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SOME METEOROLOGICAL OBSERVATIONS OF THE SOUTHERN HEMISPHERE STRATOSPHERE AND MESOSPHERE

by

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1968

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INTRODUCTION

In response to requests by experimenters from government and university research institutions, the National Aeronautics and Space Administration organized and funded a sea-going expedition during 1965 to obtain rocket sounding measurements of the atmosphere from sites otherwise inaccessible. The participants of the expedition agreed upon a Southern Hemisphere course because comparatively few observations above a 50 km altitude have been made there.

In March and April, 1965, a ship which NASA had equipped to serve as a mobile rocket range sailed south along the west coast of South America from the equator to 60°S. The ship was the escort aircraft carrier, the USNS Croatan. Seventy-seven rocket soundings, including eight Nike Apache pitot-static tube experiments were conducted during the expedition. The results of those eight soundings, as well as other pertinent data, are presented in this report.

OBSERVATIONAL TECHNIQUE

The pitot-static tube technique was applied to rocket-borne observation of the upper atmosphere by Ainsworth, et al. (Reference 1) more than ten years ago. In this experiment, both ambient atmospheric pressure and density are measured directly as the rocket ascends. Useful data are obtained from approximately 25 to 100 km altitude. The temperature profile is then derived from the pressure and density profiles using a different variation of the hydrostatic equation and the equation of state in each case. The estimated maximum errors included in the pitot-static data presented here are approximately ±1 percent below 84 km, ±4 percent between 84 and 100 km, and ±10 percent above 100 km. The technique utilized to obtain the data reported here is basically the same as that of Ainsworth and his co-workers. The details of the present experimental technique have been published by Horvath, et al. (Reference 2) and Rupert (Reference 3).

The pitot-static soundings were made from the equator to 60°S in order to obtain a representative cross-section of the Southern Hemisphere atmosphere. A similar expedition during 1959, which provided stratospheric data between the latitudes 27°S and 65°S, has been reported by the Russian investigators, Borovikov, et al. Their results are published in Reference 4. The NASA expedition was carried out during the Hemisphere's late summer-early autumn period of 1965. The dates, times and locations of eight shipboard soundings analyzed in this paper are given in Table 1. These soundings are tabulated in detail in Reference 5. The eight soundings include a pair of soundings conducted 12 hours, 37 minutes apart at the equator, and a pair conducted 11 hours, 55 minutes apart at 60°S. These two pairs of soundings provided data concerning the diurnal effects. The results are published in Reference 6. Six of the soundings were conducted during daylight hours and five of these were launched within 75 minutes of local solar noon to remove as much of the diurnal effect as possible.

The shipboard soundings were made during a five week period. This resulted from the practical considerations of scheduling as many experimenters' requirements as possible, but it precluded the possibility that all of the synoptic and even seasonal effects could be separated from the purely latitudinal effects. However, the analyses of temperature and wind (pressure) fields produced smooth latitudinal variations, indicating that the short term variations are probably minimal. Unfortunately, there is no means by which the results of the gradual seasonal changes that may have occurred during this interval can be eliminated.

Table 1

Dates, times, and locations of pitot-static tube experiments conducted in the Southern Hemisphere during 1965

Date	GMT	Local Solar Time	Location
8 March	1748	1212	Shipboard 0°00', 84°04'W
9 March	0626	0049	0°52'S, 84°09'W
4 April	1607	1102	24°05'S, 76°08'W
6 April	1634	1137	35°14'S, 74°15'W
9 April	2026	1515	44°23'S, 77°47'W
13 April	0405	2253 (12 April)	60°00'S, 78°00'W
13 April	1600	1048	60°00'S, 78°00'W
15 April	1600	1047	52°35'S, 78°20'W

RESULTS AND DISCUSSION

The temperature data obtained from the six daylight pitot-tube soundings as well as the balloonsonde and rocketsonde data from lower altitudes (below 25 km) are presented as a space-time cross section which extends from the equator to 60°S (Figure 1). Minor differences between overlapping balloonsonde and rocketsonde data are not uncommon, and data from these techniques do not necessarily agree exactly with the pitot-static measurements at the same altitude. Some of the discrepancies result from differences in the times at which the data were taken, and some are due to inherent errors in all three techniques. This cross-section runs primarily along the west coast of South America between the 74th and 84th meridians, and covers a five week period of time. With these limitations in mind, the following analysis is presented. A detailed analysis of the troposphere, stratosphere and lower mesosphere, including the balloonsonde and rocketsonde observations reported here, is published in Reference 7.

