EISCAT 3D: Design Specification Document

Index

Issued by: U G Wannberg

Approved by: A P van Eyken

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1 Introduction

1.1 Brief Background

The high latitude environment is of increasing importance, not only for purely scientific studies, but because of the direct effects on technological systems and climate which are principally mediated through interactions with solar produced particles and fields and whose effects are overwhelmingly concentrated in the polar and high latitude areas. These effects are of importance not only from a European dimension, but globally, since the European arctic and high arctic areas are the most accessible, and best supported by installed infrastructure and existing communities, of any place on the Earth from which the necessary observations and measurements can be made.

Mankind is entering a period where full knowledge and understanding of the Earth's environment as part of the linked Sun-Earth system is essential and it is important to exploit existing advantages to provide effective and continuous monitoring of the critical interaction regions. Incoherent scatter radar is the most effective, ground-based technique for studying and monitoring the upper atmosphere and ionosphere.

The radars of the EISCAT Scientific Association have defined the state of the art within the World's incoherent scatter community for the last several years. EISCAT has been very successful in exploiting its two radars located on the Scandinavian mainland (one operating at 928 MHz and the second at 224 MHz) and this success led directly to the design, construction, and operation of the EISCAT Svalbard Radar nearly 1000 km further north almost ten years ago.

Other incoherent scatter radars exist at Irkutsk (Russia), Kharkov (The Ukraine), Kyoto (Japan), Sondrestrom (Greenland), Millstone Hill (USA), Arecibo (Puerto Rico, USA), Jicamarca (Peru), and in Indonesia. Substantial recent investment by the USA will lead to the availability of new American sector high-latitude radars, to be located in central Alaska, and in northern Canada, by late 2007. These radars will have technical abilities beyond those which can be provided by the existing EISCAT radars either in their present form or through reasonable upgrades.

The EISCAT Scientific Association, in co-operation with the University of Tromsø, Norway, Luleå University of Technology, Sweden, and the Rutherford Appleton Laboratory, United Kingdom, has therefore started a four-year design study, supported by European Union funding under the Sixth Framework initiative which builds on its past successes and aims to maintain Europe's world leadership role in this field.

Mindful that the driving issues in ionospheric research continuously evolve, this document outlines the required specifications of a new concept in incoherent scatter radars which can both replace the two existing, but now aging, European mainland systems and also substantially extend the systems' capabilities as required to address the scientific and service requirements of the next fifteen to twenty years. The facility envisaged in this design study will surpass all other facilities, both existing and under construction, and will provide European researchers with access to the World's most advanced and capable facility.

In order to best exploit and enhance European technological resources and to arrive at the best possible design to address the needs of the present, and expanding, European community, the design study must evaluate a number of different approaches which are now possible in order to meet the required performance as efficiently, and cheaply, as possible.

The study will require the development of new radar and signal processing technology, together with crucial developments in polarisation control, built-in interferometric capabilities, the provision of remote receiving installations with electronic beam forming, signal processing, and automated data analysis. In order to allow the construction of the large phased array systems required, the design study also envisages seminal developments in the design and production of VLSI technology components.

The design study also includes a component to design communication, data distribution, and data archiving systems, which leverage the available and developing skills, networking, and grid infrastructures within the Community. These developments will allow European scientists and other users to access data from the new systems irrespective of their location within the community.

1.2 Science Goals

The new facility will greatly extend the range of available data, dramatically improving its temporal and spatial resolution as well as the geographic, altitude, and temporal extent. The design goals mandate improvements in the achievable temporal and spatial resolution (both parallel and perpendicular to the radar line-of-sight) by about an order of magnitude, to extend the unambiguous instantaneous measurement of full-vector ionospheric drift velocities from a single point to cover the entire altitude range of the radar, and to increase the operational time by a factor of at least four (from 12 to 50%), and possibly to full-time.

The facility will provide high-quality ionospheric and atmospheric parameters on an essentially continuous basis for academic researchers and practical service consumers as well as providing near-instantaneous response capabilities for scientists and users who need data to study unusual and unpredicted disturbances and phenomena in the high-latitude ionosphere and atmosphere.

Besides supporting data consumers for service driven applications (such as space weather effect forecasting), the new facility will support studies of such topics as: ion outflow to the magnetosphere, induced changes in the ionosphere, magnetic reconnection, sub-storms, auroral electrodynamics, ionosphere-neutral atmosphere coupling, mesospheric physics, small scale plasma physics, micrometeors, planetology, and solar wind acceleration.

