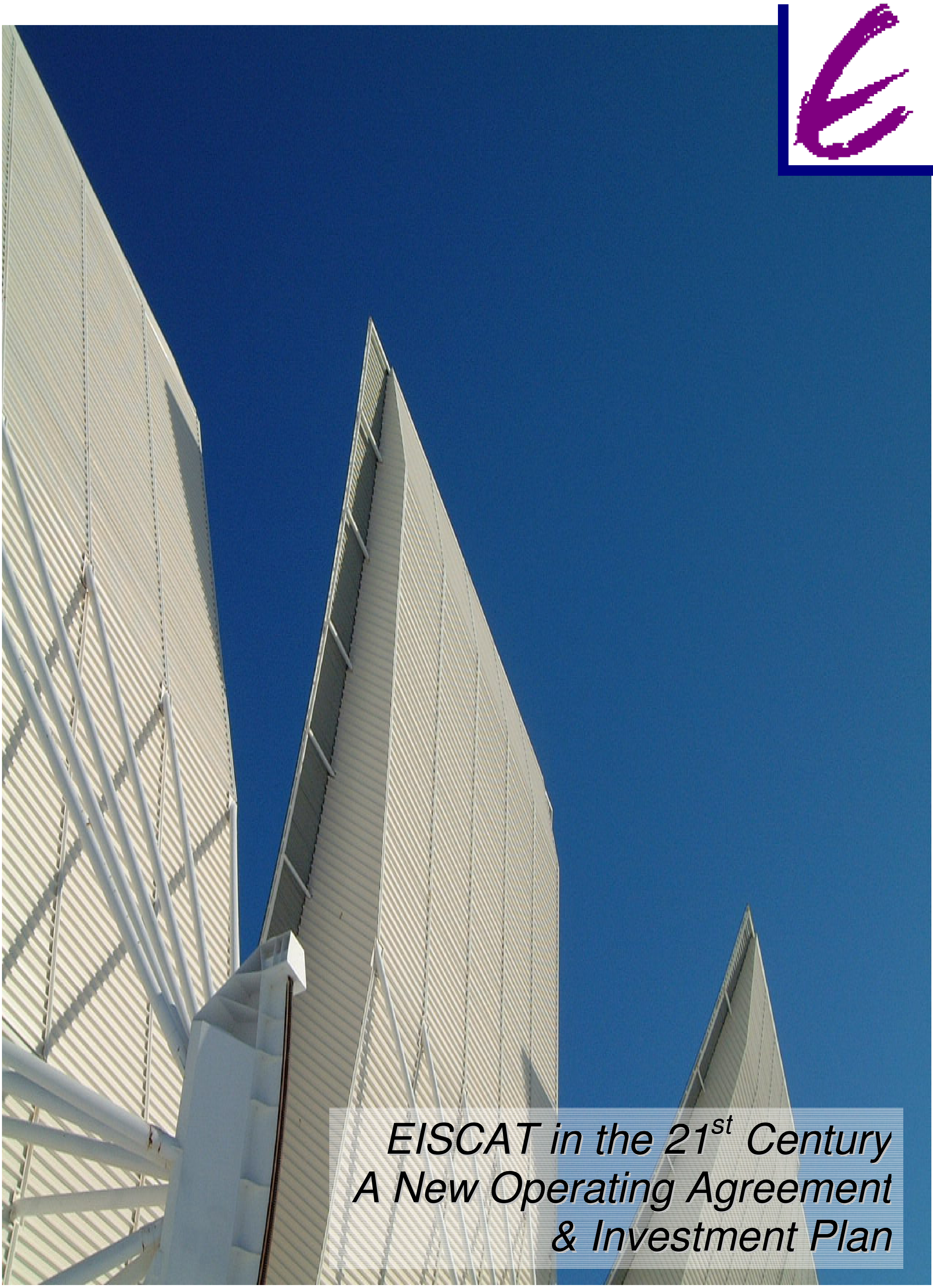

EISCAT in the 21st Century
A New Operating Agreement
& Investment Plan

PROSPECTUS

An Opportunity to join the World's premier High-Latitude Space Plasma Research Association

Recent extensive updating, involving both radar hardware and software, has positioned the EISCAT Scientific Association as a uniquely capable facility to address the priority research topics in high latitude geophysics. Further possibilities exist, not only to extend and maintain this leadership position to enable the Association to address already identified future priority areas, but also to permit the Association to become the premier data source for continuous, quality, high latitude data. New and existing Associates are invited to join in exploiting these unique scientific opportunities.

EISCAT Futures Core Group
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With valuable contributions from
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Presented to the EISCAT Council, June 2003

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Executive Summary

The EISCAT Scientific Association has lead the World in ionospheric and atmospheric studies using incoherent scatter for most of its lifetime. At present, the Association operates the three most advanced radars in the World and the most powerful ionospheric heater.

Work by scientists of the EISCAT community has largely illuminated the scientific problems for which the Association was created, and has also revealed many new and even more important questions which must be resolved if we should properly understand our environment within the Sun-Earth system. The advances in understanding, and the need to answer the questions raised, have already led to the construction and operation of one new radar (on Svalbard) within the Association's lifetime and more developments are required in the future if the community's scientists should be able to continue to play a leading role in World research.

The Existing EISCAT agreement terminates at the end of 2006 and a new agreement must be negotiated well before that date to ensure both continuity and timely provision of new facilities.

Based on the scientific drivers, a series of upgrades and improvements are proposed, with a general investment budget frame of about 50-80M€. In addition, changes in the organisational and operational structure of the Association in conjunction with the creation of the new Agreement can reduce the recurrent cost of operational hours while increasing the availability of quality data, even to a point were it is essentially continuously available. These upgrades will allow EISCAT to continue to address new, significant, and socially important problems.

The detailed planning, costing and financial arrangements form the bulk of the work to be completed in the coming year.

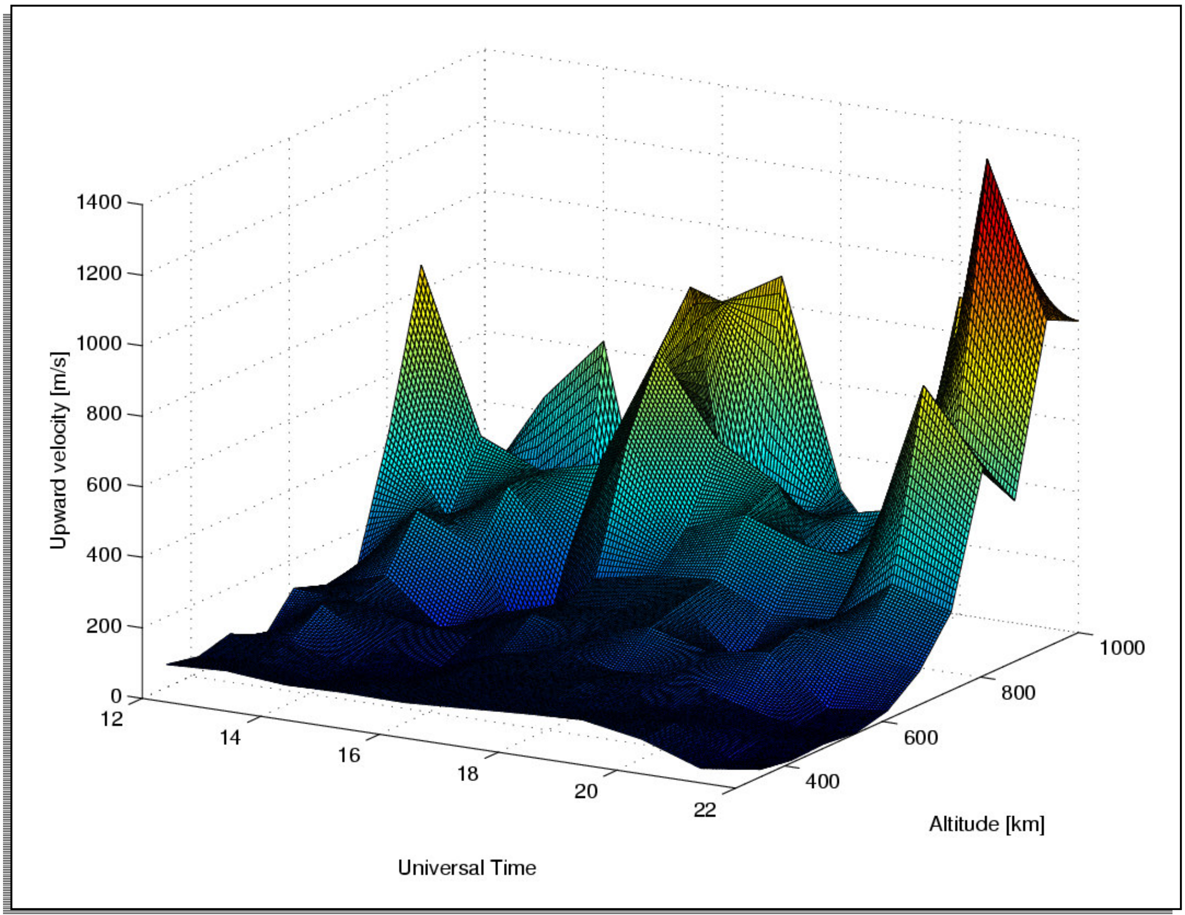


Figure 1: Two-dimensional plot of hydrogen outflow velocity as a function of time and height on April 11, 1997; individual profiles represent 15 minute integrations. Routine observation of the polar wind was believed to be an easy task when EISCAT was first conceived, but, in practice, the measurements proved to be impossible until a combination of technical developments and scientific understanding, based on EISCAT observations of many previously-unknown high-latitude features, finally made it a reality twenty years after EISCAT started operations (Løvhaug, Hagfors and van Eyken, 2001).

Introduction

Background

The EISCAT Scientific Association is composed of the Research Councils, or equivalent, of Finland, France, Germany, Japan, Norway, Sweden, and the United Kingdom. The Association has constructed and operates World-class facilities in northern Scandinavia including the three most sophisticated incoherent scatter radars and the World's most powerful ionospheric heater.

Since coming into full operation during the 1980s, the EISCAT Scientific Association has been the world leader in incoherent scatter research. During that time, the Association has made important contributions in every one of the research areas for whose investigation it was established (e.g. Figure 1). In the process, scientists working with EISCAT have made many unexpected discoveries, opening up new areas of scientific investigation and being at the forefront of technological developments in many areas.

EISCAT has achieved world leadership in the three critical areas of radar hardware, modulation schemes, and data processing and its expertise and capabilities are ideally placed to make further key contributions to future international science programmes. From large-scale processes in energy coupling to micro-scale plasma physics, EISCAT offers an unparalleled range of high-quality observing instruments, with a fully proven range of experimental modes, analysis software and data distribution capabilities.

The present EISCAT Agreement between the Associates expires at the end of 2006 and a new Agreement must be negotiated in order for the Association, and the experimental facilities it provides, to continue to operate. The renewal of the EISCAT operating agreement at, or before, the end of 2006 provides an opportunity to re-evaluate the priorities and future direction of the organisation to best address the scientific opportunities in the coming decades.

While there are excellent plans for such an Agreement, and for substantial enhancements in the systems themselves, only pressure form the user communities in the Associate countries will provide the Research Councils of existing, and potential new, member countries with the motivation, and justification, to adopt a future Agreement and fund continued operations.

The scientific community has therefore developed a substantial range of questions which should be addressed. The outline of the new agreement reflects these drivers and provides a sound experimental base for their solution. In the present funding climate, there is every reason to introduce a new Agreement as soon as possible rather than waiting until 2007.

EISCAT will build on its present world-leading activities in the areas of fundamental plasma physics, energy coupling, and space weather research, and remain at the heart of international collaborative programmes in space physics.

There is a strong, and expanding, demand for analysed EISCAT data as a component of larger datasets synthesised from the output of many instruments, particularly ground based optical measurements and satellite observations of all types. The collaboration with ESA's CLUSTER satellite mission represents a dramatic example of this mechanism (Figure 2) and support for spacecraft missions will continue to be a key part of the future programme, building on the Association's long experience of collaboration with missions from AMPTE to CLUSTER.

Atmospheric, ionospheric and STP studies will become more globally orientated, more time critical and of more significance in human affairs and even the superlative EISCAT facilities must be extended ensure that our community continues to enjoy access to the most appropriate observational systems

Incoherent scatter radars have never been operated as production research tools, but the EISCAT radars can fill this role, delivering fully processed, calibrated, and validated data sets on a continuous basis.

To properly address current and future scientific investigations, the existing capabilities must be expanded, including the possibility to image in a large number of simultaneous radar beams and the capability to probe key atmospheric coupling regions in the mesosphere and lower thermosphere. The radar data must also be supplemented by a range of complementary instruments, operated by our international collaborators, for which EISCAT will provide infrastructure and logistical support, as well as expediting the distribution and assimilation of the data.

Datasets derived from complementary instrumentation at high latitude and must be tailored to address the exact needs of Space Weather data consumers, global modellers and other non-traditional data consumers, as well as supporting both the traditional user community and event driven researchers who were previously unable to exploit such major instrumentation because of the cost implications of sole use of facilities over extended periods.

