OBSERVING SYSTEM EXPERIMENTS ON NESDIS STATISTICAL RETRIEVALS OF TOVS SATELLITE DATA USING THE 1988 ECMWF DATA ASSIMILATION SYSTEM

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ABSTRACT

We report an observing system experiment on SATEM data during a 15½ day period in January-February 1987, using the operational ECMWF system as it was in late July 1988. The forecast results show a negative impact of the SATEM data in the Northern Hemisphere, and a strong positive impact in the Southern Hemisphere. Recent changes in the analysis/forecast system have made the system more sensitive to data, and therefore more vulnerable to bad data. We show that the statistical retrievals have serious errors and biases. The biases are air-mass dependent, and so have strong regional variations.

1. INTRODUCTION

Satellite soundings (SATEMs), produced by NESDIS from the "TIROS Operational Vertical Sounder" (TOVS), have been widely used in global operational assimilations during the last ten years. Several studies have evaluated the impact of the SATEMs on the quality of the analysis and of the forecast. Gilchrist (1982) summarises a series of studies using the data from the First Global GARP Experiment (FGGE).

The standard technique to evaluate the impact of a data system is to perform an Observing System Experiment (OSE). In such an experiment two data assimilations are run in parallel, one including and the other excluding the observing system under investigation. The parallel sets of analyses and subsequent forecasts are then compared to see the impact of the data system under study.

In this paper we discuss an impact study concerned with SATEM data produced by NESDIS using a statistical retrieval scheme (Reale et al., 1986). The period of interest is 30 January to 14 February 1987, for which NESDIS provided raw and cloud cleared radiance data. The assimilation system used for the impact study was the operational ECMWF system as of late July 1988.

The present study is the latest in a series of OSE studies on SATEM data at ECMWF. Uppala et al. (1984) carried out an OSE on NESDIS statistical retrievals from FGGE, using the 1982-1983 ECMWF operational assimilation system. Two FGGE periods were studied in detail: one in November 1979 (OSE-1) and the second in February 1979 (OSE-2). In the Southern Hemisphere the impact of satellite sounding data on forecast skill was large and positive in both the FGGE periods studied. In the Northern Hemisphere there was a positive impact during OSE-1 and a neutral impact during OSE-2.

Observing system experiments usually produce the clearest answers in the following circumstances:

- the data used for the study are no more inaccurate than the first-guess;

- there is significant meteorological activity in the area studied during the period studied;

- the data under study are the only data available in the area of interest, so there is no data redundancy. (Data redundancy of some kind is of course essential for quality control.)

Comparisons of impact studies using different assimilation systems can produce ambiguous results, and this has led to lively controversy in the past. Some of the controversy arises because assimilation systems do not use observational data to best effect (Hollingsworth and Lönnberg, 1989), and so the response to the insertion or removal of a new observing system will vary with the assimilation system used in the OSE. However since the conditions for an unambiguous OSE are easily satisfied in the Southern Hemisphere, many groups concur with Uppala et al. (1984) that there is a clear beneficial impact of SATEM data on the analysis and the forecast in the Southern Hemisphere.

Impact studies in the Northern Hemisphere have much more variable results. In general it is difficult to demonstrate a clear and consistent positive impact from SATEM data. The impact varies according to the meteorological situation as found for hemispheric impact studies by Uppala et al. (1984), and in regional impact studies by Durand (1985).

In a recent study Kelly and Pailleux (1988) used the 1987 ECMWF data assimilation system to make SATEM impact studies on two periods, one from 1979, and the other from 1987. In their impact study of the 1979 data, Kelly and Pailleux re-assimilated part of the 1979 period studied by Uppala et al. (1984), and repeated three of the forecasts using the latest analyses. They found clear positive impact in the Southern Hemisphere, as had all previous studies. They also found a positive impact in the Northern Hemisphere, though the impact was smaller than the impact found by Uppala et al. (1984).

In their second SATEM impact study, Kelly and Pailleux (1988) used the 1987 ECMWF data assimilation system in parallel assimilations with and without SATEM data (the assimilations are referred to as OPS-JUL87 and NOSATEM-JUL87 below) for a 15½ day period from 30 January 1987, 00 UTC to 14 February 1987, 12 UTC. In general the results are equivalent to those of the FGGE OSE-2 experiment: a large positive impact of SATEM data in the Southern Hemisphere and a neutral impact in the Northern Hemisphere. Regional investigation of the analyses and the forecasts in the Northern Hemisphere showed that the overall neutral impact on the Northern Hemisphere results from a compensation between a positive impact on one side of the hemisphere (North America - Atlantic - Europe) and a negative impact on the other side (East Asia and Pacific). Kelly and Pailleux found evidence that in some areas the SATEM quality was very poor and that the rejection tests of the analysis scheme are not stringent enough to reject all the bad SATEM data.