While users will sometimes visit the facility to obtain maximum access and response from the system, it will be possible for the radar to be operated entirely remotely and access to both the control and monitoring systems and the various data streams will be provided through secure network connections.

1.3 A Priori Knowledge and the Questionnaire

The EISCAT radar systems have provided the scientific community with outstanding data for more than 25 years. Many unexpected and surprising observations have been made during this time, leading to the opening of new fields of research such as: the study of transient coherent echoes from the ionosphere, polar mesospheric summer echoes (PMSE), the detection of extremely narrow natural layers of ionisation in the E region, observations of micrometeors interacting with the atmosphere, detailed studies of artificially induced plasma turbulence.

Common to many of these new research areas is that the processes to be studied are transient, small-scale and spatially compact, so much so that the sensitivity and temporal and spatial resolutions of the present UHF and VHF radars have been found wanting. Also, many of the physically most interesting situations occur under conditions of low electron density and/or very high electron-to-ion temperature ratio, both of which lead to reduced scattering cross sections and, indirectly, noisy data.

Thus a new incoherent scatter radar system in the auroral zone should be designed to deliver substantially better sensitivity and spatial and temporal resolution than the existing EISCAT systems in order to represent a scientifically worthwhile and future-proof investment. The new system should retain the unique and extremely powerful multi-static capability of the mainland EISCAT UHF system. To obtain the best possible performance in low electron density conditions, an operating frequency in the high VHF band is preferable. A much greater variety of data products than that available from the existing systems would also be required, in particular time-resolved complex amplitude data.

An outline of a tentative new radar system with these general characteristics was outlined in our application for a FP6 design study grant and was subsequently made an integral part of the Contract.

However, within this framework, a large number of specific parameters, such as: system location, field of view, spatial and temporal resolution, number of simultaneous antenna beams etc. remained to be defined according to users' requirements. To quantify better how varying these free parameters would restrict or enhance the performance of the radar in specific cases, the Steering Group issued a Questionnaire, the complete text of which is enclosed as Appendix 3.

The Questionnaire was organised in three sections. "General Questions" were included to give an idea of the potential size and makeup of the user community for the new radar. In the "System Specification" section, the recipients were asked to provide us with values for system parameters such as: field-of-view, spatial and temporal resolution, number of baselines, system bandwidth, etc. and in the "Data Products" section users were asked to rate the relative importance of having different types of data available in real-time. In early June 2005, the Questionnaire was e-mailed to some 40 individual scientists known to be past, present or potential new EISCAT users. A second mailing to an extended group of ionospheric scientists was made in early August 2005. When the process was closed immediately before the Performance Specification meeting on September 12-13, 2005, a total of 22 replies had been received. Several of these were collective replies from entire research groups, so the response reflects the views of about 40 individuals.

A statistical, de-personalised breakdown of the response is enclosed as Appendix 4. There is a surprising degree of agreement on some of the most important issues, such as: spatial and temporal resolution requirements, the location of the transmitter/receiver site and the preferred data product. The majority opinion on these is in surprisingly good agreement with our initial assumptions and has been reflected in the baseline specification.

2 EISCAT 3D Radar System Design Baseline

Below, the design baseline for the EISCAT 3D radar system, as established by the Steering Group, is summarised in terms of overall configuration, general operational characteristics, field-of-view, spatial resolution and sensor performance. The baseline configuration and parameters presented here are based on user input as received via the Questionnaire and otherwise, White Papers published by several national EISCAT user communities, and the collective experience of past and present EISCAT staff and colleagues at other radar installations.

We have elected to use this ‘black box’ format because it allows the characterisation of the system in terms of physical and geometrical parameters relevant to the scientific end user, leaving the task of specification at the engineering level open to be addressed by the subsystem-specific Work Packages in later phases of the Design Study.

2.1 System configuration

The 3D radar will comprise the following subsystems:

- A *central transmitting/receiving core*, located at, or close to, the EISCAT Tromsø radar site at Ramfjordmoen, Norway,
- *At least two receiving facilities for 3D measurements in the ionospheric F1, F2 and topside regions*, located at ground distances of ~220-280 km roughly south and east of the transmitting facility, respectively,
- *At least two receiving facilities for 3D measurements in the ionospheric D and E regions*, located at ground distances of ~90-120 km roughly south and east of the transmitting facility, respectively,
- *Data storage and communication systems* located at, or close to, each facility.

