EISCAT Forward Look – Science Plans for existing and upcoming facilities: 2019 onwards

By the EISCAT Scientific Advisory Committee

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Introduction

This document outlines the current and near future science priorities from researchers within the EISCAT Associate countries. In the past this document took the form of a science strategy, spanning a 5-year period. SAC took the decision to frame the current document as an overview of current research plans and a look into the near future. This should not be taken as a concrete work-plan, but rather as a means of providing scientific context and direction for EISCAT operations as overseen by the Director and Council. The future for EISCAT is of course changing – in the next few years the much-anticipated EISCAT_3D radar system will come on-line, bringing new opportunities and capabilities. The ideas in this document include plans for the new system and for continuing work on the existing radars. EISCAT benefits from being surrounded by a multitude of additional instrumentation and many of the user community are deeply involved and operating these facilities.

This Forward Look has been split into different topics but has not been split by the different Associates. This reflects the considerable overlap of ideas and significant collaboration that has been revealed in surveying the EISCAT community. On occasion, specific nations may be mentioned when there is a distinct contribution to an area, for example the installation of a new instrument to support EISCAT science. Topics are presented in no order of importance or priority and there can be overlap between the different subjects discussed. This is not a complete account of all ideas that were put forward by the EISCAT community but does represent areas where there was significant interest.

1. *Auroral Science*

Traditional auroral work remains a principal target of the EISCAT radars. In the short term there is a desire to exploit the EISCAT ESR in conjunction with auroral imaging, particularly at very high spatial resolutions, to identify local electric field variations and how they relate to the particle energy deposited in and around arcs. Highly dynamic auroras will be investigated to assess their structure and kinematics using time-dependent electron transport codes to estimate primary electron precipitation characteristics of the rapidly varying precipitation. Deriving energy and flux of precipitation was a repeated theme in several areas – multiple codes exist for determining these parameters at different scales and including different physical processes. For example, test-particle simulation codes including non-linear whistler electron interaction processes will be used to support work combining high time resolution EISCAT data with measurements from the ARASE satellite near the equator. This will be used to identify the generating mechanism behind pulsating aurora. The simulation is useful to understand what physical process cause the observed ionization profile. The predictions from this code can be carefully compared and verified with the EISCAT data and updated optical instruments.

EISCAT_3D will provide a means to examine the 4-D structure of arcs in conjunction with tomographic imaging – simultaneous measurements of the optical emission and the plasma parameters behind it. The volumetric capability will measure the ionospheric convection and field-aligned currents at horizontal ranges of a few km. Particular targets will be the different phases of the substorm to distinguish the different acceleration and dynamic processes that occur. Sub-beam horizontal structures will be probed using interferometric techniques to extract the fine-scale structure and identify enhanced non-thermal backscatter. The overlap of EISCAT_3D and the SMILE satellite mission will provide a means of probing auroral structure on multiple scales simultaneously, placing small scale arcs in the context of the large scale auroral oval.

2. Atmospheric Heating

Closely associated with auroral science are the processes of atmospheric heating. This is an area of key interest across the Associates. Heating of the upper atmosphere is caused by thermal and mechanical dissipation processes related to the current systems in the aurora (1). It both influences and is influenced by compositional changes in the thermosphere, which EISCAT_3D in combination with cameras, lidars and other instruments, is well positioned to investigate. The small-scale measurements of EISCAT will complement the larger scale measurements of Joule Heating that can be made from satellites and radar networks. The archive of EISCAT data will be mined to provide statistics on the response of small-scale heating to space weather at different local times and to establish the balance between heating and cooling from chemical changes induced by precipitation. Using EISCAT, and especially EISCAT_3D in conjunction with new networks of Fabry-Perot and Scanning Doppler Interferometers will provide the plasma/neutral data at spatial and temporal resolutions that have not been achievable to date. These neutral measurements are highly important for estimates much closer to the true heating rates. Similarly, the multi-scale nature of EISCAT_3D will allow investigations of how failure to capture small scale variations in the electric field and conductance can lead to underestimates of the heating rate. This could then be used to provide corrections for large scale models for use in space weather prediction and estimates of the energy balance in coupling between the magnetosphere and ionosphere. EISCAT observations during different geomagnetic storms will form the basis for experiments with global scale models (e.g., WACCM-X) to determine the impact on the density of the thermosphere and by extension the drag effect that increased density has on satellites in low earth orbit.

3. The High Latitude ionosphere

Although EISCAT_3D is much anticipated by the community, there is still much interest in using the ESR and studying the dynamics of the high latitude ionosphere, particularly the cusp region. Joint measurements with the Cluster satellites continue to be pursued by several Associates, most notably in studies of the spatial and temporal extent of the cusp. Missions such as SMILE and TRACERS will rely on data from ESR to study the small scale features in the cusp region and to provide spatial information via scanning. This will lead to detailed information on the electrodynamics including the rate of reconnection.

