# Statistical Assessment of the Quality of TIROS-N and NOAA-6 Satellite Soundings

ARNOLD GRUBER AND CARMELLA DAVIS WATKINS

*National Earth Satellite Service, NOAA, Washington, DC 20233*

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## ABSTRACT

A statistical evaluation of satellite soundings from TIROS-N and NOAA-6 is presented. Collocated satellite-radiosonde data were collected by season from July 1979 through May 1980 for clear and cloudy retrievals. In addition to RMS and mean error statistics, vertical correlations, ratio of satellite variance to radiosonde variance, and land minus sea differences for 30–60°N, 30–60°S and 30°N–30°S were examined. The results indicate that the mean and RMS differences are larger for cloudy retrieval paths than for clear retrieval paths. The largest RMS errors occur in the 1000–850 mb layer and in the tropopause region. Vertical correlations are highest between adjacent layers.

The ratio of satellite variance to radiosonde variance is considerably higher than reported in Phillips *et al.* (1979), with clear retrievals exhibiting a higher ratio than cloudy retrievals. Land minus sea differences suggest that there is a continental influence in the coefficient data base used to generate cloudy retrievals.

## 1. Introduction

TIROS-N began operational production of soundings on 28 February 1979 and NOAA-6 started producing soundings on 16 October 1979.

The first evaluation of soundings from this series of operational polar-orbiting satellites was made for two limited periods 30 January–28 February 1979 and 29 March–27 April 1979 (Phillips *et al.*, 1979). Thus, we will be presenting an additional year's worth of statistical evaluations with much larger data samples than was previously studied. Furthermore, our comparisons will be for mean layer temperatures between mandatory pressure levels, ranging from 1000 to 100 mb. These mean layer temperatures are derived from the retrieved geopotential by first calculating the thickness and then expressing thickness in terms of mean layer temperature through application of the hypsometric equation.

Satellite coverage is generally uniform, but this study depends upon the availability and location of radiosonde data as well as the reliable performance of the sounding system. We will show results for the 30–60°N, 30°N–30°S, 30–60°S, latitude zones mainly because radiosonde coverage is best in these latitude belts. During 2–4 March 1980, the retrievals were not properly matched to the radiosondes. Thus that time period was deleted from our data set. Also, TIROS-N failed on 20 January 1980, but it was reactivated on 30 January 1980. Another gap in satellite data occurred because TIROS-N orbits were not processed in May, in preparation for the launch of NOAA 7, which was intended to replace TIROS-N but failed to achieve a satisfactory orbit.

In general, collocated data coverage between satellite and radiosondes is quite extensive over most continental areas. The only areas which have sparse collocations are central areas of the USSR, the eastern portion of the Pacific Ocean, and northern China. For the 30–60°S zone, data match-ups congregate near the land masses. However, since this region is chiefly composed of ocean, match-ups between satellite and radiosonde are few in this latitude belt. In the 30°N–30°S zone, there are dense areas of radiosonde and corresponding satellite coverage in Central America and the Caribbean Islands, India, Indonesia and southern China. However, there are relatively few collacated reports from South America, Africa and Australia.

## 2. Structure of data processing

A part of the operational procedures for deriving soundings from satellite observations are the quality checks on the data performed by the comparison of satellite soundings with collocated radiosonde soundings. Soundings are separated as to type (i.e., clear, partly cloudy and cloudy) and terrain features (land or water). Clear and partly cloudy soundings utilize both infrared and microwave observations. Cloudy soundings are derived from microwave data only in the troposphere and infrared channels in the stratosphere. More specific information about the processing procedures and sounding channels is available in Smith *et al.* (1979). The spatial window for collocation shown in Table 1 varies somewhat with latitude zone, and is smallest in regions of high radiosonde density. Radiosondes are interpolated to the

TABLE 1. Space and time* windows for retrieval/radiosonde match.

| Latitude zone | Space window |
|---|---|
| 90–80°N | 2° × 2° |
| 80–70°N | 1.5° × 1.5° |
| 70–60°N | 1.5° × 1.5° |
| 60–50°N | 1° × 1° |
| 50–40°N | 1° × 1° |
| 40–30°N | 1.5° × 1.5° |
| 30–20°N | 2° × 2° |
| 20–10°N | 2° × 2° |
| 10°N–90°S | 3° × 3° |

* Time interpolated between 0000 and 1200 GMT radiosondes for all zones.

time of the satellite observation. Only radiosondes that have passed the National Meteorological Center's most thorough quality check, the A type soundings, are used in the collocation procedure. The height and temperature of A type soundings are monitored for vertical consistency using the hydrostatic equation. Collocations are performed for every 10° latitude zone twice per day from 90°N to 90°S. Level-by-level comparisons are made between geopotential and temperature. These data provide the basic input for the statistical evaluation presented here.

We have collected these data for the five broad latitude zones corresponding to the zones used for generating retrieval coefficients (60–90°N, 60–90°S, 30–60°N, 30–60°S, 30°N–30°S). We have further summarized the statistical comparison by satellite (TIROS-N or NOAA 6), season, summer (July–August 1979)[1], fall (September–November 1979), winter (December 1979, January, February 1980) and spring (March–May 1980) and by retrieval path. When we refer to seasons, we generally will use the conventions of the Nothern Hemisphere.

## 3. Results

Tables 2–4 present mean and RMS differences for clear and cloudy soundings over all terrain features for the three zones 30–60°N, 30°N–30°S and 30–60°S. This series provides an opportunity to examine seasonal and retrieval path variations. The RMS differences calculated include the mean error as well as the radiosonde error. In general, the mean error makes a small contribution. However, examination of the results does show certain locations where this error can make a sizable contribution, such as the 1000–850 mb layer. Not much is known about the tropospheric error in randiosondes, although several assessments were made which quote 1 K for radiosonde RMS errors, Meteorological Working Group (1971) and Bengtsson (1975). Most of the statistical summaries presented are self-explanatory. Consequently, we will only summarize the data and comment upon the highlights.

