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Sequential sporadic-E layers at low latitudes in the Indian sector

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Abstract. A study of the formation and movement of sequential Sporadic-E layers observed during the night-time hours at two Indian low-latitude stations, SHAR (dip 10°N) and Waltair (dip 20°N) shows that the layer are formed around 19:00 h. IST at altitudes of ~180 km. They descend to the normal E-region altitude of about 100 km in three to four hours and becomes blanketing type of Es before they disappear. However, the absence of these descending layers at an equatorial station, Trivandrum (dip 2°N) gives the experimental evidence for wind shear theory. The meridional neutral wind derived from the height variation of the F-layer showed significant poleward wind during the descent of these layers. Hence it is inferred that these layers are formed as a consequence of the convergence of plasma by the poleward wind and the equatorward propagating gravity waves (inferred from the height fluctuations of F-layer).

Key words. Ionosphere (active experiments; equatorial ionosphere, ionospheric irregularities)

1 Introduction

The term Sporadic-E (E_s), which is an important example of the irregular structure of the lower ionosphere seen on ionograms encompasses the processes such as particle precipitation, plasma instabilities and gravity waves. The different processes which can form the E_s layers are the horizontal convergence of ionization due to the vertical shears of horizontal neutral winds in the E-region (Whitehead, 1971), gravity waves (Hook, 1970; Lanchester, 1991) and tidal motions (Chimmonas, 1971). But the net effects of the tides and gravity waves are the winds. From the study of ionograms, Castel and Faynot (1970) observed that the irregularities first appear in the F-region and then move downward producing weak E_s. The whole configuration is field aligned and the horizontal neutral air motion produces the downward plasma movement. Shen *et al.* (1976) studied the formation of ionized layers in the night-time E-region valley above Arceibo. They observed broad layers of ionization at the bottom of the F-layer which ultimately descend through the valley (region between E and F layers). Rocket measurements provided evidence that these layers are the ionization convergence-driven layers aided by the neutral wind system (Smith, 1970).

Here, we present evidence for the formation of descending Sporadic-E layers in the night-time low-latitude ionosphere by gravity waves (TIDs) and poleward neutral wind by using data from three ionosondes located nearly in the same meridional plane in India and provides experimental evidence for the winds shear theory.

2 Experimental observations

The study has been carried out by using ionogram taken every 15 min interval by identical ionosondes (KEL-IPS 42) located at three stations namely, Trivandrum (an equatorial station), SHAR and Waltair (low latitude stations), the coordinates of which are given in Table 1.

The virtual height of F-layer (h′F) is scaled at a frequency of 3 MHz so that the group retardation due to underlying ionization are negligible. The vertical drift velocity is obtained from the scaled values of h′F by computing the value of $\Delta h'F/\Delta t$ for every 15 min interval. At the bottom side of the F-region, the electron loss manifests as a rise in the altitude of constant level of electron density and results in an apparent vertical drift. The correction for this apparent vertical drift due to

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Table 1. Coordinates of the observing stations

Station	Geographical Latitude (°N)	Geographical Longitude (°E)	Dip Angle (°N)
Trivandrum	8.3	76.9	0.3
SHAR	13.7	80.3	10.0
Waltair	23.0	83.3	20.0

recombination is applied to the vertical drift velocity using the method suggested by Krishna Murthy *et al.* (1990). The meridional wind over SHAR and Waltair is also calculated using the method given by Krishna Murthy *et al.* (1990).

The study is made from the data obtained during a one year period from November 1990 to October 1991. During this period, descending Sporadic-E layers are observed during 17 nights which are magnetically quiet days (Ap $<$ 4). For comparison, 24 November, 1990, a typical day, is taken as control day on which the layer is absent and the Ap value is only 2.

