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Atmospheric structure over Antarctica and equatorial India in southern summer

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ABSTRACT. Average vertical profiles of zonal and meridional components of winds, and of temperatures as obtained from M-100 meteorological rocket soundings conducted at Molodezhnaya, Antarctica in January-February 1972 (southern summer) are compared with those of the corresponding ascents from Thumba, South India. The actual results are also compared with the Groves atmospheric model and the corresponding departures of the actuals from the model are worked out. It is found that in the southern summer the polar tropopause and stratopause were about 27°C and 13°C warmer than the corresponding equatorial tropopause and stratopause, while the mesopause was about 25°C colder. At both the stations the zonal winds in the stratosphere were predominantly easterly in January with speed less than 50 m/s and westerly in February with speed less than 35 m/s while the meridional winds were variable. Zonal wind departures of the actuals from the Groves model were found to be in a range of about ± 35 m/s, while the temperature departures were mostly negative which gave an indication that the mesospheric temperatures in the model are given in excess by about 25°C.

1. Introduction

Until 1960 synoptic investigations of the terrestrial atmosphere were confined to only balloon altitudes of about 30 km. With the advent of the Meteorological Rocket Network (MRN) such analysis was extended to higher altitudes of about 80 km. Such data are available for a large number of stations in the northern hemisphere. However, in the southern hemisphere there is a sparsity of rocket sounding stations due to which it is relatively less explored. The study of the atmospheric circulation around the South Pole is important since the weather and climate over the globe are strongly influenced by that circulation.

Under a joint Indo-Soviet agreement the author was the first Indian scientist to winter in Antarctica during the 17th Soviet Antarctic Expedition, 1971-73. In particular, the author carried out Meteorological rocket soundings of the upper atmosphere at the station Molodezhnaya, located at 67° 41′S, 45° 51′E at an altitude of 42 m above mean sea level in East Antarctica (Fig. 1). At the station there is a series of east-west ridges made up of some exposed bed rocks where the ridges are separated by ice-filled valleys with elevations ranging from about 20 to 200 m along the coast. In a narrow zone about 10 km wide parallel to the coast exposed rock and soil are found in abundance which are, however, very rare inland. Although the station bed itself is confined to erratic and frost-churned mixed materials, yet nearby there are two outlet glaciers, Campbell and Hays, which form active moraines.

In 1972 the mean annual temperature observed at the station was —10.5°C varying from a lowest minimum of —35.8°C to a highest maximum of 7.0°C. South-east winds prevailed over the surface with frequent gusts of speed 21 to 41 ms^{-1}. Annual mean relative humidity was 65 per cent and the annual mean precipitation observed was 0.14 cm.

Simultaneous M-100 meteorological rocket soundings were conducted weekly on all Wednesdays from Molodezhnaya, Antarctica and from Thumba (8° 30′N, 76° 52′E), South India in 1972. This investigation is confined to January and February months of the southern summer. Average vertical profiles of zonal and meridional components of winds and of temperatures are studied and an intercomparison is made. A typical summer profile of January 26 is also discussed. The results are compared with the Groves atmospheric model (Groves 1971) and the corresponding departures of the actuals from the model are worked out. Tropospheric, stratospheric and mesospheric circulation indices are computed using a method devised by Webb (1964).

TABLE 1

Summary of the M-100 meteorological rocket soundings conducted from (*i*) Molodezhnaya, Antarctica and (*ii*) Thumba, South India in January-February 1972

Station	Date 1972		Time (GMT)	Wind track (km)	Temperature track (km)	(i) 5-15 km (ii) 10-20 km TsCI (m/s) Meridional	Zonal	45-55 km SCI (m/s) Meridional	Zonal	70-80 km MsCI (m/s) Meridional	Zonal
Molodezhnaya	Jan	5	1450	80-10	82-10	—0·8	—1·7	—1·3	—35·6	2·4	—41·5
Thumba	Jan	5	1433	55-10	70-10	0·7	—1·1	—32·5	—49·6	N/A	N/A
Molodezhnaya	Jan	12	1425	48-10	78-10	—7·6	—4·0	N/A	N/A	N/A	N/A
Thumba	Jan	12	1430	64-10	80-10	5·1	2·7	—42·5	—34·2	N/A	N/A
Molodezhnaya	Jan	19	1440	(84-62) (43-10)	73-10	—4·1	—9·0	N/A	N/A	5·5	—29·3
Thumba	Jan	19	1431	65-10	70-10	5·7	8·5	29·6	—34·3	N/A	N/A
Molodezhnaya	Jan	26	1435	86-10	80-10	—5·0	—2·7	2·1	—26·9	—16·4	—13·1
Thumba	Jan	26	1655	58-25	80-25	3·9	6·6	10·1	20·7	N/A	N/A
Molodezhnaya	Feb	2	1448	48-10	78-10	8·9	—5·8	N/A	N/A	N/A	N/A
Thumba	Feb	2	1430	45-10	60-10	—2·4	2·0	N/A	N/A	N/A	N/A
Molodezhnaya	Feb	16	1535	82-10	76-10	—5·1	6·0	—19·1	27·8	5·1	—30·5
Thumba	Feb	17	1430	56-10	77-10	—2·5	—2·5	1·2	6·4	N/A	N/A
Molodezhnaya	Feb	23	1530	55-10	73-10	—4·5	—10·8	—21·6	33·8	N/A	N/A
Thumba	Feb	23	1430	56-24	77-24	—0·1	—0·2	—8·5	18·1	N/A	N/A

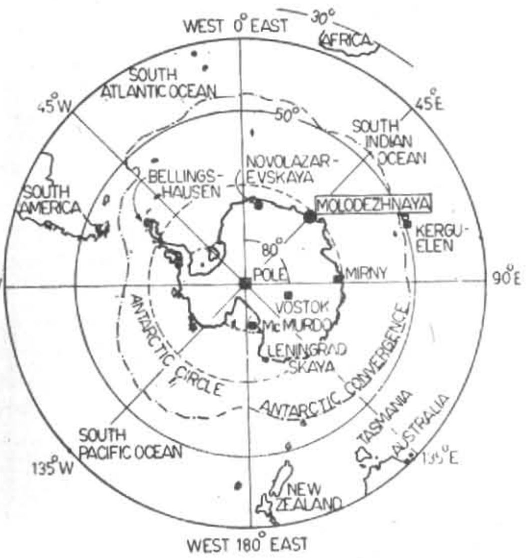

Fig. 1

Map of Antarctica showing the position of the station Molodezhnaya and surrounding area

