



# **LPMR-09**

The 9<sup>th</sup> International Workshop on  
Layered Phenomena in the  
Mesopause Region

**Stockholm, Sweden, July 12-15, 2009**



**Stockholm  
University**

# **ABSTRACTS**

(in alphabetic order)

[www.misu.su.se/lpmr09](http://www.misu.su.se/lpmr09)

## **A working group for determining the state-of-the-art in mesospheric ice particle sizes**

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One of the most fundamental yet still poorly constrained elements of mesospheric clouds is the distribution of particle sizes. Currently there are several satellite and ground based instruments routinely observing mesospheric ice particle sizes; however, it is not clear that the agreement among the various instruments is good. The average mode radii reported by the experiments can differ by factors of two or more. Some of this discrepancy is most likely due to the differing sensitivities among the various experiments. Some is also most likely rooted in the different assumptions made in determining particle sizes. Since no experiment can measure the distribution of ice particle sizes directly, some assumptions must be made. It is now common to assume a normal distribution of particle sizes. Many experiments must constrain the distribution further and assume a width as well. In order to compare the various observations of particle sizes, we must understand the influences of the different sensitivities and assumptions and place the data sets on some common framework.

In recent months a working group has formed that includes representatives from those experiments currently observing mesospheric cloud particle sizes as well as others who possess relevant expertise in modeling and in mesospheric ice properties. Our goal is to determine the state-of-the-art in mesospheric ice particle size distributions and determine the cause of any discrepancies among the current observations. We have formulated an approach to comparing our data sets that accounts for differing sensitivities and to the extent possible uses similar distribution assumptions for each. We are currently in the process of implementing that approach. By the time of the LPMR meeting, we will have held numerous teleconferences, met in person twice, and held a workshop to analyze and interpret the comparisons. In the presentations following this one, participants will discuss their data sets, contributions to the working group, results achieved so far as part of this effort as well as other results they have. In this introductory talk, we will summarize the approach that the working group has taken, overview our results so far, and discuss the next steps.

## **FTIR-studies on water nanoparticles in the aerosol phase**

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A last-minute presentation given by G. Witt. No abstract available.

## **New lidar developments for the mesosphere**

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Active remote Sensing by lidar allows to study processes on small (<1km, 5min) to medium scales (6h). As most lidar instruments can be internally calibrated reliable databases for climatological studies can be compiled. Due to the rather complicated instrumental setup only a few stations are available for sounding the mesosphere by lidar and spacebased lidar is still in the development phase.

# **A network of ground based digital cameras for online observation of NLC from 63N to 37N: Image analysis, examples and comparison to other Instruments**

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The IAP has developed a digital camera system allowing to record and transfer high resolution images (>7 Mpixel) of NLC online. A network of 7 cameras is in operation for more than two seasons covering latitudes from 63N to 37N. Additional extremely high resolution studies (~100 m, ~10 seconds) have been performed to investigate small scale developments in NLC.

During the ECOMA / MASS rocket campaign, performed in summer 2007 from the Andoya rocketrange, large scale NLC / PMC were observed by satellite, lidar and camera from polar to mid latitudes. We investigate the morphology of the cloud with different instruments to put the results from the sounding rockets into a broader perspective. Lidar observations from Kühlungsborn (54N), Esrange (68N) and ALOMAR (69N) show a highly dynamic NLC layer. The cloud was detected by cameras from Trondheim (63N), Juliusruh (55N) and Kühlungsborn. Using the camera observations at Trondheim and the wind information from the meteor radar at ALOMAR we investigate the formation and destruction of NLC structures.

## **Additional Information:**

We will bring one camera system as example (will be mounted in middle Sweden after LPMR). We will show the results of the camera network online.

## **Observation of three parameters to describe noctilucent clouds particles above ALOMAR (69°N)**

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Noctilucent clouds (NLC) are the visible manifestation of icy particles persistently present in the polar summer mesopause region. Their formation is a rather complicated physical process depending on atmospheric background parameters, such as temperature and water vapor, which are highly variable and hardly to measure directly at the altitudes of interest.

The ALOMAR RMR-lidar, located in Northern Norway at 69°N, is capable to observe NLC on a regular basis since 1997. From single color measurements (532 nm) basic cloud parameters like brightness, altitude and occurrence frequency are derived. From the backscatter coefficients of three widely separated wavelengths (355nm, 532nm, 1064nm) we deduce simultaneously three particle properties describing the ensemble of particles in the sounding volume. The vertically resolved mean size, width of size distribution and number density allows detailed studies of the observed variations and helps to understand the physical processes involved. We investigate conceptual differences of the lidar technique to other instruments sounding NLC. Furthermore we present microphysical aspects of the observed variations throughout the NLC layer.

## **Ambipolar diffusion with hot electrons: PMSE overshoots or undershoots?**

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Bellan [1] recently proposed that PMSE is caused by Bragg scattering of radar waves from metal-coated aerosol particles instead of from gas-phase electrons, the mechanism traditionally assumed. The metal-coated aerosol model was motivated by observations [2] that maximum PMSE is sometimes correlated with bite-outs in which case the gas-phase mechanism would imply a reduction in PMSE. In a Comment [3], Rapp and Lubken argued that the excellent agreement between predictions and observations of PMSE overshoot in HF heating experiments validates the gas-phase explanation.

A detailed analysis of the overshoot problem has been conducted by extending Hill's [4] ambipolar diffusion equations to include variable electron temperature and the resulting coupled changes in (i) ice particle charge  $Z$  and (ii)  $\lambda$ , the ratio of aerosol-attached electrons to gas-phase electrons. Ambipolar diffusion of the Bragg component of electron density is found to be mathematically equivalent to the problem of a fictitious particle with coordinates  $\{X,Y\}$  seeking a localized minimum in a two dimensional potential  $U(X,Y)$  while constrained to a line in  $\{X,Y\}$  space determined by initial conditions. The stopping point of the fictitious particle corresponds to the diffusion problem final state. Consideration of such final states shows that HF heating produces either overshoot or undershoot depending on the initial values of  $Z$  and  $\lambda$ . Overshoot occurs only if  $\lambda \ll 1$ , but PMSE amplitude is presumed to be very small in this regime. When  $\lambda \sim 1$  or larger, the model predicts undershoot. This is because strong electron heating causes nearly all Bragg-component electrons to become deposited on aerosol grains so few remain to contribute to PMSE. Since PMSE is presumed associated with  $\lambda \sim 1$ , observations of overshoot are not in good agreement with the predictions of the Hill ambipolar diffusion equations extended to take into account the coupled changes in  $\lambda$  and  $Z$  resulting from electron heating.

Re-examination of the metal-coated aerosol model shows that it too has shortcomings. Spherical metal-coated particles are subject to an internally produced polarization electric field that nearly cancels the incident radar electric field at the aerosol surface. This greatly attenuates the reflected signal as in Rayleigh scattering. However, the polarization field will be become substantially reduced with resulting significant reflectivity if the aerosols have a needle shape with large aspect ratio. Enhanced radar reflectivity of needle-shaped aerosols is qualitatively similar to radar chaff, albeit on a much smaller scale. Needle-shaped aerosols will be subject to less sedimentation than spherical aerosols because of increased surface to area ratio.

[1] P. M. Bellan, *JGR-Atmospheres*, 113, D16215, 2008.

[2] M. Rapp, F. J. Lubken, and T. A. Blix, *Atmospheric Chemistry and Physics*, 3, 1399, 2003.

[3] M. Rapp and F. J. Lubken, *JGR-Atmospheres* (in press).

[4] R. J. Hill, *JGR-Space Physics*, 83, 989, 1978.

# **Are low-latitude mesospheric radar echoes also of non-turbulent origin? A comparison between mesospheric winter echoes from polar and low latitudes**

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Climatology studies with the Indian MST radar, located at Gadanki (13.5° N, 79.18° E), have shown that daytime low-latitude mesospheric echoes (LLME) occur throughout the year (Kishor Kunmar et al, 2006). However, most strong and frequently occurred echoes were observed in preferred height regions (70-75 km) and seasons (equinox). No conclusive evidence is obtained on the aspect sensitive nature of these echoes. Some similarities were found between LLME and polar mesosphere winter echoes (PMWE) that have been investigated in Kiruna, Sweden with ESRAD MST radar. It was suggested that PMWE are generated when incident infrasound waves are partially reflected from a region of strong gradient of temperature or wind shear (Kirkwood et al., 2006). In order to better understand the similarities/differences between PMWE and LLME, several special experiments were conducted using Indian MST 53 MHz radar during 23 November 2008 - 12 April 2009. The Rayleigh lidar at Gadanki complemented radar experiments by providing temperature profiles on some of the days. We will present the results concerning LLME reflectivity, spectral parameters, aspect sensitivity, and wave signatures and compare them with those of PMWE.

## **AIM CIPS observations of the last four PMC seasons using an SBUV-type analysis**

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We provide an overview of the latest four Polar Mesospheric Cloud (PMC) seasons as seen by the Aeronomy of Ice in the Mesosphere (AIM) Cloud Imaging and Particle Size (CIPS) experiment. These PMC results are based on an algorithm similar to the Solar Backscatter Ultraviolet instrument (SBUV) algorithm. The latest algorithm improvements are described. We provide an evaluation of CIPS nadir data by comparing to SBUV data. Using CIPS data at forward scattering angles leads to a higher sensitivity of cloud detections. Thus this facilitates correlations between PMC data and measurements of temperature and water vapor from the Microwave Limb Sounder (MLS). Changes in the Rayleigh background during a season and from season to season are correlated to concurrent ozone satellite measurements such as MLS.

## **Long-term changes of mesospheric summer echoes at polar and middle latitudes**

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Strong VHF radar echoes have been observed during summer months at polar latitudes (polar mesosphere summer echoes, PMSE) but also at middle latitudes (mesosphere summer echoes, MSE). These echoes are closely connected with small ice particles, thus containing information about mesospheric temperature and water vapour content. But the (P)MSE depend also on the ionisation due to solar wave radiation and precipitating high energetic particles. Observations with VHF radars at Andenes (69.3°N; 16.0°E) since 1994 and at Kühlungsborn (54.6°N; 11.8°E) since 1998 until 2008 are used for investigations of the solar and geomagnetic control of the (P)MSE and its latitudinal dependence. After the elimination of solar and geomagnetically caused contributions, MSE and PMSE reveal slightly positive trends. However, due to the limited observation period, the significance levels of the detected (P)MSE trends are small. Nevertheless, the trends are in general agreement with long term changes of PMC and NLCs.

