Max Planck Institute, Germany)

Arctic sea-ice extent has decreased significantly during the melting season in recent decades. At the same time am-plified warming is observed in the Arctic troposphere. A number of recent studies debate whether the retreating sea-ice is driving the warming, or vice versa. A key to establishing this cause-and-effect relationship is the vertical structure of the warming, which differ among atmospheric reanalysis products leading to diverging conclusions in recent studies. Here we reconcile these apparently contradicting findings concerning the vertical structure of the Arctic warming as being largely due to deviating averaging periods - not reanalysis artifacts.

We suggest that a considerable part of the observed sea-ice reduction is driven by the warming aloft. As shown by the figure, the September sea-ice area is highly anti-correlated with tropospheric temperatures in the beginning of the summer and surface temperatures in the end of the summer. Positive anomalies of free tropospheric tempera-tures in June-July increase the energy flux towards the surface by longwave radiation and turbulent mixing. As the sea-ice hereby melt, a series of surface-based processes start acting, among them the surface albedo feedback, which contributes to a surface warming by the end of the summer.



Upper panel: time series of September ice area and June-August mean atmospheric temperatures averaged over the area north of 70 N and over the atmospheric column between 300 and 925 hPa. Middle and lower panels: correlation of September ice area with temperature and humidity, respectively, as function of height and month. White contours indicate that correlations differ from zero at a 99 and a 99.9 % significance level. The Ice data are from NASA satellite observations, and temperature and humidity data are from the ERA-Interim reanalysis.

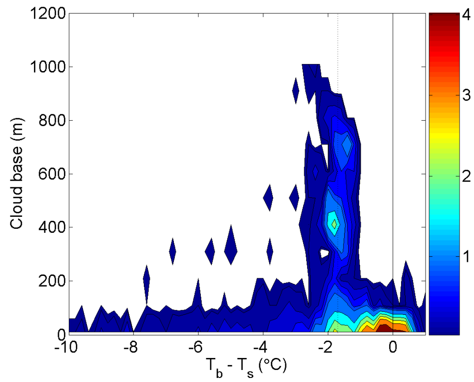
Vertical coupling of clouds and the surface in the summer Arctic

Michael Tjernström, Thorsten Mauritsen, Joseph Sedlar (SMHI), Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA), Ian Brooks (Leeds University, UK)

The question if the cloud layer is coupled to the surface, or not, has many implications. For example if there is a dynamical coupling between the surface and the cloud this means that locally formed aerosols may become participate as CCN in the cloud formation since they can be transported from the surface up to the cloud layer. But such a dynamical coupling may arise not from turbulence generated by shear or convection at the surface but also by negative convection due to radiative cloud-top cooling and subsequent overturning that may or may not reach the surface. Even if there is no dynamical coupling, there will be other processes that contribute to a connection between the surface and the cloud; the slow precipitation from a strato-cumulus layer will in fact mean a flux of aerosols from the cloud layer since each precipitation particle will contain one or several CCN. The radiation from the clouds to the surface and vice versa also contributes to a coupling.

Using data from the Arctic Summer Cloud Ocean Study (ASCOS) we studied the longwave balance between the clouds and the surface or a three-week period, using only data when the cloud cover was 100%. It then turns out that the difference between the surface temperature and the apparent sky temperature is mostly found in two regimes. When the surface temperature is above -0.5 °C this temperature difference is near zero or slightly positive, i.e. the sky is somewhat "warmer" than the surface. However, when the surface temperature is below -0.5 °C the difference is around -1.8 °C, corresponding to a net longwave radiation of ~ -7 Wm^{-2}. The first of these regimes obviously corresponds to the melt season, but the second regime is surprisingly stable. This net longwave radiation is not a function of neither the surface temperature (in the range -6.0 °C < Ts < -0.5 °C) nor the cloud base (below 600 m); obviously a higher cloud base means a lower cloud-base temperature but this does not seem to affect the net longwave radiation.

The connection between the surface and the clouds is made up by several processes; possibly if the cloud base goes up and inversion forms between the shear-driven boundary layer and the buoyancy-driven cloud layer such that the end result in long-wave radiation stays the same. Why this difference becomes ~ -7 Wm^{-2} is not clear, however, during ASCOS it once stayed this way for a prolonged period of several days.



