14th International Workshop on

Layered Phenomena in the Mesopause Region (LPMR)

September 30- October 4, 2019
Williamsburg, Virginia, USA

Workshop Abstracts
(in alphabetic order- last name)

http://www.cpe.vt.edu/lpmr/
Meteorology of noctilucent clouds observed by lidar over Alaska

Jennifer H. Alspach1,2, Richard L. Collins1,2, Jintai Li1,2, Bifford P. Williams3, Denise Thorsen4, Katrina Bossert1,4

1Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA
2Department of Atmospheric Sciences, University of Alaska Fairbanks, Fairbanks, AK, USA
3GATS Inc., Boulder, CO, USA
4Department of Electrical and Computer Engineering, University of Alaska, Fairbanks, AK, USA

Noctilucent clouds (NLCs) have been observed by Rayleigh lidar at Poker Flat Research Range in Chatanika, Alaska (65°N, 147° W) on an ongoing basis since 1998. In this study, satellite, lidar, and radar data is used to investigate the meteorological conditions impacting NLC occurrence and NLC brightness. Peak backscatter coefficients and integrated backscatter coefficients are used to characterize NLC brightness. Aura microwave limb sounder (MLS) temperature and water vapor data from 2004-2019 is used to determine values of temperature relative to the frost point for each observation during these NLC seasons. Deviations from the frost point are compared to NLC occurrence and brightness. A Sodium Resonance Wind Temperature Lidar (SRWTL) was established in 2017 and a meteor wind radar was established in 2018 at Poker Flat and have operated since. The SRWTL and meteor wind radar provide local meteorological measurements and are used to supplement the analysis in the 2018 and 2019 NLC seasons.

Corresponding author: Jennifer Alspach, jalspach@alaska.edu
Three-Dimensional Time-Dependent General Circulation Model Simulation of a Pure Water Vapor Plume in the Mesosphere and Lower Thermosphere and Implications for Ice Cloud Formation and Transport

Irfan Azeem, ASTRA
M. H. Stevens, Space Science Division, Naval Research Laboratory, Washington, DC

Satellite observations of water vapor exhaust in the lower thermosphere from the Space Shuttle's main engines near Florida have been shown to lead to the formation of Arctic Polar Mesospheric Clouds (PMCs) within one day of the launch [Stevens et al., 2005, 2012]. However, the full chain of coupled thermodynamic processes involved in the genesis and transport of these man-made PMCs are not fully understood. On 26 January 2018, a sounding rocket experiment, called “Super Soaker”, released 220 kg of water at 85 km altitude over Poker Flat Research Range near Chatanika in Alaska and induced a PMC, which was successfully observed in the Rayleigh lidar data. In this paper, we describe a modeling study using the Thermosphere-Ionosphere-Mesosphere Energetics General Circulation Model (TIME-GMC) to interpret observations of the artificial PMCs from Super Soaker and examine the energetics and dynamics of the Mesosphere and Lower Thermosphere (MLT) in the presence of a water plume. TIME-GCM simulations indicate that water vapor released near 85 km altitude actively cools the atmosphere via radiative cooling, which enables the local formation of ice clouds. The infrared cooling from water dominates any residual impact of the plume on any other sources of heating and cooling terms in the model. The net cooling from the plume is shown to modify the MLT horizontal and vertical winds via changes in the pressure gradient forces and the horizontal advection term in the momentum equation.

Corresponding Author: Irfan Azeem, iazeem@astraspace.net
The Roles of Greenhouse Gas, Solar Cycle Forcing, and Atmospheric Coupling on the Interannual Variability of Temperature near the Mesopause Region

Scott M. Bailey (1), Cora E. Randall (2), Mark E. Hervig (3), David Siskind (4), Brentha Thurairajah (1), James M. Russell, III (5)

(1) Virginia Tech, (2) LASP/ U. Colorado, (3) GATS, (4) NRL, (5) Hampton University

The Solar Occultation for Ice Experiment (SOFIE) on the Aeronomy of Ice in the Mesosphere (AIM) mission has been observing the upper atmosphere since its 2007 launch. Among its data products, SOFIE measures Polar Mesospheric Cloud (PMC) ice properties and the temperature of the air in which the ice forms. SOFIE has shown that over the course of the AIM mission, the northern hemisphere, July temperature at PMC altitudes has generally decreased, while PMC ice mass for the same period has generally increased. While this inverse relationship is as expected, the trends are opposite to expectations as solar activity has generally increased during the period of AIM observations. This suggests that another forcing is overwhelming the effects of solar activity, at least for this particular solar cycle. Candidate forcings include both interhemispheric and intrahemispheric coupling, as well as cooling due to greenhouse gas increases. In this talk, we examine observations from SOFIE, the Sounding of the Atmosphere by Broadband Emission Radiometry (SABER), and the Halogen Occultation Experiment (HALOE) to look at the decadal variation of polar mesosphere temperature at PMC altitudes and disentangle the relative effects of solar cycle and other forcings. We show that intrahemispheric coupling is the largest driver of temperatures at PMC altitudes during the SOFIE era and that greenhouse gas forcings play a role over longer time periods.

Corresponding Author: Scott Bailey, baileys@vt.edu
Using WACCM6-PMC to study long-term trends in polar mesospheric clouds

Charles Bardeen¹, A. W. Merkel², M. E. Hervig³, C. E. Randall²

¹ National Center for Atmospheric Research
² University of Colorado, Laboratory for Atmospheric and Space Physics
³ GATS, Inc.

SBUV observations of polar mesospheric clouds (PMC) have suggested that PMCs respond to the solar cycle; however, this response appears to be missing in observations since ~2000. To investigate drivers of this variability, we have ported the Merkel et al. (2009) PMC parameterization from version 3 to version 6 of the Whole Atmosphere Community Climate Model (WACCM). WACCM6 introduces many new parameterizations, and the PMC representation in the model is sensitive to the gravity wave tuning. Data from the Solar Occultation for Ice Experiment (SOFIE) and the Cloud Imaging and Particle Size (CIPS) instrument has been used to evaluate these PMCs and tune the new model. A preliminary run has been done over a longer time period to look at begin looking at drivers of the long-term trends.

Corresponding Author: Charles Bardeen, bardeenc@ucar.edu
Investigating the vivid looks of noctilucent clouds by camera and lidar

Gerd Baumgarten, Jorge L. Chau, Jens Fiedler, Michael Gerding, Franz-Josef Lübken, Britta Schäfer

Leibniz-Institute of Atmospheric Physics (IAP), Schlossstr. 6, 18225 Kühlungsborn, Germany

When looking at noctilucent clouds (NLC) by naked eye or by remote sensing techniques we observe structures in the horizontal appearance, in the vertical profile, and the time evolution of the clouds. These structures are generated by microphysical processes affecting the ice particles, pure fluid dynamics, or a combination of both. Previous studies have shown that on centennial time scales the NLC are linked to microphysical changes, mostly of water vapor. On scales of hours to days the clouds are linked to temperature or the large scale flow. On scales of minutes the structures are often wave-like and associated to gravity waves.

For timescales below a few minutes only a small number of observations were previously available. To systematically investigate the structure of NLC on such scales we make use of the ALOMAR RMR-lidar, located in Northern Norway at 69°N, that is detecting NLC with subsecond resolution. On these timescales NLC are a unique tracer. This allows to study the dissipation of gravity waves, that ultimately lead to the cold temperatures required for the generation of NLC.

We have developed a classification scheme to identify the most important features on timescales of a few seconds based on lidar observations in the years 2011 to 2018. To understand the mechanisms generating these structures we use a combination of active and passive remote sensing by lidar, radar and camera that allows studying the structure of noctilucent clouds and their environment on timescales down to seconds and horizontal / vertical scales of a few meters. We will present new results from lidar and cameras that look above ALOMAR and Kühlungsborn (54°N) at different scattering angles. The observations are used to investigate the mechanisms that generate the vivid appearance of NLC and allow studying the transition of waves to turbulence.

+ Invited Talk
Corresponding Author: Gerd Baumgarten, baumgarten@iap-kborn.de
Common volume analysis of Polar Mesospheric Cloud Albedo, Ice and Particle sizes from CIPS and Tomographic OSIRIS

Lina Broman, Jörg Gumbel and Susanne Benze

Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden

Long term observations of polar mesospheric clouds from both satellite and ground-based instruments have proven to be a valuable tool for studies of the complex dynamics as well as the long term changes of the upper atmosphere. Combining satellite instruments that adapt different measurement technique gives the possibility to also study cloud structures, and the microphysical processes involved with the lifecycle of the clouds. In an ongoing project, we compare common volume polar mesospheric cloud observations from a special set of tomographic limb observations from the Optical Spectrograph and Infrared system (OSIRIS) to the nadir viewing Cloud Imaging and Particle Size (CIPS) instrument from NH 2010 and NH 2011. While OSIRIS retrieves cloud properties using spectral analysis, CIPS adapts phase function analysis. Combing these different approaches is challenging due to differences in scattering conditions, observation geometry and sensitivity. Taking this into account, we establish a consistent method for comparing cloud albedo and ice water content from limb tomography and nadir imaging. We find that OSIRIS albedo and Ice water content show very good agreement with CIPS. However, OSIRIS albedo has a small positive bias of 3.4 (+/- 2.9)G on average, and OSIRIS ice water content has a small negative bias of -22 (+/- 14)g/km² on average. An essential and intriguing question is how to best compare particle sizes between different satellites. Since no direct observations of particles sizes have been performed, an assumption of the particle size distribution (PSD) is needed. The instrument-specific sensitivity and observation volume inevitably affect the range of particles that can be observed by each instrument and further the choice of PSD to use for particle radius comparison studies. In the presentation we will discuss our ideas and approach for comparing the mean radius between CIPS and OSIRIS.

