Stockholm University

INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

DEPARTMENT OF METEOROLOGY, STOCKHOLM UNIVERSITY

BIENNIAL REPORT 2007 – 2008

FRONT COVER | The icebreaker Oden anchored to an ice floe near 87˚N in support of the ASCOS field program in 2008.

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

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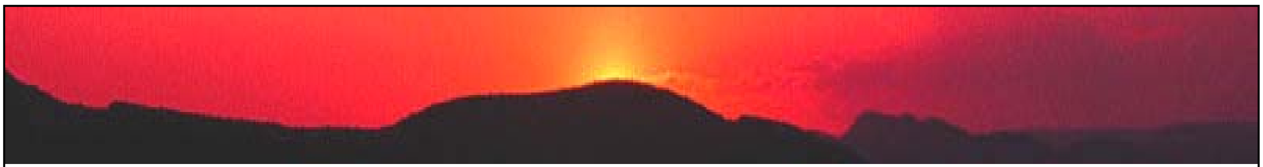

THE INSTITUTE

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 is financed by a direct contribution from the Swedish Government and indirectly through Stockholm University by the fact that its Department of Meteorology is an integral part of the institute.

GOVERNING BOARD

Lars-Erik Liljelund, Director General, Swedish Environmental Protection Agency, Chairman, Appointed by the Swedish Government.

Joakim Langner, Research Director at the Swedish Meteorological and Hydrological Institute. Appointed by the Swedish Government.

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Erland Källén, Professor of Dynamic Meteorology, Stockholm University. Appointed by the Board.

Henning Rodhe, Director of the Institute. Ex Officio Member.

Secretary of the Board: Albert de Haan, Economist.

DIRECTOR

Henning Rodhe, Professor of Chemical Meteorology.

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). 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. 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.

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 co-operative research. This co-operation is directed to fundamental research as well as to providing scientific knowledge in the development of society on the national and international levels. The specific scientific research projects are dealt with in some detail in the following chapters. The present 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 years, including participation in the World Climate Research Programme (WCRP) the International Geosphere-Biosphere Programme (IGBP) and several international research projects funded by the European Commission and the European Space Agency (ESA).

IMI/MISU scientists including Erland Källén and Caroline Leck participated actively in the preparation of IPCC's fourth assessment report published in February 2007.

International co-operation in the area of dynamic meteorology takes place both within several international programs and with individual universities or laboratories. Within European programs there is collaboration within ESA programmes for satellite observations; ESA plans to launch a research satellite in 2008, dedicated to wind measurements using a Doppler lidar technique, the Atmospheric Dynamics Mission Aeolus. Erland Källén is chairman of the ADM advisory group.

Several projects concern model development. The Arctic Model Inter-comparison 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 improving the COAMPS™ atmospheric model.

MISU's physical oceanographers are actively engaged in international collaboration via three large-scale international programmes: EC-Earth is a consortium constituted by national weather services and various universities with the aim of developing and implementing a global climate model. 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 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 established an extensive international collaboration with scientists in several Asian countries (India, Nepal, Maldives, Thailand, China) and in the US in projects focusing on regional and continental scale air pollution problems in Asia: Composition of Asian Atmospheric Deposition (CAAD) and Atmospheric Brown Cloud (ABC).

Caroline Leck and Michael Tjernström coordinated the Arctic Summer Cloud-Ocean Study, an inter-disciplinary expedition to the high Arctic in the summer of 2008 as a part of the International Polar Year. This expedition was aimed at understanding the formation and lifetime of Arctic summer low clouds, their microphysics and relations to boundary-layer processes and to natural formation of aerosol particles, as well as their effects on climate.

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. The Odin satellite mission is based on collaboration with scientific groups in Canada, France and Finland. Major partners foe the scientific data analysis are the University of Saskatchewan(Canada), the Laboratory of Atmospheric and Space Studies in Boulder (USA), the University of Bremen (Germany) and Chalmers University of Technology (Sweden). Beyond Odin, new middle atmosphere satellite collaborations for MISU concern mainly ESA's plans for PREMIER, NASA's AIM satellite mission, the European ENVISAT community, as well as the ACE mission on the Canadian SciSat.

The Atmospheric Physics group has continued to collaborate in international rocket programmes, participating with instruments in rocket launches led by our collaborators at the Leibniz Institute of Atmospheric Physics (Germany), the Norwegian Defense Research Establishment (Norway) and the University of Colorado (USA). The group also participated in two rocket projects within the extended ALOMAR Research Initiative (eARI), an opportunity funded by the European Commission We are now leading the preparations for a comprehensive international rocket project from Esrange, Sweden, in 2011.

Ground-based and model studies in the Atmospheric Physics group have been intensified during recent years. After taking over the lidar facility at Esrange, close collaboration with other lidar groups has been established. Major partners for middle atmosphere model studies are the Leibniz Institute of Atmospheric Physics (Germany), the University of Toronto (Canada) as well as the National Center of Atmospheric Research and the University of Colorado in Boulder (USA).

Michael Tjernström is a member of the Science Advisory Committee (SAC) of the European Center for Medium Range Weather Forecasts (ECMWF). Michael Tjernström is also chair of the Science Steering Group of the International study of Arctic Change (ISAC) and a member of the Science and Technology Advisory Committee for the American Meteorological Society. Caroline Leck is a member of Surface Ocean Lower Atmosphere Study (SOLAS) implementation committee; Gunilla Svensson is the vice chair of the GEWEX Atmospheric Boundary Layer (GABLS) Science Panel; Henning Rodhe has been the vice chair of the Atmospheric Brown Cloud (ABC) Science Team.

R E S E A R C H   A C T I V I T I E S

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 both numerical weather prediction and climate modelling are key research areas at the institute. Within the area of numerical weather prediction we have looked at the predictability problem, investigating new techniques for ensemble prediction. Also data assimilation has continued to be a focus area of research, in particular methods for assimilating wind data using variational and Kalman filter techniques. Large scale wave dynamics has been studied in the context of climate change. Both man induced global warming and its effects on large scale wave structures as well as climate change on the ice age time scale has been areas of interest. A newly emerging area of interest is the coupling between impacts of aerosol emissions on radiative heating/cooling and the large scale flow. The couplings are very involved, not only the direct effects of particles on the radiative fluxes matter but also their indirect effects on cloud formation. In particular tropical circulation patterns are primarily driven by clouds, aerosols can thus have a substantial impact on tropical flow dynamics.

Atmospheric mass-transport inconsistencies in the ERA-40 reanalysis

Rune Grand Graversen, Erland Källén, Michael Tjernström and Heiner Körnich

The ERA-40 reanalysis from the European Center for Medium Range Weather Forecasts (ECMWF) is an atmospheric data set based on a comprehensive collection of observations as well as a state-of-the-art system for assimilating data. These high-quality data, encompassing more than four decades, have successfully been used in a wide range of applications including climate change studies. However, even though the ERA-40 data set benefits from improvements of the assimilation procedures, which have taken place since the release of earlier reanalyzes, ERA-40 exhibits unrealistic behavior as regards some atmospheric quantities, including the water-budget and the Brewer-Dobson circulation. In addition, our results show significant mass-budget inconsistencies. Over inter-annual time-scales (> 1 year), the vertically averaged meridional mass transport is unrealistic and cannot be explained by naturally occurring physical processes. This mass-inconsistency yields, in addition, spurious signals in meridional fluxes of other atmospheric quantities. The total atmospheric mass content, on the other hand, shows a realistic evolution on daily time-scales during the satellite era from about 1979 and onwards. Through this period, the variability of the total mass on intra-annual (< 1 year) and annual time-scales is consistent with differences between evaporation and precipitation. We hypothesize that unrealistic mass-fluxes are present in ERA-40 are due to inherent properties of the data assimilation process where surface pressure (mass) is more constrained by observations than the for example winds (transport). A correction method can be applied in order to eliminate the spurious fluxes. For trend calculations it is demonstrated that the correction method yields more realistic results than those obtained from the raw ERA-40 data.

Publications

Graversen, R. G., E, Källén, MT and H. Körnich, 2007: Atmospheric mass-budget inconsistency in the ERA-40 reanalysis, Quarterly Journal of the Royal Meteorological society, 133: 673–680

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

Anna Lewinschal, Annica Ekman, Dongchul Kim (MIT, Cambridge, USA), Chien Wang (MIT, Cambridge, USA), Erland Källén

The atmospheric aerosol population displays a large spatial and temporal variation where each aerosol has a different climate impact depending on its size and its composition. On average, aerosols cool the Earth's surface, but the radiative forcing pattern is unevenly distributed, affecting both large-scale circulation regimes and precipitation patterns. In this research project, global climate models of different complexity are used together with global temperature and precipitation data to examine how different aerosol concentrations and compositions alter large-scale wind and precipitation fields. The following research questions are examined: a) can regional variations in the aerosol concentration and composition be detected in observational records of temperature and precipitation? b) if so, how does this affect large-scale circulation regimes and how will the patterns change in the future? c) if not, how come the aerosol footprint is not detectable?

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:10.1029/2007JD00975

Aerosol data assimilation

Anders Engström, Annica Ekman, Erland Källén, Heiner Körnich

Future development of numerical weather prediction models aim to include aerosols as a prognostic variable, i.e aerosols will interactively take part in model physical processes, cloud formation and radiative transfer calculations. The spatial and temporal distribution of aerosols must therefore be known to obtain to obtain a reliable result from such integration in models. A growing number of aerosol observations (primarily from satellite) have made data assimilation of aerosols of key interest. Being considered as a prime uncertainty in climate prediction, the possibility to make aerosol analyses opens up for a new way to quantify the effects of aerosols on climate through actual re-analysis of the global aerosol distribution. The objectives for this project are to study data assimilation of aerosols and how vertically resolved aerosol information can be used in numerical weather prediction models and climate models. We aim to examine different aspects of the aerosol data assimilation problem within a simplified model using different assimilation techniques (3D-var and 4D-var). Of particular interest is too see if aerosol information, obtained as a bi-product of direct wind observations by the lidar onboard the Earth Explorer Atmospheric Dynamics Mission ADM-Aelous, can be used in variational data assimilation to improve the analysis situation in the tropics.

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 Chemical Meteorology

Thermodynamic analysis of the atmospheric circulation

Björn Stensen, Jonas Nycander, Heiner Körnich, Kristofer Döös

The energetics and thermodynamics of the atmospheric circulation are examined by calculating a streamfunction with specific volume and pressure as coordinates. Thereby, the circulation in the atmosphere and stratosphere can be displayed in a classical thermodynamic pV-diagram. The sign of a circulation cell in such a diagram immediately shows whether it is thermally or mechanically driven. This new formulation is compared to traditional overturning streamfunctions with latitude and pressure as coordinates, and the overturning streamfunction as a function of latitude and potential temperature. Differences between the calculated streamfunctions are examined from data of an axisymmetric two-dimensional model (2D) and a non-axisymmetric three-dimensional model (3D). The data will be produced by the KMCM-model, which is a simplified general circulation model.

The Ocean's Role in ENSO Changes under Global Warming

Qiong Zhang in collaboration with Haijun Yang (Department of Atmospheric Science, School of Physics, Peking University, Beijing, China)

A revisit on observations shows that the tropical El Niño–Southern Oscillation (ENSO) variability, after removing both the long-term trend and decadal variation of the background climate, has been enhanced by as much as 50% during the past 50 yr. This is inconsistent with the changes in the equatorial atmosphere, which shows a slowdown of the zonal Walker circulation and tends to stabilize the tropical coupling system. The ocean role is highlighted in this paper. The enhanced ENSO variability is attributed to the strengthened equatorial thermocline that acts as a destabilizing factor of the tropical coupling system. To quantify the dynamic effect of the ocean on the ENSO variability under the global warming, ensemble experiments are performed using a coupled climate model [Fast Ocean Atmosphere Model (FOAM)], following the "1pctto2x" scenario defined in the Intergovernmental Panel on Climate Change (IPCC) reports. Term balance analyses on the temperature variability equation show that the anomalous upwelling of the mean vertical temperature gradient (referred as the "local term") in the eastern equatorial Pacific is the most important destabilizing factor to the temperature variabilities. The magnitude of local term and its change are controlled by its two components: the mean vertical temperature gradient Tz and the "virtual vertical heat flux" $-w'T'$. The former can be viewed as the background of the latter and these two components are positively correlated. A stronger Tz is usually associated with a bigger upward heat flux $-w'T'$, which implies a bigger impact of thermocline depth variations on SST. The Tz is first enhanced during the transient stage of the global warming with a 1% yr^{-1} increase of CO2, and then reduced during the equilibrium stage with a fixed doubled CO2. This turnaround in Tz determines the turnaround of ENSO variability in the entire global warming period.

Publications

Zhang Q., Y. Guan, and H. Yang, 2008: ENSO amplitude change in observation and coupled models. Adv. Atmos. Sci., 25, 361–366.

Yang H., and Q. Zhang, 2008: Anatomizing the Ocean's Role in ENSO Changes under Global Warming, J. Climate, 21, 6539–6555.

Northern High Latitudes climate response to mid-Holocene insolation: model-data comparison

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

The orbitally_induced changes in mid-Holocene insolation cause an amplification of the seasonal cycle in the Northern Hemisphere. The high latitudes are the most affected region by this orbital forcing. The climate response over Northern high latitude in mid-Holocene has been investigated in three types of PMIP (Paleoclimate Modelling Intercomparison Project) simulations to study the different feedbacks in the climate system. The model results have also been compared with the collected reconstructions, which is mostly distributed over the Northern Atlantic region.

The orbital forcing in PMIP models leads to an increase by 23.5W/m2 of the insolation in northern high-latitude (60˚N north) in summer, and a slight decrease by -2.3W/m2 in winter over the region. PMIP1 atmosphere-only simulations with the fixed SST show that the atmospheric response to this orbital forcing produces a 0.8˚C warming in summer and a cooling in the rest of the year. In PMIP2 coupled ocean-atmosphere simulations, the sea-ice-albedo feedback enhance the summer warming to 1.1˚C, and the thermal inertia of the ocean lead to a 1.2˚C warming in autumn and a 0.5˚C warming in winter, while the cooling in spring remains the same as in PMIP1 simulations. The PMIP2 ocean-atmosphere-vegetation coupled simulations show warming in all seasons, the changes beyond 1˚C in winter, summer and autumn.

The collected reconstructions show about 1.0˚C warming in summer and 0.6˚C warming in winter during mid-Holocene. It is indicated that the climate response in PMIP2 simulations is better agreement with the reconstruction data than the PMIP1 simulations, while the vegetation feedbacks amplify the response in temperature both in summer and winter.

Albedo, clouds, aerosols and global climate

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

See Chemical Meteorology

Arctic regional climate modeling

Michael Tjernström, Joseph Sedlar, Matt Shupe (CIRES, University of Colorado, Boulder, USA), Mark Zagar (Slovenian Met Service), Anette Rinke and Klaus Dethloff (Alfred Wegner Institute, Germany), John Cassano (CIRES, University of Colorado, Boulder, USA), Susanne Pfeifer and Tido Semmler (MPI for Meteorology, Germany), Klaus Wyser and Colin Jones (SMHI, Sweden)

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 and cloud-resolving models or designing, participating in, and 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. Simulation of convection requires special non-hydrostatic cloud-resolving modeling and the MIT CRM has been applied to tropical convection to elucidate the impact of aerosols on the development of convective systems and the effects of convective cloud-system processing of aerosol population.

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 CASES-99 and also involves field experiments in the Arctic, for example SHEBA , AOE-2001 and ASCOS. Scientists at the institute coordinated a major Arctic field campaign, Arctic Summer Cloud-Ocean Study (ASCOS), for the International Polar year (IPY), and takes part in the leadership of GABLS.

GABLS (GEWEX Atmospheric Boundary Layer Study)

Gunilla Svensson, Thorsten Mauritsen, Michael Tjernström, Florence Bouquet (CIRES, Colorado, USA), 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, two model intercomparison studies have been performed and one is ongoing. The participating models range from operational forecast models to higher order closure research models and MISU is participating in all three experiments. 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

Observations of stably stratified shear-driven atmospheric turbulence at low and high Richardson numbers

Thorsten Mauritsen and Gunilla Svensson

Stably stratified shear-driven turbulence is analyzed using the gradient Richardson number, Ri, as the stability parameter. The method overcomes the statistical problems associated with the widely used Monin-Obukhov stability parameter. The results of the Ri-based scaling confirm the presence of three regimes; the weakly and the very stable regimes and the transition in between them. In the weakly stable regime fluxes scale in proportion with variance, while in the very stable regime stress and scalar fluxes behave differently. At large Ri, the velocity field becomes highly anisotropic and the turbulent potential energy increases to approximately equal half of the turbulent kinetic energy. It appears that even in the strongly stable regime, beyond what is known as the critical gradient Richardson number, turbulent motions are present.