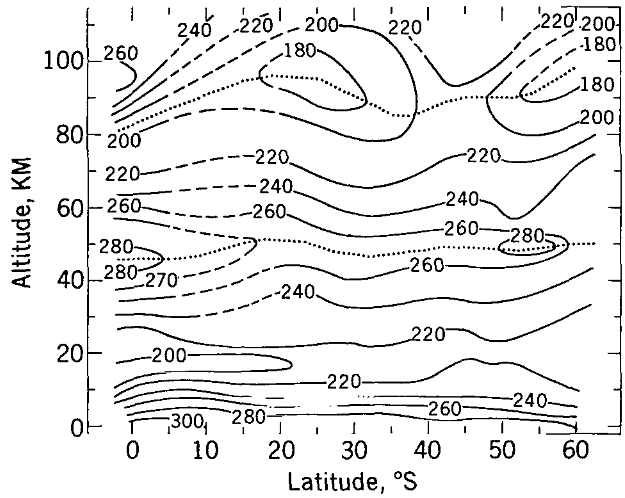

Figure 1—Space-time cross section of temperature from the equator to 60° S during the March-May period, 1965. (See Table 1.) The cross section is composed of balloonsonde and rocketsonde data below 25 km altitude and pitot-static tube data above 25 km. Isotherms are given in °K.

Temperature structure

As can be seen in Figure 1, the 25-45 km region was fairly well stratified and had a negative lapse rate ($dT/dZ > 0$) up to the stratopause which is indicated by the dotted line ranging between 42 and 50 km altitude. The two warm regions of the stratopause centered above the equator and 55°S caused the horizontal temperature gradient to reverse its direction twice. However, the warm region above 55°S was not extensive enough to cause a pressure gradient (and hence wind direction) reversal.

The Southern Hemisphere (hereafter referred to as S.H.) mesosphere was neither stratified nor uniform. The mesospheric lapse rate varied considerably with latitude, and the height of the mesospause varied from about 80 km to over 95 km within 20° of latitude, resulting in large horizontal temperature gradients which reversed direction several times. The maximum horizontal temperature gradient occurred at 95 km in the tropics where an average value of 5°K per degree of latitude was observed. Unfortunately it was not possible to make direct wind observations along with these temperatures, but the sharp temperature gradients, if real, were most likely accompanied by very large wind shears.

In order to compare the S.H. space-time cross section described above with a corresponding Northern Hemisphere (N.H.) cross section, atmospheric soundings from the N.H. are chosen to cover both the late summer-early fall period of time and the range of latitudes for the N.H. which were covered by the S.H. expedition. The equatorial sounding of 8 March 1965 is also used for the N.H. case and 17 March 1965 Ascension Island is used as though it were 8°N instead of 8°S. Table 2 lists the N.H. soundings.

Comparison of the space-time cross section based on the expedition soundings (Figure 1) and the cross section of N.H. data from Table 2 (Figure 2) shows that the cross sections are not symmetric. However, the N.H. cross section contains data from a very wide range of longitudes, which undoubtedly accounts for some of the asymmetry.

Table 2

Dates, times, and locations of rocket soundings in N.H. during 1965 used in this comparison.

