

Study of travelling ionospheric disturbances using IPS array at Rajkot

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Using a novel radio astronomical technique, the presence of travelling ionospheric disturbances (TIDs) are detected from observations of radio star signals by the interplanetary scintillation (IPS) system at Rajkot for the first time in India. The periods of the TIDs (20-24 min) and north-south component of their velocity (66-273 m/s) indicate that they belong to the medium scale category. The results are discussed in the light of a model of atmospheric gravity waves (AGWs) originating in auroral electrojet region and propagating meridionally equatorward.

1 Introduction

Travelling ionospheric disturbances (TIDs) are ionospheric manifestations of propagating atmospheric gravity waves (AGWs). They are frequently detected by a variety of ionospheric techniques. Their properties such as occurrence, periods, velocity of propagation, horizontal wavelength, etc. have been quite extensively studied by a variety of radio techniques, including fixed-frequency sounders¹, ionosondes^{2,3,4}, total-electron-content systems^{5,6,7}, Doppler sounders^{8,9}, backscatter radars with azimuthal scanning ability¹⁰ and differential Doppler measurements using the satellites of the Navy Navigation Satellite System¹¹ (NNSS). In addition, they have been detected by *in situ* instruments aboard satellites¹² and by tomographic reconstruction¹³. Based on these observations they are classified into (i) large scale with periods greater than 30 min, horizontal wavelengths up to a few thousand kilometers and speeds of 300-1000 m s⁻¹, (ii) medium scale with typical periods of 10-30 min, horizontal wavelengths between 100 and 300 km and speeds of 100-300 m s⁻¹ and (iii) small scale with speeds up to 1000 m s⁻¹, but periods less than a few minutes.

Recently, radio astronomical techniques like radio interferometry in which signals from two separate aeri- als are fed into one receiver¹⁴, have been used for TID studies. Bougeret¹⁵ showed that the Nançay Radioheliograph, while observing solar radio sources, provided useful data on TIDs. Mercier^{16,17} and Mercier *et al.*¹⁸, using the same instrument, extended the technique to study the propagation characteristics, temporal period, polarization and seasonal

climatology of TIDs. Jacobson *et al.*¹⁹, viewing four exceptionally strong, quasi-point celestial sources at 50 MHz from the Clark Lake Radio Observatory, observed quasi-periodic perturbations in the frequency range $f < 2$ mHz (medium scale TIDs).

Measurements with Westerbork Synthetic Aperture Radio Telescope combined with differential Doppler shifts observed by NNSS satellites²⁰, show that the average direction of propagation of a sample of medium scale TIDs observed during the first three months of 1982 and 1983 is towards about 10° west of south, the speed and horizontal wavelengths being typical for medium scale TIDs. The results are in satisfactory agreement with the observations from Nançay (France). Most of the observations are in mid and high latitudes, thus indicating a paucity of observations at low latitudes. In this paper, the radio astronomical technique, using the interplanetary scintillation (IPS) system at Rajkot (22° 18' N, 70° 48' E), has been used to study TIDs for the first time in India.

2 Experimental system and methodology

Block diagram of IPS system at Rajkot is shown in Fig. 1. It can be divided into four main parts: (a) Antenna array, (b) Pre-amplifier and multibeam forming Butler matrices (BM), (c) Correlation receiver and (d) Data recording system.

Antenna array is an array of 64 rows of open wire transmission lines in E-W plane, connected with each are 16 full wave dipoles in N-S plane. Parallel reflectors are kept below these to enhance the collection of radio waves from sky. The 64 pre-

amplifiers are connected, one each to all transmission line in order to enhance the signal. The output of the pre-amplifiers is brought to the BM inside the laboratory via underground cable in order to maintain phase and gain stability.

The signal is then fed into BMs, which are multibeam forming matrices with small aperture, from different directions. The signal from required beam from BMs output is fed to correlation receiver which reduces background noise and all other uncorrelated components.

The quadrature outputs of the receiver consisting of cosine and sine channel are recorded both on analog chart recorder and on digital data acquisition system (computer) which form the primary raw data.