Publications

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.

A total-turbulent energy closure model for neutral and stably atmospheric boundary layers

Thorsten Mauritsen, Gunilla Svensson, Sergej Zilitinkevich (University of Helsinki, Finland), Igor Esau (Nansen Environmental Remote Sensing Center, Norway) Leif Enger (Uppsala University, Sweden) and Branko Grisogono (Zagreb University, Croatia).)

A new type of turbulence closure for neutral and stratified atmospheric conditions is formulated. The closure is based on the concept of the total turbulent energy, the sum of the turbulent kinetic energy and the turbulent potential energy. The turbulent potential energy is proportional to the potential temperature variance. In formulating the closure, recent observational findings are used to take into account the mean-flow stability. These observations indicate that the turbulent transfer of heat and momentum behaves very differently under very stratified conditions. Whereas the turbulent heat-flux tends to zero beyond a certain stability limit, the turbulent stress stays finite. The suggested scheme avoids the problem of self-correlation. This is a significant improvement over the widely used Monin-Obukhov based closures. Numerous large-eddy simulations, including a wide range of neutral and stably stratified cases, are used to estimate likely values of two free constants. In a benchmark case, the GABLS first experiment the new model performs indistinguishably from independent large-eddy simulations.

Publications

Mauritsen, T., G. Svensson, S. Zilitinkevich, I. Esau, L. Enger, and B. Grisogono, 2007: A total turbulent energy closure model for neutral and stably stratified atmospheric boundary layers. Journal of the Atmospheric Sciences, 64, 4113-4126.

Sensitivity of the dry stable boundary layer to external surface forcing

Thorsten Mauritsen and Gunilla Svensson

We investigate the sensitivity of the surface temperature in the dry stable boundary layer to a hypothetical external surface forcing. A simple model setup allowed a dry atmospheric boundary layer to interact with a conducting surface and a simple radiation parameterization. Two cases are studied representing Arctic wintertime conditions and midlatitudinal diurnal cycle. A set of experiments is run with and without external forcing. The sensitivity to the forcing is larger when the boundary layer is shallow, i.e. when the boundary layer is strongly stably stratified. This is because stable stratification tends to suppress the boundary layer depth, making the column that responds to the surface forcing smaller. The results indicate a possible explanation for the observed polar amplification of global warming and global decrease in the diurnal temperature range. In addition, this sensitivity is likely to be underestimated by present day climate models due to the parameterizations commonly used for the turbulent heat exchange at the surface.

Evaluation of the stable boundary layer and diurnal cycle in the mesoscale models MM5, COAMPS® and HIRLAM for three contrasting nights in CASES-99

Gert-Jan Steeneveld (Wageningen University, The Netherlands), Thorsten Mauritsen, Cisco de Bruijn (Royal Netherlands Meteorological Institute, De Bilt, The Netherlands), Jordi Vilà-Guerau de Arellano (Wageningen University, The Netherlands), Gunilla Svensson and Bert Holtslag (Wageningen University, the Netherlands))

This study evaluates the ability of three state-of-the-art limited area models to predict the diurnal cycle of the atmospheric boundary layer over land. We pay special attention to the stable boundary layer. Limited area model results for different ABL parameterizations and different radiation transfer parameterizations are compared with in situ observations for three contrasting diurnal cycles during the CASES-99 campaign. Model forecasts were found sensitive to the choice of the boundary layer parameterization both during day- and nighttime, while during night the sensitivity to the radiation scheme is similarly large. Non-local mixing schemes are favorable during daytime, while at night the local turbulence closure schemes provide the best results in the present study. A common deficiency of the models is the underestimation of the amplitude of the diurnal cycle of near surface wind speed and temperature. Furthermore they overestimate the stable boundary-layer height and underestimate the stratification in the nighttime surface inversions. Favorable parameterizations for the stable boundary layer enables rapid surface cooling and have reduced mixing. For modeling the Great Plains low-level jet a large model domain is preferable.

A positive, nighttime near surface temperature bias in the MM5-MRF scheme was removed with the introduction of a vegetation layer and combined with mixing based on the local scaling hypothesis at night. Models with limited mixing at night, together with an isolating stagnant vegetation layer are in favor for representation of the diurnal cycle.

Publications

Steeneveld, G.J., T. Mauritsen, E.I.F. de Bruijn, J. Vilà-Guerau de Arellano, G. Svensson and A.A.M. Holtslag, 2008: Evaluation of limited area models for the representation of the diurnal cycle and contrasting nights in CASES99. Journal of Applied Meteorology and Climatology, 47, 869-887. DOI: 10.1175/2007JAMC1702.1

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), Charles Meneveau (John Hopkins University, USA), and Marc Parlange (École Polytechnique Fédérale de Lausanne, Switzerland)

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, 2009: Impact of surface flux formulations and geostrophic forcing on large-eddy simulations of the diurnal atmospheric boundary layer flow. Submitted to Journal of Applied Meteorology and Climatology

Representation of the diurnal cycle of near-surface parameters in the current and next version of NCAR community atmospheric model (CAM4)

Gunilla Svensson, Phil Rasch (NCAR, Boulder, CO, USA) and Bert Holtslag (Wageningen University, the Netherlands)

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

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 a remnant of the previous day's deeper well-mixed convective boundary layer. We have used information from the CIRES Tethered Lifting System (TLS) to analyze RL variability and 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, from the surface up 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.

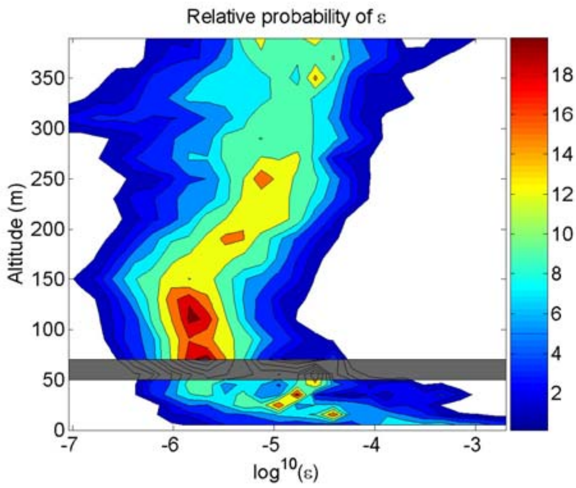
The RL is often considered as a quiescent mostly laminar layer developing only by larger-scale dynamics until next day's convective boundary layer is established again. We find that this conventional picture of the RL is false. The structure of the RL is often highly variable, with values of ε varying 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 feeding on local gradients, primarily in wind speed. When the Richardson number (Ri) is estimated at progressively smaller scales, we find that the flow is indeed unstable in the sense of featuring sub-critical values (Ri < 0.25) when evaluated at the scales of the observed structures, rather than over fixed deeper layers. We also 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.

From this study we conclude:

1) The RL is often actively turbulent, with large variations in turbulence intensities in well organized structures

2) The RL is, more often than not, sub-critical with respect to Ri provided that Ri is estimated at the spatial scales of the observed turbulence structures;

3) The instabilities may be triggered by upward propagating gravity waves generated by very modest terrain as they approach a critical layer.



Color contours of probability (%), of turbulence dissipation expressed as log(ε) as a function of height for one night of the CASES-99 experiment. The gray band denotes the varying stable boundary-layer top through the night

Publications

Balsley, B. B., G. Svensson and M. Tjernström, 2007: On the scale-dependence of the gradient Richardson number in the residual layer. Boundary-Layer Meteorology, 127, 57 - 72, DOI 10.1007/s10546-007-9251-0.

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

Ubiquitous turbulence in atmospheric flows

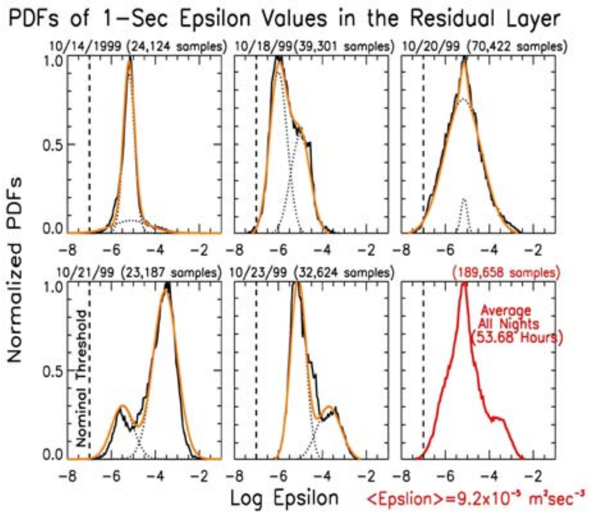
Michael Tjernström, Gunilla Svensson and Ben Balsley (University of Colorado).

In meteorology there has historically been a subdivision between boundary-layer flows being turbulent and dynamic meteorology considering free-tropospheric laminar flow. This highly simplified picture has been under attack noting that turbulence does occur also in the free troposphere, for example in clouds, near the synoptic-scale jet stream or in relation to gravity waves especially near mountainous areas.

We now question this on a more fundamental level. We do this using the CIRES Tethered Lifting

System (TLS) instrumentation, specifically estimates of turbulence dissipation rate (ε) analyzed from inertial sub-range power spectra due to 1-second samples of the 400 Hz hot-wire wind-speed measurements. The data is obtained from all flights carried out with this instrument package during the CASES-99 field study. By contrasting stable boundary-layer (SBL) conditions with those aloft we find while compositing the dissipation-rate data for all flights for both layers, that the probability density functions (PDF) of ε can be described by the sum of two log-normal Gaussian distributions. The two peak values of ε are typically separated by one or two orders of magnitude (on average a factor of 35). But even the value for the lower peak is clearly above the instrument threshold. The probabilities of the two peaks are switched in magnitude between the SBL and aloft such that the higher-ε peak dominates in the SBL while the opposite is true aloft. We would expect that the dominance of strong boundary-layer turbulence in a daytime convective boundary layer would be strong enough to completely obscure the lower peak.

The interesting aspect here is that in all data collected with the TLS systems, regardless of altitude, the two peaks are virtually always present. This leads us to hypothesize that atmospheric flows are *always* turbulent, at least at some minimal level. The upper peak, which is dominant in the boundary layer, represents the "active" turbulence that has always been associated with the boundary layer, which is very sensitive to the ambient flow characteristics (i.e. wind speed, static stability etc.). The lower peak, however, represents a "dormant" type of turbulence which seems to be ever-present but much less variable. Its presence, however, serves as a rapid trigger for active turbulence in the case when the mean vertical gradient of the flow changes, as for example when a buoyancy wave approaches a critical layer and starts to deposit its momentum to the mean flow. Although this turbulence is very weak, its ever-presence could make it important to consider in climate studies



Probability Distribution Functions (PDFs) of the turbulent energy dissipation rate, ε, for 54 hours of measurements when the TLS sensors were somewhere above the SBL. Thin dashed lines illustrate the bimodal distribution while the colored lines is the actual PDF, showing that it can on any given night be approximated by two log-normal Gaussian curves of differing amplitudes and mean value.

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. Analysis using the same method is performed for modeled profiles in one dimension with interesting results and the next step is to have full interaction between the wave-generated stress and the flow model.

Low-level marine clouds in global models and their influence on climate

Johannes Karlsson, Gunilla Svensson och Henning Rodhe)

Simulations of subtropical marine low clouds and their radiative properties by nine coupled ocean/atmosphere climate models participating in the fourth assessment report (AR4) of the intergovernmental panel on climate change (IPCC) are analyzed. Satellite observations of cloudiness and radiative fluxes at the top of the atmosphere (TOA) are utilized for comparison. The analysis is confined to the marine subtropics in an attempt to isolate low cloudiness from tropical convective systems. All analyzed models have a negative bias in the low cloud fraction (model mean bias of –15%). On the other hand, the models show an excess of cloud radiative cooling in the region (model mean excess of 13 W m–2). The latter bias is shown to mainly originate from too much shortwave reflection by the models clouds rather than biases in the clear-sky fluxes. These results confirm earlier studies, thus no major progress in simulating the marine subtropical clouds is noted. As a consequence of the combination of these two biases, this study suggests that all investigated models are likely to overestimate the radiative response to changes in low level subtropical cloudiness.

Publications

Karlsson, J., G. Svensson and H. Rodhe, 2008: Cloud Radiative Forcing of ***subtropical*** *low level clouds in global models. Climate Dynamics. doi:10.1007/s00382-007-0322-1.*

Aerosol-cloud interaction in shallow and deep convective clouds

Annica Ekman, Radovan Krejci (SU/ITM), Anders Engström, 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. Clean episodes are put in contrast to polluted events to explore how the climate system works under pristine conditions and under anthropogenic influence. We study how aerosols, which are necessary for cloud formation, affect convective cloud properties and precipitation development. The effect of cloud processing on the local and global aerosol population is also examined, i.e. how aerosols are formed and transformed within convective clouds.

Publications

Ekman, A. M. L., Wang, C., Ström, J., Krejci, R., 2006. Explicit simulation of aerosol physics in a cloud-resolving model: Aerosol Transport and Processing in the Free Troposphere. Journal of the Atmospheric Sciences, Vol. 63, No. 2, 682–696.

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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.

The Arctic boundry-layer diurnal cycle

Michael Tjernström and Ola Persson (NOAA/ESRL)

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

The vertical structure of the lower Arctic atmosphere

Michael Tjernström and Rune Grand Graversen (KNMI)

See Arctic studies

The simulation of Arctic clouds and their radiative properties for present day climate in the CMIP3 multi-model dataset

Johannes Karlsson and, Gunilla Svensson

See Arctic studies

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Spokes, L., T. Jickells, K. Weston, B. Gustafsson, M. Johnsson B, Liljebladh, D. Conley, C. Am¬belas-Skjødth, J. Brandt, J. Carstensen, T. Christiansen, L. Frohn, G. Geenaert, O. Her¬t¬el, B. Jensen, C. Lundsgaard, S. Markager, W. Martinsen B. Møller, B. Pedersen, K. Sauer¬berg, L. Sørenson, C. Hasager, A. Sempreiva, S. Pryor, L. Søren, M. Tjernström, G. Svensson, M. Žag¬ar, 2006: MEAD – An Interdisciplinary study of the marine effects of atmospheric deposi¬tion in the Kattegatt, Environmental Pollution, 140, 453-462.

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PHYSICAL OCEANOGRAPHY

The main activities of MISU's physical oceanographers are focused towards two general fields of inquiry: the Baltic Sea and the World Ocean. To pursue these investigations a wide span of different methods are used, ranging from numerical modelling to field surveys.

Baltic oceanographic research

Kristofer Döös, Hanna Kling, Peter Lundberg, Markus Meier, Jenny Nilsson, Peter Sigray in external collaboration with Janek Laanearu (Tallinn Technical University, Estonia), Riikka Hietala/Kai Myrberg (Finnish institute of Marine Research, Helsinki), Hans Burchert/Thomas Neumann (Baltic Sea Research Institute, Warneműnde), and Bror Jönsson (GFDL, Princeton).

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. Field surveys of the Understen-Märket passage as well as of the Stolpe trench have been carried carried out on board the Finnish research vessel N/O Aranda.

Research focusing on the horizontal, mainly upper-layer, circulation 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. To a not insignificant extent this modelling work is supported by a geo-electric monitoring system 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, viz. useful information for assimilating into numerical models.

Publications

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the Arctic in a regional coupled ocean-ice-atmosphere model. Clim. Dyn., accepted.

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Hietala, R., P. Lundberg and J.A.U. Nilsson, 2006. A note on the deep-water inflow to the Bothnian Sea. J. Mar. Sys. 68, 253-264.

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Nilsson, J. A. U., P. Sigray and R. H. Tyler. 2007. Geo-electric Monitoring of Wind-Driven Barotropic Transports in the Baltic Sea. J. Atmos. Ocean. Techn. 24, 1655-1664..

Oceanographic investigations of the Faroe region

Linda Fransson, 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.

