Pageoph, Vol. 118 (1980), Birkhäuser Verlag, Basel

The Structure of the Equatorial Mesosphere at Thumba

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Abstract – The structure of the equatorial mesosphere is being investigated at Thumba by rocket borne ultraviolet absorption photometry as well as by the meteorological M-100 rocket launching programme. Whereas the meteorological M-100 rocket launching programme has been regular, the UV absorption studies have been few in number and sporadic in nature. In this paper an attempt is made to consolidate the results so far obtained from both these investigations.

Key words: Stratosphere; Mesosphere; Ultraviolet absorption; Gravity waves.

Introduction

In spite of the great improvement (brought about by space-borne *in situ* techniques) in our understanding of the physical state of the upper atmosphere *vis a vis* its structure and composition, the mesosphere and the lower thermosphere remain largely unexplored. Meteorological programmes based on balloons, rockets, and more recently satellites, have contributed a great deal towards the understanding of the structure and circulation at tropospheric and lower stratospheric levels. In the thermosphere, at altitudes above about 200 km satellite drag technique and the satellite borne mass-spectrometers have contributed towards an understnading of the atmospheric structure and composition as well as their variations. In recent years satellite measurements have been extended to lower heights, down to about 150 km. The intermediate regions, the mesosphere and the lower thermosphere, however, have till recently been dependent mostly on rocket borne techniques, and a significant gap in observational data exists in the upper atmosphere for the altitude range of 60 km to about 150 km. Further, geographically there is much less observational coverage for the equatorial regions than for the other latitude regions and the presently available standard atmospheric models are based to a large extent on mid-latitude data.

The Thumba observational programme

At the equatorial rocket launching station, Thumba (8° 31′N, 76° 52′E), the low latitude mesospheric structure has been explored by rocket borne ultraviolet absorption photometry, a technique which yields molecular oxygen concentration profiles, as well

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as by the Indo–USSR collaborative meteorological rocket programme which involves weekly soundings with the M-100 rocket carrying standard meteorological payload to measure temperatures and winds. Both programmes were initiated in 1970–71. The M-100 meteorological rocket launchings are generally effected every Wednesday around 2000 h local time. Molecular oxygen concentrations in the mesosphere and lower thermosphere have been determined by solar ultraviolet absorption photometry. An ultraviolet ion chamber can be used to measure the solar radiation flux within a selected wavelength band in the extreme ultraviolet (HINTERREGGER, 1969). Molecular oxygen concentrations can be determined from the absorption profile of these radiations in the upper atmosphere since molecular oxygen is the main absorbing constituent in the Earth's atmosphere at these wavelengths (FREIDMAN, 1960). At altitudes below about 90 km the atmosphere is well mixed, and the molecular oxygen concentration measurements can be used to study the atmospheric structure. For these altitudes, a nitric oxide filled ion chamber with MgF_2 or LiF window is found to be most convenient since it includes the hydrogen Lyman-Alpha line (1216 Å) in its passband 1120–1340 Å (CARVER and MITCHELL, 1967). The Lyman-Alpha line dominates this wavelength region of the solar spectrum, contributing nearly 90% to the flux in the total passband that penetrates these altitudes. O_2 densities can be estimated by using a single effective absorption cross section at the Lyman-Alpha line and molecular oxygen concentrations can be obtained in the 65–95 km altitude region (HALL, 1972). The instrumentation used at Thumb has been described in the literature (SUBBARAYA *et al.*, 1973). The special features of the instrument are:

1. Use of positive bias to the ion chamber to reduce effects due to photoelectric emission.
2. Use of linear amplifier with gain switching to give a large dynamic range as well as high sensitivity throughout the range.

The ion chambers used by the authors at Thumba were fabricated and calibrated indigenously at the Physical Research Laboratory, Ahmedabad.

