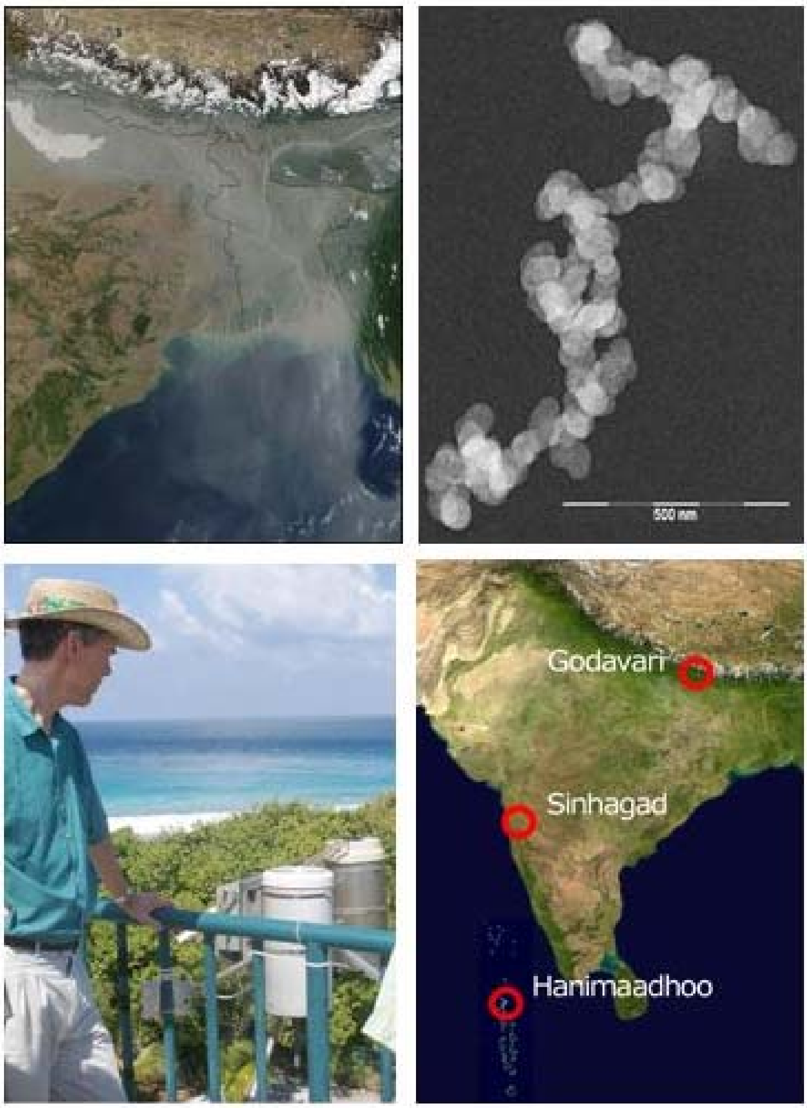
INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

DEPARTMENT OF METEOROLOGY, STOCKHOLM UNIVERSITY



BIENNIAL REPORT 2005 – 2006

FRONT COVER | Illustration of the involvement of IMI/MISU in the Atmospheric Brown Cloud (ABC) projekt.

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

BIENNIAL REPORT 1 JANUARY 2005 – 31 DECEMBER 2006

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INNEHÅLLSFÖRTECKNING

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

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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

Erland Källén, Professor of Dynamic Meteorology. Until 31 December 2005.

Peter Lundberg, Professor of Physical Oceanography. From 1 January 2006.

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 participated actively in the preparation of IPCC's fourth assessment report. Erland Källén served as the Swedish delegate during the final drafting session of the WG1 Summary for Policy Makers 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 presently a 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.

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).

Preparations are underway for a new Arctic expedition in collaboration with several research groups in Europe and the US: the Arctic Summer Cloud-Surface Study (ASCOS) within the International Polar Year (IPY). This expedition which will take place in the summer of 2008 is 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 satellite missions, rocket projects and ground-based measurement networks. International collaboration is of central importance for this research. The Odin satellite project is based on a collaboration with scientific groups mainly in France, Finland and Canada. After Odin's successful launch on February 20, 2001. Joint studies with Odin's optical instrument concern mainly the University of Saskatchewan, York University and the University of Waterloo in Canada, the University of Leeds in the U.K., the University of Bremen in Germany and the Finnish Meteorological Institute in Helsinki, Finland. Work with Odin's microwave instrument has relied on our contacts at Chalmers Technical University in Sweden and the Observatory of Bordeaux in France. Beyond Odin, new satellite collaborations for MISU concern mainly ESA's plans for PREMIER, the European ENVISAT community, as well as the ACE mission on the Canadian SciSat.

The Atmospheric Physics group also continues to collaborate in international rocket experiments. The MAGIC project aimed at the study of mesospheric aerosols is a prominent example of these collaborations. The MAGIC instruments have been developed at the Naval Research Laboratory in Washington D.C. in close collaboration with MISU scientists. We participate in the extended ALOMAR Research Initiative (eARI), an opportunity funded by the European Commission to launch scientific instruments on rocket payloads from Andøya, Norway. We are currently also preparing instruments for studies of noctilucent clouds both for German/Norwegian and NASA launches in 2007. Our major partners for these missions are the Leibniz Institute of Atmospheric Physics in Kühlungsborn, Germany, the Norwegian Defense Research Establishment, the University of Colorado and NASA's Goddard Space Flight Center in the USA. Ground-based measurements and their analysis are conducted in collaboration with groups at British Arctic Survey and Instituto Nacional de Pesquisas Espaciais, Brasil.

Erland Källén and Gunilla Svensson have taken an active part in the Arctic Climate Impact Assessment (ACIA); Caroline Leck is a member of the International Commission on Atmospheric Chemistry and Global Pollution (CACGP) of ICSU and the Surface Ocean Lower Atmosphere Study (SOLAS) implementation committee; Gunilla Svensson is a the vice chair of the GEWEX Atmospheric Boundary Layer (GABLS) Science Panel; Henning Rodhe is the vice chair of the Atmospheric Brown Cloud (ABC) Science Team; Erland Källén was the chairman of the ECMWF Scientific Advisory Committee in 2005 and Michael Tjernström is presently a member; Michael Tjernström is a co-chair of the Science Steering Group of the International study of Arctic Change (ISAC).

RESEARCH ACTIVITIES

RESEARCH ACTIVITIES

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

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

DYNAMIC METEOROLOGY

LARGE SCALE DYNAMICS

In the area of large scale dynamics 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.

Initial conditions for ensemble prediction systems

Erland Källén, Linus Magnusson and Jonas Nycander

Ensemble techniques for numerical weather prediction has been established as a basic method for determining forecast reliability and uncertainty. In particular it has been shown that the modelling results are dependent on the analysis technique used as well as method to produce initial ensemble member perturbations.

Due to the chaotic nature of the atmosphere, small errors arising in a data assimilation system will grow during a forecast integration. To simulate the effects of those errors in a numerical weather forecast, forecasting centres produces ensemble forecasts. By adding a perturbation to the analysis, of the same magnitude as the analysis error (uncertainty), it is possible to obtain new initial conditions for the forecast model. By repeating this several times and integrating forecasts from each initial condition it is possible to obtain an ensemble of forecasts, where all members are equally likely to verify against reality.

However, how to design the perturbations is an open question. One technique is the singular vector method, adapted by ECMWF, which is designed to optimise the perturbation growth over 48 hours. Another is the breeding method, using errors growing during a short forecast as initial perturbations. In this project we have studied the properties of the methods both in a very simple model and in ECMWF Ensemble Prediction System. By using a simple model we have identified weaknesses in both methods and tried to design perturbations avoiding those. By using the ECMWF Ensemble Prediction System we have found that the two methods give very different perturbation structures and have distinctly different physical properties during the beginning of the simulation (first 2-3 days). Nevertheless, the quality of the ensemble forecasts in the medium range in terms of different skill scores, is almost the same for the two different methods.

Ensemble methods for data assimilation

Andreas Grantinger, Nils Gustafsson and Erland Källén

Ensemble techniques for data assimilation have been developed to increase the accuracy of initial state analyses and to enhance the use of observations for short forecast time scales and small spatial scales. In numerical weather prediction it is normally assumed that most of the energy in midlatitude flow structures is geostrophically balanced. This is not true on small scales, for motion systems smaller than 100 km or so ageostrophic circulations have a significant influence. To use observation information optimally on these scales it is necessary to apply some non-geostrophic constraints on the flow structures that are utilised in data assimilation systems. We have used Kalman filters as a method to determine these structures. In a Kalman filter the structures change with the flow situation, they are determined using an ensemble technique to calculate spatial structure correlations. These structures may be geostrophic or ageostrophic depending on the particular flow situation. We have established how well the Kalman filter technique uses ageostrophic observational information and compared it to optimal interpolation where the flow structures are stationary. In a simplified setup we have shown that the Kalman filter technique is superior, work is in progress to generalise the results to an operational limited area forecast model.

Publications

Grantinger, A., 2007: Ensemble Kalman filters in mesoscale limited area numerical weather prediction. Filosofie licentiate thesis, Department of Meteorology, Stockholm University, March 2007.

Equatorial balance relationships in global data assimilation

Heiner Körnich, Erland Källén, Nils Gustafsson, Nedjeljka Žagar (University of Ljubljana, Ljubljana, Slovenia), Erik Andersson, Mike Fisher and David Tan (ECMWF, Reading, England)

Mass/wind balance relationships pose important constraints in data assimilation and allow the derivation of non-observed variables. In midlatitudes, such a relationship is geostrophy which is widely applied in data assimilation. For tropical latitudes, a new balance relationship based on tropical wave modes was developed at MISU. This approach was constructed in view of future wind observations by the Earth Explorer Atmospheric Dynamics Mission ADM-Aeolus.

In order to combine the midlatitudinal and equatorial formulations, a new assimilation scheme has been developed. It is shown that the application of an incomplete balance relationship like only geostrophy leads to a misinterpretation of observational data and thus, to enhanced errors in the analysis. So, the combined balance relationship improves the tropical analysis in a global data assimilation and it will optimal use of future wind observations, as expected from the ADM-Aeolus.

Publications

Stoffelen, A., J. Pailleux, E. Källén, J. M. Vaughan, L. Isaksen, P.Flamant, W. Wergen, E. Andersson, H. Schyberg, A. Culoma, R.Meynart, M. Endemann and P. Ingmann. 2005. The Atmospheric Dynamics Mission for Global Wind Field Measurement. Bulletin of the American Meteorological Society: Vol. 86, No. 1, pp. 73–87.

Žagar, N., N. Gustafsson and E. Källén. 2004. Dynamical response of equatorial waves in four-dimensional variational data assimilation.Tellus, 56A, 29-46.

Žagar, N., N. Gustafsson and E. Källén. 2004. Variational data assimilation in the tropics: the impact of a background error constraint. Q. J. R. Meteorol. Soc., 130, 103-125.

Žagar, N. 2004. Assimilation of equatorial waves by line of sight wind observations. J. Atmos. Sci., 61, 1877-1893.

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Albedo, clouds, aerosols and global climate

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

The objectives of this project are to estimate the impact of aerosols and clouds on global climate and to identify feedbacks in the climate system as well as in climate models. The relative stability of global temperature climate 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. To investigate how the choice of tuning to ERBE rather than to CERES affects model behaviour, specifically if it may change the sensitivity of a model to GHG forcing, an experiment has been carried out with the NCAR CAM3.1, in which the TOA radiative balance is tuned to agree with ERBE and CERES respectively through alterations in the model cloud parameterization. The equilibrium climate sensitivities of the two model configurations are found to differ by 0.24 K, a difference which is small compared to e.g. the spread in estimated climate sensitivity in state-of-the-art climate models. Still, that the values differ 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 to avoid arbitrariness in climate sensitivity estimates and future climate predictions.

Publications

Anderson, T.L., Charlson, R.J., Schwartz, S.E., Knutti, R., Boucher, O., Rodhe, H. and Heintzenberg, J. 2003. Climate Forcing by Aerosols – a Hazy Picture. Science, 300, 1103-1104.

Anderson, T. L., Charlson, R. J., Schwartz, S. E., Knutti, R., Boucher, O., Rodhe, H. and Heintzenberg, J. 2003. Response to "The parasol effect on climate" by P. J. Crutzen and V. Ramanathan. Science, 302, 1680-1681.

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.

Stationary waves in future climate projections

Jenny Brandefelt, Heiner Körnich and Erland Källén

The model-projected increase in the global mean surface temperature in response to enhanced anthropogenic forcing varies in the range 1.4--5.8°C. Part of this range is explained by differences in the anthropogenic forcing used, but even using the same forcing the inter-model differences are large. The spatial patterns of the response also varies among climate models. These patterns are important for the regional climate and day-to-day weather. In this project we study the stationary wave response to the enhanced greenhouse gas (GHG) forcing in coupled global climate model (CGCM) simulations. Physically based connections between the mean flow response to the enhanced GHG forcing and the changes in the stationary waves are sought with focus on Northern Hemisphere (NH) winter.

A common signature in CGCM simulations of the response to the enhanced GHG forcing is an increase in the zonal mean upper level wind and an associated increased pole-to-equator temperature gradient at upper levels. In the present study, we examine the response to the enhanced GHG forcing as simulated by the Intergovernmental Panel on Climate Change Fourth Assessment Report ensembles of CGCMs. We hypothesise that the stationary wave response is largely determined by the change in the zonal mean background flow. This hypothesis is tested using a linear barotropic model.

Publications

Brandefelt, J. and Källén, E., 2004. The response of the Southern Hemisphere atmospheric cirulation to an enhanced greenhouse gas forcing. J. Clim. 17, 4425-4442.

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Brandefelt, J. , 2006. Atmospheric modes of variability in a changing climate. J. Clim. 19, 5933-5942.

Körnich, H., Schmitz, G. and Becker, E., 2006: The role of stationary waves in the maintenance of the northern annular mode as deduced from model experiments. J. Atmos. Sci., 63, 2931-2947.

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 around the use and development of high-resolution mesoscale and cloud-resolving models, or in designing and 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 of the mean flow.

The main mesoscale research modeling tool used at the institute is the COAMPS® atmospheric model, developed by the US Navy. It is has been applied to coastal meteorology, Arctic meteorology, katabatic flows over melting glaciers and air pollution transport studies. Most of the work has taken place within international research projects, such as ARCMIP and NEAQS. Simulation of convection processes requires special non-hydrostatic cloud-resolving modeling and scientists at the institute are involved in developing such a tool in collaboration with MIT. Work is ongoing to study both how local properties of deep convection may change in a changing climate, how aerosols affect deep convective cloud and precipitation development and vice versa, how convective cloud processing may affect the 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 AOE-2001 and SHEBA. Scientists at the institute are coordinating a major Arctic field campaign, Arctic Summer Cloud-Ocean Study (ASCOS) for the International Polar year (IPY).

GABLS (GEWEX Atmospheric Boundary Layer Study)

Gunilla Svensson, Thorsten Mauritsen, 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. The first model intercomparison study was a weakly stably stratified case simulated with 19 participating models. These models range from operational forecast models to higher order closure research models – MISU participated with two research models. The results from the intercomparison clearly show that the operational models generate deeper boundary layers as a consequence of using boundary-layer schemes that enhance turbulent mixing while the research models show close agreement with results from Large Eddy Simulations of the same case.

Further analysis of the model results from the first experiment reveal 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 pressure system that determines the lifetime of a cyclone.

The second experiment focuses on a diurnal cycle of a dry boundary layer. The experiment is 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 preliminary analysis reveals that all models under predict the diurnal variation in low-level wind speed. Especially the transition from night to day is poorly modeled.

Publications

Cuxart, J., A.A.M. Holtslag, R. J. Beare, E. Baxile, A. Beljaars, A. Cheng, L. Conangla, M. Ek, F. Freedman, R. Hamdi, A. Kerstein, H. Kitagawa, G. Lenderink, D. Lewellen, J. Mailhot, T. Mauritsen, V. Perov, G. Schayes, G-J Steeneveld, G. Svensson, P. Taylor, W. Weng, S. Wunsch, and K.-M. Xu, 2006: Single-column model intercomparison for a stably stratified atmospheric boundary layer. Boundary-Layer Meteorology, 118, 273-303.

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 becomes approximately equal to 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, 2006: Observations of stably stratified shear-driven atmospheric turbulence at low and high Richardson number. Journal of the Atmospheric Sciences. In press.

A total turbulent energy closure model for neutrally and stably stratified atmospheric boundary layer flows

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. Theses observations indicate that the turbulent transfer of heat and momentum behaves very differently under very stably 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.

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 mid-latitudinal 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.

