RESULTS FROM TWO RECENT OBSERVING SYSTEM EXPERIMENTS AT ECMWF*

S. Uppala, A. Hollingsworth, S. Tibaldi
ECMWF, Reading, UK.

P. Kållberg
SMHI, Norrköpping, Sweden

Abstract

Two Observing System Experiments have been carried out at ECMWF. The impact of various observing systems have been examined for two periods during the FGGE year: 8-9 November 1979 (OSE-I) and 22 February-7 March 1979 (OSE-II). Attempts have been made to understand the effect of the observing systems on both the analyses and the quality of the short and medium range forecasts.

The results confirm that the impact of a particular observing system (e.g. SATEM) is dependent on the level of synoptic activity present in the areas where this particular observing system is the main source of meteorological information. SATOB data are also shown to be important for the analyses of tropical regions, whereas SATEM data are of paramount importance for the extra-tropical analyses over ocean areas. Aircraft data, where available, are an invaluable addition to the global observational data base. These results, therefore, demonstrate clearly the value of each of the observing systems. The fact that, in particular circumstances, there may be some redundancy between the systems is a strength rather than a weakness of the composite global observing system.

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*Based on a paper presented to the Twelfth Session of the ECMWF Scientific Advisory Committee, 12-14 September, 1984.

1. INTRODUCTION

The purpose of the Observing System Studies carried out at ECMWF is to estimate the information content of individual components of the Global Observing System as to their impact on objective analyses, short range and medium range numerical weather products, and ultimately to contribute to the design of a "best-mix" system for operational use in the coming decade.

Observing system studies fall into two broad categories - Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs).

At the Centre an OSSE has been initiated in collaboration with several European and non-European institutions in order to evaluate the usefulness and reliability of OSSEs. However, the main emphasis at the Centre has recently been on completing two OSEs using FGGE data. The first of these, OSE-I, covers the period 8-18 November 1979, and the second set, OSE-II, consisted of similar experiments, but for the period 22 February-7 March 1979. This report will concentrate on OSE-II, though results from OSE-I will be used throughout to evaluate the experiment.

Our OSE work can be divided into two broad categories:

(1) The study of the effect of the addition of a single observing system to a minimum system which is taken as the conventional data distributed on the GTS - SYNOP, SHIP, TEMP, PILOT and DRIBU. The systems to be added to this minimum system are SATEM or SATOB or AIREP/AIDS/ASDAR.

(2) "Best-mix" studies where a single observing system is withdrawn from the maximum composite observing system.

Initially, studies of the second category were undertaken. However, the results of these studies indicated that a full understanding required consideration of the simple single-system problems which fall in the first category. This report will be mainly devoted to such studies.

OSE work is notoriously very difficult because the results may depend on the assimilation and forecast system used, the synoptic situation and possibly on the redundancies in the data in certain regions; we shall refer to examples of these difficulties later in the report.

Another major difficulty, characteristic of OSE-type studies, is that when one is studying the effect of moderate changes in the accuracy of the analyses, the signal in the verification of the forecasts against the true atmospheric state is sometimes weak after the first two days. This is because the model errors grow so rapidly that they can swamp the signal from the analysis error. Fig. 1.1 shows an estimate for the relative contributions to total mean square forecast error of the model error and the analysis error, in analysis comparison experiments (Arpe et al., 1984). The analysis error is a relatively large contributor to total forecast error in the short range forecasts (day 0-1.5) and in the late medium range (after day 5). In the intervening period the approximately linear growth of model error is so rapid that it can mask the effect of the roughly exponential growth of analysis error in the verifications against reality. For this reason, statistics on the forecast divergences are a useful tool in studies of data impact. This also has as a consequence that a true appreciation of the significance of analysis differences and data impact can only be had by a combination of detailed synoptic investigation and the application of the available objective tools.

2. THE SYNOPTIC SITUATION, DATA COVERAGE AND EXPERIMENTAL SCENARIOS

The selection of the period for OSE-I, 8-19 November 1979, was based on the very good data coverage (there were two polar orbiting satellites) and the marked activity over the Pacific, for the FGGE winter. Fig. 2.1 shows the mean circulation at the surface and 500 mb during this period. The intense activity over the Pacific is connected with the movement of the deep trough towards North America. However, over the North Atlantic the flow is relatively blocked; further east there is a deep trough extending to the Mediterranean.

A second set of experiments, OSE-II, was performed in order to see if the conclusions based on OSE-I are valid for an independent period. The period used, 22 February-7 March 1979, was chosen because of its relatively high activity for the FGGE winter over the eastern North Atlantic and Western Europe. Another reason is that it had different observational characteristics

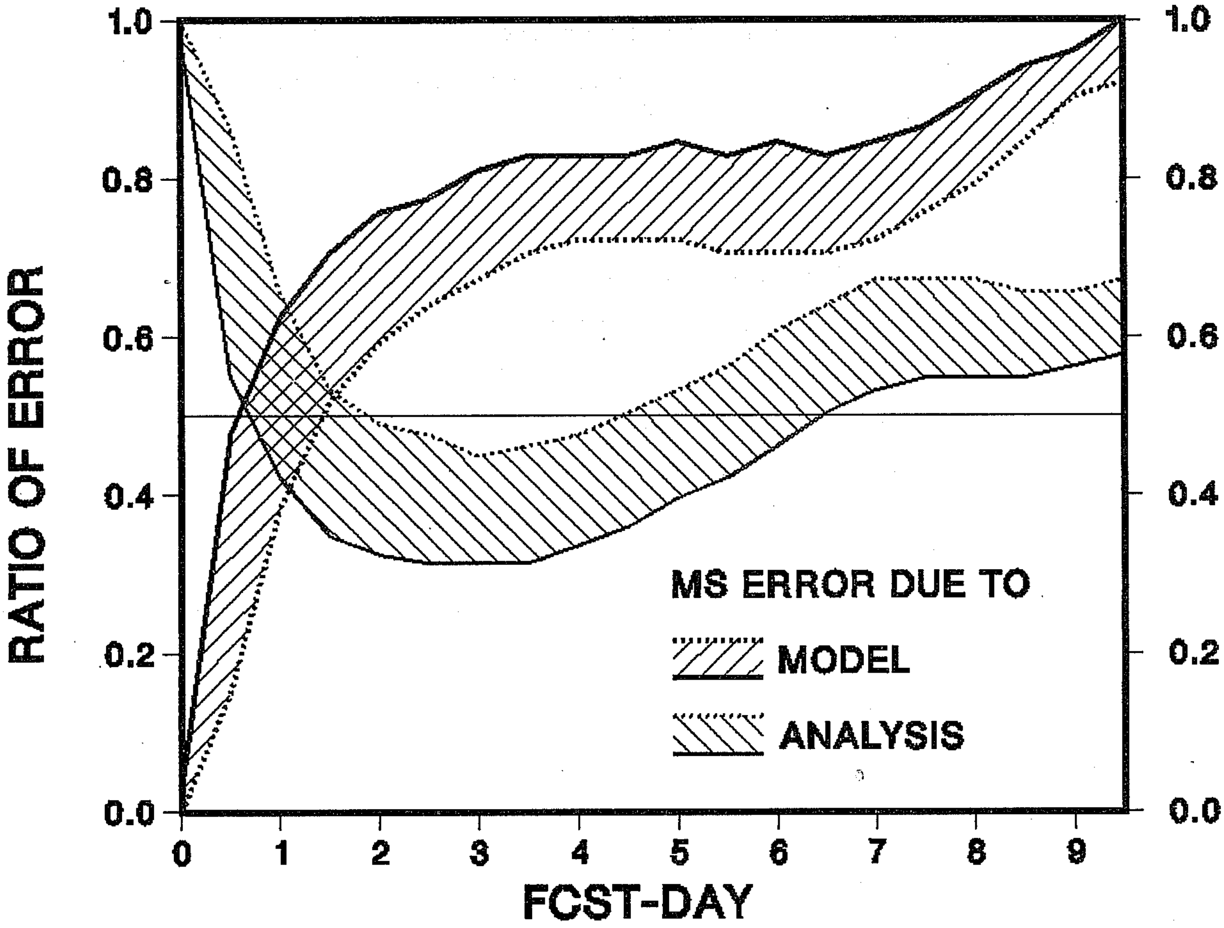


Fig. 1.1. : Relative contribution of analysis error and model error to the forecast error as a function of forecast time.

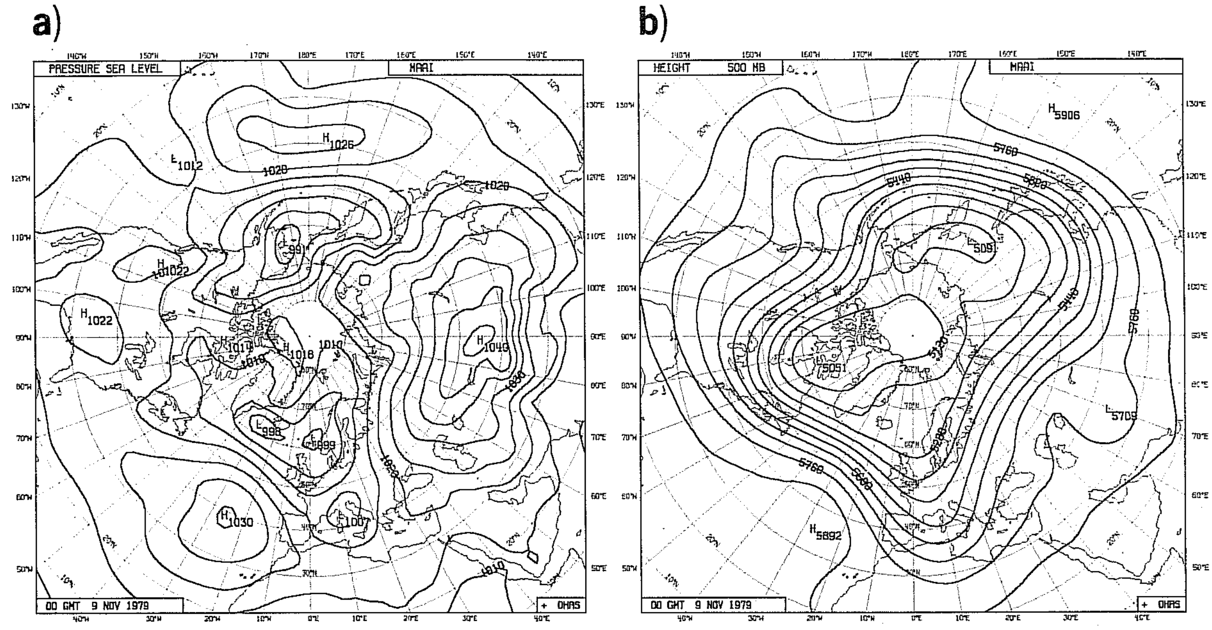


Fig. 2.1. : Time averaged mean sea level pressure (a, left) and 500 mb height (b, right) for OSE-I, for the Northern Hemisphere.

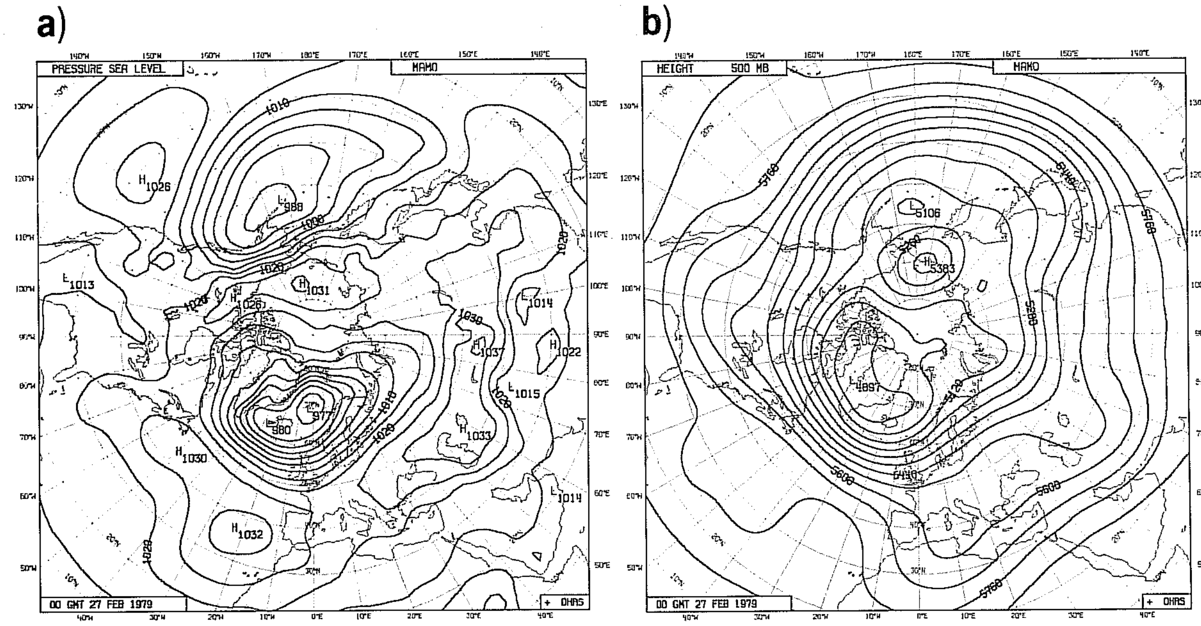
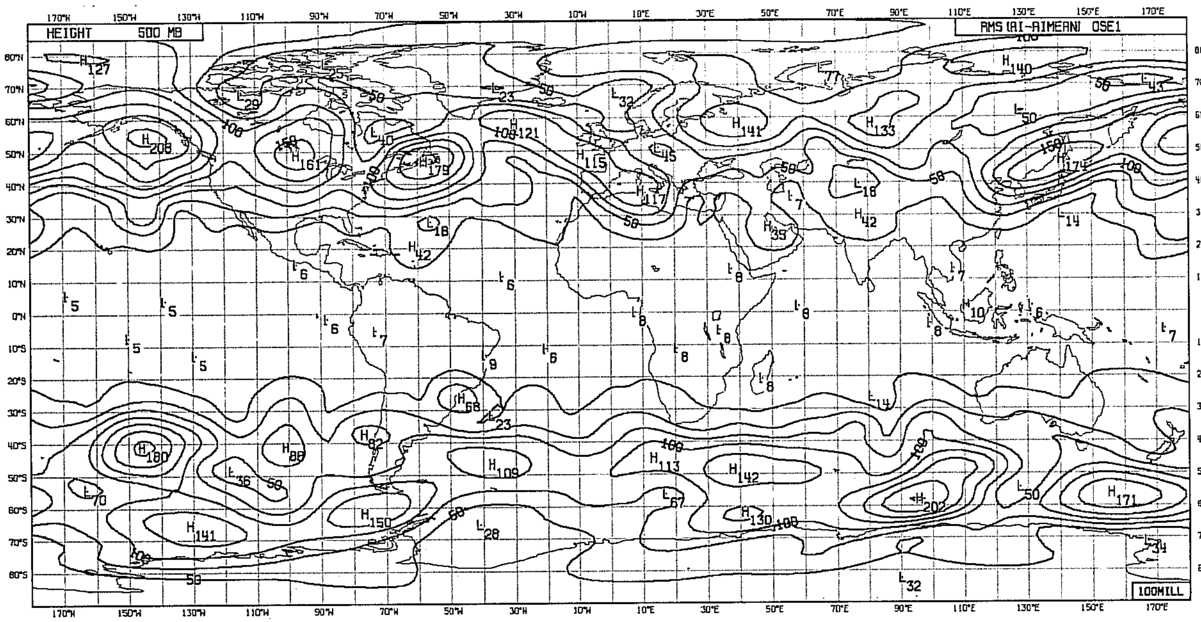


Fig. 2.2. : Time averaged mean sea level pressure (a, left) and 500 mb height (b, right) for OSE-II, for the Northern Hemisphere.

