

ON THE USE OF SIRS DATA IN STRATOSPHERIC SYNOPTIC ANALYSIS

KEITH W. JOHNSON and RAYMOND M. McINTURFF

National Meteorological Center, Weather Bureau, ESSA, Suitland, Md.

ABSTRACT

The satellite infrared spectrometer aboard Nimbus 3 has provided a new source of temperature data and height data for the atmosphere. Problems of applying these data in synoptic stratospheric analysis are briefly reviewed. It is found that consistent summertime synoptic charts for the Northern Hemisphere (at 50, 30, and 10 mb) may be prepared using a 100-mb objective analysis as a base chart and thicknesses above 100 mb from SIRS retrievals. Some improvement is made possible by use of concurrent wind observations. It is noted that the SIRS observations have yielded a significant improvement in the data base for the stratosphere.

1. INTRODUCTION

The Nimbus 3 satellite, launched in a sun-synchronous orbit on Apr. 14, 1969, includes among its meteorological sensors a Satellite Infrared Spectrometer (SIRS). The operation and capability of this instrument have been extensively described elsewhere (Wark and Fleming 1966, Twomey 1966, Hilleary et al. 1966, U.S. Goddard Space Flight Center 1969, and Wark and Hilleary 1969). In brief, the instrument measures upward radiation in a number of narrow spectral intervals of the 15μ carbon dioxide absorption band as well as in the window region near 11μ . Radiance values are recorded at intervals of 8 sec and read out to satellite tracking stations during each orbit of the satellite.

The radiances may be used in a number of ways. However, this paper will consider only one technique developed by Smith and Woolf (Smith et al. 1970) in which a statistical procedure is utilized to derive temperature-pressure profiles from a set of radiance observations. Each temperature-pressure profile obtained in this manner may be regarded as a simulated mean radiosonde profile averaged over an area about 120 n.mi. square. A compilation of several hundred of these atmospheric profiles (known as SIRS retrievals) is made available each day to the National Meteorological Center (NMC). Since June 2, 1969, these compilations have been used in objective analysis for levels up to 100 mb, and since June 25, 1969, for the 50-, 30-, and 10-mb levels. (The technique used in the objective analysis system for the stratosphere is described by Finger et al. 1965.)

The purpose of the present paper is to show how SIRS retrievals may be used in synoptic stratospheric analysis and to indicate some of the problems involved in this utilization. In particular, it has been found that SIRS retrievals for stratospheric use are more consistent when "tied" (in the sense explained in section 2) to the 100-mb conventional analysis than when tied to analyses for lower standard levels. The use of wind data from rawinsonde observations is considered. A tentative explanation

is provided for systematic differences between conventional heights and temperatures and the SIRS retrievals; but it must be emphasized that this problem requires the analysis of much more information than was used in the present study. A complete investigation into the compatibility of radiosonde and SIRS data for stratospheric levels is presently underway and will be reported on by the authors in a subsequent paper.

Comparisons of analyses using three data bases are made: (1) SIRS retrievals only, (2) SIRS retrievals plus on-time rawins, and (3) NMC operational objective analyses. Two periods are considered in detail—late May 1969 and mid-July 1969. Hence it should be emphasized that conclusions stated here concerning the utilization of SIRS retrievals in stratospheric analysis are valid only for late spring and summer in the Northern Hemisphere, that is during a period of relatively small day-to-day temperature changes over a section of the globe in which comparatively large amounts of rawinsonde data are available.

Restriction of the study to the stratosphere is based on these considerations: (1) the stratosphere possesses circulation and thermal regimes that are markedly different from those of the troposphere, and consequently the associated problems of analyzing for stratospheric data are different and require separate consideration; and (2) the fact that the stratosphere is generally free of clouds makes SIRS temperature retrievals for the lower stratosphere inherently more reliable (Smith 1969).

2. STRATOSPHERIC ANALYSIS OF SIRS AND RAWIN DATA FOR MAY 27-29, 1969

The period May 27-29, 1969, was chosen for part of this study because (a) the system of obtaining SIRS retrievals for the stratosphere had by this time been validated, and (b) it was possible for this period to make a threefold comparison of analyses at stratospheric levels: (1) those based on SIRS data alone, (2) those based both on SIRS data and rawinsonde winds, and (3) those derived

