Report to SAC on EISCAT's future from users in Sweden

The Swedish EISCAT users have held a small workshop discussing the future needs and the science cases for a continuation and expansion of EISCAT after 2006. It took place in Uppsala on 24-25 April 2003, and attracted nearly 30 participants. The Swedish Research Council (VR) supported generously our workshop. Sixteen presentations were given, and fruitful discussions were held. Based largely on this workshop and the response from EISCAT users in Sweden we can give the following input to the Scientific Advisory Committee (SAC).

1. Present usage of EISCAT

EISCAT users in Sweden are presently active in the areas of

- atmospheric physics;
- active plasma turbulence physics;
- active geospace physics;
- auroral physics;
- investigations of large scale phenomena in geospace (upper atmosphere, ionosphere, magnetosphere, and the solar wind at 1 AU) using groundbased instruments and spacecraft;
- solar system physics, particularly the study of dust and meteors impinging onto the Earth.

In these areas the usage of the EISCAT facilities has started recently or is likely to happen in the future:

- calibration of a (groundbased) GPS network via a model for the total electron content;
- adaptive beam forming and signal processing in general, design and use of future multi-antenna/receiver systems.

EISCAT is being used in courses for undergraduate students. This usage is likely to increase.

Within each research area, EISCAT related research priorities and their anticipated development, relative importance of current EISCAT facilities and types of observations, and ranking of possible extensions are briefly:

Atmospheric physics research:

For wind studies, the EISCAT IS radars covers a height region above 100 km which is not covered by other radars. It is also the only radar which can be used to determine temperature and density around 90–110 km altitude (and in fact the only instrument which can do this well all the year round). It has distinct advantages over other radars when electron densities are enhanced, and it can offer much better time resolution (e.g. for PMSE).

Long-term trends in circulation, density, temperature and analysis measurements covering the first solar-cycle of EISCAT observations was completed in 1996. This showed both direct solar-radiative effects and evidence for circulation changes following the solar cycle. A second solar-cycle of observations will be available in the next year or two and it may then be possible to look also for any longer term trend.

PMSE - Dusty plasma at the summer mesopause - particularly studies of the microphysics of the scattering mechanism which can be revealed through modification of PMSE by HEATING. Here the Swedish group was the first to succeed in observing such a modulation (in 1999) which has led to substantially increased activity in this area. Fine-scale structure with frequency-domain interferometry techniques to allow higher spatial resolution than previously available have been developed for the PMSE study.

PMWE - Dusty plasma in the WINTER mesosphere - in the last two years evidence for charged aerosol layers in the winter mesosphere has been found primarily using the ESRAD radar. However, it has become clear that the EISCAT VHF radar observes the same layers, offering the possibility for detailed studies comparing the different scale-sizes.

Further, EISCAT could make a significant contribution to understanding whether/how atmospheric disturbances related to quasi-stationary planetary waves can propagate from high altitudes (50-100 km) down to the troposphere. This can be achieved if regular observations with EISCAT can be made simultaneously with an IS radar in Alaska or Arctic Canada. In summary, to serve the needs of atmospheric science EISCAT should:

- Continued regular CP-1 (UHF) (min. 1 day per month)
- Retain the VHF radar and measure the mesosphere often (e.g. 1–2 h around noon, 3–7 days every week). Run CP-1 at the same time.
- Retain HEATING
- Improve possibilities to run at short notice, when atmospheric conditions are particularly interesting
- Coordinate measurements with other high-latitude IS radars
- Improve low altitude capabilities (mesosphere/stratosphere)

Apart from this, there are good possibilities for EISCAT in future to contribute to further atmospheric dynamic studies if low altitude (15–60 km) capabilities can be introduced, for example by implementing a phased-array VHF receiving site in Kiruna. This would allow the stratosphere to be studied by radar - something which is not possible with the other (less powerful) radars available.

Active plasma and geospace physics experiments:

The Heating facility is the world's most powerful HF transmitter for research. In active experiments the Heating facility is used to induce perturbations in geospace, for the purpose of studying fundamental plasma physics and for investigating the natural geospace environment. The powerful radio waves can be used to derive parameter values of the ionosphere, middle and upper atmosphere, to visualize turbulence and geospace phenomena, to investigate geospace phenomena by performing stimulus-response experiments, and to interact with free (natural) energy sources. Particularly the latter two types of uses of HF waves are likely to become of increasing importance in future physics research using EISCAT. The active experiments complement and expand on commonly used more passive observations of naturally induced phenomena in geospace using the incoherent scatter radars alone.

Artificially induced optical emissions are detected with the multi wavelength (557.7 nm, 630.0 nm, 427.8 nm, 844.6 nm) and multi-station Auroral Large Imaging System (ALIS) in the Kiruna area. Our initial experimental results on the optical emissions were rapidly confirmed by others at EISCAT as well as HAARP in Alaska.

