List of Abstracts for Oral Presentations

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Anita Aikio *University of Oulu, Finland*

Effects of geomagnetic storms on the ionosphere

Geomagnetic storms can be caused by different solar drivers including interplanetary coronal mass ejections (ICMEs) and solar wind high-speed streams (HSSs) with associated stream interaction regions (SIRs). Significant changes to the ionosphere-thermosphere system can be caused even by moderate storms with the Dst index ranging between -100 and -50 nT. In this talk, I review some of the findings related to storms carried out in our research group by using observations from the EISCAT and Millstone Hill incoherent scatter radars, global total electron content (TEC) measurements by GNSS satellites, magnetometers, optical instruments, and solar wind data. During a storm, a typical feature at high latitudes is a decrease in F-region densities and in TEC, also known as storm negative phase. At mid-latitudes, a positive storm phase with an increase in TEC and in peak F density may be observed, as well as traveling ionospheric disturbances (TIDs). Storms are also associated with strong horizontal electrojets and field-aligned currents. Changes in the current systems produce on the ground rapid geomagnetic variations (dH/dt), possibly driving geomagnetically induced currents (GICs) to power grids, pipelines, etc. Observations of storm effects and processes behind the observations are discussed. The presentation underlines the need to carry out multi-instrument studies to understand magnetosphere-ionosphere-thermosphere (M-I-T) coupling during geomagnetic storms.

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Paul Bernhardt *Geophysical Institute University of Alaska*

High Power HF Experiments to Improve the Longevity of Satellites in Low Earth Orbit

The number of satellites launched into low Earth orbit (LEO) is increasing at an exponential rate. Launches support deployment of multi-satellite constellations for many applications. High power HF experiments with HAARP in Alaska have been conducted to (a) better locate the positions of satellites and space debris for prevention of collisions and (b) reduce the fluxes of energetic particles that destroy satellite electronics.

Currently, there are about 27,000 known space objects and over 100 million of unknown pieces of space debris. Collision avoidance requires precise knowledge of the positions for all space objects. New techniques are being developed to detect the small, < 10 cm, objects by the plasma waves they generate in space. The bases for this technique is that all space objects in orbit around the Earth (1) pass through a magnetized plasma, (2) become electrically charged, and thus (3) produce detectable plasma waves. The University of Alaska (UAF) High-frequency Active Auroral Research Program (HAARP) is employing high power HF waves to generate field aligned irregularities in the path of orbiting space objects. The location of field aligned irregularities (FAIs) is monitored by the SuperDARN radar at Kodiak island in Alaska. Space debris and satellites moving through these irregularities and can excite plasma emissions such as whistler, compressional Alfven, or lower hybrid waves. Orbital kinetic energy is the source of lower hybrid waves which is converted into an electromagnetic plasma oscillation when a charged space object encounters a field aligned irregularity (FAI). Such whistlers propagate undamped at around 9000 km/s from the source regions and can be detected at ranges of several earth-radii.

Satellites also have to avoid collisions with energetic particles that can damage solar panels and electronic components. Whistler and electromagnetic ion cyclotron (EMIC) can scatter trapped radiation into the atmospheric loss cone and, thus, reduce energetic particle fluxes. New techniques have been developed to excite and to amplify these waves in the ionosphere using simultaneous HF transmissions two separate radio beams. The first HF beam generates VLF and whistler waves by modulation of the electrojet currents with X-Mode transmissions. These whistlers normally propagate through the F-layer to be captured by field aligned ducts and guided to the radiation belts. The amplitude of the whistlers from electrojet modulation is typically 5 pT or less. The second beam of the HF facility uses a vertical O-Mode beam to excite lower hybrid (LH) waves in the F-region. These LH waves provide a pump for a whistler traveling wave parametric amplifier (WTWPA) that intensifies the VLF signals. Satellite measurements of the VLF wave amplitudes in the ionosphere in have reached values between 200 pt and 10 nT. HAARP HF can be modulated with both continuous wave or linear frequency ramps to generate VLF whistlers. Simulations have shown the HF amplified whistlers can reduce trapped electron fluxes at a rate 5000 times those from unamplified whistlers. All of these experiments with space debris detection and radiation belt remediation can conducted by both EISCAT Heating in Tromso, Norway or HAARP in Alaska, USA.

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Lindis Merete Bjoland *National Institute of Polar Research*

Characteristics of the ambipolar electric field for a selection of ion upflow events measured by ESR

A significant amount of magnetospheric plasma originates from the ionosphere and has been transported to the magnetosphere through the ion outflow process. Cold ions in the magnetosphere predominantly stem from the polar cap ionosphere, where an ambipolar electric field, driven by pressure gradients, initiates the upward flow of ions.
In this study, the EISCAT Svalbard radar database for 27 years (1996-2023) was used to investigate the characteristics of the ambipolar electric field. A selection of ion upflow events has been made using the long-term dataset of ESR data. The ambipolar electric field is calculated for each event, and we examine the relationship between the ambipolar electric field and various factors such as solar activity, geomagnetic activity, diurnal and seasonal variations. A comparison between the selected events will be presented and discussed.

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Nicholas Brindley *University of Southampton*

A statistical survey of selected fine-scale aurora types, and consistency with a non-linear dispersive Alfvén wave acceleration mechanism

Relatively little is known about the causes of fine-scale aurora with scale sizes of ~1 km and less. We analyse images from the Auroral Structure and Kinetics (ASK) instrument, a multi-monochromatic spectral imager located on Svalbard, Norway. We analyse five categories of fine-scale aurora, based on those in the citizen science project Aurora Zoo. Of these, the particularly dynamic types are 'chocolate sauce' and 'psychedelic' aurora. Psychedelic has not – to the best of our knowledge – yet been presented in the literature as a distinct category. Psychedelic appears as rapid variations in brightness flowing through and along other auroral structures. 'Chocolate sauce' appears turbulent but has relatively constant brightness. The analysis comprises: MLT dependence, characteristic precipitation energies, occurrence relative to the auroral oval, and adapted local intermittency measure (LIM) analysis of radially averaged image 2D power spectra. LIM analysis allows us to estimate the widths of the smallest structures typically associated with each aurora type. We find that 'chocolate sauce' and 'psychedelic' aurora are associated with nightside processes. This is based on their tendency to be higher energy, to occur at late dusk/midnight MLTs, and to occur on the poleward boundary of the auroral oval. For the four non-psychedelic aurora types, we find the smallest widths (~330–500 m) and distribution of energies (typically less than 10 keV) to be consistent with a dispersive non-linear inertial Alfvén wave acceleration mechanism (described elsewhere in the literature). For psychedelic aurora, the smallest widths (~200 m) and high energies (median 10.9 keV) make it unlikely that it is produced by the aforementioned mechanism, which predicts arc widths of ~0.3–4.6 km and energies less than ~10 keV.

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Impacts of spatiotemporal variability of ionospheric upflow driven by poleward moving auroral forms observed during the Rocket Experiment for Neutral Upwelling 2 (RENU2) sounding rocket campaign

Poleward moving auroral forms (PMAFs) are quasiperiodic sequences of poleward propagating auroral features, likely associated with pulsed reconnection at the magnetopause. Each PMAF can be comprised of smaller subarc structures, with spatial extents down to 100m, that may play a role in variable responses. Cusp PMAFs are likely to have a direct impact on ionospheric plasma escape because of the highly transient nature of the associated soft particle precipitation. Direct entry of $\sim$100 to 500 eV electrons results in energy deposition at altitudes around 200 to 300 km where ambient electron temperatures can remain elevated, due to minimal collisional loss to the rarefied neutral atmosphere, and large field-aligned flows can be initiated. PMAF sequences typically have repetition rate between 2 and 15 min and each successive PMAF deposits energy into the local ionosphere which has been altered to a varying degree by the previous PMAF. This results in a cumulative and complex upflow effect. These upflows may be further energized by broadband extremely low frequency (BBELF) waves, also common in the cusp.

The Rocket Experiment for Neutral Upwelling 2 (RENU2) sounding rocket was launched from the Andoya Rocket Range on December 13th, 2015. The EISCAT Svalbard Radar data has transients in electron temperature consistent with PMAF activity and all-sky imager data from the campaign shows dynamic PMAF activity. The RENU2 rocket was launched at 0734 UT into the 4th of a series of PMAFs.

In this study we demonstrate a data-representative (as opposed to data-driven) modeling approach to incorporate brightness from all-sky imagers as a constraint for auroral ionospheric model inputs. This method allows for realistic ionospheric forcing that is not captured with traditional “on-off” descriptions of PMAFs. This study uses the ionospheric model GEMINI-TIA with inputs derived from in-situ and ground-based RENU2 sounding rocket campaign data. Simulation results show agreement between the electron temperatures measured in-situ by the rocket and the modeled electron temperatures along the rocket trajectory during PMAF #4 when the rocket was in flight, indicating that this data-representative method works well for the local-scale features. The variable dwell time of the PMAFs in any given latitudinal region significantly impacts the ion flux generated there and not all PMAFs had the same latitudinal extent. In contrast, another simulation was run with constant dwell time and it generated almost double the O+ upflow transport through 1,000 km when compared to the variable dwell time PMAF simulation. Using the full PMAF sequence generates significant spatiotemporal variation of field-aligned ion velocities and fluxes within the model. At high altitudes, model results show a spread in upflow response time dependent on ion mass. While the soft electron precipitation is itself insufficient here to accelerate ions to escape velocities, source populations available for higher-altitude energization processes, such as BBELF waves, are greatly increased.

Meghan Burleigh (US Naval Research Laboratory)

Lei Cai *Space Physics and Astronomy, University of Oulu, Finland*

Multiscale temporal variabilities of the upper thermospheric wind at high latitudes

The neutral wind plays a key role in the dynamics and electrodynamics in the coupled ionosphere-thermosphere system. Recent studies have revealed that the thermospheric wind is not a passive, slowly changing medium, in contrast to the conventional perspective. This study assesses the upper thermospheric wind variability and its drivers in different time scales, using the measurements by an FPI (630 nm) collocated with the EISCAT incoherent scatter radars at Tromso, Norway. Events with simultaneous CP2 experiments are priorly analyzed. The CP2 experiments are used to estimate the convection electric field and calculate the ion drag rate and Joule heating. The 2-D field-aligned currents (FACs) derived from the AMPERE project and equivalent currents from the ground-based IMAGE network are used to indicate the horizontal distribution of ionospheric convection and Joule heating. For the upper thermospheric wind, we apply a low band-pass filter to the horizontal wind components with different sliding time windows, including 20, 40, and 60 min, and calculate the corresponding wind acceleration rates. On the temporal scale of 60~min, the wind is primarily driven by ionospheric convection, because the magnitude of the wind is well correlated with the large-scale ionospheric plasma convection. However, the wind acceleration rates sometimes mismatch with the ion drag rates. The associated FAC distributions indicate that the Joule heating-induced pressure gradient plays a secondary role in modulating the wind variations during active geomagnetic activity conditions. On a shorter temporal scale, we study two types of wind accelerations: (1) pulse-like wind acceleration during a few to tens of minutes, and (2) periodic wind oscillations. The formal is attributed to the local auroral electrodynamics and magnetospheric energy input. The latter is associated with the propagation of atmospheric gravity waves (AGWs). Sometimes, waves with strong amplitude are revealed in UHF radar measurements, so we can characterize the altitude distribution of AGWs using both the FPI and the EISCAT radar.

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Lasse Clausen *University of Oslo*

The Polar Geospace Observatory – a new facility on Svalbard?

The current EISCAT Svalbard Radar (ESR) has provided the scientific community with unprecedented observations of the cusp and polar cap regions since 1994 and has been instrumental in expanding our understanding of the coupling between the IMF and geomagnetic field. The radar relies on a system of 16 klystrons to generate the beam; technology that is no longer manufactured. The ESR has all remaining klystrons in existence, in storage, at the site. The aging, un-replaceable technology puts a finite lifetime on the system taking it (optimistically) into the early 2030s. Here we present an overview of a recently submitted proposal to the EU Horizon program for a 3-year design study for the next generation observatory on Svalbard – The Polar Geospace Observatory (PGO). We envisage this being a state-of-the-art system, serving a far wider community than the current ESR, powered by renewable energy sources. The project has representatives from the ionospheric, atmospheric, radio astronomy, solar and renewable energy research communities. We welcome suggestions and input for the facility from the community here at the symposium.

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Mark Conde *University of Alaska Fairbanks*

New Instrumentation for ground-based tristatic observations of Earth's thermosphere and ionosphere in support of EISCAT-3D

The universities of Alaska, Michigan, and Nagoya are working together with colleagues in Finland & Sweden to establish a tristatic network of ground-based instruments that will observe and characterize Earth's ionosphere and thermosphere within the field of view of the new EISCAT-3D radar system. During period from 2021-2023, we worked with our industry partners, Battelle Memorial Institute and Summit Logistics, to construct three portable aeronomy labs based on modified ISO-668 1C 20-foot shipping containers. Each lab is fitted with five transparent domes on the roof, to accommodate sky-viewing optical instruments. The labs were deployed and commissioned in early 2024, to sites at Kevo and Aakenus in Finland, and Abisko in Sweden. Each lab will house two Fabry-Perot spectrometers (one all-sky, one narrow-field zenith-looking), a KeoSentry filtered all-sky camera, a Septrino GNSS receiver, and a three-component fluxgate magnetometer. Deployment and commissioning of the instruments themselves began in April of 2024, and by September we anticipate that all five instruments will be fully operational in each of the three labs. This will leave two unoccupied domes and some spare lab space available to accommodate future "guest" instruments. The scientific objective is to characterize auroral and magnetospheric forcing of Earth's high-latitude thermosphere and ionosphere, and to measure the resulting neutral and ionsospheric responses - with a particular emphasis on thermospheric neutral wind & temperature fields. All observational data will be openly published on the internet with the lowest practically achievable latency. In this talk I will present the latest status of this facility, and preview how the resulting observations may be accessed and used to support synergistic studies with EISCAT-3D.

Mark Conde, Don Hampton, Kylee Branning (University of Alaska Fairbanks),
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Juan Miguel Urco Cordero *Leibniz Institut of Atmospheric Physics*

High-resolution radar imaging of dynamic targets for upper atmospheric research

Recent progress in radar imaging, exemplified by methods like MIMO imaging [Urco et al. 2019] and the advent of new radar infrastructure such as EISCAT 3D, has revolutionized our ability to capture atmospheric phenomena with unprecedented spatial resolution. However, traditional radar imaging techniques, which rely on the assumption of target stationarity, face difficulties at high resolutions where target motion can significantly degrades image quality. To overcome this challenge, we propose a novel radar imaging approach capable of maintaining high spatial resolution even in the presence of dynamic targets. Our method involves modeling the unknown target as a Markov random process and utilizing the Ensemble Kalman Filter (EnKF) to estimate its properties. We validate our approach through numerical simulations and real-world experiments conducted with the MAARSY radar. Results demonstrate that the EnKF method outperforms established imaging techniques such as Capon and MaxEnt, providing higher resolution estimates both temporally and spatially.

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Logan Cordonnier *University of New Mexico*

Connections between Meteor Persistent Trains and Ozone Content in the MLT

Ozone is an important trace species in the mesosphere and lower thermosphere (MLT) region. We obtained ozone data from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument; the average peak ozone volume mixing ratio (vmr) of the secondary ozone maximum (~90-95 km) from SABER was found to be strongly correlated with the percentage of sporadic meteors that produce persistent trains (PTs). PTs are long-lasting, self-emitting phenomena that occasionally form after a meteor, arising from exothermic reactions between meteoric metals and atmospheric ozone. The strong correlation between ozone and PTs implies that the ozone content can be estimated just by determining the fraction of sporadic meteors that left behind detectable PTs. This represents a new, ground-based technique for estimating ozone content in the upper atmosphere. We also examined the connection between ozone content and the duration of PTs and found no clear trend.

L. E. Cordonnier - University of New Mexico; Air Force Research Laboratory;
K. S. Obenberger - Air Force Research Laboratory;
J. M. Holmes - Air Force Research Laboratory;
G. B. Taylor - University of New Mexico;
D. Vida - University of Western Ontario

Bengt Eliasson *University of Strathclyde*

Full-wave simulations of Satellite-plasma interaction during active ionospheric experiments

We present a simulation study of the interaction of satellites with trajectories that traverse the perturbed ionosphere during active ionospheric experiments using powerful radio waves injected into the overhead ionosphere. When the satellite flies through the heating beam, it can interact with the Langmuir turbulence caused by the radio wave, and give signatures in the stimulated electromagnetic emissions (SEE) reaching ground. On the other hand, when the satellite passes through the ionosphere above the reflected heating beam, it will fly through bunches of magnetic field aligned irregularities (FAIs) that are formed due to thermal parametric instabilities near the upper hybrid layer and which extend several tens of kilometres above the heated region. The satellite can interact with the FAIs to excite whistler and magnetosonic waves in the kHz range, and satellite-generated lower hybrid waves may also mode convert to whistler waves on FAIs. Generated whistler waves may propagate down to be amplified parametrically by lower hybrid waves at the upper hybrid layer and recorded on ground, and whistler and magnetosonic waves may be recorded by nearby satellites during conjunctions as have been recently observed. Similar processes may also occur for satellites passing through natural FAIs found at high latitudes, allowing space debris detection with using a ground-based HF facility.

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Nada Ellahouny *University of Oulu*

Statistical characteristics of electron precipitation during storms analysed using EISCAT measurements at Tromso

We provide a statistical study of ~ 1–100 keV electron precipitation characteristics using the EISCAT incoherent scatter radar data over Tromsø at 66.7° MLAT. The data are measured between 1998 and 2023 covering more than two solar cycles. The peak energy, energy flux, and number flux of precipitating electrons are derived from the field-aligned measurements of electron density using the ELSPEC analysis method (Virtanen et al., 2018). We study the derived parameters for storm and non-storm times for energy fluxes that exceed 2 mW/m2. The geomagnetic storms are identified based on the algorithm by Pedersen et al. (2021) and the updated storm and storm phases and driver lists by Pedersen et al. (2024, submitted to JGR). We will show the dependence of energetic electron precipitation on storm drivers (high-speed streams and interplanetary coronal mass ejections), and storm phases (main phase and recovery phase), with magnetic local times (MLTs). The mean peak energy of precipitating electrons increases monotonically from afternoon (14 MLT) to morning hours reaching a maximum near noon during storms and non-storm times. Peak energies are somewhat higher for HSS-driven storms than ICME-driven storms. In the morning to noon sector, peak energy is higher during recovery phase than in the main phase. The mean energy flux peaks at 18-20 MLT during storms and has double the non-storm time value. ICME storms have larger energy fluxes in the post-midnight sector than HSS storms. Energy and number fluxes are also higher during the main phase than recovery phase in the morning sector.

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Nina Kristine Eriksen *The University Centre in Svalbard, The University of Bergen*

Multi-Scale and Multi-Instrumental Observations of a Decaying Airglow Patch

Airglow patches are viewed as the optical footprint of dense ionospheric plasma patches in the polar cap. They enter the polar cap on the dayside and some patches are seen to reach the auroral oval on the nightside. Others, on the other hand, see their end of life within the polar cap. There is currently no scientific consensus as to why some patches reach the nighside auroral oval, and others, not. In our study, we present a multi-scale observation of an airglow patch reaching its end of life within the polar cap. The patch in question emerged from a poleward moving auroral form over Svalbard and transited over northern Greenland before the number density and airglow emission rapidly decayed over Resolute Bay, Canada. Optical, satellite, and radar data are used to connect the patch properties; velocity drift (in-situ and remote), plasma number density, and 630.0 nm emission. The influence of these properties on the rapid decay of the patch was investigated.

Nina K. Eriksen (1,2), Dag A. Lorentzen (1), Lisa J. Baddeley (1), Kjellmar Oksavik (1,2), Kazuo Shiokawa (3), Keisuke Hosokawa (4), Asti Bhatt (5), and Leslie Lamarche (5).

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DING Feng *Institute of Geology and Geophysics, Chinese Academy of Sciences*

Vertical features of the ionospheric holes during rocket launches observed by the Sanya Incoherent Scattering Radar

Previous observations shows that during rocket launches, the water in the plume released by rockets usually caused a wide range of ionosphere electron density depletion. While a number of publications devoted to the horizontal variations of such ionosphere holes, observation of the vertical features of ionosphere holes has seldom been reported. In this paper, we used the Sanya Incoherent Scattering Radar (SYISR) to observe the vertical variations of the ionosphere hole during two rocket launch events in year 2022. Both the rockets passed through the topside ionosphere over the China South Sea, with an estimated minimum distance of ~100-300 km from SYISR. About ~15 min after the rocket launch, we observed the ionosphere hole with an altitude range of ~200-800 km. The maximum electron density depletion of -20% occurred at ~420 km, with a duration of 2.2 hours. Based on the observations, we discussed the diffusion of water molecules and its influences on altitude distribution of the ionosphere holes during the rocket launches.

