Relationship between solar magnetic sectors and mesospheric temperatures at Thumba

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Abstract

Variations in equatorial mesospheric temperatures in the 51–70 km altitude region recorded from 115 M–100 rocket soundings at Thumba (8° N, 77° E), have been analysed in relation to solar magnetic sector structure over the period December 1970–May 1973. The pattern of mesospheric temperature variations is found to be dependent on the type of sector. Heating effects of ~5–10° C are observed in the mesosphere following both types of sector boundary crossings. These effects are found to be preceded by mesospheric temperature decreases. An explanation in terms of the changes in energetic particle fluxes within the sectors is suggested for the observed variations in mesospheric temperature. Similar variations dependent on sector structure are possible in stratospheric parameters.

Key words : Solar activity, mesosphere, sun-weather relationships.

1. Introduction

Relationships between solar and geomagnetic activity and several neutral atmospheric parameters have been investigated extensively by a large number of workers[1–6]. These investigations have used a very wide range of solar and geomagnetic indices and consequently, an integrated and comprehensive analysis of the available results has been vitiated. In recent times there has been a suggestion[7] for using a common index which will enable intercomparison, of results or observations, amongst different investigators. The solar magnetic sector structure has been suggested as the most suitable index of solar and geomagnetic activity and the times of sector boundary crossings past the earth have been suggested as suitable timing marks for these analyses. Subsequently, a few investigations have been carried out on the relationship between the solar magnetic sector structure (referred to henceforth as 'sector structure' in the rest of the paper) and the electric potential of the ionosphere[8] and the D-region absorption[9]. Wilcox[7] has advocated the use of the sector boundary crossing as a timing mark for future investigations on sun-weather relationships, in view of the several advantages inherent in such a choice.

We have earlier carried out analyses[10, 11] of solar and geomagnetic activity effects on mesospheric temperatures, using the solar 2800 MHz radio flux index $F_{10.7}$ and the geomagnetic A_p and K_p indices. In the earlier analysis[10] we had observed a mesospheric heating effect occurring within 24 hr after $F_{10.7}$ enhancements. This heating was attributed[12] to solar UV flux enhancements in the 2000–3000 Å range.

In the light of the advantages mentioned by Wilcox[7] we have now used the sector structure as an index of both solar and the consequent geomagnetic activity. This paper presents the results of an investigation of the relationship between the sector structure and equatorial mesospheric temperatures. In the present paper we consider the solar magnetic sector boundary crossing days as key days in a superposed epoch analysis.

2. Data and analysis

Mesospheric temperature data from 115 rocket soundings over the period December 1970–May 1973 at Thumba (8° N, 77° E) were used in the analysis. A description of the method and data has been presented in the earlier investigation[10] in which 51 soundings in 1970–71 were analysed. Practically all the soundings were carried out in the post-sunset period between 1900 and 2300 hrs IST. This feature almost eliminates the diurnal variation effect in mesospheric temperature.

The sector boundary crossing dates, for the away-toward and toward-away sector boundaries observed during the same period (*i.e.*, December 1970–May 1973) were taken from the comprehensive list of observed and well-defined sector boundaries for the period 1957–1975, listed in Shapley *et al*[13].

The analysis was carried out by considering the day of sector boundary crossing as Day Zero and allocating the sounding days over the period Zero to 8 days relative to Day Zero. This was done by normalizing[14] the sector lengths to 8 days and assigning the sounding days according to their position in the away (+) or toward (–) sector. The values were rounded off to the nearest integer.

Average temperatures for the 51–70 km layer, representative of the mesosphere, were computed for each sounding and these values were averaged over all the soundings corresponding to a particular day in the sector, from Day Zero to Day 8 with Day Zero as (*a*) the away-toward (+/—) sector boundary crossing day, (*b*) the toward-away (–/+) sector boundary crossing day, for the period of the analysis. This was the period over which the temperature data from the soundings were available. The soundings were also separated into summer and winter sets, by considering March 23 and September 22 as the transition days. The average mesospheric 51–70 km layer temperatures were again computed for both sets of soundings and ordered with respect to the key days. The results of the analysis are presented below.

