Sodankylä Geophysical Observatory
Reports

19th International EISCAT Symposium
and
46th Annual European Meeting on Atmospheric Studies by Optical Methods

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Abstracts

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Foreword

The 19th International EISCAT Symposium and 46th Annual European Meeting on Atmospheric Studies by Optical Methods in 2019 is the second time these two conferences have been combined; the first time took place in 2015 in Hermanus, South Africa. While the EISCAT Symposium is organized every second year, the optical meeting (46AM) takes place every year. We expect great synergy by combining these two communities, which already have a large overlap.

At the moment, we are living in very exciting times, since construction of the EISCAT_3D facility in Norway, Finland, and Sweden has been started by the EISCAT Scientific Association. The plan is to have all three radar sites operational in 2022 for studying the upper ionized atmosphere in the Arctic region. Now it is time to plan future joint activities and collect new ideas, so that when the new facility starts operations, we can utilize its potential to the full extent, together with complementary instruments.

The conference has about 100 oral and poster presentations, covering a broad range of topics that can be studied by using incoherent scatter radars, optical instruments and other scientific instruments for geospace research. The contributions are divided into five sessions, with the aim to foster collaboration between both communities around joint science topics; the first session focusing on the development of new innovative instruments and analysis methods.

We are very happy to host this meeting in Oulu, Finland. The University of Oulu together with its independent department Sodankylä Geophysical Observatory (SGO) lead the EISCAT efforts in Finland and participate in building the Karesuvanto EISCAT_3D site. We thank the University of Oulu for providing the conference facilities and the City of Oulu for hosting the welcoming reception at Tietomaa Science Center.

Warmly welcome,
Anita Aikio
Chairperson of the Science Programme Committee

Thomas Ulich
Chairperson of the Local Organizing Committee

Session 1

Novel instruments and methods: EISCAT_3D and optical instruments, other infrastructures and missions

Conveners
Anita Aikio
Ian McCrea

EISCAT_3D for atmospheric dynamics research

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

EISCAT_3D will be innovative infrastructure to study dynamics of the middle atmosphere by providing measurements of winds, atmospheric waves and tides, narrow scattering layers (polar mesosphere echoes) among of others. For the first time EISCAT_3D will have capabilities to measure neutral wind and turbulence starting from the lower altitudes and to track gravity wave propagation and breaking. Due to higher power and sensitivity, EISCAT_3D will allow significantly extended height coverage compared to present atmospheric and meteor radars in the Northern Scandinavia and will sample a different location in the mountain-wave field. Thus, the EISCAT_3D will attract new users e g atmospheric modellers. In the atmospheric dynamic communities e g Atmospheric dynamics Research InfraStructure in Europe (ARISE) there is a need for continuous measurements of vertical profiles of horizontal and vertical winds over a broad range of altitudes from the ground up to the mesosphere/lower thermosphere. In the presentation I will consider what a new EISCAT system will be able to measure, what requirements are for new experiments/modes and will present possible research topics to study atmospheric dynamics, atmosphere-ionosphere coupling etc.

ALIS_4D progress report

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ALIS_4D is a new Swedish optical infrastructure for low-light multi-station imaging under development in northern Sweden. The facility will replace the decommissioned Auroral Large Imaging System (ALIS) and is expected to become operational during fall 2019. Like ALIS, the new system will be able to use tomography-like inversion in order to reconstruct the volume emission rate. As opposed to ALIS the new system is designed for continuous measurements as well as for campaign observations. 4D signifies that ALIS_4D will be able to measure with considerably higher time-resolution than the previous system.

Initially ALIS_4D will consist of 4 modern EMCCD imagers with six-position filter-wheels intended for 3" narrow-band interference-filters. Field-of-view will be about 140 degrees. The first imager received "first-light" during the spring 2019. This report focuses on the current status of the project and discusses matters related to EMCCD configuration and calibration.

ALIS_4D will furthermore be used as a test-bed for establishing a common user interface and scheduling system for complementary instruments and EISCAT_3D. A layered approach is suggested enabling platform independent interoperability between EISCAT_3D and participating complementary instruments and infra-structures. This approach also opens up the possibility to combine participating national instruments and infrastructures from different countries into larger units as desired depending on the scientific objectives for a particular experiment.

Daedalus: A Low-Flying Spacecraft for the Exploration of the Lower Thermosphere - Ionosphere

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The Daedalus mission has been proposed to the European Space Agency (ESA) in response to the call for ideas for the Earth Observation programme's 10th Earth Explorer. It was selected in 2018 as one of three candidates for a Phase-0 feasibility study. Also selected were Stereoid and G-Class, both carrying synthetic aperture radars in novel ways aiming to provide views of processes at the Earth's surface.

The goal of the Daedalus mission is to quantify the key electrodynamic processes that determine the structure and composition of the upper atmosphere, the gateway between the Earth's atmosphere and space. An innovative preliminary mission design allows Daedalus to access electrodynamics processes down to altitudes of 150 km and below. Daedalus will perform in-situ measurements of plasma density and temperature, ion drift, neutral density and wind, ion and neutral composition, electric and magnetic fields and precipitating particles. These measurements will unambiguously quantify the amount of energy deposited in the upper atmosphere during active and quiet geomagnetic times via Joule heating and energetic particle precipitation, estimates of which currently vary by orders of magnitude between models. An innovation of the Daedalus preliminary mission concept is that it includes the release of sub-satellites at low altitudes: combined with the main spacecraft, these sub-satellites will provide multi-point measurements throughout the Lower Thermosphere-Ionosphere.

The synergy with ground-based volumetric imaging of the ionosphere-thermosphere by E3D was an important argument of the Daedalus proposal. We specifically discuss how Daedalus and E3D measurements would complement each other.

Using Optical Doppler Spectroscopy to Infer 4D Resolved 3-Component Thermospheric Vector Wind Fields

M. G. Conde, J. Elliott, and K. Branning

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Doppler spectroscopy of optical airglow and/or auroral emissions has been used since the 1960s for ground-based remote sensing of thermospheric wind fields. A major limitation of this technique is that it only measures one component of the vector velocity field, i.e., the component parallel to the instrumental line-of-sight. Nevertheless, by looking from a single site in many directions across the sky (and subject to some rather severe assumptions), it is possible to derive an approximate representation of the two-component horizontal vector wind field, resolved over longitude and latitude, but limited to one constant altitude. Further, a number of techniques now exist for combining line-of-sight wind data from several geographically dispersed sites to more accurately infer the geographically resolved flow field, because these ”multistatic” methods require fewer and much less severe assumptions. With appropriate viewing geometry, it is even possible to infer all three components of the vector flow field. However, previous methods have all been limited to using Doppler spectra of a single optical emission line, this producing vector fields representing just one altitude (i.e., the assumed height from which the observed emission originates.) Here, I will describe a new approach that combines multistatic all-sky Doppler spectra of emissions at two wavelengths (558 nm and 630 nm) to obtain three-component thermsopheric winds resolved over four dimensions: longitude, latitude, altitude, and time. Although only two wavelengths are used, the height of the aurorally excited 558 nm emission varies between roughly 100 and 150 km, depending on the characteristic energy of the auroral precipitation. Thus, with appropriate aurora, it is possible to exploit this variation to obtain continuous height resolution in the lower thermosphere. In this talk I will present a new ”evolutionary” algorithm that we are developing to implement this strategy, along with some initial results showing three-component thermospheric vector wind fields over Alaska, resolved over the four dimensions of longitude, latitude, altitude, and time.

Progress of the Chinese Qujing incoherent scatter radar measurement and data analysis

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China Research Institute of Radio wave Propagation (CRIRP)

The Qujing incoherent scatter radar (QJISR), the first one in China with the geographic location (25.6° N, 103.8° E), was brought into operation since the spring of 2014. The QJISR was a mono-static pulsed radar working in 500 MHz, the peak power 2 Megawatt, and a 29-m steerable parabolic dish. After the description about the technical implementation, data analysis software and usable experiment modes, this paper presents some scientific cases including the temporal variations of the Ne (mainly the NmF2 and hmF2) and plasma temperature (Te and Ti), the variations of valley and Es echo, the location of EIA, the bi-static scatter echo, space debris measurements, the periodic echo etc, which shows the important scientific merits in the mid-low latitude of East Asia.

EISCAT_3D Status and Capabilities

C. Heinselman

EISCAT Scientific Association

The EISCAT_3D project is now well under way. Nearly all of the major hardware contracts have now been awarded and the awardees are producing prototype hardware, design reviews are being held, test results compiled, and planning done for full scale production. Progress is being made at the sites as well, with trees cut at some sites, gravel pads prepared, and even a few short roads cut through the forest. In addition to this more visible progress, the project is also making substantial progress on identifying data flow bottlenecks, processing demands, data formats, and software architectures.

This talk will provide an overview of the status of the project as well as the initial and eventual capabilities of the system.

Conjugations of the ERG(ARASE) satellite and ground-based support at Kola Peninsula

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The ERG project (Exploration of energization and Radiation in Geospace, also known as Arase) is a spacecraft mission to elucidate acceleration and loss mechanisms of relativistic electrons in the near-Earth space during geomagnetic disturbances. Successful use of the ERG project data depends largely upon the ground-based observations in conjugate regions. The ERG spacecraft orbit is planned in such a way that its apogee is often conjugated with Scandinavia and Kola Peninsula. The observatories of Polar Geophysical Institute (PGI) located at Kola Peninsula can give important extension of the ground-based support of the ERG mission. In this report we review the available conjunctions of the ERG spacecraft with optical, VLF/ULF and other ground-based instruments at Kola Peninsula.

Large-scale Hierarchical Models for EISCAT_3D

Lassi Roininen and Sari Lasanen

LUT University

Our main goal is to develop novel Gaussian and non-Gaussian hierarchical models for large-scale computational inverse problems with a full-blown uncertainty quantification. We consider modelling and computational limitations, when applying the methods developed to the upcoming next-generation high-power incoherent scatter radar EISCAT_3D radar. While the overall objective is to enable spatiotemporal 3D volumetric vector field and scalar field ionospheric plasma-parameter measurement – the practical implementation is hampered by huge data loads. Thus we are dealing with large-scale inversion, i.e. cases where we cannot store covariance matrices in computer memory, or computation times are exceedingly long for practical purposes. We further complicate the situation by deploying spatiotemporal hierarchical models based on novel Gaussian, Lévy α-stable, and Student's t random fields.

Hyper Spectral Imager for Drones and micro Satellites

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The arrival of technologies the last decade such as drones, small optics and 3D printing has opened new opportunities in instrumental and sensor development. Size and weight may now be minimized to achieve high performance airborne Hyper Spectral Imager (HSI) capabilities at extreme low cost. Furthermore, a novel concept called Parallel Internet Prototype Production (PIPP) of a satellite HSI aimed to study ocean color will be presented.

Estimating neutral wind patterns using line-of-sight data from multiple Scanning Doppler Imagers

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We present a new analysis technique for estimating 2D neutral wind pattern using data from a single Scanning Doppler Imager (SDI) or a combination of SDIs, incoherent scatter radars (ISR) and Fabry-Perot interferometers (FPI) within overlapping field-of-views. Neutral wind plays an important role in ionospheric electrodynamics and Ionosphere-Thermosphere coupling, by for example affecting the Joule heating rates and plasma transport. However, reliable and extensive measurements of the neutral wind are rather difficult to obtain.

Pointwise measurements can be obtained with ISRs or FPIs, but these measurements can not provide 2D latitude-longitude maps of the neutral wind pattern needed in mesospheric studies. A Scanning Doppler Imager can measure the line-of-sight (LOS) component of the neutral wind in dozens of directions simultaneously. However, further modeling is needed to convert the LOS velocities into 2D velocity maps. Unfortunately these maps are far from unique, as perpendicular velocities (e.g. rotation around the measurement site) are not visible in the LOS data. This can be mitigated by combining data from several nearby SDIs, or a combination of SDIs, FPIs and ISRs.

Our analysis technique is based on fitting the LOS data with special vector basis functions called Spherical Elementary Current Systems (SECS). In this approach the wind is naturally divided into curl-free and divergence-free components, and there is no need to provide any explicit boundary conditions on the wind pattern.

We present several synthetic test scenarios as well as first results using data from SDIs located in Alaska. Using the synthetic test scenarious we further estimate optimal locations for 2 or 3 SDIs that could be located around the future EISCAT_3D radar system in northern Scandinavia.

Space debris observations using EISCAT

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Monitoring the evolution of the space debris environment requires regular radar observations of the space debris population. This study presents the results from 24 hours of beam-park observations of space objects conducted simultaneously with the EISCAT Svalbard and Tromsø radars on and between January 4th and 5th, 2018. The measurements are processed with a new matched filter bank analysis program, which doubles the coherent in- tegration time, and hence sensitivity, compared with the previous program. We observe 2077 objects with the Tromsø radar and 2400 objects with the Svalbard radar. The detections are correlated with the NORAD catalog. We find that 68% of the Tromsø and 85% of the Svalbard radar detections are from objects in the NORAD cata- log, with most of the catalog object detections being in the side lobes of the radar antenna. The beam-park data are compared with a simulated beam-park experiment for catalog objects. The simulation uses a radar detection model that includes the effects of coherent integration and an antenna beam shape with side lobes. We find that the simulation agrees well with the measurements, indicating that the radar sensor response is accurately modeled. Our results highlight the importance of modeling antenna side lobes when analyzing beam-park measurements. Not taking taking into account side lobe detections can lead to an underestimation of radar cross-sections and an overestimation of population density.

Temperature and composition fits in high-resolution incoherent scatter observations by means of Bayesian filtering

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Incoherent scatter radar observations of auroral particle precipitation and ion frictional heating are challenging, because commonly used data analysis tools cannot extract ion composition information from the scattered signal and they can typically fit electron and ion temperatures only with time resolution of some tens of seconds. However, the ion frictional heating is known to affect the molecular-to-atomic ion ratio and the auroral particle precipitation may vary in time scales down to sub second level. Previous studies have shown that ion composition estimation in the molecular-to-atomic ion transition region around 150-300 km altitudes is possible when the incoherent scatter spectrum estimates are sufficiently accurate, or by means of full-profile analysis. However, the high-accuracy spectrum estimates usually require long radar integration times, and even the full-profile analysis has typically been used with rather coarse time resolutions.

We propose a new, Bayesian filtering -based analysis technique for the incoherent scatter plasma parameter fits. While typical full-profile solvers look for plasma parameter profiles smooth in altitude, our approach allows us to control plasma parameter gradients both in space and time. The level of smoothness in space is controlled by means of grid-independent prior models called correlation priors, which allow us to define the smoothness in physical units and to allow larger gradients in areas where they are expected. Furthermore, the actual iterative plasma parameter fit is still ran for each measurement volume separately, which makes the analysis computationally light-weight. This will be an important aspect especially in analysis of volumetric observations with the EISCAT3D radar.

We have implemented a simple version of Bayesian filtering as an additional module to the standard EISCAT analysis tool GUISDAP. We assess the problem of finding suitable prior models and validation of the analysis technique by using simulated data as in put to GUISDAP with Bayesian filtering. We show fit results of electron density, ion and electron temperatures, ion composition, and line-of-sight ion velocity. Extension of the technique to other beam pointing directions, where sharp gradients in the plasma parameter profiles may exists, and volumetric observations with the EISCAT3D radar are discussed.

The status of SanYa Incoherent Scattering Radar (SYISR) Development

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Institute of Geology and Geophysics, Chinese Academy of Sciences

Funded by the National Science Foundation of China (NFSC), the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS) is building a new Incoherent Scattering Radar (ISR) in SanYa (18oN, 109oE), which is a low latitude station over Hainan province of the P. R. China. In this presentation, we will generally describe the scientific objectives and current status of SYISR. We will also show some preliminary results obtained by the small array of SYISR, which was build to test the firmware and hardware of the radar system. Furthermore, we will show the near-term and long-term plan of the SYISR development.

