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Equatorial F-region Plasma Drift Measurements and Observations using Doppler Interferometry at Parit Raja

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Abstract— The measurements of ionospheric drift and convection using the digital doppler interferometer at the Wireless and Radio Science centre (Waras) at UTHM, is used to provide high temporal and spatial resolution measurements of the dynamics of the ionosphere at the Parit Raja station in Batu Pahat, Johor. These measurements include Doppler shifts, angles of arrival, as well as group ranges from the significant numbers of ionospheric echo sources simultaneously at the same time. By employing Doppler inteferometry reception technique at four receivers connected to four spaced antennas nearby, it is possible to identify the three dimensional locations of various scattering points reflected back from the ionosphere as a result of vertically-incident HF waves transmitted at frequencies of 5.9MHz, 7MHz, and 8MHz. These three frequencies cover the local F-layers since the critical frequencies lie between 6MHz and 8MHz for this local station. The technique of Doppler interferometry treats signal returns from the ionospheric F-region as reflections from individual scatterers. Spectral analysis is performed on the complex voltages generated from the four receivers' in-phase (I) and quadrature-phase (Q) detectors to produce Doppler frequency functions. Both spectral phase functions and amplitude functions are generated using Fast Fourier Transform or FFT by the receivers from the Doppler frequency functions. This will then result in a skymap display containing echo coordinates, ranges and Doppler shifts. By further processing of the echoes, drift velocities which can be deduced by a least-squares fitting algorithm can be found. The behaviour of the plasma movements under certain variations of the geomagnetic and solar activities can also be studied so as to be able to estimate the influence of geomagnetic storms and equatorial electrojets on the ionosphere, which is vital for navigation, surveillance and telecommunications.

Keywords— Doppler drift, doppler interferometry, ionosphere, skymap, spaced antennas

I. INTRODUCTION

The ionosphere has been extensively studied in the past. Monitoring of the plasma drifts and convection behaviour brings new informations concerning the various phenomena that affect the ionospheric processes. Scientific interest in ionospheric research in our country has intensified due largely to the need of modern military and civilian navigation, satellite, together with over-the-horizon or OTH terrestrial communications systems to provide precise positioning information as well as backup services for remote communications in times of disasters (eg., earthquakes and tsunamis). Knowledge of the behaviour and variations of ionospheric plasma drifts with local time, heights, solar cycles, geomagnetic storms as well as equatorial electroiects provide valuable informations that are important for development of ionospheric forecast models [1].

In order to gain a better understanding of ionospheric motions that affect signals for the above-mentioned applications, advanced Doppler sounders using digital interferometric reception technique is being employed at

UTHM Waras centre for ground-based observations that is capable of providing detailed informations regarding the structure and dynamics of the bottomside ionosphere at this local station. This digital ionosonde acts as an HF radar that measure more than just the time of flight and amplitude of the reflected echoes; they also determine the arrival angles, wave polarisations, and Doppler frequency shifts [2].

The technique relies on total reflection of the radio waves from the plasma structures that have plasma frequency f_N equal to the vertically-incident radio frequency f. This way, the ionospheric F-region (up to about 1000km) is excited for up to a few hundred square kilometers. And because of the non-uniform ionospheric surfaces and the volume inhomogeneities, the signal is reflected back from various reflection point sources to the Doppler interferometer at the ground for amplitude and phase processing in the frequency domain where valuable data can be extracted for further analysis.

A study of the plasma drift characteristics from measurements made at this local station is considered important in order to make comparisons with current modelling (theoretical or empirical) of the ionosphere or for development of future forecast models of ionospheric behaviour at this equatorial F-region station.

II. THEORY

The ionosphere is a very dynamic and disturbed region containing irregularities which, may be considered as providing a rough reflecting surface that varies with time. As a result of this roughness, signals associated with each propagation mode may arrive at the receiver over a range of angles in both azimuth and elevation or zenith angles. Furthermore, ionospheric movements close to the reflection points often impose large Doppler shifts and spreads onto the signal.

