20th International EISCAT Symposium

and

15th Intenational Workshop on Layered Phenomena in the Mesopause Region (LPMR)

Sundbyholm Castle, Sweden, August 14-19, 2022

Abstracts

(sorted by first author)

Status: 2022-08-10

Nitric Oxide in the Polar Winter Observed by the Sub-Millimeter Radiometer (SMR)

Scott M. Bailey[1], Brentha Thurairajah[1], Lynn Harvey[2], Cora Randall[2], Kristell Perot[3], and Donal Murtagh[3]

[1] Virginia Tech, VA, USA,
[2] University of Colorado, CO, USA,
[3] Chalmers University of Technology, Sweden

The polar winter upper atmosphere is an important, yet insufficiently characterized region. Energetic Particle Precipitation (EPP) leads to the production of NO in the polar lower thermosphere throughout the year, but the long period of darkness during winter removes the primary loss process for NO, photodissociation. The removal of this loss process leads to a long chemical lifetime for NO molecules, which allows time for them to descend to and within the polar vortex. As the NO reaches the lower mesosphere it participates in the catalytic reaction with O_3 which leads to some of the NO being converted to NO_2. The sum of NO and NO_2 (and N if present) is referred to as NO_x. It is known that significant amounts of EPP-produced NO_x reach the stratosphere in polar winter. This descent and the relative roles of diffusion and advection have not been fully characterized by observations.

The Sub-Millimeter Radiometer (SMR), launched in 2001 on board the Odin satellite, has been observing Nitric Oxide (NO) globally from the stratosphere to the lower thermosphere for two decades. Using microwave limb emission, SMR NO observations are made during both day and night time conditions. The nighttime measurements are especially useful for studying NO in the long polar winter. Throughout most of the SMR mission, NO observations were made approximately four days per month. While this sampling hinders the characterization of any one season, there are now sufficient observations over different winters to describe an average seasonal evolution. We will show that the SMR observations reveal an evolution of NO over the season that peaks in magnitude and has a minimum in altitude of peak near winter solstice. A layer of enhanced NO (relative to the sunlit atmosphere) between 80 and 100 km is persistent throughout the polar night. We will show that most of the EPP-produced NO is ultimately destroyed by transport to sunlit latitudes. We will further show that the observed average annual flux of polar NO_x into the stratosphere is consistent with the estimates of Randall et al. (2007).

A comparative assessment of the distribution of Joule heating as estimated by EISCAT and TIEGCM over one solar cycle

D. Baloukidis[1], T. Sarris[1], A. Aikio[2], I. Virtanen[2], S. Tourgaidis[1], S. Buchert[3], P. Pirnaris[1], and K. Papadakis[4]

[1] Dept. of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi, Greece
[2] Space Physics and Astronomy Research Unit, University of Oulu, Finland
[3] Swedish Institute of Space Physics (IRF), Uppsala, Sweden
[4] University of Helsinki, Department of Physics, Helsinki, Finland

During geomagnetically active times, Joule heating in the Lower Thermosphere - Ionosphere is a significant energy source, greatly affecting density, temperature, composition and circulation. At the same time, Joule heating and the associated Pedersen Conductivity are amongst the least known parameters in the upper atmosphere in terms of their quantification and spatial distribution, and their parameterization by geomagnetic parameters shows large discrepancies between estimation methodologies, primarily due to a lack of comprehensive measurements in the region where they maximize. In this work we perform a statistical comparison of Joule heating as calculated by the NCAR Thermosphere - Ionosphere - Electrodynamics General Circulation Model (TIEGCM) and as obtained through the European Incoherent Scatter Scientific Association (EISCAT). Statistical estimates of Joule heating and Pedersen conductivity are obtained over a solar cycle spanning from 2009 until 2019. The results are binned according to MLT and Kp and are compared in terms of median and percentiles. Similarities between TIEGCM and EISCAT are outlined and potential sources of discrepancies are discussed.

Noctilucent clouds and their use as tracers on multiple scales: From turbulence to trends

G. Baumgarten, J. L. Chau, J. Fiedler, R. Latteck

Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany

Noctilucent clouds have been called the miner's canary of the mesosphere and lower thermosphere since their occurrence is governed by temperature and water vapour (created from methane in the middle atmosphere). Model studies have shown that their occurrence, brightness, and altitude on centennial scales may be linked to greenhouse gas increases, i.e., carbon dioxide and methane.

On the other hand, model simulations on time scales of seconds to minutes indicate that icy particles forming noctilucent clouds behave partly as inert tracers.

We present lidar, radar, and camera results to investigate cloud morphology, motion, and microphysical properties. Observations on time scales of seconds to decades will be studied to enlighten their relation to the background atmosphere.

Infrasound as a Probable Cause of Fast-travelling Polar Mesosphere Winter Echoes

E. Belova[1], V. Barabash[2], O. A. Godin[3], J. Kero[1], S. P. Näsholm[4,5], E. Vorobeva[4,6], and A. Le Pichon[7]

[1] Swedish Institute of Space Physics, Kiruna, Sweden
[2] Luleå University of Technology, Kiruna, Sweden
[3] Naval Postgraduate School, Monterey, USA
[4] NORSAR, Kjeller, Norway
[5] Department of Informatics, University of Oslo, Oslo, Norway
[6] Norwegian University of Science and Technology, Trondheim, Norway
[7] CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives), Arpajon, France

Polar mesosphere winter echoes (PMWE) are relatively strong signals from 50-80 km altitudes observed by radars operating at a broad frequency range, at polar latitudes during the equinox and winter seasons. A majority of PMWE can be explained by the neutral air turbulence with or without the presence of charged small particles (presumably meteor smoke particles). However, in some cases strong, quasi-specular radar echoes with high horizontal speeds exceeding 350-400 m/s were observed (Kirkwood et al., 2006; Kirkwood, 2007). Since atmospheric scatterers moving with velocities of hundreds of m/s cannot be attributed to the atmospheric turbulence or nano particles moving with the wind, there is a need to understand what are the physical mechanisms that can generate such PMWE. We consider three recent PMWE events, when the signals travelling with high horizontal velocities above 300 m/s were measured by the 52 MHz atmospheric radar ESRAD located at Esrange, near Kiruna in northern Sweden. We propose four mechanisms of generation of such PMWE that involves microbaroms, i.e. infrasound waves at 0.1 - 0.35 Hz frequencies created by ocean swell. These mechanisms are (i) generation of viscous waves, (ii) generation of thermal waves, (iii) direct contributions of infrasound, and (iv) generation of secondary waves at sound dissipation and they necessarily accompany sound propagation in inhomogeneous, thermally conducting and viscous fluid (air). The infrasound measurements at the IS37 station located about 170 km north-west from the ESRAD radar, modelled maps of the microbarom sources, infrasound propagation conditions and ionospheric conditions for three PMWE events support the proposed mechanisms.

Formation and IMF dependence of the early morning electron density depletion region observed in ESR data

L. M. Bjoland[1,2], Y. Ogawa[3], S. Hatch[2], K. Laundal[2], D. Lorentzen[1,2]

[1] Arctic Geophysics Department, The University Centre in Svalbard, Longyearbyen, Norway
[2] Birkeland Centre of Space Science, University of Bergen, Bergen, Norway
[3] National Institute of Polar Research, Tokyo, Japan

In this work, we are investigating the statistical high-latitude electron density depletion region in the early morning sector observed by the EISCAT Svalbard radar (ESR) using data from 1996-2021. We propose that the formation of the observed depletion region is connected to ion frictional heating, and that this formation might be affected by both the background neutral temperature and seasonal changes in the O/N_2 ratio and solar zenith angle (Bjoland et al, 2021). The depletion region also seems to be affected by the interplanetary magnetic field (IMF). Preliminary ESR results show that the depletion region is clearer when IMF By is positive. Using the Newell coupling function (Newell, 2007), our results also indicate that the observed electron density depletion region is more prominent when the solar wind driving is strong.

In addition, the ESR results have been compared with statistical results from the CHAMP and Swarm satellites and with the TIE-GCM model. In general, the satellite data confirm the ESR results with the early morning depletion region being clearest during high driving conditions. The TIE-GCM model also shows electron density depletion in the early morning, and this model has been used to further investigate the formation of the early morning depletion region. An area with strong frictional heating is observed in TIE-GCM data just south of the depletion region. Results from our comparison between the ESR data, CHAMP/Swarm data and the TIE-GCM model will be presented and discussed.

The Grand Challenge Initiative – CUSP and M/LT projects status and future plans

Kolbjørn Blix[1], Jøran Moen[2], Douglas Rowland[3], Christopher Koehler[4]

[1]Andøya Space, [2]University of Oslo, [3]NASA Goddard Space Flight Center, [4]Colorado State University

The Grand Challenge Initiative (GCI) - CUSP project was a major international rocket-based research project, with participation from NASA (six scientific projects), JAXA (1 scientific project) and UiO / ASP (1 scientific project). In addition, all three nations participated in a joint two-stage student rocket – RockSat-XN "G-CHASER", launched from Andøya as part of GCI CUSP in January 2019.

12 rockets are successfully launched from Andøya and Ny-Ålesund, Svalbard between 2018-2021, several times with both launch sites operated simultaneously. GCI CUSP is one of the largest scientific rocket projects NASA has ever participated in.

The project idea and ownership are Norwegian, conceived in 2012 by Professor Jøran Moen (UiO) and Kolbjørn Blix (ASP):

"Gathering scientists working on issues related to the gap in the Earth's magnetic field (CUSP) over Svalbard and for the first time ever launch sounding rockets from both Andøya and Ny-Ålesund in the same campaign".

This way, Andøya Space launch NASA's largest sounding rockets – and fly them horizontally through the CUSP, high above Svalbard. While from Ny-Ålesund, we launch smaller rockets, straight up and into the CUSP.

Doing this at different heights and with different instruments is important when trying to understand the processes going on in and close to the CUSP. Coordinating already planned CUSP related projects and motivating the creation of new and complementary efforts was utterly important during the initial phase of the work with GCI CUSP. It was also important to ensure that necessary ground-based instruments and modelling communities were included in the team at an early stage.

Another important goal from the Norwegian side was to ensure that all data from rockets and ground-based instruments is available from a common database, where all active participants have equal access. After all, data is the most important part of a scientific campaign, and these must be easily available for potential users after quality control and necessary quarantine time. The GCI data-sharing agreement was signed by SIOS (The Svalbard Integrated Earth Observing System), NASA, JAXA and UiO in Tokyo in 2017.

The next GCI project – M/LT (mesosphere / lower thermosphere) is already in operation. It includes US, Norway, Germany, Sweden, Russia, UK, Canada, Japan and Poland, but other nations are more than welcome to join. Due to working with lower altitude science than its CUSP cousin, GCI M/LT has a potential for even more activities. Rockets, measurements using aircrafts, satellites, balloon borne and ground based instruments. Launching out of even more sites is also a possibility to be discussed, all based on the science topics raised during the planning phase. The first project to launch in M/LT was the XENON French balloon (Europian balloon infrastructure project HEMERA and CNES balloon campaign KLIMAT 2021) with their flight to 32.6 km altitude on the night 16-17 August 2021 from ESRANGE. The second project was the Sounding rocket project "PMWE" for investigation of polar mesosphere winter echoes by IAP in Germany. Two instrumented sounding rockets were launched on 13th and 18th of April under PMWE and non-PMWE conditions, respectively.

The people working with the GCI projects are highly devoted to including students, and also for the M/LT project a student sounding rocket mission will be provided by NASA and Andøya Space. The GHOST – "Grand cHallenge MesOsphere Student rockeT" has a preliminary launch date set for November 2024, but this may change to a later date depending on the process and other projects. It is important for us that the students get to experience the feeling of being part of a real GCI M / LT (or similar) rocket operation, and this can also mean that the launch time must be changed to adapt to this.

Joule Heating and the Atmospheric Dynamo

S. C. Buchert

Swedish Institute of Space Physics

Joule heating in the thermosphere occurs when electric fields transformed into the local reference frame of the neutral gas are non-zero. This is also the condition for having electric currents according to the well-known Ohm's law for the ionosphere. A prominent cause of such current driving electric fields is magnetosphere-ionosphere coupling at high latitudes. Also the atmospheric dynamo is known to drive currents. For example, at mid-latitudes the Sq currents are dominating in geomagnetically quiet periods. Sq is driven by tidal winds, and so mechanical energy is converted to electriciy and ultimately to heat because the ionosphere is a dissipative medium. Also gravity (buoyancy) waves involve neutral motions and can constitute a dynamo. The electric currents arising from the dynamo in turn affect the neutral dynamics via Lorentz (jxB) forcing or, equivalently, ion drag.

To obtain a general description of the coupling between neutrals and the ionospheric plasma we present an atmospheric dynamo equation where the well-known Pedersen and Hall conductivities appear. The derivation is based on a paper by Parker (1996). A dynamo effect occurs when $\nabla x(uxB) \neq 0$, where u is the neutral wind and B the magnetic field. Because the conductivity parallel to B is orders of magnitudes higher than the Pedersen and Hall conductivities, the condition is approximately that if uxB is not constant along magnetic field lines, then dynamo electric fields drive currents. Since gravity waves are a result of non-electrodynamic forces, generally their uxB varies along magnetic field lines, and dynamo effects are produced when they propagate into the dynamo regions of the lower thermosphere.

We estimate that the tidal Sq dynamo globally dissipates roughly a power of 2 GW quasi-permanently. Also the electrodynamic dissipation by medium and small scale gravity waves propagating from the mesosphere into the lower thermosphere could be a significant source of heat. Unlike the current systems coupling the magnetosphere and ionosphere which are observed by satellites like Swarm, the currents of a gravity wave dynamo are confined to the lower thermosphere and can only be observed with a very low orbiting satellite or sounding rockets.

Effect of polar cap patches on the neutral winds in the nightside high-latitude ionosphere

L. Cai[1], A. Aikio[1], S. Oyama[2], I. Virtanen[1], , H. Vanhamäki[1], N. Ivchenko[3], and S. Buchert[4]

[1] University of Oulu, Finland
[2] Nagoya University, Japan
[3] KTH Royal Institute of Technology, Sweden
[4] Swedish Institute of Space Physics, Sweden

Polar cap patches (PCPs) are islands of enhanced F-region plasma in the polar cap ionosphere. Previous studies mainly focus on the formation and evolution of PCPs, as well as their impact on satellite navigations and communications. The effect of PCPs on the ionosphere-thermosphere coupling has been rarely discussed. In this study, we report a particular event when the strong F-region neutral winds (>400 m/s) were observed in the auroral oval with simultaneous evolution of PCPs. We use conjugate measurements by the FPI at Tromsø, EISCAT incoherent radars at both Tromsø and in Svalbard, global GPS TEC maps, and DMSP and Swarm satellites. Our analysis shows that when the PCPs turn into blobs in the nightside auroral oval, the enhanced F region plasma density increases the efficiency of ion-neutral coupling. The collision frequency between the neutrals and ions is increased by a factor of 2-4. This causes higher ion drag rates. We suggest that primarily the ion drag force drove the strong neutral winds observed by the FPI. Since PCPs can last as long as several hours, the effect of PCPs on the neutral winds can be both regional and global. Our study brings this as a new aspect of the ionosphere-thermosphere coupling, namely that PCPs contribute to the acceleration of thermospheric winds.

GeospaceLab: A Python package for data analysis in space physics and its application for incoherent scatter radar measurements

Lei Cai[1], Anita Aikio[1], Anita Kullen[2], Yue Deng[3], Yongliang Zhang[4], Shunrong Zhang[5], Ilkka Virtanen[1], Heikki Vanhamäki[1]

[1] Univerisity of Oulu, Finland
[2] KTH Royal Insititute of Technology, Sweden
[3] University of Texas at Arlington, USA
[4] Johns Hopkins University Applied Physics Laboratory, USA
[5] Haystack Observatory, Massachusetts Institute of Technology, USA

Python has become popular for scientific data analysis in the space physics community. Aiming to access, manage, and visualize various observational and modeling data easily and quickly, we have developed the python package, GeospaceLab. The package contains three base classes as the core components: (1) “DataHub” used as a data manager for downloading, loading, and processing data; (2) “Dashboard” for data visualization, including time-series plots and map projections; and (3) “SpaceCS” for space coordination transformation. In addition, the package provides a series of utilities for data analysis. So far, GeospaeLab can access several online databases (OMNI, WDC, Madrigal, ESA-EO, CDAWeb, SuperMAG, etc.) with more than twenty different data sources (EISCAT, solar wind, geomagnetic indices, AMPERE, GPS/TEC, DMSP/SSUSI, DMSP/SSJ, SWARM/LP, etc.). Benefiting from the objective-oriented design, the code in the package is reusable and flexible for an extension. More and more data sources and customized functions will be added in future. The package is open-sourced and available at https://github.com/JouleCai/geospacelab. We welcome everyone in the community to contribute in the future development.

GeospaceLab has been applied particularly for incoherent scatter radar (ISR) data analysis. So far, the package supports to automatic download of data from the Madrigal database for EISCAT, Millstone Hill, PFISR ISR measurements. It provides several functions to check the radar beams, convert azimuth/elevation/range to latitude/longitude/height, and map in geographic/geomagnetic coordinate systems. Quicklook plots can be easily generated. The user can make customized plots for different parameters. More functions will be added according to the users’ demands. Also, the package will be extended for the coming EISCAT_3D project.

A novel infrared imager at IRF for studying hydroxyl and oxygen emissions in the mesopause above northern Scandinavia

P. Dalin[1], U. Brändström[1], J. Kero[1], T. Nishiyama[2], and T. Trondsen[3]

[1] Swedish Institute of Space Physics, Kiruna, Sweden
[2] National Institute of Polar Research, Tokyo, Japan
[3] Keo Scientific Ltd., Calgary, Canada

The polar mesopause region (80-100 km) is the most sensitive environmental region of the Earth's atmosphere that is subject to human and natural variabilities both on short and long-term perspectives. Airglow emissions coming from the hydroxyl and molecular oxygen layers in the polar mesopause region provide valuable information on the physical, chemical and dynamical state of the mesopause environment. We propose to study nightglow emissions using a novel infrared imaging instrument (OH imager) that will measure infrared emissions of the selected lines in the hydroxyl OH(3-1) band and O_2 IR A-band to produce emission intensities and temperature maps in the mesopause region above northern Scandinavia. The neutral temperature will be determined using the brightness ratio of two rotational lines P1(2) and P1(4) in the OH(3-1) band.

