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Study of Large & Medium Scale Irregularities Using 140 MHz ATS-6 Faraday Rotation Records from Three Stations

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The drift velocities of medium and large scale irregularities have been estimated utilizing the 140 MHz ATS-6 Faraday rotation records obtained simultaneously at Delhi, Kurukshetra and Pilani. The triangulation method of determining the velocities in a general case has been described. The drift velocities of these irregularities have been found to vary from 30 to about 500 m/sec, the commonest speed being about 140 m/sec during the day and about 110 m/sec during the night. These velocities are found to be spread in all possible directions except that during daytime no irregularity was found to be moving in south-east direction while during nighttime only one irregularity was found to be moving in north-east direction. Both periodic and non-periodic TIDs have been observed but most of the disturbances belong to medium scale rather than to large scale TIDs.

1. Introduction

Evidence for the existence of large scale irregularities in the F-region with dimensions of several hundred kilometres was obtained by Munro,[1,2] by comparing virtual height records taken at different times and different places. Such irregularities were also observed by Vitkevitch and Kokurin[3] and Lawrence *et al.*[4] from observations of slow, irregular variations in the apparent position of radio stars.

Large scale ionospheric irregularities representing variations of the order of 1% in total electron content and having dimensions of the order of 100 km were detected by Little and Lawrence,[5] de Mendonca,[6] Liszka and Taylor[7] and Bhonsle,[8] by measuring the total electron content from the Faraday fading and Doppler shift of satellite signals. Titheridge[9] showed how the size and density of ionospheric irregularities could be determined from satellite amplitude records. In addition, the height of the irregularities can also be determined if the time difference between similar fluctuations in the Faraday fading of orbiting satellites at two stations separated by a distance of the order of 100 km is known.[10,11]

One class of these irregularities is known as travelling ionospheric disturbances or simply TIDs. The spectrum of TIDs has been characterized by Georges[12] as comprising two distinct categories of waves, namely large scale TIDs and medium scale TIDs. The principal distinction between the two is that the horizontal speeds of large scale TIDs are substantially greater and those of medium scale TIDs substantially less than the lower atmospheric-sound speed ($\approx$ 300 m/sec). Large scale TIDs have horizontal speeds between 400 and 1000 m/sec, periods from 30 min to 3 hr, and horizontal wave lengths exceeding 1000 km. Medium scale TIDs have horizontal speeds commonly between 100 and 250 m/sec.[13] These are the more common types, which often appear as a train of quasi-periodic oscillations.

In electron content measurements many records often show isolated fluctuations that clearly are not of periodic nature. Titheridge[14] has noted that both periodic and isolated fluctuations occur in approximately equal numbers and mostly belong to medium scale TIDs which are more common than large scale TIDs. The periodic observations may then correspond to the existence of a single wave with a well defined period, a train of quasi-periodic oscillation, while the isolated or non-periodic irregularities indicate a wave packet with a range of periods.

The Radio Science Division of the National Physical Laboratory, New Delhi, had set up a companion station at Kurukshetra University, Kurukshetra, for recording Faraday rotation of

140 MHz transmissions from the geostationary satellite ATS-6 (35°E). The Delhi University set up a 140 MHz Faraday rotation recording system at Pilani in collaboration with the National Physical Laboratory. The Faraday rotation records at 140 MHz from the satellite ATS-6 were simultaneously obtained at New Delhi (28·6°N; 77·2°E), Kurukshetra (29·9°N; 76·8°E) and Pilani (28·2°N; 75·6°E), for the period Apr. to July 1976. These recordings have been utilized to calculate the drift velocities of the medium scale (periodic as well as isolated) irregularities identified at all the three stations. The height of the irregularities was assumed to be 350 km, based on a previous study which made use of 40 MHz Faraday fading records obtained at New Delhi and Kurukshetra.[11] The other characteristics of these irregularities such as size, the amplitude in terms of percentage changes in electron content and occurrence, etc. have also been studied in the present paper.