EISCAT has many close university connections and these will be further expanded to support proposed new initiatives in data processing, analysis, distribution, interpretation, and modelling. Academic connections will also underpin a vigorous graduate and post-graduate programme, aimed at exploiting the many training and educational opportunities of EISCAT operations.

This Prospectus outlines a new initiative, E', designed to take EISCAT beyond the lifetime of the present operating agreement. E' is based on three foundations, each of which offers totally new opportunities but each of which leverages unique features of the present Association's expertise, installed infrastructure, and location: a programme of continuous observations, an umbrella philosophy bringing together a wide range of instrumentation for co-ordinated studies on a range of spatial scales, and education and outreach activities. The proposals are ambitious but achievable, and the technological investment can be phased to match funding availability. When implemented, they will assure EISCAT an extremely productive future, placing it at the heart of many national and international initiatives in solar system science.

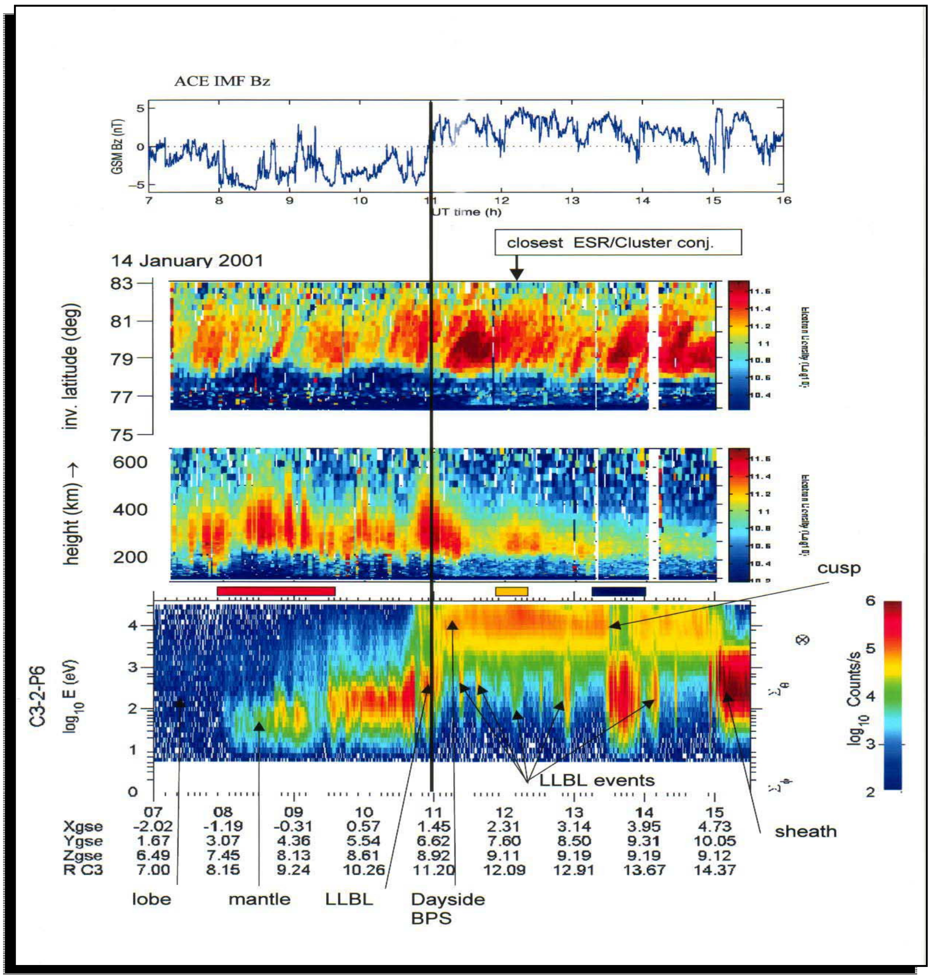


Figure 2: The first co-ordinated ESR-Cluster observations covered an interval when Cluster traversed the high latitude ionospheric cusp above Svalbard on 14 January 2001. Simultaneous observations of electron density by the ESR steerable (top) and fixed antenna (middle panel), and ion measurements made by one of the Cluster spacecraft as it moved from the lobe into the magnetosheath gave crucial insights into the processes in this complex and important region were much of the energy transfer from the solar wind to the magnetosphere takes place (Opgenoorth, et al. 2001).

The present EISCAT facilities

The facilities of the EISCAT Scientific Association presently comprise the state of the art in global Incoherent Scatter Radars. All three incoherent scatter radars have recently been substantially renovated and upgraded and all are in excellent technical shape to address the demands of cutting edge, twenty-first century research.

The radars produce more than 4000 hours of high quality data every year; real-time raw and processed data are available on the web, and checked analysed data is normally loaded to EISCAT's web-accessible database within 24 hours of the completion of an experiment. EISCAT hosts experiments from a wide range of scientists and institutions, within the present seven Associate countries and farther afield. In addition, about half of the EISCAT observing time is devoted to playing a full role in co-ordinated World-wide Incoherent Scatter observations under a programme arranged through the URSI Commission G Incoherent Scatter Working Group. Data from the later programme, as well as a considerable proportion of the special programme data, is distributed freely through on-line databases at EISCAT, in France (CDDP), the USA (CEDAR), and elsewhere.

The EISCAT Svalbard Radar (Figure 3) is the most recent addition to the World's incoherent scatter radars. It is built around low maintenance transmitter technology, and presently delivers in excess of 1800 hours of data of unsurpassed quality and resolution each year (80% above target). The radar is located near the main Svalbard settlement, Longyearbyen, where it benefits from excellent supporting infrastructure, transport, and accommodation facilities. There is direct collaboration with many other installed instruments including a wide range of optical systems, two rocket launching facilities, MST and meteor scatter radars, and (presently under construction) an ionospheric heating facility.

The mainland radars are built around a tri-static UHF radar with its transmitter at Tromsø (Norway) and additional receivers at Kiruna (Sweden) and Sodankylä (Finland) and a VHF radar at Tromsø. The former is the World's only such facility, able to measure full vector ionospheric plasma velocities at a single point without the need to integrate across wide spatial extents. Again, these facilities enjoy access to superb local supporting infrastructure and to an even wider range of locally installed instruments including optical, radio wave, LIDAR, and two major rocket launching facilities. In addition to the two Incoherent Scatter Radars, the EISCAT facilities at Tromsø also include the World's most powerful ionospheric Heater and a research ionosonde. The combination of the Heater and the co-located tri-static UHF radar offers a unique possibility to study the 3-D spatial properties of artificially heated ionospheric plasma. The mainland radars currently deliver close to 2000 data hours per year in the same format and quality as that produced by the radar on Svalbard.

Figure 3: The two antennas of the EISCAT Svalbard Radar, the most advanced, effective, and operationally efficient Incoherent Scatter Radar in the World.

All three of EISCAT's incoherent scatter radars have recently been significantly upgraded with improved signal processing capabilities and observing codes and their present capabilities in spatial, temporal and spectral resolution are unequalled. Special data processing and distribution can be arranged where particular programmes may have requirements for unusually rapid data availability or non-standard analysis techniques.

In addition, procedures have also been streamlined as part of an effort to further extend the operational efficiency of radars and much extended operations are now possible. The EISCAT Svalbard Radar has completed runs of 18 and 31 days and further such runs are planned. Extended operations provide access to unpredictable and infrequent phenomena, allow the collection of unbiased event statistics, and provide completely new, and very stringent, challenges and opportunities to the various modeling communities.

The present annual budget is about 32 MSEK with the bulk of the costs being associated with the two transmitting sites at Tromsø and Longyearbyen and lesser amounts with the additional receiver sites at Kiruna and Sodankylä. The Headquarters of the Association is also in Kiruna.

The EISCAT Scientific Association currently employs a team of about 35, including first-class engineers, technicians, and support staff as well as outstanding scientists in key positions.

Future evolution of Solar Terrestrial Physics

Solar Terrestrial Physics (STP) is becoming a mature field; STP research has moved beyond the cataloguing of the basic phenomena which characterise the solar-terrestrial system, and is now increasingly directed at understanding how the observed behaviour occurs in detail. In particular, it seeks to address the way in which the various regions of the geospace system couple together. The most important questions, in which EISCAT has a substantial role to play, are summarised below in the section on E' Science goals. The key science drivers include ion outflow, auroral acceleration, small scale plasma physics, induced changes in the ionosphere, magnetic reconnection, substorms, ionosphere-neutral atmosphere coupling, mesospheric physics, and solar wind acceleration, all of which can be addressed by the developments proposed in this document.

Research in STP is also developing beyond the use of single diagnostics, becoming more and more oriented to the use of networks of instruments whose different observing capabilities complement each other, with each providing a distinctive insight into a particular process or mechanism. This trend is most evident in global observations, but it is not confined to large-scale studies. The current programme of CLUSTER and Ground-Based observations makes use of a global network of instruments, comprising incoherent and coherent scatter radars, imagers, riometers, and magnetometers to add considerable value to the data from the unique constellation of CLUSTER spacecraft. EISCAT has been at the heart of this endeavour, carrying out co-ordinated operations in close consultation with the CLUSTER community, other radars around the world and experimenters operating a variety of other equipment. In the future, more undertakings of this kind can be expected with forthcoming missions such as Double Star and MMS. The International Living With a Star (ILWS) programme, currently being advanced by NASA in collaboration with its international partners, establishes exactly this type of model. The way to make progress in understanding the Solar-Terrestrial system is through the well-planned co-ordination of many state-of-the-art diagnostics of different types. NASA is driving this initiative forward and EISCAT already has a long track record of exactly this type of co-operative endeavour, and is well placed to perform a central role in future studies of this kind.

The benefits of multi-instrument collaboration may be most obvious when dealing with global-scale phenomena, but they are certainly not confined to these.

Not least because of the insights which can be obtained into basic plasma physics processes, one of the most scientifically promising areas of EISCAT research for the near future is the study of plasma phenomena on the very smallest scales, whose sizes can be much smaller than the radar beam width. Examples of such studies include the microphysics of artificially modified plasmas (e.g. using ionospheric heating), high-resolution investigations of spatially complex systems such as auroral arcs, and the probing of important regions for energy transfer such as gravity wave and tidal dissipation at the mesopause. In each of these cases, the EISCAT radars can secure very important observations, which would be complemented by extensive measurements of optical emissions, particle fluxes, wave modes, and neutral dynamics, in order to establish the full picture.

To support these studies, the EISCAT Scientific Association must continue to operate the best incoherent scatter radars in the world, and can do more in order to make substantial new progress. In order to provide the observations demanded by future science studies, EISCAT must change the basis of its operations. Currently, EISCAT experiments are limited to about 4000 hours per year. Too often, important and interesting events are missed because no radar operations are scheduled, or not exploited because the true nature of an event is not realised until the data are processed and therefore the system may not have had the optimal settings for studying that specific event. A new observing paradigm, where continuous observations are coupled to a detailed programme of event-driven research will enable us to identify when interesting conditions are occurring and to exploit such events to the full.

In addition, EISCAT needs to supplement its world-leading radar data by effectively assimilating and exploiting local networks of complementary instruments whose data must be combined to make co-ordinated investigations into STP phenomena by a variety of routes.

These ideas are both timely and consistent with what is happening in this part of our field internationally.

However, it should not be forgotten that much of the work of the Association is focussed on areas of ionospheric physics, plasma physics, and extraterrestrial studies which bear little relation to the STP umbrella, but nevertheless form important parts of the programme and lead to frequent advances in the understanding of our environment.

A new initiative, `E′`, is proposed below. It is based on both continuous observations and an "umbrella philosophy" bringing together a wide range of instrumentation for co-ordinated studies on a range of spatial scales.

These proposals can assure EISCAT a scientifically productive future, placing it firmly at the heart of many national and international initiatives in solar system science.

The E′ Proposal

The EISCAT Council has established a Futures Group to prepare the way for the new Agreement.

The Futures Group has developed a plan under the working title of E′ (E prime) and identified four main pillars of the future Association:

- To provide the highest class facilities to support World class research and to deliver timely, fully processed, calibrated and validated data addressing detailed plasma physics and the traditional user community.
- To provide near continuous operation and proper support for event driven research, Space Weather and environment applications, and global models.
- To provide first class eeducation and training opportunities with uuniversity connections underpinning aggressive graduate and post-graduate training programmes.
- To provide value added data services enhancing the Association's role in co-coordinating high latitude studies.

There are already several initiatives in progress to construct new incoherent scatter radars throughout the World, reflecting the applicability, reliability, and cost effectiveness of these machines in atmospheric, ionospheric and Solar-Terrestrial physics applications and EISCAT must evolve if it to keep pace with these plans. The principal projects include:

- AMISR: a US effort led by SRI to establish new incoherent scatter facilities at Gakona and Poker Flat, in Alaska, and close to the northern magnetic pole at Resolute Bay, in northern Canada. The AMISR (Advanced Modular Incoherent Scatter Radar) concept is built around extensible, transportable, UHF phased array radars with output powers of a few MWatt.
- In China, plans are in hand to convert a surplus military radar system for use as an incoherent scatter radar at mid-latitudes
- The Japanese are developing a new radar (Pansy), with capabilities similar to the MU radar operated by Kyoto University, to be deployed at their Antarctic station, Syowa.
- ZIP: another US initiative led by the Millstone Hill group based on the concept of a simplified incoherent scatter radar with a fixed vertically pointing dish at a cost low enough to allow many such ZIPs (Zenith Ionospheric Profiler) to be deployed at widely dispersed locations.