Corresponding Author: Lina Broman, lina.broman@misu.su.se
The Super Soaker Experiment: Cloud Formation from a Localized Water Release in the Upper Mesosphere

Richard L. Collins¹, Irfan Azeem², Michael H. Stevens³, Michael J. Taylor⁴, Miguel F. Larsen⁵, Bifford P. Williams⁶, Jennifer H. Alspach¹, Jintai Li¹, Pierre-Dominique Pautet⁴, Yucheng Zhao⁴, Xun Zhu⁷

¹Geophysical Institute and Department of Atmospheric Sciences, University of Alaska Fairbanks, AK, USA
²ASTRA LLC, Boulder, CO, USA
³Space Science Division, Naval Research Laboratory, Washington, DC, USA
⁴Center for Atmospheric and Space Sciences and Department of Physics, Utah State University, Logan, UT, USA
⁵Department of Physics, Clemson University, Clemson, South Carolina, USA
⁶GATS Inc., Boulder, CO, USA
⁷Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

On the night of 26 January 2018, 220 kg of pure water was released at 85 km altitude from a sounding rocket at Poker Flat Research Range (PFRR) in Chatanika, Alaska (65° N, 147° W). The experiment, called “Super Soaker”, was designed to investigate the impact of concentrated water vapor plumes in the upper mesosphere. The experiment included a suite of ground-based instruments (i.e., Rayleigh lidar, sodium resonance wind-temperature lidar, advanced mesospheric temperature mapper) at PFRR that observed the cloud and its environment. We explosively released the water and almost immediately observed mesospheric water ice clouds using the Rayleigh lidar pointed toward the release point. The temperature measured at 85 km by the ground-based lidars immediately beforehand was 223 K and well above the frost point. The clouds appeared at 85±7 km between 18 s and 205 s after the water was released. Here we present an overview of the Super Soaker experiment and the key observations made during the experiment. These observations were used in a modeling study to determine how the clouds appeared so rapidly after the release. The results of the modelling study are presented in a companion presentation (Stevens et al., 2019).

+ Invited Talk
Corresponding Author: Richard Collins, rlcollins@alaska.edu
Statistical Study of Gravity Wave Variations associated with Stratospheric Sudden Warming using long-term high-resolution model output.

Chihoko Cullens¹, Brentha Thurairajah², and Peter Bechtold³

¹ University of California Berkeley
² Virginia Polytechnic Institute and State University
³ European Centre for Medium-Range Weather Forecasts (ECMWF)

A Sudden Stratospheric Warming (SSW) is the most dynamic event to occur in the stratosphere. During SSWs, the temperature increases and the eastward polar night jet reverses to westward in the winter polar region. Although SSWs have been considered as events in the winter polar stratosphere, various studies have shown that SSWs have global impacts from the troposphere to the thermosphere and ionosphere and also affect the summer polar mesopause region. Gravity waves are believed to play a key role in atmospheric coupling during SSWs. Previous studies have shown that enhancements of gravity waves prior to SSWs and significant reduction after SSWs. The causes of their variations are changes in wave propagation and/or wave sources. Gravity wave variations have been found to be dependent on individual SSW event, and their detailed roles on SSWs are not fully understood. A problem of gravity wave study during SSWs has been limitation of long-term gravity wave observations and their limitations of latitudinal and geographical coverage. Most GCMs use simplified gravity wave parameterization and only allow vertical propagation of gravity waves, causing difficulty in gaining a complete picture of gravity wave influences. Recently a long-term global high resolution ERA5 data with 0.25 degree horizontal resolutions are released. ERA5 can resolve small-scale gravity waves, and in this study, 40-years of ERA5 data from 1979 to 2018 are used to understand characteristics of resolved gravity waves during the lifetime of SSWs.

SSWs are separated by different SSW types including minor SSWs, major SSWs, and final warmings. SSWs are further separated to split or displaced polar vortex events. As previous studies showed, our study shows gravity wave enhancements prior to SSWs and significant reductions in gravity wave amplitudes after wind reversal for major SSWs. However, for some minor SSWs, changes in gravity waves varies. Causes of differences in gravity wave responses to SSWs will be discussed.

+ Invited talk
Corresponding Author: Chihoko Cullens, yamashita@berkeley.edu
Formation of Es layers by background homogeneous wind and tidal wind

G. Dalakishvili, G. G. Didebulidze, M. Todua

Abastumani Astrophysical Observatory of Ilia State University, Kakutsa Cholokashvili ave. 3/5, Tbilisi 0162, Georgia.

Theoretically and by corresponding numerical simulations it is shown that the formation and localization of sporadic E (Es) layer at its mainly observable mid-latitude lower thermosphere heights can be determined by homogeneous horizontal wind velocity direction and value. In the suggested theory, differently from 'windshear' theory, the wind direction and value, in addition to geomagnetic field and vertically changing ion-neutral collision frequency, determine the minimal negative value of the divergence of heavy metallic ions drift velocity, which in turn causes ion convergence into Es type horizontal thin layer. Here, in the upper heights of the lower thermosphere, the Es layer peak density and thickness are also controlled by ion ambipolar diffusion.

This theory does not exclude the formation of Es layer under an influence of tidal wind or atmospheric waves. The tidal wind with vertical wavelength about 40-60km additionally can influence on ion convergence into thin dense layer in region of its polarization changes. In this case the sporadic E mostly have multilayered structure, with peak heights close to regions where ion drift velocity becomes equal to zero (ion drift factor is zero) and secondary peak close to regions where tidal wind polarization changes.

In this case the lower thermosphere of the northern hemisphere, the Es layer caused by horizontal homogeneous wind can be located at height regions where (1) the ions vertical drift velocity is zero and its divergence is negative (east-northward wind), (2) the ions drift downward (northward and westward wind), which occurs more frequently, or (3) the ions drift upward (eastward wind) and their negative divergences vanish and (4) in the case of dominance of southward wind the divergence of ion drift velocity is positive, consequently ion density divergence occurs and Es type layer formation is not expectable. The Es layer density increase and its vertical motion to its expectable location are faster for greater values of the horizontal wind velocity.

Acknowledgements: This study is supported by Georgian Shota Rustaveli National Science Foundation Grant no. FR17-357.

Corresponding Author: Giorgi Dalakishvili, giorgi.dalakishvili@iliauni.edu.ge
OMPS Limb Profiler PMC Variability and Tomography

Matthew T. DeLand\textsuperscript{1} and Nick Gorkavyi\textsuperscript{1}

\textsuperscript{1}Science Systems and Applications, Inc. (SSAI)

The Ozone Mapping and Profiling Suite (OMPS) set of instruments was launched on the Suomi NPP satellite in October 2011 to measure ozone and stratospheric aerosols. OMPS includes a Limb Profiler (LP) sensor that makes hyperspectral limb scattering measurements with simultaneous 1 km vertical sampling and broad spectral coverage (290-1000 nm). While the nominal altitude coverage of OMPS LP is 0-80 km, measurements typically extend to 90-95 km in southern polar regions and ~85 km in northern polar regions, enabling PMC detection. The LP viewing geometry (backwards along the orbit track) gives brighter PMC signals in the NH due to forward scattering from small ice particles. Nevertheless, LP sensitivity to PMCs is also good in the SH, with typical PMC season start dates comparable to those observed by the CIPS instrument on AIM. LP hyperspectral measurements cover a broad wavelength range, providing the opportunity (in principle) for direct evaluation of particle size in each PMC detection. However, the limited UV spectral range means that consideration of upwelling radiation is an important factor in wavelength selection. LP stray light characterization is also less robust above 50 km. Preliminary results will be shown. The combination of good vertical sampling (1 km) and horizontal sampling (125 km along-track) also enable the potential use of tomographic analysis with LP measurements, as has been done with special OSIRIS measurements. We will show initial results from our analysis.