3 Results

Figure 1 shows the sequence of ionograms recorded at the three stations during the night of 23 November, 1990. On this night, the descending E_s layer is first observed at Waltair at 20:00 IST (85°EMT) and then at 20:30 IST on SHAR ionograms, i.e. after a lapse of about 30 min. The layer is not observed at Trivandrum, the equatorial station. At Waltair, the layer is first seen at an altitude of 160 km and then at SHAR at an altitude of 145 km (all the heights are virtual height). Figure 2 shows a sequence of a descending E_s layer observed at Waltair on the night of 19 November, 1990. It is found from Fig. 2 that layer forms at altitude of 180 km at 19:30 IST. During the descend of the layer, the critical frequency of the layer (f_oE_s) increases and the layer transforms of in to a blanketing type of E_s layer (blanketing is not clear in the figure because of the second order echoes of the E_s layer) and then disappears. On this day (19 November, 1990) the layer is observed at SHAR at an altitude of 160 km at 20:25 IST, i.e. with a delay of 45 min. The main features observed from the study of these layers are:

1. The layers are formed during the post-sunset hours between 19:30 and 21:30 IST.
2. The layers form at altitude ranges of 160 to 180 km.
3. The layers are first observed at Waltair and later at SHAR. The time delay in the occurrence of these Es layers between Waltair and SHAR varies between 15–30 minutes.
4. The layers observed at higher altitudes at Waltair than at SHAR.
5. During the descent, the critical frequency of the layer increases. The layer transforms in to blanketing type of E_s at an altitude of 100 km and then disappears.
6. These layers are not observed at Trivandrum (equatorial station).
7. The complete process of formation, descend and disappearance of the layers takes about 4 hrs.
8. Spread-F was also present at all the three stations, during all 17 nights on which layers were observed.

To study the dynamical behaviour of the F-layer during the formation and descent of these layers the minimum virtual height of F-layer (h′F), the vertical drift of the F-layer (V_z) and the meridional neutral wind velocity (U) during the two nights of 19, 23 November, 1990 are computed and presented in Figs. 3a–c and 4a–c respectively. Along with these parameters the height of the E_s layer for these two days are also presented in Figs. 3a and 4a. The variation of h′F, vertical drift velocity (V_z) and U during the night of 14 November, 1990 (a control day) is presented in Fig. 5a,b and c respectively. These figures show that the peak value of h′F is almost the same during all three nights considered. However, on 14 November, 1990 (the control day) the rise and fall of F-layer (Fig. 5a) is gradual, but on 19 and 23 November, 1990 the rise and fall of the F-layer is rather sharp. During the nights of 19 and 23 November, 1990 (Figs. 3a and 4b) wave like variations are seen in h′F, which is also seen in the variations of V_z. The periods of which are found to vary between 50 and 60 min. The periods of the quasi periodic variation in h′F found to vary between 20 and 60 min for all 17 events.

It may be seen from Figs. 3c and 4c that the meridional wind is poleward up to 21:00 IST and then it becomes equaotorward. The maximum poleward wind velocity during these events (Figs. 3c and 4c) is ~150 m/s which is almost twice higher than the control day value (Fig. 5c). The horizontal drift velocity calculated using the time delay between occurrence of these layer at SHAR and Waltair varies between 25 and 65 m/s and the vertical drift velocity of these layers varies between 3 and 18 m/s. We have subjected the height fluctuations to spectral analysis using the maximum entropy method (MEM) to find out the dominant periodicity. The height of the layer formation is plotted as a function of the periodicity of the wave and is shown in Fig. 6. It is seen from the figure that the height of formation of these layer increases as periodicity of the wave increases.

4 Discussion

The results presented describe the effect of meridional neutral wind and the gravity waves (TIDs) in contributing to the formation of descending Sporadic-E layers at night-time in the low-latitude ionosphere.

The vertical drift velocity of the F-region at any latitude can be written as

$$V_z = E \times B/B^2 - U \cos I \sin I - W_d \sin^2 I \qquad (1)$$

where E is the electric field, B is magnetic field, U is the neutral wind, I is the dip angle and W_d is vertical drift due to diffusion (which is neglected for the present case).