In the present paper we perform an OSE on the same February 1987 period studied by Kelly and Pailleux (1988) using the more recent version of the ECMWF assimilation system which became operational at the end of July 1988 (these assimilations are called OPS-JUL88 and NOSATEM-JUL88 hereafter).

In the present study the overall impact of SATEM data in the Northern Hemisphere is negative. Comparison of the present results with the Kelly and Pailleux study for the same period leads to some interesting conclusions. The changes to the assimilation system between 1987 and 1988 (which affected both the analysis system and the assimilating model) improved both the NOSATEM forecasts and the SATEM forecasts. The assimilation changes had a larger positive effect in the NOSATEM experiments than in the SATEM experiments. As a result the neutral impact of SATEM data in the OSE with the 1987 assimilation system became a negative impact in the OSE with the 1988 assimilation system, as discussed in Section 3.

Detailed synoptic and statistical investigations of the effect of SATEM data in the analyses are reported in Sections 4 and 5. These studies show that there are serious air-mass dependent biases in the SATEM statistical retrievals. The results are discussed in Section 6.

2. DEVELOPMENTS IN THE ECMWF ASSIMILATION SYSTEM 1987-88

The ECMWF assimilation system as of July 1987 is documented in Kelly and Pailleux (1988). Between July 1987 and July 1988 there were changes to both the analysis system and the model used for assimilation and forecasts.

2.1 Analysis Changes

Two sets of changes were made to the analysis system. The first change was the implementation of divergent structure functions in February 1988, as described by Undén (1989), following Daley (1985). This was found to have a beneficial effect on the analysis of the divergent wind field in the tropics, but had little effect in mid-latitudes.

The second set of modifications were implemented in July 1988 and are described in detail in Lönnberg (1988). The main elements of this modification set are:

- A reduction of the horizontal scale of the forecast error correlation function in data rich regions of the Northern Hemisphere mid-latitudes, so that the local truncation on the analysis increments is increased from the equivalent of total wave number 35 to total wave number 65;

- A widening of the forecast error vertical correlation over the Pacific Ocean;

- A retuning of the observation error standard deviations and of the rejection thresholds for all the observation types. The rejection criteria become more severe for certain observation types, especially for cloud track winds (SATOBs) and for SATEMs, partly because of the revised first-guess check and partly because of modifications in the OI check.

The main consequence of the forecast error horizontal correlation modifications is to produce a higher horizontal resolution in the analysis. The analysis scheme draws more closely to the data, and the assimilation is then more sensitive to the observations. As a result the system is more vulnerable to bad data, and much of the development reported by Lönnberg (1988) is concerned with the improvements needed in the quality control procedures to make the high resolution system robust enough for operational use. As shown by Lönnberg (1988) the overall effect is that OPS-JUL88 is better than OPS-JUL87, although there are important case-to case fluctuations in forecast skill scores.

2.2 Model Changes

The most important change made to the forecast model between July 87 and July 88 was the virtual elimination of the vertical diffusion above the planetary boundary layer of the model (Miller, 1988). This leads to more accurate forecasts, with a higher level of kinetic energy than before. The change also reduces the systematic errors of the model.

3. IMPACT OF SATEM DATA ON FORECASTS WITH THE 1988 ECMWF SYSTEM

We repeated the observing system experiment reported in Kelly and Pailleux, (1988), using the operational system as it was after the changes reported by Lönnberg (1988). We therefore have four sets of forecasts to compare, OPS-JUL87, NOSATEM-JUL87, OPS-JUL88, and NOSATEM-JUL88, with each set consisting of fifteen global forecasts to day-10. Fig 1a is a comparison of the anomaly correlation scores for the Northern Hemisphere for the OPS-JUL87 and OPS-JUL88 forecasts. These results confirm the results of Lönnberg (1988) and Miller (1988) that the model and analysis changes to the operational system were positive. Fig 1b is a comparison of the NOSATEM results for the two experiments. This shows that the changes to the analysis forecast system were also positive when one runs without SATEM data. Moreover, the impact of the analysis/forecast system changes were larger in the NOSATEM case than in the operational case, where SATEM data were used. As a result the neutral impact of satellite data in the Kelly and Pailleux (1988) study with the 1987 system becomes a negative impact in the present study, as shown in Fig 1c. The corresponding plots for the Southern Hemisphere (Figs 1e and f) show substantial positive impact of SATEM data with both the 1987 and 1988 systems, and also a negative impact of the 1987-1988 developments on the Southern Hemisphere forecasts in the NOSATEM context.