### a. *Mean and RMS differences*

#### 1) 30–60°N

The mean and RMS differences for summer for the 30–60°N latitude zone are the first group of data shown in Table 2. The clear retrievals show small RMS differences, which are less than 2 K everywhere except in the 1000–850 mb and 100–150 mb layers. The smallest RMS difference is 1 K and occurs in the 500–700 mb layer. The bias (satellite-radiosonde) is generally negative throughout most of the troposphere and attains its greatest value of −0.9 K in the 250–300 mb layer. The cloudy soundings illustrate markedly different behavior. The RMS differences are generally greater; this is usually the case for all seasons and latitude zones as well. The RMS difference varies from a maximum of 3.9 K in the 1000–850 mb layer to a minimum of 1.7 K in the 500–700 mb layer, but is generally between 2.5 and 3 K throughout most of the troposphere. A sizable bias in the cloudy retrievals, approaching 3 K in the 1000–850 mb layer contributes significantly to these large RMS differences. Possible reasons for the poorer results under cloudy conditions are:

1) The Microwave Sounding Unit (MSU) uses essentially three channels to derive temperature profiles. Its poor vertical resolution and relatively coarse (∼100 km) horizontal resolution lead to poorer results than the combined infrared and microwave retrievals.

2) Of the three MSU channels, none measures the lower atmosphere. Depending upon the scan angle, the lowest channel peaks at about 600 mb.

3) Coefficients are generated from clear radiances and then are used under cloudy conditions. Thus the coefficients may not be representative of the conditions to which they are being applied.

4) Before mid-February 1980 no attempt was made to remove precipitating areas from the microwave soundings. This can degrade the retrieval accuracy, and generally produces soundings that are too cold (Phillips, 1980). However, we suspect this is a relatively minor problem because only ∼10% of the cloudy soundings are affected.

The tendency for the RMS differences to be large in the 1000–850 mb layer, to decrease in the middle troposphere, and to then increase again in the upper troposphere in the vicinity of the tropopause is also a characteristic of the other seasons. This is interpreted as the inability of the sounding system to de-

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[1] The July–August 1979 data are for TIROS-N only and for limited longitudinal extent in the 30–60°N latitude zone.

30–60°N

TABLE 2. Satellite-radiosonde differences*. *N* is number of observations.

*Clear*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| 334 | −0.1 | 2.0 | 1390 | 0.7 | 2.7 | 917 | −0.5 | 2.9 | 760 | −0.1 | 2.5 | 100-85 |
| 991 | 0 | 1.3 | 3463 | 0.2 | 1.9 | 2417 | −0.6 | 2.1 | 2041 | −0.3 | 1.9 | 85-70 |
| 989 | −0.3 | 1.0 | 3418 | 0.1 | 1.5 | 2390 | −0.2 | 1.7 | 2020 | −0.4 | 1.6 | 70-50 |
| 985 | −0.5 | 1.4 | 3403 | 0.1 | 1.9 | 2367 | 0 | 1.9 | 2003 | −0.6 | 2.0 | 50-40 |
| 986 | −0.8 | 1.7 | 3381 | 0.1 | 1.9 | 2352 | 0.2 | 2.0 | 1998 | −0.4 | 2.0 | 40-30 |
| 994 | −0.9 | 1.8 | 3381 | −0.1 | 2.1 | 2364 | 0.5 | 2.7 | 2002 | −0.1 | 2.3 | 30-25 |
| 983 | −0.4 | 1.9 | 3400 | 0.1 | 2.2 | 2393 | 0.6 | 2.5 | 2016 | 0.2 | 2.5 | 25-20 |
| 985 | 0.3 | 1.8 | 3422 | 0 | 2.2 | 2396 | −0.3 | 2.2 | 2018 | −0.6 | 2.4 | 20-15 |
| 981 | 0.4 | 2.0 | 3427 | −0.2 | 1.9 | 2390 | −0.4 | 1.9 | 2015 | −0.4 | 1.8 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 1138 | 0.4 | 2.3 | 1251 | 0.3 | 2.7 | 1282 | 0.4 | 2.2 | 100-85 |
| | | | 2874 | −0.1 | 1.8 | 3288 | −0.3 | 2.1 | 3651 | 0 | 1.7 | 85-70 |
| | | | 2844 | 0.1 | 1.4 | 3239 | −0.2 | 1.8 | 3603 | −0.2 | 1.6 | 70-50 |
| | | | 2833 | 0.1 | 1.7 | 3226 | −0.2 | 2.0 | 3585 | −0.5 | 2.0 | 50-40 |
| | | | 2814 | 0.1 | 1.8 | 3193 | 0 | 2.1 | 3565 | −0.5 | 2.1 | 40-30 |
| | | | 2815 | −0.1 | 2.2 | 3189 | 0.5 | 2.9 | 3576 | −0.3 | 2.4 | 30-25 |
| | | | 2828 | 0.1 | 2.1 | 3208 | 0.6 | 3.2 | 3597 | −0.2 | 2.9 | 25-20 |
| | | | 2843 | −0.1 | 2.1 | 3242 | −0.2 | 2.9 | 3625 | −0.9 | 2.8 | 20-15 |
| | | | 2857 | −0.4 | 1.9 | 3260 | −0.4 | 2.1 | 3614 | −0.7 | 2.0 | 15-10 |

*Cloudy*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| 137 | 2.8 | 3.9 | 535 | −0.5 | 3.6 | 507 | −1.4 | 4.0 | 527 | 0.1 | 3.8 | 100-85 |
| 293 | −1.0 | 2.7 | 1488 | −0.1 | 2.7 | 1333 | −0.9 | 3.0 | 1388 | −0.3 | 2.7 | 85-70 |
| 289 | −0.9 | 1.7 | 1475 | 0.1 | 2.0 | 1322 | −0.4 | 2.2 | 1374 | −0.4 | 1.9 | 70-50 |
| 289 | −1.3 | 2.3 | 1469 | −0.2 | 2.5 | 1325 | −0.2 | 2.4 | 1378 | −0.8 | 2.6 | 50-40 |
| 291 | −1.6 | 2.6 | 1457 | −0.3 | 2.6 | 1311 | 0.2 | 2.5 | 1355 | −0.9 | 2.8 | 40-30 |
| 293 | −1.0 | 2.8 | 1457 | −0.2 | 2.8 | 1305 | 0.8 | 3.1 | 1352 | −0.6 | 3.2 | 30-25 |
| 291 | 0.7 | 2.6 | 1472 | 0.2 | 2.5 | 1311 | 1.0 | 2.9 | 1364 | −0.1 | 3.0 | 25-20 |
| 287 | 0.5 | 2.2 | 1474 | 0.4 | 2.3 | 1314 | 0 | 2.3 | 1381 | −0.3 | 2.5 | 20-15 |
| 282 | −0.5 | 1.9 | 1473 | 0.1 | 1.9 | 1314 | −0.3 | 1.9 | 1374 | −0.3 | 1.8 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 371 | 0.3 | 3.5 | 588 | −0.8 | 4.1 | 559 | 1.5 | 4.0 | 100-85 |
| | | | 908 | 0.2 | 2.7 | 1593 | 0 | 3.3 | 1493 | 0.6 | 3.0 | 85-70 |
| | | | 902 | 0.1 | 2.0 | 1588 | 0.3 | 2.4 | 1484 | 0 | 2.0 | 70-50 |
| | | | 891 | −0.4 | 2.3 | 1583 | 0.1 | 2.4 | 1480 | −0.8 | 2.6 | 50-40 |
| | | | 884 | −0.5 | 2.6 | 1566 | 0 | 2.6 | 1465 | −1.4 | 3.2 | 40-30 |
| | | | 887 | −0.3 | 2.9 | 1564 | 0.2 | 3.4 | 1451 | −1.6 | 3.7 | 30-25 |
| | | | 893 | 0.3 | 2.4 | 1570 | 0 | 3.6 | 1454 | −1.3 | 3.6 | 25-20 |
| | | | 896 | −0.4 | 2.2 | 1590 | −0.8 | 2.8 | 1487 | −1.2 | 2.9 | 20-15 |
| | | | 899 | −0.1 | 2.0 | 1580 | −0.7 | 2.0 | 1477 | −0.7 | 1.9 | 15-10 |