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Identification and characterization of the dayside ionospheric low energy precipitation region based on ISR measurements

The high-latitude, dayside ionosphere is a dynamic region characterized by particle precipitation due to the region being coupled to the solar wind-magnetosphere system. Enhanced ionospheric electron temperatures are a well-known indication of particle precipitation and is easily observed by incoherent scatter radars (ISR). In this work, we take advantage of these observations to identify the region of low energy particle precipitation and the open closed field line boundary (OCB) in the high-latitude dayside ionosphere. The method is applied to EISCAT Svalbard radar (ESR) observation obtained in the fast elevation scanning mode. By slicing the observations at a selected altitude, it is possible to create slices of observations as a function of only latitude and time, removing latitude-altitude ambiguities. The identified precipitation regions are compared to established methods for identification of precipitation and dayside aurora.

Further, we present results of estimating the effect of varying electron densities and heat sources due to precipitation in the enhanced electron temperatures. Finally, we present some case examples of the variation in the observed ionospheric parameters in relation to variation in the solar wind and statistical results of the variation in the parameters based on their position relative to the obtained OCB.

Ingeborg Frøystein (1), Andres Spicher (1), Kjellmar Oksavik (2,3), Björn Gustavsson (1)

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Experimental observations and modelling of ionospheric electron heating during frequency sweeps through the third double resonance

The ionospheric response to HF radio wave pumping is highly variable and depends on the pump wave frequency offset from the nearest double resonance frequency. In this work, we present results from a series of EISCAT Heating experiments designed to investigate possible asymmetries in the ionospheric F-region electron heating when the HF pump frequency is stepped, both up and down, through the third multiple of the electron gyro frequency and the upper hybrid frequency. We present results of estimating the altitude and time variation of electron heating rates as a function of pump frequency offset from the third double resonance frequency. The heat source parameters for each time-step during Heating ON periods have been estimated iteratively by integrating the electron energy equation for model temperatures and fitting the model temperatures to the observed temperatures. As a result, possible indications of asymmetries in the electron heating rates are found. Finally, current challenges, improvements and outlook are discussed.

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Mizuki Fukizawa *National Institute of Polar Research*

Three-dimensional ionospheric conductivity associated with pulsating auroral patches: reconstruction from ground-based optical observations

The three-dimensional (3-D) current system is essential to understand the Magnetosphere-Ionosphere coupling process because they are connected through the filed-aligned current (FAC). The pulsating aurora (PsA), which typically has a patchy shape and quasi-periodic modulation in its luminosity with a time scale of seconds, emerges over a long time from around midnight to the morning side. In several previous studies, magnetic field observations by satellites showed that PsAs were accompanied by FACs. These FACs are thought to be driven by the inhomogeneity of the electric conductivity in the ionosphere. However, it is not completely clear which part of the PsA the FACs associated with the PsA flow and how they are closed in the ionosphere. One reason for this is the difficulty in observing the ionospheric electric conductivity of PsAs, which fluctuates within seconds. This study aims to reconstruct the 3D distribution of ionospheric electric conductivity associated with PsAs from monochromatic auroral images acquired by all-sky cameras installed at multiple ground-based stations using Generalized-Aurora Computed Tomography (G-ACT).

First, we reconstructed the 3-D distribution of volume emission rate from the auroral images using G-ACT. We used 427.8 and 557.7 nm auroral images. The 427.8 nm auroral images were obtained at Abisko (68.36°N, 18.82°E), Kilpisjärvi (69.05°N, 20.78°E), and Skibotn (69.35°N, 20.36°E) while the 557.7 nm ones at Kilpisjärvi, Skibotn, and Tromsø (69.58°N, 19.23°E). The temporal resolution of all-sky cameras was 2 seconds. Second, we derived the 3-D distribution of ionospheric electron density from the volume emission rate by solving the continuity equation of electron density. Finally, the 3-D Pedersen and Hall conductivities were reconstructed by combining the neutral atmosphere model MSIS-E00. The reconstructed Hall conductivity reached its maximum value of 1.4×10^{-3} S m^{-1} at 94 km altitude, while the Pedersen conductivity reached its maximum value of 2.6×10^{-4} S m^{-1} at 116 km altitude. Due to electron motion, a secondary peak in the Pedersen conductivity at 9.9×10^{-5} S m^{-1} appears at 86 km altitude. The electron Pedersen conductivity maximum value in the D region was approximately 38 % of the ion Pedersen conductivity maximum value in the E region. The FAC, derived under the assumption of a uniform ionospheric electric field, was approximately 70 μA m^{-2} near the edge of the PsA patch. This FAC value was approximately 10 times that observed by satellites in previous studies. If the conductivity around the patch is underestimated or the assumption of a uniform field distribution is incorrect, the FAC could be overestimated. By contrast, due to sharper boundary structures, the FAC could actually have had such a large FAC.

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Etienne Gavazzi *UiT*

Time dependent electron transport calculations of small-scale dynamic precipitation

Small-scale dynamic aurora are typically associated with Alfven waves. As the waves travel along magnetic field lines, they accelerate electrons downward toward the ionosphere. Due to the dynamic nature of Alfven waves, the associated precipitations are challenging to study and their effect on the ionosphere are not well understood. To advance our understanding of these small-scale dynamic precipitations, we combine in-situ observations and numerical simulations with high resolution in time. We use data from one of the Visualizing Ion Outflow via Neutral Atom Sensing-2 (VISIONS-2) sounding rockets launched from Ny-Ålesund, Svalbard in December 2018 that flew through the active dayside auroral region. The in-situ observations of electron flux during the flight between altitudes of 400 to 600km reveal many time-energy dispersed structures typically associated with Alfven waves. We use the electron flux measurements as input to AURORA, the time dependent electron transport code developed by Gustavsson (2022), which allows us to model the propagation of electron flux through the ionosphere along one magnetic field line. We present the calculated temporal variations of ionization and optical emission rates in the ionosphere associated with different precipitation regimes. Implications for past and future IS radar observations will also be discussed.

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Cessateur Gaël *BIRA-IASB*

Latest news about the auroral emission polarisation

We review the last advances in the study of upper atmospheric emissions polarisation. Since 2008, observations and modelling were carried out for understanding the auroral emission polarisation, observed in all four main auroral visible emissions lines (the red (630 nm), green (557.7 nm), blue (427.8 nm) and purple (391.4 nm)), in several geomagnetic and auroral activity levels. While the origin of this polarisation is still debated, results indicates its ionospheric origin.

We are using several instruments dedicated to the observations of the auroral emission polarisation, mainly located at the Skibotn observatory in Norway. The CRU series instruments, which are spectro-photo polarimeters able to measure faint polarized signals in a 2° FOV, are coupled with PLIP, for Polar Lights Imaging Polarimeter, able to measure polarization of the three main auroral emissions on a large FOV. Some results will be presented from our last observation campaigns from Skibotn, Norway and Kilpisjärvi, Finland.

Gaël Cessateur(1) Hervé Lamy (1), Jean Lilensten (2, 4), Mathieu Barthelemy (2), Magnar G. Johnsen (3)

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Lindsay Victoria Goodwin *New Jersey Institute of Technology*

Probing ion temperature anisotropy using ISRs

It is commonly assumed that the ion velocity distribution in the weakly-ionized, magnetized F-region ionosphere is an isotropic-Maxwellian. However, in the presence of moderate to strong electric fields (>50 mV/m) O+-O collisions distort the ion velocity distribution and create anisotropic temperatures with respect to the magnetic field. Here, Monte-Carlo simulations of O+-O collisions are used to generate theoretical Incoherent Scatter Radar (ISR) backscatter spectra. These spectra are then compared with actual ISR backscatter to more accurately resolve the true nature of O+-O collisions, and by extension F-region ion temperature anisotropy. Additional studies into ion temperature anisotropy are also performed here using ISR high-latitude measurements of ion temperatures. By comparing ion temperatures taken at different aspect angles within the same magnetic flux, the ion temperature parallel and perpendicular to the magnetic field is inferred and used to monitor ion temperature anisotropy. This presentation will discuss this work, and its potential incorporation of EISCAT_3D data.

Lindsay V. Goodwin (New Jersey Institute of Technology)
Chirag R. Skolar (New Jersey Institute of Technology)
Aidan Thayer (New Jersey Institute of Technology)
William J. Longley (New Jersey Institute of Technology)

Lindsay Victoria Goodwin *New Jersey Institute of Technology*

Using ISRs to resolve plasma density spatial-scale variations due to magnetosphere-ionosphere coupling

To provide new insights into plasma density scale-sizes in the polar cap, irregularity spectra are developed and tracked relative to: 1) magnetic local time, and 2) geomagnetic activity. A novel Incoherent Scatter Radar (ISR) technique is applied to develop spectra between 20 km and 300 km using 2016 to 2018 imaginglp mode data from Resolute Bay ISR-North. This technique leverages: 1) volumetric plasma density measurements from Advanced Modular ISRs, 2) the slow F-region cross-field plasma diffusion at scales greater than 10 km, and 3) that high-latitude geomagnetic field lines are nearly vertical. The results of this work find that the largest spectral features within periodograms that use sunlit or dayside plasma densities are predominately above 100 km, indicating that structures that are above 100 km are more common than structures below 100 km in dayside/sunlit plasma. However, the opposite is true when plasma is in the dark or on the nightside, where the largest spectral features are predominately below 100 km. This work also finds that structures larger than 100 km are slightly more prevalent under stronger geomagnetic conditions, but structures smaller than 100 km are more prevalent under quieter geomagnetic conditions. Furthermore, the solar wind angle generates spatial-scale variations, particularly on the nightside. This presentation will discuss this work in more detail.

Lindsay Goodwin (New Jersey Institute of Technology)
Magnus Ivarsen (University of Saskatchewan; University of Oslo)
Leslie Lamarche (SRI International, Menlo Park)
Gareth Perry (New Jersey Institute of Technology)
Catalin Negrea (Institute of Space Science)

Björn Gustavsson *UIT, the Arctic University of Norway*

Ionospheric HF-heating to the North!

In this talk observations of electron-density and temperatures during an experiment where EISCAT Heating pointed 12 degrees north will be presented. These observations will be used to test model-predictions of electron-density reductions during off-B-heating. Similarities and differences will be discussed and examined. EISCAT Heating was operated with a long on-off-cycle to ensure that steady-state would be reached such that ionospheric modeling with fluid equations could be safely used.

Björn Gustavsson, UIT, the Arctic University of Norway
Andreas Kvammen, UIT, the Arctic University of Norway

Florian Günzkofer *Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR)*

Application of dual-frequency EISCAT measurements to determine ion-neutral collision frequencies with the difference spectrum method

The ion-neutral collision frequency \nu_{in} affects the typical two-peak incoherent scatter spectrum. However, additional assumptions about the ion and electron temperatures are required to infer \nu_{in} from incoherent scatter radar (ISR) measurements. Direct measurements of ion-neutral collision frequencies require simultaneous measurements with two ISRs at distinctly different radar frequencies. Since \nu_{in} is directly correlated with the neutral particle density, such measurements are one of the very few possibilities to obtain information about the neutral atmosphere and atmosphere-ionosphere interactions in the mesosphere-lower thermosphere (MLT) region. We present the difference spectrum method to infer the vertical profile of the ion-neutral collision frequency across the MLT region. Other than using a simultaneous fit of the two spectra with a combined error function, the differences spectrum method can be based on standard ISR analysis software, i.e. GUISDAP, and therefore, is more widely applicable. We present ion-neutral collision frequency profiles obtained from several combined EISCAT UHF and VHF campaigns, utilizing manda and beata pulse codes. We demonstrate that \nu_{in} can significantly deviate from climatological profiles inferred from empirical models such as NRLMSIS. The impact of auroral particle precipitation on the neutral atmosphere density and, thus, the ion-neutral collision frequency is shown as well. Dual-frequency EISCAT campaigns were conducted around the fall and spring equinoxes in the same measurement mode to investigate seasonal variations of the collision frequency profiles.

Florian Günzkofer, Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany
Gunter Stober, Institute of Applied Physics & Oeschger Center for Climate Change Research (OCCR), Microwave Physics, University of Bern, Bern, Switzerland
Johan Kero, Swedish Institute of Space Physics (IRF), Kiruna, Sweden
Yasunobu Miyoshi, Department of Earth and Planetary Sciences, Kyushu University, Fukuoka, Japan
Dimitry Pokhotelov, Institute of Physics, University of Greifswald, Greifswald, Germany
David R. Themens, University of Birmingham, Birmingham, UK
Claudia Borries, Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany

Maria Hajdukova *Astronomical Institute of the Slovak Academy of Sciences*

Meteor Observations: Hyperbolic Orbits and Interstellar Meteoroids‘ Identification

Meteor observations provide us with direct information about the original extraterrestrial material involved in the formation of our solar system and its distribution in the neighborhood of Earth and in the solar system. The detection of an interstellar meteoroid would give us clues about the material in the nearby solar environment or about the building blocks of exoplanetary systems.

However, the sole indicator of a particle's interstellar origin is, so far, a hyperbolic meteoroid orbit with respect to the Sun, and the expected hyperbolic excess of a meteoroid's heliocentric velocity closely approximates the common uncertainty in velocity determination. Therefore, identifying an interstellar meteoroid is extremely challenging and requires a thorough examination of the potential biases and errors. Such an approach enables an estimation of the statistical significance of the results of the data analysis, and may unveil not only a misdetermination of parameters but also a common tendency to underestimate uncertainties in the data. This presentation will illustrate the effect of errors in the geocentric meteor parameters on the heliocentric meteoroid orbit and introduce a general tool for estimating the accuracy of the determined uncertainties in the data.

The particle size range corresponding to a meteor observation is of significant interest since a comprehensive picture of the population of interstellar particles and bodies in the solar system does not yet exist. The only reliable observations are from the extremes of the total mass scale - for interstellar dust particles and for asteroid sizes.

Maria Hajdukova
Astronomical Institute of the Slovak Academy of Sciences

Charlotte van Hazendonk *UNIS, UiB*

Energy dissipation of ULF waves in the polar ionosphere observed using the EISCAT radar, a case study

Ultra-low frequency (ULF) waves transfer energy and momentum into the ionosphere-thermosphere system. To quantify this energy deposition, in-situ measurements of ionospheric parameters are needed, such as provided by EISCAT. The ULF waves are detected in the EISCAT parameters using a novel 2D-FFT technique to identify the wave characteristics. In parallel with other datasets, including optical, magnetometer, satellite, and models, we use EISCAT data to present the first full ionospheric energy dissipation rates for a ULF wave, split into electromagnetic (EM) and kinetic fluxes. The EM energy deposition is calculated from the use of the Poynting theorem, looking at Joule and frictional heating rates, where both rates show the same order of magnitude (1.24×10^{13} J and 7.3×10^{12} J) respectively when integrated over the wave lifetime of 2 hr 15 min and an area of 4° magnetic latitude x 74° magnetic longitude. However, contrary to the common assumption that the EM flux is dominant, we determined the kinetic flux, to be almost equal in magnitude (8.7×10^{12} J). This indicates that previous papers might have underestimated the total energy dissipation by ULF waves.

C.M. van Hazendonk (Department of Arctic Geophysics, University Centre in Svalbard, Longyearbyen, Norway & Department of Physics and Technology, University of Bergen, Bergen, Norway)

L. Baddeley (Department of Arctic Geophysics, University Centre in Svalbard, Longyearbyen, Norway)

K.M. Laundal (Department of Physics and Technology, University of Bergen, Bergen, Norway)

J.L. Chau (Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany)

Unmasking Aurora Imposters

Most ionospheric emissions seen during the dark skies either fit into the categories of 'aurora' or 'airglow', where the former is caused by magnetospheric particles precipitating into the atmosphere and the latter by chemical processes. In recent years, features have been observed over Svalbard that do not fit neatly into either category.

An example of such a feature is called Fragmented Aurora-like Emissions (FAEs) or simply 'fragments'. They appear as small splinters of green emission and typically last for under a minute. Sometimes long chains of fragments form with regular spacing, typically close to auroral arcs, and other times the fragments are individual and move more unpredictably. The orientation of the fragments is almost perpendicular to the field-line direction and their emission spectra suggest that the generation mechanism is local in the ionosphere rather than caused by particle precipitation.

The fragments have been observed at a range of magnetic local times over Svalbard and have on occasion been accompanied by a pale arc which shows continuous emissions over a wavelength range of 400-700 nm and at 1100 nm observed with spectrographs at the Kjell Henriksen Observatory. This is the first observation of an arc of continuous emission at such high latitudes and in the dayside aurora.

Our research now focuses on understanding the cause of these aurora-like features and their relationship with each other and the nearby aurora. We will outline our research plan, including first results and how we will work towards our goal using a combination of optics, EISCAT radars, and citizen scientist photographers.

Katie Herlingshaw (The University Centre in Svalbard)
Noora Partamies (The University Centre in Svalbard)
Rowan Dayton-Oxland (The University of Southampton)
Dan Whiter (The University of Southampton)
Members of the International Space Science Institute team entitled Auroral Research Coordination: Towards Internationalised Citizen Science (ARCTICS)

Meteoroid speed and trajectory determination using BRAMS data

BRAMS (Belgian Radio Meteor Stations) is a Belgian radio network using forward scatter to detect and characterize meteoroids. It comprises a dedicated transmitter and about 50 receiving stations spread all over Belgium and neighboring countries. All receiving stations are identical except one which is a radio interferometer. The transmitter emits a CW signal at 49.97 MHz with no modulation. Hence no range information is available to reconstruct the trajectory and speed of a meteoroid. The only available inputs are the time delays measured between appearances of meteor echoes at various GPS-synchronized receiving stations. A method based solely on using these time delays will be presented [1]. Accuracy of the method is determined by comparing our results to solutions provided by optical observations obtained with the CAMS-Benelux network. Because the method is ill-conditioned, it is strongly sensitive to measurement errors on the time delays. Hence, additional information is required to alleviate this ill-conditioning. One possibility is to use data from a radio interferometer providing the direction of one specular reflection point but requires that this station detects a meteor echo for this meteoroid. Another possibility is to use an extension of the pre-t0 phase technique [2] to forward scatter system which also greatly helps the reconstruction and has the advantage of being used for any station with a good signal-to-noise ratio. The results obtained with these methods are also compared to optical observations and illustrate the great benefits of these techniques. The talk will end with recent improvements done with the network.

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Keisuke Hosokawa *University of Electro-Communications*

Exceptionally gigantic aurora in Earth’s polar cap on a day when the solar wind almost disappeared

Discrete-type auroras are characterized by their highly variable nature and highly structured appearance, while diffuse-type auroras show dynamically changing features such as pulsation. Here, we show the first ground-based view of a completely different type of visible aurora in the Earth’s polar cap, characterized as exceptionally gigantic in size and smooth in shape, which possibly reflects the solar surface plasma environment. We demonstrate that this gigantic smooth aurora in the polar cap is a natural extension of polar rain auroras at the brightest end, which manifest the direct entry of solar coronal electrons into the atmosphere after traveling a long distance along the interplanetary magnetic field. This gigantic polar rain aurora was detected when the solar wind proton density was extremely low, i.e., during an interval known as ‘the day the solar wind almost disappeared’. Ground-based high-resolution imaging enabled visualization of complex internal structures within the gigantic polar rain aurora as possible manifestations of fine-scale systems in the solar wind or on the solar surface. These findings suggest that ground-based optical observations in the polar cap have potential for remote-sensing of the structure and temporal variability of the solar wind and solar surface plasma environment.

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EISCAT VHF Meteor Head Echo Analysis for 2015-2020

EISCAT data contain a large number of meteor head echoes. The head echoes occur due to reflections from the high density plasma surrounding the incoming extra-terrestrial dust/meteoroid as it ablates in the terrestrial atmosphere, typically at altitudes of 80-120 km. Data from the EISCAT VHF radar running the 'Manda' experiment mode are able to be processed for meteor head echo detections. We have created a software processing chain to convert the raw-voltage measurements of the EISCAT VHF radar into meteor events. This includes the initial detection of the meteor head echo with a determination of the Doppler, range, SNR, and East-West interferometry. From there the data is clustered corresponding to the different meteor events. Data from 1000+ hours of measurements are analyzed during the years of 2015-2020 when the Manda radar experiment was operating in a zenith pointing direction. Two directions of the 3D velocity vector are able to be determined from this dataset, leaving some ambiguity in the ecliptic plane origin of the meteor and the absolute velocity.

The distributions of the meteor head echo population measured by the EISCAT VHF radar will be presented, including daily and annual variations.