When Doppler spreading is observed in the received signal, a variation in the bearing or directions of arrival with Doppler frequency is also evident giving rise to positive and negative Doppler shifts. These are attributed to the reflections from the layers of ionospheric irregularities drifting across the reflection points. From [5], the drift velocity is related to the Doppler shift by fitting of the equation:

$$d_s = (1/\pi)\mathbf{v}.\mathbf{k}_s$$

where
- s = index number of reflection point
- d = Doppler shift of reflection point at Rx
- **v** = reflecting plasma drift vector velocity
- **k** = unit vector from the ionospheric reflection point towards digisonde

The results presented in this paper are generally based on the above relationship.

III. MEASUREMENTS

The digisonde at Waras is used to measure and monitor the plasma drift or convection behaviour as a function of time for the Parit Raja station located at longitude 1^o 52’ and lattitude 103^o 48’. The digisonde operates alternately between the ionogram mode and drift mode whereby the iograms are spaced by 5-minute intervals and the time in-between is filled with a number of F-region drift measurements from vertically-incident fixed HF frequencies of 5.9MHz, 7MHz, and 8MHz using a delta-type transmitting antenna co-located with 4 receiving dipole antennas arranged across a North-South and East-West baselines at a nearby field. The transmitter uses a 13-bit Barker-coded waveform with phase modulation that produces compressed waveforms with radiation patterns which minimise interference between the transmitter and receiver antenna sidelobes. This will give a further 11dB or $10^{1.1}$ = 13 times more transmitted power at the output.

In order to ensure accuracy in the measurement of phase differences across each antenna pair, the phase responses of the 4 receivers are matched during installation and the antenna cables are cut to identical lengths. The technical specifications of the digisonde used in the measurement are given by the following table below:-

Table 1 Specification of DOPPLER interferometer used

1	Transmitter Peak Power	600W
2	Transmitter RF Frequency Range	1 – 20 MHz
3	Receiver Bandwidth	35 KHz
4	Pulse Repetition Frequency	40 Hz
5	Pulse Width	40 μsec
6	Range Resolution	6 Km
7	Pulse Compression	13-bit Barker code
8	Number of Receivers	4
9	Number of Receive Antennas	4
10	Dimension of Receive Dipole	19m

The receiver antennas constructed are based on an arrangement proposed by Wright and Pitteway [3] and configured on a North-South and East-West baseline pairs. There are 4 dipoles along the centres of 4 sides of a 60m square. Each dipole is an untuned dipole of overall length 19m. The centre of each dipole is fed to a balanced high input impedance preamplifier. In order to make vector measurements related to plasma drift, the system is operated in a spaced receiver mode whereby the 4 antennas at the field are linked to the 4 identical phase-coherent receivers [4].

Apart from that, the transmitter and receiver together with the phase modulator and gating pulses derive their frequencies from the same source achieved through the use of a Direct Digital Synthesiser or DDS unit which provides the transmitter frequency as well as the receiver local oscillator frequency from a 50MHz reference source. This then effectively renders the system phase-coherent which is an important requirement before Doppler interferometry processing is applied at the 4 receivers of the digisonde.

This process of data acquisition produces ionospheric channel statistics such as critical frequencies, echo amplitudes, virtual heights, Doppler shifts, angle of arrivals and plasma drifts in real-time that are important for ionospheric research at this station.

Drift measurements are made with fixed transmitter frequencies at 5.9MHz, 7MHz, and 8MHz. These correspond to wavelengths (λ) over a range of 37.5m up to 50.8m. In terms of half-wavelengths (λ/2), these correspond to 18.75m up to 25.4m for half-wave dipole (λ/2) operation. Since the length of each receiver dipole used is 19m (see Table I), therefore it will cover up to the critical frequency of the F3-layer for this local station (foF3 = 8MHz) [6].

For each sounding, the in-phase (I) and quadrature-phase (Q) amplitudes are measured for each of the 4 receivers. A drift measurement is made for 60 seconds interleaved between 5-minute intervals of ionogram measurements and consists of 64 soundings made at a pulse repetition frequency PRF = 40Hz. The 64-point FFT complex time series vectors for each range bin for each antenna is Fourier transformed in real-time. If the power in a Doppler height bin for the first antenna is above a stipulated noise threshold, then that bin is saved for all antennas. This way, there is also a limit on the quantity of data being saved.

