

Compatibility of Radiosonde and Nimbus 4 SIRS-Derived Data at Stratospheric Constant-Pressure Surfaces

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ABSTRACT—The usefulness of Nimbus 4 satellite infrared spectrometer (SIRS)-derived temperature and height data for constant-pressure analyses at stratospheric levels is investigated by comparing SIRS data with rawinsonde observations and objective analyses of those data. Results from the various methods of comparison are difficult to interpret since systematic and random errors of observations at stratospheric altitudes do not permit the observed data to be used as an unquestioned standard. In addition, conclusions must be qualified by the fact that the SIRS information derived to date has depended in part on analyses of rawinsonde data.

The following conclusions were reached from the various comparison studies: (1) SIRS data are useful for constant-pressure analyses at stratospheric levels, (2) mean differences between analyzed rawinsonde temperatures and SIRS derivations are generally less than 3°C, (3) differences are greater during stratospheric warmings, but SIRS data generally indicate the proper trend of the temperature changes, thus adding information about the temperature of the real atmosphere to an analysis, and (4) stratospheric SIRS data after Nov. 5, 1971, can be used with more confidence than those derived before that date.

1. INTRODUCTION

The satellite infrared spectrometers, SIRS A and SIRS B, (Wark and Hilleary 1969, Goddard Space Flight Center 1970), have provided worldwide information concerning the radiant energy emitted by the earth's atmosphere in various spectral bands. This radiance information can be processed to derive temperature profiles up to at least the middle stratosphere. The derived thermodynamic information assumes a relatively greater importance at stratospheric levels, where the number of in situ reports has been considerably less than at tropospheric levels. Observational sparsity, together with the notorious inaccuracy of high-level radiosonde temperature measurements, has always posed major problems for stratospheric analysis (McInturff and Finger 1968).

Methods for deriving temperature profiles from the basic SIRS radiance data have undergone continual development during the past few years. For example, the original statistical procedure used to obtain temperature information from SIRS A radiances depended heavily on collections of radiosonde temperature and height data from the preceding several days (Smith et al. 1970, Hayden 1971). Johnson and McInturff (1970) showed that SIRS data generated in this way were sufficiently compatible with radiosonde data to be utilized in constant-pressure analysis during the stratospheric summer period.

Although this statistical regression system appeared to produce acceptable results, a different system was initiated for SIRS B (Smith et al. 1972), which used an

iterative method for adjusting "guess" profiles in accordance with the measured SIRS radiances. The guess temperature profiles were obtained from the National Meteorological Center (NMC) operational tropospheric forecasts or analyses up to the 100-mb level, analyses above 100 mb up to the 10-mb level, and representative climatological profiles above the 10-mb level. A modification introduced in November 1971 allowed observed analyzed temperatures at 50, 30, and 10 mb and observed SIRS radiances to specify, through regression, the guess profile above 10 mb (Gelman et al. 1972).

A primary purpose of this paper is to discuss methods for determining compatibility between radiosonde data and SIRS-derived temperature and height information and thus determine their usefulness in stratospheric analyses. The methods include direct comparisons of data as well as comparisons by means of analysis. Emphasis is placed on autumn and winter since winter stratospheric phenomena exhibit the greatest spatial and temporal variability and, therefore, are most difficult to depict.

2. COMPARISONS OF ANALYSES OF SIRS DATA WITH ANALYSES OF RAWINSONDE DATA

The stratospheric objective analysis system used in the current compatibility study is the NMC operational version for production of Northern Hemisphere charts at the 100-, 70-, 50-, 30-, and 10-mb levels. For the comparisons presented in this section, the objective analysis program was used to produce separate analyzed fields

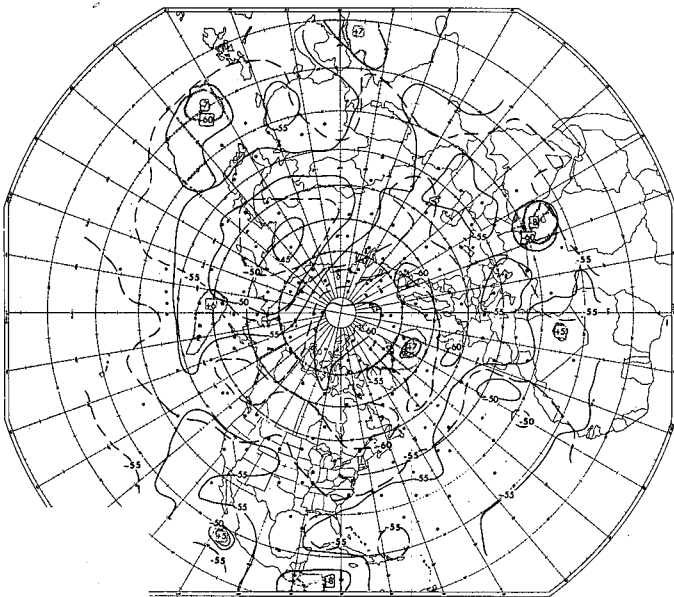


FIGURE 1.—Objective temperature analyses on Oct. 9, 1970, at 30 mb for SIRS (dashed lines) and radiosonde (solid lines). Shaded areas are regions where the differences between the analyses (radiosonde minus SIRS) are greater than 5°C. Closed circles indicate distribution of SIRS data.

