U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 220

Impact of Remotely Sensed Data on Numerical Weather Prediction

Ronald D. McPherson
Development Division

JULY 1980

I. Introduction

The space-based remote sensing observation systems that have contributed so heavily to the expansion of the global data base require a sensor platform--an artificial satellite--to be placed into orbit by a powerful rocket, and then extensive ground facilities to acquire and process the data. To establish and operate such a system is very expensive; perhaps not so much as a radiosonde network yielding the same coverage, if such were possible, but nevertheless still very expensive. Once such systems had been established enquiries as to whether the usefulness of the data justified the cost of acquiring it were not long in coming. Managers, in particular, have been concerned about the cost-effectiveness of remotely-sensed data partly to evaluate past decisions to support those systems, and partly to determine whether large investments in proposed future systems would be prudent. Numerical weather prediction scientists clearly have a stake in this question, since their voices have been loudest in the cry for more data. Now that these data are available, it is important to address the scientific question of whether the remotely-sensed data contribute positively to the improvement of weather forecasts, and if not, to determine whether the fault lies with the data or with the methods of their use.

Several examinations of this question have appeared in the literature, dating to the middle of the 1970's. All save one have dealt with remote sounding data. Ohring (1979) has recently published a review of the remote sounding impact tests that have been conducted by various groups in several countries, including the U.S. National Meteorological Center. This lecture is a summary of the NMC impact test results, including both remote temperature sounding data, and the one exception referred to above, a test of cloud-motion wind vectors. The following section briefly discusses each of the several impact tests conducted by NMC, beginning with a 1973 examination of the early temperature soundings provided by the Vertical Temperature Profile Radiometer (VTPR) devices on board a succession of satellites. These soundings were used operationally from 1972 until they were superceded by the TIROS-N soundings in March 1979. The third section compares the NMC results to those from some other groups, and presents a tentative explanation for the differences that arise from the comparison. Some speculations on the future data base, and its likely impact on numerical weather prediction, are offered in the concluding section.

II. Data Impact Testing at NMC*

All of the impact tests to be described in this section, although differing in detail, followed the same general experimental design. The NMC data assimilation system operational at the time of the test was executed (not in real time) in two modes: one in which the subject

---

*Much of the material in this section parallels the paper by Tracton and McPherson (1977).

of the impact test was included in the data base (SAT mode), and the second identical in every way except the subject data set was excluded (NOSAT mode). Differences between analyses produced by the two modes then constitute the impact of the subject data set on the analyses. From selected times during the test period, extended numerical predictions were made from the SAT and NOSAT analyses with the prediction model operational at the time of the test. Differences between these forecasts and their verification scores represent the impact of the data set on the forecasts. Obviously, if the forecasts from SAT mode analyses exhibit better scores than those from NOSAT analyses, the impact of the data set is positive.

a. VTPR test (Bonner, et al., 1976)

The subject data set for this test was the VTPR temperature sounding data referred to earlier. Limited vertical resolution and serious vulnerability to cloudy conditions were the chief limitations of this sounder. Radiance measurements were made at only seven frequencies, and because of the overlapping of the layers emitting at each frequency, the seven measurements were equivalent to approximately only three independent temperatures. Furthermore, the frequencies were all in the infrared portion of the spectrum so that reliable soundings were possible only in clear areas. Retrievals were made statistically and only over water. Thus both the vertical resolution and the coverage were rather severely limited. Both constituted serious handicaps to good data utility.

SAT and NOSAT modes were produced independently of each other for a 30-day period in March and April, 1973. Both had access to the conventional data base, which over the oceans was composed of surface ship observations, aircraft winds, cloud-motion winds, and a few ship and island radiosondes. In addition, both modes included subjectively-generated "bogus" data at the surface and the 300 mb level. The NOSAT bogus data were generated by analysts not having access to the VTPR data.

The data assimilation system operational in March 1973 consisted of the Shuman-Hovermale (1968) six-layer primitive equation model and the successive-corrections objective analysis method designed by Cressman (1959). Each 12 h the hemispheric forecast was updated by data with a cutoff time of about 10 h. For the impact test, independent sequences of 60 analyses each were produced. From nine of those pairs, forecasts to 48 h were made also using the Shuman-Hovermale model. Four features of the 1973 assimilation system mentioned in previous lectures should be reemphasized here:

1) The updating sequence began at 1000 mb and 300 mb and worked upward and downward, respectively, to the middle levels; the influence of bogus data was thus spread through the entire model troposphere.

2) No capability existed for discriminating between data types; all data - radiosondes, remote soundings, and bogus - received equal consideration.

3) The analysis of the geopotential height field was used in the balance equation to provide a background field for the wind analysis. If the remote sounding data affected the height analysis, the balance-equation procedure assured that they would also affect the wind analysis. Thus, there was little possibility of the rejection of the sounding data as a result of the geostrophic adjustment process discussed in the second and third lectures.

4) Both assimilation system and prediction model were applied only to the Northern Hemisphere. This test, then, did not address impact of sounding data in the Southern Hemisphere.

On the average, about 100 VTPR reports entered each analysis. These resulted in rms differences in the 500 mb height fields of only 15m in the Atlantic and 25 m in the Pacific. Such differences are small enough to have been caused by the difference between the bogus generated for each mode. Analysis differences resulting from the inclusion of VTPR were therefore regarded as not significant, although Bonner, et. al. noted a tendency for the SAT mode analyses to have less amplitude than their NOSAT counterparts.

Not surprisingly, the forecasts produced from the SAT and NOSAT analyses displayed little difference in skill. Figure 1 displays the 500 mb S1 score, a measure of the accuracy of gradients, for the NOSAT forecasts on the ordinate and the SAT forecasts along the abscissa. Along the 45° line, the scores are equal; points falling above the line represent a lower (better) score for the SAT mode than the NOSAT mode - positive impact. Below the line represents negative impact. In this diagram the S1 scores for Europe and North America and for 36h and 48h forecasts are combined. Most of the points fall close to the null-impact line. There is a slight advantage for the SAT-mode forecasts when all scores are averaged; however, this advantage is the sum of both positive and negative contributions rather than being small but consistently positive.

b. Data Systems Test - Northern Hemisphere Summer (Tracton, et al., 1980)

In 1975-1976, several U.S. institutions conducted a joint exercise called the Data Systems Test (DST) as a trial, or practice, for the Global Weather Experiment. One of the major systems being tested was the experimental sounder flown on the Nimbus-6 spacecraft. This sounder, considered the prototype for the now-operational TIROS-N series, had both more infrared channels to improve its vertical resolution and microwave channels to reduce the vulnerability to clouds. It thus represented an improvement over the VTPR instrument, at least in theory.