Non-traditional magnetic merging is also of interest: identifying the features of transpolar arcs and the driving mechanism behind them, including the impact they have on the thermosphere. Again, this work will be supplemented by large scale auroral observations from SMILE and from the existing DMSP/SSUSI auroral images. The EISCAT archive has a role to play in this study. Similarly, it will prove useful in studies of the ionospheric variation in the dayside polar cap during solar-minimum.

Beyond the cusp using the EISCAT radars in conjunction with other high latitude ISR will provide a real opportunity to trace polar cap patches through the high latitude ionosphere and to assess the role they play in forming irregularities and causing scintillation. Structuring of mesoscale flow channel features within the large scale polar cap convection, both in relation to polar cap patches and in terms of ionospheric energy dissipation through frictional heating (1) is also of interest. The Dynasonde will also play an important role in this by providing a source of long-term continuous observations. EISCAT measurements of patches will be made in conjunction with SuperDARN and GNSS. EISCAT_3D will allow probing of the structure of the lower latitude patches in high detail.

4. Ion Outflow

The cusp continues to be a focus as plans are set to study the acceleration processes that cause ion outflow and to analyse the asymmetries that occur. Measurements with the SWARM satellite will be compared with ESR data to study the equinoctial and interhemispheric differences in the pattern of ion outflow. Combined studies with the ARASE satellite will identify the mechanisms that drive the outflow of molecular ions. Future observations of ion composition by EISCAT_3D are also important for this study. These ions have been frequently observed by the satellite in the ring current during geomagnetically moderate and active periods. This suggests that molecular ion outflow is rather common during moderate geomagnetic disturbances and that the transport/heating is rapid in the lower altitude ionosphere (250-400 km).

Rocket launches will be made in conjunction with ESR observations to probe ion outflow in the cusp region, one focus being on the ability of small-scale electric field fluctuations to drive the vertical motion (related to (2)). EISCAT observations will play a part in the Grand Challenge Initiative (GCI) Cusp project; a high-altitude sounding rocket will provide in-situ observations of the wave-particle interactions that are predicted to be effective above 700 km altitude.

5. Atmospheric Waves in the Mesosphere-Thermosphere

The dynamics of the mesosphere and lower thermosphere are areas of continuing interest, including analysis of tides, planetary and gravity waves. EISCAT measurements will be coordinated with observations from other ISR and MF/meteor radars to investigate the characteristics of the waves.

This is important for establishing the impact of lower atmosphere waves on the dynamics of the thermosphere and ionosphere.

Joint EISCAT and SuperDARN observations are planned to study the source regions of Travelling ionospheric Disturbances (TID) and ascertain what percentage originate in the lower atmosphere, whether directly, or through wave acceleration in the mesosphere. Satellite observations of will be combined with those from EISCAT to perform raytracing through the atmosphere to establish the probabilities of waves observed in the thermosphere having their origin in the lower atmosphere, whether this be via direct propagation or the generation of secondary waves following wave breaking.

6. Mesospheric Echoes

PMSE (and PMWE) have been a focus for EISCAT users in recent years, and that interest remains strong. There is still work required to understand the mechanisms behind the generation of these features and what they say about the underlying state of the atmosphere. There are strong connections here with the work on atmospheric waves (5) and there are plans to make comparative observations using the PANSY radar in Antarctica.

The imaging capability of EISCAT_3D will provide a means of probing PMSE and PMWE to really identify the overall structure and determine the true roll of neutral dynamic features such as gravity waves. Simultaneous measurements of the local wind field will shed light on the background processes; low altitude measurements of winds from the multiple beam directions could prove very useful in identifying periods when the lower atmosphere is driving processes in the upper. Looking at the precipitation effects on temperature in the mesopause were noted as ongoing work with potential for future expansions, including looking at the effect on PMSE.

7. Coupling through the lower Ionosphere

The role of energetic charged particle precipitation in changing the atmosphere is a topic of much interest. Combining EISCAT observations with those from other instruments and from models (e.g., WACCM-D) is something several nations described. For example, the Japanese have installed a ground-based millimetre wave spectroradiometer at Tromsø (in collaboration with Norway), to make continuous observations of O_3 and NO concentrations in the mesosphere and lower thermosphere. Similarly, the UK with Finland have a radiometer in Sodankyla for the same purpose. Detailed studies of the ion-line in the D-layer have the possibility to reveal more information on the structure and ion-chemistry of the region, combining these measurements with the multitude of measurements from rockets, lidars, cameras and other radars will reveal much about this still poorly understood region.