2.2 Operational characteristics

- The system will be designed for essentially unattended, continuous operation.
- System control, monitoring, and data access will take place over the Internet.
- Data access over the DataGrid will also be available, once the Grid is extended to the deployment area.
- Built-in test equipment (BITE) and test software will enable remote monitoring of system performance, fault identification, remote diagnostics, and some degree of remote fault recovery.
- Relative time between sites will be maintained to better than 100 ns, while absolute time will be maintained to GPS/Galileo standards.
- A formal experiment scheduling system will allow scheduling protocols and experiment files to be uploaded and tested well in advance of the scheduled execution times, and executed automatically according to a pre-set schedule.
- An override facility will enable experiments to be initiated by overriding the nominal schedule, either manually or automatically, in response to certain criteria being satisfied. The evaluation of whether the criteria have been met will involve the use of EISCAT’s own real-time analysed data, as well as data from other diagnostics.

2.3 Central transmitting/receiving core

This will comprise:

- a *phased-array transmit/receive (TX/RX) system with at least one antenna*,
- *RF signal generation equipment and RF power amplifiers*,
- a *transmit/receive switching system*,
- *beam-steering systems for transmission and reception,*

- several (4–10) outlier, *receive-only phased-array antennas for in-beam interferometry*,
- an *incoherent-scatter receiver* subsystem,
- an *interferometry receiver* subsystem*,*
- *time and frequency synchronisation equipment*,
- *digital signal processing equipment*,
- *built-in test equipment (BITE*)

2.4 Receiving facilities

Each of these will comprise:

- a *phased-array antenna* with its associated *receivers*,
- at least five *beam-formers*,
- *time and frequency synchronisation equipment*,
- *digital signal processing equipment*,
- *built-in test equipment (BITE)*

2.5 Spatial resolution

The transmitter and antenna parameters will be selected such that, over the multi-static field-of-view:

- the resolution along the transmitted beam direction(s) can be made better than 100 m at any altitude,
- the horizontal –3 dB resolution at 100 km altitude is better than 150 m.

2.6 Radar field-of-view (FOV)

The beam generated by the central core transmit/receive antenna array will be steerable out to a maximum zenith angle of ≈40° in all azimuth directions. At 300 km altitude, the radius of the resulting field-of-view is approximately 200 km. In the N-S plane this corresponds to a latitudinal coverage of ±1.80° relative to the transmitter site.

The antenna arrays at the 3D receiving facilities will be arranged to permit tri-static observations to be made throughout the central core FOV at all altitudes up to 800 km.

2.7 Beam steering

It will be possible to steer the beam from the central core transmit/receive antenna array into any one of ≥12000 discrete pointing directions, regularly distributed over its FOV and separated by on average 0.625° in each of two orthogonal planes. The beam steering system will operate on a <500 μs timescale.

2.8 Multi-beam 3D receiving

Each receive-only phased array will be equipped with at least five beam-formers, permitting the simultaneous generation of independently steerable receiving beams that can intersect with the central core beam at different altitudes. It will be possible to steer each beam into any one of ≥12000 discrete pointing directions, regularly distributed over the array FOV and separated by on average 0.625° in each of two orthogonal planes. The beam steering systems will operate on a <500 μs timescale and will be synchronised with the central core beam steering.

The D/E region receiving sites will provide 3D coverage over the central core FOV from the bottom of the mesosphere out to a maximum altitude of approximately 250–300 km, while the F/topside region receiving sites will provide 3D coverage over the range 200-800 km, thus providing truly simultaneous 3D measurements over the entire vertical extent of the ionosphere for the first time in the history of incoherent-scatter diagnostics. The transmit site will also provide continuing coverage into the topside to ~2000 km where 3D coverage is not required.

2.9 Automatic/adaptive beam pointing calibration

Software for automatic beam pointing calibration using celestial sources will be installed at each receive-only phased array. Under normal operating conditions, one of the available beams will be dedicated to tracking one or more of the strongest circumpolar celestial calibrators (e.g. Cas-A and Cyg-A) whenever they are in the array FOV. Pointing corrections will be continually computed from the measured data and fed back into the beam-former control system. Since the primary celestial sources will not be continuously in the FOV of the transmitting and local receiving array(s), a separate, local calibration source will be provided to fill the same role.

