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Stratospheric Temperature Variations in Autumn—Northern and Southern Hemispheres Compared

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ABSTRACT—The Satellite Infrared Spectrometer onboard Nimbus 3 has a 5 cm^{-1} spectral interval centered at 669.3 cm^{-1} (15μm). The stratosphere contributes nearly all the outgoing terrestrial radiation at this frequency, and, consequently, the observed radiances provide a measure of a weighted mean temperature of the upper 100 mb of air. Maps of the 669.3 cm^{-1} channel radiances indicate layer-mean stratospheric temperature patterns. Such patterns are studied for both the Northern Hemisphere and the Southern Hemisphere, mainly for the periods of transition from summertime to wintertime circulation regimes. The periods under consideration are of special interest because pockets of warm air remain in spite of the seasonal cooling due to decreasing solar radiation over each hemisphere. Changes in location and intensity of both cold and warm areas are described. The principal region of high radiance (warm air) over the Northern Hemisphere, traditionally associated with the Aleutian anticyclone, was found to be mainly over Siberia. A corresponding warm region over the Southern Hemisphere was found, and its mean position during the transition period is only 25° of longitude farther to the west. Possible explanations for these positions are discussed.

1. INTRODUCTION

It is well known that the stratospheric Aleutian anticyclone is associated with warm air in the general region between Siberia and the Aleutian Islands. Scherhag (1969) points out that the establishment of the Aleutian anticyclone begins in mid-October; and he attributes its maintenance through the winter to the advection of warm air associated with the Japanese jet stream. The explanation of these facts has sometimes been tied to orographic factors (e.g., Godson 1963). Yet, while the orography of the Southern Hemisphere is quite different from the orography of the Northern Hemisphere, the Southern Hemisphere stratosphere also experiences warming in autumn at times (Fritz 1970).

Several authors have discussed the relationship between warming events in the Southern and Northern Hemispheres (Godson 1963, Zhdanov 1967). They emphasized events in the winter and spring seasons. Zhdanov noted that the "warm and cold fields" tended to occur near the same longitude in both hemispheres and at similarly high latitudes. However, the data available in these studies have generally been limited to the Antarctic areas with even sparser data available over the oceans.

Although most studies are concerned with stratospheric events in the winter and spring seasons, the autumn is interesting in its own right. In the Northern Hemisphere, a warm zone first appears over the Aleutian-Siberian area after a summer of approximate zonal symmetry in the fields of temperature and geopotential height. In the Southern Hemisphere, warmings may also occur in the autumn and, moreover, in 1969 and 1970, at least, tended to occur at the same longitudes as in the Northern Hemisphere. The relation of these phenomena to the tropospheric jet streams in both hemispheres will be discussed.

In each of the two hemispheres, centers of cold air are established during autumn (Scherhag 1969). The motion and intensity of these will also be described for the autumn months.

Up to the time of launch of the Nimbus 3 satellite, stratospheric data had been obtained almost exclusively from high-level radiosondes and rocketsondes, and most of these were in the Northern Hemisphere. Discrepancies were known to exist between the reports, owing to many factors including principally radiation errors and random variability (McInturff and Finger 1968, Miller 1969). Even with the application of correction systems for the various instrument types, it has not always been possible to achieve an adequate degree of compatibility among these "conventional" data. But with the aid of the first satellite infrared spectrometer, SIRS A, worldwide comparisons can be made with a single instrument, thus avoiding some of the problems just cited.

Background information on the use of SIRS data in depicting stratospheric temperature variations, together with an account of the relative advantages and disadvantages of the sensing systems on board the various TIROS and Nimbus satellites, has been reviewed earlier (Fritz 1970). The relevant basic facts are as follows: SIRS A includes a 5 cm^{-1} spectral interval centered on 669.3 cm^{-1} (about 15 μm) described by Wark and Hilleary (1969). At this frequency, radiation impinging on the SIRS instrument comes almost exclusively from the stratosphere. Therefore, the observed radiances at 669.3

cm^{-1} are measures of the weighted stratospheric temperatures for the upper 100 mb of air. SIRS A (Nimbus 3) was launched on Apr. 14, 1969, and data are now available for more than 1 yr.

There are significant advantages in using radiances alone instead of temperatures derived from radiances. The accuracy of the SIRS A instrument has been very high—the root-mean-square (rms) noise being about 0.25×10^{-7} J · cm^{-2} · s^{-1} · (ster)$^{-1}$ · (cm^{-1})$^{-1}$.* It is possible, by using radiance data from several of the eight SIRS channels, to derive atmospheric temperature profiles—only, however, with the aid of some assumptions involving the temperature structure (Smith 1969, Fritz 1969). In this paper, we will avoid the complications of deriving temperature profiles from radiance data, but we will occasionally refer to temperatures of the upper atmosphere obtained from radiosondes and rocketsondes. However, the radiance variations can be considered to be spatial and temporal variations of the *mean weighted* temperature of the upper 100 mb of air.