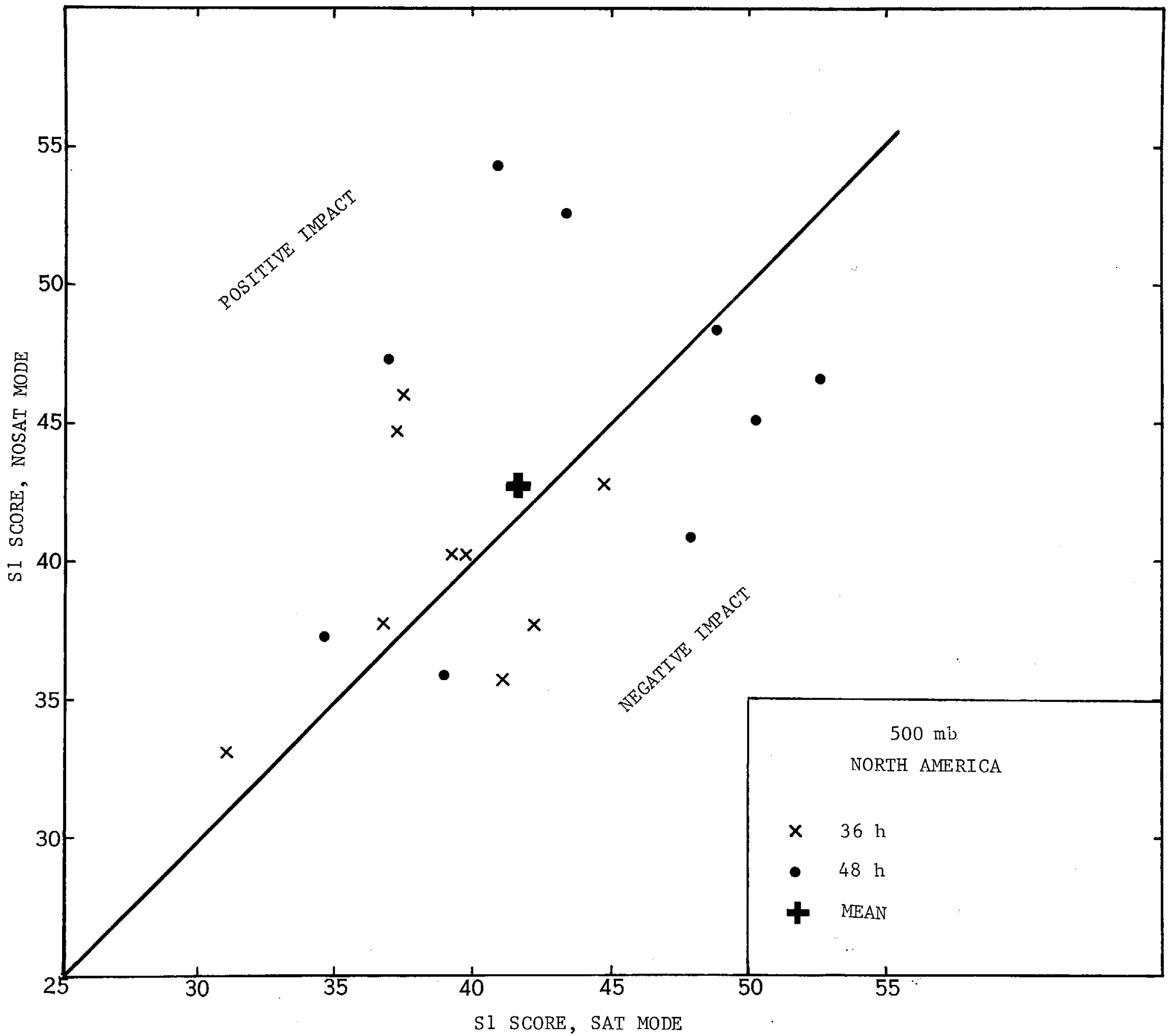

Figure 1. Impact diagram for the 1973 VTPR impact test. See text for explanation.

SAT and NOSAT modes were generated for the period 18 August - 4 September 1975. The operational data assimilation system at that time consisted of the global finite difference prediction model (Stackpole, et al., 1974) referred to in earlier lectures, but with eight layers instead of nine in the vertical. Every 12h it was updated using the global spectral objective analysis method devised by Flattery (1971). The data assimilation system was therefore global, but the operational prediction model used for extended prediction was still the hemispheric Shuman-Hovermale six-layer model. The SAT mode included all of the conventional data, plus special observing systems unique to the DST (Desmarais, et al., 1980) as well as both VTPR and Nimbus-6 soundings. The NOSAT mode was identical except that both VTPR and Nimbus-6 soundings were excluded from the Northern Hemisphere.* No bogus data were allowed in either mode. Forecasts to 72h were made on 10 of the days using the Shuman-Hovermale model.

As in the VTPR test, a few points are worth noting concerning the assimilation system used in this test:

1) The spectral objective analysis method is a "credulous" one (Phillips, 1976) which reflects the available data to the greatest degree possible for its resolution. Over oceanic areas where only remote sounding observations of the mass field are available, the analysis represents the sounding data quite accurately, without regard to errors in the data.

2) The wind law inherent in the spectral objective analysis method is such that where only remote temperature soundings are available, the analysis will effect a correction to the background wind field tending to bring the wind analysis into quasi-geostrophic equilibrium with the mass field. However, the mass-motion constraint is probably weaker in total effect than that associated with the successive-corrections method used in the VTPR test. The possibility of partial rejection of remote temperature sounding data through the geostrophic adustment process is somewhat larger in this test than in the previous one.

3) Although the test was conducted in the Northern Hemisphere summer, it was an unusually active period meteorologically. Potential for impact was therefore not suppressed by the customary weak gradients and disorganized synoptic-scale systems typical of summer.

4) As in the previous test, the impact of remote sounding data was considered only in the Northern Hemisphere.

Examination of the differences between the SAT and NOSAT mode analyses were once again quite small; for example, rms 500 mb height differences over the entire hemisphere and averaged over all cases amounted to only 9.4 m. Largest differences were 60-90 m, and typically the SAT mode was

---

* At least some remote sounding data in the Southern Hemisphere were considered essential for the stability of the data assimilation cycle. Thus the impact of the sounding data in the Southern Hemisphere was large, but not measurable.