It is known that the dynamics of the night-time equatorial and low-latitude ionosphere is mainly

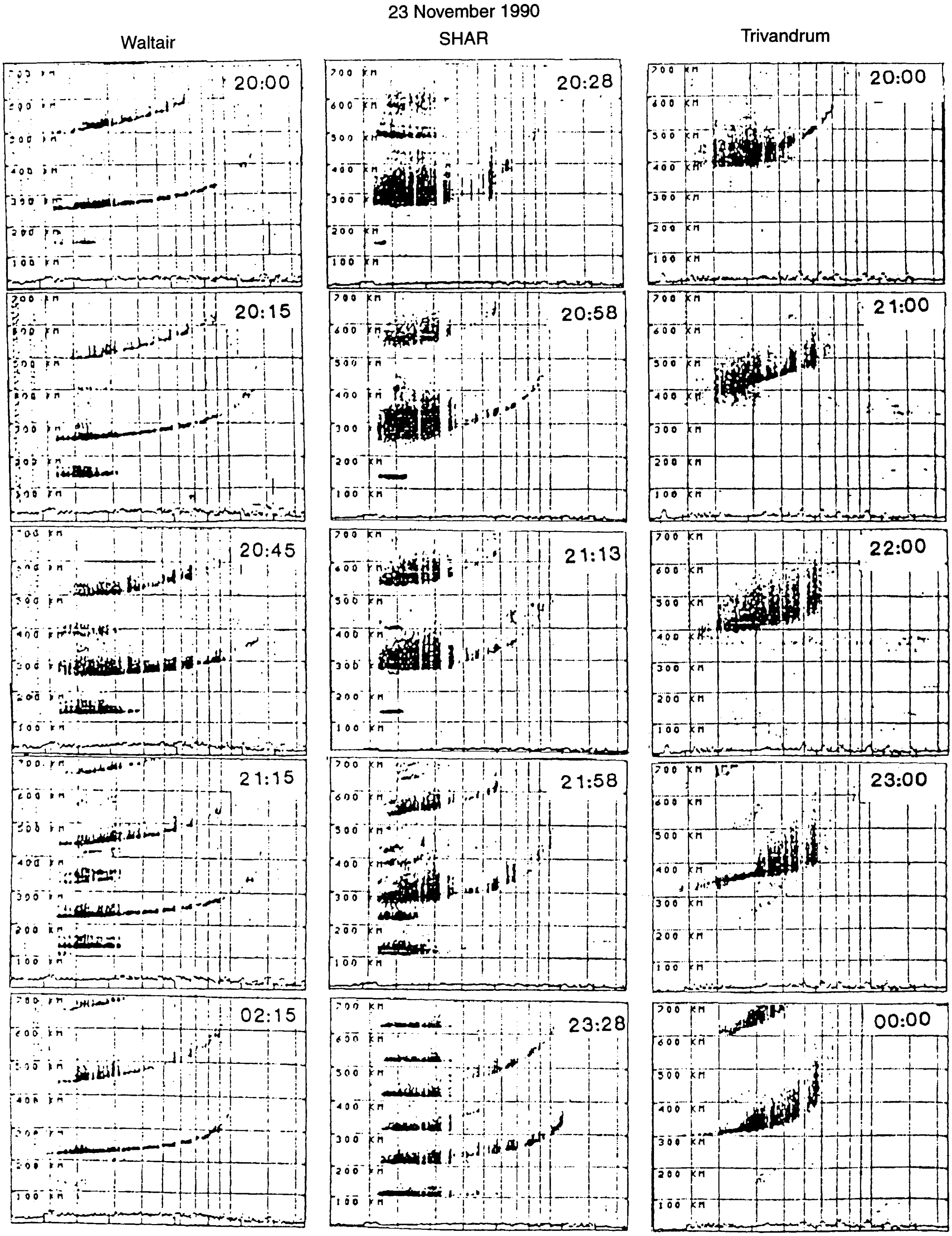

Fig. 1. Ionograms showing the descending Es layers at Waltair and SHAR during the night of 23 November, 1990. The ionograms at an equatorial station, Trivandrum is also shown for the same day, but the layer was not observed at Trivandrum