The main purpose of this paper is to compare the transition of the stratospheric temperature fields in the Northern and Southern Hemispheres during autumn as revealed by SIRS radiance data. The discussion will be restricted to results primarily for the year 1969 although comparisons will be made with Southern Hemisphere observations for the autumn transition period of Apr. 15–May 15, 1970.

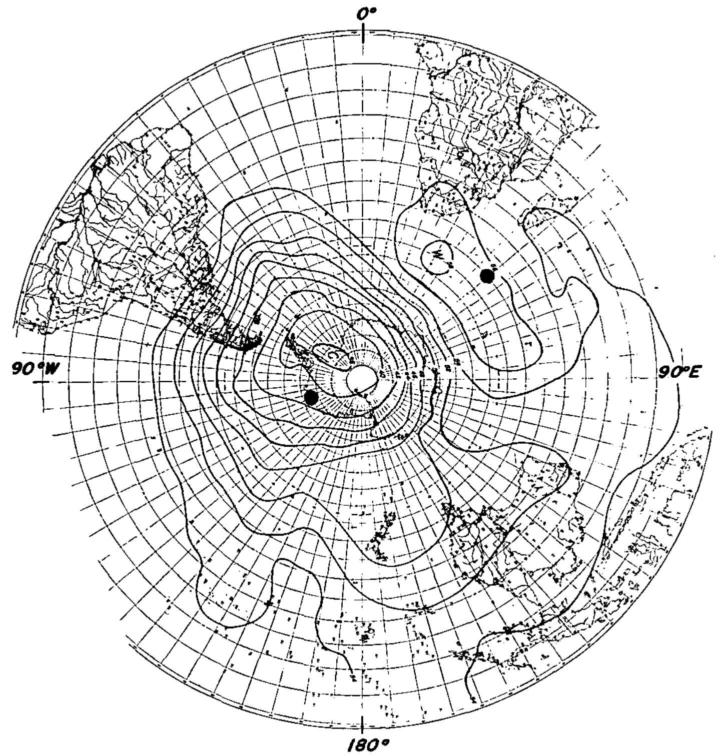

FIGURE 1.—Map of radiances at $\mu=669.3$ cm^{-1} for May 4, 1969, in Southern Hemisphere. Radiance unit: 10^{-7} J · cm^{-2} · s^{-2} · (ster)$^{-1}$ · (cm^{-1})$^{-1}$ abbreviated 10^{-7} J/. C is cold, W is warm. The ● symbols mark the projections of the cold and warm centers from figure 2.

2. ANALYSIS OF DATA

The summer–winter transition period was chosen to be April 16–May 16 for the Southern Hemisphere; for the Northern Hemisphere, the corresponding period extends from October 15–November 14. Daily analyses of the radiance fields (669.3 cm^{-1}) were performed for these periods in 1969 for all latitudes in both hemispheres poleward of 20° (figs. 1 and 2 are examples). In addition, some Southern Hemisphere radiance maps for the period Apr. 15–May 15, 1970, have been analyzed. Maps for other dates were analyzed as needed to illustrate various points. Position of the centers of the highest radiance areas varied somewhat. It was therefore easiest to study the radiance variations at fixed latitudes.

3. LONGITUDINAL RADIANCE DISTRIBUTIONS, 1969

In the course of the investigation, we found that the distribution of radiance along latitudes 55°S, 55°N, 40°S, and 40°N could adequately describe the warmings. The longitudinal distributions of radiance at 30°N and 30°S were also useful, but the main effects were noted at higher latitudes.

The choice of latitudes for the construction of zonal sections is somewhat arbitrary, but an inspection of the

