# 11.3 A COMPARISON OF THE TOVS TEMPERATURE PROFILE WITH ECMWF ANALYSIS AND STATION-OBSERVED DATA IN MIDDLE AND HIGH SOUTHERN LATITUDES

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## 1. INTRODUCTION

The purpose of this study is to validate the TOVS (Television Infrared Observational Satellite Operational Vertical Sounder) Pathfinder A dataset using radiosonde observations and ECMWF analyses over middle and high southern latitudes. The TOVS Pathfinder A dataset is a global and multiyear satellite dataset. It is particularly suitable for climate studies because surface, atmospheric, cloud and radiative parameters are all produced simultaneously in an internally consistent manner (Susskind et al. 1997). In recent years, much effort has been devoted to using this dataset to derive the upper level atmospheric winds and then using the winds to estimate the moisture transport and net precipitation over the Southern Ocean and Antarctica (Slonaker and Van Woert 1999; Zou and Van Woert 2001,2002). The works by Slonaker and Van Woert (1999) and Zou and Van Woert (2001,2002) have shown that virtual temperatures from the TOVS Pathfinder Path A dataset can be used to derive yearly and monthly mean atmospheric wind and moisture transport over the Southern Ocean with reasonable accuracy. It should be noted that the performance of their studies is dependent on the temperature accuracy. However, the performance of TOVS data in middle and high southern latitudes is not yet clear.Though Susskind et al.(1997) have validated TOVS products globally against surface observations and ERA reanalyses, the statistical biases over the polar regions may not be reflected by the global mean values. Moreover, their validation was generally limited to December 1989. Currently, a multi-year wind and moisture flux dataset has been produced based on the method of Zou and Van Woert (2001, 2002) at the National Ice Center. Therefore, it is necessary to understand the performance characteristics of TOVS Path A temperature data at middle and high southern latitudes. In this paper, we compare the temperatures from TOVS with ECMWF analyses and surface station observations and thus establish a foundation for the TOVS Path A product to be used in future Southern Ocean and Antarctic climate studies.

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## 2. DATA

### a. TOVS Pathfinder A Dataset

TOVS Pathfinder A dataset contains three kinds of temperatures: (1) the retrieved atmospheric temperatures at the surface and at mandatory levels from surface to 30mb; (2) four deep layer-mean temperatures, which are believed to be more accurate than point temperatures because of the limited vertical resolution of TOVS; and (3) auxiliary gridded layer mean virtual temperature, defined at 10 different layers from the surface to 10 mb. These products are presented on 1°×1° latitude-longitude grid and stored as individual satellite's local A.M. and P.M. orbits. The auxiliary gridded layer-mean virtual temperatures are used in this study. The detailed description of this dataset can be found in Susskind et al (1997).