Joint probability of the difference between surface and apparent sky during ASCOS as a function of cloud base height, using only fully cloudy conditions. Note the maximum likelihoods for a slightly positive temperature difference at very low cloud bases, corresponding to the melt season, and the robust -1.7 °C temperature difference elsewhere regardless of cloud base height.

Surface layer fluxes in the summer Arctic

Michael Tjernström, Cathryn Birch and Ian Brooks (Leeds University, UK)

During the Arctic Summer Cloud Ocean Study (ASCOS) a full micro-meteorological site was deployed on the ice in the central Arctic for a period of three weeks. These observations make it possible to test various model assumptions on surface-layer fluxes for the Arctic. In one 15-m high mast 5 levels of turbulence and profile observations was taken while a supplementary telescopic 30-m mast held an additional turbulence instrument at the top.

When comparing to the ASCOS data the UK MetOffice Unified Model overestimate the turbulent flux of momen-tum; this particularly true for operational weather forecast models and can be explained by the positive bias in the transfer coefficients computed by model. Causes of this bias were examined, including whether or not the assumptions of Monin-Obukhov similarity theory are valid under the observed conditions and the accuracy of the representation of surface roughness in the parameterization scheme. Apart from at the very lowest level, observed values of the non-dimensional wind shear were greater than that those predicted by the traditional functional forms any given value of z/L. This suggests turbulent properties observed during ASCOS are more similar to those observed under more stable conditions during other experiments.

Spectra and cospectra, normalized by Monin-Obukhov similarity scaling was used to investigate this. Normalized spectral and cospectral curves computed from the observations were shifted downwards compared to the universal forms, suggesting that the amount of energy associated with all scales of turbulence is smaller than predicted by the similarity theory, consistent with what was found from the comparisons of the non-dimensional wind shear. Peaks in normalized spectral and cospectral were also shifted increasingly towards the right with increasing measurement height. This indicates that at the upper measurement levels, a larger fraction of the total energy is from the higher frequencies, i.e. manifested in smaller eddies. For much of the ASCOS observation period, boundary-layer depths were less than 200 m and therefore, surface layer depths were less than 20 m. This explains the difference in turbulent properties between the upper and lower levels; the lowest measurement level (0.94 m) was always in the surface layer while the uppermost level (30 m) was almost always in the inversion above the surface-mixed layer where the larger turbulent eddies were suppressed by stable conditions. Values of the momentum roughness length, z0, computed from the ASCOS observations were found to vary by an order of magnitude depending on surface type; from 3.7×10^{-3} m over rough, broken ice to 5.9×10^{-4} m in flow over the large, relatively smooth ice floe.

Evaluation of the UK MetOffice Unified Model operational forecast using ASCOS data

Michael Tjernström, Cathryn Birch and Ian Brooks (Leeds University, UK)

The UK MetOffice graciously supported the Arctic Summer Cloud Ocean Study (ASCOS) by supplying column output from the global version of the Unified Model (UM) during expedition for operational planning. These data were also used for an evaluation of the UM after the end of the expedition. The comparisons between the operational MetUM forecasts and the ASCOS observations have reinforced what was found from the study using the AOE 2001 data set.

The positive bias in modeled surface temperature was found to exist during both the AOE-2001 and ASCOS obser-vation periods. This is caused by a feedback of errors involving the surface albedo and surface energy budget; errors in cloud occurrence cause too much radiation to be absorbed at the surface, which causes the surface temperature to be overestimated and the temperature-dependent albedo to be underestimated. More shortwave radiation is thus absorbed at the surface, which locks the surface temperature at 0 °C and the albedo at 50 %.

Unlike the AOE 2001 period, however, a different set of model errors occur in the pre-conditioning period of the ASCOS observations period. The onset of these errors was caused by an erroneous clear period in the model, which significantly cooled the surface. Large biases in the turbulent heat fluxes then offset the positive bias in the radiation budget and thus surface temperature became colder than that observed. Cloud occurrence was found to be generally represented poorly by the model and therefore, the pre-conditioning period was used as a case study to investigate it in more detail. The modeled cloud layer that existed during this period was too thin and too low in the operational forecasts compared to the observations. This was caused by two distinct problems in the model. Firstly, a problem with data assimilation in the operational forecast-assimilation cycle prevented the cloud layer from evolving and moving higher in altitude. Every 12 hours the model is forced back into a preferred state, which does not agree well the observations from the ASCOS campaign. The cause of this is not obvious from the analysis and requires further investigation. The 7-day unconstrained forecasts did, however, demonstrate that the model is able to develop a cloud layer that is similar to the observations.