E' Science Goals

The E' proposal has been developed to address the new important problems in this area of science and builds on the many successes of EISCAT in over twenty years of operation.

The contributions that EISCAT has made in all the research areas for which it was originally proposed are outlined in Appendix 3. In addition to resolving important questions, EISCAT has opened up many avenues of new research. As our understanding of solar-terrestrial physics has advanced, fundamental questions continue to present themselves. In many cases, our ability to make progress is limited by the constraints of our existing observing capabilities. For example, we are aware that a wealth of small-scale structure exists in auroral arcs, and that this structure is probably of crucial importance in determining the mechanisms responsible for energy deposition. Our comprehension of such mechanisms is, however, limited by our inability to make detailed measurements at the small scale lengths involved. In addition, EISCAT experiments have revealed a number of phenomena, such as anomalous radar echoes and stimulated emissions, whose existence seems difficult to account for with existing theories. Once again, the explanation of such observations may depend on the acquisition of data, for instance related to the auroral acceleration region, which is presently beyond our grasp, but would become accessible given suitable additions to our hardware capabilities.

The E' proposal has been developed to address these important new problems and Appendix 4 presents a list of currently identified areas where E′ would make crucial contributions.

The EISCAT facilities, and the extensions proposed in this initiative are located in a area where they are surrounded by a dense concentration of other ionospheric and atmospheric measuring instruments which constitute a longitudinal chain from high-latitudes to populated mid latitudes in the European sector.

The realisation of E' will provide the EISCAT user community with access to facilities uniquely capable to study the coupling of mass and energy from the solar wind to the magnetosphere, ionosphere, and thermosphere, global change phenomena, magnetosphere-ionosphere coupling processes, Space Weather and synoptic studies, basic plamsa physics, and a variety of detailed topics including mass exchange, ion outflow, conductivity studies,and pulsation phenomena.

Other planning exercises, such at that recently completed in Germany, have identified similar priority areas for New EISCAT-related science in the polar/auroral region including studies of the Polar troposphere, stratosphere and mesosphere, studies of the Polar thermosphere,and studies of the Polar/auroral ionosphere, as well as basic plasma physics and contributions extraterrestrial science such as measuring extra high energy cosmic rays, interstellar dust fluxes, and Solar wind velocity and turbulence.

The addition of a powerful MST capability to the EISCAT suite of instruments will support important studies of the mesosphere, which, though one of the least-studied atmospheric regions, is becoming clearly identified as a region is of great importance to energy coupling between the upper and lower atmosphere, as well as making significant contributions to studies of the polar troposphere and stratosphere.

The philosophy of E′

The E′ initiative visualises a significant change from the present operating philosophy of EISCAT. Rather than operating for a limited number of hours, with observing time divided between Common and Special Programmes, it is proposed that a subset of the radar systems will run continuously in survey modes similar to the present Common Programmes. The data from this continuous operation will be analysed and distributed in real-time, being combined with results from a variety of other observing techniques and used as input to models to provide a forecasting capability for solar-terrestrial conditions. The real-time data, together with the modelling results, will be used to trigger a variety of event-driven observing modes on the remaining radar systems, each of which will be carefully designed to exploit particular conditions and optimised for detailed study of phenomena such as CMEs, proton events, substorms etc. This mode of operation will enable the radars to maximise their potential for making observations appropriate to the key science questions, and will ensure that unusual conditions, whenever they arise, are exploited in the most effective manner possible.

In addition to the principle of continuous operations, it is proposed that E′ should fulfil an "umbrella" function for the large group of other instruments which will be deployed in close proximity to the radar sites. Many such observing systems, such as HF sounders, optical imagers, magnetometers and radars, have already been deployed in conjunction with EISCAT. Currently, such diagnostics are usually owned by individual research groups, each of which has its own methods for data analysis and distribution. The E′ proposal envisages that, in the future, such instruments will continue to be owned and operated by individual user groups. It is proposed, however, that E′ should provide such instruments with access to its computer networks, hosting their data capture and analysis and facilitating their data distribution in standardised formats. Such homogeneous methods of data analysis and distribution would facilitate the kind of multi-diagnostic data assimilation techniques discussed above.

As the understanding of solar-terrestrial physics evolves, a natural development is the synthesis of observations and modelling. This entails the use of well-calibrated, real-time, multi-instrument observational data as inputs to models that can provide a predictive capability that, in turn, can be tested against observations.

The E′ initiative seeks to capitalise on the existing excellence of the EISCAT facilities and infrastructure to perform new, cutting-edge research in a number of specific topical, important and technically demanding areas and to address modern demands for continuous high-quality data.

E′ Development Model

The E′ initiative envisages three phases of future operations and development.

In the first phase, covering approximately the years 2003 and 2004 (and already contained within the 2004 budget proposal), the capability to operate at increased data production rates will be further developed. Recently implemented observing modes will be used, exploiting the new hardware and software capabilities of the systems to address demands for both higher quality data with improved temporal resolution as well as more predictable and more continuous data availability. At the same time, the Association will begin to implement data assimilation strategies and systems, providing data handling facilities for the operators of other high latitude diagnostics of relevance to EISCAT (including modellers and forecasters).

In the second phase, the requirement to upgrade or replace the current mainland radar systems to support the demands for improved spatial resolution, as well as near-continuous operation, coincides with the development of a new EISCAT Agreement which will carry the Association into the future. This is an ideal opportunity for new Associates to join the EISCAT community, and for existing Associates to renew their commitment, further capitalising on their existing investments in people, techniques and equipment embodied in the present Association. The upgrading or replacement of the mainland systems calls for substantial financial investment which will maintain the newly reconstituted Association at the forefront of ionospheric and magnetospheric research for many years.

The third phase of `E′` development sees the Association bringing the upgraded facilities on line and expanding both its research and monitoring activities in line with their enhanced capabilities.

The three phases require different levels of financial provision within the overall `E′` structure.

In the first phase, no additional investment is required (though continued funding, at a level adequate to support both operations and appropriate maintenance requirements, is essential).

Various options and timings are possible during the second phase, but all scenarios require a substantial investment in new hardware, to allow the capabilities of the EISCAT systems to be extended, and to supplement them with the additional infrastructure required to support an expanded research programme.

These options include:

Modification of the existing VHF antenna feed structure to allow access to the field aligned direction for the first time. This is a critical upgrade to support many aspects of both low and high altitude research as well as providing proper diagnostics for an increasing range of Heater related plasma physics and ionospheric studies. While the VHF transmitter's future seems secure for a number of years following the recent repair of one klystron, it would also be prudent to plan for it's replacement with a modern system, also capable of much extended operations, within the planning period.

The addition of phased array passive receivers in conjunction with the upgraded VHF system provides effective possibilities for continuous interferometric work, using arrays closely collocated with the transmitter, and an essentially unlimited, number of simultaneous intersection volumes along the transmitter beam and improved data quality, relative to Tromsø throughout the range, using arrays in the vicinity of the existing receiver sites in Sweden and Finland.

The addition of a further steerable antenna to the Svalbard system would provide the three-dimensional ambiguity resolution in velocity which was included in the original design of that system and which is still needed to resolve the details of rapidly changing phenomena.

A new IS radar based on a substantial active phased array supplemented with one or more receiver arrays to support interferometric studies would support continuous operaton and supplement the existing VHF and UHF systems for specific and unpredictable investigations.

The existing 32 m antennas at Kiruna ans Sodankylä should be equipped with dual band feed systems allowing near-instantaneous switching between radar operation at 928 MHz and IPS observations at 1.4 GHz.

The existing ESR should be supplemented by an expanded building to support related instruments including optical imagers, SPEAR, etc.

In the third phase, funding to support continuous operations and planned maintenance is needed, together with adequate staffing and financial provision to sustain appropriate reliability and ensure continuing development and effective exploitation of the data and facilities.

The Role of `E′`

The expanded systems incorporated into the `E′` concept address the specific, detailed research goals identified in Science Goals section and the related Appendix.

The phased array systems will provide for continuous interferometric sounding of sub-kilometre structures whose investigation is substantially beyond the capabilities of the existing systems, which are limited by the present beam width. New developments in hardware and low altitude codes, operated in conjunction with other diagnostic systems, will be more capable in addressing the physics of the low altitude region (40-70 km where the radar echoes are extremely weak) and the coupling between the ionised and neutral atmosphere in this little-studied region. Improved time resolution, including sub-second data, will open up new possibilities for the study of non-equilibrium plasma physics, including the re-interpretation of highly time-varying processes such as plasma turbulence, in a manner analogous to earlier studies of non-Maxwellian scattering mechanisms. The combination of improved temporal resolution with the higher spatial resolution offered by interferometry will be particularly powerful.

The phased array systems at the remote receiver sites will precisely monitor ionosphere-thermosphere coupling, simultaneously probing a range of heights from the low E-region to the upper F-region. Such observations will also allow long-term studies of neutral dynamics, including the full height profile of the response to forcing mechanisms such as substorms, and investigation of the "flywheel" feedback from the neutral atmosphere to MI coupling.

Of equal importance to the new hardware will be the change in operational philosophy envisaged in the development of E′. This operation will be of two basic kinds:

A subset of the E′ radars will be used for near-continuous synoptic operations. Such operation will enable long-period phenomena of the high-latitude atmosphere, such as multi-day planetary waves, to be characterised much more fully than in the past. Access to a long-term database of continuous measurements would enable the climatology of such waves to be studied, in addition to their modulation by external forcing mechanisms. Long-term continuous observations of phenomena such as PMSE will lead to an improved understanding of their occurrence and possible significance in diagnosing long-term change. An important aspect of continuous observation is the value that would be added to observations from other diagnostics. Satellite overpasses above Scandinavia would, for example, always be supported by high-quality ground-based radar data, while data from a wide range of other ground-based systems (many of which are operated continually) would always have radar data available for joint studies. EISCAT has, throughout its lifetime, been heavily involved in many of the leading international study programmes in STP (CEDAR, SCOSTEP, LTCS etc). The trend for co-ordinated multi-instrument studies is now well established, and co-ordinated international programmes such as International Living With a Star (ILWS) and CAWSES will provide a strong framework for such studies in the early years of the 21st century. The new E′ facility will be a very important data resource for ILWS and other such multi-national programmes.

Perhaps the most important aspect of continuous operation is the possibility to identify relatively infrequent but extremely interesting events (ionospheric storms, pressure pulses, CMEs, solar proton events etc) and ensure that these are supported with the kind of high-quality data needed to improve our understanding of their effects. Continuous data taking would allow the acquisition of an unbiased database, reflecting the real occurrence statistics of the events under study. One way of identifying interesting phenomena would be by the use of automated event-seeking software to search the database. An even more interesting possibility would be to use the real-time radar data in conjunction with results from other diagnostic systems, as inputs to models to predict the occurrence of interesting phenomena - see section on Data Synthesis. Such a capability would be particularly powerful, as the E′ radars could then be optimally configured to make the observations best suited to the conditions.

Those radars not in use for continuous synoptic observations would be used for a variety of research-driven investigations, more along the lines of the current EISCAT Special Programmes, but would rapidly switch into special event-oriented modes whenever requested. The ability to respond rapidly to the availability of the desired conditions, e.g. for high-resolution studies of the aurora, or for detailed observations of ion outflow, will be crucial. However, the possibility to run such modes at the appropriate times will be vastly improved over present capabilities by the availability of the continuous synoptic data, which will be analysed and distributed in real time.

In summary, the E′ system, implemented via a combination of hardware upgrades and new operational philosophies, will maximise the usefulness and appropriateness of the data obtained. Other measures which would be put into place as part of the E′ development, would facilitate the handling of these data, their distribution and their combination with data from other observing systems - see Section on Data Synthesis. The aim would be to utilise the radar systems to their fullest extent to give the scientific users of E′ the data best tailored to their studies, in terms of quantity, quality, appropriateness, and ease of use.