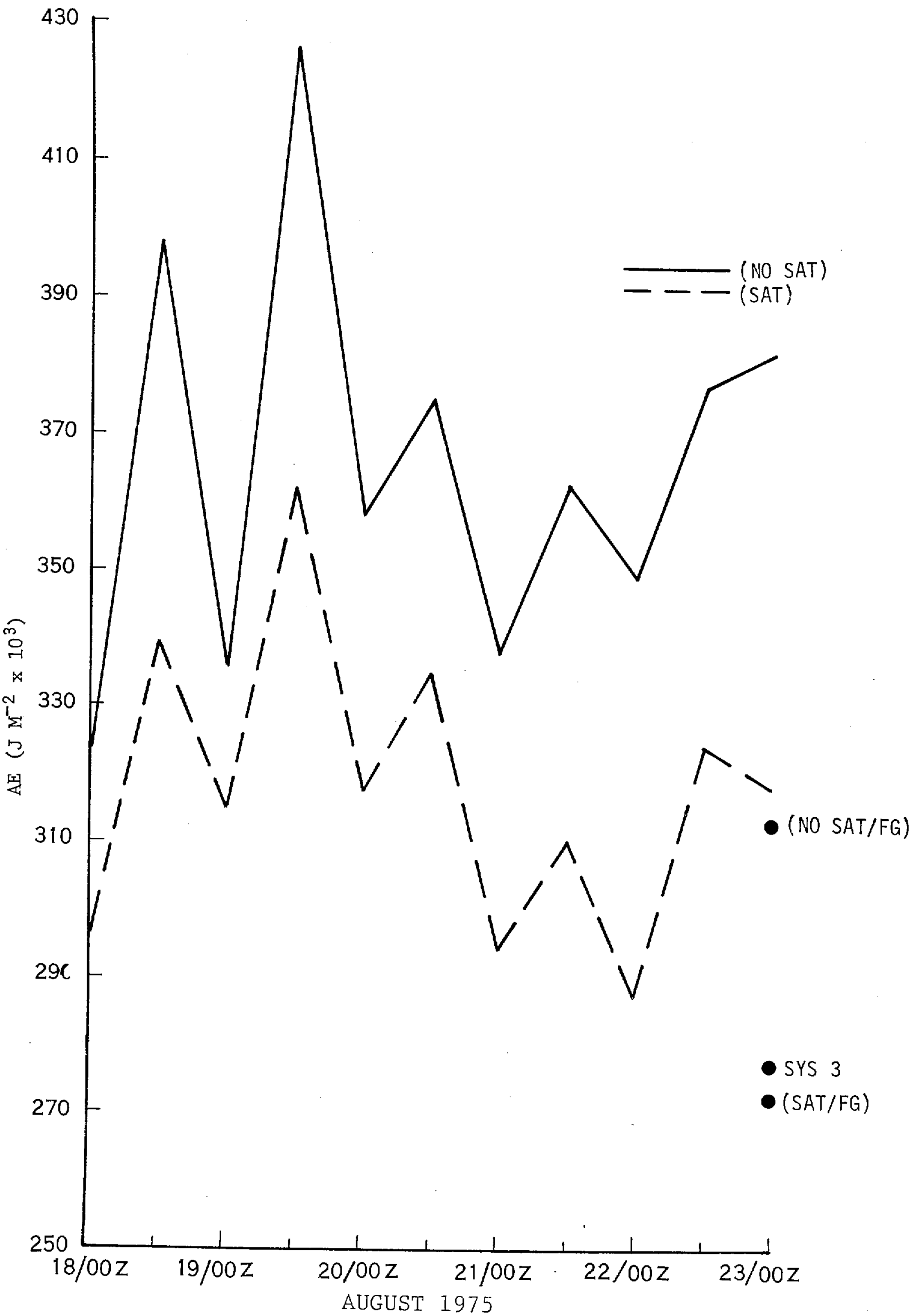

Figure 2. Eddy available energy as a function of time for the DST/summer impact test. After Tracton and McPherson (1977).

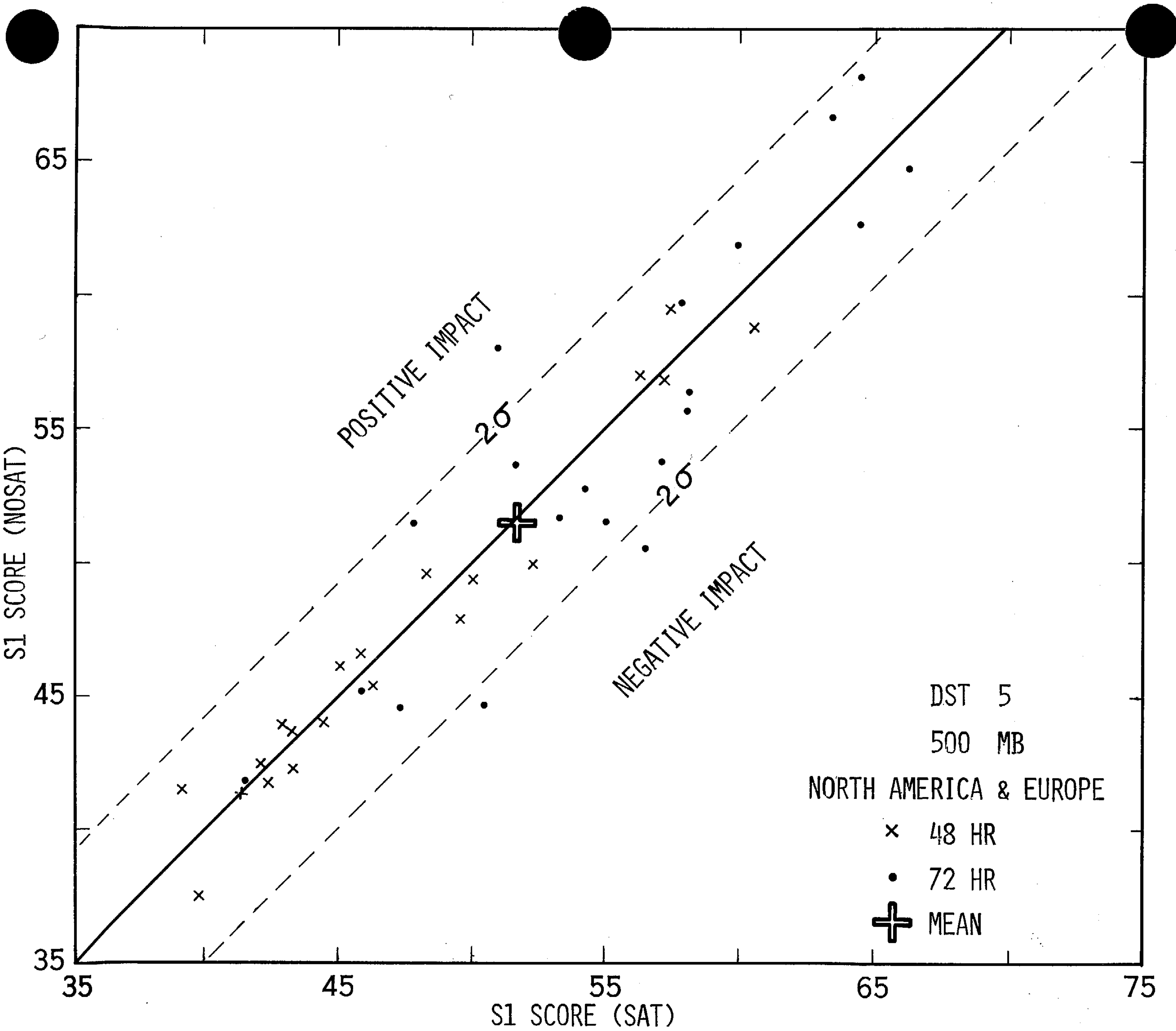

Figure 3. Impact diagram for the DST/summer test. After Tracton et al., (1980a).