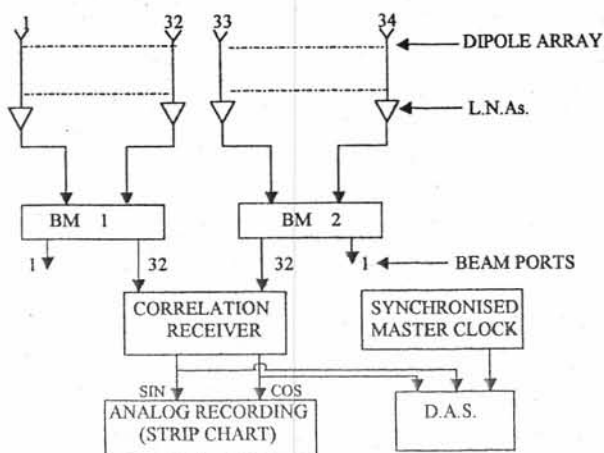
2.1 Identification of TID and period determination

To study the ionospheric irregularities, signals from different radio stars are recorded daily using the radio telescope at Rajkot at 103 MHz. In the absence of TIDs, ionosphere remains unperturbed and radio waves suffer no deviation and intensity remains constant [Fig. 2(a)], while in the presence of TIDs, when the radio wave passes through undulated ionosphere, it suffers ray deviation which gives rise to apparent position shift of the source as illustrated in Fig. 2(b), resulting into quasi-periodic variation of intensity. In the present case beam is fixed. Therefore, the apparent position shift of the source will give rise to a corresponding slow variation of the signal strength, as the radio rays go in and out of the beam as illustrated in the bottom traces of Fig. 2(a). When TID occurs, such fluctuations in 'SIN' and 'COS' channels

of chart recorder are observed. A typical example of such case is shown in Fig. 3. The typical record of radio source signal in the absence of TID corresponding to the situation in Fig. 2(a) is shown in the Fig. 3(a) for comparison. The tracings of cosine channel of the source 3C123 in 4R beam and 3C119 source in 9R beam recorded simultaneously using two separate receivers and recorders on 22 June 1998 are shown in Fig. 4. The mean time shift between successive peaks or troughs in the record is a measure of TID speed.

2.2 Determination of TID velocity

To find out the velocity component of TID, simultaneous observation of two sources are made by two different receivers. If a particular peak or trough of TID is observed at time t on beam-x and after a time delay, δt , if it is observed on beam-y then one can find the velocity component of this TID, provided the angular separation θ between the two beams and



DAS = DATA ACQUISITION SYSTEM
BM = BUTLER MATRIX
L.N.A. = LOW NOISE AMPLIFIER

Fig. 1—Block diagram of IPS array at Rajkot

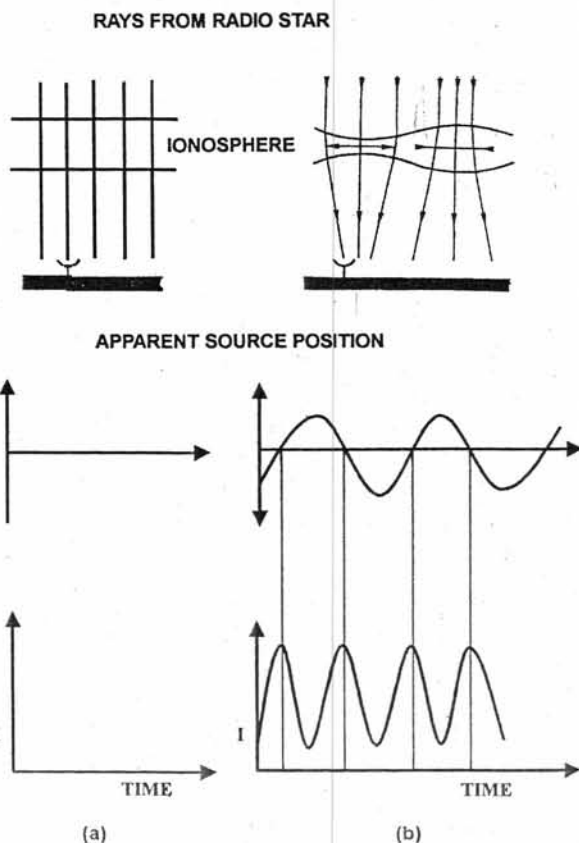


Fig. 2—Schematic drawing of the radio waves path through the ionosphere, (a) unperturbed ionosphere : the radio waves suffer no deviation with variation in signal intensity; (b) disturbed ionosphere : produces quasi-periodic shift to the radio source position with variation in signal intensity [I – signal intensity resulting from the convolution between the source position function and receiving antenna beam]

