EISCAT_3D Project

WP10 Final Report

New Techniques

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1. Summary

The present chapter summarizes the three deliverables that were produced during the lifetime of WP10 and one deliverable produced after the re-structuring of the work-package in which the description of work was changed. The first report has a list and evaluation of non-traditional or new uses that potentially could be implemented with the EISCAT_3D radar. The necessary radar specifications for new uses that could be implemented do not depart much from the agreed specifications for this design. During this term, a retrospective analysis of the EISCAT database was started and an overview of the available data was obtained. The first of two reports delivered in 2007 contains an overview of satellite navigation systems and remote sensing satellite systems. The role of Total Electron Content (TEC) in the degradation of radio signals and its measurement, especially by the EISCAT radars, is described. The overviews presented here validate the need for this study and lay the groundwork for future studies. The second report delivered in 2007 describes the development and utilization of a software package to retrieve incoherent scatter radar data from large databases (e.g., Madrigal). The package was employed to obtain synoptic overviews of ionospheric parameters measured by the EISCAT radars over their lifetime up to the present (2006) over one (Svalbard radar) and two (mainland radars) solar cycles. The synoptic overviews have exceedingly great potential for climatic and global change studies. The final report on ionospheric signatures of Global Change identifies the potential of the EISCAT_3D radar to contribute to the detection of these signatures and confirms the potential of the synoptic overviews mentioned above. It discusses operational and planning issues that have an impact on the collection of long-term data sets that are necessary for Global Change studies.

2. Introduction

Section 3 contains a summary of the first report/deliverable that was submitted in April 2006. Section 4 and 5 deal with two reports submitted in April of 2007: One focusing on long-term time series of radar data and its potential for climatic studies; and the other about the contributions that electron density measurements with incoherent scatter radar can make to help mitigate the deleterious effects of ionospheric variability on radio-wave propagation employed by global navigation and positioning satellite systems (GPS and Galileo) and Synthetic Aperture Radar (SAR) techniques. Section 6 contains a summary of the new project on ionospheric signatures of Global Change that replaced the original description of work of WP10. Section 7 has a live list of web links to the original reports in the EISCAT_3D web site. Section 8 contains a list of references. Finally, Section 9 contains acknowledgments and a list of contributors to Work Package 10.

3. D10.1 Progress Report — Final Version, March 2006

A search for recent scientific papers dealing with non-traditional uses of geospace research radars has been performed to obtain an overview of the state-of-the-art in the field. Based on the results of the search, possible new uses of incoherent scatter radars have been outlined with special focus on global climatic change. In total over 200 documents were processed of which 150 pertain climatic change and 50 non-traditional uses of incoherent scatter radars. Since climatic monitoring is an essential part of WP10, an important objective of the literature search was to evaluate the extent to which incoherent scattering radars, or similar, have been employed for climatic studies.