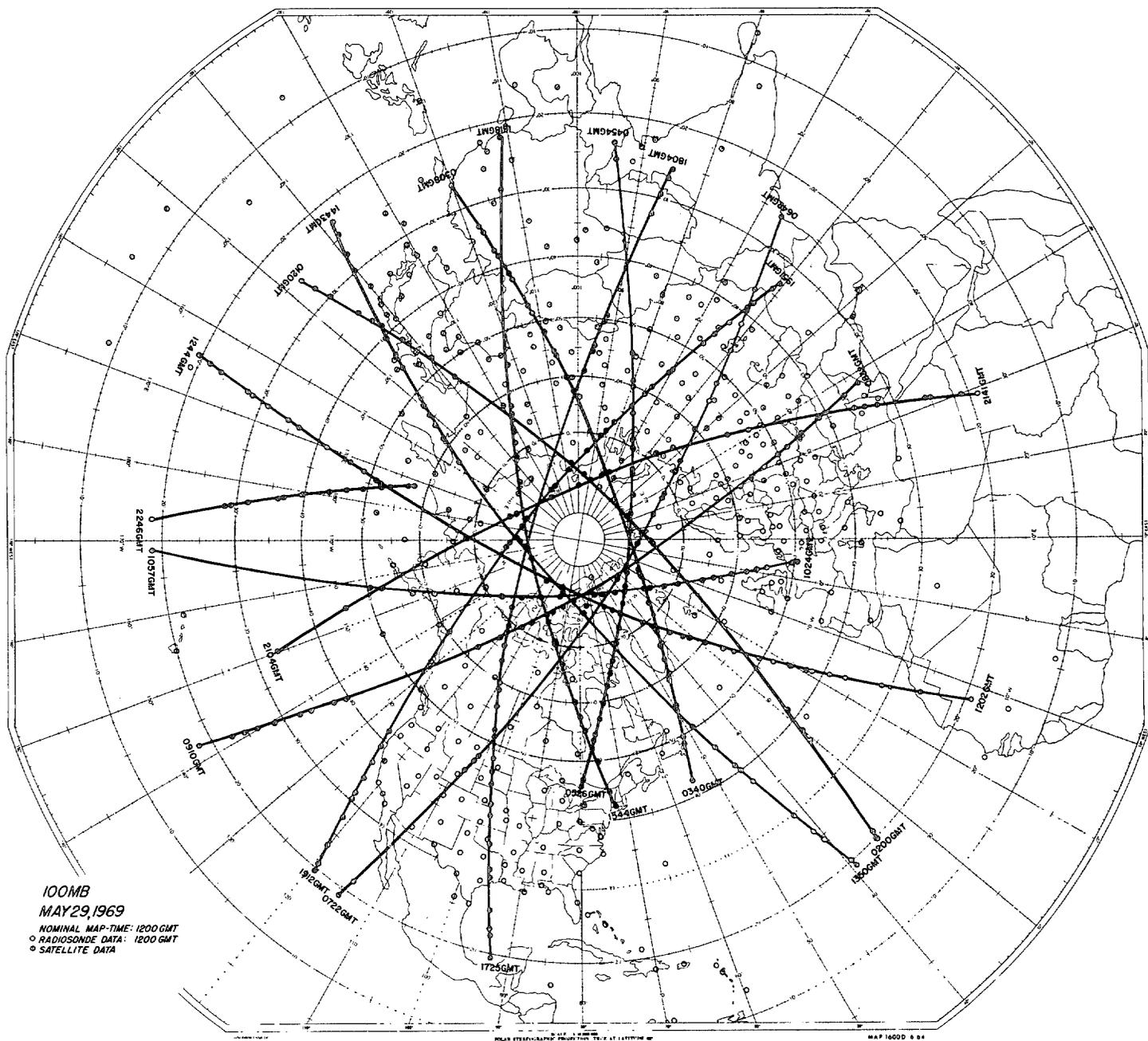


FIGURE 1.—Nimbus 3 orbital tracks over the Northern Hemisphere for the 24 hr of May 29, 1969. The closed circles represent SIRS-derived temperatures and heights obtained for the full 24-hr period; open circles indicate rawinsonde measurements taken only at 1200 GMT.

from rawinsonde data exclusively. The reason for (b) is that prior to June 2 the NMC objective analysis for levels up to 100 mb was performed twice daily, first with radiosonde data alone and then with both rawinsonde data and SIRS retrievals; whereas after June 2, the analysis was run only once (with both SIRS and rawinsonde data). Since a regression system is used to obtain first-guess fields at levels above 100 mb (based on correlations with 100-mb contours), SIRS retrievals had some influence on this analysis after June 2. On June 25, SIRS retrievals were introduced into the on-level data sets for stratospheric altitudes. Consequently, a study of the

impact of SIRS data on stratospheric analyses can be made in a much more straightforward manner for periods prior to June 2 than for subsequent periods.

The Smith-Woolf method for deriving meteorological parameters from SIRS measurements is carried out by means of a system of regression equations (different from those referred to in the preceding paragraph) whose coefficients are determined by correlations between two simultaneous data sets: (a) SIRS radiances and (b) heights and temperatures objectively analyzed from rawinsonde data. These coefficients are continuously updated; and for determining the temperature and height fields cor-

responding to the radiances observed at a particular time (the so-called independent data set), the correlations obtained from data of the preceding several days (the dependent data set) are used, with the assumption that they are appropriate to the current synoptic situation.

The following procedure was followed: SIRS-retrieved heights and temperatures at 100, 50, 30, and 10 mb were plotted for a 24-hr period over the latitudes 18.5°–80.0° N. (Fig. 1 shows a typical data set.) The chart was then analyzed, resulting in analysis I (SIRS data only). (Throughout this paper, analysis I refers to analyses based on SIRS data alone; analysis II to those based on SIRS data plus rawinsonde winds; analysis III to those based only on all available rawinsonde data.) It was later decided that additional detail could be depicted at lower latitudes by including more tracks; so tracks from the preceding 24 hr were included at latitudes south of 50° N. (This procedure is valid, of course, only during periods of slow synoptic change.)

After analysis I was complete, the 1200 GMT winds were plotted on the data charts, and a different analyst using the geostrophic wind relationship to obtain height gradients performed an independent analysis (analysis II, fig. 2) of the height field. The wind data provided some additional detail for height analyses at 100 mb and above. An example of analysis I with the changes introduced by analysis II is shown in figure 2. The changes over northern Mexico and over the southern United States appear to be most significant; the changes in the vicinity of Hudson Bay are based on very scanty information. Comparison with objectively analyzed charts based on rawinsonde data alone (analysis III, fig. 3) shows little difference in the placement of major systems north of 20° N., although the Highs and Lows were in general slightly less intense on analysis II.