Date	GMT	Local Solar Time	Location	Experiment*
17 September	1600	1502	Ascension Island (7°59'S)	BT
29 September	1700	1253	Antigua (17°09'N)	BT
6 October	1600	1038	Cape Kennedy (28°27'N)	BT
13 October	1601	0535	Barrow (71°21'N)	BG
13 October	1612	0957	Churchill (58°44'N)	BTG
13 October	1651	1149	Wallops (37°50'N)	BTG

*B denotes balloonsonde; T, thermistorsonde, G, grenade experiment.

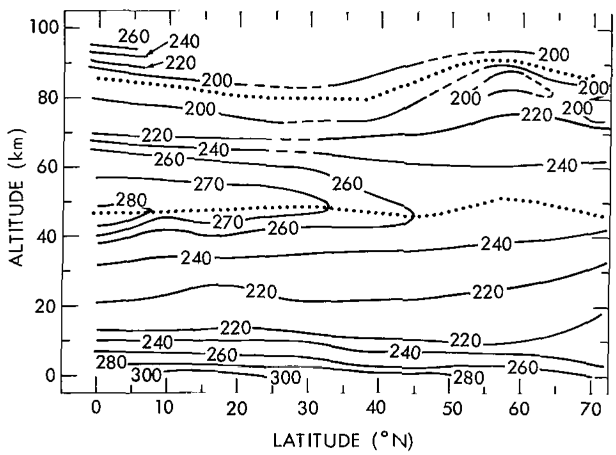

Figure 2—Space-time cross section of temperature from the equator to 71° N during the September-October period, 1965. The cross section is composed of balloonsonde, rocketsonde and grenade data as indicated in Table 2. Isotherms are given in °K.

The tropical stratopause was approximately 5 km lower than the polar stratopause at 60° latitude in both hemispheres, but this difference disappeared poleward of 60°N in the N.H. case. The N.H. stratosphere was warmer than its S.H. counterpart between the equator and 30° latitude, but poleward of 30°, the reverse was true. At the higher latitudes, particulary at 50°, the S.H. stratopause temperature was over 280°K while the N.H. stratopause temperature was less than 260°K. In both hemispheres, the polar stratosphere had a very small temperature variation; between 216°K and 220°K in the 10-25 km altitude region at 60° latitude.

The two mesospheric hemispheres presented somewhat differing pictures. The N.H. mesosphere was relatively uniform with no intense horizontal temperature gradients above 60 km. The S.H. mesosphere, on the other hand, had sharp horizontal temperature gradients in several regions. The S.H. mesopause varied in altitude from 80 km above the equator to almost 100 km above 60°S. The N.H. mesopause altitude ranged only from 80 km to about 90 km. Data in the subtropical latitudes were not available for direct comparison. In the N.H., the mesopause closely paralleled the stratopause, resulting in a remarkably uniform mesosphere thickness with latitude. The N.H. mesosphere thickness varied from approximately 35 km near the equator to 40 km at middle latitudes. In contrast, the thickness of the S.H. mesosphere varied from 35 km to almost 55 km. The coldest portion of the S.H. mesosphere lay above subtropical latitudes where a minimum temperature of 167°K occurred at 95 km above 24°S. The higher latitudes included in this expedition (50-60°S) did not exhibit the extremely low temperatures observed at the summer mesopause in the N.H. (Reference 8). However, another minimum did exist above these latitudes and was responsible for a reversal of the horizontal temperature gradient along the mesopause poleward of 45°S. The average mesospheric lapse rates ranged from 2.4°K/km near the equator to 1.8°K/km at 60°S and 1.6°K/km at 60°N.