3. Results

Figs. 1 and 2 show the pattern of 51–70 km layer average temperatures in relation to the —/+ and +/— sector boundary crossings, for: (*a*) all the soundings, (*b*) the winter

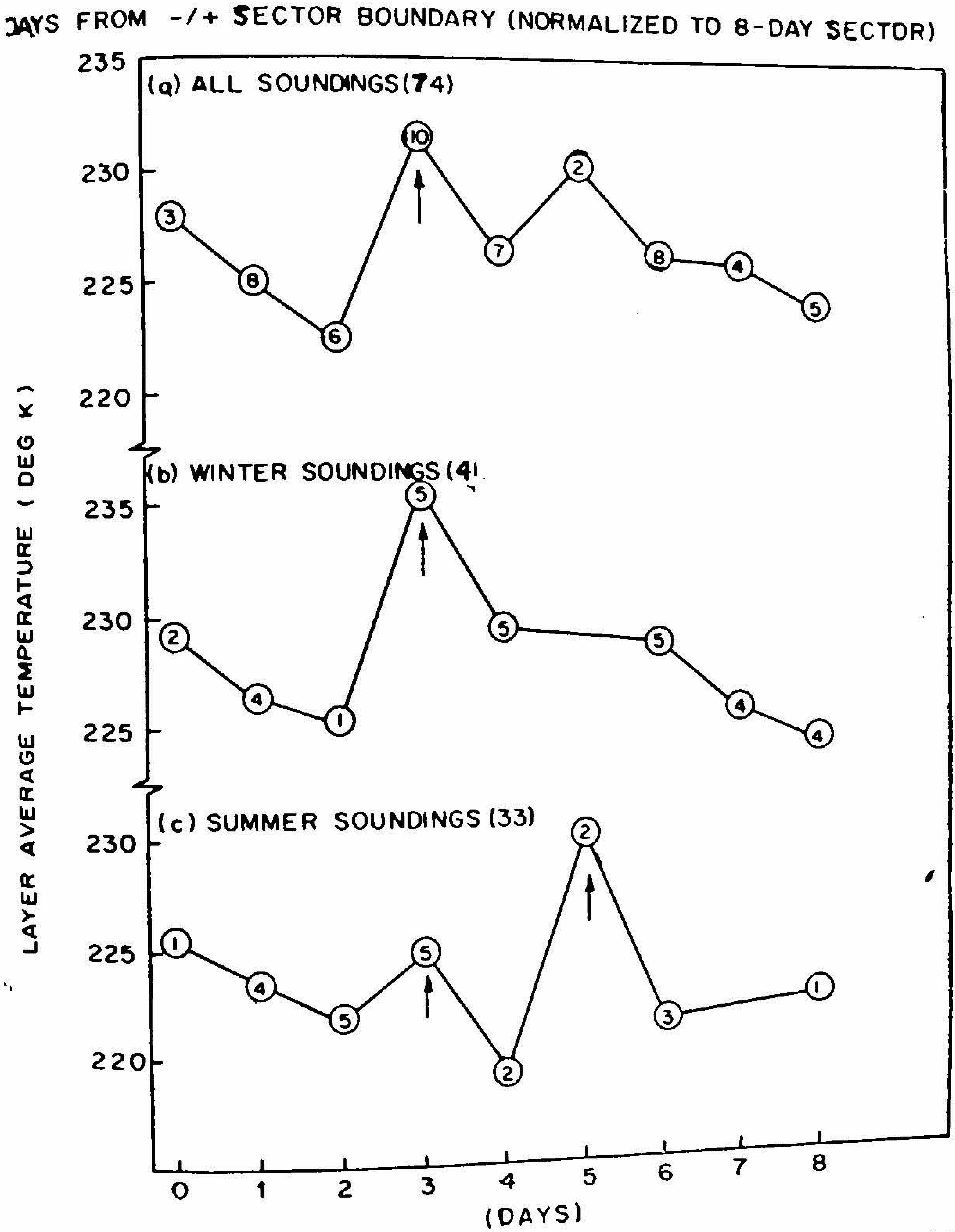

FIG. 1. Variation of 51–70 km layer average temperature in the mesosphere at Thumba, relative to position in the away sector with the toward-away sector boundary crossing on Day Zero. Sector lengths normalized to 8 days: (*a*) all soundings, (*b*) winter, (*c*) summer. The number of soundings corresponding to each point are indicated within the circles.