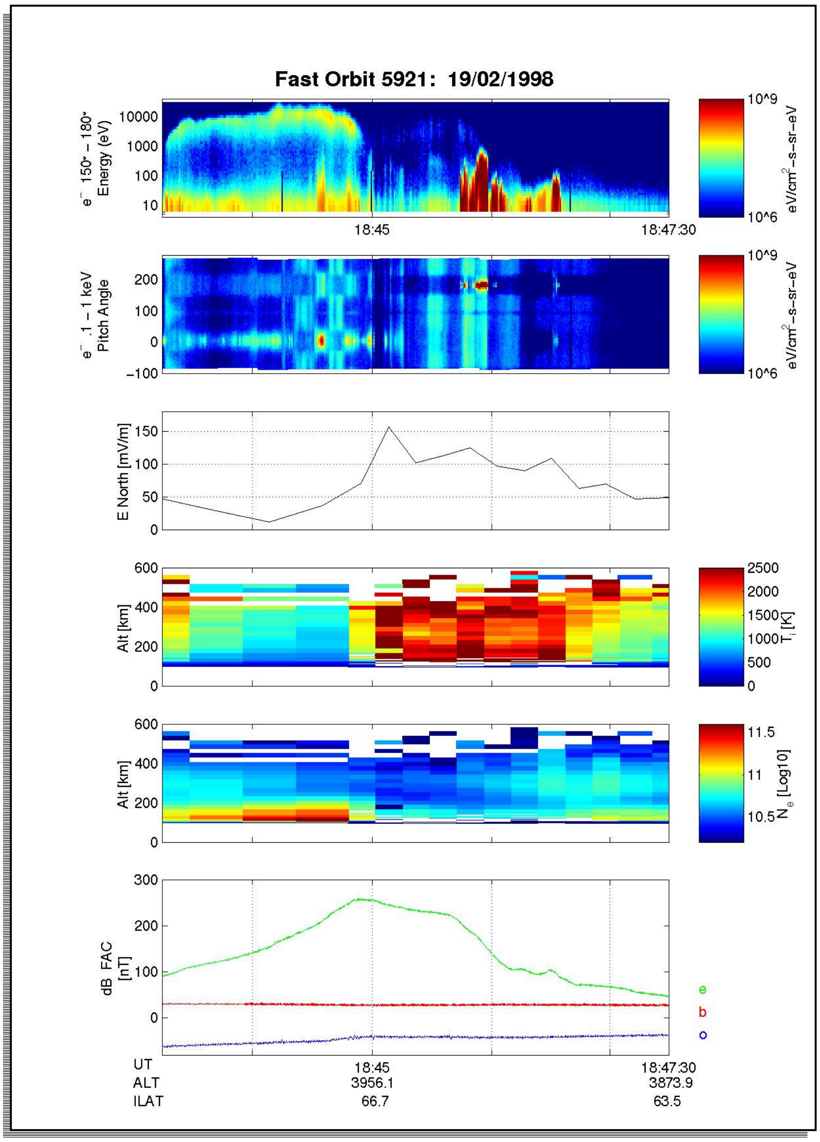


Figure 4: In a classic example of data synthesis, the FAST satellite passed through an auroral arc and associated precipitation pattern, down-going electrons (upward field aligned currents) are observed in the arc, and up-going electrons (downward current) just over EISCAT, to the south of the arc.. The link between strong electric fields, electron density depletion and high Pedersen current closure in the region of downward currents just equator-ward of arcs had been suspected by Opgenoorth et al., 1990, and Williams et al., 1990, but never proven.

E′ Data Synthesis

During the twenty-year lifetime of EISCAT, a profound change has occurred in the way in which the data have been used. In the early days of EISCAT, most of the papers used radar data only. Much of the best science to come from EISCAT over the last few years, however, has arisen from the collaborative use of data from the EISCAT radars and other data sets. These data sets have come from other ground-based facilities (IS Radars, HF Radars, Magnetometers, Riometers, Imagers etc) from spacecraft (CLUSTER, POLAR, DMSP etc) and from models (NCAR, CTIP etc). The main factor has been the increasing realisation that the solar wind, magnetosphere, ionosphere and neutral atmosphere are all parts of a single coupled system, and that different aspects of this system can be best studied using a range of different techniques (e.g. Figure 4).

As the understanding of solar-terrestrial physics evolves, a natural development is the synthesis of observations and modelling. This entails the use of well-calibrated, real-time, multi-instrument observational data as inputs to models that can provide a predictive capability that, in turn, can be tested against observations. At this stage in the development of our science, we are a long way from having the detailed physical understanding needed to make reliable predictions on anything but the grossest of scales. The ultimate goal of STP (as with any science) must be to obtain a sufficient understanding of the processes involved that detailed and reliable predictions of the evolution of the coupled system can be made on the basis of multi-diagnostic measurements.

Such an undertaking is enormously challenging. At one level it involves the understanding of processes occurring on short temporal and spatial scales, such as reconnection and auroral acceleration. These processes may involve turbulent or chaotic processes, and may very well not be entirely deterministic. At the other extreme lies the understanding of long-term secular processes, such as variations in the Sun and the corresponding effects on climate, where the underlying mechanisms may be more deterministic, but are no better understood.

The enormously rapid expansion of computer processing capacity and networking capability over the past five years is now starting to make such data synthesis a real possibility. As a result, a host of initiatives have sprung up within the STP community. Examples include the SPARC and AMIE projects in the US, the STP Data Facility and the "Virtual STP data object" recently proposed in the UK. The interest in this area is not confined to STP alone. The possibilities afforded by this kind of "e-science" have attracted the attention of funding agencies in fields ranging from particle physics to astronomy. By its very nature, however, solar-terrestrial physics is uniquely well suited to such a philosophy. Every STP instrument, whatever it measures, is probing an aspect of the same coupled system. For example, there is a very direct link to the observations of the solar corona made by SOHO at the L1 point, with observations made by satellites in the solar wind and magnetosphere, and with ground-based radars, riometers and magnetometers when Coronal Mass Ejections arrive at the Earth. Because of this, one can imagine that the data from any STP diagnostic, whatever its technique and wherever it is located, could be sensibly combined in a large data synthesis. This is not the case, for example, in astronomy where a range of ground-based instruments measure a wide variety of unrelated astronomical objects.

The requirement for real-time data synthesis, including not only multi-diagnostic ground-based and space-based data, but also integration of that data into models, is becoming so fundamental to our scientific approach that it has to be a key part of the E′ philosophy from the very beginning. The philosophy of E′ becoming an umbrella organisation which provides logistical support for a large range of observing facilities has been referred to in Section on the Development Model. Part of this logistical support will be the management of the operation and computing provision for this portfolio of instruments to ensure that their data formats, measurement philosophies and data access protocols are consistent with their easy inclusion into such data synthesis tools.

It is envisaged that, rather than being a passive contributor of data to such a synthesis program, E′ will be a key facility in the implementation and development of such technology. E′ will be a world-leading facility in both instrumentation and computing terms, and as such it will be the best-placed facility (certainly within Europe) to host the synthesis software and collate the storage of a wide range of multi-diagnostic data. Note that it would not be the only such centre; the whole philosophy of such data synthesis lends itself to the idea that the data processing should be distributed around the World. However, E′ will be one of the leading centres for the development of the data synthesis technique, providing high powered computers to host and combine data, run models and generate predictions which can in turn be fed back into a co-ordinated international programme of observations. It will also provide a focus for both the observing and modelling communities to work together as the underlying techniques are refined.

The operational programme of E′ will be heavily geared to the data synthesis philosophy. With one radar in continuous operation on both the mainland and Svalbard, E′ will be providing continuous incoherent scatter data in a routine observing mode, as well as data from the other diagnostics for which it provides logistical support. These data will form part of the input to the data synthesis.

The radars will be used in one of a number of "Unusual Programmes" to provide key data in areas where observations are presently lacking. Examples might include survey modes to catch the precise time and place of a substorm onset, or low-altitude observations to catch the leading edge of a Polar Cap Absorption event as high-energy protons arrive at the Earth.

In this way, E′ will be very much more than a single instrument. Rather than distributing only its own data, E′ will play an active role in bringing together data sets, integrating them into models and reacting to both observed and predicted events. Using state-of-the-art computing and networking technology, `E′` will act as a key nerve centre, orchestrating the response of ground-based instruments throughout the Scandinavian sector, and maybe further afield, to important and infrequent observational opportunities.

This vision is very ambitious, but it is achievable with near-present technology. A further advantage of such a system is that it is highly scaleable. In other words, an initial data synthesis system could encompass only those facilities and models under the `E′` umbrella. As long as the data formats and computing protocols conformed to some agreed standard, however, the system could be easily linked to those of other data providers and modellers elsewhere in the world. The ultimate goal would be an integrated system encompassing all the major observational and modelling systems capable of providing real-time STP data. With such a system in place, our capability of responding to changes in the coupled STP system and probing them in the way needed to answer outstanding scientific questions would be truly unparalleled.

E′ Educational Opportunities

EISCAT represents a tremendous, largely unexploited, educational opportunity. The Association has expertise in depth not only in ionospheres, magnetospheric, and solar terrestrial physics but also in radar technology, signal processing and data handling.

EISCAT staff scientists and senior engineeres could be linked directly with University groups and other higher educational facilities to allow effective in-house PhD programmes while school and public outreach, work experience, and apprenticeships programmes can be exploited to spread EISCAT expertise into a much wider community.

International Schools arranged over several week periods can also be very effective in this context.

Financing E′

E′ Investment opportunities

Many of the hardware upgrades proposed can be costed relatively accurately, because they follow on from recent related projects or proposals. The phased array radar proposed for Tromsø (and/or Svalbard), for instance, could use AMISR (Advanced Modular Incoherent Scatter Radar) technology. The AMISR project was initiated as an attempt to develop incoherent scatter radars at relatively low cost, capable of continuous operation. Because these systems are based on modular phased array panels, they are almost infinitely extensible, and the design allows for a graceful degradation of the system in the event of a module failure. Although the technology has not yet been used in an ISR system, AMISR radars are already in practical use. A small AMISR system is being used for wind profiling at the HAARP facility in Alaska. Major construction of AMISR modules is currently underway for the creation of a major new incoherent scatter radar, ultimately to be deployed at the US Polar Cap Observatory in Resolute Bay, Canada. This system will be a natural partner to EISCAT's high-latitude radars.

Nevertheless, the creation of powerful incoherent scatter radar based on phased array technology remains a challenging and costly undertaking. Based on the Polar Cap Observatory project, we estimate the cost of developing and deploying an AMISR phased array system for Tromsø at around 26M EUR. However, as the expertise and capabilities to design and mass-produce phased-array systems exists within the telecom industry establishment in several EISCAT countries, it is likely that a call for proposals would produce even more competitive offers. VHF Receiving systems for the mainland remote sites, using the same size of array, but without the transmitters, would cost of order 20M EUR each, making the cost of a VHF tri-static array system of the order of 60M EUR. The gain would, however, be substantial, in terms of multi-beam imaging capability, continuous and unattended operation, multiple common volumes, and the possibility to probe very small-scale structures using interferometry. Production of the AMISR modules for EISCAT could probably begin in 2006, after the construction of the panels for the US system. An early commitment to such a system would help ensure the continuity of the production process.

Upgrades to the signal processing, data handling and data distribution systems currently in place at EISCAT will be needed in order to realise the proposed umbrella function of `E′`. In addition, it is proposed (in conjunction with our Norwegian collaborators) to extend the building housing the EISCAT Svalbard Radar, to accommodate many of the optical and other observing systems currently housed in the Adventdalen hut, and to offer improved logistical support for neighbouring facilities such as SPEAR. Taken together, these upgrades would cost of order 10M EUR.

E′ Cost Options

Besides expected evolutionary developments in pulse coding, radar hardware, data analysis, radar control software, operational modes, extended operations, quality control, data distribution, and specifically tailored data products to suit different user communities, there are a number of major investment projects which would substantially extend the Association's capabilities to address these topics. The potential investments, together with capital cost estimates, time scales and the scientific problems they address, are given in the table below.

Investment	Estimated capital cost	Time scale	Applicability
Upgraded VHF feed (+field aligned)	~20M€		Low altitude studies, plasma physics, Heater, high altitudes
Passive (VHF/UHF) arrays at Sodankylä and Kiruna	~10M€ each		3D parameter profiles
Replace VHF transmitter		10 years	Continuous operation, Space Weather and forecasting
Additional ESR antenna(s) and transmitter			Detail convection studies, Solar Terrestrial coupling, auroral mechanisms
Dual band (928MHz/1.4GHz) feeds on existing 32 m antennas			IPS: solar wind acceleration
Low power interferometric system			Plasma physics, small scale acceleration process in the ionosphere
Building extensions to support visiting experimental equipment	~1M€ (ESR)		Synergy withy other instrumentation, value added data assimilation services
Active phased array radar (Mainland/Svalbard) with interferometric capabilities	~ 30M€		Continuous operations, Space weather and forecasting, event studies requiring high temporal and spatial resolution
Large MST radar on Svalbard			Mesosphere, coupling and energy flow between atmospheric regions, energy balance

Some options easily lend themselves to a capital investment programme spread over a number of years, while for some others the need to develop new hardware would require a large proportion of the new investment would have to be made at the start of the project. Capital costs would decrease thereafter, as elements of the new hardware reached completion, with the total investment being spread over up to ten years.

E′ Recurrent Costs

The actual future running costs depend on the details of the new Agreement, and on whether some part of the investment costs would be included in the annual budgets with the total investment being spread over a substantial period.

The expiry of the current EISCAT operating agreement and the proposed development of the E′ facility, allows the possibility to revise the funding model which has been used for many years. Although substantial levels of detail would have to be clarified, two models are basically possible. One funding model would be similar to the present arrangement, but allowing for the possibility for new partners to join the Association. In this scenario, the entire operating budget (35-40 MSEK per year) would be distributed in a small number of equal shares, with member countries taking a share each (larger members might take more than one share).

A second possibility would be to divide the operating budget in two (perhaps one part of 25 MSEK and one of 15 MSEK). The largest share would be financed directly by the member countries as above, but the remainder could be financed from the sale of observing time to non-members on a "pay-per-view" basis. Preliminary discussions with potential collaborators have indicated that there is some interest in the latter type of model.

In either model, the recurrent costs necessarily contain a component which relates directly to the number of hours of operation. While present estimates are based on a modest expansion of the observing program, continuous operation would require appropriate increases in the overall funding support.