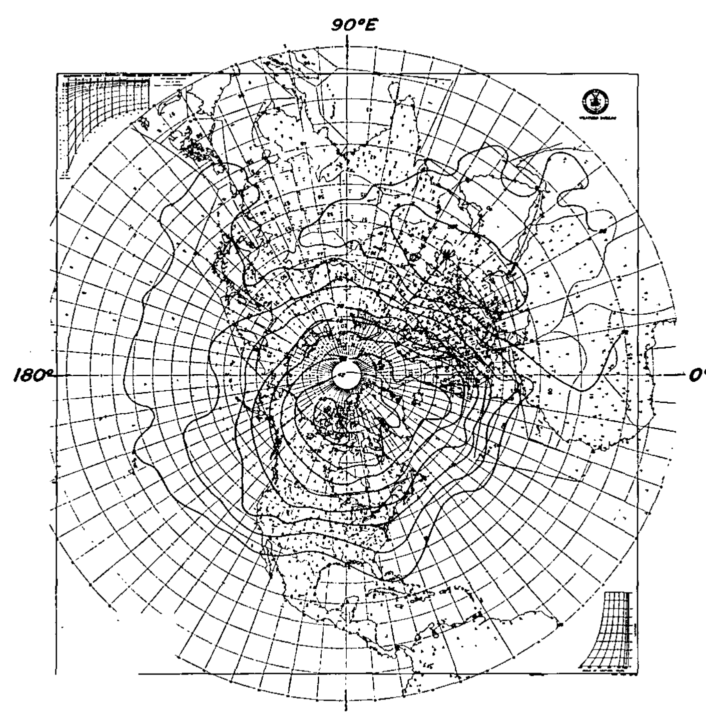

FIGURE 2.—Map of radiances at $\nu=669.3$ cm^{-1} for Nov. 2, 1969, in Northern Hemisphere (units as in fig. 1.)

*This radiance unit will hereafter be abbreviated to read 10^{-7} J/. The rms noise increased somewhat, to about 0.5×10^{-7} J/, toward the end of 1969.

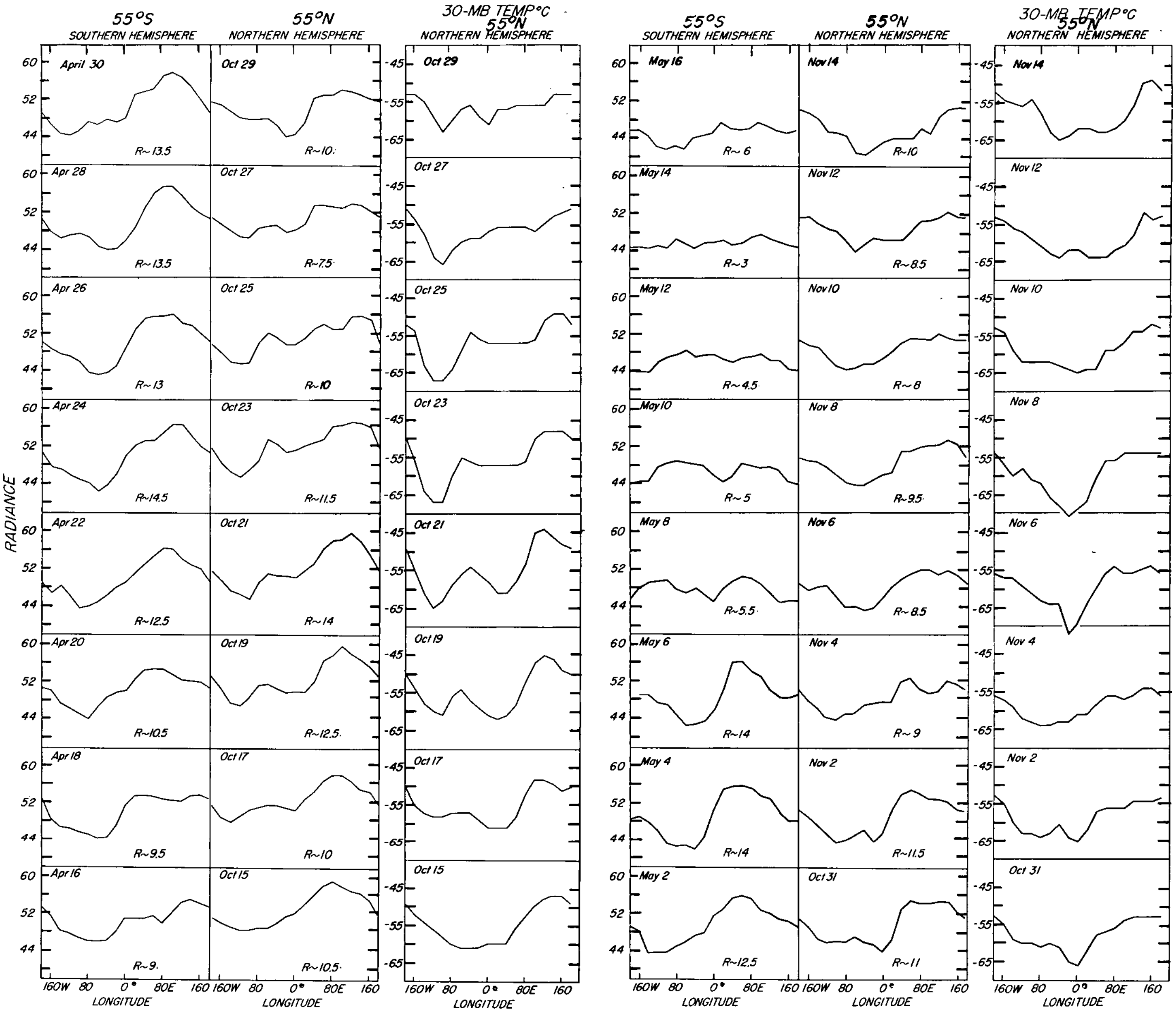

FIGURE 3.—Comparison of zonal sections of radiance (radiance vs. longitude) for 55°S, Apr. 16–May 16, 1969, with zonal sections of radiances and 30-mb temperatures for 55°N, October 15–November 14. R is range from maximum to minimum (units: 10^{-7} J/).

