Publishable summary

Project context and objectives

EISCAT_3D will be an international research infrastructure that is using radar observations and the incoherent scatter technique for studies of the atmosphere and near-Earth space environment above the Fenno-Scandinavian Arctic as well as for support of the solar system and radio astronomy sciences. The radar system is designed to investigate how the Earth's atmosphere is coupled to space but it will also be suitable for a wide range of other scientific targets. It will be operated by EISCAT Scientific Association and hence be an integral part of an organisation that has successfully operated incoherent scatter radars for more than thirty years.

The EISCAT_3D system will consist of five phased-array antenna fields located in the northernmost areas of Finland, Norway and Sweden, each with around 10,000 crossed dipole antenna elements. One of these sites (the core site) will transmit radio waves at 233 MHz, and all five sites will have sensitive receivers to measure the returned radio signals. Digital control of the transmission and low-level digitisation of the received signal will permit instantaneous electronic steering of the transmitted beam and measurements using multiple simultaneous beams. The central antenna array at each site will be surrounded by smaller outlying arrays which will facilitate aperture synthesis imaging to acquire sub-beam transverse spatial resolution. The central array of each site will be of a size of about 70 m from side to side, and the sites will be located from 90 km to 250 km from the core site in order to be able to maximise the coverage by the system.

EISCAT_3D will measure the spectra of radio-waves that are back-scattered from free electrons, whose motions are controlled by inherent ion-acoustic and electron plasma waves in the ionosphere. The measured spectra reveal high-resolution information on the ionospheric plasma parameters, but can also be used for obtaining atmospheric data and observations of meteors and space debris orbits. In both active and passive mode, the receivers will provide high-quality scientific and monitoring data from the ionosphere as well as from space within its designed frequency spectrum. The research will both be organised through common observation modes and through requests from individual groups.

EISCAT_3D is designed to use several different measurement techniques which, although they have individually been used elsewhere, have never been combined together in a single radar system. The design of EISCAT_3D allows large numbers of antennas to be combined together to make either a single radar beam, or a number of simultaneous beams, via beam-forming. While traditional radar systems with a single slow-moving antenna, and thus a single beam, can only show us what is happening along a single line in the upper atmosphere, volumetric imaging allows us to see geophysical events in their full spatial context, and to distinguish between processes which vary spatially and those which vary over time.

Since EISCAT_3D is very flexible compared to traditional ionospheric radars, it will allow several new operating modes, including the capabilities to determine vector velocities of moving objects and to respond intelligently to changing conditions, for instance by changing the parameters of a scanning experiment. EISCAT_3D will also allow remote continuous operations, limited only by power consumption and data storage. This is important for monitoring the state of the atmosphere, especially as a function of solar variability, as well as capturing events that appear suddenly and are hard to predict. Radio astronomy observations will be performed when the transmitters are inactive.

The Preparatory Phase, running from October 2010 to September 2014, aimed to ensure that the project will reach a sufficient level of maturity so that the implementation of EISCAT_3D can begin after its conclusion.

Description of work and main results

The EISCAT_3D Preparatory Phase was concerned with forming a consortium, procuring the financing, selecting the sites, preparing for the data handling, considering the scientific requirements and planning the construction and operation of the system.

The present EISCAT Scientific Association, which will be the basis for the future EISCAT_3D consortium, is funded by research councils and funding bodies in six countries. EISCAT revised its membership policy in May 2013 in order to make it more attractive to new members, and is now open also for institutional members with a smaller financial commitment. Procedures are also implemented within the research infrastructure to safeguard good scientific practice and to ensure the commitment to excellent research. EISCAT has made progress in the work to revise its data policy to prepare for the new system.

To procure the finances, major investments will be needed from several countries. The current estimate of the investment required for EISCAT_3D is 128 M€ over 8 years. This estimate is based on figures given by individual manufacturers, and reductions may still be possible on individual parts, depending on the exact specification as well as bidding from several competitors. Proposals for funding EISCAT_3D have been submitted in Norway and Sweden, and the process is well under way in Finland, Japan and the United Kingdom.

A number of sites for the EISCAT_3D arrays were surveyed, and a list of preferred sites was finalised. In the first stage of the construction of the EISCAT_3D system, the core site and two receiver sites will be built. Areas near Bergfors in Sweden and Karesuvanto in Finland were identified as suitable for the first receiver sites. For the later stages of the construction, areas near Andøya (Norway) and Jokkmokk (Sweden) were identified as locations for receiver sites.

