HF Doppler observations of nighttime F-region over Nagpur: Preliminary results

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A HF Doppler radar operating at 5.5 MHz has been developed for phase path measurements and regular nighttime observations have been made over Nagpur since October 1992. Data for the period October 1992-August 1993 have been analysed for vertical drift velocities. Vertical velocity ranges from 0 to 26 m/s with a mean value of about 8 m/s during equinoxes and about 6 m/s during solstices. The post-sunset upward velocity is maximum during equinoxes and is related to the EXB drift. Premidnight upward drift is maximum during summer months and is associated with the neutral winds. The data are in fair agreement with those obtained at Waltair except for the movement related to the electrodynamic effect which is much stronger at Waltair.

1 Introduction

Vertical plasma velocity is one of the important parameters in ionospheric measurements. Sato related the vertical and horizontal drifts to the anomalous post-sunset F2-increase most prominently seen at 16-17° geomagnetic latitudes. Park and Meng showed that the magnetospheric substorms cause layer vertical motions of the midlatitude F-layer, readily identifiable in ground-based ionosonde records, particularly, during winter nights. Jain and Rajasekaran had shown that the vertical drift in the F-region helps in maintaining the nighttime ionosphere.

The vertical plasma drift in the F-region at the magnetic equator is a measure of the east-west electric fields. Electric fields are known to play an important role in essentially all processes governing the F-region dynamics at the magnetic equator. Vertical drifts in the post-sunset F-region, play a major role in the occurrence of equatorial spread-F, and its onset seems to be closely associated with the upward-to-downward reversal and the velocity.

Various techniques have been used for the measurement of vertical drift. Mitra et al. used nighttime electron density curves at different heights; Balsley used rate of change of the height of maximum ionization density $h_{\text{max}}$ and Woodman and Hagfors used incoherent scatter radar. Abdu et al. also used ionograms for determining vertical drifts. In the present study, phase path technique has been used to measure vertical velocity. The technique developed by Findlay and modified later by Reddi, has been extensively used by Reddi and Rao and many others.

In most of the phase path recorders developed by these workers, the phase of the ionospheric signal is compared in the receiver at intermediate frequency (IF) against that of a stable reference oscillator of a frequency differing from the IF by about 20 kHz. The reference oscillator is triggered by the transmitter pulse and is thus phase coherent with it. The beat pattern across the width of the ionospheric echo is shaped and displayed on an oscilloscope for reading the movement of the beat maxima and hence phase path changes as a fringe pattern of sloping lines on photographic film. This method was later modified by Balan et al. so as to record data continuously on strip chart recorders. The HF Doppler radar developed for the present study is similar to that used by Balan et al. In the present paper we report the system developed for the measurement of vertical drift and the results of the measurements made over Nagpur (21.1°N, 79.1°E, Dip 29.3°N), a station in the anomaly crest region and also compare the results with those reported for other latitudes. The compact solid state HF receiver has been described in detail by Dhopte and Navaneeth.
2 System design

The HF pulse Doppler radar was designed with the following specifications.
- Operating frequency: 5.5 MHz
- Pulse repetition frequency: 50 Hz
- Pulse width: 150 μs
- Output power: 3 kW
- Transmitter output impedance: 300 ohm

The HF pulse Doppler radar consists of a pulse transmitter, a phase coherent receiver, frequency programmer, the associated antennas and the recording unit. The block diagram of the system is shown in Fig. 1. All the frequencies required for the system are generated by frequency programmer which is phase coherent to a 10 MHz crystal oscillator with short term stability better than one part in 10^7. The minimum vertical velocity that can be measured in the F-region with this stability is about 0.03 m/s for the operating frequency of 5.5 MHz.

A pulsed RF of 5.5 MHz with a keying pulse is generated in the frequency programmer and is given to the pulse transmitter. This is amplified by a chain of power amplifiers and finally transmitted by a 300-ohm half-wave folded dipole antenna. The ionospheric echo is received by a small active antenna. The received signal at a frequency of 5.5 MHz ± Δf (where Δf is the Doppler shift) is amplified in a small active antenna and given to the phase coherent receiver. At the receiver input it is mixed with a 5 MHz signal, and the resulting 500 kHz ± Δf is amplified by the IF amplifier. This signal at 500 kHz ± Δf is given to the quadrature detector. The local oscillator frequencies for quadrature detection are again derived from the frequency programmer (500 kHz < 0° and 500 kHz < 90°).