ALIS enabled also tomographic estimates of the airglow volume. In addition to giving important information on the dissipation processes in plasma turbulence, the optical emissions also provides information of the background neutral atmosphere.

The interaction of an HF pump wave and the ionospheric plasma leads to an organization of the plasma into narrow filamentary density irregularities that are stretched along the geomagnetic field. The formation of these striations is connected with anomalous heating and anomalous absorption of electromagnetic waves. Research on fundamental turbulence using powerful radio waves in the ionosphere is of general interest to plasma physics and nonlinear physics, in addition to space physics.

Research on the optical emissions at the auroral latitudes of EISCAT will be developed with focus on its use as a diagnostic of the complexity of the excited plasma turbulence. It is also most important to extract information of the ambient neutral atmosphere (thermosphere and mesosphere) since the optical emissions can be used to measure a variety of parameters which are not easily accessible by other means (without, e.g., chemical releases from sounding rockets). This includes tomographic inversion of prompt emissions to visualize structure in the turbulence region. Also, it is of high priority to explore the potential of HF pump-induced ionization as a diagnostic tool of different atmospheric constituents.

Further, the present research on the effects of powerful electromagnetic radiation on the ionosphere and atmosphere is significant for a solar power satellite that has been conceptualized to supply future energy needs. In the solar power satellite solar energy would be collected by solar panels in space without interference from diurnal variations and clouds. The solar energy would then be beamed to earth via, e.g., microwaves, to be fed into the power grid. In order to minimize losses it is therefore essential to understand the interaction of the electromagnetic radiation with the ionosphere and atmosphere.

Implementing a phased-array VHF site in Kiruna with interferometric capabilities would make EISCAT an even more valuable tool for our research. We suggest to consider also:

- Heating facility/MF radar near Kiruna.

  There is a consensus in the scientific community that the single most important experiment to increase our understanding of electromagnetically pumped turbulence is to perform *in situ* measurements. It is therefore suggested that a new heating facility is constructed near the Esrange sounding rocket site in the Kiruna area. The facility could preferably be of the SPEAR-type that is presently constructed on Svalbard by the UK.

- Incoherent scatter radar transmitter at Kiruna

  When upgrading and replacing the mainland incoherent radar systems it is suggested to place a radar transmitter also at the Kiruna site. This would give a unique possibility to make measurements parallel to the geomagnetic field simultaneously from Kiruna and Tromso to obtain a high spatial resolution in the important horizontal north–south direction in the auroral zone. In addition, field-aligned observations would significantly strengthen the diagnostics during sounding rocket launches from Esrange. To facilitate bistatic measurements at larger magnetic field angles a receiving antenna could be placed in Russia in the event that Russia wants to become a member of EISCAT.

- Powerful laser/LIDAR

  It is suggested to construct a powerful laser at the Tromso site. The laser should be powerful enough to cause ionization and breakdown in the upper atmosphere, which long has been suggested to constitute a useful diagnostic tool for upper atmosphere research. A Sodium laser would also be used as a very sensitive LIDAR, e.g., of the Sodium layer in the D/E region. With the unique set of instruments at EISCAT, including the incoherent scatter radars and the possibility to modify the ionospheric layers with the Heating facility, new types of research can be performed and new research groups would be attracted to use EISCAT. This includes also simultaneous measurements with the LIDARs at ALOMAR in Andenes, Norway. However, the ALOMAR LIDARs cannot be aimed over the Tromso site which limits cooperative science with EISCAT.

Auroral physics

The main scientific goal is the study of the optical and electrodynamical fine structure of the aurora in three dimensions and the coupling with magnetosphere and upper atmosphere processes. The colocation of the tristatic EISCAT system and the Auroral Large Imaging System (ALIS) provides unique opportunities to make significant progress in this respect.

With ALIS time-resolved 3-D optical imaging of the ionosphere and atmosphere can be performed and also tomographic inversion. At present ALIS consists of six unmanned remote-controlled station located in a grid of ~ 50 km in northern Sweden. Each station is equipped with sensitive high-resolution unintensified CCD-camera with field-of-view of 60° or 90°. Each camera has a six-position filter-wheel for narrow-band interference filters providing absolute spectroscopic measurements of the auroral emissions. It has been most successfully for studying in 3 dimensions artificially induded optical emissions as described above.

Also the natural aurora can be studied well with ALIS in combination with EISCAT, and the aims are to obtain

- the 3D-distribution of auroral optical emissions and electrodynamice parameters like densities, electric fields and currents to study small-scale spatial and temporal dynamics of the particle precipitation over auroral forms.
- the connection between the characteristics of the auroral particles inducing the optical aurora and thermosphere/ionosphere composition disturbances.