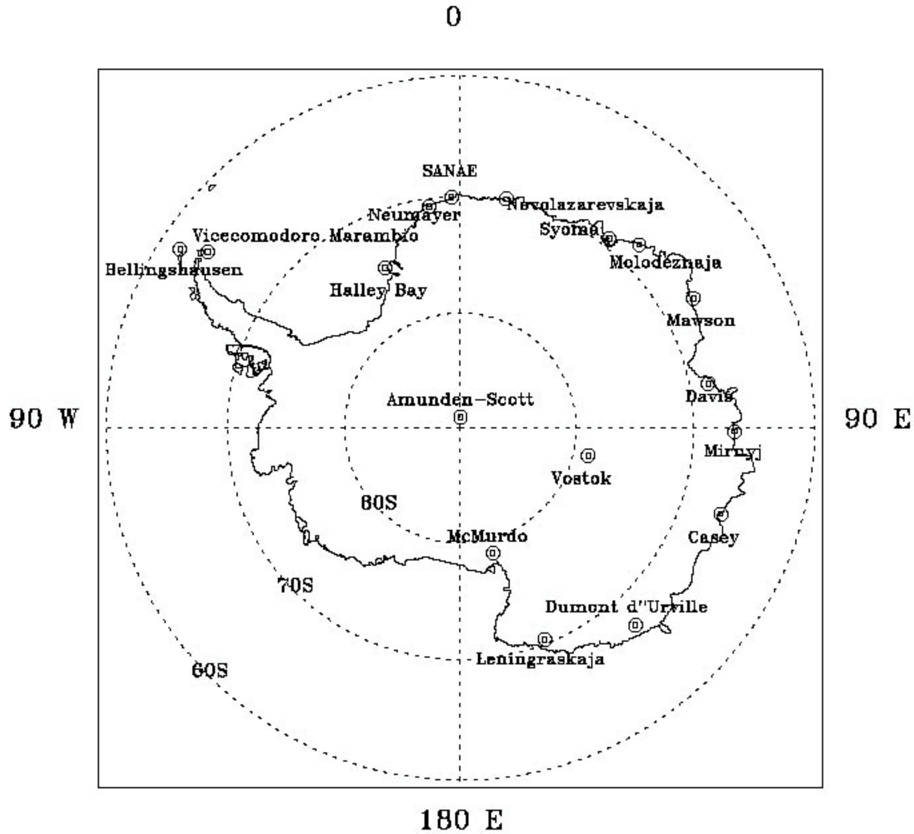


Figure 1. Physical locations of Antarctic radiosonde stations

**b. ECMWF ANALYSES**

ECMWF analyses are produced from four-dimensional data assimilation by incorporating all available observational data (including satellite data) with a 6-hour "initial guess" provided by the ECMWF medium-range weather forecast model (Trenberth 1991). This dataset is global with a horizontal resolution of 2.5°×2.5° latitude and longitude. Prior to 1991, there are 14 standard levels in the vertical to 10 mb. After 1991, the 925 mb data is added to the archives. The temperature and other variables are reported twice daily (0000 and 1200 UTC).

**c. Radiosonde Data**

Macquarie Island station, which is located at 54.5°S and 159.9°E, is selected to represent the Southern Ocean region. The complete, twice-daily soundings at Macquarie Island are available for 7 year period in this study (1987-1993). Over the Antarctic continent, approximately 17 stations have fairly complete records. Antarctic station data were obtained from the Antarctic Meteorological Research Center at the University of Wisconsin. The Macquarie Island observations were obtained from the National Climate Data Center (NCDC) archives. The physical locations of Antarctic radiosonde stations are shown at Figure 1.

**3. METHODOLOGY**

**a. Spatial Interpolation and Temporal Average**

As mentioned in the Section 2, TOVS data are presented on a 1°×1° longitudinal and latitudinal grid and ECMWF data are on a 2.5°×2.5° grid. Thus, to compare both datasets, TOVS gridded data are interpolated onto a 2.5°×2.5° grid using a linear interpolation scheme. To compare gridded TOVS data with station sounding data, the gridded TOVS data are also interpolated onto the sounding locations with a simple "nearest neighbor" method.

Temporally, TOVS data are archived separately as local A.M. and P.M. files. ECMWF data consists of 0000 and 1200 UTC analyses and the station soundings are generally recorded once or twice daily. Therefore, these three datasets do not exactly match each other on an hourly basis. However, because our interests in this study are for monthly and yearly climatology, the hourly time interpolation is not necessary. To get a monthly mean value, all available observations in a month are used. Yearly or multi-year means are computed from the monthly averaged values. Multiyear statistics are also computed using this rule.

**b. Layer-mean Temperature Calculation**

To compare with the TOVS layer-mean temperatures, the ECMWF analyses and the radiosonde temperature profiles are weighted to provide a layer-mean value as follows (Iredell, private communication),

$$\bar{T} = \frac{\sum_{1}^{N} w_i T_i \log_e\left(p_1 / p_2\right)}{\sum_{1}^{N} w_i \log_e\left(p_1 / p_2\right)} \qquad (1)$$

where $T_i$ is the temperature at the $i$ th level, $w_i$ is weighting function, and $p_1$ and $p_2$ are the bottom and top bounding pressures. In this study, the weighting function is chosen to be 1 for all layers.