Fig 2a shows a scatter plot of the individual day 5 Northern Hemisphere forecast scores for the NOSATEM-JUL87 and OPS-JUL87 scores in the Kelly and Pailleux (1988) study. The small cross indicates the centroid of the points and falls almost exactly on the diagonal, indicating little net impact of the SATEM data. Fig 2b shows the corresponding results for the present experiment with the 1988 system. The 1988 results show much more variability in daily forecast scores with a marked increase in scatter of the anomaly correlation at day 5 in the OPS versus NOSATEM comparison between the 1987 and 1988 systems. It is clear that a large sample is required to determine the forecast impact. Nevertheless the results in Fig 2 raise the question: Given that the 1988 system is more sensitive to data, do the results suggest that there are errors in the data which are more serious for the 1988 assimilation system than for the 1987 system?

To explore further the negative impact of SATEM data in the Northern Hemisphere in the July 88 system we computed a series of 15-day mean regional forecast scores, Fig 3. The SATEMs have a negative impact after day three in China, Japan, North Pacific and North America. The regional scores for North Atlantic and Europe show a small positive impact of SATEM data after day three. This suggests that there may be data problems over Asia and the Pacific which propagate downstream with time. Kelly and Pailleux (1988) have previously noted that the SATEM data were of poor quality over Eurasia during the study