# **Gravity Wave influences on the large-scale PMC occurrence variability: A study from PMC structures observed from the CIPS experiment on the AIM satellite**

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In this presentation we look at new evidences of atmospheric gravity wave (AGW) influence on the large-scale PMC occurrence variability observed from the Cloud Imaging and Particle Size (CIPS) experiment on the Aeronomy of Ice in the Mesosphere (AIM) spacecraft. CIPS is one of the three instruments on board the AIM spacecraft that was launched into a 600 km sun-synchronous orbit on April 25, 2007. CIPS images have shown distinct wave patterns and structure in Polar Mesospheric Clouds (PMCs), around the summertime mesopause region, which are qualitatively similar to ground based photographs of Noctilucent Clouds (NLCs). The structures in PMCs are generally considered to be manifestations of upward propagating AGWs. Variability of AGW effects on PMCs reported by several lidar sites have led to the suspicion of longitudinal differences in this relationship. This study compares the longitudinal variability in the CIPS observed wave occurrence frequency with CIPS measured PMC occurrence frequency and albedo along with mesospheric temperatures from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on board the TIMED spacecraft. Our results show a distinct anti-correlation of wave structures detected in PMCs with cloud occurrence frequency and strong correlations with temperature perturbations supporting the idea of gravity wave induced cloud sublimation. Maps of the locations of the observed wave events in the PMC fields show regions of high wave activity in both hemispheres. In both hemispheres, while the longitudinal variability in observed wave structures show changes from the 2007 to 2008 seasons, there exists regions of both low and high wave activity common to the two seasons. These persistent features may explain the some of the observed differences in PMC activity reported by ground-based lidar distributed at different longitudes. The propagation directions of the waves are considered to infer information about possible sources for the AGWs. We also present preliminary results from the Community Aerosol and Radiation Model for Atmospheres (CARMA 2D) model of AGW effects on PMCs. The model shows differences in ice particle size and brightness of PMCs depending on the scale and periods of the AGWs.

## **A comparison between ground-based observations of noctilucent clouds and Aura satellite data**

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A comparison is made between ground-based observations of noctilucent clouds (NLC), obtained with a network of automatic digital cameras, and Aura satellite data (the MLS instrument).

The advantage of the ground-based network is that the cameras are located along nearly the same latitude circle producing comparable measurements. Both techniques allow tracing and studying (both in space and time) the large-scale atmospheric phenomena around the mesopause such as 2-day and 5-day planetary waves. The Aura MLS data (water vapor and temperature) demonstrate reasonable values around the summer mesopause fostering NLC formation in June through August.

The 2-day and 5-day planetary waves, extracted from the Aura MLS temperature field, have definite influence on the occurrence frequency, geographical distribution and brightness variations of NLC.

An attempt is made to estimate what type of these planetary waves has a greater effect on the NLC variability.

## **Studies of the upper mesosphere and lower thermosphere from the International Space Station**

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The aim of the project is to study a number of unique layered phenomena of the Earth's atmosphere and gravity wave activity, from the International Space Station (ISS). These phenomena are noctilucent clouds (NLC) and atmospheric emissions: nightglow and dayglow.

NLC are the highest clouds in the Earth's atmosphere at the 80-85 km altitude. The nightglow and dayglow is the intrinsic atmospheric emission at about 90 km altitude.

Two compact automatic imagers (each composed of four digital cameras of high-resolution and high-sensitivity) are supposed to be placed onboard the ISS. The first imager will be used to carry out observations of the O<sub>2</sub> atmospheric band (0,0) emission at 762 nm. The second imager, equipped with three interference filter at different wavelengths (450, 540, 700 nm), will be used to determine physical properties (the size distribution) of NLC ice particles and their variability in space and time.

Two successful previous experiments, conducted onboard the ISS in 2001 and 2004-2006, demonstrated the robustness and importance of the proposed technique for studying of the nightglow, dayglow and gravity wave activity in the lower thermosphere.

## **PMC trends derived from SBUV version 4 data**

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Detection of polar mesospheric clouds (PMCs) by Solar Backscatter Ultraviolet (SBUV) instruments requires identification of the cloud against the atmospheric Rayleigh scattering background, which is dominated by stratospheric ozone absorption. This method has limitations in its ability to identify faint PMCs, particularly at high latitudes. We have recently modified the SBUV algorithm to more effectively constrain the calculated background albedo, and thus improve our detection of faint PMCs. This revised algorithm has been used to create a Version 4 SBUV PMC data set that extends through the SH 2008-2009 season. The PMC brightness threshold used as one of the detection tests in the SBUV algorithm can be defined in different ways, and the subjective choice between these definitions will affect the occurrence frequency and brightness values that we produce. Calculation of long-term PMC trends from SBUV data also depends on adjustments for local time variations (which are not well-defined) and the method used to merge 30 years of data sets from seven separate instruments. Nevertheless, we will present our updated analysis of trends in PMC occurrence frequency and albedo using these Version 4 data.

## **Local time variations in PMCs observed by Aura OMI**

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The Ozone Monitoring Instrument (OMI) is a hyperspectral nadir-viewing spectrometer that has been flying on the EOS Aura spacecraft since July 2004. OMI data cover the spectral range 265-500 nm, and can be analyzed using a modified version of the Solar Backscatter Ultraviolet (SBUV) polar mesospheric cloud (PMC) detection algorithm. OMI's smaller pixel size (13 km x 48 km at nadir) and 110 degrees cross-track viewing geometry provide observations for 6-8 consecutive orbits, covering 11-13 hours in local time, at most locations between 70 degrees and 90 degrees latitude on a daily basis. This capability allows the direct examination of PMC local time variability in occurrence frequency and brightness as a function of latitude and longitude. We have recently modified the OMI PMC detection algorithm to significantly improve the quality and cross-track continuity of the data analysis. We will present results for both Northern Hemisphere and Southern Hemisphere locations.

# **Correlative analysis of ice clouds properties and mesospheric temperature and water vapour during polar summer seasons of 2002-2008**

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In this work, mesospheric temperature and water vapor concentration measured by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on board the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite are used to study the properties of PMCs with respect to the surrounding atmosphere. The cloud parameters, namely location, brightness, and altitude, are obtained from the observations made by the Optical Spectrograph and Infrared Imager System (OSIRIS) on the Odin satellite. We utilized two approaches to tracing the correlations between ice particles and pressure, temperature and water vapour in mesosphere. First, we analysed the weekly averages of the above mentioned parameters in high latitude mesospheric regions and established the general correlation between the PMC occurrence rate and average temperature of the PMC forming area as well as between the PMC peak height and the mesopause altitude. The second approach used simultaneous common volume measurements by SABER and OSIRIS with stringent overlapping criteria to relate the instantaneous 'snapshots' of the atmospheric profile to coincidental ice particles observation. We have found about a thousand of such coincidental events measured in both hemispheres from 2002 until 2008. The relation between PMC parameters, frost point temperature, and gaseous water vapour content in and below the cloud is discussed. Interseasonal and interhemispheric differences and trends in the above parameters, as well as in PMC peak altitudes and mesopause altitudes are evaluated.

# **The properties of noctilucent clouds above ALOMAR**

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NLC are an attractive tracer for dynamic processes in the atmosphere. Cloud parameters show variabilities at different time scales, ranging from minutes to decades, including tidal and solar cycle variations. Between 1997 and 2008 NLC have been observed by the ALOMAR Rayleigh/Mie/Raman (RMR) lidar in Northern Norway at 69N, 16E. During a total of 3657 measurement hours, being well distributed over the 12 years, season and local time, NLC were detected for 1457 hours, which is the largest NLC data base acquired by lidar.

NLC occurrence, altitude as well as brightness show a remarkable persistence concerning diurnal and semidiurnal variations, which allows to conclude that NLC above ALOMAR are significantly controlled by atmospheric tides. From 1997 to 2007 the year-to-year occurrence frequency of strong NLC is anti-correlated to solar activity until 2004 and decreases monotonously thereafter. The water content of the clouds is unchanged or even decreasing after 2004.

The combination of basic cloud parameters and microphysical particle properties allows detailed studies of the observed variations and helps to understand the physical processes involved. We investigate and compare variations from yearly to hourly time scales. We also investigate the feasibility of the new Doppler Rayleigh Iodine System to perform detailed studies of the cloud movement by direct detection of the Doppler shift by moving NLC particles.

## **Bite-outs and other "Black Holes" for mesospheric electrons**

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*D*-region electron densities significantly depend on the background mesosphere. The relevance of particles larger than molecules as only recently been appreciated. In the polar summer very pronounced depletions have been observed, but also at other seasons free electrons are lost, however without necessarily leading to conspicuous profiles. A collection of confirmed bite-outs and suspicious night-time profiles are presented, which suggest that at all seasons meteoric smoke particles impact on the *D*-region ionosphere.

## **SOFIE data – current and projected results**

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The Solar Occultation for Ice Experiment (SOFIE), aboard NASA's Aeronomy of Ice in the Mesosphere (AIM) satellite, is taking measurements at 16 wavelengths for study of noctilucent clouds (NLCs). It is providing measurements in northern and southern polar latitudes with extremely high sensitivity to NLCs while acquiring simultaneous temperature, water, ozone and methane measurements. Additional accomplishments, including cosmic smoke detection and temperature profiles independently determined up to 60 km by refraction bending angle, are first-time achievements in remote sensing. This poster presents an overview of current results and an assessment of data quality, limitations and uncertainties. It also reviews challenges and objectives for future data releases.

## **Eight years of NLC observations by Odin**

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The Odin satellite is currently in its 15th season of noctilucent cloud observations. This poster describes NLC data obtained from the Optical Spectrograph and Infrared Imager System (OSIRIS). These data comprise cloud occurrence, cloud brightness, and particle size information. We present a general overview over the Odin NLC database with focus on interannual, seasonal and latitudinal climatologies. Of particular interest are also hemispheric differences and diurnal variations.

Odin is now run as an ESA Third Party Mission and data is made available within this framework. The mesospheric observation programme has successively been extended and comprises now daily measurements during the noctilucent cloud season.

# **An extended spectral analysis of noctilucent clouds observed by the Odin satellite**

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Since the launch of the Swedish-led Odin satellite in 2001, the Odin observation programme for the summer mesosphere has continuously been extended. Summer seasons now feature daily limb measurements up to 110 km, reaching to 82°N in the Northern Hemisphere and to 90°S in the Southern Hemisphere. The continued operation of Odin is now provided through an ESA Third Party Mission.

This presentation gives an overview over the Odin NLC database and the underlying retrieval ideas. Information on NLC particle sizes is inferred from spectra of scattered sunlight obtained by the Optical Spectrograph and Infrared Imager System (OSIRIS). While OSIRIS covers the spectral range 275-815 nm, the spectral analysis of NLC has been restricted to wavelengths shorter than 310 nm. At these wavelengths absorption by stratospheric ozone prevents uncertainties in the scattering analysis due to upwelling radiation. As a downside, this narrow spectral range does not allow the retrieval of more than one NLC size parameter, e.g. an effective radius. An improved spectral calibration of OSIRIS in combination with the limb scattering model SASKTRAN has now made it possible to better quantify upwelling radiation and multiple scattering. In this paper we show how this allows an extension of the NLC analysis into the visible part of the spectrum.

As part of the working group for mesospheric ice particle sizes, we discuss the constraints that an extended spectral analysis can put on the ice population. We also discuss constraints that may be deduced from a statistical co-analysis of OSIRIS and other instruments.

# **Diurnal tides in the upper mesosphere water vapor content measured by ground based microwave spectroscopy**

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For more than a year has our high time-resolution spectrometer been running at the ALOMAR observatory in Northern Norway. It measures the 22.235 GHz rotational transition line of water vapor in horizontal and vertical polarization. The high sensitivity of the instrument allow us to resolve daily variations in the water vapor distribution in the upper mesosphere. Tides in the upper mesosphere are predicted to affect physical parameters such as the water vapor content. We here present the current capabilities to detect such tides by ground based microwave spectroscopy. Projected detection of the modeled water vapor diurnal variations are compared to actual measurements.