## 4. RESULTS

**a. Comparisons with ECMWF Data**

A comparison of 7-yr averaged layer mean temperatures at 700-500 mb between TOVS and ECMWF is shown in Figure 2. In general, they have similar spatial patterns over the Southern Ocean. The differences are less than 0.5°K for most grid points. Over the Antarctic continent, fairy good agreement north of $75^0$S is observed. However, south of 75°S larger differences are found. At some grid points, the difference can be larger than 2°K. At lower layers (not shown here), the difference becomes even larger, especially below 850 mb. This feature can be seen in Figure 3, which shows the altitude-longitude cross section of the 7-yr mean temperatures of the satellite-derived and ECMWF analyses at 70°S. Above 850 mb level, no significant difference exists; The larger differences are mainly confined to the 1000-850 mb layer. The main reason is probably due to missing satellite data. Careful analysis reveals many missing data below 850 mb over the Antarctic continent. In particular, more than 90% of the 1000-850 mb layer data are missed from some grid points in the region between 45°E and 135°E. In contrast, very few data are missed over the Southern Ocean.

**b. Comparisons with Station Observations**

The comparisons between the satellite measurements and radiosonde data at select stations are summarized in Table 1 using statistical variables, such as the correlation coefficient, mean value, standard deviation (SD), root-mean-square (RMS) and bias. The time series of average monthly temperatures at 850-700 mb layer are plotted together in Fig. 4 for comparison.

At Macquarie Island (54.5°S, 158.9°E), the correlation increases with increasing layer height. The correlation coefficient is 0.7 at 1000-850 mb, increases to 0.8 at 850-700 mb, and reaches 1.0 at 700-500 mb and above. The RMS errors are less than 2.0°K above 850 mb, but at 1000-850 mb the RMS is 2.5. The 7-yr averaged bias shows that the satellite temperature has a cold bias for the 1000-850 mb and 300-100 mb layers, and a warm bias in the mid-troposphere. The smallest bias is found at 850-700 mb, and largest at 1000-850 mb. In addition, the similar magnitudes of standard deviations suggest that TOVS data represent the characteristics of the actual temperature change over the Southern Ocean. The time series of monthly mean temperatures (Figure 4) also suggest that the satellite-derived mid-troposphere temperatures capture the variability observed in the radiosonde soundings.

At Halley Bay (75.5°S, 26.65°W), the satellite measurements are slightly warmer than the

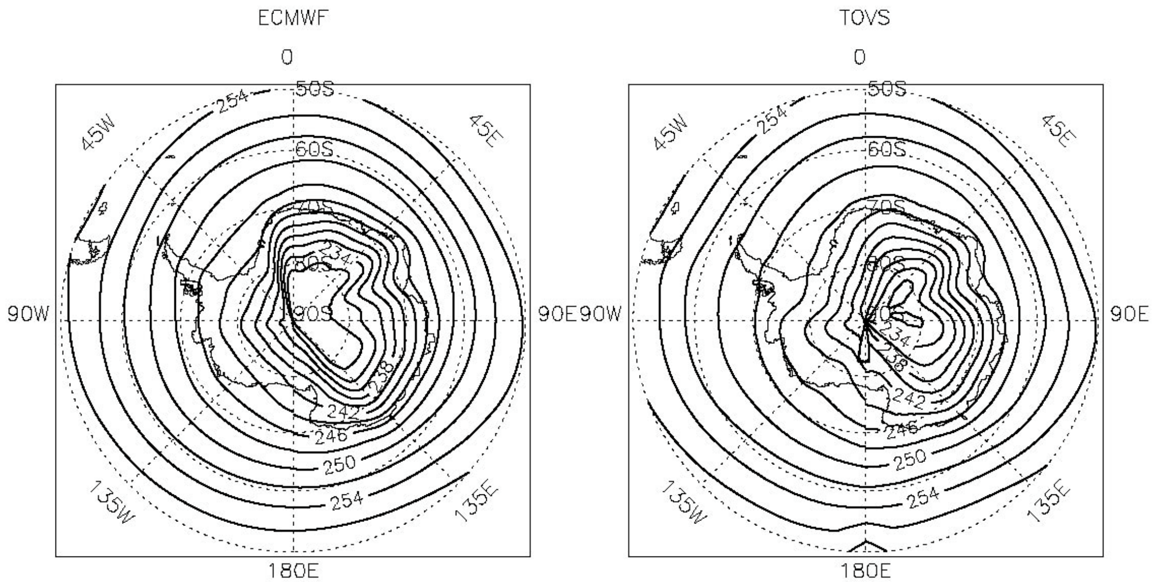


Figure 2. Multi-year mean temperatures for 1987-1993 at 700-500 mb layer.
Left is for ECMWF; Right is for TOVS.