at 30 mb for radiosonde temperature and height data only [corrected for systematic instrumental errors induced by solar and infrared radiation (Finger et al. 1965)], and then for SIRS-derived temperature and height data only. To maintain independence of the two analyses, we specified the 30-mb analysis first-guess fields through regression from 100 mb, instead of the usual practice of using 50-percent regression from 50 mb and 50-percent persistence from the previous analysis. In all cases, the 100-mb chart was the NMC operational analysis constructed as usual with the aid of both rawinsonde and satellite data. Parallel analyses were prepared using data collected over a 24-hr period for each of 5 selected days in October 1970. Days were chosen according to the number of SIRS and radiosonde reports available for analysis. Difference charts between the height fields and the temperature fields were then produced.

The parallel analyses of radiosonde and of SIRS temperatures for one of the 5 days (Oct. 9) are shown in figure 1. The two analyses are in general agreement in the magnitude and location of the major features of the thermal field, and no hemispheric bias is evident. Although differences exceed 5°C in isolated areas, these occurrences are interpreted as due chiefly to variations in observational coverage, which is a basic problem associated with this comparison method. As can be seen, the fields are much more consistent over northern latitudes where data from both systems are abundant.

The height difference chart for the same day is shown in figure 2. The difference field is fairly smooth, with the largest differences of about 110 m (SIRS lower) located over the polar areas. Middle latitudes are dominated by negative values (SIRS higher). As with the temperature

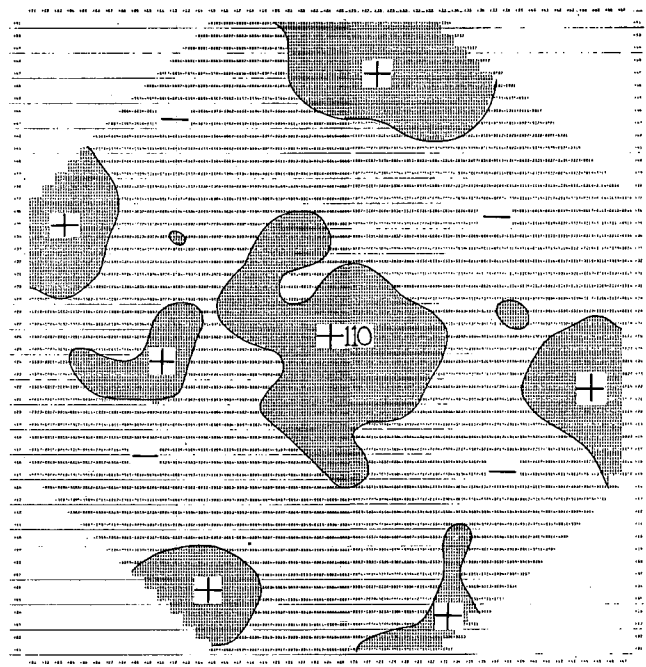


FIGURE 2.—Height difference (m) between 30-mb objective analyses on Oct. 9, 1970, (radiosonde minus SIRS) over the Northern Hemisphere. The computer printout is in the form of the standard NMC 1977 gridpoint polar stereographic projection.

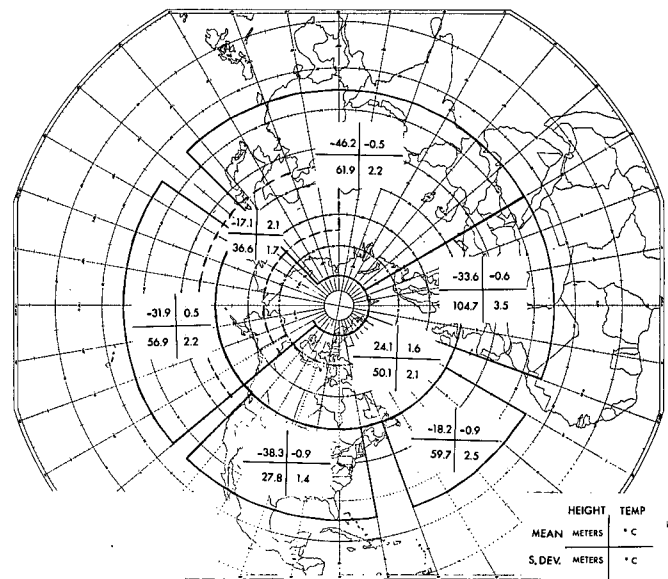


FIGURE 3.—Mean 30-mb height and temperature differences (radiosonde minus SIRS) and their standard deviations for the 5-day October period.

charts, the areas of differences become segmented over lower latitudes with some large values apparent.