Significance of the proposed project is determined by unique observations of the OH and O2 airglow emission layer, which will allow us to obtain the following information on atmospheric processes at the high latitude mesopause region:

(1) To validate temperature and gravity wave characteristics at the mesopause region as measured by the upcoming EISCAT_3D radar and Swedish MATS satellite mission.

(2) To study the regular variability of the mesopause region such as long-term potential changes as evidence of the evolution in the Earth's climate system, solar thermal tides, lunar gravitational tides, multi-year trends, Quasi-Biennial Oscillation.

(3) To study the irregular variability of the mesopause region such as: spatial and temporal variabilities due to atmospheric gravity and planetary waves on daily and seasonal scales, Sudden Stratospheric Warming effects on the mesosphere, response of airglow emissions and temperature to geomagnetic activity and solar proton events.

(4) To study artificial wave disturbances due to rocket launches from Esrange and Plesetsk.

The OH imager will be part of Kiruna Atmosfärs- och Geofysiska Observatorium (KAGO) at the Swedish Institute of Space Physics (IRF-Kiruna) and will be put into the operation in 2022-2023. The project obtained financial support from the Swedish Research Council in 2021 (Vetenskapsrådet, grant No 2021-00360).

Looking for signs of EMIC acceleration in proton aurora

R.A.Dayton-Oxland and D.K.Whiter

University of Southampton

Aurora caused by energetic proton precipitation can be observed by its hydrogen spectrum, as energetic precipitating protons charge exchange with the atmosphere and decay as excited Hydrogen. The Doppler shift of the proton spectrum shows that auroral protons can have energies of ~100keV, an acceleration of two orders of magnitude from the 1keV solar wind. The acceleration mechanism for auroral protons is an open question in solar-terrestrial physics and links to ion acceleration in space plasmas in general, for example in solar flares. One candidate acceleration mechanism is through electromagnetic ion-cyclotron (EMIC) waves. If EMIC waves are a mechanism for the acceleration of auroral protons we expect to see a periodic 'flickering' in intensity, with periodicity corresponding to Pc1 magnetic pulsations ranging from 0.2-10 s. Using Southampton's high-time resolution High-Throughput Imaging Echelle Spectrograph (HiTIES) instrument located at the Kjell Henriksen Observatory on Svalbard, observations of proton aurora are collected and analysed for flickering at these periodicities. Combining optical data with magnetometer data, flickering in the proton aurora can be correlated with EMIC wave detections and so can be investigated as a possible acceleration mechanism. We can also use HiTIES to investigate more broadly the evolution and periodicity of the energy spectrum of the proton precipitation.

43 Years of SBUV PMC Data: Trends, Solar Effects, and More

Matthew T. DeLand

Science Systems and Applications, Inc., Lanham, Maryland, USA

Long-term variations in the occurrence frequency and intensity of polar mesospheric clouds (PMCs) are important for understanding the Earth's upper atmosphere, because they are very sensitive to changes in mesospheric temperature and water vapor. Measurements of backscattered UV radiation from the atmosphere can be used to identify and characterize PMCs at 80-85 km because of the dark background created by stratospheric ozone absorption.

We have used data from a series of nadir-viewing profile ozone instruments, beginning with Nimbus-7 SBUV in 1978 and extending to the currently operating OMPS Nadir Profiler, to create a continuous record of global PMC behavior that now covers more than 43 years. The use of a consistent design between 10 separate instruments (so far) allows us to apply a single PMC retrieval algorithm to all of these measurements, which greatly improves our ability to merge multiple data sets together. We also characterize these measurements in terms of column ice water content (IWC) to limit any dependence on viewing conditions.

Our merged PMC data set can be analyzed for long-term trends and solar activity effects using multiple linear regression. We find significant positive trends in IWC in both hemispheres through the late 1990s, with reduced magnitude during more recent decades. Similarly, there is a clear response in IWC to solar activity prior to ~2000, but a considerably smaller response in more recent years. The SBUV PMC data set has also been used to investigate variations due to tidal forcing (local time dependence) and rocket exhaust plumes. The current series of OMPS NP instruments is expected to operate through 2040, so we anticipate extending our PMC data set to 60 years in the future.

Improved PMC Detection from OMPS Limb Profiler Measurements

M. T. DeLand

Science Systems and Applications, Inc., Lanham, Maryland, USA

Measurements of scattered radiation on the Earth's limb provide a valuable source of data about polar mesospheric clouds (PMCs) because they offer good sensitivity to faint clouds, accurate altitude determination, and comprehensive spatial coverage. The Ozone Mapping and Profiling Suite (OMPS) Limb Profiler (LP) instrument has been making hyperspectral measurements of UV/visible/near-IR limb scattered radiation from the Suomi NPP satellite since January 2012. We have previously demonstrated a PMC detection algorithm using OMPS LP data that has comparable sensitivity to AIM CIPS observations.

However, the current algorithm is subject to "false positive" detections caused by charged particle effects, most notably in the South Atlantic Anomaly, and has reduced detection capability in the Northern Hemisphere due to spacecraft viewing geometry effects. We have revised our algorithm to improve our confidence in Southern Hemisphere mid-latitude PMC detections, as well as extending NH PMC observations. Results from this improved algorithm will be presented. We anticipate further improvements with additional measurements from the next OMPS LP instrument, which is scheduled to be launched on the JPSS-2 satellite in late 2022.

Characteristics of F-region during an HSS/CIR-driven magnetic storm at the high-latitude ionosphere

N. Ellahouny[1], A. Aikio[1], H. Vanhamäki[1], I. Virtanen[1], L. Cai[1], G. P. Geethakumari[1], J. Norberg[2], A. Coster[3], A. Maute[4], A. Marchaudon[5], P.-L. Blelly[5], M. Grandin[6], S. Oyama[7], A. Kozlovsky[8]

[1] Space Physics and Astronomy Research Unit, University of Oulu, Finland
[2] Finnish Meteorological Institute, Finland,
[3] MIT Haystack Observatory, United States
[4] National Center for Atmospheric Research High Altitude Observatory, USA
[5] IRAP, University of Toulouse, France
[6] Department of Physics, University of Helsinki, Finland
[7] Institute for Space-Earth Environmental Research, Nagoya University, Japan
[8] Sodankylä Geophysical Observatory, Finland

Solar wind High-Speed Streams (HSSs) and associated co-rotating interaction regions (CIRs) affect the high latitude ionosphere in several ways, e.g., on varying auroral structure, magnetic field disturbances, changing the F-region behaviour, and modifying the energetic particle precipitation as studies have shown. This study examines a HSSs driven storm in solar cycle 24 with a CIR that hit the Earth's magnetopause at about 17:20 UT on 14 March 2016. The storm duration was exceptionally long by seven days, and the Dst index reached a minimum of -56 nT, putting it in the category of moderate storms.

We focus on the regional behaviour of the high-latitude ionosphere in the Scandinavian sector using a very comprehensive set of measurements covering the whole time period of this storm. Based on these regional observations, we examine day-to-day variations in the F-region plasma and identify storm related phenomena such as the ionospheric trough using the EISCAT radar CP3 latitude scan data from Tromsø and Svalbard, complemented by TomoScand regional 3D ionospheric tomography electron density results. To provide the global context we employ the global field-aligned currents (FACs) that are provided by AMPERE. Solar wind parameters and geomagnetic indices are used to study the coupling of solar wind- magnetosphere-ionosphere system. Previous studies have shown both increases and decreases in electron density during geomagnetic storms. At high latitudes, Grandin et al. (2015) showed that a decrease in F-region electron density could last for several days in the afternoon to evening sector measured by a single high-latitude ionosonde station (Sodankylä). In this study, we examine the extent of the depletion in latitude and the potential connection with plasma parameters (specifically ion temperature, which is indicative of ion frictional heating) in order to identify possible physical processes behind the depletion.

Creation, Depletion and End of Life of Polar Cap Patches

N. K. Eriksen[1,2], D. Lorentzen[1,2], K. Oksavik[2,3], and L. Baddeley[1,2]

[1] The University Centre in Svalbard, Longyearbyen, Norway
[2] Birkeland Centre for Space Science, Bergen, Norway
[3] University of Bergen, Bergen, Norway

We present the transit time and decay rates of three polar cap patches. The patches were identified in the dayside ionosphere using the EISCAT Svalbard Radar before using a tracking method based on Super Dual Auroral Radar Network convection maps.

The two first polar cap patches were created within 12 minutes of each other and journeyed through the throat of the convection cells, before entering the nightside auroral oval after 112 and 106 minutes. When the patches got close to the nightside auroral oval, intensification in the poleward boundary occurred close to their exit point, followed by a decrease in transit velocities.

The airglow decay rates of patches 1 and 2 were found to be 0.625% and 0.89% per minute, respectively. The third patch were observed to completely decay within the polar cap and had a lifetime of only 78 minutes. 24 minutes after the change in the transit direction and 16 minutes after stagnation the third patch had completely disintegrated. An increase in frictional heating due to a difference in the direction of ion drift and neutral wind is believed to have sped up the recombination rate. We suggest that the increase in frictional heating is a major reason for the stagnation of polar cap patches, and that the ensuing change in the recombination rate can determine whether or not a polar cap patch cap exit through the nightside auroral oval.

The self-consistent global atmosphere model of meteoric metals in Community Earth System Model (CESM2-metals)

Wuhu Feng[1,2,3], John Plane[1], Daniel Marsh[1,4], Jianfei Wu[5], Hanli Liu[4], Joe McInerney[4], Martyn Chipperfield[3], Chester Gardner[6], Xinzhao Chu[7], Mario Vittoria Guarino[1], Tasha Aylett[1], Titus Yuan[8], Alan Liu[9], Guotao Yang[10], Jing Jiao[10], Xianghui Xue[5], Tao Li[5], Xiankang Dou[5], Juan Diego Carrillo-Sanchez[11], Diego Janches[11], Jonas Hedin[12], Jörg Gumbel[12] and Michael Mills[4]

[1] School of Chemistry, University of Leeds, Leeds, LS2 9JT, UK
[2] National Centre for Atmospheric Science, University of Leeds, Leeds, LS2 9PH, UK
[3] School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK
[4] National Center for Atmospheric Research, Boulder, CO, 80301, USA
[5] School of Earth and Space Sciences, University of Sci. and Technol. of China, Hefei, Anhui, China
[6] University of Illinois at Urbana Champaign, Urbana, IL, USA
[7] CIRES, Colorado University, Boulder,CO, USA
[8] Physics Department, Utah State University, Logan, Utah, USA
[9] Department of physical Science, Embry-Riddle Aeronautical University, Daytona Beach, FL, USA
[10] National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China.
[11] Space Weather Lab., Mail Code 674, GSFC/NASA, Greenbelt, MD 20771, USA
[12] Department of Meteorology, Stockholm University, Stockholm, Sweden

A global atmospheric model of meteoric metals (Na, Fe, Mg, Si, K, Ca, Ni, Al etc.) in the mesosphere and lower thermosphere (MLT) has been developed in the Community Earth System Model Version 2 (CESM2), which is termed as CESM2-metals. The model has considered the injection of metals from meteoric ablations of individual cosmic dust particles entering the Earth's atmosphere from different sources (short period Jupiter family comets, Long period Comets (i.e. Halley-type and Oort-cloud comets) and the asteroids belet). The metal chemical reactions in the MLT region have been implemented in the chemical mechanisms in CESM2 for the middle atmosphere (MA) in the following configurations: Whole Atmosphere Community Climate Model (WACCM), with thermosphere and ionosphere extension (WACCM-X) and with D-region (50-90 km) ion chemistry (WACCM-D).

In this work, we have done a few model simulations to investigate the metal layers under different model configurations. First two long term simulations (1980-2014) have been performed in a free running version of WACCM6 using 1 and 2 degree horizontal resolutions to examine the effects of model resolutions on metal layers and their trends.

We have also carried out a short term simulations using different model composts (WACCM6, WACCMX, WACCMD) including our recent improvements of new gravity wave parameterisation representing wave driven constituent transport in WACCM and ion transport processes in WACCM-X. An evaluation of model simulations of CESM2-metlas against satellite and lidar measurements is presented.

To investigate the impact of different sources of energetic particle precipitations on the metal layers, we focus on one strong solar proton event in January 2005 as one special case. Several model experiments under different geomagnetic conditions have been designed to quantify the changes of metal layer.

This study has produced a global model of the meteoric metal layers and serve as a benchmark and testbed for the planned release of metal chemistry (Na and Fe) in the next version CESM3.

Reconstruction of precipitating electrons and three-dimensional structure of a pulsating auroral patch from monochromatic auroral images obtained from multiple observation points

M. Fukizawa[1], T. Sakanoi[2], Y. Tanaka[1,3,4], Y. Ogawa[1,3,4], K. Hosokawa[5], B. Gustavsson[6], K Kauristie[7], A. Kozlovsky[8], T. Raita[8], U. Brändström[9], T. Sergienko[9]

[1] National Institute of Polar Research, Tachikawa, Japan
[2] Graduate School of Science, Tohoku University, Sendai, Japan
[3] Polar Environment Data Science Center, Joint Support-Center for Data Science Research, Research Organization of Information and Systems, Tachikawa, Japan
[4] Department of Polar Science, The Graduate University for Advanced Studies (SOKENDAI), Tachikawa, Japan
[5] Graduate School of Informatics and Engineering, University of Electro-Communications, Chofu, Japan
[6] Institute for Physics and Technology, Arctic University of Norway UiT, Tromsø, Norway
[7] Finnish Meteorological Institute, Helsinki, Finland
[8] Sodankylä Geophysical Observatory, University of Oulu, Oulu, Finland
[9] IRF-Swedish Institute of Space Physics, Kiruna, Sweden

Aurora Computed Tomography (ACT) is an inversion analysis method to reconstruct the three-dimensional (3-D) structure of auroral luminosity using multipoint monochromatic auroral images. The ACT method has been applied to discrete auroras. On the other hand, the reconstruction of pulsating aurora (PsA) patches has not been reported since it is difficult to apply ACT to PsA patches due to low signal-to-noise ratio (SNR) of PsA images. In this study, we reconstructed the 3-D volume emission rate (VER) by improving the ACT method and using high-sensitive cameras. The horizontal distribution of precipitating electrons in PsA patches was also reconstructed. The reconstruction accuracy was evaluated using a model aurora and the EISCAT radar. The characteristic energy of the reconstructed precipitating electron flux ranges from 6 keV to 23 keV and the peak altitude of the reconstructed VER ranges from 90 to 104 km. These results are consistent with previous studies. We found that the horizontal distribution of precipitating electron's characteristic energy was neither uniform nor stable in the PsA patch during the pulsation. The observed spatial temporal variations of PsAs are important to understand the background magnetic field and plasma conditions in the magnetospheric source region.

To quantitively evaluated the reconstruction results from the observed auroral images, we compared them with those from pseudo auroral images. We confirmed that the center part of the PsA patch was correctly reconstructed. In addition, we converted the VER to the electron density to compare with the electron density observed by the EISCAT radar. Considering the time derivative term in the electron continuity equation, the electron density was reconstructed with sufficient accuracy even when the PsA intensity decreased from ~1 kR to ~0.1 kR. If the time derivative term is not considered, the electron density rapidly decreases as the PsA intensity decreases. This result suggests that the time derivative term should be considered when we derive the electron density associated with PsAs from the continuity equation.

The Morphology of Poleward Moving Auroral Forms (PMAFs)

A. Goertz[1,2,3], N. Partamies[2,3], D. Whiter[4], L. Baddeley[2,3]

[1] Intelligence and Space Research, Los Alamos National Laboratory, Los Alamos, New Mexico, United States of America

[2] Department of Arctic Geophysics, University Centre in Svalbard, Longyearbyen, Norway

[3] Birkeland Centre for Space Science, University of Bergen, Norway

[4] School of Physics and Astronomy, University of Southhampton, United Kingdom

We investigated the morphology of poleward moving auroral forms (PMAFs) qualitatively by visual inspection of all sky camera (ASC) images and quantitatively using the arciness index. While there have been previous studies commenting on PMAF morphology this is the first work dedicated to the morphological evolution of PMAFs. The PMAFs in this study were initially identified with a meridian scanning photometer located at Kjell Henriksen Observatory (KHO), Svalbard, and analyzed using ASC images taken by cameras at KHO and in Ny-Ålesund, Svalbard. We present a detailed six-step evolution of PMAF morphology in two dimensions. This evolution includes (1) an equatorward expansion of the auroral oval and an intensification of auroral brightness at the open-closed boundary, (2) the appearance of an arc-like structure in the oval, (3) poleward and possible west/eastward propagation, (4) azimuthal expansion events, (5) rebrightening of the PMAF and eventual (6) fading away. Moreover, the morphology of PMAFs is quantified using the arciness index, which is a number describing how arc-like auroral forms appear in ASC images. We present the results of a superposed epoch analysis of arciness in relation to PMAF occurrence. This analysis uncovered that arciness increases suddenly during the onset of a PMAF event and decreases over the PMAF lifetime to return to its baseline value once the event has concluded. This behavior may be understood based on changes in the morphology of PMAFs and the auroral oval and furthermore may be used to identify PMAFs from arciness data.

A new model for ionospheric absorption of HF waves due to protons

A. Goertz, C. Jeffery

Intelligence and Space Research, Los Alamos National Laboratory, Los Alamos, New Mexico, United States of America

Solar energetic proton events (SEPs) cause enhanced ionization in the D-region of the ionosphere. This can lead to significantly higher absorption of high frequency (HF) radio waves that propagate through and are reflected by the ionosphere. We have developed a new model to determine the absorption of HF waves caused by SEP events based on first principles. The model input is the proton flux spectrum as measured by the MEPED instrument on the GOES satellite constellation.

We have compared the modeled absorption during the September 2017 geomagnetic storm against data taken by the Poker Flat incoherent scatter radar (ISR) in Alaska. Furthermore, we also compared the performance of our model against the National Oceanic and Atmospheric Administration's (NOAA) D-region absorption prediction (D-RAP) algorithm. First, we validated our model by reproducing electron density profiles of the disturbed ionosphere measured by the Poker Flat ISR. We subsequently compared absorption time series as obtained from Poker Flat and our model. The time series agree well, and we believe the differences between the measurement and our model are largely attributable to other sources of absorption, such as high energy electron precipitation and enhanced X-ray fluxes associated with solar flares, which are not part of our model.

We have found that our model generally outperforms the SEP model of the D-RAP algorithm in reproducing HF absorption during the September 2017 event.

