Cyprus Radar for Ionospheric Situational Awareness

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Abstract

CYprus Radar for Ionospheric Space Situational Awareness (CYRISSA), is a collaborative project funded from the Cyprus Research and Innovation Foundation (RIF) under the Call for Proposals for the «Small Scale Research Infrastructures» Programme within the framework of the «RESTART 2016-2020» Programmes for Research, Technological Development and Innovation. The key element of CYRISSA is the deployment of a mid-latitude Super Dual Auroral Radar Network (SuperDARN) system in Cyprus (CyDARN). This will be a unique infrastructure with the capability to provide useful products based on advanced signal processing and visualisation techniques and associated algorithms developed through long-term efforts of the SuperDARN community. The radar field of view will cover a significant part of central and northern Europe making its placement ideal for synergies with other projects and an abundance of scientific instruments such as ionosondes, GPS receivers, magnetometers and LOFAR (Low Frequency Array). CYRISSA scientific objectives cover the investigation of a broad spectrum of topics including: the impact of SAPS on the mid-latitude ionosphere over Europe, large scale (km) irregularity occurrence in the mid-latitude ionosphere, Traveling ionospheric disturbance (TID) monitoring and multi-instrument plasma velocity comparison with Digisondes and satellite missions.

Keywords: Ionosphere, Mid-latitude SuperDARN, Plasma convection, Ionospheric irregularities

1. INTRODUCTION

The Super Dual Auroral Radar Network (SuperDARN) is a network of high-frequency (HF) radars operated under international cooperation. Initially, the network was intended for high-latitude upper atmosphere dynamics monitoring but over the last 16 years, it has expanded into the mid-latitude regions first in the USA and then in Japan facilitating a wide spectrum of new scientific findings. More than 16 such radars are currently operating as part of the SuperDARN network, demonstrating an array of scientific achievements[1]. Observations by mid-latitude radars, i.e. radars that are located at mid latitudes and make observations of the ionosphere between mid-latitudes and auroral regions, depend upon range and the level of activity in the magnetosphere-ionosphere system. SuperDARN radars are coherent scatter radars that operate at frequencies between 8 and 20 MHz (although most radars actually operate over a narrower range of frequencies, typically between 10 and 14 MHz) and receive returned signal (backscatter) from ionospheric irregularities, the ground (or sea) and meteor trails[2]. These radars have at least 16 different look directions along which they can sample range gates. The normal range resolution along each of the 16 beams is normally 45 km and the number of range gates is typically 70 but this can be increased if necessary. This paper aims at highlighting the importance of the deployment of a mid-latitude radar over Europe and how it can facilitate remote sensing of strong plasma convection over European mid-latitudes during severe geomagnetic storms.

2. CYRISSA CHARACTERISTICS AND PURPOSE

The radar that will be deployed in Cyprus, will scan 16 directions with beam widths of the order 2.5^o, and range gates of typically 45 km along each beam. As can be seen from Figure 1, the Cyprus radar (Yellow field of view) will fill in a gap over middle and northern Europe. It is worth pointing out that the radar field of view will cover much of central Europe, the UK and the auroral regions in Norway, Sweden and Finland looking over the field of view of the new EISCAT3D radar. Backscatter from ionospheric irregularities can occur at a range of different altitudes, in the E, and F regions of the ionosphere. Ionospheric scatter received by the radar has a Doppler shift imposed on the signal due to the drift of the irregularities in the upper atmosphere. These line-of-sight velocities will provide detailed information on the meso-scale ionospheric velocity fields over Europe, which are controlled by electric fields. The normal, or common, operational mode of the radar provides a full azimuth scan every 1 or 2 min with integration times that vary between 3 and 6 s per beam. In this mode, the scan is always synchronized to the start on the 1-min boundary. The ground backscatter will also be used to detect travelling ionospheric disturbances (TIDs), which are manifestations of