a) OSE- I



b) OSE-II

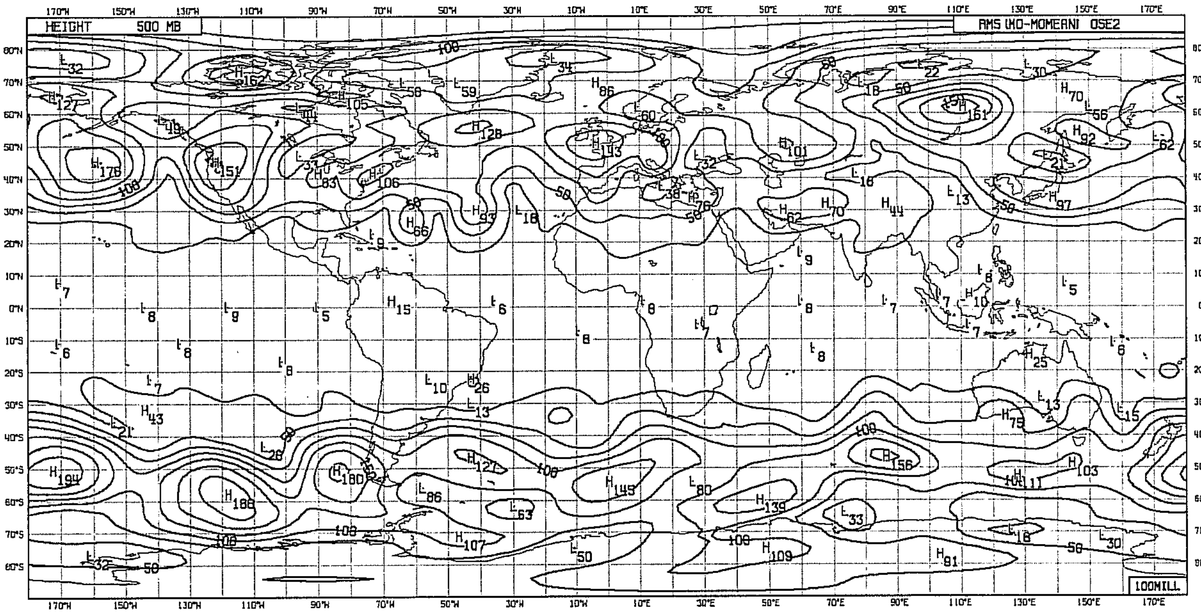
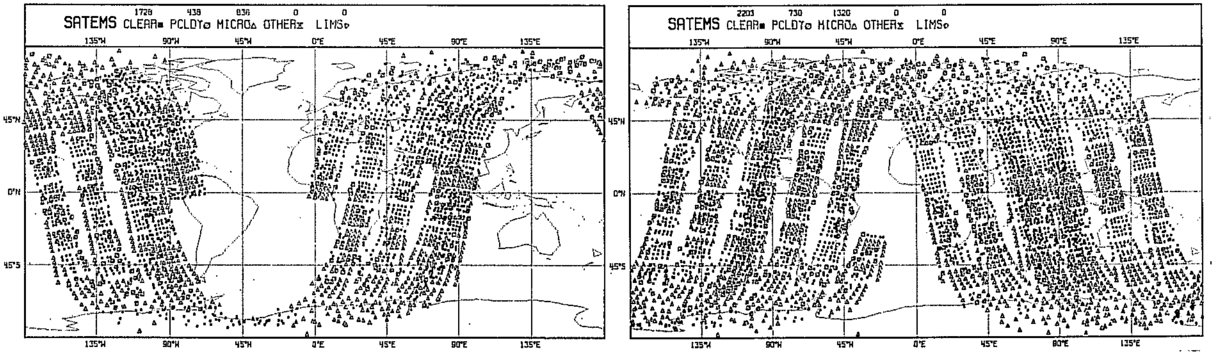
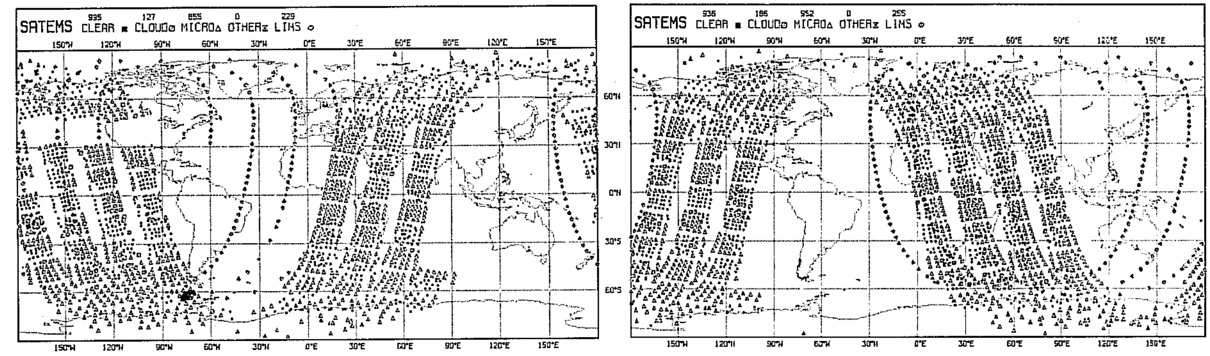


Fig. 2.3. : Time variability (RMS z-mean) of 500 mb height field during 10-19 November 1979 (OSE-I, a) and during 27 February- 7 March 1979 (OSE-II, b).



a) OSE-I 00GMT

b) OSE-I 12GMT



c) OSE-II 00GMT

d) OSE-II 12GMT

Fig. 2.4. : Representative SATEM coverage examples during OSE-I :
a) at 00 GMT Nov. 13 1979, b) at 12 GMT Nov. 11 1979.
The same during OSE-II :
c) at 00 GMT Feb. 7 1979, d) at 12 GMT Feb. 7 1979.

since it belonged to the Special Observing Period I, and thus contains data from special platforms which were mainly in the tropics. Also there was only one polar orbiting satellite. Fig. 2.2 shows the mean PMSL and 500 mb height fields for the period. Note that at the surface the Aleutian and Icelandic lows are very distinctive. At 500 mb the mean flow over the Pacific and Atlantic is relatively zonal, and this indicates that during OSE-II there is generally less activity than during OSE-I. This is confirmed by Fig. 2.3 which shows that variability of the 500 mb height during OSE-I and OSE-II. In the northern hemisphere it is clear that there is much more activity over the oceans in OSE-I than in OSE-II; this is particularly true over the eastern and western Pacific, and over the North Atlantic. It is also worth mentioning that preceding OSE-II there was a strong stratospheric warming which split the polar vortex.

The difference in the activity between the two OSE periods will, as can be seen later, be reflected in the quality of the forecasts using different observational scenarios. The space based observations - SATEMs, SATOBs and aircraft data - will be of greater importance when the main activity occurs in areas where they are the main source of observations.

As will be shown later, neither SATEM or SATOB data had a great influence on forecast quality during OSE-II. The reason may be associated with the gap in the SATEM data over the eastern Pacific which is apparent in the data used for the 00 GMT analyses during this period (all forecasts were run from 00 GMT analyses). The gap is clearly illustrated in Fig. 2.4c, and comparison with Fig. 2.3b shows that it coincides with a particularly active region. Examination of the sounding around the gap reveals that many of them are micro-wave soundings which are given a low weight in the analysis scheme. As a comparison, a typical 12 GMT SATEM coverage is also shown in the same figure. During OSE-I, forecasts were run from both 00 and 12 GMT analyses, and Fig. 2.4a and b also show typical SATEM coverages at these hours. Clearly the Pacific is well covered at both times, while sometimes the Atlantic has only a few SATEMs.

During OSE-I, 10 day forecasts were run from selected dates and times: Nov 10/00 GMT, 11/00 GMT, 11/12 GMT, 13/00 GMT, 13/00 GMT, 14/00 GMT, 16/00 GMT, and 18/00 GMT. In all there are 7 forecasts.

For OSE-II, 10 day forecasts were run from 00 GMT data from 9 consecutive days between 27 February and 7 March.

Table 1 gives a list of all experimental configurations run for both OSEs and their characteristics.

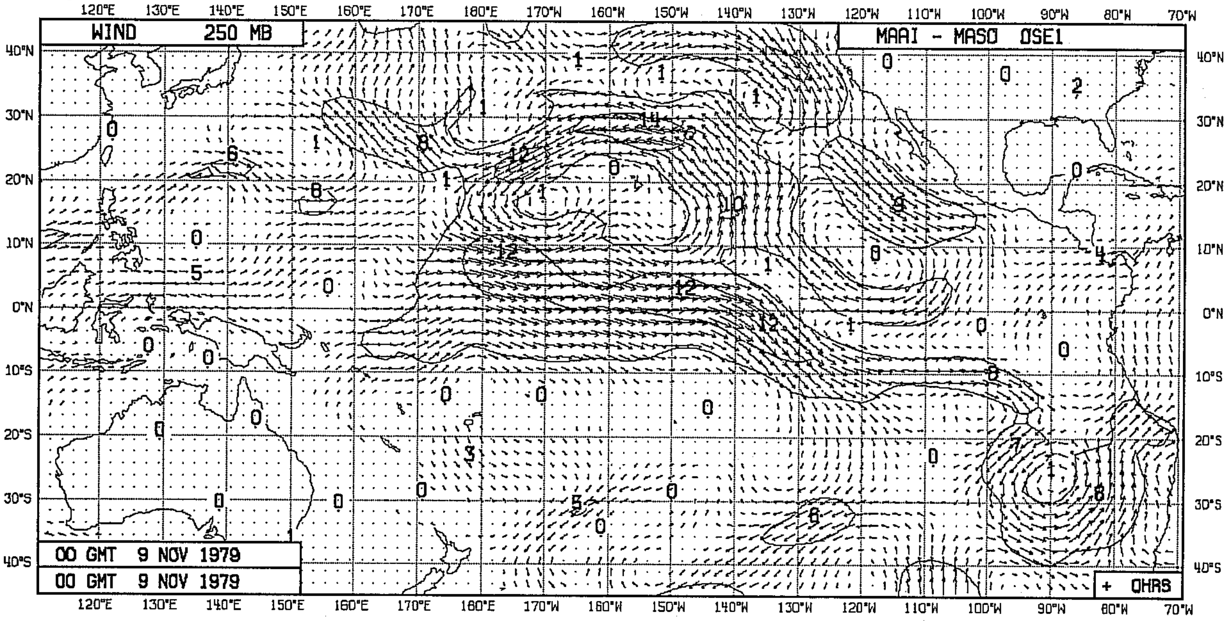
Maximum System (CONTROL)	AI
Minimum System (SURFACE based) = Maximum System minus SATEMs SATOBs and ACFTs	SO
SATEM System = Minimum System + SATEMs	SM
SATOB System = Minimum System + SATOBs	SB
ACFT System = Minimum System + ACFTs	SX
SPACE based System = Maximum System minus TEMPs, PILOTs and SYNOP winds	SP
1 Polar orbiting satellite only As SM (SATEM System), but with 1 satellite instead of 2 (OSE-I only)	N1

Table 1 Table listing the acronyms identifying the scenarios for which data have been assimilated for the two OSE periods:

OSE-I : 7.11.79-18.11.79; 7 forecasts, 6 from 00 and 1 from 12 GMT data

OSE-II: 22.2.79-7.3.79; 9 forecasts, all from 00 GMT data.

a) AI-SO



c) SB-SO

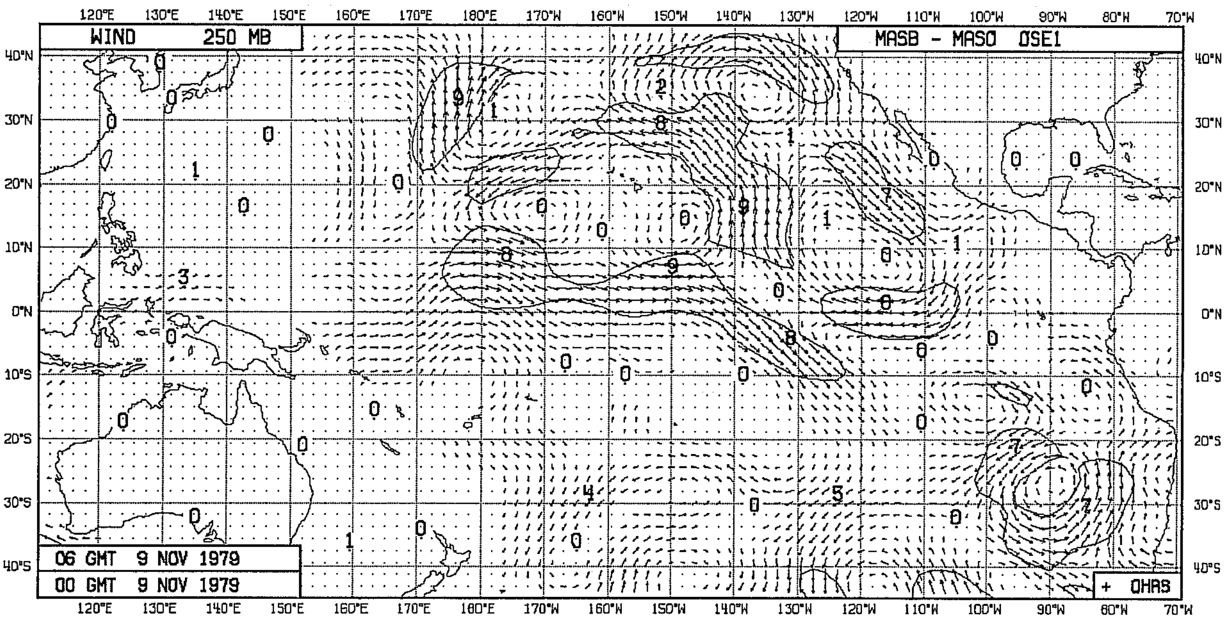
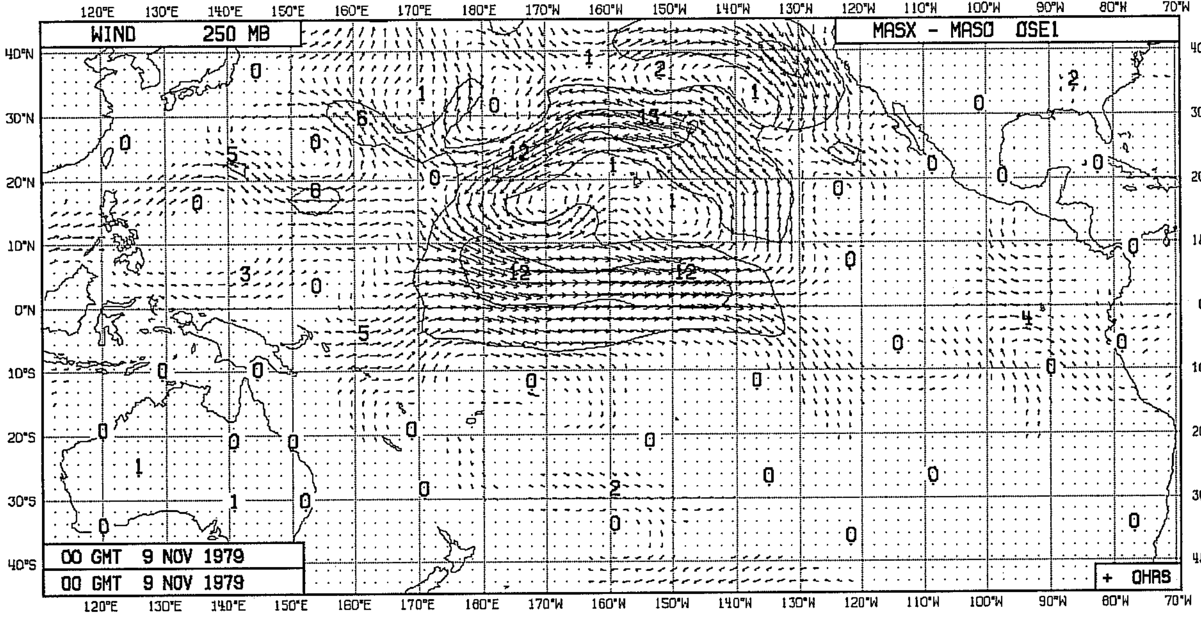