The revised method for retrieving daytime distributions of atomic oxygen and odd-hydrogens in the mesopause region: The evaluation of the importance of the reaction $H + O_3 \rightarrow O_2 + OH$ in the ozone balance.

M. Grygalashvyly[1], M. Yu. Kulikov[2], M. V. Belikovich[2], G. R. Sonnemann[1], A. M. Feigin[2]

[1] Leibniz-Institute of Atmospheric Physics at the University Rostock in Kuehlungsborn, Schloss-Str. 6, 18225 Ostseebad Kuehlungsborn, Germany

[2] Institute of Applied Physics of the Russian Academy of Sciences, 46 Ulyanov Str., 603950 Nizhny Novgorod, Russia

Atomic oxygen in the mesopause region is a critical species, governing the chemistry, airglow, and energy budget in that region. However, it cannot be measured directly by satellite remote sensing techniques and so inference techniques, by airglow observations, are used. Such techniques are based on two assumptions, namely on photochemical ozone equilibrium and on processes entering into the ozone balance equation. This investigation devoted to the last one.

By 3D modelling we find that the reaction of ozone with atomic hydrogen is an important loss processes for ozone under daytime conditions and should not be omitted from the ozone balance equation. Unfortunately, it is frequently ignored in satellite retrieval procedures. We take this reaction into account, developed a new retrieval procedure for atomic oxygen under daytime conditions, and illustrate its applicability by SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) observations. Additionally, this procedure offers the possibility to obtain distributions of OH and HO_2 at daytime conditions.

This work was partially supported by RSF(22-12-00064) grant.

The MATS satellite mission - gravity waves in the mesosphere and lower thermosphere

Jörg Gumbel[1], Linda Megner[1], Donal P. Murtagh[2], Nickolay Ivchenko[3], and the MATS Team

[1] Department of Meteorology (MISU), Stockholm University, Stockholm, Sweden
[2] Department of Earth and Space Sciences, Chalmers University of Technology, Göteborg, Sweden
[3] School of Electrical Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden

The Swedish MATS satellite (Mesospheric Airglow/Aerosol Tomography and Spectroscopy) is waiting for a launch into orbit. This presentation provides an update on mission status, retrieval methods and scientific goals. MATS applies space-borne limb imaging in combination with tomographic and spectroscopic analysis to study gravity waves and atmospheric structures over a wide range of spatial scales. Measurement targets are O2 Atmospheric Band airglow in the near infrared, and sunlight scattered from noctilucent clouds in the ultraviolet, resulting in 3D fields of temperature, composition, and cloud properties as primary retrieval products. Based on these, MATS will provide a climatology on mesospheric wave spectra during a 2-year mission, thus aiming at a wide range of collaborations on gravity waves processes and interactions with the lower and upper atmosphere.

Simultaneous AGW-TID detection with EISCAT and HF coherent scatter radars for retrieval of the neutral dynamics in the thermosphere using a dissipative anelastic GW dispersion relation

F. Günzkofer[1], D. Pokhotelov[1], G. Stober[2], S. Vadas[3], I. Mann[4], A. Tjulin[5], C. Borries[1]

[1] Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany
[2] Institute of Applied Physics & Oeschger Center for Climate Change Research, Microwave Physics, University of Bern, Bern, Switzerland
[3] NorthWest Research Associates, Inc., Boulder, CO, USA
[4] UiT The Arctic University of Norway, Tromsø, Norway
[5] EISCAT Scientific Association, Kiruna, Sweden

Travelling Ionospheric Disturbances (TIDs) are observed with a wide range of wavelengths and periods. Daytime Medium-Scale TIDs (MSTIDs) are the ionospheric inprint of upward propagating Atmospheric Gravity Waves (AGWs). These AGW-TIDs can be described by an analytically derived dissipative anelastic GW dispersion relation (Vadas and Fritts, doi.org/10.1029/2004JD005574, 2005). From this relation, horizontal/vertical GW wavelengths and wave period are related to the neutral atmosphere parameters e.g., horizontal mean wind, neutral density, scale height and the kinematic viscosity. While the vertical wavestructure of a TID can be extracted from Incoherent Scatter Radar (ISR) measurements, determination of the horizontal wavelength has proven more difficult. The horizontal structure of TIDs has been derived from GNSS measurements (van de Kamp et al., doi.org/10.5194/angeo-32-1511-2014, 2014) or by performing multibeam experiments with a phased array ISR (Nicolls and Heinselman, doi.org/10.1029/2007GL031506, 2007). The latter has been applied for measurement of background neutral winds in the thermosphere (Vadas and Nicolls, doi.org/10.1029/2007GL031522, 2008).

A new approach presented here is the simultaneous measurement of AGW-TIDs with a classical ISR system and a meteor radar network. For this purpose, we combined data from the Nordic Meteor Radar Cluster (Stober et al., doi.org/10.5194/amt-14-6509-2021, 2021) with EISCAT VHF measurements obtained during a three day campaign in July 2020. A least-square wave fit is applied on an AGW-TID found both in EISCAT and Meteor Radar data. Vertical/horizontal wavelengths, vertical phase lines and propagation direction can be determined from this respectively. The horizontal wavelength can be assumed to be constant above the mesopause/turbopause, since the horizontal wind shear is small and the GW phase speeds are large (Vadas and Nicolls, doi.org/10.1029/2007GL031522, 2008). Using a model neutral atmosphere like NRLMSISE-00, we infer the horizontal wind along the propagation direction of the AGW from measurement of the vertical wavelength via use of AGW dissipative anelastic dispersion relation similar to (Vadas and Nicolls, doi.org/10.1029/2007GL031522, 2008). Operating the ISR in a mode that allows for the determination of the 3D neutral wind velocities would allow for a validation of these results, thereby opening up the possibility that this technique could be used in the future as a means to obtain the neutral horizontal wind in regions where it cannot be measured directly.

Improvements to the ELSPEC method

B. Gustavsson

UIT, the Arctic University of Norway, Tromsø

In this presentation the ELSPEC method for estimating the differential energy flux of electron precipitation in aurora from incoherent scatter radar observations of the ionospheric electron density profile is given two improvements. The ELSPEC method is based on integration of the electron continuity equation and spectrum model selection with the Akaike information criterion. This approach automatically adapts the model complexity of the electron-spectra to variations in the signal-to-noise ratio. The experience from using this method show that some problems arise when too small measurement uncertainties are given to spuriously large electron-densities. The two methods to reduce this type of sensitivity are: integration of the electron continuity equation backwards in time, and usage of robust statistics to diminish the weight of the largest residuals.

PITHIA-NRF offer access to European upper atmosphere research facilities

I. Häggström and M. Mihalikova

EISCAT Scientific Association, Kiruna, Sweden

"One of the objectives of the PITHIA-NRF project is to provide effective and convenient access to the best European research facilities for observations of the upper atmosphere, including the plasmasphere, ionosphere and thermosphere. The access is organised through the Trans-National Access (TNA) programme, and provides an opportunity for researcher and other users to execute and carry out their own projects at one of the twelve PITHIA-NRF research facilities. Through these activities new users will learn how to work with the facilities during the full access cycle, from setting up a campaign, to collection, analysis and finally exploitation of data with the help of tools and services provided by PITHIA-NRF.

The PITHIA-NRF nodes provide access to key experimental and data processing facilities for studies and modelling of physical processes acting in the Earth's plasmasphere, ionosphere and thermosphere. The facilities connected to the nodes are geographically distributed over Europe, as well as internationally, and their expertise and dedication span over a wide range of topics within the research area. This variety of expertise and techniques, all with the purpose to study specific parts of the ionosphere-thermosphere-plasmasphere (ITP), allows for a common ground and a platform for a better understanding of the many different complex couplings and interactions within ITP as well as between ITP and the magnetospheric/space environment.

Users can request either physical access (one-week visit at the node with support at site) or remote access (one month access from distance with weekly support). Users with granted projects will learn how to work with the facilities during the full access cycle, from setting up a campaign, to collection, analysis and finally exploitation of data with the help of tools and services provided by PITHIA-NRF via the e-science center. For virtual access - typically referring to access to data and digital tools - there are no restrictions to the number of simultaneous users, and no selective process is needed. Access can be requested by scientific users from academia, Small and Medium Enterprises, large companies and public organizations by propose a scientific project."

Observations of kilometer-scale instabilities using PMSE as tracers: A case study of varicose mode events

J. Hartisch, J. L. Chau, R. Latteck, T. Renkwitz, K. P. Ramachandran, M. Clahsen, M. Urco, G. Baumgarten

Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany

As the boundary layer between the Earth's atmosphere and outer space, the region of the mesosphere and lower thermosphere (MLT) represents a particularly exciting, but at the same time difficult to study, area of research since it is unreachable for balloons and satellites. In particular, the investigation of dynamical processes, which at this altitude (60-120 km) are largely determined by the breaking of waves and the associated turbulence, are of special interest. While the MLT is difficult to access for in-situ measurements, investigations with remote sensing devices such as radars have proven to be valuable for the exploration of this region.

We recently described an event observed by MAARSY, an MST radar located in northern Norway, characterized by extreme (vertical velocities exceeding three times the standard deviation) simultaneous up- and down-drafts (varicose mode) strongly localized in space and time using Polar Mesospheric Summer Echoes (PMSE) as tracers. Direct Numerical Simulation studies show a non-Gaussian probability density distribution of vertical velocities in flow regimes similar to the MLT. Thus, the probability of the occurrence of such extreme events is not low (1 in 1000). Manually searching for them through a longer data set revealed that this kind of structures, i.e. a varicose mode, does indeed occur more frequently. In our work, we will present a selection of events taking into account their spatial and temporal features, and background atmospheric and ionospheric conditions in order to understand the physics behind them.

CIPS observations of gravity waves at the edge of the polar vortices

V. L. Harvey[1,2], C. E. Randall[1,2], J. Carstens[3], E. Becker[4], and S. Bailey[3]

[1] University of Colorado – Boulder, Laboratory for Atmospheric and Space Physics, Boulder, Colorado, USA
[2] University of Colorado – Boulder, Atmospheric and Oceanic Sciences Department, Boulder, Colorado, USA
[3] Virginia Tech, Blacksburg, Virginia, USA
[4] NorthWest Research Associates, Boulder, Colorado, USA

Gravity wave (GW) variance data from the Aeronomy of Ice in the Mesosphere (AIM) Cloud Imaging and Particle Size instrument (CIPS) was analyzed to investigate GWs at the edge of the polar vortices. In the winter stratosphere, the background wind field is dominated by westerly flow around the polar vortex. This wind filters GWs with eastward phase speeds and allows GWs with westward phase speeds to reach the mesosphere. CIPS measures GWs at or just above the stratopause, around 50-55 km in altitude. GWs at the CIPS observation altitude often break in the mesosphere, generating secondary GWs that propagate higher in the mesosphere. These secondary GWs break and can seed higher order waves that drive variability in the thermosphere and ionosphere. GWs are prevalent in the vortex jet region and the geographic distribution of GWs in the winter stratosphere and mesosphere depends strongly on the location, strength, and stability of the polar night jet that encircles the polar vortex. We will present GW occurrence frequency statistics in both hemispheres as well as illustrate CIPS GW activity during the 2019 sudden stratospheric warming (SSW) in the Antarctic, and during the 2019 and 2021 SSWs in the Arctic.

Generation of a synthetic EISCAT_3D dataset

S. M. Hatch[1], L. Juusola, S. Kaeppler, S. Käki, L. Lamarche, K. M. Laundal, G. Lu, M. Madelaire, A. Maute, J. P. Reistad, Y. Tanaka, A. Tjulin, H. Vanhamäki, I. Virtanen, S. Walker, M. Zettergren

[1] University of Bergen, Bergen, Norway

We present a set of synthetic EISCAT_3D measurements of density, temperature, and ion velocity based on a Geospace Environment Model of Ion-Neutral Interactions (GEMINI) simulation of field-aligned currents and auroral precipitation over the EISCAT_3D core site in Skibotn, Norway. Using the ISgeometry R package we model tristatic sampling volumes based on the EISCAT3D site geometry to sample simulated quantities and estimate their uncertainties. As a basic demonstration, we use synthetic EISCAT_3D density measurements and uncertainties in a simple model based on radial basis functions to reconstruct the plasma density within the observed volume.

EISCAT and EISCAT_3D

C. J. Heinselman

EISCAT Scientific Association

EISCAT is now in the midst of a transition from its legacy systems to EISCAT_3D. This presentation will compare and contrast the systems as well as present an overview of the status of the EISCAT_3D implementation.

Long-term observations of meteoric influx from SOFIE, Wind, and Ulysses

Mark E. Hervig[1], David Malaspina[2,3], Lynn B. Wilson III[4], Veerle Sterken[5], Silvan Hunziker[5], John M. C. Plane[6], and David E. Siskind[7]

[1] GATS, Driggs, Idaho, USA.
[2] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, USA
[3] Astrophysical and Planetary Sciences Department, University of Colorado, Boulder, Colorado, USA
[4] NASA Goddard Spaceflight Center, Greenbelt, Maryland, USA
[5] Swiss Federal Institute of Technology, Zürich, Switzerland.
[6] School of Chemistry, University of Leeds, Leeds, UK.
[7] Space Science Division, Naval Research Laboratory, Washington, DC, USA.

The solar system is filled with meteoric particles, or cosmic dust, which constantly enter Earth's atmosphere. The meteoric influx (MI) at Earth is primarily due to interplanetary dust (IPD), with interstellar dust (ISD) comprising <1%. This study examines variations in MI using observations from two different satellite measurement techniques. The first is optical detection of meteoroid ablation products (meteoric smoke) in the mesosphere by the Solar Occultation For Ice Experiment (SOFIE), and the second is in situ dust detection by the Wind and Ulysses spacecraft. SOFIE smoke measurements in both hemispheres are used to characterize the meteoric flux into Earth's atmosphere, during 2007 - present. These results indicate a hemispheric asymmetry with greater influx in the North compared to the South, in addition to variability on longer time scales. The hemispheric smoke asymmetry is consistent with stronger transport in the North, and is supported by SOFIE and model water vapor distributions. Wind observations during 1995 - present detect both interstellar and interplanetary dust. The ISD component in Wind observations shows annual and decadal variations that are consistent with ISD simulations. The Wind IPD measurements were used to derive the MI at Earth, using a prescribed mass distribution and accounting for Earth's gravity and size. The Wind MI results are in good agreement with SOFIE, and confirm long term variations in MI seen by both instruments. These variations are explored in terms of solar variability, which can alter dust trajectories within the heliosphere. Finally, Ulysses IPD measurements were used to derive a meteoric influx of 26 metric tons per day (t/d) at Earth, in good agreement with the average results from SOFIE (25 t/d) and Wind (24 t/d).

ICEBEAR-3D: A New High-resolution VHF Coherent E-region radar

G.C. Hussey[1], A. Lozinsky[1], D. Huyghebaert[2], D. Galsechuk[1], K.A. McWilliams[1], J.-P. St. Maurice[1], J. Vierinen[2], M.F. Ivarsen[3,1]

[1] Institute of Space and Atmospheric Studies (ISAS), University of Saskatchewan, Saskatoon, SK, Canada

[2] Department of Physics and Technology, UiT The Arctic University of Norway, Tromso, Norway

[3] Department of Physics, University of Oslo, Oslo, Norway

The Ionospheric Continuous-wave E-region Bistatic Experimental Auroral Radar (ICEBEAR) is a new digital software defined radio (SDR) high-resolution 50 MHz VHF coherent E-region radar with an auroral zone field-of-view situated in western Canada (58N, 106W geographic). In 2019 the final design of ICEBEAR was implemented with the re-configuration of the ICEBEAR receiver antenna array into a non-uniform co-planar T-shaped double interferometer layout. Applying highly advance tailored aperture synthesis radar imaging techniques, radar echoes can be unambiguously located within the ICEBEAR-3D field-of-view with a nominal resolution of 1-2 km in 3-dimensions (range, azimuth, elevation). This presentation will introduce ICEBEAR-3D design, hardware, antenna array configuration, imaging technique, validation, and some initial results. It would be highly scientifically productive to have complementary EISCAT and ICEBEAR-3D observations of the same scattering volume, such as the proposed Norwegian Isbjorn radar which is inspired by ICEBEAR-3D.

EISCAT 3D Norway - An Overview

Devin Huyghebaert[1], Ingrid Mann[1], Lisa Baddeley[2], Magnar G. Johnsen[1], Lasse Clausen[3], Michael Gausa[4], Dag Lorenzen[2], Kjellmar Oksavik[5], and Inger Solheim[1]

[1] UiT The Arctic University of Norway
[2] University Center Svalbard
[3] University of Oslo
[4] Andøya Space Center
[5] University of Bergen

The space science community in Norway greatly anticipates the implementation of EISCAT 3D. Researchers from multiple Norwegian institutions are involved in preparing for the new system and are ready to utilize its advanced capabilities when it is operational. This presentation provides an overview of the different science objectives for the Norwegian EISCAT consortium, and the potential key performance indicators that will be used during operations. The geographic location of Norway with respect to the EISCAT 3D sites makes it important for supporting EISCAT 3D operations and hosting complementary instrumentation. The adaptability of EISCAT 3D operations resulting from the ability to rapidly switch observation modes will greatly enhance the opportunities for studies performed with multiple instruments. Tromsø Geophysical Observatory (TGO) is part of The Arctic University of Norway (UiT) and operates and hosts many geospace instruments in the vicinity of Skibotn, Norway. These instruments will provide complementary measurements with EISCAT 3D and include auroral imagers, riometers, magnetometers, Meteor radars, a Partial Reflection radar and an ionosonde. There are also plans to expand the TGO infrastructure at the Skibotn site for additional instrument support.

The Participation in EISCAT 3D in Norway consists of researchers from multiple different Norwegian institutions - the University of Bergen (UiB), the University of Oslo (UiO), the Norwegian University of Science and Technology (NTNU), the University Center in Svalbard (UNIS), and the Andøya Space Center (ASC). The Arctic University of Norway (UiT) in Tromsø is the host institution for the EISCAT instruments in Norway and leads the national EISCAT_3D Norway 2014 project.