* Seasons defined as in text.

tect small-scale vertical structures, i.e., low-level inversions near the surface and upper-level inversions near the tropopause.

For the fall season, also, the mean differences are small for both clear and cloudy soundings, although the RMS and mean differences of the cloudy soundings are greater than those of the clear retrievals. RMS differences for both clear and cloudy conditions

30°N–30°S

TABLE 3. Satellite-radiosonde differences*.

*Clear*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| | | | 1708 | 0.2 | 1.9 | 1355 | −0.4 | 2.1 | 1060 | −0.2 | 1.9 | 100-85 |
| | | | 3334 | 0.2 | 1.8 | 2706 | −0.1 | 1.9 | 2098 | −0.1 | 1.7 | 85-70 |
| | | | 3298 | −0.1 | 1.3 | 2665 | −0.1 | 1.4 | 2059 | −0.1 | 1.3 | 70-50 |
| | | | 3290 | −0.1 | 1.6 | 2578 | 0.1 | 1.7 | 2020 | −0.2 | 1.6 | 50-40 |
| | | | 3227 | −0.1 | 1.6 | 2551 | 0.1 | 1.8 | 2018 | −0.1 | 1.7 | 40-30 |
| | | | 3212 | −0.1 | 1.7 | 2547 | −0.2 | 2.2 | 1997 | −0.1 | 1.9 | 30-25 |
| | | | 3201 | 0 | 1.7 | 2557 | −0.3 | 2.0 | 1960 | −0.1 | 1.9 | 25-20 |
| | | | 3229 | 0 | 1.9 | 2628 | −0.2 | 1.9 | 2022 | −0.1 | 2.1 | 20-15 |
| | | | 3239 | 0 | 2.2 | 2610 | −0.1 | 2.2 | 2027 | −0.1 | 2.3 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 1156 | 0.2 | 1.8 | 1123 | 0.3 | 2.5 | 1226 | 0.1 | 1.9 | 100-85 |
| | | | 2410 | 0.2 | 1.7 | 2785 | −0.1 | 2.0 | 2800 | 0 | 1.7 | 85-70 |
| | | | 2393 | 0 | 1.3 | 2747 | 0.1 | 1.5 | 2762 | 0.1 | 1.4 | 70-50 |
| | | | 2383 | −0.1 | 1.5 | 2655 | 0.3 | 1.8 | 2717 | −0.1 | 1.6 | 50-40 |
| | | | 2340 | 0.1 | 1.6 | 2664 | 0.1 | 1.9 | 2713 | −0.1 | 1.7 | 40-30 |
| | | | 2333 | 0.1 | 1.8 | 2716 | −0.3 | 2.1 | 2722 | −0.1 | 2.1 | 30-25 |
| | | | 2333 | 0.1 | 1.7 | 2690 | −0.5 | 2.3 | 2690 | −0.1 | 2.2 | 25-20 |
| | | | 2369 | 0.1 | 1.9 | 2704 | −0.3 | 2.3 | 2713 | −0.1 | 2.2 | 20-15 |
| | | | 2365 | −0.1 | 2.2 | 2701 | −0.1 | 2.3 | 2701 | −0.2 | 2.3 | 15-10 |

*Cloudy*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| | | | 636 | −1.1 | 3.0 | 492 | −0.7 | 3.4 | 486 | 0.5 | 2.9 | 100-85 |
| | | | 1175 | −0.8 | 2.8 | 822 | −0.9 | 3.2 | 828 | 0 | 2.5 | 85-70 |
| | | | 1159 | −0.6 | 1.5 | 820 | −0.7 | 1.7 | 810 | −0.6 | 1.5 | 70-50 |
| | | | 1142 | −0.9 | 2.0 | 812 | −0.7 | 2.1 | 791 | −0.9 | 1.9 | 50-40 |
| | | | 1134 | −1.3 | 2.2 | 800 | −0.8 | 2.5 | 797 | −1.1 | 2.3 | 40-30 |
| | | | 1070 | −1.4 | 2.5 | 788 | −0.8 | 2.7 | 787 | −1.2 | 2.5 | 30-25 |
| | | | 1072 | −0.9 | 2.2 | 788 | −0.6 | 2.3 | 786 | −0.8 | 2.5 | 25-20 |
| | | | 1146 | −0.3 | 2.1 | 815 | −0.1 | 2.0 | 811 | −0.1 | 2.5 | 20-15 |
| | | | 1154 | 0.5 | 2.3 | 805 | 0.5 | 2.2 | 808 | 0.3 | 2.4 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 335 | −1.5 | 3.6 | 667 | 0.8 | 3.5 | 729 | 1.2 | 3.4 | 100-85 |
| | | | 712 | −1.0 | 2.9 | 1084 | 0.5 | 3.2 | 1309 | 0.7 | 2.8 | 85-70 |
| | | | 707 | −0.2 | 1.6 | 1085 | 0.1 | 2.0 | 1285 | −0.1 | 1.5 | 70-50 |
| | | | 698 | −0.1 | 2.1 | 1068 | −0.6 | 2.3 | 1270 | −0.8 | 2.0 | 50-40 |
| | | | 682 | −0.3 | 2.0 | 1054 | −1.4 | 2.9 | 1282 | −1.2 | 2.4 | 40-30 |
| | | | 668 | −0.2 | 2.1 | 1051 | −1.9 | 3.6 | 1273 | −1.4 | 2.8 | 30-25 |
| | | | 676 | 0.1 | 2.0 | 1054 | −1.9 | 3.3 | 1273 | −1.2 | 2.7 | 25-20 |
| | | | 709 | 0.3 | 2.0 | 1084 | −1.0 | 2.4 | 1292 | −0.6 | 2.3 | 20-15 |
| | | | 701 | 0.4 | 2.4 | 1067 | 0.4 | 2.2 | 1285 | 0 | 2.2 | 15-10 |

* Seasons defined as in text.

are greater than those of summer. Note also the close agreement in RMS difference between the NOAA-6 and TIROS-N satellites. This is an indication of the consistency of the two systems.