Devin Huyghebaert (1,2)
Juha Vierinen (1)
Ingrid Mann (1)

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2 University of Saskatchewan, Saskatoon, Canada

Interferometric Imaging of the Ion-Line with EISCAT 3D

While some previous incoherent scatter radars have utilized phased array technology to make volumetric imaging measurements of the incoherent scatter spectra from the ionosphere possible on large scales, the capability of EISCAT 3D to make in-beam incoherent scatter spectra measurements at scales of less than 1 km will be unique. The feasibility of making the measurements of the incoherent scatter spectra ion-line on spatial scales down to 50 m was investigated. This investigation was accomplished using a synthetic data set created from the Geospace Environment Model of Ion-Neutral Interactions (GEMINI - https://github.com/gemini3d/gemini3d) software for obtaining physics-based plasma parameters in the ionosphere. Once the synthetic ionosphere data were created, each point in a 2D grid with 50 m × 50 m resolution was converted to an incoherent scatter spectrum using the ISRSpectrum software package (https://github.com/jswoboda/ISRSpectrum). The spectra in the ionosphere were forward propagated down to the EISCAT 3D expected baselines, and noise was added to the measurements. From there the original incoherent scatter spectra were attempted to be reconstructed with interferometric imaging using a singular value decomposition inversion with Tikhonov regularization. The results show great promise when a 1% signal-to-noise standard deviation ratio for the cross-baseline measurements between two 91-antenna panels can be achieved.

The presentation will discuss the range and time integration trade-offs when obtaining the signal-to-noise standard deviation of 1%, as well as when and where the interferometric imaging techniques with EISCAT 3D can most effectively be used.

Devin Huyghebaert (1)(2), Björn Gustavsson (1), Juha Vierinen (1), Andreas Kvammen (1), Matthew Zettergren (3), John Swoboda (4), Ilkka Virtanen (5), Spencer Hatch (6), and Karl M. Laundal (6)

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(6) University of Bergen, Bergen, Norway

Ionospheric response at Tromsø location to the persistent solar wind forcing

As one of the drivers of Earth's ionosphere, solar wind kinetic energy is of great importance. This energy source is always present and, particularly at high latitudes, transforms and dissipates in the polar atmosphere, modifying the background composition and circulations and therefore causing significant changes to the global thermosphere and ionosphere conditions. Our main objective is to investigate how the thermosphere-ionosphere system responds to solar wind variability at high latitudes and to provide an explanation for the possible mechanisms driving this continuous response.
Using a dataset covering more than twenty years of measurements of the high latitude ionosphere in Tromsø, Norway (70°N, 20°E), the variation of total electron content (TEC) with variability in the solar wind forcing is investigated on larger timescales such as days, weeks, months, and years. We use a 2-hour resampled Advanced Composition Explorer (ACE) solar wind magnetic field and plasma dataset, as well as 2.5°x5° degree spatial and 2-hour temporal resolution International GNSS Service (IGS) TEC maps. Applying a cross correlation analysis with moving 90-day window method, we generate a dataset illustrating the temporal variation of the correlation values. In addition, with an offset varying from 0 to 48 hours we apply to solar wind data in the cross correlation analysis, we derive the response time of TEC to the solar wind variations.
According to our preliminary results from the cross correlation analysis, there are moderate correlations detected (±0.8) between TEC and the merging electric field.There is a strong solar cycle, seasonal and local time dependence evident in the correlation values: 1) a positive correlation during winter nighttime, 2) a noontime anomaly throughout the year with a positive correlation, and 3) a negative correlation during summer. Additionally, we observe a shorter delay, ≈4 hours, in the response time during winter nighttime and a longer delay, ≈18 hours, in the response time during summer conditions. It is suggested that particle precipitation, Joule heating, and plasma convection are the driving mechanisms behind the response. The details will be discussed in the meeting with respect to thermosphere background conditions and possible participating processes.

Pelin Iochem (1), Claudia Borries (1), Samira Tasnim (1), Jürgen Kusche (2)

(1) German Aerospace Center (DLR), Institute for Solar-Terrestrial Physics, Neustrelitz, Germany
(2) The Rheinische Friedrich-Wilhelms-University of Bonn, Bonn, Germany

Yuri Ito *The Graduate University for Advanced Studies (SOKENDAI), National Institute of Polar Research (NIPR), Japan*

Relationships between the pulsating auroral shape, the energy of precipitating electrons, and ducted chorus wave propagation: simultaneous observations by Arase satellite, EISCAT radar, and ground-based imagers

Pulsating auroras (PsA) are believed to be generated by precipitation of a few to a few tens of keV electrons scattered by lower-band whistler-mode chorus waves in the magnetosphere through the cyclotron resonance. Recent studies demonstrated that, during intervals of PsA, more energetic, i.e., relativistic/sub-relativistic, electrons precipitate into the ionosphere at the same time. Recent modeling studies suggested that such highly energetic electrons can be scattered in the higher latitude part of the magnetosphere by whistler-mode chorus waves propagating away from the magnetic equator. However, there have been no actual cases of simultaneous observations of precipitating electrons causing PsA (PsA electrons) and chorus waves propagating towards higher latitudes; thus, we still do not fully understand under what conditions PsA electrons become more energetic and precipitate further down to lower altitudes.
To address this question, we investigated a long interval of PsA on January 12, 2021, during which simultaneous observations with the Arase satellite, the EISCAT radar, and ground-based all-sky imagers were successfully conducted. We found that, during the interval when the PsA shape was patchy, precipitating PsA electrons had higher energies, and Arase detected intense chorus waves at magnetic latitudes above 20º. Considering what factors control the relationships between the PsA characteristics (e.g., spatial structure and electron precipitation energy) and propagation characteristics of chorus waves, we speculate that magnetospheric density ducts play an important role in allowing the chorus waves to propagate along the magnetic field towards higher latitudes without attenuation and to scatter relativistic/sub-relativistic electrons in a region where the resonant energy is higher. Furthermore, since the scattering should be confined within density ducts, the region where the scattered electrons precipitate should be patchy, reflecting the cross-sectional shape of density ducts.
To test the "duct model," the magnetospheric electron density was compared with the optical intensity at the magnetic footprint of the satellite. Overall good correspondence between the irregularities of the electron density and the emission intensity of PsA patches suggests that the PsA morphology and the energy of corresponding electrons are actually controlled by the presence of ducts. In the presentation, we will show the detailed results and discuss to what extent the hypothesis can universally explain the relationship between the characteristics of PsA and the propagation characteristics of chorus waves.

Yuri Ito [1, 3], Keisuke Hosokawa [2], Yasunobu Ogawa [3, 1], Yoshizumi Miyoshi [4], Fuminori Tsuchiya [5], Mizuki Fukizawa [3], Yasumasa Kasaba [5], Yoichi Kazama [6], Shin-ichiro Oyama [4, 3], Kiyoka Murase [3], Satoko Nakamura [4], Yoshiya Kasahara [7], Shoya Matsuda [7], Satoshi Kasahara [8], Tomoaki Hori [4],
Shoichiro Yokota [9], Kunihiro Keika [8], Ayako Matsuoka [10], Mariko Teramoto [11], Iku Shinohara [12]

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Magnus Fagernes Ivarsen *University of Oslo*

The Bulk Motions of the Radar Aurora: Automatic Tracking of Turbulent Structures

In the auroral E-region, during disturbed conditions, strong, penetrating electric fields create an environment characterized by fast plasma drifts, and kinetic instability processes cause the growth of small-scale turbulence. Radio signals scatters off of this turbulence, giving rise to the radar aurora. Rather than reflecting the plasma flow in the E-region, the radar aurora Doppler shift is limited by instability physics. With recent advances in radar interferometry we are able to produce 3D echo location data from the radar aurora. We apply celebrated point-cloud clustering algorithms, allowing us to accurately track the bulk motion of the radar aurora. We are thus possibly able to overcome the aforementioned fundamental limitation. The radar aurora faithfully tracks the motion of turbulent source regions, and we can infer an electric field that is associated with this motion. Through a number of case studies, as well as a statistical analysis, we show that the radar aurora bulk motion is closely associated with F-region ion drifts. We discuss the possible reasons for this association, and suggest that the motion of electric field source regions ExB-drift in a field of their own making. Although it has yet to be perfected, the method of tracking the radar aurora bulk motions has the potential to accurately and consistently estimate the ionospheric electric field, important measurements that are notoriously difficult to obtain.

M F Ivarsen (1,2), J-P St-Maurice (2), D R Huyghebaert (3), G C Hussey (2)

1 University of Oslo, Norway
2 University of Saskatchewan, Canada
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Mykola Ivchenko *KTH*

SYSTER sounding rocket

The Systematic Study of lower Thermosphere Energetics by a Rocket (SYSTER) experiment is a multi-payload sounding rocket study of Joule heating in the auroral region, to address the following questions: (i) What is the altitude distribution of Joule heating in the evening sector of the auroral zone? (ii) How well do different estimates of Joule heating agree with each other, and what are the sources of any discrepancies? (iii) What is the contribution of small scale structuring in plasma, currents and electric fields to the energetics of the lower thermosphere? SYSTER will use a suite of instruments to simultaneously measure electric and magnetic fields, plasma parameters, auroral electron and energetic electron precipitation, neutral gas density, temperature and winds, ion drifts. The SYSTER sounding rocket is planned to be launched in the autumn of 2025.

The presentation will describe the current status of the project.

Mykola Ivchenko, Joan Stude (KTH)
Boris Strelnikov (IAP Kühlungsborn)
Stefan Loehle (University of Stuttgart)
Johnathan Burchill (University of Calgary)
David Malaspina (University of Colorado)
James Clemmons (University of New Hampshire)
Rod Heelis (University of Texas at Dallas)
Allison Jaynes (University of Iowa)
Robert Michell, Marilia Samara (GSFC)
Matt Zettergren (Embry-Riddle Aeronautical University)

Allison Jaynes *University of Iowa*

Investigating Pulsating Aurora with Ground-based Imagers and ISR Observations

Pulsating aurora constitutes a significant amount of energy that is transferred from the magnetosphere to the ionosphere, yet the amount of energy and the associated energy spectra are not well predicted. Here we present several new studies that quantify that energy deposition using results from ground-based all-sky imagers and PFISR observations. We include data from the LAMP sounding rocket launch campaign. Statistical results show a connection between substorm onset and higher energy content in pulsating aurora spectra. The LAMP case study shows that at these times of higher energy content, the Arase satellite observed strong electron injections and measured enhanced chorus wave amplitudes. We comment on the implications of the fact that substorms and/or particle injections are directly related to the total energy content of pulsating aurora, and we discuss new insights that can be achieved with the EISCAT 3D capabilities.

Allison N. Jaynes (1), Jodie McLennan (1), Riley Troyer (2), Stephen Kaeppler (3), Roger Varney (4), LAMP Sounding Rocket Team

1: University of Iowa
2: Space Dynamics Lab
3: Clemson University
4: UCLA

Daniel Kastinen *Swedish Institute of Space Physics*

Digging for debris: generalized matched filtering and discrete polynomial-phase transforms

EISCAT has been and is currently being used to conduct measurements of space objects in orbit around Earth. Both space debris, previously known and unknown, and active satellites from public catalogues. These measurements have significantly contributed to many topic, such as the calibration of the space debris environment model MASTER currently in use by ESA. Now that EISCAT_3D is coming online and the need for space surveillance and tracking measurements are greater than ever, we have taken a second look at the processing pipeline that has been supporting these effort. We will present the refactoring efforts done to make the signal processing generally applicable as well as improvements done to the generalized matched filtering process using the theory of discrete polynomial-phase transforms.

Daniel Kastinen(1), Juha Vierinen(2), Tom Grydeland(3)

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(2) University of Tromsø, The Arctic University of Norway, 9037 Tromsø, Norway
(3) NORCE Norwegian Research Centre, 9019 Tromsø, Norway

Andrew Kavanagh *British Antarctic Survey*

EISCAT contributions to Space Weather research

The EISCAT radars have played an important role in increasing our understanding of the Earth-Space environment; The data they have taken have allowed scientists to unravel key processes involved in solar wind-magnetosphere-ionosphere-atmosphere coupling.

The study of Space Weather often includes increased consideration of the impacts of those processes, on technology, society, and our environment. It revolves around our ability to apply our knowledge to predict those impacts. There are three main areas to consider: general improvement of models, identifying key unknowns, improving operational capability for prediction and now-casting. Data and operations from EISCAT has a key role to play in each of these areas.

In this presentation I will discuss how EISCAT data can be used to probe the unknowns, identifying pathways to improving our large-scale models. Both the archive of existing EISCAT data and the potential of EISCAT_3D will be discussed, particularly emphasizing how the lessons learned from the past can shape how we approach the future.

Andrew J. Kavanagh, British Antarctic Survey, UK

Antti Kero *University of Oulu/Sodankylä Geophysical Observatory*

Non-linearity of the HF heating waves observed by the SUOMI 100 satellite

We have conducted a set of transionospheric HF-propagation research campaigns utilizing the SUOMI 100 nanosatellite on a low-Earth polar orbit and the EISCAT HF Heating facility as a powerful radio source. As axpected, the satellite's radio spectrometer usually detected the strongest HF signals at the center of the heater main lobe. However, the received signal power was found to be non-linearly related to the heater's antenna pattern and to the transmitter power. These experiments are the first observations of the “self-absorption” measured from the transionospheric signal path.

Antti Kero (University of Oulu/SGO), Esa Kallio (Aalto University), Erik Varberg (EISCAT Scientific Association)

Venla Koikkalainen *University of Helsinki*

Magnetospheric transition region phenomena in a global hybrid-Vlasov simulation

The transition region between the Earth's dipole field and the magnetotail is a highly dynamic region of space where a variety of interesting phenomena occur. In this study we aim to understand the formation and evolution of large-scale vortices in the magnetospheric transition region, and study their effect on the Earth's ionosphere. The hybrid-Vlasov global magnetospheric model Vlasiator has recently been complemented with a more robust ionosphere solver, allowing for the study of magnetosphere-ionosphere coupling. The inclusion of the ionospheric solver has contributed to the emergence of the presented phenomena.

Large-scale vortices with wavelengths of about 4 RE (Earth radii) form and dissipate in the transition region (radial distance $\sim$ 8-10 RE) over a time scale of 300 seconds. As the simulation progresses, multiple vortices appear in a highly structured manner leading to wave-like patterns of velocity and density in the azimuthal direction. The vortices have counterparts on the ionospheric grid, where periodic patterns of field-aligned currents are observed to match the structure of the magnetospheric waveform.

Prior to the formation of the vortices, magnetotail reconnection drives Earthward plasma bulk flow. The chain of events leading to the formation of the waveform and ionospheric signatures is explored in detail. The features of the event in the magnetosphere, such as changes in flux tube entropy and the presence of magnetic field Bz minima indicate that the vortices could originate from the ballooning/interchange instability. We compare our results to earlier simulations and observations of ballooning/interchange instability.

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Andreas Kvammen *UiT - The Arctic University of Norway*

Automatic ionogram classification and scaling with deep neural networks

Every year, millions of ionograms are acquired to monitor the ionosphere. These data, spanning a range of locations, multiple solar cycles, and diverse geomagnetic conditions, contain untapped information. Reliable and automatic processing of ionograms is therefore wanted. Still, traditional rule-based programs often fail to consistently analyze ionograms, particularly at high latitudes where auroral precipitation is common.
In this work, we propose the use of deep convolutional neural networks for the automatic classification and scaling of high-latitude ionograms. We implement a supervised approach, training and testing the networks with manually analyzed oblique ionograms from a receiver station in Skibotn, Norway. The classification routine categorizes ionograms based on the presence or absence of E- and F-region traces, while the scaling procedure autonomously determines the E- and F-region virtual distances and maximum plasma frequencies.
We found that deep convolutional neural networks are suitable for the automatic processing of ionograms, even in auroral conditions, achieving an average classification accuracy of 93% ± 4% for the E-region and 86% ± 7% for the F-region. The networks also provide scientifically useful scaling parameters.
The developed networks may support studies of ionogram data, such as examining the temporal and spatial variability of traveling ionospheric disturbances, and further facilitate EISCAT_3D and other instruments in Fennoscandia by automatic cataloging and scaling of ionospheric features.

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Norah Kaggwa Kwagala *University of Bergen, Norway*

EISCAT 3D space weather product concept development and feasibility study

This work presents the overview of and results from an ESA funded activity “EISCAT 3D Space weather product concept development and feasibility study”. The objective of the study was to assess how foreseen EISCAT 3D measurement data can be utilized within the context of the ESA Space weather service network to enhance existing space weather products and services and potentially develop new products. The study involved consultation with experts within space weather service sector and the EISCAT community. Different product ideas and their feasibility were explored to the extent possible given the status of EISCAT 3D and the information that was already known at the time of the study.

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Hervé Lamy *Royal Belgian Institute for Space Aeronomy*

Optical auroral spectra obtained at the Skibotn Observatory

In October 2023, a spectrograph has been permanently installed at the Skibotn Observatory (Norway) in order to regularly monitor the auroral spectrum between ~ 400 and 700 nm with a time resolution of 30 seconds. Using a 300 lines/mm grating and a slit of 100 nm width, the wavelength resolution is approximately of 0.3 nm. The instrument is pointing field-aligned.
The characteristics of the instrument will be provided as well as examples of spectra obtained during quiet, moderate and strong geomagnetic conditions. A relative and possibly absolute flux calibration is currently under way and will be discussed. This will allow the computation of line ratios or a comparison with synthetic spectra obtained using kinetic transport codes such as e.g. Transsolo. Both approaches will provide an estimate of the precipitating fluxes (for electrons but also possibly for protons).

Later on we aim to provide a database of low resolution auroral spectra accessible to the community, which will nicely complement data obtained with the new EISCAT_3D radar located a few kilometers from the observatory and data from the other optical instruments located at the observatory itself. We will also consider the possibility to obtain higher resolution spectra using a 1800 lines/mm grating during specific requested campaigns.

This project is a joint collaboration between BIRA-IASB (Belgium), IPAG (France) and UiT (Norway).

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Karl Laundal *University of Bergen*

Volumetric reconstruction of ionospheric electric currents from tri-static incoherent scatter radar measurements

We present a new technique for EISCAT 3D (E3D) to perform a volumetric reconstruction of the 3D ionospheric electric current density vector field, focusing on the feasibility of the E3D system. The input to the technique is estimates of the 3D current density perpendicular to the main magnetic field, and its co-variance, to be obtained from E3D observations with two main assumptions: 1) Ions are fully magnetised above the E region, and 2) electrons are fully magnetised above 90 km. In this way, the perpendicular current is obtained without assumptions about the neutral wind field. The volumetric reconstruction of the full 3D current density is implemented as vertically coupled horizontal layers represented by Spherical Elementary Current Systems with a built-in current continuity constraint. We demonstrate that our technique gives the full 3D current, using an idealised setup and synthetic data from a simulation of an active auroral ionosphere using the Geospace Environment Model of Ion-Neutral Interactions (GEMINI). The vertical current is typically less constrained than the horizontal component, but we outline strategies for improvement by utilising additional data sources in the inversion. The ability to reconstruct the neutral wind field perpendicular to the magnetic field in the E region is demonstrated to mostly be within 50 m/s in a limited region above the radar system in our setup.

Karl Laundal (University of Bergen), Jone Reistad (University of Bergen), Spencer Hatch (University of Bergen), Kjellmar Oksavik (University of Bergen), Heikki Vanhamäki (University of Oulu), Ilkka Virtanen (University of Oulu), Matt Zettergren (Embry-Riddle Aeronautical University), Michael Madelaire (University of Bergen), Fasil Tesema (University of Bergen)

Björn Linder *Stockholm University*

The MATS satellite mission: MLT observations from spring 2023

MATS (Mesosphere, Airglow/Aerosol, Tomography & Spectroscopy) is a Swedish research satellite launched in 2022. During the first four months of operations, the mission collected millions of images of the mesosphere and lower thermosphere (MLT) observed through the atmospheric limb. These high-resolution measurements include images of noctilucent clouds (NLCs) over the southern hemisphere summer pole and images of atmospheric oxygen airglow collected globally. The data products ultimately to be provided by MATS include MLT temperatures and wave parameters of the gravity waves propagating through the region.

Development of higher-level data products is ongoing. Through tomographical analysis, the images of NLCs are combined to provide a three-dimensional representation of the clouds present over the South Pole. Inversions of the airglow images have been performed to provide global maps of volume emission rates (VER) - a field that is clearly modulated by large-scale motions of the atmosphere, tides and planetary waves. In this talk, we take a look at the first results from the early operational period of MATS, including three-dimensional NLCs and the global maps of airglow emissions. We further hope to present the first joint retrieval of VER and temperature.