Some of the troughs and ridges depicted in analysis III depend on isolated observations (for example, the ridge depicted over Lower California). If these isolated reports were suppressed, analysis III would closely resemble analysis II. This example suggests that SIRS data are compatible with rawinsonde data at 100 mb.

At the end of May, the 50-mb level over most of the Northern Hemisphere is near the boundary between the troposphere-controlled circulation (low pressure centered near the North Pole) and the summer stratospheric easterly circulation (with high pressure over the North Pole). Height gradients are weak, and the apparently random variation among height values provided by successive SIRS retrievals (for example, 100 m/500 km) approaches the magnitude of height gradients across the entire latitudinal extent of the chart; thus considerable difficulty was encountered in performing analysis I at 50 mb. The apparently random variability, which increases with height, will be discussed more fully in connection with figure 7.

Another problem, which is perhaps more serious, becomes evident at the 30- and 10-mb levels. This may be

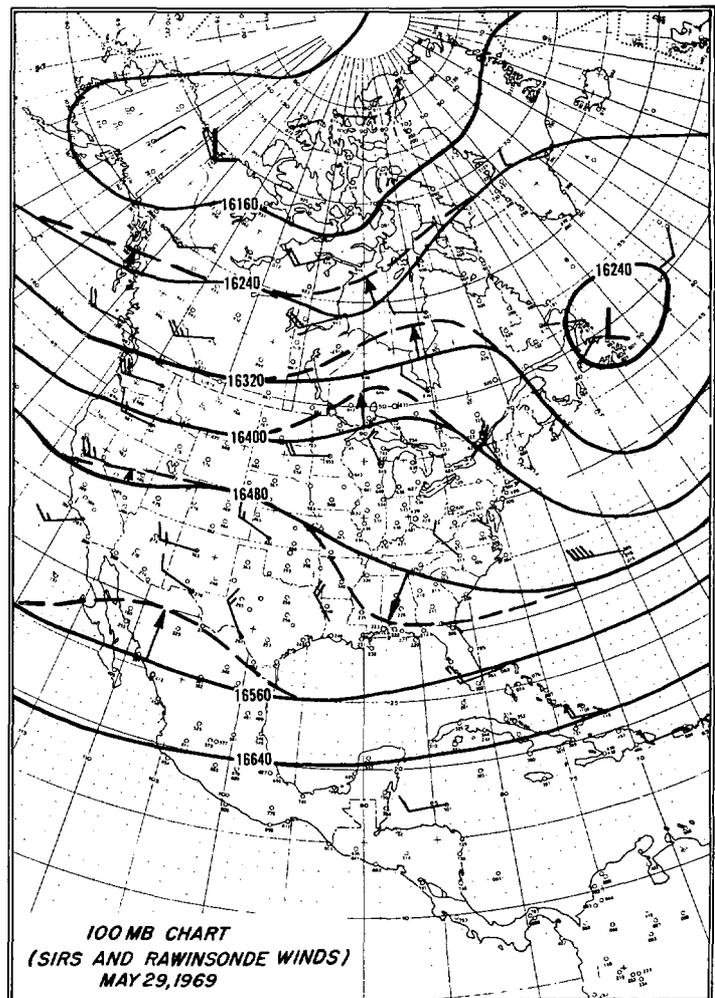


FIGURE 2.—Chart of contour heights of the 100-mb surface based on satellite data for May 29, 1969. Dashed lines indicate adjustments required over North America by addition of 1200 GMT rawinsonde winds; arrows show directions of displacement. Wind speeds are given by full barbs for each 10 kt, half barbs for 5 kt. The contour interval is 80 gpm.

seen by a comparison of figure 4 (analysis I) with figure 5 (analysis III). In middle and low latitudes, the SIRS-derived analyzed height and temperature fields are consistently lower and colder than the rawinsonde objectively analyzed height fields by differences of up to 150 m and 5°C. The difficulty is best illustrated in figure 6 in which SIRS heights along a satellite track lying across North America are depicted together with objectively analyzed heights at the retrieval points. Nearby radiosonde heights are also shown. Sets of curves for other tracks across North America (not shown) have similar configurations.

Figure 6 shows two curves for 10-mb SIRS retrievals. One of these, (C), is obtained by modifying the statistical estimate of heights at 850 mb by setting them equal to the objectively analyzed height values at this level (based on all usable radiosonde and SIRS data). This results in the so-called "850-mb tie-on." The cross marks represent