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, viz. 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.

Publications

Enmar, L., K. Borenäs, I. Lake, and P. Lundberg, 2008. Comment on "Is the Faroe Bank Channel Overflow Hydraulically Controlled?" J. Phys. Oceanogr. (in press)

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Lake, I. and P. Lundberg,. 2006. Seasonal Barotropic Modulation of the Deep-water Overflow through the Faroe Bank Channe. J. Phys. Oceanogr. 36, 2328-2339.

Mathematical aspects of geophysical fluid dynamics

Jonas Nycander and Peter Lundberg 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, and the improvement of perturbation series.

Publications

Bahrami, F. and J. Nycande, 2007. Existence of energy minimizing vortices in a to a flattop seamount. Nonlin. Analysi.: Real World Applications. 8, 288-294.

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Laanearu, J. and P. Lundberg. 2005. Analysis and improvement of a perturbation solution for hydraulic flow in a rotating parabolic channel. Z. Angew. Math. Mech. 85, 490-498.

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Ocean circulation

Kristofer Döös, Johan Nilsson, Jonas Nycander, Hanna Kling, in external collaboration with Andrew Coward (National Oceanography Centre, Southampton), Olivier Marchal (Woods Hole Oceanographic Institution), Ole-Anders Nøst (Norsk Polar Institutt)

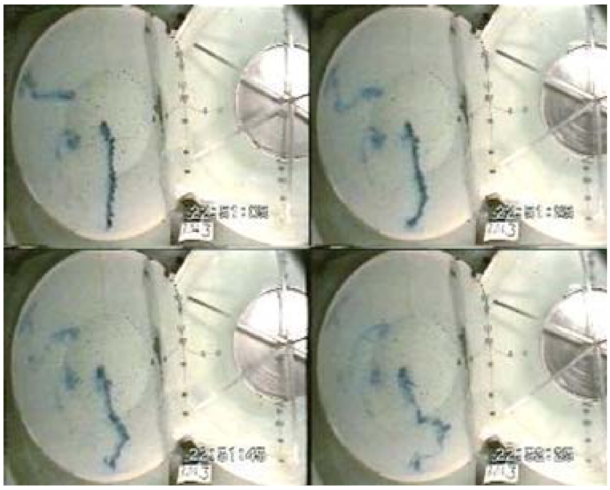
The exchange of water between the deep ocean and the surface layer is called the overturning circulation. It is weaker than the horizontal gyre circulation, but since it involves heating and cooling of water masses it is directly linked to the meridional heat transport, which is of crucial importance for climate.

A new way of diagnosing the overturning circulation has been developed, in which the stream function is computed as a function of depth and density. This stream function directly shows the energy transformations of the flow; for example, the sign of a circulation cell shows whether it is driven mechanically or thermally. Vertical mixing plays a key role in the overturning, since it heats the deep water and thereby allows it to upwell. Previously, hemispheric models have been used to show that the way in which this mixing is parameterized is crucial for the response of the overturning circulation to changes of the surface fluxes of heat and freshwater. However, in a model with both a northern and a southern hemisphere, allowing the circulation to be asymmetric, the qualitative features of the overturning circulation proved to be less sensitive to the mixing parameterization.

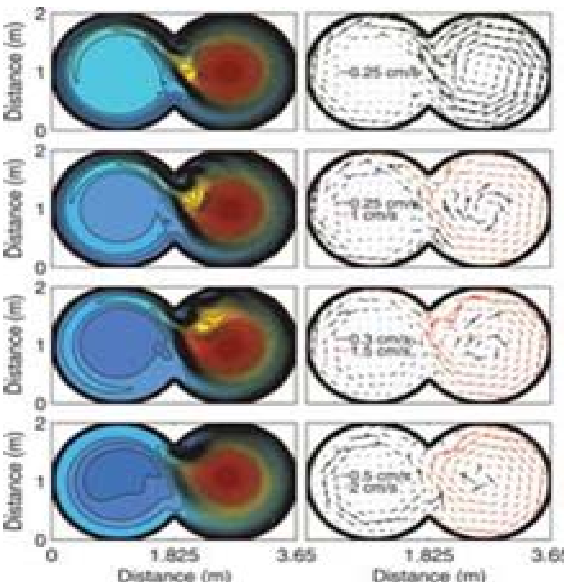
To examine the dynamical role of the bottom topography, a series of rotating-tank laboratory experiments have been conducted. The experimental setup was designed to capture some crucial aspects of the circulation in the Arctic Ocean and the Nordic Seas. In the experiments, cyclonic flows traced closely the depth contours around the entire basin. A remarkable result was that, in the case of anticyclonic flows, no such isobath-tracing flows could be establish unless their amplitude was below a threshold value. These intriguing results, of immediate relevance of the Arctic Ocean circulation, were corroborated on the basis of numerical simulations and theoretical analyses.

A conceptual model of the coupled atmosphere-ocean water cycle in the Hadley cell region has been developed. The model predicts that the meridional surface salinity difference in the Hadley cell should increase with temperature according to the Clausius-Clapeyron relation for the saturation water vapour pressure. This prediction tested against global warming simulations based on comprehensive climate models. It was found that the conceptual model yields a leading-order description of tropical surface salinity response in the climate-model simulations.

The paleoceanography of the Arctic Ocean during the early Miocene (about 18 million years ago) has been studied in collaboration with scientists from the Dept. of Geology and Geochemistry at Stockholm University. Sediment records show that there was a transition from an anoxic to an oxygenated state during this period and this transition is attributed to the opening of the Fram strait.



Rotating-tank experiment of Arctic Ocean dynamic. The flow is unstratified and forced by a rotating disk over the right-hand side sub-basin. Injected dye delineated the flow field, which here is cyclonic.



Numerical simulation of the flow in the rotating-tank experiment. A situation with anticyclonic flow of increasing strength is illustrated. Note that for high amplitude, the flow deviates strongly from the depth contours

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Generation of internal waves by tides

Jonas Nycander, Mondheur Zarroug

The vertical mixing caused by breaking internal waves is a critical link in the global overturning circulation. These waves are also essential for the dynamics of the bottom sediments. In the deep ocean internal waves are mainly generated by the interaction of tides with rough bottom topography. Here this process is studied analytically, and the generation of internal waves is computed numerically from first principles using linear wave theory.

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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, aerosols, 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, ecosystems - including acidification – and human health. The specific research areas include:

- REACTIVE TRACE GASES AND AEROSOLS
- PRECIPITATION CHEMISTRY
- MODELLING OF TROPOSPHERIC CHEMISTRY

REACTIVE TRACE GASES AND AEROSOLS

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.

Microphysical characterization of aerosol particles produced under controlled bubble bursting experiments using Baltic Sea, North Sea and Atlantic Ocean sea waters

Kim Hultin and Douglas Nilsson (ITM), Radovan Krejci, Monica Mårtensson (ITM), Gerrit de Leeuw (Univ. of Helsinki, Finland)

Bubble bursting from whitecaps is considered to be the most effective mechanism for particulate matter to be ejected into the atmosphere from the Earths' oceans and lakes. The material reaching the atmosphere as aerosols can consist of pure sea salt or various internal and external mixtures including organic matter as well as microorganisms. With respect to the ocean coverage of the Earth, it is one of the major sources of atmospheric aerosol on global scale. The overall embracing aim of this study is to quantify and improve the parameterizations of the primary marine aerosol source emissions. Our goal is to study microphysical properties of the primary marine aerosol emissions as a function of various environmental variables including water temperature, salinity and dissolved oxygen.

Several experiments were performed using a carefully sealed and slightly over pressurized tank, in which a waterfall jet simulated the action of a breaking wave. The aerosol size distribution and total aerosol number density at various sizes were observed. In addition we were able to obtain information about the volatility and mixing state of the particles by using thermo-denuder heated to 300 °C. The Baltic and North Atlantic experiments were conducted in water that was sampled continuously and simultaneously with co-located with in situ eddy covariance flux measurements. The role of the laboratory experiments is partly to cover the size range below 0.2 µm, for which the flux measurements have no size resolution. The North Atlantic experiments were conduced onboard the Irish research vessel Celtic Explorer as part of the EU project MAP.

Size distributions from the different waters show similar fundamental features, with a wide mode centered between 0.070 to 0.4 µm. In high salinity water, more particles smaller than 0.060 µm and fewer particles over 0.230 µm was observed. In the Baltic Sea, the number of small particles increases with water temperature, while the opposite seems to be true for the Skagerack and North Sea waters. The number of small particles also increased with an increasing concentration of dissolved oxygen in the Baltic Sea and the Skagerack

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 substantial 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 atmospheric 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,

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.

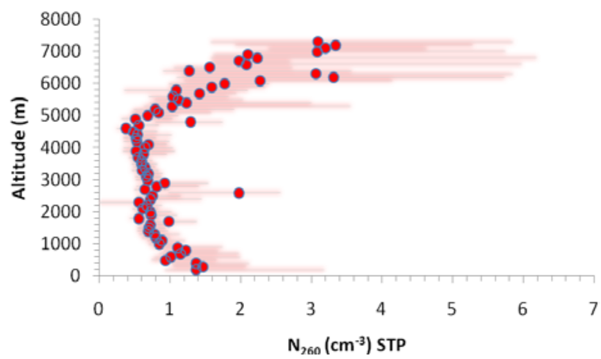
At the Cape Grim station a host of meteorological and trace substance information is available for the interpretation of aerosol data in terms of natural and anthropogenic sources, local regional and long-range influence. The combined ancillary information has been used to harmonize the two parts of 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.

ANTSYO II – Antarctic Trace Gas and Aerosol Airborne Measurement Study (AGAMES)

Radovan Krejci and Ann-Christine Engvall, Johan Ström (SU/ITM), Andreas Herber, Renate Treffeisen (AWI, Germany), Andreas Minikin (DLR, Germany), Keiichiro Hara, Takhashi Yamanouchi (NIPR, Japan)

During the AGAMES German/Japanese/Swedish Antarctic aircraft campaign from December 2006 to January 2007 a unique aircraft experiment was performed in Antarctica devoted to observations of aerosol properties and trace gases. This field study constituted one of the very first comprehensive airborne campaigns devoted to studies of tropospheric aerosol over Antarctica. The overall main objective in this context was to characterize the aerosol physico-chemical properties in the Antarctic troposphere (during summer season) and to identify the main sources and transport pathways for the aerosol particles. Flight operations during the first half of the campaign were based at the German Antarctic research base Neumayer in the Weddell Sea sector of Antarctica. For the second half of the campaign the aircraft was transferred to the East to the Camp S17, close to the Japanese research base Syowa. The Swedish group contributed with aerosol microphysical measurements delivering information about the aerosol number density, size distribution, size segregated aerosol volatility properties and measurements of light absorption by aerosol particles. It was found that the vertical variability of aerosol concentrations is relatively small if compared to mid-latitude observations, but the vertical distribution is not in general homogeneous. Even more pronounced vertical structure was observed for accumulation mode particles where strong enhancement was observed in the upper troposphere. More details can be found on project website: http://www.pa.op.dlr.de/aerosol/agames/



Vertical profiles of number concentrations of accumulation mode particles (>0.26 µm) measured during 15 research flights in the Neumayer area, Antarctica, during AGAMES in December 2006. Median number densities are indicated by red spots. Shadowing indicates range between lower and upper quartiles.

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 components 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 determined by a High Resolution GC coupled to a High Resolution Mass detector (HRGC-HRMS), r.p. 10 000. All steps in the method will be optimized due to recoveries with commercial amino acid standards and thereafter be applied to samples collected north of 80° during an icebreaker expedition in the summer of 2001.

Characterization of exopolysaccharides in marine colloid by capillary electrophoresis

Qiuju Gao, Åsa Emmer (KTH) and Caroline Leck

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 processesing 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.

Amazonian biosphere-atmosphere aerosol fluxes in view of their potential control of cloud properties and climate (AMAFLUX)

Douglas Nilsson (ITM) and Lars Ahlm (ITM), Radovan Krejci, Monica Mårtensson (ITM) Maria Greger (SU/Dept. of Botany), Paulo Artaxo (Univ. of Sao Paulo, Brazil)

The overall objective of the project is to study and quantify fluxes of the biogenic aerosol particles from the Amazonian tropical rain forest vegetation and explore possible links to plant physiological behavior. This main objective is based on the hypothesis that the fluxes of organic biogenic aerosols control the cloud condensation nuclei and thus cloud properties and through cloud properties also the hydrological cycle and radiative balance over the Amazon basin under conditions undisturbed by biomass burning or other anthropogenic activities.

The eddy covariance method was used between February and August 2008 to measure emission fluxes of aerosol particles of different size, volatility (chemical composition) from a tower over the rain forest during both, wet and dry seasons. First results show that accumulation mode aerosol exhibit a deposition pattern with increased magnitude during dry season due to stronger influence of biomass burning. For smaller particles more complex pattern was observed indicating periods of net source of aerosol primary biogenic particles from rain forest linked probably to dynamics of mixed layer growth and associated ventilation of forest canopy.

Observations of Free Tropospheric atmospheric Aerosol at high altitude site in Venezuelan Andes (OFTA)

Radovan Krejci, Nils Walberg and Leif Bäcklin (MISU), Johan Ström (ITM), Birgitta Noone (ITM) and Sten Lundström (ITM), Pedro Hoffmann and Silvia Calderon.(Universidad de Los Andes, Merida, Venezuela), Gerd Hoschild (IFK, Karlsruhe, Germany)

The main objective of this project is to study tropical free tropospheric aerosol physico-chemical properties at the Atmospheric Research Station Alexander von Humboldt, Pico Espejo, Merida, Venezuela. This station located at 4765 MSL offers unique opportunity to investigate the temporal variability of the free tropospheric aerosols in the tropical region. As far as we are aware, this is the only location at present, where intensive in-situ seasonal free tropical tropospheric atmospheric observations can be performed covering both meteorological hemispheres.

The field observations started in March 2007 and so far covered nearly two years. Total aerosol number density and black carbon measurements show pronounced trend with higher values during dry season and minima during period of passing ITCZ (wet season). Aerosol size distribution is dominated by accumulation mode aerosol during dry season, while during wet season Aitken mode dominates. Infrequent nucleation events can be preliminary linked to periods with intensive convection in a vicinity of the station. The local meteorology at the station exhibit a repetitive diurnal cycle. During late night and morning hours the station is in free troposphere. Since approximately midday until evening outflow from shallow convection reaches the station (S winds) or eventually pollution from Merida and lake Maracaibo region is lifted uphill (N winds).

Panoramatic view of the Atmospheric Research Station Alexander von Humboldt, Pico Espejo, Merida, Venezuela (4765 MSL). (Photo: Courtesy of Gerardo Sanchez, CIDA)

Characterization of aerosol multi-component properties (CAMP)

Johan Ström, Douglas Nilsson and Maria Svane (SU/ITM), Radovan Krejci

The main goal of this project is to develop, test and deploy new state-of-the-art mobile multipurpose instrumentation to measure physico-chemical properties of atmospheric aerosols. The experience with various methods to count and size particles as well as study aerosol composition and cloud nucleation properties will be used in this effort. The new instrumentation based on several differential mobility analyzers, particle counters and devices to study aerosol volatility and hygroscopic properties will be used in various projects covering regions from pole to pole geographically and applications ranging from urban aerosol to marine aerosol emissions, free tropospheric, tropical and polar aerosols. The project is now in its first stage of designing, acquiring and testing of necessary components.

Anthropogenic effect on natural cloud properties

Radovan Krejci, Kevin Noone (ITM), Birgitta Noone (ITM), Annica Ekman, Laura Gallardo (Universidad de Chile, Chile), Ana Maria Cordova (Universidad Valparaiso, Chile), Javier Fochesatto (University of Alaska, USA).

The overall aim of the project is to study aerosol-cloud interactions in persistent stratocumulus cloud deck surrounding coastal region of northern Chile and aerosol properties in free troposphere entering marine boundary layer. It is of the best natural laboratories available, where aerosol-cloud interactions in natural and anthropogenicaly influenced air masses can be studied. This offers unique opportunity to investigate manmade influence on cloud properties and better understanding of anthropogenicaly induced indirect effects of atmospheric aerosols on Earth climate. The process of aerosol activation into cloud droplets and how they influence cloud properties will be studies with Couterflow Virtual Impactor (CVI), which allows separation of the cloud droplets from surrounding air and consequent analysis of physical and chemical properties. The main scope of the modelling part of this project is assessment of the regional distribution of the oxidized sulphur and its direct and indirect radiative effects over central and northern Chile. The field experiment took place in October – November 2007 will take a place in northern Chile at Paposo mountain site near Antofagasta (700 MSL) and at ESO Paranal observatory (2635 MSL). This project was synchronized with field phase of the large international VOCALS-REX experiment (http ://www .eol. ucar.edu /projects/vocals/).