Tenth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2024), edited by
A. Christofe, S. Michaelides, D. Hadjimitsis, C. Danezis, K. Themistocleous, N. Kyriakides, G. Schreier,
Proc. of SPIE Vol. 13212, 132120M · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3037212

atmospheric gravity waves propagating through the upper atmosphere. TIDs represent a significant space weather effect on trans-ionospheric propagation as well as on ground based radars. The new Cyprus radar will benefit from the Borealis radar system which is a hardware and software upgrade to the conventional Super Dual Auroral Radar Network radar system (since the early 1990s). Using software defined radios, Borealis has improved the flexibility, capabilities, and security of the radar system, as well as monitoring and diagnostics, enabling more complex experiments and enhanced spatial and temporal resolution. The system can perform full field-of-view imaging, pulse phase encoding and simultaneous multi-frequency operations with better data quality and system reliability. This allows experimental modes to run simultaneously which is particularly useful for the investigation of travelling ionospheric disturbances where multiple frequencies provide much more information than one single frequency.

3. CYRISSA SIGNIFICANCE FOR EUROPE

The operation of CyDARN will fully exploit the strategic position of Cyprus at the south-eastern border of the European region as its Field Of View (FOV) will cover a significant part of central and northern Europe making its placement ideal to be exploited fully through synergies with an abundance of other scientific instruments such as ionosondes, GPS receivers magnetometers and EISCAT installations (Figure 1). It will be the first mid-latitude SuperDARN operating in Europe and it will therefore offer significant prospects for utilisation within ESA Space Situational Awareness (SSA) activities. Therefore a quantitative assessment of the benefit of introducing CyDARN products in Ionospheric Weather Expert Service Centre (I-ESC) of ESA SSA (which facilitates provision of accurate, reliable and timely products and (pre-)operational services to end users to assess the influence of Space Weather), is vital.

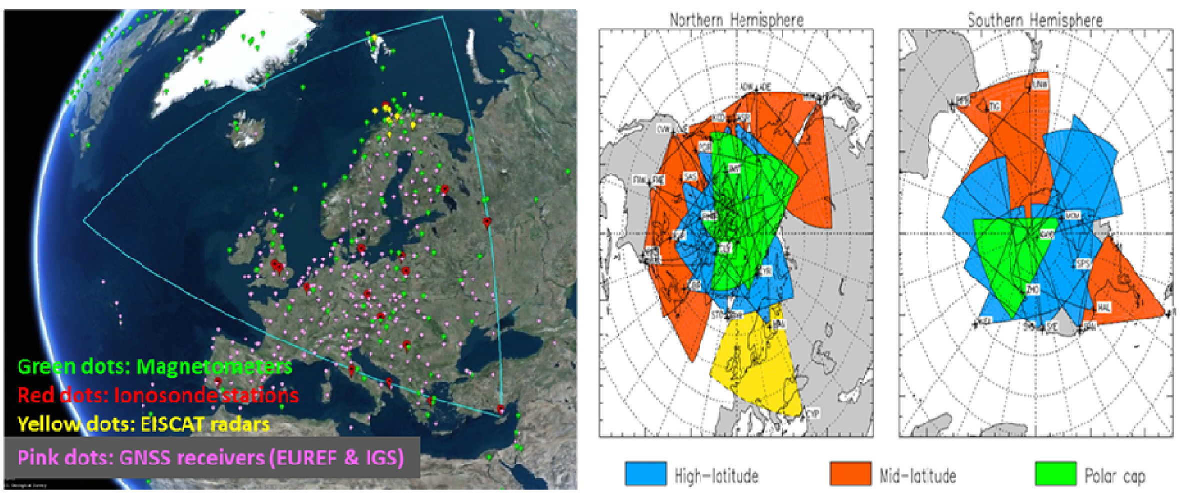

Figure 1. Map of the CyDARN field of view with associated overlapping instrumentation. Maps of SuperDARN radar fields of view in both the northern and southern hemispheres. The colour coding represents the latitude region primarily covered by the individual radars. The Yellow field of view represents the potential CyDARN field of view.