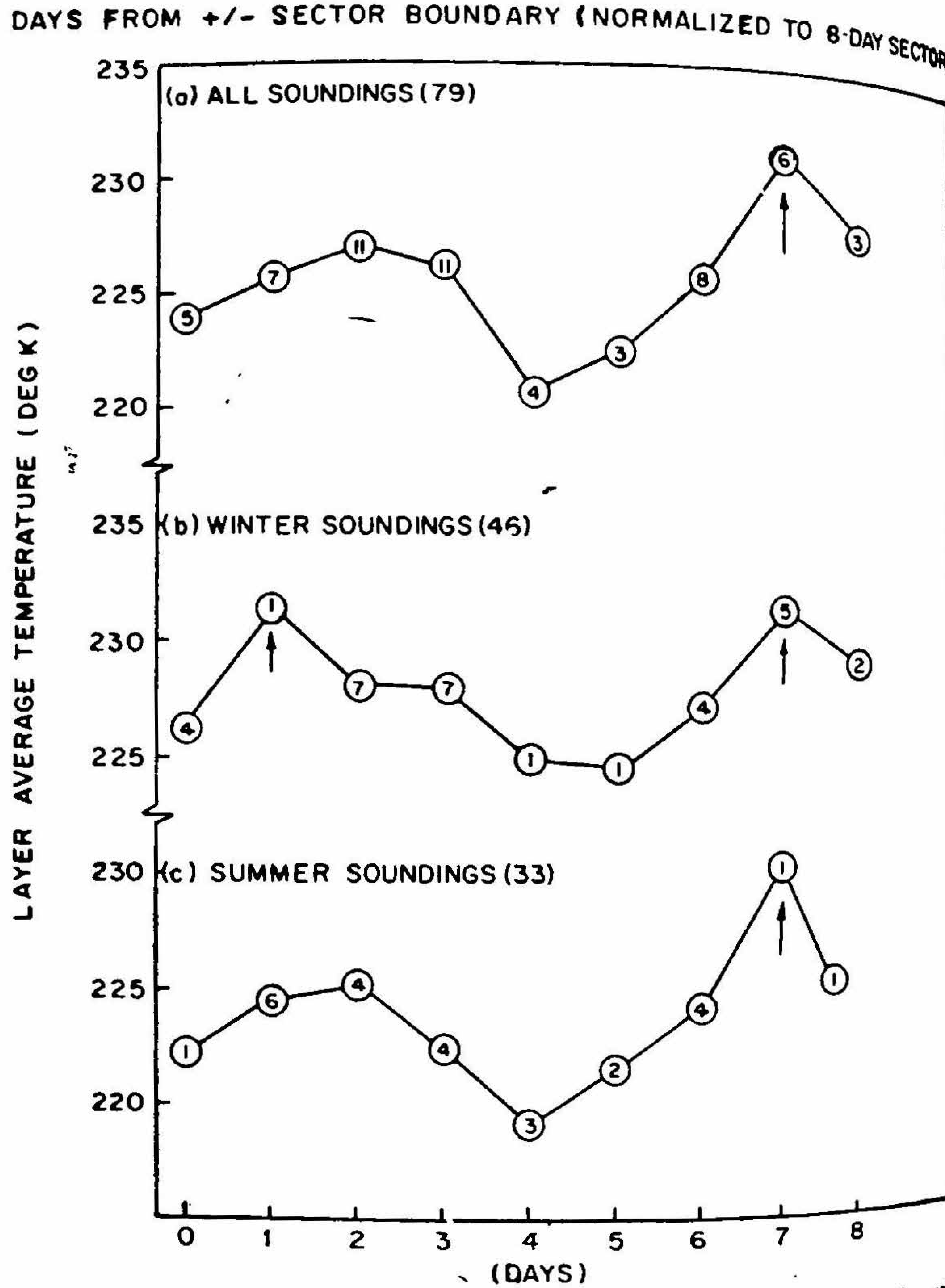

FIG. 2. Variation of 51–70 km layer average temperature in the mesosphere at Thumba, relative to position in the toward sector, with the away-toward sector boundary crossing on Day Zero. Sector lengths normalized to 8 days: (*a*) all soundings, (*b*) winter, (*c*) summer. The number of soundings corresponding to each point are indicated within the circles.

sounding set and (*c*) the summer sounding set. The number of soundings corresponding to each point are indicated in the Figures. The peak values in each case are indicated by short vertical arrows.