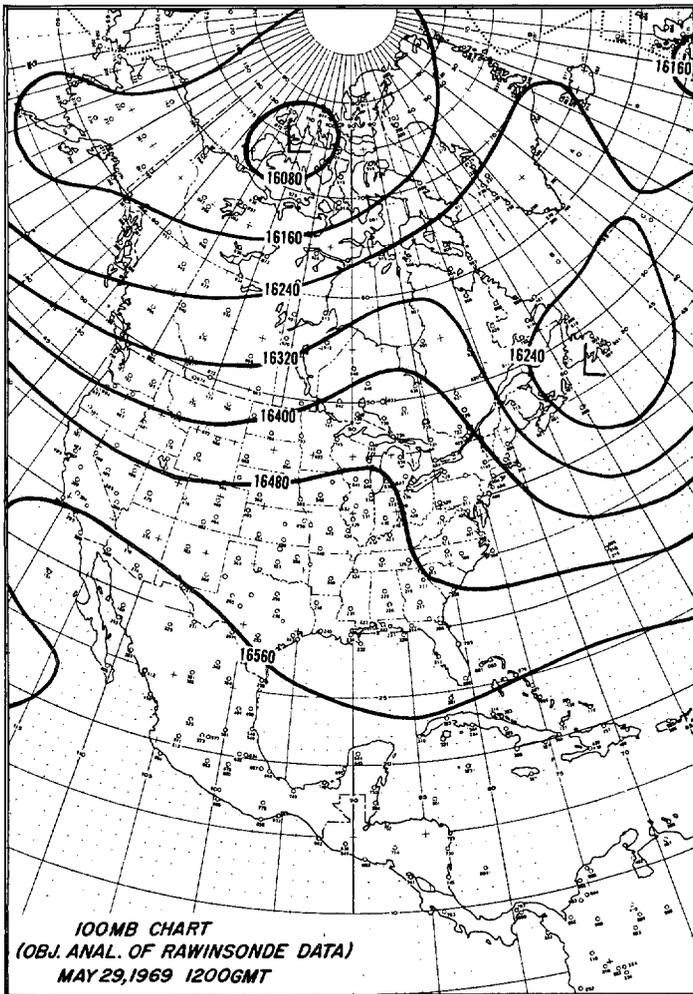


FIGURE 3.—Objective (computerized) analysis of the 100-mb height field for May 29, 1969, based on rawinsonde data exclusively (winds and heights). The method of analysis is described by Finger et al. (1965).

heights derived from the SIRS regression procedure without use of any tie-on level at all; and it is evident that there is not much difference at 10 mb between the results of an 850-mb tie-on and the results of no tie-on at all. If either one were correct, there would be occasional reversals of geostrophic flow from easterly to westerly winds at middle and high latitudes. No such small-scale perturbations in the wind field have been observed during this season. Since the tie-on level is arbitrary, a test was conducted to discover the lowest level for which the tie-on could be made and still produce a consistent 10-mb height field. Use of a level as high as 200 mb for the tie-on still resulted in noticeable spurious reversals in the 10-mb height gradients, while the use of the 100-mb level for tie-on resulted in a nearly monotonic profile (solid line B).

The radiosonde heights plotted in figure 6 exhibit much greater variation about the objectively analyzed height field than do the SIRS data, even data tied on at 850 mb. It appears, therefore, that the data base provided by

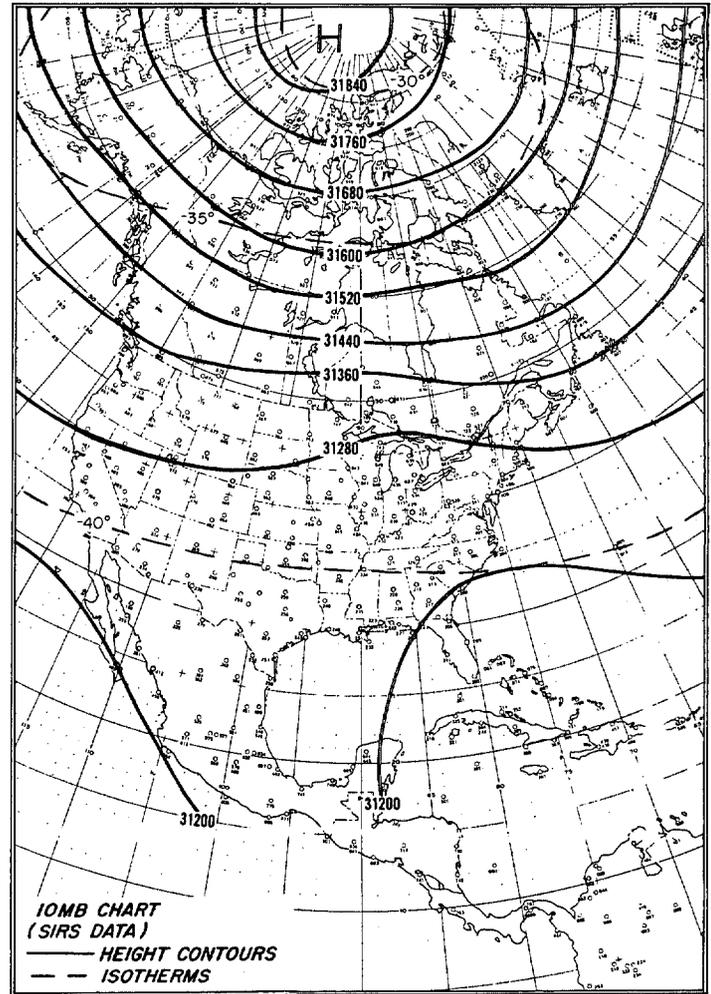


FIGURE 4.—Chart of contour heights and temperatures of the 10-mb surface based on SIRS data only for May 29, 1969.

SIRS retrievals is more consistent than that provided by radiosondes.

Figure 7 shows that, while mean SIRS retrieval heights over North America are lower than objectively analyzed heights, outside North America they are higher. Temperatures show a similar variation. An explanation is being sought in the differences between dependent-data sets.