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

Johannes Karlsson, Gunilla Svensson och Henning Rodhe

Simulations of low clouds and their radiative properties by 9 coupled climate models participating in the fourth Assesment 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 are utilized for comparison. The analysis is confined to the marine subtropics in an attempt to isolate low cloudiness. All analyzed models have a negative bias in the low cloud fraction (model mean bias of -15\%). On the other hand, the models have an excess of cloud radiative cooling in the region (model mean excess of 13 Wm-2). The latter bias is shown to mainly originate from too much shortwave reflection by the models clouds. This may have important implications on the effect these clouds have on future climate simulations.

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

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

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

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

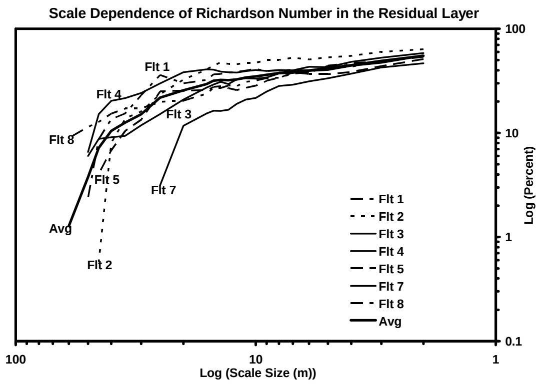
In this project simulations of a diurnal cycle of atmospheric boundary layer over a homogeneous terrain are performed using Large Eddy Simulation with the Lagrangian scale-dependent dynamic subgrid-scale model. The geostrophic forcing, surface boundary condition and initial conditions are based on the setup for the second GABLS single column model inter-comparison study. In spite of the highly idealized nature of forcings and boundary conditions, the simulation results display good qualitative agreement with the observations from CASES-99 study and capture the well-known features of the diurnal cycle of ABL. The first simulations performed at different resolutions to assess the impact of numerical resolution on the quality of the results. The intention of the study is to examine the influence of what type of surface boundary condition that is used in idealized studies, especially in model intercomparison work. There are two options to force the model with observed surface values of temperature or with heat fluxes. Previous work indicates that if one is fixed different models will produce very different values for the other – far from the observations

Richardson number scale dependence in a semi-turbulent residual layer from CASES-99

Gunilla Svensson, Michael Tjernström and Ben Balsley (CIRES)

The residual layer (RL) forms on top of the nighttime stably stratified boundary layer as a remnant of the previous days upper well-mixed convective boundary layer. We have used information from the CIRES Tethered Lifting System (TLS) to analyze RL variability using data from the CASES-99 experiment. The TLS is a tethered lifting platform that enables detailed observation through the entire layer, from the surface up through the stable boundary layer and the RL into the free troposphere. In addition to detailed information on profiles of the mean variables, turbulence is analyzed at high temporal, and thus also spatial, resolution using a technique where power spectra of high-frequency wind observations are used to estimate the dissipation rate of turbulence, from inertial sub-range spectra. Multiple payloads can be carried on the same tether to enable simultaneous observations at many heights.

The RL has been considered a mostly laminar quiescent layer that develops only as dictated by larger-scale dynamics until next days convective boundary layer re-establishes. We find that this conventional picture of the RL is in fact false. Instead, the structure of the RL is highly variable, with values of the dissipation rate of turbulence varying orders of magnitude in structures that are unexpectedly consistent. The only explanation for such organize turbulence structures is that they are generated by persistent local instabilities feeding off local gradients, primarily in wind speed. When the Richardson number (Ri) is estimated at progressively smaller scales, we also find that the flow in the RL is unstable in the sense of featuring subcritical values of Ri (< 0.25) when the latter is evaluated at the scales of the observed turbulent structures, rather than over fixed deeper layers, as is usually done. From this study we thus conclude: 1) The RL is generally turbulent with large variations in turbulence intensities in well organized structures; 2) The RL is more often than not subcritical with respect to Ri provided that Ri is estimated at the spatial scales of the observed turbulence structures. These results call for a reevaluation of the dynamics of the RL.



Plot of the percentage of the heights between 115-350 m with Ri <0.25, as a function of scale size. Each thin line shows the result from an individual profile with the TLS, while the thick solid line depicts the average of all profiles.

New England air-quality study (NEAQS)

Michael Tjernström, Mark Žagar and Wayne Angevine (NOAA/AL, USA)

The New England Air Quality Study (NEAQS 2002, http://www.al.noaa.gov/neaqs) was conducted in July and August 2002. The motivation was the frequently exceeded regulatory standards for ozone along the coast of New Hampshire and Maine, in spite of limited local emissions. These are instead located farther south, e.g. along the Boston/New York metropolitan corridor, and pollutants are often transported to the New Hampshire and Maine coastlines across colder ocean water; a pool of cold water typically persist offshore in the northern and eastern Gulf of Maine and the Bay of Fundy. As a result, high-pollution episodes are often not related to stagnation periods as in other highly polluted coastal areas, for example Los Angeles in California or Athens in Greece, but are instead related to mesoscale coastal circulations such as sea breezes.

In this study we utilize the COAMPS® mesoscale model to investigate the transport of inert tracers released from Boston and New York, respectively, for two cases, one with weak and one with strong synoptic scale forcing. An unexpected feature in the simulations for both cases is a very strong diurnal offshore flow, presumably an inertial oscillation triggered by the breakdown of the mesoscale pressure gradient due to the daytime land-sea temperature contrast. Another peculiar feature is the return flow in the sea breeze, which has the appearance of a gravity wave triggered by the sea breeze front, more than a classical return flow. The sea breeze has a significant impact on the simulated tracer concentrations. Much of the low-level tracer that during the night is advected off shore is during the day caught up by the sea breeze circulation and advected inland with high local concentrations as a consequence. On the other hand, the stronger wind case also showed some coastal influence. While most of the tracer advected off shore remained over the ocean, it still remained close to the slightly curving coast and affected other locations very far downstream although at rather low concentrations.

Publications

Angevine, W. M., M. Tjernström and M. Žagar, 2006: Modeling of the coastal boundary layer and pollutant transport in New England. Journal of Applied Meteorology, 45, 137 – 154.

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Numerical modeling of katabatic flow

Stefan Söderberg, Oskar Parmhed, Michael Tjernström and Branko Grisogono

Katabatic flows occur over sloping surfaces that are cooled relative to the ambient air and common glaciers. In this study we apply the COAMPS® mesoscale model to Breidamerkulljökull, an outflow glacier in the Vattnajökull complex. The simulation results agree reasonably well with measurements from a field experiment on this glacier. Two factors contribute to the katabatic flow: 1) The melting snow surface maintains a surface temperature close to 0 ºC, while the air descending the slope warms adiabatically, providing a "self enhanced" negative buoyancy; 2) The jet shape of the flow provides a large so-called "curvature-term" in the Scorer parameter, that becomes negative in the upper jet, preventing vertical wave propagation and isolating the very shallow boundary layer from influence from the free troposphere aloft. The modeled turbulence structure conforms in principle to the same local scaling as found in coastal jets off the US West Coast, and resembles that observed in katabatic flows over Alpine glaciers, with one notable difference. The strong persistence of this flow maintains a low-level down-glacier flow for practically all large-scale wind directions. In this case, the wind direction thus changes enough to maintain a wind shear even where the scalar wind speed approaches its maximum. Thus the momentum flux remains larger than zero through the katabatic jet.

Publications

Söderberg, S., and O. Parmhed, 2006: Numerical modelling of katabatic flow over a melting outflow glacier. Boundary-Layer Meterology, DOI 10.1007/s10546-006-9059-3.

Wave flow simulations over arctic leads

Thorsten Mauritsen, Gunilla Svensson and Branko Grisogono (Zagreb University, Croatia)

See Arctic studies

The arctic boundary-layer diurnal cycle

Michael Tjernström and Ola Persson (NOAA/ESRL)

See Arctic Studies

Arctic boundary-layer temporal variability

Michael Tjernström and Thorsten Mauritsen

See Arctic Studies

Arctic boundary-layer vertical structure

Michael Tjernström and Linda Hildeberg

See Arctic Studies

Arctic regional climate modeling

Michael Tjernström, Mark Žagar, Gunilla Svensson, Johannes Karlsson and Joe Sedlar, 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 (SMHI) and Colin Jones (University of Montreal)

See Arctic Studies

The vertical structure of the arctic warming amplification

Rune Grand Graverssen and Michael Tjernström

See Arctic Studies

Distribution of atmospheric DMS in the high arctic - a model study

Jenny Lundén, Gunilla Svensson and Caroline Leck

See Arctic studies

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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), and Hans Burchert/Thomas Neumann (Baltic Sea Research Institute, Warneműnde)

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 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.

Global ocean circulation

Göran Broström, Kristofer Döös, Johan Nilsson, Jonas Nycander

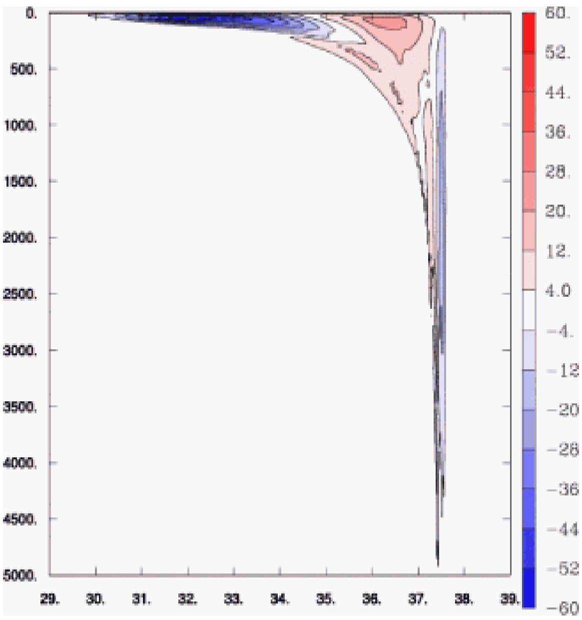
The exchange of water between the deep ocean and the surface layer is called the overturning circulation. It is weaker than the horizontal gyre circulation, but since it involves heating and cooling of water masses it is directly linked to the meridional heat transport, which is of crucial importance 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. In the upper figure on next page it is shown for the global ocean model OCCAM.

Vertical mixing plays a key role in the overturning, since it heats the deep water and thereby allows it to upwell. Hemispheric models were used to show that the way in which this mixing is parameterised is crucial for the response of the overturning circulation to the surface fluxes of heat and freshwater. However, it has also been shown that in a model with both a northern and a southern hemisphere, allowing the circulation to be asymmetric, the overturning circulation is much less sensitive to the mixing parameterisation.

The vertical mixing is caused by breaking internal waves. These can be generated by the interaction of tides with rough bottom topography. The energy of the internal waves generated by this process has been computed for the global ocean. The result is shown in the lower figure on next page. The computation is based on linear wave theory, which is invalid if the topographic slope is too steep. As an attempt to understand the scaling of the internal wave radiation in the non-linear regime, the radiation of internal waves from a periodic array of vertical walls has been calculated analytically.

Furthermore it has been shown that in a basin with sloping bottom there is a unique steady-state circulation forced by the large-scale horizontal buoyancy gradient. This circulation includes diapycnal flows along the sloping bottom, caused by the bottom friction, and they contribute to the overturning circulation.



Global distribution of the energy flux from the diurnal M2 tidal component to internal waves. The unit is W/m^2 and the colour scale logarithmic; e.g., -3 means 10^{-3}W/m^2.

Publications

T. Rossby and J. Nilsson, 2003. Current switching as the cause of rapid warming at the end of the last Glacial Maximum and Younger Dryas. Geophys. Res. Lett. 30 (2) , 1051, 10.1029/2002GL015423.

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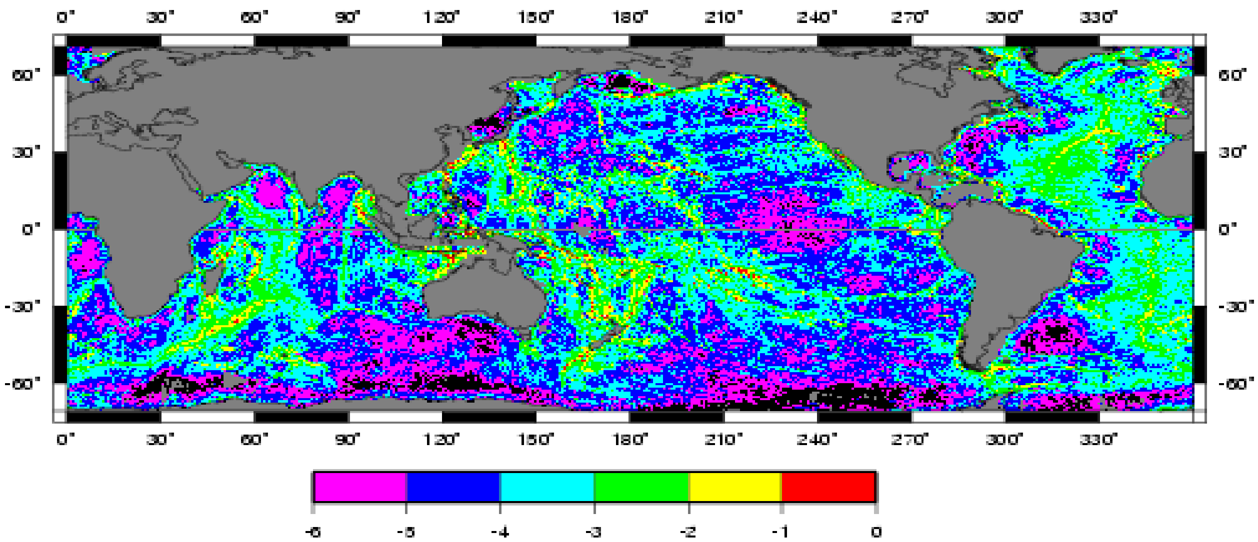

Overturning stream function from the global ocean model OCCAM, with potential density on the x-axis and depth on the y-axis. The colour represents the stream function in Sverdrups (10^6 m^3/s), with anticlockwise (i.e. mechanically driven) circulation in positive overturning cells

Mathematical aspects of geophysical fluid dynamics

Jonas Nycande 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. Nycander. 2006. Existence of energy minimizing vortices attached to a flattop seamount. Nonlin. Anal. (in press).

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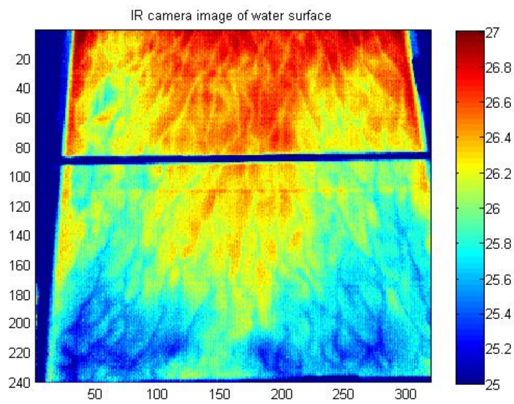
How variations of heat flux at the ocean surface affect the climatologically important thermohaline circulation in the ocean.

Anna Wåhlin

The large-scale ocean circulation influences our local climate since the atmosphere is warmed by northward traveling Atlantic water. At low latitudes the ocean water is heated by the sun, after which it moves poleward and cools and sinks at high latitudes. However, the ocean is not forced directly by the sun. The reason is that it is both heated and cooled from above, which only gives rise to a weak circulation compared to if the sea had been heated from below and cooled from above. According to the laws of thermodynamics it should, in principle, be impossible to have any circulation at all in the ocean; the reasons why this in fact takes place have only recently been discovered. The circulation appears to require turbulence that mixes the surface- and bottom-waters and moves cold water up to the surface. Laboratory experiments and analytical theory have been used to study the dynamics of the global ocean circulation. A laboratory model of the ocean consisting of a tank filled with fresh water that is heated at one end and cooled at the other has been studied. The influence of the Earth's rotation has been studied in a separate experiment on the world's largest rotating table, the Coriolis platform in Grenoble.



Top view of the rotating platform experiment. Salt water is dyed red, fresh water is clear, and ammonium sulfate solutions and comparison with the pure products.

Publications:

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The role of sea surface waves for the mass transport in the upper ocean.

Göran Broström in external collaboration with J. E. Weber (Oslo University) and K. Christensen (Oslo University)

Oceanic surface waves are ever present at the sea surface. The fact that waves possess a certain mass transport, and momentum content, has been well known since the pioneering work of Stokes (1847). However, given that surface waves give different results in an Eulerian vs. Lagrangian description of motion the wave mean-flow interaction is not easily described, and even today there is no well accepted theory for including wave-drift in ocean models. Over the last few years we have worked intensively on showing that the Eulerian and Lagrangian description is essentially equal when similar approximations are used. Furthermore, we have developed a new concept in describing the wave mean-flow interaction based on consistent wave-induced drift in a layered ocean. Using this formulation (described as a quasi-Eulerian quasi-Lagrangian model), the vertical structure of wave mean-flow interaction can be calculated in a consistent way, and is thus easily incorporated into an Eulerian ocean model.