Thus, the recorded data for a Doppler drift measurement consists only of the strongest parts of the Doppler spectrum for the 4 antennas. And with an interpulse period of 25msec, the maximum Doppler spread can be calculated to be 1/25msec = 40Hz which corresponds to a maximum Doppler shift of +/- 20Hz.

Also, since the system at Waras uses a 64-point FFT, therefore it measures all observables of the received signals at each of the 64 ranges in question, like the Doppler spectrum amplitude and phase. Spectral analysis performed on the complex voltages generated from the 4 receivers' quadrature phase detectors produces Doppler frequency functions which then generates spectral amplitude as well as phase functions using the 64-point FFT. A Skymap display then results showing the various reflection sources from the drift measurements which have been carried out.. This Skymap displays the spatial distribution as well as Doppler shifts of ionospheric echo sources in a horizontal view at this station.

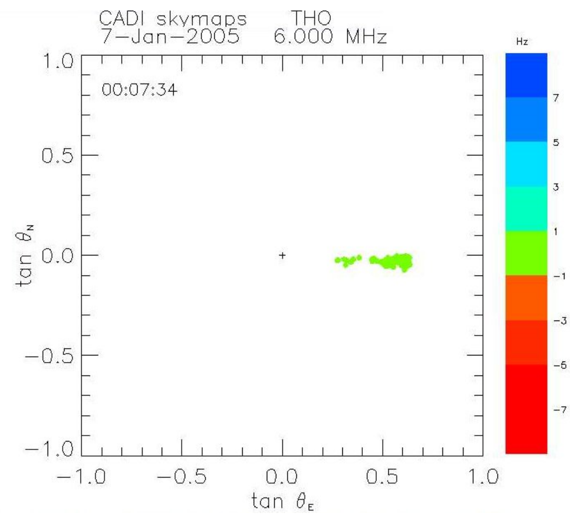

Figure 1 Plasma Skymap Display

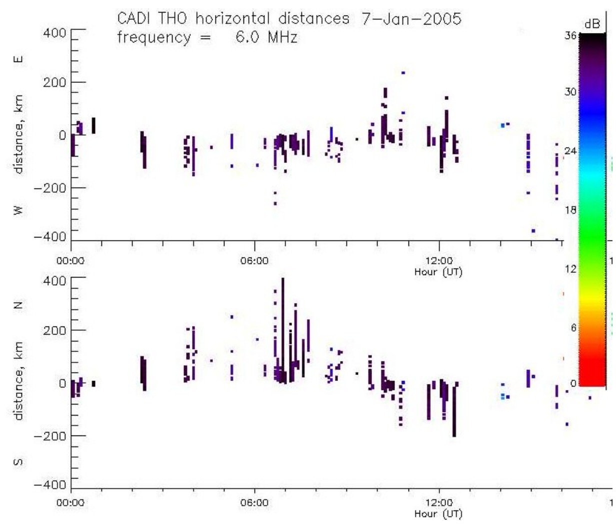

Figure 2 Plasma Drift Distance

IV. RESULTS AND DISCUSSION

A representative January 2005 Skymap display result with 6MHz sounding frequency is shown below in Figure 1 with geomagnetically quiet condition (Kp<4). A North-South (N-S) and East-West (E-W) drift distance covered by the plasma cloud with time is also shown in Figure 2.

Processing of the drift data begins by forming the cross spectra from the saved spectrum segments for each of the E-W and N-S antenna pairs. Each saved Doppler bin has significant power and is assumed to correspond to an ionospheric reflection point or source. The cross phases of the two antenna pairs give the angle of arrival (AOA) information of the echo (zenith and azimuth) ie. the direction of the reflection point source.