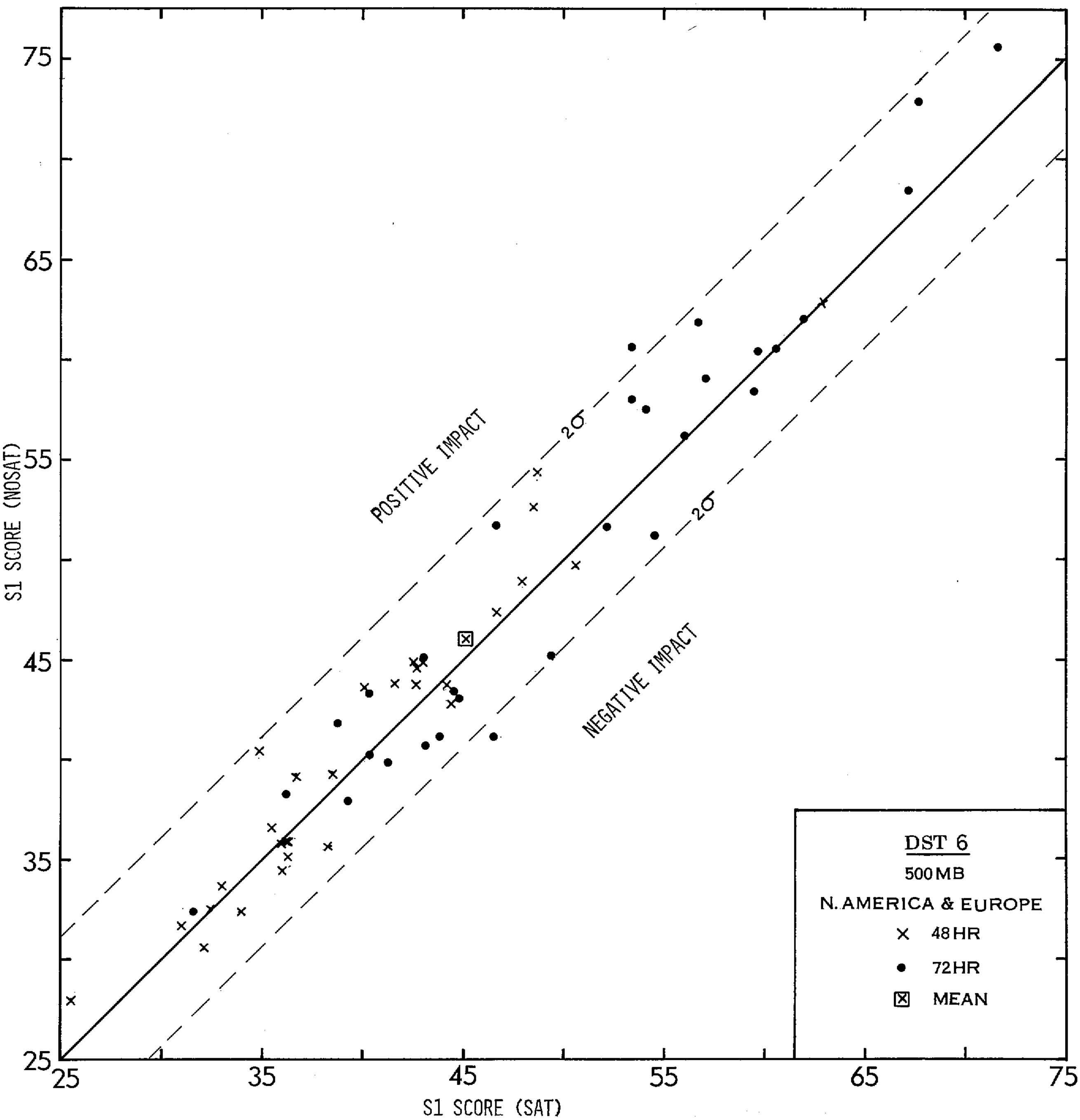

Figure 4. Impact diagram for the DST/winter test.
After Tracton et al., (1980a).

warmer (larger geopotentials) than the NOSAT. Furthermore, a systematic investigation confirmed the tendency noted in the VTPR test for the SAT mode to exhibit less amplitude of weather systems. Figure 2 depicts the eddy available energy as a function of time for the two modes. The consistently lower value in the SAT mode is evident. Evidently, however, the Shuman-Hovermale forecast model, with its relatively coarse resolution, was not responsive to analysis differences of this sort. Figure 3 presents the same kind of impact diagram as Figure 1, although for a slightly different mix of forecasts. Once again, the scores definitely tend to be grouped along the null-impact line. The average in this experiment is slightly negative, but as in the VTPR test it is composed of small contributions of both signs. The significance of the slight negative impact obtained in this DST/summer test is neither greater nor smaller than the slight positive impact obtained in the VTPR test.

c. Data Systems Test - Northern Hemisphere Winter (Tracton, et al., 1980a)

During February and early March, 1976 the experiment outlined in the previous section was repeated, so as to examine remote temperature sounding impact in the Northern Hemisphere winter. Several attempts were necessary before a satisfactory experiment was achieved. The last attempt - reported here - was conducted in 1977, after several modifications of the data assimilation system had been effected. For the purposes of this paper the most important was the decrease of the update interval from 12 to 6 hours. Asynoptic data, such as remote sounding data, were then stratified in 6h time blocks and treated as synoptic at the central time of the block. Thus the error of asynopticity was at most 3h rather than the 6h of the previous test.

Over the period of the test, rms differences between the SAT and NOSAT analyses were larger than in the summer experiment; at 500 mb the height difference over the Northern Hemisphere was 22.6m, compared to 9.4m in the summer. Individual centers of 500 mb height difference of 100 m were not uncommon during the winter test, whereas no difference in excess of 90 m occurred during the summer test. The systematic difference in the amplitudes of weather systems also appeared in the winter test.

Forecasts to 84h were made on 15 days, again using the Shuman-Hovermale model. Figure 4 corresponds to Figures 1 and 3 for the DST/winter experiment. As in the previous tests, the scores group around the null-impact line. On the average, the impact is positive; but the lack of consistency evident in the two previous tests is also present here.

d. Cloud-Motion Wind Test (Tracton et al., 1979)

In November, 1978 a seven-day period was selected for the execution of a short test of the utility of cloud-motion wind vectors. The global data assimilation system based on statistical interpolation, operational for slightly more than one month, was used to produce the SAT/NOSAT modes.

Cloud-motion wind vectors were available at the time of the test from the two U.S. geostationary satellites and one operated by the Japan Meteorological Agency. The SAT mode assimilation cycle contained data from all three, as well as the remainder of the operational data base. In the NOSAT mode, only data from the two U.S. satellites were excluded. It should be reemphasized that these data are primarily available at around 850 mb and 250 mb. Their only competition in the low levels are surface ships, which at the time of this test were not permitted to directly affect the upper air analysis except through the redefinition of the vertical coordinate. At upper levels, aircraft data are generally available at the same levels as the upper cloud motion vectors. However, the data producers avoid areas near major aircraft routes, wisely preferring to supplement the aircraft data rather than compete with it. Typically, then, there is little or no competing wind data in the immediate vicinity of cloud-motion winds. Considerable potential thus exists for cloud motion winds to register an impact on analyses and forecasts.

SAT and NOSAT analyses were produced each 6 h by the NMC assimilation system, the only difference being the presence of the U.S. cloud motion winds in the SAT mode. These data are produced three times each day, nominally valid at 0000 GMT, 1200 GMT, and 1800 GMT, and provide coverage with maximum longitudinal extent from 20 W to the dateline, and between 50N and 50S.

Examination of the SAT and NOSAT analyses revealed large differences in the winds - up to 30 $msec^{-1}$ rms in the vector wind - especially in low latitudes and high levels and in the Southern Hemisphere. Figures 5 and 6 represents the NOSAT vector winds and the SAT/NOSAT vector differences at 250 mb on 7 November 1978, 0000 GMT same five days after the beginning of the experiment, while Figure 7 is the vector difference for the 850 mb level. Note that the vector wind differences are well-organized, indicating that the cloud motion winds imply coherent (as opposed to random) changes in the background wind field.

Partly as a result of the shape of the vertical wind forecast error correlation, and partly through the five days of assimilation, the influence of the data inserted at essentially two levels - 850 mb and 250 mb has spread to the intermediate levels. Figure 8 is the same as Figures 6 and 7, but for the 500 mb level. Note that the same general pattern apparent in Figure 6 also appears in Figure 8, but with smaller amplitude.

Another important effect caused by the insertion of cloud motion wind data is the resultant increase in the kinetic energy of SAT mode analyses relative to the NOSAT mode. This could be seen synoptically in stronger subtropical jet streams and general increase in circulation around centers defined by the winds.

Forecasts were made from only one pair of initial analyses, 0000 GMT 7 November 1978. The particular week selected for the test was rather unchanging with respect to synoptic scale events in the Northern Hemisphere. By 0000 GMT on 7 November, a cyclonic circulation which had been nearly stationary near 20N, 120W since the start of the test began to accelerate