The second problem involved the interaction between modeled clouds and vertical atmospheric structure. The model produced a boundary layer that was always too deep and almost always too well-mixed, due at least in part to the low model vertical resolution. Unlike the observations, the modeled cloud was often within the boundary layer, which caused the cloud layer to be too low even though boundary layer top was too high. During some periods the model produced a stratocumulus layer that was decoupled from a stable surface layer. This is much closer to the type of boundary layer observed and during these times the cloud layer agreed better with the observations.

Observations of aerosols and optically thin clouds in the Arctic from a space-borne lidar

Michael Tjernström: Abhay Devasthale (SMHI), Joseph Sedlar (SMHI), K.-G. Karlsson and Colin Jones (SMHI), Mannu Anna Thomas (University of East Anglia, UK), Ali Omar (NASA Langley, USA)

Clouds and aerosols play a crucial role in the Arctic climate system and therefore, it is essential to accurately and reliably quantify and understand their properties over the Arctic. It is also important to monitor and attribute changes in Arctic conditions. Here, we exploit the capability of the CALIPSO-CALIOP instrument and provide comprehensive statistics of tropospheric thin clouds and aerosols, otherwise extremely difficult to monitor from passive satellite sensors. We use 4 yr of data (June 2006–May 2010) over the circumpolar Arctic, here defined as 67–82◦N, and characterize probability density functions of layer base and top heights, geometrical thickness and zonal distribution of cloud or aerosol layers, and discuss seasonal variability of these properties.

When computed for the entire study area, probability density functions of cloud base and top heights and geometrical thickness peak at 200–400, 1000–2000 and 400–800 m, respectively, for thin water clouds, while for ice clouds they peak at 6–8, 7–9 and 400–1000 m, respectively. In general, liquid clouds were often identified below 2 km during all seasons, whereas ice clouds were sensed throughout the majority of the upper troposphere and also, but to a smaller extent, below 2 km for all seasons. The bulk of aerosols, from about 65% in winter to 45% in summer, are confined below the lowermost kilometer of the troposphere. In the middle troposphere (3–5 km), spring and autumn seasons show slightly higher aerosol amounts compared to other two seasons. The relative vertical distribution of aerosols shows that clean continental aerosol is the largest contributor in all seasons except in summer, when layers of polluted continental aerosols are almost as large. In winter and spring, polluted continental aerosols are the second largest contributor to the total number of observed aerosol layers, whereas clean marine aerosol is the second largest contributor in summer and autumn. The PDFs of the geometrical thickness of the observed aerosol layers peak about 400–700 m. Polluted continental and smoke aerosols, which are associated with the intrusions from mid-latitudes, have much broader distributions of optical and geometrical thicknesses, suggesting that they appear more often optically thicker and higher up in the troposphere.

Publications

Devasthale, A., MT, K.-G. Karlsson, M.A. Thomas, C. Jones, J. Sedlar, and A. H. Omar, 2011: A view of tropo-spheric thin features over the Arctic from CALIPSO observations. Part I: Optically thin clouds. Tellus, 63, 77-85, DOI: 10.1111/j.1600-0889.2010.00516.x.

Devasthale, A., MT, and A.H. Omar, 2011: A view of tropospheric thin features over the Arctic from CALIPSO observations. Part II: Aerosols. Tellus, , 63, 86-95, DOI: 10.1111/j.1600-0889.2010.00517.x.

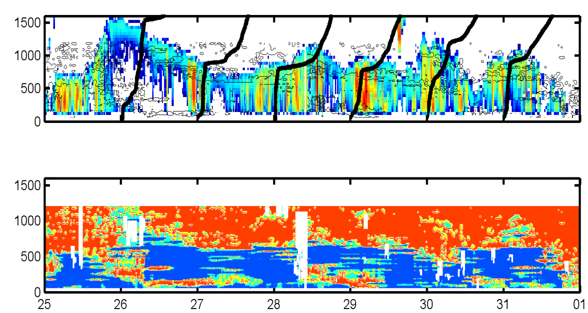
Multisensor analysis of lower troposphere stability in the summer Arctic