Corresponding Author: Matthew DeLand, matthew.deland@ssaihq.com
Investigation of Space Traffic Effects in SBUV and OMPS PMC Data

Matthew T. DeLand$^1$ and Gary E. Thomas$^2$

$^1$Science Systems and Applications, Inc. (SSAI)
$^2$Laboratory for Atmospheric and Space Physics (LASP)/University of Colorado

Water-rich rocket exhaust plumes, such as those emitted by the NASA Space Shuttle, have been suggested to make a significant contribution to long-term trends in polar mesospheric cloud (PMC) ice water content (IWC). We investigate this claim using the combined Solar Backscatter Ultraviolet (SBUV) PMC data record from eight separate instruments, which includes 60 Shuttle launches during PMC seasons between 1985 and 2011. No statistically significant post-launch signal in PMC total ice is observed based on superposed epoch analysis of the SBUV record. A few Shuttle launches show individual peaks in total ice anomaly above the seasonal background that exceed an empirical threshold. The maximum cumulative signature from each of these infrequent cases is typically less than 5% of the season total in ice mass. Other non-Shuttle launches show circumstantial evidence of possible PMC effects, although supporting evidence for plume transport is not available. More recent observations by the OMPS Limb Profiler (LP) instrument appear to show rapid meridional transport in the middle atmosphere of exhaust plumes from non-Shuttle launches. However, it is not clear whether they can lead to enhanced PMC production.

+ Invited Talk
Corresponding Author: Matthew DeLand, matthew.deland@ssaihq.com
The role of the two-day wave in coupling planetary waves in the winter hemisphere to temperature in the polar summer mesopause has been documented in recent work. Planetary wave breaking in the winter stratosphere drives low latitude warming in the mesosphere and cooling in the stratosphere, increasing shear and curvature of the zonal winds along the equatorward flank of the easterly jet. The resulting instability produces conditions favorable for the growth of the two-day wave, which weakens the residual circulation and warms the polar summer mesopause, driving a decline in polar mesospheric clouds. Additionally, planetary wave breaking in the winter hemisphere leads to areas of anomalous potential vorticity at low latitudes, giving rise to inertially unstable regions. Inertial instability is manifest by narrow vertically stacked anomalies in temperature and wind known as pancake structures and can promote the growth of two-day wave numbers 3 and 4. Here we consider the role of inertial instability in driving two-day wave growth in 2014. EP-flux associated with observed pancake structures are input into a primitive equation model and results indicate that inertially unstable structures contribute to two-day wave growth during 2014 and the decline of polar mesospheric clouds.

Corresponding Author: Jeff France, jeff.france@lasp.colorado.edu
Atmospheric Band Fitting Coefficients Derived from Self-Consistent Rocket-Borne Experiment

Mykhaylo Grygalashvly, Leibniz-Institute of Atmospheric Physics
Martin Eberhart, University of Stuttgart, Institute of Space Systems, Stuttgart, Germany
Jonas Hedin, Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden
Boris Strelnikov, Leibniz-Institute of Atmospheric Physics at the University Rostock in Kühlungsborn, Schloss-Str. 6, D-18225 Ostseebad Kühlungsborn, Germany
Franz-Josef Lübken, Leibniz-Institute of Atmospheric Physics at the University Rostock in Kühlungsborn, Schloss-Str. 6, D-18225 Ostseebad Kühlungsborn, Germany
Markus Rapp, Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
Stefan Löhle, University of Stuttgart, Institute of Space Systems, Stuttgart, Germany
Stefanos Fasoulas, University of Stuttgart, Institute of Space Systems, Stuttgart, Germany
Mikhail Khaplanov, Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden
Jörg Gumbel, Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden
Ekaterina Vorobeva, Department of Atmospheric Physics, Saint-Petersburg State University, Universitetskaya Emb. 7/9, 199034, Saint-Petersburg, Russia

The mesopause region is characterised by different airglow emissions and, particularly, by the emissions of the Atmospheric Band which is produced by the excited state of molecular oxygen $O_2\left(b^1Σ^+\right)$. Airglow observation in the Atmospheric Band is a useful method to study the environment in which ice layers form, for an example, in order to infer atomic oxygen concentration, which is essential for thermal regime of mesopause. This emission was used to obtain information about other processes controlling the state of the mesopause: gravity waves, planetary waves, and tides. In number of works inferred the temperature by Atmospheric Band observation.

Based on self-consistent rocket-borne measurements of temperature, densities of atomic oxygen and neutral air, and volume emission of the Atmospheric Band (762 nm) we examined the one-step and two-step excitation mechanism of $O_2\left(b^1Σ^+\right)$ for night-time conditions. Following McDade et al. (1986), we derived the empirical fitting coefficients, which parameterize the Atmospheric Band emission $O_2\left(b^1Σ^+_g − X^3Σ^-_g\right)(0,0)$. This allows to derive atomic oxygen concentration from night-time observations of Atmospheric Band emission $O_2\left(b^1Σ^+_g − X^3Σ^-_g\right)(0,0)$. The derived empirical parameters can also be utilised for Atmospheric Band modelling. Additionally, we derived fit function and corresponding coefficients for combined (one- and two-step) mechanism. Simultaneous common volume measurements of all the parameters involved in the theoretical calculation of the observed $O_2\left(b^1Σ^+_g − X^3Σ^-_g\right)(0,0)$ emission, i.e. temperature and density of the background air, atomic oxygen density, and volume emission rate, is the novelty and the advantage of this work.

Corresponding Author: Mykhaylo Grygalashvly, gryga@iap-kborn.de
The missing solar cycle response of the polar summer mesosphere

Mark E. Hervig1,*, David E. Siskind2, Scott M. Bailey3, Aimee W. Merkel4, Matthew T. DeLand5, and James M Russell III6

1GATS, Driggs, Idaho, USA.
2Space Science Division, Naval Research Laboratory, Washington, DC, USA.
3Virginia Polytechnic Institute, Blacksburg, Virginia, USA.
4University of Colorado, Boulder, CO, USA.
5Science Systems and Applications, Inc., USA.
6Hampton University, Hampton, Virginia, USA.

The response of the polar mesosphere to the 11-year solar cycle is investigated using satellite observations from 1979 - 2018. Solar maximum is expected to cause higher temperatures and lower water vapor in the upper mesosphere, thus reducing the amount of ice in polar mesospheric clouds (PMC). While PMCs showed a clear anti-correlation with the solar cycle before roughly 2002, this response is absent during recent years. PMCs are controlled by temperature and water vapor, which were examined using mesospheric observations during 1992 – 2018. The main cause of the diminished solar cycle in PMCs near 68°S and 68°N appears to be a dramatic suppression of the solar cycle response of water vapor. The solar cycle response of temperature also decreases after 2002, but calculations show that the decreased H2O response had more than three times the impact on PMCs than the reduction in temperature response.

Corresponding Author: Mark Hervig, mark@gats-inc.com
Secondary Instabilities and Billows in Kelvin-Helmholtz Instabilities observed by PMC-Turbo on 12 July 2018

C. B. Kjellstrand, Columbia University
David Fritts, GATS, Inc.
Christopher Geach, University of Minnesota
Shaul Hanany, University of Minnesota
Glenn Jones, Columbia / Rigetti Computing
Bernd Kaifler, German Aerospace Center
Natalie Kaifler, German Aerospace Center
Michele Limon, Columbia / UPenn
Amber Miller, Columbia / USC
Jason Reimuller, Integrated Space Flight
Biff Williams, GATS, Inc.

PMC-Turbo is a balloon-borne experiment that imaged Polar Mesospheric Clouds (PMCs) above the Arctic from 8 July to 14 July 2018. PMC-Turbo was designed to further our understanding of gravity waves and gravity wave breaking and shear instabilities accounting for turbulence, mixing, and gravity wave energy and momentum deposition via high-resolution imaging of the dynamics over the life cycles of multiple events. The PMC Turbo payload includes seven optical cameras and a Rayleigh backscatter lidar. Due to the high viscosity in the upper mesosphere, PMC Turbo imaging captured large scale dynamics with scales of 10-100 km, instability dynamics at scales from about 1-10 km, and fine structure down to scales of approximately 100 m.

On July 12th around 1300 UTC, we captured PMCs tracing KHI containing numerous complex dynamics. The formation and subsequent turbulent dissipation of KHI is an important method of energy and momentum deposition by gravity waves (GWs). The PMC-Turbo experiment observed complicated interactions between KHI billows which break into turbulence. The data was recorded with high temporal resolution of 2 seconds and spatial resolution resolving fine structure, while the full field of view spans hundreds of kilometers.

This presentation will examine the small-scale dynamics observed in the bright KHI event, as well as the larger-scale context of the GW background during the event of interest. This will include the first confirmed secondary KHI observed in the atmosphere, strong convective instabilities, and the first “tubes” and “knots” reported outside of laboratory studies. The observations from the PMC-Turbo cameras will be paired with the data from the onboard Rayleigh lidar to understand the advection of PMC ice particles by the small scale dynamics. We will provide quantitative measurements of the observed dynamics and discuss the implications of these dynamics to the atmospheric conditions allowing for their formation. We will also discuss corresponding modelling results which indicate that the energy and momentum dissipation rate of the tubes and knots are 2-3 orders of magnitude larger than the rate resulting from stable KHI. This discovery supports the theory that KHI and their associated instabilities are an important step in the transport of energy and momentum from low to high altitudes by GWs.