One could argue that the 10-mb analyses of the SIRS data might be more accurate than those analyzed directly from rawinsonde data, since the SIRS retrievals depend upon radiance values from one instrument, and thus the problem of radiosonde instrument variability and incompatibility might be avoided (McInturff and Finger 1968). However, as already noted, the temperatures and heights derived from SIRS radiance values are dependent on radiosonde observations because the Smith-Woolf method makes use of regression equations whose coefficients are derived from SIRS radiances and objectively analyzed heights and temperatures for a period of several days prior

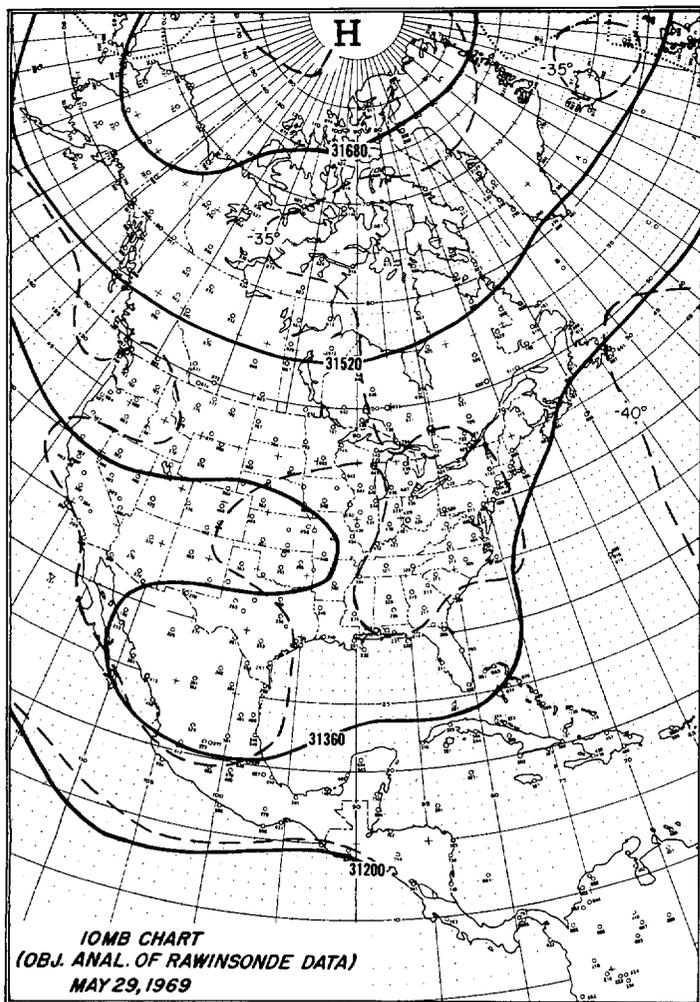


FIGURE 5.—Objective (computerized) 10-mb analysis of the height and temperature fields for May 29, 1969, based on rawinsonde data exclusively.

to the date of application. A consequence of this seems to be that SIRS data tend to “lag behind” radiosonde data. At the times of year under consideration, 30- and 10-mb heights and temperatures are increasing on the average over the Northern Hemisphere as the wintertime circulation regime is replaced by a summertime regime; but with the movement of large-scale systems and the influence of short-term trends, the “lag” may result in either SIRS values being higher than radiosonde values, or vice versa, over large areas of the hemisphere. Although figures 6 and 7 illustrate this problem, obviously the samples involved are too small to permit one to reach firm conclusions. A comprehensive study has been undertaken in the Upper Air Branch of NMC in an effort to find a solution to the entire problem of compatibility between concurrent SIRS and radiosonde data for the stratosphere.

3. ANALYSES FOR JULY 14-16, 1969

The introduction of the SIRS retrievals into NMC stratospheric analyses on June 25, 1969, more than doubled the data base of heights and temperatures at these levels; however, the capacity of the automatic data-

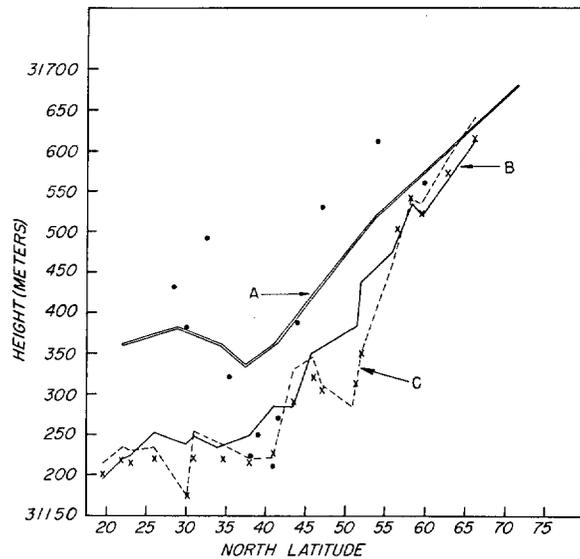


FIGURE 6.—Heights of the 10-mb surface along a Nimbus 3 track on May 29, 1969, as depicted by (A) objective analysis of rawinsonde data, (B) analysis of SIRS data with 100-mb tie-on, and (C) analysis of SIRS data with 850-mb tie-on. The dots represent corrected radiosonde heights; the crosses represent heights derived from the SIRS regression procedure without use of a tie-on level.