During the winter (Table 2) there is still further growth of both mean and RMS differences. Mean differences, however, are still less than 1 K in magnitude for both TIROS-N and NOAA-6 clear and cloudy conditions.

Root mean square differences for clear retrievals

30-60°S

TABLE 4. Satellite-radiosonde differences*.

*Clear*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| | | | 883 | −0.5 | 2.8 | 576 | −0.1 | 3.3 | 502 | −0.4 | 2.7 | 100-85 |
| | | | 1679 | 0 | 2.4 | 1275 | 0.1 | 2.6 | 879 | 0.2 | 2.2 | 85-70 |
| | | | 1620 | 0.1 | 1.9 | 1242 | −0.2 | 2.0 | 852 | 0.1 | 1.7 | 70-50 |
| | | | 1624 | 0.1 | 2.1 | 1234 | −0.3 | 2.1 | 836 | 0.1 | 1.9 | 50-40 |
| | | | 1607 | 0.3 | 2.2 | 1206 | −0.1 | 2.1 | 832 | −0.1 | 1.9 | 40-30 |
| | | | 1584 | 0.6 | 2.4 | 1219 | 0.3 | 2.2 | 834 | 0.1 | 2.1 | 30-25 |
| | | | 1633 | 0.8 | 2.7 | 1226 | 0.6 | 2.4 | 852 | 0.6 | 2.3 | 25-20 |
| | | | 1631 | −0.1 | 2.4 | 1218 | 0.2 | 2.5 | 844 | 0.1 | 2.4 | 20-15 |
| | | | 1505 | −0.3 | 2.1 | 1136 | −0.1 | 2.3 | 813 | −0.1 | 2.0 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 657 | 0.2 | 2.5 | 865 | 0.3 | 2.9 | 731 | 0.1 | 2.5 | 100-85 |
| | | | 1257 | 0.2 | 2.3 | 1890 | 0.3 | 2.4 | 1468 | 0.4 | 2.2 | 85-70 |
| | | | 1199 | 0 | 1.9 | 1845 | 0.2 | 1.8 | 1412 | 0.4 | 1.8 | 70-50 |
| | | | 1205 | −0.1 | 2.2 | 1819 | 0.3 | 2.0 | 1388 | 0.4 | 1.9 | 50-40 |
| | | | 1218 | 0 | 2.1 | 1799 | 0.3 | 2.0 | 1396 | 0.1 | 1.8 | 40-30 |
| | | | 1200 | 0.6 | 2.4 | 1813 | 0.2 | 2.2 | 1400 | 0.3 | 2.1 | 30-25 |
| | | | 1226 | 0.7 | 2.4 | 1805 | 0.1 | 2.3 | 1424 | 0.5 | 2.4 | 25-20 |
| | | | 1225 | −0.1 | 2.3 | 1798 | −0.6 | 2.6 | 1410 | 0.1 | 2.5 | 20-15 |
| | | | 1100 | −0.2 | 2.1 | 1691 | −0.4 | 2.4 | 1356 | 0 | 2.1 | 15-10 |

*Cloudy*

| Summer 79 | | | Fall 79 | | | Winter 79 | | | Spring 80 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | *N* | Mean | RMS | Layer (cb) |
| TIROS-N | | | | | | | | | | | | |
| | | | 364 | 0.4 | 3.3 | 245 | 0.9 | 3.4 | 212 | −0.2 | 3.1 | 100-85 |
| | | | 708 | −0.6 | 2.7 | 622 | −0.7 | 2.9 | 397 | −0.3 | 2.9 | 85-70 |
| | | | 685 | −0.8 | 2.4 | 600 | −1.3 | 2.5 | 369 | −0.4 | 2.2 | 70-50 |
| | | | 688 | −1.1 | 2.7 | 600 | −1.6 | 3.0 | 361 | −0.7 | 2.4 | 50-40 |
| | | | 689 | −0.8 | 2.5 | 572 | −1.3 | 2.8 | 367 | −1.0 | 2.5 | 40-30 |
| | | | 676 | 0 | 2.7 | 577 | 0 | 2.5 | 366 | −0.7 | 2.7 | 30-25 |
| | | | 681 | 1.2 | 3.2 | 566 | 0.8 | 2.5 | 394 | 0.1 | 2.8 | 25-20 |
| | | | 682 | 0.3 | 2.4 | 588 | 0.4 | 2.5 | 392 | 0.2 | 2.6 | 20-15 |
| | | | 644 | −0.1 | 2.2 | 574 | 0.1 | 2.3 | 366 | 0.1 | 2.5 | 15-10 |
| NOAA-6 | | | | | | | | | | | | |
| | | | 291 | 0.5 | 3.8 | 381 | 1.3 | 3.5 | 407 | 0 | 3.7 | 100-85 |
| | | | 553 | −0.4 | 2.8 | 794 | 0.1 | 3.0 | 715 | −0.2 | 3.2 | 85-70 |
| | | | 526 | −0.7 | 2.3 | 781 | −0.3 | 2.3 | 688 | −0.4 | 2.4 | 70-50 |
| | | | 537 | −1.0 | 2.6 | 800 | −0.6 | 2.6 | 670 | −0.9 | 2.4 | 50-40 |
| | | | 541 | −0.6 | 2.5 | 758 | −1.1 | 2.7 | 671 | −1.1 | 2.5 | 40-30 |
| | | | 527 | 0.2 | 2.5 | 760 | −1.0 | 3.0 | 671 | −0.8 | 2.8 | 30-25 |
| | | | 556 | 1.1 | 2.8 | 763 | −0.9 | 3.1 | 701 | 0.1 | 2.9 | 25-20 |
| | | | 553 | 0.1 | 2.4 | 766 | −0.9 | 3.0 | 701 | −0.1 | 3.0 | 20-15 |
| | | | 516 | −0.5 | 2.2 | 734 | −0.3 | 2.6 | 666 | 0 | 2.3 | 15-10 |