radiance maps revealed that, on the average, 55° latitude permits the depiction of most of the contrast between the warm centers and cold polar center. This latitude generally lies between the latitude of maximum radiance and that of minimum radiance. On the other hand, the mean latitude of the warm air in both hemispheres is between 40° and 55°.

An additional consideration has been that, for the months of October through March, the mean position of the warm air associated with the Aleutian anticyclone is approximately 55°N, 150°E at 30 mb and 10 mb, as revealed by mean Northern Hemisphere maps for 1964–68.

Figure 1 shows the map for May 4, 1969 (Fritz 1970). This date is near the peak of the Southern Hemisphere warming that was already in progress on April 14 when Nimbus 3 was launched. A corresponding map for the Northern Hemisphere, for Nov. 2, 1969, is shown in figure 2. The positions of the warm and cold centers in figure 2 have been indicated on figure 1. It is apparent that the corresponding centers on the two maps occurred near the same longitudes and at similarly high latitudes. The existence of one principal cold region and one principal warm region in each hemisphere was typical of the periods under consideration. However, as will be seen, there was a tendency for this wave number 1 pattern to weaken intermittently in the Southern Hemisphere, whereas the wave number 1 pattern did not tend to weaken as much in the Northern Hemisphere as the season advanced.

Figure 3 shows the zonal sections of 669.3 cm^{-1} radiances at 55°S and 55°N. This figure also shows 30-mb tempera-

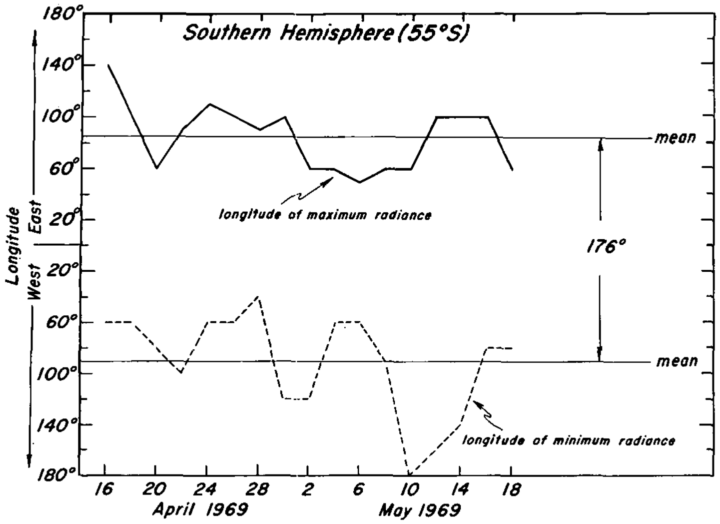

FIGURE 4.—Longitudes of maximum and minimum radiance at 55°S as a function of time, Apr. 16–May 18, 1969.

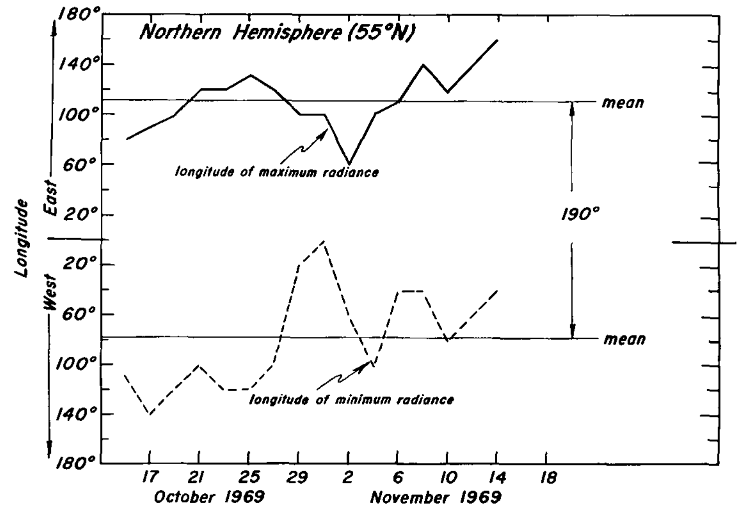

FIGURE 5.—Longitudes of maximum and minimum radiance at 55°N as a function of time, Oct. 15–Nov. 14, 1969.

tures at 55°N as derived from objective operational map analyses for the autumn transition periods. [The 669.3 cm^{-1} radiance values should be more closely correlated with 30-mb temperatures than with temperatures at any other level (Smith 1969).] The adjacent graphs were selected for days when good data coverage was available, and their dates represent equivalent time periods relative to the approaching winter solstice.