EISCAT 3D data portal and data transfer development: The EOSC-CC and NeIC support projects

Carl-Fredrik Enell(1), Ingemar Häggström(1), Andrei Tsaregorodtsev(2), Andrii Lytovchenko(2), Ari Lukkarinen(3), Vincent Garonne(4), Mattias Wadenstein(5), John White(6)

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This poster presents an overview of the latest developments in the data and e-infrastructure support projects for EISCAT 3D. The DIRAC data portal and job submission system is being developed in the EOSC-Hub Competence Centre for EISCAT 3D, and file transfer tests between Nordic sites are carried out within the NeIC collaboration. Test users are welcome to try the data portal and job submission.

The development and the calibration of hyperspectral Imaging Systems

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The Hyperspectral imager is a useful optical instrument for remote sensing of Earth environments. The traditional hyperspectral imager consists of (1) object lens system, (2) spectrometer system, and (3) imaging system. The detected light from the object lens system is dispersed by a spectrometer system (e.g., grating or a krypton), and sequentially recorded as the hundreds of bandwidths of the visible/infrared emission by the imaging system. People use the characteristics of spectral to identify substances, such as the investigation of land and water resource. The derived hyperspectral data cube is a 3D data composed of 2D spatial and 1D spectral data. We design the engineering model of the hyperspectral imager with continuous emission band between 450-650 nm with high wavelength resolution (2nm). The instrument uses a push-brom method to acquire hyperspectral images, FOV (field of view) is about 0.028 ° * 2.69 °, The Swath width is about 23.5 kilometers at a height of 500 kilometers, the center wavelength is 500nm, and the FWHM is 2nm. We conducted the following experiments to confirm the performance of the instrument: 1. Wavelength correction 2. Absolute luminosity correction 3. Laboratory simulation environment verification. First, we use a mercury-argon correction lamp for wavelength position correction, then use the optical power meter to measure the brightness and find the absolute luminosity. After the experiment, confirm that it meets the specifications we need. In the future, we plan to develop the flight model for the rocket and 6U CubeSat missions.

Capabilities of Auroral Tomography with the Auroral Large Imaging System

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Auroral tomography with the newly proposed Auroral Large Imaging System (ALIS) 4D in conjunction with European Incoherent Scatter (EISCAT) 3D radar will be a valuable tool for studying simultaneously the volume emission rates and the plasma parameters of auroral events. We present here capabilities and error analysis of 3D auroral tomography with the current Auroral Large Imaging System (ALIS) and the proposed ALIS 4D. Inverse problem techniques are used to estimate the correlation of the tomographic reconstruction parameters and are further used to analyze the error function and the sensitivity of the reconstruction problem. Typical signal-to-noise ratio limits are presented for reliable reconstructions of simple auroral blobs and auroral arcs. The Akaike Information Criterion is used to estimate a suggested number of modeling parameters for different signal-to-noise levels.

Design of two-color cameras for brightness variability studies on stellar astrophysics

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The aim of this student project is to design the two-color cameras for stellar astrophysics, similar to BRIGHT project [https://brite-constellation.at]. Photometric variability of bright stars is an important tool to diagnose the intrinsic variability (e.g., pulsations, rotational modulations, stochastic variations such as flares) [Aerts et al., 2010; Pablo et al., 2016 ; Ramiaramanantsoa et al., 2018; Kallinger et al., 2019]. The measurement of the period and corresponding frequency using high precision and temporal resolution of star brightness with red/blue filtered bands can be used to probe the internal structure and their asteroseismic characteristics. To precisely measuring photometric variation for bright stars (apparent magnitude), we design a lens system which has wide field of view (≈24°) and the high sensitive imager sensor (1688*1248 pixels and each pixel size is 4.4μm*4.4μm) for CubeSat mission, so that up to 15 bright stars (> magnitude 6) will be located in one frame. In order to produce highly precious data without sharp stellar image, the photometric requirement calls for a point spread function, which is as smooth as possible, illuminating an area of up to about 8 × 8 pixels on the imager sensor [Weiss et al., 2010]. Designing a small and low-cost camera system to fit the requirement of the space mission will contribute more quality and frequency data of bright stars than that obtained from the ground telescope observation.

Spectral Observation Theory for Volumu Scatter Radar

K. Nishimura (1)

Research Organization of Information and Systems

In the long history of atmospheric radars, including mesosphere-stratosphere-troposphere (MST) radar, and small wind profiler radar, as well as incoherent scatter (IS) radar, the relationship between the true variance of the target velocity and observed spectra has been treated in essentially approximated and simplified ways using the wavelength and "beam pattern", or "beam width". However, the simplification is not well suited for such cases where the beam pattern is not symmetric, the target has a long correlation time, the radar has a small aperture, not monostatic, and so on. In this study, we clarified the mathematical relationship between the observed spectra and the true velocity variance of the target, together with the radar configuration parameters [1]. The theory is applicable to any type of volume scatter radar including bistatic systems, and has a potential to enhance their functionalities. In this talk, some direct application of this theory will be presented.

Reference:

[1] Nishimura K., Kohma M, Sato K, and Sato T (2018), A Beam De-Broadening Algorithm for Atmospheric Radar, XXIIIrd International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory, doi:10.1109/DIPED.2018.8543268.

Investigation of spatial and temporal resolution of Eiscat 3D

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EISCAT3D is a high power large aperture radar that will be built in Skibotn, Norway, and operate in 2022. It will consist of a main array consisting of 109 antenna groups and ten outlier arrays where the farthest is 1.2 km from the main array. Only the core array is planned to transmit, but all antennas can receive. We have investigated the performance of the Skibotn core site of aperture synthesis imaging of incoherent scatter signals from space plasma. We have calculated the achievable time and range resolution for typical conditions in the E-region. The range resolution is some hundred metres with an integration time of some tens of seconds. A better range resolution requires a longer integration time. When the electron density is enhanced, an integration time of some seconds is possible. The horizontal (image) resolution of EISCAT 3D depends on the locations and sizes of its antennas, including the displacements between transmitters and receivers (baselines), but also on the image reconstruction technique. In imaging, the signals received with the different antennas are correlated with each other. The correlations are then used to reconstruct an image of the ionosphere. When considering multiple independent transmitters, it is assumed that the signals from different transmitters can be distinguished. We consider imaging of a horizontal slice of the ionosphere inside of the EISCAT 3D radar beam and at a range of 100 km, which is divided into multiple equal-sized volumes (pixels). We have simulated EISCAT 3D measurements to find an algorithm that does a good reconstruction of the true image and is little influenced by noise. We have compared a matched filter (beamforming), truncated least squares, Capon filter, and CLEAN. A preliminary result is that the best reconstruction algorithm is truncated least squares. The Capon filter is faster and less memory consuming, but is much more biased. We conclude with that radar imaging with EISCAT 3D is feasible.

Bayesian Filtering in incoherent scatter radar analysis: Validation with simulated data

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Plasma parameter estimation from incoherent scatter radar measurements typically requires integration time of some tens of seconds and, at the same time, the standard analysis tool cannot fit the ion composition. As a result, the incoherent scatter radar observations have not been able to follow the rapid variation of auroral electron precipitation, and temperature estimation in the molecular-to-atomic ion transition region has often been biased due to the ion temperature-mass ambiguity.

In order to enable temperature and composition fits in high-time resolution observations, we have applied a Bayesian filtering technique to the analysis of incoherent scatter radar data. The technique allows us to incorporate prior information about plasma parameter gradients in space and time, which enables the fitting procedure to estimate electron density, electron and ion temperatures, ion velocity and ion composition.

In this work, simulated plasma parameter profiles are used for validation of the proposed incoherent scatter radar data analysis method. The simulation consists of two steps. Plasma parameter profiles corresponding to selected electron precipitation and electric field are first generated. The plasma parameters are then converted into incoherent scatter autocorrelation function (ACF) data using the standard theory of incoherent scatter.

The simulated ACF data corresponding to the plasma parameters are then analyzed by means of the Bayesian filtering technique and the results of the fit are compared to the plasma parameters used in the simulation. We find that all the five parameters mentioned above can be fitted simultaneously although the temperature and composition estimates have effectively a coarser time resolution than the electron density estimates.

6-meter wavelength polarimetric inverse synthetic aperture radar mapping of the Moon

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Remote sensing of planetary surfaces is an effective method for gaining knowledge of the processes that shape the planetary bodies in our solar system. This is useful for uncovering the environment of the primordial solar system and to study the current state of the upper crusts of the other planets in our neighborhood. A recent 6-meter wavelength polarimetric radar map of the Moon [?] showed unexpectedly low depolarized radar returns in two regions on the lunar nearside. These two areas were a highland region between Mare Imbrium and Mare Frigoris, and the highland area surrounding the Schiller-Zucchius impact basin. These two regions showed characteristics unlike those of typical highland regions of the lunar surface. So far, there has been no readily available explanation for this observation. In this study, it is shown that the likely cause is an increased loss tangent due to chemical differences in the first few hundred meters of the lunar soil. We also show the absence of any coherent subsurface, which could be the preserved remains of an ancient basaltic plain. We do this by comparing the 6-meter polarimetric radar map to other relevant data sets: 1) surface TiO_2 and FeO abundance, 2) surface rock population, 3) radar maps of the Moon with other wavelengths, and 4) visual spectrum images of the Moon. The area near the Schiller-Zucchius basin was shown to be consistent with other areas with similar surface chemical compositions, but the region between Mare Imbrium and Mare Frigoris showed significantly lower mean power in comparison to otherwise similar regions. While we can not conclusively determine the cause, we hypothesize that the low radar return is explained by an increased concentration of iron and titanium oxides in the volume beneath the surface, potentially due to remnants of primordial lunar volcanism. The results show that long wavelength polarimetric radar measurements of the Moon are very powerful tools for studying the earliest stages of the evolution of the Moon. The new EISCAT 3D installation will enable new measurements in a wavelength which has not been used before. The facility can also track the Moon to obtain a long observation time, increasing resolution. The multiple receiving locations will provide excellent interferometric baselines to, among other things, resolve the range-Doppler ambiguity. Polarimetric measurements are useful for separating surface and volume scattering, as well as potential target-based decomposition modelling.

Introduction and experiments results of SYISR prototype system

Lingqi Zeng, Xinan Yue, Weixing Wan, Baiqi Ning, Biqiang Zhao, Feng Ding

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We introduce a 256 antenna elements UHF radar which is developed as the prototype system for Sanya Incoherent Scattering Radar. The parameters and function of the instrument has been described. Some typical experiments, such as stratospheric wind observing, meteor trail and Es detection has been conducting and preliminary results are presented.

Session 2

Aurora, Magnetosphere-Ionosphere-Thermosphere Studies and Space Weather

Conveners
Yasunobu Ogawa
Daniel Whiter

Auroral precipitating power and Joule heating in the auroral ionosphere estimated from EISCAT data during a geomagnetic storm event

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Interaction of the solar wind with the terrestrial magnetosphere by means of magnetic merging on the dayside and nightside results in significant energy input into the magnetosphere. This energy can further be dissipated in the ring current, plasma sheet heating, ejected away from the magnetosphere as plasmoids, and dissipated in the ionosphere as Joule heating and particle precipitation. Currently, the proportions of energy dissipation into different processes are not well known, but it is generally estimated that ring current, Joule heating, and particle precipitation are the most important ones. The relative importance of the two ionospheric processes have been estimated based global modeling with on coarse resolution and by using global indices as proxies, but a detailed distribution is not known.

The EISCAT radars provide a unique tool to quantify the local energy dissipation in the forms of Joule heating and auroral particle precipitation with good temporal and height resolution. In this presentation, we will follow ionospheric energy dissipation during one solar wind high-speed stream (HSS) event in 2008, which produced a weak magnetic storm (SYM-H minimum -32 nT). We quantify the local power dissipated in the ionosphere-thermosphere system at Tromsø latitude (67° aacgm) by Joule heating and auroral particle precipitation, look at their height profiles and compare their relative importance during three days of the storm time.

Modeling the response of vibrational redistribution in N_2 1PG emission to the variation in auroral electron flux

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We have developed a time dependent model for N_2 triplet manifold that can have a versatile applicability. All the known reaction mechanisms such as the electronic impact excitation, radiative and intra-system cascade, electronic quenching and inter-system collisional transfer (ICT) are successfully implemented into this model. The reaction rate coefficients, cross-sections, quenching and the electron flux are based upon the latest theoretical studied as well as from experimental observations. The vibrational population of N_2 triplet manifold is calculated by solving their respective continuity equations. The importance of the present model is that it can be used to study any auroral emissions resulting from N_2 triplet states. The model results are validated with ground based and space borne observations such as Auroral Large Imaging System (ALIS) and Reimei satellite. As an application, the present model is used to study the response of vibrational redistribution in N_2 1PG emission to the variations in auroral electron flux using different sets of cross-sections and auroral electron fluxes at different altitude regions.

High-latitude electron density depletion regions and their dependence on geomagnetic activity

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Electron density in the ionosphere depends on several factors including altitude, season, time of day, solar and geomagnetic activity. Data from the EISCAT Svalbard radar (ESR) now covers more than two decades and are therefore suitable for studying semi-permanent features and characteristica of the parameters. In the present study the primary focus has been on investigating regions with reduced electron density and their dependence on geomagnetic activity and season. An electron density depletion region was observed in the ESR data in the early morning sector. The depletion region was often co-located with an ion temperature enhancement. As the geomagnetic activity increases, the depletion region expands accompanied with an enhanced anti-sunward convection flow. This could be due to the expansion of the polar cap and enhanced ion frictional heating during high geomagnetic activity. When geomagnetic and solar activity is high, the observed decrease in electron density expands to daytime for altitudes below 350 km. Possible explanations of the depletion region are presented and their dependence on geomagnetic activity is discussed.

Aurora and ionosphere irregularities based on GNSS data in the polar region.

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In this study the space-time characteristics of the aurora from the all-sky cameras juxtaposes with the ionosphere irregularity distribution based on GNSS network data in the polar region. 6 GNSS stations and 4 all-sky cameras on the Kola peninsula were used. Ionosphere irregularities are determined by the RoTI level, amplitude and phase scintillations. This GNSS data were analyzed for every satellite pass and compared to the simultaneous all-sky image of the corresponding regions. The H-component magnetic field disturbance and the polar oval model also were analyzed. The data both in quiet and disturbed geomagnetic conditions were processed. The correlation between ionosphere irregularities based on radio signals from the GNSS and auroras based on optical measurements was established. This correlation can allow to detect auroras when the optical observations is obstructed. Hypothesis about the morphology of ionosphere irregularities related auroras were also proposed. Authors thanks the RFBR for their grant 17-45-510341 for partial support of this work.

High-latitude thermospheric wind reponses to magnetospheric substorms

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Thermospheric winds are important for mass, momentum, and energy transfer in the coupled magnetosphere – ionosphere – thermosphere system. In this study, we investigate the responses of the thermospheric winds during magnetospheric substorms using ground-based measurements by the Fabry-Perot interferometer at Tromsø, Norway, the IMAGE magnetometers, the EISCAT radar, and an all-sky camera. The upper thermospheric winds have distinct responses to substorm phases. During the growth phase, westward acceleration of the wind was observed in the premidnight sector within the eastward electrojet region. Ion drag force is dominant for the westward acceleration. During the expansion phase, the zonal wind had a prompt response to the intensification of the westward electrojet (WEJ) overhead Tromsø. The zonal wind was accelerated eastward, which is likely to be associated with the eastward plasma convection within the substorm current wedge. During the expansion and recovery phases, the meridional wind was frequently accelerated to the southward direction, when the majority of the substorm WEJ current was located on the poleward side of Tromsø. This meridional wind acceleration is related to a pressure gradient produced by Joule heating within the substorm WEJ region. Mesoscale wind structures in the lower and upper thermosphere are found in the vicinity of aurora arcs. In addition, strong atmospheric gravity waves during the expansion and the recovery phases were observed.