Stratospheric and mesospheric structure over Thumba

Data from the Indo–USSR collaborative M-100 rocket sounding programme at Thumba for the period 1971–74 has been used to study the behaviour of the stratosphere and mesosphere over Thumba. Data for this period is available in the form of monthly means (mean of four rocket flights) for 2000 h local time, tabulated as a function of altitude up to 80 km. The data for representative heights in the stratosphere and mesosphere are plotted in Figs. 1a and 1b to show the variations in stratospheric and mesospheric structure. The most striking feature of these figures is a strong semi-annual variation in density and temperature at all heights above 40 km with maxima in the equinoxial months, and minima in the winter and summer months.

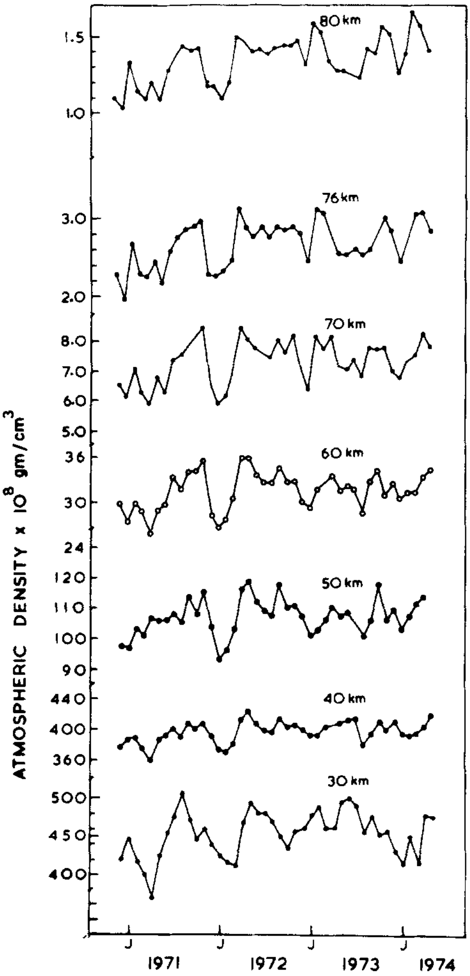

Figure 1a
Atmospheric densities at selected heights in the 40–80 km altitude region obtained from the M-100 rocket programme at Thumba for the period 1971–74.

The figures also show that the winter minimum is deeper than the summer minimum. Further, the amplitude of the semi-annual feature shows an altitude dependence and there are differences from year to year (SHYAM LAL *et al.*, 1979). Semi-annual variations in the atmospheric densities were first recognized by PAETZOLD and ZSCHORNER (1961) in the satellite drag data for the 300–400 km altitude region. Since then it has been the subject of several studies (JACCHIA, 1965; KING HELE, 1967; JACCHIA *et al.*, 1969; JACCHIA, 1971; MAROV and ALPHEROV, 1971; GROVES, 1972; WALKER, 1978) and the existence of a semi-annual variation in atmospheric densities is well established for the entire thermosphere and exosphere. COOK (1969) has recognized a semi-annual effect at an altitude of 90 km in phase with the variation at higher altitudes. At lower