# **Polar mesospheric summer and winter echoes modulated by artificial electron heating**

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Both the Polar Mesospheric Summer Echoes (PMSE) and the Polar Mesospheric Winter Echoes (PMWE) are affected by artificial electron heating which make the radar backscatter vary in what is called an overshoot characteristic cycle (OCC). In an OCC the PMSE and PMWE radar backscatter is very rapidly reduced, often by a large factor, as soon as the electrons are heated. There is normally some recovery of the signal, especially for the PMSE, during the heater on phase but in some cases there may also be a further moderate or small weakening of the signal. As the heater is switched on, the typical behavior is that the signal rapidly increase (overshoot) to a level which for PMSE can be up to 6-7 times the radar signal before the heater was switched on. For the PMWE the overshoot is very low, only up to a few times 10%. The heater is kept switched off for ca 2-3 min to allow the volume sampled by the radar to relax back to its undisturbed phase.

We discuss various aspects of the PMSE and PMWE and their reaction to artificial electron heating in overshoot cycling, mainly on the assumption that the radar reflection is caused by electron gradients controlled by irregularities in the density of charged dust particles. We discuss if and how the backscatter strength may vary with dust size and density but we also show from observations, that other factors must have a strong influence on at least the PMSE strength. We also look at similarities and differences between the overshoot for PMSE and PMWE. The very small overshoot for PMWE indicate that mainly small nanometer sized particles are involved. The observations for PMSE at VHF (224 MHz) and UHF (930MHz) show that finite diffusion time effects are not important and that the basic overshoot model, which assume instant adjustment of the electrons and ions as the heater is switched on and off, seem to be adequate. However, the PMWE observed at 56 MHz indicate that the simple overshoot model cannot fully explain the observed OCC profiles and that other effects, possibly a finite diffusion time of electrons and ions or an adjustment of the dust density profiles during the heater cycling, or other effects must be included.

# **Depolarization lidar applied to Polar Mesospheric Clouds**

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It has been of general assumption in many PMC studies that the cloud shapes are spherical allowing for the use of Mie theory to describe their scattering properties. A test of this assumption is to probe the PMCs with a depolarization lidar. Owing to the small particle size and visible wavelengths of lidar systems, the amount of depolarization will only be a few percent. This imposes the requirement that any polarization cross talk introduced by the lidar optical system must be very small. In this paper, we perform a polarization analysis of the Greenland ARCLITE lidar. We evaluate cross talk contributing factors in the system to employ hardware compensation and notably reduce systematic effects on depolarization measurements. With the aid of software correction techniques, depolarization error contribution from the system falls below the shot noise limit. This technique ensures non-bias detection of PMC depolarization by the Greenland ARCLITE lidar with its accuracy limited by shot noise.

## **The PHOCUS project – particle interactions in the polar summer mesosphere**

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The PHOCUS project (Particles, Hydrogen and Oxygen Chemistry in the Upper Summer mesosphere) will study mesospheric particles and their interaction with their neutral and charged environment. Starting out from first ideas in 2005, PHOCUS has developed into a comprehensive venture that connects to a number of new and renewed scientific questions. Interactions of interest comprise the charging and nucleation of particles, the relationship between meteoric smoke and ice, and the influence of these particles on gas-phase chemistry. In particular, the role of meteoric particles as condensation nuclei for mesospheric ice particles has recently been challenged. New challenges also concern our understanding of charging mechanisms in the mesospheric D-region. The possible redistribution of water vapour by mesospheric ice raises questions about local supersaturation and gas-phase O<sub>x</sub>/HO<sub>x</sub> chemistry. A more controversial topic is the idea of heterogeneous surface chemistry on mesospheric particles.

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

## **First satellite observations of meteoric smoke in the upper atmosphere**

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We report the first remote observations of meteoric smoke particles from satellite, by the Solar Occultation For Ice Experiment (SOFIE) onboard the Aeronomy of Ice in the Mesosphere (AIM) platform. Smoke particles are the leading candidate for the nucleation of ice particles that make up noctilucent clouds and polar mesospheric summer radar echoes, however, the role of smoke is a subject of debate because the current understanding of these particles has been derived mostly from theory combined with limited observations. SOFIE measurements indicate smoke particles from roughly 35 to 85 km altitude and a strong seasonal cycle with reduced smoke abundance during polar summer. The observations agree favorably with two meteoric smoke models, confirming that reduced smoke in summer is due to meridional transport. These new measurements are important to understanding a variety of other phenomena including mesospheric ion and neutral chemistry, nucleation of polar stratospheric clouds which are critical in ozone hole chemistry, and the long term accumulation of extraterrestrial material in polar ice.

## **PMC particle size from SOFIE observations**

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Measurements from the Solar Occultation For Ice Experiment (SOFIE) on board the Aeronomy of Ice in the Mesosphere (AIM) satellite are used to derive polar mesospheric cloud (PMC) particle effective radii and the parameters of a Gaussian size distribution. SOFIE observations are also used to derive ice particle shape, mass density, and the column ice abundance (or ice water content). The retrieval methods are reviewed and results from two southern and two northern PMC seasons are described.

## **Mesospheric wave activity at high latitudes during summer and their relation to PMSE**

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Continuous MF and meteor radar observations at Andenes (69°N, 16°E) allow detailed studies of the wind field in the mesosphere and lower thermosphere, which is characterized by a high variability due to the presence of gravity and tidal waves as well as planetary waves. Variations of the gravity wave activity are examined in relation to the filtering processes due to the changes of the background winds, tides and planetary waves. The presence of transient planetary waves in the mesosphere is indicated by long period oscillations of the wind field.

Particular attention is directed to the influence of the activity of waves with different scales on the occurrence of polar mesospheric summer echoes (PMSE) as observed with the ALWIN VHF radar at Andenes. Motivated by microphysical model simulations (e.g. Rapp et al., 2003), the predominant role of long period gravity waves and their interannual variations in relation to mean PMSE occurrence rates are studied using observations from 1999 - 2008. Detailed investigations during the MIDAS/MaCWAVE campaign in summer 2002 gave evidences of an unusual summer circulation and warmer temperatures in the mesopause region arising from interhemispheric coupling due to the influence of strong planetary waves in the southern hemisphere (e.g. Becker and Fritts, 2006). An analysis of mesospheric gravity waves reveals a markedly reduced gravity wave activity above 80 km, and enhanced gravity wave activity below 78 km. This result confirms a downward shift of the gravity wave breaking in the summer mesopause as suggested by rocket experiments and model calculations. Caused by temperatures closer to the sublimation point of water vapour, long period variations of meridional winds impact the PMSE in summer 2002 more than during other PMSE seasons.

# **The morphology of Noctilucent Clouds and Polar Mesosphere Summer Echoes: The role of air parcel trajectories from gravity waves**

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Virtually all Noctilucent Clouds (NLC) display propagating gravity waves (buoyancy waves) of long and medium horizontal wavelengths. From other observations of atmospheric gravity waves in this height region, we would expect them to look like deepwater waves. However, the wave structures in NLC usually resemble shallow water waves, except at the shortest wavelengths. (See, for instance, both images on the conference website, <http://www.misu.su.se/lpmr09>.) Many Polar Mesosphere Summer Echoes (PMSE) in VHF radar data show single, double or multiple layers of strong echo power which slowly descend and jump to a higher layer from time to time. The descent agrees with the assumption of a downward propagating gravity wave, with apparent jumps to the same phase one vertical wavelength higher up. Furthermore, precise radar observations of vertical velocity in the PMSE displays indicate significantly more vertical convergence than divergence as well as a slight majority of downward velocities in the volumes with strongest PMSE power. Aerosol particles (ice particles) of typically 20 to 50 nm equivalent radius create the NLC visible by eye and by lidar as well as the Polar Mesosphere Clouds (PMC) observed from satellites. The same particles can modify the spatial distribution of free electrons and positive ions to create PMSE when the charge density is large enough. This is independent of whether they are large enough to be visible or not. This presentation shows how the air parcel trajectories in a typical gravity wave field near the summer polar mesopause can explain the structure and morphology described above, and how the NLC and/or PMSE particles tend to collect at certain positions in the gravity field, moving with those positions as the wave propagates horizontally and downward.

# **Direct observation of micrometeoroid differential ablation: Insights into the deposition of meteoric chemical constituents in the MLT**

D. Janches, L. P. Dyrud, S. L. Broadley and J. M. C. Plane

Meteoric smoke is believed to be the condensation nuclei (CN) for the formation of ice particles in the Mesosphere and Lower Thermosphere (MLT). These are the necessary precursor for the formation of ice particle layers, noctilucent clouds (NLC) and polar mesospheric summer echoes (PMSE). The smoke forms from the re-coagulation of meteoric material ablated from the billions of extraterrestrial particles entering our atmosphere every day. However it is not clear, from all the chemical constituents evaporated from the meteoroid, which is the best candidate for the formation of smoke. This makes the accurate understanding of the meteoroid ablation process a crucial step towards the complete elucidation of the microphysics of ice layers. We present the first direct observation of meteoroid differential ablation, providing evidence that this is the main mechanism through which micron-sized particles deposit their mass in the MLT. These results are obtained utilizing two state-of-the-art models to correlate temporal behavior in the received signal of observed radar meteor head-echoes with the precise moment at which a particular chemical constituent is predicted to evaporate from the main body. Prior to this work, differential ablation was merely a hypothesis and there was no known mechanism for remote sensing the individual chemical constituents of meteors so small that they create no measurable light. The coupling of a differential ablation model with an astronomical model of the meteoric flux combined with large aperture radar observations, will therefore enable the origins of meteoroids within the solar system to be related to the deposition of their constituents in the upper atmosphere, and shed new light on their aeronomical impacts.

# **Atmospheric coupling processes inferred from models and measurements of noctilucent clouds**

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The year-to-year variability in both northern and southern hemispheric noctilucent clouds is surprisingly linked to the planetary wave activity in the winter stratosphere in the opposite hemisphere. In spite of the great distance involved, this inter-hemispheric link is suggested to account for a significant part of the year-to-year variability, the intra-seasonal variability and the hemispheric differences that have been observed in these high-altitude clouds. First suggestions for an ‘inter-hemispheric coupling’ came from a model study by Becker and Schmitz (2003). Since then, several models and observations have confirmed the existence of this link and contributed to a better understanding of the mechanism behind it. An overview of the current knowledge of the inter-hemispheric coupling and its effects on the summer polar mesopause region is presented in this talk. The results shown in this presentation are based on NLC observations from the Odin satellite and the Aeronomy of Ice in the Mesosphere (AIM) satellite, as well as on model results from two GCM models; the extended Canadian Middle Atmosphere Model (CMAM) and the Whole Atmosphere Community Climate Model (WACCM), the latter including parameterized PMC ice mass. As an important complement to the GCM studies, results from the Kühlungsborn Mechanistic general Circulation Model (KMCM) are shown, which has been used to pinpoint the proposed mechanism behind the inter-hemispheric coupling.

# **Polar Mesosphere Winter Echoes modulated by the HF heating experiments**

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The mechanism behind the modulation of Polar Mesospheric Winter Echoes (PMWE) observed in active HF heating experiments [Kavanagh et al., 2006] is considered.

