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Preface

Preface to special issue: Layered Phenomena in the Mesopause Region

Historically, the Layered Phenomena in the Mesopause Region (LPMR) workshops have focused on studies of mesospheric clouds and their related science, including spectacular noctilucent clouds (NLCs), polar mesospheric clouds (PMCs), and polar mesospheric summer echoes (PMSEs). This is because, in the pre-technology era, these high-altitude (∼85 km) clouds revealed the existence of substance above the 'normal atmosphere' — our near-space environment is not empty! The occurrence and nature of these clouds have commanded the attention of atmospheric and space scientists for generations. Modern technologies developed in the last 50 years have enabled scientists to significantly advance our understanding of these layered phenomena. Satellite observations expanded these studies to global scales, while lidar and radar observations from the ground enabled fine-scale studies. The launch of the Aeronomy of Ice in the Mesosphere (AIM) satellite in 2007 brought mesospheric cloud research to a more mature level.

As we step into a more technological society, the studies of several more layered phenomena are dramatically enhanced via measurements with advanced lidar, radar, rocket, imager, interferometer, spectrometer, and particle detector, etc. These phenomena include, but are not limited to, meteoric metal layers that extend from the upper mesosphere well into the thermosphere, a variety of airglow emissions distributed at different altitude ranges, cosmic dust and related meteors, meteoroids, and meteorites. The coordinated studies of these phenomena with observations, laboratory measurements, numerical models, and theoretical studies have opened new doors to study the space-atmosphere interaction region and pushed the envelope of atmospheric and space sciences. Mesospheric clouds and echoes, meteoric metal layers, and airglow layers have also been used as tracers for very high-resolution lidar, radar, and imager measurements to study high-frequency atmospheric waves and turbulence. Therefore, the 12th LPMR workshop topics were expanded significantly to help facilitate the science growth.

This special issue of the *Journal of Atmospheric and Solar-Terrestrial Physics* comprises a collection of papers, the majority of which were presented at the 12th Layered Phenomena in the Mesopause Region Workshop, held at the University of Colorado Boulder on 10–13 August 2015. The 12th LPMR workshop covered the topics on mesospheric clouds and echoes (NLCs, PMCs, PMSEs, and PMWEs—polar mesospheric winter echoes), thermospheric and mesospheric metal layers, cosmic dust and meteoric smoke particles, the influence of the solar cycles and lunar tides on layered phenomena, atmospheric wave dynamics and turbulence inferred from, or connected to, layered phenomena, and new observational capabilities. The workshop also had a tribute to "Georg Witt: A Pioneer in Upper Atmospheric Science".

The 17 scientific papers in this issue cover most of these topics from several aspects: observations from lidars, radars, satellites, and ground-based imagers; laboratory and theoretical studies of underlying physical-chemical processes; and modeling on a range of scales from detailed microphysics and turbulence to global chemistry-climate interactions. The papers are grouped into four categories that are described in the following sections.

1. Atmospheric wave dynamics and turbulence

Lu et al. use high-resolution Na Doppler lidar measurements of vertical winds and temperatures in the mesosphere and lower thermosphere (MLT) to characterize the high-to-medium frequency mesoscale gravity waves at Boulder, Colorado. A unique point of this study is to infer the intrinsic period and horizontal wavelength from the observed vertical wavelength, amplitude ratio of temperature to vertical wind perturbations, and designated eddy viscosity by applying the gravity wave polarization and dispersion relations. *Kaifler et al.* analyze high-resolution Rayleigh lidar data to characterize upward phase progression waves occurring frequently between 30 and 85 km altitude in both the southern and the northern hemispheres. It is likely that these waves propagate energy downward, indicating in-situ wave generation in the middle atmosphere or reflection of upward-propagating waves. *Chen and Chu* develop a two-dimensional (2-D) Morlet wavelet transform and wave recognition methodology to extract 2-D wave packets and study the persistent gravity waves discovered using Fe Boltzmann lidar observations at McMurdo, Antarctica. *Ridder et al.* develop a pattern recognition method to analyze small-scale structures in high-resolution lidar observations of NLCs. Nearly 5000 single wave structures were identified from 738 h of data. *Fritts et al.* go further to observe small-scale instabilities and turbulence from PMC images and then model these dynamics with high-resolution direct numerical simulations. Some of the high-resolution PMC imaging was obtained with star cameras on board a stratospheric balloon flying over Antarctica.