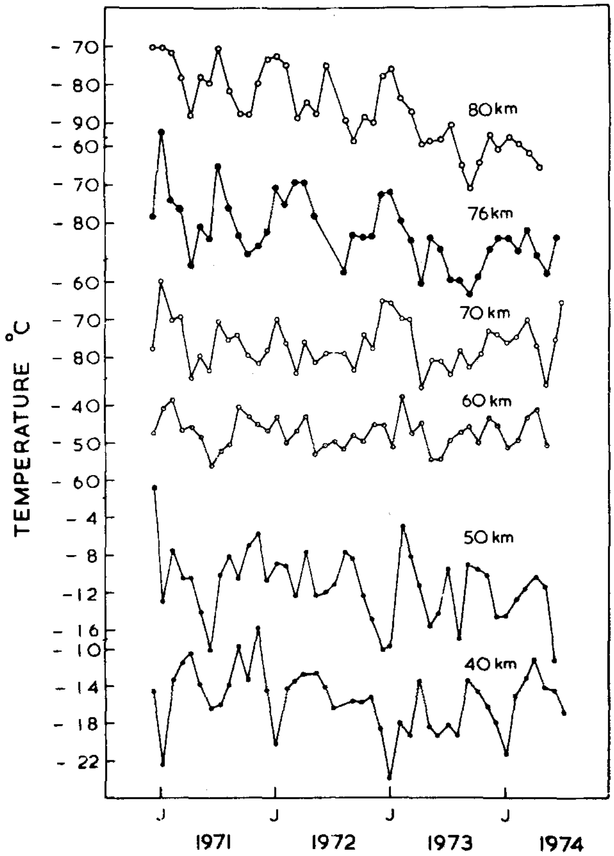

Figure 1b
Atmospheric temperatures at selected height in the 40–80 km altitude region obtained from the M-100 rocket programme at Thumba for the period 1971–74.

altitudes, in the stratosphere and mesosphere, seasonal effects have been known in the circulation, especially at tropical and sub-tropical latitudes where the annual oscillation becomes small (Cole, 1975). Studies based on satellite measurements (e.g. Heath *et al.*, 1974) have shown that the average stratospheric temperatures are lower in December–January than in June–July. However, the semi-annual feature in low latitude stratospheric and mesospheric densities does not seem to have been noticed so far. A comparison of the density behaviour with that of the temperatures shows further interesting results. While there is a semi-annual feature both in densities and temperatures, they go in phase below about 50 km. A change of phase occurs somewhere in the 50–60 km range and in the mesosphere the temperature and density are opposite in phase. The data of Figs. 1a and 1b are subjected to a seven point running average and shown in Figs. 2a, b to study features with longer periods. An annual cycle is clearly evident. Further, a long term trend of temperatures decreasing and densities