Fig. 3.1. : Differences of the mean wind at 250 mb over the Tropical Pacific during OSE-I :

a) CONTROL ACFT minus SURFACE
b) SURFACE + ACFT minus SURFACE
c) SURFACE + SATOB minus SURFACE
d) SURFACE + SATEM minus SURFACE

b) SX-SO



d) SM-SO

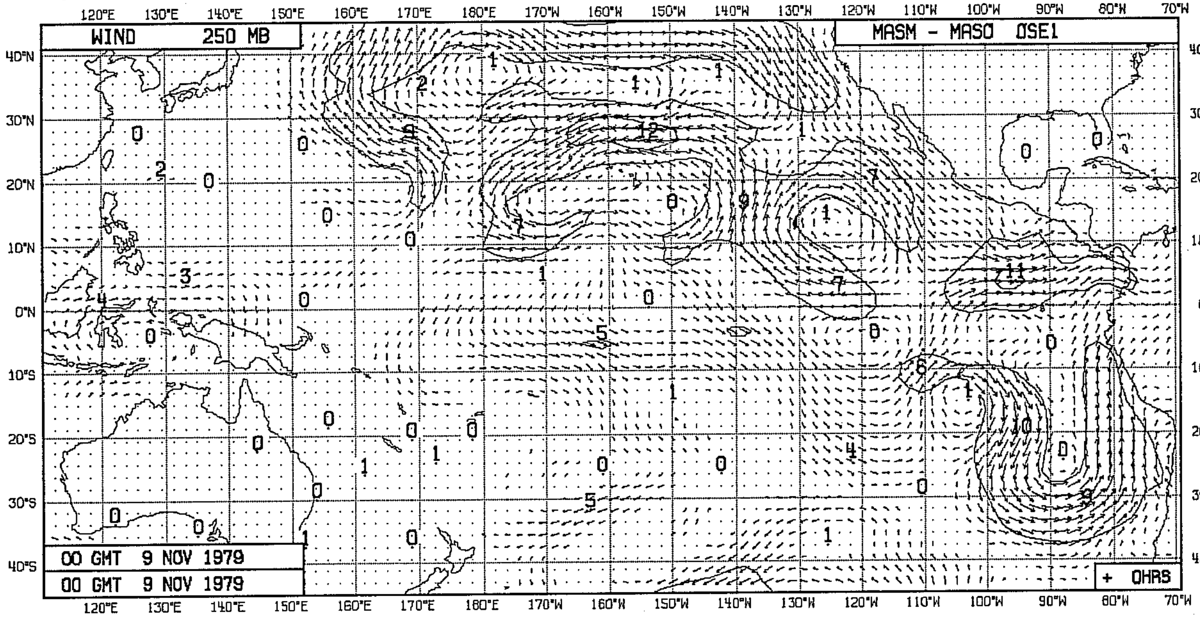


Fig. 3.1. : (cont).

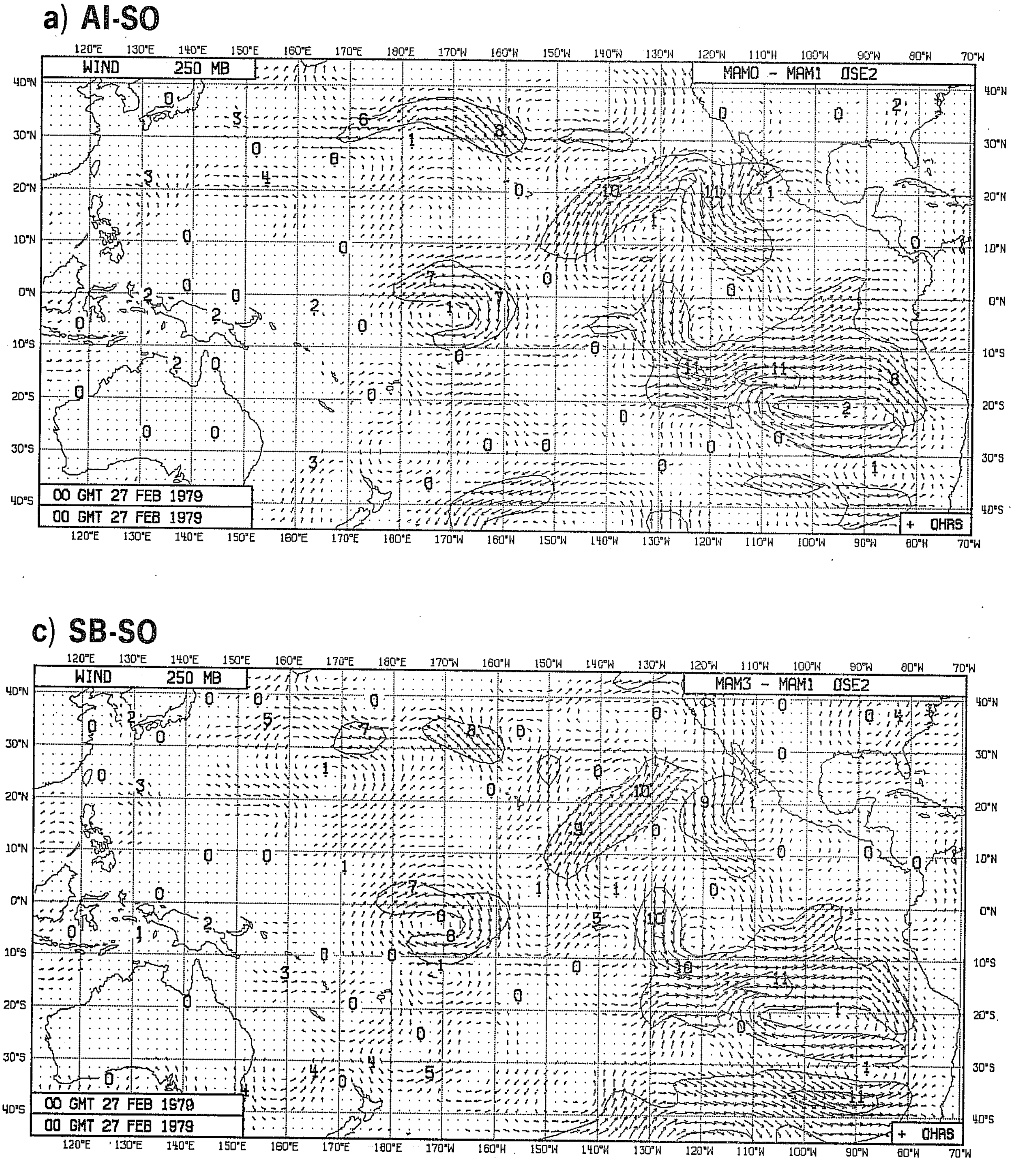


Fig. 3.2. : Differences of the mean wind at 250 mb over the Tropical Pacific during OSE-II :

a) CONTROL minus SURFACE

c) SURFACE + SATOB minus SURFACE

d) SURFACE + SATEM minus SURFACE

b) SX-SO

Not available

d) SM-SO

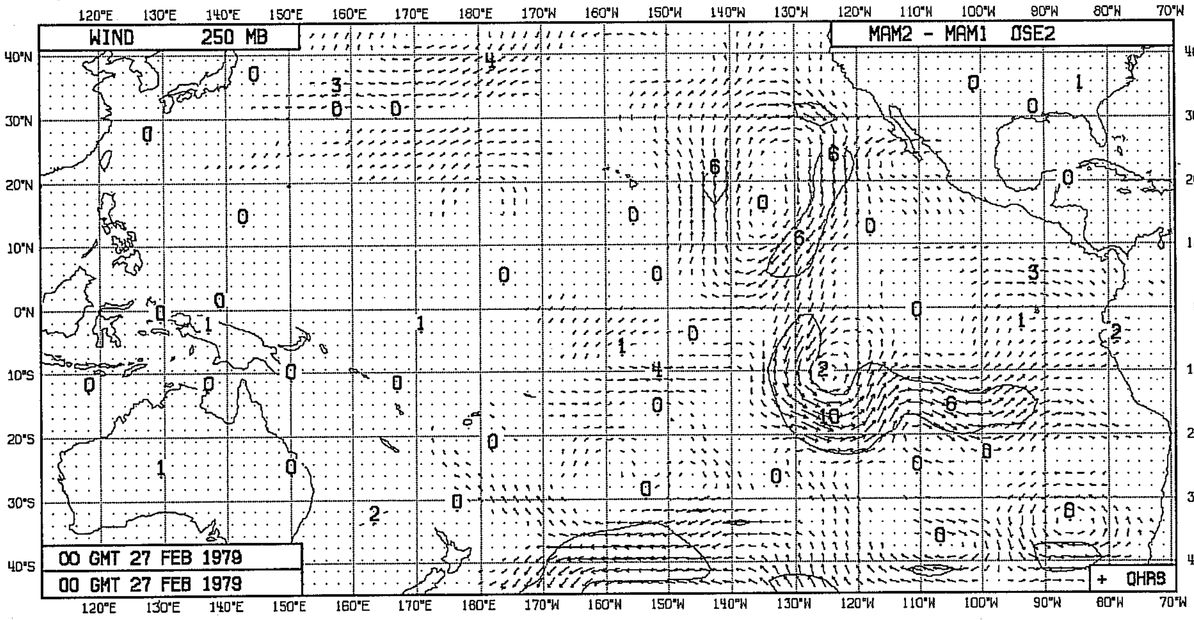
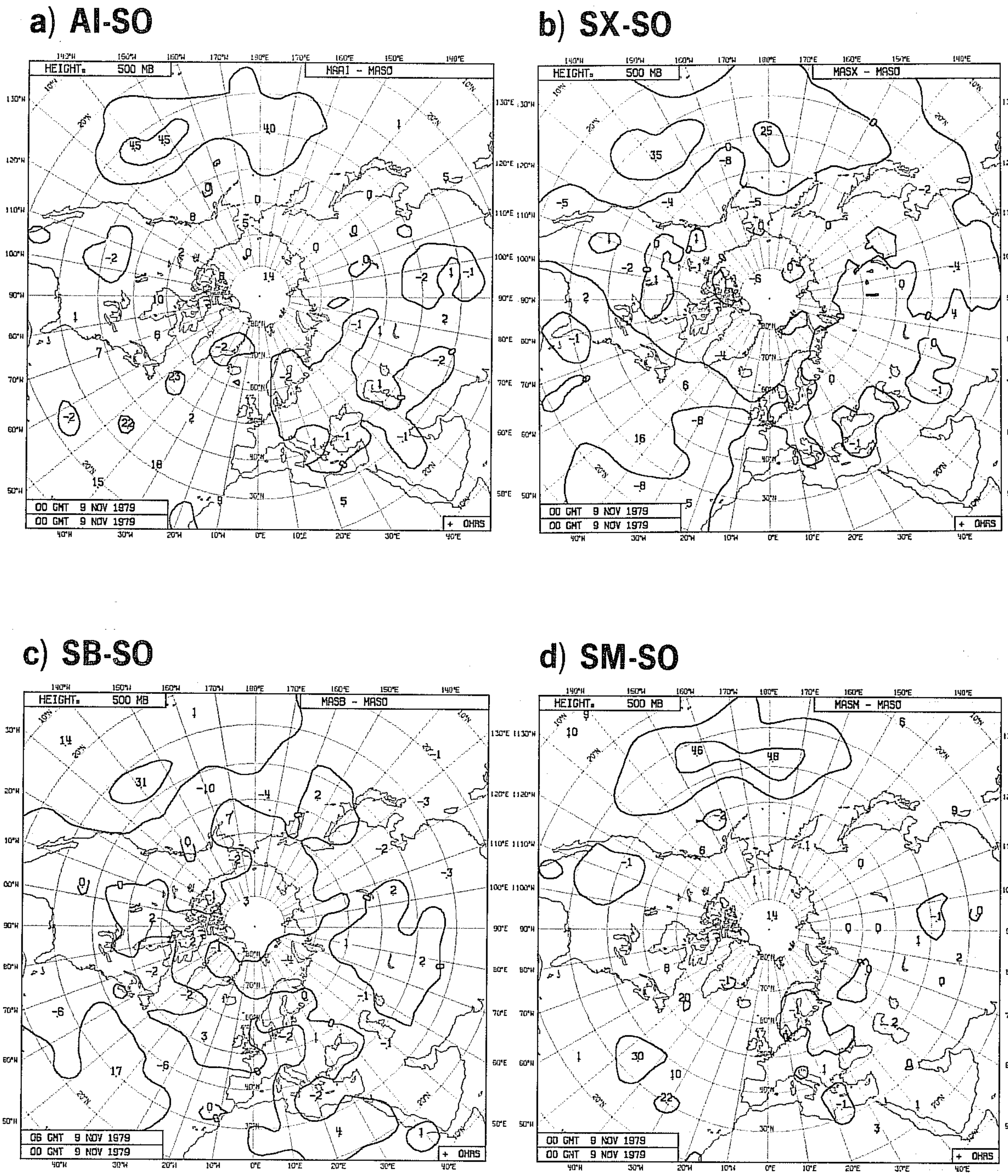


Fig. 3.2. : (cont).



a) AI-SO

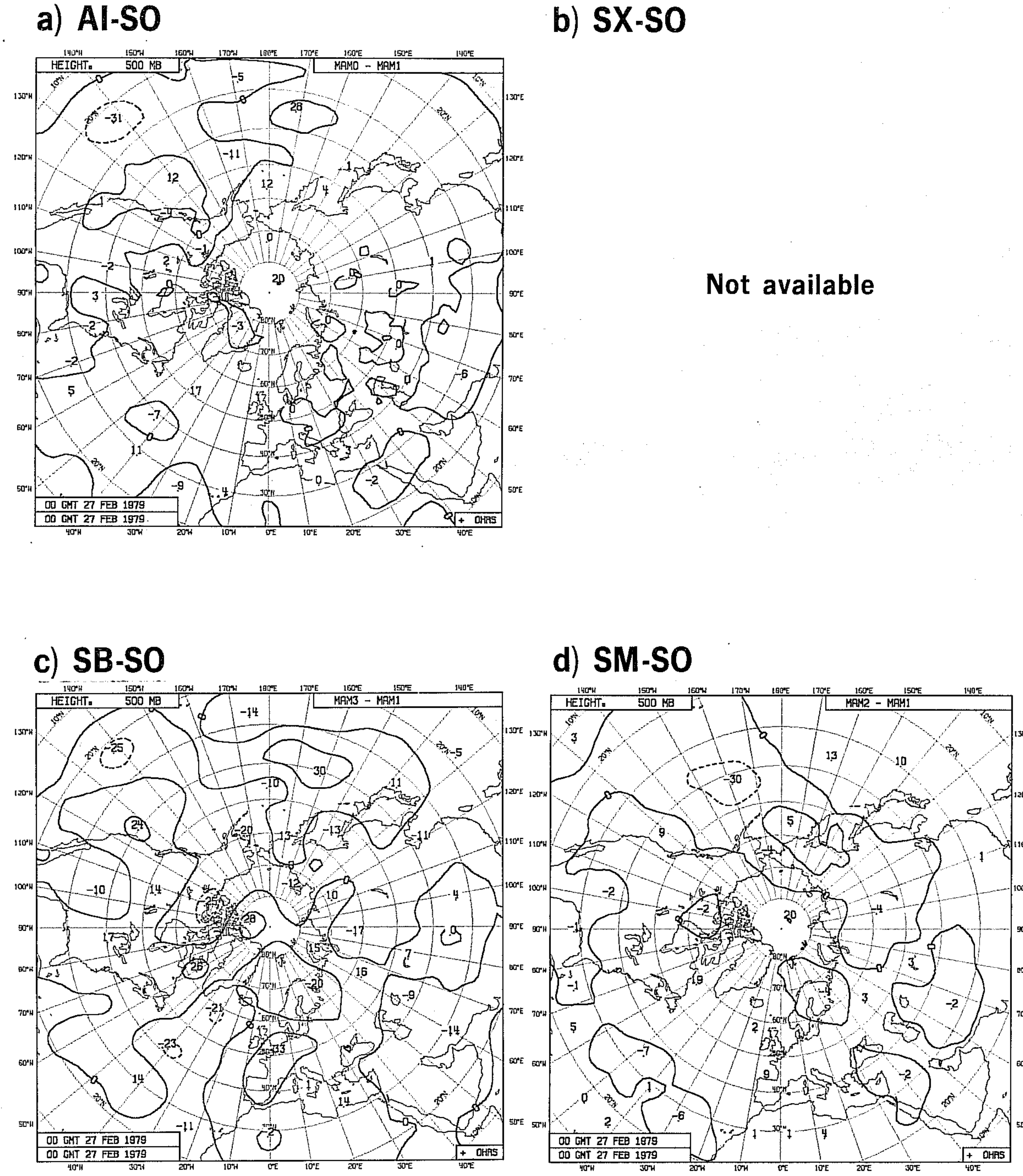
b) SX-SO

c) SB-SO

d) SM-SO

Fig. 3.3. : Differences of the mean 500 mb height over the Northern Hemisphere during OSE-I :