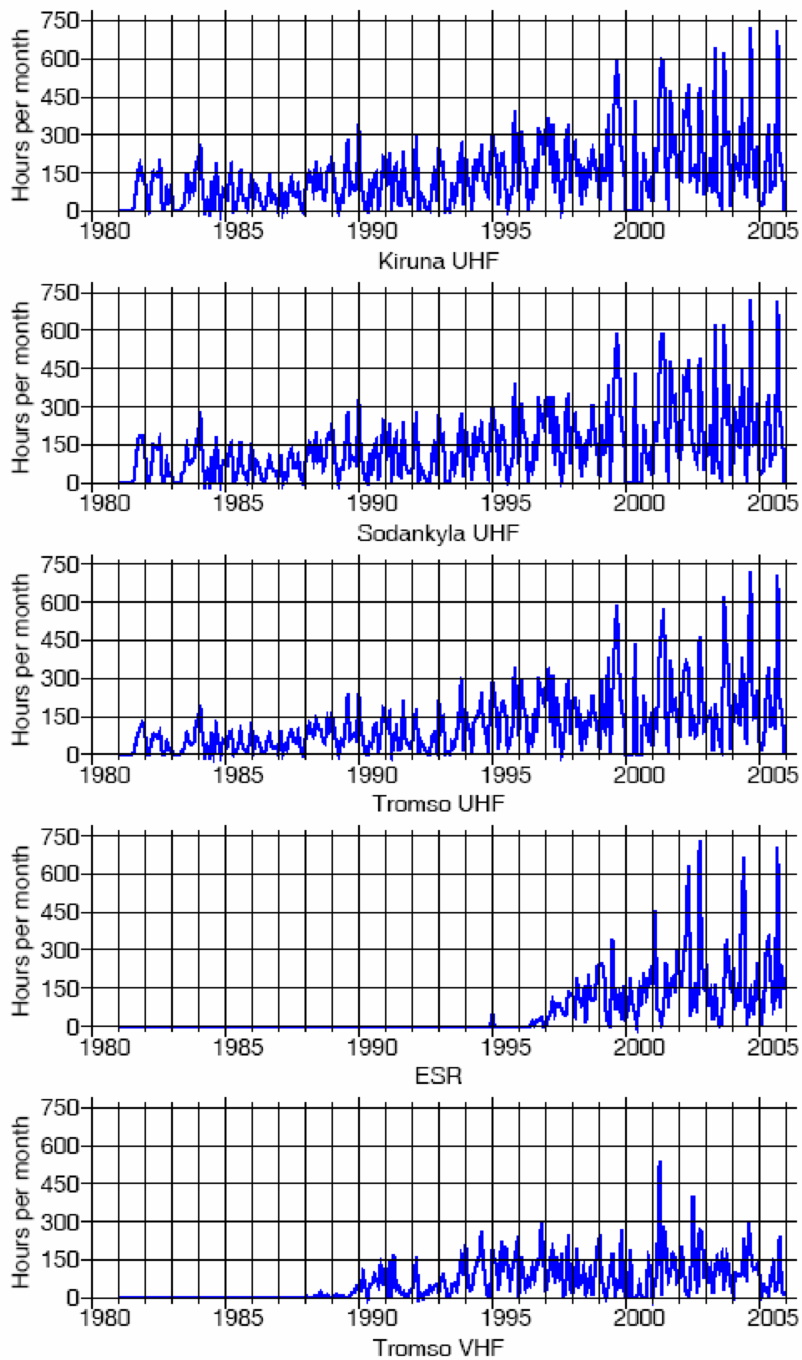

Figure1. Number of observational hours per month at the EISCAT ISR instruments obtained from the EISCAT auto-generated schedule.

Among the parameters that have been studied as proxies for trends attributable to global climatic change are: total electron content (TEC), the ionospheric critical frequency $foF2$ and its height, ratios of molecular ions in the $F1$ region, the distribution of electron number density with height, and others.

The literature search was also employed to investigate possible new or non-traditional uses of the new radar. The objective of this item was to evaluate the feasibility of different "unusual" applications. The following major subjects were identified and their prospects analysed:

Artificial ionospheric targets	Feasible, warrants further investigations.
Space debris	Feasible.
Planetary radar	Feasible.
Magnetospheric radar	Seems feasible; requires high sensitivity and longer integration intervals. Requires further investigation.
General relativity theory	Requires exceedingly high accuracy. Seems infeasible but requires further consideration.
Radiation belts monitoring	Needs further investigations.
Meteor radar	Feasible.
SETI (search of extra-terrestrial intelligence)	Feasible, requires specialized software and processing techniques

A retrospective analysis of observations made by the currently operating EISCAT radar systems has been done aimed at assessing the computational resources that will be necessary to carry out another task of Work Package 10, namely the development of tools for the utilization of long-term data series, whose principle application will be the study of climatic change signatures in geospace accessible to the eventual EISCAT_3D radar system. Long-term data series are necessary to discover trends of ionospheric parameters possibly connected to global climatic changes. Figure 1 shows the number of operating hours per month of each of the EISCAT instruments since operations started in 1981 (1995 for the Svalbard radar) up to the end of 2005. The data obtained in this period has been employed in the studies undertaken in the next report.

An assessment of the desirable technical specifications of the new radar was undertaken in order to fulfill the most demanding new applications identified in this study and to compare them to desired operational capabilities. The resulting specifications do not deviate considerably from the specifications borne out from the user poll made at the start of the project.

In summary, the review of scientific publications and the subsequent analysis of possible non-traditional uses of the new radar demonstrate how difficult it is to find entirely new uses. Most of imaginable new applications of IS radars have been tested in one or another form. The potential for climatic studies provided by the already existing EISCAT data appears very high and promises new important scientific results, in particular after the new radar is put into operation with its superior specifications and the prospects of continuous operations. The technical specifications desirable from the point of view of the most demanding new applications have proven to be in an agreement with those already suggested for the new radar. Retrospective analysis of scheduled observations and the geophysical data computed from EISCAT data show ever growing potential of the radar system for long-term studies. This work has been continued in the subsequent report focused on the EISCAT raw data archive, the production of a software package to extract the data from the data archive in a systematic manner from widely differing types of experiments and the employment of the data base for studies on climatic change and for studies of ionospheric variability deleterious to ionospheric radio wave propagation, satellite communications and global navigation and positioning systems.