The expiry of the current agreement would also offer a chance to revise the staffing arrangements for E′, perhaps allowing the organisation greater freedom to sub-contract staff and more autonomy from the existing national host institutions. A possible scenario, making use of substantial cost reductions which might be achieved through radical changes to the staffing model, is given in Appendix 7.

E′ Prospective Partners

EISCAT's existing Associates have already enjoyed a long and productive membership of the organisation. In all of these countries, active communities of academics, researchers and students continue to exploit the EISCAT radars and to push the further development of the radar systems. Existing Associates should both play an active role in the development of the new agreement and renew their membership of the Association when it is introduced.

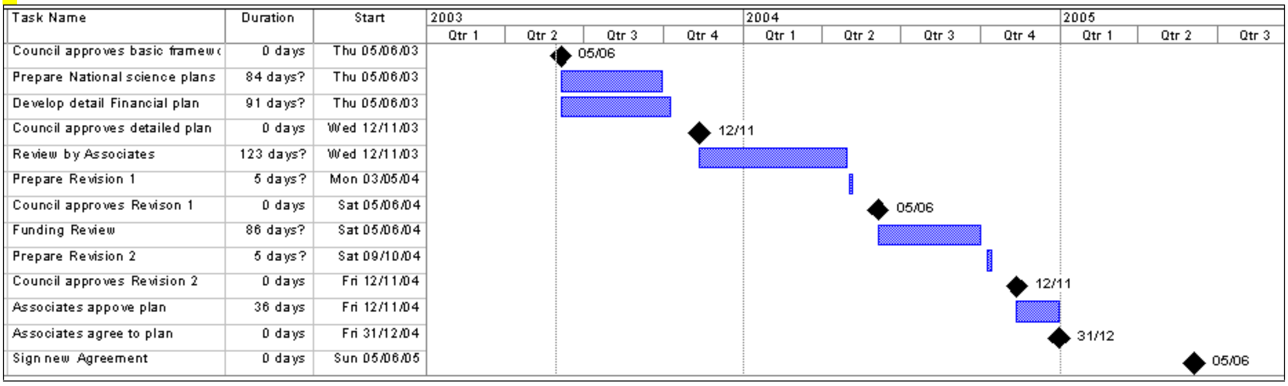
In order to bring the E′ proposal to fruition, however, the Association can invite new members to join the organisation, whether as formal members or "pay-per-view" partners. No "threshold level" of finance is needed in order to join the organisation, though the amount of access to the facilities will continue to depend on the level of contribution. In addition, arrangements for supplementing financial contributions with "in-kind" donations of hardware, software, or staff effort can be explored.

Strong interest in joining the Association has been expressed by scientists in China, Russia and Eire, and progress towards a new Agreement is being closely monitored in the USA.

E′ proposal represents a unique chance for researchers to join the world's leading upper atmosphere research project of the 21st century. Contact details of individuals who can be approached with enquiries related to membership of the organisation can be found in section 4.

E′ Critical timelines

It is very important that the new agreement is in place well before the old agreement expires (on Dec 31, 2006), preferably by mid-2005 if possible, and certainly Jan 1, 2006 should be the absolute deadline for getting the new agreement approved, with partners making firm commitments; even if it doesn't actually start until Jan 1 2007. To do otherwise would require the development of a complete closure plan in case the new agreement cannot be signed; this should be avoided at all cost. With such a timescale in mind, it is possible to draw up a plan to allow the new Agreement to be signed at the Spring 2005 Council Meeting and to develop a timeline for the critical milestones leading up to that as required by the administrative structures of the various Associate, and potential Associate, funding bodies.



Task Name	Duration	Start
Council approves basic framew	0 days	Thu 05/06/03
Prepare National science plans	84 days?	Thu 05/06/03
Develop detail Financial plan	91 days?	Thu 05/06/03
Council approves detailed plan	0 days	Wed 12/11/03
Review by Associates	123 days?	Wed 12/11/03
Prepare Revision 1	5 days?	Mon 03/05/04
Council approves Revison 1	0 days	Sat 05/06/04
Funding Review	86 days?	Sat 05/06/04
Prepare Revision 2	5 days?	Sat 09/10/04
Council approves Revision 2	0 days	Fri 12/11/04
Associates appove plan	36 days	Fri 12/11/04
Associates agree to plan	0 days	Fri 31/12/04
Sign new Agreement	0 days	Sun 05/06/05

Summary

After 40 years of steady progress, the Incoherent Scatter Radar technique is benefiting from major advances in hardware, software, pulse coding techniques, data analysis and data distribution systems. Based on these improvements, data of previously undreamt of quality and resolution will become available on a near continuous basis from several radar systems.

The quality, availability and applicability of these data will drive progress in many areas of geophysics, including many which have previously been unable to exploit data of this type.

However, to ensure the continued availability of World class experimental facilities to support the work of scientists in the member countries of the Association, a continuing program of development, including some major new facilities, is required.

References

Opgenoorth et al., 1990

Williams et al., 1990

Løvhaug, Hagfors and van Eyken, 2001

Opengenoorth et al Cluster paper, 2002

Appendix 1

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Appendix 2

Acronyms, abbreviations, etc.

AMPTE	
AMISR	Advanced Modular Incoherent Scatter Radar
AU	Astronomical Unit The distance between the Sun and the Earth is 1 AU
CAWSES	Climate and Weather of the Sun-Earth System
CDDP	
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CLUSTER	
CME	Coronal Mass Ejection
CTIP	
DMSP	
E′	E (for EISCAT) prime – the (first) EISCAT derivative PRIME = Priority Research In Man's Environment
EISCAT	European Incoherent Scatter
FAST	
HAARP	High frequency Active Auroral Research Program
IS	Incoherent Scatter
ISR	Incoherent Scatter Radar
IWLS	International Living With a Star
L1	Lagrange 1 point (approximately 0.01AU upstream of the Earth towards the Sun)
LIDAR	
LTCS	Lower Thermosphere Coupling Study
LWS	Living with a STAR (NASA)
M-I	
MHD	Magneto-hydrodynamic
MMS	
NCAR	National Center for Atmospheric Research
Ne	Electron density
NASA	
PCA	Polar Cap Absorption
PMSE	Polar Mesospheric Summer Echo
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SOHO	Solar and Heliospheric Observatory (at the L1 point)
SOUSY	Sounding System
SPARC	Space Physics and Aeronomy Research Collaboratory
SPEAR	Space Plasma Exploration by Active Radar
STP	Solar Terrestrial Physics
SuperDARN	Super Dual Auroral Radar Network
Te	Electron temperature
Ti	Ion temperature
UHF	Ultra High Frequency (300-3000 MHz), EISCAT 931MHz radar
URSI	Union Radio-Scientifique Internationale (International Union of Radio Science)
VHF	Very High Frequency (30-300 MHz), EISCAT 224MHz radar
Vi	Ion velocity
WAGS	Worldwide Atmospheric Gravity-wave Study

Appendix 3

A review of the past scientific achievements of EISCAT

The original feasibility study for the EISCAT radar facility, written in the early 1970s, set out eleven science goals for the project. This appendix reviews the successes of the EISCAT facility as measured against those original aims. Note that in addition to these, EISCAT has facilitated many initially unexpected advances in the study of plasma physics, meteors, space debris, and solar wind acceleration.

1. Detection of the Polar Wind and Ion Outflow.

The detection of upward plasma-flows in the auroral zone, the polar cap and the magnetospheric cusp/cleft has been one of the most readily achievable observations delivered by the EISCAT facility, basically from day one. Such outflows are now commonly observed in all the regions mentioned above and they occur under a variety of different magnetospheric conditions. One of the main findings emerging from studies using the EISCAT facility was that the variability and efficiency of topside ionospheric processes, leading to upward ion acceleration, is much more dramatic and effective than originally expected. The major anticipated outflow mechanism, the so-called polar wind, was thought to be due to upward plasma acceleration (up-welling) over the polar cap, controlled by convection. Subsequent EISCAT results proved this to be the least important (and probably least effective) source of ionospheric plasma to the magnetosphere. Instead, EISCAT data have shown that two much more dynamic and variable zones of upward ion acceleration exist, in the dayside magnetospheric cusp/cleft zone and within the entire night side auroral oval. Depending on the character of Solar wind driven magnetospheric activity, strong ionospheric flow channels and regions of particle precipitation lead to structured upward ion acceleration. The observed intensity is so high, that the term "ion fountain" has been used in the literature to describe the observed phenomenon. It was also found that these processes of ion outflow are both effective and dynamically fast enough to populate the magnetosphere with heavy ions of terrestrial origin, thereby altering magnetospheric processes during the lifetime of a substorm growth phase. Along with ionospheric field suppression, current diversion, and plasma wave reflection, EISCAT added ion outflows to the main list of active ionospheric responses to magnetospheric forcing.

While the thermal up-welling of Joule-heated plasma in active flow channels can be well explained on the basis of EISCAT data, the highly structured and more effective upward ion acceleration in regions of moderately energetic electron precipitation, both in the cusp/cleft and auroral oval remains poorly understood. Such precipitation-excited upward ion acceleration is often observed in conjunction with extreme heating of the topside electron gas, and non-linear plasma phenomena like so-called anomalous echoes (see below). The study of such transient ion acceleration is an ever-growing field in modern incoherent scatter research. Its future understanding will have an important impact on our understanding of global and meso-scale ionosphere-magnetosphere coupling and the micro-scale plasma physics involved.

Other more general questions concerning ion outflow, which still remain open, include how to monitor the net balance of what amount of flux is really escaping from the upper atmosphere, as EISCAT cannot follow the particles to altitudes where they reach escape velocity. It would also be important to identify the relative efficiency of several (at least three) ion injection mechanisms into the Magnetosphere: the Cleft Ion Fountain, the thermal Polar Wind, and sporadic auroral accelerations in the night side sector, the Auroral Fountain.

2. Measurement of thermospheric winds.

Measurements of thermospheric winds and the consequent coupling between the neutral and ionised components of the ionosphere have successfully been carried out, and are considered a standard data product of the EISCAT facility in certain common program modes. Often they are combined with data from other supporting instrumentation such as imagers and interferometers. One remaining outstanding thermospheric problem, which has proven to be more difficult to address than expected, is the exact determination of the O+- O collision frequencies. Even though its value has been considerably improved using EISCAT measurements, it is still not satisfactorily well determined. It is very important, however, as the exact knowledge of how much the up-welling of hot oxygen ions would affect the neutral atmosphere will be of utmost interest for amongst others space weather applications, as this has increases atmospheric drag on low orbiting satellites.

Standard observations of thermospheric winds have also allowed the study of long-term variations in the wind patterns. Such long-term EISCAT observations have made it very clear that the wind patterns display a large variability, and the continuation of such measurement series is highly desirable for climate change research.

3. Determination of ionospheric electric fields

The measurement of ionospheric electric fields on large and medium scales has been one of the major successes of the EISCAT facility. The unique tristatic UHF facility has revolutionised our understanding of electric fields within active auroral forms and other ionospheric structures in the meso-scale realm, which are predominantly caused by magnetospheric activity. By using the UHF and VHF antennas together, or by beam-swinging methods with one antenna, the electric fields associated with large-scale magnetospheric convection have been derived, and their dynamics, in particular transient features in the vicinity of the cusp, have been successfully addressed. EISCAT has proven to be the world leading facility in this field in comparison to other incoherent scatter radars. Bi-static coherent scatter radar systems have the advantage of delivering two-dimensional data but at a relatively coarse spatial resolution (25-50 km depending on the used frequency range). EISCAT is, however, considered far superior to these as regards the measurement of active convection and electric fields in the vicinity of aurora, where higher resolution is needed. Furthermore coherent scatter radars often lose their scattering echoes under very active auroral conditions such as substorms. Consequently EISCAT is an invaluable complement to the more global convection radar networks like Super-DARN.

Another recently identified problem, which will need to be addressed in detail in the future, is the so-called self-limiting effect on Joule heating by ionospheric electric field suppression, which limits the magnetospheric energy input into the ionosphere, and actively changes magnetosphere-ionosphere coupling.

Even though EISCAT has facilitated particular progress in the understanding of electric field structures and detailed ionosphere-magnetosphere coupling within thin auroral arcs, the study of such small scale and very intense electric fields has now reached the limit of EISCAT's beam resolution. However, all available EISCAT results, and in particular recent satellite results from FAST, point to the suggestion that the most intense M-I coupling occurs in filamentary structures characterised by extremely strong field-aligned currents (mA/m2) and extremely narrow and strong electric fields (several 100 mV/m) in the ionosphere. It will be one of the main tasks for future EISCAT facility to address such features with an improved technical approach, using phased array antennas and interferometric methods to overcome the intrinsic limitation in resolution imposed by the beam width of a single antenna.

4. Measurements of ionospheric currents

As with the determination of ionospheric electric fields, the determination of ionospheric currents in large scale electrojets, meso-scale auroral forms and narrow filamentary currents in the cusp and active night side aurora has been one of the major contributions of EISCAT to the modern understanding of MI coupling. EISCAT on its own, and even more efficiently in coordination with magnetospheric satellite missions such as Viking, Freja, FAST and CLUSTER, has addressed the three-dimensional current flow in all known auroral features. As already described in the context of electric field measurements, the conclusion has been that auroral currents and their magnetospheric feed-currents along the magnetic field are more structured than originally anticipated when EISCAT was planned on the basis of our knowledge from magnetometer network studies of auroral currents. The largest and most effective currents appear to flow in the filamentary structure of the aurora, and so the antenna beam width is again a natural limitation to further progress using the present EISCAT facility.