Zonal circulation

Since the pitot-static tube experiment has no capability for measuring winds directly, the zonal winds are derived by substituting the measured pressure profiles into the geostrophic wind equation:

$$u = -\frac{1}{f\rho}\frac{\partial p}{\partial y},$$

where u is the zonal wind component, f is the Coriolis parameter, $2\Omega \sin\phi$ (Ω = earth's rotation rate, ϕ = latitude), ρ is the atmospheric density, and $\partial p/\partial y$ is the latitudinal pressure gradient. The results of these computations are given in Figure 3, a space-time cross section of the S.H. zonal wind which includes the data from the seven daytime pitot-static tube experiments listed in Table 1. The pressure gradients are smoothed by averaging adjacent measured values, a procedure which aids in reducing irregularities resulting from the time lapse between soundings. Warnecke and Nordberg (Reference 10) were able to identify and analyze pressure systems up to about 70 km altitude, but found that an abrupt change in the wind occurred above this level. They attributed this change to the increasing importance of tidal forces. On the basis of their finding, our geostrophic analysis is terminated at 70 km because the acceleration terms in the equations of motion, which are assumed to be zero in the geostrophic approximation, are no longer negligible. Since the observations do not provide adequate horizontal resolution of the pressure gradient force, and because the horizontal component of the Coriolis force diminishes rapidly near the equator, it is not possible to compute meaningful geostrophic winds of 15° latitude.

Figure 3 shows predominantly westerly flow with two intense regions of westerlies at 60-70 km between 20° and 40°S and 45-70 km poleward of 50°S. The other important feature of this cross section is the weak easterly flow at 20-40 km altitude equatorward of 20°S. These features compare favorably with Figure 4 which shows the zonal winds obtained from ship launched balloonsondes and rocketsondes during the same time period. The computed zonal cross section (Figure 3) appears to have slightly overintensified the westerly core at 50°S and underestimated the extent and magnitude of the

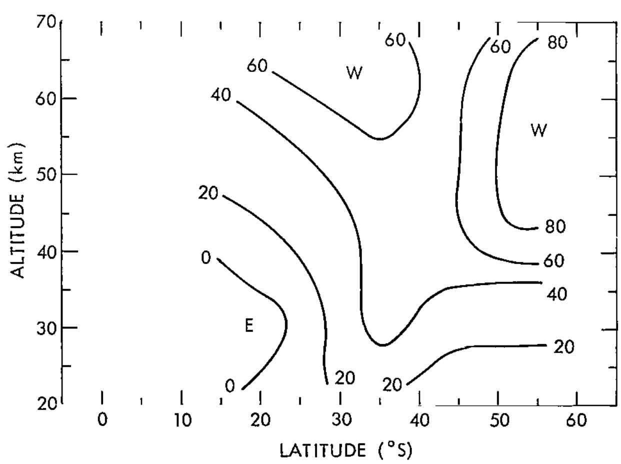

Figure 3—Space-time cross section of zonal winds over the latitudes 15°-57°S, computed from the pitot-static tube pressure profiles. Isotachs are given in m/sec.

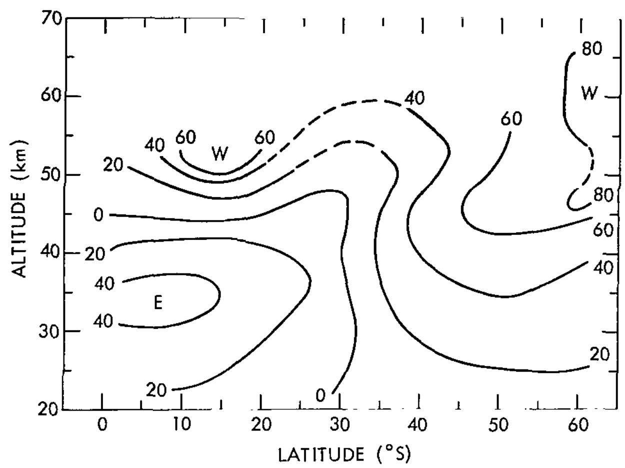

Figure 4—Space-time cross section of zonal winds from the equator to 60° S observed by balloonsondes and rocketsondes. Isotachs are given in m/sec.

easterly flow in the tropics. Possibly some of these differences arise from the nearly instantaneous nature of the measurement in time and space of the rocketsonde and balloonsonde techniques as opposed to the averaged time and space resolution of the pressure profile approach. Aside from these differences, the geostrophic approximation is generally consistent with the observed winds in the stratosphere and lower mesosphere.