4. D10.1 Use of Long-time Data Series of Incoherent Scatter Radar Data for Improving ionospheric Correction Models at High Latitudes, April 2007

Plasma turbulence in the ionosphere is considered of significant importance for communication, navigation and surveillance systems based on trans-ionospheric radio links, since radio scintillation caused by electron density irregularities in the ionosphere may result in signal degradation and outage. In addition, some remote sensing techniques may also experience severe disturbances. With the help of ionospheric models it is possible to correct for these disturbances up to certain levels. However, these models do not represent very well the real ionosphere at high latitudes, since models have been built with the use of empirical data obtained at mid- and low-latitudes. Thus, one of the purposes of WP10 is to investigate the feasibility and utility of employing long time-series of incoherent scatter data to improve the integrity of trans-ionospheric radio communication signals, especially at high latitudes. A critical area in which this contribution can be important is in improving the ionospheric models used by the GPS and the Galileo global navigation satellite systems. This report gives an overview of satellite navigation systems and remote sensing satellite systems. In addition, the physical basis of the Total Electron Content (TEC) is introduced, as well as different ways of retrieving other ionospheric parameters that play a role in the degradation of the radio signals. Finally, a review is presented of previous work concerning the measurement of electron density by means of incoherent scatter radar, in particular by EISCAT, and includes a comparison with electron density measurements obtained by other instruments as well as comparisons with existing models. The overviews and reviews presented here validate the need for this study and lay the groundwork for future studies.

In Section 2 of the report a short overview over the working principles of Global Navigation Satellite Systems (GNSS) and Synthetic Aperture Radar (SAR) are given. General problems for GNSS systems that are caused by ionospheric disturbances are the increased time necessary to fix signal phase ambiguities, a reduced number of available satellites without ambiguities and without phase and amplitude fluctuations and a decrease in the integrity of the reference network model. Regarding SAR, ionospheric irregularities can lead to pixel mis-registration and artifacts in the phase differences.

Section 3 presents the physical background of the influence of TEC on trans-ionospheric radio signals. The main effects are that code pseudo ranges are measured too long and carrier phase pseudo ranges are measured too short in comparison with the geometric range between the satellite and the receiver. In addition, deviations in electron density can lead to ionospheric scintillations, most likely caused in the F-region of the ionosphere. At high latitudes these irregularities frequently occur with scale sizes of 100 km (called "blobs"). The polar F-layer in the auroral zone is often dominated by blobs. Poleward of the auroral oval, in the polar cap, "patches" with scale sizes up to 1000 km play an important role spatial distribution of irregularities in the ionosphere.

Section 4 presents alternative means of measuring the electron density in addition to incoherent scatter radar. Common measurement techniques include the use of GPS receivers by means of occultation techniques and by scintillation or tomography techniques.

Section 5 presents a selection of previous work of electron density measurements made by EISCAT often in combination with GPS and tomographic measurements as well as comparisons with ionospheric models with commonly are used for correcting GPS and SAR measurements. Firstly, these publications show the need for accurate measurements of ionospheric electron densities for calibrating other instruments or observations. Secondly, comparison with ionospheric models clearly state the need of large data inputs into these models at high latitudes since models and observations often differ significantly, not least because the polar ionosphere is a highly variable environment.

Finally, section 6 presents a summary and outlook.

5 First results of an open-source based program for acquiring long time series of ionospheric parameters from the EISCAT Madrigal database, April 2007

A software package has been designed and implemented to retrieve and process data from the EISCAT Madrigal database. The software package is an important tool to achieve the objectives of the EISCAT_3D Work Package 10, namely to explore the potential of the new radar to carry out climatic studies based on examination of long-term data series and to construct models of ionospheric electron density relevant to improve the accuracy of navigation and positioning parameters produced by the GPS and Galileo satellite constellations. Included are examples produced by the tool that show daily, seasonal and solar cycle variations of electron density measured by the EISCAT radars over two solar cycles. Work is already under way to use the data acquired and processed by the tool to assess current ionospheric models, including those used to make corrections to positioning parameters produced by the Galileo and GPS satellite constellations.