Michael Tjernström, Joseph Sedlar, Thorsten Mauritsen, Matt Shupe and Ola Persson (CIRES, University of Colorado, Boulder, USA)

The vertical dynamical coupling between layers in the lower atmosphere remains and issue in Arctic climate studies. The problem remains that direct turbulence observation cannot easily be made at heights higher than short masts. In the Arctic Summer Cloud-Ocean Study (ASCOS) the highest mast was 30 m while the capping inversion was sometimes as high as 1 km. The inversion was capping a cloud and indirect evidence, an reasonable theory, indicates that the cloud layer was turbulent; this turbulence, driven by cloud-top radiative cooling, has the potential to reach the surface but it is not easy to determine when and if it does. The shear-driven surface boundary layer on the other hand is typically seldom deeper than a few hundreds of meters.

In an attempt to elucidate at least the possibilities for mixing to occur between different layers, we instead of using direct observations try and combine the results from several remotes sensing instrument to classify the temporal development of profiles of a stability indicator, the Richardson number (Ri). To do this profiles of static stability under moist or dry conditions and wind speed profiles are needed. The profiles of static stability are derived from a scanning microwave radiometer which, when supported by 6-hourly radiosounsings provide 5-minute resultions of temperature profiles up to about 1 km. Information from the millimeter-wavelength cloud Doppler radar, along with a dual-wavelength microwave radiometer and a lidar, is used to mask the vertical temperature profiles according to clouds (ice or liquid water). From this set of observations we derive the vertical equivalent potential temperature gradient and thus the Brunt-Vaisala frequency. Wind speed profiles are derived from a combination of observations from a Doppler sodar below 600 m and from 1 449 MHz wind profiling radar aloft; the sodar is preferred and wherever there are no sodar observations the wind profiler observations are used. Ri is the ratio of the Brunt-Vaisala frequency and the wind speed gradient squared.

Due to the highly variable wind speed profiles and dividing with the square of a gradient, the resulting Richardson number as a function of time and height is very noisy. Time filtering is required and the end result is a mask of time/heights where: Ri<0, vigorous turbulence exist; 0<Ri<0.25, turbulence should exist; 0.25<Ri<1, turbulence may exist.0; Ri> 1.0, no turbulence.



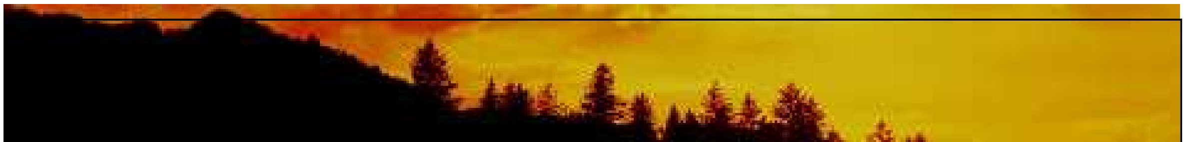
Time-height cossections from ASCOS (date of August) showing (top) cloud radar reflectivity, with a few sounding potential temperature profiles, and (bottom) a Ri-number classification, where blue colors indicate that turbulence would be possible while red indicates it should be suppressed.

ADDITIONAL PUBLICATIONS: ARTIC STUDIES

Karl, M., A. Gross, C. Leck and L. Pirjola, 2007. Intercomparison of Dimethyl sulfide Oxidation Mechanisms for the Marine Boundary Layer: Gaseous and particulate sulfur constituents. J. Geophys. Res., 112 (D15), D15304.

Lundén J., G. Svensson and C. Leck, 2007, Influence of meteorological processes on the spatial and temporal variability of atmospheric dimethyl sulfide in the high Arctic summer., J. Geophys. Res.,. 112, D13308.

Paatero, J., P. Vaattovaara, M. Vestenius, O. Meinander, U. Makkonen, R. Kivi, A. Hyvärinen, E. Asmi, M. Tjernström, and C. Leck, 2009, Finnish contribution to the Arctic Summer Cloud Ocean Study (ASCOS) expedition, Arctic Ocean 2008, Geophysica, 45(1–2), 119–146.