Publications

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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 primarily 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

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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 (SO2, DMS, SO42-), nitrogen (NOx, HNO3, NO3-) 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

Distribution of marine boundary layer ammonia over the Atlantic and Indian oceans

Caroline Leck and Michael Norman

In maritime air a substantial fraction of the acid particles appears to be at least partly neutralized by a gas phase reaction with ammonia (NH3). As a consequence NH3 influences the chemical and physical properties of aerosol particles linked to clouds and climate. The Aerosols99 cruise, January to February 1999, from Norfolk (USA) to Mauritius gave us the opportunity to measure atmospheric NH3 concentrations in the marine boundary layer (MBL) over the Atlantic Ocean and southern Indian Ocean.

An overall large variation in gas phase NH3 was encountered with peak values occurring in regions heavily influenced by the smoke plume from biomass combustion and dust sources on the African continent. Concentration showed typically in the range 7 to 22 nmolm-3.

Within the remote MBL over the South Atlantic and Indian Oceans median NH3 concentrations ranged between 1.1 and 3.2 nmol m-3. It was reasonable to assume that the ocean was a net emitter of NH3 to the atmosphere and thus responsible for the NH3 levels measured. An average residence time of the order of a few hours was estimated. One implication of such rapid removal of NH3 is that it prevented equilibrium to exist between the gas phase and particulate phase ammonium. On the contrary, areas under influence of African biomass burning or dust, the particulate phase ammonium was concluded to be in equilibrium with the gas phase NH3.

The removal of atmospheric NH3 during the time of travel from the African continent to the position of the ship was estimated using a simplified Lagrangian approach. A response or residence time of 20 to 130 hours resulted. Thus in order to explain the observed atmospheric NH3 levels at the ship it seemed necessary to allow for an NH3 residence time of the order of several days within the plume which largely differs from previous reported estimates.

Publications

Norman, M. and Leck, C. 2005. Distribution of marine boundary layer ammonia over the Atlantic and Indian Oceans during the Aerosols99 cruise. J. Geophys. Res. 110, doi:10.1029/2005JD005866.

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 aerosol multi-component properties (CAMP)

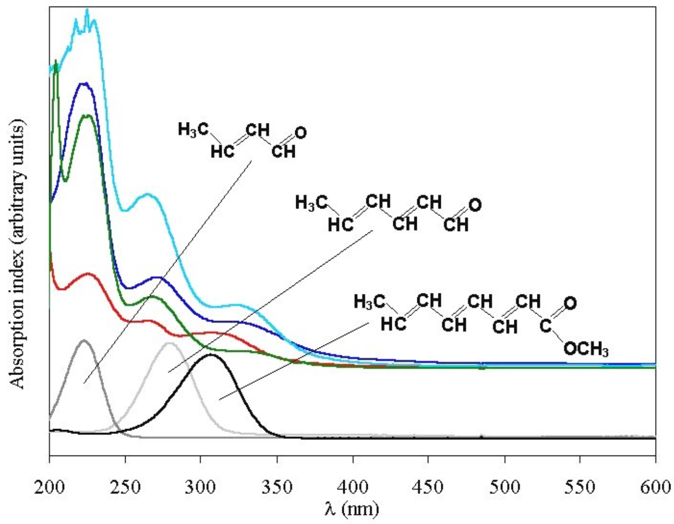
Johan Ström, Douglas Nilsson and Maria Svane (SU/ITM), Radovan Krejci

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.

Chemical transformations of organic compounds affecting the optical properties of aerosols

Barbara Nozière (MISU), Armando Cordova and Pawel Dziedzic, (SU/Department of Organic Chemistry), Louise Carlqvist (KTH/Department of Physical Chemistry)

This laboratory-based chemical study started in January 2006 with Barbara Nozière's Marie Curie Chair at MISU. It had for objective to identify new chemical reactions producing compounds that absorb light in the near-UV and visible wavelengths (300 – 800 nm) inside aerosol materials that are otherwise transparent over this range (absorption index < 10-8). The focus was on aldol condensation, the polymerization of carbonyl compounds, which are common constituents of the water-soluble fraction of atmospheric aerosols. Previous studies had shown that these reactions produce light-absorbing compounds inside sulfuric acid aerosols of concentrations typical for the upper troposphere and stratosphere. In this study it was established that these reactions also take place in aqueous solutions such as pure water and sea salt in the presence of amino acids, and in ammonium sulfate even in the absence of any catalyst. The products of these reactions display unique similarities with compounds previously identified in fog water and in the water-soluble fraction of fine aerosols, which strongly confirm the atmospheric relevance of this study. Based on the results, realistic concentrations of carbonyl compounds were found to significantly increase the absorption index of ammonium sulfate particles (equivalent to a content of 10 % of soot after only a few days) and therefore to have a potential impact on the radiative properties of sulfate aerosols.



Absorption spectra of the products of acetaldehyde in pure water, rainwater, sodium chloride, and ammonium sulfate solutions and comparison with the pure products.

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

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

The overall objective of the proposed 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 project will help reduce the large uncertainties in aerosol-cloud climate forcing in the tropics and help us understand the effects of biomass burning. The eddy covariance method will be used to measure emission fluxes of aerosol particles of different size, volatility (chemical composition) from a tower over the rain forest during intensive campaigns in the wet and dry seasons. The methodological expertise regarding aerosol flux measurments and analysis will be transferred to the Brasilian partner with the goal to establish permanent and continuous aerosol flux measurements at the experimental site in Brasil.

During the first stage of project, week long experiment took place at Botaniska Institutionen, SU to test the suitability of climate chamber for experiments on single or group of plants level to study primary aerosol emissions and their dependance on solar insulation flux, relative humidity and temperature

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

Radovan Krejci, Nils Walberg and Leif Bäcklin (MISU), Johan Ström, Birgitta Noone and Sten Lundström (SU/ITM), Pedro Hoffmann (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.

- Detail objectives of this project can be summarized as follow:
- Study the tropical free tropospheric aerosol microphysical (aerosol number density, aerosol size distribution) and optical properties (light absorption and scattering) at Pico Espejo station.
- Study temporal variability of the tropical free tropospheric aerosol physico-chemical properties on a scale ranging from short-term pollution outbreaks to seasonal and changes.
- Investigation of size segregated aerosol chemical composition and mixing state of aerosol particles.
- Perform radiative closure calculations between observed and calculated aerosol properties (direct aerosol climate effect).
- Estimate contribution of different major sources of atmospheric aerosols (biomass burning, biogenic aerosol, Saharan dust, and anthropogenic pollution) to the aerosol load in the free troposphere.
- Provide over determined aerosol data set, which can be used for validation and improvement of global chemical transport models (e.g. MATCH).

Until know the major activity was focused on all necessary connections and formal steps including establishing contacts with reliable partners in Venezuela as well as on logistical aspects and installation of equipment. Special heated multipurpose inlet was designed and built at our workshop and instrumentation prepared and tested. The installation itself at the station is planned for early 2007.

Georg von Humboldt research station at Pico Espejo, Merida, Venezuela (4765 MSL).

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 (SU/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 between 0.012 µm to 2.2 µm and total aerosol number density at various sizes were observed by set of instruments including DMPS, OPC and CPCs. 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 as 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.

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 ANTSYO II German/Japanese/Swedish Antarctic aircraft campaign from December 2006 to January 2007 a unique aircraft experiment will be performed in Antarctica devoted to the measurement of aerosol particles and trace gases, called AGAMES (Antarctic Trace Gas and Aerosol Airborne Measurement Study). (The ANTSYO I campaign, a geophysical study, was performed one year earlier, in the season 2005/6.) This field study constitutes one of the very first comprehensive airborne campaigns devoted to studies of tropospheric aerosol over Antarctica. The overall main objective in this context is to characterize the aerosol physico-chemical properties in the Antarctic troposphere (during summer season) and to identify the main transport pathways of aerosol particles.

More particular scientific objectives addressed are as follows:

- study aerosol size distribution and number densities of the Antarctic tropospheric aerosol during austral summer
- investigate composition and mixing state of Aitken and accumulation mode aerosols by means of size segregated volatility measurements, bulk chemical analysis and single particle analysis
- study processes of new particle formation in the Antarctic troposphere with respect to air mass history and origin of gaseous precursors.
- investigate the origin of aerosols deposited on the Antarctic plateau with special emphasis on relative importance of local sources, long-range transport and stratosphere-troposphere exchange. Estimate the aerosol mass potentially available for deposition.
- assess how representative ground-based long-term monitoring measurements are at Syowa, Aboa and Neumayer stations on a regional/continental scale.

Flight operations during the first half of the campaign will be performed from the German Antarctic research base Neumayer in the Weddell Sea sector of Antarctica. Flights to inland ice positions like Kohnen station and to Swedish/Finnish station Wasa/Aboa are planned. For the second half of the campaign the aircraft will be transferred to the East to the Camp S17, close to the Japanese research base Syowa. Both operation bases will allow for flights surveying open water and sea ice as well as elevated inland ice positions. The Swedish group contributes 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. More details can be found on project website: http://www.pa.op.dlr.de/aerosol/agames/

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.

Carbon-14 analysis of soot in ABC

Henning Rodhe, Örjan Gustafsson (SU/ITM), Caroline Leck, 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. Preliminary results indicate that during the winter monsoon period a large part of the soot carried out over the Indian Ocean is derived from biomass burning rather from fossil fuel combustion.

Distribution of atmospheric DMS in the high Arctic   model study

Jenny Lundén, Gunilla Svensson and Caroline Leck

See Arctic Studies

Intercomparison of Dimethyl sulfide 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)

See Arctic Studies

Arctic study of tropospheric aerosols, clouds and radiation (ASTAR 2004)

Radovan Krejciet al.

See Arctic Studies

Biogenic particles over the central Arctic Ocean

Caroline Leck and Keith Bigg

See Arctic Studies

New evidence of fog-related aerosol sources over the arctic pack ice in summer

Jost Heintzenberg, Caroline Leck and Michael Tjernström

See Arctic Studies

Evidence of a surface source of ultra fine aerosol particles in the Arctic 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

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 shows that the relative loss of analyte increase with sample volume but decrease with sample concentration. The exposure time showed no influence on the analyte loss. The total precision of the filtration method for weak samples (marine air) is 25 % in relative standard deviation and for strong samples (continental air) 5 %. Samples from summer monsoon have an estimated optical density over the detection limit and samples from winter monsoon are 3-4 times more concentrated.

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.

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 co-operation 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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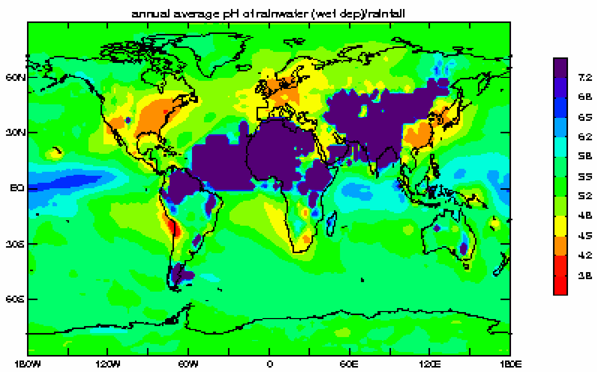
The global distribution of acidifying wet deposition and ecosystem sensitivity

Henning Rodhe, K Hicks and J.C. Kuylenstierna (Stockholm Environment Institute, York, UK), Frank Dentener (Joint Research Institute, Ispra, Italy) and Hans Martin Seip (Oslo University, Norway)

The acid-base status of precipitation is a result of a balance between acidifying compounds – mainly oxides of sulfur and nitrogen – and alkaline compounds – mainly ammonia and alkaline material in windblown soil dust. We use current models of the global atmospheric distribution of such compounds to estimate the geographical distribution of pH in precipitation (c.f. Figure) and of the rate of deposition of hydrogen ion or bicarbonate ion. The lowest pH values – mainly due to high concentration of sulfuric acid – occur in eastern parts of North America, Europe, and China. A comparison with observed pH values shows fair agreement in most parts of the world. However, in some areas, e.g. western North America, south-western Europe, and northern China the estimated pH is too low, indicating that we have underestimated the deposition flux of alkaline material, probably mainly CaCO3.

A methodology investigating the extent of acidification risks from sulfur and nitrogen emissions in Asia has been developed. Atmospheric transfer models have been used to calculate transfer and deposition of sulfur, nitrogen and alkaline soil dust. A soil chemistry model is used to investigate the dynamical behavior of typical Asian soils under various assumptions about future emission and deposition rates. The results show that the risk of adverse effects in the immediate future is probably limited to some parts of SW China. In a longer time perspective - a few decades - several other areas may become significantly affected.



Model estimate of the annual average pH of precipitation. (Rodhe et al., 2002)

Washout ratio of black carbon in the Maldives

L. Granat, E. Engström and C. Leck, J. Schauer (Univ. of Wisconsin-Madison), S. Praveen (Maldives Climate Observatory Hanimaadhoo) and H. Rodhe

We report a unique set of data 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 as a part of the Atmospheric Brown Cloud (ABC) APMEX campaign. Additional data were collected during 2005 and 2006.

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, but only moderately so, than that of nss sulfate. This information has a bearing on the life time of BC in the atmosphere and may 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.

Aerosol-cloud interaction in deep convective clouds

Annica Ekman, Chien Wang (EAPS, MIT, Cambridge, USA), Anders Engström, Johan Ström (SU/ITM, Stockholms Universitet), Radovan Krejci

Convective clouds have been recognized as an important mechanism for transferring chemical compounds from the surface to the free troposphere. Several observations have also indicated high number concentrations of small aerosols in the vicinity of the anvils of convective clouds. One theory has been that the environment in this area is favorable for nucleation of particles as both the relative humidity and the concentration of aerosol precursors are relatively high. Another explanation for the small aerosols found near the top of convective clouds could be direct transport from the surface to the free troposphere by strong vertical updrafts. Using the model, it is concluded that up to 10% of small/middle size (Aitken mode) sulfate aerosols may reach the free troposphere by direct transport. An equal amount of hydrophobic aerosols (black carbon) are also transported from the surface to the cloud anvil.

Atmospheric aerosols may be efficient as cloud condensation nuclei (CCN) or ice nuclei (IN). An increasing number of aerosols in the atmosphere may therefore affect deep convective cloud development and precipitation formation. Sensitivity simulations performed using the model indicate that the onset of precipitation formation, and thus deep convection, is delayed with an increase number of CCN. The total precipitation amount is also lowered. An increased number of IN in the atmosphere, generally result in higher updraft velocities, a prolonged precipitation event and larger total precipitation amounts (cf. Figure).

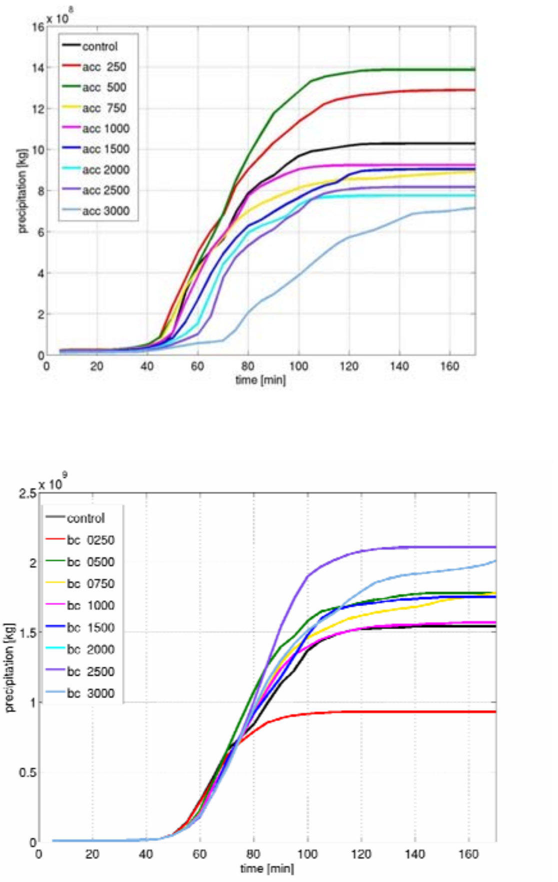


Figure 1. Model simulated total precipitation amount vs. time for a) varying CCN concentrations b) varying IN concentrations.

Simulated effects of varying sea-surface temperatures on local convective cloud development and cloud radiative properties

Frida Bender, Johannes Karlsson and Annica Ekman

A changing climate may imply a local response of deep convective cloud dynamics and microphysics to variations in the ocean sea-surface temperature (SST). This may cause feedbacks on the climate system in terms of e.g. a change in radiative properties of the cloud anvil or an altered vertical distribution of water vapor. In this research project, we perform sensitivity simulations to study the development of a deep convective cloud for a range of different SSTs. Specifically, we look at differences in the vertical distribution of condensed water in the convective cloud core, efficiency of precipitation formation, anvil characteristics and anvil extent, and the vertical distribution of specific humidity below the cloud anvil.