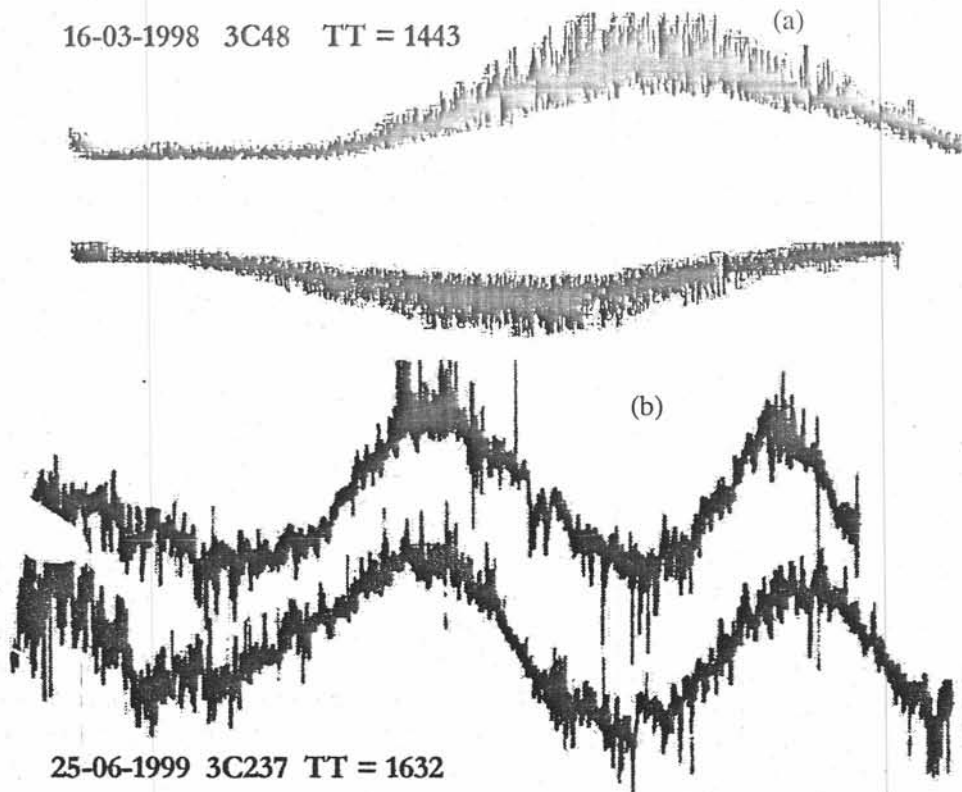


Fig. 3—Typical recording of a radio source (a) in absence of TIDs and (b) in presence of TIDs

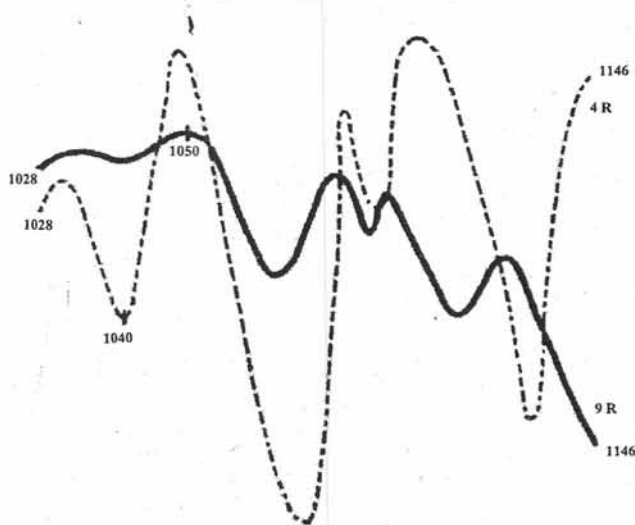


Fig. 4—Tracings of cosine channel of the source 3C123 on 4R beam and 3C119 source on 9R beam recorded simultaneously using two separate recorders on 22 June 1998.