The following are the most noteworthy points in connection with figure 3:

1. In each hemisphere, the radiance maxima occurred at eastern longitudes, the minima at western longitudes. The radiance curves are similar to the Northern Hemisphere temperature curves for 30 mb.
2. The range (R) of radiance values (maximum to minimum) at 55°S increased from 9×10^{-7} J/ on April 16 to a maximum of 14.5 $\times10^{-7}$ J/ on April 24. It then remained at a high level (roughly 13–14$\times10^{-7}$ J/) until May 6, when it abruptly decreased to about 5×10^{-7} J/ with a minimum of 3×10^{-7} J/ on May 14.

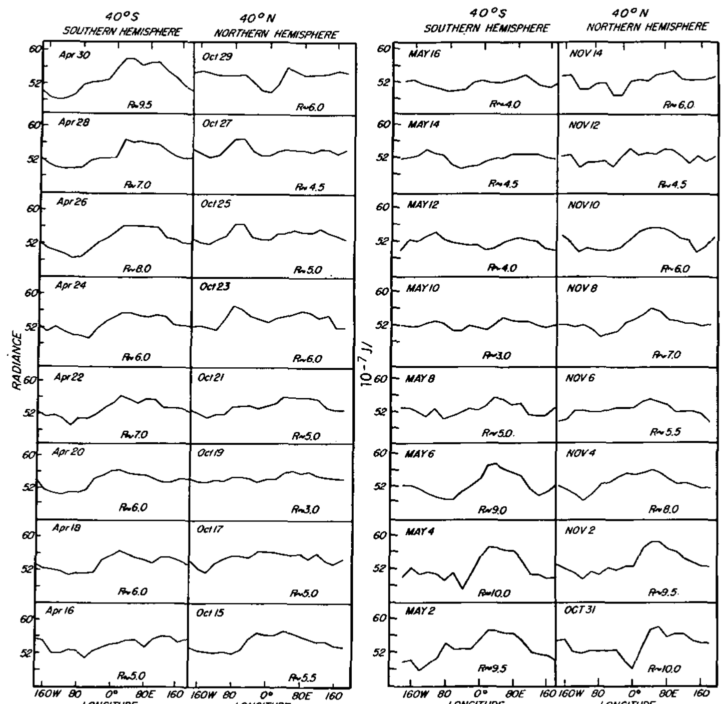

FIGURE 6.—Zonal sections of radiance (10^{-7} J/) for 40°S and 40°N. R is range (units 10^{-7} J/).

The range of radiance values at 55°N underwent a smaller variation. In the Southern Hemisphere, a distinct end of the warm pool of air, clearly indicated by the maps of radiance values, is reflected in the range after May 6. But in the Northern Hemisphere the warm pool persisted, as evidenced by the fact that the range varied between 7.5 and 14×10^{-7} J/ and remained at a relatively high level throughout the period.

To illustrate the similarity better, the longitude of maximum radiance and the longitude of minimum radiance from figure 3 have been plotted in figure 4 for 55°S and in figure 5 for 55°N. Although differences are evident, the most striking fact is that the maxima in both hemispheres occurred near longitude 100°E; at 55°S the mean longitude was at 85°E and at 55°N it was at 110°E. Similarly, the minimum radiance values generally were near 90°W. Figure 3 shows that after May 6 the amplitude was very small, and the positions of the maxima and the minima were less significant. If one ignores the data in figure 4 after May 6, the agreement with the Northern Hemisphere is even better.[1] The distance between the mean positions of the maxima is about 180° longitude in both hemispheres, indicating that a wave number 1 pattern predominated most of the time.

The zonal sections for 40°N and 40°S are given in figure 6. At these lower latitudes, a wave number 2 pattern is sometimes dominant, although the most striking feature is the relative flatness of the curves. The radiance had maximum values approximating those at latitudes

[1] With old centers disappearing and new ones forming, there is an appearance of movement in figures 4 and 5 which should not necessarily be regarded as such. In constructing the figures, it was always the absolute maximum and the absolute minimum that was plotted.