Simultaneous conjugate observations of the energy of pulsating auroral electrons by Arase satellite, EMCCD all-sky imager and EISCAT radar

Y. Ito[1], K. Hosokawa[1], Y. Ogawa[2], Y. Miyoshi[3], S. Oyama[3], S. Nakamura[3], Y. Kasahara[4], S. Matsuda[4], and I. Shinohara[5]

[1] University of Electro-Communications, Tokyo, Japan
[2] National Institute of Polar Research, Tokyo, Japan
[3] Institute for Space-Earth Environment Research, Nagoya University, Aichi, Japan
[4] Kanazawa University, Ishikawa, Japan
[5] JAXA Institute of Space and Astronautical Science, Kanagawa, Japan

Auroras are classified into two broad categories based on their shape: discrete auroras, which have a distinct shape, and diffuse auroras, which have an indistinct shape. Most of the diffuse auroras are known to show a quasi-periodic luminosity modulation and are called pulsating auroras (PsA). Magnetospheric electrons, which are scattered through the wave-particle interaction with "chorus waves" and precipitated into the ionosphere are called “PsA electrons”. Recent studies demonstrated that sub-relativistic electrons of radiation belt origin simultaneously precipitate into the ionosphere during intervals of PsA. This means that the loss process of such highly energetic electrons in the magnetosphere can be visualized by observing the form/distribution of PsA and the energy of PsA electrons. For this purpose, it is important to understand the factors that control the morphology of PsA and the energy of PsA electrons, which have not been clarified in previous studies.
In this study, the geospace exploration satellite Arase, the EMCCD all-sky imager, and the European Incoherent SCATer (EISCAT) UHF radar were used in combination for simultaneous observations of PsA. By using this data set, we investigated the relationship between the morphology of PsA and the energy of PsA electrons. Two energies of PsA electrons was estimated from the altitude distribution of electron density obtained from the EISCAT-UHF radar, GLOW model (Solomon et al., 2017), and CARD method, and it was found to be consistent with the resonance energy of the chorus wave calculated from the observation of chorus waves by the Arase satellite. In addition, the energy of PsA electrons tended to change in accordance with the transition of the morphology of PsA. Specifically, when the spatial structure of PsA was clear (i.e., the boundary of the patch structure is distinct), the energy of the corresponding PsA electron exceeded 20 keV. This fact suggests that both the morphology of PsA and the change in the energy of PsA electrons are controlled by the existence of "ducts," tube-like regions where the electron density is lower or higher than the surrounding area, and resultant propagation of chorus waves to higher latitudes. In presentation, we will introduce the observational results and discuss the factors controlling the morphology of PsA and energy of PsA electrons.

A UAV platform for optical observations of the upper atmosphere

N. Ivchenko, R. Mariani

KTH, 10044 Stockholm, Sweden

We report on the development of a Unmanned Aerial Vehicle (UAV) platform to enable optical observations of upper atmospheric phenomena from the stratosphere. A novel electrically-propelled UAV is designed for above cloud, arbitrary location autonomous long duration flight, carrying instrumentation for imaging of phenomena in the upper atmosphere such as aurora, airglow, noctilucent clouds, etc. The work on the UAV was initiated at KTH as a student project, and the current status is presented. We discuss also the outlook of the project, including currently considered payload options.

Instability dynamics in the MLT region observed by lidar and camera

N. Kaifler[1], D. Fritts[2], B. Kaifler[1], G. Baumgarten[3], B. Williams[2], C. Geach[1], B. Kjellstrand[4], P.-D. Pautet[5], M. Rapp[1]

[1] German Aerospace Center, Institute of Atmospheric Physics
[2] GATS, Boulder, CO, USA
[3] Leibniz Institute of Atmospheric Physics at the Rostock University, Schloss-Str. 6, 18225 Kühlungsborn, Germany
[4] Arizona State University
[5] Center for Atmospheric and Space Sciences/Physics Department, State University, Logan, UT, USA

During the PMC Turbo campaign in July 2018, the polar mesospheric cloud (PMC, or noctilucent cloud) layer was imaged with cameras and a Rayleigh lidar from the balloon floating altitude in the upper stratosphere, providing a view unhindered by clouds or solar background. The Balloon Lidar Experiment BOLIDE provided vertical profiling of the NLC layer, and the seven cameras the surrounding spatial structures. The high-resolution camera and lidar data revealed a variety of instability signatures, among them secondary Kelvin-Helmholtz (KHI) instabilities and vortex rings often found in environments perturbed by gravity wave fronts or mesospheric bores. The figure shows small-scale structures within a PMC layer sounded on 11 July 2018 above central Greenland. Dark colors indicate large gradients on short distances. The temporal lidar measurements were for the first time converted to horizontal distances by evaluating the speed of small-scale spatial structures from consecutive PMC Turbo images. From the balloon-lidar dataset, we derived statistics of small-scale gradients and typical signatures indicative of specific types of instabilities. We demonstrate that one of them, the tube and knot dynamics of KHI, are widespread in layered phenomena of the MLT region, as can e.g. be seen in OH airglow and the sodium layer. Tube and knot dynamics lead to accelerated transitions to turbulence and increased energy dissipation rates, as shown by idealized modelling.

Noctilucent clouds above a southern-hemisphere mid-latitude site

N. Kaifler[1], B. Kaifler[1], M. Rapp[1], G. Liu[3,4], D. Janches[3], G. Baumgarten[5], P.-D. Pautet[6], J.-L. Hormaechea[2]

[1] Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2] Estación Astronomica Rio Grande, Facultad de Ciencias Astronomicas y Geofisicas, Universidad Nacional de La Plata & CONICET, Argentina
[3] Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD, USA
[4] Space Sciences Laboratory, University of California, Berkeley, Berkeley, CA, USA
[5] Leibniz Institute of Atmospheric Physics at the Rostock University, Schloss-Str. 6, 18225 Kühlungsborn, Germany
[6] Center for Atmospheric and Space Sciences/Physics Department, State University, Logan, UT, USA

After the installation of the Compact Rayleigh Autonomous lidar (CORAL) in southern Argentina to study gravity waves in the stratosphere and mesosphere, we were surprised to detect noctilucent clouds at this latitude of 54°S. Because temperatures in the mesosphere, lower thermosphere region are higher here than at comparable latitudes in the northern hemisphere, we would expect less bright and less frequent NLC. But this is not the case. CORAL has detected NLC in every summer season since, among them very bright displays. The mean altitude is around 83 km. The peak occurrence and peak brightness are found in the morning hours around 7 UT before sunrise, ideal for visual observations. Coincident and common-volume images of the NLC layer from visual and OH cameras are used to relate large-, medium- and small-scale gravity waves in the NLC layer with the vertical lidar profiling, showing a dynamic atmosphere above Rio Grande including Kelvin-Helmholtz instabilities induced by breaking gravity waves. Tierra del Fuego is not only known for record-strong stratospheric gravity waves, but also for a pronounced semi-diurnal tide and planetary wave periods of 2 to 16 days in the meridional wind component. Based on Southern Argentina Agile Meteor Radar (SAAMER) wind measurements, we find increased meridional transport of air from more poleward latitudes during the hours before and during NLC occurrences and conclude that typically NLC do not form locally above Rio Grande but are transported from Antarctica.

Studies of the OH Meinel and CO_2 4.3-μm Emissions in Planetary Atmospheres

K. S. Kalogerakis[1], A. A. Kutepov[2], A. G. Feofilov[3]

[1] Center for Geospace Studies, SRI International, Menlo Park, California, U.S.A.
[2] Institute for Astrophysics and Computational Sciences, The Catholic University of America, Washington DC and NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
[3] Laboratory for Dynamic Meteorology, Ecole Polytechnique, Palaiseau, France.

The OH Meinel band emissions, originating from vibrationally excited hydroxyl radicals, OH(v), represent some of the most important airglow features in the upper atmospheres of the terrestrial planets. These emissions can be used as an indicator of atmospheric composition, variability, circulation, gravity waves, and as a probe of local temperature. A detailed understanding of the sources and sinks of these emissions is a prerequisite before they can be reliably used to study the above processes. Despite several investigations, the details of the relevant OH(v) relaxation kinetics and pathways are not well understood. Our recent studies demonstrated a previously unknown, efficient pathway for vibrational relaxation of OH(v) by O atoms that connects the mesospheric OH(v) emissions with the CO_2 4.3-μm emission and resolves a long-standing problem of severe discrepancies between model predictions and observations of the 4.3-μm emission in the Earth's atmosphere [1, 2]. We will report on our laboratory and atmospheric modeling studies of the OH Meinel and CO_2 4.3-μm emissions and their relevance to airglow in planetary atmospheres.

[1] Panka et al., Atmos. Chem. Phys. 17, 9751-9760 (2017).

[2] Kalogerakis et al., Geophys. Res. Lett. 43, 8835-8843 (2016).

This research was supported by NASA Grants 80NSSC19K0535 and 80NSSC20K0915.

EISCAT 3D Science outlook for small bodies in Geospace: 2 - Meteoroids, NEOs and Space debris

D. Kastinen and J. Kero

Swedish Institute of Space Physics

We present ongoing research at the Swedish Institute of Space Physics and the science outlook for using EISCAT 3D for measuring meteoroids, near Earth objects (NEO) and space debris, i.e. small bodies in Geospace.

On the topic of meteoroids we present the possibilities for multi-static long term measurements, revealing exotic populations such as interstellar or high altitude meteors. We can also better couple dynamical simulations of meteoroid streams in the solar system with observations using the expected high quality orbital data for each detected meteoroid. For NEOs, the EISCAT 3D configuration and wavelength might make asteroid tomography possible and e.g. polarimetric radar studies could constrain regolith grain size and shape distribution, bulk density, ect. The impressive scheduling and scanning ability allows EISCAT 3D to assist in improving the orbits of already known NEOs and multi-purpose experiments can allow for the potential discovery of e.g. temporarily captured near Earth asteroids (minimoons). The same applies for space debris where the advantage of having a multi-static phased array is key to mitigate the growing problem of space debris. For example, shortly after a fragmentation event danger is afoot for all objects in similar orbits as the fragmented object. EISCAT 3D can with its rapid pointing and tri-static configuration quickly track these dangerous objects (if whitelisted), either as part of a multi-purpose experiment or in gaps between other experiments. Repeated measurements of space debris can also probe help probe the variations in atmospheric density not included in models.

DRIIVE - DRivers and Impacts of Ionospheric Variability with EISCAT_3D

A. J. Kavanagh, the DRIIVE team

British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK

EISCAT_3D will give us an unprecedented opportunity to study key processes in the auroral latitude ionosphere across multiple scales. The UK has funded two £2M projects to exploit the unique multiscale capabilities of EISCAT_3D, with emphasis on questions related to small-scale Joule heating, the electrodynamics of auroral arcs, the formation and evolution of irregularities and how variability is driven by space weather and by meteorology. The combined projects involve >25 investigators from 12 UK institutes with many project partners from across the world.

The key question to be answered by the DRIIVE project is: "How does the high latitude ionosphere vary on small scales in response to driving from above and below?". To answer this the project is split into four distinct but interconnected areas: identifying lower-atmosphere forcing; measuring changes to local composition and the effect on electrodynamics; the energy input from currents and particle deposition; and the impacts on small scale variability on the upper atmosphere and hazards such as space debris.

To do this we are relying on a network of support instruments and complementary satellite observations, at the hub of which sits EISCAT_3D. The project also relies on numerous collaborators, spanning the EISCAT community and beyond.

This presentation will give an overview of the science and methods that DRIIVE will implement and discuss the steps being taken in preparation for initial observations.

Sensitivity of middle-atmospheric chemistry to energetic particle precipitation

A. Kero

SGO / University of Oulu

There is plenty of evidence that the energetic particle precipitation (EPP) can significantly modulate the middle-atmospheric ozone related chemistry, and possibly alter the global atmospheric circulation, via ionic production of minor species such as odd hydrogen HO_x (H, OH and HO_2) and odd nitrogen NO_x (N, NO and NO_2).

In this presentation, the response of the HO_x and NO_x chemistry to the EPP forcing is studied by using the Sodankylä Ion and neutral Model (SIC) in terms of ionisation rate and duration. In particular, a lower limit for the particle forcing to have a noticeable chemical impact at different altitudes is estimated. As this limit also directly links to the electron density caused by the ionisation, this survey enables a direct comparison to the EISCAT and EISCAT_3D datasets, i.e., are the electron densities (observed during some events) high enough to expect any chemical changes?

EISCAT 3D science outlook for small bodies in geospace: 1 – Meteors

Johan Kero and Daniel Kastinen

Swedish Institute of Space Physics (IRF), Kiruna, Sweden

Earth is constantly bombarded by meteoric material. Current estimates of the total influx are uncertain and range from a few to several hundred tons per day. Radar observations give access to a part of the mass distribution which is difficult to quantify using other methods. Multistatic meteoric head echo observations such as those by EISCAT_3D enable accurate trajectory and orbit information.

A meteor observation programme implemented in parallel with regular ionospheric and atmospheric observations at EISCAT_3D will provide important data to constrain the mass influx estimation, the mass distribution indices of sporadic meteors and meteor showers, and will open new windows to the physics of meteors such as atmospheric fragmentation processes and differential ablation.

We review previous and current head echo observations performed using a variety of high-power large-aperture radar systems and put the results into context of what to expect from EISCAT_3D. We give examples of how meteoroid masses have been estimated using electromagnetic scattering models calibrated with simultaneous radar-optical and multi-frequency radar observations as well as how radar observations contribute to the search for meteor shower outbursts and their characterization.

Response of the semidiurnal tide to the electron density to solar activity variation in the polar E-region using EISCAT UHF radar

H. Koyama[1], S. Nozawa[1], Y. Ogawa[1,2,3], A. Brekke[4]

[1] Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Aichi, Japan
[2] National Institute of Polar Research, Tachikawa, Tokyo, Japan
[3] The Graduate University for Advanced Studies, SOKENDAI, Kanagawa, Japan,
[4] UiT The Arctic University of Norway, Tromsø, Norway

We studied the variability of the semidiurnal tide in the polar lower thermosphere with respect to season, solar activity, and geomagnetic activity using 328 day data obtained by the EISCAT UHF radar from October 1984 to February 2020. We found that one of the main modulation sources of the semidiurnal tide is ion drag which depends on electron density and electric field. Some studies (ex. Nozawa and Brekke 1995) showed importance of the electric field on the semidiurnal tide during the high auroral activity period, but no studies have been made to evaluate contribution of the electron density. The purpose of this study is to investigate the solar activity dependence and solar zenith angle dependence of the electron density, and to statistically clarify the variation of the electron density in the polar E-region.

We have analyzed EISCAT UHF radar data (common program one and two) obtained from January 1987 to February 2019, only during quiet geomagnetic activity ($Kp \leq 3$) to reduce the influence of geomagnetic activity. The electron density was integrated for 1 hour between 12 LT-13 LT on a day. We use F10.7 index, which is high correlation with EUV, as a proxy of the solar activity.

We have found that the electron density increases as the solar activity (F10.7) increases in each season between 95 and 120 km altitude. The increase rate of the electron density relative to F10.7 in summer is about twice as high as that in winter. Further, we have investigated the solar zenith angle dependence of the electron density using data obtained under low solar activity conditions ($F10.7 \leq 80$) to avoid the effect of the solar activity dependence. The electron density varies greatly with the solar zenith angle even in the same season. The electron density increases in proportion to the cosine of the solar zenith angle. It should be kept in mind, the atmosphere at an altitude of 100 km is exposed to sunlight at a solar zenith angle of less than about 100 degrees above Tromsoe (69.6 degrees N, 19.2 degrees E). The solar zenith angle at 12-13 LT in winter is between 80 and 95 degrees. This is the reason why the electron density has solar activity dependence in winter. Thus, in winter the ion drag would has solar activity dependence due to the solar activity dependence of the electron density, and this is the reason that the semidiurnal tide in the auroral E-region in winter shows solar activity dependence.

In this presentation, the response of the semidiurnal tide to the electron density will also be discussed.

Signatures of Pulsating Aurora in the Polar Mesosphere Summer Echoes

A. Kozlovsky

Sodankylä Geophysical Observatory of the University of Oulu, Sodankylä, Finland

Using data of the all-sky interferometric meteor radar (SKiYMET, 36.9 MHz) operating in the Sodankylä Geophysical Observatory (67°22'N, 26°38'E, Finland) we found a specific type of polar mesosphere summer echo (PMSE), the power of which exhibits irregular variations at a frequency of the order of a few Hz. We classified such radar echoes as pulsating PMSE. These echoes were observed in late June – July in the morning sector (4 -12 MLT) during geomagnetic storms. They were received from a narrow range of altitudes near 82 km, which corresponds to the altitude of noctilucent clouds where ice particles of about 50-nm radii exist. During pulsating PMSE the SGO ionosonde showed an electron density of the order of $3 \cdot 10^{11}$ m-3 around 82 km, and enhanced D region ionization was manifested in the cosmic noise absorption. We suggest that the power of PMSE is modulated by bursts of electron precipitation corresponding to the few-Hz internal modulation of pulsating aurora. During a short precipitation burst of 50-100 keV electrons, additional electrons can attach to the ice particles due to the presence of hyperthermal electrons. This leads to an increase of the power of PMSE. After the burst is ended the ice particles are deionized with a characteristic time of about 0.2 s due to attractive interaction with ions.

REFERENCE: Kozlovsky, A., Shalimov, S., Lester, M., & Belova, E. (2021). Polar mesosphere summer echoes and possible signatures of pulsating aurora detected by the meteor radar. Journal of Geophysical Research: Space Physics, 126, e2020JA028855. https://doi.org/10.1029/2020JA028855

Local Joule heating profile near small scale auroral features estimated using high resolution electric fields measurements

P. Krcelic, R. C. Fear, D. K. Whiter, B. S. Lanchester

University of Southampton

We use a combination of ASK, HiTIES and EISCAT measurements to estimate the local Joule heating profile near highly dynamic small scale auroral features during an event on February 2nd 2017. ASK consists of 3 cameras each having a narrow band filter centred around different distinct auroral emissions. The ratios of various measured emissions, as well as careful modelling of auroral features, allow us to estimate localised electric fields on a sub second resolution. HiTIES is a spectrograph measuring auroral emissions including N_2 1P. The obtained N2 spectrum is dependent on the atmospheric neutral temperature, which is estimated from fitting of synthetic spectra to the measured one. From EISCAT measurements we use profiles of electron densities as well as ion and electron temperatures. All measurements are taken from the same, narrow field of view. We use a horizontal wind model (HWM14) to provide the neutral wind profiles. Results show little dependence of the local Joule heating profile on the neutral wind profile. Our reasoning is that electric fields near auroral features have such high intensity and variability compared to the more stable neutral wind that the E-fields dominate the calculation of the Joule heating rate. Furthermore, our Joule heating estimates are significantly larger (up to 100 times higher) than those estimated with more broad, lower resolution measurements. Such intense local heating in the auroral region may play an important role in the ionosphere and must be further researched.