2. Data acquisition

For acquiring meteorological data of the upper atmosphere high altitude balloons and rockets are employed which incorporate a network of ground-borne and rocket-borne equipments. The objectives of the M-100 rocket system are to measure the meteorological parameters of the upper atmosphere upto an altitude of about 80 km. It is a two stage rocket lifted by a solid propellant of nitrocellulose upto about 95 km. As the head part with the payload is separated on the ascending trajectory a parachute with a surface area of 35 m^2 is opened. The instruments start measurement when the shielding device is thrown away after 60 seconds from the take off.

Head part consists of the steeple with the temperature sensors and an instrument bay for telemetry transmitter, commutator, responder, power supply and control unit. The telemetry transmitter on board the vehicle works at a frequency of 22150 $\pm$ 100 KHz. The mechanical commutator provides scanning of 60 channels per cycle. A special super regenerative radio transponder working at a frequency of 1770-1795 MHz is used. The payload incorporates 4 variable resistance thermometers made of 40 micron tungsten-rhenium wire connected in one arm of a balanced Wheatstone bridge. The radar data on the drift of the trajectory of the parachute, which gets completely filled around 60 km on the descending trajectory of the rocket, is used for measurement of the wind speed and direction. The ground telemetery consists of FM receiver with an input sensitivity of 2 micro volts. The transmitter signals are amplified in the receiver and are fed to the screen of a panoramic oscilloscope. The signals are photographed on a 35 mm film with the help of a cine-camera. During the complete flight the Meteor radar automatically tracks the rockets which is fitted with the transponder. The computers Minsk-2/IBM-360 finally process the data and apply all the necessary temperature and wind corrections using a standard programme written for this purpose.

3. Analysis of data

Winds upto an altitude of about 60 km are determined by measuring the drift of the parachute from the radar (Meteor-1) position data and above 60 km by using an additional wind sensor ('chaff'). In 1972, sixteen chaff-borne rocket flights were conducted from Molodezhnaya, Antarctica and none from Thumba, South India. Upper mesospheric wind results derived from the chaff flights have been discussed by the author in an earlier paper (Sehra 1974).

The temperature data are obtained from the variation in the resistance of the sensor coil using the relation :

$$R_t = R_0 \ (1+\alpha t+\beta t^2)$$

where R_t is the resistance of the thermometer wire at temperature t °C and R_0 at 0°C and α and β are the thermal factors of wire resistance. Temperature corrections for conductivity between the sensor wire and the insulating blocks, aerodynamic heating, thermal inertia of the thermometers, ohmic heating of the sensor wire and radiation from it, and heating due to long wave radiation, are all applied. In these measurements the accidental root mean square error in the determination of the temperature over the altitude region from 60 to 80 km does not exceed 7° to 10°C, at 50 km it is 5°C, and below 40 km the error is less than 3°C. In 1972, more than 60 M-100 meteorological rockets were launched from Molodezhnaya, Antarctica. The stratospheric and mesospheric temperature results derived from such flights are discussed by the author in another paper (Sehra 1975).

The vertical profiles of atmospheric winds and temperatures over Molodezhnaya, Antarctica and Thumba, South India for the period January-February (southern summer) are drawn in Figs. 2 and 4 and a brief summary of the flights conducted is given in Table 1. Radiosonde data are used for completing the profiles in the lower atmosphere as each rocket flight was preceded by a standard radiosonde release. Figs. 2 and 4 show the monthly average profiles for January and February, while Fig. 3 represents a typical summer profile of January 26, 1972.

The actual results of the zonal winds and the temperatures in the altitude region from 25 to 85 km at an interval of 5 km are compared with the Groves atmospheric model (Groves 1971) and the corresponding departures of the actuals from the model are drawn in Figs. 5 and 6 for Janaury and February, respectively. As the values in the Groves model apply to the first of each month, the model average values are obtained from the data of two successive months for comparison. Thumba (8° 30′ N) actuals for January are compared with the corresponding 10°N data of the model. Since in the model no data are available for 70°S station, actuals over Molodezhnaya (67° 41′S) for January are compared with the 70°N data for July of the Groves model and similarly for the February actuals with those for August of the model (Figs. 5 and 6).

Tropospheric, stratospheric and mesospheric circulation indices (TsCI, SCI and MsCI) are computed by using a method devised by Webb (1964) and are given in Table 1.

4. Results

Various results derived from this investigation are given below :

4.1. *Zonal winds*

From the solid curve (A) of Fig. 2 it is evident that average zonal wind components at Molodezhnaya, Antarctica in January 1972 were easterly throughout the atmosphere upto about 84 km. In the troposphere the easterlies were weaker with speed less than 10 ms^{-1}. In the stratosphere the winds became stronger with speeds ranging from about 20 to 30 ms^{-1} around the strotopause. However, the wind maximum was found in the mesosphere at 70 km which had a speed of 47 ms^{-1}. Above 70 km the easterly winds decreased with height which had an average wind shear of about 0.004 s^{-1}.