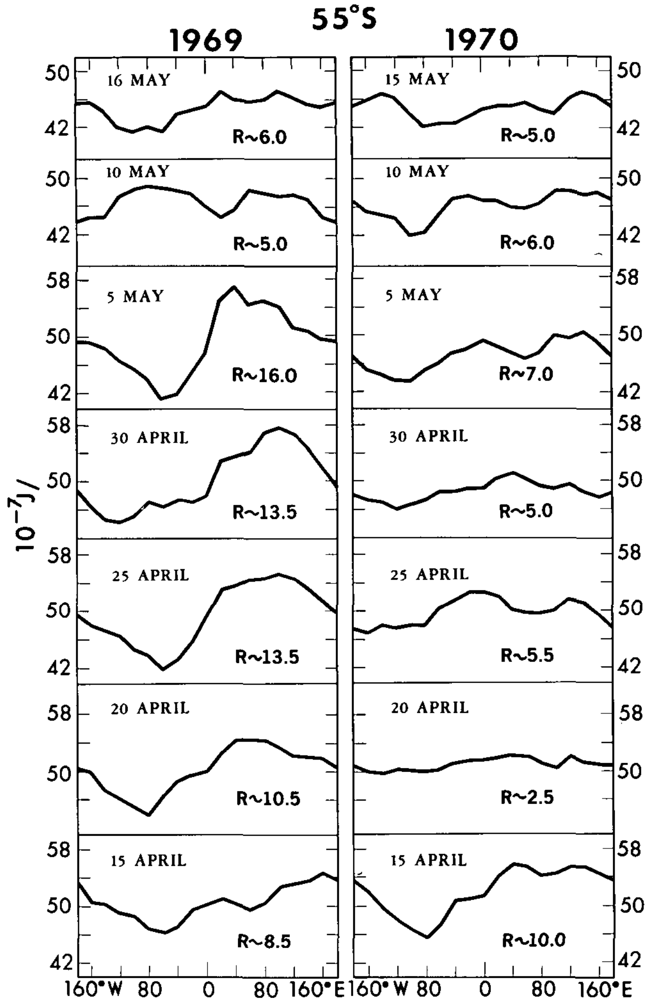

FIGURE 7.—Zonal sections of radiance (10^{-7} J/) for 55°S, at 5-day intervals, Apr. 15–May 15, 1970, compared to sections for April–May 1969. (Since May 15 was not available for 1969, May 16 was substituted.)

55°N and 55°S, but the minimum values were not so low. This is undoubtedly related to the large gradient in the radiance "troughs" compared to the small gradients near the radiance "ridges" at these latitudes (see figs. 1 and 2). Figure 6 suggests that the maxima tended to be displaced to the west of their positions at 55°N and 55°S.

At 30°N and 30°S (not shown), the range of radiance values was even smaller than at latitude 40°; the wave number 2 pattern seemed more frequent than at the higher latitude.

4. COMPARISON OF THERMAL PATTERNS IN THE SOUTHERN HEMISPHERE OF AUTUMN 1969 WITH THOSE OF AUTUMN 1970

A second autumn period of SIRS A data for the Northern Hemisphere is not available (Nimbus 3 became inoperative in September 1970). However, stratospheric maps based on radiosonde data show that the Aleutian anticyclone and its associated warm air are semipermanent features; they become established in autumn and persist until spring and exhibit little year-to-year variability—with exceptions, of course, in years of major midwinter stratospheric warmings (Scherhag 1969).

It was of interest, therefore, to see whether the autumnal warm pool was also present in the Southern Hemisphere in 1970. To test this, we compared the longitudinal radiance distribution at 55°S for April–May 1969 with the corresponding period for 1970 (fig. 7). There was a tendency in 1970 for the maximum radiances to appear also in the Eastern Hemisphere; however, on April 25, one maximum appeared also near 10°W longitude. As in 1969, the minima in 1970 tended to be in the Western Hemisphere, between about 80°W and 180°.

In comparing the amplitudes of the radiances, however, one sees that a warming may have occurred before Apr. 15, 1970, judging by the 1×10^{-6} J/ amplitude on April 15. But after Apr. 16, 1970, the amplitude decreased markedly, in contrast to the events in April–May 1969 (fig. 3).

Thus, the longitude of the maximum radiance was similar in the Southern Hemisphere in both 1969 and 1970. In that respect, at least, it was similar to what might have been expected in the Northern Hemisphere.

5. THE CLOSED COLD POLAR AREAS

Figures 1 and 2 show that closed isolines of low radiance occur in the polar regions. These appear every day in the autumn season in agreement with conventional stratospheric temperature data (Scherhag 1969).

Figures 8 and 9 depict the movement of the closed low-radiance areas in the Southern and Northern Polar regions during the 1969 autumn periods. The trend toward increasingly high latitudes is more in evidence in the case of the Southern Hemisphere after April 28 (fig. 8); and this agrees with the known fact of greater circular symmetry in the fields of height and temperature in the Southern Hemisphere winter, as the cold air tends to remain closer to the pole than in the Northern Hemisphere (Godson 1963). After May 4 and November 2, there was an eastward movement in both hemispheres but more rapid and more sustained in the Southern Hemisphere.

