# Comparison of 15-μ TIROS VII Data with Radiosonde Temperatures[1,2]

A. D. Belmont, G. W. Nicholas and W. C. Shen

*Control Data Corporation, Minneapolis, Minn.*

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## ABSTRACT

Temperatures derived from the 15-μ $CO_2$ channel of the radiometer carried aboard the TIROS VII satellite were compared to the radiosonde temperatures at 100, 70, 50, 30, 20 and 10 mb at 97 stations in the Northern Hemisphere from 20 January to 17 February 1964. The 15-μ temperature is rarely colder than the 30-mb temperature, and it generally falls between the 10- and 30-mb temperatures. The highest correlation between 15-μ and radiosonde temperatures was 0.7 at both 30 and 20 mb, near the level of maximum weight which applies to the 15-μ radiance weighting function profile. The variation of 15-μ temperatures with longitude closely follows the variation of 10–100 mb thickness pattern.

## 1. Introduction

Extensive observation of temperature in the stratosphere on a quasi-global scale began with the launch of the TIROS VII satellite on 19 June 1963. One of the five channels of the radiometer carried aboard the satellite measured the thermal radiation at wavelengths ranging from 14.8–15.5 μ which is emitted by $CO_2$. As the $CO_2$ temperature can be assumed to be the same as the air in which it is located, the intensities can be interpreted in terms of a weighted-mean, equivalent blackbody temperature over the mid- and lower stratosphere. Radiative transfer theory shows that the radiation in this spectral range is mainly emitted in the region from 15–35 km (Nordberg *et al.*, 1965), and the radiance is therefore best associated with the mean temperature (or thickness) between these levels. Although the maximum contribution at low nadir angles generally originates at about 23–25 km, the 15-μ temperature[3] corresponds best to different heights from time to time, as the temperature at various levels changes. However, as the pressure surfaces vary in phase with the temperature (i.e., rise when temperature increases), there is reason to expect better correlation of 15-μ temperature with constant pressure than with constant height surfaces.

According to Nordberg (1966), cloudiness below 5 km does not affect the 15-μ temperatures, but radiation from thick high clouds, such as over large thunderstorms, may cause 15-μ temperature decreases of 5–10C. Clouds raise the peak of the weighting function profile, which means the effective 15-μ temperature represents a higher layer in the atmosphere than without the cloud layer. In this limited study, however, the effect of cloudiness could not be considered.

The TIROS VII orbits were nearly circular with a mean height of 635 km. The aperture angle of the radiometer was approximately 5°; thus, the instantaneous area viewed on the earth's surface when the radiometer was directed straight down was a circular spot of about 55 km in diameter. The inclination of the orbital plane was 58°, resulting in data coverage to about 60N and 60S when the nadir viewing angles were restricted to the range from 0° to 40°. Readings were taken at the rate of 16 $\sec^{-1}$. This method of obtaining quasi-global temperatures is potentially a very useful means for studying stratospheric phenomena both synoptically and climatologically. Nordberg *et al.* (1965), Warnecke (1966), and Teweles (1966) have demonstrated that the 15-μ temperature pattern can reflect certain large-scale thermal events in both space and time in the middle and lower stratosphere.

However, because the 15-μ temperatures are weighted mean temperatures over an indefinite height range in the stratosphere, the question which the stratospheric meteorologist raises is "which pressure level or height do these temperatures really represent, or can one, in fact, interpret them at all in terms of temperature at a single pressure level or height?" The purpose of this paper is to compare the 15-μ temperatures with radiosonde data to determine at which pressure level there is optimum correspondence.

## 2. Data

The sampling rate of the radiation data was chosen to permit overlapping of one-half for successive scan spots each of which is at least 55 km in diameter. The data are referred to the center of each scan spot. When the

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[3] In this paper the temperatures derived from the 15-μ channel radiation intensities will be referred to as 15-μ temperatures.

data are mapped, the computer averages all the individual values that are located within a rectangular area. For the 1:40 million Mercator map used to map the 15-$\mu$ temperatures in this study, the size of the rectangular area was constant at 5° of longitude in the zonal direction and variable in the meridional direction, ranging from 5° at the equator to approximately 2.5° at 60° latitude. As a result each grid-point temperature represented an average of up to about 200 individual observations. If a grid-point average resulted from 10 or less single observations, the value was not included in the isothermal analysis.