5. Simultaneous measurements of neutral winds and electric fields

This goal has been successfully addressed considering the intrinsic limitations of the present EISCAT facilities. However, it must be remembered that the need for a cyclic antenna scan in order to derive an altitude profile of ion-drift vectors limits the temporal and spatial resolution of simultaneous measurements of the neutral winds and electric field. In particular since the most effective interactions between the neutral atmosphere and the ionised plasma occurs in intense flow channels and regions of high conductivity, an improved antenna configuration, utilising phased array antennas with multiple beams, will be necessary for further progress in this field. Only truly simultaneous and continuous E-field measurements, both at collision-free altitude and collision-dominated altitudes will provide measurements good enough to drive this particular field onwards from where the present EISCAT facility has brought it.

Studies using EISCAT data have also shown that the ionospheric conductivities inside auroral structures can be up to ten times higher than assumed in earlier models. At the same time, the electric fields are observed to be extremely small, as a result of the self-limiting effect of the ionospheric Joule heating, giving rise to reasonably strong currents within the aurora. This extreme anti-correlation of the electric field and conductivity in the most pronounced current channels results in the effect that even small neutral winds can drive very intense ionospheric currents, which are largely decoupled from the original magnetospheric current systems.

6. Determination of the energy balance of the thermosphere

As already described, a remaining problem in the thermospheric realm is the exact determination of the Oxygen ion-neutral collision frequencies. The temperature and dynamical responses of the theormosphere to convection transport and local ionospheric heating by electric fields and currents are now very well understood. Ion and electron temperature structures are routinely used as proxies for other phenomena (plasma flow channels, and low energy precipitation, for example), and have thereby considerably added to the usefulness of low elevation experiments, allowing EISCAT scientists to resolve spatially and temporally dynamic structures in M-I coupling. Many very interesting physics problems remain to be investigated through experiments utilising active ionospheric heating, like the production of stimulated electromagnetic emissions in heated ionospheric plasmas and the excitation of airglow by supra-thermal ion populations. Also not all aspects of ionospheric heating by auroral particle precipitation and/or directly associated wave-particle interaction are satisfactorily understood, particularly in the topside ionosphere. In particular, extreme situations of particle flow and/or wave activity can lead to so-called "anomalous echoes" which have not yet been fully understood, but are associated with anomalous ionospheric heating. Again it appears that most of the fundamental processes occur on sub-kilometre scales and are therefore not accessible to the present EISCAT system.

7. Measurement of plasma lines

This measurement has proven to be much more elusive than initially anticipated. In spite of many serious attempts from several outstanding research groups, no clear and regularly useful results have been achieved, except for studies using artificial plasma line stimulation by the heater. It is widely appreciated that successful routine measurements of the natural plasma lines would provide a valuable additional plasma parameter in the EISCAT measurements, thereby reducing some ambiguity in (for example) the determination of the ion composition from normal ion line spectra. This in turn would have an immediate impact on other principal goals of the facility, such as the more exact determination of the ion-neutral collision frequency for various species.

Unfortunately the occupation of frequency space by other non-radar applications will make such plasma line observation more and more difficult in the future. Even now, the reserved spectral bandwidth for the EISCAT facility hardly allows for observations of both the up- and down-shifted plasma-lines at the same time. So it appears that the observation of plasma lines, and the physical exploitation of such observations, constitutes the one scientific topic in which EISCAT has quite surprisingly not performed above the initial expectation.

8. High time resolution measurements of D- and E-region auroral electron density profiles

The observation of temperatures and plasma densities in the D- and E-regions has become the trademark of the EISCAT facilities. During the last 10 to 15 years, not a single geophysical meeting was held, which did not include at least one presentation of the by know well known colour-coded Ne, Te, Ti, and field aligned vi panels. Such standard EISCAT data are often used to illustrate various transient phenomena associated with particle precipitation and electric field heating. The format is well understood, without provoking questions from the audience. These data have given the ultimate answer to the understanding of particle precipitation in many regions and under many energy states of the magnetosphere. Throughout the years, mainly though the ever more ingenious contributions of the previous director Tauno Turunen and his Finnish colleagues, EISCAT's pulse-coding routines and analysis packages have made spatial and temporal resolutions possible, which at the design state of EISCAT were believed to be impossible. Nowadays all IS radars around the world use the pulse-coding and corresponding analysis routines developed by EISCAT. Improved techniques are still emerging and a new code, utilising the latest state of the art, gives high-resolution measurements in the E-region with temporal and spatial resolutions of about 2 s and 1 km respectively. The success of EISCAT in this field has been at least one order of magnitude beyond our best expectations. In terms of covered altitude range EISCAT has achieved an unexpected range extent, both in the bottom and topside ionosphere, from 60 to 1500 km.

9. D-region measurements of stratospheric warmings

The original goal of measuring stratospheric warmings has not been achieved by EISCAT. It turned out that, for such observations to succeed, uncommonly long runs (many days to weeks) would have been needed. In addition, sufficient D-region electron would have been needed to obtain the necessary signal-to-noise ratio, which was found only to be the case during disturbed periods. Although attempts were made to secure corresponding stratospheric and tropospheric measurements, the EISCAT radars were not designed for studies of these lower altitudes, and it has not been possible to make such observations routinely with the existing hardware.

Measurements of the D-region with EISCAT were, however, very successfully performed in several other instances, shedding major new light into mesospheric aeronomy and dynamics. Mesosphere and D-region measurements have been carried out during many international campaigns, together with measurements with rockets and other instrumentation. Examples of studies where EISCAT played a major role included the Cold Arctic Mesopause Project and the Middle Atmosphere Program "Winter and Summer in Northern Europe", as well as many special turbulence and wave campaigns in connection with the rocket ranges in Kiruna and Andoya.

EISCAT data facilitated the measurement of many mesospheric parameters with unprecedented temporal and spatial resolution. Examples have included D-region electron density profiles, the negative ion to electron ratio, the occurrence of heavy ion clusters, mesospheric temperature estimates, upper mesosphere ion layers, and gravity wave, tides and wind observations in the mesosphere and lower thermosphere. Particular emphasis has been placed on the observations of Polar Cap Absorption events (PCA) and Polar Mesosphere Summer Echoes (PMSE). The former shed absolutely new light into the aeronomy of the mesosphere during energetic particle precipitation, and the latter were a completely new event, seen on 224 and 933 MHz with the EISCAT VHF and the UHF radar, respectively.

The introduction of advanced coding schemes and interferometer modes to the EISCAT VHF radar allowed observations of the fine structure of PMSE layers and their modulation by turbulence and gravity waves. The EISCAT observations of PMSE proved that these layers are not caused by neutral atmosphere turbulence, but supported the theory of reduced electron diffusion in the presence of heavy ions, charged dust or ice particles in the cold summer mesopause. It was also shown, by using the EISCAT Heating Facility, that enhancement of electron temperature in the D-region reduces the scatter cross section of PMSE, through changes to the electron diffusion.

The EISCAT Svalbard Radar has been used to investigate the polar cap mesosphere, measuring electron density profiles, velocities and scatter cross section of PMSE. The value of the latter measurements has been increased by the unique combination of the data with those obtained by the co-located SOUSY Svalbard Radar, operating in the VHF band on 53.5 MHz. All such observations were only done as case studies over limited time periods. The required information on the long-term climatology of the various dynamical and aeronomic processes has not and cannot be obtained with the EISCAT radars in their present configuration. A most relevant topic in this context is the possible relevance of middle atmosphere observations to global climate change, the study of which requires long-term observations.

10. Seasonal and storm-time measurements of F-region composition

The goal of fitting ion composition from EISCAT data was a major initial objective, and a substantial amount of work, including the development of appropriate data analysis algorithms, was directed to this end. It eventually proved that reliable ion composition estimates could be obtained from EISCAT data, but only under conditions of high Signal to Noise Ratio. This required the use of long integration times that, in turn, were only meaningful under relatively stable conditions. In spite of this limitation, EISCAT has achieved much in the measurement of composition. The normal composition of the high-latitude F region has been explored, and the dramatic increase in molecular ion species during intervals of Joule heating has been well shown. Important studies have also been made of the effect of composition on three-dimensional ion temperature distributions, through changes in the ion-neutral collision frequency.

Effort has also been directed to resolving the transition between oxygen and light ion species (hydrogen and helium) which occurs at topside altitudes. The difficulty in such measurements is that the properties of the different ion species become increasingly independent of each other, increasing the number of free parameters and therefore the complexity of the data analysis. Combined use of observation and modelling has enabled properties such as the density, temperature and velocity of the light ion species to be inferred under conditions where the data quality is sufficiently high.

A great deal still remains to be done in understanding the nature of F region composition changes in highly dynamic situations (e.g. in response to storms, or in a highly-structured ionosphere). In particular, the study of light-ion dynamics in response to time-varying forcing mechanisms has much to tell us about outflow processes (see topic 1). Three-dimensional studies of high-altitude collisions could also provide new information about the changing role of collision processes such as Coulomb interactions at these altitudes.

For such measurements to be possible, improvements will be needed in the integration time needed to achieve a given Signal to Noise Ratio from a plasma of given density and range. This requires improvements in both receiver gain and transmitted power, such as might be achieved by the use of an expandable phased array system.

11. Measurements of Atmospheric Gravity Waves (AGWs) and Traveling Ionospheric Disturbances (TIDs)

EISCAT has proved to be a very useful instrument for the measurement of atmospheric gravity waves through the observation of TIDs, which are their ionospheric proxies. EISCAT has played a unique role in a number of international studies of such waves, including the influential WAGS (Worldwide Atmospheric Gravity-wave Studies) intervals of the mid-1980s. In addition to observing the waves themselves, EISCAT has also made important observations of their high-latitude source regions, showing convincingly that large-scale waves observed to propagate over many degrees of latitude could be traced back to sources in the auroral zone. Detailed observation of the auroral electrojet has also shed light on the nature of the source mechanisms of such waves, showing that both Joule heating and Lorentz forcing are probably involved in the production of the observed disturbances.

Appendix 4

The following table seeks to outline some of the scientific areas where the new observational and data handling capabilities brought in through the E′ initiative can make a substantial contribution. The reason for the importance of each topic is explained, together with a brief summary of the remaining questions and the key measurements, which would allow further progress to be made.

Topic	**Importance**	**Remaining Issues**	**Key Observations**
Ion outflow	The ionosphere ejects ionised material into the magnetosphere, much of which, directly or indirectly, precipitates back down to Earth, but some of which escapes into the solar wind. Such plasma processes are important factors in the evolution of the atmospheres of several planetary bodies	The outflow process is still not well-understood. We do not know how outflowing particles reach the energies observed in the magnetosphere. Quantification of the upward flux is needed to establish whether this might be a major loss process for some species over very long time scales.	A full description of all the mechanisms responsible for plasma outflow is needed, with a statistical study of when and where each occurs. The total outflow rate and its variability need to be measured, and compared to the flux of particles that precipitate back to Earth.
Auroral acceleration	The aurora is the most dramatic phenomenon in space physics, but we still do not understand the processes responsible for producing either the particle energies or the spatial structures that we observe. Many theories have been invoked, but all fail to explain the dynamics and scale sizes of auroral arcs. The role of proton precipitation has not been well understood in the past, but it is becoming clear that a significant fraction of the energy transported via aurora is carried by protons. A full understanding of the chemical and ionisation effects of both protons and electrons is required for correct interpretation of auroral signatures in the ionosphere.	The parallel electric field responsible for the acceleration has been discussed in terms of the phase fronts of standing Alfven waves, solitons, lower hybrid waves or using quasi-static concepts of anomalous resistivity. Reliable observations of auroral behaviour down to the smallest scale sizes are needed to assess how well the various theoretical predictions compare to observed phenomena. The mechanism also needs to explain "black aurora" as the symmetry of these regions of downward field aligned current with the conventional aurora in regions of upward field-aligned current is striking. Upward ion acceleration in the same region also needs to be explained (see above).	Measurements are needed to characterise auroral phenomena on scale sizes much less than the present EISCAT beam width. Measurements of "black aurora" are needed to understand how the phenomena are linked. Both ions and electrons need to be measured, to understand the role of proton precipitation and to investigate the acceleration mechanisms for both species. Supporting satellite and optical measurements are an important requirement.
Small scale plasma physics	The large-scale fluid description of MHD has been very successful in explaining the gross features of the magnetosphere-ionosphere	EISCAT offers a unique opportunity to study a range of non-linear plasma processes, both natural and man-made. A number of	A more systematic approach is needed to characterise the possible non-linear plasma phenomena observed by