Figure 10 shows the central radiance values of the cold areas in the two hemispheres. The downward trend is evident here. The radiance values are generally lower in the Southern Hemisphere, but only by about 4×10^{-7} J/, corresponding to a mean temperature difference of only 5°K. Even this small difference may have been due in part to the fact that the radiance minimum was nearer to the pole in the Southern Hemisphere.

6. CONCLUSIONS AND FURTHER DISCUSSION

We have presented some similarities and some differences between radiance (stratospheric temperature) distributions of the Northern and Southern Hemispheres in autumn.

In 1969 and 1970, the highest radiances (warmest stratospheric air) were found near the same longitude in

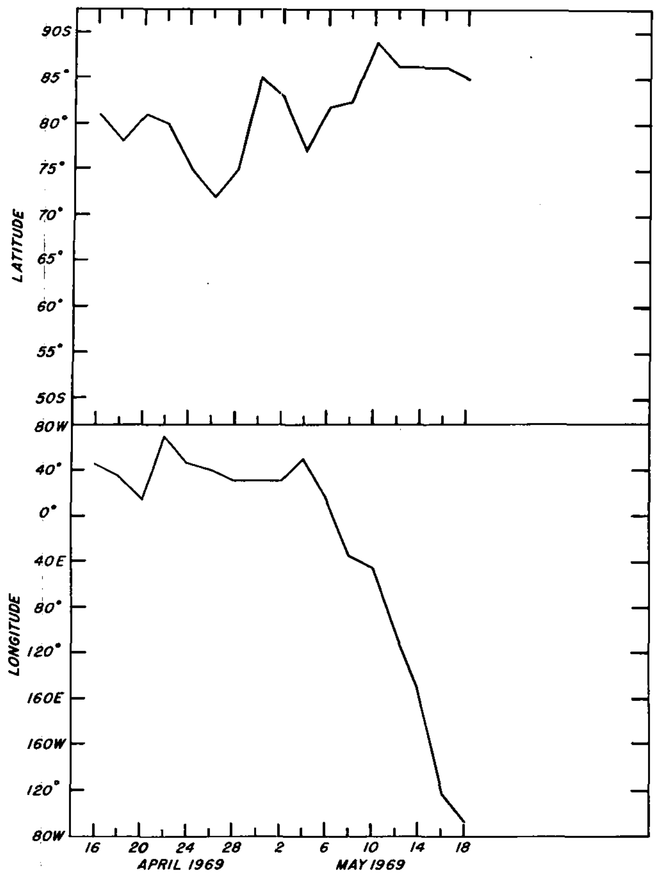

FIGURE 8.—Movement of the polar cold center over the Southern Hemisphere, indicated by graphs of latitude and longitude versus time, Apr. 16–May 18, 1969. Movement south of 80°S has been determined by extrapolation.

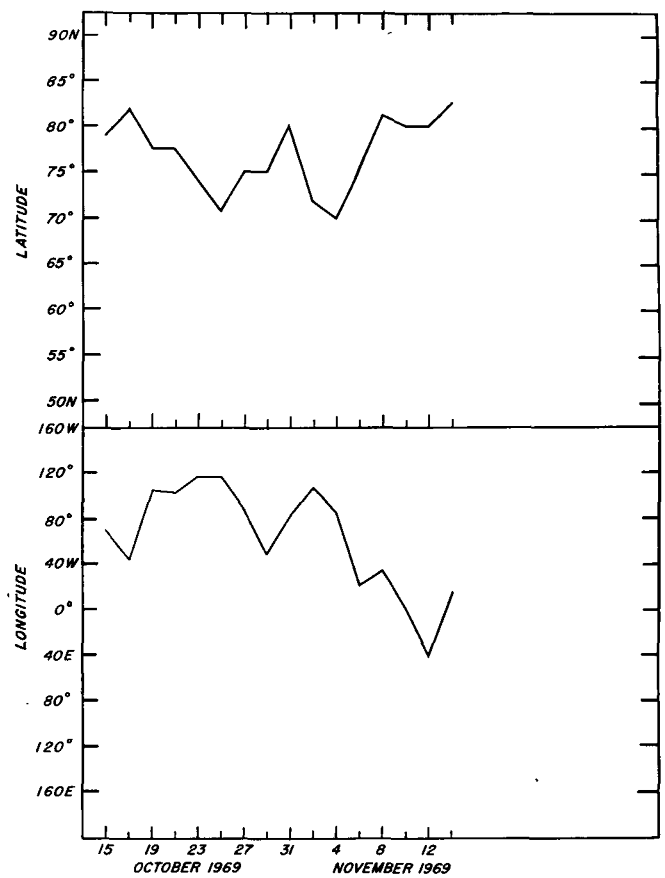

FIGURE 9.—Movement of the polar cold center over the Northern Hemisphere, indicated by graphs of latitude and longitude versus time, Oct. 15–Nov. 14, 1969. Movement north of 80°N has been determined by extrapolation.