In the future our plans concern the aurora, namely the auroral arc study. A successful theory of auroral arcs must explain their spatial structure and temporal variability as well as mechanisms of particle acceleration. Comprehensive measurements of temporal and spatial dynamics of the auroral electron spectra over the arcs are needed to constrain candidate theories. Combining ALIS measurements of the optical auroral emissions and measurements of the ionosphere E-regions by EISCAT with high spatial and temporal resolution provide good opportunities to solve this problem. The atmosphere composition strongly affects the intensities of auroral emissions as well as auroral ionization. Therefore, combined ALIS-EISCAT measurements are good candidates for diagnostic of both small-scale variations and long-term trends of lower thermosphere, particularly, of concentrations of such important gases as O an NO. These gases play key roles in the lower ionosphere-thermosphere coupling, dynamics and the energy budget of this region. Furthermore, knowledge of the O and NO densities is very important for understanding the chemistry and dynamics in the mesosphere-thermosphere coupling region.

ALIS resolves temporal scales down to a few hundred meters. For strong enough echoes, EISCAT measurements over ALIS could achieve similarly good spatial resolution, if a receiving antenna for the VHF or UHF system with interferometric capabilities were available near the Kiruna site. For the VHF system this would be most valuable, if also the VHF transmitter beam from Tromso could be directed southward and illuminate common volumes over the ALIS stations.

Remote sensing of geospace

Investigations of large and meso-scale phenomena in geospace rely on multipoint measurement, generally involving groundbased and in-situ instruments, and networks of these. Several parameters can presently be measured only with incoherent scatter radars, some paramters only indirectly or less accurately with other instruments compared to IS radars. These parameters include full profiles of electron densities, ion and electron temperatures, the ion velocity vector, conductivities, Joule heating rates and electromagnetic energy transfer. This makes EISCAT one of the most interesting instruments for these studies.

In connection with several Swedish space missions, Viking, Freja, and Astrid, many event studies of nightside auroral phenomena have been performed. Presently exciting data are coming from the Cluster mission, and this moved the focus of research more towards the dayside, to the cusp and polar cap. Also, in connection with Cluster, the degree of coordination of the EISCAT schedule with those of in-situ instruments has become higher than before. We anticipate that the coordination efforts will continue and include also other future space missions, such as Double Star and Themis. Even if EISCAT were in the future to operate nearly continuously, some coordination of the experimental modes with other groundbased and in-situ instruments would still be very desirable.

In order to investigate more optimally the highly dynamical processes both near the dayside cusp and in the auroral zone, more IS radar beams for sampling more densely in space should be available. Presently, with the ongoing Cluster and approaching Double Star missions, one would place such additional IS radar extensions or new facilities perhaps with highest priority on Svalbard and other very high latitude sites. Noting that our American colleagues are also planning to build a new generation ionosphere radar at such places, we think that an extension of EISCAT on the mainland, with the center in the auroral zone and reaching the dayside midlatitude, might be equally useful and perhaps complement very well the future worldwide network of IS radars.

Concerning long-term studies, we note that the ESR has not yet been operating a complete solar cycle. The location of the ESR should make it an ideal instrument to investigate long-term variations in the upper thermosphere in response to mass and energy input from the solar wind where the dayside cusp perhaps plays a larger role than auroral activity on the dawn-, dusk-, and night-sides.

Investigations of the origin of extraterrestrial dust/meteoroid distribution and the meteors interaction with the atmosphere

Already today EISCAT has a good potential to be one of the most powerful instruments to study the off-ecliptic component of the interstellar and interplanetary dust distributions as well as to study the near Earth space environment effects of the meteor influx. The tristatic EISCAT UHF is the only facility at high latitudes with the capability to measure the 3d velocity vector of meteors entering the radar beam. The present rates are about 1.5 tristatic observations per hour. This can be compared for example with Ulysses rates, which were about 1/day for small particles and 1/70 days for particles close to the size observable with radars. Here the 0.1 m^2 dust detection area can be compared with the 1 km wide observation surface of the radar beam.

The major sources of the dust population in the inner solar system are comets and asteroids, but the relative contributions of these to sources are not quantified. The observations near 1 AU provide clear evidence for the contribution of asteroids and short period comets to the dust cloud, which is concentrated in the ecliptic plane. On the other hand, it is difficult to estimate the cloud at high latitudes and the contribution from long period comets, which ranges to high latitudes is not well established yet. The dust production from long-period comets is especially important for understanding the dust cloud composition inward the Earth orbit, where additional dust production is required to maintain the dust cloud and where comets are the most plausible source.

The meteoroid interaction effects with and impact effects on the atmosphere generate valuable scientific topics to be studied. Strong meteoroid shower effects on the ionosphere/atmosphere can be analysed by performing measurements in standard incoherent scatter modes besides the meteor modes. Sporadic E layers affect radio waves while neutral and plasma environment variations and impact risks affect low Earth orbit satellites. Results from such studies can contribute to input values for various spacecraft environment software.