To a first-order approximation, scattering from Bragg-scale gradients caused by turbulence can be considered to be proportional to the electron density squared [Lübken et al., 2006]. We showed in Kero et al., (2008) that, under this assumption, the electron density variation calculated by the detailed Sodankylä Ion Chemistry model (SIC) predicts correctly both the magnitude and the timescale of the modulation observed with the EISCAT VHF radar. The electron density modulation was due to electron temperature dependent negative ion chemistry.

In this study, the role of the negative ions in the PMWE modulation is reconsidered based on a set of Finnish EISCAT heating experiments during 2006 and 2008.

## **Similarities and Differences between Arctic and Antarctic PMSE – ESRAD, MARA and Davis**

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The Moveable Atmospheric Radar for Antarctica (MARA) has been operated during two PMSE seasons at Wasa/Aboa in Antarctica (54.5 MHz, 73° S, 13° W). The ESRAD radar has operated continuously since 1996 in Kiruna (68°N, 21°E), and the Davis radar (55 MHz, 69°S, 78°E) has operated almost continuously since 2003. Comparisons of the PMSE strength between the sites show relatively small differences, with similar occurrence rates and local-time variations. Seasonally, PMSE occurrence correlates well with the occurrence of temperatures below the frost point as measured by the Aura-MLS instrument. PMSE height, and its variation over the season, show distinctly different behaviour between the two hemispheres. These features can also be found in temperature structure (Aura-MLS) and in noctilucent clouds (Odin and AIM satellites). Inter-hemispheric coupling may provide an explanation.

# **Multi-year characteristics of polar mesospheric clouds measured by lidar at Davis, Antarctica**

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We present climatologies of Polar Mesospheric Cloud (PMC) characteristics derived from Rayleigh Lidar measurements during austral summers spanning 2001/02 to 2008/09 at Australia's Davis station in Antarctica (68.6°S, 78.0°E).

We find that on average PMC are higher (by ~1 km), have lower backscatter and are less prevalent than observed at similar northern hemisphere latitudes. These findings are consistent with other southern hemisphere measurements, and provide further demonstration of inter-hemispheric differences in the climate of the summer mesopause region.

We discuss diurnal, seasonal and inter-annual variations in PMC characteristics using wind data from co-located atmospheric radars, and satellite-derived temperature and water vapor measurements.

## **Mass-analysis of charged aerosol particles in a PMSE/NLC layer during the ECOMA/MASS rocket campaign**

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Two sounding rockets were launched carrying the MASS instrument (Mesospheric Aerosol Sampling Spectrometer) from the Andoya Rocket Range (Norway) the first week of August 2007. In addition, the payloads carried electric field booms, a photometer for cloud brightness, and Faraday rotation antennas for electron density. The charged aerosol particles were detected using the MASS instrument, an electrostatic mass spectrometer. The MASS instrument collects charged aerosols in four different mass ranges on four biased collector plates, one set for positive particles and one set for negative particles. The first sounding rocket was launched into PMSE and NLC on 3 August. The sun was 4 degrees below the horizon and NLC were seen in the previous hour at 83 km by the ALOMAR RMR lidar. NLC were detected at the same altitude by rocket-borne photometer measurements. The charged aerosol data from the MASS instrument shows the density of negative particles with radius greater than 3 nm rising sharply at 83 km and continuing until 89 km, collocated with PMSE detected by the ALWIN radar. Particles with 1-2 nm radii with both signs of charge and particles with less than 1 nm radius charged positively were detected at 86-88 km. The occurrence of the positive particles in the smallest size range in the region of lowest temperature suggests that NLC origin is nucleation and growth on ions. Initial charge-density estimates are several thousands per cubic centimeter for each of these size ranges. The second rocket launch was 6 August into PMSE without NLC. The 1-2 nm particles were seen from 85.4 to 87.4 km, again with both signs of charge, while larger sizes were nearly absent as expected.

# **The interhemispheric coupling of the middle atmosphere circulation in an idealized model**

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

# **Microphysical parameters of mesospheric ice clouds derived from calibrated PMSE observations at 53.5 MHz and 500 MHz**

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It is now common belief that polar mesosphere summer echoes (PMSE) are caused by turbulent scatter in combination with a large Schmidt number caused by the presence of charged ice particles. In this study, we test this theory with calibrated observations obtained with the EISCAT Svalbrad radar (ESR) and the SOUSY Svalbard radar (SSR), which are collocated near Longyearbyen on Svalbard (78°N, 16°E). The ESR and SSR operate at frequencies of 500 MHz and 53.5 MHz (corresponding to Bragg wavelength of 0.3 m and 2.8 m), respectively. According to the above mentioned theory, the radar scattering should either come from a spectral range dominated by a  $k^{-3}$ -dependence (the so-called viscous-convective subrange) or from a spectral range which is dominated by an exponential decay at the smallest spatial scales (the so-called viscous-diffusive subrange). According to this theory, the expected reflectivity ratio should thus be equal to or larger than the ratio of the frequencies to the third power. Our experimental results show that 85 % of the observations are in full accord with this expectation, i.e., the ratio of the SSR volume reflectivity to the ESR volume reflectivity is larger than a value of 816 (the ratio of these two frequencies to the third power) and is hence in reasonable agreement with theory. The remaining 15 % which show too small ratios can be attributed to an incomplete filling of the scattering volume of the SSR which is significantly larger than that of the ESR. These results give strong support that PMSE is indeed created by turbulent scatter in the presence of a large Schmidt number. Applying this theory to our observations we derive Schmidt numbers and radii of the charged aerosol particles and find excellent agreement with expectations from microphysical models and independent observations of microphysical ice parameters.

## **Measurements of polar mesospheric clouds in infrared emission by MIPAS/ENVISAT**

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Polar mesospheric clouds (PMCs), also called noctilucent clouds (NLCs), occur at the coldest regions of the atmosphere near the summer high latitude mesopause where they form a layer of a few kilometers wide, peaking near 83 km and located at latitudes poleward of 50 degrees. They are being discussed as potential early indicators of global change since they are very sensitive to temperature and water vapour concentration in that region. NLCs have been intensively studied by observations from ground, rockets (in situ), and space, as well as by sophisticated models. The observations of PMCs in emission in the infrared is, however, very difficult because of the low icy particle volume concentration and the very cold mesopause temperatures, thus requiring very sensitive instruments for their detection. In this paper we report on the infrared emission (10-12  $\mu\text{m}$ ) of polar mesospheric clouds as measured by the MIPAS instrument on Envisat. We analyze the measurements taken by MIPAS in its NLC mode (39-102 km) during July 2005. The shape of MIPAS spectra in this region is very similar to that simulated for ice particle emission at low temperatures (below 150 K) and hence provide a further evidence of the water ice nature of the PMC particles. The simultaneous measurements of temperature from the MIPAS CO<sub>2</sub> 15  $\mu\text{m}$  region allows us to retrieve the ice particles volume density. 3D (longitude, latitude, altitude) distributions of the ice particles volume density retrieved from MIPAS spectra for 19-21 July 2005 in the Hemisphere are presented and analyzed from their comparison with previous measurements and model predictions.

# **Odin/SMR water measurements in the summer mesopause region**

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Since 2001 measurements of the Sub-Millimetre Radiometer (SMR) aboard the Odin satellite provide information of several parameters interesting for the understanding of the mesosphere on a global scale. This instrument measures the thermal emission of several trace gases in the frequency range between 480 GHz and 580 GHz. Mesospheric water vapour information is derived from the 557 GHz emission line. Here an overview of the Odin/SMR water vapour results with focus on the summer mesopause region will be presented. In the centre of attention will be the absolute amount of water vapour, the inter-annual variability and inter-hemispheric differences of the water vapour distribution in this region.

# **Stratospheric and solar cycle effects on long term variability of mesospheric ice clouds**

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Ice layers in the summer mesosphere at middle and polar latitudes are very sensitive to background conditions, such as temperatures, water vapor, and transport. These layers appear as 'noctilucent clouds' (NLC) and 'polar mesosphere clouds'(PMC) when observed by optical methods from the ground or from satellites, respectively. A newly developed model of the atmosphere called LIMA (Leibniz Institute Middle Atmosphere Model) nicely reproduces the mean conditions of the summer mesopause region and is used to study the ice layer morphology (LIMA/ice). The background variability has a major impact on the geographical distribution of ice clouds. Since ice layer formation is very sensitive to the thermal structure of the mesopause region the morphology of NLC and PMC is frequently used to study, for example, inter-hemispheric differences of upper mesosphere temperatures and long term variations. Model runs of LIMA/ice are now available for 1961 until 2008. We present results regarding inter-annual variability of upper mesosphere temperatures, water vapor, and ice clouds, and also long term and solar cycle variations. There are no greenhouse gas trends present in the current version of LIMA/ice. We still find temperature trends which result in significant trends in ice layer brightness and occurrence rates (less so in altitude). The model results are compared with lidar and satellite borne (PMC) observations. LIMA reproduces the main features of solar cycle and trends deduced from long term observations. We present an explanation of the trends in the background atmosphere and in ice layers in terms of variations in the stratosphere. From the long term runs and from sensitivity studies we find significant correlations between ice layer parameters and the background atmosphere which are used to derive climate changes in the middle atmosphere.

## **PMC retrievals from CIPS: algorithm description, error analysis and cloud detection sensitivity**

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The Cloud Imaging and Particle Size (CIPS) instrument is a nadir-viewing UV imager aboard the Aeronomy of Ice in the Mesosphere (AIM) satellite. CIPS measures scattered solar radiation at 265 nm using a unique four-camera configuration providing an instantaneous field of view of 120° (along-track) by 80° (cross-track). Full instrument resolution for nadir pixels is 1 by 2 km. By combining data from multiple cameras, CIPS observes a given volume of air (or ice) at seven different scattering angles ranging from 20 to 180°. Level 4 data processing, which includes PMC detection and cloud parameter retrievals, typically uses binned data with a spatial resolution of 5 x 5 km. The detection algorithm discriminates a PMC signature from the Rayleigh-scattered background by exploiting the fact that the former is strongly forward scattered, whereas the background signal is symmetric about 90° scattering angle.

We present an overview of the CIPS data processing and retrieval algorithms, concentrating on the separation of cloud and background Rayleigh signatures in the CIPS measurements. The primary CIPS PMC retrieval parameters – albedo, particle mode radius, and ice water content – are discussed and retrieval error estimates are given.

We also discuss analyses of the CIPS cloud detection sensitivity, with the goal of deriving an effective cloud brightness (albedo) threshold. This threshold varies with solar zenith angle (and hence latitude) due to both the CIPS measurement sampling characteristics and the geophysical variation in the Rayleigh background. Simulations show that it also depends on the cloud particle radius, as well as the desired spatial resolution of the cloud product (data binning). By quantifying these dependencies we can account for the residual effects of varying detection sensitivity in interpreting the cloud occurrence frequencies observed by CIPS, particularly the latitude dependence. This understanding will also provide a quantitative foundation for comparing the CIPS observations with other data sets.