Corresponding Author: Carl Bjorn Kjellstrand, bkjell@gmail.com
Comparison Between Phase Velocity Spectra of Gravity Wave over Syowa and Davis, the Antarctic, using OH Airglow Imagers

Masaru Kogure¹,², Takuji Nakamura²,¹, Yoshihiro Tomikawa²,¹, Mitsumu K. Ejiri²,¹, Takanori Nishiyama²,¹, Masaki Tsutsumi²,¹, Michael J. Taylor³, Yucheng Zhao³, P.-Dominique Pautet³, Damian Murphy⁴

¹Department of Polar Science, Sokendai, Tachikawa, Japan
²National Institute of Polar Research, Tachikawa, Japan
³Physics Department, Utah State University, Logan, Utah, USA
⁴Australian Antarctic Division, Kingston, Tasmania, Australia

Gravity waves (GWs) transport their momentum and energy from the lower atmosphere to the upper atmosphere and drive the general circulation, which significantly changes the temperature in the middle atmosphere [Fritts and Alexander, 2003]. Understanding this role quantitatively will improve the modern general circulation models [Garcia et al., 2017]. However, spatial and temporal variations of GW characteristics (e.g., phase velocity) are poorly understood. In particular, it is necessary to understand the GWs over the polar night jet region since this region is one of the GW hot spots.

To understand those GWs, our group has observed the GWs over Syowa (69°S, 40°E) using various instruments (e.g., lidar, OH imager, and MF radar). We recently compared the GWs over Syowa and Davis (69°S, 79°E), which have similar terrain and meteorological conditions, to show their horizontal variation over the East Antarctic. We found, from the lidar temperature observations, that vertical profile of GW potential energy is similar between Syowa and Davis, except for a clear enhancement around 30-40 km over Davis [Kogure et al., 2017]. Horizontal propagation characteristics are more clearly observed by airglow imaging measurements of ~90 km altitude. The comparison of four imagers’ results between April-May 2013 have indicated that the major propagation directions were westward at three stations (Syowa, McMurdo, Halley), but at Davis GWs seemed to propagate in all the directions, which was different from the other three. [Matsuda et al., 2017]. It seems like the GWs over Davis did not suffer wind filtering in the middle atmosphere.

The goal of this study is to reveal what causes the difference in the mesospheric GW characteristic over Syowa and Davis. In this study, we will show the ground-based horizontal phase velocity spectrum at ~87 km altitude over the two stations derived from OH imagers in more details. We analyzed the OH airglow imager data obtained for eight months (from March to October in 2016) over the two stations with M-transform [Matsuda et al., 2014]. This included only the data without clouds and aurora contaminations continuously for at least one hour. The numbers of nights with such data sets are 40 nights at Syowa and 55 nights at Davis. We will compare the GW spectra in winter mean and their seasonal variations at both stations. We will also compare GW events on the same nights. Clear sky and aurora free data were available at both stations on ten nights. Comparison of phase velocity spectrum obtained on the same night events showed very similar characteristics on only one night out of ten. On five nights, the spectra were quite different. On the other four nights, the spectral peaks with slow westward phase velocity (> 50 m/s) were commonly observed, but additional spectral peaks were found over Davis and not over Syowa.

We investigated, using raytracing method, where the GWs with the common spectrum and additional spectrum on one of the four nights (29th Aug.), propagated from. This investigation suggested the common waves could propagate from the right below each station. On the other hand, the additional waves could propagate from the stratosphere over the sea. This presentation will show the results of OH imager observations and of the raytracing results, and we will discuss what causes spatial and temporal variations of the GW characteristics.

Corresponding Author: Masaru Kogure, kogure.masaru@nipr.ac.jp
A statistical analysis of the spectral width of the PMWE observed by the PANSY radar at Syowa Station (69°S, 40°E) in the Antarctic.

M. Kohma, K. Sato (Univ. of Tokyo), K. Nishimura, and M. Tsutsumi (NIPR, SOKENDAI)

The PANSY radar has been operated with its full system since October 2015 at Syowa Station in the Antarctic (Sato, et al., 2014). We analyzed the polar mesosphere winter echoes (PMWE) detected by the radar in March through October of 2016–2018. The PMWE spectral width is estimated by the most likelihood method assuming the Gaussian distribution. The beam broadening effect is subtracted in advance from the echo spectra by taking the irregular antenna distribution and mean wind into account (Nishimura et al., in revision).

Figure 1 shows the frequency distribution of PMWE spectral width in each month for two height ranges of 60–65 km and 70–75 km. In the middle PMWE season from May through August, the spectral width in 70–75 km is significantly larger than that in 60–65 km. The modes of the distribution are less than 0.4 m/s for 60–65 km and are 1–1.5 m/s for 70–75 km. This height dependence is consistent with the result using data from the EISCAT VHF radar at Tromsø (Strelnikova and Rapp, 2013). However, in the early and late PMWE seasons of March, April, September, and October, the modes of the distribution are less than 0.4 m/s in both height ranges. This result suggests that the height dependence of the PMWE has seasonality.

References:


Corresponding Author: Masashi Kohma, kohmasa@eps.s.u-tokyo.ac.jp
Presenting author: Kauro Sato
A New Source of the O2 Atmospheric Band Emission in Earth's Nightglow

Konstantinos S. Kalogerakis

1Center for Geospace Studies, SRI International, Menlo Park, California, USA

The Earth’s night sky continuously produces a faint chemiluminescence known as nightglow. Two prominent nighttime emissions around 90 km are the O2 Atmospheric and the OH Meinel band systems. Despite a plethora of studies since their identification seven decades ago, significant gaps persist in our understanding of the mechanisms that control them. This report shows that oxygen atoms connect these two emissions: Fast, multi-quantum, vibrational-to-electronic relaxation of OH(v) by O atoms activates a pathway that generates O2 Atmospheric band emission. This newly discovered source exhibits strong altitude dependence and can contribute a majority of the observed O2 Atmospheric band emission when the OH and O-atom layers overlap. The new findings call for a reinterpretation of Earth’s nightglow emissions and a revision of relevant atmospheric models [1].


Corresponding Author: Konstantinos Kalogerakis, ksk@sri.com
High spatiotemporal imaging of PMSE using MAARSY in a MIMO configuration

R. Latteck\textsuperscript{1}, J. L. Chau\textsuperscript{1}, J. M. Urco\textsuperscript{1}, J. Vierinen\textsuperscript{2}, C. Schult\textsuperscript{1}, T. Renkwitz\textsuperscript{1,3}

\textsuperscript{1}Leibniz Institute of Atmospheric Physics, Rostock University, Kühlungsborn, Germany,
\textsuperscript{2}UiT, The Arctic University of Norway, Tromso, Norway
\textsuperscript{3}Hochschule Wismar, University of Applied Sciences Technology, Business and Design, Wismar, Germany

Atmospheric structures due to gravity waves, turbulence, Kelvin Helmholtz instabilities, etc. in the mesosphere are being studied with a varying of ground-based and satellite-based instruments. At scales less than 100 km, they are mainly studied with airglow imagers, lidars, and radars. Typical radar observations have not been able to resolve spatial and temporal ambiguities due to the strength of radar echoes, the size of the system, and/or the nature of the atmospheric irregularities. In this work we observed spatially and temporally resolved structures of PMSE with unprecedented horizontal resolution, using the improved radar imaging accuracy of the Middle Atmosphere Alomar Radar System (MAARSY) with the aid of a multiple-input multiple output (MIMO) technique. The studies are performed in both the brightness of the mesospheric echoes and their Doppler velocities. The resolutions achieved are less than 1 km in the horizontal direction, less than 300 m in altitude, and less than 1 minute in time, in an area of ~15 km x 15 km around 85 km of altitude. We present a couple of wavelike monochromatic events, one drifting with the background neutral wind, and one propagating against the neutral wind. Horizontal wavelengths, periods, and vertical and temporal coverage of the events are described and discussed. We will also present our plans for complementing these measurements with tristatic observations (MAARSY 3D).