Atmospheric Brown cloud (ABC) Asia

Caroline Leck, Henning Rodhe, Lennart Granat and Erik Engström, 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 has 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 multi-component 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 – Reginal As-sessment with Focus on Asia. United Nations En-vironmental Programme, Bangkok

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: biomss or fossil fuel combustion? Science 23 January.,

ASCOS (The Artic Summer Cloud Ocean Study)

Caroline Leck and Michael Tjernström

See Arctic Studies

The high artic spatial variability of atmospheric DMS in the high artic region

Jenny Lundén, Gunilla Svensson and Caroline Leck

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

Intercomparisition of dimethyl sulphide oxidation mechanisms for the marine boundary layer: gaseous and particulate sulphur constituents

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

See Arctic Studies

Distribution Artic study of the tropospheric aerosols, clouds and radiation (ASTAR)

Ann-Christine Engvall, Radovan Krejci, et al

See Arctic Studies

Artic aerosol properties during transition from spring to summer at Ny Ålesund, Svalbard

Johan Ström (ITM), Ann-Christine Engvall, Radovan Krejci, et al.

See Arctic Studies

Biogenic particles over the central artic ocean

Caroline Leck and Keith Bigg

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

Evidence of a surface source of ultra fine aerosol particles in the artic ocean ocean pack ice during summer

Caroline Leck, Keith Bigg, Erik Swietlicki and Michael Tjernström

See Arctic Studies

Importance of submicrone surface active organic aerosols for pristine arctic clouds- a model study

Ulrike Lohmann and Caroline Leck

See Arctic Studies

Troposperic long-range transport of a forest fire plume to the central summer artic

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

See Arctic Studies

Aerosol-cloud interaction in shallow and deep convective clouds

Annica Ekman, Radovan Krejci (SU/ITM), Anders Engström, 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, German)

See Boundary Layer and Mesoscale Meteorology

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

Anna Lewinschal, Annica Ekman, Dongchul Kim (MIT, Cambridge, USA), Chien Wang (MIT, Cambridge, USA), Erland Källn

See Dynamic meteorology

Aerosol data assimilation

Anders Engström, Annica Ekman, Erland Källén, Heiner Körnich

See Dynamic meteorology

Modeling the greenhouse artic 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

PRECIPITATION CHEMISTRY

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

Erik Engström, Caroline Leck and Lennart Granat

Measurement of light absorbing matter at $\lambda = 550$ 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.

Composition of Asian Deposition (CAD)

Lennart Granat and Henning Rodhe, R. Bala (University of Singapore), P.S.P. Rao (Indian Institute of Tropical Meteorology, Pune, India),U. Kulshrestha (Indian Institute of Chemical Technology, Hyderabad, India), P.Gupta (National Physical Laboratory, Delhi), S.N. Das and R..Das (Regional Research Laboratory, Bhubaneswar, India)

The purpose of this project is to estimate the wet and dry deposition of biogeochemically important trace species, including sulfur and nitrogen compounds, calcium, sodium, chloride etc., to terrestrial ecosystems in S and SE Asia. Wet deposition is measured using both bulk and wet-only samplers and dry deposition is estimated from measurements of the concentration of gaseous and aerosol components in surface air. The project is funded by the Swedish International Development Co-operation Authority (Sida) through the Regional Air Pollution in Developing Countries (RAPIDC), program coordinated by the Stockholm Environment Institute (SEI). The focus of CAD is on rural areas such that the data can also be used in studies of regional transport of air pollutants.

Two genuinely rural stations in eastern and western India, respectively, are now running in cooperation with RRL and IITM. Wet deposition at the station in eastern India is about neutral in terms of acidification (pH is about 5.5), but since ammonium is the major cat-ion the composition may lead to acidification in the soil due to ecosystem processes. The western part of India receives more carbonate and less ammonium and here the wet deposition is still alkaline despite increase in anthropogenic emission of acidifying components. The regional distribution of wet deposition has compares only moderately well with output from regional chemical tracer transport models. Substantial discrepancies, especially regarding ammonium deposition, may be due either to inaccurate emission estimates or to poor representativeness of the measurements. Measurements are now being extended to NE and SW parts of India where soils are expected to be most sensitive to acidic deposition.

Publications

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Soil sensitivity to acidification in asia

Henning Rodhe, K Hicks, Anne Owen and J.C. Kuylenstierna (Stockholm Environment Institute, York, UK), Frank Dentener (Joint Research Institute, Ispra, Italy), Anne Owen and Hans Martin 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 Western 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 assessment 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

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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.

MODELLING OF TROPOSPHERIC CHEMISTRY

Meso-scale studies of aerosol and climate effects on deep convective cloud development and cloud microphysics

Deep 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 ocean temperatures and high surface air humidity result in many deep convective systems. In the following research projects we use a 3-D cloud-resolving non-hydrostatic atmospheric model to look at how local properties of deep convection may change in a changing climate. We also study how aerosols, which are necessary for cloud formation, affect deep convective cloud and precipitation development and vice versa, how convective cloud processing may affect the aerosol population.

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)

Within this project, the general atmospheric circulation model Oslo-CAM (based on the Community Climate System Model of the National Center for Atmospheric Research and developed at the University of Oslo) is used to simulate global sea spray aerosol emission fluxes during different climates. The simulations are evaluated versus present and previous interglacial and glacial ice core archives to examine if a) can a global climate model, using a realistic description of sea salt aerosol emission fluxes, simulate current and past sea salt aerosol concentrations? b) can the records of the Holocen Climatic Optimum and/or the previous interglacial Eem in ice core-climate archives be used as analogies for a future "green house Arctic Ocean"? c) what is the influence of different climate parameters on the global sea salt aerosol distribution? d) what is the influence of sea spray aerosols on the global production of cloud condensation nuclei and radiative balance during different climates?

Albedo, clouds, aerosols and global climate

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

See Chemical MeteorologyThe 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.

A comparison between two sets of satellite observations and output from 20 CGMs shows a discrepancy between models and observations, where the modelled global mean TOA albedo is systematically higher than that observed. Deviations are especially pronounced in certain regions, e.g. marine subtropical areas dominated by stratocumulus clouds. Furthermore, it is found that models deviate more from the more recent CERES measurements than from the older ERBE measurements as a consequence of being tuned to agree with ERBE TOA fluxes.

In GCM experiments with the NCAR CAM3.1 the TOA radiative balance is tuned to agree with ERBE and CERES respectively through alterations in the model cloud parameterization, and this results in two model configurations that differ in equilibrium climate sensitivity by 0.24 K.. This difference is small compared to e.g. the spread in estimated climate sensitivity in state-of-the-art climate models, but still elucidates the fact that climate sensitivity calculations are indirectly based on parameters that are not well restricted by observations and make clear the need for more restricting measurements.

In contrast to the Holocene albedo stability climate models show that under strong CO2 forcing (1% increase per year) the global mean albedo decreases by up to 0.0015 (corresponding to 0..5W/m2) per decade. This trend can be attributed partly to changing surface albedo (decreasing areas of ice and snow) and partly to changes in cloud properties. To further investigate the role of clouds in the albedo trend we use GCMs' albedo and total cloud fraction to determine how cloud albedo varies over time in different regions. To evaluate the models their calculated cloud albedos are compared with those based on observations from CERES, MODIS and CALIPSO.

The effect of volcanic aerosol on the global climate is investigated in 10 GCMs for the eruption of Mount Pinatubo, that is also well captured by the instrumental record. A relation between sensitivity to the radiative perturbation caused by the volcanic aerosol and the equilibrium climate sensitivity is found among the models, and assuming a similar relation holds for the real climate system, the observed TOA SW flux and surface temperature data is used to estimate the equilibrium climate sensitivity to 2.7 ± 0.8 K.

The way IPCC handles the uncertainty in aerosol forcing has been scrutinized and found to be too simplified. This has bearing on the uncertainty in the modelling of the temperature during the 20th centuryPublications

Bender, F. A- M., Rodhe, H., Charlson, R.J., Ekman, A.M.L. and Loeb, N. 2006. 22 views of the global albedo—comparison between 20 GCMs and two satellites. Tellus A 58, 320-330.

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The high Arctic spatial variability of atmospheric DMS – a model approach

Jenny Lundén, Gunilla Svensson and Caroline Leck

See Arctic Studies

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

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

See Arctic Studies

ADDITIONAL PUBLICATIONS: CHEMICAL METEOROLOGY

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ATMOSPHERIC PHYSICS

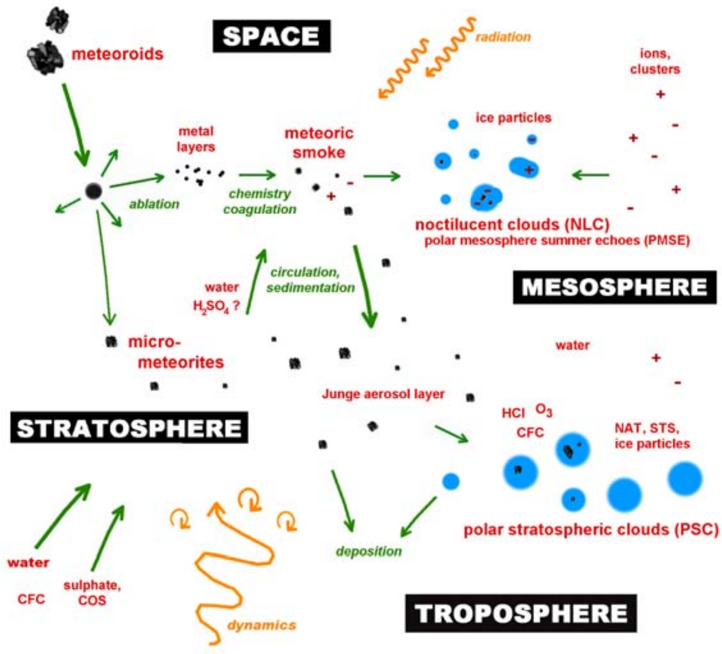
The Atmospheric Physics group (AP) at MISU/IMI continues its research programme on the aeronomy of the middle atmosphere. Focussing on the altitude range 10-100 km, the field of research of our Atmospheric Physics group concerns in particular radiative and chemical interactions of aerosols and trace 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.

In recent years, we have developed a programme in this field of research that now includes a wide range of experimental and theoretical techniques. The experimental component aims at the development, improvement and application of a variety 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 today from global dynamics to the microphysics of particle formation.

The long-term goals for our Atmospheric Physics programme at 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 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

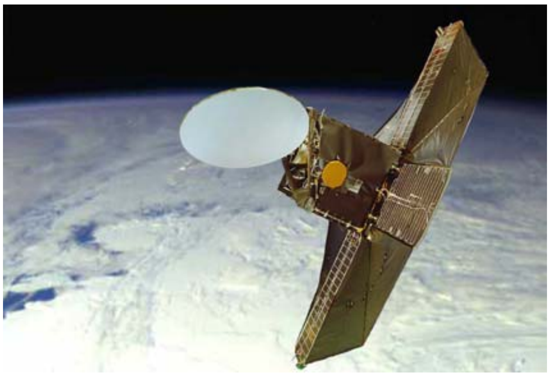
The Swedish Odin satellite has now been in orbit for more than 8 years, still providing a vast amount of valuable measurements. Odin-related studies continue to take up a major part in MISU/IMI's Atmospheric Physics activities. We are involved in both instruments on the satellite, i.e. the Optical Spectrograph 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 Odin Mission

Jacek Stegman, Jörg Gumbel, Bodil Karlsson, Stefan Lossow, Farahnaz Khosrawi, Tomas Waldemarsson, Georg Witt

The main scientific goal of the Odin project is to explore the middle and upper atmosphere and the interstellar medium using new, unexplored areas of the electromagnetic spectrum around wavelengths of 0.5 mm and 3 mm. These efforts are based on the submillimetre/millimetre receiver (SMR) onboard Odin. A second instrument, the Optical Spectrometer and InfraRed Imaging System (OSIRIS) is used exclusively for atmospheric studies and provides complementary information using ultraviolet, visible and infrared wavelengths. 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.



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 basic stratospheric mode, Odin scans the Earth's atmosphere between 7 and 60 km. In recent years the observation programme for the mesosphere has been significantly 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 AP group remains strongly engaged in the Odin entire aeronomy programme and the management of the mission. A particular focus is on mesospheric water (water vapour, noctilucent clouds) and the continued development of UV-Vis retrieval algorithms for ozone-destroying species in the stratosphere and atomic and molecular species in the mesosphere. Ongoing studies concern the sodium layer and other metals in the mesosphere as well as the retrieval of upper mesospheric temperatures from the O2 A-band dayglow emission.

Studies of noctilucent clouds

Bodil Karlsson, Heiner Körnich, Jörg Gumbel, 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 latitude. A case study for the austral summer 2004/2005 showed that NLC particles grow larger towards the pole. Effective optical radii were retrieved as 65 nm at 70°S and 76 nm at 90°S Microphysical modelling suggests that this is a combined effect of the mesospheric temperature structure, availability of water vapour and meridional transport times

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.

Mesospheric water vapour and temperature retrievals

Stefan Lossow, in collaboration with J. Urban, P. Eriksson and Donal Murtagh (Chalmers University of Technology, Sweden), Jörg Gumbel and Jacek Stegman

The sub-millimetre radiometer (SMR) onboard the Odin satellite measures thermal emissions of several minor constituents in the frequency range between 486 and 581 GHz throughout the middle atmosphere. The water vapour emission line near 557 GHz is of special interest. Using a non-linear retrieval scheme based on the optimal estimation method (OEM) water vapour and temperature profiles, covering the altitude range between 40 km and 100 km, can be derived. The typical altitude resolution is between 3 km and 5 km.

The possibility to measure water vapour distribution with global coverage, to thermospheric heights and with unprecedented accuracy has always represented one of the most exciting parts of the Odin mission. Water vapour acts as a tracer of dynamical processes and the preliminary studies conducted so far indicate that water vapour variability on different spatial and time scales provide interesting diagnostic tools to investigate the underlying dynamical processes. The dynamical imprint of the Quasi-biannual Oscillation (QBO) on the water vapour concentration has been observed in the mesospheric water vapour distribution in the tropics. Important conclusions about the dynamics of the lower thermosphere could be drawn from extending the SMR water analysis to altitudes above 100 km. Another important finding is that the inter-hemispheric stratosphere/mesosphere coupling postulated from our NLC studies can also been seen in water/temperature data.

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 e.g. to Odin/OSIRIS.

Publications

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

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In-situ water vapour measurements

Misha Khaplanov, Stefan Lossow, Jörg Gumbel, Jacek Stegman, Georg Witt

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). Additional information on the density profile is available from the Rayleigh lidar at Esrange operated by Bonn University. These detailed local data sets were complemented by overflights of the Odin satellite, configured in aeronomy mode and providing continuous water measurements using sub-mm limb sounding.

Three rocket campaigns addressing the distribution of middle atmosphere water vapour have now been performed by the MISU/IMI Atmospheric Physics group. All of these measurements have 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.