The amplified IF signal is phase compared against the two reference local oscillator signals in two separate phase detectors to obtain the quadrature outputs of the Doppler frequency shifts of ± Δf. The output of the two phase detectors are separately amplified and passed through an active low pass filter and a S/H circuit. The sampling gave pulse of 10 μs width and a repetition rate of 50 Hz, whose delay with respect to the transmitted pulse is generated by delay pulse, is fed to the receiver to activate the sample and hold (S/H) circuit in the two quadrature channels. The outputs of the receiver are fed to a multichannel strip chart recorder as well as to a sense finder, which detects the sign of the Doppler from the phase lag. The chart recorder is usually operated at a speed of 5 cm/min. At this speed it is possible to measure a maximum Doppler of 1.5 Hz, which corresponds to about 40 m/s of vertical velocity. Initially both the SIN and COS channels were recorded, but once the performance of the sense finder was validated, only one of the Doppler channels was recorded.

3 Data recording and reduction

The data were recorded continuously from 1800 hrs IST till the critical frequency falls below the operating frequency late in the night. Mostly the regular world days were selected for observations. No distinction is made here according to the magnetic activity and the results reported here are based on the average values comprising the quiet as well as disturbed days. The plasma drift velocity is known to change with the level of magnetic activity. However, this aspect will be studied separately. Doppler count was taken after every 5 min for a sample of 1 min. The counts were then converted into the corresponding vertical velocity. The derived velocity may also include the contribution due to the decay of the layer. However, on the basis of theoretical studies Bittencourt and Abdu have shown that the effect due to the layer decay is not significant provided the height of the layer is above a threshold of 300 km. For most of the observations made, the height of the F-layer was above 300 km. In view of this, it does not seem likely that the layer decay would alter the basic pattern of the velocity variation in any significant way and hence, no correction was applied to it.

4 Results

Examples of the Doppler data along with the sense finder output are shown in Fig. 2. Figure 2(a) shows an example with the COS channel lagging and the sense finder indicating negative Doppler, while in the example shown in Fig. 2(b),
COS channel leads the SIN channel and the sense finder indicates positive Doppler. Some examples of the records (only COS channel) taken during the evening of 18 Mar. 1993 are shown in Fig. 3. The records during 1810-1816 hrs LT [Fig. 3(a)] and 1845-1853 hrs LT [Fig. 3(b)] were made during the phase of the upward drift velocity, while the example in Fig. 3(c) was taken at the time of
drift reversal (around 2213 hrs LT). The example in Fig. 3(d) was taken during the sudden change in drift velocity (at around 2114 hrs LT). The time variation of the vertical velocity during the night of 18-19 Mar. 1993 is shown in Fig. 4.

For a comparative study of the magnitude of the vertical drift velocity observed at Nagpur during different seasons, one month data were examined for each of the three seasons. During the months of November 1992 and June 1993, vertical velocity ranged between 0 and 22 m/s with median values of 6.1 and 6.4 m/s. During the month of March 1993, velocity ranged between 0 and 26 m/s with a median value of 8.4 m/s. Thus, the average vertical velocity seems to be higher during equinoxes. Shrivastav et al.\(^ {13} \) reported the vertical velocity over Varanasi ranging between 2 and 18 m/s with the most probable value of 8 m/s. The magnitude of the vertical velocity at Nagpur and Varanasi are, therefore, in good agreement.

Seasonal mean nocturnal variations of the vertical velocity over Nagpur for the three seasons of winter, equinoxes and summer during the period October 1992-August 1993 are shown in Fig. 5. It is observed that the post-sunset upward vertical drift velocities are highest during equinoxes with a mean peak value of about 13 m/s. The premidnight upward drift velocity is maximum in summer with a value of 19 m/s and minimum during equinoxes (5 m/s). The peak occurs at around 2100 hrs LT during equinoxes and summer but is delayed to 2300 hrs LT in winter. Satya Ramesh et al.\(^ {14} \) have compared mean nocturnal variations of vertical velocity over Waltair during different seasons for the period 1982-83. They report post-sunset upward drift of 24 m/s, 18 m/s and 10 m/s during winter, equinoxes and summer, respectively. There is no significant change in the premidnight upward drift velocity which peaks to 8 m/s during each of the seasons. Results for an equatorial station Trivandrum\(^ {15} \) show higher values of post-sunset vertical drift during equinoxes with maximum mean velocities of 15 m/s during the year 1985 and 40 m/s during the year 1984. Summer values are less than 10 m/s, while winter values range between 10 and 15 m/s for different years. There is no premidnight upward velocity observed at Trivandrum.