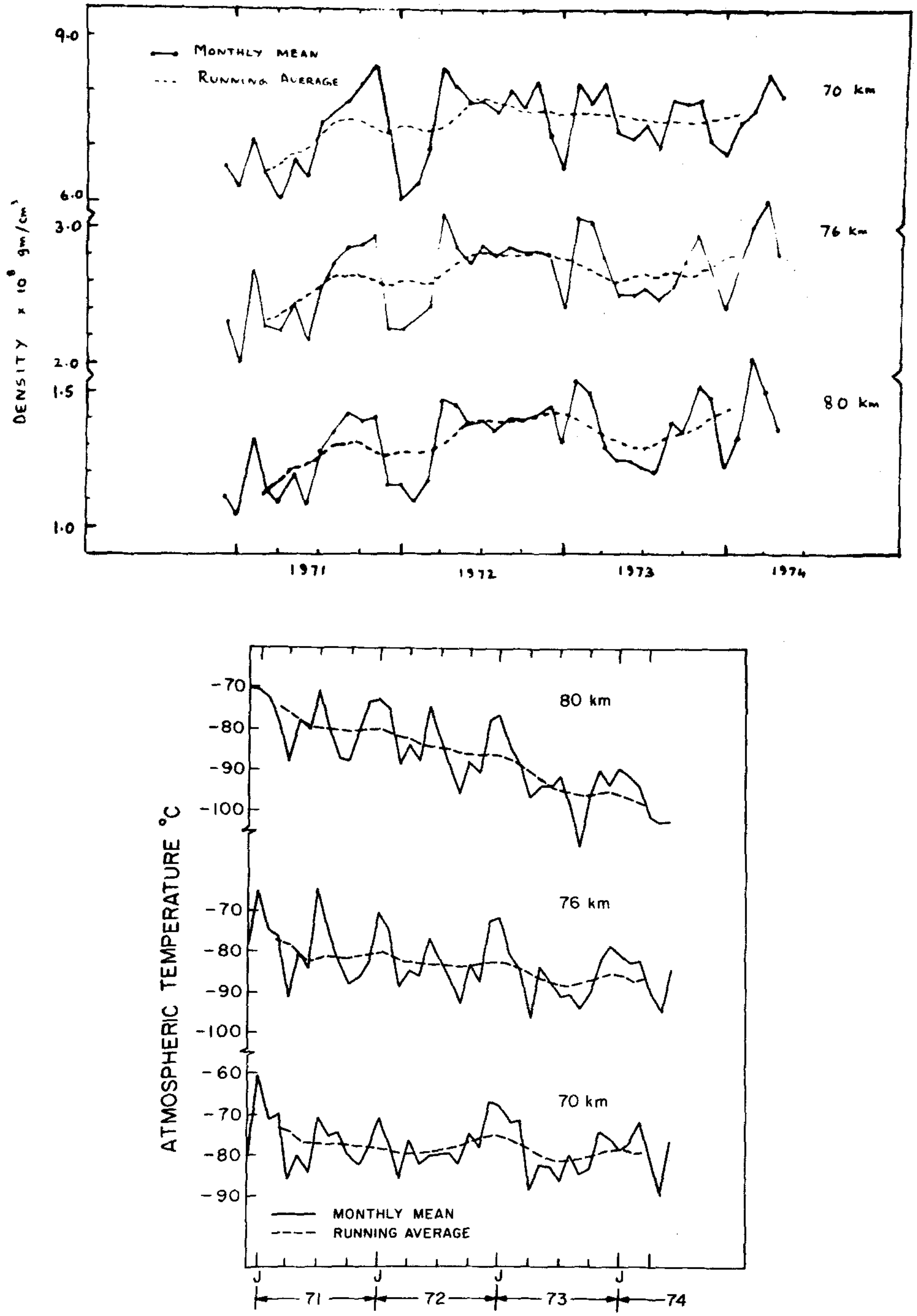

Figure 2

Long term trend in (a) atmospheric densities and (b) atmospheric temperatures in the mesosphere over Thumba. Note that the trend is clear at 80 km, still discernable at 76 km but absent at 70 km.

increasing with decrease in solar activity from 1971 to 1974 is clearly seen at 80 km. The trend persists down to about 75 km, below which height the trend does not seem to exist.

Molecular oxygen concentrations

A number of Lyman-Alpha absorption profile measurements have been made at Thumba during daytime, mostly within a few hours around noon. The measurements were made sporadically over a period of time, on rockets which were flown for various ionospheric investigations. Some of these results have been reported earlier (SUBBARAYA *et al.*, 1972, 1974). It is not possible to resolve from these occasional measurements the finer aspects of low latitude mesospheric structure such as diurnal variations, variation due to solar and magnetic activity etc. However, an attempt is made to obtain some gross features of mesospheric structure from these measurements.

Molecular oxygen concentration profiles from five rocket flights are shown in Fig. 3. Table 1 gives information regarding the flight day and time. Data of Fig. 3 is restricted to the altitude region of 65–85 km even though on some of the rocket flights measurements extend beyond 85 km. It is observed that three of these five profiles shown in Fig. 3a agree within 20% of one another, while the other two profiles shown in Fig. 3b differ markedly from these three. The O_2 concentrations of the first three profiles are less than the standard atmospheric model values such as CIRA 72,