The extensive EISCAT archive will be used to assess the variability of the D-layer on time scales of weeks to years. This will provide insights into changes in the mesosphere and D-region in response to different drivers; for example, looking at stratospheric warmings and El Nino events. The results of the analysis will be compared with data from local mesospheric radars and with outputs from the

WACCM-D and WACCM-X models with the aim of teasing out the influences of the lower atmosphere in comparison with changes due to space weather. This will identify pathways for improving our ability to predict the mesosphere as part of the whole atmosphere system.

For EISCAT -3D there is a desire to probe the structure of the precipitation inferred from the electron density, this includes for both pulsating aurora and for energetic precipitation modulated by waves in the later morning sector. Using EISCAT_3D to characterise the entire nature of substorm related precipitation is a subject from several countries; one aim was for constraining estimates of loss processes from the outer radiation belts as well as from substorms. The plasma data in the E and D region will also be used to identify the 2-D structure of geomagnetic waves in the auroral zone, including establishing how they dissipate energy in the region, particularly in relation to the deposition from energetic charged particles.

8. Turbulence and Multi-scale Electrodynamics

Data from EISCAT has been identified by several researchers as a means for studying general turbulent processes or for establishing the turbulent nature of the ionosphere. Low elevation data from the EISCAT radars and will be used to study the role of turbulence in ionospheric flow and to establish whether it displays scale free structure inherited from external driving. Ideally, high temporal resolution measurements are required for this. Combining EISCAT_3D with rocket measurements and small-scale optics (1) will also provide opportunities to assess the multi-scale physics in the context of turbulence theory.

Both the established archive and EISCAT_3D will provide opportunities for detailed analysis of the electrodynamics of the ionosphere. Combining radar measurements with satellite observations of features such as field-aligned currents, provided by Ampere and/or SWARM will reveal the nature of cross-scale observations. The structure of the current systems will be probed by analysing the interdependence of the conductivity and the electric field and how both of these parameters influences the growth and magnitude of geomagnetically induced currents, providing an important step in the link between the space environment and space weather impacts.

9. Artificial Heating and Plasma Experiments

The EISCAT Heating facility has proved to be a popular and productive facility over the years, and the community still has plans to exploit this platform. Fundamentally there is a continuing desire to use the ionosphere as a natural laboratory to understand fundamental wave-plasma properties. A diverse range of experiments have been suggested, ranging from the D-region (including modulating PMSE to further probe its nature) to the F-region. Current experiments are focused on how the electron heating varies with power, frequency, orientation with respect to the magnetic field, polarization and other parameters. Stimulated Electromagnetic Emission measurements will be made to probe the temperature and generation of irregularities in the heated volume and its spatial structure will be observed with the SHIRE array from Norway. Artificial Aurora continues to be a focus, with the opportunity to use advanced optics to conduct more detailed observations of its structure across several scale sizes. The excited Langmuir disturbance is still an interesting field and can be used to study the travelling characteristics of the Langmuir and ion acoustic waves. EISCAT_3D will bring new challenges and opportunities by fundamentally altering the geometry of the radar observations of the heated volume. At the same time, it will introduce the ability to simultaneously probe the heated volume and surrounding region such that various experiments can be carried out to examine gradients in acceleration regions and the corresponding optical signatures.

10. Miscellaneous

Several related and stand-alone topics were mentioned by EISCAT scientists. Ideas were suggested for using the new radar mode of EISCAT Heating. Additional D-layer heating experiments were suggested (particularly in the new geometry of EISCAT_3D) and simultaneous observations with rockets, lidar, meteor radar, etc, to probe the small-scale variability.

Plans were mentioned to study the ionospheric response to magnetosheath jets and using the ESR to study density depletion regions in the polar cap, possibly linked to upwelling (4). Similarly, there was a desire to study vertical winds in the polar lower thermosphere and upper mesosphere, whilst others wished to do more combined observations with meteor scatter. Plans to use ESR and EISCAT_3D to study space debris are also underway. Overall, there was a wish for greater D-region focus in the era of EISCAT_3D, including, but not limited to using EISCAT data to improve our understanding of how wave-wave and wave-particle processes can affect the propagation of HF radio, for space weather studies.

Summary

The international EISCAT community is thriving, with rich plans for the exploitation of the current radars and the new EISCAT_3D system. Although some familiar topics emerge, there is a definite emphasis on new ways of looking at these problems and using the new capabilities to drill deeper into the physics and impacts of the different processes. The community is clearly excited and prepared for EISCAT_3D to come on-line, but at the same time there is a significant desire to continue utilizing the ESR and to mine the extensive data archive that EISCAT has built up over its decades of operation.