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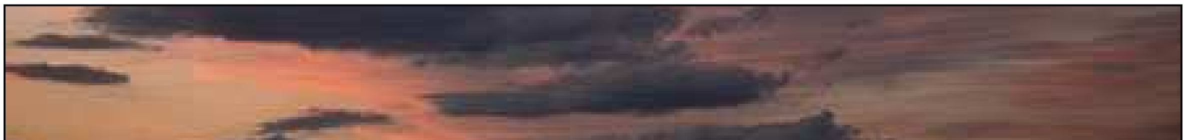

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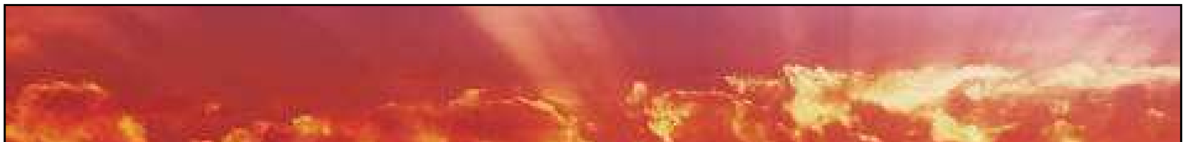

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FINANCES

	Approximate funding	*MSEK*
	2007	*2008*
International Meteorological Institute (IMI)		
Governmental support	*2.1*	*2.1*
Department of Meteorology, Stockholm University (MISU)		
Governmental support	*24.7*	*25.5*
IMI/MISU		
Additional external financial support	*18.1*	*18.3*

During the past two years the additional financial support has been obtained from:

European Space Agency

Swedish Environmental Protection Agency

European Commission

Foundation for Strategic Environmental Research (MISTRA)

Swedish Energy Agency (STEM)

Swedish National Space Board (Rymdstyrelsen)

The Swedish Research Council (VR)

The Swedish Research Council for Environment Agrcultural Sciences and Spatial Planning(FORMAS)

Stockholm Environment Institute (SEI)

Swedish International Development Cooperation Authority (Sida)

Totalförsvarets Forsknings Institut (FOI)

The Knut and Alice Wallenberg Foundation (KAW)

Luleå University of Technology (LTU)

VINNOVA

Swedish Nuclear Fuel and Waste Management Co (SKB)

PHD THESES

PhD THESES 2007-2010

Thorsten Mauritsen, 2007, On the Arctic Boundary Layer – From Turbulence to Climate

Monica Mårtensson, 2007, Submicrometre Aerosol Emissions from Sea Spray and Road Traffic

Magnus Lindskog, 2007, On errors in meteorological data assimilation

Jenny A. U. Nilsson, 2008, On methods for estimating oceanic flow

Bodil Karlsson, 2008, Noctilucent clouds in a coupled atmosphere

Ann-Christine Engvall, 2008, Properties and Origin of Arctic Aerosols

Rune Grand Graversen, 2008, On the recent Arctic warming

Linda Megner, 2008, Meteoric Aerosols in the Middle Atmosphere

Stefan Lossow, 2008, Observations of water vapour in the middle atmosphere

Frida A-M. Bender, 2009, Earth's Albedo in a Changing Climate

Erik Engström, 2009, Characterization of soot in air and rain over southern Asia

Jonas Hedin, 2009, Rocket-borne in situ measurements in the middle atmosphere

Johannes Karlsson, 2009, The influence of clouds on Earth's radiation budget in global climate change

Linus Magnusson, 2009, Sampling uncertainties in ensemble weather forecasting

Bodil Widell, 2009, Development of GC-HRMS procedures for determination of naturally occuring polar compounds in various environmental applications

Jenny Lunden, 2010, Atmospheric DMS in the high Arctic

Joseph Sedlar, 2010, Artic clouds – interactions with radiation and thermodynamic structure

Moundheur Zarroug, 2010, Asymptotic methods applied to some oceanography-related problems