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William Longley *New Jersey Institute of Technology*

The existence of density fluctuations at non-resonant frequencies and their detectability by Thomson scatter radars

Thomson scatter radars have successfully measured plasma parameters in the ionosphere for over sixty years. Fundamentally, the radars measure increased power returns when the Bragg scattering condition is met by some source of density fluctuations in the plasma. Typically, wave modes of the plasma provide the source of structuring, and the radars measure strong power returns at the “ion line” which is associated with the ion-acoustic mode; the “gyro line” which is associated with the electrostatic whistler mode; and the “plasma line” that comes from the Langmuir mode. However, the existence of an ion-acoustic mode or electrostatic whistler mode is not guaranteed in the ionosphere. For temperature ratios of $T_e/T_i < 3.5$, there is no solution for roots of the dielectric function near the ion-acoustic frequency, and therefore no wave mode exists. In this paper, a formalism is developed to explain non-resonant modes as features occurring at frequencies where the dielectric function has a local minimum, as opposed to a root corresponding to the typical resonant wave modes. This is explained by analogy to a driven oscillator, where the initial conditions of a plasma will drive an oscillation at $\omega = kv$, and a minimum in the dielectric allows for a maximum in the amplitude of the oscillating electric field. With this formalism, the frequency of non-resonant “waves” can be numerically solved for as a function of basic plasma parameters. This allows predictions of the doppler frequency and detectability of gyro lines during EISCAT 3D experiments.

William Longley, New Jersey Institute of Technology
Lindsay Goodwin, New Jersey Institute of Technology
Juha Vierinen, University of Tromso

Calum Lonie *Luleå University of Technology (LTU) and the Swedish Institute of Space Physics (IRF)*

RAIN - A communication network for sending messages between research instruments in the Nordics

The Arctic region of the Nordics is rich in ground-based research infrastructure, with a wide scope of instrumentation installed in Norway, Sweden and Finland, ranging from small passive instruments to large scale active arrays. For example, the EISCAT_3D infrastructure is spread across all three of these countries. However, these instruments usually do not have the ability to communicate directly between each other, as there is no medium for this communication to take place. There are nonetheless multiple applications for such a communication medium from requesting observations to prioritising experiments so they can be run in the conditions they require. Such a system would also have the added benefit of facilitating communication between the Principal Investigators of these instruments, particularly for campaigns involving multiple organisations.

RAIN (ReseArch Infrastructure Network) is a project that aims to create such a communication network, so that any instrument connected will be able to send and/or receive messages from the infrastructure network. This network will be decentralised, with connections being made based on a peer-to-peer model, using keypair authentication to secure communications. This project is undertaken by a student at Luleå University of Technology (LTU) as part of a Master's Thesis, under the supervision of Dr Daniel Kastinen of the Swedish Institute of Space Physics (IRF). Initially, a small number of instruments located in the Kiruna area will be connected to the network, these will be: ALIS_4D, the digital AllSky cameras in Kiruna and Abisko, AllSky7 meteor cameras and EISCAT_3D. These instruments cover a variety of complexity and inter-connectivity, which will allow for a comprehensive test of the network. Once the network is established and is operating at a suitable level, the RAIN software will be published and the network opened to all other instruments in the Nordics, should they want to be connected, and the system may then be developed and built upon further by the community.

Calum Lonie - LTU, IRF
Dr Daniel Kastinen – IRF

Michael Madelaire *UiB*

Regional data assimilation and its challenges

Addressing the challenge of high spatial resolution data assimilation in ionospheric electrodynamics, this presentation introduces the robust Lompe framework alongside forthcoming data from the EZIE cubesat mission. Lompe (Local Mapping of Polar Ionospheric Electrodynamics) facilitates the creation of regional, self-consistent, high-resolution models of the ionospheric electric field, utilizing Ohm's law and various data sources. The EZIE mission will provide critical mesospheric magnetic field measurements, enhancing our modeling capabilities with its high-resolution spatial and temporal data. The synergy between data assimilation and high-resolution measurements, including contributions from EISCAT 3D, significantly improves our ability to effectively model the ionospheric current system. With this introduction, we aim to outline upcoming possibilities and facilitate future collaboration.

Michael Madelaire (University of Bergen)
Kalle Laundal (University of Bergen)
Fasil Tessema (University of Bergen)
Spencer Hatch (University of Bergen)

The progress and decay of GNSS scintillation during a weak geomagnetic storm: A case study

The stochastic nature of the ionosphere leads to the development of electron density irregularities with sufficient gradients that are capable of modifying the L-band signal from the Global Navigation Satellite System (GNSS). Diffractive interference from Fresnel sized irregularities can cause scintillation in both signal amplitude and phase whereas refractive variations due to fast moving large scale structures impose rapid fluctuations mainly in the signal phase [Kintner et al., 2007]. These can result in signal loss-of-locks and power fadings below the threshold for continuous signal tracking, thereby impairing the receiver tracking performances leading to serious positioning, navigation and timing errors. Understanding the dynamics and evolution of the plasma during periods of both amplitude and phase scintillation is therefore necessary to develop prediction tools as well as to understand the mechanisms that help develop irregularities with different scale sizes.

Using scintillation data from receivers in the Svalbard archipelago, different intervals of scintillation were identified using amplitude scintillation index (S4) and phase scintillation index (σΦ), in order to study the evolution of scintillation in GNSS signals during a weak geomagnetic storm. The steerable 32-m European Incoherent SCATer (EISCAT) radar on Svalbard (ESR) allowed imaging the spatio-temporal variation of the vertical electron density profiles as well as the associated ionospheric conditions over an extended latitude-longitude range during the different intervals. A network of other ground and space based instruments were used to complement the observations made by the ESR and GNSS receivers. The investigation was centred on identifying the ionospheric conditions that supported the coexistence of kilometre scale sized irregularities and Fresnel structures with significant power capable of inducing significant perturbation in the GNSS signals. The occurrence of irregularities of different scale-sizes within the auroral oval and polar cap as well as the associated scintillation levels are studied. Possible instability mechanisms triggering the irregularity cascade at the dayside polar ionosphere are suggested. Furthermore, the strong influence of the Interplanetary Magnetic Field (IMF) Bz, By components on the production and decay of irregularities as well as its subsequent effects on GNSS scintillation strengths are investigated for the case presented.

This study therefore reveals the complex and stochastic dynamics of different scale-sized irregularities and their impact on GNSS radio waves in the high latitude cusp and auroral dayside ionosphere that led to intense scintillation during a weak geomagnetic storm.

References: Kintner, P. M., Ledvina, B. M., & de Paula, E. R. (2007). Gps and ionospheric scintillations.

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Sophie J Maguire *Space Environment and Radio Engineering (SERENE), University of Birmingham*

Scales of Ionospheric Plasma Structuring (SIPS): A multi-instrument campaign observing the multi-scale ionosphere and its effects on trans-ionospheric radio signals

Large-scale plasma structures in the high-latitude ionosphere can lead to the scintillation of trans-ionospheric radio signals, such as those used for GNSS. This is because these structures can seed smaller-scale irregularities that occur due to instability mechanisms. When scintillation does occur because of this, it can be difficult to determine which structures cause the scintillation, particularly if there is a concurrence of structuring with other activity, such as auroral precipitation. In an attempt to resolve this issue and to make more useful conclusions about scintillation within the multi-scale ionosphere, an EISCAT Special Programme named Scales of Ionospheric Plasma Structuring (SIPS) was conducted.

The aims of the experiment were therefore to investigate the relationship between irregularities of varying scale sizes; the formation and generation of small-scale irregularities; and determine under which conditions scintillation can occur. A total of 72 hours of EISCAT Special programme time was awarded for this experiment which was run across winter 2024. To achieve the experimental aims, a suite of ground-based instrumentation was utilised to observe the multi-scale ionosphere, in combination with the Swarm satellites. Large-scale structures on the scale of several hundred kilometres can be observed using the EISCAT radars. The smaller-scale irregularities that can occur as a result are unlikely to be captured in the EISCAT field of view, however, they are visible within the Kilpisjärvi Atmospheric Imaging Receiver Array (KAIRA), LOw Frequency ARray (LOFAR), and Swarm datasets, observing from scales sizes of several kilometres, down to 500m. Using the Swarm Ionospheric Scintillation (SWIS) model with the Swarm data, we can achieve the smaller scale sizes by identifying a spectrum of irregularities along the Swarm line-of-sight. The effects of these structures can then be observed using GNSS receivers, giving an indication of the scale sizes down to several hundred metres, while also providing insight into the Total Electron Content (TEC) and the types of scintillation that can occur (phase and amplitude scintillation in this case).
Analysis of this data is still ongoing; however, the preliminary results have already highlighted structuring across multiple scale sizes that could be responsible for scintillation effects. This experiment has delivered a wealth of results, the most interesting of which will be discussed within this presentation.

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Nicolas Martinez *UNIS, Luleå Tekniska Universitet (LTU)*

The New Meridian Imaging Svalbard Spectrograph no. 2: Towards Improved Capacities

The Meridian Imaging Svalbard Spectrograph no. 1 (MISS 1) prototype was developed in 2018-2019 at UNIS and has since been operational at the Kjell Henriksen Observatory (KHO). Designed to track auroral emissions along the geomagnetic meridian line, it uses a Tunable air spaced transmission Grating and Prism (T-GRISM) dispersive element. The necessity for a spectral pushbroom imager with enhanced capacities using a similar T-GRISM dispersive element, based on the already existing MISS 1 design, led to the initiation of the new MISS 2 project. The project aims to incorporate a complete instrumental description of hardware and software. The instrumental design has no moving parts. As a consequence, it has proven to be a reliable tool and a promising candidate to replace the Meridian Scanning Photometer (MSP) with improved spectral capabilities.

Nicolas Martinez (UNIS/LTU), Fred Sigernes (UNIS), Mikko Syrjäsuo (UNIS), Dag Lorentzen (UNIS)

Barthelemy Mathieu *IPAG (UGA-CNRS) and CSUG (UGA)*

Coupling modeling and optical observations to reconstruct the precipitating particle fluxes and the ionosphere dynamics.

Optical observations of the aurora from space and from the ground give key information for auroral physics studies. They however often need to be coupled with simulations to give their quintessence. In our works, we use imagery, spectroscopy and polarimetry instruments to observe the auroras and combine these observations with a 1D kinetic code of the ionosphere thermosphere named Transsolo. Recent developments allow to get the full synthetic spectra of the aurora both in the FUV (120-200 nm) and in the visible (380-900 nm). By running the code at different locations on a grid it is then possible to map the precipitation using different parameters of the particle distributions, especially the total flux, the mean energy of the distribution(s) and their widths. We will in this presentation also see how it is possible to couple imagery, spectroscopy, tomographic imagery, spectro-imagery and polarimetry with the output of the code to cross check the extracted information. It is also clear that additional coupling with EISCAT 3D data can be very fruitful.

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The MATS satellite mission update

The MATS (Mesosphere Airglow/Aerosol Tomography Spectroscopy) satellite was launched in November 2022 with the aim to investigate structures and gravity waves in the mesosphere/lower thermosphere. MATS observes the oxygen atmospheric band airglow in the near infrared and sunlight scattered from noctilucent clouds in the ultraviolet. Continuously taken images of the atmospheric limb will via tomography yield 3-dimensional data, allowing studies of gravity wave structures, wave parameters and their variability. The satellite is further equipped with a nadir camera which images nightglow in a sloth along the satellite orbit. This provides complementary information on spatial scales down to 10–20 km horizontal resolution.

The mission had collected operational data for four months when the pointing of the satellite started malfunctioning in May 2023. A new steering algorithm based on the magnetic field is now soon to be uploaded to the satellite. This presentation will describe the MATS mission and data products, show some of the data and results already retrieved, and detail the progress of the mission. A special focus will be given to possibilities of co-observations with other instrumentation, in particular EISCAT3D.

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EISCAT and Swarm observations of summer-time cusp

Cusp is a special region in space that provides a direct pathway for particles from the solar wind to enter the ionosphere. The location and properties of cusp depend on the IMF direction and season.

In this study, we carried out a measurement campaign where coordinated measurements of the EISCAT Svalbard incoherent scatter radar (ESR) were made during Swarm satellite overpasses. The ESR radar, located at 78oN latitude and 16o E longitude near Longyearbyen yields electron densities, electron and ion temperatures and ion velocities. During the campaign, a CP2 experiment mode was used, which provides us with ion velocity and plasma parameter measurements in three different directions. Swarm is a mission in ESA's Earth Explorer series. Two of the satellites, A and C, were in circular polar orbits at about 450 km altitude. With Swarm we observe the local plasma environment, magnetically field-aligned electrical currents, and ion drift velocities. In this study, estimates of the plasma density and electron temperature from the Langmuir probe, of the ion velocity from the Thermal Ion Imager (TII), the magnetic field vector from the magnetometers are used.

During the campaign a summer cusp event on 24 August 2021 was observed. We combine data from ESR, Swarm A/C, DMSP F17 satellite and solar wind parameters to understand the small-scale electrodynamics inside the cusp in terms of FACs, plasma parameters and electric fields. Both ESR and Swarm show electron temperature enhancement as a signature of cusp. Radar and satellite measurements also show large-scale westward ion flow with a small poleward component within the cusp region. Swarm A/C satellite measurements show that within the cusp region there are multiple sheets of intense FACs (≥ 10 microA/m2).Small-scale spatial structures and the ionospheric dynamics will be studied by using the 1 and 50 Hz magnetometer data and latitude profiles of ion flows from Swarm, as well as ESR measurements along the three beam directions. We use the F-region ion temperatures from ESR to estimate separately the magnitudes of ion velocities in the three beam directions. The estimated Joule heating from ESR varies between 8 and 15 15 mW/m2.

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John Meriwether *Center for Solar-Terrestrial Research New Jersey Institute of Technology*

Application of a Short Wave Infrared Imager as an Auroral Temperature Imager and He Nightglow Monitor

Application of a wide field Short Wave Infrared Imager to the observations of the 0-0 N2+ rotational temperature looks to be a promising technique for distinguishing between aurora produced by precipitation of mono-energetic electrons and that produced by Alfven wave acceleration. Also interesting would be the detection of He 1083 nm nightglow emisson produced by Rayleigh scattering by the metastable He 3S in the exosphere region near 450 km. These observations are made possible by the use of an InGaAs array detector combined with optics that observes images with a wide field range of 120 degrees. Results obtained in a first-light campaign at Poker Flats, Alaska will be presented and discussed in terms of possible potential for new directions in ground-based research.

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Statistics of traveling ionospheric disturbances at high latitudes using a rapid-run Ionosonde

The potential of deep learning for the investigation of medium scale traveling ionospheric disturbances (MSTIDs) has been exploited through the Sodankylä rapid-run ionosonde in this statistical study. The complementing observations of the Sodankylä ionosonde with AI implementation and those of the Sodankylä meteor radar reveals the diurnal and seasonal occurrence rate of high-latitude MSTIDs in the recent low solar activity period. In our results, the daytime, nighttime and dusk MSTIDs are predominantly identified during winter, summer, and equinoctial months, respectively. The winter daytime higher (lower) occurrence rate is well correlated with the lower (higher) altitude of the height of the F2-layer peak (hmF2), and the low occurrence rate of the summer daytime is well correlated with the mesosphere-lower-thermosphere wind shear and higher gradient of temperature.

Samson Moges (1), Ruslan Sherstyukov (1), Alexander Kozlovsky (1), Thomas Ulich (1, 2), and Mark Lester (3)

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Real-time notification service of auroras in Norway and Sweden for automated optical observations

As an activity of citizen science, pictures of auroras taken by photographers using commercial digital cameras have been used for scientific research. Such digital images contain a lot of background noise in various wavelengths, unlike professional optical data captured with a narrow-band optical filter. However, commercial digital cameras have three RGB channels and can capture what we see by eyes in full color. This capability often enables us to identify characteristics of optical phenomena that are difficult to notice in monochromatic data (MacDonald et al., 2018; Shiokawa et al., 2018). Furthermore, it has been suggested that the colors of auroras in images can be used to estimate the average energy of electrons responsible for pulsating auroras (Nanjo et al., 2021); thus, observations by photographers have the potential to play an essential role in scientific research of auroras. However, unlike professional researchers, who automatically observe auroras overnight, photographers have to wait for the appearance of auroras to take pictures, which is often a heavy burden for them. To reduce this difficulty, researchers can provide a system that notifies people of the auroral appearance in real time. One of the reasons why such a system has not been developed so far is that the aurora's complex and diverse morphology made it challenging to detect them with high accuracy. However, with the improvement of deep learning techniques, that problem has almost been solved (Clausen & Nickisch, 2018; Kvammen et al., 2020). In this study, we developed a deep-learning model that automatically detects auroras and then combined it with real-time observation by a commercial digital camera in Tromsø, Norway (Nozawa et al., 2018) to build a website "Tromsø AI" that notifies users of auroral occurrences in real-time. In the presentation, we will show how to use this website and how it can be used for the observation which automatically tracks auroras.

Sota Nanjo [1,2], Urban Brändström [2], Satonori Nozawa [3], Magnar G. Johnsen [4], Tetsuya Kawabata [3] and Keisuke Hosokawa [1]
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Hilde Nesse *University of Bergen*

The High-Energy Tail of Energetic Electron Precipitation

Precipitating plasma sheet, ring current, and radiation belt electrons will affect the ionization level and composition of the neutral atmosphere. Knowledge gaps remain regarding the frequency, intensity, and energy spectrum of the Medium Energy Electron (MEE) precipitation (>30 keV). In particular, the understanding and predictive capabilities of the high-energy tail (>300 keV) are, in general, poor. This study builds on a recently published statistical analysis based on loss cone electron flux estimates on MEPED observations on board the POES/Metop satellites over a full solar cycle from 2004-2014. Data from the Northern and Southern Hemispheres (55-70 degrees N/S) were combined in daily flux estimates. Flux peaks above the 90th percentile of the >43 kev flux were identified. The 33% highest and lowest associated responses in the >292 keV fluxes were labeled "E3 events" and "E1 events", respectively, resulting in 55 events of each type. It was evident that high geomagnetic activity increases the probability of E3 events. While no single solar wind parameter nor geomagnetic index was able to identify the type of event, Kp and Dst possessed the best predictive capabilities. By detailed examination of the 55 E1 and 55 E3 events, this follow-up study shows that the Kp-index partly classifies a different subset of E1 and E3 events compared to the Dst-index. This makes a combined determination of the limits Dst>-26 and <-48 nT and Kp<33 and >40, highly effective. Knowing the solar wind driver modifies the combined Kp and Dst limits slightly and correctly labels 85% of events. Despite their differences, common features become apparent for the ambiguous events: a persistent southward Bz alongside sustained substorm onset activity will generate high-energy tail electron precipitation. The concurrent criteria provide insight into when and why high-energy tail electron precipitation occurs.

Hilde Nesse, University of Bergen
Josephine Salice, University of Bergen

Kenneth Obenberger *Air Force Research Laboratory*

Comparing Passive LWA Observations of Meteor Radio Afterglows to SIMONe Meteor Radar Echoes

Large meteors often leave behind a lingering trail of plasma that radiates broadband radio signal in the upper High Frequency (HF) and lower Very High Frequency (VHF) bands for up to a few minutes after initial meteor ablation. These Meteor Radio Afterglows (MRAs) were first discovered in 2014 using the Long Wavelength Array (LWA) radio telescopes. It is thought that high levels of plasma turbulence in the trail create the environment in which electrons can radiate Resonant Transition Radiation (RTR). To get a better idea of the plasma dynamics we have carried out a study with the LWA station at Sevilleta (LWA-SV) and the newly constructed Spread spectrum Interferometric multistatic Meteor radar Observing Network in New Mexico (SIMONe-NM). Using LWA-SV to find and characterize the emissions from a particular MRA we compare with the non-specular echo from multiple SIMONE-NM stations at or near to LWA-SV. We find that the MRA and non-specular echo have a similar altitude profile, where the higher altitudes radiate and scatter preferentially in the beginning, but both move down the trail with time. We also find a strong windshear and present the analysis of the Doppler spreading, which indicates the level of turbulence in the trail.

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Yasunobu Ogawa *National Institute of Polar Research*

Study of long-term ionospheric variations based on Tromsø Ionosonde and EISCAT radar data

We study long-term ionospheric variations using a combination of data from the Tromsø Ionosonde since 1932 and the EISCAT Tromsø UHF radar since 1981. A unified database for 43 years, from 1981 to 2023, has been created based on different mode observations from the EISCAT Tromsø UHF radar to estimate the long-term variation of ion temperature at altitudes between 220 and 460 km. One of the results shows that ion temperature decreases at an altitude of 300 km at a rate of 1.7 ± 0.2 [K/year]. Compared to the previous analysis using EISCAT Tromsø UHF data for the past 33 years (Ogawa et al., 2014), the present analysis of 43 years of data shows better estimation accuracy at all altitudes.
To investigate even longer-term ionospheric variations, we are working on the development of a Tromsø ionosonde database with continuous data since 1932. The monthly mean ionosonde database used in previous studies (e.g., Hall and Johnsen, 2020) has been significantly extended, and a database capable of analyzing daily variations over about 90 years has been developed. A detailed comparison of the ionosonde data with the EISCAT radar data allows us to understand how various ionosonde parameters are related to ionospheric plasma parameters such as ion/electron density and temperature. By applying the results to the early ionosonde data, we elucidate the characteristics of ionospheric variations over a 90-year period. This will provide clues to understanding how the Arctic-only warming events of the 1930s and 1940s (e.g., Yamanouchi, 2011) affected the upper atmosphere in the Arctic region.
In this paper, we will present the results of long-term ionospheric variations above Tromsø and discuss their relation to the warming in the lower atmosphere.