2.10 Transmitter parameters

Centre frequency:	between 220 – 250 MHz, subject to allocation
Peak output power:	≥2 MW
Instantaneous –1 dB power bandwidth:	≥5 MHz
Pulse length:	0.5–2000 μs
Pulse repetition frequency:	0–3000 Hz
Modulation:	Arbitrary waveforms, limited only by power bandwidth

2.11 Receiver parameters

Centre frequency:	matching the transmitter centre frequency
Instantaneous bandwidth:	±15 MHz
Overall noise temperature:	≤50 K referenced to input terminals
Spurious-free dynamic range	≥70 dB

2.12 Sensor performance in incoherent scatter mode

The parameters of the different subsystems will be chosen such that, for each of the measurement scenarios tabulated below, the radar will generate estimates of incoherently scattered signal power (or equivalently, uncorrected electron density) with statistical accuracies of better than 10 % in the specified integration times:

Altitude [km]	Electron density [m^{-3}]	T_e/T_i	Ion composition	Height resolution [m]	Integration time [seconds]
80	1×10^8	1.0		≤100	30
100	3×10^9	1.0		100	1
150	1×10^{10}	1.0	50% NO^+, 50% O^+	100	1
300	3×10^{10}	2.0	100% O^+	300	1
800	3×10^{10}	3.0	5% H^+, 95% O^+	1000	10
1500	1×10^{10}	4.0	10% H^+, 90% O^+		60

2.13 Sensor performance in in-beam interferometer mode

In interferometer mode, the sensor will provide horizontal, 2D resolution of better than 20 m at 100 km altitude.

To achieve this, the interferometry receiver subsystem together with the main TX/RX antenna and the outlier receiving antenna arrays shall be arranged to provide samples of the target visibility function on ~150 different baselines with lengths ranging from about six wavelengths (λ) to more than 750λ.

The data rate from the full interferometry system is about two orders of magnitude greater than the incoherent-scatter data rate. Therefore, interferometry data will not be routinely saved to permanent media. Instead, the interferometry receiver subsystem will be equipped with local data buffers and real-time threshold logic that requests data recording only when some preset level of coherence is exceeded.

3 EISCAT 3D Data Products Baseline

3.1 Summary of Data Products

The system will generate large volumes of data and choices must be made in both the type and the storage duration of these data. To clarify the different levels of data generated by the 3D system, a number of definitions are included in Appendix 2.

EISCAT will offer standard data products from the 3D system at each of the following levels:

- *Beam-formed data* will be stored in ring buffer of relatively long duration (hours to days) in a manner which allows for users to access and copy selected intervals. Because of bandwidth and data volume considerations, the beam-formed data may have to be stored in an IO-optimised format.
- At least one set of time-integrated *correlated data* will be calculated from each set of beam-formed data, and permanently stored in a Grid/Web accessible master archive.
- At least one, and possibly several, *analysed data* sets will be permanently stored corresponding to each set of correlated data. These will be processed with well-documented analysis strategies, at least one of which will be a standard strategy making the data suitable for use in “quick-look” applications and statistical studies (provision of the data analysis software is however not within the scope of the design study). Production of the analysed data will occur in real-time, as a matter of course, both for radar operators and other users wishing to monitor and access the real-time data.
- The primary data products will also be used to derive routine *value-added parameters* (such as velocities, conductivities, currents, and heating rates) which will be made available together with the analysed data sets.

In addition to the above standard data products, the following data products will also be available from some (but not necessarily all) experiments using the EISCAT 3D radars.

- Data on the *properties of measured spectra* (both ion-line and plasma line) comprising spectral power, numbers and locations of spectral peaks, asymmetries, spectral moments, etc. The extent to which such data will be available will depend on the details of the particular experiment.
- Data produced by *interferometry applications* (cross-phase, coherence and reconstructed visibility functions) will be stored in a ring buffer of sufficient duration to allow groups interested in interferometry applications to transfer them elsewhere. Threshold logic as described in section 2.13 will be used to determine which data need to be stored. Sufficient metadata will be generated to describe which data sets were used and how the interferometry calculations were carried out.