CO_2 + O Collisions: A Grand Challenge for Upper Atmospheric Science

A. A. Kutepov[1], K. S. Kalogerakis[2], A. G. Feofilov[3]

[1] Institute for Astrophysics and Computational Sciences, The Catholic University of America, Washington DC and NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
[2] Center for Geospace Studies, SRI International, Menlo Park, California, U.S.A.
[3] Laboratory for Dynamic Meteorology, Ecole Polytechnique, Palaiseau, France.

Infrared absorption and emission by atmospheric constituents play a crucial role in determining the atmospheric temperature profiles of Earth and the other terrestrial planets, Venus and Mars. Carbon dioxide is a key contributor to the global energy balance of all three planets, mainly through its vibrational bending mode, $CO_2(\nu_2)$, which emits radiation near 15 μm (667 cm^{-1}). This emission is a key cooling mechanism for the middle and upper atmospheres of these three planets. Accurate knowledge of the excitation mechanism for $CO_2(\nu_2)$ and the corresponding rate is crucial for reliable modeling of these atmospheric layers.

The key process controlling the coupling of the 15-μm radiation with the heat reservoir is excitation/quenching in collisions of $CO_2(\nu_2)$ with thermalized atomic oxygen in its ground state, $O(^3P)$. This process is poorly understood despite numerous studies over the past several decades. Unacceptably large discrepancies by factors of 3-4 exist between laboratory rate constant determinations for O-atom excitation/de-excitation of $CO_2(\nu_2)$ and the corresponding values retrieved by analyses of space-based atmospheric observations.

We discuss the relevant background and propose a research program that will bring together diverse expertise relevant to the theme of understanding upper atmospheric cooling and energy balance. A key need is to exploit the synergy of space-based observations, modeling and theoretical calculations, as well as laboratory experiments in order to resolve the long-standing problem of CO_2 + O collisions as a source of the 15-μm emission.

Auroral Image Classification with Deep Neural Networks

A. Kvammen[1], K. Wickstrøm[1], D. McKay[2], N. Partamies[3,4]

[1] UiT - The Arctic University of Norway, Tromsø, Norway
[2] Finnish Centre for Astronomy with ESO, FINCA, University of Turku, Turku, Finland
[3] Department of Arctic Geophysics, The University Centre in Svalbard, Longyearbyen, Norway
[4] Birkeland Centre for Space Science, Bergen, Norway

Results from a study of automatic aurora classification using machine learning techniques are presented. The aurora is the manifestation of physical phenomena in the ionosphere-magnetosphere environment. Automatic classification of millions of auroral images from the Arctic and Antarctic is therefore an attractive tool for developing auroral statistics and for supporting scientists to study auroral images in an objective, organized, and repeatable manner. Although previous studies have presented tools for detecting aurora, there has been a lack of tools for classifying aurora into subclasses with a high precision (>90%). This work considers seven auroral subclasses: breakup, colored, arcs, discrete, patchy, edge, and faint. Six different deep neural network architectures have been tested along with the well-known classification algorithms: k-nearest neighbor (KNN) and a support vector machine (SVM). A set of clean nighttime color auroral images, without clearly ambiguous auroral forms, moonlight, twilight, clouds, and so forth, were used for training and testing the classifiers. The deep neural networks generally outperformed the KNN and SVM methods, and the ResNet-50 architecture achieved the highest performance with an average classification precision of 92%.

MLT parameters derived with the radio forward scatter network BRAMS : advantages and limitations

H. Lamy

BIRA-IASB, Avenue Circulaire 3, 1180 Brussels, Belgium

BRAMS (Belgian RAdio Meteor Stations) is a network using forward scatter of radio waves on ionized meteor trails to study meteoroids. It is made of a dedicated transmitter and of 42 receiving stations located in or near Belgium, including one radio interferometer. The network started in 2010 but has recently been extended and upgraded.

The transmitter emits a circularly polarized CW radio wave with no modulation at a frequency of 49.97 MHz and with a power of 130 W. Each receiving station uses a 3-element zenith pointing Yagi antenna. The first stations used analog ICOM-R75 receivers and a PC. Since 2018, new improved stations have been installed using digital RSP2 receivers, a GPSDO and a Raspberry Pi, providing better dynamic, sensitivity and stability.

With this contribution, we would like to discuss the advantages and limitations of the network to retrieve properties of the MLT such as neutral wind speed measurements.

More then two decades of long-term observations of polar mesospheric echoes at 69°N

R. Latteck, T. Renkwitz, J. Jaen, and J. L. Chau

Leibniz-Institute of Atmospheric Physics at the University of Rostock

Since 1999 radar continuous observations of polar mesospheric echoes have been conducted on the Norwegian island of Andøya (69.30°N, 16.04°E), with the ALWIN radar (1999--2008) and MAARSY (since 2011). Traditionally these observations have been named after their seasonal occurrence, i.e., Polar Mesosphere Summer Echoes (PMSE) and Polar Mesosphere Winter Echoes (PMWE). PMSE are much stronger than PMWE and are known to be due to contributions of charged-dust (ice) particles and turbulence. On the other hand, most PMWE are mainly due to turbulence. Both echoes depend on electron density and its gradients. The use of MAARSY, 17 dB more sensitive than the ALWIN radar, makes it possible to observe turbulence-dominated echoes, usually below 80 km, all year round with a mean seasonal occurrence frequency of about 14%. Their minimum occurrence rate is 2% in July and August, while there are two maxima, one in March/April (22%) and the second one in October (26%). On average the dust-dominated summer echoes starts on 14 May and ends on 26 August (i.e. 105 days) with an average occurrence in June/July of 95%. These summer echoes occur mainly between 80 and 90 km, and present a maximum daily occurrence around 13:00 LT. On the other hand, the turbulence-dominated winter echoes occur mainly between 55 and 80 km with maximum daily occurrence around 11:30 LT. Besides the seasonal and daily occurrence of these echoes, we present the variability of occurrence frequency rates for the summer layers since 1994. After eliminating the effects of geomagnetic and/or solar activity the occurrence of the summer dust-dominated echoes show a positive trend of about 0.3 %/yr over the last twenty seven years which might be related to the observed negative mesospheric temperature trends at polar latitudes. Moreover, the start of the echoes occurrence shows an earlier start of 0.5 day/yr. This behavior is also observed in the summer reversal of the mesospheric wind at mid- and high-latitudes observed with partial reflection radars combined with specular meteor radars. Significant trends were observed in the wind reversal data data indicating an earlier onset of summer, and the monthly vertical wind profiles show significant trends at mid-latitudes indicating stronger westward winds winds over the past 32 years.

Local mapping of polar ionospheric electrodynamics

Karl Laundal, Jone Reistad, Spencer Hatch, Michael Madelaire, Simon Walker, Amalie Hovland, Anders Ohma

University of Bergen

An accurate description of the state of the ionosphere is crucial for understanding the physics of Earth's coupling to space, including many potentially hazardous space weather phenomena. To support this effort, ground networks of magnetometer stations, optical instruments, and radars have been deployed. However, the spatial coverage of such networks is naturally restricted by the distribution of land mass and access to necessary infrastructure. We present a new technique for local mapping of polar ionospheric electrodynamics, for use in regions with high data density, such as Fennoscandia and North America. The technique is based on spherical elementary current systems (SECS), which were originally developed to map ionospheric currents. We expand their use by linking magnetic field perturbations in space and on ground, convection measurements from space and ground, and conductance measurements, via the ionospheric Ohm's law. The result is a technique that is similar to the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) technique, but tailored for regional analyses of arbitrary spatial extent and resolution.

VortEx: A ground-based and rocket experiment to study mesoscale dynamics in the MLT for February 2023

G. A. Lehmacher[1] and the VortEx Team

[1] Clemson University

NASA has approved the sounding rocket experiment VortEx (Vorticity Experiment) to be launched from Andoya Space Center in February 2023. Launch window is 10 Feb to 28 Feb 2023. On one or two launch nights we plan to launch four rockets, each pair with instrumented and tracer release payloads, to study gravity wave breaking and mesoscale dynamics below and above the mesopause. Key region is 80 to 140 km (MLT). It is supported by ground-based airglow and temperature imaging (AMTM), temperature and wind lidar and meteor radars. The novel techniques such as tracer release ejectable ampules, and multiple radar transmitters and receivers (MMARIA/SIMONE) have the common goal to perform horizontally distributed observations of winds in the key region. We will propose for EISCAT support for additional information on ion-neutral coupling and calculation of neutral winds in the LT. VortEx is highly relevant for the Grand Challenge Initiative Mesosphere and Lower Thermosphere (GC-MLT), since it addresses important science questions collected in the GC-MLT white paper. Principal Investigator is Gerald Lehmacher with Co-PIs from Clemson University, Embry-Riddle University, Utah State University and the Institute for Atmospheric Physics. More information can be found in Lehmacher et al., Proc. 24th Symp. Europ. Rocket and Balloon Progr., ESA SP-742, October 2019.

On exponential frequency spectra and deterministic chaos in localized plasma wave interactions pumped by powerful radio waves in the ionosphere

T. B. Leyser

Swedish Institute of Space Physics, Uppsala, Sweden

Exponential frequency spectra have been shown to be a characteristic of deterministic chaos. As established in laboratory experiments with magnetically confined plasmas, exponential frequency spectra are a feature of temporal pulses of Lorentzian shape in the signal time series, rather than resulting from a statistical property of the fluctuations. Experiments on pumping ionospheric F-region plasma by powerful radio waves, such as transmitted from EISCAT-Heating, have also given evidence of deterministic chaos in the underlying wave dynamics, for example in spectra of stimulated electromagnetic emissions (SEE). In this presentation, numerical results from a theoretical model of wave interactions is outlined to interpret the observations. The physics involves ExB drifts due to wave modes localized in cylindrical density depletions associated with pump-excited filamentary magnetic field-aligned density striations.

O_2 and OH airglow in the mesosphere through the lens of Odin/OSIRIS Infrared Imager

A. Li[1], D. Murtagh[1]. K. Perot[1], O.M. Christensen[1,2]

[1] Chalmers University of Technology
[2] Stockholm University

The Odin satellite has routinely measured $O_2(a^1\Delta_g)$ and OH Meinel band airglow emissions from 2001 until 2015. In this work, the Odin/OSIRIS infrared imager data have been studied in some depth for the first time. Numerical inversions of the observed radiances have been carried out to retrieve the volume emission rates and, thereafter, the mesospheric ozone density. This resulted in a new, long-term high-resolution airglow and ozone datasets of the middle atmosphere.

The photolysis reactions are affected by periodic changes in solar irradiance. Thus, the OHv emission should vary with the solar cycle. In terms of the 11-year solar cycle, as expected, we observed that the vertically integrated intensity of OH_v correlates positively with the Lyman-α flux and that the emission height correlates negatively at most latitudes except near the equator. Employing a time-dependent photochemical model, we showed that the changing local time sampling of the Odin satellite was the cause of the observed distortion of the solar cycle signature near the equator.

We also observed the episodic signatures in the two airglow emissions of sudden stratospheric warming (SSW) events. With the aid of the temperature and H_2O measured from Odin-SMR, we qualitatively assessed the events that occurred in 2009, 2012, and 2013. Using analytical expressions, we derived proxy O and OH_v number densities. A significant amount of atomic oxygen-rich air descends into the mesosphere a few days after the SSW onsets, resulting in unusually intense airglow emissions at a much lower altitude than average. The modelled OH_v largely resembles the temporal evolution of the observed OH_v. The synchronous structure of the two airglow emissions indicates that the vertical transport of O plays a dominant role in the observed changes.

MATS Satellite Data: How Well Can We Determine Gravity Wave Parameters?

B. Linder[1], O. M. Christensen[1], P. Preusse[2], Q. Chen[2], M. Ern[2], L. Megner[1], J. Gumbel[1] and E. Becker[3]

[1] Stockholm University, Sweden
[2] Forschungszentrum Jülich, Germany
[3] NorthWest Research Associates, United States

MATS (Mesospheric Airglow/Aerosol Tomography and Spectroscopy) is an upcoming Swedish satellite mission designed to investigate atmospheric waves in the Mesosphere and lower Thermosphere by imaging variations in O_2 atmospheric band airglow emission between 70 and 110 km, as well as structures in Noctilucent clouds (NLC, PMSE). Performing a tomographic analysis of these images, 3D reconstruction of waves can be done, allowing the MATS mission to provide global properties of atmospheric waves in all spatial dimensions. Here, we present capabilities of the MATS gravity wave parameter retrieval by analysing synthetic satellite data composed from HIAMCM (The High Altitude Mechanistic general Circulation Model) output.

Past and future development of noctilucent clouds

Franz-Josef Lübken, Gerd Baumgarten, Mykhaylo Grygalashvyly, and Ashique Vellalassery
Leibniz-Institute of Atmospheric Physics, 18225 Kühlungsborn, Germany

Noctilucent clouds (NLC) are often cited as potential indicators of climate change in the middle atmosphere. They owe their existence to the very cold summer mesopause region (~130K) at mid and high latitudes. We analyze trends derived from the Leibniz-Institute Middle Atmosphere Model (LIMA) and the MIMAS ice particle model (Mesospheric Ice Microphysics And tranSport model). We first concentrate on the years 1871-2008 and on middle, high and arctic latitudes, respectively. Model runs with and without an increase of carbon dioxide and water vapor (from methane oxidation) concentration are performed. Trends are most prominent after ~1960 when the increase of both carbon dioxide and water vapor accelerates. Negative trends of (geometric) NLC altitudes are primarily due to cooling below NLC altitudes caused by carbon dioxide increase. Increases of ice particle radii and NLC brightness with time are mainly caused by an enhancement of water vapor caused by the oxidation of methane. Several ice layer and background parameter trends are similar at high and arctic latitudes but are substantially smaller at middle latitudes. Ice particles are present nearly all the time at high and arctic latitudes, but are much less common at middle latitudes. Ice water content and maximum backscatter are highly correlated, where the slope depends on latitude. This allows to combine data sets from satellites and lidars. Furthermore, IWC and the concentration of water vapor at the altitude of maximum backscatter are also strongly correlated. Results from LIMA/MIMAS are consistent with observations. More recently, we have expanded our model runs into the future, namely up to the 2060s. We have used IPCC scenarios regarding future concentrations of carbon dioxide and methane. We find that all NLC parameters, such as occurrence rates and backscatter coefficients increase substantially in this time period. Furthermore, we have studied the extinction of solar radiation by NLC. We will present details regarding the (wavelength-dependent) extinction and the temporal and spatial distribution of this extinction. We will also present new results on the impact of solar cycle induced radiation variability on NLC.

The properties and interactions of dust in the mesosphere and its possible observational studies

I. Mann

Department of Physics and Technology, UiT, Arctic University of Norway, Tromsø, Norway

Dust particles play an important role in the layered phenomena in the mesopause region. They appear in the form of meteor smoke, accumulating from the compounds of cosmic dust injected into the upper atmosphere in the meteor process, ice particles condensing near the mesopause at high and mid-latitudes in summer, in the form of space debris, and as mixture of all these particles. The dust particles carry electric charges which influences their growth. The dust particles influence the charge balance of the electrons and ions and thus the chemical processes. The ice particles are observed in noctilucent and polar mesospheric clouds and there is evidence that they are becoming more frequent and changing their properties. Transport and growth are further influenced by the neutral atmosphere on large scales by transport and on smaller scales by waves, turbulence, and temperature variations. Surprisingly little is known about the composition and the physical properties and interactions of the dust; This presentation discusses recent theoretical and observational studies and the options for future observations. The combination of different theoretical approaches and observational studies from ground, space and laboratory shows promise.

Investigating mesospheric dust with the MXD2 rocket campaign

I. Mann[1], S.V. Olsen[1], Y. Eilertsen[1], H. Trollvik[2], A. Pineau[3,4], S. Strmic Palinkas[1], T. Gunnarsdottir[1], H.L. Greaker[1], Å. Fredriksen[1], A. Spicher[1], V. L. Narayanan[1,5]

[1] Institute for Physics and Technology, UiT, Arctic University of Norway, Tromsø, Norway
[2] Division of Space and Plasma Physics, KTH, Royal Institute of Technology, Stockholm, Sweden
[3] CELIA UMR 5107, Université de Bordeaux-CNRS-CEA Talence Cedex, France
[4] Laboratory for Laser Energetics, University of Rochester, Rochester, New York, USA.
[5] Department of Electronic and Electrical Engineering, University of Bath, Bath, United Kingdom

In situ observations and knowledge of dust composition are essential for understanding the microphysics of dust and its role in layer phenomena in the mesosphere. The MAXIDUSTY-2 rocket (MXD2) campaign addresses this issue with in-situ measurements of charged dust and the surrounding plasma components at 70 to 110 km altitude and with the collection of dust material. MXD2 includes several well-proven instruments from UiT and from the Meteorological Institute, University of Stockholm (MISU), the Leibniz-Institute of Atmospheric Physics at Rostock University (IAP) and the University of Oslo (UiO). A suit of dust detectors can measure the number density height profile of the charged dust/ice particles along the rocket trajectory; also some information can be derived on the size distribution of the meteoric smoke particles that are embedded in large ice particles. Other instruments provide data on the neutral gas and the electron number densities and the small-scale fluctuations in electron density. The new MESS (Meteoric Smoke Sampler) instrument is designed to collect mesospheric smoke particles that are embedded in more massive ice particles. The massive ice particles enter the instrument where water ice compounds vaporize and refractory compounds are collected on standard TEM grids on a sample holder. A separate container contains sample collectors that are not exposed for test purposes. Another sample collector designed by MISU is also part of the payload. MAGIC (Mesospheric Aerosol – Genesis, Interaction and Composition) instrument was operational during previous rocket flights and is designed to collect smaller particles directly which is however more challenging. We expect that FE-SEM analysis followed by TEM-EDX analysis would give us information on the size distribution and morphology of particles larger than 1 nm (FE-SEM) and their crystal structure and relative abundances of the major elements (TEM-EDX). The MXD2 rocket will be launched under PMSE conditions from Andøya Space Center in the summer and subject to project funding, we are targeting a July 2024 launch window. The campaign will benefit from synergies with other mesosphere observations and will be part of the international Grand Challenge initiative.

