Investigations into Small-Scale Disturbances in the Ionosphere Using SpICE

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Abstract

Ionospheric disturbances observed by bottom-side soundings appear at many temporal and spatial scales. Australia has many simultaneous observations from vertically orientated and oblique sounders with spatial separations on the scale of 1000km. However, with this spatial sampling only large scale ionospheric disturbances can be mapped and subsequently modelled. DSTO has an experimental program in progress to investigate the smaller spatial scale disturbances. These are often seen on vertical incidence soundings and are uncorrelated with soundings from ranges beyond 500km. They can also be uncorrelated with soundings from the same site only 15 minutes later. The DSTO program to investigate these ionospheric disturbances is called SpICE, for Spatial Ionospheric Correlation Experiment. SpICE uses a small set of transmitters and receivers with varying separations to achieve a geographically spread set of near-vertical incidence ionospheric “reflection” points separated by 50-150km. Using the latest in digital receiver technology we can collect continuous wave transmissions from a nearby transmitter that is rapidly sweeping through the HF band and process the signal at a very high resolution to achieve high quality ionograms at update rates of better than one-minute. Campaigns have been conducted in the country-side east of Adelaide, Australia (~35^o S, magnetic inclination ~67^o upwards), the Atherton tablelands, Queensland, Australia ~18^o S, magnetic inclination ~47^o upwards), and in Puerto Rico (~18^o N, magnetic inclination ~44^o downward). This paper will discuss the SpICE program goals, highlight some of the unusual features observed so far, and discuss measures of the disturbance features.

1 Introduction

Temporal and spatial variability of the electron density in the ionosphere affects HF communications, satellite telemetry, GPS accuracy and stability, and Over-the-Horizon Radar accuracy. Internationally, there is a good understanding of the monthly median and 500km-scale ionospheric electron density behaviour. This is captured in many models [1,2], the standard being the International Reference Ionosphere, IRI, which has been continuously updated since 1972 [3,4]. More locally Australian research organisations have made many simultaneous observations of the ionosphere from vertically orientated and oblique sounders for many decades [5-10], for example JORN has been using at least 12 vertical incidence sounders in the Australian region since 1997 [11]. This has allowed the large scale structure and morphology of the ionosphere over Australia to be investigated in detail [12]. However, as the typical spatial separations of these sounders are on the scale of 1000km, ionospheric disturbances smaller than this scale have not been able to be studied effectively.

The literature often discusses "Travelling Ionospheric Disturbances" or TIDs, and denotes the varying scales of these wave-like structures [13-17]. Large-scale TIDs (LSTID) have sources in the Auroral regions and travel westward and equatorward from the poles. The period of these waves range from 20 minutes to several hours. They have horizontal wavelengths of the order of 1000km and horizontal speeds of 200 to 1000 ms^{-1}. There are shorter wavelength disturbances called Medium-scale TIDs (MSTID) that travel in many directions and have a more varied set of sources, from tropospheric jet streams, to atmospheric gravity waves, to the solar terminator. MSTIDs typically have periods in the range of 10 to 60 minutes, with horizontal wavelengths of 100 to 300 km and horizontal speeds from 100 to 250 ms^{-1}

It is well known that even smaller spatial and shorter temporal scale disturbances also exist in the ionosphere, and that not all disturbances are in fact "travelling". Thus, DSTO has initiated an experimental program, SpICE (Spatial Ionospheric Correlation Experiment), to investigate the shorter period and smaller scale ionospheric variations. SpICE uses a carefully located set of transmitters and receivers with varying separations to achieve near-vertical incidence soundings, with ionospheric probing points separated by 50-150km. High time-delay and frequency resolution ionograms, with update rates less than 60 seconds, are collected using the latest digital receiver technology.

The goals of the SpICE program are to gain an understanding of:

- the physics of small-scale (< 30 minute, and < 300 km) ionospheric disturbances;
- the role of the various disturbance scales;
- and travelling versus in-situ disturbances;

2 The Equipment

The receivers and transmitters used for the SpICE campaigns were originally designed for HF radar experimentation. They were then adapted to be used for oblique incidence sounding. Both the transmitters and receivers are DSTO designed and developed, fully digital, wideband devices [18]. Both the direct digital receivers (DDRx) and the digital waveform generators (DWG) are computer controlled via tcp/ip over gigabit ethernet. Timing is controlled by a COTS GPS unit. Although the DWG is capable of arbitrary waveforms, for the current application they were producing a continuous-wave linearly swept in frequency (a "chirp" sounding). The extent and rate of the frequency sweep varied with the different SpICE campaigns, generally being swept from 3-15 MHz at a rate of between 200 and 500 kHz/s to achieve a full sweep every 60 to 30 seconds. A typical hardware arrangement for a SpICE transmit site is shown in Figure 1. The rack unit incorporates a complete vertical incidence sounding (VIS) setup comprising two digital receivers (DDrx) and a digital waveform generator (DWG) and a power amplifier (PA), as well as an oblique incidence sounder (OIS) transmitter comprising one DWG and one PA. The same computer and GPS timing units are used for both. The VIS transmitter is also used for the NVIS paths. The OIS transmitter runs on a separate schedule, with independent sweep rate and swept frequency range. This example is from the Campaign in Puerto Rico where the rack containing the equipment was placed in the cargo compartment of a minivan. In this setup there is a spare DWG. The SpICE receive sites had the same equipment without the DWGs and the PAs.