The 15-$\mu$ channel data were characterized by random noise of an rms amplitude of about 5C due to a small signal-to-noise ratio (Kennedy, 1966). The data in this study were not filtered to eliminate the short-wave perturbations due to this noise component. Spatial averaging of the observations and smoothing of the map analysis reduced the noise component to a large extent.

The TIROS data were subjected to two other important restrictions. First, to avoid gross mislocation of the data by the computer, it was instructed to reject all scans with minimum nadir angles greater than 38° occurring within the scan. This restriction eliminated most of the alternating open mode and closed mode data and retained only the open mode data that can be accurately located by the computer. Second, the computer was instructed to reject all individual measurements within a scan with nadir angles greater than 40° to minimize the effect of shifting upward the height of the peak emission in the 15-$\mu$ region. When the data were mapped, these two restrictions, plus the orbital geometry, produced several gaps in the coverage.

TIROS data for individual orbits, observed within about 12 hr of the radiosonde observation time (1200 GMT), were plotted on daily maps. The orbits for this period generally happened to occur on a single calendar day. At the beginning of the period these orbits usually occurred from 0 to 12 hr after the map reference time and with each succeeding day this 12-hr period occurred earlier so that by the last day, 17 February, the 8 daily orbits were almost centered around the noon reference time. Isotherms were drawn to produce a 15-$\mu$ thermal field which was smoothed over a 12-hr period and extrapolated across data gaps. From the 24 analyzed maps which had reasonable coverage during the period 20 January through 17 February 1964, values of the smoothed 15-$\mu$ isotherms were read at locations for which radiosonde temperatures were also available.

The best available comparative radiosonde data were those used for the daily Northern Hemisphere stratospheric map series prepared by the Environmental Science Services Administration. Temperatures were extracted at 97 stations over North America and Europe and the values at 100, 70, 50, 30, 20 and 10 mb taken at 1200 GMT were used in this study. These radiosonde temperatures were corrected for radiation by the method given by Finger *et al.* (1965).

## 3. Results

*a. Correlations.* Warnecke (1966) found a high correlation between the 30-mb and the 15-$\mu$ temperatures. Using preliminary, uncorrected 15-$\mu$ data for one day, his findings showed correlation coefficients of 0.90 for 247 values in the Northern Hemisphere and 0.94 for 234 values in the Southern Hemisphere. His scatter diagrams showed that the temperatures were distributed parallel to a line through the origin with a slope of one, indicating that the 15-$\mu$ temperature was systematically warmer than the 30-mb temperature by 11.0C and 5.1C for the Northern and Southern Hemispheres, respectively. After his comparison was made, factors were derived (Staff Members, 1965) to correct the 15-$\mu$ temperatures for instrumental degradation.

Using corrected 15-$\mu$ and radiosonde data from 97 Northern Hemisphere stations for 24 days from 20 January to 17 February 1964, correlations were computed between the 15-$\mu$ temperatures and the temperatures at six pressure levels from 100 to 10 mb. Data for 31 January and 1–12 February were not used because the 15-$\mu$ temperature coverage was too sparse to permit an isotherm analysis. The resulting coefficients are given in Table 1. The 20- and 30-mb levels show the highest coefficients of 0.71 and 0.72, respectively. The mean radiosonde temperature naturally varies greatly from level to level, and its standard deviation varies slightly, while the 15-$\mu$ means and deviations vary only with sample size. The maximum correlations occur at levels of minimum variability of the radiosonde temperatures.

Table 1. Correlation coefficients at various pressure levels (mb) between radiosonde temperature and 15-$\mu$ temperatures (both, °C) at 97 stations for 24 days.

| Pressure level | Correlation coefficient | Average radiosonde temperature | Average 15-$\mu$ temperature | Standard deviation of the radiosonde temperature | Standard deviation of the 15-$\mu$ temperature | Sample size |
|---|---|---|---|---|---|---|
| 100 | 0.33 | −61.6 | −48.1 | 10.02 | 5.08 | 1379 |
| 70 | 0.35 | −63.8 | −48.3 | 8.93 | 4.94 | 910 |
| 50 | 0.46 | −59.0 | −48.0 | 9.13 | 5.24 | 1384 |
| 30 | 0.72 | −56.7 | −48.1 | 7.21 | 5.23 | 1229 |
| 20 | 0.71 | −54.4 | −47.9 | 7.41 | 5.14 | 1078 |
| 10 | 0.61 | −48.0 | −47.9 | 9.06 | 5.02 | 840 |