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Shin-ichiro Oyama *ISEE, Nagoya Univ.*

Geomagnetic activity and IMF By dependence of thermospheric winds: statistical analysis of Fabry-Perot interferometer measurements in Tromsø, Norway

Ion drag associated with the ionospheric plasma convection plays an important role in the high-latitude thermospheric dynamics, yet changes in the thermospheric wind with geomagnetic activity are not fully understood. We performed a statistical analysis of the thermospheric wind measurements with a Fabry-Perot interferometer (FPI; 630 nm wavelength) in Tromsø, Norway, in the winter months for 9 years. The measurements were sorted by a SuperMAG (SME) index, and a quiet-time wind pattern was defined as an hourly mean under SME ≤ 40 nT. The quiet-time wind pattern can be expected to be represented by a pressure gradient associated with the solar radiation and a geostrophic force balance. With an increase in the geomagnetic activity level, the thermospheric wind turned over from eastward to westward at dusk and increased the equatorward magnitude from midnight to dawn. Deviations from the quiet-time wind presented similar patterns in the direction with the ionospheric plasma convection but were larger in magnitude at dusk than at dawn. Statistics of the wind grouped by the IMF By presented that the zonal wind bifurcates immediately before midnight for IMF By<0, but for By>0, it inverts gradually into the postmidnight sector.

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Shin-ichiro Oyama *ISEE, Nagoya Univ.*

Largest thermospheric wind ever observed with a Fabry-Perot interferometer in Tromsø, Norway since 2009 during the March 2023 storm

Solar cycles 24-25 were quiet until a geomagnetic storm with a Sym-H index of -170 nT occurred in late March 2023. On March 23-24, a Fabry-Perot interferometer (FPI; 630 nm) in Tromsø, Norway, recorded the highest thermospheric wind speed of over 500 m/s since 2009. Comparisons with magnetometer readings in Scandinavia showed that a large amount of electromagnetic energy was transferred to the ionosphere-thermosphere system. Total electron content maps suggested an enlarged auroral oval and revealed that the FPI observed winds near the polar cap instead of inside the oval for a long period during the storm main phase. The FPI wind had a strong equatorward component during the storm, likely because of the powerful anti-sunward ionospheric plasma flow in the polar cap. The positive Y-component of the IMF for six days before the storm caused a successive westward component of the FPI-measured wind during the storm main phase. On March 24, the first day of the storm recovery phase, thermospheric wind disturbed and the ionospheric density decreased significantly at high latitudes. This density depression lasted for several days, and a large amount of electromagnetic energy during the storm modified the thermospheric dynamics and ionospheric plasma density.

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Noora Partamies *University Centre in Svalbard*

Auroral breakup detection in all-sky images by unsupervised learning

This presentation outlines the first attempt to classify auroral morphological forms by unsupervised learning method on an image set that contains both nightside and dayside aurora. We used six months of full-colour auroral all-sky images captured on Svalbard, Norway, in 2019–2020. The selection of images containing aurora was performed manually. A convolutional neural network called SimCLR was used for feature extraction. The clustered and fused features resulted in 37 auroral morphological classes. In the classification of auroral image data with two different time resolutions we found that the occurrence of eight morphological classes strongly increased when the image cadence was high. These were grouped into "active aurora classes". The occurrence of 13 morphological classes experienced little or no change with changes in image cadence, and were called the "quiet aurora classes". Longer periods of the "active aurora" coincided with ground-magnetic deflections typical to substorms, as well as vortical auroral evolution typical to substorm aurora. Our unsupervised image classification method may be a way to detect auroral breakups in ground-based image datasets with a temporal accuracy determined by the image cadence.

Noora Partamies (UNIS, Norway), Bas Dol (Eindhoven University of Technology, The Netherlands), Vincent Teissier (ENSTA Bretagne, Brest, France), Liisa Juusola (FMI, Finland), Mikko Syrjäsuo (UNIS, Norway), and Hjalmar Mulders (Eindhoven University of Technology, The Netherlands)

Theresa Rexer *UiT*

Present and Future of Heating with EISCAT

Community discussion on the future of Heating

Theresa Rexer *UiT*

Improving the magic constant

The "Magic constant" in the European Incoherent Scatter Radar (EISCAT) system, and "k-sys" in the Advanced Modular Incoherent Scatter Radars (AMISR) are crucial scaling factors in the calibration process of the radars. The accuracy and resolution of the radar measurements and Signal-to-Noise ratio are affected by multiple factors within a given radar system that these constants account for, and thus calibration is a complex issue, particularly for multi-beam radars. However, even after the most meticulous technical calibration of a multi-beam radar, estimating this constant is difficult. The system gain and antenna pattern may change with time due to element failures, environmental conditions (e.g., snow and ice), or variations in experiment type, temperature, aging components, and ground conditions. In this study, we show two second-level calibration methods for multi-point electron density measurements from phased array incoherent scatter radars that add to the current calibration efforts. We use the analogy between independent measurements in camera pixels in an image sensor and multi-point radar measurements and estimate a correction factor G that is subsequently used to scale electron density measurements. This increases data quality and usability by correcting for variable, unaccounted, and unpredictable variations in system gain and is especially valuable for studies of plasma patches, irregularities, turbulence, and other research where inter-beam changes and fluctuations of electron density are of interest.
No external input is needed as the methods are strictly based on electron density measurements, proving especially valuable when independent measurements of electron densities for calibration are available only in one pointing direction or not at all. If implemented as a part of the data processing chain for multi-beam ISRs like the AMISR systems or the future EISCAT3D radar, the procedure could improve overall data quality, both for existing data and for future experiments.

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<u>Heating after 45 years: highlights, questions and the future with EISCAT_3D</u>

The EISCAT HF ionospheric heating facility has continued to produce new and unexpected phenomena for the last four decades. Some highlights from the past are shown. Many of these phenomena were discovered or investigated with the co-located incoherent scatter radars (ISR's) as the main diagnostic instruments. These radars will soon be decommissioned as the next generation phased array incoherent scatter radar, EISCAT_3D, comes on line. This new multi-static radar has its core located 52 km east-south-east from the heating facility which has important implications for future heating experiments with the existing facility. EISCAT_3D's ability to probe a 3-dimensional volume with high time and spatial resolution will be a valuable addition to the 3-dimensional imaging of the radio-induced optical emissions that has been achieved with the ALIS camera system and the 2-dimensional imaging of HF stimulated electromagnetic emissions (SEE). These new capabilities, compared to the present ISR's, should result in a dramatic new window on one of the still poorly understood phenomena produced by powerful HF-pumping experiments, namely the temporal and spatial development of multi-scale electron density irregularities in the F region and also the E region of the ionosphere. The fact that the heater beam can only be phase-steered in the north-south plane means that EISCAT_3D will probe the heated region obliquely and not be able to look along the same magnetic field line as the HF transmitter. This means that the large (100m scale) irregularities that have been postulated to be responsible for the UHF backscatter enhancements in the topside (also known as WAILES for wide altitude ion line enhancements) may be measured by EISCAT_3D, but the backscatter enhancements themselves cannot. The oblique geometry will be even greater in the mesosphere such that PMSE echoes above the heater may be very different from those measured with the present VHF radar, depending on the aspect angle dependence of PMSE. The different geometry in these future heating experiments will surely add new and interesting results, but are also a reason to consider building a new HF heater closer to the EISCAT_3D core site.

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Fabiano Rodrigues *UT Dallas*

Incoherent scatter radar observations using a 14-panel version of AMISR

We will present results of an incoherent scatter radar experiment made with a 14-panel version of the Advanced Modular Incoherent Scatter Radar (AMISR-14) deployed at the Jicamarca Radio Observatory in Peru [1]. The main goal of the experiment was to confirm the ability of the system to detect incoherent scatter (IS) echoes, despite its small aperture and reduced peak power. The experiment used a long uncoded pulse and took advantage of the electronic beam steering capability to make observations at different magnetic aspect angles. The pulse was 90 km long and observations were made in three distinct directions: (a) nearly zenith, (b) 30 deg. off-zenith to the south and (c) 30 deg. off-zenith to the north. Jicamarca and AMISR-14 are located near the magnetic equator and the off-zenith observations allowed us to make oblique incoherent scatter measurements. The zenith measurements, however, allowed us to make measurements perpendicular to the geomagnetic field. Therefore, the pointing directions provide us with an opportunity to investigate the effect of the aspect angle in the IS spectrum [2]. Results show daytime F-region echoes with SNR values near -10 dB around the F-region peak heights. Comparison with measurements made by a collocated vertical sounder (VIPR) show that the range-scaled power profiles are in good agreement with F-region density profiles. The oblique measurements also show echoes with the expected spectral features of incoherent scatter at UHF. Furthermore, reasonable profiles of electron and ion temperatures have been estimated from the measurements. We show that the spectrum of the echoes is narrower for measurements made at zenith compared to off-zenith, which is in good agreement with previous studies and theoretical expectations considering electron Coulomb collisions.

[1]Rodrigues, F.S., Milla, M.A., Scipion, D. et al. On new two-dimensional UHF radar observations of equatorial spread F at the Jicamarca Radio Observatory. Earth Planets Space 75, 120 (2023). https://doi.org/10.1186/s40623-023-01876-7[2]Sulzer, M. P., and González, S. (1999), The effect of electron Coulomb collisions on the incoherent scatter spectrum in the F region at Jicamarca, J. Geophys. Res., 104(A10), 22535– 22551, doi:10.1029/1999JA900288.

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Srimoyee Samaddar *University of Southampton*

Estimation of molecular constants for modelling the O2+ (1N) emission in aurora

Fine-scale aurora is primarily produced by interaction of precipitating electrons of varying energies with the neutral atmosphere, which primarily constitutes of N2, O2 and O. The brightest emissions in the aurora are typically the 557.7 nm and 630.0 nm of atomic O, but a preference for spectral observations which are prompt and with shorter lifetimes are preferred to study the fine-scale structures at higher temporal resolution.

In this study, we derive the fitting parameters for the O2+ (1N) auroral emission and compare it to the spectral emission measured by the HiTIES (High Throughput Imaging Echelle Spectrograph) instrument. The HiTIES is a part of the Spectrographic Imaging Facility (SIF) at Kjell Henriksen Observatory (KHO) (78.15° N, 16.04° E) and is equipped with multipaneled mosaic filters that measure spectral emissions at different wavelength ranges at high spectral and temporal resolution. During periods of energetic aurora, the middle panel of the mosaic filter (728–740 nm) measures the vibrational transition of the N2 1PG band (B 3 - A3 Σu+) combined with O2 + 1N (b 4Σg − - a 4Πu). Other emissions include the OH (8-3) band (airglow) and two auroral O+ doublets at wavelengths λ = 732.01 and 731.90 nm and λ = 733.08 and 732.97 nm. Another mosaic filter at SIF also measures the O2+ emission in the 558-565 nm range.

While good fitting models exist at wavelengths greater than 730 nm which is dominated by the N2 1PG bands, OH airglow and the O+ doublets, below this wavelength the contribution of the O2+ 1N becomes equally important. Therefore, it is essential to provide proper fitting parameters to account for the O2 + 1N emission bands in the HiTIES spectrum. Finally, accurate modelling of O2 + 1N emission bands will lead to precise estimation of the ion temperature in the Earth’s atmosphere.

Srimoyee Samaddar, Daniel K. Whiter

Hiroatsu Sato *DLR Institute for Solar-Terrestrial Physics*

Simultaneous observation of GNSS scintillation and UHF radar enhanced ion shoulder during EISCAT HF experiment

Evolution of artificial field-aligned irregularities (FAIs) is studied by coordinated observations of GNSS satellite and EISCAT UHF radar during EISCAT HF experiments. We show that the electron density variation due to artificial FAIs can be characterized by GNSS scintillation and total electron content (TEC) parameters derived from high-rate GNSS receivers located at EISCAT and in Tromsø when the satellite-receiver links intersected the expected heating impact area around 250 km altitude. GNSS amplitude scintillation and TEC fluctuation data show that the largest density perturbation is found near the magnetic zenith direction. We find that during the existence of small-scale GNSS scintillation, the UHF radar detected an enhanced ion shoulder from a narrow range of altitudes that can lead to erroneous incoherent radar fitting results. In fact, a large deviation is found between the estimated electron densities derived from GNSS TEC and UHF data during this period. We discuss that the source of this particular GNSS scintillation are likely a type of FAIs caused by parametric instabilities.

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Leonard Schulz *Institute of Geophysics and Extraterrestrial Physics, Technische Universität Braunschweig*

Space Waste: On the atmospheric effects of re-entering spacecraft

In the last years, the number and mass of spacecraft in low Earth orbit has increased in an unprecedented way. In order to mitigate the worsening on-orbit space debris problem, where satellites and rocket stages may crash into each other and generate even more debris, defunct spacecraft are required to re-enter the atmosphere after their end of life. These re-entering objects constitute space waste. During re-entry, space waste burns up and releases metal vapor and small particles into Earth's atmosphere. This anthropogenic injection is already at around 3% mass input compared to the injection of natural materials due to the constant flow of cosmic material from the solar system. Incorporating proposed spacecraft mega-constellations, which may go up to 75,000 in-orbit satellites in the future, this number might increase to 40%, with metals and aerosols nearly equaling the annual injection by natural sources. Remnants of ablated spacecraft have been found in stratospheric aerosol particles, with some metals, most importantly aluminum, exceeding the natural input already. All this raises the question on how strong the burn-up of re-entering spacecraft affects Earth's atmosphere, specifically mesospheric and stratospheric chemistry, the ozone layer, cloud formation or the climate. Comprehensive studies, especially observations of reentering spacecraft are urgently needed in order to understand the significance of the current and future human activities. Precautions should be taken to protect our atmosphere from possibly detrimental effects, which could ultimately harm our habitat.

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Tima Sergienko *Swedish Institute of Space Physics, Kiruna, Sweden*

The Barium Radio and Optical Rocket (BROR) experiment.

The Barium Release Optical and Radio rocket (BROR) experiment aims to study cross-scale energy transfer processes and small- and medium-scale structures in the auroral ionosphere using active modification of the ionosphere by multiple releases of barium and simultaneous optical and radio ground-based observations of the appeared plasma clouds. The BROR experiment was conducted at 18:23 UT on March 23, 2023, at the Esrange rocket range near Kiruna, northern Sweden. The eight canisters of the payload with the barium-strontium-thermit mixture were successfully released at various altitudes in the range of 130 - 240 km. The ALIS-4D multi-station spectroscopic optical imaging system as well as the ordinary digital cameras spread located at various locations around the Esrange were used for optical observations of motion of the neutral and ionised barium and strontium clouds. For monitoring the ionospheric parameters during the experiment the EISCAT UHF radar operated the Beata program with the special scanning antenna mode.
This report presents some preliminary results of the analyzing experimental data from the BRUR experiment. The tomography-like reconstruction of the 3D dynamic of the barium clouds was used for a detailed analysis of the motions of the neutral and ionized clouds in the vicinity of the auroral arc. The Beata plasma line measurements indicate the strong signal enhancement coinciding with each release of the barium-thermite mixture. The unusual refraction of the sunlight observed with the ordinary digital cameras in front of the release locations indicates the possible formation of the strong shock wave as a result of the barium-thermit mixture release.

Tima Sergienko, Swedish Institute of Space Physics, Kiruna, Sweden
The BROR team

A Near Infra-Red Hyper Spectral Imager

This study presents a 3D printed Near Infra-Red Hyper Spectral Imager version 7 (NIR HSI v7). The aim is to find a prototype payload design for the next generation HYPSO satellite missions. The detector is a Black Silicon CMOS sensor with high sensitivity in the 600 - 1200 nm spectral range operating at nominal speed of 90 frames per second. The spectral bandpass is 3.33 nm and the field of view across track is 11.4°. The main scientific objective is to be able to correct for atmospheric scattering of the hyperspectral data cubes obtained in orbit. The instrument is calibrated and tested to show it is capable of push-broom operations from various platforms, including drones to satellites.

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Oliver Stalder *University of Tromsø*

Effect of Ionospheric Variability on the Electron Energy Spectrum produced from Incoherent Scatter Radar Measurements

Auroral electron precipitation changes the ion composition in the E-region substantially. A fully dynamic ionospheric composition model (IonChem) is built, taking the reactions of 15 ion and neutral species at altitudes between 80 - 150 km into account. As the model does not assume chemical equilibrium, it can be used to predict the rapid ion composition variations in presence of active aurora. IonChem is used to produce realistic, time-dependent electron recombination rate estimates for the ELSPEC algorithm, which inverts differential energy spectra of the precipitating electrons from magnetic field-aligned incoherent scatter radar measurements. The effect of variable recombination rates on the inversion is shown, and the limitations of steady-state composition models are discussed.

Oliver Stalder
Björn Gustavsson

Johann Stamm *University of Tromsø*

Modelling neutral wind and electric field over a volume

Volumetric measurements of the ionosphere are important for investigating spatial variations of ionospheric features, like auroral arcs and energy deposition in the ionosphere. In addition, such measurements make it possible to distinguish between variations in space and time. With beam steering, one can measure spatial variations in scalar quantities, such as electron density or in temperatures. For measuring the ion velocity vector over a volume, it is desirable to scan large volumes fast with a multi-static radar. The first incoherent scatter radar with this capability will be EISCAT3D.

We are presenting a technique for volumetric analysis of neutral wind and electric field from simulations of EISCAT3D measurements of ion velocity. In the ionosphere, ion velocity is related to electric field by the Lorentz force and neutral wind by collisions. Estimating neutral wind and electric field from ion velocity is therefore an underdetermined problem. As a consequence, there are indefinitely many solutions to the problem. We regularize the estimates by applying Maxwell's equations and fluid-dynamic constraints [1, 2]. A stress test shows that Maxwells equations plays an important role for electric field estimates when one beam direction is missing.

[1] Stamm, Johann, Juha Vierinen, Björn Gustavsson: Observing electric field and neutral wind with EISCAT 3D, Annales Geophysicae, 39, 961–974, https://doi.org/10.5194/angeo-39-961-2021, 2021.
[2] Stamm, Johann, Juha Vierinen, Björn Gustavsson and Andres Spicher: A technique for volumetric incoherent scatter radar analysis, Annales Geophysicae, 41, 55–67, https://doi.org/10.5194/angeo-41-55-2023, 2023.

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Axel Steuwer *EISCAT Scientific Association*

EISCAT and EISCAT_3D – The Status Quo

The EISCAT Scientific Association owns and operates several incoherent scattering radar systems in the Nordics & Svalbard. It is currently constructing a new generation of incoherent scattering radar systems called EISCAT_3D based on phased array technology. The EISCAT_3D system represents a major step forward in terms of research infrastructure for investigating the coupling between the Earth's upper atmosphere, ionosphere, and magnetosphere in a key region of geospacer and allow in particular volumetric measurements.
The radar will also be located in the auroral regions of the Nordics as the old EISCAT system, and will, once completed, replace the old EISCAT system. This talk will discuss in greater detail the status of EISCAT Scientific Association and of the EISCAT_3D implementation, the initial and expanded capabilities planned for the system, as well as the schedule for making the radar available to the research community.

Axel Steuwer, EISCAT Scientific Association

Anja Stromme *ESA*

The ESA Swarm Mission and EISCAT

Swarm is the first ESA’s Earth Explorer Constellation, launched in November 2013. The constellation is composed of three spacecraft, two of them (Swarm A and C) flying side by side and one (Swarm B) flying at a slightly higher altitude with a drifting orbit respect to the A/C pair. The Swarm constellation provides highly accurate observations of electromagnetic and atmospheric parameters of the near-Earth space environment.
After more than 10 years in orbit Swarm is still in excellent shape and continues to contribute to a wide range of scientific studies, from the core of our planet via the mantle, the lithosphere and out to the ionosphere and the interaction with the Solar wind.
Although not designed as a Space Weather Mission, its multi-disciplinary measurements and the peculiar mission constellation design, place Swarm in a favourable position for developing novel Space Weather related products and services. In this presentation we will present novel results from the Swarm mission and discuss the value added and complementarity of joint Swarm EISCAT/EISCAT-3D coordination.
Anja Stromme, ESA

Fasil Tesema *University of Bergen*

Local mapping of polar ionospheric electrodynamics around EISCAT

The local mapping of polar ionospheric electrodynamics (Lompe) technique combines ground magnetometer data, space magnetometer data, radar and satellite measurements of ionospheric convection, and estimates of ionospheric conductance to a coherent picture of the 2D ionospheric electrodynamics in a region of interest. The technique is based on a spherical elementary current system representation of the electric field. The extent of the analysis region, and the resolution with which the elementary functions are positioned, is flexible. In this presentation we discuss how the Lompe technique can be used to provide a large-scale context for upcoming measurements from EISCAT3D, and also how it can be used to combine the EISCAT3D measurements itself to a high-resolution map of ionospheric electrodynamics in the radar's field of view.