To study the latitudinal changes in the vertical velocity, annual mean nocturnal variations have been compared for Varanasi, Nagpur and Waltair. The data for Varanasi and Waltair have been taken from the published results.\(^ {13,14} \) Figure 6 shows the plots of the annual mean nighttime variations of the vertical velocity for Varanasi (25.3°N), Nagpur (21.1°N) and Waltair (17.7°N). The data for Varanasi are for the period November 1968-August 1969, and for Waltair for the period September 1982-August 1983. From the comparison it is clear that the \( \mathbf{E} \times \mathbf{B} \) drift effect during post-sunset period is strongest at the low latitude station Waltair and decreases with increasing latitude. The premidnight upward velocity has been attributed to equatorward winds. The effect of neutral wind is clearly visible at these stations with some time

![Fig. 4--Variation of the vertical F-region drift velocity over Nagpur during the night of 18-19 Mar. 1993](image1)

![Fig. 5—Seasonal mean nocturnal variations of the vertical F-region drift velocity over Nagpur during the seasons (a) winter, (b) equinoxes and (c) summer of October 1992-August 1993](image2)
delay. The maximum occurs at 2100 hrs LT at Varanasi, at 2130 hrs LT at Nagpur and at 2200 hrs LT at Waltair.

5 Discussion

Srirama Rao et al.\textsuperscript{19} have explained the features of the vertical drift at Waltair on the basis of combined effect of the electrodynamic drift and neutral winds. Post-sunset vertical drift is attributed primarily due to the large E×B drift, whereas the vertical drifts later are primarily due to the neutral wind effects. Burnside et al.\textsuperscript{26} have reported average monthly nighttime variations of neutral winds over Arecibo by Fabry-Perot interferometric observations of night airglow at 630 nm. Maximum equatorward winds were found to be in the premidnight period at around 2100 hrs LT and decrease with minimum value or sometimes even reverse to poleward direction around midnight. The magnitude of equatorward wind was found to be largest in summer. The results of largest upward vertical drift during summer months over Nagpur at around 2100 hrs LT are consistent with the neutral wind observations over Arecibo. Ganguli et al.\textsuperscript{21} have reported the ion and neutral motions over Arecibo obtained from the incoherent scatter radar observations during the solar minimum period of 1974-77. Meridional drifts were shown to be generally poleward during morning and equatorward in the evening. During the high sunspot years northward/upward drifts turn positive around sunset and then become more strongly negative around 1930 hrs LT (similar to the pre-reversal enhancement at Jicamarca\textsuperscript{22}). Oliver et al.\textsuperscript{23} have reported the first observations of ionospheric electrodynamics using the incoherent scatter observations made during October-December 1986 from the MU radar in Japan. Parallel drifts were more strongly downward during the day and less strongly downward at night. The observed diurnal variation was attributed to a poleward wind by day and an equatorward wind by night. Goel and Jain\textsuperscript{24} have studied the ionospheric changes in the midlatitude F2-region associated with a major substorm event of 18 Sep. 1974 using the drift data from the multistatic incoherent scatter radar at Malvern in UK and ionosonde data at a chain of stations in Europe. Changes were also simulated using the Servo model. Changes in $h_F$ were found to be larger and occurred earlier at higher latitude stations than at lower latitude stations. Changes in zonal electric fields alone could not explain the observed changes and it was necessary to invoke large equatorward winds. The presence of southward winds was also confirmed by incoherent scatter observations. Recently Balan et al.\textsuperscript{25} have made spaced receiver measurements employing HF Doppler technique at Trivandrum for vector plasma velocity measurements.

6 Conclusions

Nighttime vertical drift measurements over Nagpur, using HF Doppler technique, for the period October 1992-August 1993 show velocities ranging between 0 and 26 m/s with mean values of 6-8 m/s during different seasons. The post-sunset upward drift is maximum during equinoxes consistent with larger equatorward drift at equator. The premidnight upward drift due to the neutral winds is maximum during summer months and is consistent with largest equatorward neutral winds in summer as reported at Arecibo and also with the measurements of plasma drifts made by incoherent scatter radar at Arecibo, Shigaraki (Japan) and UK. The consequence of these neutral winds in ionosphere needs to be examined in detail. Simultaneous observations by ionosondes and HF Doppler radars at a chain of stations in India coordinated with neutral wind measurements will be an important step towards understanding the ionosphere-thermosphere coupling at low latitudes. A chain of HF Doppler radars at 5.5 MHz with similar specifications is operational in India and campaign mode of operation will be of great value.
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References

1. Sato T, J Geomagn & Geoelectr (Japan), 18 (1966) 150.