Corresponding Author: Ralph Latteck, latteck@iap-kborn.de
Long term variations of mesospheric ice clouds

Franz-Josef Lübken, Gerd Baumgarten, and Uwe Berger (†)

Leibniz-Institute of Atmospheric Physics, 18225 Kühlungsborn, Germany

Some of the earliest observations in the transition region between the Earth's atmosphere and space (roughly at 80-120km) come from so called 'noctilucent clouds' (NLC) which are located around 83km altitude and consist of water ice particles. They owe their existence to the very cold summer mesopause region (130K) at mid and high latitudes. There is a long standing dispute whether NLC are indicators of climate change in the middle atmosphere. We use model simulations of the background atmosphere and of ice particle formation for a time period of 138 years to show that an increase of NLC appearance is expected for recent decades due to increased anthropogenic release of methane being oxidized to water vapor in the middle atmosphere. Since the beginning of industrialization the water vapor concentration at NLC heights has presumably increased by about 40 percent (1 ppmv). The water vapor increase leads to a large enhancement of NLC brightness. Increased cooling by enhanced carbon dioxide alone (assuming no water vapor increase) counter-intuitively would lead to a decrease(!) of NLC brightness. NLC existed presumably since centuries, but the chance to observe them by naked eye was very small before the 20th century, whereas it is likely to see an NLC in the modern era. The eruption of volcano Krakatoa in 1883 has seemingly triggered the first observation of an NLC in 1885. In this presentation we extend our analysis to from middle to polar latitudes.

Corresponding Author: Franz-Josef Lübken, huebken@iap-kborn.de
A model study of the influence of CFC's on Polar Mesospheric Clouds

Aimee Merkel, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO
David E Siskind, Space Science Division, Naval Research Laboratory, Washington, DC
D. R. Marsh, National Center for Atmospheric Research, Boulder CO

Polar mesospheric clouds (PMC) are excellent monitors of mesospheric conditions due to their extreme sensitivity to temperature and water vapor. Both ground-based and satellite instruments have illustrated changes in PMC characteristics on long timescales. Likely sources of PMC variability include global-scale dynamics and solar irradiance changes. In addition, there may be evidence that PMCs respond to changes in ozone depleting substances such as chlorofluorocarbons (CFC). This study used a version of NCAR’s Whole Atmosphere Community Climate Model (WACCM) that includes a parameterization for polar mesospheric cloud (PMC) formation to consider the effects of CFCs on mesospheric temperature and subsequent PMC characteristics. We compared PMCs formed in a present model atmosphere to PMCs formed in an atmosphere without CFCs (world avoided scenario).

Our results indicate that CFCs cause a 65% decrease in the PMC ice mass in the southern hemisphere. This is due to the significant ozone depletion from CFCs near the south pole which cools the stratosphere and increases the zonal winds. Increased zonal winds increases the gravity wave filtering in the stratosphere. With less gravity waves propagating and breaking in the mesosphere, the mesosphere warms resulting in less PMC formation.

In the northern hemisphere, our results indicate a 35% increase of PMC ice mass. This can be attributed to the influence of CFCs on the tropical tropopause (cold point) temperature and its subsequent influence on stratospheric water vapor. The tropical tropopause warms with ozone loss which increases the amount of water vapor in the upper atmosphere. The increase of available water vapor increases the PMC ice mass.

Our results imply that CFCs could contribute to the inter-hemispherical differences currently observed in PMC ice mass.

Corresponding Author: Aimee Merkel, aimee.merkel@colorado.edu
Problems in interpreting 557-nm green line airglow Fabry Perot interferometer measurements of MLT winds and temperatures to study MLT dynamics

J. Meriwether, Center for Solar Terrestrial Research, New Jersey Institute of Technology
M. Larsen, Department of Physics, Clemson University

The 557-nm emission of atomic oxygen from the mesosphere and lower thermosphere (MLT) region is one of the strongest night glow emissions from this region. However, it should be appreciated that ground-based Fabry-Perot interferometer measurements of the Doppler shift and Doppler broadening by high resolution measurements of the 557-nm spectral profile to determine MLT winds and temperatures are difficult to interpret. The difficulty comes in the fact that the line-of-sight path through the 10-15 km wide green line night glow layer with a peak location nominally at 95 to 97 km passes through a shear layer that is located within the night glow emission profile. High resolution sodium wind and temperature lidar measurements show this shear layer to be generally a few kms (3 to 5 km) thick. The MLT winds might be as much as 100 ms\(^{-1}\) in one direction just below this MLT shear layer and as much as 100 ms\(^{-1}\) in the opposite direction at a height a few kms higher just above the shear layer. This conclusion based upon the continual existence of the MLT shear layer and its location within the 557-nm night glow profile is also seen to be valid in MLT wind measurements obtained by the analysis of trimethyl aluminum chemical release movements against the background of fixed stars. A study based upon the convolution of a 10 km wide Gaussian night glow profile distribution with the TMA observed profile of MLT winds for 200 TMA release experiments selected was carried out to gain insight into this problem. The findings obtained show that the inferred line-of-sight averaged MLT wind across the assumed 557-nm volume emission profile is much less than the peak MLT wind amplitudes observed above and below the MLT shear layer. This result is consistent with the integration of the emission Doppler shifts across the heights of the region of the peak winds above the shear layer and across the region of the peak winds below the shear layer. Indeed, published FPI measurements of MLT winds generally show the 'MLT' winds inferred to be generally weak. Other issues regarding interpretation of ground-based green line FPI data are apparent: the shear layer height may change during the course of the night; the peak height and width of the 557-nm night glow layer may vary during the night; and finally, the intensity of the MLT shear seen may also vary within a night. These issues cannot be quantified with only ground-based FPI observations. The conclusion based upon this study and also for results obtained looking at all chemical release profiles available (>500) indicates that ground-based measurements of MLT dynamics with a FPI instrument observing the line shape of the 557-nm emission are very difficult to interpret. Thus, any meaningful insight into the processes of MLT dynamics gained using ground-based 557-nm FPI measurements is problematic.

Corresponding Author: John W. Meriwether, meriwej@clemson.edu
Simultaneous Multi-Channel Analysis of the coupled SABER/TIMED OH(v) and CO2(v) Nighttime Emissions

Alex Panka, NASA Goddard Space Flight Center
Alexander A. Kutepov, The Catholic University of America, Washington, D.C.
Artem G. Feofilov, École Polytechnique, Université Paris-Saclay, 91128, Palaiseau, France
Ladislav Rezac, Max Planck Institute for Solar System Research, Göttingen, Germany
Konstantinos S. Kalogerakis, Center for Geospace Studies, SRI International, Menlo Park, CA, USA
Diego Janches, NASA Goddard Space Flight Center, Greenbelt, MD
Dan Marsh, National Center for Atmospheric Research, Boulder, CO, USA

The recently discovered fast, multi-quantum OH(v≥5)→O(1D)+OH(v') vibrational-to-
electronic relaxation mechanism (Sharma et al. [2015], Kalogerakis et al. [2016]) provided new insight into the OH and CO2 IR emission formation in the nighttime mesosphere and lower thermosphere (MLT). The transfer of OH(v) energy to the CO2(v3) via the reaction chain OH(v) ⇒ O(1D) ⇒ N2(v) ⇒ CO2(v3) resolved the long-standing, unexplained strong 4.3-µm emissions measured by SABER/TIMED and other instruments (Panka et al., 2017). Based on this model we developed a self-consistent two channel retrieval approach for O(3P) and OH densities using SABER OH observations. The new O(3P) reconciled historically large discrepancies with O(3P) results obtained with different physical models and retrieval techniques in the WINDII, OSIRIS, and SCIAMACHY experiments (Panka et al., 2018).

The new efficient vibrational energy transfer from OH to CO2 molecules also causes significant coupling of the OH 2.0- and 1.6-µm and CO2 4.3- and 15-µm emissions measured by the SABER instrument. This makes individual retrievals of O(3P), OH, T, and CO2 from these emissions questionable and requires a multi-channel approach for retrieving these parameters self-consistently. We developed new two-channel forward-fit technique for retrieving CO2/T from the SABER 4.3- and 15-µm emissions and coupled in with our novel O/OH retrieval algorithm which uses SABER OH 2.0- and 1.6-µm emissions. We present first results of these simultaneous CO2/T/ O/OH retrievals and discuss their differences with standard single-channel retrievals.

Corresponding Author: Alex Panka, peter.a.panka@nasa.gov
AIM CIPS Measurements of PMCs and Gravity Waves

Cora E. Randall, CU Boulder
Scott M. Bailey, Virginia Tech
William Barrett, CU Boulder
Justin Carstens, Virginia Tech
James Craft, CU Boulder
Jeffrey A. France, CU Boulder
V. Lynn Harvey, CU Boulder
Jerry D. Lumpe, Computational Physics, Inc.
James M. Russell, III, Hampton University
Dave Welch, CU Boulder

The Aeronomy of Ice in the Mesosphere (AIM) Cloud Imaging and Particle Size (CIPS) instrument is a four-camera, nadir-viewing imager that measures scattered radiation at 265 nm. CIPS has been measuring polar mesospheric clouds (PMCs), as well as gravity waves near an altitude of 50-55 km, from May 2007 to the present. The CIPS field of view is approximately 2000 km x 1000 km, and the horizontal resolution of the retrieved data products is ~50 km2. This presentation describes the CIPS data products and availability, and highlights some of the science results to date. The figures below show example maps of CIPS PMC albedo on 29 June 2019 (left) and Rayleigh scattering albedo anomaly on 23 September 2010, which shows gravity wave signatures equatorward of the Antarctic continent (right).