vertical height of ionosphere where the TID propagates (which is assumed to be 350 km) is known. The velocity component from the beam in a direction in which it appears earlier, to the beam in which its appears later is given by

$$V = \frac{350 \tan \theta}{\delta t} \quad \dots (1)$$

3 Observations and results

Various sources were detected by Rajkot radio telescope and the periods of wavelike perturbations were determined. The histograms of occurrence times and monthwise distribution of TID occurrences are shown in Fig. 5 [(a) and (b)]. They show maximum occurrence during noon-afternoon hours and in the month of March. Histograms of period distribution for the period January 1997-March 2000 are shown in Fig. 6. From the histograms of period distribution the maximum occurrence of TIDs is found to be in the period 20-24 min which suggests that these belong to the category of medium scale TIDs.

The different radio source pairs were observed during January 1997-March 2000. It may be pointed out that the probability of two radio sources being located on any two suitable beams simultaneously, and the probability of a TID propagating parallel to the present baseline which is north-south, reduce greatly the number of suitable events for velocity

determination. Hence, in this span of time we found only five simultaneous events as given in Table 1. The velocity components of TIDs derived from Eq. (1) is also given in Table 1.

The TIDs were also found to vary in number with solar activity (Table 2). The number of TID occurrences is considerably more in solar maximum year (1999) indicating strong solar activity effect on TID occurrences.

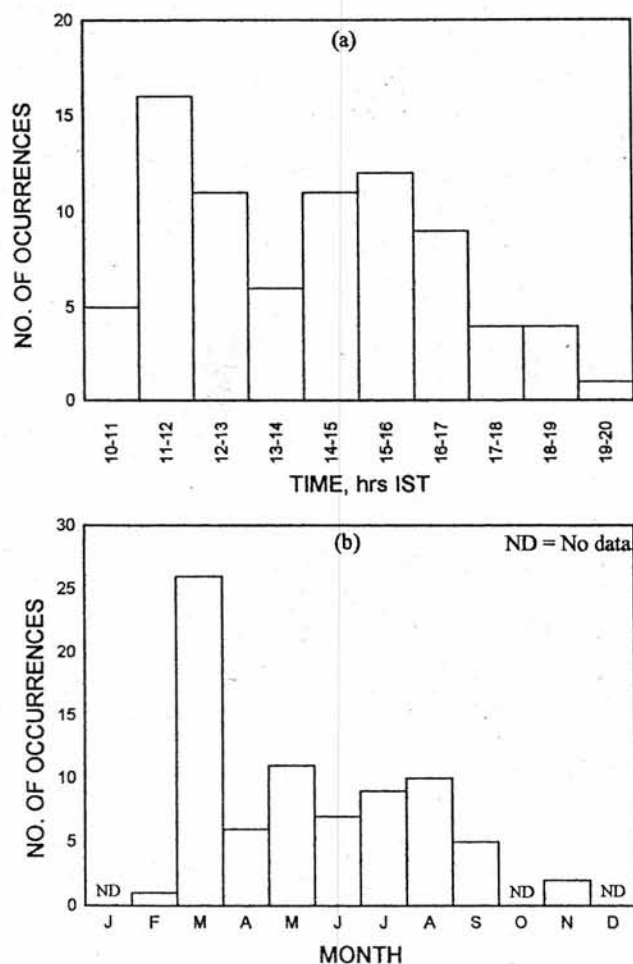


Fig. 5—Histograms of (a) occurrence times and (b) monthwise distribution of TIDs for the period January 1997–March 2000

4 Discussion and conclusions

Twenty five measurements of horizontal and vertical trace velocities of medium size TIDs were made by Davies and Jones²¹ at Boulder, Colorado (mid latitude), using HF propagation technique. They found that average speed of the TIDs was slightly larger in summer than in winter with a mean value of 143 m/s. In the present results, the mean values of TID speed is obtained to be 153 m/s. The TID observations using NNSS and radio interferometer were made by Spoelstra²⁰. The velocity and period of TIDs observed by Spoelstra²⁰ range from 118–303 m/s and 20–30 min, respectively. The present observations are in satisfactory agreement with the above results. The present results differ from those derived by Mercier²² and Spoelstra and Kelder²³ that TID occurs generally in winter mornings. In the present study we have found maximum occurrence in March (equinox month) and during noon and afternoon hours. The difference may be due to the variation in the latitude zones in the two cases. Balthazor and Moffett²⁴, using a global coupled thermosphere-ionosphere-plasmasphere model, simulated large scale AGWs originating at northern and southern auroral regions