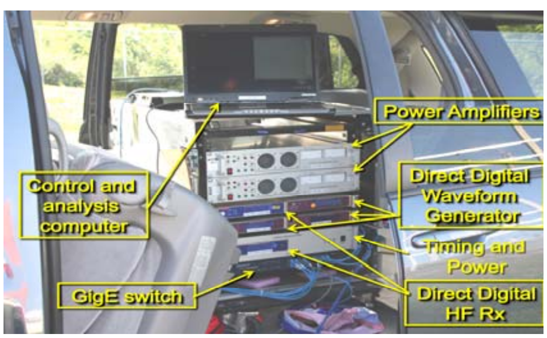

Figure 1: Typical RF hardware for a SpICE transmitter site. The system fits into a half-height 'roady' rack. This example the rack has been placed in the back of a van.

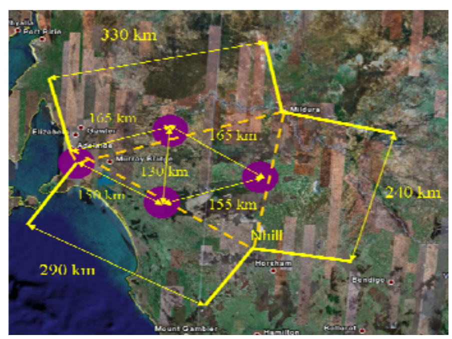

Figure 2: Geographic setup for SpICE-1 campaign near Adelaide, Australia. Magenta dots are the ionospheric probe points.

3 Results from The First Campaign

To date there have been three SpICE campaigns. This paper will concentrate on the first of these. The first campaign, SpICE-1, was conducted in the Adelaide region (~35°S, magnetic inclination ~67° upwards and declination ~8°E). Figure 2 shows the experimental setup. Receivers were located at DSTO-Edinburgh in the Adelaide outer suburbs, and in Mildura. Transmitters were located at Woodside and Nhill. Both Woodside and the site at DSTO are permanent installations hence have large (23m) good quality HF antenna. The remote sites of Nhill and Mildura had smaller mobile antennas (7.5m). Ionograms were collected continuously over 3-days (26-29 Feb 2008) over the 4 paths every 60 seconds. The magnetic conditions for the period were quiet to normal.

The typical time evolution of a TID signature (not shown here) is interpreted as a large travelling set of ripples in the isoionic contours at the path midpoint. The ripples are part of a wave packet, as they appear to come in small finite groups. The effect is that of a series of temporary additional ionospheric layers that descend in real height. Figure 3 shows what appears to be a signature of a travelling disturbance that occupies only a portion of the field-of-view for part of its appearance. The nine frames display a time sequence of near-vertical-incidence ionograms, in approximately 1-minute steps. Time progresses from the top left-hand frame (0917 LST on 27-Feb-2008) to the bottom right-hand frame (0927 LST). It can be seen that the "normal" ionospheric response is not affected by the disturbance that appears at successively decreasing group-delays and reducing frequencies just under the F2 critical frequency. Note that the disturbance feature appears at frequencies less than the normal F2 trace yet at greater group-delay. The disturbance descends in group-delay without affecting the background ionosphere until it reaches a point where its ionogram signature crosses the background F2 trace (circled in the figure). At this point the background ionosphere appears to be affected. After interacting with the background ionosphere the disturbance feature recedes the way it came. This can be interpreted as an electron density anomaly entering the field-of-view of the sounder, and then covering the field-of-view, then passing out again; receding in the F2 trace as it travels horizontally away from the observation region.

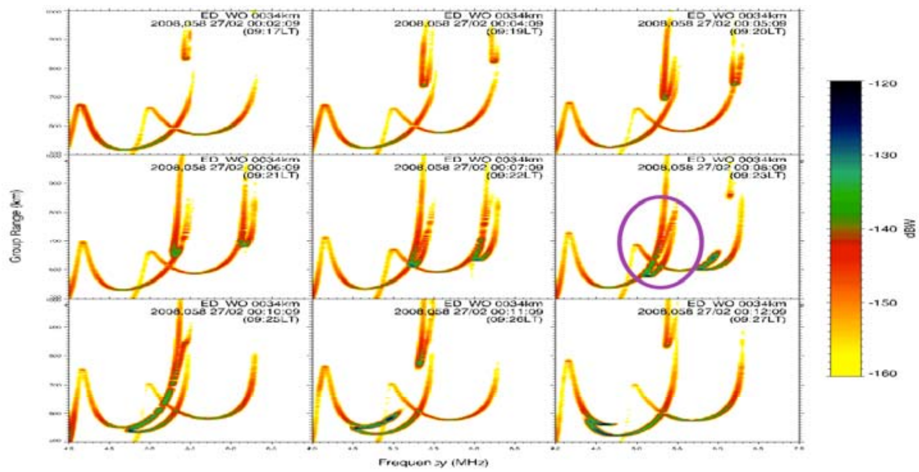

Figure 3: Example of an usual ionospheric disturbance event. Frequency is along the x-axis, group-delay on the vertical