a) CONTROL minus SURFACE
b) SURFACE + ACFT minus SURFACE
c) SURFACE + SATOB minus SURFACE
d) SURFACE + SATEM minus SURFACE



a) AI-SO

b) SX-SO

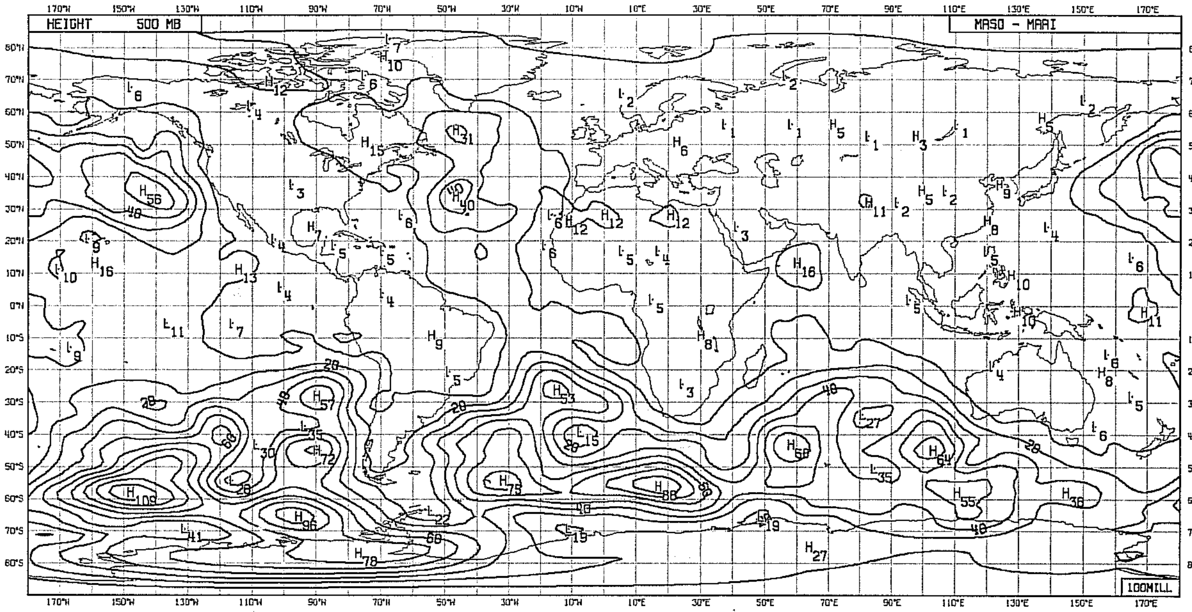
Not available

c) SB-SO

d) SM-SO

Fig. 3.4. : Differences of the mean 500 mb height over the Northern Hemisphere during OSE-II :
a) CONTROL minus SURFACE
c) SURFACE + SATOB minus SURFACE
d) SURFACE + SATEM minus SURFACE

a) **OSE-I**



b) **OSE-II**

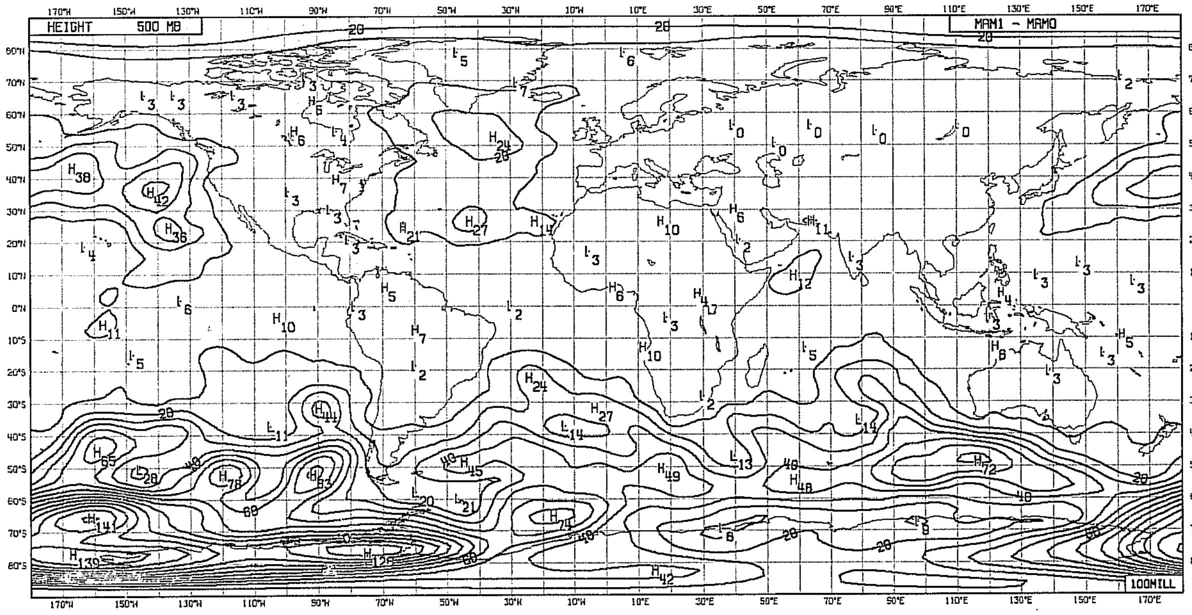
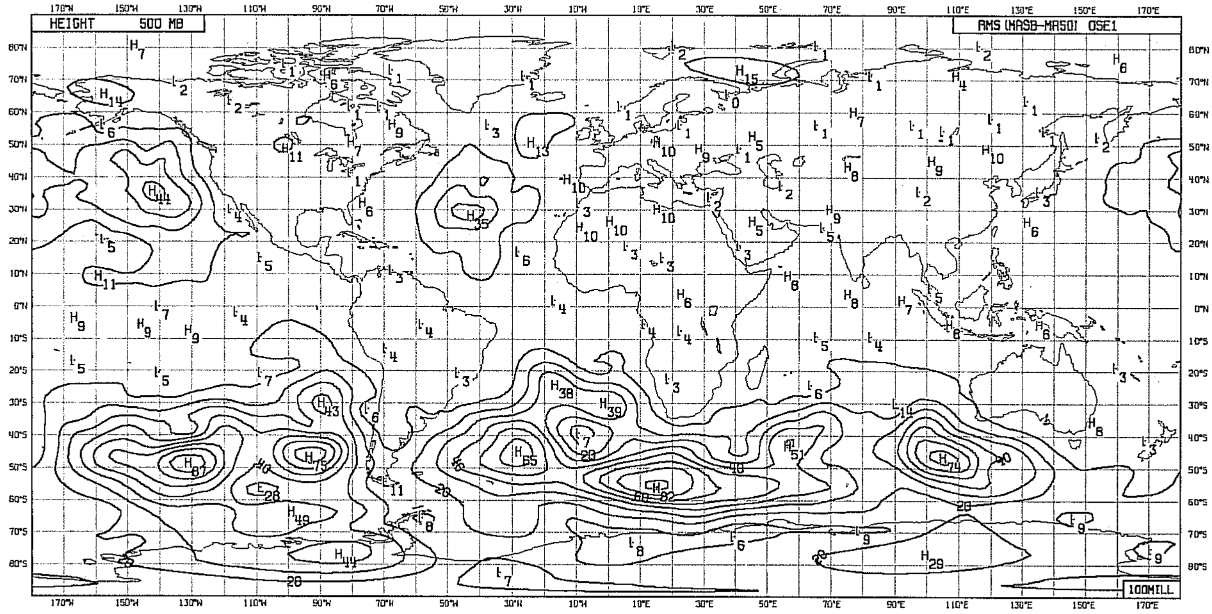


Fig. 3.5. : RMS of the difference between CONTROL and SURFACE 500 mb height analyses during OSE-I (a, top) and OSE-II (b, bottom).

a) SO-SB



b) SO-SM

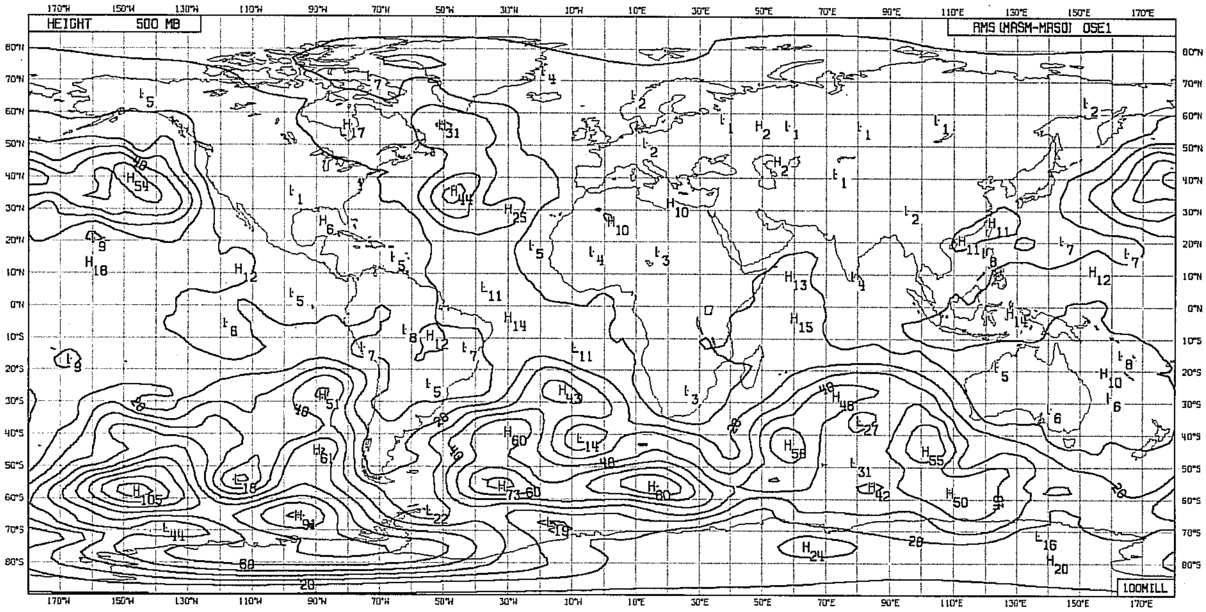


Fig. 3.6. : RMS of the difference between SURFACE analyses and SURFACE plus SATOB analyses (a, top) and SURFACE plus SATEM analyses (b, bottom) for 500 mb height during OSE-I.

3. IMPACT OF THE DATA ON THE ANALYSES

We now show examples of the impact of each observing system (aircraft data - denoted by ACFTS, SATOBS and SATEMS) on the analyses. Figs. 3.1 and 3.2 show the effect on the mean 250 mb wind field of: a) all three space based platforms together, b) ACFTs alone, c) SATOBs alone and d) SATEMs alone, when they are added to the minimum system for both OSE-I and OSE-II. Note that the ACFT data support the SATOB data in the tropics, and that all three support each other in the subtropical regions. The smaller impact of SATEMs compared with SATOBs in OSE-I is reversed in OSE-II; this illustrates the degree of sensitivity to the synoptic situation, since data coverage alone suggests the opposite behaviour (two polar orbiting satellites in OSE-I and only one in OSE-II).

Figs. 3.3 and 3.4 show a similar set of mean charts for the northern hemisphere 500 mb height. During OSE-I the largest impact of the space based observations is over the North Pacific, with SATEMs (and to a lesser extent ACFTs) having a major role in providing information. The situation during OSE-II is very different - SATOBs now play an important role and the main area of influence is now over Europe with a somewhat reduced activity over the North Pacific. The apparent influence of single level data on the 500 mb analysis (PMSL analyses showed no appreciable differences) confirms that the ECMWF Data Assimilation System is capable of successfully extracting tropospheric mass field information from single level platforms.

Fig. 3.5 shows RMS analyses differences between the CONTROL and Minimum System (SURFACE based observations only) for both OSE-I and OSE-II. This, together with Fig. 2.3, confirms that the coverage of the ocean areas by space-based platforms during OSE-I coincided with large atmospheric activity in the same areas (West and North Atlantic and, East and North Pacific). The situation was different during OSE-II, with reduced activity over the ocean areas. This effect superimposed with the above mentioned intermittent data void areas over the North Pacific to give a reduced impact of the space-based platforms.

Fig. 3.6 attempts to partition the collective impact of the space-based platforms between SATEMs and SATOBs in OSE-I; it confirms the dominant role of SATEMs over SATOBs in defining the mid-latitude mass field in the northern hemisphere. In the southern hemisphere SATOBs also seem to play an important role, probably due to the paucity of data.

4. IMPACT OF THE DATA ON THE SHORT RANGE FORECAST FIELDS

In this section we will deal with the impact of the different observing systems on the quality of the 6-hour forecasts used as first guess in the Data Assimilation cycle. As discussed by Hollingsworth and Arpe (1982), and in "Results from the analysis benchmarking", ECMWF/SAC(84)5, a useful tool in evaluating the efficiency of an assimilation is to compare the relative magnitudes of the changes made by the forecast step, analysis step and initialisation step in the assimilation system. If **F**, **A** and **I** are measures of the RMS amplitudes of these changes, then in a 'good' data assimilation cycle one should find that

$$\mathbf{F} > \mathbf{A} > \mathbf{I}$$

This, in turn, means that most of the changes from one analysis to the next are accomplished by the 6-hour forecast. Where the forecast is deficient, the analysed data should then correct the 6-hour forecast. In doing so a small amount of noise or undesirable imbalances ('gravity modes') are brought into the analysed fields, but this is eliminated by the initialisation step, that should therefore bring about even smaller changes.

Fig. 4.1 maps the magnitude of **F** for both OSE-I and OSE-II for the two control assimilations. The blocked flow in the North Atlantic is clearly evident in both periods, with most of the activity forced to take place north of the blocked ridge. This is even more evident during OSE-II. The level of activity in the 6-hour forecasts is roughly similar in the two periods in the eastern Pacific. The western Pacific, however, has its markedly larger meteorological activity during OSE-I confirmed by these short-range forecast changes.

Fig. 4.2 shows the OSE-I RMS differences between the 6-hour forecast in the AI, SX, SB and SM assimilations (for the meaning of the acronyms, see Table 1) and the verifying AI (CONTROL) analyses which are our best estimates of the true state of the atmosphere. The panel labelled AI (Fig. 4.2a) also represents, therefore, the RMS analysis changes (the quantity **A** defined above) for the AI (CONTROL) assimilation of OSE-I. A comparison between Fig. 4.1a and Fig.4.2a confirms that in the control assimilation, with all available data included, the relationship **F** > **A** is well satisfied.