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ATMOSPHERIC PHYSICS

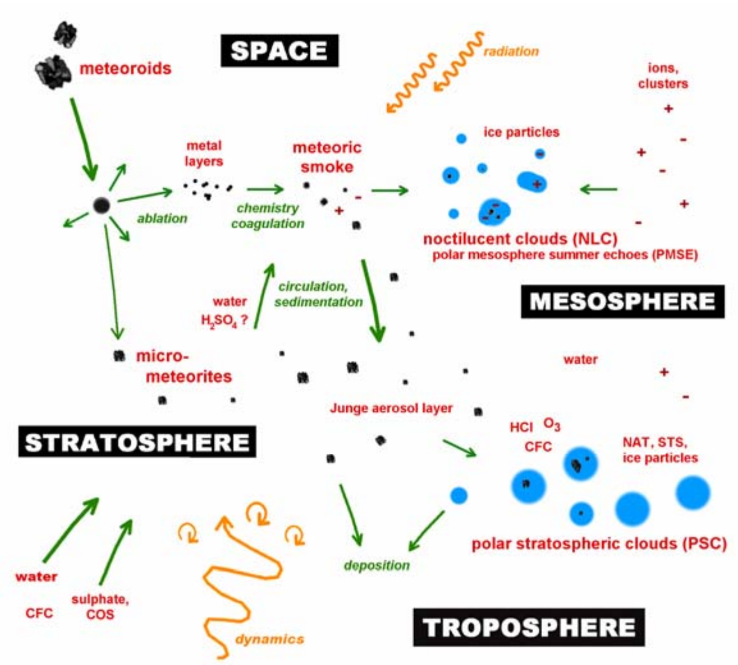
Atmospheric Physics research at MISU/IMI focuses on the Earth's middle atmosphere between 10 and 100 km, i.e. the stratosphere mesosphere and lower thermosphere. This region is highly coupled and influenced by radiative and dynamic forcing both from above and from below. Substantial temperature trends and the depletion of polar ozone are examples of the susceptibility of the middle atmosphere to human activity. In particular, middle atmospheric aerosols have been recognized as sensitive indicators of a changing atmosphere. Our Atmospheric Physics group continues its research programme with a particular focus on aerosol processes. We study sources of aerosols, particle properties and the interaction with their neutral and charged environment. In the middle atmosphere, this includes ice clouds, particles of meteoric origin, and the background aerosol formed by conversion of trace gases. In order to properly describe atmospheric processes, our research programme also concerns basic studies of composition, chemistry and dynamics.

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

Atmospheric Physics at MISU/IMI includes today a wide range of experimental and theoretical techniques. Our aeronomy programme has always contained a strong instrumental component aiming at the development and improvement of measuring techniques, including sounding rockets, satellites, balloons and ground-based instruments. Spectroscopic techniques, optical retrievals, particle microphysics and aerodynamics are examples of particular competence. Also numerical modelling has now become a basic part of our programme, thus putting our experimental results in a larger perspective of understanding the middle atmosphere.

The long-term goals of our Atmospheric Physics programme are

- to establish the distributions and properties of the most important trace gases, aerosols and clouds in the middle atmosphere,
- to determine the underlying dynamical, physical and chemical processes that control their geographical and temporal variation, and
- to better understand the interaction between solar and terrestrial radiation with the constituents of the middle atmosphere.



The middle atmospheric aerosol. Much of the MISU/IMI research in Atmospheric Physics is focused on aerosol particles and related processes in the middle atmosphere. The properties and distribution of these particles are closely coupled to dynamic and radiative influences from the lower atmosphere and from space.

SATELLITE STUDIES

The Swedish Odin satellite has now been in orbit for almost 6 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.

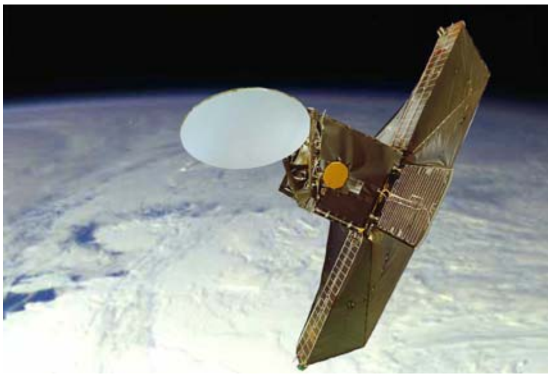
The Atmospheric Physics group has earlier been involved in the Phase A1 study for the new atmospheric satellite mission STEAM (Stratosphere-Troposphere Exchange And climate Monitor). STEAM was recommended by SNSB as the next satellite project within the Swedish national space programme, but funding has not become available. 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 recently 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.

Together with a majority of the Swedish space research community we have also been involved in a proposal for the microsatellite SOLARIS to study solar wind interaction and atmospheric processes on Mars. The SOLARIS satellite was to be part a larger U.S. mission to Mars. Unfortunately, the latter has not been selected by NASA.

The Odin Mission

Jacek Stegman, Jörg Gumbel, Bodil Karlsson, Stefan Lossow, 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.

For aeronomy studies, 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 every 3rd day. On typically 100 days per year, limb scans are performed that include the Earth's mesosphere and lower thermosphere up to 110 km. A particular focus of these measurements is on the polar summer season, featuring mesospheric phenomena like noctilucent clouds (NLC). A new observing scheme has been developed in order to extend observations throughout the entire NLC-season. These data have given us important new insights into NLC climatology and the dynamic coupling between the hemispheres. During the NH summer 2005 the NLC observing campaign was shifted to the middle of August in order to monitor the interesting transition period when the NLC cease to exist; the analysis of these results is underway.

The AP group remains strongly engaged in the entire Odin aeronomy programme and the management of the mission. A particular focus is on mesospheric water (water vapor, noctilucent clouds) and the continued development of UV-Vis retrieval algorithms for ozone-destoying species in the stratosphere and atomic and molecular species in the mesosphere. In addition to ongoing studies of the sodium layer in the mesosphere and OClO in the stratosphere, new projects aim at potassium and other metals as well as the retrieval of upper mesospheric temperatures from the O_2 A-band dayglow emission. We have also been involved in the planning and preparation for three re-calibration projects of the OSIRIS instrument against Vega, the Moon and, more recently, α-Centauri.

Publications

Llewellyn, E. J., N. D. Lloyd, D. A. Degenstein, R. L. Gattinger, S. V.Petelina, A. E. Bourassa, J. T. Wiensz, E. V. Ivanov, I. C. McDade, B. H. Solheim, J. C. McConnell, C. S. Haley, C. von Savigny, C. E. Sioris, C. A. McLinden, E. Griffioen, J. Kaminski, W. F. J. Evans, E. Puckrin, K. Strong, V. Wehrle, R. H. Hum, D. J. W. Kendall, J. Matsushita, D. P. Murtagh, S. Brohede, J. Stegman, G. Witt, G. Barnes, W. F. Payne, L. Piché, K. Smith, G. Warshaw, D.-L. Deslauniers, P. Marchand, E. H. Richardson, R. A. King, I. Wevers, W. McCreath, E. Kyrölä, L. Oikarinen, G. W. Leppelmeier, H. Auvinen, G. Mégie, A. Hauchecorne, F. Lefèvre, J. de La Nöe, P. Ricaud, U. Frisk, F. Sjoberg, F. von Schéele, and L. Nord. 2004. The OSIRIS instrument on the Odin spacecraft, Can. J. Phys., 82, 411-422.

Ricaud, P., F. Lefèvre, G. Berthet, D. Murtagh, E. J. Llewellyn, G. Mégie, E. Kyrölä, W. Leppelmeier, H. Auvinen, C. Boonne, S. Brohede, D. A. Degenstein, J. de La Noë, E. Dupuy, L. El Amraoui, P. Eriksson, W. F. J. Evans, U. Frisk, R. L. Gattinger, F. Girod, C. S. Haley, S. Hassinen, A. Hauchecorne, C. Jimenez, E. Kyrö, N. Lautié, E. Le Flochmoën, N. D. Lloyd, J. C. McConnell, I. C. McDade, L. Nordh, M Olberg, A. Pazmino, S. V. Petelina, A. Sandqvist, A. Seppälä, C. E. Sioris, B. H. Solheim, J. Stegman, K. Strong, P. Taalas, J. Urban, C. von Savigny, F. von Scheele, and G.Witt. 2005. Polar vortex evolution during the 2002 Antarctic major warming as observed by the Odin satellite, J. Geophys. Res., 110, D05302,doi:10.1029/2004JD005018.

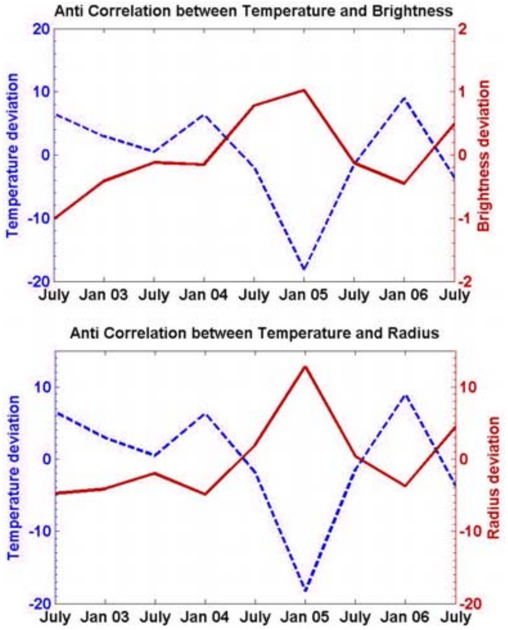
Studies of noctilucent clouds

Bodil Karlsson, Heiner Körnich, Markus Rapp, 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 modeling suggests that this is a combined effect of the mesospheric temperature structure, availability of water vapour and meridional transport times.



The dynamic coupling between the winter stratosphere and the summer mesosphere is demonstrated as an anticorrelation of stratospheric winter temperature with the mesospheric NLC particle radius (left) and NLC brightness (right). Plotted as blue line are the deviation from the mean temperature at the 10-20 hPa level (units: K). The red lines denote the deviation of the effective NLC particle (units: nm) and the deviation of the observed NLC brightness (units: 10^{10} ph cm^{-2} s^{-1} str^{-1} nm^{-1}) from the mean.

Recent 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 (see figure). 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

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Grossmann, K. U., O. Gusev, M. A. Assou, and G. Witt. 2006. Spectral emission measurements of polar mesospheric clouds by CRISTA-2, J. Atmos. Sol. Terr. Phys., 68, 1781-1790.

Mesospheric water vapour and temperature retrieval from Odin/SMR measurements

Stefan Lossow, in collaboration with J. Urban and P. Eriksson (both Chalmers University of Technology, Göteborg, Sweden)

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.

In 2005 the retrieval of the 557 GHz band has been implemented into the Odin/SMR operational retrieval scheme of Chalmers University of Technology. This first official retrieval version has been validated to correlative satellite-borne measurements. During 2006 substantial effort was focused on improving the quality of the first retrieval version. To this end, a sensitivity study of critical retrieval parameters and in-orbit test measurements have been performed in order to understand changes in the instrument characteristics. New insights won by these investigations were implemented into an improved retrieval version, which has been released by the end of 2006.

Beyond the optimization of the retrieval scheme our main scientific focus is on the summer mesopause region at high latitudes, where noctilucent clouds (NLC) can occur. One question of interest connected to these clouds is the redistribution of water vapour by the NLC ice particles. In order to assess this process Odin/SMR water vapour and Odin/OSIRIS NLC measurements will be co-analyzed.

Publications

Urban, J., N. Lautié, D. P. Murtagh, P. Eriksson, Y. Kasai, S. Lossow, E. Dupuy, J.de LaNoë, U. Frisk, M. Olberg, E. Le Flochmoën, and P. Ricaud, 2006, Global observations of middle atmospheric water vapour by the Odin satellite: an overview, Planet. Space Sci., in print.

S. Lossow, J. Urban, P. Eriksson, D. P. Murtagh, and J. Gumbel, 2006, Critical parameters for the retrieval of mesospheric water vapour and temperature from Odin/SMR limb measurements at 557 GHz: a sensitivity study focused on the polar summer mesosphere, submitted to Adv. Space Res.

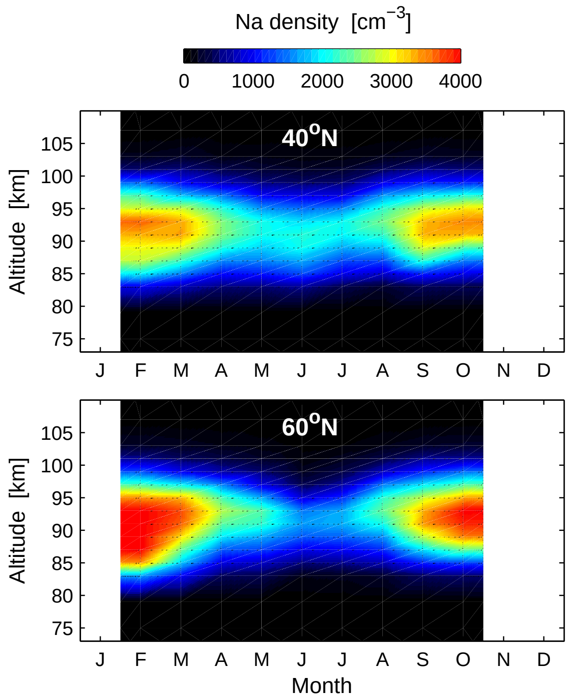
Studies of the mesospheric metal layers

Jörg Gumbel, Thomas Waldemarsson, in collaboration with Z. Fan (University of East Anglia, U.K.), and J. M. C. Plane (University of Leeds, U.K.)

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).



Seasonal dependence of the mesospheric sodium layer as retrieved from Odin dayglow observations. Shown are zonally averaged data from the years 2003-2004 for latitudes 60°N and 40°N, respectively. Note that no dayglow data is available during the dark winter months. The summertime minimum is most pronounced near 60°N, which is consistent with the uptake of sodium species onto noctilucent cloud particles.

Publications

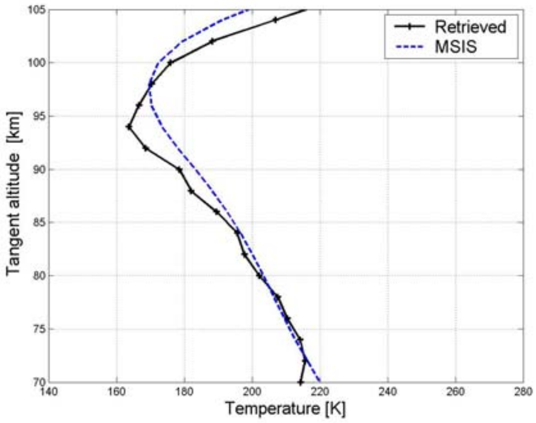
Gumbel, J., L. Fan, J. Stegman, G. Witt, E. J. Llewellyn, C.-Y. She, and J. Plane. 2007. Retrieval of the global mesopsheric sodium density from the Odin satellite, Geophys. Res. Lett., in print.

Retrieval of mesospheric temperatures from the O_2 Atmospheric band

Tomas Waldemarsson, Jacek Stegman

OSIRIS measures the spectral shape of the O_2 (0-0) A-band dayglow emission throughout the mesosphere. The rotational shape of this band is highly dependent on the emission temperature and this fact can be utilized to retrieve mesospheric temperature information. By applying an appropriate Optimal Estimation inversion algorithm, the OSIRIS line-of-sight observation can be converted into a vertical temperature profile. An example of a preliminary retrieval result is shown in the figure beside.

Global data sets of mesospheric temperatures are of large value for a variety of mesospheric processes. Consequently, this new method has been met with substantial interest from the scientific community. Work on the further development of this retrieval technique is ongoing. A final aim is to provide mesospheric temperatures from the A-band as a standard OSIRIS Level-2 product.



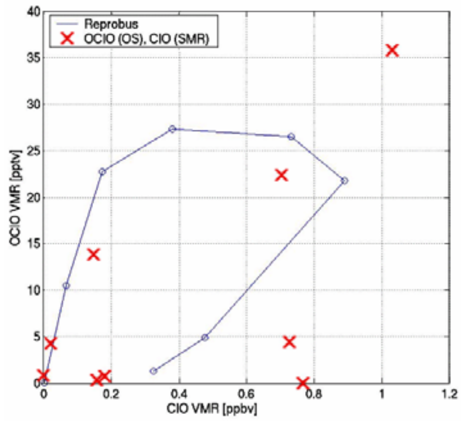
Example of an individual mesospheric temperature profile retrieved through spectral fits of the O_2 atmospheric band. Also shown is a comparison to the MSIS climatology.