Corresponding Author: Cora Randall, cora.randall@colorado.edu
Project PoSSUM: Aeronomy Citizen Science and EPO

Jason D. Reimuller¹,², Dave Fritts¹,², Gary E. Thomas³, Chris Lundeen¹, Adrien Mauduit¹, Aaron Persad¹, Yvette Gonzalez¹, Gerd Baumgarten⁴

¹Project PoSSUM, Inc., Boulder, Colorado, USA;
²GATS Inc., Boulder, Colorado, USA;
³Laboratory for Atmosphere and Space Physics, Boulder, CO, USA;
⁴Leibniz-Institut of Atmospheric Physics, University of Rostok, Kühlungsborn, Germany

Project PoSSUM, an acronym for ‘Polar Suborbital Science in the Upper Mesosphere’, is a 501(c)3 aeronomy research and education program that grew from the opportunity created by the Noctilucent Cloud Imagery and Tomography Experiment, selected by the NASA Flight Opportunities Program as Experiment 46-S in March 2012. A custom instrument was developed for this experiment to produce high-resolution noctilucent cloud and OH-layer imagery coincident with in-situ temperature measurements and neutral and charged particle densities in a manner from which tomography may be constructed. This tomography aims to characterize the roles of gravity wave and instability dynamics in the mixing and transport processes of the upper atmosphere. The experiment was the only flight opportunity ever selected by NASA for a human-tended experiment.

The human component of the PoSSUM experiment provides opportunities beyond traditional public funding sources for increased funding through private funding sources including participant tuition, commercialization of media products, and sponsorships. As of August 2019, privately-funded PoSSUM citizen-science research campaigns have included two airborne noctilucent cloud imagery campaigns and the maintenance of a citizen-scientist network of noctilucent cloud observers. PoSSUM also maintains ongoing research campaigns in partnership with the National Research Council of Canada, the Canadian Space Agency, the Royal Canadian Air Force, and Survival Systems USA that yield publications in aeronomy, bioastronautics, human factors, and educational methods.

The human component of the PoSSUM experiment also provides a means to inspire and excite general audiences while communicating science. PoSSUM manages educational programs through the Embry-Riddle Aeronautical University in Daytona Beach, FL and immersive aeronomy education programs for younger students through other institutions that have drawn students from 41 different countries. In all courses, students learn about aeronomy, remote sensing of the mesosphere, and about noctilucent clouds while they fly simulated suborbital missions using actual instrumentation in fully-pressurized spacesuits. PoSSUM also maintains three targeted outreach programs to serve under-represented communities in STEM, including ‘PoSSUM 13’ for young women, ‘Out Astronaut’ for the LGBTQ community, and the ‘PoSSUM Emerging Space Nations Project’ for individuals from nations where aeronomy research is not well represented.

Corresponding Author: Jason Reimuller, jason.reimuller@projectpossum.org
PoSSUM Citizen Science Airborne Noctilucent Cloud Imagery with the Royal Canadian Air Force

Jason D. Reimuller¹,², Adrien Mauduit¹, Theon Te Koeti¹,³, Dave Fritts¹,², Kyle Foster¹, Heidi Hammerstein¹

¹Project PoSSUM, Inc., Boulder, Colorado, USA;
²G.A.T.S. Inc., Boulder, Colorado, USA; Royal Canadian Air Force 15 Wing, Moose Jaw, SK, Canada.

Noctilucent Clouds (NLCs) are the central focus to NASAs ‘PMC-Turbo’ high-altitude balloon mission, which flew a suite of seven high-resolution camera systems and an airborne lidar system through a six-day mission around the circumpolar vortex above Northern Canada. Following the 2017 PoSSUM airborne noctilucent cloud tomography campaign from High Level Airport, Alberta, a unique opportunity arose to collaborate with the Royal Canadian Air Force (RCAF) to access altitudes of 50,000ft in a CT-155 ‘Hawk’ aircraft provided by 15 Wing from Moose Jaw.

Three sorties were flown from 29 June to 1 July 2018 from Edmonton International Airport. The aircraft flew on a constant line of latitude along the 56th parallel. A gyro-stabilized Sony a7s camera mated with a Samyang 135mm lens was affixed and operated from the back seat of the Hawk. The objectives of the campaign were to 1) observe the temporal evolution of small-scale features not observable from the ground, and 2) attempt to identify small-scale features also observed by PMC-Turbo to demonstrate that such features may be studied from lower-cost, on-demand airborne platforms.

Corresponding Author: Jason Reimuller, Jason.Reimuller@projectpossum.org
D region observations by VHF and HF radars to investigate Polar Mesospheric Winter Echoes

Toralf Renkwitz, Ralph Latteck, Boris Strelnikov, Nikołoz Gudadze
Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Polar Mesospheric Winter Echoes (PMWE) have been observed by VHF radars for quite some years. Until now, most of the studies were focused on the investigation of their properties, like statistical parameters of e.g. their seasonal and interannual occurrence rates and altitude distributions. However, especially the origin of PMWE and underlying processes are still under debate and further observations aim to contribute to this question. Recent PMWE observations with the MAARSY VHF radar included experiments using multiple beam directions to investigate the spatial structure and evolution of PMWE. Within this study we present results of MAARSY radar observations of PMWE layers complemented by simultaneous Saura MF radar measurements of horizontal winds and electron density. The spectral width of VHF and MF radar echoes for the presence of PMWE are analyzed and compared. Additionally, investigations of the angular distribution of scattering structures as seen by the Saura MF radar for different geomagnetic conditions and PMWE occurrence are included.

Corresponding Author: Toralf Renkwitz, renkwitz@iap-kborn.de
First product and initial validation of the AIM CIPS PMC tracking winds

P. P. Rong\textsuperscript{1}, J. Yue\textsuperscript{2}, J. M. Russell III\textsuperscript{1}, J. D. Lumpe\textsuperscript{3}, D. E. Siskind\textsuperscript{4}, and C. E. Randall\textsuperscript{5}

1. Hampton University, Hampton VA 23668
2. NASA Goddard Research Center, Greenbelt, MD 20771
3. Computational Physics, INC., Boulder, CO 80301
4. Naval Research Laboratory, Washington, DC 20375
5. Laboratory for Atmospheric and Space Physics, Boulder, CO 80303

The refined CIPS PMC wind tracking algorithm is elaborated and the first wind product is validated against the NOGAPS-ALPHA winds and the horizontal wind model results (HWM07 and HWM14). Three frame sizes are adopted, which are the default size 500km used before, and the 20% smaller and larger frames, 375km and 625km, to generate more robust wind set with better consistency and spatial coverage. An analytical model is used to derive the upper limits of “reliable” winds for each frame size. For both the full wind set and the threshold-restrained wind set, calculations from the three frame sizes are merged through a sampling strategy within each 1.5lon×1.5lat grid as well as three times of this grid size. The two grid sizes are used in the editing/screening to test the self-consistency of the winds. In the editing/screening strategy, after the similar wind directions (±20°) are grouped together the group with the smallest wind magnitudes are taken as representative to the winds in the given grid. On the coincident longitudes/latitudes and times of the CIPS and NOGAPS, there are about 20% of agreements. For each day among the 14 orbits the higher fractions of agreements only occur on one to three orbits. The inconsistency between the CIPS and NOGAPS winds primarily stems from the deviation between the in situ winds and the quasi-geostrophic winds. Larger overall magnitudes of the NOGAPS winds, and the inherent false wind detections due to the involvement of cloud physics and wave dynamics, both contributed to the degree of existing inconsistency. The agreement with the HWM winds appears better likely due to the fact that the latter had wind assimilation from the actual observations. The daily mean time series of the CIPS cloud tracking zonal winds indicate that these winds are primarily westward but the overall magnitude is about 20m/s smaller than the NOGAPS zonal winds.

Both the CIPS and NOGAPS winds exhibit transient variabilities on the intra-seasonal scales throughout the main period of summer but toward the start and end of the season the wind directions start to reverse. The prevailing CIPS meridional wind direction is generally southward which agrees with the climatology. The intra-seasonal variation in the 2009 CIPS meridional winds shows smaller magnitudes in July than in June and August, which appears noteworthy. Based on the NOGAPS analysis it is likely that local time dependence and how such dependence varies with the stage of the summer has played a role.

Two-five day planetary wave regression analysis indicates that in the CIPS 2009 winds stationary components rarely are dominant whereas the 2.5day waves are dominant on a notable fraction of days. CIPS 2007 and NOGAPS winds on the other hand both show stronger dominance of the stationary wave components.