* Seasons defined as in text.

are generally greater than 2 K except in the 500–700 mb layer. For cloudy conditions RMS differences range from 1.9 to 4.1 K. During this period the RMS differences in the 200–300 mb layer for NOAA-6 show a significant increase (~0.7 K) compared to TIROS-N. At higher pressures the RMS differences for TIROS-N and NOAA-6 are quite close, as they were throughout the troposphere for the fall season. This increase in RMS difference is attributed to the elimination of MSU Channel 3 from the retrieval

TABLE 5. TIROS N-Spring 1980. Vertical correlation: satellite-radiosonde differences*.

| | 30-60°N | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 85 | 85 70 | 70 50 | 50 40 | 40 30 | 30 25 | 25 20 | 20 15 | 15 10 |
| *Clear* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.41 | 1.00 | | | | | | | |
| 70-50 | −0.21 | 0.25 | 1.00 | | | | | | |
| 50-40 | −0.19 | −0.07 | 0.56 | 1.00 | | | | | |
| 40-30 | −0.11 | −0.14 | 0.21 | 0.60 | 1.00 | | | | |
| 30-25 | 0.07 | −0.06 | −0.15 | 0.05 | 0.48 | 1.00 | | | |
| 25-20 | 0.12 | 0.04 | −0.19 | −0.23 | −0.10 | 0.38 | 1.00 | | |
| 20-15 | 0.15 | 0.16 | −0.02 | −0.20 | −0.33 | −0.18 | 0.41 | 1.00 | |
| 15-10 | 0.11 | 0.14 | 0.06 | −0.04 | −0.17 | −0.22 | −0.03 | 0.45 | 1.00 |
| *Cloudy* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.61 | 1.00 | | | | | | | |
| 70-50 | −0.15 | 0.35 | 1.00 | | | | | | |
| 50-40 | −0.47 | −0.20 | 0.60 | 1.00 | | | | | |
| 40-30 | −0.48 | −0.37 | 0.18 | 0.67 | 1.00 | | | | |
| 30-25 | −0.25 | −0.32 | −0.23 | 0.11 | 0.60 | 1.00 | | | |
| 25-20 | 0.06 | −0.15 | −0.34 | −0.24 | −0.01 | 0.49 | 1.00 | | |
| 20-15 | 0.24 | 0.09 | −0.10 | −0.28 | −0.39 | −0.21 | 0.38 | 1.00 | |
| 15-10 | 0.17 | 0.16 | 0.05 | −0.10 | −0.28 | −0.30 | −0.13 | 0.36 | 1.00 |

| | 30°N-30°S | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 85 | 85 70 | 70 50 | 50 40 | 40 30 | 30 25 | 25 20 | 20 15 | 15 10 |
| *Clear* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.52 | 1.00 | | | | | | | |
| 70-50 | −0.03 | 0.21 | 1.00 | | | | | | |
| 50-40 | −0.06 | 0.03 | 0.48 | 1.00 | | | | | |
| 40-30 | −0.07 | 0.07 | 0.32 | 0.55 | 1.00 | | | | |
| 30-25 | 0.00 | 0.09 | 0.17 | 0.27 | 0.62 | 1.00 | | | |
| 25-20 | 0.03 | 0.10 | 0.12 | 0.15 | 0.33 | 0.60 | 1.00 | | |
| 20-15 | 0.06 | 0.09 | 0.14 | 0.12 | 0.07 | 0.16 | 0.51 | 1.00 | |
| 15-10 | −0.03 | 0.13 | 0.17 | 0.12 | −0.04 | −0.08 | 0.08 | 0.57 | 1.00 |
| *Cloudy* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.70 | 1.00 | | | | | | | |
| 70-50 | 0.15 | 0.38 | 1.00 | | | | | | |
| 50-40 | −0.09 | 0.10 | 0.51 | 1.00 | | | | | |
| 40-30 | −0.08 | 0 | 0.25 | 0.60 | 1.00 | | | | |
| 30-25 | −0.11 | −0.18 | 0.11 | 0.36 | 0.70 | 1.00 | | | |
| 25-20 | −0.10 | −0.22 | 0.01 | 0.19 | 0.41 | 0.66 | 1.00 | | |
| 20-15 | −0.05 | −0.12 | 0.04 | 0.07 | 0.01 | 0.14 | 0.54 | 1.00 | |
| 15-10 | −0.14 | 0.02 | −0.01 | −0.07 | −0.17 | −0.19 | 0.03 | 0.50 | 1.00 |

| | 30-60°S | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 85 | 85 70 | 70 50 | 50 40 | 40 30 | 30 25 | 25 20 | 20 15 | 15 10 |
| *Clear* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.63 | 1.00 | | | | | | | |
| 70-50 | 0.16 | 0.55 | 1.00 | | | | | | |
| 50-40 | 0.07 | 0.36 | 0.75 | 1.00 | | | | | |
| 40-30 | 0.11 | 0.29 | 0.60 | 0.76 | 1.00 | | | | |
| 30-25 | 0.11 | 0.19 | 0.44 | 0.48 | 0.67 | 1.00 | | | |
| 25-20 | 0.20 | 0.10 | 0.08 | 0.01 | 0.13 | 0.42 | 1.00 | | |
| 20-15 | 0.13 | 0.00 | −0.17 | −0.29 | −0.26 | −0.16 | 0.48 | 1.00 | |
| 15-10 | 0.10 | 0.06 | −0.06 | −0.19 | −0.23 | −0.14 | 0.19 | 0.54 | 1.00 |
| *Cloudy* | | | | | | | | | |
| 100-85 | 1.00 | | | | | | | | |
| 85-70 | 0.66 | 1.00 | | | | | | | |
| 70-50 | 0.31 | 0.55 | 1.00 | | | | | | |
| 50-40 | 0.01 | 0.26 | 0.72 | 1.00 | | | | | |
| 40-30 | −0.03 | 0.10 | 0.44 | 0.76 | 1.00 | | | | |
| 30-25 | −0.09 | −0.04 | 0.12 | 0.37 | 0.69 | 1.00 | | | |
| 25-20 | 0.00 | −0.08 | −0.27 | −0.08 | 0.13 | 0.61 | 1.00 | | |
| 20-15 | 0.10 | −0.22 | −0.36 | −0.30 | −0.33 | −0.09 | 0.40 | 1.00 | |
| 15-10 | −0.13 | −0.21 | −0.30 | −0.23 | −0.27 | −0.12 | 0.09 | 0.58 | 1.00 |

[1] Seasons defined as in text.

process early in December 1979 because its quality was rapidly deteriorating. This channel, which peaks near 250 mb, affects both the clear and cloudy retrievals by about the same amount. This characteristic is also evident in each of the other zones. Following removal, Channel 3 quality improved sufficiently so that the channel was restored to service in NOAA-6 in July 1980.