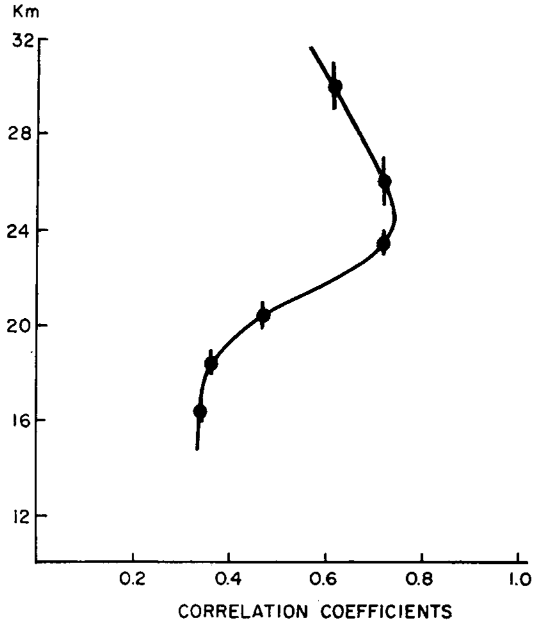

FIG. 1a. Correlation coefficients between the 15-$\mu$ temperatures and the radiosonde temperatures for six pressure levels from 100 to 10 mb plotted at the mid-point of the height range for each pressure level.

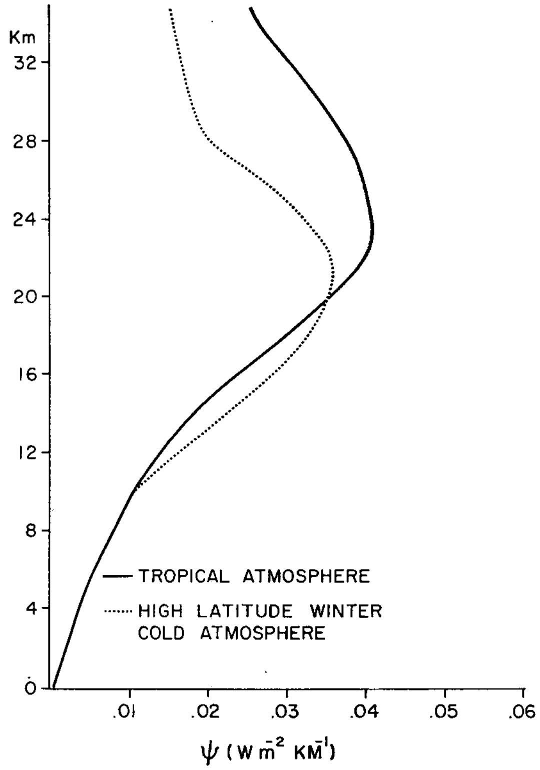

FIG. 1b. Weighting function applying to the measured outgoing radiance of the 15-$\mu$ channel at a nadir angle of zero [after Nordberg *et al.* (1965)].

The difference between the average 30-mb and the average 15-$\mu$ temperature is $-8.6$C, whereas the difference is only $-6.5$C at 20 mb although the correlations are nearly equal. At 10 mb the average temperatures are almost equal, but the standard deviation is greater and the correlation less.

The correlation coefficients were plotted as a function of height and compared to the weighting function which applies to the 15-$\mu$ outgoing radiance (Fig. 1). Only the weighting functions for the tropical and the high latitude winter-cold atmospheres are shown as these curves represent the upper and lower limits of the peak weights. Note the similarity of the shape of the curves. The height of the maximum correlation, approximately 24 km, is very near the heights of the maximum 15-$\mu$ weights, between 20 and 25 km. A slight over-correction of the 15-$\mu$ temperatures could easily result in this small difference in height of the maximum correlation and maximum weight. This adds confidence, however, that the 15-$\mu$ temperature should be more representative of the 20–30 mb temperatures than temperatures at other levels.