Retrieval of stratospheric OClO vertical profiles

Patricia Krecl, Jacek Stegman, in collaboration with C. S. Haley (York University, Toronto, Canada), S. M. Brohede (Chalmers University of Technology, Göteborg, Sweden), G. Berthet (Institut Pierre-Simon Laplace, Paris, France)

The first vertical profiles of stratospheric OClO have been retrieved from Odin/OSIRIS measurements of limb-scattered sunlight in the spectral region 403-427 nm. Our retrieval method is based on a two-step approach, using differential optical absorption spectroscopy (DOAS) combined with the maximum a posteriori (MAP) estimator. OClO can be detected inside the southern polar vortex region between about 12 and 20 km altitude with 2-5 km height resolution and a retrieval noise better than 60% at the peak. OClO concentrations are consistent with chemical transport model simulations and with independent ClO measurements. They show the expected relation to the stratospheric conditions in the austral spring 2002. This unique data set of OClO profiles is very promising for studies of stratospheric chlorine activation in the polar regions.

The major goal of this project is to study the chemistry and relationship of several key species involved in the stratospheric ozone chemistry. This involves a comparison to current theoretical knowledge as represented by a full-scale chemical transport model. Odin's particular strength is that it conducts simultaneous measurements of related (or sometimes the same) species by two very different techniques. A first objective is to study the relationship of the activated chlorine compounds OClO and ClO measured by OSIRIS and the SMR instrument, respectively. A second objective is to investigate the feasibility of extending this study to bromine chemistry by retrieving BrO from the OISRIS spectra.



The relationship of the activated chlorine species OClO and ClO in the Antartic polar vortex. Shown are mixing ratios retrieved from OSIRIS and SMR, respectively, from various altitudes. The blue line shows the altitude-dependent OClO/ClO relationship suggested by the REPROBUS chemical transport model.

Publications

Krecl, P., C. S. Haley, J. Stegman, S. M. Brohede, and G. Berthet. 2006. Retrieving the vertical distribution of stratospheric OClO from Odin/OSIRIS limb-scattered sunlight measurements., Atmos. Chem. Phys., 6, 1879-1894.

The STEAM / PREMIER satellite mission

Jörg Gumbel, Jacek Stegman

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 main mission objective is to provide vertically and horizontally resolved information on the global distributions of UT/LS key species and dynamic tracers such as water vapour, ozone, and carbon monoxide. Global fields of ozone, water and halogen compounds will also be the basis for continued studies of ozone distruction in the stratosphere. STEAM has a strong heritage from the Odin satellite. The Atmospheric Physics group has participated actively in the STEAM phase-A1 study. The group's main interest is, at this point, the definition of an optical instrument on STEAM for the detection and characterisation of clouds and aerosols.

Although STEAM has been recommended by SNSB as the next Swedish satellite project no funding within the national space programme has been allotted to the project. The concept of STEAM has more recently been combined with another new development – the Imaging Michelson Interferometric Passive Atmospheric Sounder (IMIPAS). Together, these concepts have been proposed to ESA for a new Explorer mission under the name PREMIER (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation). The proposing consortium includes now scientific groups from a number of European countries, Canada and the USA. The objective of the proposed mission is to observe the distribution of trace gases, particulates and temperature down to finer spatial scales than any previous dedicated satellite mission. PREMIER has now been selected, together with five other missions, for an Earth Explorer assessement study within ESA's Living Planet Programme.

The ACE satellite mission

Georg Witt, Bodil Karlsson, 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

Eremenko, M. N., S. V. Petelina, A. Y. Zasetsky, B. Karlsson, C. P. Rinsland, E. J. Llewellyn, and J.J. Sloan. 2005. Shape and composition of PMC particles derived from satellite remote sensing measurements, Geophys. Res. Lett., 32, L16S06, doi:10.1029/2005GL023013.

IN SITU STUDIES OF THE MIDDLE ATMOSPHERE

The interaction of radiative, chemical and dynamic processes gives rise to a variety of phenomena in the Earth's middle atmosphere. Prominent examples are phenomena like noctilucent clouds (NLC), the ablation and transformation of meteoric material, as well as 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.

Mesospheric Aerosol – Genesis, Interaction and Composition (MAGIC)

Tomas Waldemarsson, Jörg Gumbel, Misha Khaplanov, Jacek Stegman, Jonas Hedin, Bodil Karlsson, Stefan Lossow, Linda Megner, in collaboration with F. Giovane and R. Stroud (Naval Resarch Laboratory, Washington D.C., USA) and J. M. C. Plane (University of Leeds, U.K.)

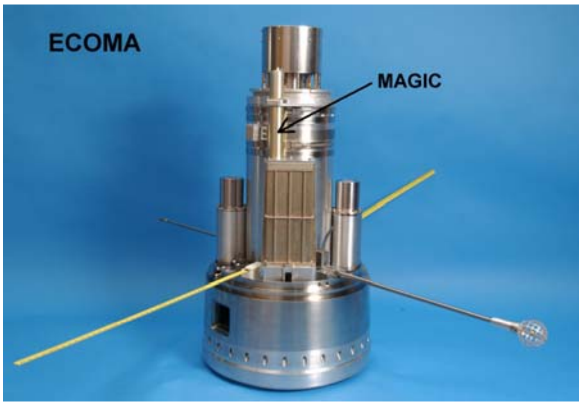
Intensive work has been going on in the MISU's Atmospheric Physics group to prepare the MAGIC rocket projects. MAGIC is a close collaboration with the Naval Research Laboratory (NRL) in Washington D.C. and focusses on the fate of meteoric material in the mesosphere. Approximately 100 ton of sub-mm meteoric particles enter the Earth's upper atmosphere each day. Our knowledge about the fate of this cosmic material is so far very limited. It is generally assumed that ablated material re-condenses into nanometer-size "smoke" particles. This smoke has been suggested to play key roles in a number of mesospheric processes related to noctilucent clouds, polar mesosphere summer echoes, charge balance, and neutral chemistry. MAGIC aims to sample and to analyse meteoric particles and to relate their distribution to the atmospheric circulation.

In order to study smoke particles in the mesosphere, a number of related processes has to be addressed by co-ordinated experiments: smoke particle distribution, charge conditions, as well as neutral atmospheric conditions and dynamics. Basic scientific questions are:

- Do re-condensed smoke particles of cosmic origin exist in the mesosphere?
- What is the number density and spatial distribution of the particles?
- What is the size distribution of the particles?
- What is their charge state?
- What is the elemental and molecular composition of the particles?

The basic idea of MAGIC is to directly sample meteoric smoke in the mesosphere. With this completely new approach we can take mesospheric material down to the laboratory. The particle samples will then be analysed in terms of altitude-dependent number density, size distribution and element composition. Basic techniques comprise transmission electron microscopy techniques, x-ray spectroscopy, and isotope determination.

The first flight of the MAGIC particle collectors was carried during the MAGIC rocket campaign at Esrange in January 2005. The campaign featured a comprehensive set of in situ and ground-based measurements of atmospheric conditions. The MAGIC rocket payload was equipped with three MAGIC collector, an optical hygrometer for water vapour measurements, as well as two charged particle detectors provided by the University of Colorado. Meteoric smoke particles were sampled between 60 and 95 km. Complementary measurements of the atmospheric dynamics and ionospheric conditions were carried out with three meteorological rockets, a stratospheric balloon and ground-based lidar and radar facilities. In order to relate the local data to the large scale atmospheric motions the MAGIC campaign was coordinated with measurements of the Swedish Odin satellite.



Part of the German-Norwegian ECOMA payload, carrying two MAGIC particle instruments (arrow) in combination with experiments addressing charged particles as well as neutral and ionospheric properties of the background atmosphere.

Through collaboration with Virginia Polytechnic Institute, a second flight of the MAGIC collection instrument took place in May 2005 in mid-latitude conditions from Wallops Island, USA. The NASA student rocket programme sponsored this launch and the payload carried one MAGIC instrument. In September 2006, the third flight of the MAGIC collector took place as part of the German/Norwegian ECOMA project from Andøya, Norway. This campaign consisted of two ECOMA rocket payloads, each featuring two MAGIC collectors.

Transmission electron microscopy (TEM) is the main tool which is used to examine the particle collected by the MAGIC detectors. This sample analysis is ongoing at NRL and the University of Leeds. Sample analysis has also started through a recently established collaboration with the TEM team at the Department of Physical Inorganic and Structural Chemistry at Stockholm University. The analysis at the Stockholm University will intensify when the new electron microscopy facility is operational at the new centre for electron microscopy. Preliminary analysis carried out at NRL has shown isolated particles, roughly spherical in shape with diameters 3 to 20 nm, and varying concentrations of Si, O, Ca, Al, Fe, and S, consistent with material of meteoric origin.

Of particular interest are MAGIC particle measurements related to mesospheric chemistry and mesospheric ice (noctilucent clouds, polar mesosphere summer echoes). Future launches of MAGIC instruments will focus on these topics. The MAGIC work is also closely related to modeling studies in our Atmospheric Physics group.

Publications

Gumbel, J., T. Waldemarsson, F. Giovane, M. Khaplanov, J. Hedin, B. Karlsson, S. Lossow, L. Megner, J. Stegman, K. H. Fricke, U. Blum, P. Voelger, S. Kirkwood, P. Dalin, Z. Sternovsky, S. Robertson, M. Horányi, R. Stroud, D. E. Siskind, R. R. Meier, J. Blum, M. Summers, J. M. C. Plane , N. J. Mitchell, M. Rapp. 2005. The MAGIC rocket campaign: an overview, Proc. 17th ESA Symposium on European Rocket and Balloon Programmes and Related Research (ESA SP-590), 141-144.

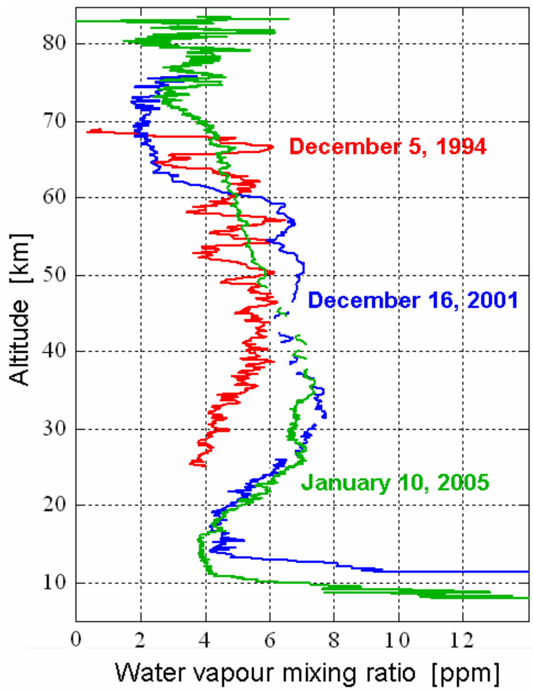
Hedin J., J. Gumbel, T. Waldemarsson, and F. Giovane. 2006. The aerodynamics of the MAGIC meteoric smoke sampler, submitted to Adv. Space Res.

Water vapour measurements

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

The Atmospheric Physics group continuous 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 (December 2001) and the MAGIC campaign (January 2005) from Esrange.



A compilation of water vapour measurements in the middle atmosphere from rocket and balloon measurements. All data were taken at Esrange (68ºN, 21ºE) during the winter season.

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 an 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 reveiled 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

Khaplanov, M, J. Gumbel, J. Stegman, G. Witt, P. Dalin, S. Kirkwood, F. J. Schmidlin, K. H. Fricke, U. Blum, N. Lautie, and the Odin Team. 2003. Middle atmospheric water vapour and dynamics during the Hygrosonde-2 campaign, Proc. 16th ESA Symposium on European Rocket and Balloon Programmes and Related Research (ESA SP-530), 551-556.

Lyman-α radiative transfer in the mesosphere

Jonas Hedin, Misha Khaplanov, Jörg Gumbel, Georg Witt

The enhanced Alomar Research Infrastructure (eARI) is a system of high quality ground-based experimental facilities concentrated at the ALOMAR observatory and the Andøya Rocket Range in Norway. The new EU contract to eARI has been extended to the sponsoring of two sounding rocket launches from Andøya. Costs of launch, integration and transports are fully covered by the EU contract. The MISU/IMI Atmospheric Physics group is particpating in both rockets.

Our contribution to the first eARI flight in August 2006 was SLAM (Scattered Lyman-Alpha in the Mesosphere). In order to better understand noctilucent clouds (NLC) and their sensitivity to mesospheric conditions, more needs to be learned about the actual cloud particle population. Optical measurements are today the only means of obtaining information about the size of mesospheric ice particles. In order to efficiently access particle sizes, scattering experiments need to be performed in the Mie scattering regime, thus requiring short wavelengths of the order of the particle size. Previous studies of NLC have been performed at wavelengths down to 355 nm from the ground and down to about 220 nm from rockets and satellites. The SLAM project aims for the first time at NLC studies in the extreme ultraviolet. Measurements at these short wavelengths are necessary to further promote our knowledge about the NLC particle size distribution. In particular, Lyman-α radiation at 121.57 nm is well suited for such studies since NLCs are well illuminated by solar Lyman-α during daytime conditions. At 121.57 nm the smaller particles in the ice population start to significantly influence the optical properties of NLC. Therefore, an investigation of the scattering and extinction properties at Lyman-α can yield unique and important information about the polar mesospheric ice layer.

While the eARI payload failed after launch and could not provide atmospheric data, SLAM still was an important instrument development for the study of mesopsheric ice particles. Based on this concept, a new flight of a Lyman-α instrument is being planned for a new NLC rocket campaign from Esrange, Sweden.

Publications

Hedin, J., J. Gumbel, M. Khaplanov, G. Witt, J. Stegman. 2007. Optical studies of noctilucent clouds in the extreme ultraviolet, submitted to Ann. Geophys.

MODELLING STUDIES

Modelling efforts in the Atmospheric Physics group have become increasingly important in order to put our measurements into a larger perspective. Significant progress has been made in modelling related both to the Odin mission and to our in situ measurements. New collaborations have been started both on chemistry/transport studies in the middle atmosphere and the radiative transfer related to present and future missions.

Climate change and ozone in the middle atmosphere

Andreas Jonsson, in collaboration with V. I. Fomichev, J. de Grandpré, , S. R. Beagley, J. C. McConnell, C. McLandress, T. G. Shepherd (University of Toronto, Canada)

These studies have been carried out at York University, Canada, in collaboration with York University and Toronto University. The Canadian Middle Atmosphere Model (CMAM) is an advanced 3D GCM, stretching from the ground to the mesopause. It has a wave driven dynamics, a comprehensive radiation scheme as well as interactive chemistry. Our early studies used a number of double CO_2 experiments. These have been analysed to assess the chemical response of the stratosphere and mesosphere. The ozone response to such a perturbation is to increase by up to 20%, depending on altitude. The ozone increase exerts a negative feedback on the greenhouse gas induced cooling of the middle atmosphere. This study has quantified the feedback and identified the set of key reactions which governs middle atmospheric trens in ozone.

Publications

Jonsson, A. J., J. de Grandpré, V. I. Fomichev, J. C. McConnell, and S. R. Beagley. 2004. Doubled CO_2-induced cooling in the middle atmosphere: photochemical analysis of the ozone radiative feedback, J. Geophys. Res., 109, D24103, doi:10.1029/2004JD005093.

Jonsson, A. J. 2005. Revisiting the "Ozone deficit problem" in the middle atmosphere: An investigation of uncertainties in photochemical modeling, Report AP42, Department of Meteorology, Stockholm University, Stockholm, Sweden.

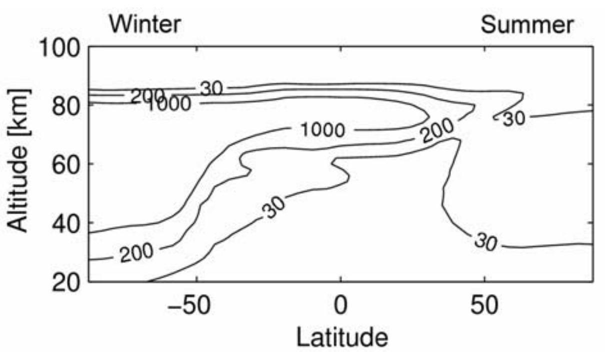
Fomichev, V. I., A. Jonsson, J. de Grandpre, S. R. Beagley, C. McLandress, K. Semeniuk, and T. G. Shepherd. 2005., Response of the middle atmosphere to CO2 doubling: Results from the Canadian Middle Atmosphere Model, submitted to J .Geophys. Res.

Global model simulations of mesospheric aerosols

Linda Megner, Jörg Gumbel, Markus Rapp, in collaboration with D. E. Siskind (Naval Research Laboratory, Washington D.C., 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 used a one-dimensional microphysical model to investigate the sensitivities of meteoric smoke properties to these poorly known or highly variable factors.

It was found that the single most important factor is the background vertical wind. Since the background wind varies greatly with latitude and season, it is clear that a one-dimensional model is too simplistic to accurately model the smoke distribution. We therefore have developed the first 2-dimensional model which includes both transport and coagulation of meteoric material. For nanometer sized particles the effect of atmospheric circulation is prominent, as it efficiently transports the particles to the winter hemisphere. Number densities of around 4000 per cubic centimeter 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.