A detailed study of auroral fragments

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Aurora occurs in various shapes, one of which is the hitherto unreported phenomenon of auroral fragments. Their properties for three periods of occurrence in the winters of 2015 and 2017 were examined in detail for this study, using mainly ground-based instrumentation located near Longyearbyen on Svalbard, Norway. A base dataset was constructed from 103 all-sky camera images, manually marking 305 fragments for further analysis. This study reports and describes the fragment observations and geomagnetic activity during the observed events.

Fragments generally seem to fall into two categories, the first being singular, apparently randomly distributed fragments, and the second being periodic fragments that occur in groups with a regular spacing close to auroral arcs. A typical fragment has a small horizontal size below 20 km, a short lifetime of less than a minute and shows no field-aligned extent in the emission. The fragments appear mainly west of zenith (73%) during the three observation nights, whereas the north-south distribution is equal. Almost all of them exhibit westward drift, the estimated speed for one of the fragments passing the field of view of ASK is $\sim$1 km/s. A spectral signature can be seen in the green auroral wavelength of O at 557.7 nm and red emission line of N_2 at 673.0 nm, but no emission enhancement was observed in the blue wavelengths. This finding suggests a limit to the acceleration mechanism in question.

One fragment passing the EISCAT Svalbard radar's field of view shows a local ion temperature increase in a small altitude range of $\sim$15 km, whereas there is no visible increase in electron density. This could be explained by fragment generation due to locally strong horizontal electric fields. A potential mechanism for this might be electric fields of atmospheric waves superposing with the converging electric fields of auroral arcs created by particle precipitation and the corresponding field-aligned currents. The resulting field would be perpendicular to the magnetic field and the auroral arcs, leading to periodic density variations of excited plasma close to the arcs. Further study is required to verify this hypothesis and improve the understanding of fragment properties determined from the limited dataset used for this study.

Time-dependent electron-transport calculations of Alfvénic electron precipitation - with implications for flaming auroral rays and naturally enhanced ion-lines.

Björn Gustavsson

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A time-dependent multi-stream electron-transport code have been developed, making it possible to calculate the variations of energetic electron-fluxes at sub-second time-scales. This is used to calculate the ionospheric response to energy-time-dispersed keV electron-precipitation and suprathermal electron-bursts. The time-altitude variation of optical emissions are modelled as are the electron-distribution-function - where bump-in-tail distributions are found. The possibility of unstable distributions leading to generation of inverse Landau-damping and generation of enhanced levels of ion-acoustic wave-activity are discussed.

Phase-shift between rapidly varying auroral emission - in agreement with theoretical predictions?

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In this talk multi-monochromatic optical observations of flickering aurora, made with the ASK-instrument 27th of January 2017, will be presented. The primary novel finding is a phase-shift between the ”prompt” 6730 and 7774 Å emissions. Since flickering aurora varies at time-scales that are comparable to the time-of-flight of precipitating electrons through the ionosphere, excitation and emission-rate variations at such time-scales have to be calculated with time-dependent electron transport models. We have developed a time-dependent multi-stream electron transport model that we use to model the ionospheric response to precipitation varying at frequencies above 5 Hz. The observed phase-shifts are found to be in agreement with theoretical predictions of time-shifts between the optical emissions. Implications for magnetosphere-ionosphere coupling will be discussed.

Meso-scale ionospheric flow cells, localized Joule heating, and ion upflow associated with throat aurora as observed by EISCAT

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Throat auroras have been suggested to be related to indentations on the subsolar magnetopause. However, the indentation generation process and the resulting ionospheric responses have remained unknown. An EISCAT Svalbard Radar experiment was designed to run with all-sky cameras, which enabled us for the first time to observe the temporal and spatial evolution of flow reversals, Joule heating, and ion upflows associated with throat aurora. The high-resolution data enabled us to discriminate that the flow bursts and Joule heating were concurrent and co-located, but were always observed on the west side of the associated throat auroras, reflecting that the field-aligned currents associated with throat aurora always flow up/down in the east/west, respectively. These results are consistent with the geometry of Southwood (1987) flux transfer events model and provide strong evidence for throat aurora being associated with magnetopause reconnection events. The results also support a conceptual model of the throat aurora.

Analysing all-sky camera pictures and EISCAT data to derive ionospheric conductance

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The Pedersen and Hall conductivities of the ionospheric E-layer can be measured by, among others, incoherent scatter radars such as EISCAT. While these measurements are accurate, unfortunately they are not continuous and are only single-point measurements. A different source from which to derive the ionospheric conductance, which would be more continuous, as well as over a spatially wider area, would therefore be useful. Given that the aurora is closely related to the ionospheric conductance, we have studied the opportunity to use the IMAGE All-Sky Cameras (ASC) which are installed in several locations in northern Fennoscandia, to estimate ionospheric conductance. These cameras take a picture of the sky, covering a circular area with a radius of about 300 km in the ionosphere, roughly every 10s continuously, whenever it is dark enough to see aurora.

For the conversion of aurora intensity to conductance, the aurora data need to be calibrated. Unfortunately, accurate intensity calibration from raw counts to Rayleighs is not currently available for the IMAGE cameras. Because of this, we have used a short-cut approach, where empirical relationships are searched between Hall and Pedersen conductance measurements by EISCAT Tromsø, and the ASC raw counts from the Kilpisjärvi (KIL) EMCCD ASC, whose view area includes the ionospheric point measured by EISCAT. For the EISCAT part we have used the data service maintained by the National Institute of Polar Research, Japan. Our KIL-EISCAT data set includes 23 EISCAT measurement campaigns, of several hours each, all within the period November 2012 – February 2016. For spotting discontinuities in KIL raw count data we have used ASC data from Sodankylä (SOD) and Abisko (ABK) whose fields-of-view overlap partly with KIL ASC. The data set of joint KIL-SOD-ABK ASC covers the imaging seasons from October 2011 to April 2019.

In the presentation we will report about the results and challenges in our calibration exercise and demonstrate how the resulting conductance estimates can be utilized in a local KRM analysis, which estimates ionospheric currents and electric fields, in the KIL field-of-view. Our event study includes data also from the ESA SWARM satellites, which allows comparison between ground-based and space-based current estimates for that particular case.

Assessing the importance of variability in Electric field and conductance for the generation of GIC

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Geomagnetically Induced Currents (GIC) are driven by variations in the ionospheric electric currents, which in turn are enhanced by space weather activity. These currents are a convolution of the structure of the electric field and Pedersen and Hall conductivities in the ionosphere and there is evidence that the meso-scale structure of the currents is important in terms of the rate of change of the surface horizontal magnetic field (dH/dt), relevant to hazardous GIC. Thus it is important to determine the relative importance of the variabilities of the electric field and conductivities.

We use data from the mainland UHF EISCAT radar to derive estimates of the local electric field and conductance. Data are taken from the archive for common programmes 1 and 2, when the radar was field aligned or conducting a short dwell scan, both in tristatic mode. We examine the relationship between conductance and electric field in the context of a large spread of local time measurements and past investigations. Finally we perform an initial analysis of the variability of these parameters in relation to an independent measure of dH/dt provided by local magnetometers (part of the IMAGE chain) to establish whether the variability in the electric field or conductivity is more important.

Characteristics of the ground echoes detected by VHF meteor radar in the substorm growth phase

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The observations are made at the Sodankylä Geophysical Observatory (SGO, geographic coordinates 67° 22' N, 26° 38' E), which is located in the vicinity of the equatorward edge of the nightside auroral oval. The SGO meteor radar radio waves at frequency of 36.9 MHz are sometime reflected in the ionospheric E layer toward the sea surface and than scattered back, so that the radar receives ground echoes. This may occur for the waves transmitted at low elevation (less than 25 degrees) to horizon if the E-layer electron density is large enough (corresponding to about 10-15 MHz plasma frequency). Such events are typically associated with the substorm growth phase auroral arcs. A few-Hz fluctuations of electron precipitation in the arc cause corresponding amplitude fluctuations of the ground echoes, due to which the meteor radar erroneously accepts such echoes as backscatters from meteor trails. Statistics of the ground echoes observed since January 2009 show their predominant occurrence in summer, with no clear dependences on the solar activity. In two cases when suitable EISCAT observations were available, a high E-layer electron density up to 10^{12} m^{-3} was detected in the presumable region of reflection of radar waves.

Thermally excited 630.0 nm emissions in the polar ionosphere

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In this work, we investigate the importance and significance of thermally excited 630.0 nm emissions in the cusp and polar ionosphere. Thermal excitation by heated ambient electrons in the cusp and polar ionosphere is a rarely studied source of 630.0 nm emissions in this region, unlike direct impact excitation by precipitating electrons and dissociative recombination which have been extensively studied. We derive the thermal excitation component of the 630.0 nm emission from EISCAT Svalbard Radar (42 m) measurements and also utilize optical measurements from Svalbard. For the first time, the thermal excitation component is separated from the observed total 630.0 nm emission intensity and its contribution is quantified and characteristics are investigated. The results show that thermal excitation can be important in the cusp and polar ionosphere, particularly on the dayside. The strong thermal excitation component maximizes around magnetic noon, with an occurrence rate of $\sim$10%. When the strong thermal component is present, it can contribute $>$50% of the total 630.0 nm emission intensity. The thermally excited emissions have a relatively high peak emission altitude of $\sim$350 km, and could be responsible for the 630.0 nm emission at such altitudes and above. Thermal excitation is most likely to give rise to 630.0 nm emission intensities of order of kRs, when the electron gas temperature exceeds $\sim$2500 K for electron densities $\sim$(1-8)$\times 10^{11}$ m^{-3}. Thermal excitation in the cusp and polar ionosphere maximizes during equinox and/or solar maximum. Thermal excitation should therefore be taken into account when studying dayside 630.0 nm emissions and electron thermal balance in the cusp and polar region.

Resolute Bay Incoherent Scatter Radar observations of electron density gradients: 3D estimates and implications for small-scale irregularity formation

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Electron density gradients in the polar F region ionosphere are essential for the structuring processes through the gradient-drift instability (GDI). The information about the typical strength of gradients is important for the theoretical studies and modeling of the GDI waves, but rarely available because of significant experimental challenges in evaluation of the gradients, particularly at small scales and in 3D. In this study, multipoint density measurements of the Resolute Bay Incoherent Scatter Radar North (RISR-N) working in a special high-spatial-resolution mode are employed. The 3D gradient vectors are estimated and analyzed statistically utilizing a large RISR-N data set. The sharpness of the density gradients reveals a significant increase around magnetic midnight due to a decreased effect of the solar smoothing. Further, sharp density gradients occur during magnetically quiet times, possibly because of the presence of the polar holes and reduced plasma precipitation. These gradients are strong enough for a direct generation of GDI waves at decameter scale (i.e. in linear regime), which implies that nonlinear turbulent cascade is not necessarily required for at least some GDI waves.

Mesospheric ozone destruction during the pulsating aurora

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Pulsating aurora (PsA) is caused by intermittent precipitations of a few to tens of keV electrons from the magnetosphere through wave-particle interaction processes, depositing the majority of their energy at altitudes around 100 km. We report an observation to identify a few hundred keV – MeV electron precipitations during a PsA event associated with a moderate geomagnetic storm. The EISCAT radar at Tromso observed significant ionization at altitudes of around 60 km, which is the lowest altitude ever observed, indicating precipitations of wide energy electrons from a few keV to MeV. Simultaneously, the Arase spacecraft observes intense chorus waves in the magnetosphere, and the observed chorus waves actually cause wide energy electron precipitations. The SIC simulation based on the EISCAT observations shows catalytic ozone destruction by more than 10% at the mesosphere during the PsA event due to electron precipitations.

Physics of the Grand Challenge Initiative Cusp Project

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The Grand Challenge Initiative – Cusp is a gigantic multi-rocket project that will be conducted in Svalbard and North Norway during the winters of 2018/19 and 2019/2020. This is a US, Japan and Norway collaborative effort that umbrellas 9 sounding rocket missions of altogether 11 rockets. GCI-Cusp is focused on dayside magnetopause reconnection and its coupling down to the cusp ionosphere, and the various impacts this have the upper polar atmosphere, including waves, instabilities, turbulence, heating processes, oxygen escape, and radio scintillation issues. The main part of the talk presents prioritized research by the 4DSpace research group at the University of Oslo. Our major goal is to explore the physical properties of plasma turbulence in the F-region cusp ionosphere. UiO will provide one sounding rocket in the GCI-Cusp project, that is the ICI-5 rocket (Investigation of cusp Irregularities), and we will contribute our multi-Needle Langmuir Probe (m-NLP) system to 1 JAXA rockets and 5 NASA rockets. We are developing a 4DSpace rocket experimental tool to uniquely discriminate between waves and turbulent plasma structures. This system will fly on G-CHASER (6 daughters) and on ICI-5 (12 daughters). The applied motivation for the 4DSpace research at UiO is to provide a basic understanding of the multi-scale processes that give rise to radio scintillations. It order to for example develop running space weather forecast models for GNSS scintillations, it is essential to explore the mesoscale drives, of the major instability processes involved, and to quantify the actual growth and decay rates of these processes under various conditions. I will review some of the recent results from the ICI-rocket program and related research, and at the end sum up with the research questions we will attack with GCI-Cusp. The project is open for new collaborations taking interests and may contribute to our effort.

Characteristics of CME- and CIR-driven ion upflows in the polar ionosphere

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We investigated how velocity and flux of ionospheric ion upflows vary during magnetic storms driven by corotating interaction regions (CIRs) and coronal mass ejections (CMEs), using data from the European Incoherent Scatter (EISCAT) Tromsø UHF and Svalbard radars between 1996 and 2015. The characteristics of ion upflows were compared with ion and electron temperature variations measured with the EISCAT radars, and also joule heating rate, electric field, and field-aligned current (FAC) distribution derived from the Weimer model. Upward ion velocity increases in the nighttime at Tromsø (66.2 deg N geomagnetic latitude) just after the CIR- and CME-driven storms, corresponding to electron temperature enhancements due to soft particle precipitation and also ion temperature enhancements in the strong westward electric field region. The CME-driven storms have larger upward ion flux (1.7×10^13 m-2s-1) than those under the CIR-driven storms (0.3×10^13 m-2s-1). In the daytime, ion upflows are seen at Longyearbyen, Svalbard (75.2 deg N geomagnetic latitude), with an upward flux of typically 1013 m-2s-1 for small CIR and CME storm cases. Substantial ion upflows last for a few days after the storm onsets under small CIR storms, whereas they last for only a day under small CME storms. Under both the cases, the substantial ion upflows are associated with an enhancement of the Region 1 FAC, eastward electric field and Joule heating rate. For large CME storms, substantial ion upflows are absent in the daytime probably due to equatorward expansion of the auroral oval.

Spatial distribution of the polar thermospheric wind acceleration and importance of the 2D measurement with SDIs

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Understanding the flow of energy and mass throughout the magnetosphere-ionosphere-thermosphere coupled system is a fundamental goal of solar-terrestrial physics. Since substantial energy accumulated in the substorm growth phase in the magnetospheric tail flows into the polar ionosphere immediately after the substorm onset, investigating the energy dissipation process at high latitudes around the time of substorm onset can contribute significantly to achieving that objective. The energy dissipation generates acceleration and heating of the ionosphere and thermosphere, but this might occur not only near aurora but also far from it by hundreds kilometers equatorward. We analyzed ionospheric and thermospheric measurements in the northern Scandinavian area (65-80 N) during periods of considerably low geomagnetic activity but with some aurorae above Svalbard (75-80 N). Thermospheric winds measured with a Fabry-Perot interferometer (FPI; 630.0 nm) at Tromsø, Norway (69.6 N) showed westward accelerations coinciding with auroral brightening at the Svalbard area at the dusk sector though the relative distance from Tromsø to the aurora was 200-500 km in some cases. Moving into the dawn sector with the earth's rotation, the acceleration direction turned to southeastward through stagnation area or period seen at magnetic local midnight. The acceleration pattern well represents thermospheric responses to the ionospheric convection, but of particular interest is its location, in which the thermospheric wind have been obtained at the sub-auroral region far from the main auroral oval. In this analysis, we cannot infer to horizontal patterns of the wind acceleration because we have only a point measurement from the Tromsø FPI. While this result suggests the importance of two-dimensional measurements of ionosphere and the thermosphere, we need a new configuration of the observation network to infer horizontal winds and accelerations. In this presentation, we will introduce "SDI-3D" project, which aims at developing 3 Scanning Doppler Imagers (SDIs) and deploying them at the same area as for the EISCAT_3D, which may start in operation in 2022.