2. Method of Analysis

In the triangulation method of drift measurements, generally the problem is simplified if three receivers are kept at the vertices of a right-angled triangle. In case of large scale irregularities, as the distances involved are quite large and it is preferable to make use of the nearby existing laboratories for recording measurements, it is not always possible to have the receivers at the vertices of a right-angled triangle. Therefore, the following general procedure was adopted to derive the drift velocities of these irregularities. Let A, B and C be the locations of the three stations. Let $B\overline{V}$ be the direction of motion of the irregularity such that its azimuth when measured from north towards east is θ. Let BC and BA make angles α and β with true north. Let AA′ and CC′ be the perpendicular lines drawn from the points A and C to the direction of motion through B. If the time differences between the moments at which a particular irregularity passes over the different stations are T_{AB}, T_{BC} and T_{AC}, respectively, then the actual velocity V is given by (Fig. 1) :

$$\frac{A'B}{T_{AB}} = \frac{BC'}{T_{BC}} = \frac{A'C'}{T_{AC}} = V \qquad ...(1)$$

or,

$$\frac{AB\cos(\pi-\theta-\beta)}{T_{AB}} = \frac{BC\cos(\theta-\alpha)}{T_{BC}} = V \qquad ...(2)$$

As there are only two unknowns θ and V in Eq. (2) above, it is easier to evaluate the velocity of the irregularities on the ground. Assuming the height of the irregularity, its actual velocity at that height can be evaluated.

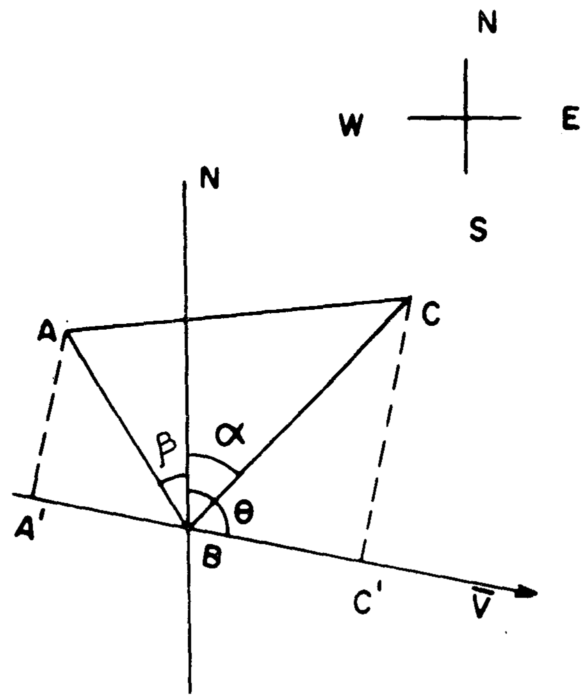

Fig. 1—Triangulation method of determining drift velocity

In a special case of a right-angled triangle and the line BC being in N-S direction, i.e. $\alpha = 0°$ and $\beta = 90°$, Eq. (2) reduces to Mitra's formula as under:[15]

$$\frac{AB\sin\theta}{T_{AB}} = \frac{BC\cos\theta}{T_{BC}} = V \qquad ...(3)$$

or,

$$\tan\theta = \frac{V_{BC}}{V_{AB}} \qquad ..(4)$$

and $$\frac{1}{V^2} = \frac{1}{V_{AB}^2} + \frac{1}{V_{BC}^2} \qquad ...(5)$$

where $V_{AB} = AB/T_{AB}$ and $V_{BC} = \frac{BC}{T_{BC}}$

The commonest height of the irregularities in Delhi-Kurukshetra region was found to be around 350 km.[11] Assuming, therefore, the height of the irregularities to be 350 km, their actual velocities have been estimated.

3. Results

3. 1 Non-periodic Irregularities

The three stations Delhi, Kurukshetra and Pilani form almost a right-angled triangle. The Faraday rotation records obtained from these stations at 140 MHz signals transmitted from the satellite ATS-6 have been examined for the study of large and medium scale ionospheric irregularities. The minimum change detectable in electron content was 6×10^{14} m^{-2} and the time resolution 1 min. On about 25 occasions isolated fluctuations in total electron content (TEC) were detected on all the three stations. A typical example of such an irregularity is shown in Fig. 2. The drift velocities of all these irregularities have been calculated following the procedure outlined in Section 2. The results are exhibited in Fig. 3 (a, b) in the form of a polar diagram, separately for day and night. From the present sample it has been found that the occurrence of these non-periodic irregularities is equally distributed from day to night. It may be noted from the diagram that the drift velocity of these irregularities