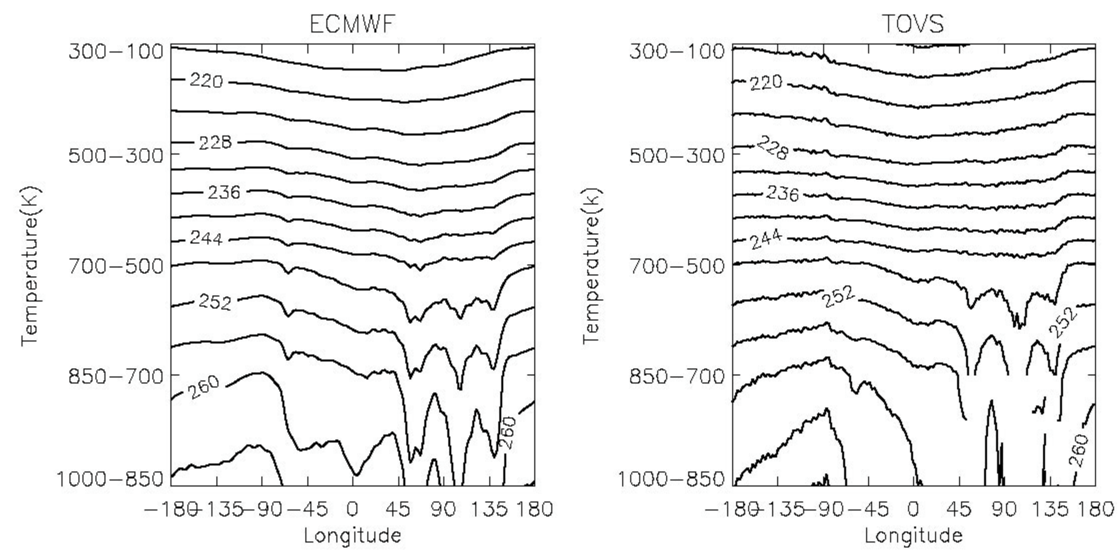


Figure 3. Altitude-longitude cross section of multi-year mean temperatures at 70°S
for 1987-1993. Left is for ECMWF; Right is for TOVS.

radiosonde observations for all layers (positive bias for all layers). The smallest difference is found at 700-500 mb layer with only a 0.15°K bias. Similar to Macquarie Island, the difference at 1000-850 mb layer is still the largest. However, the correlation is better than that of Macquarie Island at lower layers, especially for the 1000-850 mb layer, for which the averaged monthly correlation coefficients is 0.96. Another significant feature is that both satellite and radiosonde measurements have large standard deviation (over 11° K) at 300-100mb. They are much larger than that at Macquarie Island. This result is common to all stations over the Antarctic continent. Although RMS at 500-300mb is the largest with 2.39K, it is acceptable