Scatter diagrams of the 20- and 30-mb temperatures vs the 15-$\mu$ temperature were plotted (Fig. 2) using the total population of 1078 and 1229 points, respectively. These diagrams are presented to demonstrate that it would be difficult to conclude that there is a systematic difference between the radiosonde and the 15-$\mu$ temperatures at either level. Although there is considerable scatter, one can see that the two temperatures are more nearly the same at high values but the difference becomes progressively greater for lower values. Nordberg (1966) has shown by radiative transfer theory that the 15-$\mu$ temperatures will change by varying amounts depending upon where the actual temperature changes occur in relation to the weighting functions (Fig. 1b). Thus, one would not expect a one-to-one correspondence between the radiosonde temperature changes at any level and the 15-$\mu$ temperature change.

*b. Time cross sections.* Time cross sections of radiosonde temperatures between 100 and 10 mb were plotted for 19 stations varying in latitude from 16N to 52N. Only one is shown in Fig. 3. Each section covered 8 days from 24–31 January 1964. On the sections, the height corresponding to the 15-$\mu$ temperature for that location was marked. The sections showed that the 15-$\mu$ temperatures correspond to the radiosonde temperatures that fall between the 10- and 30-mb levels, and not lower than the 30-mb level.

It is also interesting to note that the 15-$\mu$ temperature follows the trend of the radiosonde temperature as a function of time. The sudden warming in the stratosphere reported by Nordberg *et al.* (1965) found over the Caspian Sea (Fig. 3) shows that the 15-$\mu$ temperature increases as the radiosonde temperature changes in the 10–30 mb range. However, the 15-$\mu$ values increase less than the radiosonde temperatures, as would be expected considering the vertical and horizontal averaging represented by the former.

*c. Longitudinal comparison of radiosonde and 15-μ temperatures.* To further illustrate that the 15-μ temperature pattern corresponds to and changes as the radiosonde temperature pattern, the 10-mb, 30-mb, and 15-μ temperatures were plotted as a function of longitude along 60N (Fig. 4) for 27 January 1964 when there was a strong longitudinal temperature gradient at this latitude. The 15-μ temperature curve is seen to follow the same general trend as both the 10- and 30-mb temperature curves. In addition, the phase of the 15-μ temperature curve is more nearly in phase with the 30- than with the 10-mb temperature curve, although the magnitude of the 15-μ temperatures correspond better to the 10-mb temperature.

The important points to be made from Fig. 4 are that 1) the 15-μ temperatures are capable of detecting stratosphere temperature changes, 2) the 15-μ temperatures are seldom colder than the 30-mb temperatures and generally fall between the 10- and 30-mb temperatures, and 3) the phase and amplitude of the 15-μ temperature curves are more nearly coincident with the 30- than with the 10-mb temperature curve. From theory one would not expect the amplitude of the 15-μ temperature curve to be exactly the same as either of the radiosonde temperature curves; but it is significant that the phase and amplitude correspond better at 30 mb as this is nearer the height of maximum 15-μ emission.

*d. Longitudinal comparison of radiosonde heights and 15-μ temperatures.* The heights of the 10- and 30-mb