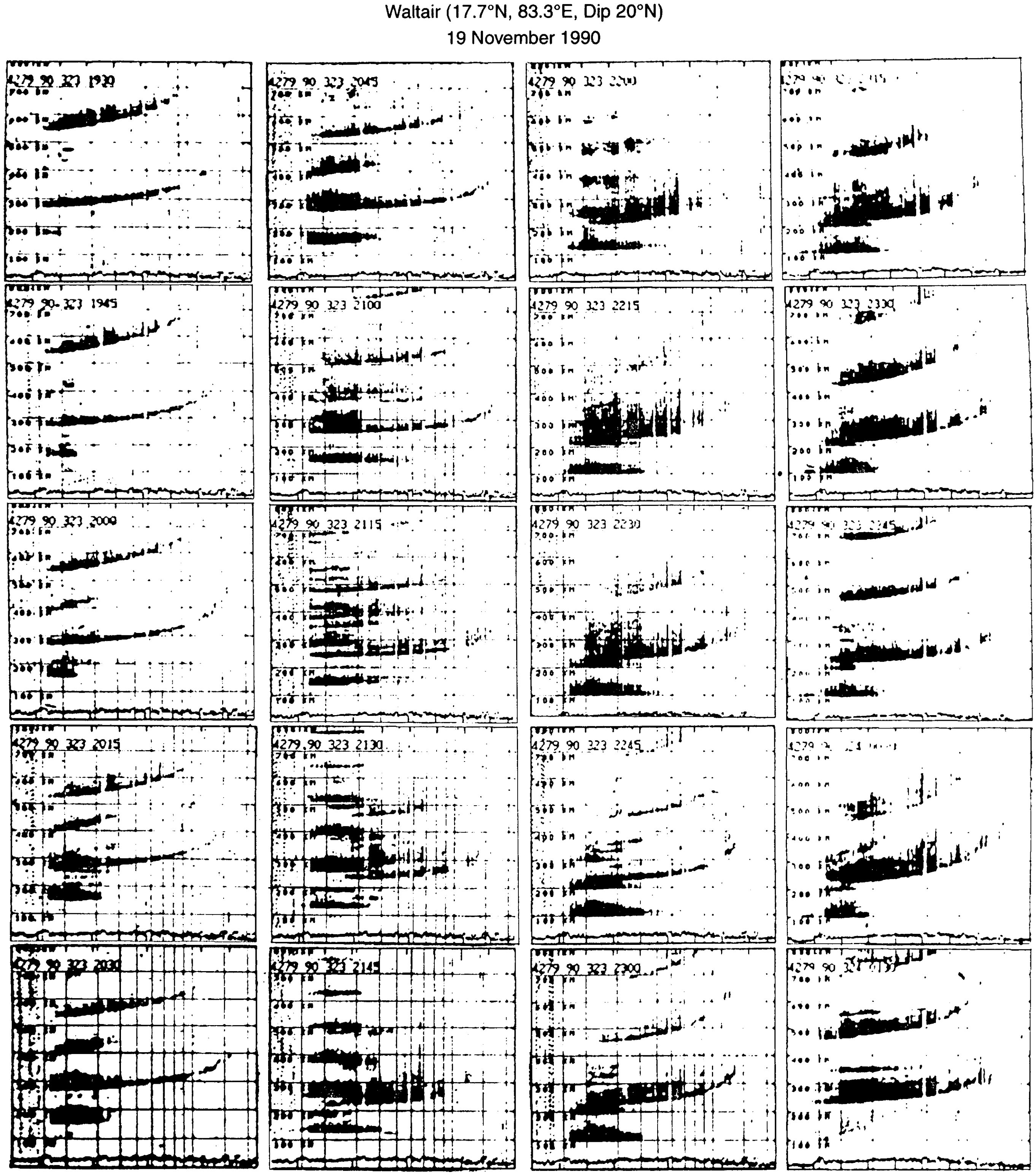

Fig. 2. Sequence of ionograms showing the onset, descent and disappearance of Sporadic E layer at Waltair during the night of 19 November, 1990

controlled by the electric field and neutral wind. Because of the parallel geometry of the magnetic field lines over the equator, the horizontal meridonal wind does not produce any vertical movements of the ionization (because I is almost 0 in the our expression). But at low latitudes, the meridional neutral wind can produce vertical movements. So any perturbation in the height of the F-layer over an equatorial (here Trivandrum) station can be attributed to the changes in the electric field or a gravity wave induced change and if the virtual height