4 4: EISCAT 3D Data Storage, Access and Visualisation Baseline

4.1 Data Storage

File-based and relational storage philosophies will be used for data storage. The storage systems will provide secure access for users and automated, secure remote backup, be Grid-compatible, and allow easy association between data and metadata.

4.2 Data Access

Two different types of data access will be offered:

- The *standard access* will apply to the majority of users, who wish to access the archived correlated and analysed data sets that EISCAT will store permanently, together with the appropriate metadata. These will be accessible via the Web and ultimately via the Grid, subject to certain access controls, with users having the capacity to retrieve the data in file-based form, or submit queries to a database optimised for event searches and statistical studies.
- The *high-volume data access* is designed for interferometry data, beam-formed data and correlated data stored in medium term “ring buffer” storage at the pulse-to-pulse time resolution level. Users of these types of data will be able to establish point-to-point connections directly to the radar sites, access the ring-buffers, and transfer limited subsets of these data to other (non-EISCAT) sites for permanent storage. Such users will also have the possibility to deploy their own dedicated storage devices at the different sites, removing the need for high volume data transfer over networks.

Access to data may be regulated according to “rules of the road” similar to those presently applied by the EISCAT Scientific Association.

4.3 Data Visualisation

The visualisation tools to be designed in this study are primarily oriented towards the operation of the radar, rather than to the requirements of the science users. However, the software will be written in such a way as to provide science users with a basic platform on which to develop more complex applications.

4.3.1 Sample-level data

“Level meters” and similar utilities will be implemented; enabling the operator to probe the data flow rates the various antenna elements, to verify that the array is operating correctly. Due to the high data rates, it is not practical to provide complete visualisation of sample-level data.

4.3.2 Beam-formed data

An approach similar to that used for the sample-level data will be implemented to enable scientists and operators to assess whether a particular beam-former is operating correctly and whether all of the input data streams from the antenna array are present.

4.3.3 Correlated data

A capability will be provided to display data from multiple beams simultaneously, and to show detailed data from particular beams on request. The software will have the capacity to display data in the frequency domain (both ion line and plasma lines) and to show time histories of raw data.

4.3.4 System Status Information

A user-friendly interface will provide operators and science users with various kinds of system information (transmitter power, system temperature, measurements of signal phase etc.), together with other “status” information required to establish that the various elements of system hardware are working correctly together. A fault-diagnostic and corrective capability will be built into the interface.

4.3.5 Analysed data

A set of tools displaying the results of the initial analysis of each correlated data set, in a format suitable for verifying the correct operation of the system, will be provided. Links between the visualisation utilities for correlated data, the analysed data, and system monitoring data will enable the presence of a fault in any one part of the system to be easily recognised elsewhere and its causes and consequences determined.

Appendix 1

Tentative EISCAT 3D System Layout

The figure shows one possible layout of the EISCAT 3D system. In this configuration, the central core (denoted by a green filled circle) is assumed to be located near the present Norwegian EISCAT site at Ramfjordmoen. The dashed circle with a radius of approximately 250 km indicates the approximate extent of the field-of-view of the central core at 300 km altitude. Phased-array receiving sites located near Porjus (Sweden) and Kaamanen (Finland) provide 3D coverage over the (250-800) km height range, while two additional receiving sites near Abisko (Sweden) and Masi (Norway) cover the (70-300) km height range.