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Habtamu Wubie Tesfaw *University of Oulu*

Estimating regional electric field from EISCAT_3D measurements

The EISCAT_3D incoherent scatter radar offers a unique capability to observe the ionosphere from multiple angles using its multistatic multibeam setup. From the three-dimensional F region ion velocity data, one can estimate the electric field , which can be mapped down to the ionospheric E region along the geomagnetic field lines, provided that the field lines are in the state of equipotential. Together with other plasma parameters measured by the radar, this allows the study of ionospheric electrodynamics in the E region. However, the radar measurements are made along line-of-sight beams, and the electric field can be mapped down only to limited points in the E region.

To obtain detailed picture of the ionospheric electrodynamics, we developed a model based on the spherical elementary current system (SECS) technique that can estimate the F region electric field at any point within the EISCAT_3D volume. The SECS amplitudes are estimated by fitting the local potential model to all F region electric field measurements. In its first phase of operations, EISCAT_3D will be providing only monostatic line-of-sight ion velocity measurements. For such scenario, we test how well the SECS model can be fitted to the line-of-sight velocities, in stead of the full velocity vectors.

Performance of the models is demonstrated by simulating the EISCAT_3D measurements using the E3DOUBT package (https://github.com/Dartspacephysiker/e3doubt.git), which can be used to estimate uncertainties of the EISCAT_3D observations. In our tests, we obtained the plasma parameters from the three-dimensional ionospheric fluid-electrodynamic model called GEMINI (https://github.com/gemini3d/gemini3d.git). The GEMINI model was run over the EISCAT_3D operational region for close to real ionospheric conditions, and produces the ionospheric electron density and temperature, ion temperature, and the three-dimensional ion velocity.

In general, uncertainty of the ion velocity is high, but the SECS based local potential fitting shows good performance when radar integration period per beam is above 10 s for quiet ionosphere. Results are better when tristatic velocity measurements are available, but even the monostatic line-of-sight velocity measurements produce usable results in favorable conditions.

Habtamu Tesfaw, Heikki Vanhamäki, Ilkka Virtanen, Spencer Hatch, Jone Reistad, Karl Laundal, and Matt Zettergren

Neethal Thomas *Sodankylä Geophysical Observatory, University of Oulu, Finland*

Observations of negative ions in the D-region ionosphere using EISCAT VHF spectral width measurements

The plasma in the ionospheric D-region altitudes is composed of positive ions, negative ions, and electrons. We have extracted information on negative ions in the D-region altitudes by analyzing the power and spectral shape of the incoherent scatter (IS) signal obtained from EISCAT VHF radar. IS spectral parameters are estimated from the backscattered signal autocorrelation function by fitting the D region lag profiles (pulse-to-pulse fitting). VHF measurements during three solar proton events with significant ionization down to 60 km altitudes are studied. IS spectral width, carries information on negative ions in addition to neutral temperatures and ion-neutral collision frequency, with an increase in negative ion density resulting in increased spectral width. As negative ions are destroyed by photodetachment during sunlit hours, they can be observed in incoherent scatter measurements as a decrease/increase in spectral width during sunlit/dark hours. Our case studies demonstrate this change in spectral width during terminator hours, indicating the presence of negative ions. The observations are compared with the Sodankylä Ion and neutral chemistry (SIC) model. The modeled negative ion-to-electron density ratio is found to be consistent with the IS spectral width measurements. Our study indicates that the total backscattered power in the D-region altitudes is modified by the presence of negative ions.

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EISCAT_3D as part of the European Arctic Science Landscape

Here we discuss the new EISCAT_3D radar in the context of complementary instrumentation envisaged and already available in the Nordic countries, and present thoughts on how to organise the EISCAT User Group to facilitate the best possible interaction and collaboration for future EISCAT science.

A lot of complementary instrumentation is available through the geophysical observatories operating in Norway, Sweden, and Finland, i.e., Tromsø Geophysical Observatory, Kiruna Atmospheric and Geophysical Observatory, Sodankylä Geophysical Observatory, Kjell Henriksen Observatory, Finnish Meteorological Institute, and the Institute of Space-Earth Environmental Research at the Nagoya University. New instruments are already being established, e.g. the Scanning Doppler Imager (SDI_3D) and additional meteor radar capabilities.

From EISCAT's perspective, the most critical questions regarding "complementary" instruments are about the future of the EISCAT Heating and the EISCAT Svalbard Radar.

What other instrumentation do EISCAT users wish for to complement EISCAT_3D?

Thomas Ulich and the EISCAT Staff; EISCAT Scientific Association, Kiruna, Sweden

Jaroslav Urbar *IAP CAS*

PLANS FOR DEPLOYMENT OF IONOSPHERIC HF DOPPLER SYSTEM IN NORTHERN SCANDINAVIA, MONITORING INFRASOUND AND 3-D PARAMETERS OF GRAVITY WAVES

Atmospheric gravity waves (GWs) represent an important wave mode that propagates at periods longer than about 5 min. GW enable the interaction, „coupling“ of the lower and upper atmosphere, influencing the dynamics of the region in which they dissipate. That causes perturbations in the ionosphere, which influence propagation of electromagnetic waves.

Multipoint Czech Continuous Doppler Sounding System (CDSS) allows monitoring the GW occurrence with individual reflection points corresponding to different sounding paths (transmitter-receiver pairs), its multifrequency option enables height-resolution as different frequencies are reflected simultaneously from different heights between ~150 and ~260 km, depending on ionospheric conditions which are monitored by the ionosonde. As CDSS deployment is currently envisaged in northern Norway, the actual reflection heights will be obtained by ionosonde operated in Ramfjordmoen near Tromso.

CDSS were deployed at several places in Europe and in South Africa, but are in operation also in areas with enhanced variability of low-latitude ionosphere (at crest of equatorial ionization anomaly) in northern Argentina and Taiwan.

The HF Doppler ionospheric measurements can along with identification of medium scale wave activity and infrasound indicate also the GNSS SPP positioning deviations.

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Observing ionospheric equivalent currents and mesospheric neutral winds with the Electrojet Zeeman Imaging Explorer (EZIE)

The Electrojet Zeeman Imaging Explorer (EZIE) mission will study the auroral electrojets using remote sensing of the associated magnetic perturbations. EZIE was selected as a NASA Heliophysics mission in December 2020, and is currently under development for a launch in October 2024. The mission consists of 3 identical 6U CubeSats, each carrying 4 compact spectropolarimeters looking downward at near-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 in the volume where the emissions originate, which in this case is around 80 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 planned data products, including 2-dimensional maps of the ionospheric equivalent current at auroral and equatorial regions, and mesospheric neutral wind around the satellite orbit. In preparation for the mission, comprehensive Observing System Simulation Experiments (OSSE) have been carried out to test the analysis algorithms and asses the quality of the data products.

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Current status of the EISCAT Heating facility

Status update of the EISCAT Heating facility and current activities

-EISCAT
-UiT

Roger Varney *University of California Los Angeles*

AMISR Investigations of E-region Farley Buneman Heating

Intense Hall currents in the E-region ionosphere can trigger the Farley-Buneman instability (FBI). The associated anomalous electron heating (AEH) will raise the electron temperatures to several thousand Kelvin in a narrow layer between 100 and 120 km altitude. This AEH signature is readily identified in incoherent scatter radar (ISR) data. We present comprehensive surveys of AEH observed by the Advanced Modular Incoherent Scatter Radars (AMISR) at Poker Flat (PFISR) and Resolute Bay (RISR). We have identified over 500 AEH events in the PFISR database from 2010-2023. A linear relationship is observed between electron temperature and electric field magnitudes. The auroral-zone AEH observed by PFISR shows correlations with geomagnetic activity and the solar cycle. The auroral-zone AEH systematically prefers local times near dusk or dawn, and no significant seasonal preference is observed. The polar cap AEH events observed by RISR, however, occur under very different conditions from auroral-zone AEH. Most RISR AEH events are observed between 16-21 magnetic local time during times when the interplanetary magnetic field (IMF) is either northward (positive Bz) or dominated by the By component. We interpret the polar cap AEH events as being directly driven by lobe reconnection events that create fast flows in the polar cap.

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Juha Vierinen *UiT*

Adaptive Methods for Processing Incoherent Scatter Radar Data at Millstone Hill

Man made radio interference and rapidly increasing space object radar echo count pose a challenge for the collective Thomson scatter radar method of observing ionospheric plasma parameters. The Millstone Hill radar currently
suffers from nearly constant interference due to space object echoes, which is most problematic at an altitude of 550 km. Various intentional and unintentional terrestrial radio transmissions also cause nearly constant interference, posing a challenge to observing weak ionospheric returns. Strong out of band interference can also cause
the receiver to become non-linear and change the receiver gain. In this study, new methodology mitigating the adverse effects of radio interference and space object echoes when analysing collective Thomson scatter radar measurements. This icludes estimation of autocorrelation functions and spectra of the ionospheric scatter from raw voltage and fitting ionospheric plasma-parameters to these estimates in a more robust manner. The methods are demonstrated using the Millstone Hill 440 MHz radar system. These new methods greatly reduce the The analysis routines are written with the Python programming language and available as open source. The software allows reanalysis of raw voltage measurements taken with the Millstone Hill incoherent scatter radar. Finally, a discussion on how these methods could be applied to EISCAT 3D is provided.

Juha Vierinen(1), Philip J. Erickson(2), William C. Rideout(2), Frank D. Lind(2), Ryan Volz(2), Shun-Rong Zhang(2), Ercha Aa(2), John Swoboda(2), Anthea J. Coster(2), Larisa Goncharenko(2)

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Juha Vierinen *UiT*

MAARSY Observations of the Geminids Meteor Shower

The Geminids is one of the most prominent meteor showers. The parent body is thought to be the asteroid 3200 Phaeton, but a great deal of uncertainty related with the origin of this dust stream still exists. The MAARSY radar in Andenes, Norway, has collected radar measurements in the months of November and December for seven years between 2016 and 2023. This study expands on previous radar studies of the Geminids shower, providing significantly larger meteor head echo dataset of the Geminids shower than previously shown. The orbital elements and masses of meteors associated with the Geminids shower are compared with those of the sporadic background. The upcoming EISCAT 3D radar has great potential for meteor science. A discussion of how this new radar could contribute to meteor observations is included.

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Ilkka Virtanen *University of Oulu*

F region ion composition in Svalbard during the IPY

The most abundant ion species in the E and F region ionosphere are the molecular NO+ and O2+, and the atomic O+. A smooth transition from purely molecular ions in the E region to atomic ions in the F2 region takes place in the F1 region. Properties of this transition are poorly known, because it takes place at too low altitude for long-term satellite observations, and incoherent scatter radars suffer from the temperature-ion mass ambiguity that makes simultaneous fits of both the O+ ion fraction and the ion temperature extremely demanding. Using GUISDAP and the Bayesian Filtering Module (BAFIM) coupled with the Ion Density Calculator (IDC) chemistry model, we have fitted F region O+ ion concentrations to data from the almost continuous ESR run during the International Polar Year 2007-2008. We find that the O+ to molecular ion ratio is strongly controlled by photoionization, with smaller effects from ion temperature variations. The molecular-to-atomic ion transition altitude undergoes diurnal variations with a day-time minimum and a morning maximum, except during winter, when lack of photoionization produces a local day-time maximum. The molecular-to-atomic ion transition altitudes are clearly lower than those predicted by the IRI-2020 model.

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Plasma parameter error modeling for EISCAT3D

A key question in incoherent scatter radar and their operation mode design is the statistical accuracy of plasma parameter estimates one can achieve with a given radar system and operation mode in given conditions. The conditions are particularly important for the incoherent scatter radars, whose SNR is controlled by the highly variable ionospheric electron density. The ISgeometry package that calculates so-called ACF noise levels using the radar equation and known background noise temperature was developed for purposes of EISCAT3D site selection. As the radar system will be soon available to users, the possibility to model its measurement errors has gained increasing interest. We have upgraded the ISgeometry package to make it more user-friendly and validated the package by means of comparisons with GUISDAP error estimates. With the latest version the output are standard deviations of plasma parameters, and a separate e3doubt frontend provides access to ionospheric models and beam scan pattern selection. The validation results show that the package provides good order-of-magnitude estimates of the measurement errors. The package is not restricted to EISCAT3D, but it can be used also for other radar systems and for designing completely new incoherent scatter radar facilities.

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Daniel Whiter *University of Southampton, UK*

Embla: A new optical instrument to measure auroral precipitation, neutral temperature and electric fields at high resolution

We have constructed a new high-resolution auroral imager, called Embla, to simultaneously measure energy and flux of auroral precipitation, neutral temperature, and electric fields in fine scale aurora. Embla is designed primarily for studies of auroral electrodynamics, substorm onset, and neutral heating by aurora. The instrument has recently been installed at Skibotn, Norway, very close to the EISCAT_3D radar transmitter site, and we expect the combination of radar and optical observations to enable better measurements for our science than either instrument can provide alone.

Embla builds on work done using the Auroral Structure and Kinetics (ASK) instrument, which has been stationed at the EISCAT Svalbard Radar since 2007. Embla has a spatial resolution in the E-region of ~30 m and a planned temporal resolution of at least 32 frames per second, allowing us to resolve the fine-scale structure and rapid dynamics of auroral features. It consists of 4 co-aligned imagers with identical 9 degree fields of view centred on magnetic zenith. Each imager is equipped with a different narrow passband interference filter, targetting emissions in N_2 1P (2 imagers), OI 777.4 nm, and O^+ 2P. The combination of N_2 1P and OI 777.4 nm observations allows us to image the characteristic energy and flux of auroral electron precipitation. The O^+ 2P emission has a long lifetime of 5 s, providing a means to observe ion drift perpendicular to the magnetic field and therefore a way to determine ionospheric electric fields at very high cadence in localised regions around the aurora. Finally, by combining observations from two of the imagers in separate regions of the N_2 1P band we can image the neutral temperature at the altitude of the auroral emission. The simultaneous measurement of these properties of the aurora and ionosphere will allow us to investigate auroral electrodynamics in detail.

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Darren Wright *University of Leicester*

Combined radar experiments with HAIRS and EISCAT_3D

EISCAT and SuperDARN have enjoyed a long and fruitful collaboration for many years with EISCAT's high spatial and temporal measurements being complemented by observations of ionospheric phenomenon over a larger multi-beam field of view provided by the former Hankasalmi (Finland) and Pykkvibaer (Iceland) radars.

The Hankasalmi Auroral Imaging Radar System (HAIRS) is a new state-of–the art digital imaging radar system, due for deployment in Summer 2024. HAIRS will look northwards from Hankasalmi in Finland, having a field of view centred over the Svalbard region, revealing the ionospheric cusp region electrodynamics at high spatial and temporal resolution over a 1 million square kilometre region of the ionosphere.

The EISCAT_3D field of view will lie within the region imaged by HAIRS and together these two instruments will provide studies of auroral electrodynamics at unprecedented resolution. Their digital capabilities will facilitate improved ways of investigating auroral phenomenon.

The main purpose of this presentation will be to provide an update on HAIRS and some of the anticipated common science goals shared with EISCAT_3D. One notable example will be observations in conjunction with low earth orbit measurements of the precipitating energetic particle signatures from the twin TRACERS spacecraft, which will facilitate the investigation of the temporal and spatial structuring of reconnection processes in the cusp.

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<u>Altitude descent and intensity overshoot of HFPL and HFIL observed by EISCAT-UHF-ISR</u>

1.Observable waves of incoherent scatter radar (ISR)Following the dispersion relation, the wave number of plasma waves depends on the traveling path. The ISR can only observe those plasma waves satisfying the Bragg condition.2.Two classical features excited by the pump(1)Altitude descents of the high frequency-enhanced ion line (HFIL)and plasma line (HFPL) An explanation [Ashrafi et.al., 2007] is that the altitude descents of the HFIL and HFPL are a result of the descent of the pump waves' resonance region, namely, due to the change in the profile of electron density. Here, an alternative explanation [Wu et.al., 2021] is that the HFIL and HFPL altitudes are governed by the dispersions of ion-acoustic waves and Langmuir waves respectively, and descend as a result of the significantly enhanced electron temperature on the traveling path of the enhanced ion-acoustic waves and Langmuir waves. As shown by the dispersion function of ion-acoustic waves, the significantly enhanced electron temperature should be matched by a larger mass of ion locating at a lower altitude, where the enhanced ion-acoustic waves meet the Bragg condition and the HFIL can be observed. Similarly, the significantly enhanced electron temperature should be matched by a smaller electron density locating at a lower altitude, where the enhanced Langmuir waves meet the Bragg condition and the HFPL can be observed.(2)Overshoot of HFPL and HFIL An explanation for the overshoots in the HFPL and HFIL[Showen and Kim, 1978] is that the pump becomes strongly reduced before it arrives at the parametric resonance altitude, either by anomalous absorption or by an electron density irregularity that scatters the pump.Our alternative explanation [Wu et.al., 2019] is that the enhanced electron temperature as well as the thermal conduction, on the traveling path of the enhanced ion-acoustic waves and Langmuir waves, may lead to the overshoots in the HFPL and HFIL. It is well known that the growth times of the parametric decay instability (PDI) and the oscillation two-stream instability (OTSI) are on the order of milliseconds, and the growth time of electron temperature is on the order of seconds. At the initial stage of evolution after the pump turns on, electron temperature on the traveling path of the enhanced Langmuir and ion-acoustic waves has not been greatly enhanced, and the enhanced Langmuir and ion-acoustic waves should exactly satisfy the Bragg condition at a particular altitude, where the strong HFPL and HFIL are observed by ISR. After the initial evolution, electron temperature is greatly enhanced on the traveling path of the enhanced ion-acoustic waves and Langmuir waves, and the wavenumbers of the enhanced ion-acoustic waves and Langmuir waves should significantly change by following their dispersion, and remarkably deviate from the Bragg condition, so that HFPL and HFIL becomes weak in intensity.

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The status of Sanya Incoherent Scatter Radar Tristatic System

Low latitude ionosphere experiences complex dynamical and electrodynamical processes, which makes the spatiotemporal variations of the corresponding electron density complicated and therefore influences trans-ionosphere radio communications. The monitoring of low latitude dynamical drivers, such as neutral wind and ionospheric electric field, is essential for both dynamic mechanism investigations and applications. The Sanya Incoherent Scatter Radar Tristatic System (SYISR-TS) was proposed with the main objective of low latitude ionospheric monitoring and investigation and has been successfully developed over the past decade. The system consists of the Sanya (18.3oN, 109.6oE) trans-receiving main station with key parameters of ~1600 m2 antenna aperture, >4 MW peak power, <120 k system noise temperature, and ~46 dBi normal gain, and Danzhou (19.5°N, 109.1°E) and Wenchang (19.6°N, 110.8°E) receiving only stations with key parameters of ~790 m2 antenna aperture, <130 k system noise temperature, and ~43 dBi normal gain. Three stations form a quasi-equilateral triangle at Hainan Island and uses GNSS satellite common view technique to achieve the time synchronization with the uncertainty of the timing and time synchronization is less than 50 ns and 10 ns, respectively. Initial collaborative satellite tracking and ionospheric common volume experiments among three stations have confirmed the detection ability of SYISR-TS and the feasibility of achieving its scientific goals in the futur

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Local Simulation of the High-latitude Ionospheric Dynamics: improving model resolution and drivers

Major challenges for high-latitude ionospheric modeling include the need to (a) simulate relatively fine-scale structures (~1-10 km for our purposes), and (b) incorporate realistic magnetospheric and atmospheric energy and momentum coupling (through energetic particles, fields, and mechanical means). It can often the case that the most intense impinging energetic particle fluxes in auroral regions are associated with small-scale structures suggesting that such features likely play a significant role in IT responses at high latitudes — both in terms of dissipation of energy from the magnetosphere and IT responses (flow channels, plasma density structuring, and traveling atmosphere-ionosphere disturbances). Further, certain types of meso-scale (100-1000+ km) plasma structures have a propensity to undergo unstable cascade to smaller scales that become important as a source of radio wave refraction and diffraction. To date, global simulations (typically having resolutions ~0.25-1 degree) are not able to resolve the range of scales in auroral arcs and various types of unstable plasma configurations so high-resolution local scale models have been employed in some past work; however, these are computationally expensive and have boundaries requiring careful treatment.