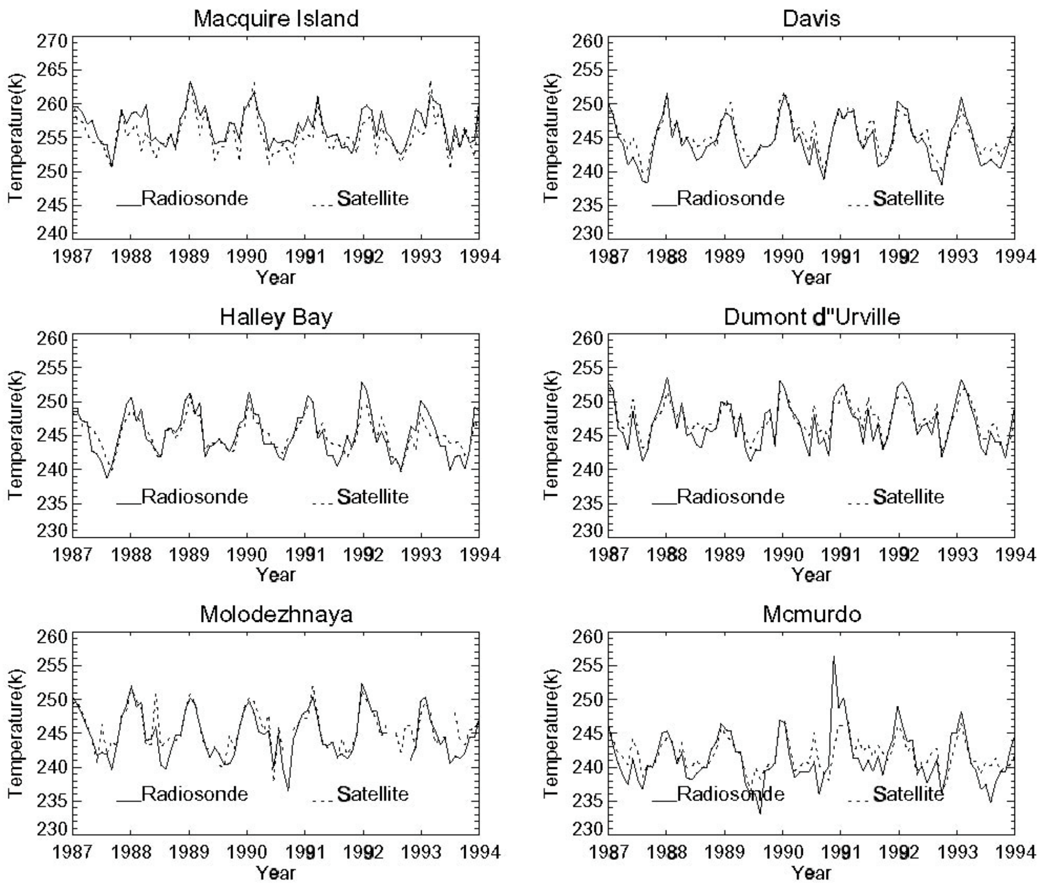


Figure 4. Monthly averaged layer-mean temperatures versus time for six radiosonde stations at 850-700 mb layer

because this value is still within the range of variation for the raob's standard deviation (3.33°K).

The comparisons for Molodezhnaya (70.77°S, 11.83°E) show RMS ranging from 1.71°K to 2.09°K, and correlation coefficients above 0.95 for the 1000-850 mb, 500-300 mb and 300-100 mb layers. Generally, the agreement is quite good. At Davis station (68.5°S, 77.95°E), however, we find a larger bias (3.71°K at 1000-850 mb). Correspondingly, the RMS is also quite large (4.11°K). Nevertheless, compared with the higher standard deviation for the radiosonde data (5.33°K), this is still considered reasonable. The good agreement is also confirmed by the higher correlation coefficient (0.95) between the satellite and raob data. At Dumont d'Urville station (66.67°S, 140.02°E), larger biases exist at 1000-850 mb and 500-300 mb, and the other layers have smaller bias. The correlation coefficients are higher for the other layers except the layer of 1000-850 mb. At McMurdo (77.85°S, 166.67°E), small biases are found between the 850 and 300 mb levels. The largest differences occur for the 1000-850 mb layer. Compared with other stations, the RMS between the satellite and raob are larger (greater than 2.50 at all layers). Possible reasons for this need to be investigated. Nevertheless, this discrepancy is not excessive because they are still less than raob's standard deviations. The correlation coefficients are also higher for all layers except for the 700-500 mb layer, which has a correlation coefficient of 0.76.

Table 1. Multi-year statistics for temperature comparison of TOVS with six stations for 1987-1993