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

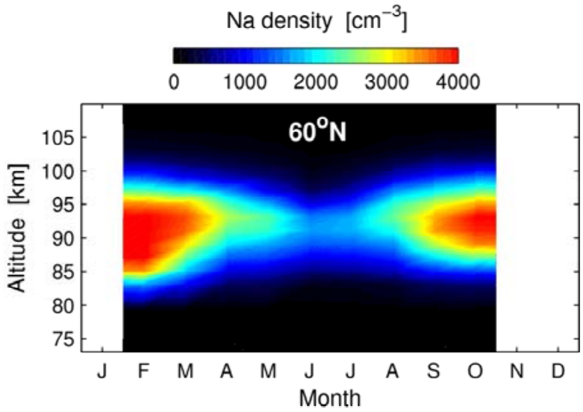
Studies of the mesospheric metal layers

Jörg Gumbel, Thomas Waldemarsson, Jonas Hedin

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 MAGIC 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 five 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)



Monthly averaged sodium at 60ºN retrieved from Odin/OSIRIS measurements of sodium dayglow at 589 nm. Processes contributing to the summertime minimum are the temperature-dependence of mesospheric metal chemistry as well as the uptake of sodium species onto noctilucent cloud particles

Publications

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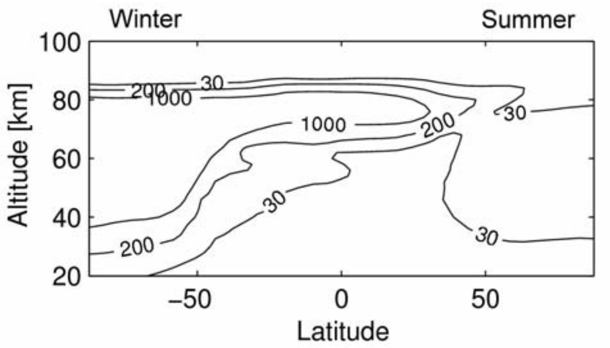
Global model simulations of mesospheric aerosols

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.

The global distribution of meteoric smoke particles larger than 1 nm radius is shown in the Figure. Number densities of around 4000 per cubic centimetre are reached at the winter pole, and only very few particles remain at the summer mesopause. This contrasts the simplistic picture of a homogeneous global meteoric smoke layer, which is currently assumed in many studies of middle atmospheric phenomena.



Global distribution of meteoric smoke particles larger than 1 nm in radius. This 2-dimensional model simulation for the middle of July shows the efficient transport of meteoric material towards the winter stratosphere.

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 is of potential importance for stratospheric nucleation processes, which in turn effect PSC and ozone destruction.

Publications

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Particle charging and ice nucleation in the mesosphere

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

The existence and properties of mesospheric clouds as well as 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 (Gumbel and Megner, 2009; Megner and Gumbel, 2008). Ablated meteoric 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 role 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.

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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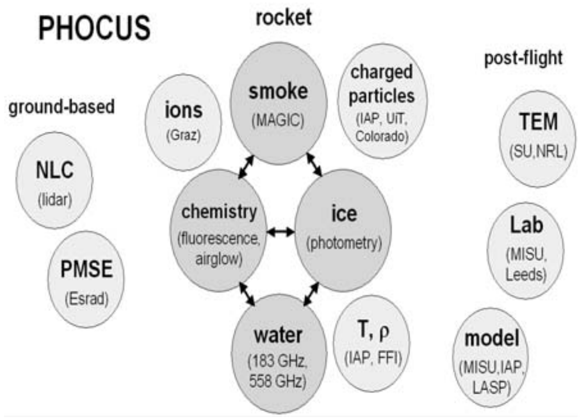
PHOCUS: A rocket study of particle interactions in the mesosphere

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

Intensive work has been going on in the MISU's Atmospheric Physics group to prepare the PHOCUS rocket project. PHOCUS (Particles, Hydrogen and Oxygen Chemistry in the Upper Summer meso¬sphere) will study mesospheric particles and their interaction with their neutral and charged envi¬ronment. 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 parti¬cles 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. Back¬bone 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 are 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.

As will be discussed more in the sections, 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.

Publications

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Strelnikova, I., M. Rapp, B. Strelnikov, G. Baumgarten, A. Brattli, K. Svenes, U.-P. Hoppe, M. Friedrich, J. Gumbel, and B. P. Williams, Measurements of meteor smoke particles during the ECOMA2006 campaign: 2. Results, J. Atmosph. Sol. Terr. Phys., 71, 486-496, 2009.

Rocket-borne photometry of noctilucent clouds

Linda Megner, Jonas Hedin, Misha Khaplanov, 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).

The photometers provided the altitude range and structures of the NLCs. Phase function measurements were applied to infer NLC particle sizes. In combination with the charged particle measurements by other research groups, completely new insight in charging mechanisms and the spatial and temporal distribution of mesospheric particles could be drawn. The analysis of the ECOMA and MASS projects is currently ongoing.

An earlier optical NLC instrument was prepared the HotPay-2 campaign from Andøya, Norway, in 2006. This was part of the enhanced Alomar Research Infrastructure (eARI) under the 6th Framework Programme of the European Commission. The SLAM instrument (Scattered Lyman-Alpha in the Mesosphere) was intended to perform the first measurement of NLC light scattering at a wavelength as short as Lyman-α (121.57 nm). This pushes NLC scattering far into the Mie regime, thus opening new ways to derive information about NLC particle sizes. While the HotPay-2 payload failed after launch, SLAM still was an important instrument development for the study of mesospheric ice particles. Based on this concept, a new flight of a Lyman-α instrument is now being prepared for the upcoming PHOCUS rocket campaign from Esrange, Sweden.

Publications

Hedin, J., J. Gumbel, M. Khaplanov, G.Witt, J. Stegman, Optical studies of noctilucent clouds in the extreme ultraviolet., Annales Geophysicae, 26, 1109-1119, 2008.

Megner, L., M. Khaplanov, G. Baumgarten, J. Gumbel, J. Stegman, B. Strelnikov, and S. Robertson, Large mesospheric ice particles at exceptionally high altitudes, Ann. Geophys., 27, 943 - 951, 2009.

Robertson, S., M. Horányi, S. Knappmiller, Z. Sternovsky, R. Holzworth, M. Shimogawa, M. Friedrich, K. Torkar, J. Gumbel, L. Megner, G. Baumgarten, R. Latteck, M. Rapp, U.-P. Hoppe, and M. E. Hervig, Mass analysis of charged aerosol particlesin NLC and PMSE during the ECOMA/MASS campaign, Ann. Geophys., 27, 1213-1232, 2009.

Rapp, M., I. Strelnikova, B. Strelnikov, R. Latteck, G. Baumgarten, Q. Li, L. Megner, J. Gumbel, M. Friedrich, U.-P. Hoppe, and S. Robertson, First in situ measurement of the vertical distribution of ice volume in a mesospheric ice cloud during the ECOMA/MASS rocket campaign, Ann. Geophys., in print, 2009

Rocket-borne nightglow studies

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

The HotPay2 rocket campaign took place in January 2008 at Andøya Rocket Range, funded through enhanced Alomar Research Infrastructure (eARI) under the 6th Framework Programme of the European Commission. The scientific objectives of this effort were to study specific atmospheric conditions: to determine NO concentrations under the specific geophysical conditions carefully monitored by a number of ground-based measurements, and to investigate the ratio of sodium D1/D2 as function of height. NO is an important parameter for studying mesospheric charging processes. NO concentrations can be retrieved from photometric measurements of NO_2continuum during the night. This technique has been developed by Georg Witt for a night-time rocket measurements in the 1970s. As the NO_2 emission is produced by the 3-body reaction

$$NO + O + M \rightarrow NO_2,$$

NO concentrations can be retrieved, once NO_2 and O are known. To this end, NO_2 is measured directly in terms of the nightglow continuum at wavelengths around 540 nm, while O concentrations are determined from measurement of the O_2 Atmospheric Band at 762 nm. The technique is based on an empirical model of common nightglow emissions.

The analysis of the photometry performed during HotPay-2 has led to important conclusions about the calibration of optical composition measurements. These findings are now being applied to the experiment development for the upcoming PHOCUS rocket project.

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, submitted to Atmos. Meas. Tech., 2009.

Simultaneous Observations of NLC from space and from ground

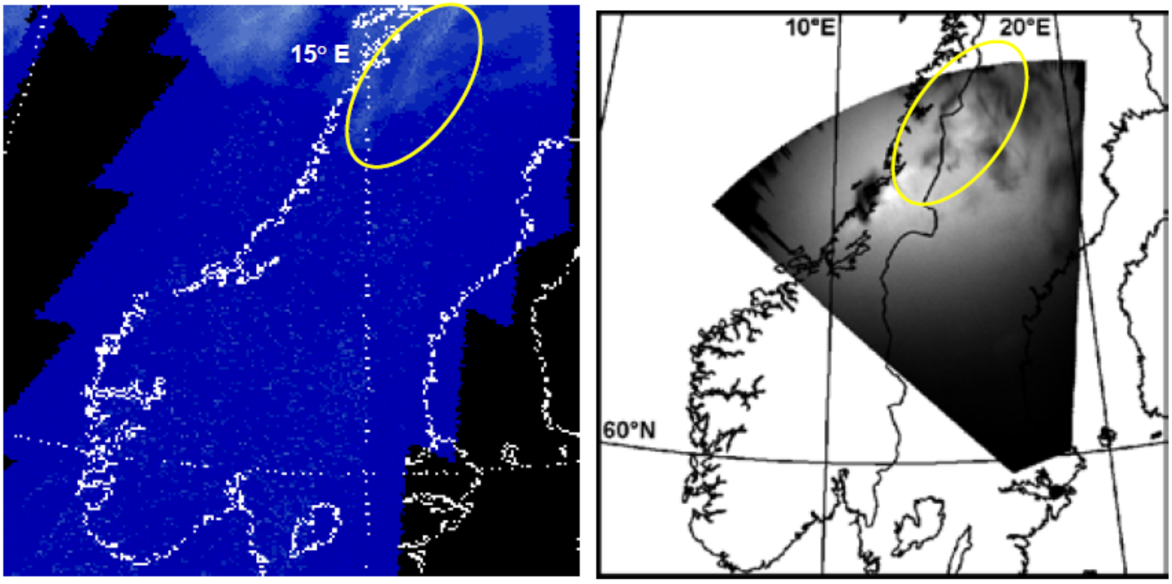
Jacek Stegman, in collaboration with P.-D. Pautet (Utah State University, USA), S. Bailey (Virginia Polytechnical Institute, USA) and D. Rush (University of Colorado, LASP, USA)

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



Left: Noctilucent clouds display registered by the CIPS instrument on-board the AIM satellite at around 22:00 UT on July 26, 2008, on its orbit #6829. Right: The same display as registered by the ground-based camera at the same time. A weak NLC band is marked in both plots.

In the figure, a weak display of noctilucent clouds has been registered by the ground-based camera on July 26, 2008 between 21:40 and 22:30 UT. A single NLC band appears along the Scandinavian coastline in the ground images. This band remains relatively unchanged for a large part of the night. The AIM satellite passed the camera's field-of-view at around 22:00 UT on its orbit #6829. A "stripe" of images taken by the CIPS instrument along the track is shown to the right and the interesting feature that appears in the field of view of the camera is marked by an arrow. A weak NLC band is also found in, basically, the same region.

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.

Hedin J., J. Gumbel and M. Rapp, On the efficiency of rocket-borne particle detection in the mesosphere, Atm. Chem. Phys., 7, 3701-3711, 2007

Lidar measurements in the mesosphere

Misha Khaplanov, Jörg Gumbel, Jonas Hedin, Stefan Lossow, Peggy Achtert, Farah Khosrwai, 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.

The ACE satellite mission

Georg Witt, Stefan Lossow

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

Carleer, M. R., C. D. Boone, K. A. Walker, P. F. Bernath, K. Strong, R. J. Sica, C. E. Randall, H. Vömel, J. Kar, M. Höpfner, M. Milz, T. von Clarmann, R. Kivi, J. Valverde-Canossa, C. E. Sioris, M. R. M. Izawa, E. Dupuy, C. T. McElroy, J. R. Drummond, C. R. Nowlan, J. Zou, F. Nichitiu, S. Lossow, J. Urban, D. Murtagh, and D. G. Dufour: Validation of water vapour profiles from the Atmospheric Chemistry Experiment (ACE), Atmos. Chem. Phys. Discuss., 8, 4499-4559, 2008.

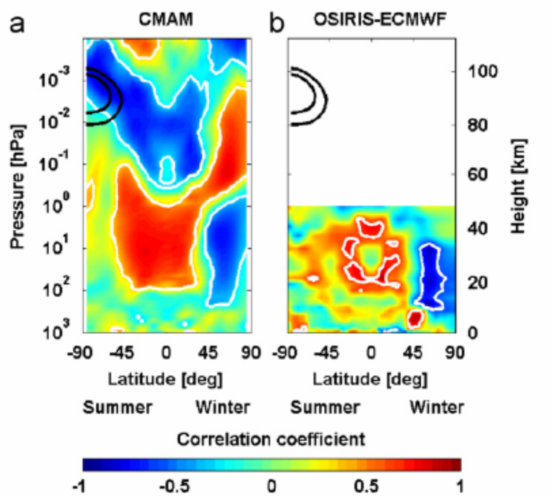
DYNAMICAL COUPLING OF THE MIDDLE ATMOSPHERE

Global observations of noctilucent clouds and water vapour 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. In spite of the great distance involved, this inter-hemispheric link is suggested to account for a significant part of the year-to-year variability, the intra-seasonal variability and the hemispheric differences that have been observed in noctilucent clouds. Various observations and model simulations have confirmed the existence of this link and contributed to a better understanding of the mechanism behind it. Odin water vapour data have been used as a tracer for the study of e.g. the mesospheric semi-annual oscillation and the lower thermospheric transport pattern.

Inter-hemispheric coupling studied by the Canadian Middle Atmosphere Model

Bodil Karlsson, in collaboration with Charles McLandress and Theodore G. Shepherd (University of Toronto, Canada)

This study investigated the dynamical influence of the winter stratosphere on the summer mesosphere using simulations from the vertically extended version of the Canadian Middle Atmosphere Model (CMAM). It is found that for both northern and southern hemispheres, variability in the summer polar mesopause region from one year to another can be traced back to the planetary-wave flux entering the winter stratosphere. The teleconnection pattern is the same for both positive and negative wave-flux anomalies. Using a composite analysis to isolate the events, it is argued that the mechanism for inter-hemispheric coupling is a feedback between summer mesosphere gravity-wave drag and zonal wind which is induced by an anomaly in mesospheric cross-equatorial flow, the latter arising from the anomaly in winter hemisphere gravity-wave drag induced by the anomaly in stratospheric conditions.



(a) Correlation between the CMAM monthly and zonal mean temperature anomaly in the summer mesopause region (from 3.10-3 to 3·10-5 hPa and latitudes poleward of 50°) and the monthly and zonal mean temperature anomalies in the rest of the atmosphere computed from combining the two summer and winter hemispheres for January and July after removing the mean for each hemisphere. The summer pole is on the left.

(b) Correlation between zonal and monthly mean NLC radii anomalies from OSIRIS data and ECMWF temperature analyses using ten NLC seasons (see Karlsson et al. (2007) for details), with summer and winter hemispheres combined as in panel (a).

Publications

Karlsson, B., C. McLandress, and T. G. Shepherd: Interhemispheric mesospheric coupling in a comprehensive middle atmosphere model., J. Atmos. Solar Terr. Phys., 71, 518-530, 2009

Inter-hemispheric stratosphere/mesosphere observed in noctilucent clouds

Bodil Karlsson, Heiner Körnich, Jörg Gumbel

Noctilucent clouds (NLC) at about 82 km and their mesospheric environment continue to play a central role in MISU's atmospheric physics research. Global model studies indicate a dynamic coupling between the winter stratosphere and the polar summer mesosphere. The suggested link between these two widely separated regions is the pole-to-pole meridional circulation which is strongly dependent on gravity waves. Planetary waves modulate the propagation of gravity waves, and thus also the pole-to-pole transfer in the mesosphere. We study this interhemispheric coupling based on global datasets from the Odin satellite and the ECMWF operational analysis. In particular, we use

Odin observations of NLC properties as a proxy for the state of the summer mesosphere and ECMWF winter stratospheric temperatures as a proxy for planetary wave activity in the stratosphere. The comparison of these two global datasets supports the predicted interhemispheric connection. This suggests a dynamic explanation to north/south differences and year-to-year variabilities commonly observed in summer mesopause conditions

Publications

Karlsson B., H. Körnich, J. Gumbel: Evidence for interhemispheric stratosphere-mesosphere coupling derived from noctilucent cloud properties, Geophys. Res. Lett., 34, L16806, doi:10.1029/2007GL030282, 2007..