1.1. Ice clouds and atomic oxygen in the MLT along with their variations and trends

Fiedler et al. report the long-term trends of NLC observed by lidar at ALOMAR. Depending on cloud brightness, various classes of NLCs show different change rates of increasing occurrence frequency and

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brightness but decreasing cloud altitude over a period spanning 22 years. Comparisons with satellite observations indicate that these trends are longitudinally dependent. *Swarnalingam et al.* analyze observations of PMSE taken by Mesosphere-Stratosphere-Troposhere radar at Eureka (80°N, 86°W) between 2009 and 2015. They find large interannual variations in PMSE occurrence frequency and PMSE backscatter signal strengths that appear to be weaker than those observed at Andenes. *Rusch et al.* study very large ice particles in regions with low ice water content observed by AIM Cloud Imaging and Particle Size (CIPS) instrument, and suggest that the responsible processes are a warming in the upper part of the saturated region combined with a cooling lower down at the normal cloud base related to gravity waves. *Lübken et al.* present further observations to investigate summer mesopause “jumps” discovered using a resonance lidar at Davis, Antarctica. Associated with these jumps are a PMSE height increase seen by a VHF radar, strong westward winds in the upper mesosphere measured by an MF radar, and large eastward winds in the stratosphere. *Savigny et al.* report the first identification of the signature of lunar gravitational semi-diurnal tides in several NLC parameters observed by the Solar Backscatter Ultraviolet satellite and find them consistent with lunar tidal measurements of mesospheric temperature made by the Microwave Limb Sounder instrument. *Thurairajah et al.* delineate the signatures of 27-day solar flux variations in PMCs observed by AIM Solar Occultation for Ice Experiment and CIPS instruments. The PMC height is found to significantly correlate with 27-day variations in solar Lyman-alpha in the Southern Hemisphere, but not in the Northern Hemisphere. *Lednyts'kyy et al.* report 27-day and 11-year solar cycle signatures in atomic oxygen concentration in the equatorial MLT from satellite observations of the green line nightglow using the SCanning Imaging Absorption spectrometer for Atmospheric CHartographY instrument.

2. Mesospheric and thermospheric metal layers

Xue et al. report an overturning-like thermospheric Na layer observed by a broadband Na lidar up to nearly 120 km altitude at Haikou, China, and establish its connection to ionospheric field aligned irregularity and sporadic E layers observed with the COSMIC radio occultation, ionosondes, and VHF radar at nearby locations of Sanya and Fuke. *Feng et al.* report Na, Fe, and temperature measurements in the MLT by lidars at ALOMAR during a major sudden stratospheric warming (SSW) in January 2009. A significant cooling with temperature as low as 136 K was observed around 90 km, along with substantial depletions of Na and Fe layers. Simulations using the Whole Atmosphere Community Climate Model, incorporating Na, Fe, Mg, and K chemistry, nudged with reanalysis data below 60 km, predict SSW perturbations to the metal layers even at equatorial latitudes. *Lautenbach et al.* present a 10-year climatology of K densities at Kühlungsborn, Germany using a K Doppler lidar. Due to severe K layer saturation (~300%) caused by the small lidar beam divergence employed, the corrected K density has ~30% uncertainty. Under such uncertainty, the dataset shows little variations of the mean layer over the 10 years, but exhibits a clear semi-annual variation with two broad maxima reoccurring every year.

3. Cosmic dust and meteoric smoke particles

James et al. demonstrate the preparation of a variety of analogues for interplanetary dust particles (IDPs) and meteor smoke particles, and characterize these analogues in the laboratory. They provide a comprehensive review of current understandings of IDP-related topics, including composition, morphology and size distribution, particle ablation on atmospheric entry, meteoric smoke formation and properties, and impacts of meteoric materials. *Gardner et al.* apply the continuity equation to show that the vertical flux of mesospheric Na atoms, induced locally by waves and turbulence, is related in a straightforward way to the meteoric influx of Na atoms, their chemical loss, and their transport by large-scale atmospheric motions. By fitting the theoretical vertical flux profile to the Na flux profile measured at the Starfire Optical Range, they derive an improved estimate for the meteoric Na flux, and further infer the global influx of cosmic dust to about 107–176 t/d, depending on the assumption of Na composition of the dust particles.

The breadth of new and exciting topics covered in this collection of papers, which is itself a subset of the 84 presentations at the 12th LPMR workshop, is a clear demonstration of the current vitality of atmosphere-space sciences.

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