The scientific requirements have a major influence on the system design and for this a Science Case has been continuously revised in collaboration with the present EISCAT user community and with prospective future users. Communication with the scientific user community was facilitated through outreach activities, conference presentations and a series of dedicated

meetings organised by the project. The website for EISCAT_3D is online since March 2009 and is regularly maintained and updated.

The planning of the construction and operation of the new system requires a detailed instrument design. The project made use of innovative theoretical studies in signal processing, radar coding, data handling and data analysis, that was summarised in a handbook of measurement principles. The EISCAT_3D will carry out signal processing using software-defined radio receiver systems. The design of the hardware elements needed for the final system and the work on the technical integration of these subsystems were the focus of several of the Work Packages in the project.

A radar system of the complexity of EISCAT_3D requires specialised software both for the system control and for the signal processing and beam-forming. The EISCAT system control software EROS was updated to be able to be used in the context of EISCAT_3D. A parallelised tool for signal processing and data analysis, RLIPS, to be used in the EISCAT_3D radar system was developed, and signal processing and beam-forming software were prepared and tested.

Some of the e-infrastructure needs of EISCAT_3D, such as the network connections between the sites and the computing and data storage near the instruments, require local solutions. Hence a plan was developed with e-infrastructure providers in the host countries for their future involvement in the planning.

Final results and potential impacts

The overall theme of EISCAT_3D is to explore the multiple facets of the question how the Earth's atmosphere is coupled to space. The EISCAT_3D science encompasses climate change, space weather, space debris and near-Earth object studies. The technical challenges to handle large data volumes will employ tools from the newly emerging field of e-science and spur collaboration with local computing centres. EISCAT_3D will provide an unprecedented resource for observations of the near-Earth space. It will provide long-term time-series data of the ionospheric conditions enabling studies of variations on a time-scale over several solar cycles.

When in operation, EISCAT_3D will be at a central position in the international, and trans-regional, space cluster of Northernmost Scandinavia, which includes large space research centres in Kiruna (Sweden), Sodankylä (Finland) and Tromsø (Norway), two rocket launch facilities in Andøya (Norway) and Esrange (Sweden), and several other instruments and instrument networks for geospace observation such as magnetometers and auroral cameras.

The scientific data from EISCAT_3D will be an invaluable asset for models and near real-time forecasts of space weather effects on modern technology, including power grids and other important infrastructures. EISCAT_3D can also contribute to the Space Situational Awareness (SSA) programme by tracking known space debris and assisting communication and navigation services like the Galileo navigation satellites. Discussions have just been

initiated between EISCAT, agencies and institutes in the Nordic countries and the European Space Agency (ESA) on the prospect of including EISCAT_3D in ESA's SSA programme. EISCAT will continue to be an active participant in global observation campaigns and international and European research projects. From its foundation EISCAT has been a purely scientific organisation. The radar technologies to be used with EISCAT_3D allow the detection and tracking of small objects in space. The new Bluebook has stipulations that ensures that the EISCAT facilities will be used strictly for scientific and civilian purposes.

The construction of EISCAT_3D requires close interaction with industry in order to ensure the production of components of the high quality and the large numbers needed. This includes the manufacturing of the antenna elements and the corresponding electronics. Engineering solutions could be a development driver for large scale distributed systems in harsh environments.

EISCAT and its users are working together with industry to develop technology and applications for EISCAT_3D. Enterprises, both regional and national, within the EISCAT member countries are expected to respond to invitations to tender for e.g. radio and the digital signal processing instruments, antenna front end and timing systems, and other advanced subsystems.

The timing of EISCAT_3D is ideal. It is now feasible to construct and operate the system and to handle the data volume that the system will provide; this was not the case a few years ago. An increasingly technology-dependent society needs to understand the ionospheric processes caused by space weather in order to minimise their effects on sensitive systems. EISCAT_3D will offer state-of-the-art instruments to the scientific community for dedicated observation campaigns to study processes important for the understanding of our environment and climate, such as the energy coupling between the upper and lower atmosphere, the linkages between the different layers of the upper atmosphere and to interplanetary space, small-scale structures and phenomena as well as micro-meteoroids that enter the atmosphere and participate in atmospheric processes.