Variations of cosmic noise absorption by energetic electron precipitation and changes of the auroral morphology

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Temporal and spatial variations of the aurora morphology in association with substorm have been studied for more than half century. In this study we focus on pulsating aurora, which is characterized by quasi-periodic oscillations in the emission intensity at periods of a few to tens of seconds, and auroral patches observed embedding in the pulsating aurora. Both types of aurora are known as typical phenomena at the recovery phase of substorm, especially from midnight to dawn. It is known that these types of aurora are often accompanied by energetic electron precipitation (EEP) exceeding several hundreds of keV [Miyoshi et al., 2015]. Elucidation of causality to produce pulsating aurora and EEP is an important theme to understand relationships between the radiation belt and upper-middle atmosphere of the earth. Analyzing measurements from satellite observations and ground-based optical/radio technique observations, the generation mechanism is thought to be mainly attributed to wave particle interactions due to plasma wave and electrons in the magnetosphere. In this study, we study relationships between auroral morphological changes, in particular spatiotemporal evolutions of patches and coinciding precipitations of the energetic electron.

Some previous studies have presented changes in morphology from pulsating aurora to patch structures and temporal variations of EEP [Shiokawa et al., 2014; Hosokawa and Ogawa, 2015; Oyama et al., 2017]. As mentioned above, the wave-particle interaction has been widely accepted with experimental evidences to support generation of pulsating aurora and EEP [Miyoshi et al., 2015; Kasahara et al., 2018].. However, our understanding has not yet reached its maturity of presenting spatiotemporal evolutions of auroral morphology and associated electron precipitation. Oyama et al. [2017] presented enhancements of cosmic noise absorption (CNA) coinciding with appearance of the patch structure but with only two events. In this study, we conducted observations to capture simultaneously time evolutions and spatial distributions of auroral morphology and EEP by utilizing a network of Electron Multiplying Charge Coupled Device (EMCCD) cameras and riometers deployed in Scandinavia.

This study will present two events (March 6-7 and 29-30, 2017) with pulsating aurora and auroral patches in the sky of Sodankylä, Finland. Spectrum analysis was applied on time series of the EMCCD count data in order to filter out modulations at oscillation periods longer than 40 seconds. Comparison with the CNA measured with the riometer at Sodankylä showed a linear correlation. This suggests that EEP due to 10s keV electrons synchronizing with the optical pulsation directly contributes to CNA or ionization in the D region (around 90 km height) in spite of vertical discrepancy between the optical emission height and CNA-related ionization height. This finding also implies a particular perspective for estimation of EEP appearance by using optical data alone. This might be an advantage to monitor the wide area of EEP activity by applying the knowledge on global camera network at auroral latitudes.

High resolution optical observations of neutral heating associated with the electrodynamics of an auroral arc

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We present results that indicate the existence of two distinct neutral heating processes associated with a discrete auroral arc over Svalbard. Pedersen currents produce a temperature increase observed over a large altitude range directly adjacent to the arc structure on its poleward edge only. In contrast, field aligned currents produce a varying temperature increase seen within the arc itself and constrained to a narrow altitude range close to the mesopause. By utilising a range of observations and new analysis methods we are able to measure the atmospheric neutral temperature profile, over auroral altitudes, at unprecedented temporal and spatial scales. HiTIES (High Throughput Imaging Echelle Spectrograph) records high resolution emission spectra of the aurora, which are then fitted with synthetic N_2 spectra, generated with modelled N_2 volume emission rate profiles and a library of trial temperature profiles. The N_2 volume emission rate profiles are retrieved from the Southampton ionospheric model using precipitating particle energies and fluxes obtained from Auroral Structure and Kinetics (ASK) and the ESR (EISCAT Svalbard Radar). The application of this technique allows us to produce a time series of neutral temperature profiles and measure the localised heating of the neutral atmosphere associated with the arc's electrodynamics.

Observation of a neutral wind jet driven by extreme plasma convection in the polar cap

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On 12 September 2014, the Resolute Bay Incoherent Scatter Radar (RISR-N) observed intense sunward ionospheric convection in response to a CME. The magnetosphere-ionosphere response was discussed by Clauer et. al. 2016, wherein RISR-N observed 3 km/s near the cusp during a strong (30 nT) and sustained (30 minutes) northward interplanetary magnetic field at 19 UT without the CPCP saturation effect observed. Here we present an analysis of the ionosphere-thermosphere response to the CME, where RISR-N measurements indicate an E region neutral wind jet associated with the strong ionospheric convection. The neutral winds peak with a speed over 500 m/s at 130 km altitude, which is unusually fast but still only a fraction of the plasma velocities. We will discuss the factors that limit the maximum neutral wind speed driven by ion-neutral collisions and a strong convection electric field.

A Reverse Flow Event as the Onset of Ionospheric Scintillation Irregularities in the Cusp

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Ionospheric irregularities and turbulence are common in the high latitude F region ionosphere. The irregularities with scale sizes ranging from a few decameters to a few kilometers are known to be important for space weather applications, as they can affect high frequency (HF) radio communication and cause disturbances in trans-ionospheric signals that are termed scintillations. With the increase of human activity in the Arctic, better understanding the physical mechanism responsible for their creation is of growing importance.

In this work, we examine the contribution of different sources of free energy for the creation of scintillation irregularities in the cusp ionosphere. We study the connection between total electron content (TEC), rate of TEC index (ROTI), and scintillations detected from a network of four GNSS receivers in Svalbard and 2D maps of densities, velocities and temperatures obtained from the EISCAT Svalbard Radar (ESR) using fast sweeps in azimuth with constant elevation. In particular, we analyze in more details the scintillations associated with a Reversed Flow Event (RFE), i.e. a narrow channel of flow in the opposite direction to the background convection, which is a typical signature of a flux transfer event. We present evidence that magnetosphere-ionosphere coupling is important for the generation of plasma irregularities and scintillations in the cusp. Using numerical simulations from the GEMINI-SIGMA code, we investigate the potential role of the Kelvin-Helmholtz instability. This study shows that wide field-of-view incoherent scatter radar experiments (e.g., our ESR fast azimuth sweeps, or future volumetric measurements with EISCAT_3D) have great potential for investigations of space weather phenomena.

Particle precipitation energy spectrum during pulsating aurora

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Pulsating auroras (PsAs) are a very low-intensity type of aurora switching on and off with a quasi-periodic oscillation period between 6 and 40 seconds. They are caused by precipitating electrons which span a wide range of energies believed to be between tens and hundreds of keV. The sources of these energetic electrons are widely accepted to originate from the pitch angle scattering and acceleration of electrons by the low band chorus and Electrostatic cyclotron harmonic wave-particle interactions. They are predominantly observed after magnetic midnight, during the recovery phase of magnetic substorms and at the equatorward boundary of the auroral oval. The main characteristics of PsA have been reported in many of previous works based on ground and space-based instruments. Their effects on the atmosphere have also been reported using integrated measurements. Even though, most of the case studies of PsA show some consistency, using an extensive data set to get a general understanding of the spectrum of the energy of precipitating electrons has not been well documented. In this study, a combination of all-sky cameras and satellite measurements is used to construct a typical energy spectrum of precipitating electrons during PsA. Among the 842 PsA events identified using FMI-MIRACLE ASC network over the Fennoscandanavia region, 192 events were found to be observed between DMSP, POES, and FAST satellites over the combined field of view of the ASCs. The combined measurements from these satellites are used to obtain an energy spectrum consisting of non-relativistic and sub-relativistic electrons during PsA. SIC-model is used to assess the chemical effect of precipitating particles during PsA and found a significant decrease in ozone concentration both for long and short time forcing.

Polar Cap Flows and Ion Heating: RISR Observations and Outstanding Questions

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The Resolute Bay Incoherent Scatter Radars (RISR-N and RISR-C) frequently observe bursts of fast flows and spikes of ion heating, particularly around noon magnetic local time. The recent addition of a small remotely-controlled generator to the Resolute Bay Observatory now allows nearly continuous low-duty-cycle operations with RISR-N. The sustained observations show that these ion-heating events happen frequently, even during otherwise geomagnetically quiet times. This talk will provide an overview of the RISR observations and discuss a number of known issues with the interpretation of the data. Reconstructing vector velocity fields and shears from a monostatic radar is an ill-posed problem, and this talk will compare a variety of techniques for estimating flow shears using RISR. The fitted ion temperatures also require careful interpretation if the flows are fast enough to create non-Maxwellian ion distributions. Despite some issues of interpretation, we are confident the RISR observations are genuine indications of energy dissipation in the polar cap ionosphere. The exact magnetospheric origin of these heating events requires further research.

Aurora Zoo - Auroral Physics Done By the Public

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The Auroral Structure and Kinetics (ASK) imaging system has been operating at the EISCAT Svalbard Radar site for 12 years, and is still going. So far ASK has produced approximately 150TB of data containing thousands of hours of video of the aurora, most of which has never been looked at. We have developed a citizen science project called Aurora Zoo to enlist the public's help in performing extremely large statistical studies of fine-scale structures in the aurora. In Aurora Zoo, the public can classify and make measurements on short sequences of ASK images, such as measuring the widths and orientations of arcs, or the occurrence of auroral curls. Citizen scientists can also send us unusual events which they find. We've used a beta version of the Aurora Zoo as a public engagement tool, including running workshops at a light art festival, a science and engineering festival, and at the Science Museum in London during the school holidays. We've found that people of all ages can produce valid and useful data, and that young children can easily become addicted. We will present some interesting events found by the public and some preliminary results of statistical studies using Aurora Zoo.

Ionospheric currents in the two hemispheres during low and high magnetic activity by the Swarm satellite

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We present statistical investigation of the high-latitude ionospheric current systems in the Northern and Southern hemispheres during low ($Kp < 2$) and high ($Kp \geq 2$) geomagnetic activity levels. We analyse nearly four years of vector magnetic field measurements from the two parallel flying Swarm satellites using the spherical elementary current system (SECS) method [Amm et al., 2015], and determine the ionospheric horizontal and field-aligned currents (FAC) for each auroral oval crossing separately. We bin the FAC as well as the horizontal curl-free (CF) and divergence-free (DF) currents in magnetic latitude and local time grid for each hemisphere and activity level separately. Bootstrap resampling is used to estimate the statistical significance, and to remove seasonal bias in the data distribution.

We find that overall the currents are stronger in the Northern hemisphere than in the Southern hemisphere, but the difference depends on the geomagnetic activity level. Large hemispheric asymmetry is observed during low magnetic activity, with larger magnitudes of FACs and horizontal currents in the Northern hemisphere. In contrast, the interhemispheric difference is very small during high magnetic activity, which suggests that the local ionospheric conditions may be important, playing a larger role during quiet than disturbed periods. The local conditions may be related to factors such as variations in solar illumination or magnetic field strength due to different offsets between the geographical and magnetic poles, and dynamics of neutral atmosphere. We plan to study these factors in the future.

A statistical investigation of algorithm-identified poleward-moving auroral forms (PMAFs)

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High sensitivity all-sky imaging observations of the 630 nm OI emission at the poleward boundary of the high latitude southern dayside auroral oval (-80° magnetic latitude) reveal the existence of a quasi-continuous stream of poleward convecting auroral patches exiting from the dayside oval and moving anti-sunward in the polar cap. These patches in keograms are designated as Poleward Moving Auroral Forms (PMAFs) and conventionally associated with intermittent dayside reconnection activity. An algorithm is developed to identify PMAFs without observer bias. With the interplanetary magnetic field (IMF) information from the THEMIS satellites, the results suggest that PMAFs are tightly related to the anti-sunward flow driven by ionospheric convection. However, the result disagrees that flux transfer events (FTEs) cause PMAFs.

Comparisons study of electron densities and temperatures measured on board CSES satellite by using ISR observations

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China Seismo-Electromagnetic Satellite (CSES) was launched On February 2, 2018, which is the first space-based platform in China for both earthquake observation and geophysical field measurement. The scientific payload is composed of several instruments which provide a nearly continuous survey of the plasma, waves and energetic particles.

In order to validate the Ne/Te observed by Langmuir probe onboard CSES, comparison is made when the CSES satellite flies passed over the incoherent scatter radar (ISR) data at Millstone Hill. We found that CSES Ne/Te is stable, while ISR Ne are stable except the data with larger kp. There are more fluctuations in ISR Te. CSES Ne is about 60% lower (average) than ISR Ne, and CSES Te is about 500k higher than ISR Te in daytime.

We also compare Ne/Te with ones calculated using local empirical model (LEM) which are constructed using ISR data in Millstone Hill. Both CSES Te and LEM Te in nighttime exhibit an annual trend with its valley in May and peak in November. Although the trend between LEM Ne and CESE Ne in nightside is opposite, we have analyzed and confirmed CSES Ne in nightside show the reasonable temporal variation because of MIT (Mid-Latitude Ionospheric Trough Structure) and MLA (Midlatitude Arc). However, we found there are linear drift in CSES Ne/Te in daytime. After removing the linear drift, CSES and LEM Ne/Te in daytime show consistent temporal variation.

When a new satellite-borne Langmuir probe operates, comparison with measurements from ISR is needed to guarantee the reliability of the new data. Of course, it is also very important and meaningful to do some jointly research using the ISR and satellite-borne Langmuir probe data.

Influence of the substorm precipitations and polar cap patches on the GPS signals at high latitudes

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This study investigates the influence of substorm-related energetic particle precipitations and polar cap patches (PCP) on GPS signal scintillations in the high-latitude ionosphere. A number of events in 2010-2017 are considered. We use data collected by the GPS scintillation receiver (University of Oslo) at Ny-Ålesund. Substorms are identified through optical observations at 630.0 nm in Ny-Ålesund as well as IMAGE magnetometer data. Occurrence of polar cap patches is determined by using electron density data from the EISCAT 42-m radar at Svalbard and by considering optical observations at Ny-Ålesund. For some events, we show the onset of PCPs on the dayside and their propagation into the nightside, where the GPS receiver is located, by considering data from the Resolute Bay (Canada) incoherent scatter radar and the SuperDARN radars. We demonstrate that substorm-associated precipitations can lead to a strong GPS phase scintillations up to 3 radians which is much stronger than those usually produced by PCPs. On the other hand, PCPs can lead to a much faster rate of TEC variations. Our observations suggest that the substorms and PCPs, being different types of the high-latitude disturbances, lead to the development of different types and scales of ionospheric irregularities.

Joule Heating by Thermospheric Winds

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A highly simplified model considers the response of the ionosphere to neutral winds. An effect is obtained only in case of winds that relatively differ in magnetically connected regions, winds that are constant along a coordinate following the magnetic field have no effect. Because of the large preponderance of the neutral gas mass over the ionized component in the Earth's ionosphere the dominant effect of the plasma adjusting to the winds is Joule heating. We identify the well-known solar quiet (Sq) geomagnetic variations as being driven by wind differences at magnetically conjugate points. The amount of global Joule heating power from Sq is, with uncertainties, estimated to be lower than Joule heating from ionosphere-magnetosphere coupling at high latitudes in periods of strong geomagnetic activity. However, integrated over time the former, being a relatively constant trickle, could surpass the high-latitude Joule heating, which can spike at times of increased activity, but is small to negligible at the prevalent quiet times.

The plasma responds also to variations of the wind within the dynamo layer of the thermosphere with Joule heating, for example from gravity waves. Unlike Sq the associated current systems are unlikely to be detectable at the ground or at satellite altitudes. We estimate that the damping effect of ionospheric dynamo on gravity waves competes with that of molecular viscosity at the same altitude.