From the skymap display, several information can be seen. The display depicts the source's direction as well as Doppler shift. The observable trend in the Doppler shift across the skymap indicates the bulk horizontal drifts of the sources. From the skymap data file generated, further processing yields drift velocities deduced by a least-squares fit to at least three reflected echoes. Corresponding velocity vectors is shown in Figure 3

A number of assumptions are being made using this procedure of determining the drift velocities above. We assume minimal refraction effects and that the ionosphere is moving with a uniform bulk flow. This also means that the reflection point sources being detected by the doppler interferometer are actually embedded in the bulk flow. This is quite reasonable to assume as we are only considering the cluster of reflection points with a pronounced 'cloud' having a dominant horizontal convection pattern in either the North-South (N-S) or East-West (E-W) directions. In addition to that, for drift velocity determination above the doppler interferometer at Waras, the most relevant echo points for consideration should have incidence angles towards the receiving antennas that are close to vertical. Therefore we have selected point sources with a maximum angles of arrival of 45^o. From Figure1, this corresponds to maximum $\tan\theta_N$ and $\tan\theta_E$ values of +/-1.

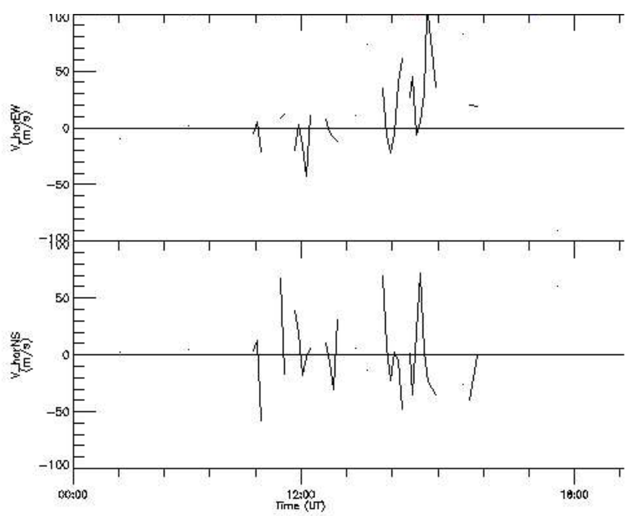

Figure 3 Plasma Drift Velocity

For best temporal resolution, an operating mode has been chosen that completes an ionogram measurement followed by an interleaved drift measurement every 5 minutes.

As shown in Figure 1, the Doppler shift is quiet small (in the range of less than +/- 1Hz) but bipolar in nature.

From Figure 2, it can be observed that the drift distances does not exceed 200km in range for the E-W direction due to quiet geomagnetic conditions (Kp<4), but horizontal distances between reflection points on a skymap during disturbed periods can reach hundreds of kilometres more in the F region.

The narrow Doppler spread actually corresponds to the cluster of reflection points that is located near the central part of the Skymap display. It is this group or 'cloud' of plasma that is of primary relevance to our study of plasma drifts being investigated. It will usually show a dominant horizontal component in convection pattern in the N-S or E-W directions. But during times of geomagnetic storms (not recorded in this study), it can be expected that a large Doppler spread may result with fast and irregular amplitude fading.

Figure 3 shows that the E-W horizontal velocity reaches as high as 100m/s after noon (UT) or around 10pm (LT) whereas the N-S velocity is somewhat smaller at 50 - 60m/s during the same period of time. It is important to realise that the derived drift velocity should be regarded more as an apparent speed since it includes also the contribution due to the decay of the reflecting F-layer ionospheric particles with time. But this effect of layer decay can be considered as not too significant provided that the height of the reflecting layer is above a threshold of about 300km [7]. Since the reflection heights recorded by the digisonde at Waras for the F region is generally more than 300km, therefore it is deemed not necessary to take into account the effects of ionization production and loss.

V. OTHER CONSIDERATIONS

Plasma drift motion in the F-region of this equatorial station can also produce measurement results such that the vertical and E-W components are driven by the electric field and the N-S components by the meridional component of the neutral wind [8]. This can actually be observed in Figure 2 for the N-S direction at around 7.00 am UT (or 3pm LT). There may even be a pattern of variation that might show an upward drift during daytime and a downward drift during night time. Further studies may need to be carried out in order to confirm this trends.

VI. CONCLUSIONS

This preliminary study of plasma drift motion at this local station is being performed on data collected at UTHM Waras ionospheric research station during the period of low solar activity of early January 2005. Some assumptions have been made in the determination of plasma convection flow and since this is the first such study being undertaken, the results and discussions made serve as a starting point for future investigations.

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