Special Issue: Layered Phenomena in the Mesopause Region

Introduction

This special issue of the Journal of Atmospheric and Solar-Terrestrial Physics comprises a collection of papers which were mostly presented at the 11th Layered Phenomena in the Mesopause Region (LPMR) Workshop, held at the University of Leeds between 29th July 2013 and 1st August 2013. The topics covered at the workshop included atmospheric dynamics, mesospheric ice clouds, meteoric metal layers, meteoric smoke particles, and airglow layers. There was also a session on the potential of planned sub-orbital spacecraft for making measurements in the mesosphere and lower thermosphere (MLT).

The 17 scientific papers in this issue cover most of these topics from several aspects: observations from satellites, rockets, radars and lidars; laboratory and theoretical studies of underlying physical-chemical processes; and modelling on a range of scales from detailed microphysics to global chemistry-climate interactions. The papers are grouped into four categories which are described in the following sections. Finally, the special issue starts with an additional paper which celebrates the life and scientific contributions of Professor Georg Witt, who passed away in July, 2014. The 11th LPMR workshop was the last scientific meeting that Georg attended, and this poignant (and at times amusing) memorial by Gumbel and Stegman is a fitting tribute to a man who had a huge influence on the field.

Mesospheric dynamics and coupling to the lower atmosphere

Zhao et al. use images of polar mesospheric clouds (PMCs) obtained with the Cloud Imaging and Particle Size (CIPS) instrument onboard the NASA Aeronomy of Ice in the Mesosphere (AIM) satellite to study mesospheric gravity wave activity in the summer polar mesosphere, where previous measurements have been sparse. The properties of medium and large horizontal scale (>100 km) gravity waves are determined. Over a period of 6 years, wave activity in the southern hemisphere is found to be consistently higher than in the northern hemisphere. Wave activity in both hemispheres was observed to decrease systematically during the course of each summer season, consistent with previous observations of wave energy in the stratosphere and suggesting a direct influence of lower atmospheric sources on polar mesospheric dynamics. de Wit et al. used a new meteor radar to measure the high-frequency gravity wave momentum flux at Trondheim, Norway (63^{o}N). The vertical flux of zonal momentum is observed to change from westward to eastward with increasing altitude in winter, and from eastward to westward in summer. This vertical divergence results in westward gravity wave forcing in winter, and eastward forcing in summer, and can be interpreted in terms of selective filtering of a uniform spectrum of vertically propagating gravity waves.

Stray et al. report observations of planetary wave activity in the polar summer MLT, using winds from a chain of SuperDARN radars to monitor the meridional wind between 51 and 66^{o}N. A stationary longitudinal structure characterised by a strong zonal planetary wave number 1 is persistently observed during summer each year. Gravity wave modulation by lower atmospheric planetary waves, and direct propagation of planetary waves from the lower atmosphere, do not appear to explain the phenomenon. Kopp et al. describe a new Rayleigh-Mie-Raman lidar developed at the midlatitude station Kühlungsborn, Germany (54°N). This instrument, in combination with a potassium resonance lidar, provides full diurnal measurements of the temperature tides between 40 and 100 km. Mean tidal amplitudes and phases with 24-, 12-, and 8-h periods are derived. More than 2 years of complete seasonal data are used to examine the relative contributions of the diurnal, semidiurnal and terdiurnal tides as a function of height, in unprecedented detail.

Ice clouds in the mesosphere

Bailey et al. describe common volume observations of PMCs using two instruments on the AIM satellite: the nadir-viewing CIPS instrument and the limb-viewing Solar Occultation For Ice Experiment (SOFIE) instrument. CIPS uses the variation of the PMC-scattered radiance with scattering angle to determine cloud particle size distribution and Ice Water Content (IWC), which SOFIE measures by solar occultation in the infra-red. An initial comparison of the two instruments using observations from 2007 to 2009 is poor, with SOFIE predicting particle size distributions shifted to smaller sizes and a factor of two more albedo and IWC than observed by CIPS. However, much improved agreement is obtained by introducing several refinements: assuming that the PMCs are 0.5% meteoric smoke by mass; removing Rayleigh scattered sunlight below the clouds in the CIPS data; and using a log-normal or exponential, rather than a Gaussian, ice particle size distribution. Brinkhoff et al. use CIPS data to determine the fractal perimeter dimension of the clouds, which can then be used to improve understanding of atmospheric processes responsible for the cloud shapes. A sensitivity analysis shows that cloud holes need to be accounted for in the area–perimeter method of data analysis. Between 2007 and 2009 no significant differences in the fractal perimeter dimension are observed, either between the seasons or between hemispheres.

Fiedler et al. report an unusually early onset of noctilucent clouds (NLCs, which by convention are mesospheric ice clouds observed from the ground, rather than the PMCs observed from space) on 21 May in 2013. The observations were made using the Rayleigh-Mie-Raman lidar at ALOMAR in Northern Norway (69^{o}N). For several weeks beforehand, enhanced planetary wave activity induced a strong upwelling from the stratosphere into the mesosphere, leading to about 6 K lower temperatures and higher water vapour mixing ratios. A perturbation in polar middle atmosphere dynamics on this scale is unprecedented in 20 years of observations.