Statistical studies of morphological variations of power spectral density contained in EISCAT Svalbard radar data

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One way to experience the normal, the Naturally Enhanced Ion-Acoustic Lines (NEIALs) or the hard object morphology spectra is by observing and evaluating the morphology of power spectral density variations among each raw data dump. Here, we have observed the statistical behavior of the power spectral density morphology among the consecutive data dumps, with a time resolution of 6.4-seconds per dump. The analyzed data represent the atmosphere scan using EISCAT Svalbard Radar (ESR) 42m antenna, for 9.14 hours on 01 June 2004, starting from 07:22:55 UT to 18:01:07 UT. Among the 5141 data dumps observed, normal spectra was dominating with a frequency of 4170 data dumps. Hard objects (satellite, space debris, etc.) were very frequently contained in the spectra (941 data dumps), and a relatively small number of NEIALs processes were observed (totaling 30 data dumps). We found NEIALs and hard objects which develop inside one single data dump, but such processes can develop in up to five consecutive data dumps, as well. Enhancements in left, right and both ion line shoulders were observed. Our observations showed that the down-shifted NEIALs, as well as up-shifted NEIALs, realized their maximum of the intensity in the F region. On average, the up-shifted NEIALs realized their maximum of intensity around 50 km below the down-shifted NEIALs. Among the thirty profiles of the NEIALs we found, we did not find any up-shifted NEIALs that realized the maximum of intensity positioned at the E region of the ionosphere, even though there are some up-shifted NEIALs that were extending from the F region to the E region. In terms of whole spectral shift, we found that the ion line enhancements, down-shifted in frequency, dominated the statistics.

Energetic spectra of auroral electrons in rayed aurora: deductions from triangulation and model simulation

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The energetic spectra of the electron fluxes precipitated into the atmosphere and stimulated rayed auroral structures have been derived. The triangulation observations of auroral rays emission by the Multiscale Aurora Imaging Network (MAIN) system on the Kola Peninsula served as an experimental data for spectra recovery.The MAIN system of auroral cameras has two identical synchronized digital cameras with diagonal field of view of 18 degrees [1-3]. The cameras are equipped with glass filters that separate the blue-green part of the visible spectrum. The observation points are separated by 4 km in longitude, so it is possible to triangulate small-scale auroral forms. The spectra of precipitating electron fluxes were estimated from these altitude profiles using a numerical model of electron degradation in the atmosphere [4-6]. We found that the electron fluxes have wide energy spectra with a degree dependencies of the flux on the energy F(E) E^{-a}, which distinguishes their from the typical spectra forming pulsing patches and bands. The intensities of main auroral emissions have been calculated using physicochemical model of auroral ionosphere [6-7].

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Characterization and modeling of the ionosphere at high latitudes for the propagation of electromagnetic waves

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The ionosphere can have a significant impact on the propagation of radio waves. At low frequencies, typically for frequencies below a few megahertz, the ionosphere can induce a total "reflection" of waves emitted from the Earth. Beyond and up to about 10 Gigahertz, the ionosphere induces large group delay, polarization rotation and refraction effects and rapid fluctuations in amplitude and phase on radio signals. These are particularly troublesome for satellite navigation systems (GNSS), leading to location errors, or even receiver stalls. Today the ionospheric effects on the propagation of electromagnetic waves are still poorly understood because the ionospheric layer itself is not perfectly described by the models. Turbulent processes in the ionosphere are responsible for scintillation or absorption phenomena. Currently, there is no extensive study capable of establishing correlations between the physics of irregularities observed (or at least observable) and their impact on electromagnetic waves, characterized by the S_4 and σ_ϕ parameters. This is why we conducted a study comparing the data and models from the study of ionospheric physics with those from GNSS ground stations. Using SuperDARN, EISCAT and GNSS data as well as IPIM, EPEE and STIPEE models, a first study was conducted in the Polar Regions. Indeed, in this region, the charged particles transported by the solar wind penetrate into the terrestrial magnetosphere and modify the state of the ionospheric layer. To date, the insufficiency of fine ionospheric scintillation characterization does not allow further studies of radio system improvement and receiver algorithms. The first results of this combined study will be shown here, analyzing a low-impact event to make links between accessible radar and GNSS data.

Characteristics of an HSS-driven magnetic storm in the high-latitude ionosphere

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Solar wind High-Speed Streams (HSSs) affect the auroral ionosphere in many ways, and several separate studies have been conducted of the different effects seen e.g. on Aurora, geomagnetic disturbances, F-region behavior, and energetic particle precipitation. In this presentation, we study a HSS event in the current solar cycle (24), which was associated with a co-rotating interaction region (CIR) that hit the Earth's magnetopause at about 18:30 UT on 14 March 2016. The associated magnetic storm lasted for eight days, and the Dst index reached -56 nT. We use a very comprehensive set of measurements to study the whole period of this storm, following day by day for the magnetic indices and solar wind parameters and relating its consequences on the Ionospheric plasma parameters. We use EISCAT ISR data in Tromsø and Svalbard stations to see the response in plasma parameters at different altitudes, riometer data for cosmic noise absorption, and IMAGE magnetometers to see the intensities of auroral electrojets. TomoScand ionospheric tomography provides us electron densities over a wide region in Scandinavia and AMPERE data the global field-aligned currents. We identified NN local substorms in the Scandinavian sector from the IL (MAGE lower) index. Altogether, there were 11 global substorms, for which the AE index reaches 1000 nT. We discuss the development of currents, as well as E and D region precipitation during the course of this long-duration storm and compare local versus global behavior.

IONO-HF: HF wave propagation in realistic ionosphere

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Multiple ray tracing tool already exists, but often fail to model accurate wave propagation behavior in the ionosphere, mostly because a majority of them use the IRI model (International Reference Ionosphere) as input. Such model gives realistic physical properties estimation during "quiet" solar period but rather poor results during high solar activity. In this poster, we present some results obtain with a new ray tracing tool developed at IRAP. This new ray tracing tool solves in a three dimension spherical frame, the eikonal equation, derived from the Fermat principle. It solves the HF wave trajectories of a few tenth of MHz. In particular, this ray tracing tool is designed to use as input the ionosphere modelled by IPIM (IRAP Plasmasphere-Ionosphere Model). IPIM is a numerical ionosphere model, solving the chemical, energetic and transport equations along magnetic field line with a 16 moment-resolution. Therefore, using IPIM provides access to realistic ionosphere properties, during any kind of solar activity period. We will present the numerical modelling of SuperDARN radars and we will analyze the trajectories obtained with our ray tracing tool in realistic ionosphere profile and process our data to locate the Effective Scatter Volume (ESV) along each trajectory. Then we will estimate the error done when taking into account the refractive index impact on the wave velocity. With the coupling of an accurate ionosphere model and a consistent ray tracing tool, we aim at giving a better understanding on the wave propagation across the ionosphere.

Recent studies on Throat aurora

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Optical aurora can be classified into two broad categories, i.e., diffuse and discrete auroras. Recent studies based on optical observations obtained on the dayside reveal some important processes occurred in the dayside magnetosphere and are reviewed in this paper. Dayside diffuse auroras (DDAs) are classified into unstructured and structured DDAs. Unstructured DDAs predominantly occur in the morning but structured ones are mainly observed near magnetic local noon. Because structured diffuse auroras have been suggested to be associated with cold plasma structures in the magnetosphere, distribution and generation of cold plasma structures in the dayside outer magnetosphere are discussed based on the detailed observational properties of DDAs. A particular discrete auroral form, i.e., throat aurora, is defined during study on DDA. The main observational properties of throat aurora have been presented, which suggest that generation of throat aurora is affected by factors from either inside or outside the magnetosphere. These observational results have not been well understood. In the future, a physical model of throat aurora that can explain all of the observational results should be proposed.

Advanced modular incoherent scatter radar studies of plasma structuring processes at high latitudes

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An overview of recent observations of plasma structuring processes using advanced modular incoherent scatter radars in Poker Flat (PFISR) and Resolute Bay (north face; RISR-N) is given. PFISR observations are presented that demonstrate that the E-region electron temperatures are lower than expected at extreme electric fields, owing due to, in part, stronger vibrational cooling. A comparison between the PFISR- and GNSS-derived TEC estimates showed that the topside contribution to TEC (above 660 km) range between 14%-30% and are most consistent during daytime hours, while observations near the solar terminator and during the night suffer from large uncertainties. RISR-N observations are presented that show that deep depressions in the plasma density in the polar cap (polar holes) do not necessarily require very slow or very fast convection, in contrast with model predictions. Electron density gradients derived from multi-point RISR-N measurements are utilized in testing a hypothesis that small-scale plasma structures may be generated directly by the gradient-drift instability rather than through the nonlinear cascade, as it is often assumed.

Spectral investigations of near infrared aurora and airglow in 1.0-1.6 microns using InGaAs imaging spectrograph: 1-year ground-based observation at Syowa station (69.0°S, 39.6°E)

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The motivation of this study is further understanding of dayside magnetosphere and terrestrial atmosphere coupling system by using continuous observation. Dayside aurora, polar patch, and airglow should be key phenomena for the understanding of the coupling, and In particular, those phenomena in near infrared (NIR) wavelength are crucially important because lower background sky luminosity by Rayleigh scattering may allow us to conduct ground-based optical observation even in dayside. However, NIR aurora has a total lack of its spectral information with enough resolutions to make a feasibility study in comparison to that in visible wavelength.

We designed a narrow field spectrometer with medium-high spectral resolution that mainly consists of Czerny-Turner type imaging spectrometer (HORIBA, iHR320) with one entry port and two exit ports. This spectrometer has two mirrors and three diffractive gratings in a rotating turret. A toroidal mirror for collimating corrects for astigmatism so that the tangential (resolution optimized) and sagittal (imaging optimized) focal planes cross at the center of the focal plane. Another larger focus mirror allows the entire flat field to be used without vignetting. Collecting optics, equipped outside the spectrometer, are a gold coated off-axis parabolic mirror and a NIR longpass filter for removal of secondary diffracted light in visible wavelength. Using 1-d InGaAs array (1024 pixels) and 600 gr/mm grating, spectral range and spectral range per pixel are 119 nm and 0.11 nm/pixel, respectively.

We have carried out ground-based spectroscopic observation in NIR wavelength ranging from 1.0 to 1.6 microns, which covers strong OH airglow emissions and auroral emissions in N_2 1st Positive (1.2 microns) and N_2^+ Meinel (1.1 and 1.5 microns) [Jones 1974; Gattinger and Jones, 1981], at Syowa Station (69.0°S, 39.6°E), Antarctica from March to November 2018. OH airglow spectrum in NIR can be well resolved even in water vapor absorption region. OH rotational temperature is successfully estimated using OH 3-1 band P1(2) and P1(4) emissions. In this presentation, we are going to report the results including NIR auroral emissions at 1.10, 1.24, and 1.52 microns in more detail based on one year observation.

Impact of Solar Wind High Speed Streams on Ionospheric Current Systems and Associated Space Weather Effects

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High speed streams (HSS) and associated co-rotating interaction regions (CIR) in the solar wind are one of the major drivers of geomagnetic activity, especially during declining phases of sunspot cycles and near sunspot minima. We have identified 42 HSS/CIR driven geomagnetic storms that coincide with a DST drop to less than -50nT during the period 2009-2018 and will investigate their impact on ionospheric current systems. Our approach is to study the evolution of the global scale current systems, i.e. the auroral electrojets and Region-1/2 field-aligned currents (FAC), with the SuperMAG magnetometers and AMPERE satellite data, respectively. The selected events will be studied individually and in conjunction with a superposed epoch analysis centered around the storm onset to see the general behavior of the current system globally and in four different MLT sectors: noon, dusk, midnight and dawn.

Changes in the ionospheric current systems are also reflected in the space weather. Increased Joule heating by ionospheric currents makes the thin upper atmosphere expand, thereby increasing atmospheric drag experienced by low-Earth orbiting (LEO) satellites. We will also study this effects in some of the selected HSS/CIR events and its correlation with changes in the ionospheric current systems by using measurements of the neutral density from the Swarm spacecrafts.

Subauroral arc emissions and sunlit aurora

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Recent collaborations between the scientific community and citizen scientists, have led to the discovery of a previously undocumented in the scientific literature, auroral phenomenon. The new emissions, called the Strong Thermal Emission Velocity Enhancements, or STEVE, appear at sub auroral latitudes in stable, east-west aligned arcs in the premidnight sector and last on average for approximatley 60 minutes. The emissions, first studied by MacDonald et al. 2018, are associated with a strong westward ion flow and a significant temperature increase.

Subsequent studies by Gallardo-Lacourt et al.(2018) found that the emissions are not directly associated with high energy particle precipitation, and in a statistical study of 28 events, Gallardo-Lacourt et al.(2018a) further found that the emissions have an average latitudinal width of ~20 km. The unusual color, described as purple white-ish, is reminiscent of what is found in sunlit aurora during twilight hours. Sunlit aurora dominated by blue-violet light was first observed by Størmer [1929, 1939], who noted that the intensities at 3914 and 427.8nm from N2+ were relatively brighter than the emission from atomic Oxygen at 557.7nm. The discovery of STEVE comes with new, unanswered questions about the physical processes that lead to the generation of the emissions, its structure and spectral composition and spatial distribution. We present model calculations, from a one dimensional self-consistent high latitude ionosphere model (SCIM) [Fallen 2011], of the ionospheric responses to auroral precipitation with characteristic energies below 50eV, testing the hypothesis that it can account for the observed emissions. Additionally we discuss the possibility that STEVE is sunlit aurora first observed by Størmer.

Horizontal distribution of plasma density irregularities in auroral ionosphere

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We present a coordinated observation of auroral ionosphere by using all sky imager and spaceborne L-band synthetic aperture radar (SAR) over Tromsø, Norway. During an aurora event detected by 558 nm all sky images at 22:05 UT on January 25, 2015, ALOS-2 satellite passed over EISCAT area from south to north direction. The SAR data contains phase variation due to the changes of Total Electron Content (TEC), which appear as band like structure stretching in east-west direction in SAR subband images. The result shows that small scale density variations exist within or above the auroral emission altitude. The height of irregular plasma density is estimated from SAR data.

Analysis of magnetosheath jets observed by CLUSTER during minimum and maximum solar activity

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The magnetosheath is the transition region between the solar wind and the magnetosphere and is characterized by strong variability of plasma properties and electromagnetic field. Magnetosheath jets (MS-J) are localized, short lived, increases of the dynamic pressure that have an effect on the magnetosphere-ionosphere coupling. Here we present an analysis of MS-J observed by CLUSTER at minimum and maximum of solar activity (i.e. 2007-2008 and 2013-2014). An attempt is made to classify several types of jets, based on their associated parameters and ionospheric effects. The MS-J properties span quite a broad range of parameters and cannot be readily associated with clear effects on the magnetosphere-ionosphere coupling

Auroral features and their duration following substorm onsets derived by SOPHIE

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Substorms are a major consequence of coupling between the magnetosphere, the ionosphere and the solar wind. The SOPHIE (Substorm Onset and PHases from Indices of the Electrojet) algorithm uses the SMU and SML indices from the global SuperMAG magnetometer network (analogous to AU and AL) to determine times and durations of substorm expansion, recovery and possible growth phases using free statistical parameters. Any single magnetometer can record the geomagnetic deviation that triggers a phase commencement in SOPHIE, providing insight into the region of the associated ionospheric current variation. We have selected SOPHIE phase timings given by the magnetometers on Svalbard, thus subsetting the list to include those that occur at appropriate magnetic latitude (MLAT) and magnetic local time (MLT) values. The local substorm phase times are then compared with corresponding optical observations from all sky cameras, alongside the Auroral Structure and Kinetics (ASK) and High Throughput Imaging Echelle Spectrograph (HiTIES) instruments to identify morphological features of the auroral oval at expansion onset and recovery. A selection of events are chosen and presented in greater detail. In this way, localised, high-resolution observations are compared with substorm phases derived from global magnetic deviations.