| Station | Layer (mb) | RMS (°K) | Bias (TOVS-RAOB) (°K) | Corre-lation | Mean (RAOB) (°K) | Mean (TOVS) (°K) | SD (RAOB) (°K) | SD (TOVS) (°K) |
|---|---|---|---|---|---|---|---|---|
| Macquire Island | 300-100 | 1.6 | -0.8 | 1.0 | 219.6 | 220.4 | 4.4 | 4.7 |
| | 500-300 | 1.1 | 0.5 | 1.0 | 235.4 | 234.9 | 3.1 | 3.5 |
| | 700-500 | 1.8 | 1.3 | 0.9 | 256.6 | 255.3 | 2.5 | 2.7 |
| | 850-700 | 1.4 | 0.2 | 0.8 | 267.7 | 267.5 | 2.0 | 2.4 |
| | 1000-850 | 2.5 | -2.0 | 0.7 | 274.0 | 276.0 | 1.5 | 1.9 |
| Halley Bay | 300-100 | 1.73 | 0.50 | 0.99 | 211.16 | 210.67 | 11.02 | 11.70 |
| | 500-300 | 2.39 | 0.38 | 0.93 | 225.54 | 225.16 | 3.33 | 5.10 |
| | 700-500 | 1.62 | 0.15 | 0.88 | 245.29 | 245.14 | 3.24 | 2.37 |
| | 850-700 | 1.79 | 0.58 | 0.88 | 255.67 | 255.09 | 3.54 | 2.97 |
| | 1000-850 | 1.89 | 0.90 | 0.96 | 258.32 | 257.43 | 5.79 | 5.97 |
| Molode-zhnaya | 300-100 | 1.71 | 0.00 | 0.99 | 214.36 | 214.36 | 9.55 | 9.90 |
| | 500-300 | 2.09 | -0.91 | 0.95 | 226.74 | 227.64 | 3.58 | 4.95 |
| | 700-500 | 1.81 | -0.63 | 0.86 | 245.17 | 245.79 | 3.30 | 3.07 |
| | 850-700 | 2.08 | 0.94 | 0.86 | 255.61 | 254.67 | 3.63 | 3.49 |
| | 1000-850 | 1.95 | -0.77 | 0.98 | 262.75 | 263.53 | 3.91 | 2.21 |
| Davis | 300-100 | 1.32 | -0.03 | 0.99 | 213.69 | 213.72 | 9.82 | 10.02 |
| | 500-300 | 2.32 | -0.87 | 0.95 | 226.01 | 226.88 | 3.57 | 5.18 |
| | 700-500 | 1.44 | -0.64 | 0.92 | 244.57 | 245.21 | 3.25 | 2.66 |
| | 850-700 | 1.36 | 0.08 | 0.93 | 254.62 | 254.55 | 3.67 | 3.36 |
| | 1000-850 | 4.11 | 3.71 | 0.95 | 260.47 | 256.76 | 5.33 | 5.43 |
| Dumont d'Urville | 300-100 | 1.52 | 0.24 | 0.99 | 217.22 | 216.98 | 8.99 | 9.40 |
| | 500-300 | 2.71 | -1.36 | 0.91 | 228.29 | 229.66 | 3.37 | 4.93 |
| | 700-500 | 1.56 | -0.51 | 0.91 | 246.93 | 247.44 | 3.33 | 2.47 |
| | 850-700 | 1.53 | 0.26 | 0.90 | 256.34 | 256.08 | 3.50 | 2.98 |
| | 1000-850 | 4.25 | 0.94 | 0.65 | 261.21 | 260.27 | 5.21 | 4.68 |
| McMurdo | 300-100 | 3.04 | 1.87 | 0.98 | 215.0 | 213.13 | 11.33 | 12.07 |
| | 500-300 | 2.84 | -0.25 | 0.83 | 224.52 | 224.77 | 3.86 | 5.06 |
| | 700-500 | 2.55 | -0.42 | 0.76 | 241.42 | 241.82 | 3.81 | 2.39 |
| | 850-700 | 2.50 | -0.21 | 0.88 | 250.39 | 250.60 | 5.07 | 3.75 |
| | 1000-850 | 3.84 | 2.95 | 0.94 | 255.76 | 252.81 | 6.97 | 7.48 |

Further analysis shows that there are negative bias between TOVS and radiosonde temperatures for the 700-500 mb and 500-300 mb layers for all stations located in the Western Antarctic region. In contrast, positive biases are found at 1000-850 mb, 850-700 mb and 300-100 mb layers for most of stations. This suggests that the TOVS temperatures are lower (colder) than radiosonde soundings for the middle troposphere, and higher (warmer) than radiosnde soundings for the lower layers and top of troposphere in the Western Antarctic. However, in the Eastern Antarctic, all stations except SANAE have positive biases for the 700-500 mb and 500-300 mb layers.