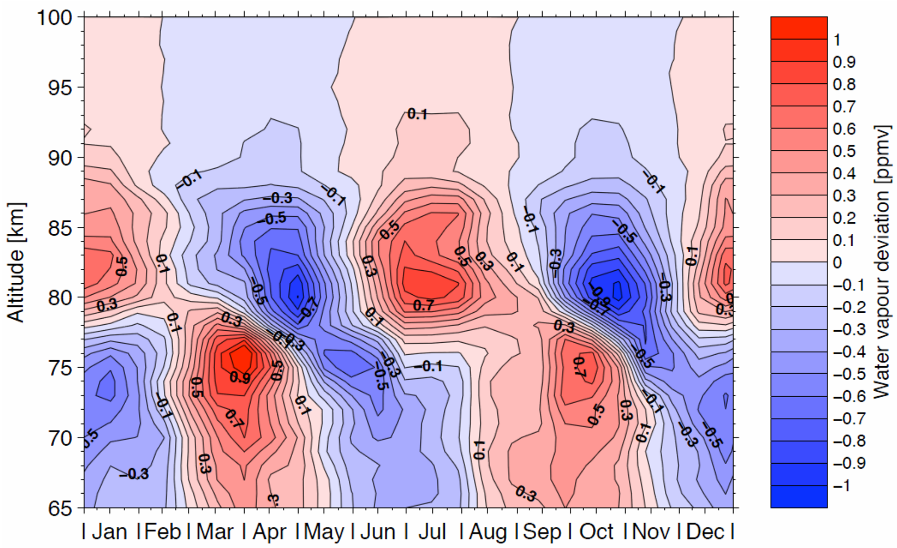
The mesospheric semiannual oscillation

Stefan Lossow, in collaboration with J. Urban, P. Eriksson and D. Murtagh (Chalmers, Sweden), and J. Gumbel

Mesospheric water vapour measurements taken by the SMR instrument aboard Odin have been analysed with focus on the mesospheric semi-annual circulation in the tropical and subtropical region. This analysis provides the first complete picture of mesospheric SAO in water vapour, covering altitudes above 80 km where previous studies were limited. Our analysis shows a clear semi-annual variation in the water vapour distribution in the entire altitude range between 65 km and 100 km in the equatorial area. Maxima occur near the equinoxes below 75 km and around the solstices above 80 km. The phase reversal occurs in the small layer in-between, consistent with the downward propagation of the mesospheric SAO in the zonal wind in this altitude range.

Publications

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.



Amplitude and phase of the mesospheric semi-annual oscillation averaged between 10°S and 10°N. The plot shows the deviation of the water vapour distribution with respect to a 180-day running average of the mean distribution

A simple model of the interhemispheric coupling

Heiner Körnich, Erich Becker (Leibniz-Institute of Atmospheric Physics, Germany), Bodil Karlsson, Linda Megner, Theodore G. Shepherd and Charles McLandress (Department of Physics, University of Toronto, Canada), Jörg Gumbel, Stefan Lossow

The interhemispheric coupling of the middle atmosphere is a robust feature 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 nonzonally propagating gravity waves. In the model simulations, the strength of the winter polar vortex can be controlled externally. A weaker polar vortex leads to a downshift 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., E. Becker, and B. Karlsson, A simple model for the interhemispheric coupling of the middle atmosphere circulation, submitted to Adv. Space Res., 2009..

Stratospheric warmings from the troposphere to the mesosphere

Heiner Körnich, Erich Becker and Peter Hoffmann and Werner Singer (Leibniz-Institute of Atmospheric Physics, Germany)

The winterly stratosphere displays occasionally strong warmings in the polar latitudes. These warmings are caused by increased planetary wave activity which originates in the troposphere. The related change in the stratospheric circulation affects also gravity waves propagating into the mesosphere. Thus, the stratospheric warming is accompanied by a response in the mesospheric residual circulation and by a cooling in the polar winter mesosphere. This process is investigated in a mechanistic circulation model and on basis of radar soundings as well as analysis data.

Publications

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.

Becker, E., H. Körnich, P. Hoffmann, and W. Singer, Planetary Rossby waves and gravity waves in the mesosphere during sudden stratospheric warmings, to be submitted.

Transport patterns in the lower thermosphere

Stefan Lossow, in collaboration with J. Urban, P. Eriksson and D. Murtagh (Chalmers, Sweden), H. Schmidt (MPI for Meteorology, Germany), D. Marsh (NCAR, USA), and J. Gumbe

Odin/SMR water vapour measurements have been analysed in the upper mesosphere and lower thermosphere. Measurements since 2003 have been compiled to provide for the first time an overview of the water vapour distribution in this altitude range. The observations show a distinct increase of the water vapour concentrations during winter at a given altitude above 90 km. Above 95 km the observations exhibit the annual water vapour maximum during wintertime. Model simulations from HAMMONIA and WACCM3 show very similar results as the observations. We suggest that the observed increase in water vapour during winter is mainly caused by a combination of upwelling moister air from lower altitudes and diffusion processes. Distinct inter-hemispheric differences are found in the winter water vapour distribution, with the polar seasonal increase much more pronounced in the southern hemisphere. This is most likely due to inter-hemispheric differences in the underlying dynamics and diffusion processes

Publications

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., 2008JD011462, in print, 2009

Vertical Aeolus Measurement Positioning

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

The mission objective of the ADM-Aeolus is to provide global observations of wind profiles. The Aeolus mission will demonstrate the impact of these data on operational weather forecasting and on climate research. The current study “Vertical Aeolus Measurement Positioning” (VAMP) is to consider the atmospheric dynamical and optical characteristics and their interaction with ADM-Aeolus measurement system in order to optimize the user benefit of the Aeolus system. As a first step, dynamical and optical properties are derived from high-resolution radiosondes, cloud resolving models, and ECMWF analysis. The impact of different vertical sampling scenarios is assessed by data assimilation theory and experiments.

Publications

Stoffelen, A., H. Körnich, G.-J. Marseille, K. Houchi, and J. de Kloe, Assessment of Optical and Dynamical Atmospheric Heterogeneity, ESA Technical Note, under review, 2008.

STRATOSPHERIC CLOUDS, AEROSOLS AND COMPOSITION

Renewed efforts of the MISU/IMI 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 of water vapour and other species 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.

Seasonal cycle of monthly averages of N_2O and O_3

Farahnaz Khosrawi, in collaboration with R. Müller (FZ Jülich, Germany), M. H. Proffitt (Proffitt Instruments, USA), J. Urban and D. P. Murtagh (Chalmers, Göteborg), R. Ruhnke (FZ Karlsruhe, Germany), J.-U. Grooß (FZ Jülich, Germany), H. Nakjima (NIES, Japan)

Northern and Southern hemispheric monthly averages of ozone (O_3) and nitrous oxide (N_2O) have been suggested as a tool for evaluating atmospheric photochemical models. An adequate data set for such an evaluation can be derived from measurements made by satellites which in general have a high spatial and temporal coverage, like e.g. measurements made by the Improved Limb Atmospheric Spectrometers (ILAS and ILAS-II) which use the solar occultation technique and by the Odin-Sub Millimetre Radiometer (Odin/SMR) which passively observes thermal emissions from the Earth's limb. From ILAS/ILAS-II and Odin/SMR observations 1-year data sets of monthly averaged O_3 and N_2O, covering a full seasonal cycle, were derived for the latitude range between 60° to 90° N and 60° to 90° S, respectively, by partitioning the data into equal bins of altitude or potential temperature. Since Odin/SMR provides measurements globally, a 1-year data set of monthly averaged N_2O and O_3 are derived for both the entire Northern and Southern Hemispheres from these measurements. Further, these hemispheric data sets from Odin/SMR are separated into data sets of monthly averaged N_2O and O_3 for the low latitudes, mid-latitudes, and high latitudes. The resulting families of curves help to differentiate between O_3 changes due to photochemistry from those due to transport. These 1-year hemispheric data sets of monthly averaged N_2O and O_3 from Odin/SMR and ILAS/ILAS-II as well as the data sets of monthly averaged N_2O and O_3 for the specific latitude regions from Odin/SMR provide a potentially important tool for the evaluation of atmospheric photochemical models.

Publications

Khosrawi, F., R. Müller, M. H. Proffitt, J. Urban, D. Murtagh, R. Ruhnke, J.-U. Grooß, H. Nakajima (2008): 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.

Evaluation of CTMs and CCMs simulations in the lower stratosphere

Farahnaz Khosrawi, in collaboration with R. Müller and J.-U. Grooß (FZ Jülich), M. H. Proffitt (Proffitt Instruments, USA), R. Ruhnkeand O. Kirner (FZ Karlsruhe, Germany), P. Jöckel (MPI for Chemistry, Germany), J. Urban and D. P. Murtagh (Chalmers, Göteborg), H. 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, mid-latitudes 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 N_2O 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

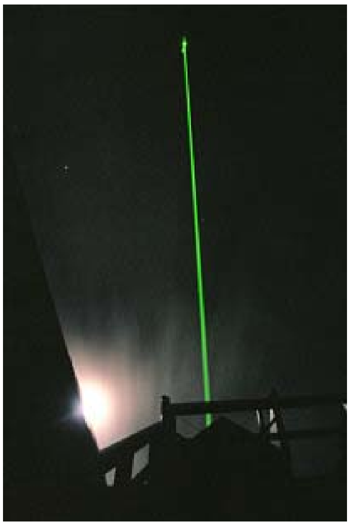
Khosrawi, F., R. Müller, M. H. Proffitt, R. Ruhnke, O.Kirner, P. Jöckel, J.-U. Grooß, J. Urban, D. Murtagh, H. Nakajima, Evaluation of CLaMS, KASIMA and ECHAM5/MESSy1 simulations in the lower stratosphere using observations of Odin/SMR and ILAS/ILAS-II, Atmos. Chem. Phys., in press. 2008.

Lidar measurements in the stratosphere

Peggy Achtert, Misha Khaplanov, Farahnaz Khosrawi, Stefan Lossow, Jonas Hedin, Jörg Gumbel, 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 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. One important objective is the study of polar stratospheric clouds (PSCs).

PSCs play a key role in stratospheric ozone depletion since heterogeneous chemical reactions on the surfaces of the cloud particles activate halogen compounds which initiate the chemical reactions which lead to the observed destruction of ozone in the polar regions during winter. Lidar measurements are well suited to observe and classify PSCs. PSC measurements by the Esrange lidar have been performed each winter since 1997. The availability of this long-term data set is very valuable to classify the PSCs due to their scattering characteristics and to investigate the frequency of appearance of the individual PSC types. An extension of the lidar to a Rotational Raman channel is anticipated to obtain also detailed temperature measurements in the vicinity of PSCs. The Esrange lidar is located at the east side of the Scandinavian mountain ridge, which is a major source of orographically induced gravity-waves that can rapidly cool the atmosphere below PSC formation temperatures. Simultaneous measurements performed by the RMR Alomar lidar at Andøya Rocket range which is located at the west side of the Scandinavian mountain ridge provides the unique possibility to investigate the formation of orographically induced PSCs. Using box model simulations along air parcel trajectories allows to investigate when, where and under which conditions the PSCs have formed.



The laser beam of the Esrange lidar (68°N, 18°E) near Kiruna.

Occurrence and properties of PSCs

Peggy Achtert, Farahnaz Khosrawi, Jörg Gumbel, Misha Khaplanov, Stefan Lossow, Ulrich Blum (University Bonn, Germany), K. H. Fricke (University Bonn, Germany), Peter Völger (IRF Kiruna), Peter Dalin (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 spaceborne 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. 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).

Publications

Blum, U., F. Khosrawi, G. Baumgarten, K. Stebel, R. Müller, K. H. Fricke, Simultaneous lidar observations of a polar stratospheric cloud on the east and west side of the Scandinavian mountains and microphysical box model simulations, Annales Geophysicae, 24, 3267-3277, 2006.

Denitrification, dehydration and formation of PSC

Farahnaz Khosrawi, Peggy Achtert, Misha Khaplanov, Stefan Lossow, Ulrich Blum (University Bonn, Germany), K. H. Fricke (University Bonn, Germany), Peter Völger (IRF Kiruna), Peter Dalin (IRF Kiruna), Sheila Kirkwood (IRF Kiruna), Joachim Urban (Chalmers, Göteborg) 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 sedimentation 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.

Bi-static lidar studies of cirrus particle properties

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The effect of atmospheric clouds and aerosol on the Earth' climate is not yet completely understood. 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. First successful results were obtained in the October 2006. CABLE is financed by the enhanced ALOMAR Research Infrastructure (eARI) under the 6th Frame Programme of the European Union.

Publications

Olofson, K. F. G., Witt, G. and Pettersson, J. B. C., Bistatic lidar measurements of clouds in the Nordic Arctic region, Appl. Opt., 47, 4777-4786, 2008.

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., in print, 2009.

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 Centre 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 beginning 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.

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.

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.

After intensive preparations during 2007 and spring 2008, 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. Prior to this the team spent weeks of preparations and loading of instruments on Oden, first in the shipyard in Landskrona in southern Sweden during the first week of June and then in transit to Svalbard immediately after. After a brief start-up and installation phase in the fjord off Longyearbyen, 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 struc¬ture and phase of precipi¬ta¬tion 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; atmos¬pheric 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.

The high Arctic spatial variability of atmospheric DMS – a model approach

Jenny Lundén, Gunilla Svensson and Caroline Leck

The main source of dimethyl sulfide (DMS) is from phytoplankton living in the surface layers of the oceans. DMS concentration varies with latitude, with highest concentration found in polar regions. The exchange of DMS from the ocean surface to the atmosphere depends on the concentration above and below the air-sea interface as well as on sea-surface temperature and on the state of the sea-surface.

In the High Arctic (above 80°N), the oxidation products of DMS (i.e. sulfuric acid, methane sulfonic acid and sulfur dioxide) are important due to their cloud forming ability. These sulfur components can aid growth of pre-existing particles and subsequently become large enough to act as cloud condensation nuclei and thereby contribute to cloud formation. Past observations in the high Arctic show a large spatial variability of atmospheric DMS. This study has been performed to investigate the extent to which meteorological processes could be the cause of the observed variability during the Arctic Ocean Expedition 2001.

The atmospheric part of Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) have been used together with observations from three Arctic expeditions (International Arctic Experiment 1991, Arctic Ocean Experiment 1996 and 2001) to model the advection of DMS from its source in the Greenland Sea.

The air-sea exchange of DMS depends strongly on wind speed. This leads to a significant variability in DMS concentration over oceans surrounding the pack ice region. This was captured by the model despite that a constant concentration of seawater DMS was assumed.

Our results showed that DMS was advected in confined plumes from the source regions in the open ocean surrounding the pack ice. Atmospheric DMS concentrations over the pack ice area will therefore depend heavily on the location of observation. The effects of the modeled meteorological processes such as the location of high and low pressure systems and the associated flow can describe the entire range of the observed temporal variability of DMS during the selected period, August 10 – 24, 2001.

Publications

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

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

Dimethyl sulfide (DMS) is produced by phytoplankton in the ocean surface. DMS is exchanged at the air-sea interface, a process highly influenced by wind speed and turbulence. In the atmosphere, DMS is photochemically oxidized. The oxidation products from DMS (i.e. sulfuric acid, methane sulfonic acid and sulfur dioxide) can condensate on pre-existing particles in the atmosphere and thereby take part in the activation of cloud condensation nuclei and hence cloud formation. This is important in remote areas, such as the Arctic, where the anthropogenic influence is limited.

The atmospheric part of Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) have been used to model the advection and mixing of DMS in the atmosphere over the Arctic pack ice. The model gave reasonable results even though a simplified description of DMS chemistry was used (i.e. a constant seawater DMS concentration in grid-points defined as ocean and an exponential decay of DMS in the atmosphere).

The results showed that the modeled distribution of atmospheric DMS over the pack ice was determined by transport in association with synoptical weather systems. In 2001, the monthly average DMS concentration for July and August respectively, showed different patterns over the pack ice. In July the DMS concentration was rather uniform over the ice with a smooth decrease of DMS from the ice edge and inwards while the gradually decrease was overlapped by a distinct plume from the Kara Sea in August.

Analysis of the model results showed that on average the vertical distribution of DMS over the pack ice decline with altitude and was less than 0.1 nmol m-3 at 2.5 km. The modeled vertical distribution showed different patterns over ocean and over ice. Over ocean DMS was well mixed in the lowest atmospheric layers (below 500 m) while over the pack ice DMS maximum (with concentration of at least 1 nmol m-3 above the local boundary layer) were occasionally present.