Appendix 2

Definitions of terms and acronyms used in the text

2D	Two dimensional.
3D	Three dimensional. Generally referring to the simultaneous and unambiguous derivation of three independent components of the full velocity vector.
Analysed data	these data are formed by appropriately post-integrating the correlated data and then passing them through an analysis program, such as the GUISDAP code presently used by EISCAT, to produce ionospheric parameters. At this level, the data volumes will be roughly equivalent to those handled in the current EISCAT system, except that several equivalent data sets can exist simultaneously (corresponding to a number of simultaneous beams).
az	azimuth.
Beam-formed data	these consist of the weighted sum of a number of streams of sample level data, each of which is multiplied by a different complex-valued weighting coefficient in order to form a “beam”. Like sample-level data, these data are time-sequenced and unintegrated. The data remain uncorrelated, and still have a time resolution at the IPP level. At the receive-only sites a number of such beam-formed data streams will be generated concurrently.
BITE	Built-in test equipment
Correlated data	these comprise the auto-correlated power domain data from each beam. A correlated data set will generally be appreciably larger than a beam-formed data set, because correlation will involve generating the whole lag profile matrix. However, this inflation in size may be off-set by post-integrating in time (typically to the order of 1 second). There is no requirement that correlated data from all experiments should have the same time resolution – the time resolution will depend on the properties of the experiment (as at present).
EISCAT	The European Incoherent Scatter ISCAT Scientific Association.
el	elevation.
FOV	Field of View.
FP6	European Union Sixth Framework Programme.
IPP	Inter-pulse period.
Metadata	these are time-stamped data, containing comprehensive information about the system state and radar operating mode, as well as data from co-located and/or remote auxiliary instrumentation. They are automatically generated whenever the system is operating, such that every data-set of type (a-d) automatically gets a metadata set associated with it. Analysis and visualization software processing any of the other data types can reference the metadata to retrieve the data context and to configure itself appropriately. Metadata can also be accessed and visualised independently for e.g. event-search or maintenance purposes.
n_e	Electron number density (in the ionosphere).
PMSE	Polar Mesospheric Summer Echoes (also in winter PWME)
Sample-level data	consist of the complex-amplitude data coming from the antenna array elements and composed of at least two orthogonally polarised channels per element, each sampled at sub-microsecond resolution. These data are produced by the first-stage digitisation of the received signal. They are time-sequenced and unintegrated.
VLSI	Very Large Scale Integration.

Appendix 3

The Questionnaire

UGW 2005-04-07, 2005-06-01

EISCAT 3D QUESTIONNAIRE

1. General Questions

What is your primary field of scientific expertise?

What is your current primary research direction?

Which parts of the ionosphere and/or middle atmosphere do you study by radar?

Which radar techniques (e.g. meteor scatter, coherent scatter, incoherent scatter) are used in your research?

Which other instruments (apart from radar) do you use in your research?

Are you heading a research group?

In which direction do you expect your (and your group's, if applicable) science to be heading over the next five years?

Do you expect to become an active user of a future EISCAT 3D radar, on the basis that this radar will replace the existing EISCAT mainland radar facilities? Remember, the earliest we can expect to have even a subset of it on line is about seven years from now, i.e. in 2012…

What do you believe that the primary science goals of such a radar should be? Bear in mind that your answer should not be constrained by the capabilities of the current EISCAT system.

What particular features would the new radar system need to possess, in order to address these science goals?

2. System Specifications:

Please provide well-argued, scientifically justifiable answers to as many of the points below as you feel you are competent to judge, and/or are relevant to your current and future research requirements:

2.1 Transmitter:

Assuming that only one radar site can be equipped with a transmitter:

- *Should this be one of the existing sites?*
- *If YES, which one?*
- *If NO, approximately where should it be located?*
- *If NO, should the transmitter site also have receiving capabilities?*

Assuming that there is enough money or sufficient pressure to equip more than one site with a transmitter:

- *Where should the second transmitter go?*
- *Why? What specific science should it be used for?*

- *How powerful should it be (in percent of the main transmitter and/or in absolute terms)?*

2.2 Multi-static reception:

3D electric field measurements are possible already with two properly oriented baselines, but adding more baselines will improve the 3D imaging capabilities of the radar as well as the statistics. Please indicate the minimum number of multi-static baselines your science requires, their lengths, and their approximate orientations relative to the transmitter site and the minimum number of independent receiving beams along each baseline.

2.3 Multi-static field-of-view:

Please indicate the approximate geographic latitude and longitude boundaries of the field-of-view over which you would like to see the new radar offer full multi-static, multi-beam performance. Remember that these boundaries are likely to be a function of height, so you might want to define the multi-static viewing areas required separately for a number of different heights (e.g. 80 km, 150km, 300 km, 800 km).

2.4 Mono-static field-of-view:

Please indicate the approximate geographic latitude and longitude boundaries of any additional field-of-view, extending outside the multi-static field-of-view specified above, over which you would like to see the new radar offer reasonable mono-static, multi-beam performance. Note that this is likely to be one of the areas where design compromises might be necessary. As above, it would be useful if you could define the viewing areas required at a range of different heights, including heights above the maximum limit of multi-static operations.

2.5 Spatial resolution:

Please indicate the approximate spatial resolution (half-power points) needed in the vertical and horizontal planes over the field-of-view. Once again, it would be useful to define this parameter for a range of different altitudes (e.g. 80 km, 150km, 300 km, 800 km).