Moreover, we have shown that the global input of meteoric material into the mesosphere efficiently is transported to the winter stratosphere. This is of potential importance for the formation of polar stratospheric clouds and in particular for the nucleation of Nitric Acid Trihydrate. It may also provide an explanation for the the so-called polar stratospheric CN (condensation nuclei) layer which repeatedly forms in the spring at polar latitudes and at altitude between 20 and 30 km.

We are planning to compare this results to experimental data from the Magic rocket project.

Publications

Megner, L., M. Rapp, and J. Gumbe. 2006. Distribution of meteoric smoke - sensitivity to microphysical properties and atmospheric conditions, Atmos. Chem. Phys., 6, 4415-4426.

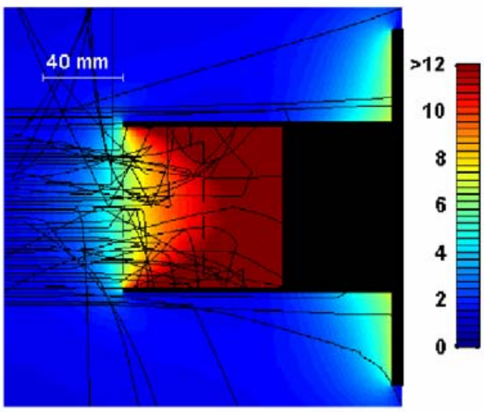
Megner, L., J. Gumbel, M. Rapp, and D. E. Siskind. 2006. Reduced meteoric smoke abundance at the summer pole - implications for mesospheric ice particle nucleation, submitted to Adv. Space Res.

Megner, L., D. E. Siskind, M. Rapp, and J. Gumbel. 2007. Global and temporal distribution of meteoric smoke; a 2D simulation study, submitted to J. Geophys. Res.

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.



Brownian motion trajectory simulation of meteoric smoke particles of radius 2 nm approaching a rocket-borne detector. The flow is from the left and the colour scale describes the relative compression of the background airflow. The simulation is representative for measurement conditions at an altitude of 90 km.

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 MAGIC and ECOMA and will be applied to future rocket launches from Andøya, Norway, and Esrange, Sweden. We intend to extend this model to include the flow of ions, payload charging and electric fields.

Publications

Smiley, B., S. Robertson, M. Horányi, T. Blix, M. Rapp, R. Latteck, and J. Gumbel. 2003. Measurement of positively and negatively charged particles inside PMSE during MIDAS SOLSTICE 2001, J. Geophys. Res., 108(D8), 8444, doi: 10.1029/2002JD002425.

Robertson, S., B. Smiley, M. Horanyi, Z. Sternovsky, J. Gumbel and J. Stegman. 2004, Rocket-borne probes for charged ionospheric aerosol particles, IEEE Trans. Plasma Sci., 32, 716-723.

Hedin, J., J. Gumbel, and M. Rapp. 2005. The aerodynamics of smoke particle sampling., Proc. 17th ESA Symposium on European Rocket and Balloon Programmes and Related Research (ESA SP-590), 145-150.

Hedin J., J. Gumbel, and M. Rapp. 2007. On the efficiency of rocket-borne particle detection in the mesosphere, Atmos. Chem. Phys. Discuss. ,7, 1183-1214.

The microphysics of noctilucent clouds

Markus Rapp, in collaboration with G. E. Thomas (Colorado University, USA)

Considerable progress has been made over the past years concerning the experimental capabilities to observe mesospheric ice particles from space, from the ground, and in situ. Despite this progress regarding the observational database, a quantitative description of related physical and chemical processes is still a challenging task due to uncertainties of several microphysical aspects concerning ice evolution in the harsh environment of the poilar summer mesosphere region. This project concerned a review of our current knowledge of mesospheric ice particles including issues like nucleation, water vapour saturation pressure at mesopause temperatures, particle sedimentation, the thermal equilibrium of ice particles, and particle coagulation. The sensitivity of ice particle properties towards these microphysical uncertainties and external forcings was assessed using the community aerosol and radiation model for atmospheres (CARMA). Simulated ice particle size distributions have been analyzed applying Mie scattering calculations. Defining a hierachy of uncertainties, the simulation results suggest that the nucleation rate and number density of ice nuclei are most important. Our study of the cloud sensitivity to changes in the forcing variables further reveals that mesospheric ice properties most strongly depend on variation of water vapour, followed by temperature and eddy diffusion.

Publications

Rapp, M., and G. E. Thomas. 2006. Modeling the microphysics of mesospheric ice particles: Assessment of current capabilities and basic sensitivities, J. Atmos. Solar Terr. Phys., 68, 715-744.

The charge of mesospheric particles

Jörg Gumbel, Markus Rapp

Meteoric smoke particles and ice particles in the mesosphere become part of the D-region plasma. They are charged by the capture of electrons and ions. In fact, the measurement of the charged fraction of the particles has so far been the primary technique of detecting mesospheric particles *in situ* by rocket-borne instruments. Hence, it is of major importance to determine what fraction of the particles is actually charged as a function of particle properties and ionospheric conditions. Furthermore, the charge state of the particles can be expected to have major influences on processes like coagulation, nucleation etc.

With this project, we seek a microphysical description of processes contributing to the charging of particles in the "dusty plasma" of the D-region. We find that the charging of nanometer particles cannot be described by conventional continuum plasma equations. Rather, discrete charging models are needed in order to properly account for the low charged numbers and charge fluctuations in the mesosphere. Under usual mesospheric conditions more than 90% of 1-10 nm grains carry 1 negative charge. However, the average particle charge can be reduced significantly if the particle number density exceeds the undisturbed plasma density. An important conclusion is that measurements of the ambient plasma conditions are crucial for any studies of mesospheric smoke particles.

Publications

Gumbel, J., D. E. Siskind, G. Witt, K. M. Torkar, and M. Friedrich. 2003. Influences of ice particles on the ion chemistry of the polar summer mesosphere, J. Geophys. Res., 108(D8), 8436, doi: 10.1029/2002JD002413.

Smiley, B., S. Roberston, M. Horányi, T. Blix, M. Rapp, R. Latteck, and J. Gumbel. 2003. Measurement of positively and negatively charged particles inside PMSE during MIDAS SOLSTICE 2001, J. Geophys. Res., 108(D8), 8444, doi: 10.1029/2002JD002425.

Rapp, M., J. Hedin, I. Strelnikova, M. Friedrich, J. Gumbel and F.-J. Lübken. 2005. Observations of positively charged nanoparticles in the nighttime polar mesosphere, Geophys. Res. Lett., 32, L23821, doi:10.1029/2005GL024676.

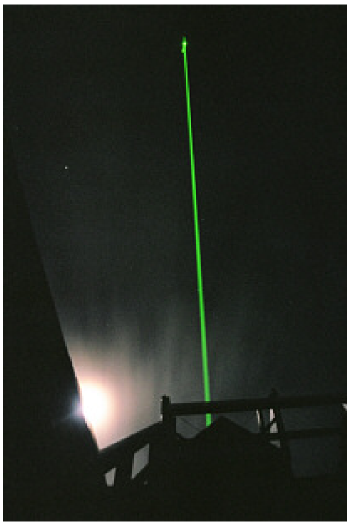
GROUND BASED STUDIES

Lidar measurements in the middle atmosphere

Misha Khaplanov, Jörg Gumbel, Jonas Hedin, Bodil Karlsson, Stefan Lossow, Linda Megner,Farah Khosrawi, in collaboration with P. Dalin, P. Voelger (Institute for Space Physics, Kiruna, Sweden), and K. H. Fricke (University of Bonn, Germany)

Since summer 2004 the MISU/IMI Atmospheric Physics group is involved in lidar measurements carried out at Esrange. The lidar at Esrange was 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 and noctilucent clouds. The formation of these clouds is closely connected to the dynamics of the polar atmosphere. The vicinity of the Scandinavian mountain ridge provides excellent opportunities for dynamics studies related to the activity and effects of mountain waves. Of particular interest in this respect is the collaboration between the Esrange lidar and the Norwegian Alomar lidar facility 250 km to the northwest of Kiruna. In addition, a major advantage of the lidar at Esrange is the possibility to associate with scientific rocket, balloon and aircraft campaigns that address arctic climate processes and middle atmospheric chemistry.

Since 2004, MISU/IMI has participated in lidar measurements concerning the middle atmosphere temperature structure, noctilucent clouds and polar stratospheric clouds. In particular, the lidar has been operated during the Swedish MAGIC rocket campaign and the German/Swedish ECOMA rocket campaign. In 2007, MISU/IMI will take over the responsibility for the Esrange lidar. The lidar will then be operated in close collaboration with the Institute for Space Physics in Kiruna.



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

Publications

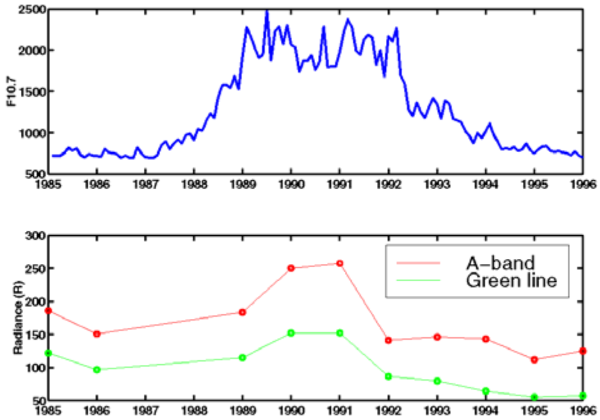
Blum, U., F. Khosrawi, G. Baumgarten, K. Stebel, R. Müller, and K. H. Fricke. 2007. Simultaneous lidar observations of a polar stratospheric cloud on the east and west side of the Scandinavien mountains and microphysical box model simulations, Ann. Geopys., in print.

Oxygen airglow

Jacek Stegman, in collaboration with P. Espy (British Antarctic Survey, UK)

The Atmospheric Physics group has conducted for many years a systematic study of temporal variability of the oxygen-related nightglow. This programme provided an extensive database comprising more than an entire solar cycle 22. Between 1985 and 2001 the measurements were made automatically on every clear night utilising a highly luminous 1-m Ebert-Fastie spectrometer and a battery of complementary filter photometers. Since 1993 these measurements were accompanied by measurements of the intensity and rotational temperature of the hydroxyl infrared airglow by means of a Fourier scanning spectrometer. This instrument has more recently been moved to a new site at Onsala Space Laboratory where it operated for another 4 years. As an example of the long-term variability, an obvious solar cycle signature can be seen in both the O(^{1}S) green line and the O_2 A-band nightglow. In contrast to these results, this dependence is not at all obvious in the OH signal.

On a shorter time scale the analysis of these data led to the discovery of springtime depletion of atomic oxygen in high latitude mesopause region more recently also labelled "a springtime transition". The transition appears to be a global phenomenon, associated with a planetary scale redistribution of atomic oxygen due to the reversal of the large-scale circulation patterns. The analysis work proceeds.



Yearly averged A-band and green line radiances for the solar cycle 22. The upper panel shows corresponding F10.6 flux as a measure for solar activity.

Publications

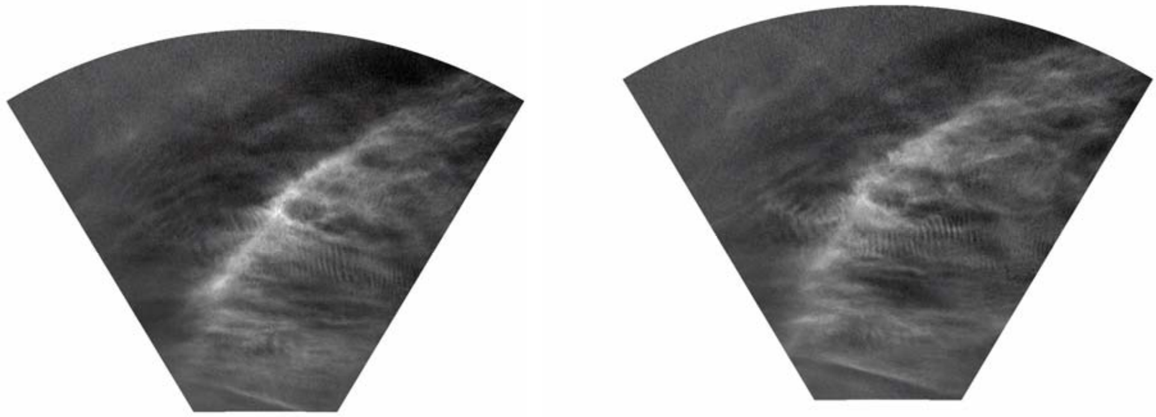
Beig, G., P. Keckhut, R. P. Lowe, R.G. Roble, M. G. Mlynczak, J. Scheer, V. I. Fomichev, D. Offermann, W. J .R. French, M. G. Shepherd, A. I. Semenov, E. E. Remsberg, C. Y. She, F. J. Lübken, J. Bremer, B. R. Clemesha, J. Stegman, F. Sigernes, and S. Fadnavis. 2003. Review of mesospheric temperature trends. , Rev. Geophys., 41, 4, 1015, 10.1029/2002RG000121. **WMO Norbert Gerbier-MUMM International Award 2005!**

Shepherd, G. G., J. Stegman, W. Singer, R. G. Roble. 2004. Equinox transition in wind and airglow observations, J. Atmos. Sol. Terr. Phys, 66, 481–491.

Weather in the mesopause region – NLC monitoring from the ground

Jacek Stegman,in collaboration with Hisao Takahashi (INPE, Brasil)

Since the summer 2004 the MISU Atmospheric Physics group has been conducting systematic, continuous monitoring of noctilucent clouds (NLC) from an observing site at the department. Digital photographs of northern sky are automatically taken at a rate of 1 picture per minute during the entire NLC-season (May - August). These picture series are merged into time-lapse movies, which, except for the climatological record of presence, extension and brightness of the clouds, also provide a remarkably clear visualisation of the dynamical characteristics of the mesopause region. The movies can be seen and downloaded at http://www.misu.su.se/~jacek/nlcmovies.html. Ultimately, the analysis of these time-lapse movies is expected to provide information on medium and small-scale mesopause dynamics. Parameters that we hope will be obtained are prevailing winds, information on wave motions – wavelengths and phase velocities. A possibility of back raytracing the waves to their sources by a technique earlier applied to airglow images is now being investigated.



Two NLC images of a display on 12/13 July 2006., taken 10 minutes apart. to demonstrate the spatial and temporal vaiability of different features in the NLC. The images have been processed to represent a projection on a horizontal plane.

Bi-static lidar studies of cirrus particle properties

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

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 form 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 finansed by the enhanced ALOMAR Research Infrastructure (eARI) under the 6th Frame Programme of the European Union.

ARCTIC STUDIES

The Polar Regions are the primary heat sinks for the global atmosphere and the Arctic Ocean with its sea ice is a major 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 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. 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 no good 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 regulates 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 Wold 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 (ERA-40) results.

Arctic Climate Impact Assessment

Erland Källén and Gunilla Svensson

The Arctic Climate Impact Assessment is a comprehensive review of natural, medical and social science research investigating Arctic climate change. The starting point is observed climate trends in the Arctic and projections for the future. The following chapters deal with impacts on a range of Arctic activities and natural phenomena. River flow, glacier and sea ice melting, forest growth, fisheries, human health and technological infrastructure are some of the impact areas covered in the report. We contributed to the chapter on future climate projections. Using results from the published literature we assessed climate change scenarios and discussed the uncertainties and limitations inherent in climate model projections. A special emphasis was put on signal to noise ratios and the importance of natural variability versus climate change induced by global warming. The assessment was presented at an international conference in Reikjavik in November 2004 and the book was published by Cambridge University Press in 2005.

ASCOS (The Arctic Summer Cloud Ocean Study)

Caroline Leck and Michael Tjernström

ASCOS (http://www.misu.su.se/~michaelt/ASCOS/ASCOS.htm) is a multi-month Arctic field experiment based on the Swedish icebreaker Oden, to be launched 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, in order to reduce the large uncertainty in projections of future Arctic climate. Model simulations of Arctic clouds are particularly deficient, impeding correctly simulated radiative fluxes, vital for the snow/ice-albedo feedback.

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 sea-ice interface to the cloud-topped boundary layer. The necessary interdisciplinary scientific approach will include marine biochemistry, aerosol and cloud chemistry/physics, and meteorology.

ASCOS will concentrate on an ice-drift operation when Oden will be moored to an ice floe, starting near the North Pole and drifting passively during the biologically most active period and into autumn freeze-up conditions, roughly July through September.