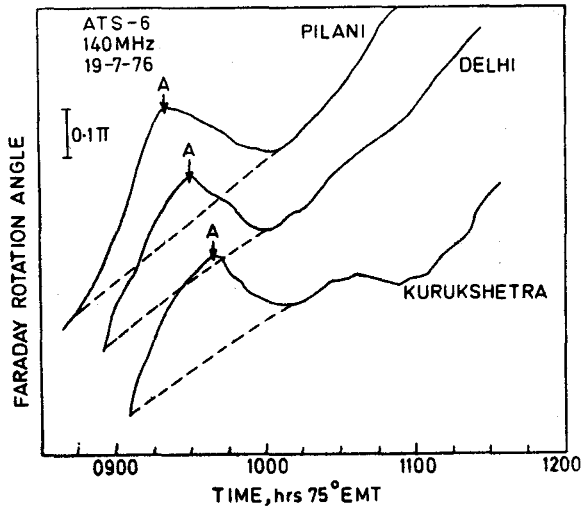

Fig. 2—Isolated (non-periodic) medium scale irregularity

varies from 30 to 500 m/sec. It is interesting to note that only in two cases the velocity exceeds the lower atmospheric sound speed of about 300 m/sec. Therefore, all these irregularities can be classified as medium scale isolated TIDs[12] except in two cases where these can be grouped as large scale isolated TIDs. The commonest speed of medium scale isolated TIDs was found to be about 140 m/sec during the day and about 110 m/sec during the night. These velocities have been found to be spreading in all possible directions except that during daytime no irregularity was found to be moving in south-east direction while during nighttime practically no irregularity was found to be moving in north-east direction.

The sizes of the isolated irregularities discussed above have been found out in the north-south as well as in the east-west direction. The sizes were found to vary from about 15 to 3000 km, the commonest size being 400 km. It was also noted from the comparison of their sizes in N-S and E-W direction that 60% of the irregularities have more or less equal size both in N-S and E-W directions, while 24% were found to be elongated in E-W and 16% in N-S direction.

The irregularity content was found to vary from about −40% to + 40% of the background electron content. About 60% of the irregularities were positive, i.e. their content was above the background,

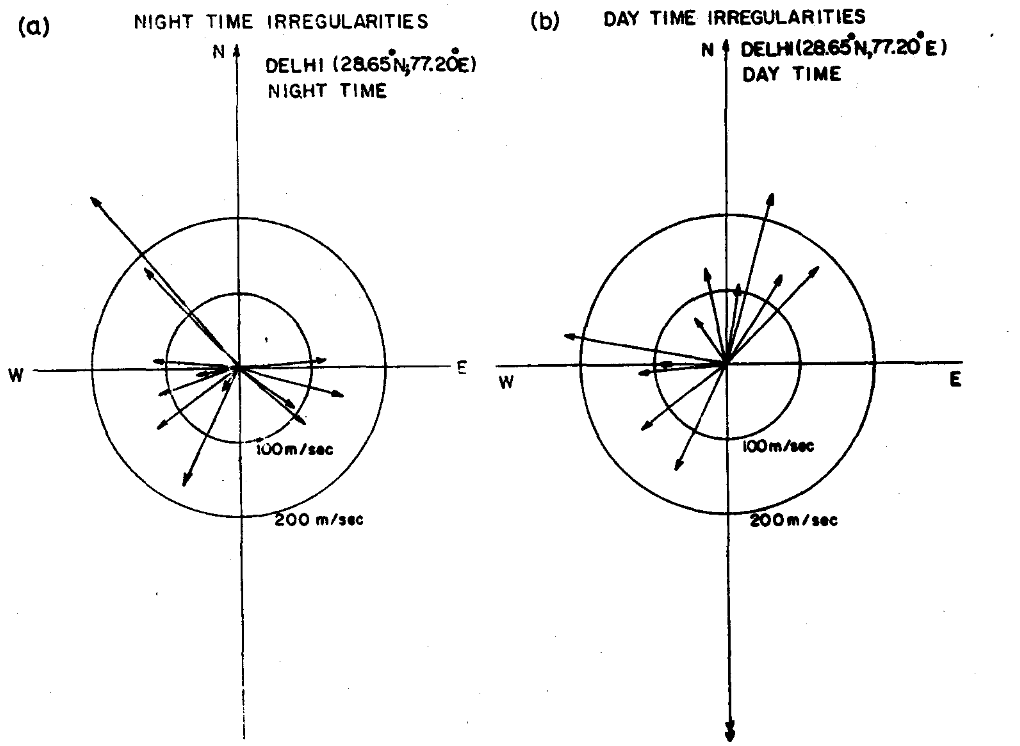

Fig. 3—Velocity distribution of isolated medium scale irregularities during (a) nighttime and (b) daytime

the commonest content being about 11% higher than the normal value, while 40% were negative, the commonest content being 6% lower than the normal value.