Objectives of the work package, as formulated in the description of work, are the use of long and continuous time series of physical parameters in the polar upper atmosphere for:

Climatic studies, that is, the climatic conditions in the upper parts of the atmosphere
Corrections for ionospheric disturbances in satellite data especially Galileo and GPS
Space weather studies
Correction of SAR remote sensing data

In order to develop a technique for accomplishing the objectives it is necessary to have access to databases that provide information about ionospheric parameters similar to that to be obtained by the new incoherent scatter radar. Most natural for the task at hand is to use the Madrigal database (http://www.openmadrigal.org). The Madrigal system is capable of serving archival and real-time data in a variety of formats and from a wide range of instruments including the existing EISCAT incoherent scatter radar systems. The EISCAT data available at Madrigal cover virtually the entire periods of routine observations since the radars were put into operation since 1984, 1990, and 1997 for UHF tristatic system, VHF, and EISCAT Svalbard (ESR) radars, respectively. A software package designed to be a tool to acquire and process the EISCAT data in Madrigal format has been developed and successfully employed. The python programming language was chosen for the development for a number of reasons, among them, for being internet compatible, object oriented, open source- and standards based, platform independent, non-proprietary, and others. The program is highly modular and can be easily scripted to execute many common necessary tasks such as acquire particular data-sets, integrate the acquired data with given strategies, and others. The report contains illustrative examples of scripts that perform common tasks.

At first, the acquisition was made by accessing the databases remotely through internet connections. The transfers proved to be too slow given the sheer size of the data-sets. The solution was to create a local database containing a copy of the needed databases. This proved to be fast and effective. To illustrate the power of the software, the entire data-set