Rarer disturbance features are also seen that appear at closer group delays moving to higher frequencies and greater group-delay. In at least one example, this apparent “upward” travelling disturbance meets and passes through another disturbance which is behaving in more the typical TID manner of descending in group-delay and frequency. Apparent "upward" motion (increasing in group-delay) is most likely a small scale electron density gradient that is moving horizontally away from the sounder, while the more typical downward feature are presumably from large/medium-scale TIDs exhibiting downward phase progression due to the atmospheric gravity wave drivers.

4 Analysis

There are several algorithms to "automatically" scale ionograms: that is, reduce the ionogram to a set of parameters that allow a reconstruction of the electron density height profile. Unfortunately all of these algorithms assume a set of 3 ionospheric layers. Disturbances are generally not dealt with specifically and result in an averaged layer profile or a parameter extraction failure. Because of this a 140-minute segment of the SpICE-1 dataset was manually scaled using a scheme that allowed for disturbances. The manually scaled data was recorded during the quietest magnetic conditions for the experiment yet it revealed several classical TID signatures as well as several unusual signatures, only one being reported here. Based on the "typical" TID features, the parameters scaled were the cusp or maximum frequency and the minimum group delay, for both the Ordinary and Extraordinary modes, for all layers present as well as any disturbances. Prior to scaling, all ionograms were transformed to equivalent midpoint ionograms using Martyn’s theorem and the secant law with an obliquity factor of unity. The parameter time series were then subjected to correlation and spectral analyses.

The power spectrum of the scaled minimum group-delay for the F2 layer, h’F2, for the Woodside-Mildura path midpoint showed that the main energy derived from the long period disturbances with powers peaking in the 60-90 minute period oscillations. Other periodicities were also evident in the power spectrum. Initial analysis focussed on periodicities which were greater than or less than 45 minutes, by low-pass filtering the parameter time series. Looking at the times series formed by the filtering (Figure 4) it is very suggestive that the high-passed h’F2 (short period oscillations) respond to the ionospheric disturbances in a measurable way. As a TID-like disturbance begins to appear on the ionogram the base of the F2 layer, h'F2, has already started to rise to meet the disturbance. As the disturbance passes through the F2-layer, h'F2 then drops. On many occasions the disturbance does not produce a noticeable group-delay or frequency perturbation, yet h'F2 will still rise and fall as shown here, suggesting that a disturbance has gone through the observation region. There is also often a power enhancement that ripples down the ionogram trace.

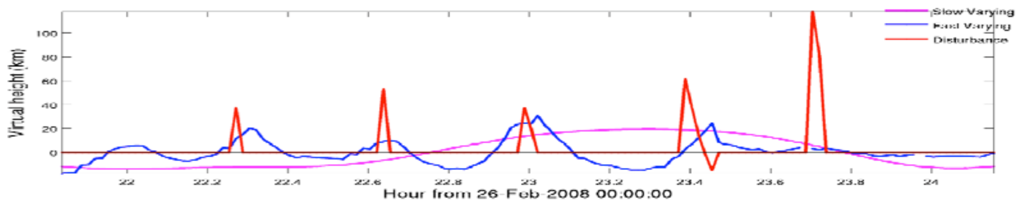

Figure 4: Timeseries of the low-pass (magenta), and high-pass (blue), and the disturbance components (red) of the scaled h'F2 parameter. The episodic nature of the disturbance feature and correlation with short period motion clearly is shown.

5 Conclusion and future work

We have reported on one of the unusual events recorded in the SpICE-1 dataset, as well as reporting on the relation of h'F2 to disturbance features. It appears as though the bandpassed h'F2 is a sensitive indicator of medium and small-scale TID-like disturbances. This has been reported in the literature over the years [19,20] for observations of LSTID (which fall into the long-period, >45 minutes, low-passed timeseries in this discussion). We have shown that this is also the case for shorter period disturbances as long as h'F2 is filtered appropriately to remove the large trends that would normally dominate the shorter period motions.

Modelling studies have been instigated to verify our understanding of what form of disturbance could create the observations. These studies will be reported elsewhere. Auto-correlation and cross-correlation studies, which give information about TID horizontal scales and velocities, are also underway. Finally, the character of the disturbances data revealed in SpICE-2 and SpICE-3 was different to the Adelaide dataset. More details of these experiments will be reported at a later date.

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