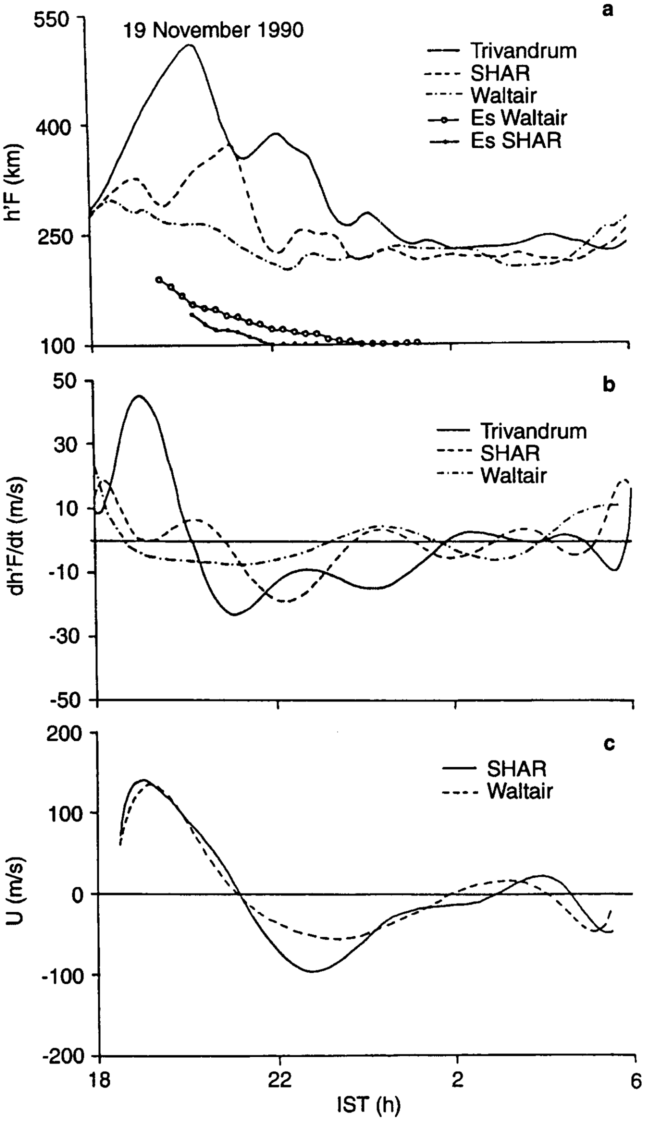

Fig. 3a–c. Variations of **a** h′F, **b** V_z and **c** *U* at the three stations during the night of 19 November, 1990. The height of the Es layers is also indicated