## **Odin, a rebirth as a pure aeronomy research satellite**

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The aeronomy and astronomy scientific mission Odin, a Swedish led project in cooperation with Canada, Finland and France, was designed for a lifetime of two years. As the satellite now is in its ninth year of operation, it has exceeded all original expectations. Also funding plans has become obsolete and new and more cost-effective ways of operations is therefore a necessity.

Odin is since May 2007 a pure aeronomy research satellite as a long atmospheric measurement period is the most important argument for a continuation of the mission. Supporting only one discipline stabilises the on-board environment which together with the fixed geometry, pointing towards the earth's limb, allows for more streamlined planning and increased autonomy. Satellite behaviour is since long well known, with a fine tuned attitude control system, a well modelled power system, a very well working data handling system, clear signatures on the most common anomalies and experienced staff. Together, these facts made the eclipse seasons of 2007 and 2008 the calmest ever and the satellite has started this year's season in a very positive way.

A very important step for a prolonged life of Odin is the fact that ESA in May 2007 included the spacecraft in its Third Party Mission programme for Earth monitoring satellites. As a consequence, all aeronomy data collected since launch is now made available for every registered user for the benefit of the whole aeronomy research society.

Odin's payload status is good and the platform has so far only lost one redundancy, in April 2007, when one of the reaction wheels stopped and had to be replaced.

## **NLC nucleation on charged aerosols**

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Recondensed meteoric material, so called meteoric smoke, has long been considered the main candidate for condensation nuclei for mesospheric ice formation. Recently however, model studies has shown that meteoric smoke particles are transported away from the region where ice phenomena such as noctilucent clouds and polar mesospheric summer echoes occur. In particular, they are transported away before they can grow large enough to serve as ice condensation nuclei. Here we argue that charged meteoric smoke particles may solve this dilemma by significantly altering the efficiency of the particles as condensation nuclei. The ionospheric charge density, the presence of energetic radiation and, not the least, measurements of charged particles are all evidence that a significant fraction of the meteoric smoke particles are charged and, hence, that charging effects on ice nucleation must be considered. Unfortunately, limited knowledge about charging processes in this region, and about charging of sub-nanometer particles in general, makes quantification of the fraction of charged particles, a key parameter in charged nucleation, difficult. Here we analyze the time scales of processes such as charging, recombination, and particle growth, in order to narrow down the problem.

We show that under most circumstances, the rapid recombination of positively charged particles and free electrons prevents the positively charged particles from acting as efficient ice condensation nuclei. Hence, concerning mesospheric ice nucleation, it appears that the primary importance is to quantify the number of negatively charged particles. This depends on the ionospheric conditions and on the extent to which the smallest smoke particles are charged by thermal electrons. Large variability of the former and very limited knowledge about the latter impose considerable uncertainties on the expected number of condensation nuclei at the polar summer mesopause. Nevertheless, we show that reasonable assumptions yield number densities of charged condensation nuclei that are consistent with what is expected for mesospheric ice phenomena. Thus, while it remains highly questionable whether neutral smoke can provide sufficient amounts of condensation nuclei for ice formation at the polar summer mesopause, charged meteoric smoke proves to be a promising candidate.

## **WACCM simulations of long-term changes in polar mesospheric clouds**

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Satellite measurements of PMCs have been made regularly since 1978 by the Solar Backscattered Ultraviolet (SBUV) instrument on board various NASA and NOAA satellites. SBUV has provided a continuous dataset of the brightest PMC extending over nearly three solar cycles. Published analyses of the SBUV dataset indicate seasonally averaged PMC brightness increases in both hemispheres by ~16% over the 30 year period. Increases in occurrence frequency in the northern hemisphere are even greater. In addition there is a significant anti-correlation between brightness and solar activity with a lag of ~0.5 years. To interpret these trends, we present results of a 30-year simulation from the Whole Atmosphere Community Climate Model with a PMC parameterization module (WACCM-PMC) to analyze PMC response to greenhouse gas and solar forcing. The WACCM-PMC model is a free running 3 dimensional global circulation model extending from the surface to the thermosphere with fully interactive chemistry. The time series of solar spectral irradiance is based on an empirical reference spectrum and its year to year variations are parameterized in terms of the F10.7 solar index. The model is tuned to provide realistic summer mesospheric background conditions. The results of the simulations show a clear positive trend in PMC brightness and ice mass on the order of 18% over 30 years with a strong anti-correlation with solar activity and a lag of 0.5 years. To address the question of forcing mechanisms, we compare the 30-year simulation to case-study simulations that illustrate the PMC response without greenhouse forcing and constant solar conditions.

## **Microphysical studies of mesospheric sulfate aerosol as PMC nuclei in WACCM3**

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We present new three-dimensional calculations of the mesospheric sulfate layer, a class of particles that have been suggested as a source of nuclei for polar mesospheric clouds (PMCs). Recent modeling studies have raised questions about whether sufficient number densities of meteoritic dust particles large enough to nucleate PMCs can exist in PMC nucleation regions. By contrast, our calculations show that sulfates should grow on the smaller dust particles in these cold regions, creating nuclei of sufficient size and number density to account for observed PMCs. We have incorporated sulfur chemistry and aerosol microphysics into the Whole Atmosphere Community Climate Model 3 (WACCM3), a comprehensive model that spans the range of altitude from the Earth's surface to the thermosphere. We have tuned the gravity wave parameterization in WACCM3 to reproduce well observed temperatures in the mesopause region that are critical to PMC and sulfate formation, and present sensitivity studies for such tunings. Our calculations show that where temperatures are coldest and meteoritic dust is present, sulfates will grow on them. We discuss the feasibility of observing mesospheric sulfates containing dust cores with the Solar Occultation For Ice Experiment (SOFIE) on board NASA's current Aeronomy of Ice in the Mesosphere (AIM) experiment.

## PMSE observations in both hemispheres

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Polar mesosphere summer echoes (PMSE) were first reported in 1979 in the northern hemisphere (NH) and subsequently a rich observation record were compiled spanning latitudes from 54°N to 78°N. Two decades later PMSE were finally observed in the southern hemisphere (SH) at latitude 62.1°S and recently to 75°S. A range of different radar techniques (or frequencies) were employed in the study of these enigmatic radar backscattered echoes, including MF radars near 2 MHz, MST radars near 55 MHz, SuperDARN HF radars around 10-12 MHz, Incoherent Scatter Radars in the 224-933 MHz band, and UHF at 1.29 GHz. Initial research naturally focused on PMSE characteristics, morphology and seasonal properties primarily through intra-hemispheric studies. Although, studies from individual sites predominated, excellent quality data led to much early interest with PMSE theoretical interpretation and a range of hypotheses were canvassed, evolving to the current well accepted interpretation. Whereby charged ice-aerosol production occurs around condensation nuclei (meteor smoke) in the extremely cold summer mesopause  $\sim 150$  K – a consequence of adiabatic cooling by gravity waves breaking in this turbulent region. Early inter-hemispheric studies revealed the necessity to rigorously calibrate radars in both hemispheres. A clearer morphology followed where PMSE at similar latitude bands had a higher reflectivity in the NH with more abundant occurrence rates, but the mean occurrence versus height profiles peaked  $\sim 1$  km higher in altitude in the south. Calibrated radars of varying types and frequency also yielded intra-hemisphere PMSE reflectivity profiles as a function of latitude. Reported lower reflectivity PMSE within the polar cap were recently linked to less electron precipitation at these latitudes. A raft of studies followed using: multi-instrument suites from the ground; rocket based techniques to measure *in situ* temperature, ice-aerosol charge and turbulence; and satellites measurements of temperature and ice-aerosol characteristics. These studies clearly showed the dependence of PMSE with mesopause region temperatures. The perturbation of the temperature field by the mesospheric wind field, tides, gravity waves and planetary waves, highlights the tracer value of the PMSE layer to provide a proxy for atmospheric processes that would otherwise be stealth to radar. A brief account of coincident PMSE radar and Polar Mesospheric Cloud (PMC) lidar observations from near conjugate latitudes  $\sim 69^\circ$  is presented. Finally the future direction for PMSE research utilizing existing and new radar facilities in both hemispheres will be discussed.

## **The investigation of small scale structures in NLC with the ALOMAR RMR-Lidar**

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The ALOMAR RMR lidar is located at 69°N in Northern Norway and has been used to collect more than 1500 hours of noctilucent cloud data since 1996. The temporal resolution is 1-3 minutes. The lidar is operated day and night throughout the entire NLC season whenever weather conditions permit. In this paper we present a detailed analysis of this NLC data set in terms of vertical structures and NLC layer movements. A predominant apparent downward motion of NLC layers is found, consistent with microphysical models.

Oscillations in NLC height and brightness are investigated by wavelet analysis, suitable for detection of periods less than 2 hours. We present examples and statistics of multiple layered NLC which occur in about 15% of the NLC detections.

Since the RMR lidar is a twin lidar system we occasionally observe NLC at two different locations separated horizontally by typically 50 km. We find similar NLC structures in both lidars which implies that the timescales involved are typically several hours. Furthermore, we have used wind measurements from the nearby MF and meteor radars to extract information about the origin of the NLC. We also compare our NLC data with PMSE observed by the ALWIN radar at the same location. The lower edges of NLC and PMSE are very similar which is in agreement with our current understanding of ice particle formation, growth, charging, and evaporation.

# Homogeneous nucleation of amorphous solid water particles in the upper mesosphere

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Condensed water particles are known to exist in the high latitude upper mesosphere during the summer months. However, the mechanism or mechanisms through which they nucleate remains uncertain. It is postulated here that particles of amorphous solid water (ASW, condensed water with a non-crystalline structure also called amorphous ice) may nucleate homogeneously in the summer mesosphere. Using classical nucleation theory and a one-dimensional model, it is shown that more than  $10^5 \text{ cm}^{-3}$  amorphous solid water particles can nucleate homogeneously under mesopause conditions. Furthermore, it is shown that homogeneous nucleation competes with heterogeneous nucleation on meteoric smoke particles when the cooling rate is greater than  $\sim 0.5 \text{ K/hour}$ ; in fact, cloud properties are highly sensitive to the cooling rates induced by gravity waves. The homogeneous nucleation of amorphous solid water could provide an explanation for the high density of ice particles (many thousands per  $\text{cm}^3$ ) thought to be required for the formation of polar mesospheric summer echoes and electron depletions in the upper mesosphere. A parameterisation for homogeneous nucleation based on the self consistent classical theory is presented which can be used in other mesospheric cloud models.

## Atmospheric drivers for mesospheric clouds

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Twenty years ago we proposed that Noctilucent Clouds arose as a direct consequence of the buildup of water vapor within the middle atmosphere from methane oxidation (Thomas et al, Nature, 338, 1989). We have subsequently become aware of several other processes and effects that play important roles in the development and evolution of *ice clouds at the mesopause*. Humidifying the mesosphere is still a necessary condition but it is now clear that transport through the TTL (Tropical Tropopause Layer) can be the most important influence on this process. A potentially even more important issue is the temperature of the mesopause layer in summer as it produces supersaturation with respect to ice. Throughout much of the middle atmosphere, there has been an observed cooling trend in recent decades. This is tied both to the observed decreases in stratospheric ozone, and related solar heating rates, and also to the buildup of greenhouse gases, especially CO<sub>2</sub>. The changes in the radiative forcing associated with increasing greenhouse gas loading drive both heating of the surface, and lowest atmospheric layers, as well as strong cooling of the middle and upper atmosphere. We discuss the latest information on atmospheric methane, H<sub>2</sub>O fluxes through the TTL, and cooling of the middle atmosphere.