Session 3

Mesosphere, D-region, Airglow, Noctilucent Clouds and Meteors

Conveners
Noora Partamies
Andrew Kavanagh

The structure of the atmosphere emission layers recording from the ISS in 2017

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The concept of "the emission layers of the upper atmosphere" was included in the terminology adopted in the physics of the upper atmosphere in the 1970s after visual observations from manned spacecraft of the heterogeneous luminous layers over the Earth night horizon. Initially, the observers described this effect as the presence of 2–3 thin layers 1°– 2° width, located at the height up to 8° above the night horizon. In some cases, the existence of a thin, colored vertical structure of such formations was observed. Instrumental registration of these objects at specified time had certain difficulties associated with low brightness of emission layers and the need to guide shooting objects during sufficiently long exposures. The first high-quality photos of these phenomena were obtained at the Soviet space station "Salyut 7" in the early 1980s, in particular, in1982 during the Soviet-French experiment "PCN" (Photofraphier de Ciel Nocturne – Photographing of the Night Sky). Modern tools of registration: digital photo- and video cameras with high sensitivity by orders of magnitude superior to the sensitivity of film equipment and allow one to shoot low-light objects with short exposures. This equipment makes it possible to conduct regular, high-quality observations of various atmospheric emissions. During the 51th expeditions to the ISS (November 20, 2016 – April 10, 2017), the European Space Agency astronaut Thomas Pesquet had got a number of remarkable photos of the emission layers of the Earth's atmosphere in various geographical regions. The images clearly show the stars of different constellations, that allow to make sufficiently accurate determination of the parameters of the emission layers – the height of the layers above the ground, thickness and the visibility of the layers depending on the illumination conditions.

High spatiotemporal imaging of atmospheric structures at the polar mesosphere during summer using MAARSY in a MIMO configuration

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

Measurement of Q-branch Einstein coefficients for Meinel-bands with Δ v = 2 and Δ v = 3

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Spectroscopic measurements of the hydroxyl (OH) nightglow emissions have been used to infer neutral temperatures near the mesopause. To accomplish this, correct Einstein coefficients for the various transitions in the OH airglow are needed to calculate precise temperatures. However, studies from French et al. in 2000 and from Pendleton et al. in 2002 showed experimentally and theoretically that the most commonly used Einstein coefficients for the Q-branch of the (6,2) Meinel transition are overestimated.

Extending their work to vibrational levels v= 3 to 9, we will present new measurements of the Einstein coefficients for the first four Q-branch lines for the Meinel-band transitions with Δ v = 2 and Δ v = 3. These have been derived from spectroscopic observations of the OH airglow in the night sky from the Nordic Optical Telescope. The Q-branch Einstein coefficients calculated from these high signal-to-noise spectra show that tabulated values currently in use, for example, the HITRAN database, contain a systematic and significant overestimation of the Q-branch transition probabilities. Our results indicate that the findings of Pendleton et al. and French et al. for the OH Meinel (6,2) transition also occur for the Δ v = 2 and 3 transitions.

Sporadic perturbations in the high latitude D-region ionosphere

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The propagation of very low frequency (VLF) radio waves permit us to study the response of the D-region (60-90 km) to sporadic events originating in space or in the Earth. In this study, we use the 37.5 kHz VLF signal transmitted from NRK (Iceland, L=5.5) recorded at Sodankylä (Finland, L=5.5) during the period October 2011 – March 2012. The analysis considered the positive variations of the VLF perturbations with respect to the quiescent level. We compare the observed variations with changes in nitric oxide (NO) concentration, atmospheric temperature, solar proton events. We found that the positive variations are mainly associated with temperature and NO concentration enhancements. Some large positive variations in 2012 also coincided with a period of sudden stratospheric warming, and solar proton event emissions. We also present insights of electron density variations below 120 km using ultra high frequency (UHF) radio waves recorded by the EISCAT receiver in Tromso, Norway.

Simultaneous observations of polar mesosphere winter echoes and cosmic noise absorptions in a common volume by 47-MHz VHF radar, Antarctica (69.0°S, 39.6°E)

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This study focuses on the one-to-one relationship between the morphology of polar mesosphere winter echo (PMWE) and cosmic noise absorption (CNA) as determined by measurements made with a single atmospheric radar, the Program of the Antarctic Syowa mesosphere-stratosphere-troposphere/incoherent scatter (PANSY) radar. CNA was calculated using the noise level in radar signal data collected during May 2013, including data of a solar proton event on 23 May. Using PMWE and CNA data in a common volume, their temporal variations and relation were examined in detail. PMWE altitude was clearly anticorrelated with CNA magnitude in a statistical sense: When a large CNA exceeding 0.50 dB took place, PMWE seemed to concentrate around 65 km and disappear above 70 km. The electron density behind the PMWE was estimated by using the ionospheric model for the auroral zone for the solar proton event. PMWE occurrence roughly coincided with a high electron density in the model, except that no PMWE was observed above 70 km at 0730 UT despite the electron density being higher than 10^8 m^{-3}. Additionally, the estimated radar volume reflectivity with the Schmidt number Sc less than or equal to 1 is qualitatively consistent with the observed PMWE. Although weak turbulent energy dissipation rate can also play a dominant role in the observed PMWE decay, a plausible mechanism was small Sc or reduction of Sc that is equal to an increase in electron diffusivity resulting from an unusually high electron density, which significantly reduced radar volume reflectivity above 70 km.

Some local and global results on NLC ground-based monitoring

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This presentation provides basic information on ground-based monitoring of mesospheric noctilucent clouds (NLC), briefly describes the main stages of its improvement, gives some geophysical results obtained with its help and outlines the prospects for its development. As a new result, a study of the dependence of brightness and other characteristics of NLC on solar activity, based on the Moscow (57 N, 36 E) database of monitoring of noctilucent clouds, is presented in more detail. The NLC and solar activities are considered on two time scales, i.e. year-to-year and day-to-day variations. In the both cases, the statistically significant negative dependencies on solar Lyman alpha flux are obtained with zero or very small time lags. The short time lags (0 - 3 days) between the NLC activity and solar forcing on the day-to-day scale suggest that the observed variations of NLC brightness are induced mainly by direct solar heating/cooling and dynamically-driven mechanism (atmospheric circulation and vertical movements), leaving photodissociation of water vapor by Lyman alpha flux as secondary.

The ground-based NLC monitoring proved to be more productive when considering several local sites of observations combined into a united network working on a coordinated program. In the Northern hemisphere, the NLC network is operating from 2004 to present. Now it contains 8 local sites placed in Russia, Kazakhstan, Lithuania, Denmark, the UK and Canada at the 54-57 N degrees latitudinal belt that is highly preferable to ground-based NLC observations. Some network results of the analysis of NLC behavior are addressed.

The presented results are obtained thanks to partial support of the Russian Foundation for Basic Research, 19-05-00358a.

Spatial-temporal distribution of anomalous enhancement of ambipolar diffusion coefficient

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When a meteor enters the Earth's atmosphere, it leaves behind a trail of ionized neutral atmosphere along its path of travel in the mesosphere and lower thermosphere (MLT) region. The meteor trail rapidly expands by the ambipolar diffusion depending on an ambient electron (Te) and ion (Ti) temperature. A meteor radar provides the ambipolar diffusion coefficient (Da) by the decay time of echo power from the meteor trail. By assuming Te=Ti=Tn, Da has been used for an estimation of the neutral temperature (Tn). Therefore, Da is one of the critical parameters in the MLT region. However, the meteor radar installed at Tromsø, Norway (69.6 deg. N, 19.2 deg. E) sometimes observed significantly enhanced Da (hereafter called the anomalous enhancement), which was unlikely to be caused by a fluctuation of Tn (Tsutsumi et al. 2017, Proceedings of the 30th Atmospheric Science Symposium, 2017).

To reveal a generation process of the anomalous enhancement, we derived a spatial-temporal distribution of the anomalous enhancement by meteor radars at Tromsø, Bear Island (74.5 deg.N, 19.0 deg. E), and Longyearbyen (78.2 deg. N, 16.2 deg. E). The occurrence rate of anomalous enhancement showed a geomagnetic activity dependence. During the low geomagnetic activity (Kp<3), the occurrence rate reached 40% at 0-3 and 19-21 MLT between 89 and 71 deg. magnetic latitudes. During the high geomagnetic activity (Kp<3), the aforementioned high occurrence region shifted to clearly later and earlier time in the morning and evening sector, respectively. Of particular interest is that the high occurrence rate newly appeared at the following regions. The occurrence rate increased to (1) 30% in the cusp, (2) 50% inside and the edge of the auroral oval in the morning sector, (3) 70% at the edge of the auroral oval in the evening sector.

The strong electric field, which is regarded as the flow channel, seems to be applied in the region of (1). The polarization electric field inside the auroral/PsA patch and the electric field associated with the discrete aurora sometimes appear in addition to the convective electric field in the region of (2) and (3), respectively. Therefore, we concluded that the Farley-Buneman instability, which is driven by the strong electric field (<80 mV/m around 90 km) and selectively increases Te rather than Ti, caused the anomalous enhancement.

The role of negative ions in the D region studied by the EISCAT_3D incoherent radar

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Excess ionisation of the lower ionosphere occurs during solar proton events, high-energy auroral electron precipitation and hard x-ray emissions from solar flares. Relativistic electron precipitation and extraordinary galactic cosmic ray events are less quantified as variable ionisation sources. The special role of odd nitrogen, as generated originally by particle precipitation events, ionisation, dissociation and consequent ion-neutral chemical reactions, the role being enhanced by transport to lower altitudes and lower latitudes, is clearly recognized.

Less known is the role of negative ions in the lower ionosphere. Negative ions emerge as a special feature of the D region. The major formation process in the collisional atmosphere is electron attachment to oxygen molecules in 3-body collisions. The initial ion O2- is converted to more complex terminal negative ions, including cluster ions, via chemical reactions. Another initial negative ion is O-, which is created from ozone. An interesting feature of both of these initial ions is the strong dependence of their production rates on prevailing electron temperature. The role of negative ions in general is important in cases of high ionization and at night when they are not destroyed by photodetachment. Higher concentrations of ions, in turn, do alter the concentrations of chemically active minor neutral components, such as NO, O, and O3, for instance.

We investigate theoretically how measured incoherent scatter spectra, specially with the future emerging data from EISCAT_3D, will improve our understanding of the role negative ions in the coupled ion and neutral chemistry of the ionospheric D region.

WACCM-D: Global, Multi-Decadal Simulations of D-region Ionosphere for Particle Precipitation Studies

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Energetic particle precipitation (EPP) and ion chemistry affect the neutral composition of the polar middle atmosphere. For example, production of odd nitrogen and odd hydrogen during strong events can decrease ozone by tens of percent. However, the standard ion chemistry parameterization used in atmospheric models neglects some important effects, such as production of nitric acid and active chlorine. We present WACCM-D, a variant of the Whole Atmosphere Community Climate Model, which includes a set of lower ionospheric D-region chemistry: 307 reactions of 20 positive ions and 21 negative ions.

We show that WACCM-D produces well the main characteristics of the lower ionosphere, as well as the overall proportion of important ion groups, thus providing a global representation of the D region. Comparison with satellite observations indicates that WACCM-D improves the modeling of HNO_3, Cl_x, HO_x, and NO_x response during EPP events. As a chemistry-climate model, WACCM-D allows for multi-decadal simulations of the ionosphere, neutral atmosphere, and their interaction and can support also ionospheric research and interpretation of ground-based observations. We discuss possibilities to use WACCM-D simulations to complement measurement projects such as the EISCAT_3D.

Exploring the Region where Earth Weather meets Space Weather: Ionospheric Connection Explorer (ICON)

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The NASA's satellite mission Ionospheric Connection Explorer (ICON) is designed to target on the mesosphere and lower thermosphere (MLT) region where the earth weather meets space weather. ICON is expected to launch in 2019 in Florida. To work together to monitor the dynamic of the ionosphere, ICON has four instruments on board: 1. Michelson Interferometer for Global High-resolution Thermospheric Imaging(MIGHTI) provides the neutral wind velocity retrieving from 630.0 nm and 557.7 nm airglow, while the neutral temperature is extracted from 762.0 nm. 2. The Far Ultra Violet Imaging Spectrograph (FUV) measures 157.0 nm to retrieve the atmosphere O/N2 ratio and 135.6 nm recombination emission of O^+ ions in the nighttime.3. The Extreme Ultraviolet Spectrograph (EUV) measures 83.4 and 61.7 nm to retrieve O^+ in the daytime.4. The Ion Velocity Meter (IVM) provides the in-situ measurement of the meridional ion drift perpendicular to the magnetic field at the spacecraft altitude near 575 km. IVM is used in conjunction with the other ICON instruments to understand the connection between the dynamics of neutral atmosphere and ionosphere through the generation of dynamo current. An overview of the ICON mission and the process from airglow intensity to the science data product will be focused in this talk.

Spectral characteristics of partially reflected radio signals as a tool for research of the atmosphere parameters

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Temperature in the mesosphere is one of the most important characteristics, determining the dynamic and photochemical processes in the upper atmosphere. Experimental researches of temperature in the mesosphere so far have been carried out in a much smaller volume than for the lower layers of the atmosphere. The use of radio physical methods for obtaining information about the temperature of the mesosphere can be useful in the case when measurements by other means are impossible, for example, during heavy clouds. One of the effective methods for studying the D-region of the ionosphere is the partial reflection method. It is radar sounding of the lower ionosphere in the range of medium waves. The partial reflection method is based on the emission of ordinary and extraordinary waves in the form of alternating pulses and back scattering of the radio partially reflected waves by plasma irregularities. In this case, separate reception of the back scattered signals and their amplitudes are measured depending on the time delay, which determines the height of the reflection. The method allows obtaining information about amplitudes of partially reflected ordinary and extraordinary waves as well as electron density and the parameters of irregularities at the heights of the lower ionosphere. The partial reflection facility of the Polar Geophysical Institute for the study of the lower ionosphere consists of a transmitter, a receiver, a receiving-transmitting phased array and an automated data acquisition system. It is located at the observatory Tumanny (69.0N, 35.7E). The basic acoustic-gravity wave theory in the atmosphere gives an opportunity to describe many of wave-like oscillations in the atmosphere. In case of the plane-stratified, isothermal atmosphere and constant gravity with height there are two frequency domains for atmospheric waves where they can propagate as acoustic and gravity waves. The domain can be described by two resonant periods of the atmosphere: the acoustic cut-off period and the Brunt-Vaisala period. For the heights of D region the periods are less that 6 min. We use measurements of amplitudes of partially reflected ordinary and extraordinary waves above the observatory for to calculate experimental characteristic periods of the atmosphere during disturbances of different kinds in the atmosphere. In our case we use the solar terminator as the source of the regular and well known process which causes disturbances in the atmosphere above the point of observations. For consideration of influence of the solar terminator passages on the ionosphere we took data for the quite geomagnetic days with Kp less or equal 1 and also days when there were no any sources of other strong disturbances in the atmosphere. The first results show season dependence of the calculated temperature. For the point of observations a seasonal change in neutral temperature at the height of 75 km was obtained: temperature decreases from 235 K in January to 210 K in April and increases from 210 K in October to 270 K in December.

Balloon-borne observations of noctilucent clouds from the stratosphere: a new approach in studying large-scale mesospheric dynamics

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Noctilucent clouds (NLC) are the highest clouds in the Earth's atmosphere forming between 80 and 90 km at the summer high-latitude mesopause region, where the temperature reach its minimum values in the entire atmosphere as low as 120-150 K. The clouds are composed of small water-ice crystals of a few tens of nm in radius. NLC exhibit waves of various types and wavelengths and are an excellent natural laboratory to study mesospheric wave dynamics at scales from tens of metres to thousands of km.