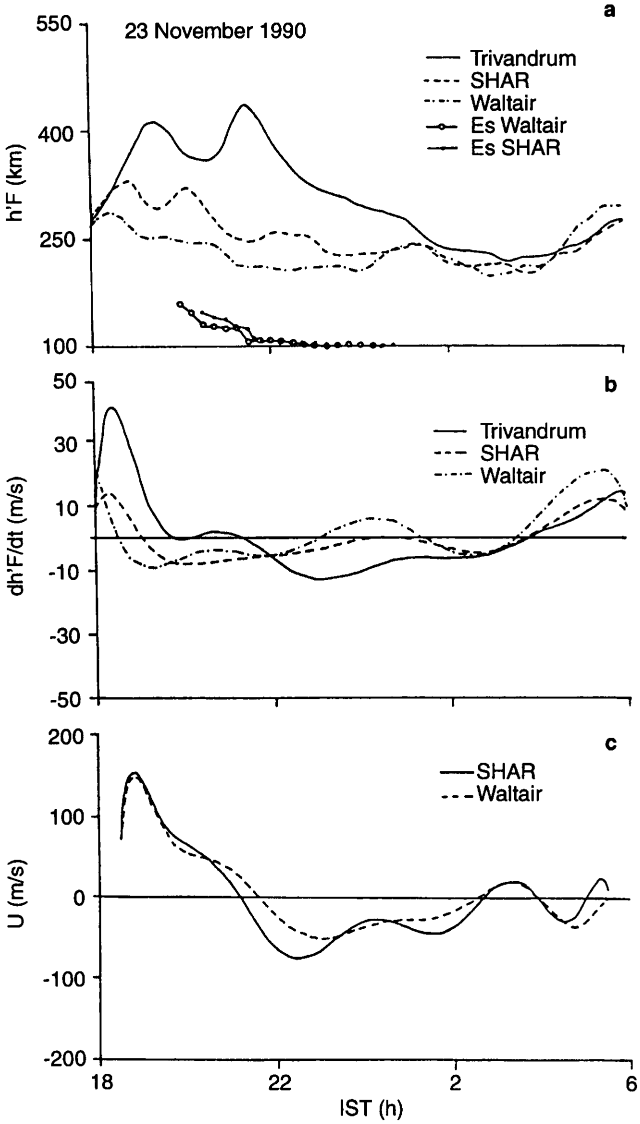

Fig. 4a–c. Variations of **a** h′F, **b** V_z and **c** *U* at the three stations during the night of 23 November, 1990. The height of the Es layers is also indicated

variation is due to the global electric field its effects will be almost the same and simultaneous at all latitudes. Hence we attribute the changes in the height of F-region to the action of gravity wave. According to wind shear theory (Whitehead, 1971) the vertical movement of ionization can be written as (Mac Dougall, 1974):

$$V_z = -U_n F_n - U_e F_e \ , \qquad (2)$$

where U_n and U_e represents the horizontal meridional and zonal neutral wind and F_n and F_e are the drift factors (Mac Dougall, 1974). The drift factors for all the three stations are calculted using the method given by Mac Dougall (1974). We have used the derived merido-ional wind and zonal wind from HWM-90 (Hedin *et al.*, 1991) used to calculate the drift factors. Since the neutral wind which we have derived is at the F-region height, we have used a linear approximation in deriving the meridional wind at lower height. This done by using HWM meridional wind for different heights and obtaining the height variation of meridional wind. The drift factors for the three stations (Waltair and SHAR) are shown in Fig. 7. Figure 7 shows that the effect of meridional wind (F_n) in the ionization drift is above 140 kms and is much less over equator and is higher at low latitudes. This may be one of the reasons for the absence of the layer over equator. The calculated vertical ionization drift velocity varied between 3–18 m/s which corresponds to 6–25 km in 30 min. The downward drift velocity of the F-layer is also 10–15 m/sec. But on the control day the downward velocity was 25 m/s and the calculated vertical drift velocity was also higher. This shows that the time required to collect the ionization was very short.

Assuming that the electric field is the same at the three stations, the magnitude of the meridional wind determines the fall of the F-layer of the low-latitude