**c. Intercomparison of Satellite Soundings**

For climate monitoring and analyses, a stable and consistent observing system is important. However, for satellite soundings, a satellite usually lasts only a few years. Thus, a long-term climate dataset from satellite sounding is usually based on data from several satellites. Therefore, verifying the stability of satellite soundings is

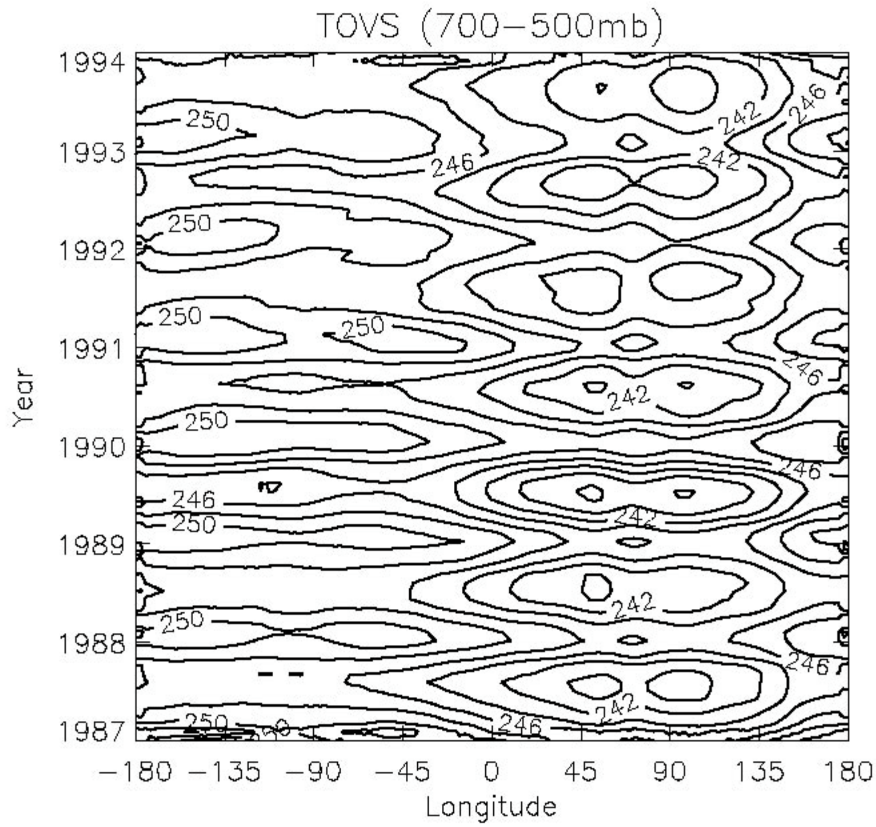


Figure 5. Hovmoller diagram of TOVS meridionally averaged temperature between 50°S and 90°S for 1987-1993

Table 2. Multi-year statistics for comparison between NOAA-10 and NOAA-11 temperatures at Molodezhnaya for 1989-1990

| Station | Layer (mb) | RMS (°K) | Bias (TOVS-RAOB) (°K) | Corre-lation | Mean (RAOB) (°K) | Mean (TOVS) (°K) | SD (RAOB) (°K) | SD (TOVS) (°K) |
|---|---|---|---|---|---|---|---|---|
| Molode-zhnaya | 300-100 | 0.6 | -0.5 | 1.0 | 213.6 | 213.8 | 10.1 | 10.3 |
| | 500-300 | 0.8 | 0.2 | 1.0 | 227.4 | 227.3 | 5.4 | 5.6 |
| | 700-500 | 1.3 | 0.3 | 0.9 | 245.7 | 245.5 | 3.1 | 3.6 |
| | 850-700 | 0.8 | 0.1 | 1.0 | 254.8 | 254.6 | 3.8 | 4.1 |
| | 1000-850 | 1.4 | 0.1 | 1.0 | 265.5 | 267.0 | 6.1 | 6.5 |

required. For the TOVS dataset from 1987 to to 1993, three NOAA satellites were on orbits. (Susskind et al. 1997). In order to ensure realistic climate change from the TOVS data, we need to confirm the consistency and stability of the TOVS data. .