Under extremely active conditions a mid-latitude radar would make observations from more than one region of the ionosphere, e.g. mid-latitudes, sub-auroral and auroral, while under extreme quiet conditions it would probably only remotely sense the mid-latitude ionosphere. As a result, the radar data will facilitate monitoring of a wide spectrum of plasma physics phenomena. Motivation for the first SuperDARN radar located equatorward of 50° MLAT, and the subsequent expansion at mid-latitudes, was largely due to the inability of the existing high- latitude network to measure the full latitudinal extent of ionospheric convection during geomagnetically active periods. During times when the auroral region expands equatorward of the lower latitude limit of the existing network (~ 60° MLAT), radars are no longer able to measure the complete extent of convection. In addition, absorption due to enhanced precipitation can significantly attenuate radar signals at auroral latitudes, further reducing measurements of the ionospheric convection electric field. In this context CyDARN is expected to provide critical measurements in these regions over the European sector enabling near-continuous monitoring of convection in the mid-latitude region. Regarding the European sector EISCAT radars and existing SuperDARN systems can monitor the equatorward progression of the auroral convection before observations are disrupted by enhanced precipitation and E region backscatter at nearer ranges. However, during these periods, the mid-latitude CyDARN will be able to track the convection expansion at much lower latitudes offering additional degrees in latitudinal coverage and corresponding improvement in mapping the instantaneous global convection pattern, particularly on the nightside during increased geomagnetic activity where convection extends[2]. Such a case was the 2015 St Patrick storm. Figure 2 demonstrates enhanced convection for this event through consecutive Total Electron Content (TEC) maps which also indicate the locations of Fairford and Juliusruh mid-latitude ionosonde stations (Digisondes) in the UK and Germany respectively.

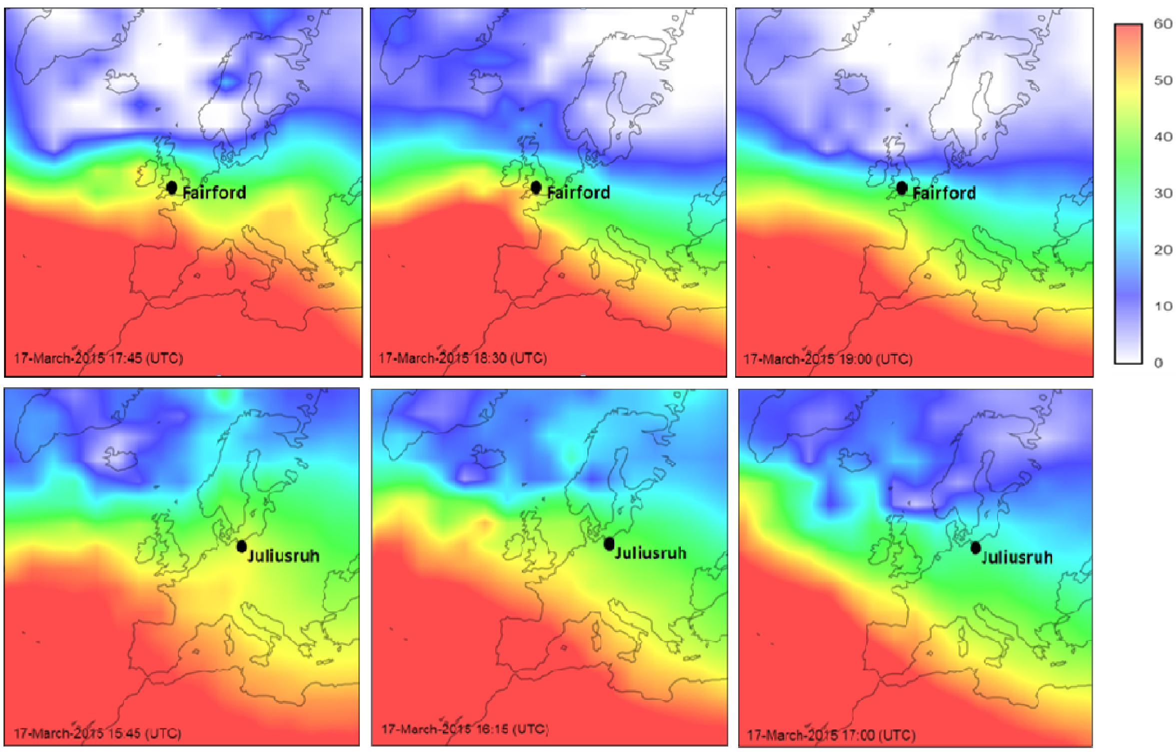

Figure 2. Maps of TEC over Europe on 17 March 2015, (from left to right). Black dots indicates the position of Fairford station and Juliusruh Digisonde stations.