The corresponding average zonal winds profile of January for Thumba, South India given by the dashed curve (a) in Fig. 2 shows that upto about 7 km the winds were weak easterlies having speeds

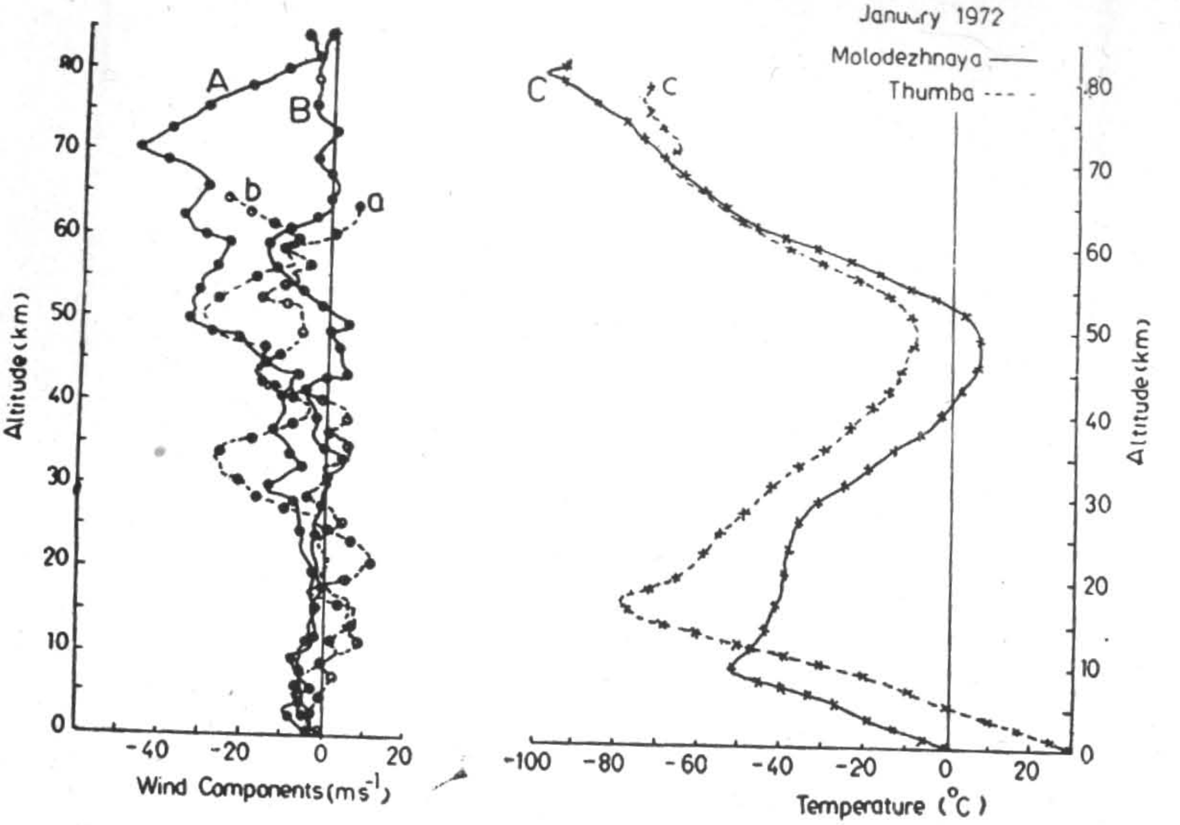

Fig. 2

Average vertical profiles of zonal winds (curves A, a), meridional winds (curves B, b) and temperatures (curves C, c) over Molodezhnaya, Antarctica (solid curves A, B, C) and Thumba, South India (dashed curves a, b, c) in January 1972. The curves (A, a) passing through solid circles represent zonal components of winds in m/s, the curves (B, b) passing through open circles represent meridional compoents of winds in m/s, and the curves (C, c) passing through cross marks represent temperatures in °C over Molodezhnaya, Antarctica and Thumba, South India, respectively.

less than 7 ms^{-1}. Around 7 km the zonal winds changed to weak westerlies of speeds less than to 11ms^{-1} with the maximum at 21 km. From 25 to 60 km the zonal winds were easterlies in toto, with speeds ranging from about 5 to 31 ms^{-1} having the maximum at 50 km, the stratopause. However, above 60 km the zonal winds showed a westerly trend.

It is obvious from the solid curve (A) of the typical summer profile shown in Fig. 3 that on January 26, 1972, the zonal winds over Molodezhnaya, Antarctica were predominantly easterly in the atmosphere upto about 55 km altitude having tropospheric maximum wind speed of 22 ms^{-1} at 3 km and stratospheric maximum at 48 km with 43 ms^{-1} speed. In a narrow altitude region from 55 to 60 km westerly winds with speed ranging from 5 to 12 ms^{-1} were detected. In the mesophere the winds were strong easterlies having maximum speed of 47 ms^{-1} at 70 km. However, in a narrow region from 78 to 85 km the easterly winds changed to westerlies with speeds ranging from about 5 to 13 ms^{-1} which again showed a reversal to easterlies aloft 85 km.

The corresponding dashed curve (a) in Fig. 3 shows that on January 26 the zonal winds over Thumba, South India were weak and variable in the lower troposphere upto about 12 km altitude. And from 12 to 23 km the winds were mainly westerly with a maximum speed of 15 ms^{-1} at 15 and 22 km showing a sudden reversal at 17 km, the tropopause. The lower stratospheric weak westerlies changed to strong easterly winds at about 24 km and persisted in the stratosphere up to 45 km with a maximum speed of 61 ms^{-1} at 42 km which showed a large wind shear. The stratospheric easterlies showed a reversal to westerlies at about 46 km which attained a maximum speed of 28 ms^{-1} at 49 km, the approximate stratopause. The westerlies persisted in the lower