This work presents recent technical updates to and applications of our local-scale ionospheric modeling that attempt to address computational expense and need for realistic inputs. Our physics-based ionospheric model, GEMINI (https://github.com/gemini3d/), has been extended to include a partial implementation of adaptive mesh refinement (AMR) and to incorporate more flexible input energetic electron precipitation, electric field, and initial state data. GEMINI is used to provide example event simulations of auroral arc effects on the ionosphere (e.g. ionization, currents, heating, and upflow) and the evolution of polar cap patches (e.g. chemical decay and gradient-drift instability). These simulations use boundary conditions derived from from filtered all-sky cameras, incoherent and coherent scatter radar, and in situ data (where available) — the conversion of these data sources into model-usable formats is itself a complex activity requiring adroit use of data assimilation and interpolation procedures which we also discuss briefly.

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Study of neutral wind inversion based on SYISR tri-system

The SYISR tri-system is a high-power, large-aperture phased array incoherent scattering radar located in the low latitude region of the ionosphere. Technically, it has the advantages of continuous observation, full spatial coverage, and rapid scanning. The line-of-sight velocity can be obtained by multi-beam detection, and then vector velocity can be obtained. The neutral wind of the ionosphere E region and F region can be further calculated by the ion vector velocity. The neutral wind are all consistent with the morphological changes of the ionosphere, and the accuracy is verified by comparing with empirical model, theoretical model, and other observation.

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List of Abstracts for Poster Presentations

Alphabetically ordered list of abstracts for all posters

Lindis Merete Bjoland *National Institute of Polar Research (NIPR)*

Long-term variations and trends in the polar E-region: An update

As the EISCAT UHF radar system in Northern Scandinavia started its operations in the early 1980s, the collected data covers several solar cycles. Bjoland et al (2017) investigated long-term variations and trends in the peak altitude of the Hall conductivity and the ion temperature around noon using data from 1981-2015. Their results indicated a weak descent (~0.2 km/ decade) in the peak altitude of the Hall conductivity and a cooling trend (~10 K/ decade) in ion temperature at 110 km, after adjusting for seasonal and solar cycle dependence. However, other factors than solar zenith angle and solar activity also influence the ion temperature at this altitude and a further investigation of these factors are necessary to derive a conclusive trend.

We present an update using the EISCAT database from 1981-2023 to investigate how the trends in the E-region have evolved since the previous study. Preliminary results indicate a consistent trend in the peak altitude of the Hall conductivity (~0.2 km/decade), while the trend in ion temperature at 110 km altitude appears weaker. However, the trend in ion temperature over Tromsø using the IRI model over the same period and at the same altitude shows a clear cooling trend of about 3 K per decade. In this paper we discuss the updated findings and explore seasonal variations of the trends.

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Lindis Merete Bjoland, NIPR
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Stephan C. Buchert *Swedish Institute of Space Physics*

Atmosphere-Ionosphere-Coupling and Joule heating

Loosely following works by Parker (1996) and Vasyliūnas (2012) we present a self-consistent description of an atmospheric dynamo and its power dissipation by Joule heating. Compared to other works and simulations a feedback of the dynamo action on the neutral dynamics is included. It simply consists of adding the Lorentz force jxB to the dynamic equations for the neutral gas or air, lifting the kinematc dynamo to a hyddomagnetic one. In proofing the validity of this (within the assumptions of magnetized electrons and ion-neutral collisions) a generalized Ohm's law of the form E=... (as in plasma physics) is presented for a cold ionosphere with given conductivity tensor. As usual, inserting this generalized Ohm's law into Faraday's equation results in a dynamo equation completing the set of dynamic equations for B and the neutral velocity u complying with Parker's B,u paradigm. However, we find that this determines the currents and electric field not completely because of generally spatially inhomogeneous conductivites and the Hall term. By setting both curl and divergence of E to zero an approximate complete description is obtained.

The meanings or semantics of Joule, frictional and Ohmic heating in the ionosphere have been discussed in previous works. In the frame of our description the locally dissipated power can be written as the square of the current density times a Cowling factor, that is as heating by dissipative currents.

Wind fields exist which do not drive any dynamo currents, and a uniform motion of conducting air along a direction of constant B, e.g. magnetically zonal wind in a dipole field, per se, have no electrodynamic effects. Generally, the term uxB with units V/m does not follow Maxwell's equations, Faraday's and Coulomb's laws for electric fields, and this leads to dynamo currents. jxB is forcing winds towards conditions where uxB complies with Maxwell and the dynamo vanishes, which is perhaps an analogy to Lenz's law. However, jxB competes with other forces like gravity, pressure gradients, Coriolie, etc. In the Earth's ionosphere the atmosphere-ionosphere coupling is weak and a zero-dynamo state is practically unlikely to occur.

The very high conductivity along the direction parallel to the geomagnetic field compared to the perpendicular Pedersen and Hall conductivities short-circuits parallel electric fields. To avoid dynamo currents and their dissipation, uxB needs to be constant along B. The observed solar-quiet (Sq) magnetic variations can be understood as consequencee of that neutral winds where uxB at magnetically conjugate points don't match. We estimate that the tidal Sq dynamo globally dissipates roughly a power of 2 GW quasi-permanently, and jxB forcing seems to be partially successful in aligning neutral winds magnetically.

Also atmospheric gravity waves (AGWs) involve variable wind fields where uxB generally is not constant along B. Thus they should cause electric currents within the dynamo region, dissipation and a damping of AGWs which propagate upward from the lower and middle atmosphere. This electromagnetic damping may exceed the one by the in the thermosphere only small viscosity.

The work should be relevant for answering the question whether dissipation associated with the atmospheric dynamo contributes to heating the thermosphere of Earth and other planets, and how the dynamo affects neutral winds.

Stephan C. Buchert, IRF Uppsala, Sweden

Stephan C. Buchert *Swedish Institute of Space Physics*

Local and global effects of the geomagnetic storm on Mach 23-24, 2023

On March 23-24, 2024, a Kp 8+ geomagnetic storm occured, with a complex development of the IMF and therewith a complex course. The active phase of the storm was covered, among many different instruments, by EISCAT KST and ESR and by Swarm A and C orbiting in post-sunset/pre-sunsrise orbits. Local effects, electric currents and fields, Joule heating, and precipitation are investigated as well as more global ones such as a roughly 100 % increase of the neutral density at ~500 km altitude and a supression of equatorial plasma bubbles. The fortunate combination of various observations allows to complement our quantitative understanding of these in principle well-known characteristics of geomagnetic storms.

Stephan Buchert, IRF Uppsala, Sweden

Rebecca Coulson *University of Leicester, UK*

Investigating the impact of energetic particle precipitation on middle atmosphere climate chemistry using high altitude measurements of NO in conjunction with EISCAT.

The influence of geomagnetic activity on the magnetosphere-ionosphere-neutral atmosphere coupled system has been well documented to impact the middle atmosphere's climate chemistry. It has now been considered as a driver for influencing the presence of chemical species which can react catalytically to deplete ozone. It is important to understand the mechanism of ozone, as its removal in the stratosphere can have vital consequences for the environment and heating of our planet. This is a multi-instrumental study which combines satellite measurements and radar with aims to link the energy transfer from energetic particle precipitation (EPP) to the formation of nitrous oxide (NO) in the mesosphere via the direct effect and stratosphere via the indirect effect. This study utilises the comprehensive solar occultation for ice experiment (SOFIE) dataset, extending the work by Smith-Johnsen et al. (2017), to determine the relative change in NO density over the solar cycle from 2008 to 2019. This will be used alongside the EISCAT database to analyse the variability in the NO density following periods of intense geomagnetic activity and associated EPP. EISCAT provides a wealth of information about the electron density profiles associated with these events. The next stage will be to identify specific events where the direct and indirect effects have occurred. The direct effect will correlate with events where the electron density enhancements are constrained to higher altitudes and are collated with localised NO enhancements. The indirect effect will be identifiable when the NO formed during direct events have been transported in altitude and latitude. Some of these events already been identified for the year of 2010 and we are continuing this over the whole solar cycle to provide a greater understanding of how solar variability influences our climate.

Rebecca Coulson, University of Leicester, UK
Dr Darren Wright, University of Leicester, UK

Mizuki Fukizawa *National Institute of Polar Research*

Feasibility study to estimate the ion velocity field in the F region from EISCAT_3D radar observations

We conducted a feasibility study to estimate the ion velocity field in the ionospheric F region from ion velocities observed by the EISCAT_3D radar. We assumed a 27-beam configuration with a minimum elevation angle of 30 degrees. The beam configuration was determined so that the latitude intervals were equally spaced at 250 km altitude for low-elevation beams and that observations could be made at the same magnetic field lines for high-elevation beams. Assuming that ions above 200 km altitude follow the E x B drift, observed ion velocity data from 200 to 500 km altitude were projected to 200 km altitude. Then, we reconstructed ion velocity vectors for ±250 km in the east-west direction and ±500 km in the north-south direction at 200 km altitude. The resolution in north-south and east-west directions was 25 km. The reconstruction was conducted by maximizing a posterior probability based on Bayes’ theorem. To solve the underdetermined problem, we set three constraints, which minimize the L2 norms of the following three vectors: (1) the second derivative of three components of the ion velocity vector, (2) the divergence of the ion velocity perpendicular to the magnetic field lines, and (3) the ion velocity parallel to the magnetic field lines. The weighting factor of each term was determined by maximizing the marginal likelihood.
The reconstruction accuracy was evaluated using a synthetic shear flow field with a maximum ion velocity of 1 km/s. The residual between the synthetic and reconstructed flow fields was 9.7% of the synthetic flow field on average. The root mean square error (RMSE) was 97 m/s. The reconstruction accuracy of the divergence of the electric field required to derive the field-aligned current was 66% on average and the RMSE was 0.12 mV/m2. The residuals were small in the central part but large where the data points are widely spaced. The beam configuration had the same latitudinal spacing at an altitude of 250 km, but the observation points projected along the magnetic field lines were shifted to the north due to the inclination angle of the geomagnetic field. As a result, the beam spacing was denser to the north of the core site and sparser to the south. When the beam alignment was rearranged so that the azimuthal spacing centred on the magnetic zenith at an altitude of 250 km was the same, the residual of the shear flow field and the RMSE reduced to 5.2% and 42 m/s, respectively. This unbiased beam arrangement around the magnetic zenith also reduces the dependence of reconstruction accuracy on the north-south position of the shear in the EISCAT_3D radar field of view.

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Shucan Ge *China Research Institute of Radiowave Propagation*

Impact of polar particle precipitation on HF signal at the Arctic shipping routes: a research study

The Arctic shipping routes, connecting the Atlantic and Pacific Oceans through the Arctic Ocean, are rapidly evolving and will have profound implications for global geopolitics and the economy. High-latitude communication is a critical element in ensuring the safe navigation of vessels along the Arctic shipping routes. However, existing single-station HF (High Frequency) signal communication systems are vulnerable to the challenging polar space environment, resulting in limited reliability and an inability to provide a secure guarantee for the safe navigation of vessels along the Arctic shipping routes. Therefore, it is imperative to study the impact of the polar ionospheric disturbances (such as particle precipitation) on HF signal propagation to assess the communication performance of coastal stations. In response to the communication needs of the Arctic shipping routes, a theoretical framework for evaluating HF signal communication coverage based on deterministic models has been established. Furthermore, the calculation methods for power in complex refractive index ray tracing have been focused on. We evaluated the communication effects of HF signal networking along the Arctic shipping routes, and researched the impact of polar ionospheric disturbances, such as high-energy particle deposition, on the HF signal propagation effects in polar. This research provides a solid theoretical basis for assessing the communication effectiveness of HF signal access networks and the design of station networks for communication along the Arctic shipping routes.

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Maxime Grandin *University of Helsinki, Finland*

Advances in auroral and subauroral research leveraging citizen science: an ARCTICS story

With the tremendous technological improvement of commercial cameras and smartphones, a growing number of (professional and amateur) auroral photographers capture high-quality images of the nightsky. This novel type of optical data has enabled the discoveries of previously unknown optical emission displays which reveal the presence of complex and unexplored processes at work in the near-Earth plasma. Those discoveries are the result of what is known as "citizen science", i.e. scientific research involving contributors outside the academic world and who provide data and are co-authors of the resulting publications. Typically, auroral citizen science has been combining astrophotographers' pictures with observations from ground-based instruments and satellites, hence requiring a multidisciplinary approach and a broad range of expertise and skills.
The ARCTICS (Auroral Research Coordination: Towards Internationalised Citizen Science) Working Group sponsored by the International Space Science Institute in Bern brings together academics and citizen scientists from Europe, North America and Oceania to investigate auroral and subauroral physics. We combine citizen scientist observations with satellite and ground-based measurements to shed light on elusive optical phenomena such as STEVE, the dunes, fragments, and continuum emission. We also set up a Handbook to provide guidance and recommendations for collaborations between academics and citizen scientists to be as smooth and fruitful as possible.
With this poster, we will give an overview of the ARCTICS collaboration and highlight some of its first results.

Maxime Grandin(1), Bea Gallardo-Lacourt(2,3), Mathieu Barthelemy(4), Emma Bruus(5,6), Rowan Dayton-Oxland(7), Eric Donovan(8), Katie Herlingshaw(9), Eero Karvinen(6), David Knudsen(8), Donna Lach(10), Vincent Ledvina(11), Carlos Martinis(12), Lena Mielke(9), Toshi Nishimura(12), Noora Partamies(9), Chris Ratzlaff(10), Marjan Spijkers(13), Neethal Thomas(5), and the ARCTICS WG external collaborators

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(10) Citizen Scientist, Canada
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(13) Citizen Scientist, Netherlands

Aspect angle effect on ISR plasma lines.

In the Incoherent Scatter Radar (ISR) spectrum, we detect significant scattered power at frequencies corresponding to plasma electrostatic modes imposed by the radar's wavenumber and geometry. The commonly occurring resonant frequencies are ion and plasma lines. Ion lines are signatures of ion-acoustic waves travelling towards and away along the scattering direction and are always observable. Plasma lines are signatures of high-frequency electrostatic Langmuir or upper hybrid waves and are observable when enhanced above the thermal level in the presence of a suprathermal electron population.

We use a suprathermal electron velocity distribution function derived from an electron transport code to model the plasma line frequency at arbitrary angles to the magnetic field. We compare the model results with the measurements derived from EISCAT Tromsø UHF radar. We also explore the correlation between plasma line enhancement and features in the electron velocity distribution function.

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Keisuke Hosokawa *University of Electro-Communications*

Optical manifestation of cold dense plasma sheet and subsequent appearance of extremely bright aurora

Here we report a unique interval of faint reddish aurora, followed by extremely bright greenish aurora, captured in Tromsoe and Skibotn, Norway on the night of November 12, 2023. The faint reddish aurora appeared in the pre-midnight sector and continued for more than 4 hours, manifesting continuous low-energy electron precipitation without any substorm activities. During the later half of this interval of faint reddish aurora, EISCAT UHF radar observed intense ionization in the F region (say above 200 km), which is consistent with the continuous appearance of the faint reddish aurora at high-altitudes. Subsequently after the prolonged interval of faint reddish aurora, extremely bright greenish aurora appeared indicating that substorm occurred with precipitating electrons whose flux was much higher than usual. IMF was strongly northward during the faint reddish aurora and turned southward slightly before the appearance of extremely bright greenish aurora. During prolonged intervals of northward IMF, cold and dense plasma population is often seen in the plasma sheet, which is known as cold dense plasma sheet (CDPS). Plasma density and temperature in the CDPS correlate with those in the solar wind during the northward IMF period, indicating that the solar wind is the source of plasma in CDPS. The faint reddish aurora in the evening of Nov 12, 2023 may be a signature (i.e., optical manifestation) of CDPS in the magnetotail, which has not been captured ever from the ground at the auroral latitudes. We speculate that CDPS was being formed during the prolonged period of northward Bz from ~14 UT on Nov 12 without any substorm activities. Sudden southward turning of IMF at around 24 UT on Nov 12 led to the occurrence of substorm with well-accumulated cold/dense plasmas in the plasma sheet. The prolonged northward Bz condition and subsequent southward turning of IMF probably made this observation largely different from typical aurorae. The successive occurrence of faint reddish aurora and bright greenish aurora indicates that ground-based optical observations in the aurora zone can be used for diagnosing the formation of CDPS and subsequent release of dense plasmas stored in the magnetotail.

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Ingemar Häggström *EISCAT Scientific Association*

The EISCAT software tools in Jupyter notebook

The present era of rapid technological advances creates a challenge for data providers and scientists to create and maintain FAIR data and services not just for future operations but also for historical data gathered and analysed with technologies that are slowly phasing out of their usage. The EISCAT tools are open source software package, written in general environments (Matlab, C, Fortran, python...) and provided and maintained by EISCAT, for analysis and visualisation of its incoherent scatter radar data as well as for some other radars in the world. As the new incoherent radar system (EISCAT_3D) is built, the current mainland radar systems will cease their operations. Thus, the development and maintenance of the compatibility of the tools with newer computational technologies will become more challenging.
One way how to preserve operability and accessibility by the user community is to make it accessible through a Jupyter notebook docker deployment through EISCAT resources. This will help to ensure the FAIRness of historical EISCAT data by providing tools for reanalysis and visualisation that will be accessible by any potential EISCAT user. This poster will present tools for the EISCAT radars, (GUISDAP, RTG, madrigal,...) in a Jupyter notebook environment.

Ingemar Häggström and Mária Mihálikova
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In-situ observations of plasma blob inside the nightside auroral region and features of small-scale irregularities

Polar cap patches can be pulled in the nightside auroral region to form plasma blobs that are often associated with significant small-scale ionospheric irregularities. These irregularities can cause considerable GNSS scintillations. A few plasma processes have been proposed to explain the significant enhancement of small-scale irregularities. Due to the potential adverse space weather impact, more investigations are needed for better understand the detailed plasma processes of such phenomenon. In this study, we present a case of plasma blob using coordinated ground-based and in-situ measurements. On February 19, 2015, the ground-based TEC maps show a series polar cap patches exiting into the nightside auroral region. The observations from the EISCAT Svalbard and UHF radars further confirm the newly formed plasma blobs. These plasma blobs are associated with rapid equatorward flows and electron temperature enhancements. The all-sky images at Skibotn indicate that auroral streamers were observed with the plasma blobs. The ICI-4 sounding rocket was successfully launched to target one plasma blob. The high-resolution (8.68 kHz) in-situ electron density measurements show significant small-scale irregularities. To characterize the irregularity, the power spectral density of the electron density fluctuations is computed. Very steep spectral slopes (k ~ -5) are observed both in the region of inverted-V and in a region without particle precipitation. This suggests that drift wave instability may play a role in the diffusion of small-scale irregularities.

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Stefan Johansson *Dept of Computing Science, Umeå University*

Efficient Computation of Ionospheric Volumetric Images for Real-time Interpretation of EISCAT 3D Data

The upcoming EISCAT_3D system in the northern Fennoscandia region will be capable of generating the highest resolution ISR datasets that have been ever measured. We present a novel computational strategy for the generation of high-resolution and smooth volumetric ionospheric images that represent ISR data. Through real-time visualization, our computational framework will enable a fast decision-making during the monitoring process, where the experimental parameters can be adapted in real time as the radars monitor specific phenomena. The proposed strategy employs an efficient mesh generator combined with an optimized sparse interpolator specialized for ISR technologies. The framework has been extended for the estimation of ionospheric conductivities and post processing of derived physical quantities by employing Finite Element discretizations of plasma models.

In our strategy, a structured mesh is generated by employing a Transfinite Interpolation combined with a parametrization of the convex hull of radar measurements dictated by ISR programmes. The sparse interpolation of the ISR data consists of a specialized implementation of Inverse distance weighting. The explicit interpolation strategy takes account of the challenging cases of missing data and multi-scalar interpolation, where we reuse the weights of each interpolation-data point. Furthermore, we have structured the data to minimize cache misses and promote efficient vectorized operations. Finally, we efficiently parallelized our implementation for multi-core architectures with OpenMP and computations confirm outstanding speed-ups of our strategy with execution times that allows for real-time usage.