The spring season (Table 2) is similar to the winter season. Biases in the clear soundings remain relatively high and are mostly cold. Cloudy soundings for NOAA-6 exhibit some of the highest biases, exceeding 1.5 K in the 250–300 mb layer. However, this may be related to the lack of MSU Channel 3. As summer approaches, the RMS values are somewhat smaller than during the winter season.

### 2) 30°N–30°S

Table 3 represents the statistical summaries for the 30°N–30°S latitude zone. A seasonal variability in the RMS differences is in evidence although it is generally smaller than the variability found in midlatitudes. This reflects the relatively small variability found in the tropics. For clear conditions, TIROS-N and NOAA-6 the biases are generally less than ±0.5 K for all seasons. RMS differences are largest in winter and range from 1.4 to 2.4 K and smallest in fall when the RMS values are generally less than 2 K.

Higher RMS differences and considerably higher mean differences are found under cloudy conditions in the 30–60°N latitude zone. RMS differences are generally between 2 and 3 K except for the lowest atmospheric layers (1000–850 mb, 850–700 mb) where RMS differences generally exceed 3K. The rainfall contamination, which would be expected to be large in this zone, may be partly responsible for the generally large cold bias of the cloudy retrievals.

### 3) 30°S–60°S

Table 4 presents a set of statistical information for the latitude zone 30–60 S. As for the other latitude zones, clear retrievals have smaller mean and RMS differences than the cloudy retrievals. It is interesting to note that in contrast to the 30–60°N latitude zone the Southern Hemisphere's summer season exhibits larger RMS differences than the other seasons. The larger Southern Hemisphere summer RMS differences run contrary to our expectations that a summer atmosphere should exhibit smallest variability hence lowest RMS differences. We cannot explain this result.

### 4) DISCUSSION

These collocated statistical comparisons reveal a characteristic that is common to all latitude zones: the tendency for the mean and RMS differences to be smaller for the clear conditions than for cloudy conditions. Reasons for this were offered in the discussion of the results for the 30–60°N latitude zone. There were larger differences in the 1000–850 mb layer and near the tropopause region than in the middle troposphere. This represents an inability of the sounding system to accurately detect inversions, both near the earth's surface as well as those associated with the tropopause.

Of all the periods studied, the largest RMS differences occurred in the December–February period for both hemispheres. This was consistent with our expectations for the Northern Hemisphere since it is the season of greatest atmospheric variability, but was contrary to our expectations in the Southern Hemisphere. These statistical comparisons include the error in the radiosonde so that the retrieval errors can be expected to be less than the RMS differences. For all seasons and for the three zones the maximum RMS differences usually occur in the 1000–850 mb layer and that the smallest RMS differences are generally present in the 700–500 mb layer. This is probably related to the weighting function distribution which is rather good at the 700–500 mb layer, where several long- and short-wave channels peak in this area (Smith *et al.*, 1979).

Before leaving this section it should be pointed out that because the sample sizes are large the degrees of freedom are also large and consequently differences are small as 0.1 and 0.2 calculated within categories as well as between categories, e.g., between cloudy and clear, are usually statistically significant. Thus the important points to emphasize are the underlying causes of the differences, especially if they exhibit systematic patterns. In most cases we have been able to offer physically reasonable explanations of the calculated differences and in a few cases we were unable to do so. These comments are also applicable to the sections that follow.

## *b. Vertical correlations, variance ratios and land minus sea differences*

In addition to the mean and RMS differences between retrievals and radiosondes, we have calculated other statistical measures of retrieval accuracy. These are the vertical correlations of the retrieval differences, the ratio of the retrieval to radiosonde mean layer temperature variances, and the land minus sea differences found in Tables 5, 6 and 7, respectively. These tabulations should be useful in statistical objective analysis procedures. In general, TIROS-N and NOAA-6 results were similar, so only TIROS-N results will be shown.

### 1) VERTICAL CORRELATIONS

Vertical correlations of retrieval error were calculated for each latitude zone. We will show only vertical correlations for TIROS-N for the spring season. The results shown in Table 5 are quite similar to those reported by Phillips *et al.* (1979) for March–

April 1979; that is, correlations that are high in adjacent layers decrease away from those levels and often become negative. These results are also consistent with an earlier study on Nimbus-6 retrievals performed by Schlatter and Branstator (1979) and the study on TIROS-N data by Schlatter (1981).

### 2) RATIO OF VARIANCES

The ratio of variance of the satellite retrieval to the radiosonde for TIROS-N was first reported by Phillips *et al.* (1979) for the periods 30 January–28 February 1979 and 29 March–27 April 1979. Their computations covered selected stations in the midlatitudes of the Northern and Southern Hemispheres and the tropics, as well as mostly clear and mostly cloudy conditions. Unfortunately, sample sizes were relatively small in the Northern Hemisphere midlatitudes, and varied from ~6 in cloudy situations to 98 during clear conditions. This computation provides a rough measure of the loss of amplitude in the wave patterns noted in the impact studies by Tracton *et al.* (1980) using Nimbus-6 data.

Table 6 shows the ratio of variances for the 30–60°N, 30°N–30°S, 30–60°S, latitude zones for TIROS-N for the seasons defined in Table 2. In the midlatitudes of both hemispheres this ratio is frequently in excess of 0.9 for the low and middle tro-

TABLE 6. Variance ratio, satellite/radiosonde, TIROS *N**.