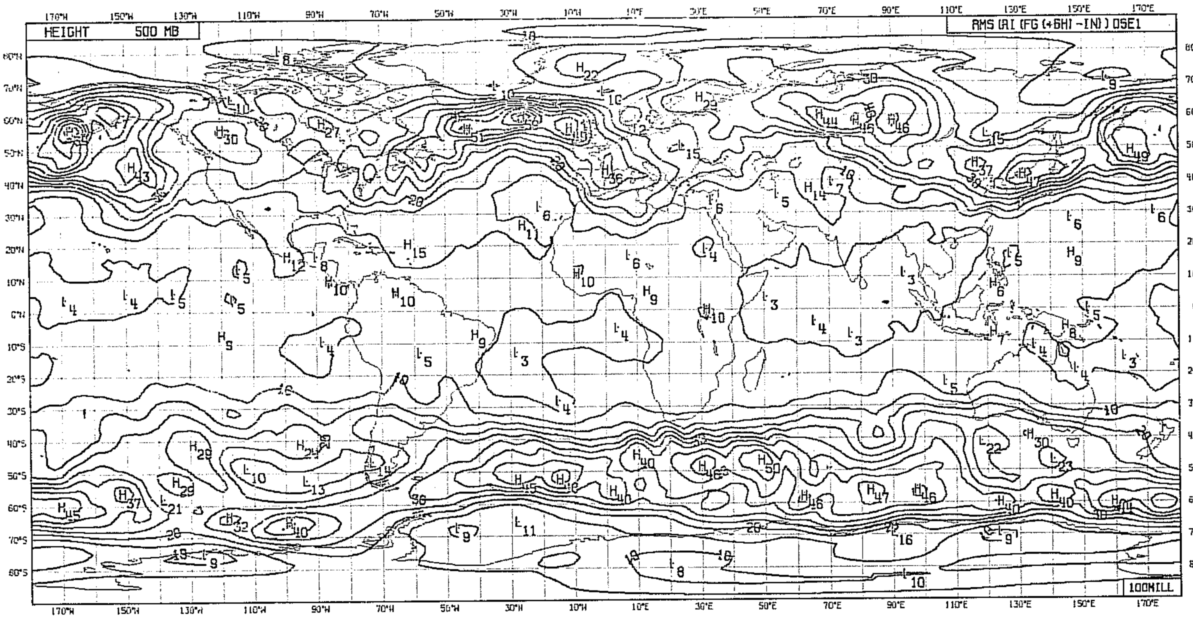
Comparison of the four panels of Fig. 4.2 shows a number of important features. The dominant information source for the southern hemisphere are the SATEMs. The SATOBs also contribute to the accuracy of the assimilating forecast well to the south of 45°S. It is gratifying to note that the two data sources together give a noticeably more accurate forecast in the southern hemisphere than either system alone. Aircraft data were extremely sparse in the southern hemisphere. In the northern hemisphere sub-tropics both the SATEM and SATOB data lead to more accurate short range forecasts, while poleward of 45°N the SATEM data have the larger effect.

These maps of short-range forecast error are probably the most accurate estimates available for the accuracy of the analyses (and therefore for the impact of the data) in the different assimilations. It is clear that the SO (SURFACE based) system has large errors over the northern hemisphere oceans. These are much larger over the Pacific than the Atlantic in this period, because of the synoptic situation. It should be noted that all Ocean Weather Ship data are included in the Minimum System.

Fig. 4.3 shows the corresponding results for OSE-II. The main results in the southern hemisphere are just as they were in OSE-I. The SATEMs are essential for the high mid-latitudes, while the SATOBs are essential for the tropics (wind data not shown, however), and both systems complement each other in the sub-tropics.

In the northern hemisphere the results for OSE-I and OSE-II are not similar. It should be remembered that only one satellite was available during OSE-II. Although the short range forecast errors are smaller in the SM assimilation than in the SO assimilation over both oceans of the northern hemisphere, the differences are modest, and the patterns are very similar. This similarity

a) OSE I



b) OSE II

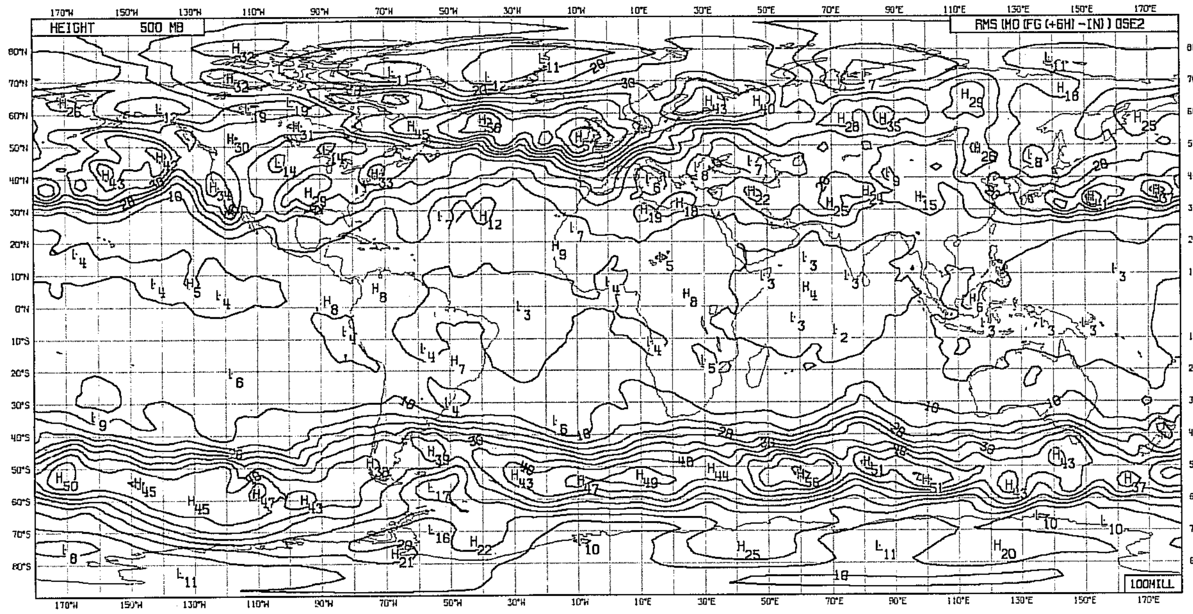


Fig. 4.1. : The meteorological activity in the 6h forecast measured as RMS of 6h forecast minus intitial state in OSE-I (top panel) and in OSE-II (lower panel), for 500 mb height.

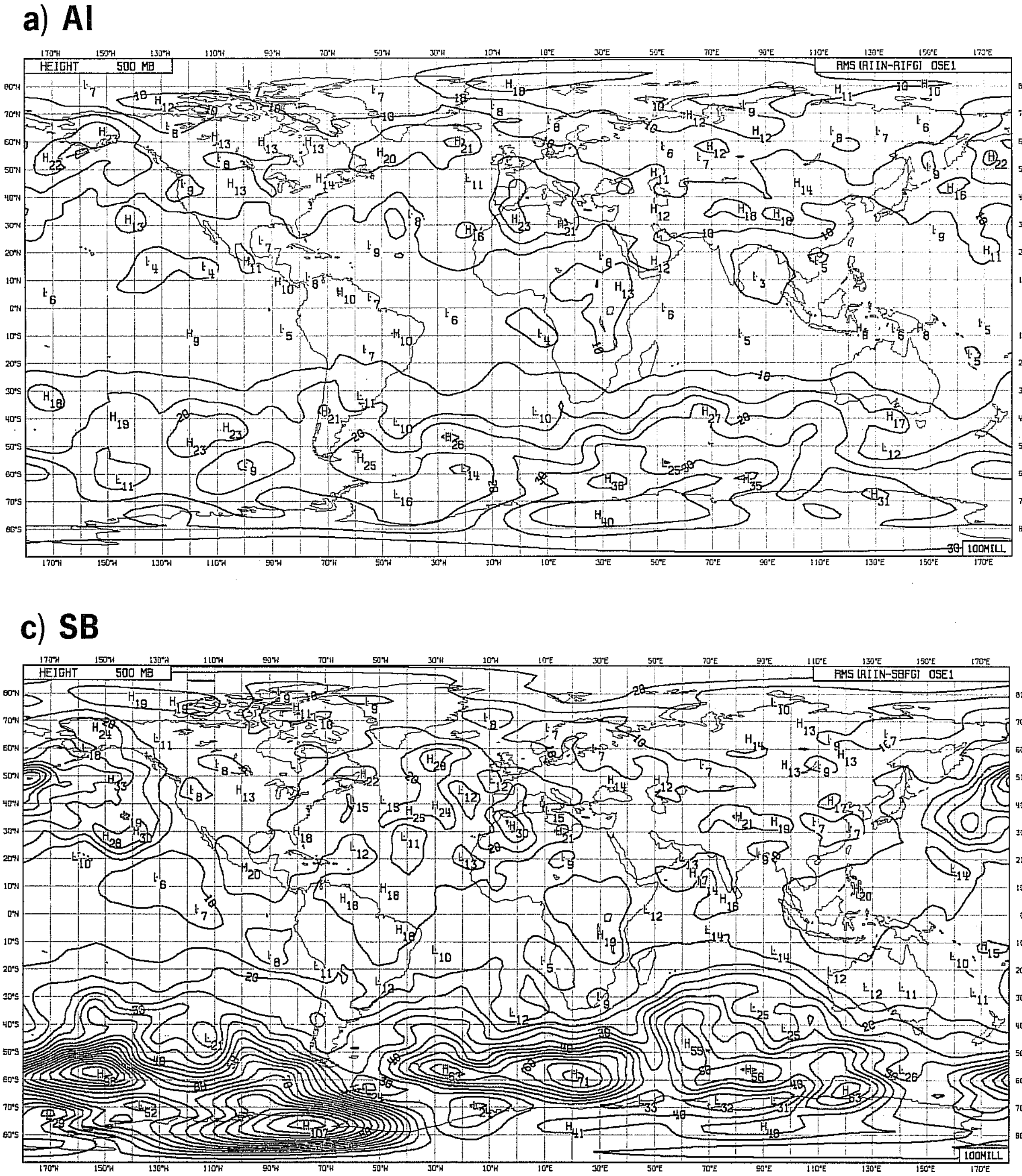
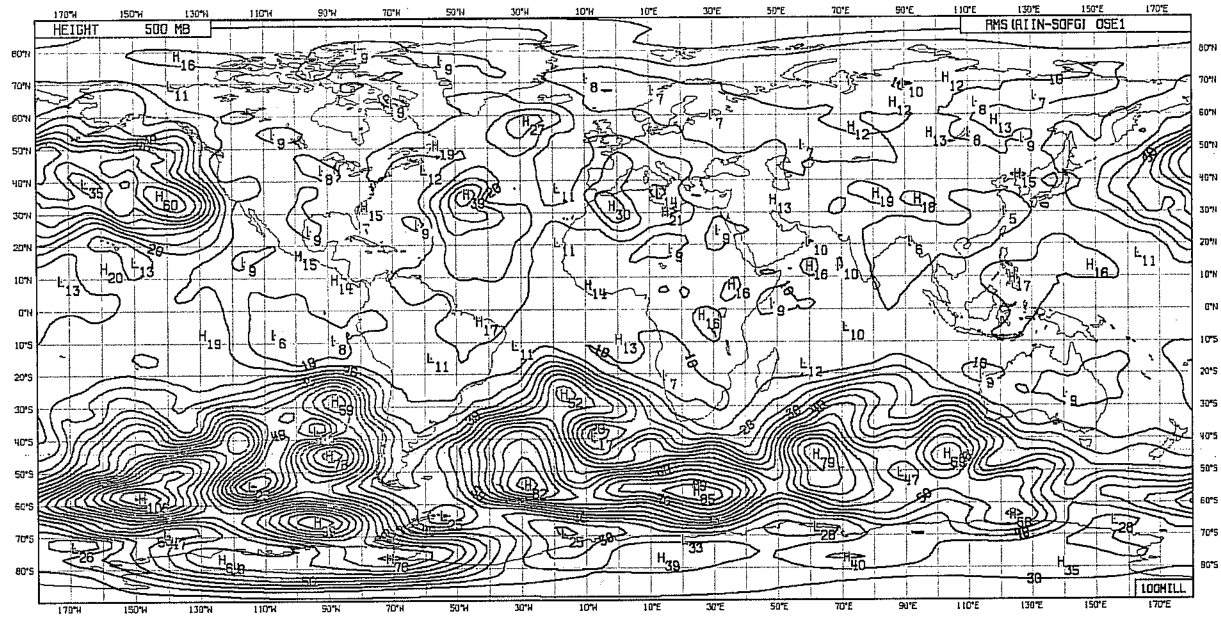


Fig. 4.2. : RMS of the 6h forecast error for 500 mb height in OSE-I when verified against control initialized analyses ; a) CONTROL, b) SURFACE, c) SURFACE + SATOB, d) SURFACE + SATEM.

b) SO



d) SM

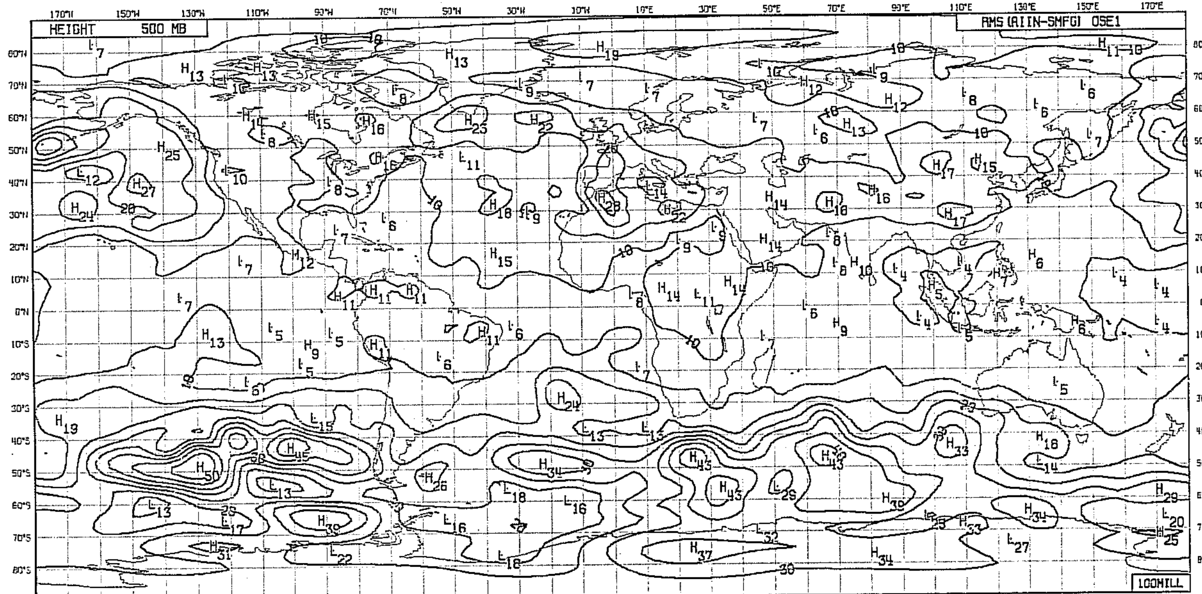
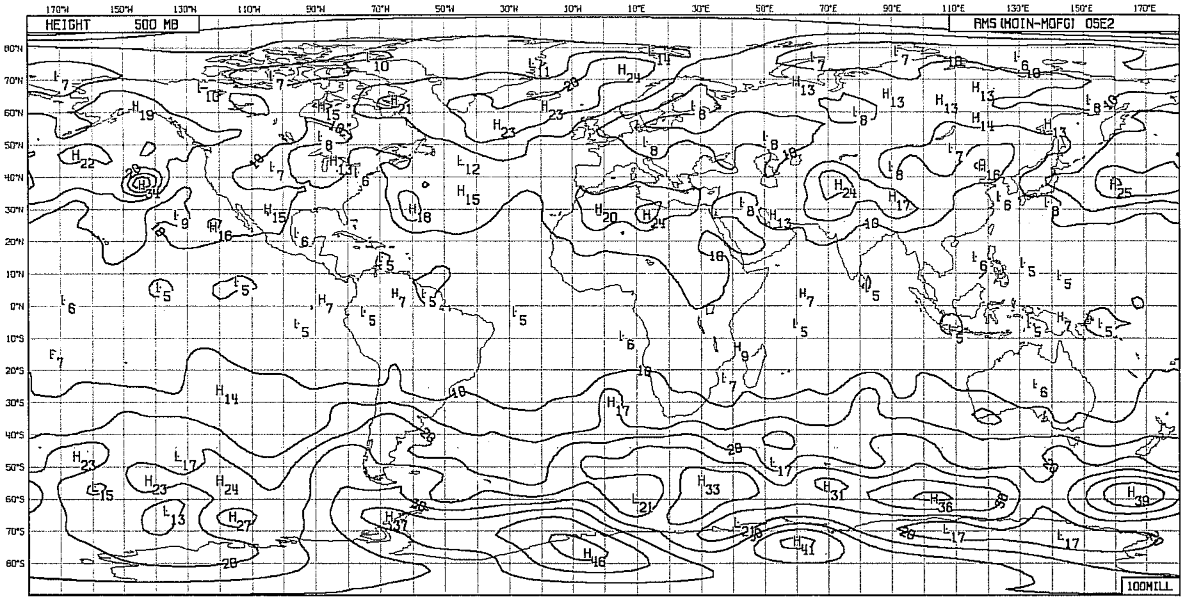