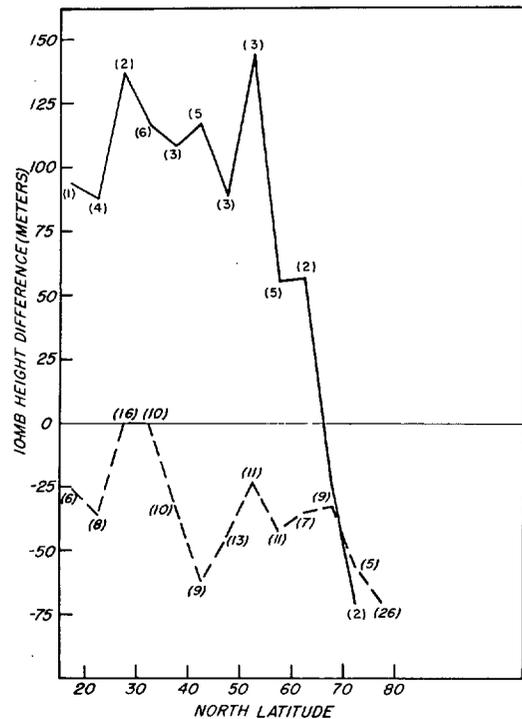


FIGURE 7.—Results obtained by subtracting SIRS-derived heights (with a 100-mb tie-on) from heights given by 10-mb objective analysis and taking averages of the differences. The solid line indicates differences corresponding to SIRS retrievals over the United States and Canada south of 75° N.; and the dashed line indicates differences corresponding to SIRS retrievals outside the United States and Canada south of 75° N. In parentheses are numbers of data points on which the means are based.

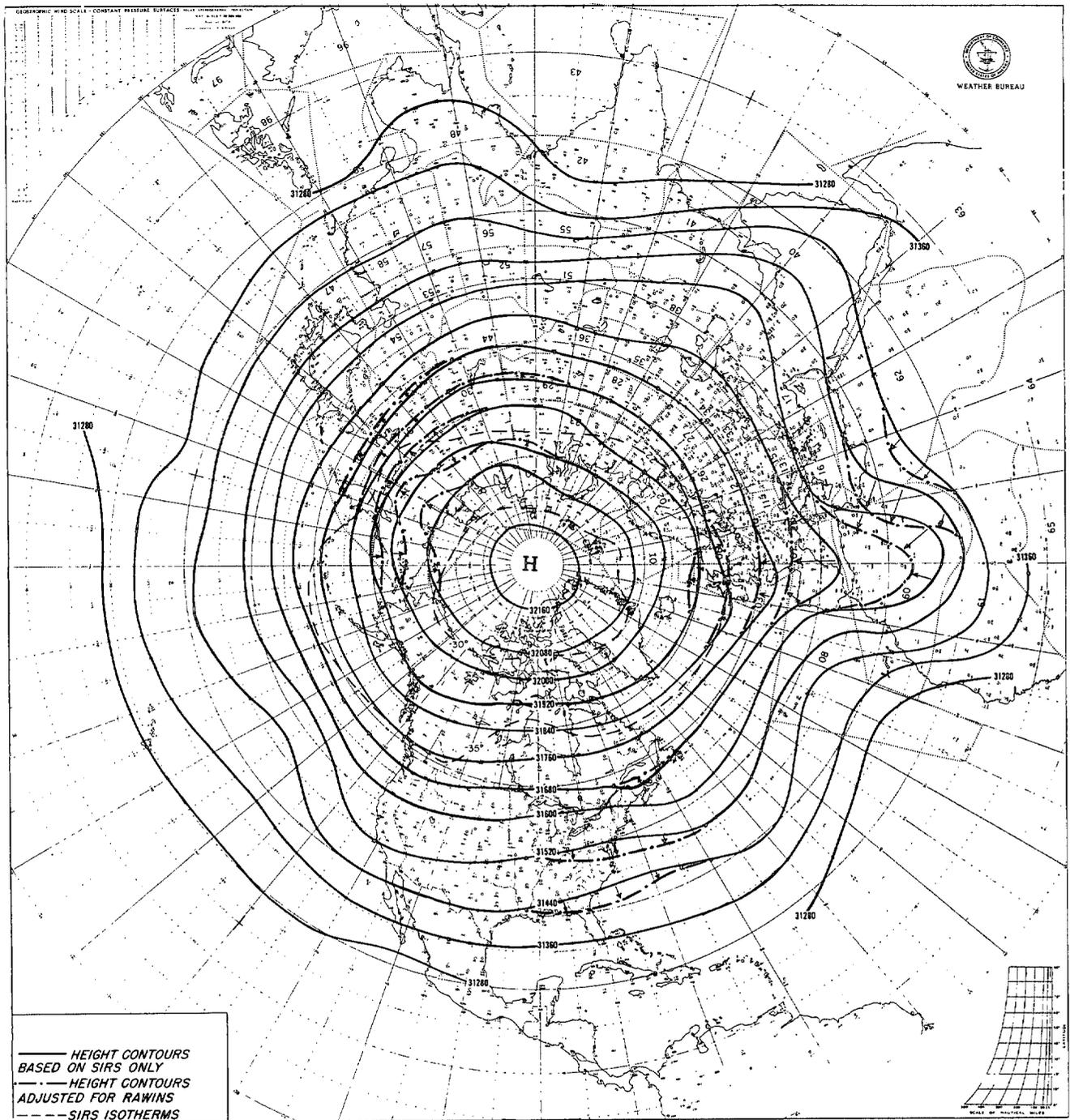


FIGURE 8.—Chart of contour heights of the 10-mb surface for July 16, 1969. Solid contours are based on SIRS data along with a 100-mb tie-on; modifications dictated by rawinsonde winds are indicated by the dot-dash lines.

processing system was not great enough to make use of all the data. The objective analyses (analysis III) for June 25 and following are thus based on a merging of rawinsonde and SIRS retrieval data; but it has not always been possible to ascertain how much of the SIRS data was actually used in the objective analysis.