A novel balloon-borne experiment "Stratospheric Observations of Noctilucent Clouds (SONC)" was conducted on the night of 5-6 July 2018 in order to photograph noctilucent clouds for studying spatial dynamics at large scales of more than 100 km. We launched a sounding balloon to 20.4 km altitude above the Moscow region in Russia (57°N, 41°E), which lifted a scientific payload consisting of a high-resolution automated camera (SONY Alpha A7S, 12 Mpix) equipped with a wide-angle lens (a view field of 115° in diagonal).

A large NLC field of about 1400 km extension in the west-east direction was observed on that night. The clouds were modulated by atmospheric gravity waves having horizontal wavelengths from 10 km to 350 km. A unique final stage of the NLC evolution, represented by thin parallel bands of gravity waves, was registered. Since then (in about 20 min) the weak NLC completely disappeared in the twilight arc.

In general, a novel concept of the usage of balloon-borne observations of NLC provide us with the following new opportunities: (a) an unique combination of observations of NLC from the stratosphere at scales from metres to thousands of km is currently unachievable either from the ground or space; (b) NLC can be registered from the stratosphere for 24 hours a day due to very little Rayleigh atmospheric scattering above 20 km; (c) very weak NLC can be observed at the very beginning and/or final stage of their evolution; (d) mesospheric dynamics at various scales, extending from small-scale turbulent processes (down to 1 meter) to large-scale gravity waves up to 1500 km can be studied with high temporal and spatial resolutions; (e) neutral wind velocity at the summer mesopause can be measured at large scales; (f) in case of a long duration flight of several days around the North Pole, large-scale wave processes such as solar tides and planetary waves can be studied using balloon-borne NLC imagery.

Metallic atom/ion and temperature variability near the mesopause obtained with a frequency-tunable resonance scattering lidar at Syowa (69.0°S, 39.6°E), Antarctica in austral winter 2017-2018.

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The National Institute of Polar Research (NIPR) is leading a prioritized project of the Antarctic research observations. One of the sub-project is entitled the whole atmosphere coupling process revealed through the highly precise measurement of Antarctic atmosphere. Profiling dynamical parameters such as temperature and wind, as well as minor constituents is the key component of observations in this project, together with a long term observations using existent various instruments at Syowa, Antarctica (69.0°S, 39.6°E). Since Syowa is located in auroral zone, the upper and middle atmosphere is known to be often affected drastically by solar and magnetospheric activity, such as X-ray, ultraviolet radiations, precipitating energetic electrons, and solar energetic protons. As a part of the sub-project, we developed a new resonance lidar system with multiple wavelengths. The lidar transmitter is based on injection-seeded, pulsed alexandrite laser for 768-788 nm (fundamental wavelengths) and a second- harmonic generation (SHG) unit for 384-394 nm (second harmonic wavelengths). The laser wavelength can be tuned into the resonance wavelengths by a wavemeter which is calibrated and validated using a wavelength-stabilized He-Ne laser and a potassium vapor cell for Doppler-free spectroscopy. This lidar has capabilities to measure density variations of minor constituents such as atomic iron (Fe, 386 nm), atomic potassium (K, 770 nm), calcium ion (Ca^+, 393 nm), and nitrogen ion (N_2^+, 390, 391 nm) and temperature profiles in the mesosphere and lower thermosphere (MLT) region. It can also estimate temperature profiles from the upper Stratosphere to the lower mesosphere using signals of Rayleigh scattering. The lidar system was installed at the Syowa Station by the 58th Japan Antarctic Research Expedition in January 2017, and then it was operated for two austral winter seasons of 2017 and 2018. In this presentation, we are going to report temperature and metallic atom/ion density variability in MLT region based on 2-years observations.

Observation plan for noctilucent clouds in midlatitude region from a geostationary satellite, airplanes, a balloon, and ground-based imagers

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Noctilucent clouds (NLCs) are the highest clouds in the Earth which appear in a mesopause region during summer season in both sub-polar regions. Since their occurrence is highly sensitive to the mixing ratio of the water vapor and atmospheric temperature in the mesopause region, NLCs are considered to be the one of the proxies to monitor the global atmospheric variations. Several models predict that global warming in the lower atmosphere caused by global increasing of greenhouse gasses promotes cooling of the upper atmosphere. In addition, photochemical reactions involving greenhouse gasses such as CH4 would increases mixing ratio of water vapor which is a source of water ice clouds (NLCs). Thus, enhancement of global warming due to greenhouse gasses can extend NLC region towards lower latitudes than current typical latitudes (50-60 degrees in latitudes). Due to this reason, it is important to know the precise occurrence of NLC in mid-latitudes region to monitor the progress of the global warming. Japanese research group started NLC observation from ground in North area of Japan (Hokkaido) since 2012. They have reported the first detection of NLC from multiple sites in Hokkaido (43.17N-45.36N) Japan on June 21, 2015 [Suzuki et al., 2016]. However, they have not reported further NLC events from Japan after this event until now although radar observations sometimes detect mesospheric echoes (MSE) which closely relate with NLCs. One of possible causes which prevents them to precisely monitor the occurrence of visible NLCs is a bad weather condition during early summer season in Japan. A comparison between past NLC periods (summer season) and records of sky conditions in the northernmost part of Hokkaido (Wakkanai) archived by JMA shows that only 10.8% (3.1%) of morning (night) twilight times were clear on the days of MSE events from 2009 to 2015. It is highly desired to monitor the precise occurrence of NLC in middle latitude region without interruption by bad weather conditions. Therefore, we have planned to observe NLCs from airplanes, balloons in addition to current ground-based imagers. NLC observations from jets will be achieved by small cameras installed in a cockpit of passenger jets connecting North America, Europa and Japan. Balloon-born observations will be conducted by using compact cameras combined with small balloon which are usually hired in meteorological sonde systems. We will flight 2 balloons per a day from Hokkaido, Japan during the NLC period (summer solstice +/- 7 days) and collect data from landed payloads. Ground observation also will be updated to improve the spatial and temporal resolutions of the NLC images. In this presentation, an entire plan of the combined observation of NLC in middle latitude area using both air-born and ground-born methods is introduced. Current status of the preparation of these observations and some results from test observation and experiments are also presented.

PMC observations utilizing full disk images obtained from the Japanese Geostationary Earth Orbit meteorological satellite Himawari-8

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Polar mesospheric clouds (PMCs) or noctilucent clouds (NLCs) consist of water-ice particles, which can be produced in summer at the mesopause region, mainly at high latitudes. Since the first report on PMCs in 1885, various methods have been used to perform PMC observations. Optical observations by ground-based cameras, imagers, or lidars are often limited by weather conditions because a clear sky is required for such observations. Hence, satellite observations from space are valuable for more continuous observations, which enable significant systematic data coverage. Such systematic data coverage would be of benefit, for example, for monitoring long-term PMC activity, which may be related to global changes, because water-ice particle production can be enhanced by CO2 cooling and H2O increase, which may be induced by increases in the greenhouse gases such as CO2 and CH4.

Many PMC observations have been done by low-Earth-orbit (LEO) satellites. By contrast, there are only few reports of PMC observations by Geostationary Earth Orbit (GEO) satellites, which includes Meteosat First Generation (MFG) and Meteosat Second Generation (MSG). This kind of GEO satellite can provide full-disk images including the Earth's limb, which would give valuable opportunities for PMC observations by continuous limb-viewing from its almost fixed location relative to the Earth. In this presentation, we make an initial report on PMC observations by the Japanese GEO meteorological satellite Himawari-8. Heights of the observed PMCs were estimated to be 80–82 km. Observed PMCs were active only during summertime in both the northern and southern polar regions. These characteristics are well consistent with known PMC behavior. From its almost fixed location relative to the Earth, Himawari-8 is capable of continuously monitoring PMC every 10 min with three visible bands: blue (0.47 µm), green (0.51 µm), and red (0.64 µm). Thus, Himawari-8 can contribute to PMC research in the near future.

Contribution of Proton and Electron Precipitation to the Observed Electron Concentration in October-November 2003 and September 2005

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Understanding the altitude distribution of particle precipitation forcing is vital for the assessment of its atmospheric and climate impacts. However, the proportion of electron and proton forcing around the mesopause region during solar proton events is not always clear due to uncertainties in satellite-based flux observations. Here we use electron concentration observations of the European Incoherent Scatter Scientific Association (EISCAT) incoherent scatter radars located at Tromsø (69.58°N, 19.23°E) to investigate the contribution of proton and electron precipitation to the changes taking place during two solar proton events. The EISCAT measurements are compared to the results from the Sodankylä Ion and Neutral Chemistry Model (SIC). The proton ionization rates are calculated by two different methods, a simple energy deposition calculation and the Atmospheric Ionization Model Osnabrück (AIMOS v1.2), the latter providing also the electron ionization rates. Our results show that in general the combination of AIMOS and SIC is able to reproduce the observed electron concentration within $\pm$50% when both electron and proton forcing is included. Electron contribution is dominant above 90 km, and can contribute significantly also in the upper mesosphere especially during low or moderate proton forcing. In the case of strong proton forcing, the AIMOS electron ionization rates seem to suffer from proton contamination of satellite-based flux data. This leads to overestimation of modelled electron concentrations by up to 90% between 75–90 km and up to 100–150% at 70–75 km. Above 90 km, the model bias varies significantly between the events. Although we cannot completely rule out EISCAT data issues, the difference is most likely a result of the spatio-temporal fine structure of electron precipitation during individual events that cannot be fully captured by sparse in-situ flux (point) measurements, nor by the statistical AIMOS model which is based upon these observations.

Session 4

Active Experiments and Plasma Physics

Conveners
Björn Gustavsson
Michael Rietveld

Artificial plasma turbulence in the high latitude ionosphere F region induced by extraordinary polarized HF pump wave at EISCAT

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Experimental results concentrating on distinctive features and behaviors of various phenomena in the high latitude ionosphere F-region induced by X-mode HF pump waves at high heater frequencies (fH = 5.4 - 8 MHz) are discussed. The results were obtained from a large body of Russian campaigns at the EISCAT HF heater facility near Tromsø, Norway with the use of phased array 1 resulting in the effective radiated power of 450 – 750 MW. HF pumping was produced at high heater frequencies which were above as well as below the critical frequency of the F2 layer (fH/foF2 > 1 and fH/foF2 ≤ 1). The EISCAT UHF incoherent scatter radar (930 MHz) at Tromsø, the CUTLASS (SuperDARN) HF coherent radar in Finland, and the equipment for the narrowband stimulated electromagnetic emission (NSEE) observations at a distance far from the HF Heater (about 1200 km), were utilized as diagnostics. The behavior of the HF-enhanced plasma and ion lines from the EISCAT UHF radar spectra are compared with the growth time of artificial field-aligned irregularities (FAIs) from CUTLASS measurements. It was found that X-mode ion and plasma lines developed with a time delay relative to the onset of HF heating. After appearance, their intensity gradually increased and reached a maximum within about 1 min or even longer when FAIs are fully generated. It was found the coexistence of strong HF-induced plasma and ion lines and FAIs. The NSEE spectra, recorded at a large distance (about 1200 km) from the Tromsø HF Heater, revealed the generation of a wide variety of spectral components in the course of X-mode pumping which can be associated with the electrostatic ion cyclotron (EIC) waves and their harmonics (otherwise known as neutralized ion Bernstein waves). It was shown that the growth times of FAIs and various spectral components in the NSEE spectra strongly depend on the preconditions. The development and features of various non-linear phenomena induced by the X- and O-mode HF pump waves, for heater frequencies below the critical frequency of the F2 layer (fH/foF2 ≤ 1), clearly demonstrated the radical difference between them. The potential mechanisms of strong plasma modification in the F-region of the high latitude ionosphere induced by X-mode pumping towards the magnetic zenith are discussed.

Efficiency of HF-Heating at frequencies around the third electron gyro-frequency harmonic

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Ionospheric response to HF-radio-wave heating at frequencies between 4 and 4.25 MHz will be presented. The efficiency of electron-heating around the third double-resonance, where the electron-heating is suppressed, have been estimated for the first time. Comparisons with the frequency-variation of radio-induced optical emissions and the SEE-signatures will be made.

Incoherent scatter radar measurement of ionospheric D-region heating and cooling times

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Heating and cooling times of the ionospheric D-region electron plasma were, for the first time, directly measured by the incoherent scatter radar by superposing 90 minutes worth of EISCAT VHF data coherently together with the 15.0 ms ON, 40.6 ms OFF heating modulations.

The VHF radar transmission modulation was a sequence of 128 61-bit alternating codes with 2.4 μs bit length. The VHF radar pulses were transmitted with 1.5 ms inter-pulse period, which is intentionally not matched with the 55.6 ms IPP of the heating pulses. The mismatch causes a relative drift between the VHF radar and heating pulse positions, making it possible to cover the whole heating cycle with a time resolution that is only one third of the VHF radar IPP.

The data-analysis reveals unexpectedly long timescales (circa 10 ms) for both heating and cooling time of the electron gas between 75-85 km, indicating that the heating and cooling rates of the electron gas should be reduced, at least, by a factor of 15.

Electron heating for HF-pumping near magnetic zenith by EISCAT Heating

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High frequency (HF) electromagnetic pumping of F-region plasma from the ground gives the strongest plasma response in magnetic zenith, antiparallel to the geomagnetic field in the northern hemisphere. This magnetic zenith effect has been observed in optical emissions from pump-induced plasma turbulence, electron temperature enhancements, filamentary magnetic field-aligned density irregularities, and as self-focusing of the pump beam in magnetic zenith. We present results of EISCAT Heating-induced magnetic-zenith effects observed with the EISCAT UHF incoherent scatter radar. With Heating transmitting a left-handed circularly polarised pump beam towards magnetic zenith, the UHF radar was scanned in elevation in 1.0°- and 1.5°-steps around magnetic zenith, respectively, in experiments in 2014 and 2017. Further, the electron energy equation was integrated to model the electron temperature and associated electron heating rate, optimized to fit the radar measurements of the electron and ion temperatures, and electron concentration. The experimental and modeling results are consistent with pump wave propagation in the L mode in magnetic zenith, rather than in the O mode.

Observations of systematically recurring topside ionline enhancements during multiple HF modification experiments near multiples of the electron gyro frequency

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Observations of ion line enhancements on the topside ionosphere (THFIL) have been made with incoherent scatter radars (ISR) during active experiments in the polar ionosphere. Results from multiple daytime experiments at the European Incoherent SCATer (EISCAT) UHF radar and Heating facilities near Tromsø, Norway, are presented. During transmission of a high power, high frequency (HF) radio wave, the HF-pump frequency was slowly stepped around the double resonance of the 3rd and 4th multiple of the electron gyro frequency and the local upper hybrid frequency in the F-region. The previously well-documented enhancements on the bottom side of the F-layer at the HF reflection height are observed simultaneous to weaker, but clear, ion-line enhancements above the F-region peak. Topside ionline enhancements occurred systematically and a gyro harmonic effect is observed for numerous heating on cycles during the experiments. We present the first ISR observations of systematically recurring HF-enhanced topside ionline spectra from multiple experiments. The results are discussed in terms of transionospheric propagation facilitated by density striations in the ionosphere and possible mechanisms are considered.

Ducting of incoherent scatter radar signals by field-aligned irregularities: an explanation for wide-altitude extent ion line enhancements

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We provide an explanation for a mysterious phenomenon that has been recognized in recent years in EISCAT UHF incoherent scatter radar (ISR) data during many HF ionospheric pumping experiments. The phenomenon is an apparent increase in electron density observed above the HF reflection altitude extending up to the observable limits usually in the range 400-650 km as shown in several publications in recent years. It was shown by Senior et al. [2013] that several examples of these enhanced backscatter could not be explained by increases in electron density. A summary of characteristics of the backscatter enhancements is presented as well as the results of a survey of events. We propose that large-scale HF-induced field-aligned irregularities (100's m to km scale) act to refract the radar signals along the magnetic field, thereby acting as a guide so that the free-space R^{-2} spreading of the signals no longer applies. The nature of the irregularities and the physical mechanism of their production by powerful HF waves is an exciting topic for future research since, surprisingly, they appear to be preferentially excited by X-mode waves. The explanation proposed here involving HF-induced irregularities may well apply to other ISR observations of the ionosphere in the presence of specific natural irregularities.