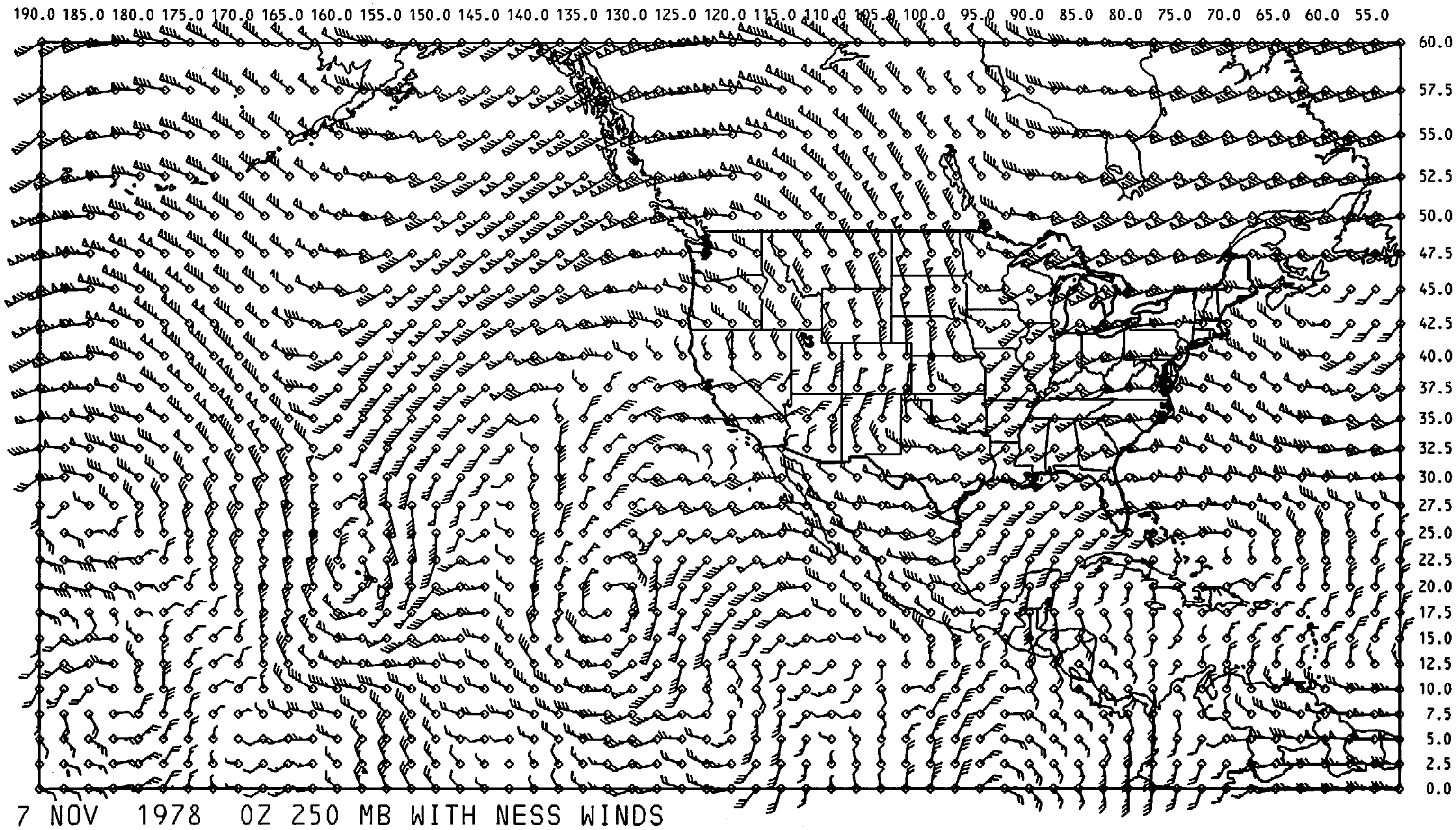

Figure 5. 250 mb vector wind field (kts), SAT mode, for 0000 GMT 7 November 1978.

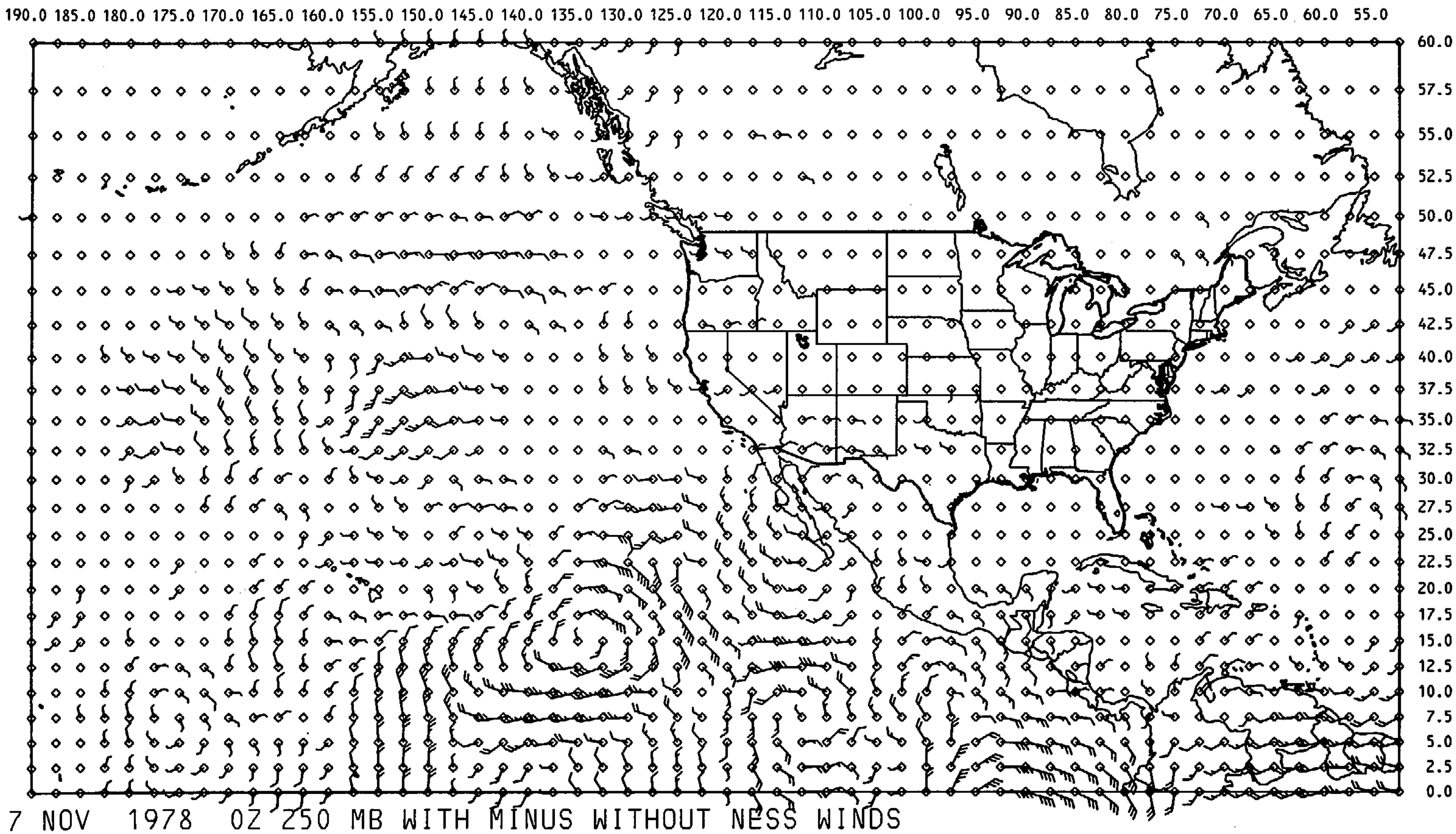

Figure 6. 250 mb vector wind difference (kts), SAT minus NOSAT, for 0000 GMT 7 November 1978.