Fig. 4.2. : (cont).

a) AI



c) SB

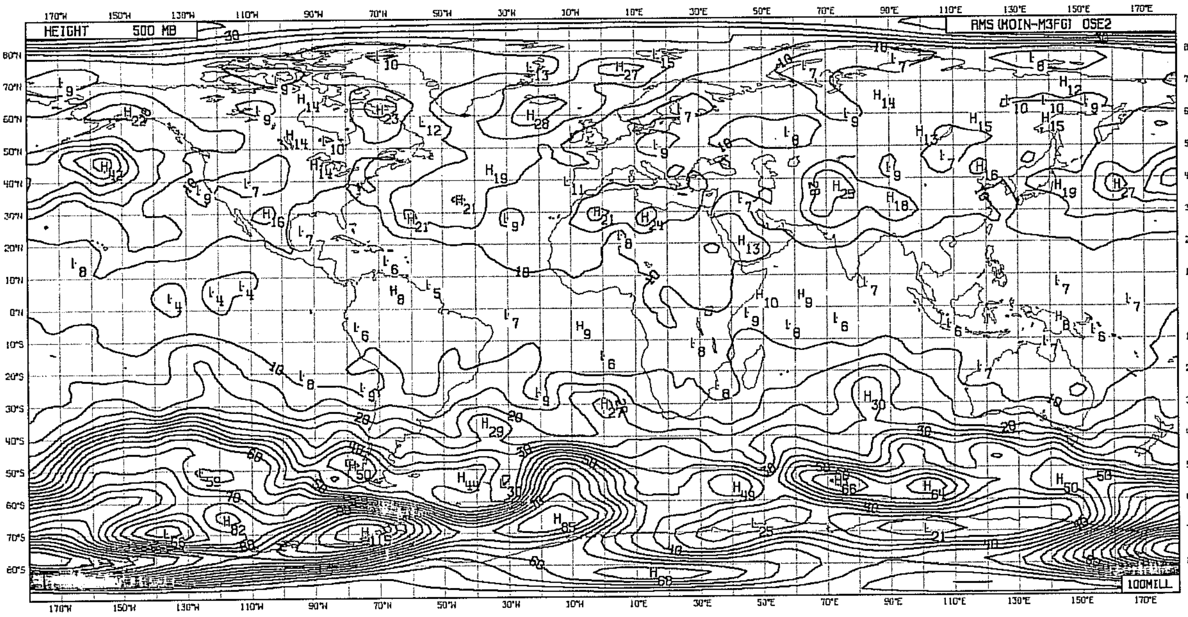
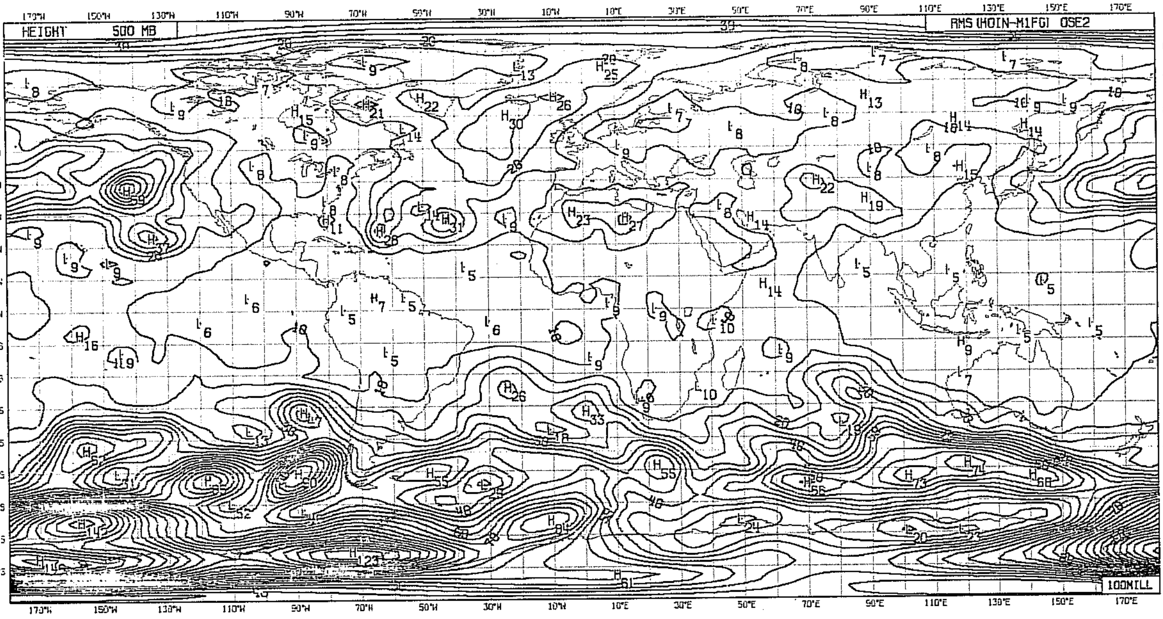


Fig. 4.3. : RMS of the 6h forecast error for 500 mb height in OSE-II when verified against Control initialized analyses ; a) CONTROL, b) SURFACE, c) SURFACE + SATOB, d) SURFACE + SATEM.

b) SO



d) SM

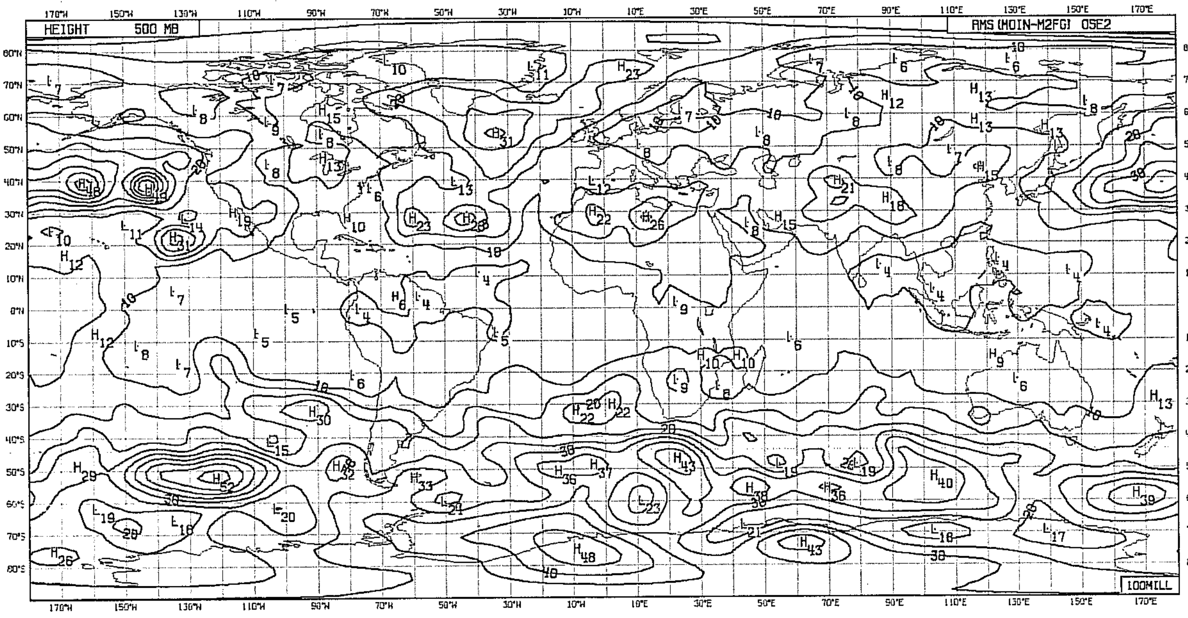


Fig. 4.3. : (cont).

prompted a thorough perusal of all the data coverage maps, which showed that for the 00 GMT analyses from which all the forecasts were run, there were many missing swathes in the Eastern Pacific, every swathe but one in the 10-day period had a gap between about 50°N and 30°N, and many partial swathes terminated at 50°N, or began at 30°N. There was little SATEM cover in the Eastern Pacific between 30°N and 50°N for the 00 GMT analyses of OSE-II.

We conclude, therefore, that the missing SATEM data during OSE-II contributed substantially (together with the reduced activity over the northern hemisphere oceans) to the reduced impact of this observing system, compared to the one observed during OSE-I.

5. IMPACT OF THE INDIVIDUAL SYSTEMS IN OSE-I AND OSE-II

In this section we discuss the impact of the individual systems on the assimilations through a study of the divergence of the forecasts of the SM, SB, SX systems from the SO system.

As already anticipated in the introduction, a difficulty common to most OSE-type studies is that, by the time the analysis differences caused by different observing system configurations have had the opportunity to produce suitable forecast differences, the model-generated errors have reached such a dominating level that they tend to mask any other effect (see Fig. 1.1). An alternative approach is to analyse the forecast differences from a given configuration (in our case the Minimum System, SO). In such a case one is able to attribute all detectable differences to the differences in initial conditions, arising from the differences in observing system.

The divergences of the forecasts from each other give no indication of their absolute quality. This question will be addressed in the next section. For the moment it can be taken for granted that in OSE-I the addition of data to the Minimum System improved the forecast, while this is not so obviously true in OSE-II. We did not find ever that the addition of data to the assimilation degraded the forecasts.

In the next two subsections we deal with the forecast divergences from a synoptic and statistical point of view.

5.1 Synoptic examples of forecast divergence

Two examples were chosen from the OSE-I and OSE-II periods. For each example we show the impact of a single data system on an analysis and forecast by presenting difference maps between the forecast based on the Minimum System (SO) and the forecasts based on the Minimum System plus SATEMs (SM), or the Minimum System plus SATOBs (SB), or the Minimum System plus ACFTs (SX). The results from the latter have only been analysed for OSE-I.

The sequence of forecasts from 12 GMT on 11 November, Figs.5.1-5.3, show remarkable similarities in the impact of each individual system. The SATEM and ACFT data show extraordinary similarity out to day 7, while all three data systems have quite similar impact out to day 4. The analysis system was therefore capable of using any one system, or all three systems, very effectively.

The corresponding charts for an equivalent experiment in OSE-II (Figs.5.4-5.6) show dramatically different results. This case was chosen because it had the most complete 00 GMT SATEM coverage in the Pacific for the whole period. The important activity in the Pacific was associated with a jet near 20°N, 120°W. The impacts of the SATOB and SATEM data on the forecast are quite different, with essentially zero impact from the SATEM data out to day 5.

5.2 Statistics of forecast divergences

The examples above show that there can be much or little redundancy among the observing systems depending on the synoptic situation. Statistics of forecast divergence are a useful way to quantify the impact of the data. For this purpose, we have used the forecasts from the AI system as a reference. Fig. 5.7 shows the divergences in 500 mb geopotential as measured by anomaly correlations for the two hemispheres poleward of latitude 20°, and for both OSE periods. We recall here that 7 forecasts were run during OSE-I and 9 during OSE-II.

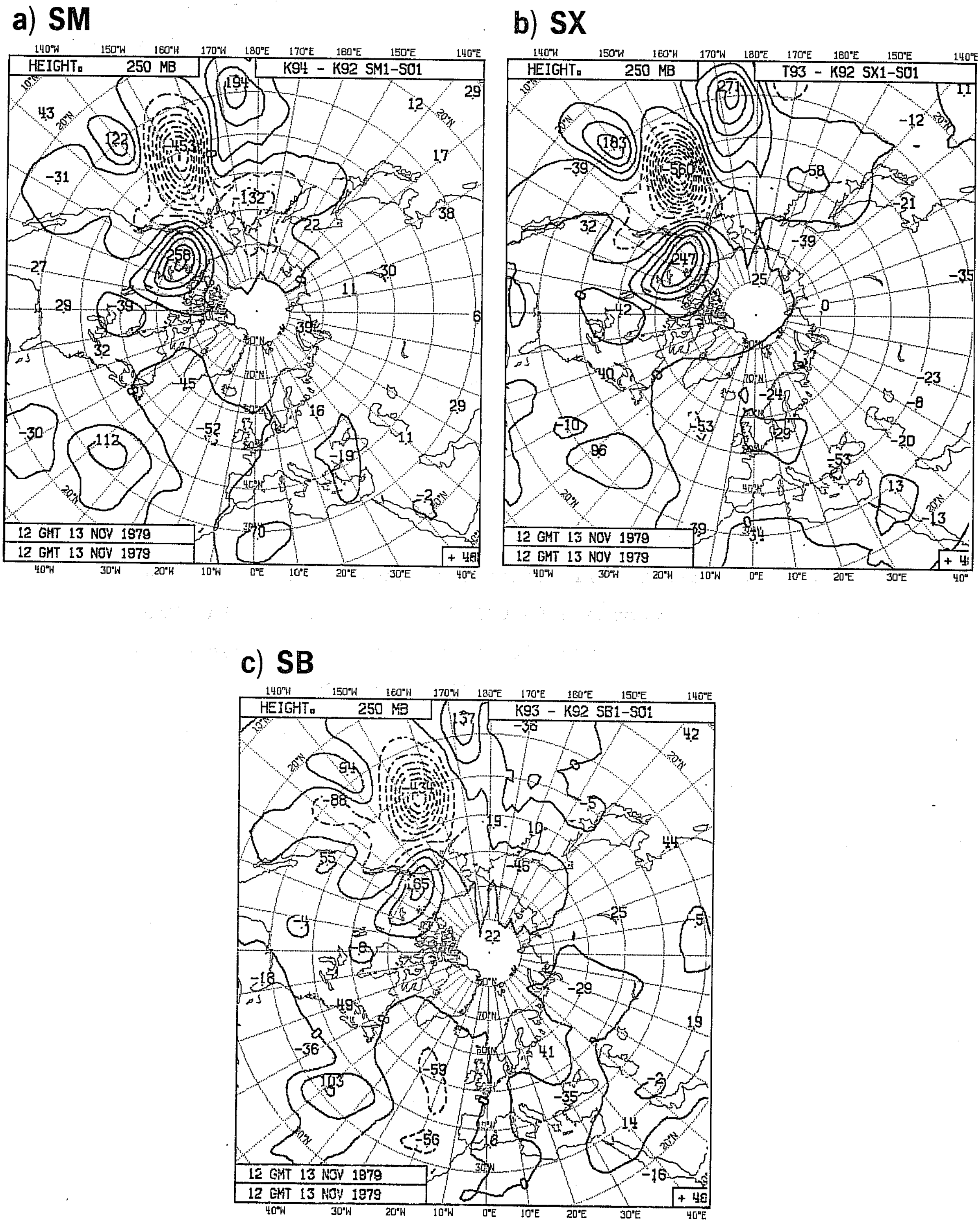


Fig. 5.1. : Day two (+48h) forecast divergences from the SURFACE forecast started from 11 November 1979 12GMT/OSE-I at 250 mb level for : a) SURFACE + SATEM (top left), b) SURFACE + Aircraft (top right), c) SURFACE + SATOB (lower panel).