	system and the heliosphere with which it interacts. However, it is clear that idealised MHD descriptions do not apply to many small-scale plasma phenomena. An understanding of these highly localised breakdowns is the key to understanding many phenomena in space physics (for example in the reconnection diffusion region and in the auroral acceleration region).	phenomena observed by EISCAT (e.g. field-aligned coherent echoes) are not well understood. The field-aligned coherent echoes observed by the EISCAT systems offer a great opportunity to study these non-thermal plasma-physical processes. However, we have only glimpsed these events and many questions need to be definitively answered before theories of their occurrence and significance can be developed:	EISCAT and investigate their behaviour, particularly on shorter temporal and spatial scales than are possible currently, and determining their geophysical context. Many of the processes to be studied are relatively uncommon, so a proper study will depend crucially in fully exploiting such observations when they occur.
Induced changes in the ionosphere	The EISCAT heater is unique in having two outstanding incoherent scatter radars as diagnostics. Fundamental plasma processes such as wave coupling, plasma instabilities and cavitation can be studied by heating, which also allows the study of atmospheric chemistry and dynamics, through processes such as emission and recombination. The heater also creates artificial irregularities over a wide spatial area, which can be used as targets by HF radars. This technique is a very powerful tool for investigating ionospheric coupling and dynamics.	Some of the most interesting future science is likely to come from studies of the small-scale structure of modified plasmas. For instance, observations of stimulated emission suggest the presence of very high temperatures on small spatial scales, which is hard to explain theoretically. The use of the heater to stimulate waves, whose coupling and transport can then be measured, could be a powerful tool for exploring the near-Earth magnetosphere, including field-line mapping, probing the spectrum of naturally occurring waves, and the auroral acceleration region. The possibility of using the EISCAT heater as magnetospheric radar has been discussed at various points during the lifetime of EISCAT. Feasibility studies will be undertaken to determine whether the heater array can be used for the reception of HF backscatter from the magnetosphere and what such echoes might tell us.	Recent developments in high gain "superheating" need to be combined with new interferometric capabilities in order to investigate modified plasma on shorter spatial scales than have been accessible to date. Wave generation experiments should be conducted over a range of frequencies under varying conditions, to establish (for instance) whether resonances can be stimulated. Satellite-borne wave detectors would also be needed to prove that stimulated waves can be field-guided to high altitudes.
Magnetic reconnection	It is clear that reconnection is the fundamental process responsible for transfer of	Spacecraft in the magnetosphere can now identify reconnection sites,	Combined studies with spacecraft are of great importance here. EISCAT

	mass energy and momentum from the solar wind into Earth's magnetosphere-ionosphere-thermosphere system. It is also a key process in solar physics and almost certainly vital to understanding star formation and astronomical objects such as pulsars.	not only from the inflow and outflow regions described by ideal MHD, but also by the Hall currents in the outer diffusion region of the X-line where electrons are un-magnetised, but not the ions. However, most of the key questions about reconnection remain unanswered. Among the most important questions are the following. What determines the reconnection rate? To what extent are reconnection voltage changes associated with reconnection rate changes and how much is due to changes in X-line length? What determines where reconnection takes place? Is reconnection "component" or "anti-parallel" in nature? What causes the reconnection rate to be pulsed during steady interplanetary conditions?	can measure phenomena related to reconnection, such as poleward-moving transients, as they pass over the radar and move through the field-of-view. The particle populations in these events reveal much about the time-history of the reconnection, while spacecraft data can shed light on the location and extent of the reconnection region. Missions such as Cluster, Double Star and MMS will offer unique opportunities to make the necessary measurements.
Substorms	The substorm is the dominant response of the magnetosphere-ionosphere system to energy input from the solar wind. The precise sequence of events varies from one substorm to another, but most of the features that make up a substorm are now identified. However, there are several key questions for which we do not have answers and without these we cannot make predictions about the timing and strength of the energy and particle deposition which the substorm causes in the ionosphere and inner magnetosphere.	What triggers a substorm onset? Where will a substorm commence? What determines its strength, in terms of the energy deposition it causes? How is substorm behaviour influenced by the prior state of the magnetosphere-ionosphere system?	Once again, combined ground and space-based observations, coupled with models, will be important in understanding the sequence of events. The ability to respond rapidly to (or even predict) the appearance of a substorm and to secure appropriate observations will be of crucial importance.
Ionosphere-neutral atmosphere	A good understanding of this coupling is extremely important, as of order half the solar wind energy	The response of the neutrals to momentum transfer, as a function of altitude, is critical, yet we still have great	An important extension to the current observing capability would be the possibility of making

coupling	extracted by the magnetosphere is deposited as Joule heating. The neutral atmosphere responds to this energy deposition on a global scale, through thermal expansion and the generation or modification of winds, waves and tides. The ability to predict the response of the high-latitude atmosphere to such energy inputs is crucial to understanding how solar-terrestrial processes can couple to lower altitudes. Thermospheric heating is also the key variable in predicting satellite drag and orbital decay.	uncertainties in the crucial O^+-O collision frequency. The effect of rapid variations due to the non-linearity of the thermosphere-ionosphere coupling on energy deposition rates remains to be quantified. This is an important topic, given that many of the ionospheric parameters involved can change on very short timescales. It is becoming clear that there is an unexpected level of small-scale structure in the thermospheric winds. We need to understand how this structure arises, and its effects on energy deposition and dissipation. There is not yet a complete understanding of how non-thermal ion velocity distribution functions influence ionospheric behaviour and the coupling to the thermosphere. Such situations characterise the most energetic coupling events, and are hence likely to be important in understanding energy transfer.	simultaneous tri-static observations at a range of altitudes, for instance using a phased array. This would allow the possibility to derive winds in both the E and F-regions and investigate the full height profile of the neutral atmosphere response. Such observations should be combined with continuous monitoring of waves and tides from the mesopause to the F-region, allowing a simultaneous investigation of their evolution and development.
Mesospheric Physics	The mesosphere is one of the least-studied atmospheric regions, but it is becoming clear that this region is of great importance to energy coupling between the upper and lower atmosphere. Waves and tides, propagating upward from the lower atmosphere, are modified by the neutral dynamics of the thermosphere. The interactions are likely to be complex and non-linear - both observation and modelling will be needed to understand the observed effects. Because the mesosphere is the coldest part of the	There is a need to understand the dynamics of the neutral atmosphere on both sides of the mesopause, and how it is affected by forcing processes from both above (e.g. solar-terrestrial effects) and below. The way in which such interactions are mediated by the mesopause, and what processes affect this, will be a key to a proper understanding of energy coupling in the atmosphere. Sufficient observational data are needed to confirm or deny theories about the origin of PMSE. Other types of low-altitude energy deposition mechanisms,	Because incoherent scatter radars cannot cover the whole height range of interest, multi-diagnostic measurements will be of great importance. Such techniques will include lidars, rockets, spectrometers and lower frequency radars. Long-term synoptic monitoring will be of great importance to establish the variability of the coupling processes and look for long-term trends.

	atmosphere, it is the seat of processes like PMSE, whose nature is still not fully understood, which occur nowhere else. Such phenomena may contain information on long-term change, so an understanding of their composition and formation is potentially of great importance.	such as energetic cosmic rays and penetrating electric fields, need to be measured and their importance characterised.	
Solar Wind Acceleration	The process by which the solar wind is accelerated as it leaves the sun, up to its "cruising speed" of around 100 kms^{-1}, is still unclear. Interactions between solar wind streams and plasma waves, or between multiple streams, are likely to be important in determining the structure and velocity of the wind. Measurements of the solar wind acceleration and its evolving structure as it moves outward from the Sun are of great importance for identifying the fundamental plasma processes, and predicting the effects that Solar wind streams will have when they arrive at Earth.	We need to understand exactly where the acceleration of the solar wind occurs and what the dominant mechanisms are. It is also important to understand the cause of the turbulent processes that produce the irregularities responsible for scintillation, since this will shed light on the amount of energy carried by plasma waves in the Solar wind. New techniques have the promise to allow studies of the effect of solar wind streams on the polarisation of signals propagating through them, which may open up the possibility of probing the magnetic structure of the solar wind.	The use of higher frequencies (1.4 GHz) to measure interplanetary scintillations offers improved resolution, allowing us the possibility to probe the solar wind at distances closer to the limb of the Sun. exploring the acceleration region. New EISCAT UHF receiver hardware and real-time software to make polarisation measurements in the solar wind may enable the magnetic field structure to be explored for the first time by a ground-based system

Appendix 5

Technical achievements of EISCAT

1980s

First ever regular use of very high transmitter duty cycle factors and multi-frequency, frequency-hopping modulations permits the transmission of several different code patterns, optimised for different ionospheric regions, in the same radar cycle and avoids distant clutter problems almost completely.

A custom real time operating environment, EROS I (the EISCAT Real-time Operating System), is designed and installed at all EISCAT sites. This software provides an intuitive command-line user interface into all receiver, signal processing and antenna hardware, in the process handling the complex task of synchronising arbitrary and/or interactive antenna pointing patterns with the radar timing at the two remote UHF receivers. It also offers scripting features that for the first time in ISR history provide users with the flexibility to pre-define whole experiments involving simultaneous, synchronised operation of multiple radar sites with a few script files, execute filed experiments at will, and switch between different radar modes almost seamlessly. EROS immediately becomes an organic feature of the EISCAT system. It continues to develop through several versions up to the present, all the time retaining the original familiar command syntax while at the same time coping with fundamental and far-reaching changes to the underlying hardware systems.

Cryogenically cooled broadband GaAsFET preamplifiers for the 900 MHz band are developed and constructed. These bring the UHF remote receiver system noise temperature down to the state-of-the-art level at 30-35 K, bringing the vector velocity time resolution down to ~10 seconds, a fourfold improvement on the original UHF system performance.

Following the appearance of the first cell phone systems in the 900 MHz range, the UHF receivers are completely redesigned for vastly improved out-of-band large-signal handling performance, while retaining in-band sensitivity at the radio-astronomy level.

First-ever routine use of the so-called Alternating Codes technique (invented and pioneered by scientists from the Finnish EISCAT user group) is made possible through the design, development, and installation of a co-processor unit for the EISCAT Digital Correlators. Alternating Codes, which deliver superior statistics and range resolution at all altitudes while retaining full frequency spectral coverage, have constituted the backbone modulation for most EISCAT experiments from this point in time and are now the World's de facto standard modulation for scientific incoherent scatter radars.

1990s

A number of novel approaches to ISR system design are introduced with the new EISCAT Svalbard Radar (ESR):

First ever use of standard UHF TV power amplifiers in a ISR transmitter allows radar duty cycles of up to 25 % (the highest ever used in a pulsed ISR system), reduces maintenance and operations cost dramatically and allows for unattended, remote-controlled operation.

Using 1 MW peak power, antennas optimised for very low noise pickup, and extremely low-noise cryogenically cooled receiver front ends delivering outstanding receiver sensitivity, the ESR demonstrates convincingly that cutting-edge ISR performance no longer requires extremely high power levels.

EISCAT-designed digital transmitter exciter and digital receiver back ends provide sub-microsecond-level frequency agility, fully programmable filter impulse responses and near-perfect time stationarity, offering experimenters unprecedented flexibility in manipulating even the most complex coding schemes.

Electronic pulse-to-pulse switching of the full transmitter output power between the two ESR antennas allows, for the first time, the use of two quasi-simultaneous beams in a non-phased array radar system.

2000s

The whole EISCAT system is upgraded to ESR standards:

Digital receiver back ends and multi-processor UNIX servers replace the old signal processing systems, for the first time allowing regular use of a totally new approach to pulse coding. Transmissions are modulated with special pseudo-random binary codes, selected on the condition that their ambiguity functions are well behaved also when computed over different subsets of the codes. Using the massive signal-processing power of the upgraded system, the received signals are decoded in several different ways simultaneously, so delivering multiple pairs of range/time resolutions from a single experiment. In this way, experimenters are no longer forced to decide a priori whether to prioritise time resolution or spatial resolution in their observations. The new technique is expected to lead to breakthroughs e.g. in the study of auroral electrodynamics, where signals are typically weak and target characteristics are vary rapidly in time.

A unified release of EROS, called EROS IV, is installed at all sites, providing users with a single, familiar user interface everywhere. To the extent that the radar hardware allows it, experiment scripts can now be ported freely between the mainland installations and the ESR.

A 1.4 GHz receive-only capability is added to the Kiruna and Sodankylä UHF systems to provide much improved system performance in the interplanetary scintillation (IPS) mode used to observe solar wind acceleration near the Sun.

Appendix 6

The Future of EISCAT Research of the Mesosphere, Stratosphere and Troposphere

The Polar Mesosphere: Some Outstanding Problems

One of the most surprising results obtained by EISCAT are the observations of Polar Mesospheric Summer Echoes (PMSE) occurring in the altitude region between 80 and 90 km during summer time. These echoes are found in the same height region as noctilucent clouds, radar echoes observed by HF- radar and layers of meteoric dust and ice particles as observed by the ALOMAR lidar at Andenes (a facility of the Leibniz-Institut für Atmosphärenphysik in Rostock and the Norwegian Space Board). These echoes came as a big surprise to the science community involved in EISCAT at the late 1980s and could not be explained according to any accepted theory for scattering at the time. Theories have subsequently been presented that relate these echoes to multiply charged dust particles, and special rockets equipped with dedicated instruments have been developed to investigate these layers in situ at the same time as they are observed by EISCAT and other ground based probing techniques including the SOUSY radar on Svalbard to be adopted by EISCAT.