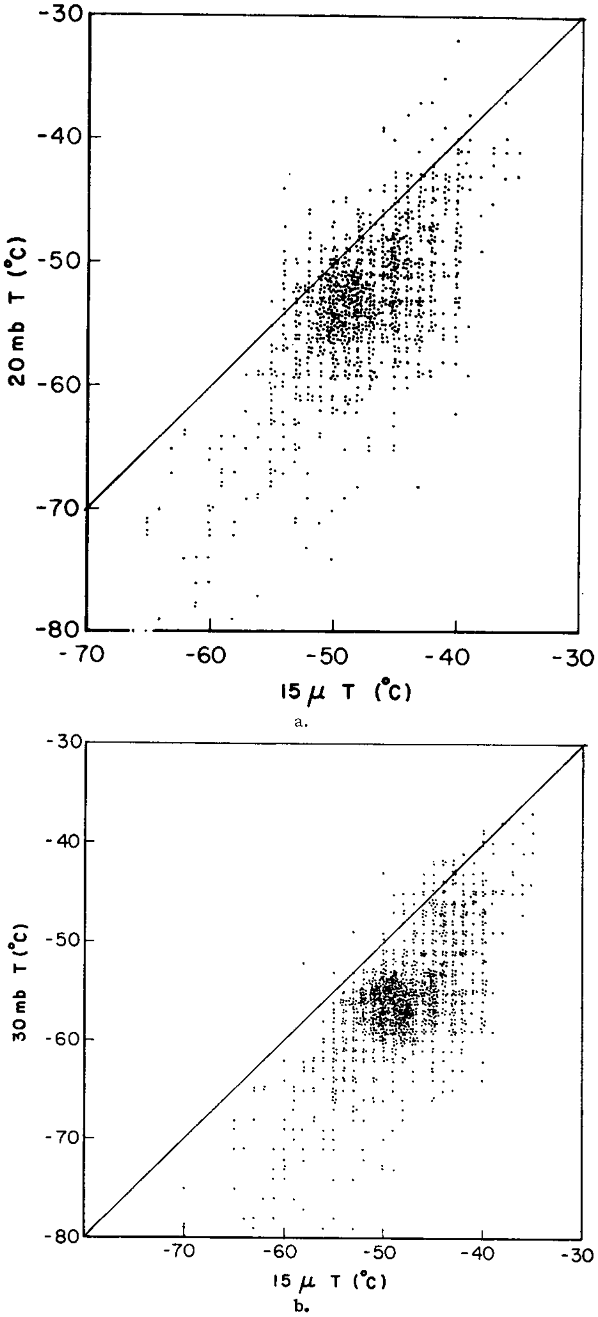

Fig. 2. Scatter diagrams of the radiosonde 20-mb temperatures, a., and 30-mb temperatures, b., vs. the 15-μ temperatures at 97 stations in the Northern Hemisphere for 24 days from 20 January through 17 February 1964.

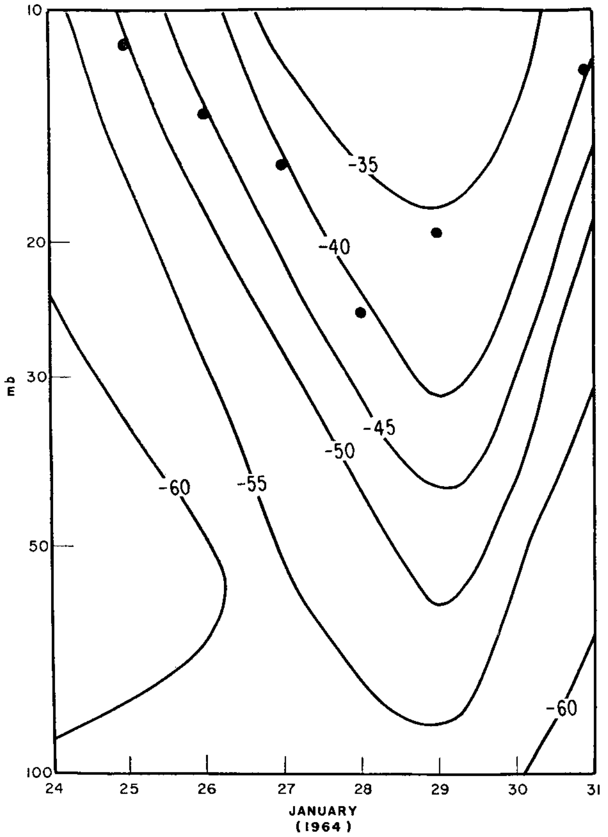

Fig. 3. Time-height section of radiosonde temperature for Orenburg (52N, 55E) for the period from 24–31 January 1964, where 15-μ temperatures are plotted at heights corresponding to the same radiosonde temperature.