Areal mean height and temperature differences and their standard deviations in six geographical regions were computed for the 5 days combined (fig. 3). Each area was selected to ensure a homogeneity of station density and/or type of radiosonde instrument.

The area summaries have several interesting features. For example, over the United States the mean differences

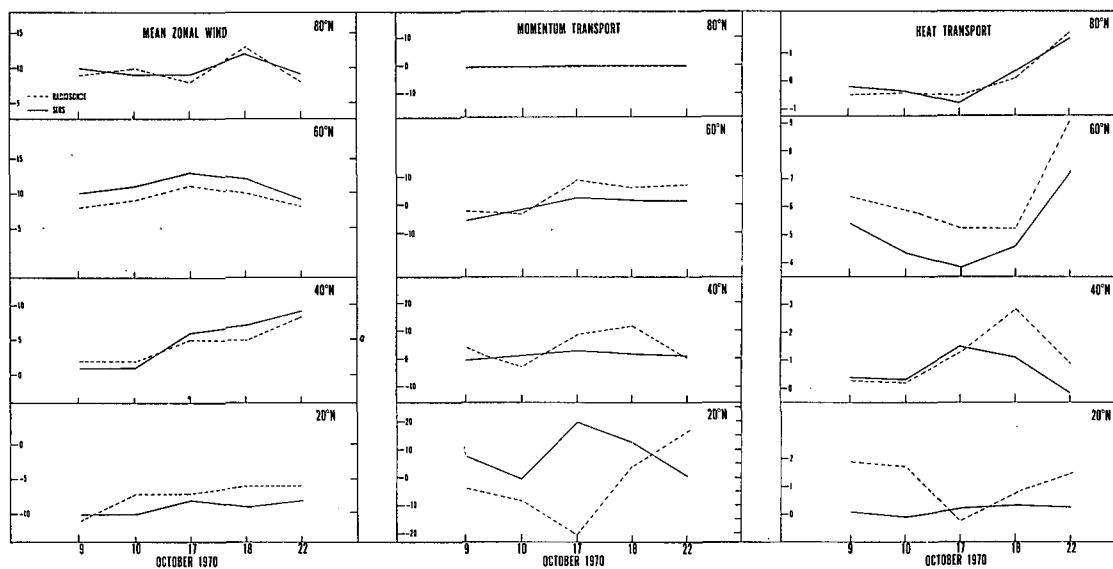


FIGURE 4.—Graphs of mean zonal speed (m/s), momentum transport (10^{15} J/mb), and heat transport (4.185×10^{11} J·s⁻¹·mb⁻¹) for days in October 1970, calculated using the objective analyses for SIRS (solid) and radiosonde (dashed).

and standard deviations are small, but over the European sector the standard deviations are considerably larger. A portion of the larger standard deviation is undoubtedly a result of the many different instrument types used in Europe. Since only a single type of radiosonde is used at United States stations, more confidence (not in terms of accuracy as much as compatibility) might be placed in analyses for that area.

For two maps derived from different data sources to be judged compatible, they must represent similar distributions of, for example, kinetic energy and of momentum and heat transport. In view of this, calculations were made of mean zonal velocity, of momentum transport, and of heat transport for the 5 October days under consideration [according to the method discussed by Miller (1971), with truncation at wave number 3]. Some resulting graphs are shown in figure 4. Agreement is fair among the various analyses with respect to mean zonal wind. However, there is a disparity between the results for SIRS and those for radiosonde data in both momentum transport and heat transport.

This disparity may be expected at lower latitudes since very little confidence can be placed in either analysis, primarily because of the data distribution. The disparity is less evident at the higher latitudes. To determine the significance of these results, we must examine more situations, especially those with stronger wind regimes since the momentum and heat transports are generally 10 times greater during winter than in autumn. Moreover, the implications of the calculations for features of the general circulation must be ascertained and compared with observations. The example given here is intended merely to indicate an approach that could be taken in any comprehensive evaluation.