ACRONYMS

ACRONYMS

ABC	Atmospheric Brown Clouds
ACC	Antarctic Circumpolar Current
ACE	Aerosol Characterisation Experiment
ACIA	Arctic Climate Impact Assessment
ADM	Atmospheric Dynamics Mission
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AO	Arctic Oscillation
AOE	Arctic Ocean Expedition
AP	Atmospheric Physics (a section of IMI/MISU)
APS	Aerodynamic Particle Sizer
ARCMIP	Arctic Regional Climate Model Intercomparison Project
ASCOS	Arctic Summer Cloud-Surface Study
ASTAR	Arctic Study of Tropospheric Aerosols, Clouds and Radiation
AWI	Alfred Wegener Institute
CABLE	Co-operation Alomar Bi-static Lidar Experiment
CACGP	Commission on Atmospheric Chemistry and Global Pollution
CAD	Composition of Asian Deposition
CANTAT	Canadian Transatlantic Circulation
CARMA	Commnity aerosol and radiation model för atmospheres
CCM	Chemistry climate model
CCN	Cloud Condensation Nuclei
CIRES	Cooperative Institute for Research in the Environmental Sciences
CM	Chemical Meteorology (a section of IMI/MISU)
CMAM	Canadian Middle Atmosphere Model
COAMPS	Coupled Ocean/Atmospheric Mesoscale Prediction System
CPC	Condensation Particle Counter
CW	Coastal Waves
DM	Dynamic Meteorology (a section of IMI/MISU)
DMPS	Differential mobility particle sizer
DMS	Dimethyl Sulfide
DMSP	Dimethyl Sufonium Propionate
DNMI	Det Norske Meteorologiske Institutt
DOAS	Differential Optical Absorption Spectroscopy
DSMC	Direct Simulation Monte Carlo technique for rarefied flows
EAPS	Earth, Atmospheric and Planetary Sciences
eARI	enhanced Alomar Research Infrastructure
ECMWF	European Centre for Medium Range Weather Forecasts
ECOMA	Existence and Charge state Of Meteoric dust in the middle Atmosphere
EPS	Exopolymer Secretions
ERA	ECMF Re-Analysis
ESA	European Space Agency
EUFAR	European Fleet for Airborne Research

FSSP	Forward scattering spectrometer probe
GABLS	GEWEX Atmospheric Boundary Layer Study
GC	Gas Chromatograph
GCM	General Circulation Model
GEWEX	Global Energy and Water Cycle Experiment
HIRLAM	High Resolution Limited Area Model
ICSU	International Council of Science
IGBP	International Geosphere-Biosphere Programme
IITM	Indian Institue of Tropical Meteorology
IMI	The International Meteorological Institute in Stockholm
IN	Ice Nuclei
INDOEX	Indian Ocean Experiment
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
ISAC	International Study of Arctic Change
ITM	Institute of Applied Environmental Research
LWC	Liquid Water Content
MAGIC	Mesospheric Aerosols Genesis, Interaction and Composition
MBL	Marine Boundary Layer
MISU	Meteorologiska Institutionen, Stockholms Universitet (Department of Meteorology, Stockholm University)
MIUU	Meteorologiska Institutionen, Uppsala Universitet
MPI	Max-Planck-Institute
MSA	Methane Sulphonic Acid
MSLP	Mean-Sea-Level pressure
NADW	North Atlantic Deep Water
NCAR	National Center for Atmospheric Research, Boulder, USA
NEAQS	The New England Air Quality Study
NLC	NoctiLucent Clouds
NOAA	National Oceanic and Atmospheric Administration, USA
NRL	Naval Research Laboratory, Washington D.C.
OEM	Optimal Estimation Method
OPC	Optical Particle Counter
OSIRIS	Odin Spectrometer and InfraRed Imaging System
PRMIER	Process Exploration Measurements Infrared Emitted Radiation
PSAP	Particle Soot Absorption Photometer
RAPIDC	Regional Air Pollution in Developing Countries
RCA	Rossby Centre Atmospheric model
RCO	Rossby Center Ocean model
SAT	Surface Air Temperature
SEI	Stockholm Environment Institute
SHEBA	Surface Heat Budget of the Arctic Ocean
Sida	Swedish International Development Cooperation Authority
SLAM	Scattered Lyman-Alpha in the Mesophere

SMHI	Swedish Meteorological and Hydrological Institute
SMR	Sub-Millimetre Radiometer
SNSB	Swedish National Space Board
SST	Sea Surface Temperature
STEAM	Stratosphere-Troposphere Exchange And climate Monitor
SU	Stockholm university
SWECLIM	SWEdish regional CLImate Modelling programme
SWIFT	Stratospheric Wind Interferometer for Transport studies
TA	Transnational Access
TEM	Transmission electron microscopy
THC	ThermoHaline Circulation
TOA	Top of Atmosphere
TRACE	Transport and Chemical Evolution
UT/LS	Upper Troposphere/Lower Stratosphere
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
ZAMM	Zeitschrift für Angewandte Mathematik und Mechanik