# **Investigating short-period gravity waves evident in noctilucent clouds over Sweden during five consecutive summers**

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Noctilucent clouds (NLCs) are high-altitude bright cloud formations visible under twilight conditions from high-latitudes during the summer months. While the nature of these clouds and the primary drivers for their formation and dissipation are still under investigation, they provide an excellent tracer to study small-scale dynamical processes at the 83 km level, and in particular short-period gravity waves propagating up into the mesopause region.

A mapping technique developed to analyze the structures visible in NLC images is described. Digital images taken from Frescati, Sweden (59.37°N, 18.06°E), using an automated CCD camera, operated over five consecutive summer seasons (2004-2008) have been analyzed in details to determine the horizontal spatial and temporal characteristics of over 40 wave events. These results will be compared with prime measurements at latitudes from the Arctic and Antarctic during the winter months.

## **First climatology of polar mesospheric clouds from GOMOS/ENVISAT stellar occultation instrument**

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GOMOS, on board the European platform ENVISAT launched in 2002, is a stellar occultation instrument combining 4 spectrometers in the spectral range 250 to 950 nm (UV - visible - near IR) and 2 fast photometers (470-520 nm and 650-700 nm). On the day side, GOMOS measures also the solar light scattered by the atmospheric molecules. In the summer polar day, polar mesospheric clouds (PMC) are clearly detected using the photometers signals. The sun-synchronous orbit of ENVISAT allows observing PMC in both hemispheres. The observation of PMC with the spectrometers provides the spectral dependence of the scattering by PMC particles from which it is possible to derive some information on particle size.

The method of detection and the climatology of PMC obtained by GOMOS will be described, focusing on the seasonal and latitudinal coverage, represented by global maps and calculation of corresponding detection frequency. The asymmetry between hemispheres and the determination of main geometrical characteristics of the clouds (mean altitude, vertical thickness and geometric extent) will also be presented, as well as a first estimation of the particle size. A very high accuracy is possible thanks to the stellar occultation technique.

## Temperature in mesospheric ice retrieved from the ACE-FTS data

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Understanding the formation and morphology of mesospheric ice particles is important as their properties reflect the physics of the upper mesosphere and are linked to global change. While temperature plays an important role in ice formation and growth, the accurate data on temperature in mesospheric ice are still very limited. We present a new approach to retrieve the temperature of mesospheric ice particles from the infrared extinction spectra of ice measured in the solar occultation regime by the Fourier Transform Spectrometer on the Atmospheric Chemistry Experiment satellite. The position of ice O-H stretch band peak varies with temperature, which enables the retrieval of ice temperature by fitting a model spectrum to a measured one. The retrieved temperature is independent of cloud vertical and horizontal patchiness. It is also sensitive to the chosen particle shape: cubes, hexagons and spheroids of certain forms give same result. Spheres and rectangular prisms (aspect ratio > 2) change temperature by 3-4 K. For nearly 400 ice spectra analysed the retrieved temperature for cubes ranges from 120 K to 150 K with the distribution maximum centred at ~135 K. The standard temperature for same ice spectra retrieved from the gas phase differs considerably and sometimes reaches values of 200 K and above.

## Silicon and Magnesium - the forgotten meteoric elements

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Silicon and magnesium are the two most abundant elements (after O) in meteoroids. The only observations of silicon species in the atmosphere are of Si<sup>+</sup> ions by rockets, and an understanding of its chemistry has to come from laboratory studies. We have now completed a comprehensive study of both the neutral and ionized chemistry of this element. There are several surprising contrasts with the meteoric metals - not least, that reactions of Si<sup>+</sup> and SiO<sup>+</sup> with O<sub>3</sub> and O<sub>2</sub> produce *neutral* Si atoms, which indicates that there are unusually efficient ionization pathways for SiO. The dominant silicon species throughout the MLT is SiO<sub>2</sub>, which polymerizes rapidly to form beautiful cage-like structures. These presumably interact with metallic species to form Fe-Mg-SiO<sub>4</sub> smoke particles. We will present laboratory experiments where tertiary Fe<sub>x</sub>Mg<sub>2-x</sub>SiO<sub>4</sub> smokes ranging from fayalite (Fe<sub>2</sub>SiO<sub>4</sub>) to forsterite (Mg<sub>2</sub>SiO<sub>4</sub>) are made photochemically in the gas phase.

We know much less about magnesium than the other meteoric metals (Na, Fe, K and Ca). However, within the last 3 years the first global record of atomic Mg (and Mg<sup>+</sup>) in the MLT has been obtained using the SCIAMACHY spectrometer on Envisat. We have complemented these observations with a laboratory study of the important ion-molecule reactions of magnesium. For LPMR we will report a truly unexpected discovery: unlike all the other meteoric metals, atomic Mg does not disappear in the vicinity of noctilucent clouds. We will show using *ab initio* quantum calculations why this is the case.

## **Impact of solar proton events on the occurrence of noctilucent clouds**

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The impact of SPEs (Solar Proton Events) on NLCs (Noctilucent Clouds) is studied using the 28-year NLC data set based on measurements with SBUV instruments on NIMBUS 7 and the NOAA 9-17 satellites. We scanned the GOES proton flux and NLC time series in order to find significant anticorrelations between proton fluxes and NLC occurrence rates and albedo. We focused on the analysis of the years 1989, 1991, 2000 and 2004 when strong SPEs occurred during the main NLC season. The  $E > 5$  MeV energy channel of GOES proton flux record was used for this work. For several cases anti-correlations of NLC and proton fluxes were found. For a strong increase of the proton flux (2-3 Mag) during the main NLC season we find a NLC depletion of up to 50% (relative to maximum). These results indicate an extra-terrestrial influence on NLC. In order to explain the anti-correlation of proton fluxes and NLCs a further detailed study is required including time series of temperature, water vapor abundance, planetary wave perturbation and solar activity.

## **An overview of AIM Cloud Imaging and Particle Size (CIPS) data**

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The Cloud Imaging and Particle Size (CIPS) instrument on the Aeronomy of Ice in the Mesosphere (AIM) satellite mission is now in its fifth season of polar mesospheric cloud (PMC) measurements. The CIPS instrument consists of four cameras that detect 265-nm radiation scattered by the earth's atmosphere. Images are acquired throughout the PMC region with a field of view of 120 x 80 degrees and high spatial resolution of 5 km x 5 km. Retrieved quantities include cloud presence and albedo, particle size, and ice water content. The goal of this presentation is to introduce the CIPS data to make it more accessible to the audience. We will describe the available data products and how to obtain them. We will also present an overview of the PMC morphology for the four seasons observed, emphasizing general use of the data and best practices for interpreting it, including limitations of the current retrieval.

# **New results on particle charging in the mesosphere**

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Over the past 15 years it has been well established that charged aerosol particles play a significant role in several phenomena occurring in the middle atmosphere. The most prominent example of these is the occurrence of extremely strong radar echoes from the polar summer mesopause region which are now known as polar mesosphere summer echoes or PMSE. PMSE are now understood as being due to the presence of charged ice particles in the 5-100 nm size range and their coupling with the free electrons in the gas phase. These charged ice particles leave significant signatures, "fingerprints", in the ambient plasma, i.e., they can lead to both severe depletions but also local enhancements in the electron and ion density. Besides the well established presence and significance of charged mesospheric ice particles, it has also recently been shown that there is a second class of even smaller charged aerosol particles which are most likely of meteoric origin, and which have been termed meteoric smoke particles or MSPs. These particles, in turn, have been suggested to be of great importance for phenomena like the nucleation of mesospheric ice particles, the D-region charge balance, the properties of incoherent scatter radar spectra, as well as the physical process giving rise to so called "polar mesosphere winter echoes". In this paper, we provide an overview of recent experimental results from several rocket campaigns as well as measurements with the EISCAT and Arecibo incoherent scatter radars. Physical mechanisms of particle charging will be discussed and a possible explanation for the repeated observation of the coexistence of positively and negatively charged particles in the environment of mesospheric ice clouds will be presented. Finally, key uncertainties will be identified and suggestions for future studies will be made.

## **Studies of PMSE and PMWE at the IAP: Recent results and future directions**

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PMSE and PMWE are strong radar echoes from the mesosphere which have been intensively studied at IAP using radars, lidars, in-situ observations from rockets, and modeling. While it is now established that charged ice particles are a necessary prerequisite for the occurrence of PMSE, it is currently under debate whether charged particles of meteoric origin contribute to PMWE in a similar way. The current paper gives an overview of recent research regarding both phenomena. For the case of PMSE, we will shortly review the current physical understanding of PMSE and then discuss several multi-frequency data sets covering frequencies from 50 MHz up to about 1 GHz. We will show that the majority of these observations can be explained in the frame of a PMSE-theory which combines the effects of neutral air turbulence with a large Schmidt-number caused by the presence of large ice particles. We will further present recent rocket observations of Schmidt-numbers which corroborate earlier radar estimates indicating that the Schmidt-number can in fact reach values of several thousands. In this context we will also briefly discuss alternative theories and apparently conflicting results from previous PMSE observations. Regarding PMWE, we will discuss the available experimental evidence in favor of a turbulence-related excitation mechanism as well as unexplained conflicting results. Based on our recent rocket observations of meteoric smoke particles in the entire winter mesosphere, we will also discuss the potential effect of such charged particles in the low nanometer-size regime on the radar backscatter. Finally, we will report about recent developments at IAP regarding the construction of a new and powerful MST-radar and outline capabilities for novel related studies.

# **Evidence of a 27-day signature in noctilucent cloud occurrence frequency**

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This paper presents evidence of a connection between the 27-day modulation of the solar activity and noctilucent clouds occurrence frequency as measured by SCIAMACHY as well as the SBUV instruments. Cross-correlation analysis show that there is a strong anti-correlation between the NLC occurrence rate anomaly and the Lyman- $\alpha$  irradiance variation throughout the summer season for some years. The anti-correlation is most pronounced for the northern hemisphere according to both instruments. MLS mesospheric products suggest that the most likely driver for the variation is a change in temperature, but the mechanisms responsible for the observed variation are not yet fully understood.

## **A comparison of PMC size retrievals from satellite observations: spectral versus phase function approaches**

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Contemporaneous satellite measurements from the Cloud Imaging and Particle Size (CIPS) experiment, the Optical Spectrograph and Infrared Imager System (OSIRIS), and the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) provide an opportunity to compare Polar Mesospheric Cloud (PMC) particle sizes derived from PMC phase function measurements (CIPS) and PMC spectrally dependent limb scattered measurements (OSIRIS and SCIAMACHY). The algorithms will be presented and their strengths and limitations explored. We will discuss how they complement and contrast each other with respect to the derivation of cloud properties.