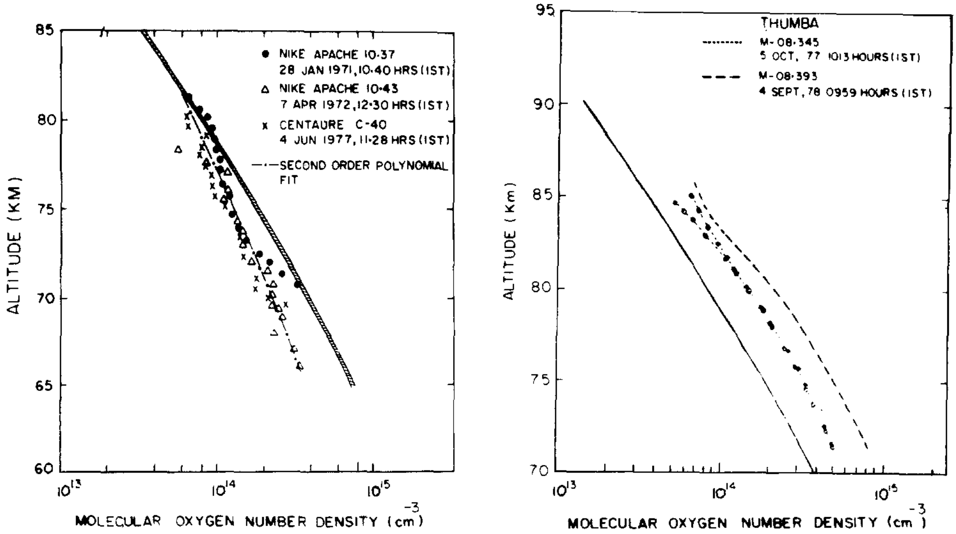

Figure 3
Molecular oxygen concentrations obtained at Thumba using the Lyman alpha absorption technique, compared with the atmospheric model CIRA 72 for 10°N. The shading in 3a represents the spread in the model values for January, April and June months.

Table 1

Solar UV absorption measurements from Thumba

Flight no.	Date	Launch time	Solar zenith angle	Sunspot no.	2800 MHz flux ($X10^{-22}$ Wm^{-2} Hz^{-1})	Geomagnetic index Ap
Nike Apache 10.37	28 January 1971	1040 IST	34.0°	99	171.3	39
Nike Apache 10.42	7 April 1972	1230 IST	17.2°	76	121.1	8
Centaur 0.40	4 June 1977	1128 IST	18.2°	49	91.5	5
M-100 08.345	5 October 1977	1013 IST	32.0°	38	104.0	8
M-100 08.393	4 September 1978	0959 IST	35.3°	161	171.5	8

below about 80 km. A second order polynomial fit to the observations of these three flights meets the CIRA model at an altitude of about 82 km. Scale heights, and hence the gas temperatures, deduced from this mean profile exceed the standard atmospheric model values by 30–50% in the altitude region of 65–80 km. The two profiles from the September 1977 and October 1978 rocket flights show a behaviour quite different from the earlier three profiles. The observed densities on these flights are larger than the model atmospheric values by factors lying between 1.8 and 2.7 throughout the altitude region. The larger values of these two profiles would be in qualitative agreement with the semi-annual feature of Figs. 1a and 1b which shows maximum values for September–October months. The excess amplitudes are, however, larger than given by Figs. 1a and 1b. This, however, could be attributed to the fact that Figs. 1a and 1b refer to 2000 h local time whereas the O_2 densities of Fig. 3 are for day time conditions. Diurnal variations in the tropical atmosphere are known to exist (HEATH *et al.*, 1974) and there could be differences in the features of the day time and night time atmospheric structure even though no definitive observational evidence exists for the same. Further, the rocket flight which has yielded the largest O_2 densities, flight No. 08.393 was on a large solar flux day, the 2800 MHz flux index was 171.5 and the sunspot number was high ($Rz = 161$). Note the increase in O_2 densities by about 50% between the flights 08.348 and 08.393 for an increase in 2800 MHz index from 104 to 170 for the same September–October period. These results indicate a large variability in mesopheric O_2 density and hence the mesospheric structure with solar UV flux if 2800 MHz index is taken as an indicator of solar UV flux.