The zonal wind space-time cross section for the N.H. resulting from the soundings listed in Table 2 is given in Figure 6. There is obviously some similarity between the zonal winds in Figures 4 and 5, but hemispheric symmetry outside of the tropics is not evident in these cases. The easterly core in the tropical stratosphere which appeared in both S.H. cross sections also appeared in the N.H. case, but the well organized westerly flow at middle latitudes of the S.H. was not found in the weak and confused circulation of these latitudes in the N.H. Thus, these observations confirm the observations of Finger and Woolf (Reference 7) who found that during the late summer-early fall period of 1965, the S.H. circulation exhibited a better established wintertime circulation pattern characterized by a developing polar vortex, and in contrast, the N.H. during the corresponding period of the same year was still in the transitional autumnal regime which is characterized by the lack of intense flow and organized patterns.

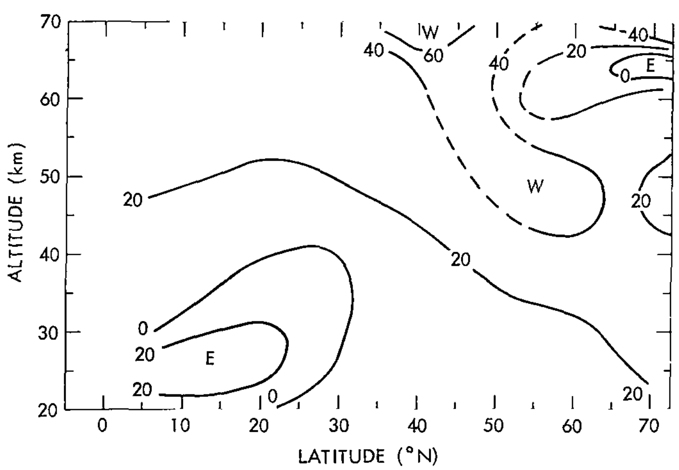

Figure 5—Space-time cross section of zonal winds from 8°-71° N observed by balloonsondes, rocketsondes and grenades (see Table 2). Isotachs are given in m/sec.

SUMMARY

The S.H. space-time cross sections which were made possible by the shipboard expedition in 1965 show that:

1. The temperature structures in the S.H. stratosphere and mesosphere were somewhat different from their N.H. counterparts during the corresponding season. Especially at temperate latitudes, the S.H. upper atmosphere was characterized by a warmer stratopause and a colder

mesopause than the N.H. The vertical extent of the mesosphere varied more in the S.H. than in the N.H. largely because of the wide altitude fluctuations of the S.H. mesopause itself.

2. The geostrophic approximation provides a reasonably accurate method for obtaining average winds in the stratosphere and lower mesosphere (up to 70 km altitude). This conclusion arises from the comparison of zonal winds which were measured directly by balloonsondes and rocketsondes and those computed from horizontally separated vertical pressure profiles.

3. The zonal wind patterns in the S.H. stratosphere and lower mesosphere were somewhat different from the corresponding N.H. flow, particularly poleward of 30° latitude. The S.H. circulation was characterized by an easterly core centered 30-35 km above the tropics, and a westerly flow which increased with latitude and altitude to a maximum of 60 km above 60°S. This circulation was associated with the developing winter polar vortex. However, the N.H. circulation outside the tropics was not well organized and a strong westerly core did not exist at higher latitudes.

ACKNOWLEDGMENTS

The authors are grateful to Mr. Wendell S. Smith, who heads the program at Goddard Space Flight Center under which these experiments were conducted, and to the personnel at the Space Physics Research Laboratory of the University of Michigan who designed, fabricated, and prepared the experiments for launching and reduced the data. Thanks are also due Mr. Harold Tolefson, Langley Research Center, who supplied the balloonsonde and rocketsonde data, the Wallops Station personnel, who provided launch support aboard the Croatan, and the Physical Science Laboratory of the New Mexico State University, who provided tracking support.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, August 1, 1967
607-15-01-01-51

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