## **The Aeronomy of Ice in the Mesosphere mission: Science results after four PMC seasons**

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The Aeronomy of Ice in the Mesosphere (AIM) mission was launched from Vandenberg Air Force Base in California at 1:26:03 PDT on April 25, 2007 becoming the first satellite mission dedicated to the study of noctilucent clouds. A Pegasus XL rocket launched the satellite into a near perfect 600 km, noon - midnight, sun synchronous orbit. AIM carries three instruments - a nadir imager, a solar occultation instrument and an in-situ cosmic dust detector. This paper will provide a brief mission overview, instrument descriptions and scientific findings. Results from the first two years of AIM observations show that the NLC season turns on and off like a “geophysical light bulb” transitioning at the season start from no clouds to 100% occurrence frequency in days and vice versa at the season end. Data show that temperature change is a dominant factor in controlling season onset, variability during the season and season end. Rising water vapor levels at the beginning and falling values at the end also play a key role in season initiation and cessation. Structures seen in the clouds look very much like complex features seen in tropospheric clouds including large regions of near circular ice voids. This paper will also describe the first satellite observations of cosmic smoke input to the atmosphere measured by the SOFIE instrument.

## Ice nucleation by refractory nanoparticles

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Although meteoric smoke particles have long been considered as a strong candidate for the heterogeneous nucleation of ice in the mesosphere, the only experimental study which has attempted to characterise the nucleation potential of such recondensed refractory material was conducted under conditions relevant to the troposphere (Bigg & Giutronich, *J. Atmos. Sci.*, 24, 46-, 1967).

We have therefore attempted to study the role of nanoparticles of meteoric composition (i.e. metal and silicon oxides) in the heterogeneous formation of ice at the AIDA facility in Karlsruhe, Germany - an 84.3 m<sup>3</sup> stainless steel chamber in which ice nucleation by aerosol particles at temperatures down to ~180 K can be monitored using a variety of in-situ techniques. Ar<sup>+</sup> (488 nm) laser scatter and depolarisation measurements of ice crystal formation and growth were used to characterise the critical threshold conditions of ambient relative humidity (RH) with respect to water and ice, at which nucleation occurred in experiments conducted on powders/nanoparticles of Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and MgO injected into the chamber.

Although, under conditions of supersaturation with respect to ice (RH<sub>ice</sub> > 100%), deposition mode ice formation was routinely observed on a significant fraction (> 10%) of the initial particle population, experimental runs conducted at RH<sub>water</sub> approaching 100% indicated a bi-modal nucleation mechanism (water droplets + ice crystals). This can most readily be explained by the initial uptake and growth of a quasi-liquid water layer on the particles followed by homogeneous freezing within this layer to form ice, possibly of an amorphous nature.

# **Recent advances in midlatitude tidal and mean temperature/wind climatology and long-term temperature trends deduced from Na lidar observations**

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The Colorado State University (CSU) sodium lidar, first light in August 1989, has conducted regular observations of nocturnal mesopause region temperature and Na density continuously for more than 18 years since May 1991. Between 1993 and 1997, considerable technology innovations were made that led to improved capabilities, enabling full-diurnal-cycle (24 hour continuous), simultaneous mesopause region temperature and zonal and meridional wind (TUV) observations, weather permitting. Since 2002, the hourly mean Na density, temperature, zonal and meridional wind profiles at 2 km vertical resolution deduced from CSU lidar observations have been deposited in the CEDAR data base for community use. The data from full diurnal cycle observations are most suitable for climatological studies of tidal-period perturbations and tidal-removed mean states in all three dynamical fields. The long-term data in nocturnal temperatures is of course suited for the evaluation of solar cycle effect and temperature trends.

In this paper, I will report recent advances in temperature and wind climatology as well as temperature trend at a midlatitude site deduced from these lidar observations, which will be compared to the prediction of general circulation models. Within the time allotted, I will highlight 3 different aspects of the recent advances. First, the climatology of semidiurnal tide based on Yuan et al. [JGR, 2008a]. In addition to a favorable comparison with the HAMMONIA model prediction, I will provide a physical explanation on the seasonal variation of semidiurnal tidal phases by invoking on the effect of mean temperature and wind distributions throughout the year. Second, the tidal-removed mean-state climatology, deduced [Yuan et al., JGR, 2008] from the full-diurnal-cycle campaigns between 2002 and April 2006, revealed the seasonal variations that support our current understanding of the mesopause region. When compared to the predictions of HAMMONIA, TIME-GCM and WACCM3, one finds general agreement with some differences. That the difference between model and observation is smaller than the difference between models revealed the modeler's difficulty in getting the parameterization of gravity waves right on the one hand, and suggested the usefulness of observation to constrain the models on the other. The long-term nocturnal temperature record has been used to reveal episodic response after Mt. Pinatubo eruption, 11-year solar cycle effect and temperature trends. Though the observed cooling reported in the literature from different researchers at different geographic locations is inconclusive, ranging between 0 and 10 K per decade, when all 3 long-term effects are included, the CSU data produced a temperature trend [She et al., JASTP, in press] with maximum cooling of  $\sim 1$  K/decade at 91 km and a profile in general agreement with HAMMONIA and SMLTM model predictions.

## **PMC observations compared with coincident MLS temperature and water vapor measurements**

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The Solar Backscatter Ultraviolet [SBUV/2] instrument on NOAA-18 and the Microwave Limb Sounder [MLS] on Aura, have nearly the same equator crossing time of ~1345. This means with their different orbital periods (102 minutes versus 99 minutes) and altitudes (854 vs. 705 km), every ~34 orbits Aura will catch up with and pass underneath NOAA-18. This will allow us to compare the detections of Polar Mesospheric Clouds (PMC) by the SBUV/2 instrument with the coincident temperature and water vapor measurements by MLS. For a coincidence we require the location of the MLS measurement to be inside the SBUV/2 field of view (170x170 km), within 15 minutes of the SBUV measurement. This provides several thousand coincidences during each PMC season, including several hundred with PMCs. There are four PMC seasons available for comparison in the Northern Hemisphere starting with May 2005 launch of NOAA-18, and five PMC seasons to date in the Southern Hemisphere (including data from NOAA-16 for the 2004-05 season). We calculated the saturation ratio with respect to ice from the MLS measurements of temperature and water vapor. As expected, the probability of SBUV/2 detecting a PMC increases with decreasing temperatures and with increasing saturation ratio. The PMC events occurred at higher saturation ratios than the non-PMC events, with nearly all of them occurring with saturation ratios greater than 1.0. Cloud brightness tends to increase with decreasing temperature and increase with increasing saturation ratio. The nadir viewing SBUV/2 only detects the brightest 10% to 15% of PMCs, since they are detected as enhancements above the relatively bright UV background of Rayleigh scattering from the atmosphere. This means many of the weaker PMCs are not detected by SBUV/2 above the normal variations in the UV background due to ozone variations.

# **Polar mesosphere summer echoes with MST radar ESRAD, Kiruna, Sweden: Variations and trends over 12 years**

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Polar Mesosphere Summer Echoes (PMSEs) are strong radar echoes detected in the altitude of 80-90 km in the polar region during summer. Since 1997, PMSE measurements have been carried out with a 52 MHz MST radar (ESRAD), located at Esrange, near Kiruna in northern Sweden. Making use of a unique data set of 12 years (1997-2008), the diurnal, day-to-day and year-by-year variations of the occurrence of PMSE are studied. The PMSE occurrence rate on a diurnal scale shows two maxima (4-7 LT and 13-16 LT) and two minima (7-13 LT and 20-23 LT), a signature of diurnal and semidiurnal tides. Not much variation is seen in the shape of diurnal curves for occurrence rate between years; however the magnitude of occurrence rate differed from year to year by 1.5-3 times. The occurrence of PMSE usually starts in third week of May reaches its peak by the beginning of June, remains at the highest level until the end of July and then decreases gradually to the end of August in every year. The length of the PMSE season varies from year to year (85 days in 2000 to 101 days in 2003). The possible relationship between PMSE occurrence rate, meridional wind, zonal wind shear and mesopause temperature was examined. The data on winds and temperature, starting from 2003, were obtained with collocated SKiYMET meteor radar. It was found that few days before the start of PMSE season the mean meridional wind becomes southward and also intensifies. At the same time, the amplitude of zonal wind shear increases and then continues to grow. The analysis shows that in most cases there is no significant correlation between day to day variations of PMSE occurrence rate, temperature and meridional wind in the same altitude range. The possible dependence of year-by-year PMSE occurrence rate and length of PMSE season on solar and geomagnetic activity has also been investigated. No significant correlation between the year-by-year PMSE occurrence rate and solar activity, represented by the solar 10.7 cm radio flux, was found. However, a positive significant correlation is found between year-by-year variation of PMSE occurrence rate and geomagnetic activity. The variations of occurrence rate and length of PMSE season do not show any statistically significant long-term trend during the period 1997-2008.

# Simultaneous observations of NLC from space and from the ground

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Simultaneous detection of the same NLC scene from space and from ground is reported and discussed.

Noctilucent Clouds (NLC) have been extensively observed and characterised from the ground since their first identification in 1885. More recently it has been demonstrated that NLC properties and occurrence frequency are intimately related to the dynamic coupling processes on global scale. Since the summer 2004, photographs of noctilucent clouds (NLC) are taken from a site in Stockholm, Sweden (59.37°N, 18.06°E). A digital camera takes every summer night hundreds of images of twilight sky at the rate of 1 to 2 pictures per minute. A technique to re-project these images to a horizontal plane in order to correctly represent movements and actual spatial scales has been developed.

Noctilucent clouds were first detected from space by an instrument on the OGO-6 satellite in 1972. Using the same instrument it was also discovered that a permanent scattering layer exists over the polar cap during the summer. NLCs are now considered to be equatorward extensions of this permanent layer, also sometimes called Polar Mesospheric Clouds (PMC). More recently NLC/PMC have been extensively studied by the Swedish satellite Odin launched in 2001. The AIM satellite mission, launched in 2007, is entirely dedicated to research into noctilucent clouds. The Cloud Imaging and Particle Size (CIPS) experiment on AIM is a wide angle (120° along track by 80° across track) imager consisting of four identical cameras arranged in a cross pattern. CIPS is the first space borne instrument that takes images of PMCs with a high spatial resolution and in the viewing geometry that makes comparison with the ground imagery possible.

# **The diurnal variation of Polar Mesospheric Clouds using multisatellite observations with a data assimilation system**

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Polar mesospheric clouds (PMCs) respond sensitively to small changes in the ambient conditions of the upper mesosphere. Tidally induced variations are a particularly important source of PMC variability, in part because many PMC datasets are collected at fixed local times. Reconciling datasets from two or more satellites therefore typically requires a quantitative understanding of diurnal variations at all PMC latitudes. To this end, we employ the Advanced-Level Physics High-Altitude (ALPHA) Navy Operational Global Atmospheric Prediction System (NOGAPS). NOGAPS-ALPHA assimilates satellite temperature observations from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) on the NASA TIMED satellite and the Microwave Limb Sounder (MLS) on the NASA Aura satellite as well as water vapor observations from MLS from the ground to ~90 km altitude. NOGAPS-ALPHA was run for the northern 2007 summer in a continuous 6-hourly forecast-assimilation update cycle in order to produce synoptic “nowcasts” of the global atmosphere. The assimilation component has an effective horizontal resolution of 2° latitude by 2° longitude. We assemble the NOGAPS-ALPHA results in local time and latitude for temperature, water vapor and vertical winds and use them to drive the one-dimensional Community Aerosol and Radiation Model for Atmospheres (CARMA). We also consider the effects of meridional transport by calculating parcel trajectories from NOGAPS-ALPHA results. We compare our PMC results to available observations and discuss the implications to multi-satellite comparisons at all latitudes.