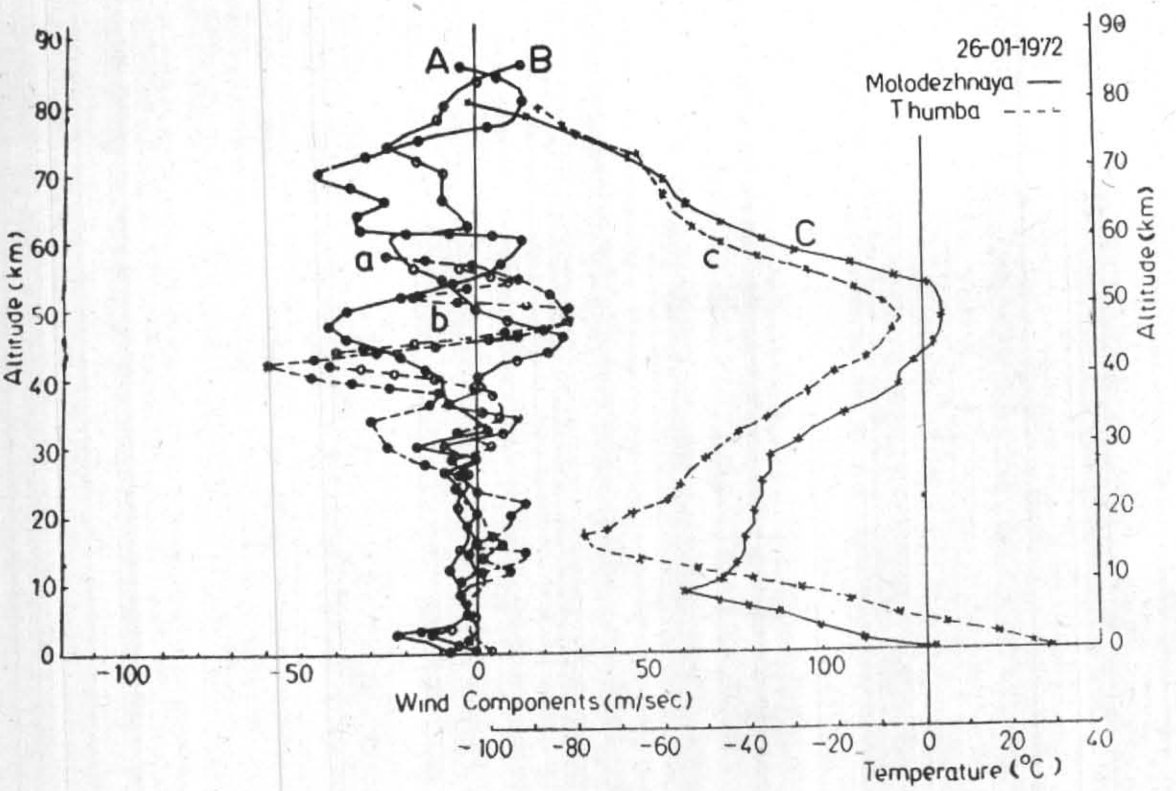

Fig. 3

Typical southern summer vertical profiles of zonal winds (curves A, a), meridional winds (curves B, b) and temperatures (curves C, c) over Molodezhnaya, Antarctica (solid curves A, B, C) and Thumba, South India (dashed curves a, b, c) on January 26, 1972. The cuves (A, a) passing through solid circles represent zonal components of winds in m/s, the curves (B, b) passing through open circles represent meridional components of winds in m/s and the curves (C, c) passing through cross marks represent temperatures in °C over Molodezhnaya, Antarctica and Thumba, South India, respectively.

mesosphere upto about 56 km and changed to easterly winds aloft.

Fig. 4 gives an average profile for February 1972. The solid curve (A) in the figure shows that over Molodezhnaya, Antarctica the zonal winds were easterly with speeds less than 10 ms^{-1} upto about 10 km and were weak and variable in an altitude range of about 10 to 30 km. In the middle stratosphere, altitude region from 30 to 40 km, easterly winds of speed about 10 ms^{-1} were detected which showed a reversal to strong westerly winds in the upper stratosphere with a maximum speed of 36 ms^{-1} at 49 km, the approximate stratopause. The winds remained westerly in the lower mesosphere upto 60 km with speeds in a range of 20 to 30 ms^{-1}. A large wind shear of about 0.04 s^{-1} was detected around 60 km where the westerly winds showed a sudden reversal. The winds in the upper mesosphere were strong easterlies with speeds ranging from about 10 to 100 ms^{-1}. Around 80 km there was a wind shear of 0.02 s^{-1} with a wind speed of 96 ms^{-1} at 82 km.

The corresponding dashed curve (a) drawn in Fig. 4 shows that in February 1972 the zonal winds over Thumba, South India were predominantly weak easterly with speeds less than 10 ms^{-1} up to 17 km, the tropopause where the weak easterlies showed a reversal to weak westerlies which again showed a reversal at 25 km. Strong easterly winds persisted in the stratosphere from 26 to 49 km which attained a maximum speed of 28ms^{-1} at 33 km. The stratospheric easterlies showed a reversal at 49 km, the stratopause, and changed into strong westerly winds with speeds ranging from about 10 to 50 ms^{-1} in the lower mesosphere.

4.2. *Meridional winds*

Average meridional wind profile, given by the solid curve (B) in Fig. 2, shows that in January