For reasons explained in section 2, it has not been possible to evaluate the impact of SIRS data on objective stratospheric analysis for periods subsequent to June 2 in

as straightforward a manner as for earlier periods. However, it is of interest to consider briefly objective stratospheric analysis based both on SIRS data and rawinsonde data. The period of July 14–16, 1969, was chosen for a comparison of synoptic analyses with those of the period May 27–29. The method of obtaining SIRS retrievals for this period was significantly different from that used in the earlier period. In the NMC analysis system, the 850-mb tie-on had come into use for all standard levels. (Only

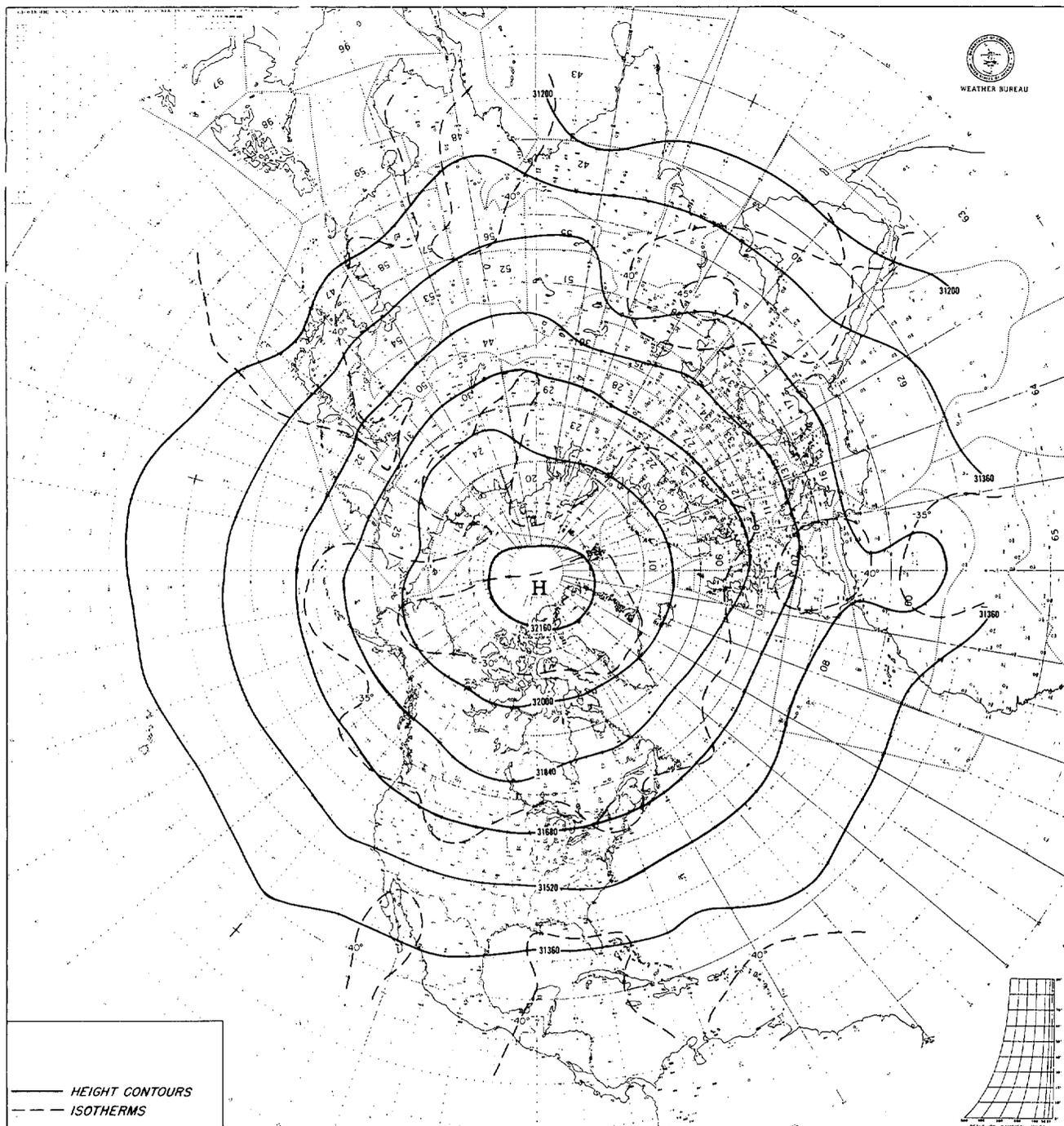


FIGURE 9.—Objective (computerized) analysis of the 10-mb height and temperature fields for July 16, 1969.

much later, in autumn 1969, did the 100-mb tie-on replace the 850-mb tie-on at stratospheric levels.)