both hemispheres. Earlier results based on radiosondes (Godson 1963, Zhdanov 1967) indicate that winter-spring warmings in the Southern Hemisphere stratosphere tend to make their first appearance in the south Indian Ocean, between Africa and Australia or roughly between 45°E and 100°E longitudes. Our results, based on radiances measured from satellites, show that warmings occur in that longitude zone in autumn too. Since this is also the longitude where warm air appears in the Northern Hemisphere, there is general agreement from both data sources that the warm air tends to appear in the same longitude zone in both hemispheres.

In the Southern Hemisphere autumn of 1970, we did not observe a warming as well defined at 55°S as the one that occurred in the autumn of 1969, but the warmest air did occur at generally the same longitude in both years.

Dynamical effects doubtlessly produce the warm pools of air since the overall tendency in the entire hemisphere is toward cooling as winter advances. Several attempts have been made to account for the appearance of warm air in the stratosphere, with most emphasis, however, on the explosive midwinter warmings (Godson 1963, Reed 1963). It is natural to speculate that the cause of

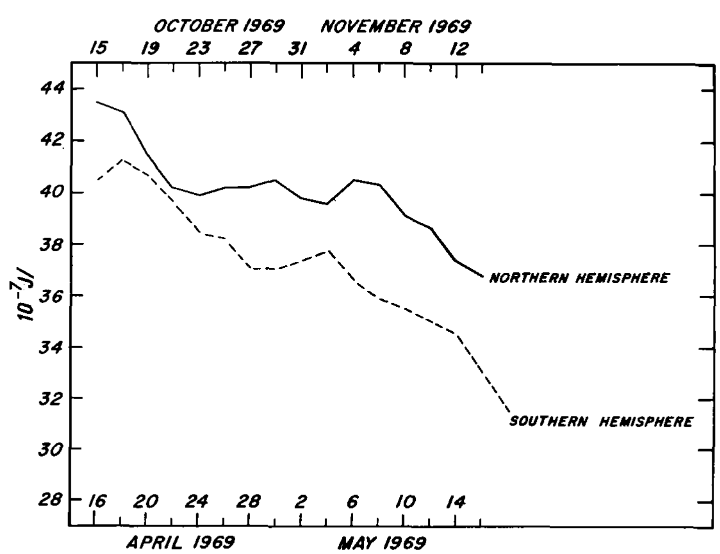

FIGURE 10.—Central radiance (10^{-7} J/) values of cold polar areas in the two hemispheres during comparable periods Oct. 15–Nov. 14, 1969, for the Northern Hemisphere (solid curve, scale at top) and Apr. 16–May 18, 1969, for the Southern Hemisphere (broken curve, scale at bottom).

the warmings may be the same in both hemispheres. Why does it appear at the same longitudes in both hemispheres?

Several reports (e.g., Scherhag 1969) have emphasized the role of the jet stream in the production of stratospheric warmings; the warmings frequently occur in the general vicinity of the jet. The climatological record for 1949–53 indicates that upper tropospheric winds are stronger over east Asia (35°N, 140°E) than anywhere else in the Northern Hemisphere (Heastie and Stephenson 1960). This is approximately 20° of latitude south and 20° of longitude east of the mean position of the highest radiance (warmest stratospheric air) for the season discussed in this paper (and for the Northern Hemisphere autumns of other years as determined by maps based on rawinsonde data). Similarly, in autumn the upper tropospheric wind speeds over Kerguelen Island (50°S, 70°E) are climatologically higher than elsewhere at 50°S. Moreover, the highest 100-mb temperatures occur in this vicinity (Taljaard et al. 1969).

Thus, in both hemispheres in the autumn periods, strong winds were found in the vicinity of 100°E longitude. Perhaps this tends to produce vertical motions or advection in the stratosphere that results in a collection of warm air in the stratosphere near those longitudes.

If the jet stream locations are related to orographic effects, perhaps the fact that the Antarctic continent extends farther north in the region between Africa and Australia (except for the Palmer Peninsula near South America) may be a factor. Could this set up a low-level temperature contrast that would increase the wind with height, causing a stronger jet stream in that sector? If so, orographic effects in both hemispheres might fix the longitude of the strongest wind and thereby fix the associated warm autumnal stratosphere in the eastern part of each hemisphere.

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