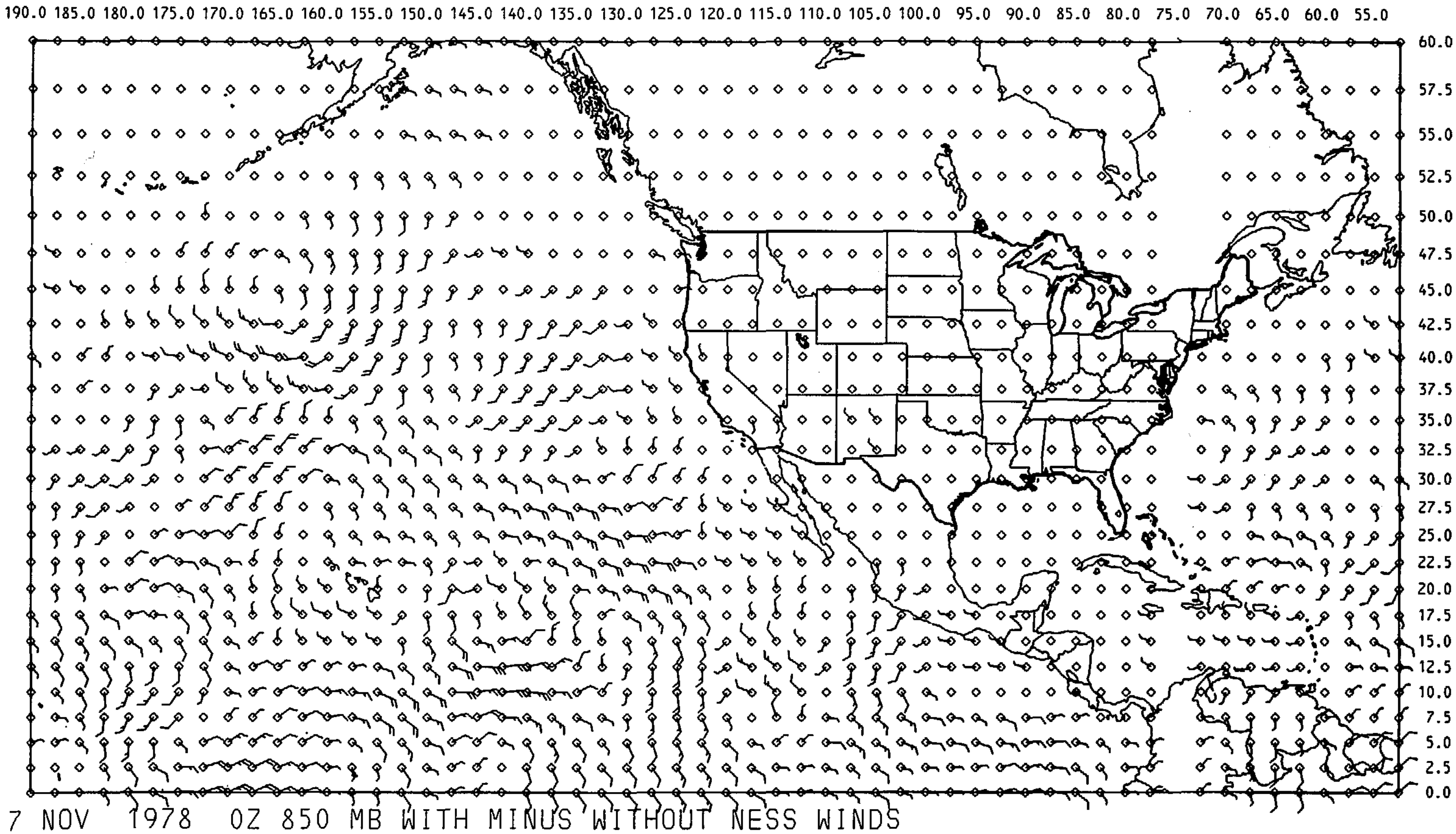

Figure 7. Same as Figure 6, but for 850 mb.

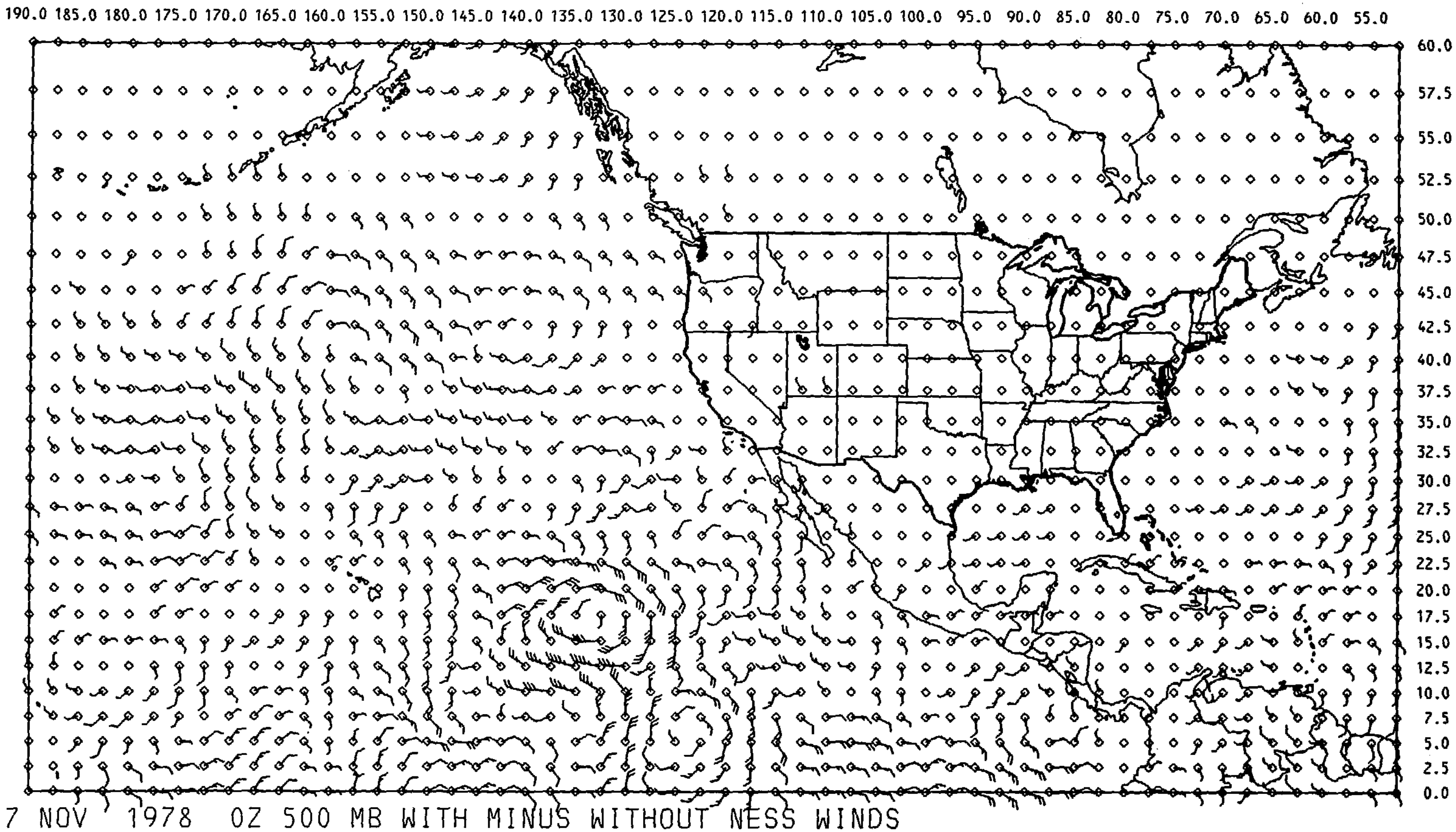

Figure 8. Same as Figure 6, but for 500 mb.

northeastward and three days later had moved into the central U.S. Because of the relatively stagnant situation, it was decided that additional forecasts would not constitute additional independent information.

Table 1 illustrates impact of cloud-motion winds on the single pair of forecasts over western North America produced by the Shuman-Hovermale model. At 84h, all categories except the 850 mb wind exhibit better scores for the SAT mode than the NOSAT mode.

Table 1. Verification of SAT and NOSAT 84 h forecasts against western North American radiosonde data.