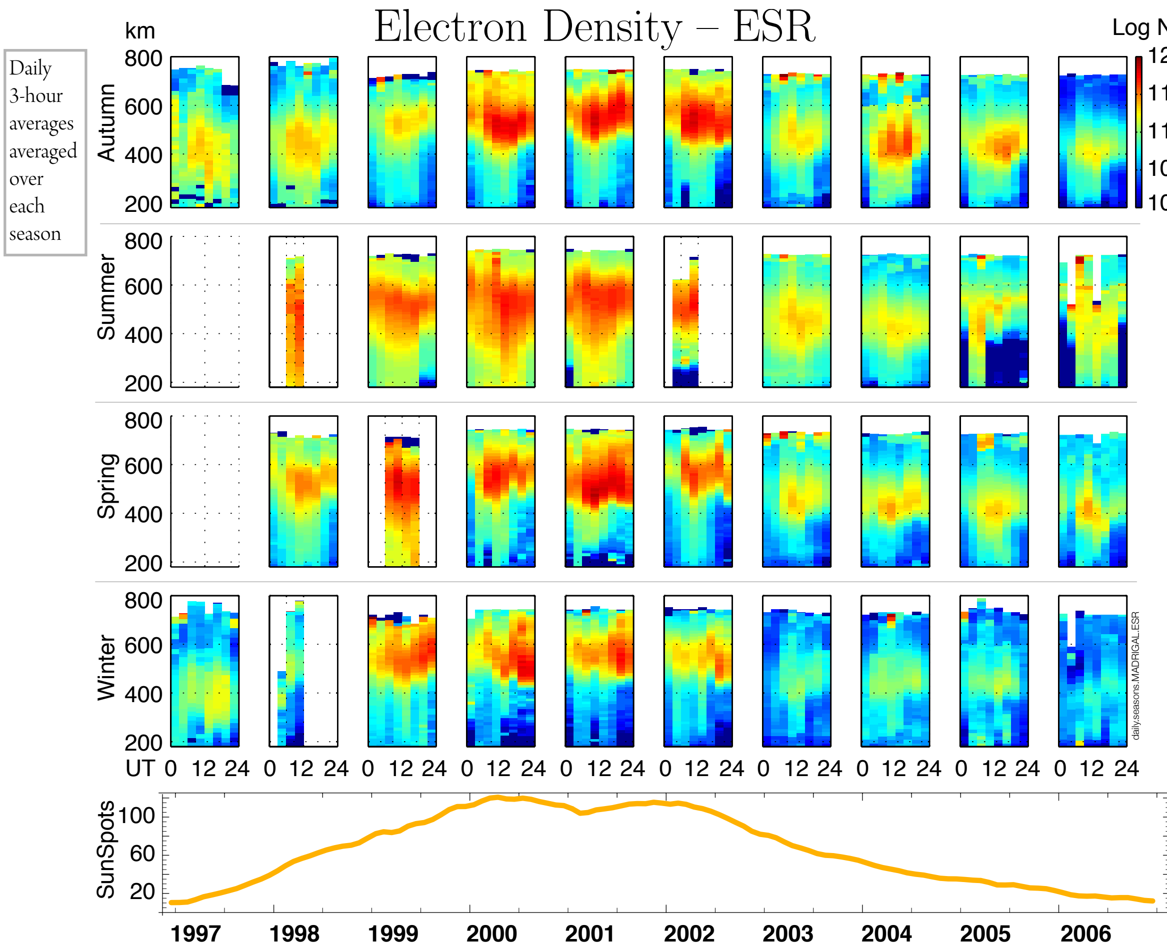

Figure 2. Electron density over Svalbard integrated over 3 hours and binned by season. The whole EISCAT Svalbard Radar data until the end of 2006 was

of electron density was acquired with the software and processed in various ways in order to have synoptic overviews over one (Svalbard) and two solar (mainland) cycles with different binnings to emphasize different trends of hourly, daily, seasonal, and solar cycle behaviour. An example is shown in Figure 2 which shows the seasonal variability of electron density as a function of altitude over one solar cycle covering from 1997 to 2006 over Svalbard (Belyey and La Hoz, 2007). The data has been integrated over three hours and binned over each of the three months of each season. The figure shows in a striking way the variability over height, season and phase of the solar cycle. Subsequently these data were compared to the predictions obtained from the IRI model (International Reference Ionosphere) resulting in marked deviations of the model from reality.

6. Ionospheric Signatures of Global Change

The increase of anthropogenic greenhouse gas emissions in the atmosphere is expected to cause an increase of the global temperature in the lower atmosphere and the oceans, while a decrease is expected in the middle atmosphere and ionosphere (Ulich et al., 2007). For instance, Brasseur and Hitchman (1998) anticipate a cooling of the stratosphere by 8–15 K, whereas Roble and Dickinson (1989) predict the mesosphere and thermosphere to cool by 10 and 50 K respectively, for a doubling of concentrations of carbon dioxide and methane. These changes are much larger than the changes in the upper atmosphere, and possibly some of its consequences should be easier to detect. Among others, changes in the electron concentration are expected (Rishbeth, 1990) that can be parameterized by the values of maximum plasma frequency in the E- and F-regions (foE and foF2) and the height of foF2, hmF2. Earlier work on this topic has been reviewed in this report. An assessment has been made as to what and how EISCAT_3D can contribute to studies of Global Change. The long-term time series of ionospheric parameters already organized as synoptic data (see the previous section) over one and two solar cycles can be utilized for Global Change studies showing that it is feasible to employ incoherent scatter radar data for this purpose. A few important issues have to be taking into account. To ensure data quality, it is advisable that changes in equipment and experimental setups (such as modulation codes) should be kept to a minimum. Long-term planning would minimize the impact of changes made to software and hardware on the small residuals that represent the trends that can be attributed to Global Change.

7. List of live web links to reports and deliverables

1. New techniques, D10.1 Progress Report, March 2006.
2. New techniques, D10.2 Second Progress Report (Part1): Feasibility Study Report: Use of Long Time Series ISR Data for Improving Ionospheric Correction Models at High-Latitudes, April 2007.
3. New techniques, D10.2 Second Progress Report (Part2): First results of an open-source based program for acquiring long time series of ionospheric parameters from the EISCAT Madrigal database, April 2007.
4. Ionospheric Signatures of global Change

8. References

Belyey, V., and C. La Hoz, First results of an open-source based program for acquiring long time series of ionospheric parameters from the EISCAT madrigal database, Abstract (2007), 13th EISCAT International Workshop August 6-10 2007, Åland, Finland.

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Rishbeth, H., A greenhouse effect in the ionosphere? (1990), *Planet. Space Sci.*, **38**, 945-948, doi:10.1016/0032-0633(90)90061-T.

Ullich, T., *Solar variability and long-term trends in the mososphere* (2000), Ph. D. thesis, Sodankylä Observatory, Sodankylä, Finland.

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9. Acknowledgments and Contributors to WP10

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