## **Coordinated AIM satellite and ground-based optical and radar observations of polar mesospheric clouds and echoes**

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The NASA Aeronomy of Ice in the Mesosphere (AIM ) satellite is designed to investigate the formation, properties and variability of Polar Mesospheric Clouds (PMC). Here we report novel 3-D radar, lidar and optical image measurements in coordination with an AIM overpass. Common volume mesospheric measurements were made over central Alaska using the new Poker Flat Incoherent Scatter Radar (PFISR), a co-located Rayleigh lidar and remote, two-station digital image observations, enabling the first detailed investigation of the horizontal and vertical structures of PMC and associated Polar mesosphere Summer Echoes (PMSE). Coincident measurements were made of a bright display recorded on 10–11 August 2007, characterized by a broad luminous band that contained several prominent wave forms. During the AIM overpass detailed mapping of the satellite PMC and ground-based Noctilucent Cloud (NLC) signatures indicated a significant gap in the spatial location of the NLC and PMC.

Subsequent lidar and image measurements established the presence of NLC within the radar common volume. Strong but intermittent PMSE were detected by PFISR, with distinct patchy structures that exhibited a similar southward motion as the NLC. Detailed comparison of the 3-D PMSE structures and the NLC lidar and image data have revealed striking similarities when account was taken of the NLC layer altitude, suggesting a direct link between their small-scale spatial signatures (within the current resolution of the radar measurements).

## **Local time variations of polar mesospheric clouds: 45 seasons from SBUV and 4 seasons from AIM CIPS**

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Sun-synchronous orbits in low-earth orbit maintain a constant local time over most latitudes, which is convenient for many scientific and technical reasons. However, at the highest latitudes (~78-82 degrees), the satellite motion is predominately from West to East, passing continuously through a number of time-zones, for which the local time coverage is typically 7 hours. The length of this coverage can become greater than 7 hours when multiple satellites are available. Such is the case for SBUV (Solar Backscattering Ultraviolet Experiment), when as many as three spacecraft have been in orbit at the same time with different equator-crossing times. For example, the SBUV/2 coverage from NOAA-16,-17 and -18 in 2007 extended from 0330 to 1930 hrs, a span of nearly 16 hours. Fortunately, the AIM mission was in its first northern PMC season in 2007. This affords an opportunity to compare the local time variability of PMC at high latitude between these different data sets. Because of the nearly 30 years of SBUV coverage, dating back to 1979 (multiple satellites since 1985), there is a large data base for determining the average properties of any diurnal and semi-diurnal components. The results for the northern PMC albedo, occurrence frequency and ice water content indicate semi-diurnal peaks at 0600 and 1800 hrs, with variations of several hours from year to year. In the south, the phase behavior is different, with a single maximum near midnight. The implications of these results for the interpretation of CIPS data and for assessing long-term PMC variability are discussed.

## **Modeling particle size distributions in Polar Mesospheric Clouds**

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The size distribution of ice particles is perhaps the most important observable aspect of microphysical processes in mesospheric cloud formation and evolution. Yet it is one of the most difficult cloud properties to measure. Since in situ techniques are not yet available, the only quantitative information available is from optical observation of scattering, either passive solar scattering from photometric or spectrometric techniques, or active backscattering by lidar. The latest results are summarized elsewhere (see Bailey et al, this workshop). We present simulated size distributions from two models using CARMA sectional microphysics: WACCM/CARMA, in which CARMA is interactively coupled with WACCM3 (Bardeen et al, 2008, 2009), and stand-alone CARMA forced by WACCM3 meteorology (Merkel et al, 2009). Both models provide well-resolved size distributions as a function of height, location and time within the cloud season for realistic environmental conditions, but vary somewhat due to different nucleation schemes, etc. We present some representative results, indicating among other things the dependence on height, and how column-integrated measurements contrast with vertically-resolved distributions. Optical measurements provide only low-order moments of the distribution averaged over a finite spatial volume. The model simulations provide guidance as to the limitations and strengths of optical measurements.

## Upper-atmospheric NO<sub>x</sub> production by energetic particle precipitation: A mechanism for sun-earth coupling?

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Odd nitrogen (NO<sub>x</sub> = NO + NO<sub>2</sub>) is produced in the polar upper atmosphere by energetic particle precipitation: aurora, relativistic electrons and solar protons. Increasing evidence from instruments such as Envisat/GOMOS, EOS-Aura/MLS and VLF receivers show that downward transport of NO<sub>x</sub> takes place in the winter polar vortex and affects the chemistry of the stratosphere, especially ozone. This is therefore a mechanism that indirectly couples solar activity to possible long-term variations in Earth's atmosphere, because of the importance of ozone for the thermal balance of the atmosphere.

In this poster a review of current observations and theoretical studies with the Sodankylä Ion-neutral Chemistry (SIC) model is given, as presented in Turunen et al. (JASTP, in press, 2009), Seppälä (2007) and Seppälä et al. (2008). Large SPEs are found to produce higher initial NO<sub>x</sub> concentrations than long-lived REP events, which themselves produce higher initial NO<sub>x</sub> levels than auroral electron precipitation. Only REP microburst events were found to be insignificant in terms of generating NO<sub>x</sub>. We show that the Envisat/GOMOS observations from the Arctic winter of 2003~2004 are consistent with NO<sub>x</sub> generation by a combination of SPE, auroral precipitation, and long-lived REP events.

### References:

A. Seppälä, Observations of production and transport of NO<sub>x</sub> formed by energetic particle precipitation in the polar night atmosphere, Ph. D. thesis, Finnish Meteorological Institute, Helsinki, 2007

A. Seppälä et al: The Effects of Hard Spectra Solar Proton Events on the Middle Atmosphere, J. Geophys. Res., 2008

## **SLICE - a new meteor radar in Finnish Lapland**

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The Department of Physics and Astronomy of the University of Leicester has installed a new SKiYMET Meteor Radar at the Sodankylä Geophysical Observatory (SGO), Sodankylä, Northern Finland (67° 22' N, 26° 38' E). SGO will operate the radar as part of the joint research endeavour SLICE (Sodankylä-Leicester Ionospheric Coupling Experiment).

The radar has seven crossed dipole aeriels in a cross configuration (14 receiver channels) and one crossed dipole transmitter antenna. It operates currently at 7.5kW power, which will be upgraded in the near future to 15 kW; centre frequency is 36.9 MHz. Operations began in early December 2008.

Here we will present some first results. We invite colleagues interested in the data to get in touch with us ([thomas.ulich@sgo.fi](mailto:thomas.ulich@sgo.fi)). Furthermore we wish to point out that the final deadline for our FP7 Transnational Access project LAPBIAT will be in October 2009. The project, which ends in October 2010, provides full funding for collaborative visits to SGO.

# **Dynamical heating of the polar summer mesopause during solar proton events and its effects on NLCs**

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Recent studies suggest a reduction of the occurrence frequency of noctilucent clouds (NLCs) during and after solar proton events (SPEs). SPEs are caused by solar coronal mass ejections (CMEs) and correspond to the precipitation of highly energetic protons into the Earth's polar cap regions. The observed reduction in the NLC occurrence frequency during the January 2005 SPE appeared to be driven by a mesopause temperature increase. However, the physical mechanisms linking the energetic proton precipitation with the temperature increase were not understood. In this contribution we propose a chain of effects leading to a dynamically induced warming of the polar summer mesopause region caused by SPEs, which can be summarized as follows: The catalytic ozone loss caused by SPE-produced HOx leads to a reduction in the diabatic heating in the polar middle mesosphere. The resulting reduction in the meridional temperature gradient causes a reduction in the mean zonal wind according to the thermal wind balance, which in turn lowers the critical level for gravity wave breaking. This vertical shift in the mesospheric residual circulation leads to a decrease in adiabatic cooling at the summer mesopause and hence a temperature increase. Model simulations with the Kühlungsborn Mechanistic general Circulation Model (KMCM) were performed with a temperature perturbation corresponding to the expected decrease in diabatic heating caused by the ozone destruction. The model results are consistent with the cause-and-effect chain described above, which suggests that the physical mechanisms leading to a polar mesopause temperature increase during SPEs can be considered more or less understood.

# **Gravity wave impacts on the atmospheric coupling from the MLT region to the stratosphere during stratospheric sudden warming with TIME-GCM**

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The stratospheric sudden warming (SSW) is a dramatic event with the sudden increase of temperature and wind reversal. Although SSWs only occur in winter stratosphere, SSWs have significant impacts on global atmospheric circulation from the troposphere to the thermosphere. The SSWs is the great example to understand the atmospheric coupling. TIME-GCM captured the general features of SSWs; however, the discrepancies between simulations and SABER observations still exist. These discrepancies lie in two major categories: (1) the locations and depth of cooling and warming regions in MLT, and (2) the downward progression of temperature anomaly from the mesosphere to the stratosphere. Both discrepancies may be due to unrealistic gravity wave parameters in TIME-GCM. Mesospheric cooling and lower thermospheric warming during SSWs are believed to result from the changes in the gravity wave transmission. For the downward propagation of temperature anomaly, we hypothesize that the gravity waves may play an important role in it through influencing the height of the zero-wind line that is the critical layer for the stationary planetary waves. In this study, the gravity wave roles in two discrepancies are investigated with the TIME-GCM through varying the gravity wave parameters in the model.

# A stepwise mechanism for ice particles formation in the polar summer mesosphere: thermodynamic and kinetic aspects

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In the absence of convincing experimental evidence for the presence of sufficient amount of cloud condensation nuclei in the mesosphere, disagreement still exists as to whether mesospheric ice particles (including NLC) form heterogeneously or homogeneously. Aside from other fundamental problems, this issue becomes of even greater significance because it is now believed that the NLC formation rate, frequency of occurrence, and brightness are linked to climate change.

We suggest a stepwise transition mechanism that makes the ice formation scenario based on homogeneous nucleation feasible and provide quantitative estimates for some properties of ice particles. The entire formation pathway from water vapor to ice particles is given as: *Supersaturated vapor - Amorphous cluster (>1 nm) - Cubic ice (>1 nm) - Hexagonal ice (>15 nm)*. Specifically, the first step is nucleation of small amorphous clusters, which then freeze into water ice (apparently cubic ice) when they reach the critical size. The estimates based on the equilibrium thermodynamics give the critical radius of amorphous water clusters as about 1.0 nm. The same estimates for the transformation of cubic to hexagonal ice give the critical size of about 15 nm at typical upper mesospheric conditions.

The thermodynamic parameters (e.g. temperature, water vapour pressure, etc.) used in our calculations are obtained from the observations made by the infrared Fourier Transform Spectrometer on the Atmospheric Chemistry Experiment satellite (ACE-FTS). We also report the estimates for the growth rate and shape of ice particles retrieved directly from the ACE-FTS spectra. The formation rate for ice particles is a very strong function of temperature and water vapor pressure. Based on the ACE-FTS retrievals, we find the NLC formation time in the range from ~2 hours at 150 K to ~18 hours at 125 K, during which ice particles come to equilibrium with water vapour reaching the size (radius) between 20 and 70 nm.