Intercomparison of dimethyl sulphide oxidation mechanisms for the marine boundary layer: gaseous and particulate sulfur constituents

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

An intercomparison of seven dimethyl sulfide oxidation chemical mechanisms for the marine boundary layer is conducted using a coupled gas phase/aerosol box model. They range from schemes with very detailed description of the dimethyl sulfide oxidation with up to 65 reactions to very simple schemes with only six reactions suitable for global modeling. Results from all seven schemes are presented for three scenarios covering cold (high Arctic) to warm (Amsterdam Island, Southern Ocean) and clean to polluted marine (Mediterranean) boundary conditions. Coupling each oxidation mechanism to a monodisperse aerosol dynamics model allows for the simultaneous comparison of predicted gas phase and particulate concentrations of sulfur-containing constituents together with the predicted contribution of dimethyl sulfide to aerosol formation and growth. In addition sensitivity analysis of major pathways of the formation of sulfuric acid and methane sulfonic acid is applied to one of the seven mechanisms.

Significant differences for sulfur-containing compounds between the compared schemes are observed. The sensitivity analyses identified that the most sensitive rate parameters for sulfuric acid and methane sulfonic acid formation are the reaction of DMS + OH, the reaction $CH_3SO_2 + O_3$, and the thermal dissociation of CH_3SO_2 . The temperature dependence and magnitude of the ratio between methane sulfonate and non-sea-salt sulfate is investigated for each scheme and compared to observations. Liquid phase oxidation processes are missing in the model and the capability of individual schemes to correctly predict observed ratios can only be assessed in part. No new particle formation was found when applying binary nucleation in the three marine boundary layer scenarios. Furthermore, the results suggest that several uncertainties limiting our understanding of atmospheric oxidation of dimethyl sulfide with implications for climate still exist.

Publications

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Arctic study of the tropospheric aerosols, clouds and radiation (ASTAR)

Ann-Christine Engvall, Radovan Krejci, Nils Walberg, Leif Bäcklin, Thorsten Mauritsen and Gunilla Svensson (MISU), Johan Ström, Birgitta Noone and Juri Waher (ITM), Andreas Herber, Renate Treffeisen and Roland Neuber (AWI, Germany), Andreas Minikin (DLR, Germany), J.F Gayet, Alfons Schwarzenboek (Univ. Blair Pascal, Clermont-Ferrand, France), Andreas Stohl (NILU, Norway), Keiichiro Hara (NIPR, Japan)

During the years 2007 and 2008 continued detail evaluation of data collected during ASTAR 2004 airborne field campaign. Overall more than 60 hours of data from 22 mission flights is available covering almost whole tropospheric column around Svalbard region and period from early May to early June 2004. The major aim was to study aerosol properties aerosol cloud interactions during late spring and early summer period.

Ground based data from Ny Ålesund show dramatic change in aerosol size distribution during this period on annual basis and airborne data showed that during 2004 similar rapid change occurs in not only in boundary layer, but also in free troposphere. Several flights were performed in vicinity of Ny Ålesund research station to compare both measurement sets and using airborne data get a good overview about representativnes of the Ny Ålesund observations in broader vertical and horizontal scales. The follow up of the ASTAR 2004 campaign in this long-term collaboration lead by AWI and DLR - Germany, NIPR – Japan and Stockholm University was the ASTAR 2007 campaign.

This field experiment, which was part of the International Polar Year, in turn focused on period of the Arctic Haze. The data analysis is ongoing. The Swedish group contributes to ASTAR program with aerosol microphysical payload delivering information about the aerosol number density, size distribution, size segregated aerosol volatility properties and measurements of light absorption by aerosol particles.

Publications

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Arctic aerosol properties during transition from spring to summer at Ny Ålesund, Svalbard

Johan Ström (ITM), Ann-Christine Engvall, Radovan Krejci,Ulrika Behrenfeldt, Nils Walberg, Leif Bäcklin, Birgitta Noone (ITM), Juri Waher (ITM), Andreas Stohl (NILU, Norway)

Arctic atmospheric aerosols in the Arctic undergo annually a rapid change in aerosol size distribution from accumulation mode dominated spring conditions to Aitken mode dominated size distribution during summer. Six years of ground-based observations from Ny Ålesund research station from 2000 to 2005 were used to analyze this transition and better understand the processes behind. Main conclusion from this study was that the changes in source strength and transport are important for the annual variations of the aerosol properties, but these factors alone could not explain the observed rapid transition. Instead the complex interplay between the increase of solar radiance associated with the polar sunrise as well as a decreasing condensation sink with increasing cloudiness have been judged as having the potential to make new particles dominate the aerosol-distribution characteristics in summer. In 2004 samples for single particle were collected at Ny Ålesund covering transition from spring to summer conditions and analyzed by scanning electron microscope. During summer conditions enhancement of organic aerosol was observed, however, summer samples present also enhanced abundance of particles associated with both marine as well as continental sources. Hence, even if the numerical transport simulations indicate the Arctic as the main source region, the samples retain or acquire some continental signature (15 to 25 % of the particles).

Publications

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Modeling the greenhouse Arctic Ocean and climate effect of aerosols

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Within this project, the general atmospheric circulation model oslo-cam (based on the community climate system model of the national center for atmospheric research and developed at the University of Oslo) is used to simulate global sea spray aerosol emission fluxes during different climates. The simulations are evaluated versus present and previous interglacial and glacial ice core archives to examine if a) can a global climate model, using a realistic description of sea salt aerosol emission fluxes, simulate current and past sea salt aerosol concentrations? B) can the records of the holocen climatic optimum and/or the previous interglacial eem in ice core-climate archives be used as analogies for a future “greenhouse arctic ocean”? C) what is the influence of different climate parameters on the global sea salt aerosol distribution? D) what is the influence of sea spray aerosols on the global production of cloud condensation nuclei and radiative balance during different climates?

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 and Keith Bigg, Patricia Matrai (Bigelow Laboratory, USA) and Lars Tranvik (Uppsala University)

Collection of the surface microlayer (<100µm thick) of the open leads during the month of August between latitudes 88 and 89°N (AOE-2001) 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 2107ml-1 to more than 1014ml-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 appeared to have very similar characteristics to the "microcolloids" observed in bulk seawater in lower latitude oceans. X-ray analyses of the elements with atomic numbers >16 showed all signals to be weak, suggesting a mainly organic composition. One other feature of the particulates was that they were joined together by a diffuse material, which had properties entirely consistent with those of exopolymer secretions (EPS) of algae and bacteria. 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.

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. Ice algae were present in high concentrations, mostly at the bottom of the ice floe, and may have affected the levels of particulate organic matter observed. 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 and DMS, 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

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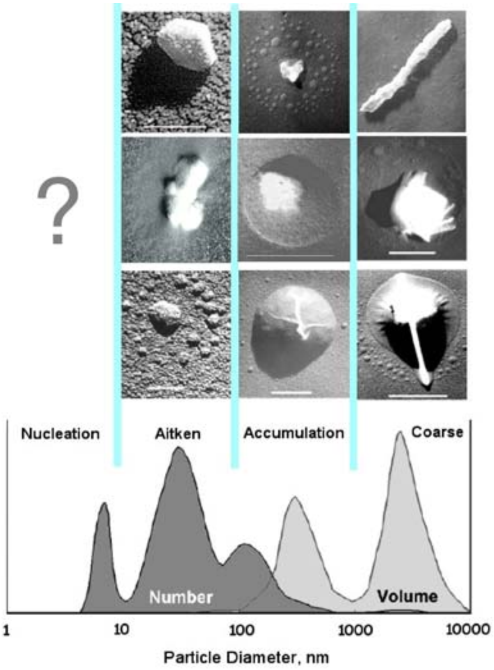
Biogenic particles over the central Arctic Ocean

Caroline Leck and Keith Bigg

Transmission electron microscopy photographs of airborne particles are compared with those of particles found in the surface microlayer of the open water between ice floes during the summer between latitudes 88 and 89°N (AOE-2001). 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 micro-organisms found in both, strongly suggests that the airborne particles were ejected from the water by bursting bubbles. On average, during the five weeks spent in the pack ice region, 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 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 micro-colloids 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.

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.



Transition electron micrographs (TEM) of the Aitken mode (25-70nm; 1st column), accumulation mode (70-1000nm; 2nd column) and coarse mode (1-10 µm; 3rd column) sampled over the high Arctic leads. The Aitken mode particles are organically derived, pentametric particles (top left panel) or small micro-colloid aggregates with EPS (centre left panel). As they grow, we see the particles resulting from deposition of acids/organic vapors on a micro-colloid aggregate (top and centre middle panels) or typical of a sulfur-containing particle in which any nucleus has become obscured by the surrounding of a sulfate-methane sulfonate-ammonium complex (bottom middle panel). Finally, the coarse mode includes particles such as sea salt, only present on rare occasion of high winds >12 ms-1 (centre right) or a bacterium (top right) and particles resulting from multiple sources (bottom right), showing sea salt and a bacterium coated with an organic film and by the concentric rings typical of droplets of sulfuric acid.

Publications

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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.

Evidence of a surface source of ultrafine aerosol particles in the Arctic Ocean pack ice during summer

Caroline Leck, Keith Bigg, Erik Swietlicki (Lund University) and Michael Tjernström

Vertical (up to 2000m) and horizontal profiles of aerosol particle concentrations in several size ranges were measured from 35 helicopter flights during the Arctic Ocean Expedition in July- August 2001 (AOE-2001). Most measurements were performed at latitudes north of 87° over broken pack ice with ice-free leads covering about 15% of the ocean surface. The aerosol particle size concentrations were measured at 1 Hz in several size ranges using two Condensation Particle Counters (UCPC and CPC) and an Optical Particle Counter (OPC: diameters >300nm. A sounding was always conducted in connection to each flight. Onboard the icebreaker (27m asl) aerosol by number in the range below 5nm to 45µm diameter was simultanously measured. Data from a scanning microwave radiometer, a cloud base lidar and a cloud radar contributed to estimates of cloud and inversion base and cloud top immediately before and after each flight.

As pictured in Figure X below Ultrafine particles (3-15nm diameter) were confined within the shallow (normally below 150 m) boundary layer. This layer was capped with a strong inversion preventing mixing with overlying air. Only weak signs of elevated particles were observed aloft. On the contrary peaking accumulation mode numbers (<300nm diameter) were found just above the inversion base (concentrations increased abruptly by typically an order of magnitude) where the cloud top was located preceding the flight. The ultrafine particles within the boundary layer were also confined horizontally. Close to meter-sharp horizontal borders separating regions of high and zero ultrafine particle concentrations was found.

It is in general difficult to explain the high Arctic findings with the typical nucleation event followed by uninterrupted "banana shaped" growth for several hours. Instead simultaneous increases in particles occurred in certain size ranges up to 50nm. A surface mixed layer <150m deep capped by a temperature inversion and a stable layer ~1km in depth excluded a tropospheric source. Instead a surface source was indicated with ultrafine concentrations nearly constant in vertical from the surface up to the base of the inversion. The most vigorous nucleation episodes were associated with rapid dissipation of intermittent fogs. During these episodes particles ca <50nm diameter contained no detectable sulfuric acid implying recent formation or growth from material other than the acid. Through tests on particles, nucleation is suggestive to be attributed to oxidation of amino acids formed from enzymatic transformation of proteins. This result is not yet conclusive.

The hypothesis to be tested for future is that particles injected into the atmosphere from the ocean surface microlayer will become embedded in cloud drops, break into smaller pieces, and be released separately into the atmosphere when the drops evaporate, providing the material for both nucleation and larger particle formation.

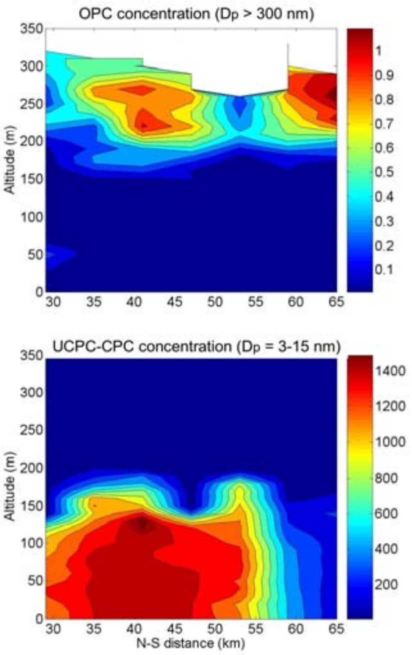


Figure X. Profiles of accumulation mode and ultrafine mode particles collected during AOE-200

Importance of submicrone surface active organic aerosols for pristine Arctic Clouds – A Model study

Caroline Leck and Ulrike Lohmann (Institute for Atmospheric and Climate Science, Switzerland)

In searching for a relationship between the properties of the summer high Arctic aerosol north of 80° and its ability to form cloud condensation nuclei (CCN), given the presence of a multi phase (inorganic/organic) aerosol system, past calculations showed by assuming equilibrium Köhler theory and measured number size distribution that other components than sulfate or sea salt, probably organics, depressed the nucleating ability of the particles during cloudy conditions. However, on clear sky days, there were a majority of occasions on which measured CCN concentrations were more numerous than predicted from a pure sulfate/sea-salt composition. Since the Köhler theory cannot take kinetic effects into account, which can cause erroneous results when the competition for water vapor for different size aerosol particles, the cloud nucleation process was instead simulated with a Lagrangian parcel model.

These new simulations showed that as the time of advection from the open ocean over the pack ice increased, the relative contribution of an Aitken mode (25 to 70 nm in diameter) to the observed CCN population increased, and a source of Aitken mode particles over the pack ice was required to maintain the CCN population. This activated Aitken mode had to be composed of an external mixture of water soluble inorganic/organic compounds and some almost water insoluble organic material covered with highly surface-active material such as exopolymer secretions (EPS). EPS originates from the open lead surface microlayer. If the Aitken mode consisted just of DMS oxidation products, that are not surface active, the observed CCN population over the inner parts of the pack ice could not be explained.

We therefore have to assume the presence of a larger natural source of particles available for nucleation into cloud droplets than can result from DMS oxidation products alone. If there should be an increase in anthropogenically produced particles in the area at some future date the effect of the presence of activated Aitken mode particles on resulting effective CCN concentrations depends entirely on the relatively spread of supersaturations at which the two groups can form cloud drops. The natural particle population is likely to be active at lower supersaturations than the anthropogenic one, because of the surface active material. In any case, the indirect aerosol effect (added cooling) is enhanced relative to a DMS-oxidation product source of CCN alone.

Publications

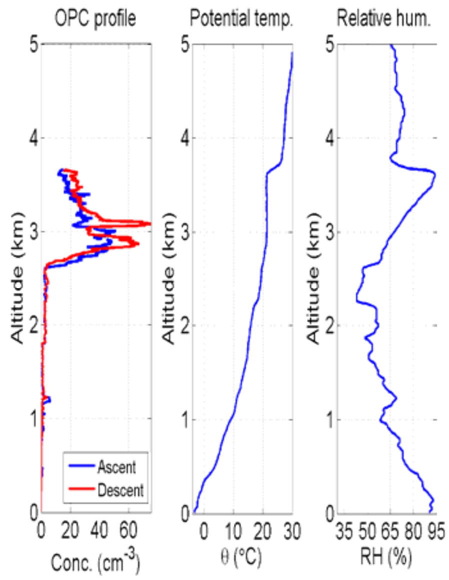
Lohmann, U., and C. Leck, 2005, Importance of submicrone surface active organic aerosols for pristine Arctic Clouds, Tellus 57B, 261-268.

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)

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 effectively 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.

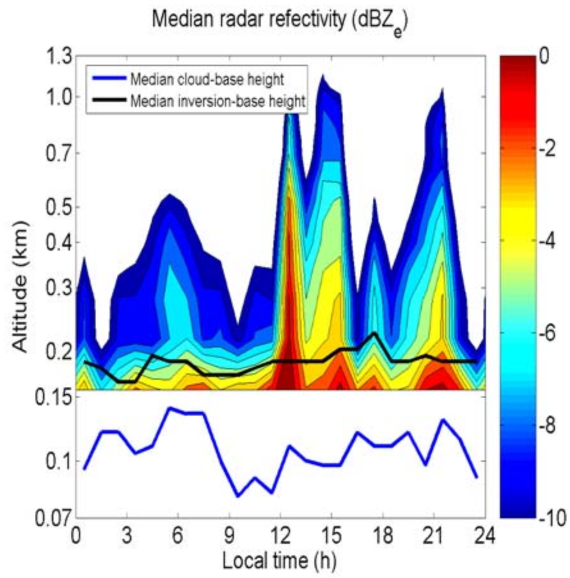
The arctic boundary-layer diurnal cycle

Michael Tjernström and Ola Persson (NOAA/ESRL)

The diurnal cycle of the summer Arctic boundary layer was studied using a composite of several in-situ and remote sensing instrument systems from the Arctic Ocean Experiment 2001 (AOE-2001). For most local near-surface variables, for example near-surface temperature, there is only a weak although statistically significant diurnal cycle. Low-level wind speed and direction, however, show a pronounced diurnal cycle with lower wind speed and smaller surface turning angle at local noon, indicating more non-local convective mixing. Near-surface net radiation has a maximum at late morning, rather than at local noon as could be expected. This indicates that the cloud layer plays an important role in this cycle.