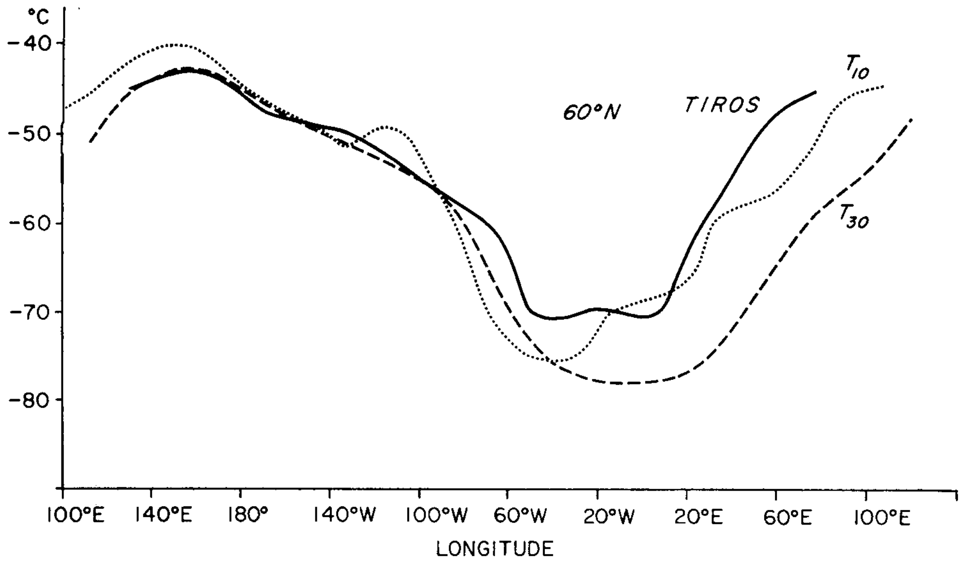

FIG. 4. 30-mb, 10-mb, and 15-$\mu$ temperatures vs longitude at 60N, for 27 Jaunary 1964.

surfaces and the 15-$\mu$ temperatures were plotted as a function of longitude (Fig. 5) to determine the relationship between pressure changes and the vertical mean temperature represented by the 15-$\mu$ temperature. There is a good relationship: where the 10- and 30-mb pressure surfaces are high the 15-$\mu$ temperature is high, and vice versa. However, the 15-$\mu$ temperature minimum lags by about 40° to 60° of longitude west of the height curves.

*e. Longitudinal comparison of thickness and 15-$\mu$ temperatures.* The next obvious question is "how well do the 15-$\mu$ temperatures correspond to the thickness between two pressure levels at heights near the maximum 15-$\mu$ radiance?" The thickness between 100 and 10 mb and the 15-$\mu$ temperature were plotted as before as a function of longitude (Fig. 6). There is good agreement in the phase of the two curves which is better than the previous relationship with height. A comparison of the amplitudes is not possible as the units are different. It would seem possible that one could obtain thickness patterns from the 15-$\mu$ temperatures and by graphical addition to the contour pattern of a lower level obtain a contour pattern at a higher level. This constitutes a study of its own and will not be pursued here.