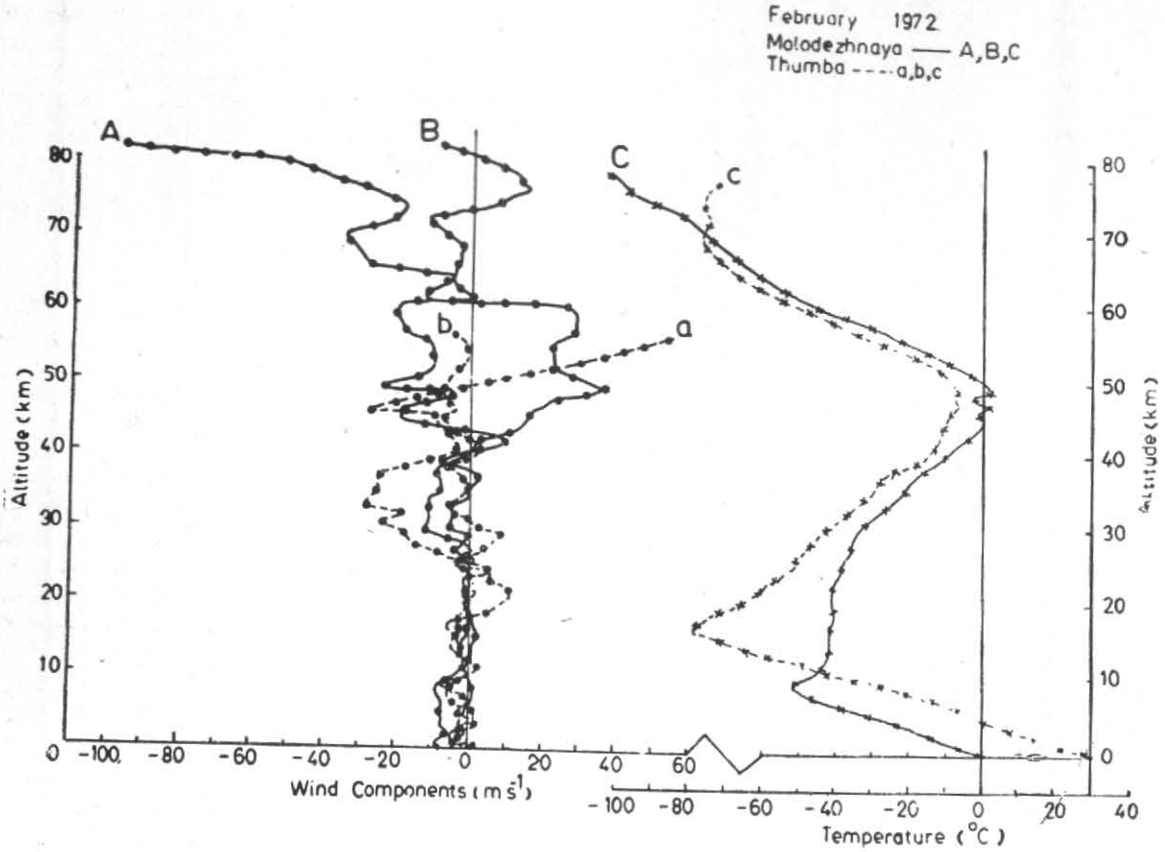

Fig. 4

Average vertical profiles of zonal winds (curves A, a), meridional winds (curves B, b) and temperatures (curves C, c) over Molodezhnaya, Antarctica (solid curves A, B, C) and Thumba, South India (dashed curves a, b, c) in February 1972. The curves (A, a) passing through solid circles represent zonal components of winds in m/s. The curves (B, b) passing through open circles represent meridional components of winds in m/s, and the curves (C, c) passing through cross marks represent temperatures in °C over Molodezhnaya, Antarctica and Thumba, South India, respectively.

the winds over Molodezhnaya, Antarctica were predominantly northerly upto the mesopause. Upto 30 km the northerlies were weak with speeds less than 8 ms^{-1}. In the altitude region from 30 to 50 km the meridional components were weak and variable. In the 50 to 60 km region the northerlies were relatively stronger having a maximum speed of 16 ms^{-1} at 58 km which again became weaker in the upper mesosphere.

The corresponding average profile for Thumba given by the dashed curve (b) in Fig. 3 shows that in January the meridional winds over South India were weak and variable upto about 40 km with speeds less than 10 ms^{-1}. Above 40 km the winds were predominantly northerly with speeds ranging from 5 to 25 ms^{-1}.

The solid curve (B) in Fig. 3 shows that the meridional components of winds in the terrestrial atmosphere over Molodezhnaya, Antarctica on 26 January 1972 were weak northerly upto an altitude of 27 km with wind speed less than 8 ms^{-1}. In an altitude region from 28 to 38 km the winds were variable with speed less than 20 ms^{-1}. In the upper stratosphere, altitude region 38 to 50 km, strong southerly winds were found which had a maximum speed of 26 ms^{-1} at 45 km. The stratospheric southerlies changed to mesospheric northerlies at about 50 km. In the mesosphere the northerly winds persisted upto 83 km having a maximum speed of 25 ms^{-1} at 74 km with a secondary maximum of 24 ms^{-1} at 60 km. Above 83 km the profile showed a southerly trend, From the corresponding dashed curve (b) in Fig. 3, it is obvious that the meridional winds over Thumba, South India on January 26 were variable with weaker winds of speeds less than 13 ms^{-1} upto 40 km and stronger winds aloft. In an altitude region from 40 to 45 km the meridional winds were strong northerlies which had a maximum speed of 47 ms^{-1} at 43 km. The upper stratospheric northerly winds showed a reversal to southerlies around 46 km which had a maximum speed of 28 ms^{-1} at 49 km. Above 50 km the meridional winds were again variable with speeds ranging from about 5 to 25 ms^{-1}. Thus the upper stratosphere and the lower mesosphere were in a turbulent state having large wind shears with meridional winds rapidly shifting from northerlies to southerlies and *vice versa*.

The meridional wind components over Molodezhnaya, Antarctica in February 1972 are shown by the solid curve (B) in Fig. 4. Upto an altitude of 43 km the winds were weak and variable with speed less than 11 ms^{-1}. Above 44 km the winds were predominantly northerly with a maximum speed of 23 ms^{-1} at 49 km, the stratopause. The northerlies persisted upto 73 km in the mesosphere with a maximum speed of 20 ms^{-1} around 60 km which showed a reversal to southerly winds at 74 km. The southerlies had wind speed ranging from 5 to 16 ms^{-1} in the upper mesosphere with the maximum at 76 km. Above 80 km the winds showed a northerly trend.

The corresponding average profile of the meridional winds over Thumba, South India in February given by the dashed curve (b) in Fig. 4 shows that the winds were weak and variable upto 30 km with speeds less than 10 ms^{-1}. Above 30 km the winds were predominantly weak northerlies in the upper stratosphere and the lower mesosphere.

4·3. *Temperatures*

Average temperature profile for January 1972 over Molodezhnaya, Antarctica given by the solid curve (C) in Fig. 2 shows that the polar tropopause was at 9 km altitude with air temperature of —51·8°C. The lapse rate in the troposphere was —5·6°C km^{-1}. In an altitude region from 12 to 28 km a quasi-isothermal temperature structure prevailed with a lapse rate of +0·5°C km^{-1}. In the upper stratosphere the lapse rate was about 2°C km^{-1}. The profile shows that the stratopause was at 47 km with a temperature of 6·5°C. In the mesosphere the lapse rate was —3·8°C km^{-1} with the mesopause at 80 km having a temperature of —99°C.

The corresponding temperature profile for Thumba, South India is given by the dashed curve (c) in Fig. 2. It shows that in January the equatorial tropopause was at 17 km with a temperature of —78·8°C and that the lapse rate in the troposphere was —6·8°C km^{-1}. In the stratosphere the lapse rate was +2·4° C km^{-1} with the stratopause at 50 km having a temperature of —8·8°C km^{-1} and the mesopause was at 77 km with a temperature of —77·5°C.