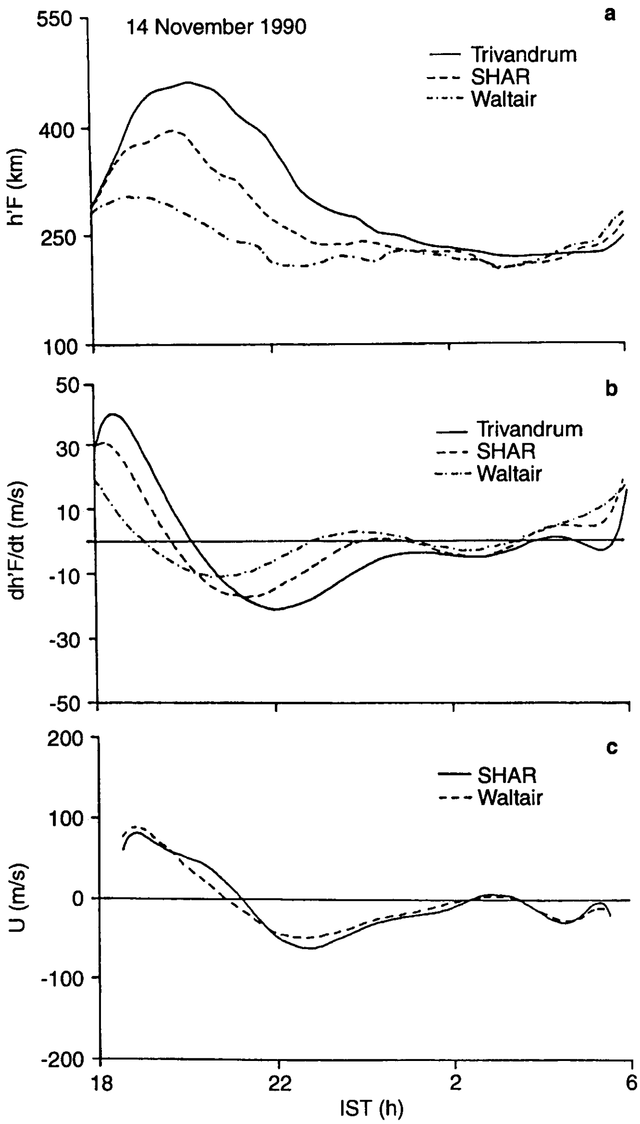

Fig. 5a–c. Variations of **a** h′F, **b** V_z and **c** *U* at the three stations during the night of 14 November, 1990 (control day)

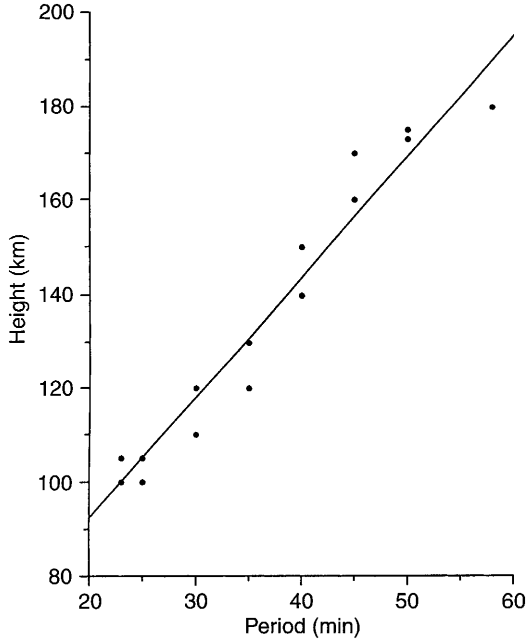

Fig. 6. Variation of height of the occurrence of Es layers with the periodicity of the gravity waves

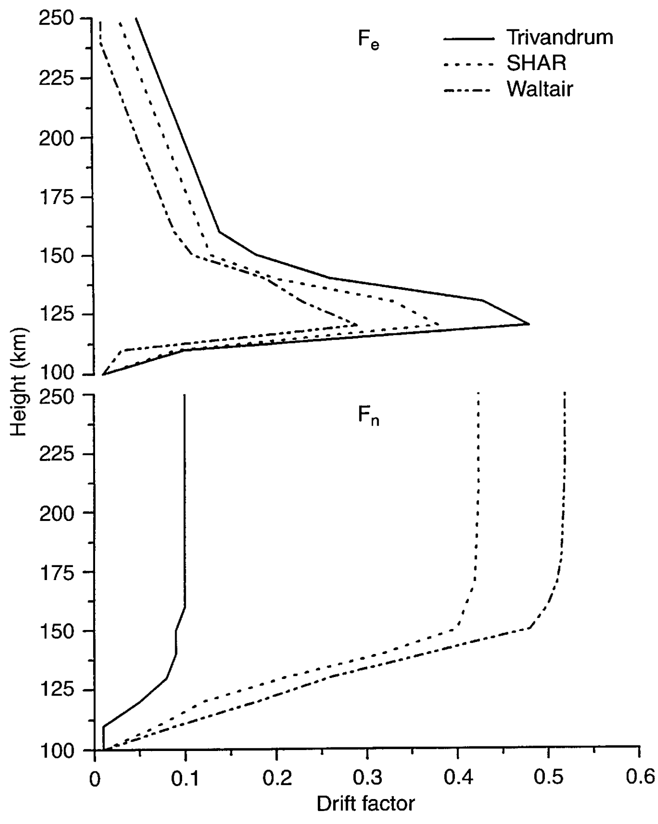

Fig. 7. Drift factors calculated using the method by MacDougall (1972) for the three stations under study