| 30–60°N | Fall | | | | Winter | | | | Spring | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clear | | Cloudy | | Clear | | Cloudy | | Clear | | Cloudy | |
| Layer (cb) | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio |
| 100-85 | 1390 | 0.88 | 535 | 1.00 | 917 | 1.01 | 507 | 0.93 | 760 | 0.98 | 527 | 1.33 |
| 85-70 | 3463 | 0.94 | 1488 | 0.90 | 2417 | 0.98 | 1333 | 0.84 | 2041 | 0.97 | 1388 | 0.99 |
| 70-50 | 3418 | 0.95 | 1475 | 0.90 | 2390 | 0.92 | 1322 | 0.82 | 2020 | 0.95 | 1374 | 0.86 |
| 50-40 | 3403 | 0.95 | 1469 | 0.82 | 2367 | 0.90 | 1325 | 0.77 | 2003 | 0.94 | 1378 | 0.72 |
| 40-30 | 3381 | 0.95 | 1457 | 0.82 | 2352 | 0.94 | 1311 | 0.82 | 1998 | 0.92 | 1355 | 0.65 |
| 30-25 | 3381 | 0.90 | 1457 | 0.87 | 2364 | 0.83 | 1305 | 0.81 | 2002 | 0.83 | 1352 | 0.59 |
| 25-20 | 3400 | 0.74 | 1472 | 0.78 | 2393 | 0.75 | 1311 | 0.74 | 2016 | 0.60 | 1364 | 0.61 |
| 20-15 | 3422 | 0.65 | 1474 | 0.69 | 2396 | 0.89 | 1314 | 0.90 | 2018 | 0.65 | 1381 | 0.63 |
| 15-10 | 3427 | 0.96 | 1473 | 0.88 | 2390 | 0.99 | 1314 | 0.95 | 2015 | 0.87 | 1374 | 0.88 |

| 30°N–30°S | Fall | | | | Winter | | | | Spring | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clear | | Cloudy | | Clear | | Cloudy | | Clear | | Cloudy | |
| Layer (cb) | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio |
| 100-85 | 1708 | 0.74 | 636 | 0.60 | 1355 | 0.85 | 492 | 0.63 | 1060 | 0.77 | 486 | 0.83 |
| 85-70 | 3334 | 0.73 | 1175 | 0.50 | 2706 | 0.94 | 822 | 0.66 | 2098 | 0.79 | 828 | 0.87 |
| 70-50 | 3298 | 0.81 | 1159 | 0.85 | 2665 | 0.87 | 820 | 0.88 | 2059 | 0.85 | 810 | 0.90 |
| 50-40 | 3290 | 0.76 | 1142 | 0.99 | 2578 | 0.80 | 812 | 0.96 | 2020 | 0.77 | 791 | 0.88 |
| 40-30 | 3227 | 0.82 | 1134 | 0.90 | 2551 | 0.73 | 800 | 0.81 | 2018 | 0.75 | 797 | 0.77 |
| 30-25 | 3212 | 0.82 | 1070 | 0.68 | 2547 | 0.65 | 788 | 0.59 | 1997 | 0.73 | 787 | 0.72 |
| 25-20 | 3201 | 0.70 | 1072 | 0.53 | 2557 | 0.59 | 788 | 0.52 | 1960 | 0.60 | 786 | 0.57 |
| 20-15 | 3229 | 0.47 | 1146 | 0.86 | 2628 | 0.57 | 815 | 0.85 | 2022 | 0.33 | 811 | 0.63 |
| 15-10 | 3239 | 0.69 | 1154 | 0.77 | 2610 | 0.80 | 805 | 0.88 | 2027 | 0.71 | 808 | 0.81 |

| 30–60°S | Fall | | | | Winter | | | | Spring | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clear | | Cloudy | | Clear | | Cloudy | | Clear | | Cloudy | |
| Layer (cb) | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio | No. obs. | Var. ratio |
| 100-85 | 883 | 0.80 | 364 | 0.80 | 576 | 0.62 | 245 | 0.76 | 502 | 0.71 | 212 | 0.91 |
| 85-70 | 1679 | 1.00 | 708 | 0.82 | 1275 | 1.00 | 622 | 0.92 | 879 | 0.92 | 397 | 0.84 |
| 70-50 | 1620 | 0.96 | 685 | 0.84 | 1242 | 1.01 | 600 | 0.96 | 852 | 0.93 | 369 | 0.86 |
| 50-40 | 1624 | 0.92 | 688 | 0.82 | 1234 | 1.00 | 600 | 0.81 | 836 | 0.86 | 361 | 0.81 |
| 40-30 | 1607 | 0.79 | 689 | 0.79 | 1206 | 0.98 | 572 | 0.75 | 832 | 0.83 | 367 | 0.75 |
| 30-25 | 1584 | 0.72 | 676 | 0.81 | 1219 | 1.00 | 577 | 0.75 | 834 | 0.72 | 366 | 0.65 |
| 25-20 | 1633 | 0.54 | 681 | 0.72 | 1226 | 0.68 | 566 | 0.73 | 852 | 0.60 | 394 | 0.52 |
| 20-15 | 1631 | 0.71 | 682 | 0.81 | 1218 | 0.73 | 588 | 0.65 | 844 | 0.53 | 392 | 0.62 |
| 15-10 | 1505 | 0.91 | 644 | 0.93 | 1136 | 0.93 | 574 | 0.84 | 813 | 0.89 | 366 | 0.75 |

* Seasons defined as in text.

TABLE 7. Land minus ocean TIROS-N 30–60°N.