The solid curve (C) in Fig. 3 is the typical southern summer profile of January 26, 1972 over Molodezhnaya, Antarctica. It shows that the polar tropopause and stratopause were at 9 km and 49 km altitudes with temperatures of —56°C and +4°C respectively. The mesopause was, however, not well defined.

The dashed curve (c) in Fig. 3 is the corresponding profile of January 26 for Thumba, South India. It shows that the equatorial tropopause and stratopause were at 17 km and 48 km with temperatures of —79°C and —7°C respectively, while the mesopause was not well defined.

The solid curve (C) in Fig. 4 gives an average temperature profile for February 1972 over Molodezhnaya, Antarctica. It shows that the polar tropopause and stratopause in late summer were at 9 km and 49 km with temperatures of —52·3°C and 2·0°C respectively while the mesopause was not well defined. Temperature lapse rates in the troposphere, upper stratosphere, and mesosphere were —5·5, +2·4 and —3·4°C km^{-1} respectively, while in an altitude region from 12 to 28 km the lapse rate was very small, +0·4°C km^{-1} showing that the lower stratosphere was in a quasi-isothermal state.

The dashed curve (c) in Fig. 4 gives the corresponding temperature profile of February for the station Thumba, South India. It shows that in late summer the equatorial tropopause and stratopause were at 16 km and 49 km with temperatures of —79·3°C and —7·3°C respectively. The mesopause was found in altitude region from 70 to 75 km having a minimum temperature of —77·0° C at 70 km with a secondary minimum of —76·5°C at 75 km. Temperature lapse rates in the troposphere, stratosphere and mesosphere were —7·2, + 2·4 and —4·3°C km^{-1} respectively.

5. Comparison with the Groves atmospheric model

The above results, *viz.*, zonal winds and temperatures are compared with the Groves atmospheric model (Groves 1971) and their departures

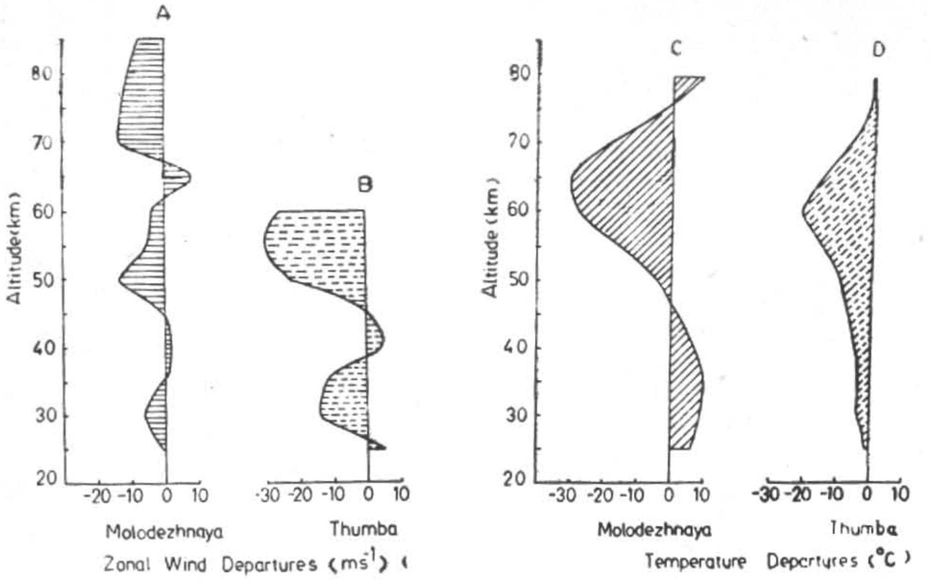

Fig. 5

Departures of the actual zonal wind and temperature results from the Groves atmospheric model over Molodezhnaya, Antarctica (curves A, C) and Thumba, South India (curves B, D) in January 1972. Zonal wind departures in m/s are given by the curves shaded with horizontal lines (solid curve A for Molodezhnaya and dashed curve B for Thumba, South India, while the temperature departures in °C are given by the curves shaded with inclined lines (solid curve C for Molodezhnaya and dashed curve D for Thumba).

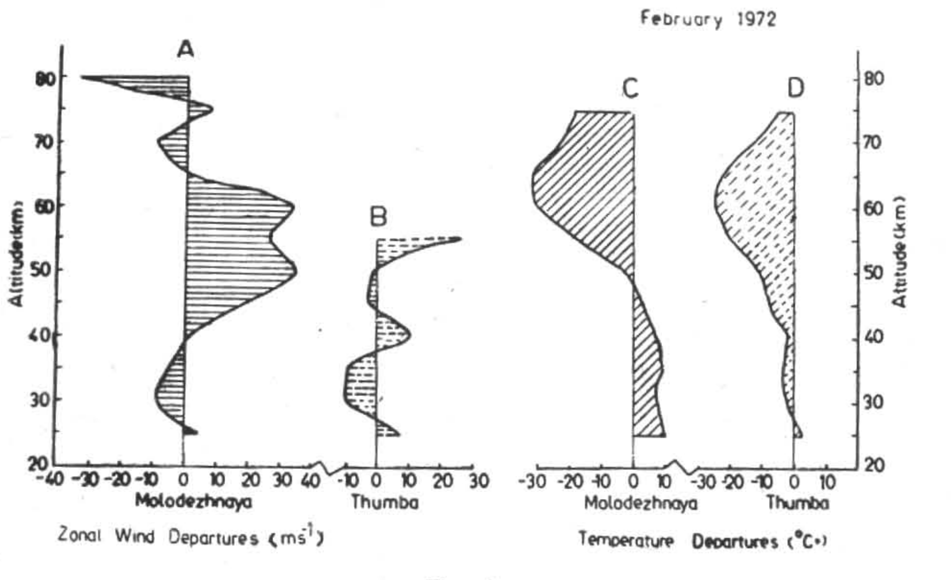

Fig. 6

Departures of the actual zonal wind and temperature results from the Groves atmospheric model over Molodezhnaya, Antarctica (curves A, C) and Thumba, South India (curves B, D) in February 1972. Zonal wind departures in m/s are given by the curves shaded with horizontal lines (solid curve A for Molodezhnaya and dashed curve B for Thumba), while the temperature departures in °C are given by the curves shaded with inclined lines (solid curve C for Molodezhnaya and dashed curve D for Thumba).

from the model for the months of January and February are shown in Figs. 5 and 6 respectively. Comparison is made for the altitude region from 25 to 85 km at an interval of 5 km.