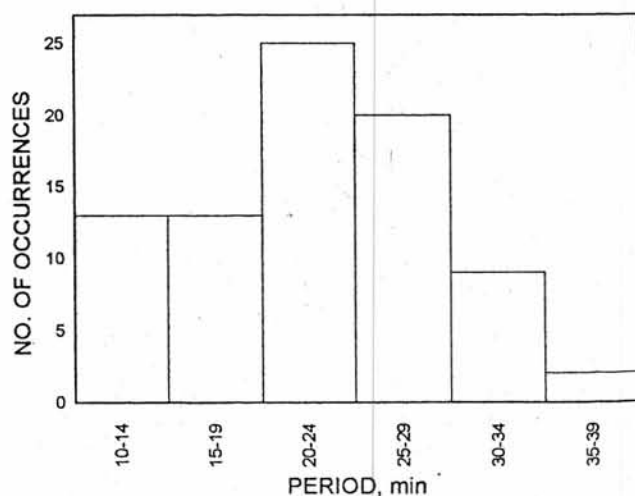


Fig. 6—Histograms of period distribution of TIDs for the period January 1997–March 2000

Table 1—Velocity components of TIDs using various source pairs during January 1998–March 2000

Date of observations	Source pair	Time shift (Δt) min	Velocity (m/s)	Direction of velocity component
22 June 1998	3C119 & 3C123	10	114	North to South
22 Mar. 2000	3C119 & 3C123	5	273	South to North
24 Mar. 2000	3C119 & 3C123	14	78	North to South
25 Mar. 2000	3C144 & 3C147	13	237	North to South
25 Mar. 2000	3C47 & 3C48	19	66	North to South

Table 2—Solar cycle dependence of TID observations which is varying with average sunspot number

Year	Average sunspot number	Total TID observation
1997	32	06
1998	88	27
1999	140	36

and propagating meridionally towards the equator. The enhanced auroral electric field (during magnetic disturbances) produces a family of gravity waves in the thermosphere. The resulting TID is parametrized in terms of $h_m F2$ and $N_m F2$. Its characteristics are latitude and altitude dependent and bear complex relationship with the forcing AGW. The characteristics of TIDs observed in the present study (for example, 4 out of 5 cases showing southward propagation) are in agreement with this model, while the above reported results for large scale TIDs may be of auroral zone origin. The medium scale TIDs can have both auroral and meteorological origin, for example, the tropospheric jet stream. Bertin *et al.*²⁵ studied medium scale TIDs using three-station observations of Faraday rotation of geostationary satellite signals at mid latitudes and found both auroral and meteorological sources for these. Employing incoherent scatter measurements of thermospheric temperature and neutral wind and ray tracing technique, they²⁵ could trace the source region from where the TIDs could have originated. They found 12 out of 14 cases to have originated from warm and cold fronts, depressions or jet streams, while the other two had auroral origin. Out of the five events given in Table 1, 22 and 24 Mar. 2000 were magnetic storm days with a maximum K index of 4 as per magnetic storm data of NGRI, Hyderabad. On all other days, apparently there was no storm. However, the TIDs observed on 22 March moved from south to north and hence cannot be interpreted as originated in the northern auroral zone as a result of the storm. Thus, the observed TID direction of this event favours more of meteorological origin.

In India, the measurements of TIDs (especially their propagation and source identification) are rare. Sen Gupta *et al.*²⁶ studied large scale TIDs from measurements of Faraday rotation of ATS-6 signals from a wide network of stations in India. They identified one case of large scale TID, probably originating from auroral zone, on a magnetically

disturbed day with large surges of auroral electrojet current and propagating equatorward. Another event, probably originating from the surges in equatorial electrojet current and propagating away from the equator, was also observed by them²⁶.

Observations of different radio star signals using the radio telescope at Rajkot give the information about TIDs. In this study, a mean velocity of 153 m/s and a mean period of 22 min are observed which belong to medium scale TIDs. The present results indicate that occurrences of TIDs are correlated with solar activity.

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