Towards a Fenno-Scandinavian Arctic natural laboratory for MLT research

Linda Megner

Stockholm University

In a year or two the Fenno-Scandinavian Arctic will have an impressive set-up of instruments observing the MLT region, permitting detailed common volume studies of for example gravity waves or solar impact. For example, MATS, ALIS4D and the OH-imager will all be able to observe gravity waves in airglow fields. At the same time EISCAT_3D observations of electron density, which at during low solar activity should be governed by the atmospheric density, could provide information of the very smallest scales of gravity waves. Bringing these data sets together could provide 3D gravity wave information from mesoscale down to perhaps 100 m, which is a far greater range than any of today's instrument. At the same time the wind field will be measured up to around 120 km, allowing for determination of both the intrinsic and the extrinsic frequency. Here we want to discuss 1) the scientific studies that can be done with such a data set, 2) under which circumstances and for which altitudes the EISCAT 3D electron density is a good estimate for the neutral atmospheric density, and 3) how we best can create such a data set.

Comparison of F-region ion velocities measured by the Swarm satellites and EISCAT radar

M. Mekuriaw[1], A. Aikio[1], H. Vanhamäki[1], I. Virtanen[1], L. Cai[1], S. Buchert[2], N. Ivchenko[3], W. Miloch[4], Y. Jin[4], J. Burchill[5], and D. Knudsen[5]

[1] Space Physics and Astronomy Research Unit, University of Oulu, Oulu, Finland
[2] Swedish Institute of Space Physics, Uppsala, Sweden
[3] Division of Space and Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden
[4] Department of Physics, University of Oslo, Oslo, Norway
[5] Department of Physics and Astronomy, University of Calgary, Calgary, Canada

Plasma flow in the ionospheric F region is driven by the solar wind-magnetosphere-ionosphere coupling. Typically, two convection cells are formed in the high-latitude ionosphere, one centred on the dusk and one on the dawn side. Several statistical models exist, which estimate the flow velocities based on solar wind properties and geophysical conditions. Typically, the values are smaller than 1000 m/s. However, at times very large plasma flow velocities have been measured, which clearly exceed the statistical average velocity values. Often the enhanced flows appear as narrow channels, therefore they are called flow channels.

In this study, we will compare ion velocity measurements by the Swarm satellites and EISCAT radars. Swarm is ESA's Earth Explorer 5 mission and a constellation of three satellites in circular polar orbits at 450-515 km altitudes. Since November 2013, Swarm provides us with information on the local plasma environment, field-aligned electrical currents, and ion velocities. In this study, we utilise the Thermal Ion Imager (TII) measurements onboard of Swarm A or B satellites for ion velocities. The EISCAT incoherent scatter radars, namely the UHF and VHF radars in Tromsø (69.6°N latitude) and the EISCAT Svalbard radar (ESR, 79°N latitude) near Longyearbyen, have been operational for several decades. EISCAT radars yield electron density, electron and ion temperature and ion velocity measurements from a large altitude range in the ionosphere.

The comparison is carried out by first searching conjugate Swarm satellite overpasses over EISCAT mainland or Svalbard sites during experiment times. The next steps include search of events which show signatures of ion frictional heating and checking availability of TII measurements from Swarm and suitable experiment mode (CP1 tristatic, CP2 or CP3) from EISCAT to enable ion velocity vector estimation. Comparison is carried out only to the cross-track component of the Swarm ion velocity, and therefore the EISCAT velocity vector is first rotated to the satellite coordinate frame and then only the cross-track component is considered. The measurement modes by EISCAT produce different spatial (and temporal) resolutions for different experiments and this must be taken into account in the comparison. The results within error bars show relatively good correspondence between Swarm and EISCAT ion velocities. However, there is a tendency for the Swarm ion velocity to have higher values than the EISCAT ion velocity. This difference will be quantified and possible reasons will be discussed.

Investigating the influence of solar cycle, greenhouse gases and volcanoes on decadal variability in the polar summer mesosphere

A. Merkel[1], M. Hervig[2], C. Bardeen[3], M. Mills[3]

[1] LASP, University of Colorado, Boulder, USA
[2] GATS Inc., Driggs, Idaho, USA
[3] NCAR, Boulder, CO, USA

The response of the polar mesosphere to decadal variability (11-year solar cycle, greenhouse gases, volcanoes) is investigated using satellite observations and attribution studies using NCAR's Whole Atmosphere Community Climate Model (WACCM). Because polar mesospheric clouds (PMC) are excellent monitors of mesospheric conditions due to their extreme sensitivity to temperature and water vapor, we use the PMC observation record to track variability in the polar mesosphere. The mesospheric satellite observation records span between 1978- 2021 and indicate that PMCs, temperature and water vapor vary with the 11-year solar cycle and show evidence of long term trends that could be associated with greenhouse gas increases. PMC observations showed a clear anti-correlation with the solar cycle before 2004, however, the solar cycle response is curiously absent during the last 20 years of PMC observations. To untangle this discrepancy, we conduct attribution studies using the WACCM-PMC model to isolate and quantify decadal influences (Sun, greenhouse gases and volcanoes) to the PMC, temperature and water vapor data record.

Designing and developing services for End Users

M. Mihalikova

EISCAT Scientific Association

It is important for Research infrastructures (RIs) to develop interoperable and reusable services to form a strong user community with potential for growth. Effective service documentation, training as well as multimedia and interactive content are needed to attract users and help them to access and successfully use the services offered by the RI, thus maximizing its full potential. To achieve this goal one of the most important inputs is the knowledge of the needs of the community. This poster will shortly present the steps of designing and developing a new service based on an example from environmental sciences and offer a brief look at tools that can be used in the process.

MesoS2D: Mesospheric sub-seasonal to decadal predictability

T. Moffat-Griffin[1], A . J. Kavanagh[1], N. Mitchell[1], C. Wright[2], D. Marsh[3]

[1] British Antarctic Survey, Cambridge, UK
[2] University of Bath, UK
[3] University of Leeds, UK

The mesosphere/lower-thermosphere/ionosphere (MLTI) region is a critical boundary in the coupling of the atmosphere, climate and space weather. However, the nature and causes of MLTI variability are so poorly understood that our ability to forecast the behaviour of this region lags far behind that of other regions of the atmosphere. In MesoS2D (a NERC funded large grant starting in 2022), we will address this problem. We will quantify MLTI variability, determine the physical drivers of MLTI variability across time scales ranging from hours to the decadal, and determine how the MLTI couples to the regions above and below. We will exploit data from high-latitude Scandinavia, which is the most heavily instrumented region on Earth for MLTI studies, and the Whole Atmosphere Community Climate Model (WACCM). Meso-S2D will thus deliver the essential tools necessary to improve sub-seasonal to decadal predictability of the MLTI.

Dusty Plasma effect in Saturn's ionosphere

M. Morooka et al.

IRF Uppsala

It is widely accepted that the layer of water aerosol and dust particles exists in the upper polar mesosphere and affects the plasma condition of the NLCs and PMSE. In Saturn, a continuous influx of the ice grains from the ring condenses in the upper atmosphere. The particles and plasma measurements onboard Cassini provided the in-situ measurements of the upper atmosphere of Saturn and the innermost ring of Saturn during the Grand Finale orbits and revealed the nature of infalling ice and organic materials from the ring and dusty nature of the plasma in the upper atmosphere. We will show the data from the Cassini Grand Finale and discuss the similarities and dissimilarities of the dusty ionosphere of the Earth and Saturn.

Middle atmospheric ionization during substorms: 5-year observation of mesospheric echoes by the PANSY radar

K. Murase[1], T. Nishiyama[2], R. Kataoka[2], Y-.M. Tanaka[2], K. Sato[3], M. Tsutsumi[2] and Y. Ogawa[2]

[1] The Graduate University for Advanced Studies, SOKENDAI, Japan
[2] National Institute of Polar Research, Japan
[3] The University of Tokyo, Japan

The middle atmospheric ionization associated with highly variable geomagnetic activities is poorly understood. Polar mesosphere winter echo (PMWE), a coherent echo observed by VHF radars in the polar region during the winter period, can be a unique phenomenon to solve this problem. PMWE is influenced by neutral atmospheric turbulence (e.g., Kohma et al., 2021) and the electron density in the mesosphere (e.g., Kirkwood et al., 2002). Recent studies reported several events of enhancements of PMWE power associated with the electron density enhancements due to energetic electron precipitation not only during the expansion and the recovery phases of substorms (Kataoka et al., 2019; Tanaka et al., 2019) but also during the growth phase under quiet auroral activity (Murase et al., 2022). In this study, we statistically investigated how PMWEs appear during different phases of substorms.

We used the data of mesospheric echo power during the nighttime (SZA>98°) obtained by the PANSY radar (Sato et al., 2014) at Syowa Station (69.0°S, 39.6°E) in five austral winter seasons from 2016. We performed superposed epoch analyses, referring to the timing of the substorm onset obtained from SuperMAG onset list (Ohtani and Gjerloev, 2020) as the zero epoch time. It is found that the event-averaged echo power increases by ~1 dB at an altitude of 75-80 km 10-25 min before the onset. This result supports the non-negligible contribution of growth-phase EEP to the mesospheric ionization, as suggested by Murase et al. (2022). We will also discuss the dependence of PMWE appearance on the substorm activity level during the expansion and recovery phases, such as positive correlation between PMWE duration and the substorm activities.

Overview of gravity waves in coexisting neutral and plasma fluids of the upper atmosphere

Viswanathan Lakshmi Narayanan[1], Linda Megner[2], Jörg Gumbel[2], Corwin Wright[1], Juha Vierinen[3], Devin Ray Huyghebaert[3]

[1] Department of Electronic and Electrical Engineering, University of Bath, United Kingdom,
[2] Department of Meteorology, University of Stockholm, Sweden,
[3] Department of Physics and Technology, UiT - The Arctic University of Norway, Norway

The importance of atmospheric gravity waves in the upper atmosphere – ionosphere system is well recognized and has been studied for decades. Most observed travelling ionospheric disturbances (TIDs) are believed to be caused by gravity waves, and the vast majority of these waves propagate into the ionosphere from lower heights. However, most previous studies have focused on either the atmospheric neutrals or the ionospheric plasma individually to study these wave perturbations. For example, wave signatures in the upper mesospheric airglow, winds and temperatures are all signatures in the neutral fluid while all TID observations are ionospheric plasma signatures. Very few studies have addressed how the coexisting plasma is affected by the neutral atmospheric waves using observations. There is a need to observe the wave signatures simultaneously in the neutrals and plasma in order to understand the finer details of the plasma-neutral coupling process involving the gravity waves. The way in which neutral atmospheric gravity waves affect the co-existing plasma component differ with height. This is because of the gradual magnetization of the terrestrial ionospheric plasma with height: the electrons are tied to the magnetic field lines at middle of the D-region around 80 km, while the ions become magnetized in the bottom of the F-region (~150 km altitude). In this presentation, we will provide an overview of the processes at play and a review of past work in this area. The relevance of this work to the forthcoming MATS satellite mission and to EISCAT 3D radar observations will also be discussed briefly.

A statistical study of static and dynamic instabilities in the upper mesosphere region above Tromsø

Satonori Nozawa[1], Norihito Saito[2], Takuya Kawahara[3], Satoshi Wada[2], Takuo T. Tsuda[4], Sakiho Maeda[1], Toru Takahashi[5], Hitoshi Fujiwara[6], Lakshmi Narayanan Viswanathan[7], Tetsuya Kawabata[1], and Magnar G. Johnsen[8]

[1] ISEE, Nagoya University
[2] RIKEN
[3] Shinshu University
[4] The University of Electro-Communications
[5] Electronic Navigation Research Institute
[6] University of Bath
[7] Seikei University
[8] UiT The Arctic University of Norway

In this talk, we will present results of a statistical study of the static and dynamic instabilities in the polar upper mesosphere. The polar Mesosphere and lower Thermosphere (MLT) is one of unique regions in terms of the vertical coupling between the Magnetosphere and atmosphere. The solar wind energy comes into the lower Thermosphere, and even the Mesosphere, but its quantitative effect on the MLT is still poorly known. Atmospheric waves (gravity, tidal, and planetary waves) generated in the Troposphere and Stratosphere propagate upward with their amplitudes growing. Most gravity waves break in the upper mesosphere (in particular, around the mesopause region), and provide energy and momentum to the atmosphere there, and could generate atmospheric instabilities (ex. Fritts and Alexander, 2003). This paper investigates how often the atmosphere in the polar upper mesosphere become unstable and what causes the atmosphere unstable.

We have studied the atmospheric stability between 80 and 100 km above Tromsø (69.6ºN, 19.2ºE) using temperature and wind data with 6 min and 1 km resolutions obtained with the sodium lidar at Tromsø. First, we have calculated Brunt-Väisälä frequency (N) for 354 nights obtained from October 2010 to December 2019, and Richardson number (Ri) for 210 nights obtained between October 2012 to December 2019. Second, using those values (N and Ri), we have calculated probabilities of the static instability ($N^2<0$) and the dynamic instability ($0 \leq Ri < 0.25$) that can be used for proxies for evaluating the atmospheric stability. The probability of the static instability varies from about 3% to 26% with a mean value of 12%, and that of the dynamic instability varies from 6% to 31% with a mean value of 14%.

We have investigated correlations of the probabilities with several parameters (F10.7, local k-index, semidiurnal tidal amplitudes), and altitude variations of the potential energy of gravity waves. Based on the results, we will discuss what causes the static and dynamic instabilities in the polar upper mesosphere region.

Possible common program (CP) modes for EISCAT_3D

Y. Ogawa[1], and EISCAT_3D CP Working Group members

[1] National Institute of Polar Research, Japan

The initial EISCAT_3D observations are scheduled for January 2023. In order to conduct the various studies summarized in the EISCAT_3D science case, basic observation modes, named Common Programs (CPs), need to be discussed and determined. The purpose of this presentation is to introduce a draft of CP modes based on discussions in the EISCAT_3D CP working group and then discuss it with the EISCAT community.

EISCAT_3D CP observations will be important to provide long-term basic ionospheric data in the polar region. The CP observations will be also important to link with the ISR radar observations that will be made around the world, mainly on ISR World day; the data including EISCAT_3D will be used to study the entire polar region and/or the global upper atmosphere. Meanwhile, individual unique and cutting-edge experiments will be conducted in Special Programs (SPs) and Peer-reviewed programs (PPs), and so on.

SDI-3D project

S. Oyama and SDI-3D project members

ISEE, Nagoya University, Japan; NIPR, Tokyo, Japan; University of Oulu, Oulu, Finland

The dynamics of terrestrial Thermosphere-Ionosphere system is governed by particle collisions between neutrals and plasmas. At high latitudes, external forces originated in the Magnetosphere accelerate ionospheric plasmas, and plasma kinetic energies are exchanged to kinetic and thermal energies of neutral particles. Since these energy transfer processes can be expressed by partial differential equations that incorporates numerous vector fields, it is essentially important to measure vector fields of the Ionosphere and Thermosphere in the common volume at the same time. European Incoherent Scatter (EISCAT) Scientific Association is now building a new international research infrastructure, EISCAT_3D, which adopts the phased-array system capable of conducting volumetric measurements of the ion velocity vector with the separated three radar systems in Norway, Sweden and Finland. The EISCAT_3D is the most powerful diagnostic to measure the ionosphere, but not suitable for measuring the Thermosphere or neutral particles. Then in 2018, a new scientific-oriented project of SDI-3D was established. SDI (Scanning Doppler Imager) is a passive optical instrument, which can measure 2D pattern of the thermospheric wind from the optical Doppler shift. The SDI-3D project has aimed for deploying three SDIs in the common volume of the EISCAT_3D in order to achieve spatiotemporally simultaneous observations of the Ionosphere and Thermosphere. A proposal including three SDIs was awarded in 2020, and we are now working for starting observation in 2023 with two SDIs in Finland and one in Sweden. This presentation will introduce the SDI-3D project.

Cosmic Dust in the Terrestrial Atmosphere

J. M. C. Plane[1], M. V. Guarino[1], N. M. Aylett[1], W. Feng[2,3], D. R. Marsh[1,4], A. D. James[1], B. J. Murray[2], G. W. Mann[2], M. D. Campbell-Brown[5], C. S. Gardner[6]

[1] School of Chemistry, University of Leeds, Leeds, UK; [2] School of Earth and Environment, University of Leeds, UK; [3] National Centre for Atmospheric Science, Leeds, UK; [4] School of Physics and Astronomy, University of Leeds, UK; [5] Department of Physics and Astronomy, University of Western Ontario, London ON, Canada; [6] University of Illinois at Urbana Champaign, Urbana, IL, USA

This paper will first discuss the amounts of cosmic dust entering the atmosphere from sources including short-period Jupiter Family Comets, the main asteroid belt, and long-period Halley Type, Kuiper Belt and Oort Cloud Comets, each of which has a different size and velocity distribution. Our current estimate of a total input of ~30 tonnes per day is constrained by the measured vertical fluxes of Na and Fe atoms in the upper mesosphere, and the accumulation rate of cosmic spherules and unmelted micrometeorites in Antarctica.

We will then discuss the fate of the dust particles during entry. Cosmic dust consists essentially of silicate mineral grains that are held together by a refractory organic "glue", and it has been proposed that loss of the organics during atmospheric entry, before a particle reaches the silicate melting point around 1800 K and starts to ablate, can lead to fragmentation into sub-micron sized fragments. At Leeds we have developed a new meteoric ablation simulator for studying the pyrolysis of the refractory organic constituents in cosmic dust during atmospheric entry. The pyrolysis kinetics of meteoritic fragments is measured by mass spectrometric detection of CO_2, and is consistent with two organic components – one significantly more refractory than the other, probably corresponding to the insoluble and soluble organic fractions, respectively. The measured temperature-dependent pyrolysis rates were then incorporated into the Leeds Chemical Ablation Model (CABMOD), which demonstrates that organic pyrolysis should be detectable using high performance large aperture radars. Atomic force microscopy was used to show that although the residual meteoritic particles became more brittle after organic pyrolysis, they will nevertheless withstand stresses that are at least 3 orders of magnitude higher than would be encountered during atmospheric entry. This suggests that most small cosmic dust particles (radius < 100 µm) will not fragment during entry into the atmosphere as a result of organic pyrolysis.

The final part of the presentation will discuss current challenges. First, the vertical transport of ablated meteoric metal atoms is too slow in chemistry-climate models, by a factor of around 5, compared with observation. We will show that this is most likely because transport by dissipating gravity waves, which mostly have horizontal wavelengths that are too small to be resolved in global models, needs to be included. A new parameterisation of dynamical transport which we have added to the WACCM model has largely resolved the problem. Second, the electro-dynamical transport of metallic ions has been incorporated into the WACCM-X model which extends up to ~500 km. We are currently using this model to explore the occurrence of sporadic E layers in the thermosphere. Although good agreement with COSMIC satellite observations is achieved at mid- and low-latitudes, more observations at high geomagnetic latitudes are needed to test the model. Third, experiments in our laboratory show that nanometre-sized meteoric smoke particles, which form from the condensation of oxidized metallic vapours in the upper mesosphere, are effective ice nuclei and can explain the formation of polar stratospheric clouds in the winter polar vortex.