The meteor observation with EISCAT type radars occure through the head echo process. This process is now understood and can be described with a physical model. The mass range of detectable meteors and consequently the expected meteor rates depend on the radar frequency, being much higher for VHF than UHF. Also the larger observation volume of the present VHF enhances the statictics of observations. Thus by upgrading the present VHF to tristatic by constructing multi-beam receiving antennas in Kiruna and Sodankylae would increase the observed vector meteor rates by an order of magnitude to some 10–15 per hour. This would be the most valuable extension for this research.

Observations supporting space based positioning and navigation systems

Incoherent scatter radar measure in a direct way profiles of the electron density over the whole ionosphere, and thus are very valuable for calibrating models of the total electron content (TEC). Knowledge of the TEC is needed in order for to correct for radia wave propagation effects and thus increase the accuracy of space based positioning and navigation systems. EISCAT is the only IS radar in the European sector while on the American continent several IS radars from a chain more or less covering all latitudes. Therefore, presently measurements south of Tromso are more useful than those north of Tromso. Regular observations south of Tromso are presently too rare.

We expect that Sweden will also make use of the European navigation system GALILEO, and thus are interested in long-term measurements of the electron density also well beyond 2006.

2. Summary in form of answers to the SAC chair person's questions

- What are the leading research priorities for your national EISCAT user community ?

  Obviously the research priorities of EISCAT user community in Sweden are quite diverse. They include

  ☞ studying long-term trends in atmospheric circulation, density, temperaturelong term studies of atmospheric winds;

  ☞ studies of the microphysics of the scattering mechanism leading to PMSE and also PMWE;

☞ whether/how atmospheric disturbances related to quasi-stationary planetary waves can propagate from high altitudes (50–100 km) down to the troposphere;

☞ active perturbation of auroral phenomena using Heating in stimulus-response experiments;

☞ fundamental investigations of artificial plasma turbulence;

☞ using Heating to study the natural mesosphere, thermosphere, ionosphere, and magnetosphere;

☞ studying dynamics of the natural aurora at small and large scale in 3 dimensions

☞ investigations of the ionospheric energy balance and energy input into the thermosphere, of ion upflow in the ionosphere

☞ obtaining the distributions of dust and meteors at 1 AU

☞ calibration of TEC models

- How do you anticipate that these will develop during the lifetime of the next agreement (beginning 2007) ?

  We expect that the research goals listed above are also highly prioretized during the lifetime of the next agreement. Several of the items are inherently long-term studies that should be pursued over at least one more solar cycle. Studies will probably come to results that suggest further research requiring extensions of the present EISCAT facilities and other instruments.

- How would you rank each of the current EISCAT facilities (UHF-Tromso, UHF-tristatic, VHF, ESR 32m, ESR 42m, Heater and Dynasonde) in terms of their importance to your national EISCAT research programme?

  Each of the current EISCAT facilties gets at least once prioretized or is essential for an in Sweden active research group (perhaps with the exception of the Dynasonde which is, however, a number one support instrument for the KST IS radars and the heater). It is presently not possible to give an absolute ranking of the current EISCAT facilities without further discussions.

- How would you rank each of the possible extensions to the existing system (see, for example, pages 12 and 13 and the table on page 17 of the E-Prime Prospectus) in terms of their potential importance to your future national EISCAT research programme?

The "democratically" most favoured extension is a receiving antenna in Kiruna for the VHF system.

investigations of small scale structures (~ 100 m) should be possible, therefore probably an interferometer mode needs to be available (the E' document is not clear enough in this respect).

the VHF transmitter beam should be visible at low altitudes for troposphere-stratosphere research.

we should be able to direct the VHF transmitter beam southward, eg near a possible ESRANGE rocket trajectory.

- Are there any other extensions to the existing system (i.e. not included in the E-Prime Prospectus) which you would consider to be important and desirable ? If so, please specify the kind of capabilities that would be needed, and explain the scientific justification.

  Heating facility/MF radar near Kiruna.

  Incoherent scatter radar transmitter at Kiruna

  Powerful laser/LIDAR

  Brief scientific justifications are explained above.

- We would also welcome other comments on any aspect of the future development of EISCAT, which your national user communities feel to be a priority.

  Particularly in the recent years there has been a shortage of Special Programme time for Swedish users. We expect that the demand for Swedish EISCAT usage will further increase in the future, and are are prepared to ask our Research Council to augment the Swedish EISCAT share. While some of our science goals would certainly greatly benefit from (nearly) continuous operation of the EISCAT radars, some goals also demand the availability of time to do taylored experiments (Special Programmes).

Stephan Buchert, Swedish Institute of Space Physics