The results show that the mesospheric temperature pattern in relation to the sector structure is dependent on the type of sector : away (+) or toward (—).

a. Away (+) Sector

The mesospheric temperature value is seen to attain a maximum value around Day 3 in the away sector, *i.e.*, about 3 days after a toward-away (—/+) sector boundary crossing. This peak is evident in all the three cases : (*a*) all soundings, (*b*) winter soundings and (*c*) summer soundings. This peak appears in both winter and summer cases, though it is comparatively smaller in the summer case. When considering all the soundings, this is the largest peak, preceded by a monotonic temperature decrease from Day Zero to Day 2.

This pattern of mesospheric 51–70 km temperature values in the away sector, with the —/+ (toward-away) sector boundary crossing day as Day Zero indicates a heating effect of the order of 5-10° C, this being the average magnitude over the whole 51–70 km region, and occurring 3 days after the toward-away sector boundary crossings. Several terrestrial phenomena have been observed to occur in conjunction with, or following sector boundary crossings, from upper atmospheric (~ 100 km) altitudes down to tropospheric altitudes. It is well known that magnetospheric, interplanetary, and geomagnetic conditions are comparatively quiescent at around the boundary crossing and become substantially disturbed within a few days after the boundary crossing[15, 16]. Hence it is reasonable to expect a perturbation in the middle atmosphere, where the absorption of particles having a range of energies, and of radiation in several wavelength bands, is known[17] to occur.

An analysis of the variation of horizontal magnetic intensity *H* at Thumba (Trivandrum Geomagnetic Observatory) for away sectors and toward sectors over the period January 1972–May 1973 showed that the *H* value undergoes a slight decrease after the toward-away sector boundary crossing (on Day Zero) and then increases to a peak at Day 4.

The pattern of temperature (and *H*) variations is quite different in the toward sectors.

b. Toward (—) Sector

The mesospheric 51–70 km temperature values show a different pattern in the case of the toward sector, over a range of Days Zero to 8, with the away-toward (+/—) sector boundary crossing day as Day Zero, considered for all soundings, winter soundings and summer soundings separately (Fig. 2).

The most consistently present, and significant, feature appearing in this case is the positive temperature peak at Day 7. This is seen to be present in all the cases (a)-(c) with magnitudes in the range 5–10° C. This positive peak can be seen, from Fig. 2, to be preceded by a negative temperature excursion around Day 4.

The horizontal magnetic field intensity at Trivandrum is also observed to decrease 1–2 days after the away-toward sector boundary crossing day, and ends with maximum values around the trailing edge (Days 6–8) of the toward sector. A positive peak is also observed on Day 1 in the winter case, but this is based only on one temperature value.

Some similarity is seen to exist between the pattern of post-sunset equatorial mesospheric temperature and that of the equatorial horizontal magnetic intensity, in relation to the solar magnetic sector structure. This can be attributed, to some extent, to the pattern of energetic particle fluxes within the sector structure[15].

The pattern[15] of radial streaming of cosmic ray particles (with velocities ~ 200 km/sec) within the sectors, shows a net motion of particles away from the sun near the leading edge of each sector and towards the sun, near the trailing edge, deduced from the diurnal variation in cosmic ray intensity. The enhanced fluxes of the cosmic ray particles could be trapped preferentially, in the earth's trapping region, with the outward bound, leading-edge stream being trapped in the away sectors and the inward bound, trailing-edge stream being trapped in the toward sectors. The drift of these trapped particles in the plasmasphere around the equatorial region would cause variations in the horizontal component of the magnetic intensity. A portion of the energy of the increased particle flux in this belt could be transferred to the equatorial atmosphere by the charge-exchange mechanism suggested by Prolss *et al.*[18]. This could partially account for the mesospheric temperature increase observed in relation to the away and toward sectors, in the present investigation. Possible mechanisms for sun-weather relationships have been discussed in greater detail in a paper under preparation, by the present authors[19].