Ground-based remote sensing will provide continuous measurements of boundary-layer and cloud structure, while in-situ instruments and vertical profiling will provide detailed process-oriented information on boundary layer dynamics, atmospheric aerosol/cloud evolution and ocean/ice biochemistry. Instruments will be deployed both onboard Oden and on the ice. Detailed aerosol-cloud profiling will be conducte by helicopter from Oden. The aims of ASCOS are:

- To determine the atmospheric processes that control boundary layer clouds north of 80°N.
- To determine the formation and evolution of cloud condensation (CCN) and ice forming nuclei (IFN).
- To determine the role of boundary-layer clouds on the exchange of heat, radiation, momentum, gases and aerosols across the ocean/ice/air interface, and with the free troposphere.
- To determine the role of marine biochemical processes for CCN and IFN formation, with emphasis on the open lead surface microlayer.
- To test and implement reliable satellite algorithms for area-covering climate monitoring.
- To provide a high-Arctic mirror-station of intense atmospheric measurements that for a limited time will sample data similar to monitoring stations around the rim of the Arctic Ocean, for example at Barrow and Alert/Eureka.
- To contribute to the data archive over the central Arctic Ocean collected during IPY.
- To provide a comprehensive data set on the high Arctic climate system, for developing and testing of integrated climate models.

Distribution of atmospheric DMS in the high arctic - model study

Jenny Lundén, Gunilla Svensson and Caroline Leck

The main source of dimethyl sulfide (DMS) is from phytoplankton living in the surface layers of world oceans. DMS concentration varies with latitude, with the highest concentration found in the 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 (north of 80oN), the oxidation products (sulfuric acid, methane sulfonic acid and sulfur dioxide) of DMS 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 particularly important during the summer when particles are scarce in the Arctic atmosphere due to a limited influence form anthropogenic sources.

We have used the atmospheric part of Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) together with observations from three Arctic expeditions (International Arctic Experiment 1991, Arctic Ocean Experiment 1996 and 2001) to simulate the advection and mixing of DMS over the Arctic pack ice. Previous studies have shown that in the high Arctic the major source of DMS is from the open ocean close to the ice edge (marginal ice zone). Local sources over the pack ice (i.e. leads) have been found to be negligible compared to DMS that is advected from the marginal ice zone.

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. Analysis of the model results show that the major sources of gas phase DMS are found over the Barents, Kara and Greenland Seas. Together they correspond to approximately 94% of the total amount of DMS present over sea (north of 65o).

Over the pack ice the picture is quite different since all of the seas south of the ice edge contribute to the DMS concentration. Based on back-trajectory analysis, DMS reaching an area north of 88^{o} (during July and August) is found to originate mainly from Beaufort (23%) and Greenland (28%) Seas; the remaining seas are contributing with approximately 10% each.

Intercomparison of Dimethyl sulfide 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 CH3SO2 + O3 , and the thermal dissociation of CH3SO2 . 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.

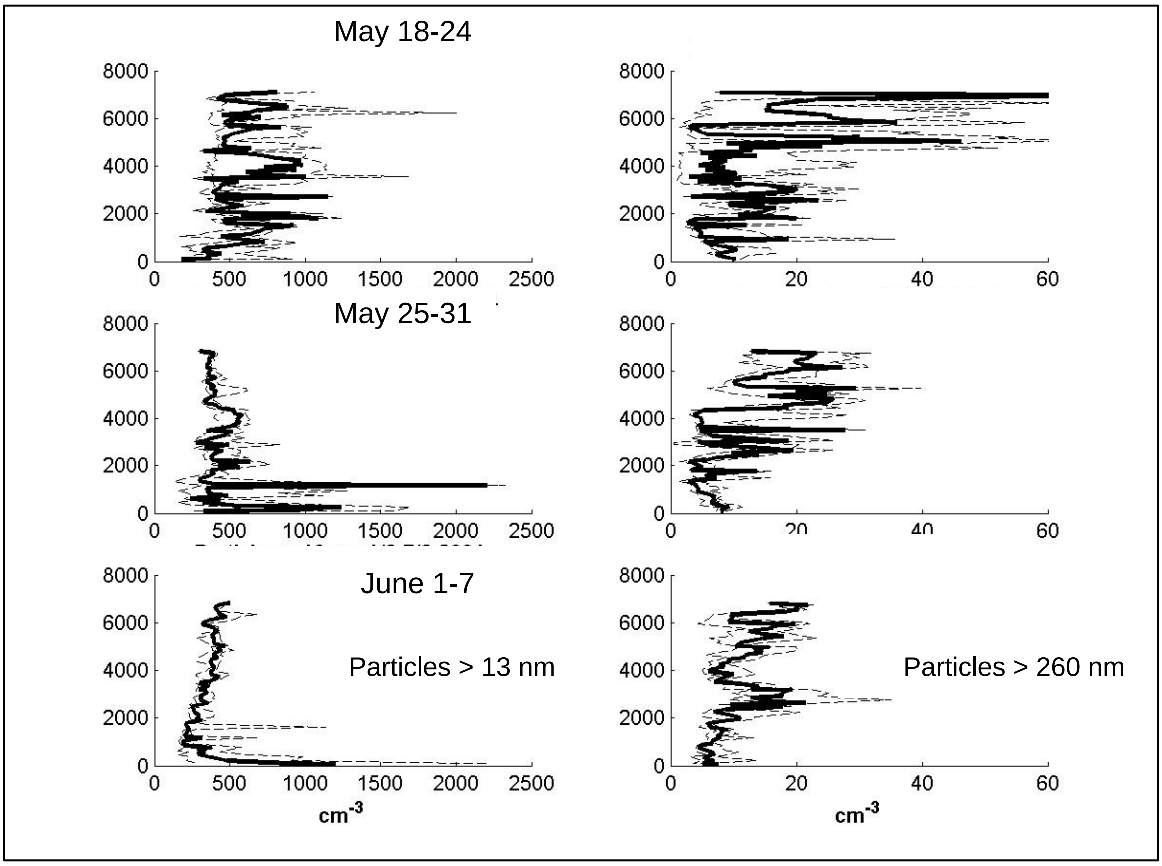
Publications

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

Arctic Study of the Tropospheric Aerosols, Clouds and Radiation (ASTAR)

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

During the years 2005 and 2006 detail evaluation of data collected during ASTAR 2004 airborne field campaign took place. Overall more than 60 hours of data from 22 mission flights is available covering 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 whole tropospheric column. 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 will be ASTAR 2007 campaign. This field experiment, which is part of the International Polar Year, in turn focuses on period of the Arctic Haze, when very different aerosol distribution in the Arctic troposphere dominated by anthropogenic influence will be studied. The Swedish group contributes 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. Both projects also form a core of the PhD work of Ann-Christine Engvall from MISU. More details can be found on: http://www.awi-bremerhaven.de/www-pot/astar/index.html

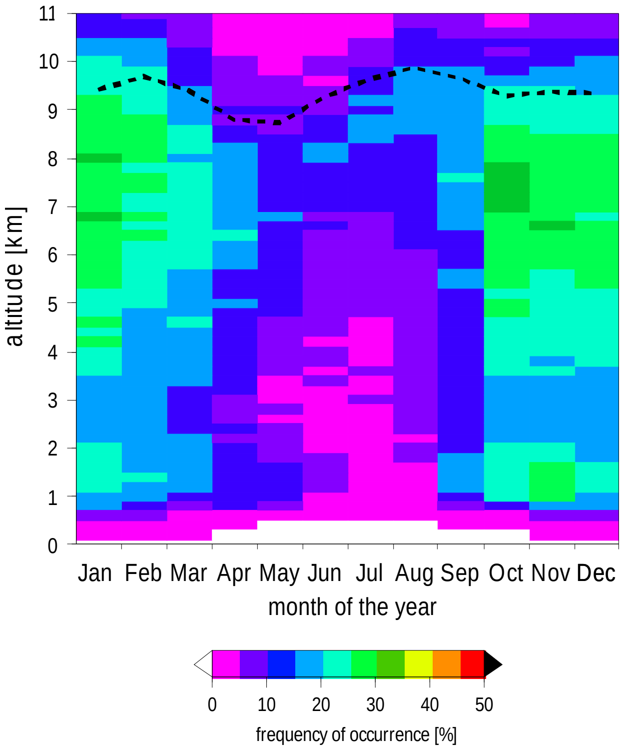


Aerosol vertical distribution during different parts of the ASTAR 2004 campaign for particles > 13 nm and > 260 nm indicating change in aerosol distribution through spring-to-summer transition in whole tropospheric column. Thick line shows median values, dotted lines indicates upper and lower quartiles. Vertical axis shows altitude in meters and horizontal axis particle concentration in cm-3.

Relative humidity long term trends in Arctic troposphere based on radisonde observations

Renatte Treffeisen (MISU, AWI - Germany), Johan Ström (SU/ITM), Radovan Krejci and Ann-Christine Engvall (MISU), Andreas Herber (AWI, Germany), Larry Thomasson (NASA, USA)

Detail analysis of daily radiosoundings from AWI Koldewey observatory, Ny Ålesund, Svalbard covering 14 years from 1991 to 2005 revealed new insight in distribution of humidity in the Arctic troposphere. It indicates that supersaturation over ice is a frequent condition in the Arctic middle and upper troposphere, particularly during the fall/winter. The mean ice supersaturation above 4 km altitude amounts to 15% on average, with a clear seasonal variation in winter of 17%, in spring of 12% and summer of 8%. The mean frequency occurrence of ice-supersaturation layers above 4 km is around ~17%. The ice supersaturation occurs mostly in a broad upper band between 6 and 9 km and undergoes a shifting towards higher altitudes in summer. The altitude distribution of ice-supersatured layers over Ny-Ålesund is similar to those of sub-visible cirrus clouds from the SAGE II experiment and thus confirms wide spread existence of sub-visible cirrus in the Arctic atmosphere. While one might expect the sounding to observe different frequencies than SAGE II, owing to the different sampling volumes (the SAGE II instrument samples horizontal distances of ~200 km), our result shows that there is a strong positive correlation between both independent observations indicating that supersaturated layers associated with sub-visible cirrus are likely to be a wide spread phenomenon over the Arctic. This brings an attention on important issue of the SVC influence on radiative budget in the Arctic, which is currently unexplored.



Monthly mean frequencies occurrence of ice-supersaturation layers. The frequency of occurrence are defined here as the number of observations in an 200 m altitude range where RH with respect to ice is greater than 100% divided by the total number of observations for this altitude range. Dashed line represents the mean tropopause height determined using the WMO's definition of the tropopause.

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

Bigg, E.K., C. Leck and L. Tranvik, 2004. Particulates of the surface microlayer of open water in the central Arctic Ocean in summer, Marin Chemistry, 91, 131-141.

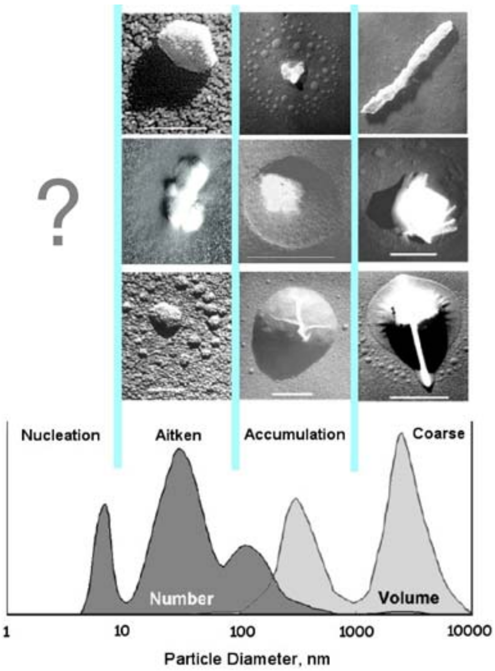
Biogenic particles over the central Arctic Ocean

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 microcolloids in most (50-90% of total number counted) of the predominantly sulphate particles. Their acquistion of sulfuric acid provides a much more direct and faster path to CCN status than having to grow from nucleated particles.

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. This invalidates the “CLAW” hypothesis by Charlson and coworkers in 1987 that DMS oxidation products alone produces particles of CCN size and poses a stronger possible link between marine biology, cloud properties and climate than is provided by DMS alone.



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

Leck, C., and E.K. Bigg, 2005a, Biogenic particles in the surface microlayer and overlaying atmosphere in the central Arctic Ocean during summer, Tellus 57B, 305-316.

Leck, C., and E.K. Bigg, 2005b, Evolution of the marine aerosol – A new perspective. Geophys., Res., Lett., 32, L19803. doi: 10.1029/2005GL023651.

New evidence of fog-related aerosol sources Over The Arctic Pack Ice In Summer

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

Fogs and low clouds are traditionally mainly seen as particle sinks due to in-cloud and sub-cloud scavenging processes. Only a few observations indicate gas-to-particle formation in the vicinity of clouds. However, no mechanisms have been deduced from these studies that could explain the new particle formation in the Aitken diameter range (25 - 70 nm) as hypothesized by Leck and Bigg in 1999 in the summer Arctic.

To search for evidence of a fog-related aerosol source in the high Arctic summer the present study covers aerosol size distribution data taken during two icebreaker expeditions in the summers of 1996 (AOE-96), and 2001 (AOE-2001). The main part of the working regions of both expeditions was the pack-ice-covered high Arctic north of 83°N for which no other aerosol data exist. The aerosol-physical instrumentation detected particles from 4 nm to 45 µm diameter and included a DMPS, an APS, and an FSSP-100. With the latter instrument fog episodes could be delineated in the aerosol database. For further interpretation the 41-channel submicrometer number size distributions were aggregated into a maximum of four lognormal size distributions called ultrafine, Aitken, accumulation and coarse modes.

Two approaches were followed, (1): time-independent size-dependent frequencies of occurrence of modal concentrations during fogs with different thresholds of drop concentrations were compared to respective data from fog-free periods. With increasing fog intensity modes in interstitial particle number concentrations appeared in particular in the size range around 80 nm that was nearly mode-free in clear air, (2): in a dynamic approach, fog periods were defined objectively with six parameters including thresholds of drop number and LWC, length of fog period and, importantly, the length of fog-free period after fog dissolution. The result is depicted in Figure X.

When including 80 fog-free post-fog minutes average Aitken mode concentrations increased strongly above their respective fog-period-medians in both years before maximum drop numbers were reached during the fog. We interpret the results of both approaches as strong indications of fog-related aerosol source processes as discussed in Leck and Bigg in1999 that need to be elucidated with further data from dedicated fog experiments in future Arctic expeditions in order to understand the life cycle of the aerosol over the high Arctic.

Publications

Heintzenberg, J., C. Leck, W. Birmili, B. Wehner and M. Tjernström, 2006. Aerosol number-size distributions during clear and fog periods in the summer high Arctic: 1991, 1996 and 2001, Tellus 58B, 41-50.

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.

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.

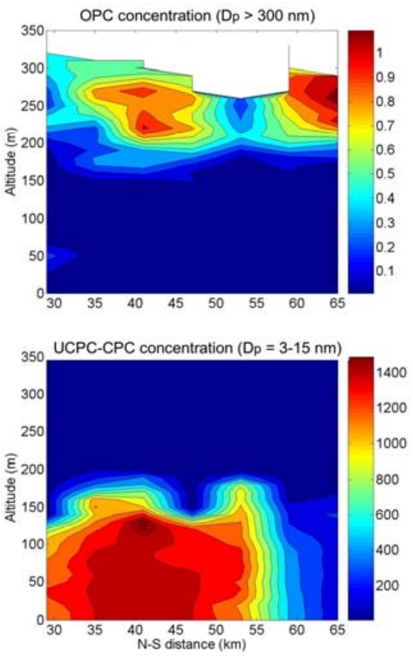


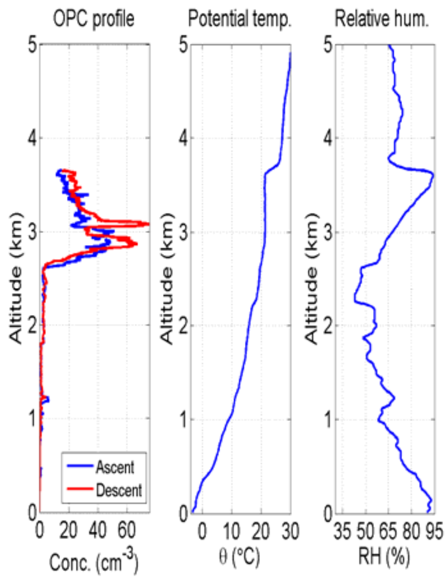
Figure X. Profiles of accumulation mode and ultrafine mode particles collected during AOE-2001

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 contineta1 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.