Figure 4 shows the molecular oxygen concentration profile obtained on 28 January 1971 at 1040 h IST (Solar Zenith angle 34°). The 65–85 km portion of this profile was included in Fig. 3a. The day was characterized by a high level of solar flux, as indicated by the 2800 MHz index which was 171, and large values for the geomagnetic index ($Ap = 39$). This profile merits special attention because of the wave type structure in the observed concentration profile. Errors of the individual O_2 concentration estimates are indicated to emphasize the fact that the wave-like perturbation is significantly above the error bars. Further, the periodicity is unrelated to the period of rocket precession and spin. Hence it is proposed that the observed perturbation is genuine. The observed wavelength is suggestive of gravity waves. Gravity wave associated features in neutral atmospheric structure at stratospheric and mesospheric altitudes have been seen earlier by several workers (THEON and SMITH, 1971; HEATH *et al.*, 1974). However, it is interesting to note that this is the only one out of the five noon time profiles obtained at Thumba that exhibits such wave-like structure. While the equatorial and the auroral electrojets have been considered as potential candidates for launching gravity waves in the upper atmosphere (cf. CHIMONAS and HINES, 1970; NAGPAL and SEN GUPTA, 1977), it should be noted that this particular day was marked by normal electrojet conditions. It is not clear how frequently such perturbations occur at Thumba and whether some of these are related to the flow of the electrojet currents.

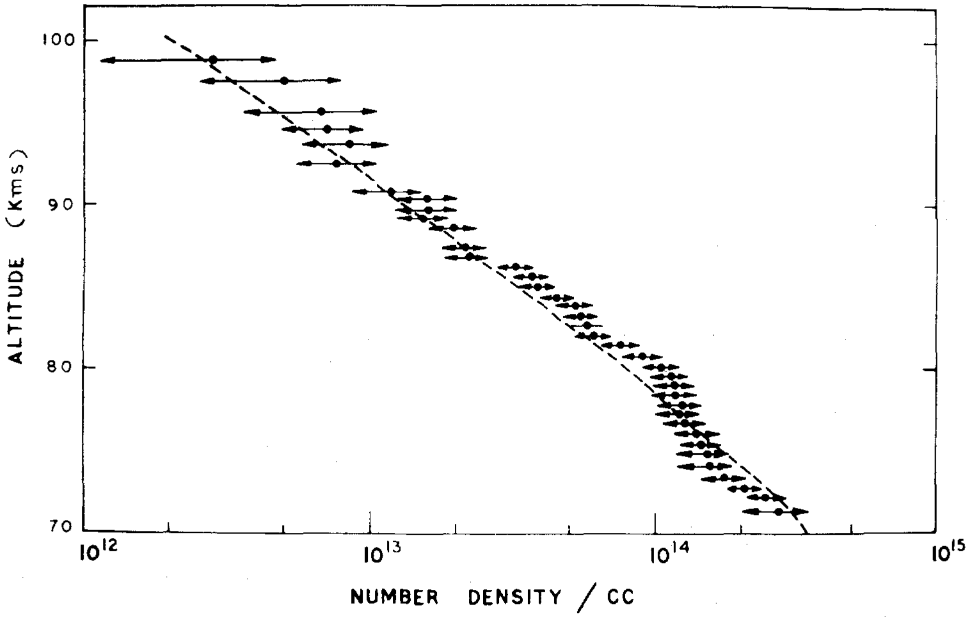

Figure 4
Molecular oxygen concentration profile obtained at Thumba on 28 Jnauary 1971 at 1030 h IST. Note the wave-like perturbation on the profile.

Acknowledgements

The ultraviolet absorption measurements were initiated under the guidance and encouragement of the late Prof. Vikram A. Sarabhai. Acknowledgements are due to Prof. Satya Prakash, who was intimately associated with the programme in the initial stages, for continued encouragement and frequent discussions. Prof. P. R. Pisharoty was the Chief Scientist for the Indo–USSR collaborative M-100 rocket launching programme.

Messrs T. M. Raval and J. T. Vinchi have been helping the authors in instrumentation. Detector fabrication and calibration were facilitated by the kind cooperation of Dr. Vijay Kumar and his associates. Messrs R. I. Patel and K. S. Patel have done most of the data reading and analysis. The authors would also like to acknowledge the cooperation of the staff at TERLS during payload integration and rocket launching phases and Dr. V. Narayanan, Meteorologist, for fruitful discussions on the M-100 data.

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(Received 15th October 1979)