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Madelen Bodin, Umeå University
Stefan Johansson, Umeå University
Francisco Lopez, Umeå University
Assar Westman, EISCAT Scientific Association

Andreas Kvammen *UiT - The Arctic University of Norway*

Simulations of the Kelvin-Helmholtz Instability in the Polar Ionosphere

The Arctic ionosphere is highly structured with plasma irregularities observed across a wide range of scales. These irregularities are significant as they can interfere with Global Navigation Satellite Systems (GNSS) and disrupt High Frequency (HF) communications. However, the mechanisms driving the formation of these irregularities and the cascading from large to small scales are poorly understood. This presentation examines the formation and evolution of one of the most commonly invoked meso-scale instabilities at high latitudes: the Kelvin-Helmholtz instability. This instability can be excited when there exists a shear in the flow velocity. At polar latitudes, such shears are associated with reverse flow events, auroral arcs, and polar cap patches.In this study, we utilize the 3D Geospace Environment Model of Ion-Neutral Interactions (GEMINI) [1] to simulate the development of the Kelvin-Helmholtz instability under varying ionospheric conditions. We present results from 27 simulations, each initialized with a unique set of parameters relevant to the instability [2], specifically: mean electron density, velocity shear strength, and shear length. Our analysis of these simulations has 3 main conclusions:1.The Kelvin-Helmholtz instability forms more rapidly under conditions of high-velocity shears or short shear lengths, with formation times ranging from a few minutes to over 30 minutes. The effect of the total electron density is complicated. 2.The growth of the logarithmic perturbation strength is imprecisely characterized by a linear function, despite a linear approximation often being assumed, and is better described by a 2-stage linear function. 3.The spatial growth of the instability progresses into the nonlinear regime, extending beyond the saturation point of perturbation strength.These results can be used as a reference to better understand observations of turbulent conditions near flow shears at polar latitudes.[1] M. D. Zettergren and J. B. Snively, “Ionospheric response to infrasonic-acoustic waves generated by natural hazard events,” Journal of Geophysical Research: Space Physics, 120(9), 21, September 2015, pp. 8002–8024,doi: https://doi.org/10.1002/2015JA021116.[2] M. J. Keskinen et al., “Nonlinear evolution of the Kelvin-Helmholtz instability in the high-latitude ionosphere,” Journal of Geophysical Research: Space Physics, 91(A1), 1, January 2015, pp. 137–152, doi: https://doi.org/10.1029/JA093iA01p00137.

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Sophie J Maguire *Space Environment and Radio Engineering (SERENE), University of Birmingham*

Large-scale plasma structures and scintillation in the high-latitude ionosphere

The Earth's ionosphere is a highly variable medium with the ability to affect the propagation of trans-ionospheric radio signals. In the high-latitude ionosphere, large-scale structures, such as polar cap patches and blobs, can be formed by a range of mechanisms. These larger-scale structures can seed smaller-scale irregularity generation as a result of instability mechanisms. It is these smaller-scale irregularities which can disrupt signals such as those used for GNSS. Similarly, in the high latitudes, the presence of auroral precipitation can also cause these effects.

To investigate large-scale plasma structuring and the scintillation effects that can occur, an EISCAT Special Programme named Scintillation and Plasma Density Gradients (SGRAD) ran in winter 2023. The aim of this campaign was originally to investigate whether a minimum electron density or density gradient was required in order for scintillation to occur. However, upon analysis of these results, the experiment yielded some interesting results. In one particular run, a polar cap patch was observed exiting the polar cap, due to transportation effects and entering the auroral oval. At this time, the plasma was further modulated and increased in density due to the presence of auroral precipitation. Therefore, the experiment directly observes multiple plasma formation mechanisms acting simultaneously on the same plasma and this exposes some interesting possibilities in the study of scintillation effects. This presentation will therefore discuss the concurrence of plasma formation mechanisms in the high-latitude ionosphere and the implications of this for GNSS scintillation.

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Subir Mandal *British Antarctic Survey*

To infer local thermospheric changes from simultaneous FPI and EISCAT measurements

The neutral dynamics that set the baseline conditions in the coupled ionosphere-thermosphere region are relatively well understood in terms of their large-scale variability. However, localised behaviours, which significantly influence thermospheric compositions, remain poorly understood due to insufficient measurements and model limitations. Therefore, identification and characterisation of such localised changes is crucial especially in the high latitudes where along with lower atmospheric forcings the short-lived space weather events can lead to meso-scale spatial structures. As part of the DRIIVE project, using long-term datasets we compare the neutral temperatures obtained from Fabry-Perot Interferometers (FPIs) in Kiruna, Svalbard, and Sodankylä, and all-sky measurement by SCANDI in Svalbard, against the ion temperatures derived from EISCAT to identify the possible thermospheric upwelling events. Comparison of neutral temperatures obtained from green line emission (various peak heights at ~90, 120 and 150 km) with those from red line emissions (~240 km altitude) will provide information on the vertical structure of the thermosphere. This, in combination with the vertical and horizontal winds measured by FPIs, and the all-sky horizontal wind field from SCANDI, will help identify and characterise the spatial structures due to thermospheric upwellings caused by localised Joule heating events. Further, we plan to estimate the neutral compositions during these periods from peak electron density and electron density height profiles obtained from EISCAT to bring out new insights in the thermosphere-ionosphere system. In this meeting, we will present the key findings from such analyses in detail.

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Maria Mihalikova *EISCAT Scientific Association*

EISCAT Virtual Organization – Identity and Access management for scientific community

The present era of rapid technological advances creates a challenge to create and maintain FAIR data and services. The number of services and amounts of data are growing and the access to them can seem to become more complicated. The need for identity and access management arises for the organizations providing the services.
The access to the data and to the present and future services offered by the EISCAT Scientific Association (like e.g EISCAT tools at EGI notebooks and EISCAT resources) needs to be made available to the present and future EISCAT users alike, while preserving the commitments of EISCAT to data availability and accessibility stipulated in the EISCAT Blue Book. To achieve these goals EISCAT Virtual Organization was created with the use of Perun system which in connection with the Single Sign-On service EGI Check-in offers a solution for identity and access management to online and computational resources while enabling users to still use their institutional and scientific accounts.
This poster will introduce the idea of the technology and organization of the EISCAT Virtual Organization (VO) together with the information about how to access and take advantage of this infrastructure which will gradually become essential for access to EISCAT data and services.

Mária Mihálikova (maria.mihalikova@eiscat.se, EISCAT Scientific Association), Ingemar Häggström (EISCAT Scientific Association)

Modelling of non-Maxwellian electron velocity distributions during heating in the ionospheric D-region

Artificial heating increases the electron temperature by transferring the energy of high power radio waves into thermal energy of electrons. Some studies show that current models most likely overestimates the effect of artificial heating in the D-region compared to observations [1, 2]. The electron velocity distribution may influence the modelling of electron temperature in the D-region during heating since a previous study has demonstrated the non-Maxwellian electron velocity distribution during heating [3]. Most following studies assumed a Maxwellian distribution. In a more recent study by [2], the authors speculate that the assumption of the Maxwellian electron velocity distribution may cause the discrepancy between model and observations. We implement the non-Maxwellian distribution from [3] with updated cross sections for the inelastic collision between electrons and neutral species. Furthermore, we are running a Monte Carlo simulation of electron velocity distributions from [4], adapted to the ionospheric conditions in the D-region, and with cross sections for both elastic and inelastic collisions between electrons and N2, O2 and O. The aim is to compare the distribution from [3] and [4], and in future work compute electron cooling rates, which are needed to model the electron temperature. References:[1] A. Kero et al. (2007): «Statistical signature of active D-region HF heating in IRIS riometer data from 1994-2004». Ann. Geophys., 25, 407-415.[2] A. Senior et al. (2010): «Diagnosing radio plasma heating in the polar summer mesosphere using cross modulation: Theory and observations». Journal of geophysical research, vol. 115, A09318. [3] P. Stubbe (1981): «Modifying effects of a strong electromagnetic wave upon a weakly ionized plasma: A kinetic description». Radio Science, Volume 3, page 417-425.[4] B. Gustavsson et al. (2004): «Simulation of high energy tail of the electron distribution function». Adv. Polar. Upper Atmos. Res., 18, 1-9.

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Short-wavelength infrared auroral spectroscopy and imaging observations at 1.1 µm in the Kjell Henriksen Observatory, Longyearbyen (78.1°N, 16.0°E)

Dayside auroras and airglows are the key phenomena for understanding of dayside magnetosphere-ionosphere-atmosphere coupling processes. The phenomena are being monitored by ground-based optical instruments in high latitude region corresponding to the polar cap and cleft, but the observations are done at limited geographic locations and in a limited season in order to avoid sky background brightness. Alternatively, active and passive radio remote sensing such as HF/VHF/UHF radars, GNSS and LF wave receiver are effective, but spatial and temporal resolutions of those radio measurements are basically not sufficient in comparison to optical measurements. In accordance with this scientific background, two cutting-edge optical instruments in short-wavelength infrared (SWIR) region have been developed to measure aurora and airglow emissions in twilight and daytime: Near InfraRed Aurora and airglow Spectrograph-2 (NIRAS-2) and Near InfraRed Aurora and airglow Camera (NIRAC). Ground-based observations with the new two instruments have been initiated at the Kjell Henriksen Observatory (KHO), Longyearbyen Svalbard, (78.1°N, 16.0°E) since November 2022.

The NIRAS-2 is a brand-new SWIR imaging spectrograph designed for the wavelength range from 1.05 to 1.35 µm in which sky background brightness is lower than in the visible subrange. It targets at strong auroral emissions such as the N2+ Meinel (0,0) band (hereafter, N2+ (M)) and the N2 1st Positive bands (0,0 and 0,1) as well as at the airglow of the OH Meinel bands. The NIRAS-2 is composed of three SWIR lenses, three slits (30-, 60-, and 90-µm), two volume phase holographic gratings (VPHGs) (950 lpmm and 1500 lpmm), an optical filter to remove higher order diffraction light, and 2-D InGaAs FPA. Different types of slits and VPHGs can be switched by stepping motors and actuators, and therefore, a wavelength and spectral resolution of the observation target can be changed remotely. If the high-dispersion grating is used, spectral bandpass are 0.21 nm and 0.44 nm with the 30- and 60-µm slits, respectively. Its field-of-view (FOV) and angular resolution are 55 degrees and 0.11 degrees per pixel. Additionally, a brand-new SWIR imager, NIRAC, has been developed focusing on N2+ (M) auroral emissions. The imager consists of a few commercial SWIR lenses, plano-convex lenses, a custom optical filter (center: 1113 nm, FWHM: 13.8 nm) and a 2-D InGaAs FPA. The total optical system is fast (F-number 1.5) and the meridional coverage of the NIRAC (84° × 68°) is slightly wider than the meridional coverage of the NIRAS-2. The NIRAC can visualize two-dimensional structures of not only aurora but also even weak OH airglow emissions (typically a few kR) with a cadence of less than 30 s. Thus, the NIRAC is used as a twin instrument to the NIRAS-2 to help in interpreting meridional scan data obtained from the NIRAS-2.

A first simultaneous observation of N2+ (M) aurora at 1.1 µm by the NIRAS-2 and the NIRAC coordinated with EISCAT Svalbard Radar (ESR) is presented. On January 21 2023, the N2+ (M) intensification that is associated with multiple aurora arcs was observed by the NIRAS-2 and the NIRAC having temporal resolutions of 30 s and 20 s, respectively. In addition, the ESR also observed electron density variations at the same time, which shows that the N2+ (M) brightness correlated with squared electron density at 100–120 km very well. It strongly suggests that a primary source of N2+ (M) emissions is direct collisions of N2 by precipitating electrons penetrating down to around 100 km altitude (up to 10 keV). The observed N2+ (M) spectrum demonstrate fine structures due to N2+ rotational motions that can be roughly reproduced by common molecular models for diatomics. In this study, further analysis results to estimate spatial and temporal variations of the N2+ rotational temperature based on several events in which N2+ (M) auroras were identified simultaneously by the NIRAS-2 and the NIRAC will be presented. In addition to the N2+ (M) aurora, OH rotational temperatures estimated using OH Meinel (5,2) band will be also demonstrated, with a focus on seasonal variations and their robustness to auroral contamination of N2+ (M).

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STEVE-like emissions observed in the poleward part of the auroral oval after the magnetic midnight

The phenomenon known as Strong Thermal Emission Velocity Enhancement (STEVE) is a purple/mauve arc-shaped atmospheric glow observed at lower latitudes of the auroral oval on the duskside. Simultaneous observations using a ground-based camera and a low-altitude satellite have shown that STEVE is accompanied by rapid westward ion flows. Such fast ion flows are termed the subauroral ion drift (SAID) or subauroral polarization stream (SAPS). Similarly, an eastward fast ion flow known as the dawnside auroral polarization stream (DAPS) is observed within the Region 1 current on the dawnside. If the optical phenomenon triggered by SAID/SAPS corresponds to STEVE, a comparable optical phenomenon should be driven by DAPS on the dawnside. Thus far, however, such a phenomenon has not been reported. This study discovers, for the first time, a purple-colored optical phenomenon characterized by the fast eastward ion flows, a possible signature of DAPS, occurring poleward of the bright green arc in the post-midnight sector. We present color all-sky images obtained by a ground-based commercial digital camera, along with wide-coverage optical measurements and in-situ data from low-altitude satellites. The results imply that this glow requires not only a high-speed ion flow but also its sharp latitudinal gradient at the boundary between the Region 1 and 2.

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On the characteristics of meso-scale ionospheric dynamics based on EISCAT radar low-elevation experiments

The high-latitude ionosphere exhibits complex processes driven both by internal and external drivers, including its coupling with the magnetosphere and solar wind systems. As a result, ionospheric structures evolving over both a wide range of temporal and spatial scales are commonly observed. Large-scale and slow varying processes are generally well described, but characterizing the dynamics at meso- and small-scales remain challenging, especially during periods of strong geomagnetic activity.
In this work, we focus on low elevation measurements made using the EISCAT VHF radar, which regularly exhibit features evolving highly dynamically both in space and time. We re-examine the data obtained from experiments measuring at low elevations performed since 2014 on the mainland, including when the EISCAT tri-static system was utilized. We study and characterize the occurrence and behavior of meso-scale structures in density, temperatures, and ion velocity, especially on the nightside. Radar observations are supplemented by other data to provide some context for the coincident magnetospheric and ionospheric conditions. This includes measurements from the Solar wind, all-sky imagers, and from satellites such as Swarm, when conjunctions are available. Altogether, this provides a unique extensive set of observations helping to improve our understanding of meso-scale ionospheric dynamics in the polar cap auroral regions.

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Mirror force effects on the electron density enhancement due to energetic electron precipitation

Energetic electron precipitation (EEP) causes various phenomena, such as changes in the atmospheric composition because of collisions with the neutral atmosphere. Previous studies addressed the relationship between the EEP and electron density of atmosphere using both observational and simulation perspectives. Some fundamental processes are not yet fully understood, such as propagation in the atmosphere and the secondary electron production of precipitating electrons. Even though magnetic field has been ignored as it is considered to have little effect, the importance of the magnetic mirror effect on atmospheric ionization was suggested by numerical simulation by Katoh et al. (2023). Then, our study aims to verify the effect of the magnetic mirror force quantitatively on atmospheric ionization using the simulation and observational data.

We used ELFIN satellite for energy distributions and pitch angle distributions of electrons above the atmosphere, and EISCAT radar for electron density in it. The ELFIN data were used as initial conditions of simulation to calculate electron density by EEP. After that, we compared the results to EISCAT data. Between September 2018 and September 2022, ELFIN and EISCAT observed these data 25 times simultaneously. Among them, 5 events showed electron density enhancements at low altitudes, possibly due to EEP. We will introduce one event which showed the most obvious difference between the simulation result with mirror force and without mirror force. On 16 December 2021, ELFIN found many electrons were out of loss cone. Due to the pitch angle distribution, the simulation results showed that the electron density in the reliable low altitude range was about 40% smaller when mirror forces are included than when they are not included. Comparing the results with the EISCAT data, we found that the electron density profile observed by EISCAT tended to be closer to the simulated result with mirror force than that without it. For other events, however, there were some differences between the simulation results and the observed results. Therefore, it is important to improve and validate the simulation code to get closer to the actual atmospheric ionization rate and to investigate cases where the mirror force effect is likely to occur significantly (time of day, geomagnetic activity level, solar activity level, etc.).

Additionally, we investigated how the electron density changes when the energy and pitch angle distribution of the electrons above the atmosphere are changed. We assumed that it has a gaussian pitch angle distribution with the mean and standard deviation parameters and a power law energy distribution with two parameters: the number flux of EEP electrons at the lowest energy. We found as initial result that the mean value of pitch angle distribution was almost the only value that determines whether there is a difference due to the mirror force and that the exponential changed the altitude gradient of electron density but did not change the difference due to the mirror force.

In our presentation, we will talk about the quantitative effect of the mirror force on electron density caused by precipitating electrons using observational data and simulation results.

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Role of inertial Alfvén waves in the generation of splitting auroral arcs

Auroral structures with spatial scale of few kilometres and temporal scale of few seconds are known as fine scale structures. The optical observations of these structures from the ground can be useful in
understanding the ionosphere and magnetosphere as they are the footprints of phenomena happening in those regions. One such phenomena is known as arc splitting, also called bifurcating elemental arcs, or packets, in which elemental arcs strip away from a central bright arc on both sides which is in turn followed by the formation of new arcs. Semeter et al., JGR 2008 suggested that these cascading arcs are happening via inertial Alfvén waves (IAWs). They emphasized that the energy of the precipitating electrons i.e., energy measured from the central bright arc to the edge of the elemental arc, should reveal decreasing trend. They argued that parallel electric field of IAWs is accelerating the precipitating electrons and the decaying electric field with respect to altitude is responsible for the decrease in energy of these electrons. However, so far numerical evidence has not been identified to support their theoretical hypothesis. In order to address the question outlined above, we have evaluated their theory using data from a multi spectral imager called ASK (Auroral Structure and Kinetics) located on Svalbard. ASK can provide the energy of the precipitating electrons which can be used to test their theoretical interpretation. Our results support the presence of IAW and from a detailed analysis of the ASK observations we have obtained the properties of the wave. We have identified the decreasing energy trend from ASK data and our results are directly in line with the suggest theory of Semeter et al., 2008. We infer from our findings that the acceleration height of the precipitating electrons is under 3000 km. We have found that the electron acceleration is caused directly by the parallel electric field of the wave rather than Landau resonance.

References:

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The PITHIA e-Science Centre and its relevance to EISCAT users

PITHIA-NRF (Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities) is a collaborative project between European facilities and infrastructures that are producing services to the international community of upper atmosphere researchers.

One of the objectives of the PITHIA-NRF project is to create and maintain an e-Science centre. This centre serves as a central web portal in order to provide a single point of entry to a large set of heterogeneous and distributed resources, the PITHIA Data Collections and Catalogues. The e-Science Centre can be used to describe, publish, and search the registered datasets and forecast models. Thus, it is a good tool for any user whos wants to have convenient access to ionospheric data and space weather models from a large set of providers.

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Stratospheric and mesospheric temperature estimations by Himawari-8/AHI limb-sounding

Himawari-8 is the Japanese Geostationary Earth Orbit (GEO) meteorological satellite, that is equipped with Advanced Himawari Imager (AHI). Himawari-8/AHI provides full disk images every 10 min in 16 observation bands, including three visible bands: blue (0.47 μm), green (0.51 μm), and red (0.64 μm). These full disk images are normally used as nadir observations mainly for meteorological purposes. On the other hand, the full disk images by Himawari-8/AHI can also provide near-global limb-sounding data as the edges of images. As an example, there are a couple of reports on polar mesospheric cloud (PMC) observations by Himawari-8/AHI limb-sounding.

In the present work, we consider temperature estimations in the middle atmosphere as a further application using Himawari-8/AHI limb-sounding data. In the limb-sounding, Rayleigh scattering of the sunlight can be observed, and thus we can obtain height profiles of line-of-sight (LOS) integrated Rayleigh scattering signals. Extinction effects in the signals can be corrected based on a simulation in the Rayleigh scattering. After that, by inversion methods, such as the Abel transforms, the LOS-integrated signals can be converted into local signals, which could be considered to be proportional to the local number densities of the atmospheric molecules. Then, applying the Rayleigh scattering temperature lidar technique, height profiles of temperature can be derived from height profiles of the local signals under an assumption of the hydrostatic equilibrium. There are a couple of previous works demonstrating this kind of temperature estimation using limb-sounding data from low-Earth-orbit (LEO) satellites. On the other hand, there is no previous example of GEO satellites, which have an advantage in providing continuous observations from a fixed point in space. In the presentation, we will show our results for temperature estimations by Himawari-8/AHI limb-sounding, and discuss the potential of the estimated temperature data.

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The ion line measurements based on Sanya Incoherent Scatter Radar Tristatic System (SYISR_TS)

The research of ion line measurements based on the newly built Sanya incoherent scatter radar Tristatic System (SYISR_TS) was introduced. SYISR_TS includes one main site with the gain of 46dBi and two other receiver sites with the gain of 43dBi. The peak power is >4MW. The transmitted frequency is adjustable from 430MHz to 450MHz. We conducted the power measurements and the power spectra measurements for the Tristatic System. Two types of ionosphere results were obtained: the raw electron density and the multiple ionosphere parameters (Ne, Te, Ti, V). The results demonstrate the feasibility and reliability of ionosphere measurements based on SYISR_TS, which enables further ionosphere physic investigations about low latitude in the future.

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