Analyses I and II were performed as described in section 2, except that the SIRS heights were tied on to objectively analyzed 100-mb heights. Figure 8 shows the 10-mb SIRS chart (analysis I) for July 16, 1969, and includes the minor changes produced by analysis II (utilization of rawins with SIRS retrieval data). Figure 9 shows the corresponding analysis III—objective analysis, including SIRS retrieval heights tied on at 850 mb.

No objective analysis of radiosonde data with SIRS data tied on at 100 mb was available for this period. In view of the fair agreement between figures 8 and 9, it may be asked whether the 100-mb tie-on is really superior to the 850-mb tie-on. However, as we have shown in constructing graphs like that of figure 6, the 100-mb tie-on gives a smoother profile with fewer spurious changes in slope than the 850-mb tie-on. Hence, the 100-mb tie-on has been judged to have greater stability and internal consistency. These features would not be obvious in a two-dimensional

analysis, objective or subjective, where smoothing is performed.

The consistent bias toward lower SIRS retrieval heights over North America, noted in connection with the May series, continues to be evident as seen in a comparison of figures 8 and 9. Also, the warm ridge over North Africa is supported only by SIRS retrievals made near local noon. It is suspected that the Smith-Woolf retrieval technique yields less accurate results over anomalously warm and anomalously cold surfaces; and this ridge, unsupported by wind data and not based on continuity, may be fictitious.

4. CONCLUSIONS AND FURTHER DISCUSSION

The analyses presented here indicate that, in spite of the many associated problems, satellite-derived temperature and height profiles may be used to construct Northern Hemisphere stratospheric synoptic charts for summer that closely resemble charts based exclusively on rawinsonde data.

Conclusions may then be summarized.

1. Consistent summertime Northern Hemisphere stratospheric synoptic height charts for 50, 30, and 10 mb may be prepared from the Smith-Woolf SIRS retrievals. Improvement in the details of the charts results from concurrent use of wind observations.
2. Charts based on 100-mb tie-ons are judged to be superior to those based on 850-mb tie-ons. Consequently, analyses at levels above 100 mb now make use of the 100-mb tie-on.
3. SIRS retrievals provide an important increase in the data base over oceans, tropical areas, etc.
4. At stratospheric levels, the SIRS heights are much more consistent with each other than are radiosonde heights, and they may be used with much less smoothing.
5. Since consecutive Nimbus 3 tracks are separated by 27° of longitude, there is a wide longitudinal separation of data points, especially at low latitudes. This problem may be partially overcome by extending the time period over which SIRS retrievals are introduced into the analysis—provided synoptic changes are slow, as in summer. Future satellites with lateral scanning should reduce the magnitude of this problem.

Further study of the effects of introduction of SIRS retrievals into objective stratospheric analyses will be made for other seasons. It is especially important to investigate effects in winter when gradients are strongest and changes most rapid. Various diagnostic energy programs will be utilized to determine whether there is any consistent amplification of certain wave numbers in the decomposition of the height field that might be traced to the uniform longitudinal spacing of the satellite tracks.

REFERENCES

- Finger, F. G., Woolf, H. M., and Anderson, C. E., "A Method for Objective Analysis of Stratospheric Constant-Pressure Charts," *Monthly Weather Review*, Vol. 93, No. 10, Oct. 1965, pp. 619-638.
- Goddard Space Flight Center, *Nimbus III User's Guide*, National Aeronautics and Space Administration, Greenbelt, Md., 1969, 238 pp.
- Hilleary, D. T., Heacock, E. L., Morgan, W. A., Moore, R. H., Mangold, E. C., and Soules, S. D., "Indirect Measurements of Atmospheric Temperature Profiles From Satellites: III. The Spectrometers and Experiments," *Monthly Weather Review*, Vol. 94, No. 6, June 1966, pp. 367-377.
- McInturff, Raymond M., and Finger, Frederick G., "The Compatibility of Radiosonde Data at Stratospheric Levels Over the Northern Hemisphere," *ESSA Technical Memorandum WBTM-DATAC 2*, U.S. Department of Commerce, Environmental Science Services Administration, Silver Spring, Md., Dec. 1968, 61 pp.
- Smith, William L., "Statistical Estimation of the Atmosphere's Geopotential Height Distribution From Satellite Radiation Measurements," *ESSA Technical Report NESC 48*, U.S. Department of Commerce, National Environmental Satellite Center, Washington, D.C., Feb. 1969, 29 pp.
- Smith, W. L., Woolf, H. M., and Jacob, W. J., "A Regression Method for Obtaining Real-Time Temperature and Geopotential Height Profiles From Satellite Spectrometer Measurements and Its Application to Nimbus 3 'SIRS' Observations," *Monthly Weather Review*, Vol. 98, No. 8, Aug. 1970, pp. 582-603.
- Twomey, S., "Indirect Measurements of Atmospheric Temperature Profiles From Satellites: II. Mathematical Aspects of the Inversion Problem," *Monthly Weather Review*, Vol. 94, No. 6, June 1966, pp. 363-366.
- Wark, D. Q., and Fleming, H. E., "Indirect Measurements of Atmospheric Temperature Profiles From Satellites: I. Introduction," *Monthly Weather Review*, Vol. 94, No. 6, June 1966, pp. 351-362.
- Wark, D. Q., and Hilleary, D. T., "Atmospheric Temperature: Successful Test of Remote Probing," *Science*, Vol. 165, No. 3899, Sept. 19, 1969, pp. 1256-1258.

[Received February 9, 1970; revised April 23, 1970]