5.1. *Zonal wind departures*

The curve (A) in Fig. 5 represents departures of the actual zonal winds at Molodezhnaya (about 68°S), Antarctica in January from the corresponding Groves profiles at 70°N in July. The departures were less than 14 ms^{-1} in the stratosphere and there was a fairly good agreement between the two in the altitude region from 25 to 45 km. The winds were predominantly easterly in both, the actual profile and the Groves profile. Maximum departure from the model was —23·5 ms^{-1} at 50 km with a wind speed of 34 ms^{-1} at Molodezhnaya and 20·5 ms^{-1} at 70°N (from the Groves model). The negative departures in the figures show that the actual easterly winds were stronger than the model easterlies, while the positive departures show the reverse.

The curve (B) in Fig. 5 gives the zonal wind departures of the actuals over Thumba (about 9°N), South India from the Groves model profiles (at 10°N) in January. It shows that in January the zonal wind departures in the stratosphere and the lower mesosphere were less than 30 ms^{-1}. The winds in the stratosphere were easterly with a westerly trend in the lower mesosphere in both the profiles, actual as well as Groves. Again, the negative departures mean that the Thumba zonal winds were stronger than the model winds. However, at 60 km where the westerlies prevailed, the Thumba winds were weaker having a speed of 2·5 ms^{-1} and the departure from the Groves model was —25 ms^{-1}. A good agreement was found around 40 km where the departures were less than +4·7 ms^{-1} showing that the Groves easterlies were somewhat stronger than the actual Thumba easterlies.

The curve (A) in Fig.6 gives the zonal wind departures of the Molodezhnaya actuals from the Groves model for February 1972. In the Groves profile the winds are predominantly easterly in the stratosphere and the mesosphere, while in the actual profile the winds were predominantly strong westerly in an altitude region from about 45 to 60 km which contributed to larger departures in this region with a maximum of +35·5 ms^{-1} at 50 km and a secondary maximum of +34·0 ms^{-1} at 60 km. The negative departures in the figure show that the actual easterly winds over Molodezhnaya, Antarctica were stronger than the corresponding Groves winds.

The corresponding zonal wind departures of the Thumba actuals from the model for February are shown by the curve (B) in Fig. 6. The winds were predominantly easterly in the stratosphere with strong westerlies aloft, in both the actual and the model profiles. Maximum departure was +26·5 ms^{-1} at 55 km with strong westerlies of 50·5 ms^{-1} at Thumba and 24·0 ms^{-1} from the Groves model. A good agreement between the actuals and the model was found around the stratopause in an altitude region from 45 to 50 km with departures of about —2 ms^{-1}. Again, the negative deviations from the model mean that the actuals were stronger than the model winds, while the positive departures mean the reverse.

5.2. *Temperature departures*

The curve (C) in Fig. 5 gives temperature departures of the Molodezhnaya actuals from the Groves atmospheric model for January 1972. In the stratosphere the deviations from the model were less than +10°C. Maximum departure was —30°C at 65 km and the minimum was +1·8°C at 45 km around the stratopause. Positive departures in the figure show that the actual temperatures were greater than the Groves temperatures, while the negative departures mean the reverse. It is thus obvious from the figure that in January the stratosphere over Molodezhnaya, Antarctica is warmer than the corresponding Groves profile with a maximum of 10°C at 35 km, while the Molodezhnaya mesosphere is colder than the model with a maximum of 30°C at 65 km. However, at 80 km around the mesopause the Molodezhnaya profile is about 8·5°C warmer than the Groves profile.

The corresponding temperature departures of the Thumba actuals from the model for January are shown by the curve (D) in Fig. 5. A sufficiently good agreement between the actuals and the model was found in the stratosphere with departures ranging from —1 to —9°C. Maximum departure was —21·8°C at 60 km. Negative departures in the figure mean that the actual temperatures over Thumba, South India were colder than the corresponding Groves model temperatures.

The curve (C) in Fig. 6 gives the temperature departures over Molodezhnaya, Antarctica from the Groves model for February 1972. Again, in the stratosphere the actual temperatures were warmer than the Groves temperatures with a maximum of 9·8 °C at 25 km, while in the mesosphere the actuals were colder with a maximum of 31·8°C at 65 km.

The corresponding temperature departures of the Thumba actuals from the model for February are shown by the curve (D) in Fig. 6. It is obvious from the figure that in February the Thumba actuals were colder than the corresponding Groves profile with a maximum of 24·8°C at 60 km. There is a sufficiently good agreement between the two in the stratosphere with departures ranging from about —2°C to —10°C.

From Figs. 5 and 6 it is obvious that the temperature departures of the actuals from the model in January had a good similarity with those in February both for Molodezhnaya, Antarctica and Thumba, South India. However, the zonal wind departures were different in the two cases.

6. Discussions

Webb (1964) devised a method for studying reversal of winds at different times during a year by calculating an average flow over a layer 10 km thick from 45 to 55 km centred at 50 km and called it the Stratospheric Circulation Index (SCI) of the appropriate layer. Using the same method average values of the wind speeds for the layers from 5 to 15 km, 10 to 20 km, 45 to 55 km and 70 to 80 km are computed for deriving from the individual soundings Tropospheric Circulation Index (TsCI), Stratospheric Circulation Index (SCI) and Mesospheric Circulation Index (MsCI) of the appropriate layers. Average winds over the layer from 5 to 15 km give TsCI for Molodezhnaya, Antarctica, while those from 10 to 20 km give TsCI for Thumba, South India. This is because the polar tropopause was found to be at 9 km, while the equatorial tropopause was at 17 km. Average winds over the layers from 45 to 55 km and from 70 to 80 km give the corresponding SCI and MsCI. The tropospheric, stratospheric and mesospheric circulation indices computed for January-February 1972 are given in Table 1. Positive values of the circulation indices refer to south in the meridional flow and to west in the zonal flow while the negative values represent north and east correspondingly.