Although the parallel analysis procedure provides significant information on compatibility, the problem of

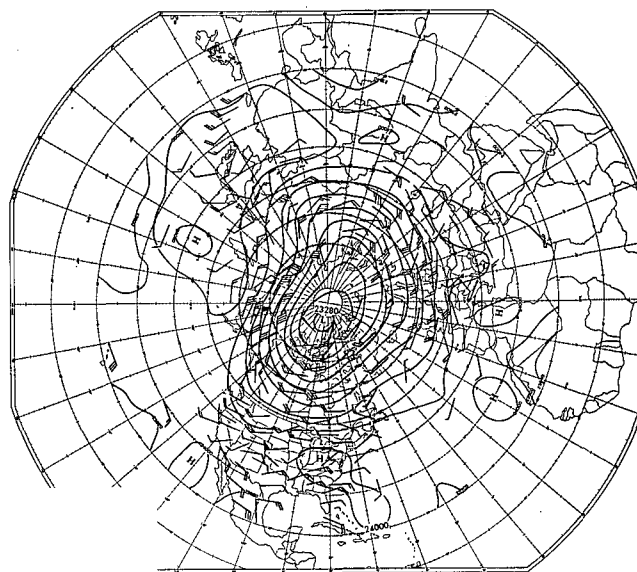


FIGURE 5.—Objectively analyzed 30-mb SIRS height field (m) for Oct. 9, 1970. Winds (kt) from rawinsonde observations on that day are shown for comparison.

determining which data system is more correct remains. We attempted to use the wind observations in an independent test for this determination. Figure 5 shows the analysis derived from the SIRS height data at 30 mb on Oct. 9, 1970. Winds from rawinsonde observations on that day are also plotted. In northern latitudes, the winds fit the independently derived satellite height field. The location of the jet stream, indicated by the contour gradient over the Alaska-Siberia region, is verified by the wind field. In areas of wind reversal such as in low latitudes, the ridge lines are only slightly displaced.

Differences between the observed and geostrophic winds were computed from the 5 days of SIRS analyses as well

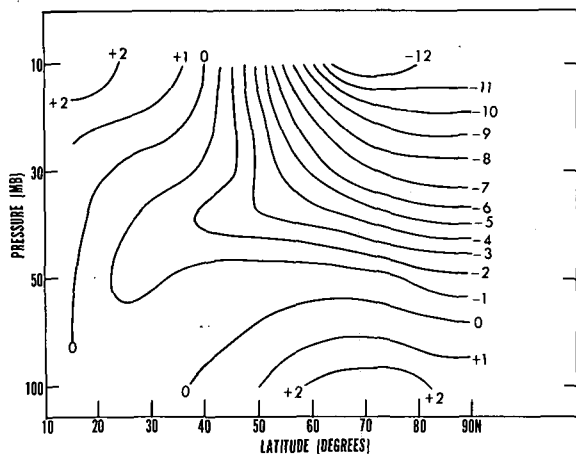


FIGURE 6.—Latitudinal mean temperature differences (SIRS data minus objective analyses of rawinsonde data, °C) for February 1971.

as from the radiosonde analyses. In each case, the average difference between the observed and computed winds was approximately 12 kt. Thus, for this October period, the wind test was inconclusive; that is, neither data system was superior. A possible explanation is that the reported winds were generally light, so that the noise in the wind and their ageostrophic components may have masked any real differences that might have existed in the analysis.

In an independent test, the reported winds were used in the regular objective analysis system to complement the SIRS height data, and, in separate analyses, the winds were used with the radiosonde height data. The wind field did not alter either set of analyses to any significant extent, and the basic height differences remained nearly equivalent to those computed before the winds were included. Again, this may suggest the accuracy and compatibility of the two height charts. In this case, it may also be reasoned that the winds are not being sufficiently considered by the analysis program. However, the October situation may not have been a fair test since the wind field noted in figure 4 is relatively weak. Unfortunately, a wintertime situation with strong winds has not yet been tested.

3. COMPARISONS OF RAWINSONDE ANALYSIS VALUES WITH SIRS-DERIVED TEMPERATURES

Differences between rawinsonde analyses and SIRS-derived data under varying stratospheric conditions have been monitored on a daily basis since 1969. To accomplish this monitoring, charts for levels above 100 mb have been analyzed for rawinsonde data only, while all data (i.e., rawinsonde and SIRS) have been plotted on the charts.

Major discrepancies, which increased with time, between the SIRS-derived temperatures and the objective rawinsonde isotherm analyses were revealed by monitoring during the winter of 1970-71. The 10-mb SIRS temperatures during December 1970 were sometimes lower than -90°C in the polar region where rawinsonde analyses

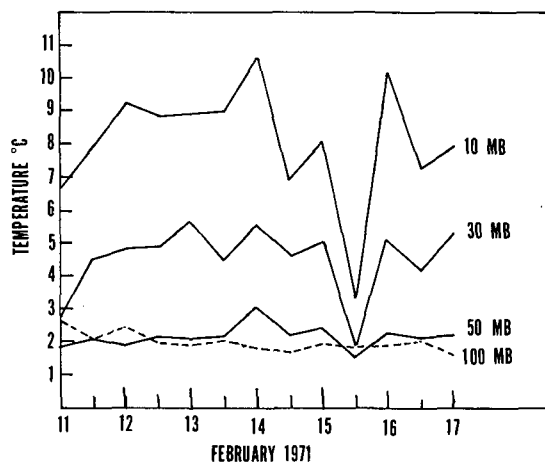


FIGURE 7.—Time series of rms values of temperature differences in figure 6.