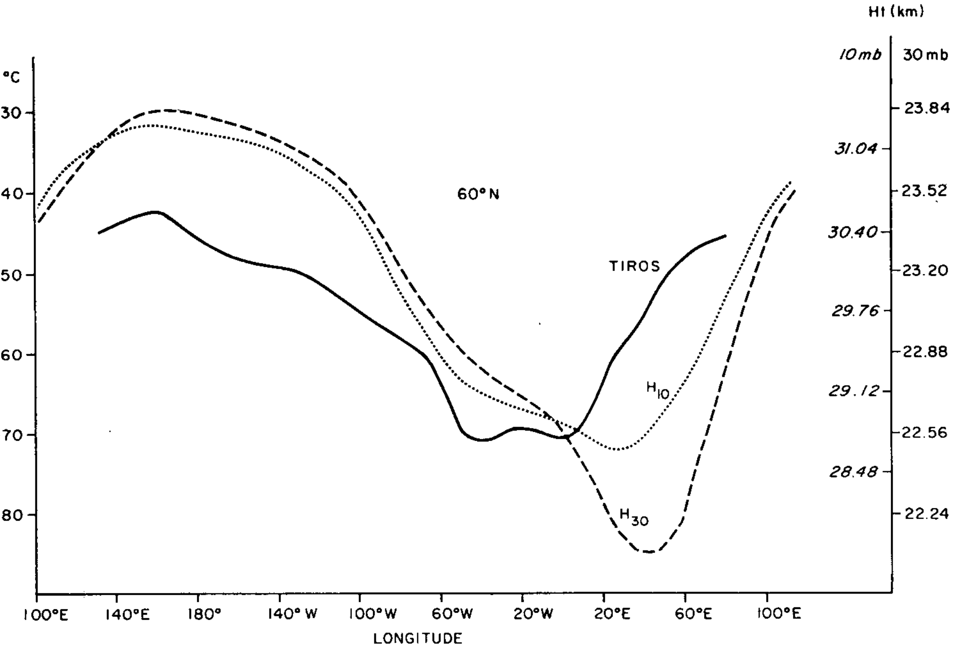

FIG. 5. 30-mb and 10-mb heights and 15-$\mu$ temperatures vs longitude at 60N, for 27 January 1964.

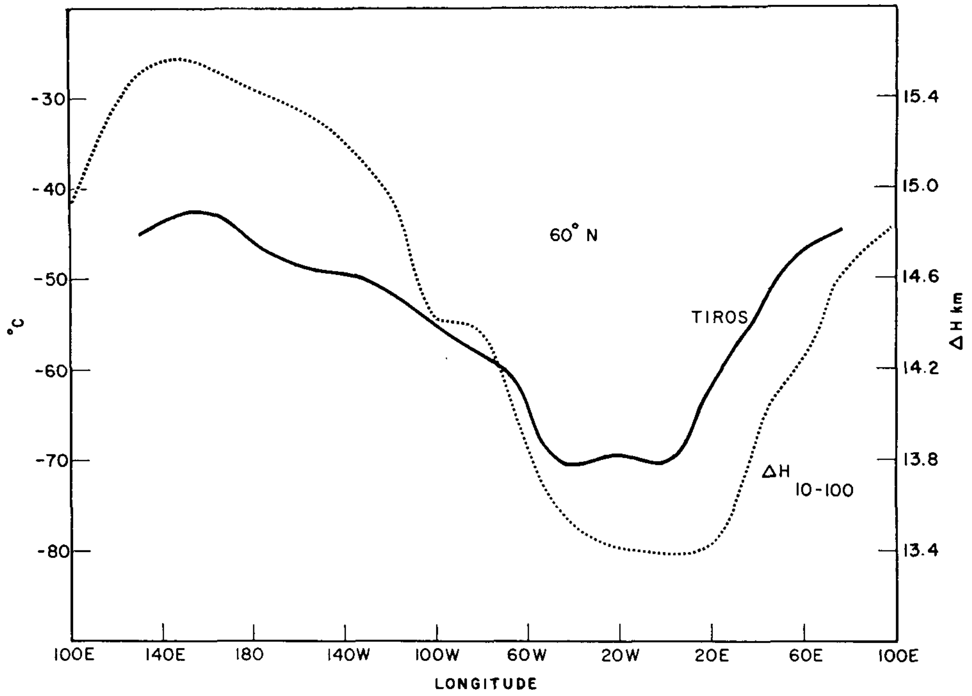

Fig. 6. 10–100 mb thickness and 15-$\mu$ temperature vs longitude at 60N, for 27 January 1964.

An attempt was also made to determine if the 15-$\mu$ temperatures were better correlated to warm high-pressure systems and cold low-pressure systems than to the total population. The radiosonde temperatures for each of the six pressure levels were divided into 16 groups by first selecting four height intervals and subdividing these height intervals into four temperature intervals. No systematic pattern could be found in the correlation for these 16 classes that would indicate that warm highs or cold lows were better correlated to the 15-$\mu$ temperatures than the population as a whole. However, this inconsistency may be due to the small sample size of each group, and should be tested with a larger population.

## 4. Summary

The evidence presented here indicates that the 15-$\mu$ temperatures correspond better to the 20- and 30-mb temperatures than any of the other commonly plotted pressure levels in the middle and lower stratosphere. One should use caution in interpreting the 15-$\mu$ temperatures as an equivalent of the 20- or 30-mb temperatures, however, as no evidence can be found of a systematic difference between the satellite and radiosonde values, nor should there be. The 15-$\mu$ temperature will change by varying amounts depending upon where the actual temperature change occurs in relation to the weighting function, although the 15-$\mu$ temperature change is more sensitive to the actual temperature change at the height where the radiance weighting function has its maximum.

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