2.6 Time resolution:

What temporal resolution (to 10% accuracy in n_e*) is required at the altitudes and respective electron densities listed below? Note that the densities listed here are on the low side of what is commonly observed; this is on purpose to start you thinking about what you might want to do and/or need if these lower densities could be observed routinely…*

- 80 km, 1×10^{8} m^{-3}
- 100 km, 3×10^{9} m^{-3}
- 150 km, 1×10^{10} m^{-3}
- 300 km, 3×10^{10} m^{-3}
- 800 km, 3×10^{10} m^{-3}
- 1500 km, 1×10^{10} m^{-3}

2.7 CP multi-beaming:

How many simultaneous multi-static measurement volumes, and at what altitudes, would you like to see for Common Programme-type experiments to be run on the EISCAT 3D system?

2.8 System RF bandwidth:

The new system will probably operate somewhere in the 200 – 240 MHz range. While it is unlikely that we can dictate the exact centre frequency (we shall have to live with what we can negotiate from the authorities), the total required RF bandwidth should be large enough to satisfy all justifiable user requirements:

- ➢ *What is the minimum transmit/receive bandwidth required to satisfy your scientific requirements?*

3. Radar data products:

How important is it for you to have access to the following data products in real time:

(a) Analysed data

(b) Raw data as correlated lag profiles from each beam

(c) Pre-correlated samples from each radar beam

(d) Sample matrix data from the antenna array, prior to beam forming

What steps should be taken to ensure inter-operability between data from the new radar, and those from other diagnostics?

4. Other comments

Please feel free to add anything else which you feel to be a significant consideration regarding the design and operation of a next-generation EISCAT radar system.

Please reply by email to ugw@eiscat.com

or by regular mail to:

Gudmund Wannberg
EISCAT Scientific Association
Box 164
SE-981 23 Kiruna
Sweden

Appendix 4

User Community Response to the EISCAT 3D Questionnaire

RESPONSE TO THE EISCAT 3D QUESTIONNAIRE

1. General Questions

What is your primary field of scientific expertise?

About equally distributed (5-7 votes for each field) between:

- atmospheric/mesospheric physics,
- ionospheric physics,
- magnetospheric physics,
- space plasma physics.

Several replies indicating multiple interests.
Solar wind studies and techniques/technology development 1 vote each.

What is your current primary research direction?

Wide diversity with some overweight for, respectively, D region/middle atmosphere studies and ionosphere/magnetosphere coupling

Which parts of the ionosphere and/or middle atmosphere do you study by radar?

Middle atmosphere/D region – 3 votes
E region/lower thermosphere – 12 votes
F region – 10 votes
Lower magnetosphere – 3 votes

Several replies indicating multiple interests.

Which other instruments (apart from radar) do you use in your research?

Are you heading a research group?

Yes – 16 replies out of a total of 22

In which direction do you expect your (and your group's, if applicable) science to be heading over the next five years?

Replies span the whole range from PMSE to solar/terrestrial interaction, but a move towards studies of small-scale structures and short-timescale phenomena is evident in nearly all replies. A strong interest in applying interferometric techniques is evident.

Do you expect to become an active user of a future EISCAT 3D radar?

Yes – 16 replies out of a total of 22

What do you believe that the primary science goals of such a radar should be?

More detailed studies of small-scale processes in basically all atmospheric regions, in particular in the mesosphere and the auroral E region.

What particular features would the new radar system need to possess, in order to address these science goals?

Multi-static configuration with multi-beaming capability,
Low altitude (< 70 km) capability,
High spatial and temporal resolution, interferometric capability,

Flexibility and continuous-operation capability.

2. System Specifications:

2.1 Transmitter:

Assuming that only one radar site can be equipped with a transmitter:

➢ *Should this be one of the existing sites?*	Yes – 10, No – 2, Abstaining – 5
➢ *If YES, which one?*	Tromsø – 8, Kiruna –1, Sodankylä - 1
➢ *If NO, approximately where should it be located?*	Andøya –1, “better site” – 1

Assuming that there is enough money or sufficient pressure to equip more than one site with a transmitter:

➢ *Where should the second transmitter go?*	Well to the south / ⊥ **B** – 3, Kiruna/Sodankylä – 1 each, Andenes/Esrange – 1 each, Finnish Lapland – 1, Tromsø – 1
➢ *How powerful should it be (in percent of the main transmitter and/or in absolute terms)?*	10 – 50 kW – 2 votes 50 – 500 kW – 2 votes Same as main TX – 6 votes