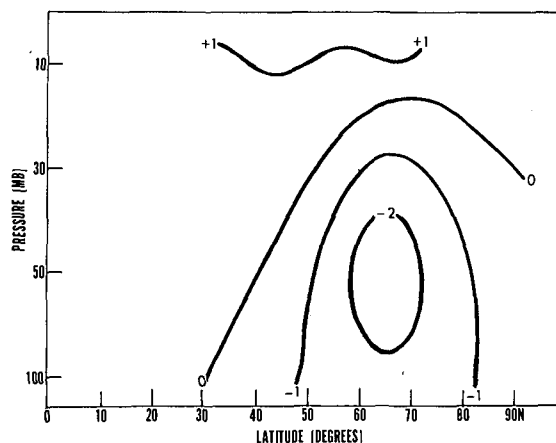


FIGURE 8.—Same as figure 6 for December 1971.

indicated temperatures of -80°C . The SIRS values were undoubtedly in error since the radiosonde temperatures from several different types of instruments were consistent and were supported by available rocketsonde measurements. To gain a more complete picture of the 1970-71 wintertime temperature incompatibility problem, we computed more precise differences between SIRS data and analysis values interpolated in time and space from twice-daily rawinsonde charts. Figure 6 displays the vertical and latitudinal structure of mean difference for 7 days during February 1971, for the Northern Hemisphere north of 20°N . At lower latitudes, the mean differences were small. From middle through high latitudes, however, values tended to increase with height above 50 mb to a maximum at 10 mb with SIRS colder by more than 10°C .

A time-section diagram of the root-mean-square (rms) values of the temperature differences obtained from the February period is shown in figure 7. Particularly evident is the sharp increase in the values above 50 mb. Day-to-day fluctuations are generally small at all levels, except at 1200 GMT on February 15. The SIRS data were inadvertently included in the analyses above 100 mb for this time instead of being withheld as had been the normal

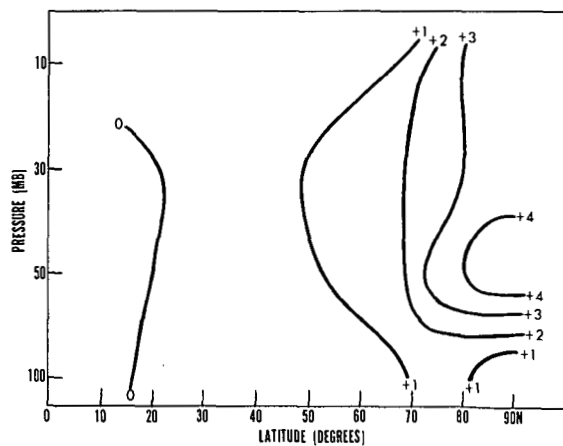


FIGURE 9.—Same as figure 6 for February 1972.

procedure. This error proved instructive in demonstrating both the speed with which the objective analysis adjusts to the current data set, and the possible impact of SIRS data in analyses of the stratosphere.

The large errors in the SIRS data shown by the February 1971 results led to changes in the method for deriving SIRS temperatures, which were incorporated into the system during November 1971. The changes improved the compatibility of the SIRS and analysis values significantly, as can be seen in the Northern Hemisphere latitudinal means, computed for a 10-day period in December 1971 (fig. 8). The large bias shown in the February 1971 case (fig. 6) is not evident, except for a slightly negative area centered at 50 mb and 65°N.

A stratospheric warming during the second half of February 1972 provided an indication of the ability of stratospheric SIRS data to define rapid and intense temperature changes. Although the warming was not as pronounced as some that have been observed, it did produce changes of up to 40°C over limited areas at the 10-mb level during a period of 10 days. Mean differences between SIRS data and objective analyses during the warming period are shown in figure 9. These indicate general compatibility at all but the most northern latitudes, where a 5°C bias is apparently associated with areas of advancing warm air. It is plausible to argue (as will be done in a subsequent section) that the objective analysis system could advantageously have utilized the higher SIRS temperatures. Hence, we do not believe that under such warming conditions the 5°C difference is unsatisfactory.

Because of the possibility of significant error in any single high-altitude radiosonde observation, objective analysis permits the most consistent representation of the stratospheric synoptic data base. A representation of the goodness of data fit can be obtained by computing rms differences between *all* data (including any which the analysis system may have rejected as erroneous) and the analyses. In figure 10, two such temperature representations are shown, one for the month of February 1969 (as calculated by Johnson 1972) and the other for the warming period in February 1972. Note that the rms values for February 1972 are only slightly larger than for 1969.