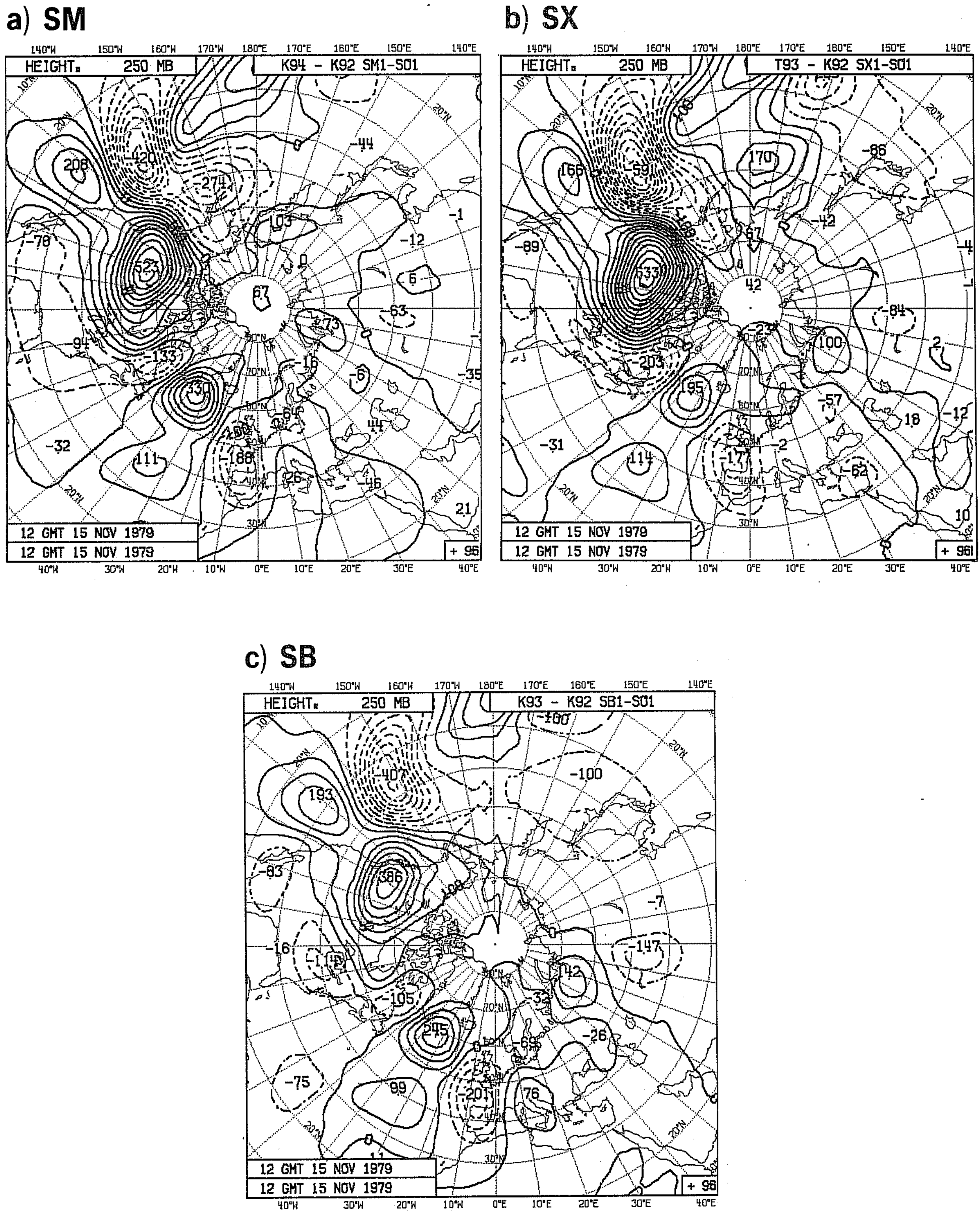


Fig. 5.2. : Day four (+96h) forecast divergences from the SURFACE forecast started from 11 November 1979 12GMT/OSE-I at 250 mb level for : a) SURFACE + SATEM (top left), b) SURFACE + ACFT (top right), c) SURFACE + SATOB (lower panel).

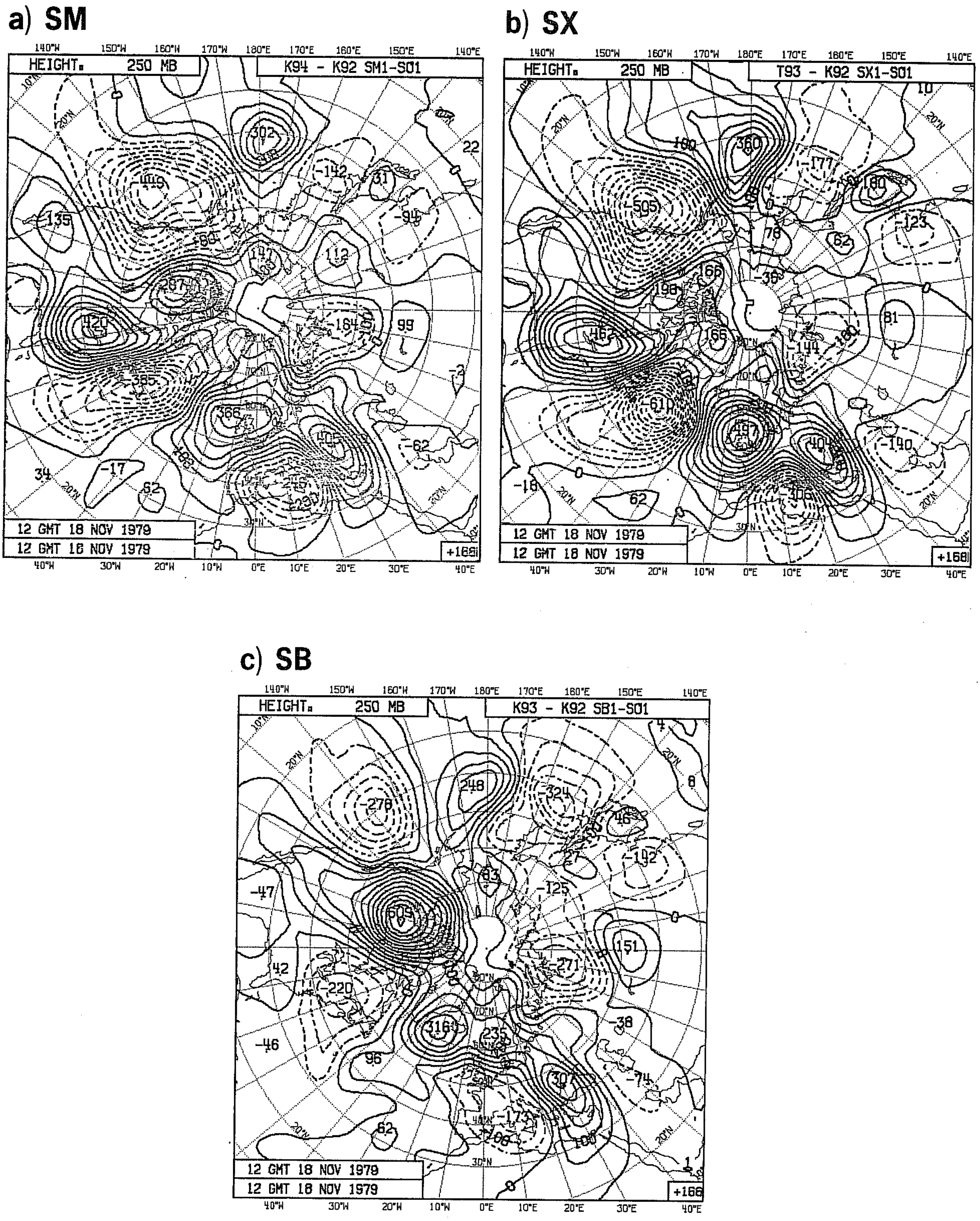


Fig. 5.3. : Day seven (+168h) forecast divergences from the SURFACE forecast started from 22 November 1979 12GMT/OSE-I at 250 mb level for : a) SURFACE + SATEM (top left), b) SURFACE + ACFT (top right), c) SURFACE + SATOB (lower panel).

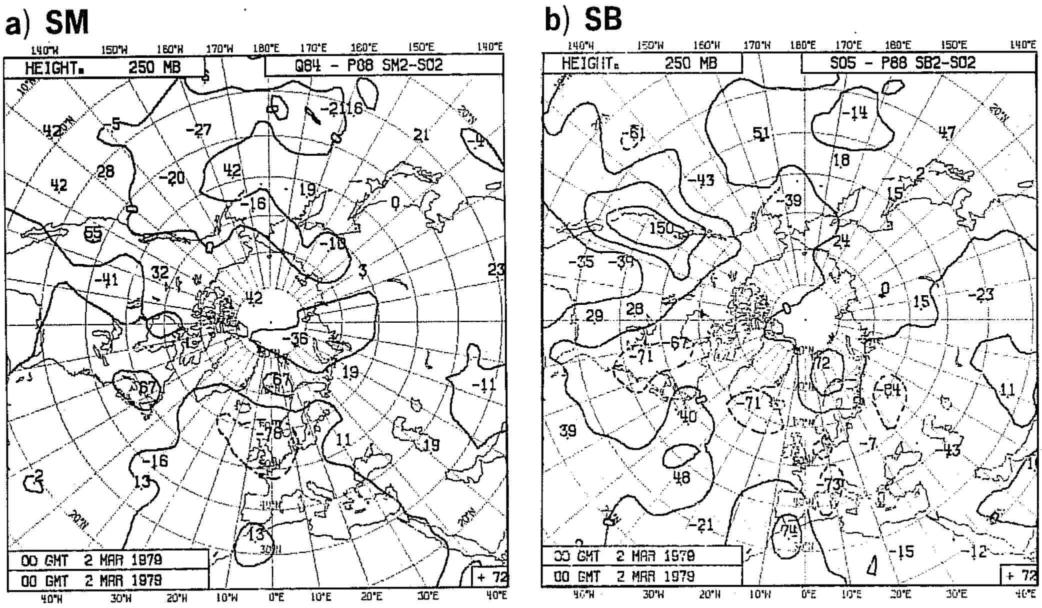


Fig. 5.4. : Day three (+72h) forecast divergences from the SURFACE forecast started from 27 February 1979 00GMT/OSE-II at 250 mb level for : a) SURFACE + SATEM (left), b) SURFACE + SATOB (right).

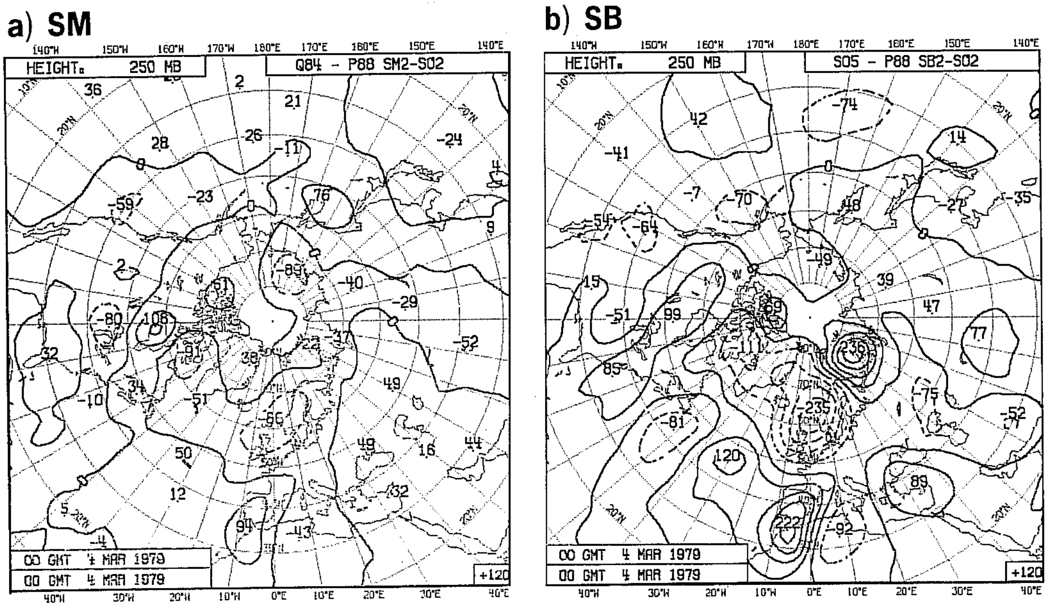
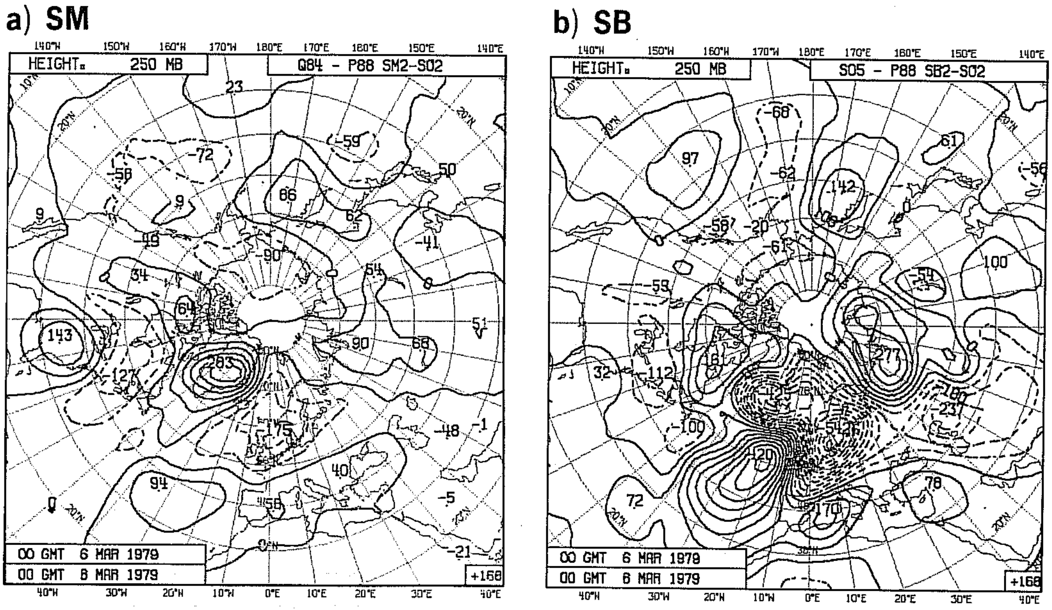


Fig. 5.5. : Day five (+120h) forecast divergences from the SURFACE forecast started from 27 February 1979 00GMT/OSE-II at 250 mb level for : a) SURFACE + SATEM (left), b) SURFACE + SATOB (right).


a) SM

b) SB

Fig. 5.6. : Day seven (+168h) forecast divergences from the SURFACE forecast started from 27 February 1979 00GMT/OSE-II at 250 mb level for : a) SURFACE + SATEM (left), b) SURFACE + SATOB (right).