	S1		RMS ht (m)		RMS (V) (m sec^{-1})	
	SAT	NOSAT	SAT	NOSAT	SAT	NOSAT
850	60.9	66.1	42.3	48.1	8.2	8.2
500	63.2	64.4	81.4	86.8	16.3	17.0
250	61.0	67.1	139.0	156.9	18.8	23.2
100	77.2	81.6	102.6	116.0	13.2	15.2

e. Discussion of NMC Impact Test Results

The single abbreviated test of cloud-motion wind vectors suggested that these data are helpful in the analysis. In every instance, insofar as sound judgement could be rendered, their inclusion produced a more reasonable analysis than was obtained without the winds. In the single forecast comparison, the more reasonable analysis led to a clear improvement in the subsequent forecasts. Even if based on only one experiment, the wind results are very encouraging, especially in view of the nature of the geostrophic adjustment process.

On the other hand, three tests of the utility of remote temperature sounding data conducted at NMC between 1973 and 1977 have shown essentially null impact on Northern Hemisphere numerical predictions. Common results from all three tests indicate that SAT mode analyses have less amplitude than their NOSAT counterparts, and that differences between forecasts made from the two sets of analyses are small and of inconsistent sign.

The null-impact test results require an explanation. Tracton and McPherson (1977) discuss five possible reasons.

1. Remote sounding data are superfluous. In the Northern Hemisphere, large-scale flow patterns are usually defined rather well by the combination of radiosonde, aircraft, cloud-motion, and surface data with an accurate prediction model capable of projecting information from data-rich to data-sparse areas. This leaves relatively little opportunity for remote temperature sounding data to contribute to improved analyses. In the Southern Hemisphere, the opportunity is undoubtedly much greater.

2. Impact tests run on the wrong cases. If the previous argument is valid, then it would be relatively easy to conduct impact tests on cases where little potential for impact exists and relatively difficult

to select cases where the potential is significant. Such cases do arise from time to time in the Northern Hemisphere; Phillips (1980) has discussed one such occasion, 1200 GMT 21 October 1979. In this case, an explosively intensifying cyclone near 40N, 140W was not adequately depicted in the operational NMC analyses. Remote temperature sounding data were prevented from affecting the analysis by processing delays; but when the data did become available it was clear that they would have improved the analysis had they been available in time. It is not clear that this improvement would have led to better forecasts downstream over North America, however. The subsequent history of this storm was to complete its occlusion rapidly, and then meander about in the Gulf of Alaska for the next several days, slowly decreasing in intensity.

3. Errors in the remote temperature sounding data. Previous mention has been made of the various errors present in remote temperature sounding data. Nevertheless, the data are reasonably accurate most of the time, if not as accurate as radiosonde measurements. Therefore, while it would not be prudent to replace the radiosonde network where it presently exists in favor of remote sounding data, the latter may nevertheless be used to advantage where the competition is not so severe. This occurs to some degree over Northern Hemisphere oceans, and occasionally to a spectacular degree, as in the 21 October 1979 case. It is undoubtedly true virtually everywhere in the Southern Hemisphere. However, the characteristics of the data will appear in the analysis of the data; specifically, SAT mode analyses will exhibit less amplitude of weather systems. This may be important in climate and general circulation studies.

4. Forecast models are not sufficiently responsive to analysis differences. In none of the remote temperature sounding impact tests conducted at NMC did evidence emerge suggesting an underestimate of amplitude in predictions made from SAT-mode analyses, although this was a constant characteristic of the analyses. For some reason, then, the prediction model did not respond to this systematic difference between SAT and NOSAT modes. We might applaud this lack of response, since an accurate response would have produced a lower-amplitude--a poorer--forecast. On reflection, though, if the model does not respond to undesirable differences, it may not respond to desirable ones, either. The sluggish response may be due to poor spatial resolution of the prediction model.

5. Assimilation models are not adequate. Alternatively, it may be that the temperature sounding data are not properly assimilated, in the sense that a wind field compatible with the sounding data is not induced by the assimilation system. Geostrophic adjustment during the early part of the forecast would then result in the mass analysis being modified back toward compatibility with the pre-existing wind field, reducing the impact of the sounding data. The present operational assimilation system's ability to discriminate between data of different quality functions reasonably well. However, its ability to induce appropriate corrections to the motion field from mass data has not been satisfactory. Considerable effort is presently being invested in research to improve this situation.

Table 2. Impact of satellite soundings on rms errors of 48 h 500 mb geopotential height forecasts (m). (Positive impact represents reduction in rms height error.) After Ohring (1979).

Source	Verification Area	Season	Data	Number of forecasts	NOSAT	SAT	Impact
Desmarais et al. (1978)	Eastern N. America	Summer	V + N	10	45.8	47.9	-2.1
	Western N. America				43.5	45.0	-1.5
	N. America	Winter	V + N	15	65.0	63.7	1.3
Halem et al. (1978)	N. America	Winter	V + N	11	77.9	72.8	5.1
Bonner et al. (1976)	N. America	Spring	V	9	63.4	60.6	2.8
Atkins & Jones (1975)	Europe, Atlantic, Canada, NE USA	Spring	V	7	94.0	88.0	6.0
Druyan et al. (1978)	Europe, Mid-East, N. Africa						
	Experimental VTPR	Winter	V	26	70.0	67.0	3.0
	Operational VTPR	Winter	V	13	69.3	67.3	2.0
Kelly (1977)*	Australia	Winter	V	9	49.0	43.6	5.4

V = VTPR soundings, N = Nimbus-6 soundings
*36 h forecasts.

Even when a satisfactory solution to this problem is achieved, however, it by no means will result in immediate positive impact of remote sounding data, for all of the reasons discussed in the preceding paragraphs.

To summarize: most of the time an accurate prediction model providing a good background field, tcgether with available data exclusive of remote temperature soundings are sufficient to define the major circulation characteristics in the Northern Hemisphere. Therefore, the potential for sounding data impact is not as great as in the Southern Hemisphere. The addition of sounding data potentially contributes negatively to the analysis, in that the amplitudes of weather systems are underestimated. Sounding data may also contribute positively on occasion, when for example a flow feature has not been described by the other elements of the data base. However, NMC impact tests have shown that the forecast models used in the tests do not respond very well to either type of contribution. The result thus far has been essentially null impact of temperature sounding data on operational forecasting in the Northern Hemisphere.

Several other groups have conducted remote temperature sounding impact tests in recent years. As noted previously, Ohring (1979) has reviewed those that have appeared in the literature, either as technical reports or published articles. His compilation of the impact tests, including those described earlier in this lecture, is presented in Table 2.

Ohring summarizes the Table as follows:

> "Our survey of the impact of satellite soundings on numerical forecasts indicates that the current satellite data as used in current analysis and forecast models produce, on average, a small improvement in the numerical forecasts...However, this small average impact is based not on consistent small positive impacts in each forecast, but rather on an average of forecasts with positive impact, negative impact, and no impact. The small effect of the satellite data is also evidenced by almost all qualitative and synoptic evaluations of their impact."

NMC's results are certainly in agreement with Ohring's conclusion.

III. System Dependency of Impact Tests

An important fact has emerged from the various remote temperature sounding impact tests: the impact obtained is a strong function of the system used to produce the impact. Let us consider two absurd extremes. For the first, let us imagine that the assimilation system consists of a 50-layer prediction model with the equivalent of 0.5° latitude resolution, being updated hourly by continuous radiosonde ascents from stations at every one degree latitude-longitude intersections over the entire earth. At any given hour, the addition of remote temperature sounding data to this extensive data base is not likely to effect an improvement in the existing numerical representation of the atmosphere. Hence, the remote sounding data would have no opportunity for positive imapct.