Figure 5 shows a time-longitude cross section (Hovmoller diagram) of TOVS meridionally averaged temperatures between 50°S and 90°S for 1987-1993. In Figure 5, it can be seen that a stable annual cycle and consistent inter-annual variability are present throughout the full records. For each year, higher and lower temperature cells correspond to the warmer and colder periods of each year, respectively. These cells are consistently found between 170°E to 45°W and 30°W to 135°E. Another interesting phenomenon is that, before 1991, warmer temperature cells (circle with 250K) have a relatively large range between 170°E and 45°W; however, from 1992 to 1993, this circle is smaller, only ranging from 180°W to 135°W. Correspondingly, colder temperature cells have a temperature gradient change. That is, the contour lines of temperatures becomes sparse after 1992. This change is not accidental, and has been linked to changes in the SOI index (Cullather et al. 1996).

Further support for the stability of the satellite sensors comes from a comparison of the overlapping periods. The Pathfinder A product from 1987 to 1993 contains TOVS data from NOAA-10, NOAA-11 and NOAA-12. To determine if different satellites generate spurious inter-satellite biases, statistical differences between NOAA-10 and NOAA-11 for 1989 and 1990 are discussed here. Also, to allow comparison with the results discussed in the section above, the statistics between NOAA-10 and NOAA-11 are also calculated at the locations of radiosonde stations. That is, data from NOAA-10 and NOAA-11 are first interpolated onto the locations of the radiosonde stations. For example, the statistical analysis for Molodezhnaya station is listed in Table 2.

From Table 2, we see that the agreement between NOAA-10 and NOAA-11 is excellent . Except at 300-100 mb, the biases for all other layers are less than 0.3°K. The RMS is less than 1.5°K. Correlation coefficients are 1.0 for all layers except for the 700-500 mb layer, which is 0.9. Standard deviations are also quite similar to each other. Similar results are also obtained for the other stations. Compared with the statistical results discussed in the last section, in general, the agreement between NOAA-10 and NOAA-11 is superior to that between NOAA-10 and the radiosonde. This provides substantial confidence in the fidelity of the TOVS Pathfinder A dataset.

## 5. SUMMARY AND CONCLUSION

The layer-mean temperatures from the TOVS Pathfinder A products are evaluated for middle and high southern latitudes by comparisons with ECMWF data and radiosonde observations. The analyses are performed for the years 1987 through 1993. Generally, TOVS temperatures have a similar spatial pattern to ECMWF data. Over the Southern Ocean, their differences are less than 0.5°K. Over the Antarctic continental region, their differences depend on locations. Larger difference are found south of 75°S. In the vertical, above 850 mb, TOVS derived temperatures are quite similar to the ECMWF analysis, but below 850 mb, the differences increase, especially over the continent.

Comparisons with radiosonde temperatures at Macquarie Island indicate that correlation between the two data sets increase with increasing height. The correlation coefficients reach 1.0 above 500 mb. The largest difference is found for the 1000-850 mb layer. RMS values are less than 1.8°K except for the lowest layer. Comparisons with radiosonde data over Antarctica show quite good results, though the TOVS performance varies with location. The correlations are typically above 0.8. A slight cold bias is found at 700-500 mb and 500-300 mb over the Western Antarctic coast, and warmer biases are found for the lower and higher layers.

The stability of satellite measurements is evaluated by analyzing the time variations of the meridionally averaged temperatures for the period 1987 through 1993. The stable yearly temperature variation demonstrates the utility of satellite data for long-term climate monitoring and diagnostics. The intercomparisons between NOAA-10 and NOAA-11 during overlapping periods from 1989 to 1990 indicate that multi-year biases at individual stations are quite smaller for all layers over the Antarctic continent.

These analyses show that the average multi-year TOVS temperatures, in general, agree well with ECMWF analyses and radiosonde soundings. This suggests that the TOVS Pathfinder A temperatures are of high quality and provide a good characterization of the Antarctic temperature field. Further analyses will be focus on other important variables, such as precipitable water and specific humidity.

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