Arctic boundary-layer temporal variability

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 nonlinear 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., 2005: The summer Arctic boundary layer during the Arctic Ocean Experiment 2001 (AOE-2001). Boundary-Layer Meteorology, 117, 5 – 36

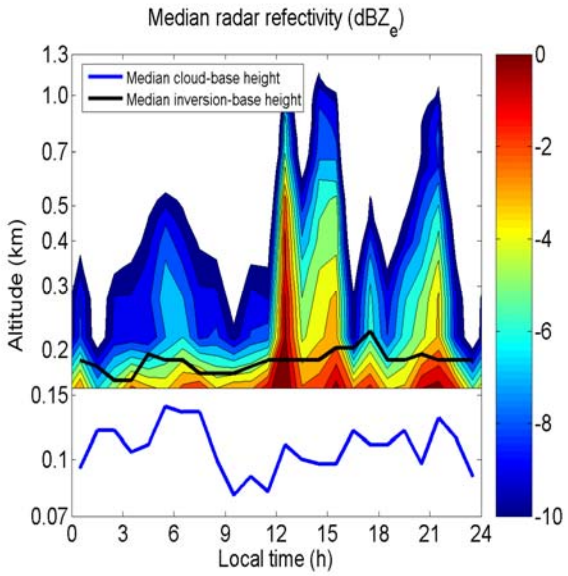
The arctic boundary-layer diurnal cycle

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., 2005: The summer Arctic boundary layer during the Arctic Ocean Experiment 2001 (AOE-2001). Boundary-Layer Meteorology, 117, 5 - 36.

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

Artic boundary layer vertical structure

Michael Tjernström and Linda Hildeberg

The vertical structure of the Arctic summer boundary layer was examined with a suite of remote and in-situ instruments 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 boundary-layer depth (the height to the first inversion base) is typically between 200 and 400 m. When more than one inversion is present in the profile, the first is usually a surface inversion. The boundary layer was typically topped by a stable inversion, usually < 500 m deep and varying in strength from usually a few, to > 10 °C in more extreme cases. Unlike most other boundary layers, the absolute moisture often increases over the capping inversion, and cloud tops appear inside the inversion rather than at the inversion base as expected. The height to the lowest cloud top was usually 300 to 800 m, typically 100 to 500 m higher than the inversion base.

The deepest boundary layers with the strongest inversions were often associated with trajectories with short travel-time from the open ocean. Additionally, the largest increase in absolute moisture across the inversion occurred in the shallowest boundary layers; those with longer travel time since contact with the open ocean. We hypothesize that the increasing moisture across the inversion and the appearance of clouds in the stable inversion is related to the air mass transformation of the deep warm and moist, well-mixed oceanic boundary layer to the shallow Arctic cool and cloudy boundary layer in an environment where low concentrations of cloud condensation nuclei is a limiting factor on cloud formation.

Publications

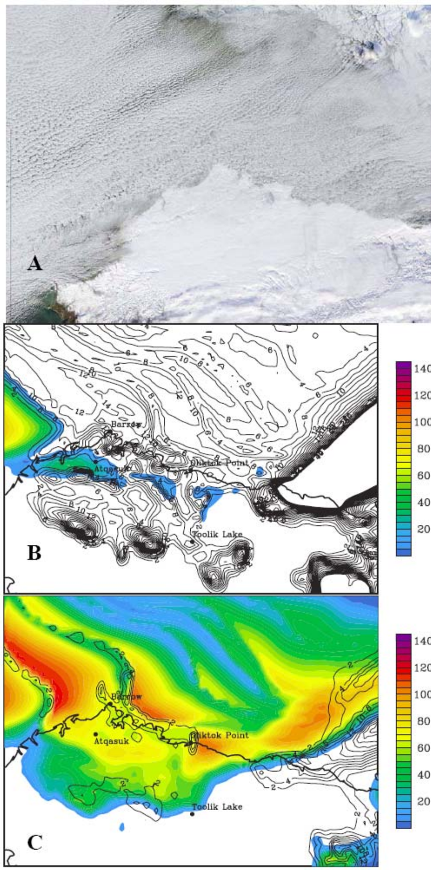
Tjernström, M., 2005: The summer Arctic boundary layer during the Arctic Ocean Experiment 2001 (AOE-2001). Boundary-Layer Meteorology, 117, 5 – 36

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

Tjernström, M., M. Žagar, G Svensson, J Cassano, S. Pfeifer, A. Rinke, K. Wyser, K. Dethloff, C. Jones and T. Semmler, 2005: Modeling the Arctic Boundary Layer: An evaluation of six ARCMIP regional-scale models with data from the SHEBA project. Boundary-Layer Meteorology, 117, 337 - 381.

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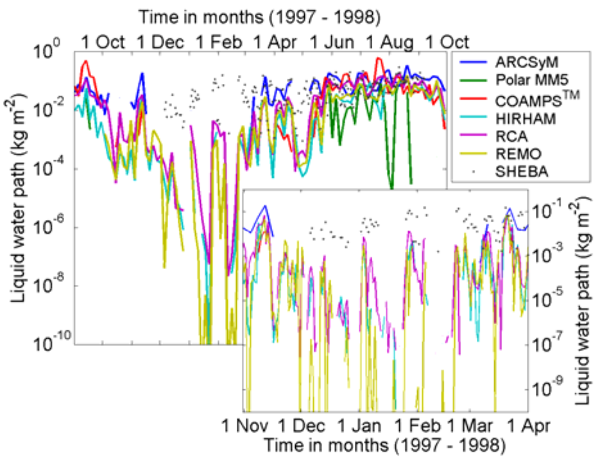
Arctic regional climate modeling

Michael Tjernström, Mark Zagar, Gunilla Svensson, Johannes Karlsson and Joe Sedlar, 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 (SMHI, Sweden) and Colin Jones (University of Montreal)

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 different regional climate models, using the same horizontal resolution and 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.

The first ARCMIP intercomparison project uses data from the SHEBA (Surface Heat Budget of the Arctic Ocean) ice-drift experiment in 1997/1998. Using six regional models and data from the SHEBA ice camp, several model deficiencies have been isolated. While the turbulent momentum flux is systematically somewhat high but shows a reasonable correlation to the observations. The magnitude of the turbulent heat fluxes (sensible and latent) on the other hand are climatologically overestimated by a factor of two to four regardless off sign and the correlation to the observations are generally below 30%. While the climatology of cloud variables is in general quite reasonable, the direct correlation to the observations are quite low, thus although clouds appear in reasonably correct fashion and frequency, they rarely do so at the right time. Perhaps the most severe problem with all the models is a systematic lack of liquid cloud water in winter, which was shown to cause a systematic negative bias in down-welling long-wave radiation in cloudy conditions of about 15-20 Wm-2. Summer low-level clouds were under predicted in most models, which was compensated by to much high clouds.



Time series of modeled and observed liquid water path for the whole year; insert shows the winter. Note the large deficit of liquid water in all models in winter

Publications

Tjernström, M., M. Žagar, G Svensson, J Cassano, S. Pfeifer, A. Rinke, K. Wyser, K. Dethloff, C. Jones and T. Semmler, 2005: Modeling the Arctic Boundary Layer: An evaluation of six ARCMIP regional-scale models with data from the SHEBA project. Boundary-Layer Meteorology, 117, 337 - 381.

Rinke, A., K. Dethloff, J. Cassano, J.H. Christensen, J.A. Curry, J.-E. Haugen, D. Jacob, C.G. Jones, M. Køltzow, A.H. Lynch, S. Pfeifer, M. C. Serreze, M. J. Shaw, M. Tjernström, K. Wyser, M. Zagar, 2006: Evaluation of an Ensemble of Arctic Regional Climate Models: Spatial Patterns and Height Profiles. Climate Dynamics, DOI 10.1007/s00382-005-0095-3.

Wave flow simulations over Arctic leads

Thorsten Mauritsen and Gunilla Svensson, Branko Grisogono (Zagreb University, Croatia)

The Arctic Ocean is covered with ice throughout the year. However, wind stress and divergent ocean currents generate long cracks in the ice called open leads. These are typically a few kilometers wide and hundreds of kilometers long. We investigate the flow over Arctic leads using a mesoscale numerical model under idealized conditions, typical of both summer and wintertime.

We find that Arctic leads may be the source of standing atmospheric internal gravity waves during both seasons. The summertime wave may be compared with the wave generated by a small ridge, however with the phase reversed. The mechanism for exciting the wave is found to be the internal boundary layer developing due to the horizontal variations in surface temperature and roughness length. During the more exploratory wintertime simulations, with substantial temperature difference between the lead and the ice surface, we find that secondary circulations and intermittent wave-breaking may occur. The effects of the lead appear far downstream.

Publications

Mauritsen, T., G. Svensson and B. Grisogono, 2005: Wave flow simulations over Arctic leads. Boundary-Layer Meteorology, 117, 259-273.

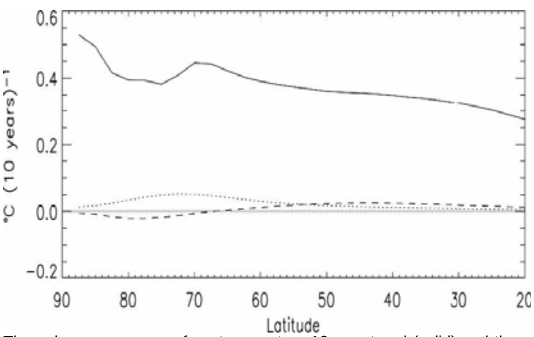
Impact of large scale dynamic changes on artic climate

Rune Grand Graversen, Michael Tjernström and Erland Källèn

While it is clear that the Arctic is warming faster than the global average, there are several hypotheses to explain this fact. For example, it is believed that changes in the albedo caused by changes in the snow and ice coverage have contributed to the larger warming of the Arctic than elsewhere. In this project we attempt to estimate the possible impact of mid-latitude, large-scale circulation changes on the Arctic Surface Air Temperature (SAT) trend using ERA-40 reanalysis data from the European Center for Medium range Weather Forecast (ECMWF). We focused on two different indicators of large-scale, atmospheric circulation: The vertically integrated total atmospheric, northward flux of energy (ANET) across 60 °N, and the so-called Arctic Oscillation (AO) index. The linkages between these two indices and the Arctic SAT trend during 1979-01were estimated using regression technique.

It is found that the Arctic SAT is sensitive to variability of the ANET across 60 °N so that a warming (cooling) of the Arctic follows large (small) ANET with a lag of a few days. In addition, a small but statistically significant part of the Arctic SAT trend can be attributed to the ANET due to a small, overall increase in the later. However, a split up of the linkage into the individual seasons reveals that in spring and autumn, the ANET explainers at least 20 % of the Arctic warming.

In contrast to many previous studies that have pointed to linkages between the AO and various aspects of the Arctic climate, we see no significant direct impact of the AO on the Arctic SAT trend. Moreover, the previously increasing AO trend is found to be broken for the last few years of the time series. Thus, although the AO probably remains an important indicator for various aspects of the large-scale atmospheric circulation, its importance for the Arctic SAT development is probably less significant than previously believed.



The polar mean near-surface temperature 10-year trend (solid) and the parts of this that can be statistically explained by the energy transport (dotted) and by the AO (dashed). The polar mean is defined as the mean from the pole to any given latitude (on the x-axis).

Publications

Graversen, R. G., 2006: Do changes in the midlatitude circulation have any impact on the arctic surface air temperature trend? Journal of Climate, 19, 5422-5438.

The vertical structure of the Artic warming amplification

Rune Grand Graversen and Michael Tjernström

Several hypotheses have been presented to explain the fact that the Arctic is warming faster than any other region on Earth. Most have the common feature that they rely on feedback related to processes at or near the surface. For example, it is believed that changes in the albedo caused by changes in the snow and ice coverage have contributed to the larger warming of the Arctic. Since the Arctic lower troposphere is generally stably stratified, it would be natural to expect that the largest warming is found close to the surface. In this project we attempt to estimate the vertical structure of the amplified Arctic warming, using the ERA-40 reanalysis data.

First we compare the vertical structure of the lower troposphere with observations from the SHEBA experiment to ascertain that 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, even in winter with shallow very stable inversions. A special consideration 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.

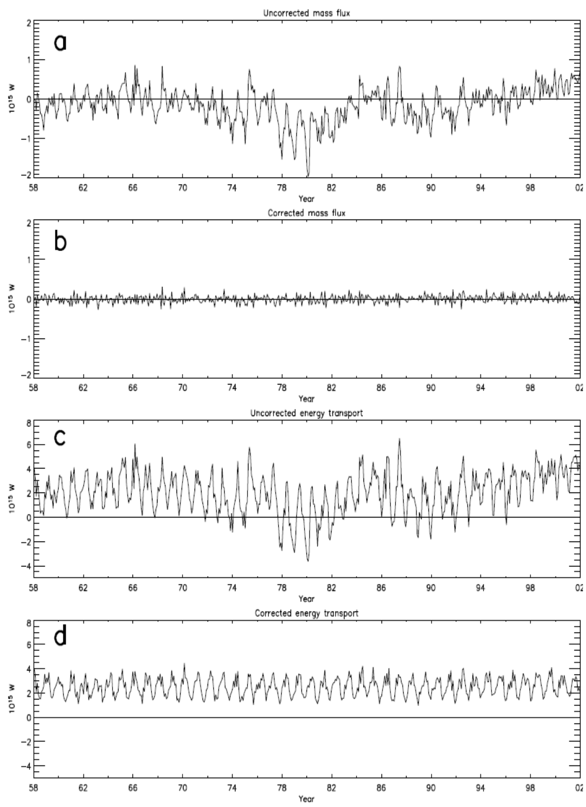
We then investigate the vertically resolved trend of the Arctic warming. We find that during winter, the largest warming does occur close to the surface, as expected from several of the hypotheses, for example that a more shallow ice cover allows for a larger heat flux to the atmosphere during winter. A surprising result is that the summer warming, which from surface data has been concluded to be small due to the presence of melting ice, is almost as large as that in winter but has a maximum around 1-2 km which has not been directly observed due to the lack of soundings in the central Arctic Ocean.

Atmospheric mass transport inconsistencies in the ERA -40 reanalysi

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 reanalyses, ERA-40 exhibits unrealistic behavior as regards some atmospheric quantities, including the water-budget and the Brewer-Dobson circulation. In addition, the results presented here show significant mass-budget inconsistencies. Over inter-annual time-scales (> 1 year), the vertically averaged, meridional mass transport is unrealistic and cannot be explained on the basis of naturally occurring physical processes. This mass-inconsistency yields, in addition, spurious signals in meridional fluxes of other atmospheric quantities such as energy. 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.

Here it is hypothesized that unrealistic mass-fluxes are present in ERA-40 due to inherent properties of the data assimilation process. 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.



Time series of (a) uncorrected and (b) corrected mass flux and (c) uncorrected and (b) corrected net energy flux both across 60ºN integrated vertically and meridonally from ERA-40 data.

ADDITIONAL PUBLICATIONS: ARTIC STUDIES

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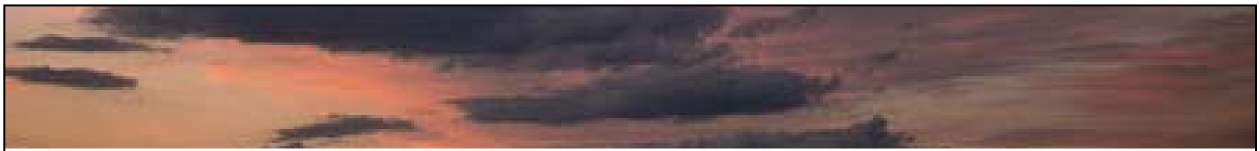

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Department of Meteorology, Stockholm University (MISU)		
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IMI/MISU		
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PHD THESES

PhD THESES 2003-2006

Michael Norman, 2003, Chemical characteristics of atmospheric aerosols. The influence of natural and man-made sources and sinks

Iréne Lake, 2003, Some aspects of the deep-water flow through the Faroe-Bank channel

Anna Nikolopoulos, 2003, Theoretical and observational aspects on deep-water overflows.
With emphasis on the Denmark Strait

Marco Seifert, 2003, Aerosol-cirrus interactions. Comparing clean and polluted air masses

Kristina Eneroth, 2003, Atmospheric transport of carbon dioxide and other trace species in high northern latitudes

Lars Gidhagen, 2004, Emissions, dynamics and dispersion of particles in polluted air

Stefan Söderberg, 2004, Mesoscale dynamics and boundary-layer structure in topographically forced low-level jets

Nedjeljka Žagar, 2004, Dynamical aspects of atmospheric data assimilation in the tropics

Oskar Parmhed, 2004, Near surface atmospheric flow over high latitude glaciers

Peter Tunved, 2004, On the lifecycle of aerosol particles. Sources and dispersion over Scandinavia

Jenny Brandefelt, 2005, Atmospheric circulation regimes and climate change

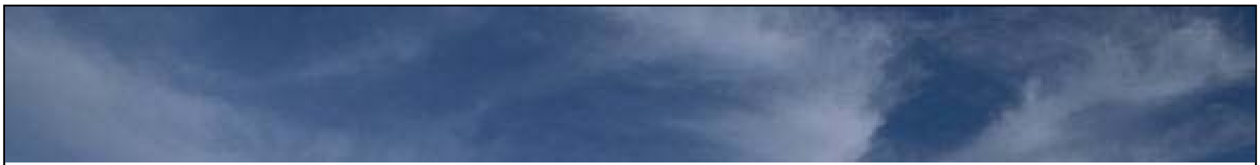
Bror Fredrik Jönsson, 2005, Some concepts of estuarine modeling

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



ACRONYMS

ACRONYMS

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

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

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