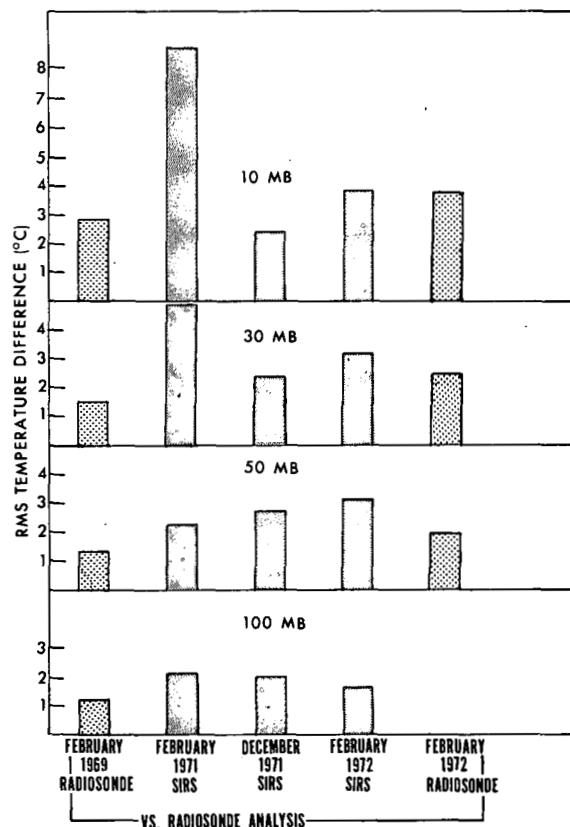


FIGURE 10.—Root-mean-square temperature differences (radiosonde data and SIRS data minus corresponding values of objectively analyzed rawinsonde temperatures).

A severe test for the SIRS-derived temperatures would be to compute the rms differences of those data from the radiosonde analyses. We call this a severe test since the SIRS data are *virtually independent* of the analyses.¹ The February 1972 SIRS rms computation was based on the same 10-day series as for the radiosonde and provides a direct comparison. It may be expected that an analysis based solely on SIRS data (assuming equivalent data distribution) or upon SIRS and radiosonde temperatures combined would result in a chart with similar or even smaller rms differences.

The second and third set of bars in figure 10 illustrate, by the same type of rms differences, the SIRS problems before November 1971. The significant reduction of rms in December 1971, especially at the higher levels, is obvious.

Another way of looking at the compatibility of SIRS and radiosonde temperature data is through *temporal change* relationships. For example, SIRS changes can be thought of as the amount by which the first guess consisting of the previous 12-hr analyzed radiosonde temperature field was modified by the observed radiances to produce the final derived SIRS temperature. This change may be adjusted according to the times of SIRS observations and compared to the difference between the 12-hr temperature analyses constructed solely from radiosonde data. Such informa-

¹ We say, "virtually independent" because the most recent analysis is used as a first-guess field in deriving temperatures from SIRS radiances between 100 mb and 10 mb.

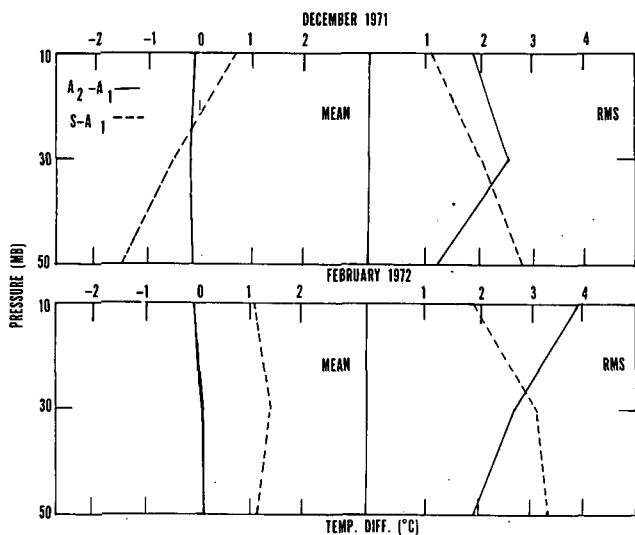


FIGURE 11.—Mean and rms temperature changes indicated by the SIRS data compared to their first guess ($S-A_1$) and the mean and rms 12-hr changes for the same periods indicated by objective radiosonde analyses (A_2-A_1).

tion obtained for several days in December 1971 and a period during February 1972 is shown in figure 11. As with the previous computations, the changes from the analyses were estimated at the points of available SIRS observations; there were generally more than 100 points per observation time throughout the hemisphere.