4. Conclusions

The equatorial mesospheric temperature at Thumba is found to exhibit a pattern dependent on the earth's position within a solar sector. It is observed to be different for away and toward sectors. A statistically significant heating is found to occur in the mesosphere, with magnitudes of the order of 5 to 10° C, in both sectors. The position of the peak heating in relation to the toward-away or away-toward sector boundary crossing is explained in terms of the variations of energetic particle fluxes within the sectors, together with an analysis of equatorial horizontal magnetic intensity variations in relation to the away or toward sector.

The relationship between horizontal magnetic intensity variations and variations in lower atmospheric (stratospheric and tropospheric) parameters with sector structure needs to be analysed, since the energetic cosmic ray particle fluxes which vary within the sectors and from one sector to the next, have an ionization rate which maximises in the lower atmosphere.

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References

1. JACCHIA, L. G. — Recent advances in upper atmosphere structure. *Space Research*, 1970, **10**, 367-388.

2. ROEMER, M. — Geomagnetic activity effect on atmospheric density in the 250 to 800 km altitude region. *Space Research*, 1971, **11**, 965-974.

3. MAROV, M. YA AND ALPHEROV, A. M. — Structure and motion of the thermosphere deduced from satellite drag. *Space Research*, 1972, **12**, 823–840.

4. BANDEEN, W. R. AND MARAN, S. P. (EDS.) — *Possible Relationships between Solar Activity and Meteorological Phenomena*, 1974, NASA Report No. X-901-74-156.

5. KING, J. W. — Sun-weather relationships. *Astronautics and Aeronautics*, 1975, **13**, 109–118.

6. CHANDRA, S. AND KRISHNAMURTHY, B. V. — The response of the upper atmospheric temperature to changes in solar EUV radiation and geomagnetic activity. *Planetary and Space Science*, 1968, **16**, 231–242.

7. WILCOX, J. M. — Solar activity and the weather. *Journal of Atmospheric and Terrestrial Physics*, 1975, **37**, 237–256.

8. REITER, R. — The electric potential of the ionosphere as controlled by the solar magnetic sector structure. Result of a study over the period of a solar cycle. *Journal of Atmospheric and Terrestrial Physics*, 1977, **39**, 95–99.

9. SCHLEGEL, K. ROSE, G. AND WIDDEL, H. U. — Interplanetary magnetic field polarity changes and D-region radio wave absorption. *Journal of Atmospheric and Terrestrial Physics*, 1977, **39**, 101–103.

10. RAMAKRISHNA, S. AND SESHAMANI, R. — The effect of solar activity on temperatures in the equatorial mesosphere. *Journal of Atmospheric and Terrestrial Physics*, 1973, 35, 1631–1641.

11. RAMAKRISHNA, S. AND SESHAMANI, R. — Mesospheric temperature response to variations in geomagnetic activity. *Planetary and Space Science*, 1973, 21, 1447–1453.

12. SESHAMANI, R. — *Solar and Geomagnetic Activity Effects on Mesospheric Temperature*, 1976, Thesis (unpublished), Indian Institute of Science.

13. SHAPLEY, A. H., KROEHL, H. W. AND ALLEN, J. H. — *Solar-Terrestrial Physics and Meteorology: A Working Document*. 1975, SCOSTEP, Washington, D.C.

14. MARKSON, R. — Considerations regarding solar and lunar modulation of geophysical parameters, atmospheric electricity and thunderstorms. *Pure and Applied Geophysics*, 1971, 84, 161–202.

15. WILCOX, J. M. — The interplanetary magnetic field. Solar origin and terrestrial effects. *Space Science Reviews*, 1968, 8, 258–328.

16. WILCOX, J. M. AND COLBURN, D. S. — Interplanetary sector structure at solar maximum. *Journal of Geophysical Research*, 1972, 77, 751–756.

17. CRAIG, R. A. — *The Upper Atmosphere: Meteorology and Physics*, 1965, Academic Press. New York.

18. PROLSS, G. W., NAJITA, K. AND YUEN, P. C. — Heating of the low-latitude upper atmosphere caused by the decaying magnetic storm ring current. *Journal of Atmospheric and Terrestrial Physics*, 1973, 35, 1889–1901.

19. SESHAMANI, R. AND RAMAKRISHNA, S. — Paper under preparation.