Investigation of Kilometre-Scale Instabilities using Airglow Imagers and Numerical Simulations: A Case Study of a Dissipating Bore.

K. Ramachandran[1], S.Mani[1], J. L. Chau[1], S. Grundmann[2], J. F. Conte[1], J: Hartisch[1]

[1] Leibniz Institute for Atmospheric Physics at University of Rostock
[2] Department of Fluid Mechanics, University of Rostock

The mesosphere and lower thermosphere (MLT) is a region that represents the boundary between Earth's lower atmosphere and the space. In this region, kilometre-scale instabilities largely account for the wave dissipation, generation of turbulence and mixing process. Airglow imagers and radar observations can help us in the investigation of the dynamics behind some of the commonly occurring instabilities, e.g., Kelvin-Helmholtz Instabilities, mesospheric bores, etc. Here we report and discuss a bright wave event that was observed between 90 and 97 km on 16 March 2021 in an all-sky airglow imager over northern Germany. This event was characterized by a sharp onset of a wave-front followed by trailing waves, whose morphology resembles an undular bore. This event is unique in that the dissipation of the bore is observed for the first time within our imager's field of view before it crosses the zenith. To understand this observation, we complement our work with a two-dimensional direct numerical simulations (DNS) using a Boussinesq approximation. Our DNS results reproduce many important characteristics of the observed airglow event like the number of trailing waves, dissipation time of the bore among others, by implementing a thermal duct and a wave-like perturbation. By the time of the meeting, we plan to present results of using different initial perturbations as well as background wind and temperature profiles.

Overview Lecture: Layered Phenomena in the Mesopause Region (LPMR)

Cora E. Randall

University of Colorado, Boulder, CO, USA

This overview lecture will summarize the overall scientific ideas and scope of the Layered Phenomena in the Mesopause Region (LPMR) investigations. LPMR began in 1979 as an international working group of the International Association of Middle Atmospheric Science (IAMAS) within the International Union of Geodesy and Geophysics (IUGG). Scientific priorities have evolved over the years, but include polar mesospheric/noctilucent clouds (PMCs/NLCs), polar mesospheric summer echoes (PMSEs), long-term trends and solar cycle variations in mesopause structure and composition, meteoric metal layers and cosmic dust, gravity waves and turbulence, particle precipitation effects, and dynamical coupling between the lower and upper atmosphere and ionosphere. Focusing on both observations and modeling, the lecture will highlight some of the major advances and outstanding questions.

In-situ mesurements of heavy ions during PMWE conditions

Markus Rapp[1,2], Joan Stude[1], Heinfried Aufmhoff[1], Hans Schlager[1], Boris Strelnikov[3], Frank Arnold[4]

[1] DLR, Institute of Atmospheric Physics, Oberpfaffenhofen, Germany
[2] LMU, Ludwig-Maximilians-Universität München, Atmospheric Physics, Germany
[3] IAP, Leibniz Institute of Atmospheric Physics e.V., Kühlungsborn, Germany
[4] MPIK, Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany

Polar mesosphere winter echoes (PMWE) are strong VHF radar echoes from the winter mesosphere. Quantitative analysis of observed volume reflectivities and their frequency dependence reveals that the echoes can hardly be explained by pure turbulent backscatter. Rather, it has been hypothesized that charged aerosol particles, i.e., most likely meteoric smoke particles, are involved in creating a large Schmidt-number and hence (in combination with neutral air turbulence) leading to the existence of Bragg scale structures in the electron gas that prevail at smaller scales than in the neutrals (similar to the case of PMSE, polar mesosphere summer echoes, were charged ice particles are responsible for explain the large Schmidt-number scatter). In order to test this hypothesis, LMU Munich and DLR have jointly developed an ion mass spectrometer which is based on a former design of the Max-Planck-Institute for Nuclear Physics in Heidelberg and which has been successfully flown in the 1980ies (e.g., Schulte and Arnold, 1992). For the present purpose, the ion mass spectrometers were optimized for the detection of large ion clusters. Two sounding rockets equipped with this revived and optimized ion mass spectrometer were launched in the scope of two PMWE-sounding rocket campaigns led by IAP Kühlungsborn in April 2018 (c.f., Stude et al., 2021) and October 2021. Here we present the results from these two rocket flights for both positive and negative ions and discuss our findings with regard to meteor smoke properties and the generation mechanisms of PMWE.

Preliminary analysis of low altitude electron density measurements from EISCAT: a focus on data handling and occurrence

J. A. Reidy and A. J. Kavanagh

British Antarctic Survey, UK

The MesoS2D project aims to improve our ability to predict and forecast variability in the mesosphere/lower thermosphere-ionosphere region (MLTI). A key consideration is how the region responds to different drivers on timescales from hours to seasons (e.g., sudden stratospheric warmings and space weather). A big component of the project is using the archive of data produced by the (primarily) mainland EISCAT radars, which have been operating for over 30 years. Although a valuable data source, the synoptic nature of the observations and the mix of different experiment modes (pulse codes and pointing directions), requires careful handling prior to large scale statistical analysis. Here we present a preliminary analysis of the seasonal and annual variation of the low altitude (D and E region) electron density. Particular attention is paid to the occurrence of polar mesospheric summer echoes; methods for both cataloguing and removing these signatures from the electron density prior to full statistical analysis are considered.

Two-dimensional imaging of plasma density structures in auroral ionosphere

H. Sato[1], J. S. Kim[2] ,Y. Ogawa[3]

[1] DLR Institute for Solar-Terrestrial Physics, Neustrelitz, Germany
[2] DLR Microwaves and Radar Institute, Weßling, Germany
[3] National Institute of Polar Research, Japan

We present multi-instrumental observation of auroral ionosphere by using the EISCAT UHF radar, all sky imager, GNSS satellites and Synthetic Aperture Radar (SAR) satellite. Plasma irregularities generated by auroral precipitating particles are imaged by SAR phase data in high resolution (less than kilometer) in the two dimensional form over the area of several tens of kilometers. The observed localized density irregularities are aligned in east-west direction near the location of 558-nm optical emission. The results suggest that highly structured plasma density gradients exist primarily near the edge of the precipitation region. The level of density enhancement is approximately 5 TECU (Total Electron Content Unit) from a GNSS receiver collocated at the UHF radar. We show that L-band satellite data provides complemental observation for the current and future EISCAT/EISCAT3D facilities to study high-latitude ionosphere in multi-scale.

Rocket experiment support with the EISCAT UHF radar.

T. Sergienko[1], N. Ivchenko[2], A. Tjulin[3] and U. Brändström[1]

[1] Swedish Institute of Space Physics, Kiruna
[2] Department of Space and Plasma Physics, Royal Institute of Technology, Stockholm, Sweden
[3] EISCAT Scientific Association, Kiruna, Sweden

The SPIDER and SPIDER2 rocket experiments were conducted at Esrange in February 2016 and 2020. The scientific goals of the experiments were to investigate the various spatial and temporal scales of the auroral ionosphere using in situ multi-point measurements of the electric field and plasma properties. These experiments were supported by the ground-based observations including the multi-station optical system ALIS and ALIS4D and the EISCAT UHF radar. The EISCAT UHF radar operated with the Arc1 program with a temporal and spatial resolution of 0.44 s and 0.9 km, respectively. For the SPIDER experiment, a special antenna scanning mode was developed. The UHF radar antenna was scanned in a vertical plane passing through Esrange. The elevation angle during scanning varied in the range of 23.4–39° with a step of 0.4° in 0.4 s. Thus, the two-dimensional distribution of ionospheric parameters (electron density, electron and ion temperature, ion velocity) in the plane of the rocket trajectory was obtained every 16 s. This report presents the results of a comparison of the in situ, optical and radar measurements of the auroral ionosphere parameters. We also discuss using the EISCAT UHF radar to support the upcoming BROR (barium release optical and radio) rocket experiment planned for launch at Esrange in March 2023.

Investigation of medium-scale travelling ionospheric disturbances by dense GNSS-receivers' network and ionsonde

R.O. Sherstyukov

Sodankyla geophysical observatory

The paper deals with the characteristics of the mid-latitude MSTIDs with intensities of dN/N~10-30%, wavelenghts 100-300 km and periods 30-70 minutes. To analyze midlatitude medium-scale travelling ionospheric disturbances (MSTIDs), the sufficiently dense network of GNSS receivers (more than 150 ground-based stations) and ionosonde operating in 1 minute regime were used. Daytime MSTIDs in the form of their main signature (band structure) on high-resolution two-dimensional maps of the total electron content perturbation (TECp maps) are compared with ionosonde data with a high temporal resolution. For a pair of events, the collocated observation of MSTIDs structure in form of banded structure on TECp maps and evolution of F_2 layer traces on ionograms is shown.

New method to measure the vertical slope of MSTIDs phase front based on data of dense GNSS receivers' network was developed. That makes possible to improve statistics of MSTIDs typical characteristics such as periods, wavelengths, direction and velocity of MSTIDs' phase front with data of vertical phase front slopes. This study also focuses on mechanisms and sources of daytime and nighttime MSTIDs' generation such as internal gravity waves and Perkins instability.

Multi-instrument multi-scale characterization of ionospheric irregularities in the cusp region

Andres Spicher[1], Juha Vierinen[1], Kjellmar Oksavik[2], Yaqi Jin[3], Devin Huyghebaert[1], and Mahith Madhanakumar[1]

[1] Department of Physics and Technology, UIT the Arctic University of Norway, Tromsø, Norway
[2] Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Bergen, Norway
[3] Department of Physics, University of Oslo, Oslo, Norway.

The ionospheric cusps are highly dynamic regions where plasma turbulence and irregularities causing phase scintillations of Global Navigation Satellite Systems (GNSS) signals are frequently observed. The creation and development of ionospheric irregularities being not fully assessed, observations and analysis revealing the nature of the structuring at different scales are of significant interest both from a theoretical aspect and in the context of Space weather impacts.

In this work, we use the scanning capability of the European Incoherent Scatter Scientific Association (EISCAT) Svalbard Radars (ESR) to image spatio-temporal characteristics of ionospheric structuring in the cusp region. We present a few selected events for which we compute two-dimensional projections showing how electron density, ion velocity, electron temperature and ion temperatures evolve with latitude and time under different geomagnetic conditions. We combine the ESR observations with coinciding in-situ measurements and inspect the properties and scaling laws of ionospheric structures in regions with enhanced phase scintillations. Finally, we combine the measurements from the 32 m ESR dish with the ones taken simultaneously by the 42 m ESR and investigate the feasibility of also using such spatially separated measurements to characterize the nature and scaling of the plasma fluctuations, e.g., by computing the structure functions.

Reference: Spicher, A., Vierinen, J., Oksavik, K., and Jin, Y.: Statistical characteristics of ionospheric irregularities in the cusp ionosphere based on multi-instrument techniques, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-8293, https://doi.org/10.5194/egusphere-egu22-8293, 2022.

Assessing small scale dynamics using multi-static meteor radar observations and 3DVAR tomographic retrievals

Gunter Stober[1], Alexander Kozlovsky[2], Alan Liu[3], Zishun Qiao[3], Masaki Tsutsumi[4,5], Njal Gulbrandsen[6], Satonori Nozawa[7], Mark Lester[8], Evgenia Belova[9], Johan Kero[9], Patrick J. Espy[10,11], Robert E. Hibbins[10,11], and Nicholas Mitchell[12,13]

[1] Institute of Applied Physics & Oeschger Center for Climate Change Research, Microwave Physics, University of Bern, Bern, Switzerland
[2] Sodankylä Geophysical Observatory, University of Oulu, Finland
[3] Center for Space and Atmospheric Research and Department of Physical Sciences, Embry-Riddle Aeronautical University, Daytona Beach, Florida, USA
[4] National Institute of Polar Research, Tachikawa, Japan
[5] The Graduate University for Advanced Studies (SOKENDAI), Tokyo, Japan
[6] Tromsø Geophysical Observatory UiT - The Arctic University of Norway, Tromsø, Norway
[7] Division for Ionospheric and Magnetospheric Research Institute for Space-Earth Environment Research, Nagoya University, Japan
[8] University of Leicester, Leicester, UK
[9] Swedish Institute of Space Physics (IRF), Kiruna, Sweden
[10] Department of Physics, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[11] Birkeland Centre for Space Science, Bergen, Norway
[12] British Antarctic Survey, UK
[13] University of Bath, Bath, UK

The mesosphere/ lower thermosphere (MLT) is a highly variable atmospheric region, driven by atmospheric waves propagating from below and solar influences from above. Here we present preliminary results of a recently developed 3DVAR+DIV tomographic algorithm to obtain 3D winds within a predefined geographic domain at altitudes between 70-110 km leveraging observations from the multi-static Nordic Meteor Radar Cluster and the Chilean Observation Network De Meteor Radars (CONDOR).

The benefit of the new retrieval algorithm is the embedded diagnostic to derive the horizontal divergence and relative vorticity, which provides a physical and mathematical consistent solution for the vertical winds assuming either an incompressible flow or a non-stationary/compressible solution. Furthermore, we demonstrate the use of the data to derive horizontal wavelength spectra for all quantities, which appears to be useful to constrain the turbulence parameterizations for comprehensive general circulation models.

New results from rocket-borne measurements inside the polar mesosphere winter echoes

Boris Strelnikov[1], Tristan Staszak[1], Philipp Seither[1], Ralph Latteck[1], Toralf Renkwitz[1], Franz-Josef Lübken[1], Gerd Baumgarten[1], Jens Fiedler[1], Robin Wing[1], Irina Strelnikova[1], Martin Friedrich[2]

[1] Leibniz Institute of Atmospheric Physics, Optical Soundings and Sounding Rockets, Kühlungsborn, Germany
[2] Graz University of Technology (TUG), Graz, Austria

In October 2021, a sophisticated sounding rocket campaign devoted to investigating polar mesosphere winter echoes (PMWE) was successfully conducted at Andya Space (69°N, 16°E). Two instrumented sounding rockets were launched in a salvo with a three-minute delay, followed by the launch of two met-rockets with chaff for wind measurements. Both sounding rockets went through the wide PMWE layer observed by the Middle Atmosphere ALOMAR Radar System (MAARSY) on both up- and down-leg. IAP's RMR at ALOMAR lidar was continuously measuring wind and temperature fields throughout the day of the rocket launches. We will discuss initial results of the rocket-borne measurements of neutral and ionospheric plasma density fields.

Characteristics of auroral electron precipitation at geomagnetic latitude 67 over Tromsø

H. W. Tesfaw, I. I. Virtanen, and A. T. Aikio

University of Oulu, Oulu, Finland

Auroral electron precipitation is one of the major energy input mechanisms for the high latitude upper atmosphere. The precipitation can be characterized by peak energy, auroral power (total energy flux), and number flux of the precipitating electrons. In this statistical study we investigate characteristics of auroral electron precipitation and their dependence on magnetic local time (MLT) and the 1-h version of the geomagnetic Kp index called Hp index (Matzka et al., 2019).

We derive the auroral power, peak energy, and number flux from EISCAT Tromsø UHF radar data measured over the last 21 years. We use the ELSPEC software (Virtanen et al,, 2018) to invert energy spectra of 1 – 100 keV auroral electrons from field-aligned electron density profiles measured with 1 min time resolution. ELSPEC solves the differential number flux by means of integrating the electron continuity equation, using empirical formulas for ion production and effective recombination rates. Differential energy flux is calculated from the differential number flux, and peak energy is defined as the energy with highest differential energy flux. Total number flux and auroral power are obtained by integrating the differential number and energy fluxes, correspondingly. We estimate location of the auroral oval using the Feldstein-Starkov model parameterized by the Kp index (Starkov, 1994).

We find that peak energies from 1 to 10 keV dominate at all MLT sectors.

Peak energies larger than 50 keV are concentrated in the post-midnight and morning sectors of the auroral oval. On the other hand, large auroral powers (greater than 50 mW m^{-2}) are observed in the evening and midnight MLT sectors, and a correlation between total number flux and auroral power is observed. Our results also show that auroral power increases with increasing geomagnetic activity, in general.

Matzka, Jürgen; Stolle, Claudia; Kervalishvili, Guram; Rauberg, Jan; Yamazaki, Yosuke (2019): The Hp geomagnetic index test dataset 2003, 2004, 2005 and 2017. GFZ Data Services. https://doi.org/10.5880/GFZ.2.3.2019.002

Starkov, G.V., Mathematical model of the auroral boundaries, Geomag. Aeron., 34 (3), 331–336, 1994a

Virtanen, I. I., Gustavsson, B., Aikio, A., Kero, A., Asamura, K., Ogawa, Y. (2018). Electron Energy Spectrum and Auroral Power Estimation From Incoherent Scatter Radar Measurements}. Journal of Geophysical Research: Space Physics, 123(8), 6865–6887. https://doi.org/10.1029/2018JA025636

Noctilucent Cloud Enhancements from Volcanic Eruptions: A test of the Krakatoa Hypothesis from the Hunga Tonga-Hunga Ha'apai Volcano

Gary E. Thomas[1] and Matt DeLand[2]

[1] Laboratory for Atmospheric Physics,vUniversity of Colorado at Boulder, USA
[2] Science Systems and Applications Inc., Lanham, Maryland, USA

The Krakatoa Hypothesis (Thomas et al, 1989) holds responsible the great Krakatoa Volcanic eruption in 1883 for the abrupt onset of noctilucent cloud (hereafter NLC) sightings in the U.K, northeastern Europe and Russia in the summer of 1885 (Gadsden and Schröder, 1980). NLC sightings before that time were almost non-existent, despite the attention of numerous sky observers in the preceding decades, and certainly did not compare to the very bright displays witnessed by many observers during the period 1885-1895. After this period, NLC reports diminished and sightings were sparse until the 1930's when renewed interest occurred in the Soviet Union, Sweden and Scotland.

This work deals with the possibility that the dramatic atmospheric effects resulting from the recent Jan 15, 2022 eruption of the Hunga Tonga-Hunga Ha'opai marine volcano could lead to NLC enhancements and serve as a 'model' for the Krakatoa eruption. Enhanced NLC may occur in the next few years due to transport of the volcanically-injected water vapor to the polar summer mesosphere (near 83 km). In this report, we address two issues: (1) What are the fingerprints of an impulsive increase of water vapor on NLC? and (2) if such an enhancement can be identified, what are the implications for the Krakatoa Hypothesis?