The mean values of the 12-hr radiosonde analysis change for both periods are near zero for all levels shown. The changes indicated by the SIRS data, however, are significantly different from those of the radiosonde analyses. Although the SIRS change for both periods are similar at 10 mb, they are increasingly opposite in sign at the 30- and 50-mb levels. Day-by-day consistency of the respective mean differences at 10 mb for the February period are shown in figure 12. The time curves are a result of considerable smoothing of the daily change values, but they clearly indicate that the results in figure 11 stem from differences that are consistent from day to day.

To what extent the mean SIRS differences reflect true atmospheric changes not fully analyzed by the objective system remains unclear. It appears, however, that the SIRS data for February are indicative of the warming then taking place, and may in fact be superior to the analysis data.

The interlevel variation of the mean SIRS changes during December 1971 is puzzling and cannot at this time be fully explained. The change in sign probably reflects the interlevel error compensation in the retrieval that is typically seen when the first-guess profile is in error.

The rms values of the 12-hr changes are also shown in figure 11. Values in both instances are higher for February 1972 than for December 1971. This may be expected since February had greater temperature variability than the previous December. It is interesting that during both periods the radiosonde analyses indicate greater rms values than SIRS data at the higher level, but that the

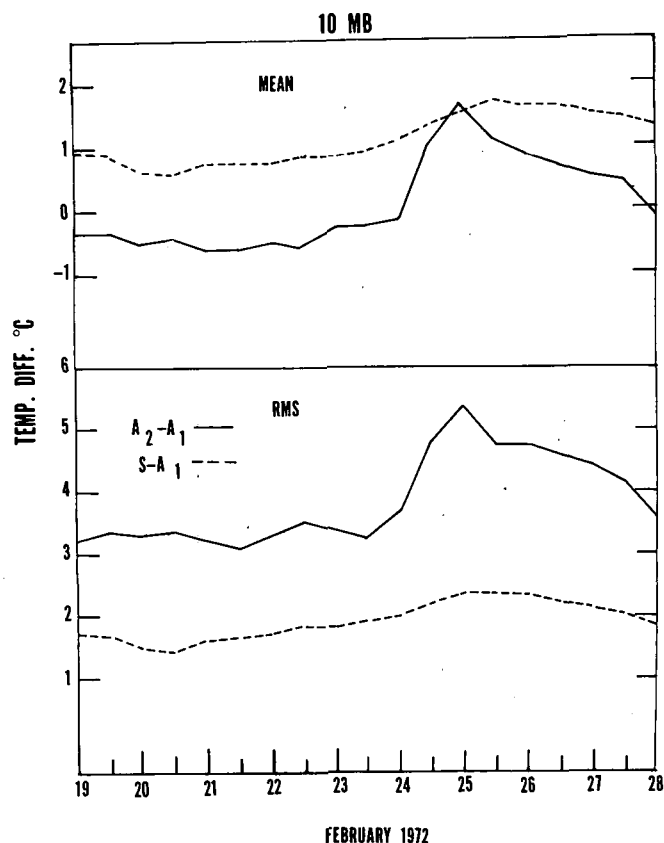


FIGURE 12.—Same as figure 11 for the day-by-day smoothed temperature differences at 10 mb during Feb. 19-28, 1972.

reverse takes place at the lower level. An indication of the day-by-day consistency of rms values at 10 mb during February is shown by the smoothed daily values in figure 12.

4. COMPARISONS OF SIRS ANALYSIS VALUES WITH RADIOSONDE TEMPERATURES

Since the SIRS observations hardly ever coincide in space or time with radiosonde observations, any direct comparison of data with data is difficult. However, hand analyses of derived SIRS temperatures are relatively easy to construct, since the data generally vary in a smooth manner. The comparative random variability of radiosonde temperatures makes their analysis more complex. It seems appropriate, therefore, to compare time-series of radiosonde-reported temperatures (corrected for radiation effects) for a particular station, with SIRS-derived temperatures estimated at the station location from analyses.

Examples of such time-series are shown in figure 13. Also plotted are the temperatures given by the routine objective analyses of radiosonde temperatures. Mould Bay (76°N , 119°W) was chosen for illustration, largely because it was situated in the region of intense temperature gradient between the cold polar vortex and the area of stratospheric warming during February 1972. Another consideration was its consistently good record of radiosonde observations.