Murray et al. investigate the metastable form of water-ice which should exist in mesospheric ice clouds. They use x-ray diffractometry to show that ice grown at mesospherically relevant temperatures (< 150 K) does not have a structure corresponding to the well-known hexagonal or metastable cubic forms (previous work on NLCs has almost always assumed that mesospheric ice is cubic). Instead, the ice is a material in which cubic and hexagonal sequences of ice are randomly arranged to produce stacking disordered ice (ice Isd). The structure of this ice is in the trigonal crystal system, rather than the cubic or hexagonal systems, and should produce crystals with aspect ratios consistent with lidar observations.

Chai and Bellan describe a new apparatus that has been developed to study the nucleation, growth, and morphology of water-ice grains spontaneously generated in a weakly ionized plasma. The growth rates of non-spherical ice grains is examined as a function of the mean free path of H_2O molecules, H_2O vapour pressure, and external magnetic field strength. Mangan et al. explore whether conditions can exist in the MLT where CO_2 molecules become trapped within amorphous mesospheric ice particles, possibly making a significant contribution to the total condensed volume (CO_2 is ~40 times more abundant than H_2O in the MLT). However, extrapolating from the results of their laboratory study shows that a temperature of less than 100 K would be required to trap CO_2 in mesospheric ice particles, and hence this process is unlikely to occur.

Meteoric metals and airglow

Viehl et al. report common volume measurements of Fe densities, temperatures and ice particle occurrence in the mesopause region at Davis Station, Antarctica (69^{o}S) between 2011and 2012. There is a strong correlation of the Fe column density with temperature, but no clear correlation with the onset or occurrence of ice particles measured as NLCs or polar mesosphere summer echoes (PMSE). A simple treatment of the relevant reaction kinetics indicates that the strong summertime depletion can be explained by gas-phase chemistry alone, and that heterogeneous removal of Fe and its compounds on ice particles plays a secondary role. Frankland and Plane report a laboratory study of the impacts of sublimation and energetic ion bombardment in releasing Fe species into the gas phase from NLC particles containing meteoritic material. The results indicate that when NLC particles sublimate the metallic species embedded in them will coalesce to form residual particles, and not co-evaporate with the H_2O. Ion sputtering of Fe from Fe-doped ice is efficient, but the proton flux in even an intense aurora will be too low for the resulting release of Fe species into the gas phase to compete with that from meteoric ablation (although this may be the source of recently observed Fe^+ in the Saturnian magnetosphere).

Dunker et al. compare the temperature and properties of the Na layer observed by the ALOMAR Na lidar at Andøya, Norway (69°N) with simulations by the Whole Atmosphere Community Climate Model with specified dynamics (WACCM-SD), a 3-dimensional chemistry-climate model. In general, the model reproduces the pronounced seasonal cycle of Na number density and temperature at high latitudes very well, and captures the large variations in temperature and Na density caused by a major stratospheric warming in January 2012. von Savigny examines the vertical volume emission rate profiles of the OH(3-1) Meinel emission near the mesopause, using nighttime limb-emission observations with the Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) instrument on the Envisat satellite. Analysis of 9 years of data (2003 – 2011) confirms a universal scaling of mean OH emission altitude and vertically integrated emission rate. Climatological fit parameters are derived which can be employed by ground-based observers of OH emission rates to infer the OH emission altitude. No obvious long-term trends or 11-year solar cycle signatures are present in the OH emission altitude time series, which partly contradicts earlier studies.

Meteoric smoke particles

Havnes et al. describe work performed over the past two decades with rocket-borne detectors to study meteoric smoke particles (MSPs) and ice particles (NLCs and PMSEs) in the mesosphere. The emphasis is on detectors developed by the Tromsø group - the DUSTY, MUDD and ICON probes – but investigations by others are also described. Four topics are discussed: the secondary charging that occurs in detectors as a result of impacts by nanoparticles; the evidence that NLC particles can contain up to several per cent of MSPs; techniques for measuring in situ the size distribution of MSPs; and future plans for sample return measurements. Asmus et al. describe refinements to an aerosol particle charging model which then better explains the data on charged MSPs obtained by CHAMPS rockets launched from Andøya, Norway (69^{o}N) in October 2011. Addition to the model of photodetachment from negatively-charged particles, negative ion formation, and a realistic ionization rate from measurements above 95 km, results in significantly better agreement with the rocket measurements of ions, electrons and charged particles. One conclusion is that the global meteoric ablation flux is only about 4 t d^{-1}, significantly smaller than most previous estimates but in agreement with the ablation flux used in the WACCM model of the Na layer described by Dunker et al.

Frankland et al. report the uptake of HNO_3, H_2O, NO_2 and NO on MSP analogue particles prepared in the laboratory. The analogues used in the study were olivine and haematite/goethite, which are possible compositions of MSPs. Uptake of HNO_3 is relatively efficient at 295 K (about 1 in every 200 collisions). The laboratory results are then included in a version of the WACCM-SD model containing MSP formation and growth. This shows that the heterogeneous removal of HNO_3 on MSPs in the winter polar vortex between 30 and 60 km is probably an important sink for this species.

The breadth of new and exciting topics covered in this collection of papers, which is itself a subset of the 51 presentations at the 11th LPMR workshop, is a clear demonstration of the current vitality of mesospheric science.

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