From the Ground up: Observatory Operations Supporting EISCAT_3D

Th. Ulich, T. Raita, A. Kozlovsky, A. Kero, E. Tanskanen

Sodankylä Geophysical Observatory, Sodankylä, Finland

EISCAT_3D will be the most advanced radar of its kind. It will provide us with an unprecedented view of the ionosphere in the European Arctic. Since long before EISCAT, observatories have provided multiple other views of the near-Earth space environment. Any one instrument demonstrates its full potential when used in combination with others.

SGO has continuously developed its instruments and data products, also with the future needs of EISCAT_3D in mind. Here we discuss the latest developments of observatory operations.

Observing mesospheric neutral wind with Electrojet Zeeman Imaging Explorer (EZIE)

H. Vanhamäki[1], R. de Mesquita[2], A. Maute[3], P. Espy[4], J.-H. Yee[2], J. Gjerloev[2,5], K. Laundal[5], W. Wang[3], and the EZIE team

[1] University of Oulu, Oulu, Finland
[2] Johns Hopkins University Applied Physics Laboratory, Laurel, USA
[3] High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA
[4] Norwegian University of Science and Technology, Trondheim, Norway
[5] University of Bergen, Bergen, Norway

The Electrojet Zeeman Imaging Explorer (EZIE) mission will study the auroral electrojets using remote sensing of the magnetic perturbations they create. EZIE was selected as a NASA Heliophysics mission in December 2020, and is currently under development at the Johns Hopkins Applied Physics Laboratory for a launch in late 2024. The mission consists of 3 identical 6U CubeSats, each carrying 4 compact spectropolarimeters looking downward at nadir and three cross-track directions. These instruments will measure the Zeeman splitting of molecular oxygen thermal emissions around 118 GHz. Remote sensing utilizing the Zeeman effect gives information about the magnetic field at the location where the emissions originate, which in this case is about 80-85 km altitude near the mesopause. In addition to the magnetic field, also highly precise line-of-sight neutral wind and temperature measurements can be retrieved.

This presentation will give an overview of the EZIE mission and details about the anticipated wind retrieval, such as expected precision, flexible observing geometry, and location. To gain further insights into the ability to capture the local wind system we use high-resolution Whole Atmosphere Community Climate Model eXtended (WACCM-X) runs to develop Observing System Simulation Experiments (OSSE). We will show examples of the OSSE used in the wind fitting based on the Spherical elementary current system (SECS) method to demonstrate the EZIE mission capabilities.

US Community Efforts for Future ISR Science

R. H. Varney[1], D. L. Hysell[2], P. J. Erickson[3], and A. Coster[3]

[1] University of California, Los Angeles, Los Angeles, CA USA
[2] Cornell University, Ithaca, NY USA
[3] MIT Haystack Observatory, Westford, MA USA

In preparation for the next Decadal Survey in Solar and Space Physics, the United States geospace community is preparing white papers on new research concepts. These include community efforts to define the future directions for incoherent scatter radar research. In particular, two significant workshops were recently held to brainstorm new ideas. The "Strategic Vision for Incoherent Scatter Radar" workshop was held April 26-28, 2021, and afterwards a report was written summarizing the discussion. That report identified 10 science areas where new facilities could make significant impacts: Cross-scale coupling, data assimilation, space weather, neutral/plasma coupling, mesospheric and lower thermospheric instabilities and mesoscale dynamics, meteor science, energetics dynamics and transport, planetary radar, plasmaspheric radar, and solar echoes. Additionally, the report highlighted cross-cutting themes and workshop findings. The report highlighted the importance of leveraging emerging technologies in facility design and leveraging knowledge from adjacent science communities, particularly the radio astronomy community that has significantly advanced low frequency array technology. The report also emphasized the importance of training the next generation of scientists and engineers to take over ISR research. More recently, another workshop was held at the NASA Wallops Flight Facility (WFF) May 23-25, 2022, to specifically discuss the science motivation for constructing an ISR at WFF. Such a system could complement the numerous sounding rocket missions dedicated to geospace science launched from WFF each year. Additionally, such a facility could address a variety of mid-latitude ionospheric science questions and fill some of the gaps in mid-latitude science left by the loss of the Arecibo Observatory.

Solar cycle effect in water vapor and PMC as seen by satellites and model. What are the mechanism pathways?

A. Vellalassery, F-J. Lübken, G. Baumgarten, and Mykhaylo Grygalashvyly

Leibniz Institute of Atmospheric Physics at the University of Rostock (IAP)

The 11-year solar cycle significantly influences temperature and water vapor in the upper atmosphere. Understanding the underlying mechanisms in detail is important because water vapor and temperature are key components of the mesosphere that influence chemistry and dynamics. Noctilucent clouds (NLCs) have been proposed as the main indicator of solar cycle effects because they are very sensitive to temperature and water vapor concentration. NLCs are located at about 83 km altitude, consist of water ice particles, and owe their existence to the very cold summer mesopause region (~130 K) at mid and high latitudes.

We use our NLC ice particle model, MIMAS, to study the solar cycle response to NLC and H_2O in the altitude range of 78 to 94 km. The model shows good agreement with satellite-observed H_2O and NLC variations in the solar cycle. We have performed model simulations with and without NLC formation and used different background conditions to investigate the role of different factors causing the observed variations.

We find an H_2O-Lyman alpha anticorrelation in the ice particle sublimation heights and a positive correlation in the ice formation zone. We have also investigated the lower response of H_2O to the solar cycle in recent years, which has been discussed in several studies based on satellite observations. We present an explanation linked to atmospheric contraction due to climate change.

Long-term studies of the D-region ionosphere using the Whole Atmosphere Community Climate Model

P. T. Verronen[1,2], M. E. Szelag[2], A. Kero[1], and N. Thomas[1]

[1] Sodankylä Geophysical Observatory, University of Oulu, Sodankylä, Finland
[2] Space and Earth Observation Centre, Finnish Meteorological Institute, Helsinki, Finland

The Whole Atmosphere Community Climate Model (WACCM) is a chemistry-coupled general circulation model covering the height range from the surface up to the lower thermosphere. It is one of the most extensive chemistry-climate models and is designed for investigating the couplings between atmospheric regions and how they are driven by external perturbations such as solar forcing. A recently developed variant, WACCM-D, incorporates a scheme of D-region ionospheric chemistry including positive and negative cluster ions. Thus WACCM-D allows for long-term simulations of ion composition and ion-neutral interaction in the middle atmosphere. Here we present WACCM-D and demonstrate its usability in mesosphere/D-region studies particularly during polar particle precipitation events. We also analyse changes in D-region ion composition over the time period 2002–-2012 and discuss the reasons for seasonal and yearly variability. Finally, we outline possibilities of WACCM-D in interpreting ground-based ionospheric observations including those from EISCAT.

Ionospheric perturbations caused by the Tonga January 2022 volcanic eruption

Juha Vierinen[1], Shun-Rong Zhang[2], Ercha Aa[2], Larisa P. Goncharenko[2], Philip J. Erickson[2], William Rideout[2], Anthea J. Coster[2] and Andres Spicher[1]

[1] The Norwegian Arctic University in Tromsø
[2] MIT Haystack Observatory

The powerful volcanic eruption on January 15th 2022 in Tonga produced an atmospheric shock wave that caused perturbations in the ionosphere around the world. This study reports observations of the thermospheric and ionospheric signatures of the eruption using a global network of approximately 5000 navigation satellite receivers that measure line of sight integrated electron density (TEC). These measurements were high-pass filtered to allow study of the fluctuating component of the ionospheric electron density, which is affected by thermospheric neutral density and winds. The measurements show long lasting ionospheric perturbations all around the world that propagate radially outward from Tonga. The traveling ionospheric disturbances (TIDs) produced by the eruption were observed propagating around the world at least three times, with a clearly discernible signature passing six times over North America. The estimated travel time around the world for the wave is approximately 36 hours. The initial wave traveled at a velocity of up to 1000 m/s, but at longer distances with a velocity of 300-320 m/s. During the first passage of the pressure wave through the Pacific and North American sectors, the initial shock wave was followed by 12 hours of increased ionospheric perturbations. The global propagation of the ionospheric disturbance is in agreement with a lower atmospheric Lamb wave that causes perturbation in the thermosphere. Further details can be found in the recently published paper [1].

[1] Zhang S-R, Vierinen J, Aa E, Goncharenko LP, Erickson PJ, Rideout W, Coster AJ and Spicher A (2022) 2022 Tonga Volcanic Eruption Induced Global Propagation of Ionospheric Disturbances via Lamb Waves. Front.Astron. Space Sci. 9:871275. doi: 10.3389/fspas.2022.871275

F_1 region ion composition fits and auroral electron precipitation energy spectra fits with ion chemistry modeling

Ilkka I. Virtanen[1], Habtamu Tesfaw[1], Roger Varney[2], Ashton Reimer[2], and Anita T. Aikio[1]

[1] Space Physics and Astronomy research unit, University of Oulu, Finland
[2] Center for Geospace Studies, SRI International, Menlo Park, CA, USA

We present the first results of EISCAT field-aligned E and F region data analysis using the Bayesian Filtering Module (BAFIM) (Virtanen et al., 2021) for plasma parameter fits and the Electron Spectrum (ELSPEC) software (Virtanen et al., 2018) for energy spectra fits, both coupled with the Ion Density Calculator (IDC) model (Richards et al., 2010). IDC calculates concentrations of the major ion species using electron density, electron temperature, and ion temperature as inputs. Parameters of the neutral atmosphere are calculated with the MSIS model.

IDC is implemented in BAFIM as a prior model with a user-defined confidence level, which allows the model information to be added without loosing the F_1 region O^+ ion concentration information available from the radar measurement and other priors. Concentrations of the molecular NO^+ and O_2^+ ions, which are needed in the electron energy spectra fits, are taken directly from the IDC model. Both the BAFIM analysis and the subsequent electron energy spectra fits with ELSPEC proceed with a few second time steps.

The results show that the combination of BAFIM and IDC can respond to rapid variations in O^+ concentration that were out of reach of the original BAFIM implementation. The $O2^+/NO^+$ ratios predicted by IDC are larger than those predicted by the International Reference Ionosphere (IRI) during intense electron precipitation. Since dissociative recombination of O_2^+ is slower than that of NO^+, ELSPEC fit results calculated with the IDC compositions show different energy spectrum shapes and smaller auroral powers than those calculated with the IRI compositions that were previously used in ELSPEC. We have implemented the analysis system in a super computer to enable large-scale data analysis.

Virtanen, I. I., H. W. Tesfaw, et al., (2021), Bayesian filtering in incoherent scatter plasma parameter fits, J. Geophys. Res. Space Physics, 126, e2020JA028700. https://doi.org/10.1029/2020JA028700

Virtanen, I. I., B. Gustavsson, et al., (2018), Electron energy spectrum and auroral power estimation from incoherent scatter radar measurements, J. Geophys. Res. Space Physics, 123, 6865– 6887. https://doi.org/10.1029/2018JA025636

Richards, P. G., D. Bilitza, and D. Voglozin (2010), Ion density calculator (IDC): A new efficient model of ionospheric densities, Radio Sci., 45, RS5007. https://doi.org/10.1029/2009RS004332

Ionospheric conductances due to electron and ion precipitations: A comparison between EISCAT and DMSP estimates

Xin Wang[1,2,3,4], Lei Cai[2], Anita Aikio[2], Ilkka Virtanen[2], Siqing Liu[1,3,4], and Juan Miao[1,3,4]

[1] National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China
[2] University of Oulu, Space Physics and Astronomy, Oulu, Finland
[3] University of Chinese Academy of Sciences, Beijing 100049, China
[4] Key Laboratory of Science and Technology on Environmental Space Situation Awareness, CAS, Beijing 100190, China

Energetic particle precipitation plays an important role in the distribution of Pedersen and Hall conductances in high-laittude ionosphere. Typically, the ionospheric conductances are estimated using either theoretical or empirical equations. The former method requires the measurements of several ionospheric parameters. The empirical equations are simple, such as Robinson formulas that have been widely used since 1980s. Recent studies have suggested several shortcomings in using of the Robinson formulas. A validation of the Robinson formulas is needed timely.

In this study, we will validate the Robinson formulas in different auroral precipitation conditions by the EISCAT incoherent scatter radars and DMSP satellites. The validation is carried out by first searching the conjugate DMSP satellites overpasses in the vicinity of EISCAT mainland or Svalbard sites. In the calculation of Pedersen and Hall conductances, the Robinson fomulas are applied with the DMSP/SSJ energetic particel measurements, and the theoretical equations with the EISCAT measurements. We compare the two kinds of conductances in four conditions, which are dominated by mono-energetic electrons, central plasma sheet (CPS) electrons without energetic ions, CPS electrons with energetic ions, and pure energetic ions, respectively. The results show that the conductances by the Robinson formulas are correlated best with the EISCAT results when CPS electrons without energetic ions are dominated. When the ion precipitation exists, the two kinds of conductances are less correlated. The ion precipitation adds an additional effect on the ionospheric conductances. About 2-7 mhos of the Pedersen conductances and 3-8 mhos of the Hall conductances can be contributed by ion precipitations. Hence, the ionospheric conductances can be underestimated if only the Robinson Formulas are used.

High resolution observations of neutral heating by auroral electrodynamics

D. K. Whiter and D. J. Price

University of Southampton, UK

The aurora can have strong electric fields and currents associated with it, which deposit a significant amount of energy in the neutral upper atmosphere through heating. Such heating must be included in global atmospheric models used to study and forecast thermospheric dynamics and chemistry, coupling between the atmospheric layers, and drag on spacecraft and space debris in low Earth orbit. However, estimates of the heating rate are typically made using measurements which are coarse in comparison to auroral arcs. Neglecting small scale spatial and temporal structure likely leads to an underestimate of the heating rate. The University of Southampton operates a high-resolution spectrograph (High-Throughput Imaging Echelle Spectrograph, HiTIES) and multi-spectral narrow field-of-view imager (Auroral Structure and Kinetics, ASK) on Svalbard. We have developed a novel technique utilising simultaneous observations from HiTIES, ASK, and the EISCAT Svalbard Radar to estimate the neutral temperature altitude profile between approximately 80 km and 200 km at high cadence down to 0.5 s Applying the technique to observations of an auroral event has revealed very steep horizontal gradients in neutral temperature immediately adjacent to an auroral arc, which we attribute to Joule heating associated with a strong but localised electric field. In addition, we have identified localised heating inside an arc associated with strong field-aligned currents embedded within auroral curls. In parallel to the development of the new technique described above, we have installed a combination of optical filters on the ASK cameras which allow imaging of the neutral temperature at E-region altitudes at a spatial resolution of a few 10 s of metres and cadence of 32 Hz. Preliminary interpretation of such observations will be presented.

Comparison of sporadic E from COSMIC-2 radio occultation and vertical wind shears from ICON/MIGHTI

Y. Yamazaki[1], C. Arras[2], S. Andoh[3], Y. Miyoshi[4], H. Shinagawa[5], B. J. Harding[6], C. R. Englert[7], T. J. Immel[6], S. Sobhkhiz-Miandehi[2], and C. Stolle[1]

[1] Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany
[2] GFZ, Potsdam, Germany
[3] Kyoto University, Kyoto, Japan
[4] Kyushu University, Fukuoka, Japan
[5] NICT, Tokyo, Japan
[6] University of California, Berkeley, Berkeley
[7] U.S. Naval Research Laboratory, Washington, DC, USA

The formation of a sporadic-E (Es) layer at mid and low latitudes is generally attributed to the vertical wind shear, which is predicted to cause vertical ion convergence. According to wind shear theory, a negative shear of the eastward wind is effective in converging metallic ions into a thin layer to produce Es. However, the direct comparison of Es with the local wind shear has been limited due to the lack of neutral wind measurements. This study examines the role of the vertical wind shear for Es, using signal-to-noise ratio profiles from COSMIC-2 radio occultation measurements and concurrent measurements of neutral wind profiles from NASA's satellite mission Ionospheric Connection Explorer (ICON). We find that the Es occurrence rate is correlated with the negative vertical shear of the eastward wind, providing observational support for the wind shear theory.

Modeling the High-latitude Ionosphere Using Local-scale Simulations Driven with Incoherent Scatter Radar Data

M. D. Zettergren[1], L. Lamarche[2], and K. Lynch[3]

[1] Embry-Riddle Aeronautical Univ.
[2] SRI International
[3] Dartmouth College

This study focuses on methods to improve our understanding of two physical phenomena, mesoscale auroral arcs and polar cap patches, using phased-array incoherent scatter radar (ISR) data that are directly fed into a local-scale physics-based ionospheric model. ISRs are routinely used for studying a wide range of phenomena in the auroral and polar ionospheres and have proven useful for studies of auroras and patches though it is often challenging to infer and attribute dynamics from these data alone. Local models can begin to address how the high-latitude ionosphere responds at small scales (~1 km) to energy inputs, but a key limitation is the ad hoc nature in which initial and boundary conditions must often be imposed. Parameters like electric fields, initial density states, and particle precipitation have immense effects on important dynamics like current closure in auroras and instability progression in patches yet are poorly (or not) constrained in existing simulation studies. In an attempt to address some of these issues, we discuss recent studies using the GEMINI high-resolution model (https://github.com/gemini3d/) with realistic specification of initial and boundary conditions using data from phased array ISRs.

Two simulation case studies are highlighted. The first examines a polar cap patch observed via an imaging experiment conducted with the Resolute Bay ISR (RISR). Patches frequently exhibit unstable cascade into smaller-scale irregularities which is though to be caused by various candidate plasma instabilities, in this event evidenced by scintillation in radio beacon data and GNSS data. We construct a simulation to study stability of this patch using RISR density and flow data as input; candidate instabilities like gradient-drift and Kelvin-Helmholtz are highly sensitive variations in these parameters. The second case study uses structured flow observations from a specialized multi-beam Poker Flat ISR (PFISR) mode and filtered all sky camera data from an auroral substorm occurring over Alaska to study ionization patterns, plasma transport, and current closure in realistic conditions. Collectively these studies illustrate the degree of complexity that arises from space and time-dependent forcing as well as the sensitivity of model results to correctly accounting for these complications. Lastly, we discuss tools for generating synthetic ISR data from GEMINI, such as may be used to plan experiments with existing ISR systems or for defining requirements for next-generation systems.