6.1. *Tropospheric Circulation Index (TsCI)*

Table 1 shows that the meridional components of the tropospheric circulation index over Molodezhnaya, Antarctica were predominantly northerly in January and February (southern summer) with a maximum wind speed of 7·6 ms^{-1} on January 12. However, a wind reversal from weak northerlies to weak southerlies of speed 8·9 ms^{-1} occurred from January 26 to February 2 which again changed to weak northerlies by February 16. The corresponding meridional TsCI over Thumba, South India was weak southerly in January with a maximum wind speed of 5·7 ms^{-1} on January 19. The weak southerlies showed a reversal to weak northerlies from January 26 to February 2 which then persisted throughout the month. January 26 to February 2 thus seems to be a transition period for the meridional winds in the troposphere over Antarctica and South India.

The zonal components of the tropospheric circulation index over Molodezhnaya, Antarctica in January-February were predominantly easterly having a maximum wind speed of 10·8 ms^{-1} on February 23 with a secondary maximum of 9 ms^{-1} on January 19. However, a wind reversal occurred around February 16 when the zonal flow became westerly with a speed of 6 ms^{-1}.

The corresponding zonal TsCI at Thumba, South India was predominantly westerly in January with a maximum wind speed of 8·5 ms^{-1} on January 19. The westerlies changed to weak easterlies during the first half of February which persisted later. Thus there seems to be a transition of the zonal winds both over Antarctica and South India around mid February.

6.2. *Stratospheric Circulation Index (SCI)*

Meridional and zonal components of the stratospheric circulation index over Molodezhnaya, Antarctica and Thumba, South India for the period from January to February (southern summer) are given in Table 1.

The table shows that the meridional SCI over Molodezhnaya, Antarctica was predominantly northerly with a maximum wind speed of 21·6 ms^{-1} on February 23. However, a weak southerly trend with a wind speed of about 2 ms^{-1} occurred on January 26. The corresponding meridional SCI over Thumba, South India was found to be variable during January to February with a strong northerly flow of maximum speed 42·5 ms^{-1} on January 12 and a strong southerly flow of speed 29·6 ms^{-1} on January 19. The southerly flow persisted till about mid February and again became northerly around Febuary 23.

The zonal SCI over Antarctica was found to be predominantly easterly in January with a maximum wind speed of 35·6 ms^{-1} on January 5, and westerly during February with a maximum speed 33·8 ms^{-1} on February 23. Wind reversal occurred some time during January 26 to February 16. The corresponding zonal SCI over South India also showed a strong easterly flow in January with a maximum wind speed of 49·6 ms^{-1} on January 5, and a westerly flow in February.

The reversal of zonal winds from strong easterlies to relatively weaker westerlies occurred during January 19 to January 26. The westerly flow had a maximum speed of 20·7 ms^{-1} on January 26.

6.3. *Mesospheric Circulation Index (MsCI)*

Table 1 gives mesospheric circulation index over Molodezhnaya, Antarctica for only those days in January-February 1972 when special chaff-borne M-100 meteorological rocket flights were conducted. The table shows that the mesospheric meridional flow was predominantly weak southerly with a reversal to northerlies of speed 16·4 ms^{-1} on January 26, while the zonal flow was strong easterly which had a maximum speed of 41·5 ms^{-1} on January 5 with a secondary maximum of 30·5 ms^{-1} on February 16. A detailed account of the mesospheric winds in Antarctica has been discussed by the author in an earlier paper (Sehra 1974).

Since no 'chaff' flights were conducted from Thumba, South India in January-February, no MsCI is available for this equatorial station. N/A in the table means not available.

6.4. *Tropopause, stratopause and mesopause*

From the combined average values of the seven M-100 meteorological soundings conducted in January-February 1972, a brief summary of which is given in Table 1, it is found that in the southern summer the polar tropopause and stratopause were at 9 km and 47 km with temperatures of —52·1°C and 4·9°C respectively, while the mesopause was around 80 km with a temperature of about —100°C. Likewise, the corresponding equatorial tropopause, stratopause and mesopause were found to be at 17 km, 49 km and 75 km with temperatures of —78·6°C, —8·2°C and —75·0°C respectively. Temperature lapse rates in the troposphere, stratosphere and mesosphere over Molodezhnaya, Antarctica were —5·5, +2·2 and —3·6°C km^{-1}, while over Thumba, South India the corresponding lapse rates were —7·0, +2·4 and —4·0°C km^{-1}. In an altitude region from 12 to 28 km, the temperature structure over Antarctica was found to be quasi-isothermal with a lapse rate of +0·4°C km^{-1}.

7. Conclusions

From this investigation a few major conclusion that can be drawn are as follows:

(*i*) In the January-February months of the southern summer the polar tropopause and stratopause were found to be 26·5°C and 12·5°C warmer than the corresponding equatorial tropopause and stratopause, while the polar mesopause was about 25°C colder than the corresponding equatorial mesopause. Also, the equatorial tropopause and stratopause were located at about 8 km and 2 km higher than the corresponding polar tropopause and stratopause while the equatorial mesopause was found at an altitude of about 5 km lower than the corresponding polar mesopause.

(*ii*) The meridional winds in the troposphere, stratosphere and mesosphere were variable both over Antarctica and South India. The zonal winds over Antarctica were predominantly easterly in the troposphere and the mesosphere as shown by TsCI and MsCI, while in the stratosphere they were easterly in January and westerly in February. Over Thumba, South India the zonal winds were variable in the troposphere, while in the stratosphere they were strong easterlies till about mid January and westerlies later. Thus the stratospheric circulation over the south pole and the equator was predominantly easterly in January and westerly in February.

(*iii*) Departures of the actual zonal winds from the corresponding Groves atmospheric model profiles were found to be quite significant lying in a range of about ± 35 ms^{-1}. There is an indication that the mesospheric temperatures in the Groves model are given in excess by about 25°C.

This investigation of the south polar and the equatorial atmospheric structure leads to an intuitive conclusion that it is very necessary to collect more meteorological rocket sonde data in the southern hemisphere in order to better understand the physical processes influencing the weather and climate all over the globe.

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