ionosphere. From Fig. 4 it is seen that the rise and fall of F-layer is gradual and vertical drift velocity (both upward and downward) are higher compared to other days. The computed meridional wind was lower on this day. This clearly indicates the action of the meridional wind in forming the layer at higher altitudes. For a gravity wave to generate the irregularities of the same period and same wave length in the E-region, the background electric field must be directed westwards (assuming that the energy flow that sustains the gravity wave propagates upwards and the phase velocity downwards). The gravity wave generated irregularities are, therefore, dominant at night-time because the electric field is westward during the night. The effect of electric field direction in the formation of the layers is described by Nygren *et al.* (1984). The irregularities thus produced occur in the 90–105 km region, but the exact height at which they form depends on the density gradients in the background ionization and the direction of the neutral wind. The irregularities will move with the direction of the wave but their motion will be modified by the neutral wind (Beer and Moorcroft, 1972).

5 Conclusion

The night-time descending sporadic-E layers are produced by the combined effect of the equatorward propagating gravity wave and the increased poleward neutral wind which brings the ionization downward through the field line. The absence of these layer at an equatorial station provides the experimental evidence for the wind shear theory. The descending plasma is controlled and converged in the lower F-region to form increased ionization layers at high altitudes (160–180 km) and descent to lower altitudes (~100 km). The height of formation of these layers are higher for longer period gravity wave.

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References

Beer, T., and D. R. Moorcroft, Atmospheric wave induced instability in the night-time E-region, *J. Atmos. Terr. Phys.*, **34,** 2025, 1972.

Castel, F du., and J. M. Faynot, Some irregularities observed simultaneously in the upper and lower ionosphere at middle latitudes, *Nature*, **204,** 984, 1970.

Chimmonas, G., Enhancement of Sporadic-E by horizontal transport within the layer, *J. Geophys., Res.*, **76,** 4578, 1971.

Hedin, A. E., M. A. Biondi, R. G. Burnside, G. Hernandez, R. M. Johnson, T. L. Killeen, C. Mazandier, J. W. Meriwether, J. E. Salah, R. J. Sica, R. W. Smith, N. W. Spencer, V. B. Wickwar, and T. S. Virdi, Revised global model of thermosphere winds using satellite and ground based observations, *J. Geophys. Res.*, **96,** 7657, 1991.

Hook, W. H., Ionospheric response to internal gravity waves 2. Lower F-region response, *J. Geophys. Res.*, **75,** 7229, 1970.

Krishna Murthy, B. V., S. S. Hari, and V. V. Somayajulu, Night-time equatorial thermospheric meridional wind from ionospheric h′F data, *J. Geophys. Res.*, **95,** A4, 4307, 1990.

Lanchester, B. S., T. Nygren, A. Huskomen, T. Turnen, and M. J. Jarvis, Sporadic-E as trace of atmospheric gravity waves, *Planet. Space. Sci.*, **39,** 10, 1421, 1991.

Mac Dougall, J. W., 110 km neutral zonal wind patterns, *Planet. Space. Sci.*, **22,** 545, 1974.

Nygren, T., L. Jalonen, J. Oksman, and T. Turunen, The role of electric field and neutral wind direction in the formation of sporadic E - layers, *J. Atmos. Terr. Phys.*, **46,** 373, 1984.

Shen, J. A., W. E. Swartz, and D. T. Farley, Ionization layers in the night-time E-region valley above Arecibo, *J. Geophys. Res.*, **81,** 31, 5517, 1976.

Smith, L. G., A sequence of rocket observation of night-time Sporadic-E, *J. Atmos. Terr. Phys.*, **32,** 1247, 1970.

Whitehead, J. D., Ionization disturbances caused by gravity waves in the prescence of electrostatic field and background neutral wind, *J. Geophys. Res.*, **76,** 238, 1971.