EISCAT and GLONASS observation of HF induced field aligned irregularities

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We present an artificial plasma density irregularity experiment with a coordinated observation of EISCAT UHF radar and GLONASS satellite. During an EISCAT HF heating experiment, a GLONASS satellite signal intersected the disturbed ionospheric volume near magnetic zenith. When EISCAT radar observed an increased electron temperature in the F region, perturbations of GLONASS signal were recorded for the phase and intensity data. The result indicates that the HF heating triggered changes in plasma density along satellite ray path. The signal perturbations were largest when the satellite–receiver link intersected near magnetic zenith. This study shows that GNSS signal can be used as diagnostic tool of HF induced density irregularity and its spatial variations.

Temporal variations of enhanced plasma line in aurora.

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An enhanced plasma line observed by an incoherent scatter radar in aurora demonstrates significant temporal variations. The auroral plasma line intensity is largely determined by the spectrum of the super-thermal electrons formed by auroral precipitation. A time-depended model of the auroral electron transport was used to calculate the supper-thermal electron spectra with high temporal and pitch-angle resolutions. Results of the calculation were applied to study the plasma line dynamic under various auroral conditions.

Aperture synthesis imaging observations of stimulated electromagnetic emissions

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High power electromagnetic waves that are resonant with ionospheric plasma can stimulate non-thermal electromagnetic waves. This phenomena is known as stimulated electromagnetic emission (SEE). The spectrum of this emission is very rich, with a wide variety of features that are dependent on the relative offset of the pump frequency with respect to the local gyro-frequency of the plasma at the interaction altitude. In this study, the spatial distribution of SEE is investigated using aperture synthesis imaging. The study uses measurements obtained during an observation campaign in October 2018. All experiments used O-mode heating and frequencies swept around 4 MHz. The aperture synthesis images were obtained using a four antenna dual polarization radio array, with baselines up to 120 meters. During the campaign, nearly all known types of SEE spectral features were observed and imaged. The emission is found to primarily originate from within the ionospheric heating beam, but different spectral features can have different arrival angles. The spatial distribution of SEE is dependent on the frequency offset between the local electron gyrofrequency harmonic and the pump frequency. When the pump frequency is below the gyroharmonic, the emission region is relatively confined an unstructured. Slightly above the gyroharmonic, the emission becomes complex, containing a wider spread of arrival directions. When combined with ionospheric radio propagation modeling, the results can possibly shed new light into various wave-particle and wave-wave interaction processes that are though to be responsible for SEE and possible help us understand the behaviour of non-thermal plasmas in general.

Possible influence of small-scale artificial irregularities on the electron density determination by the methods of incoherent scattering and radio sounding

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The combined use of incoherent scatter radars (ISR) and satellite measurements makes possible to compare the total electron content (TEC) obtained by these methods. ISR allow obtaining the values of TEC along the sight of view to a satellite, and, by moving the radar antenna pattern, along the trajectory of the satellite. Here we present the results of comparison of TEC observation data from signals of GLONASS satellites and the EISCAT UHF incoherent scatter radar (Tromso, Norway) during modification of the high latitude ionosphere by the EISCAT/Heating facility. The observations have been carried out during October 2013 and October 2018. In general changes of TEC obtained from radar data were in good agreement with the TEC variations from the satellite data. The anomalous increase of the TEC on 21 October 2013 obtained from the data of incoherent scattering of radio waves during the heating of the ionosphere in the region close to the magnetic zenith is considered. The satellite data in the same region show the reduction of the TEC. The problem of correct interpretation of ISR data during heating in the case of increasing the electron density by tens of percent was considered in various paper. This discrepancy can be explained by the influence of the coherent component in the power of the received signals due to the small-scale artificial irregularities of the electron density in the heating region. Coherent echoes from various sources may lead to erroneous electron densities when they are calculated using the incoherent scatter analysis method, and heating experiments are one such source which requires further research. The generation of small-scale artificial ionospheric irregularities in the region which was disturbed by a powerful high frequency electromagnetic wave is confirmed by observations of the GLONASS navigation satellites signals according to which the region of the sharp increase in the electron density corresponds to the area of increasing dispersion of the fluctuation component of phase measurements of the satellite signal. It was shown that when radio signals from GLONASS pass through the heated region of the ionosphere, along with reduction of the angle between the receiver-satellite line and the magnetic zenith, the phase fluctuations increase and reach values of 3-4 times greater than those outside the perturbed region. The observed increase in fluctuations can be explained by the presence of small-scale irregularities in the perturbed and the angle aspect effect with the magnetic zenith. For theoretical explanation of the effect we used an effective dielectric permittivity of the medium. When calculating the spectrum of the incoherent scattered signal, as far the thermal fluctuations are small, it is assumed that they do not contribute to the value of average dielectric permeability. However, in the ionosphere region, influenced by the powerful HF perturbation field, rather strong irregularities of the electron density can be arisen and the approximation of single scattering to describe the field in such environment is inapplicable, so rescattered fields should be taken into consideration. This leads to the fact that some effective dielectric permittivity of the medium in the region with irregularities should be used instead of the undisturbed dielectric permittivity. Using the approach it was shown that under some conditions the effect of scattering on irregularities will prevail in the signal

Angular width of wide altitude ion line enhancements at the EISCAT Tromsø Facility

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We present the first sub-radar beam resolution determination of the angular width of wide altitude ion line enhancements (WAILEs), found to be 0.5° around magnetic zenith, observed during a HF radio wave heating experiment at the EISCAT Tromsø Heating facility on 27 November 2014. The results of ray tracing simulations are detailed. The simulations are based on the hypothesis that WAILEs are caused by ducting of UHF radio waves due to artificial field aligned irregularities and the results of the experiment. Ducting of a 930 MHz radio wave was caused by 15.7% depletions from the background density in an IRI model atmosphere with $f_O F2 = 10.04$ MHz. The data analysis and modelling methods used to achieve these results are explained.

Joint Analysis Images of the Artificial Airglow Spots and TEC Maps in HF-Pumped Ionosphere at the Sura Facility

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Currently, detailed TEC maps with high space-time resolution, showing the distribution of electron concentration in the ionosphere heating region irradiated by powerful radio waves, have not yet been obtained. This is primarily due to the technical difficulties in the formulation of such experiments. The heating facilities of HAARP, EISCAT are located in the circumpolar regions, where navigation satellite spans are rare and there is no dense GNSS network of stations. The Arecibo heating facility also located in a region where there is no dense network of GNSS station. Such experiments could not be carried out in the Sura facility until recently because of the small number of GNSS stations, as well. However, the solution of this task becomes possible because of the significant increase in the number of GNSS stations in last years on the territory of the Russian Federation and at the near of the Sura facility.

The experiment was carried out at the Sura facility (56.15° N., 46.10° E.) on August 29, 2016. During the time interval from 18:52 to 19:46 UTC the ionosphere was heated at $f_0 = 4.35$ MHz with the effective radiation power $P_{eff} \approx 65$ MW. The main beam of antenna pattern was directed to zenith. The regime of pumping 3 min heating – 3 min pause was used. The experimental data of the two-frequency radio sounding of the ionosphere using navigation satellite signals were obtained on a network more than 20 GNSS stations located within a radius of 400 km from the Sura facility. On August 29, 2016, the radiation pattern of the antenna system of the Sura facility intersected almost simultaneously two satellites at once: GPS G23 (19:58 – 20:21 UTC); GLONASS R08 (19:49 – 20:12 UTC). To increase the number of line-of-sight (LOS) between receiver and satellite, and accordingly, number of points on TEC maps and there spatial coverage and resolution, another 5 satellites were taken (GPS G03; G09; G22 and GLONASS R01, R07) whose IPP passed through the considered area of the ionosphere in the interest time interval and their LOS elevation angles had acceptable values.

Then the slant TEC along the LOS between a GNSS receivers and a satellite for all GNSS sites was calculated, after it was recounted the equivalent values of vertical TEC to normalize the amplitude of TEC variations. Using the moving average filter, the trend was removed and the TEC variations stimulated by the work of the Sura facility were obtained. Thus, a two-dimensional distribution of TEC on an uneven grid was obtained. To assess the dynamics of the heating region of the ionosphere and increase the points on the TEC maps, all IPP and values of TEC were plotted on it for a 6-minute time interval. Thus 9 TEC maps were constructed. The next step in data analysis was the comparison of TEC maps with the night sky images obtained using the SBIG CCD camera at the same time interval. The measurements made it possible to conduct a direct comparison between the variations of artificial airglow in the red line of atomic oxygen and the total electron content and to get a dynamic spatial-temporal picture of the change electron density in heating region of the ionosphere.

The obtained pattern is conforming to the fact that the airglow is generated in the region of a low electron density, and it is exactly the region where the number of energetic electrons accelerated by plasma waves to the optical-level excitation potential turns out to be the largest. These issues were discussed in more detail in [1]. Thus, we can say that in the HF-pumped ionosphere for moderate pump beam power the generation of the red line artificial airglow occurs most effectively inside the large-scale plasma cavities. This result complements our previous results that were obtained at the Sura facility [1].

1. Grach S. M., Nasyrov I. A., Kogogin D. A., et al. // Geophys. Res. Lett.. - 2018. - Vol. 45, Iss. 12. P. 12,749-12,756. DOI: 10.1029/2018GL080571.

Anisotropic Electron Fluxes – An Explanation of Flat Altitude Distributions of Radio-Induced Optical Emissions

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Transmission of high-power HF radio-waves into the ionosphere produce interesting and observable phenomena, such as; electron heating, artificial ionization, stimulated electromagnetic emissions and enhancement of optical emissions. The wave-plasma interaction processes that induce these phenomena are not well understood, almost five decades after the first ionospheric heating experiments. Recently published estimates of the altitude distribution of excitation rates during heating suggest that electrons are accelerated anisotropically. Here we present multi-stream transport modeling results of energetic (2-110 eV) electrons accelerated anisotropically in space. Comparisons between the resulting electron energy-altitude distributions and excitation rates-altitude estimates infer that the accelerated electrons have an enhanced population perpendicular to the magnetic field.

Session 5

Aerosols and Clouds, Transient Luminous Events, and Atmospheric Electricity

Convener
Oscar van der Velde

A possible production mechanism for dancing red sprites supported by optical and electromagnetic observations

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Red sprites are optical emissions accompanying streamer-type dielectric air breakdown processes in the mesosphere. The appearance of red sprites is triggered most often by positive cloud-to-ground (+CG) lightning in the underlying active thunderstorm, where the charge moment change (CMC) of the sprite-parent (SP+CG) lightning stroke generally exceeds several hundred Ckm. Dancing red sprite events are a special type of sprite clusters in which the elements and/or sub-clusters appear in a rapid sequence within a few hundred milliseconds, usually laterally displaced from the preceding appearance. It is not fully understood yet why do subsequent, delayed sprites appear sometimes without a corresponding SP+CG stroke, and whether the sequence of SP+CG strokes corresponding to dancing sprite events are independent from each other or not.

Five series of short delayed +CG lightning strokes producing dancing sprite events were analyzed to find clues for answering these questions. The corresponding sprite events were observed in Central Europe above a mesoscale convective system (MCS) on the night of 6 August, 2013. The events were recorded by optical observation systems simultaneously from Sopron, Hungary ($16.6° E, 47.7° N$) and Nydek, Czech Republic ($18.8° E, 49.7° N$). GPS time stamps on the records allowed obtaining the exact appearance time of the sprites, while the geographical location of small sprite clusters and some individual sprite entities was calculated by triangulation.

Characteristics of the corresponding lightning activity were inferred from the electromagnetic radiation produced during the discharge processes. Occurrence time, location, peak current, and type (IC/CG) of the studied lightning strokes were provided by the LINET lightning detection network which detects magnetic field signals in the low/very low frequency (VLF/LF) band. Time variation of the lightning current moment and the corresponding CMC was deduced from extremely low frequency (ELF) band magnetic field time series recorded at Hylaty station ($22.544° E, 49.204° N$), Poland, about 700 km from the analyzed lightning activity.

Horizontal offsets and delay times of sprites both from their parent lightning stroke and the preceding sprite entity are evaluated. It was found that the longer the appearance of a sprite is delayed, the larger is its horizontal offset from its SP+CG. The "speed" calculated from the time delays and offsets of sequentially appearing sprites is in the same order of magnitude as that of negative polarity lightning leaders propagating in the thundercloud. Joint analysis of optical observations and electromagnetic records suggests that the SP+CG strokes in the examined series are not independent from each other and that the sequence of sprite appearances in dancing sprite events may indicate quasi-contiguous development of negative lightning leaders across the stratiform region of MCSs. Based on these findings, a mechanism is suggested which explains the production and possible connection of prompt and delayed sprites in dancing red sprite events.

Reference: Bór et al., 2018, JGR Atmospheres, doi: 10.1029/2017JD028251

Boltzmann vibrational temperature from ISUAL Imager multi-band measurement of transient luminous events

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The limb observation for Transient Luminous Events (TLEs), including sprites, elves, blue jets and gigantic jets, were presented using the ISUAL payload onboard FORMOSAT-2 satellite. One of main challenges for TLE observation is to observe TLEs in different emission bands. Here, we utilized the ISUAL 427.8nm, 630nm, N2 1P and 762 nm-filtered Imager observation, and analyzed multi-band images of TLEs for estimating Boltzmann vibrational temperature in comparison with the theoretical N2 1P spectrum. For ISUAL recorded sprites, the average brightnesses of N2 1P (I_1p), 762 nm (I_762) and 630 nm (I_630) emission were 2.3, 0.6 and 0.02 MR. The vibrational temperatures (T_v) are estimated to be 2800 K, 3200 K and 4300 K for multi-band intensity ratios of I_630/ I_1p, I_630/ I_762 and I_762/ I_1p. For observed elves, the average brightness I_1p, I_762 and I_630 are 170, 50 and 3 kR. The estimated T_v values were 3700 K, 3700 K and 3800 K for ratios I_630/ I_1p, I_630/ I_762 and I_762/ I_1p. For observed gigantic jets, the derived T_v values were 3000 − 5000 K for a ratio I_762/ I_1p. Through vibrational temperature analyses from intensity ratios of ISUAL multi-band observation, we found that he derived vibrational temperature 3000 − 5000 K in TLEs, which are also consistent with theoretical studies of vibrational kinetics at the time scale of exposure time 29 ms.

The Colombia campaign for gigantic jets of 2018 and the Atmosphere-Space Interactions Monitor (ASIM) matched with ground-based observations of lightning

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In October and November 2018 we performed a new campaign with an intensified high-speed camera system in Colombia. This time, a faster Vision Research Phantom V7.3 was used, at 5000 images per second, allowing a buffer duration of 500 ms. Initially we were located in the Páramo de Santurban, near Bucaramanga, at 3300-3500 m above sea level. Clear sky conditions however were rare during the night, although we recorded an interesting secondary transient luminous event (TLE) developing under a sprite, which thanks to the sky clarity and altitude (good blue/UV transmission) could be distinguished well at low altitudes. However, this location proved inconvenient for prolonged manned campaigns and seems mostly cloudy at night in autumn.

Subsequently, observations were done from Barranquilla and Cartagena. 8 new gigantic jets were captured, of which 3 by the high-speed camera. The optical evolution of one of the events was matched in high time precision against extremely low frequency radio waveforms from Cape Verde and Duke University and the Global Lightning Mapper.

During the same campaign, a high-speed recorded distant lightning flash was simultaneously recorded by the 337.0 nm and 777.4 nm MMIA photometers (10 microsecond interval) and imager of ASIM on the International Space Station. Another matching event was a flash registered by our Lightning Mapping Array near Barrancabermeja in Colombia. We compare the optical emissions during the mapped lightning leaders and return stroke processes, also with GLM and ISS-LIS lightning mappers in space.

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