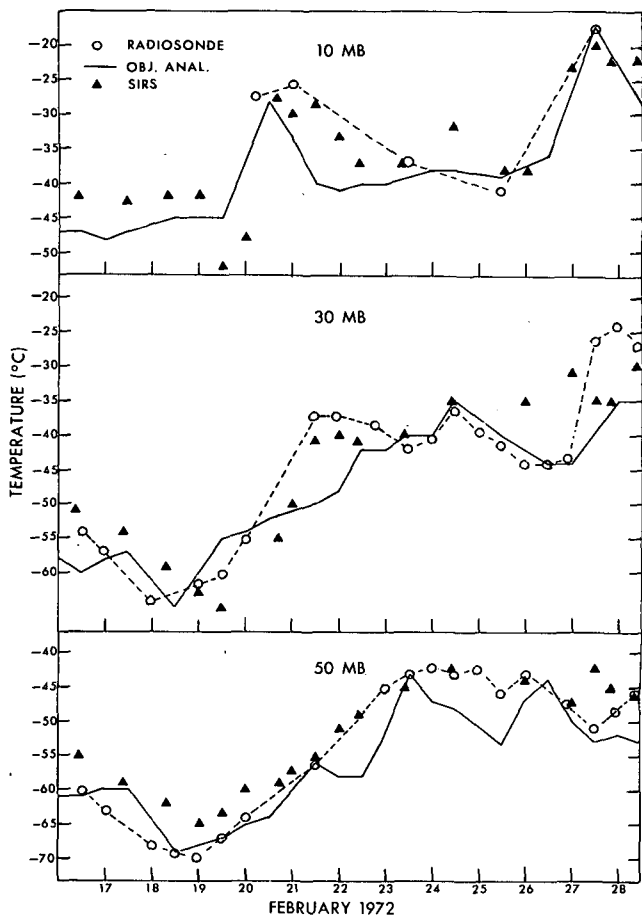


FIGURE 13.—Temperature over Mould Bay, N.W.T., Canada, indicated at 50, 30, and 10 mb by radiosonde data, by objective analysis of the radiosonde data, and by subjective analysis of SIRS data during February 1972.

The figure demonstrates:

1. There is little (if any) lag in the response of the SIRS system to changing temperatures (assuming the radiosonde reports as standards).
2. The differences between SIRS and radiosonde temperatures are generally no larger than the differences between radiosonde and the corresponding objective analysis values.
3. The SIRS radiance data adjust the stratospheric guess profile in the right direction as indicated by radiosonde observations and by objective analyses. This is most clearly illustrated between February 22 and 29 at 50 mb (fig. 13). During this period, the on-time objective analysis values are generally lower than those given directly by the radiosonde or by SIRS. However, during this period, the guess profile apparently does not prevent the SIRS system from yielding values compatible with observed radiosonde values.

It appears, therefore, that the SIRS data are compatible with the radiosonde data, and, had the SIRS data been included in the objective analysis during the period, there would have been a sufficiently large concentration of data points to depict the warming more properly.

5. CONCLUSIONS

In this study, we have evaluated the SIRS temperature and height data currently derived for use in daily ob-

jective analyses at stratospheric levels. The major limitation of such an evaluation is the lack of any information that can be used as an absolute standard. This standard is not supplied by the radiosondes, because data from a given instrument at a given time at stratospheric levels can be inaccurate. Because of the screening and interpolation processes that are performed, objective analysis usually affords the best representation of any stratospheric radiosonde data sample. Unfortunately, during times of stratospheric warmings, one cannot always accept the objective analysis uncritically.

Thus, in this study, we also had to use other methods for comparison. In every case, therefore, our results are restricted to showing the relative compatibility of SIRS information with radiosonde information at stratospheric levels.

From the studies presented it can be concluded that:

1. During autumn and most winter situations, fields of SIRS-derived temperatures and height consistent with rawinsonde-based fields can be constructed using present objective analysis techniques. Note again that the SIRS data have some dependency on rawinsonde analyses through the guess profile used in their derivation.
2. Stratospheric SIRS temperatures up to 10 mb generally differ by less than 3°C from analyzed radiosonde temperatures during autumn (and probably spring) and for nonwarming winter situations.
3. The November 1971 modification of the method for obtaining the guess profile for the SIRS data derivation improved the compatibility of SIRS data with the radiosonde objective analysis, especially at 10 mb. Even so, mean temperature differences of almost 5°C could be seen over northern latitudes during a warming period in February 1972. However, much of the differences may be due to difficulties in performing satisfactory objective analyses during a stratospheric warming rather than difficulty with SIRS data.
4. During the warming period when the radiosonde temperatures indicated rapid changes, the SIRS temperatures showed generally the same trend.
5. The fact that the SIRS temperatures generally agree with radiosonde temperatures, even with a faulty first-guess profile, indicates that the SIRS data do provide generally reliable information about the vertical thermal structure.
6. In many cases, the addition of SIRS data to the relatively sparse radiosonde data coverage would improve the resultant objective analyses.

We feel that the methods outlined in this paper should be used to assess temperature and height information derived from future satellites. We see this study, then, as only a first step in a series of research studies. Other studies would be oriented toward answering questions such as: (1) How well will the satellite data perform entirely on their own (i.e., with no dependency on current rawinsonde data for the guess profile)? and (2) What is the minimum network of rawinsonde stations needed to adequately complement the satellite observations?

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