Corresponding Author: Pingping Rong, PING-PING.RONG@hamptonu.edu
Mid-latitude Noctilucent Cloud changes over the 2002 – 2019 period using satellite data and modeling

James M. Russell III, Hampton University
Pingping Rong, Hampton University
Mark E. Hervig, GATS, Inc.
Scott M. Bailey, Virginia Tech
Cora E. Randall, University of Colorado, LASP

Polar Mesospheric Clouds (PMCs), also referred to as Noctilucent Clouds (NLCs), generally occur at latitudes above 55° in spring and summer. It is not uncommon to also see the clouds at lower latitudes as reported by numerous ground-based observers and satellite observations over the years, especially in the 40°N to 55°N range. The 2019 spring and early summer period was especially active with clouds being seen numerous times below 40°N and earlier in the season. For example, the CIPS instrument on the AIM satellite observed the clouds over the states of Colorado, Utah, Arizona, New Mexico and Wyoming, from about ~37°N to 42°N and numerous ground-based sightings were also reported at these lower latitudes. The internet “lit up” with stories of lower latitude ground-based observations of NLC occurrences. Previously, Russell et al. [2014] reported on a study of long-term PMC changes in the 40°N to 55°N range using the zero-dimensional thermodynamic equilibrium model developed by Hervig et al. [2009], and temperature and H₂O observed by the SABER and MLS instruments on the TIMED and Aura satellites respectively. The study concluded that during the 10-year period from 2002 to 2011, a statistically significant increase in the number of NLCs occurred. This paper will update the prior analysis by examining long-term NLC changes over the period from 2002 to 2019.

Corresponding Author: James M. Russell III, james.russell@hamptonu.edu
Interhemispheric Coupling Study by Observations and Modelling (ICSOM)

Kaoru Sato¹, Yoshihiro Tomikawa², Masashi Kohma¹, Dai Koshin¹, Ryosuke Yasui¹, Shingo Watanabe³, and ICSOM members

¹Department of Earth and Planetary Science, The University of Tokyo, Japan
²National Institute of Polar Research, SOKENDAI Japan
³Japan Agency for Marine-Earth Science and Technology, Japan

Recent observational and modelling studies suggest that the Northern and Southern Hemispheres of the Earth’s atmosphere are potentially coupled by the Lagrangian mean flow in the mesosphere modulated by waves interacting with the mean flow. However, observations of modulated wave and flow fields which are needed for quantitative understanding of the interhemispheric coupling are not sufficient. Simultaneous observations of gravity waves (GWs) at various locations are most important because they are a main driver of the Lagrangian mean flow in the mesosphere. Continuous observation by the full system of the PANSY radar, a large mesosphere-stratosphere-troposphere (MST) radar in the Antarctic, started in October 2015, and a global MST radar network was constructed. So far, we conducted four international observation campaigns by utilizing this MST radar network and other complementary radio and optical observation instruments, focusing on the interhemispheric coupling initiated with a sudden stratospheric warming (SSW) in the Arctic. Three major warming and one minor warming events were captured. Particularly in the latest campaign for the major SSW in early January 2019, high quality data were obtained from strong polar mesosphere summer echoes in the Antarctic by the PANSY radar. By defining the warming period of the Arctic stratosphere and that of the Antarctic upper mesosphere for each campaign, gravity wave activity modulation is being examined. In addition, we have been developing a data assimilation system and gravity-wave permitting high-resolution general circulation model which covers the height region up to the lower thermosphere for a quantitative study of the interhemispheric coupling mechanism. More than thirty scientists participate in the ICSOM project. Current status and scientific outcomes of the ICSOM project are reported.

+ Invited talk
Corresponding Author: Kaoru Sato, kaoru@eps.s.u-tokyo.ac.jp
Modeling of Acoustic and Gravity Wave Processes and Effects in the Observable Layers of the Mesopause Region

J. B. Snively, Embry-Riddle Aeronautical University

Acoustic and gravity waves (AGWs) with short periods (~few-to-10s of minutes) and small scales (~10s-to-100s of kilometers) impose variability throughout the Earth's ionosphere, thermosphere, and mesosphere (ITM), and drive effects at larger scales over longer durations. They are generated by meteorological forcing, instabilities of waves and flows, and as responses to impulsive natural hazard events, and may achieve very large amplitudes (evolving nonlinearly) in the ITM. They can be measured from ground or space, via their perturbations to airglow and species layers at mesopause (as well as lower in the stratosphere and higher in the ionosphere) and thus provide insight into their source processes, evolutions, and effects.

Here, we investigate AGWs and their observables using new versions of the nonlinear, compressible Model for Acoustic and Gravity wave Interactions and Coupling (MAGIC). Modeling case studies elucidate scenarios of wave propagation, nonlinear evolutions, and impacts within and outside the observable layers of the ITM. MAGIC neutral dynamics are also readily coupled with the airglow models of Snively et al. (2010), and with complementary ionospheric models, e.g., Zettergren and Snively (2015, 2019). Simulations thus capture the atmospheric dynamical responses to short-period AGW processes, and signatures in major and minor species densities, released tracers, and airglow layer emissions (and, via complementary models, the ionosphere) to enable comparisons with data. Details of the specific numerical methodology, plus new results for meteorological sources and natural hazard events, are reviewed. Opportunities to connect modeling with space- and ground-based observations are discussed.

Figure:
Panels show integrated “images” through planes of a 3D model, where a breaking gravity wave has disturbed four initial species layers at 90, 100, 110, and 120 km altitude. [Axis units are kilometers.]

(Note the dramatically different character of dynamics, due to varied stability and roles of molecular viscosity throughout the MLT region.)

+Invited Talk
Corresponding Author: Jonathan Snively, snivelyj@erau.edu
The Super Soaker Experiment: Water Vapor Cooling Enables Mesospheric Cloud Formation

Michael H. Stevens¹, Richard L Collins², Irfan Azeem³, Michael J. Taylor⁴, Miguel F. Larsen⁵, Bifford P. Williams⁶, Jennifer H. Alspach², Jintai Li², Pierre-Dominique Pautet⁴, Yucheng Zhao⁴, Xun Zhu⁷

¹Space Science Division, Naval Research Laboratory, Washington, DC, USA
²Geophysical Institute and Atmospheric Sciences Program, University of Alaska Fairbanks, AK, USA
³ASTRA LLC, Boulder, Colorado, USA
⁴Center for Atmospheric and Space Sciences and Department of Physics, Utah State University, Logan, UT, USA
⁵Department of Physics, Clemson University, Clemson, South Carolina, USA
⁶GATS Inc., Boulder, CO, USA
⁷Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

On the night of 26 January 2018, 220 kg of pure water was released at 85 km altitude from a sounding rocket at Poker Flat Research Range (PFRR) in Chatanika, Alaska (65° N, 147° W). The experiment, called “Super Soaker”, was designed to observe the impact of concentrated water vapor plumes in the upper mesosphere. We explosively dispersed the payload and almost immediately observed mesospheric water ice clouds using a Rayleigh lidar pointed toward the release point. The first cloud appeared at 92 km, 18 s after the water was dispersed and its observed altitude dropped monotonically over several 25 s integrations. The last cloud appeared at 78 km, 3 m 25 s clouds after the water was dispersed. The temperature measured at 85 km from ground-based lidars immediately beforehand was 223 K and well above the frost point. Here we present the first modeling results of these observations. We use the one-dimensional Community Aerosol and Radiation Model for Atmospheres (CARMA) to simulate the cloud development and for the first time we couple a water vapor radiative cooling model to CARMA. We find that concentrated meter-scale filaments of water vapor in the upper mesosphere can produce infrared cooling rates that are fast enough to drive the ambient temperature down to the frost point and form water ice clouds in seconds. The narrower the filament the stronger the cooling, with meter-scale filaments of pure water cooling the fastest, yielding rates on the order of 1 K/s. We also find that where there is pure water vapor (10⁶ ppmv) in the upper mesosphere, the frost point is between 200-205 K rather than ~150 K more typical for ambient conditions. The onset of the ice cloud in time and altitude as well as the ice mass density of the cloud are all well reproduced by the model. The results show that concentrated filaments of water vapor in the upper mesosphere are not only a reservoir for mesospheric clouds but also induce cloud formation.

Corresponding Author: Michael Stevens, michael.stevens@nrl.navy.mil
First results from PMWE-1 sounding rocket campaign

B. Strelnikov¹, T. Staszak¹, R. Latteck¹, T. Renkwitz¹, I. Strelnikova¹, F.-J. Lübben¹, M. Friedrich², J. Stude³, M. Rapp³, G. Baumgarten¹, J. Hedin⁴, J. Gumbel⁴, and E. Belova⁵

¹Leibniz Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany
²Graz University of Technology, Graz, Austria
³Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
⁴Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden
⁵Solar, Terrestrial and Atmospheric Research Programme, Swedish Institute of Space Physics, Kiruna, Sweden

Polar Mesosphere Winter Echoes (PMWE) are relatively strong coherent radar returns from ~55-85 km altitudes, which primarily occur in the winter season at high latitudes. PMWE are also observed at mid-latitudes, although very much more rarely. Because of their extremely low occurrence rate, they are still poorly investigated. As a consequence, the origin of these echoes is still under debate.