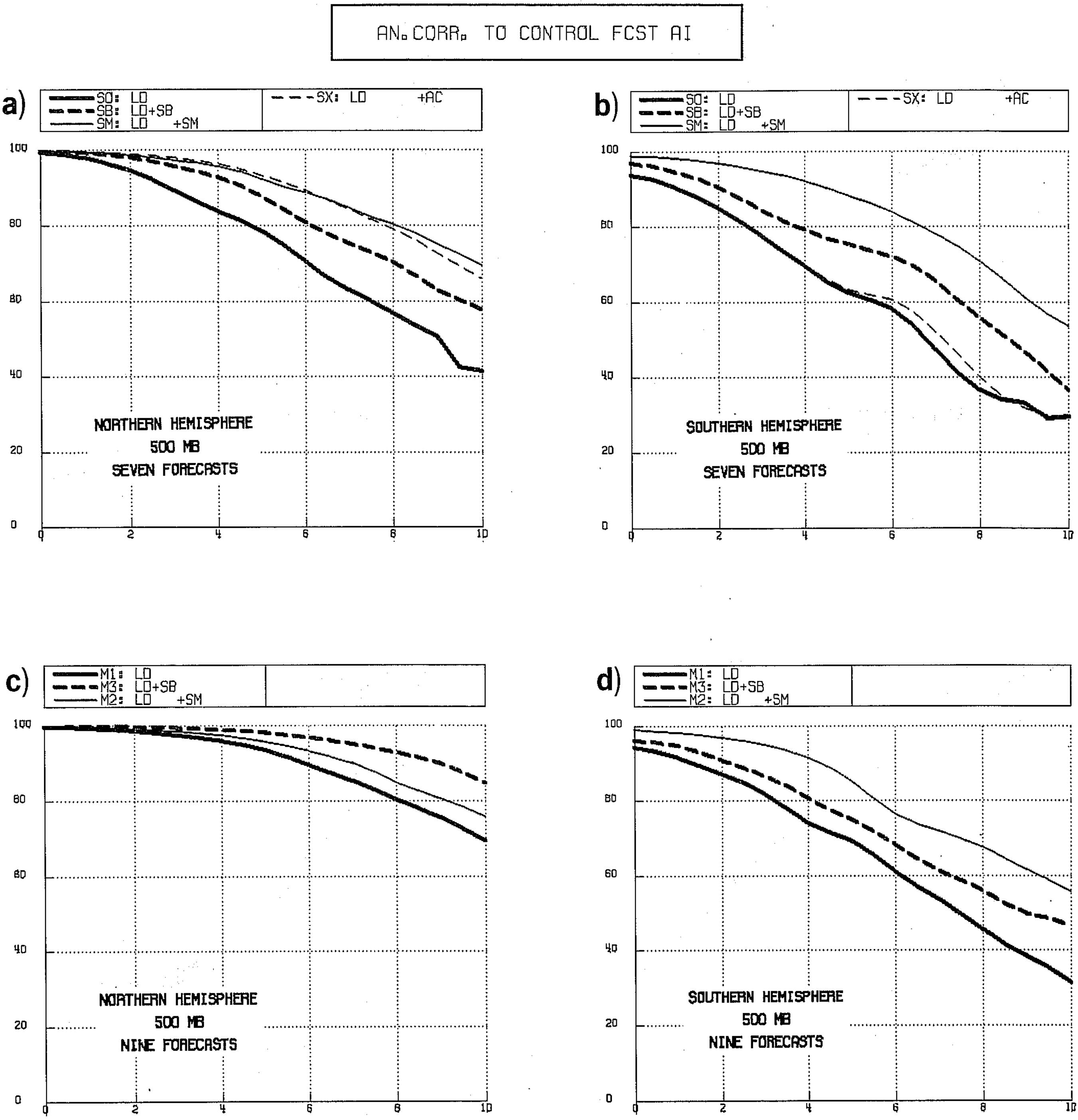


Fig. 5.7. : Mean anomaly correlations of tropospheric geopotential height for the experiment forecasts when verified against control forecasts. OSE-I, upper panels, OSE-II lower panels. Left panels : Northern hemisphere. Right panels : Southern hemisphere.

Continuous thick : SO : SURFACE

Dashed thick : SB : SURFACE + SATOB

Continuous thin : SM : SURFACE SATEM

Dashed thin : SX : SURFACE + ACFT

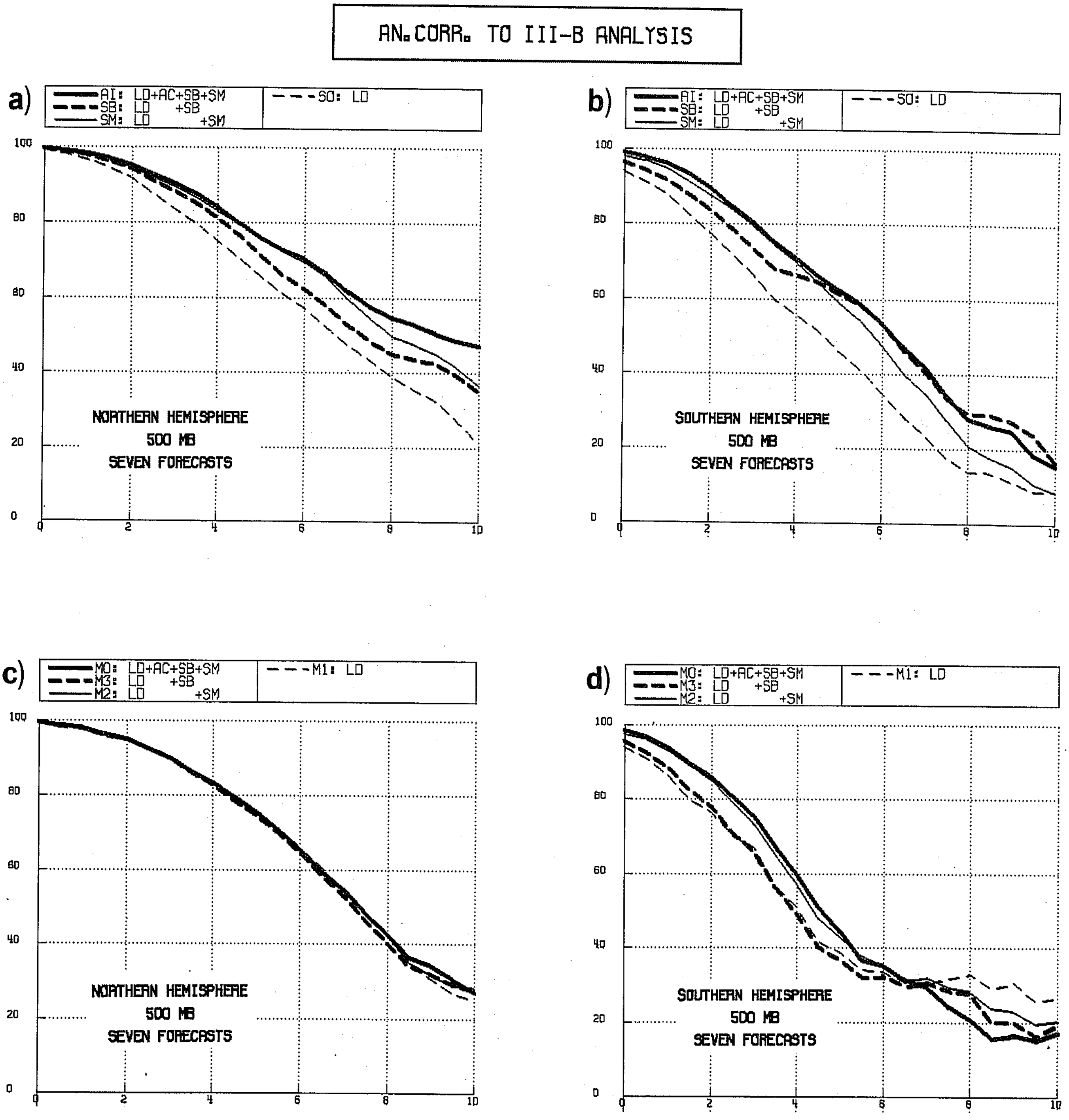


Fig. 6.1. : Mean anomaly correlation of tropospheric geopotential height verified against CONTROL analyses.
OSE-I, upper panels, and OSE-II, lower panels.
Left panels : Northern Hemisphere. Right panels : Southern Hemisphere.
Continuous thick : AI : CONTROL
Dashed thick : SB : SURFACE + SATOB
Continuous thin : SM : SURFACE + SATEM
Dashed thin : SX : LAND + ACFT

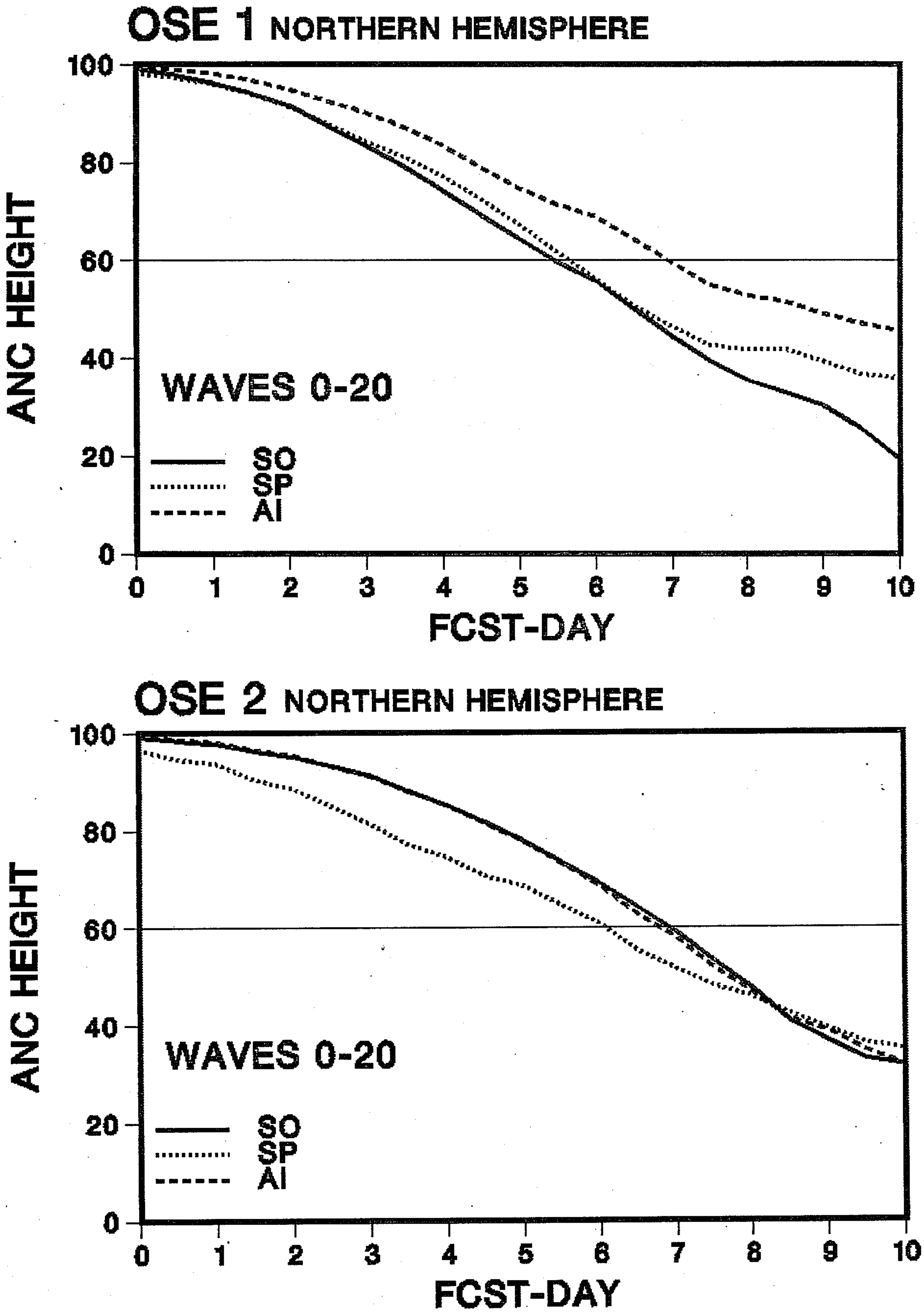


Fig. 6.2. : Mean anomaly correlations of tropospheric geopotential height for SURFACE based system (SO), SPACE based system (SP) and for CONTROL (AI) forecasts in Northern Hemisphere for OSE-I (top) and for OSE-II (bottom).

The divergence of the forecasts from the CONTROL system happens much faster in OSE-I than in OSE-II. The SATEM experiments are closest to the CONTROL in the southern hemisphere, as expected, with the SATOB data showing a considerable effect in the southern hemisphere also.

In the northern hemisphere SM and SX are closest to AI in OSE-I, with SB lying between SM and SO. In OSE-II, the relative positions of SM and SX are reversed, with SX closest to AI. This is consistent with the last synoptic case study and the considerations laid out in Sects. 2 and 4.1.

6. IMPACT OF DATA ON FORECAST SKILL

Fig. 6.1 shows the forecast anomaly correlation of 500 mb geopotential height for the OSE-I and OSE-II experiments for AI, SM, SB, SO. The most dramatic difference between the two periods is in the impact of the special data in OSE-I, the lack of impact of these data in OSE-II and the remarkably good performance of the SO system in OSE-II. These results are, however, all consistent with the differences in synoptic situation and data coverage noted earlier. In the southern hemisphere the importance of the SATEM data is confirmed in both OSE-I and OSE-II.

Finally, Fig. 6.2 shows forecast results for AI, SO, and for yet another set of experiments SP, which attempts to probe the "best-mix" problem and which consisted of data that could in principle be collected from space (surface pressure, ACFT, SATEM, SATOB, but not TEMP). These results, consistently with the single system experiment results, confirm that the "space-based" system alone is equivalent to the "surface-based" system alone only during the OSE-I period. During OSE-II, however, because of the reasons exposed above, the performance of the "space-based" platforms is considerably poorer.

The difficulties inherent to the "best-mix" problem are well illustrated by the aircraft impact studies of Baede (1983) and Barwell and Lorenc (1984). Their results showed that the deletion of ACFT data from the complete system had little effect on the forecast skill after 2 days. This is consistent with the results of Hollingsworth and Arpe (1982) and Arpe et al.(1984), that show that, provided the analyses are of good quality, model error is the dominant source of forecast error in the range between 2 and 5 days (Fig. 1.1).

7. CONCLUSIONS

The combined results of the two OSEs show that the SATOB data are crucial for the tropical analyses, that the SATEM data are important for the extra-tropical analyses over oceans, and that aircraft data, where available, are an invaluable addition to the observation data base.

In the first of our experimental periods, OSE-I, the crucial analysis area for forecast success (area of highest synoptic activity) lay in the Central Pacific mid-latitudes and sub-tropics, in an area where there was an abundance of all three types of data. The results below indicate that in this case any one of the observing systems was able to provide the essential information.

In the second of our experimental periods, OSE-II, there was much less activity over the oceans than in the first period. We studied in some detail only the SATEM and SATOB data for this second period but neither of them showed much effect on forecast quality. Further detailed investigation showed that there was a gap in the potentially available SATEM data over the Eastern Pacific that could well have affected the results. We conclude that the much reduced activity over the oceans, coupled with the absence of SATEM data, led to the negligible impact of the SATEM and SATOB data on forecast skill in this second period.

The results demonstrate clearly the value of each of the observing systems. The fact that in certain situations there may be redundancy between the systems, is a strength rather than a weakness of the composite system. Aircraft data particularly from wide-bodied jets can be much more accurate at a single level than either of the other two systems. The SATEMs and SATOBs complement each other in providing global coverage, while the aircraft data complements the rather inaccurate microwave retrievals in cloudy areas of the extratropics, and complements the SATOB data in cloud-free areas of the tropics.

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