2.2 Multi-static reception:

Please indicate the minimum number of multi-static baselines your science requires, their lengths and their approximate orientations relative to the transmitter site,

≥ 2 long (≥100 km) baselines, oriented N-S and E-W – 6,
3 – 4 baselines with the sun in the field-of-view (IPS) – 1,
≥10 short (< few km) baselines (interferometry) – 2,
Abstaining or no opinion – 8

and the minimum number of independent receiving beams along each baseline:

No clear opinion, but a general indication that multiple beams would be an advantage (≥ 2 beams and ≥ 5 beams being mentioned)

2.3 Multi-static field-of-view:

Please indicate the approximate geographic latitude and longitude boundaries of the field-of-view over which you would like to see the new radar offer full multi-static, multi-beam performance:

(65°–75° N, 6°–32° E) – 1,
(All azimuths, elevation ≥20°) – 1,
(To 500 km altitude at 73.9 ° N, 17.6 ° E) – 1,

2.4 Mono-static field-of-view:

Please indicate the approximate geographic latitude and longitude boundaries of any additional field-of-view, extending outside the multi-static field-of-view specified above, over *which you would like to see the new radar offer reasonable mono-static, multi-beam performance. Note that this is likely to be one of the areas where design compromises might be necessary:*

(Common volume @ 800 km altitude above the ESR) – 1,
(500 km radius circular coverage @ 300 km altitude) – 1,
(Current UHF az-el FOV paired with VHF range coverage) – 1,
(elevation ≥20 ° in N–S plane, ≥20 in E–W plane) – 1,
“No opinion” and N/A – 10

2.5 Spatial resolution:

Please indicate the approximate spatial resolution (half-power points), which is needed in the vertical and horizontal planes over the field-of-view:

Vertically		
	100 m	2
	50 m	2
	30 m	1
	10 m (!)	1
Horizontally (@ 100 km)		
	10 km	1
	250 m	2
	100-150 m	3
	10 m (!!)	1

2.6 Time resolution:

What temporal resolution (to 10% accuracy in n_e) is required at the altitudes and respective electron densities listed below?

80 km, 1 x 10^8 m^{-3}	5 min (2), 2 min, 30 s
100 km, 3 x 10^9 m^{-3}	2 min, 5 s (2)
150 km, 1 x 10^{10} m^{-3}	2 s, 0.1 s
300 km, 3 x 10^{10} m^{-3}	2 s, 1 s, (<< 1 s)
800 km, 3 x 10^{10} m^{-3}	15 s, 10 s
1500 km, 1 x 10^{10} m^{-3}	1 min (3)

2.7 CP multi-beaming:

How many simultaneous multi-static measurement volumes, and at what altitudes, would you like to see for Common Programme-type experiments to be run on the EISCAT 3D system?

3, at ~ 110, 150, 325 km,
3, at ~ 100, 300, 1500 km,
5, at 100, 200, 350, 600, 1500,
one beam in the F region and ≥4 beams resolving the E region,
9 abstaining / no opinion

3. Radar data products:

How important is it for you to have access to the following data products in real time:

Data Product	Very important	Important	In near-real-time	Not required
Analysed data	*10*	*0*	*1*	*1*
Raw data as correlated lag profiles from each beam	*4*	*4*	*1*	*3*
Pre-correlated samples from each radar beam	*2*	*2*	*4*	*4*
Sample matrix data from the antenna array, prior to beam forming	*0*	*2*	*2*	*5*

No preference indicated, or N/A – 4 replies

What steps should be taken to ensure inter-operability between data from the new radar, and those from other diagnostics?

- Continuous, fully automated system calibration
- Accurate absolute timing
- Standard data formats; data product better matched to plasma diagnostics needs
- Subset of analysed data available on-line in near-real time
- Easy user access to derived physical parameters
- Data product DataGrid compatible

No preference indicated, or N/A – 13 replies

4. Other comments

Please feel free to add anything else, which you feel to be a significant consideration regarding the design and operation of a next-generation EISCAT radar system:

Full mono-static system performance in a magnetic-field-aligned pointing geometry is mandatory (explicitly requested by nearly everyone who replied)!

Remote operation, flexible scheduling