At the other extreme, we assume that the assimilation system consists not of a prediction model but of climatology, and no data over the oceans other than remote sounding data. Even with the errors characteristic of the latter, they still are far closer to the actual state of the atmosphere at any time than is climatology. Thus, in this system, the remote sounding data have ample opportunity to contribute positively.

If impact tests are then conducted with these two extreme systems--one extremely bad, the other extremely good--it will be found that the same data have a large positive impact in the one, and a null impact in the other. That is, the result of the impact test is highly system-dependent.

Therefore, impact test results must be judged cautiously, mindful of the absolute accuracy of the background field provided the assimilation system exclusive of the data set being tested. Examples of this may be found in Table 1. More detailed discussion is available in Desmarais et al. (1978), and Tracton et al. (1980b).

IV. Speculations on the Future Data Base

Remote sensing technology, either surface-based or space-based, is clearly the wave of the future, as far as providing the data base for large-scale numerical weather prediction is concerned. However, partly because of the above-mentioned small impact of temperature soundings, the apparent large impact of cloud-motion winds, and a greater understanding of the geostrophic adjustment process, many numerical modelers have begun to ask that the remote sensing community emphasize wind observation systems. Two such systems are under development.

1) Optical Lidar.

This sensor is basically a laser radar, emitting an extremely narrow beam with precise pulse length. The beam is reflected off its target and returns to the transmitter. Information on the power return and its delay, the Doppler shift of the signal, and the pulse length can be used to determine the motion of the target and its approximate location in the atmosphere. Systems now under development use atmospheric aerosols--dust, etc.--as scattering targets. A surface-based system is presently being tested in Colorado. It will provide nearly continuous (in time) profiles of wind from a few hundred meters to several thousand meters above the earth's surface. Deployment of this system at a few operational locations near major United States cities appears likely by the mid-1980's.

A space-based version of the optical lidar system is expected to provide vertical wind profiles from orbiting spacecraft with resolution of about 1 km. Coverage and horizontal resolution will be comparable to present temperature sounders. Developers of this system are promising remarkable accuracy--about 2 m sec^{-1}. Operational status of this system is envisioned in the early 1990's.

2) Scatterometer. The space-based optical lidar promises to provide wind profiles through the atmosphere to as low as about 1 km above the earth's surface. However, accuracy of the lowest measurements will be adversely affected by clouds and by the larger path length from aerosol to satellite. An instrument which can partially compensate for these

deficiencies is the scatterometer. This is basically a radar which responds to capillary-scale waves on the ocean's surface. Through empirical relationships, the returned radar back-scattering coefficient can be used to infer the wind speed for a range between about 4 m sec^{-1} and 25 m sec^{-1}. Lower wind speeds do not produce sufficient signal return, and at wind speeds in excess of 25 m sec^{-1} the sea surface is too chaotic to yield a reliable return. Wind direction can be inferred if a sufficient number of measurements from different angles of incidence can be made over the same ocean area.

A prototype scatterometer was flown on the U.S. oceanographic satellite SEASAT, launched in June, 1978. The satellite failed after 99 days in orbit, but preliminary evaluation of the data collected during its lifetime is most promising. Indications are that the marine surface wind speed can be determined to within about 2 m sec^{-1} over the 4-25 m sec^{-1} range. Direction can be determined to within about 20° once a four-fold directional ambiguity is resolved. The ambiguity results from the SEASAT scatterometer having only two antennae scanning on each side of the orbital path, so that a given area of ocean surface was sensed only twice; once by a forward-looking antenna and once by the backward-looking one. From these signals alone, one cannot be certain of looking downwind or upwind with either measurements.

The successor to SEASAT, the National Oceanic Satellite System (NOSS), will have a scatterometer with two additional antennae, to reduce but not completely eliminate the directional ambiguity. Even so, a valuable source of data on the low-level marine winds will be available when NOSS is launched about 1985.

These two systems likely represent only the tip of the iceberg: remote sensing technology is still just out of its infancy, so that future developments are difficult to anticipate. Even with systems presently on the horizon for use in the last 10-15 years of the 20th century, the future represents exciting possibilities for improvements in numerical weather analysis and prediction.

References

Atkins, M., and M. Jones, 1975: "An experiment to determine the value of satellite infra-red spectrometer (SIRS) data in numerical forecasting." Meteorol. Mag., 104, 125-142.

Bonner, W., P. Lemar, R. Van Haaren, A. Desmarais, and H. O'Neil, 1976: "A test of the impact of NOAA-2 VTPR soundings on operational analyses and forecasts." NOAA Tech. Memo. NWS-57, National Weather Service, Silver Spring, MD, 43 pp.

Cressman, G., 1959: "An operational objective analysis system." Mon. Wea. Rev., 87, 367-374.

Desmarais, A., S. Tracton, R. McPherson, and R. van Haaren, 1978: "The NMC report on the Data Systems Test." NASA contract S-70252-AG, National Meteorological Center, Camp Springs, MD. 313 pp.

Druyan, L., T. Ben-Amram, Z. Alperson, and G. Ohring, 1978: "The impact of VTPR data on numerical forecasts of the Israel Meteorological Service." Mon. Wea. Rev., 106, 859-869.

Flattery, T., 1971: "Spectral models for global analysis and forecasting." Proc. Sixth AWS Tech. Exchange Conf., U.S. Naval Academy, Annapolis, MD, Sept. 1970. Air Weather Service Tech. Report, 242, 4254.

Halem, M., M. Ghil, R. Atlas, J. Susskind, and W. Quirk, 1978: "The GISS sounding temperature impact test." NASA Tech. Memo. 78063, NASA Goddard Space Flight Center, Greenbelt, MD, 421 pp.

Kelly, G., 1977: "A cycling experiment in the Southern Hemisphere using VTPR data." Austrailian Numerical Meteorology Research Center, Melbourne. (unpublished manuscript).

Ohring, G., 1979: "Impact of satellite temperature sounding data on weather forecasts." Bull. Amer. Meteor. Soc., 60, 1142-1147.

Phillips, N., 1976: "The impact of synoptic observing and analysis systems on flow pattern forecasts." Bull. Amer. Meteor. Soc., 57, 1225-1240.

Phillips, N., 1980: "Two examples of satellite temperature retrievals in the North Pacific." Submitted to Bull. Amer. Meteor. Soc.

Sela, J., 1980: "Spectral modeling at the National Meteorological Center." Manuscript submitted to Mon. Wea. Rev.

Shuman, F., and J. Hovermale, 1968: "An operational six-layer primitive-equation forecast model." J. Appl. Meteor., 7, 525-547.

Stackpole, J., L. Vanderman, and F. Shuman, 1974: "The NMC 8-layer global primitive equation model on a latitude-longitude grid." GARP Publ. Ser. No. 14, WMO, Geneva, 79-93.

Tracton, M.S., and R. McPherson, 1977: " On the impact of radiometric sounding data upon operational numerical weather prediction at NMC." Bull. Amer. Meteor. Soc., 58, 1201-1209.

Tracton, M.S., R. McPherson, J. Stackpole, A. Thomasell, and M. Young, 1979: "The impact of satellite-derived winds upon NMC's global data assimilation system." Proc. Fourth Conf. on Num. Wea. Pred., AMS, 29 October - 1 November 1979, Silver Spring, MD, 345-350.

Tracton, M.S., A. Desmarais, R. van Haaren, and R. McPherson, 1980a. "The impact of satellite soundings upon the National Meteorological Center's analysis and forecast system - the Data Systems Test results." To be published in Mon. Wea. Rev., April 1980.

______________, ___________,______________, and ___________, 1980b. "The system dependency of satellite sounding impact---comment on recent impact test results." Submitted to Mon. Wea. Rev.