The lowest significant cloud base was most often quite low, below 100 m, and has a distinct diurnal cycle with a minimum between 10 am and noon, local time. Cloud radar data indicate that the drizzle rate is the highest from noon through early evening, when the cloud fraction is also more often somewhat lower. During this time, cloud tops also often penetrate into the inversion. The interesting thing with this diurnal cycle is that it is more or less opposite to that found elsewhere in similar clouds. Temperature profiles from a scanning microwave radiometer indicate a phase difference between diurnal temperature cycles in different layers. The upper, well-mixed and mostly cloudy, 75% of the boundary layer is the coolest in the early morning and the warmest late evening, while the lowest, slightly stable and mostly sub-cloud, 25% of the boundary layer is the coolest at midnight and the warmest at local noon.

We hypothesize that the cloud layer dominates the diurnal cycle and that the timing is governed by when the local stability between sub-cloud and cloud layers is at a minimum. When this happens, around mid-morning, excess moisture from the lowest layer accumulated during the night is mixed up into the cloud, causing the cloud base to drop and triggering drizzle, which continues into the late night. Drizzle destabilizes the cloud layer but eventually depletes cloud water and to early morning, conditions with a stable sub-cloud and well-mixed but non-drizzling cloud layer reestablishes.



Diurnal cycle of median (blue) cloud and (black) inversion base, and (color scale) cloud water from about 1.5 months of data

Publications

Tjernström, M., 2007: Is there a diurnal cycle in Arctic summer cloud-capped boundary layer? Journal of Atmospheric Sciences, 64, 3974-3990.

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

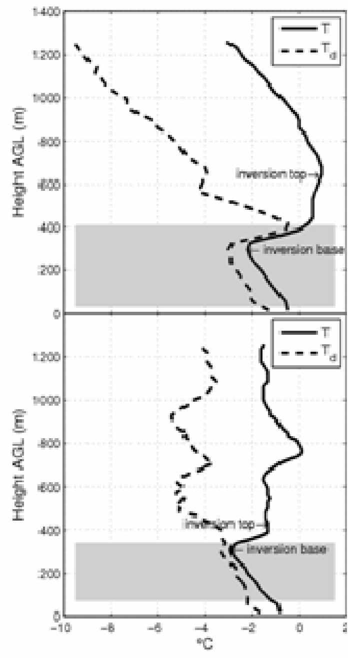
Tjernström, M., and T. Mauritsen, 2009: Mesoscale variability in the summer Arctic boundary layer. Boundary-layer Meteorology, Accepted.

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 from the Arctic Ocean Experiment 2001 (AOE-2001). The boundary-layer structure 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 inversion-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 prototypical marine cloud-capped boundary-layer structure found for example over the subtropical oceans, but the second category seems particular to the Arctic. Partitioning the data into these two categories and compositing 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 water, the type where clouds penetrate into the inversion are more often mixed-phase, with a significant portion of ice.



Radiosonde temperature (solid) and dew-point temperature (dashed) profiles on 5 August 2001, for the 1201 UTC (top) and 2336 UTC (low) sonde releases. The gray shaded region represents cloud boundaries as observed by instantaneous S-band cloud radar and ceilometer-determined cloud base.

Arctic regional climate modeling

Michael Tjernström, Joseph Sedlar, Matt Shupe (CIRES, University of Colorado, Boulder, USA), Mark Zagar (Slovenian Met Service), Anette Rinke and Klaus Dethloff (Alfred Wegner Institute, Germany), John Cassano (CIRES, University of Colorado, Boulder, USA), Susanne Pfeifer and Tido Semmler (MPI for Meteorology, Germany), Klaus Wyser and Colin Jones (SMHI, Sweden)

The Arctic Regional Climate Model Intercomparison Project (ARCMIP) aims to improve numerical simulations of regional 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 several 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.

Using data from the first ARCMIP intercomparison project and from the SHEBA (Surface Heat Budget of the Arctic Ocean) ice-drift experiment in 1997/1998, we examined several parameters in the models. In particular we examined the interplay between clouds and radiation. While incoming surface radiation in the models correlate favorably to the observations, both shortwave and longwave radiation are biased low, by about 15-20 Wm-2. Time series of modeled and observed liquid water path for the whole year reveal significant problems in the model; the temporal correlation is in general very poor and vertical distributions of the clouds are very different in the different models. On an annual basis, clouds are too optically thick for shortwave radiation for common values of cloud water path, while they are too optically thin for longwave radiation. The first problem indicates a too high albedo in summer, possibly due to inaccurate assumptions on cloud droplet number concentrations, while the latter error is believed to be caused by an almost complete absence of cloud liquid water in winter, thereby causing the clouds to have a too low emissivity.

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Wyser, K., C. G. Jones, P. Du, E. Girard, U. Willén, J. Cassano, J. H. Christensen, J. A. Curry, K. Dethloff, J.-E. Haugen, D. Jacob, M. Køltzow, R. Laprise, A. Lynch, S. Pfeifer, A. Rinke, M. Serreze, M. J. Shaw, M. Tjernström and M. Zagar, 2007: An Evaluation of Arctic Cloud and Radiation processes during the SHEBA year: Simulation results from 8 Arctic Regional Climate Models. Climate Dynamics, 30, 203–223, DOI 10.1007/s00382-007-0286-1.

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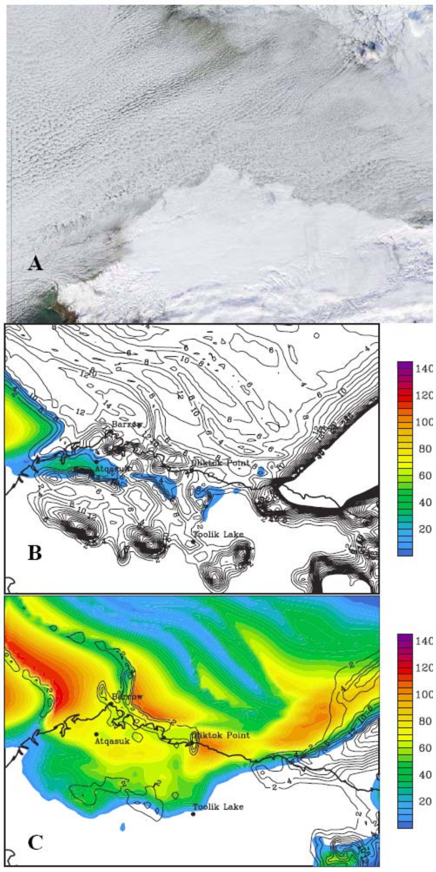
Mixed-phase clouds in the arctic

Michael Tjernström, Anthony Prenni, Paul DeMott and Sonia Kreidenweis (Colorado State University), Jerry Harrington, Alexander Avramov and Johannes Verlinde (Penn State University), Charles Long and Peter Q. Olsson (Pacific Northwest Laboratory)

One of the most surprising discoveries from the SHEBA experiment was the fact that liquid water was present also in winter clouds at very low temperatures. Since then, several experiments have been launched to answer some of the resulting questions. Simulations within the ARCMIP project show an almost total lack of liquid water in all models in winter. The consequence appears to be a systematic deficit in down-welling longwave radiation.

Data from the Mixed-Phase Arctic Cloud Experiment (M-PACE) during the fall of 2004 showed that the number concentration of ice nuclei (IN) was lower in Arctic mixed-phase clouds than typically observed at more southerly latitudes. Sensitivity tests with the RAMS modeling system for a specific case from M-PACE show that a critical factor to maintaining liquid water in cold clouds is a relative lack of ice nuclei. When the model was run with the default description of IN concentrations, the low-level clouds rapidly glaciate and snow out. With a IN-description based on the observed concentrations from M-PACE, the cloud remained mixed-phase while precipitating snow, as was observed. The difference in net long-wave radiation for this particular case amounted to about 100 Wm-2.



Plot illustrating one case from M-PACE, 10 October 2004, showing (A) a satellite image, (B) cloud water path (color for liquid and solid lines for ice) from a RAMS simulation with default IN concentration, and (C) is the same as B, but reducing the number of IN according to the observations

Publications

Prenni, A., J., J. Y. Harrington, M. Tjernström, P. J. DeMott, A. Avramov, C. N. Long, S. M. Kreid¬en¬weis, P. Q. Olsson, J. Verlinde, 2007: Do aerosols regulate Arctic cloudiness? Bulletin of the American Meteorological Society, 88, 541-550

The simulation of Arctic clouds and their radiative properties for 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 observations of cloudiness and radiative fluxes at the top of the atmosphere as well as at the surface are utilized for comparison. The analysis is performed as seasonal averages over the entire area north of 66.6 ºN, 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. Preliminary 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.

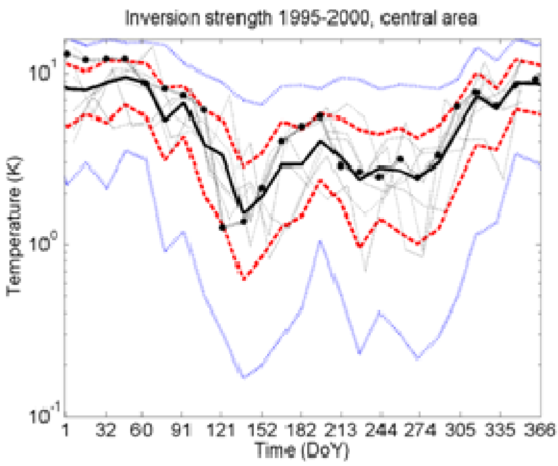
The vertical structure of the lower Arctic atmosphere

Michael Tjernström and Rune Grand Graversen (KNMI)

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.

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.



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

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

Causes for Arctic amplification and climate change impact of large-scale dynamic changes on Arctic climate

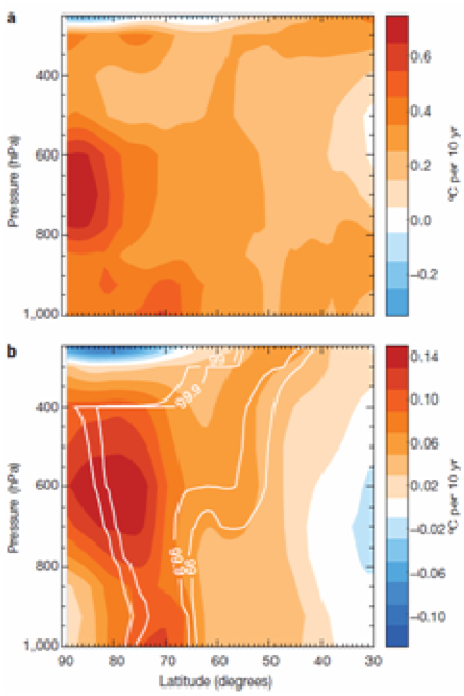
Rune G. Graversen (KNMI), Thorsten Mauritsen, Michael Tjernström, Erland Källén and Gunilla Svensson

The Arctic region is observed to exhibit larger changes in climate than the rest of the globe, a phenomenon coined Arctic amplification. The rapid climate changes that have been observed in recent decades have caused the Arctic sea ice to decrease rapidly and there is a marked decrease in the Northern Hemisphere snow cover.

A number of hypotheses have been proposed to explain Arctic amplification. As the temperature increases, and the snow and ice cover decreases, more solar radiation is absorbed at the darkened surface leading to a further warming. The reduced sea-ice cover increases the exposure of the lower atmosphere to the ocean, which is also likely to cause warming. Further, the stable stratification that prevails in the lower Arctic troposphere will tend to trap near-surface warming, contrary to the tropics where heat is distributed vertically through the entire troposphere by deep convection. Finally, it has been suggested that deposition of anthropogenic aerosols, black carbon, on the snow and ice surfaces causes a darkening of the surface and, hence, an increase in solar radiation absorption.

If any of these hypotheses were the dominating cause of Arctic amplification it implies a near-surface maximum in the Arctic warming. However, results from the ERA-40 reanalysis show that there is substantial warming aloft. This warming pattern is inconsistent with these surface based hypotheses. The same conclusion can be drawn from the Japanese JRA-25 reanalysis product, although JRA-25 exhibits a lower magnitude of the warming trend, while the older NCEP reanalysis exhibits a distinct surface warming maximum.

The elevated Arctic warming pattern could be explained by increases in the atmospheric water vapor content, cloudiness and the northward atmospheric energy. We investigated the latter possibility using a linear regression between the energy transport across 60N and the temperature (Figure 1b). The results show that a fraction, roughly one quarter, of the observed warming can be explained by an increase in the northward energy transport.



Panel a shows the temperature trend in April-October for the period 1979-2001 in ERA-40. Panel b displays the part of the trend that can be link with the increase in northward energy transport across 60˚N. Note that the color scales are different.

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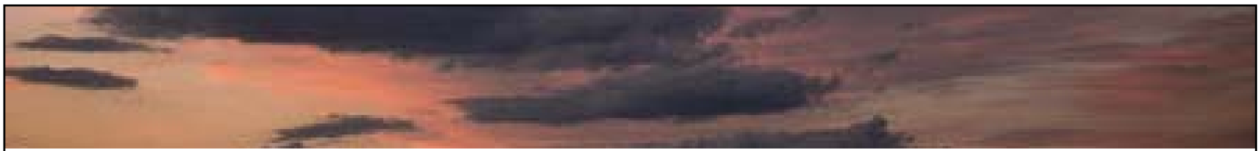

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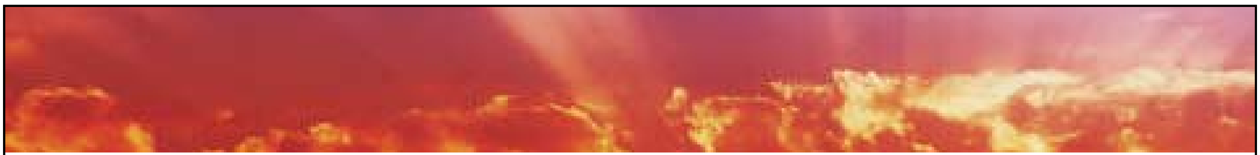

FINANCES

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	Approximate funding	*MSEK*
	2007	*2008*
International Meteorological Institute (IMI)		
Governmental support	*2.1*	*2.0*
Department of Meteorology, Stockholm University (MISU)		
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IMI/MISU		
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PHD THESES

PhD THESES 2005-2008

Jenny Brandefelt, 2005, Atmospheric circulation regimes and climate change

Bror Fredrik Jönsson, 2005, Some concepts of estuarine modeling

Rezwan Mohammad, 2005, Some aspects of the Atlantic ocean circulation

Admir Créso Targino, 2005, Regional studies of the optical, chemical and microphysical properties of atmospheric aerosols. Radiative impacts and cloud formation

Andreas Jonsson, 2006, Modelling the middle atmosphere and its sensitivity to climate change

Karl-Göran Karlsson, 2006, The use of a satellite-derived cloud climatology for studying cloud-aerosol processes and the performance of regional cloud climate simulations

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

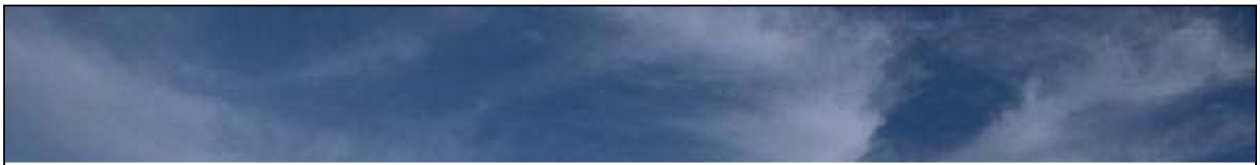
Bodil Karlsson, 2008, Noctilucent clouds in a coupled atmosphere

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



ACRONYMS

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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