These echoes are so variable that single rocket experiments cannot give adequate information about the structure, behaviour and particle composition and larger campaigns with salvos of rockets are being planned. There is a strong international interest in following the development of PMSE as they occur in the altitude region of the middle atmosphere experiencing the lowest minimum temperature in the atmosphere as a whole. It is believed, and strong evidence has been achieved recently, that the echoes are related to the presence of water vapour nucleation on dust forming small ice particles, and that the ability of water vapour to appear at these heights is related to anthropogenic activity. The latter is making these investigations particularly important in the view of global climate change.

The mesosphere is a dynamic region of the atmosphere representing the bottom of the ionized part of the atmosphere, the ionospheric D- region, where negative ions and hydrated cluster ions coexists with charged dust particles and debris of meteoric impact. The region is ionized partly by cosmic rays and partly by solar EUV and X- ray radiation. The solar component of the radiation sources is strongly dependent on the solar activity and often in anti phase with the cosmic ray component.

Strong particle eruptions on the Sun sometimes launch large plasma clouds or Coronal Mass Ejections (CME) that impact the polar upper atmosphere and release protons with energies of up to some hundreds of MeV that reach the mesosphere and create Polar Cap Absorption (PCA) events that can lead to complete black-out of HF-radio communication in high latitude regions. These events have been known for more than 50 years and believed to have an impact on the stratospheric ozone content as the particles (protons) with the highest energies reaching down to 50 km altitude or even less. Here they can produce enough ionization of molecular nitrogen that NO can be formed by chemical reactions in sufficient amounts to represent an increased threat to ozone. Indications of this happening have been seen during some of the largest solar flares in modern time. It is also expected that the upper mesosphere can be heated during these exceptional particle events and thus have an effect on the aeronomy of the region.

The mesosphere also acts as a filter for momentum transfer between the lower and upper parts of the atmosphere. Gravity waves that are created by strong ground level winds forced into vertical motions by mountain ranges (orographic wind patterns) can propagate upward and interact with the background neutral atmosphere at mesospheric heights. The gravity waves being damped below 100 km altitude transfer a significant amount of their momentum and energy to the neutral air in these height regions. During this process part of the energy is transferred to turbulent motion and the momentum transfer results in substantial changes of the prevailing wind field. Due to the high collision frequencies between the neutral air particles and the ions the neutrals will drag the ions along in their motion. Since the ions and in particular the electrons are rather easy to observe due to their strong interactions with electromagnetic waves, the D- and E- region plasmas are often used as a tracer of the neutral gas. Radar studies of the neutral dynamics in the mesosphere and lower ionosphere provide significant input to the dynamical studies of these regions. The EISCAT radars and HF- radars are often used jointly and to great benefit in this work.

Meteorology of the Polar Stratosphere and Troposphere: New Research Results Expected from Radar

The EISCAT incoherent scatter radars are used for studies of the ionosphere, which is coupled to the magnetosphere. The ionosphere, embedded in the thermosphere and mesosphere, is also coupled to the layers at altitudes below, namely the stratosphere and the troposphere. The coupling is mainly by dynamical processes such as gravity waves and tides but also by diffusion and the mean global circulation. It is, thus, advisable to extend the EISCAT observations by particular instrumentation, which is capable of observing these lower altitudes. A suitable instrument is a stratosphere-troposphere (ST) radar. Such an ST radar, the SOUSY Svalbard Radar, exists in the close vicinity of the EISCAT Svalbard Radar. It was constructed and operated by the Max-Planck-Institut für Aeronomie and is due to be taken over by EISCAT in 2002.

There are certain phenomena in the polar middle and lower atmosphere, studied by radar, in addition to the multitude of other experiments already applied to such studies in the Arctic. These are particularly those directed to the ozone variation, which is affected by dynamical processes related to the polar vortex. With ST radars it is possible to study dynamic processes in a wide scale range from planetary and synoptic scale disturbances to small-scale gravity waves and clear air turbulence. The wind field variations occurring in the polar vortex can be monitored continuously by ST radar. In polar regions it is of special interest to investigate the exchange processes between the troposphere and the lower stratosphere, namely the variation of the tropopause height and the dynamics of tropopause folds. The possibility to study vertical transport between the troposphere and the stratosphere, and the transport within the stratosphere by means of the mean vertical motion and by turbulent diffusion, is highly challenging. The transport and deposition of energy and momentum by gravity waves in the lower stratosphere, measurable with ST radar, has an impact on the mean stratospheric circulation and the polar stratosphere temperature. Furthermore, polar stratospheric clouds, which are related to mountain and lee waves, control the ozone depletion in the Arctic stratosphere. The formation of mountain waves can be studied by ST radar and thus the dynamics below, and possibly in and around polar stratospheric clouds can also be investigated by the SOUSY Svalbard Radar.

This ST radar, if operated continuously, would also yield invaluable input data for meteorological modelling and forecasting.

Another application will be to observe the correlation of gravity wave activity in the mesosphere with that in their source region in the lower stratosphere and the troposphere.

Such operations of an ST-radar can effectively contribute to research programs for studies of the climatology of the Arctic troposphere and stratosphere performed in Longyearbyen and Ny-Alesund on Svalbard. Little knowledge exists of the climatology of gravity wave energy and momentum transfer between atmospheric regions in the Arctic. Thus, continuous ST radar observations are very essential.

Meteorological Applications

The SOUSY Svalbard Radar, or an even more advanced radar system, can be operated as a wind profiler which will provide continuous wind and weather structure profiles over Svalbard. This can be used in scientific research, for instance for model initialization by monitoring wind fields and fronts in synoptic-scale disturbances, stratosphere-troposphere exchange, and gravity wave activity. It is also valuable for weather forecasting (frontal approaches and passages causing severe weather) and for real-time air traffic safety alerts at Longyearbyen/Svalbard airport (turbulence warning during approach and landing of aircraft).

There is also a good possibility for the use of EISCAT radar antennas in Norway, Sweden and Finland for troposphere and stratosphere observations, which is very useful in similar meteorological studies as pointed out for the Svalbard region.

Proposal for a New MST Radar System on Svalbard

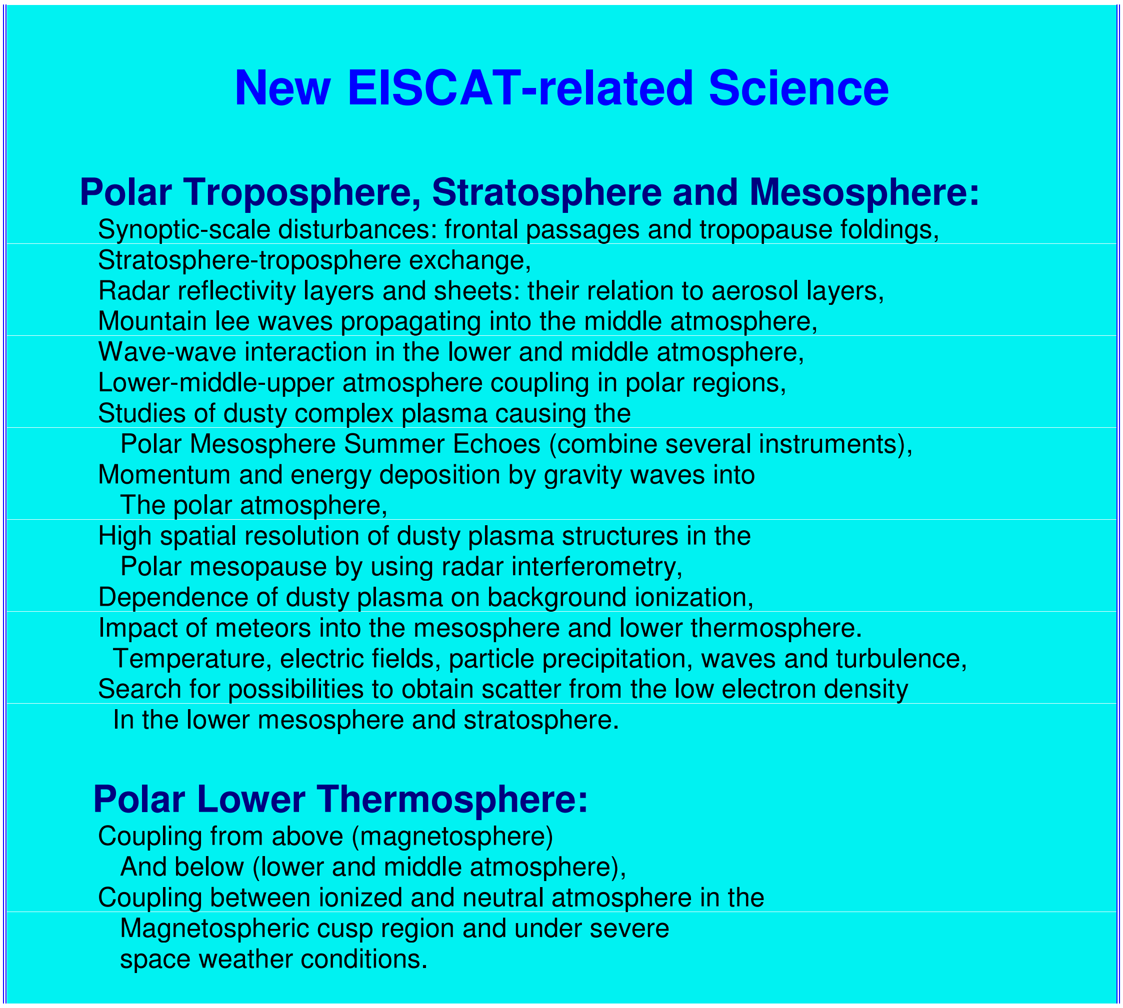
The SOUSY Svalbard Radar is a medium power research system and is not designed for long unattended operation, which is necessary for climatological studies. EISCAT in future should be expanded by a dedicated ST radar optimized for continuous operation.

Such a radar system will also allow new studies of the mesospheric scattering features, in combination with the EISCAT Svalbard Radar. This combination is unique, since it allows common volume measurements at different plasma irregularity scales in addition to determining the electron density background profile with the incoherent scatter method.

Optimum common volume studies require equal angular and range weighting, which means that a new MST radar needs to have similar antenna beamwidth as those of the two EISCAT dish antennas used on 500 MHz. This leads to a major increase of the radar antenna array. This, on the other hand, can be constructed in modules, allowing very high resolution interferometer and digital beam forming applications. The choice of a lower frequency than 53 MHz, say 30-40 MHz, would lead into new insight into the mesospheric scattering plasma properties. Such a system can also be used as high resolution riometer, independent of radar operation.

An increase of radar power level by more than an order of magnitude (up to 100 kW average power), together with the large increase of the filled antenna aperture, will allow studies of winds, waves and turbulence up to stratopause altitudes and even higher. This will lead to completely new observational results, in particular in the polar regions.

In this context it should also be considered, which frequency is an optimum and which system power aperture-product would be needed to obtain scatter from the low electron density in the lower mesosphere and stratosphere with such a new MST radar.



New EISCAT-related Science

Polar Troposphere, Stratosphere and Mesosphere:

Synoptic-scale disturbances: frontal passages and tropopause foldings,
Stratosphere-troposphere exchange,
Radar reflectivity layers and sheets: their relation to aerosol layers,
Mountain lee waves propagating into the middle atmosphere,
Wave-wave interaction in the lower and middle atmosphere,
Lower-middle-upper atmosphere coupling in polar regions,
Studies of dusty complex plasma causing the
  Polar Mesosphere Summer Echoes (combine several instruments),
Momentum and energy deposition by gravity waves into
  The polar atmosphere,
High spatial resolution of dusty plasma structures in the
  Polar mesopause by using radar interferometry,
Dependence of dusty plasma on background ionization,
Impact of meteors into the mesosphere and lower thermosphere.
  Temperature, electric fields, particle precipitation, waves and turbulence,
Search for possibilities to obtain scatter from the low electron density
  In the lower mesosphere and stratosphere.

Polar Lower Thermosphere:

Coupling from above (magnetosphere)
  And below (lower and middle atmosphere),
Coupling between ionized and neutral atmosphere in the
  Magnetospheric cusp region and under severe
  space weather conditions.

Jürgen Röttger, 28 August 2002

Appendix 7

A potential E′ operating budget

An initial estimate of the potential future annual operating costs of the Association (excluding operations) suggests that substantial cost reductions could be achieved by radically altering the Association's staff structure.

E-Prime Budget (rough estimate) - Basic costs excluding operations			In EUR
Recurrent budget			
Operation			
	Buildings and land rent and operation costs	309,500	
	Computer and system operations	31,667	
	Maintenance	12,222	
		353,389	353,389
Administration			
	Transportation and travels	76,889	
	Tele and data communications	66,389	
	Office operations	26,667	
	Corporate insurances	55,556	
	Audit	16,667	
		242,167	242,167
Personnel			
	Management, administration and scientific support staff	783,333	
	Engineers - operating	328,889	
	Engineers - development and maintenance	375,000	
	Shiftwork and overtime	36,667	
	Subsistences and other personnel costs	60,278	
		1,584,167	1,584,167
Total annual recurrent budget			2,179,722
Investment budget			
Capital operating			
	Computers and peripherals	16,667	
	Vehicles	22,222	
	Office and workshop equipment	3,333	
	Instruments	11,111	
	Radar system parts	44,444	
		97,778	97,778
Total annual budget			2,277,500

Exchange rate used	
EUR / SEK	
EUR	9.00

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