3.2 Periodic Irregularities

On several occasions the records show a sustained wave motion with a period and amplitude that is reasonably constant up to several complete cycles. An example of such wave motion is shown in Fig. 4 where periods from 8-12 min range are seen on all the three stations. Close examination of these records also reveals time shifts between similar features of the three records. The variation in these records is thought to have been caused by a medium scale travelling wave disturbance propagating through the ionosphere. The detailed results of the periodic medium scale TIDs are shown in Table 1. It may be noted from Table 1 that the disturbances have periods ranging from about 8 min to little more than 2 hr and speeds between 120 and 270 m/sec, the most probable speed being around 140 m/sec. Their directions seem to be more in the south-west irrespective of their time of occurrence.

Table 1—Results of Periodic Medium Scale TIDs

Date	Time hrs	Dominant periods min	Speed m/sec	Direction azimuth deg
17-18 May 1976	2100-0500	90, 13·5, 11·0	165·2	262·4
16-17 June 1976	2100-0400	35	122·6	246·9
17 June 1976	1400-1800	94, 80, 10	135·1	154·3
20 July 1976	1100-1700	14, 9	–	–
23 July 1976	1100-1700	50, 16·7, 11·8, 9·5, 8·0	265·16	263·9

4. Discussion

The presence of isolated (or pulse-like) and periodic irregularities was earlier reported by Titheridge[14] and also by Tyagi *et al.*[11] Titheridge[14] noted that both periodic and non-periodic irregularities occur approximately in equal numbers. The average speed obtained by him for these disturbances was around 140 m/sec.[16] Hartmann *et al.*[17] reported a mean speed of 188 m/sec. Our results of the velocities (about 140 m/sec during daytime and about 110 m/sec during night) are in broad general agreement with those of the above authors. Deshpande *et al.*[18] repoted the speeds and direction of TIDs using ATS-6 data. The medium speed was about 70 m/sec and propagation was dominantly in the north-west or south-east direction for the daytime TIDs. The present results show that the medium scale isolated TIDs propagate in the direction S-W to N-E during daytime and E to W-N during the nighttime.

A brief comment on the source mechanism is appropriate here. Medium scale TIDs are more often observed than large scale TIDs and may be excited by various sources including magnetic disturbances, which is mainly the source of large scale TIDs. Some are related to weather disturbances near the ground as found by Jordon[19] and Bertin *et al.*[20] and can go upward to reach the thermosphere. The disturbances may consist of either a wave train with several cycles (e.g. Fig. 4) or isolated pseudo-wave (Fig. 2). Francis[13] has attempted to explain the peculiar behaviour of the disturbances of these two distinct types observed. The wave-train type is a reflective wave from the ground after being radiated from a source which is taken to be a time-wise impulsive and point source at a certain height in the atmosphere. The isolated wave is a wave directly arriving from the source without any appreciable attenuation. On the other hand, earth reflected waves arriving at far off distances from the source manifest themselves as medium scale TIDs with the number of cycles increasing with the height of source.

In the observations reported here, the TIDs travel in all possible directions and most of them show no preference for equatorward propagation. This rules out the possibility of an auroral source except for the two large scale TIDs which do propagate southward. One thus needs to examine the possibility of

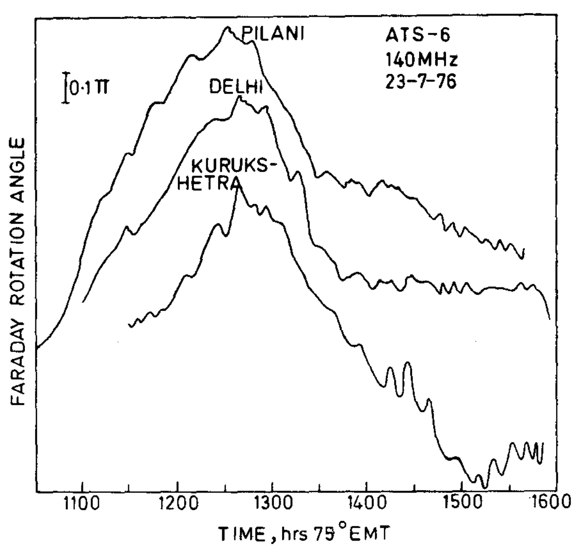

Fig. 4—An example of medium scale travelling ionospheric wave

other sources such as jet streams, thunderstorms, supersonic motion of the earth shadow terminator. The search for medium scale TIDs is further complicated by the continuously changing wave form at different stations. Often a wave cannot be identified unambiguously at two stations even if their separation is 200 km or less.

Experiments to determine the sources of medium scale TIDs should take advantage of such properties as their expected linear increase in period with distance and their dichotomy between periodic and non-periodic wave forms. The role of winds and wind shears in propagation of medium scale TIDs is also an important area of future investigation as is the role played by all gravity waves in the global redistribution of energy and momentum.

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