| | Clear | | | | | Cloudy | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number of observations | | | | | Number of observations | | | |
| Layer (cb) | Land | Ocean | Mean | RMS | Layer (cb) | Land | Ocean | Mean | RMS |
| | | | | *Fall* | | | | | |
| 100-85 | 646 | 223 | −1.0 | 0 | 100-85 | 159 | 169 | 0.7 | 0.1 |
| 85-70 | 2317 | 308 | −0.7 | −0.1 | 85-70 | 840 | 323 | −0.6 | 0.2 |
| 70-50 | 2292 | 295 | −0.1 | −0.2 | 70-50 | 832 | 322 | −0.9 | −0.2 |
| 50-40 | 2276 | 302 | 0.2 | −0.2 | 50-40 | 824 | 327 | −0.8 | −0.2 |
| 40-30 | 2247 | 306 | 0.6 | −0.2 | 40-30 | 823 | 322 | 0.1 | −0.1 |
| 30-25 | 2248 | 306 | 0.8 | −0.2 | 30-25 | 824 | 323 | 0.6 | 0.1 |
| 25-20 | 2261 | 306 | 0.7 | −0.4 | 25-20 | 824 | 327 | 1.1 | −0.2 |
| 20-15 | 2285 | 304 | 0 | −0.1 | 20-15 | 832 | 322 | 0.4 | 0 |
| 15-10 | 2293 | 306 | −0.2 | 0.3 | 15-10 | 830 | 323 | 0.4 | 0.1 |
| | | | | *Winter* | | | | | |
| 100-85 | 484 | 90 | −1.5 | 0.3 | 100-85 | 141 | 177 | 0.4 | −0.2 |
| 85-70 | 1750 | 126 | −1.0 | 0.3 | 85-70 | 654 | 352 | −1.4 | −0.2 |
| 70-50 | 1726 | 126 | −0.4 | −0.3 | 70-50 | 653 | 343 | −1.4 | −0.2 |
| 50-40 | 1704 | 123 | 0.1 | −0.2 | 50-40 | 651 | 347 | −1.2 | −0.4 |
| 40-30 | 1688 | 123 | 0.7 | −0.1 | 40-30 | 641 | 341 | −0.1 | −0.2 |
| 30-25 | 1698 | 124 | 0.5 | −0.3 | 30-25 | 643 | 340 | −1.0 | 0.5 |
| 25-20 | 1728 | 123 | −0.5 | −0.6 | 25-20 | 642 | 348 | −0.7 | 0.4 |
| 20-15 | 1731 | 121 | −0.2 | −0.3 | 20-15 | 643 | 348 | 0 | 0.2 |
| 15-10 | 1732 | 119 | −0.3 | −0.3 | 15-10 | 646 | 341 | 0 | 0.1 |
| | | | | *Spring* | | | | | |
| 100-85 | 358 | 143 | −0.9 | 0.2 | 100-85 | 127 | 202 | −1.4 | 0.2 |
| 85-70 | 1409 | 189 | −0.4 | 0.1 | 85-70 | 729 | 335 | −1.1 | 0.4 |
| 70-50 | 1389 | 187 | −0.1 | 0.1 | 70-50 | 718 | 333 | −0.9 | 0 |
| 50-40 | 1374 | 186 | 0.2 | −0.4 | 50-40 | 722 | 331 | −0.7 | −0.1 |
| 40-30 | 1374 | 183 | 0.5 | −0.6 | 40-30 | 718 | 321 | −0.3 | −0.3 |
| 30-25 | 1378 | 187 | 0.7 | 0 | 30-25 | 717 | 321 | 0.7 | −0.2 |
| 25-20 | 1393 | 187 | 0.4 | −0.1 | 25-20 | 718 | 327 | 1.0 | −0.1 |
| 20-15 | 1391 | 186 | −0.7 | 0 | 20-15 | 727 | 333 | 0.3 | 0.1 |
| 15-10 | 1388 | 186 | −0.8 | 0.1 | 15-10 | 725 | 328 | 0.2 | 0.3 |

posphere for clear retrievals, and decreases to a minimum at approximately tropopause heights. The 30°N–30°S latitude zone has the smallest ratio of the three zones and rarely exceeds 0.9. This indicates that although the RMS differences were small, the retrieval system is somewhat insensitive to the relatively small variability found in the tropics.

Under cloudy conditions the variance ratios are generally smaller than under clear conditions although there are exceptions to this. Occasional ratios far in excess of 1.0 suggest erroneous or excessively noisy data and may result from the difficulties encountered for cloudy retrievals. These variance ratios are somewhat higher in the 30–60°N and 30–60°S zones and lower in the 30°N–30°S zone than the results reported by Phillips *et al.* (1979).

### 3) LAND MINUS OCEAN DIFFERENCES

Phillips *et al.* (1979) suggest in their evaluation of early TIROS-N soundings that biases in oceanic cloudy retrievals in the Nothern Hemisphere extratropics were influenced by a two-fold meteorological bias in the NESS collocation data base of radiosondes from which the regression coefficients were derived. The first is domination by continental radiosondes; the second is acceptance of only clear radiance values for the coefficient data base. Therefore, the cloudy retrievals are based on a sample that is dominated by continental radiosondes and is for essentially cloud-free conditions. The clear and partly cloudy retrievals are also dominated by continental soundings; however, since they use infrared channels in addition to microwave information, surface temperatures are implicitly incorporated into those retrievals. The continental influence in those retrievals is therefore reduced.

We have examined this characteristic of the soundings by calculating land minus ocean differences of the mean and RMS differences shown in Table 2. We produced these values in Table 7 for TIROS-N for the 30–60°N latitude zone for clear and cloudy conditions for fall, winter and spring seasons.

In this table, a positive value of the mean difference indicates that the bias was more negative over the ocean than over the land, or that the ocean exhibits a cold bias relative to the land. Positive values of RMS differences over land minus those over the ocean indicate that the ocean has lower RMS values than the land.

For clear conditions the land minus ocean differences of the mean values exhibit a similar distribution for all seasons: negative in the lower troposphere (ocean relatively warmer than the land), positive in the middle troposphere and negative in the upper troposphere. Land minus ocean differences in RMS tend to be small and negative for fall and winter, indicating that retrievals over land have somewhat smaller RMS differences during those seasons. This indicates the dominance of continental soundings in the coefficient data base. Spring, however, does not quite follow this pattern, and shows a mixed distribution of differences which still remain small.

The cloudy soundings show some interesting features. First, the RMS differences are small as was the case for the clear soundings. They do not, however, show the predominance of negative differences which were shown in the clear soundings. For the land minus ocean mean differences, the lowest layer for fall and winter is positive indicating that the oceanic retrievals exhibit a relatively cold bias and that in the spring the lowest layers are negative indicating that the oceanic retrievals exhibit a relatively warm bias.

These results support the interpretation given in Phillips *et al.* (1979) of the continental influence on the cloudy soundings.

## 4. Concluding remarks

This evaluation has emphasized the statistical character of the retrievals relative to collocated radiosondes. In computing these statistical comparisons we treat the retrievals similarly to radiosonde data. In fact, they are not strictly similar to radiosonde data since satellites provide a volumetric measure of the structure of the atmosphere whereas radiosondes provide essentially a point measure. Perfect agreement between them can never be achieved.

Our statistical comparisons also do not provide any information on the horizontal structure and synoptic patterns achievable with the satellite data. This feature was briefly examined by Phillips *et al.* (1979) and is being pursued further by the examination of case studies of various synoptic situations such as reported by Brodrick (1980). Also, the retrieval system is continually undergoing improvements. For example, in mid-February 1980, a procedure was implemented that would eliminate rain-contaminated cloudy retrievals over the oceans as proposed by Phillips (1980). In June 1980, a new algorithm for calculating clear infrared radiances was implemented. In July 1980, the MSU Channel 3 of NOAA-6 was restored to the system and a new retrieval scheme for cloudy oceanic retrievals was implemented. This scheme is expected to reduce the large biases for the Northern Hemisphere mid-latitudes.

Our evaluation is similar to Phillips *et al.* (1979). However, in some instances the results have changed markedly, especially in the ratio of variances satellite to radiosondes variances. Our results indicated much higher ratios in the 30–60°N and 30–60°S zones, and lower values in the 30°N–30°S zone than previously reported.

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