Digisondes can provide essential ionospheric characteristics such as Frequency, Range (Height), Amplitude, Phase, Doppler Shift & Spread, Angle of Arrival and Wave Polarization. The plasma velocity components Zonal (Veast), Vertical (Vz), and Meridional (Vnorth) can be deduced from the Doppler Shift using interferometry[4]. The vertical drift component (Vz) can be estimated with a higher accuracy than the zonal and meridional drift components although the higher the horizontal (zonal and meridional) velocities, the lower the uncertainty in their estimation. There have been a number of studies exploiting these drift measurements to describe the morphology of plasma drifts in the mid-latitude ionosphere[5,6]. During the time intervals where the TEC maps over Europe correspond to, we can observe significant western drifts (>500m/s) designated by the pink dots in Figure 3 as measured by the two Digisonde stations. These drifts significantly exceed the quiet reference which is represented by the black dots on the same plots. After its deployment CyDARN will be in the ideal location to monitor the progression of such extreme mid-latitude plasma drifts which are likely to cause severe effects, on positioning and navigation systems, with great operational significance operating over European such as EGNOS.

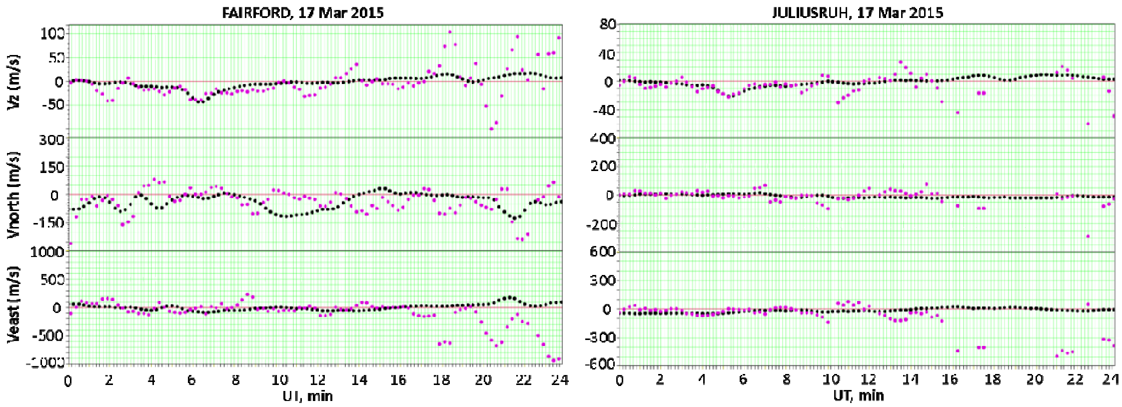

Figure 3. Plasma drifts over Fairford and Juliusruh on 17 March 2015.

4. DISCUSSIONS AND CONCLUDING REMARKS

This paper highlighted the importance of the deployment of the first mid-latitude SuperDARN over Europe. Although plasma drift velocity is currently measured by a number of European Digisondes, these velocities are valid only for a limited area around each Digisonde. In addition, based on the principle of the estimation of these drifts by Digisondes, the vertical drift component (Vz) can be estimated with a higher accuracy than the zonal and meridional components although the higher the horizontal (zonal and meridional) velocities the lower the uncertainty in their estimation. On the other hand, a SuperDARN can measure the velocities along each beam and resolve them into zonal and meridional components. Therefore the combination of the vertical drift component from the Digisondes and the horizontal velocities from the CyDARN (after its deployment) will provide an ideal framework based on which all three velocity components will be better represented over a significant area over Europe.

Acknowledgement

CYRISSA is co-funded by the Republic of Cyprus and the European Regional Development Fund ERDF (through the «Small Scale Research Infrastructures» Programme RESTART 2016-2020 Programme for Research, Technological Development and Innovation) and by the Cohesion Policy Programme “THALIA 2021-2027”.

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