The PMWE-1 sounding rocket campaign aimed at investigation of PMWE formation mechanism was conducted in April 2018 from the north Norwegian Andøya Space Center (69 °N, 16 °E). Two sounding rockets were launch to perform high resolution in situ measurements of densities of neutral and plasma species. Middle Atmosphere ALOMAR Radar System (MAARSY) was used to monitor PMWE allowing to resolve the observed structures both vertically and horizontally and to measure echoes in the common volume with the sounding rocket.

In the paper we give an overview of the conducted measurements and present and discuss the first measurement results.

Corresponding Author: Boris Strenlnikov, strelnikov@iap-kborn.de

Presenting Author: Ralph Latteck
Ice Water Content of Polar Mesospheric Clouds and Noctilucent Clouds, and Relationship to Temperature and Water Vapor

Gary E. Thomas

Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO

The AIM SOFIE experiment (2007-present) has provided highly accurate data on Polar Mesospheric Clouds (PMC), specifically ice water content (IWC), temperature (T) and water vapor. This work exploits the statistical relationship of the IWC distribution to mean seasonal temperature, <T>. Retrieval methods are described for <T> at a reference pressure (near 1 pascal) provided the data sets are sufficiently large. The methods derived from northern hemisphere (NH) data are tested on southern hemisphere (SH) data. Several tenths of a degree accuracy is achieved even though the SH is warmer than the NH. The technique can be applied to other IWC data sets, such as the AIM CIPS experiment, and the 40-yr long SBUV data. The analysis has also revealed a remarkable agreement of SOFIE and NLC IWC distributions, which demonstrates that for sufficiently large data sets, the two phenomena are the same. A conceptual model of PMC formation/destruction explains the exponential behavior of the IWC distribution, which is observed in all IWC data sets and multi-dimensional microphysical models.

Corresponding Author: Gary Thomas, gary.thomas@lasp.colorado.edu
Is Monsoon Convection a Source of High-Latitude Summer Mesospheric Gravity Waves?

Brentha Thurairajah¹, Chihoko Cullens², David Siskind³, Mark Hervig⁴, Scott Bailey⁵

¹Virginia Tech
²University of California Berkeley
³Naval Research Laboratories
⁴GATS Inc.

Model studies have shown that the latitudinal gradient of the summer easterly monsoon circulation would allow eastward propagating low-latitude stratospheric gravity waves (GWs) to be refracted to high-latitudes and can influence the summer polar mesosphere. We investigate this oblique propagation of monsoon GWs by analyzing the correlation between the 50 km low-latitude GWs derived from TIMED/SABER temperature measurements and the summer polar mesospheric variability from the AIM/SOFIE ice water content measurements using data from 8 NH summers (2007-2014). The correlation coefficients between the time series of daily averaged monsoon GWs and PMC indicate a large seasonal variability with both positive and negative values. This variability is attributed to the strength of the horizontal wind gradient with stronger gradient allowing for more efficient poleward propagation of GWs thus confirming model studies. Ray-tracing simulations confirm this oblique propagation and indicate that GWs with faster phase speeds and longer horizontal wavelength have a higher probability of reaching the high-latitude summer mesosphere.

Corresponding Author: Brentha Thurairajah, brenthat@vt.edu
Large-Scale Dynamics and Transition to Instability observed in Polar Mesospheric Clouds by the PMC-Turbo Balloon Mission

Bifford P. Williams and David C. Fritts, GATS, Boulder
C. Bjorn Kjellstrand, Columbia University
Christopher Geach, University of Minnesota

PMC-Turbo was a NASA high-altitude balloon mission that used an array of 7 cameras to image wave-modified PMC structure overhead at horizontal scales from <10m up to ~150km along a several thousand kilometer flight track from Kiruna, Sweden to northern Canada from 8-14 July 2018. We saw almost continuous perturbation of the clouds by waves and instabilities. This talk will concentrate on the larger scale dynamics by looking at the advection of the smaller cloud features to determine the horizontal wind field during the flight. We will also look at the propagation characteristics of the gravity waves with horizontal wavelengths typically 10 -50km, with 2 or 3 waves often observed simultaneously, and how these relate to the regions of instability observed in the clouds.

Corresponding Author: Bifford P. Williams, b.p.williams@gats-inc.com
8 years of airglow gravity wave observations from space

Jia Yue, Hampton University

Septi Perwitasari; Shuang Xu; Yuta Hozumi; Takuji Nakamura; Takeshi Sakanoi; Akinori Saito; Steven Miller; William Straka; Pingping Rong

We compare two contemporary space-borne observations of atmospheric gravity waves (AGW) manifested in the mesopause airglow region via a series of case studies. Since late 2011, the Suomi National Polar-orbiting Partnership (SNPP) Visible/Infrared Imaging Radiometer Suite (VIIRS) Day Night Band (DNB) has observed AGWs occurring globally, thanks to its sensitivity to weak emissions of the OH* Meinel bands. The wave features, detectable at 0.75 km spatial resolution across its 3000 km imagery swath, are often confused by the upwelling emission of city lights and clouds reflecting downwelling nightglow. The IMAP/VISI O$_2$ band, an independent measure of the AGW structures in nightglow based on the International Space Station (ISS) during 2012-2015, contains much less noise from the lower atmosphere. However, VISI offers much coarser resolution of 14-16 km and a narrower swath width of 600 km. Here, we compare DNB and VISI, focusing on several concentric AGW events excited by the thunderstorms over Eastern Asia in August 2013. The comparisons point toward suggested improvements for future sensor designs targeting AGWs.

Corresponding Author: Ji Yue, jia.yue@hamptonu.edu
Observations of mountain waves in the stratosphere and mesosphere over Antarctica

Yucheng Zhao¹, M. J. Taylor¹, J. France², S. Palo², S. Zhang³, P-D. Pautet¹, J. M. Russell III⁴

¹Utah State University
²University of Colorado
³Massachusetts Institute of Technology
⁴Hampton University

The new CIPS/AIM capability for imaging gravity waves (GW) in the stratosphere (~55km) have enabled ground-based coordinated multi-layer measurements of mountain waves (MW). As part of the Antarctica Gravity Wave Instrument Network (ANGWIN) program, the Utah State University (USU) Advanced Mesospheric Temperature Mapper (AMTM) was deployed at McMurdo station in early 2017 and austral winter-time (March to September) high-precision measurements of the infrared OH (3, 1) rotational temperature and band intensity have been obtained.

During August 2018, MW events were captured by the CIPS imager using the Rayleigh Albedo Anomaly (at ~55 km) and the AMTM at higher altitudes (~87 km) over McMurdo station. In this presentation, we examine both datasets and investigate the characteristics of the MW events. The mesospheric meteor radar winds from McMurdo station were also examined to help understand their effects on the propagation of the MWs. Possible secondary wave signature generated by the breaking of the MWs in the thermosphere are also explored.

Corresponding Author: Yucheng Zhao, yu.cheng@usu.edu
Interhemispheric comparison of wintertime mesospheric wave variability at high latitudes

Yucheng Zhao¹, M. J. Taylor¹, B. Thurairajah², P.-D. Pautet¹, D. Sower¹, W. R. Pendleton Jr.¹ and J. M. Russell III³

¹Utah State University
²Virginia Tech
³Hampton University

As part of the Antarctica Gravity Wave Instrument Network (ANGWIN) program, the Utah State University (USU) Advanced Mesospheric Temperature Mapper (AMTM) has been operated at the Amundsen-Scott South Pole Station (90°S), Antarctica since 2011. Nine years of Austral winter-time (April-August) high-precision measurements of the infrared OH (3, 1) rotational temperature and band intensity have now been obtained to date. In parallel, winter-time (November-March) measurements between 2011-2017 were obtained by a second USU AMTM sited at the ALOMAR Arctic Lidar Observatory (69°N), Norway. Later in 2017, this AMTM was relocated to Poker Flat Research Range (PFRR, 65°N) obtaining further data for the winter season of 2017-2018. In addition, a third AMTM was deployed at McMurdo station as part of the ANGWIN program in 2017. The locations of these four high-latitude sites relative to the winter polar vortex are unique with the South Pole Station located deep inside the polar vortex.

Spectral analysis of the zenith temperature and intensity data from these polar sites have revealed a rich spectrum of gravity waves and planetary waves, with minimal tidal activity at the pole. In this presentation, we compare the winter-time wave activities from these sites using the temperature and OH band intensity measurements. In particular, we compare and contrast the similarities and differences in the intra-seasonal variations of the gravity waves and planetary waves, and their year-to-year variability as measured at these geophysically distinct sites. Our results are then compared with gravity wave result in the high-latitude mesopause region as determined using the SOFIE temperature data from the NASA AIM satellite.

Corresponding Author: Yucheng Zhao, yucheng@usu.edu