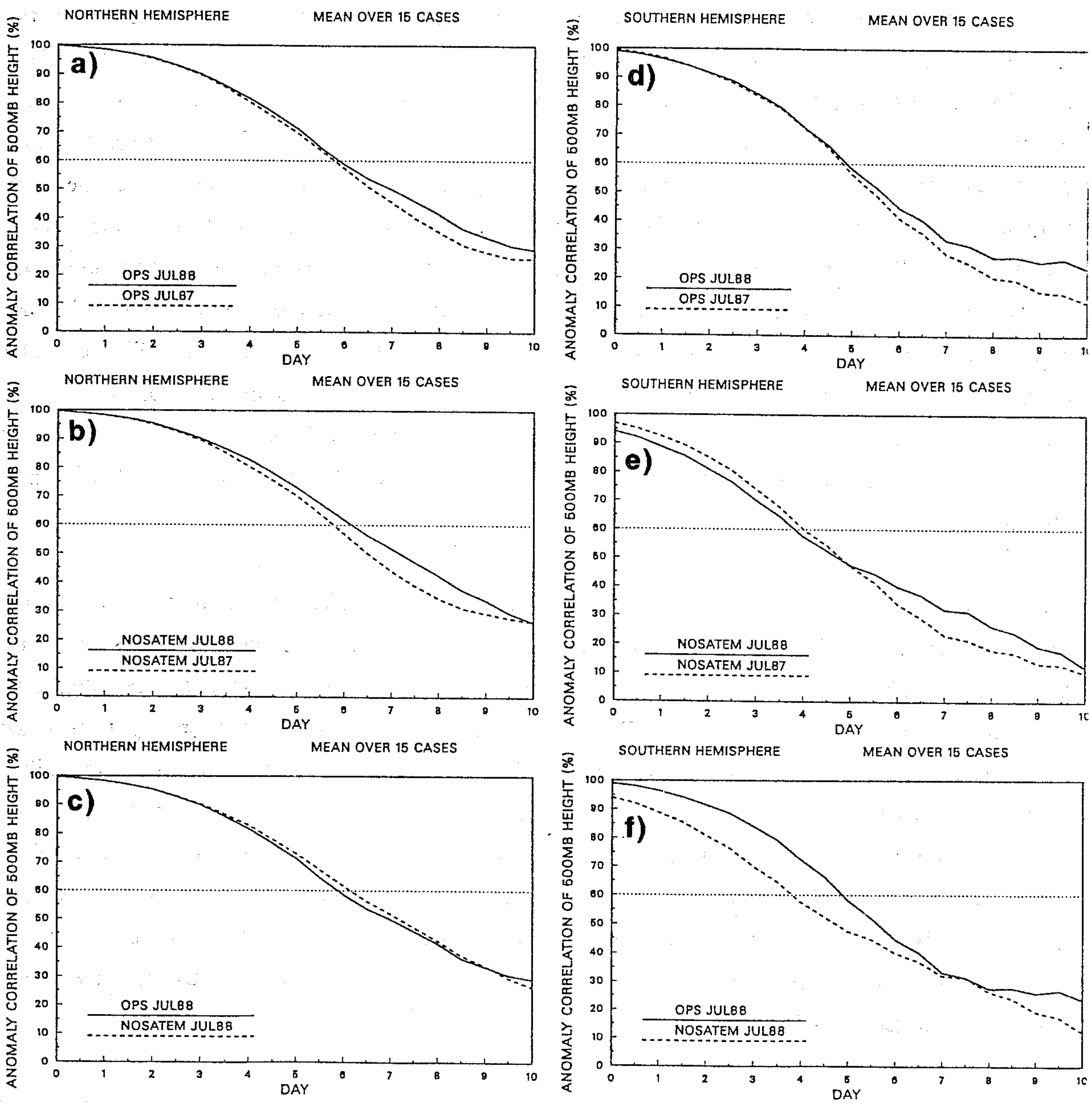
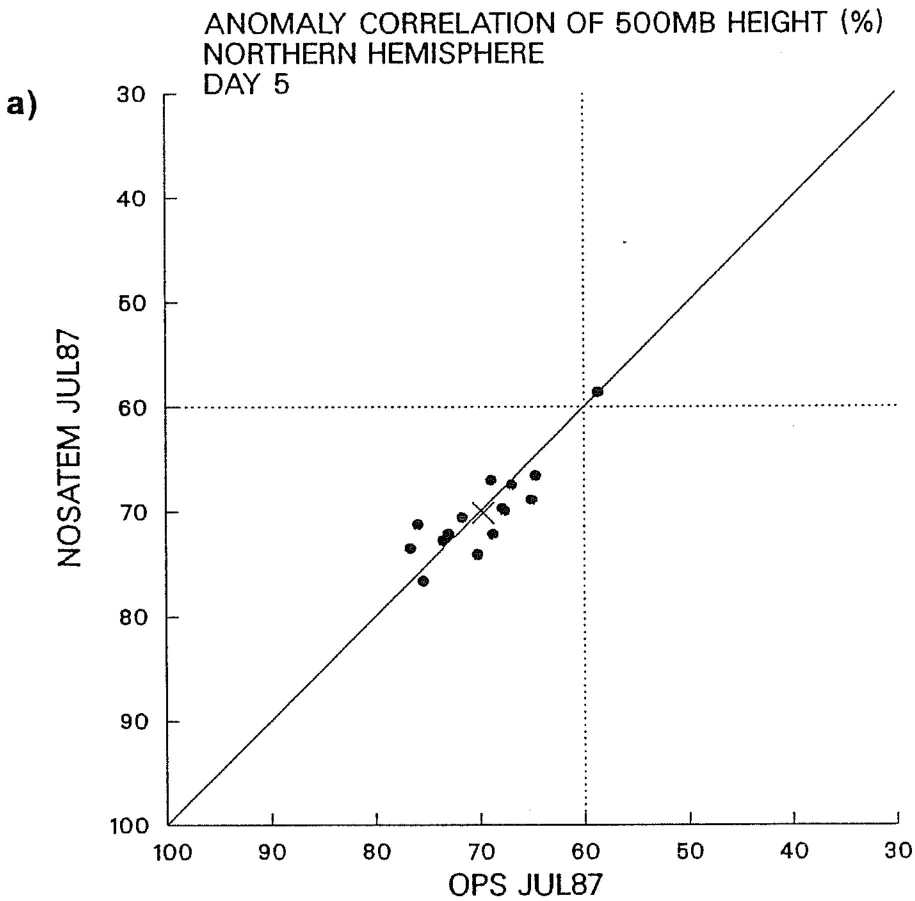


Fig. 1 Anomaly correlation of 500 hPa geopotential height for the Northern Hemisphere accumulated and averaged on 15 cases. (a) compares the operational assimilation of JULY 88 (solid line) and JULY 87 (dashed line), (b) is with SATEM data excluded and (c) shows the impact of SATEM data in the July-88 system. (d), (e) and (f) are like (a), (b) and (c) respectively but for the Southern Hemisphere.



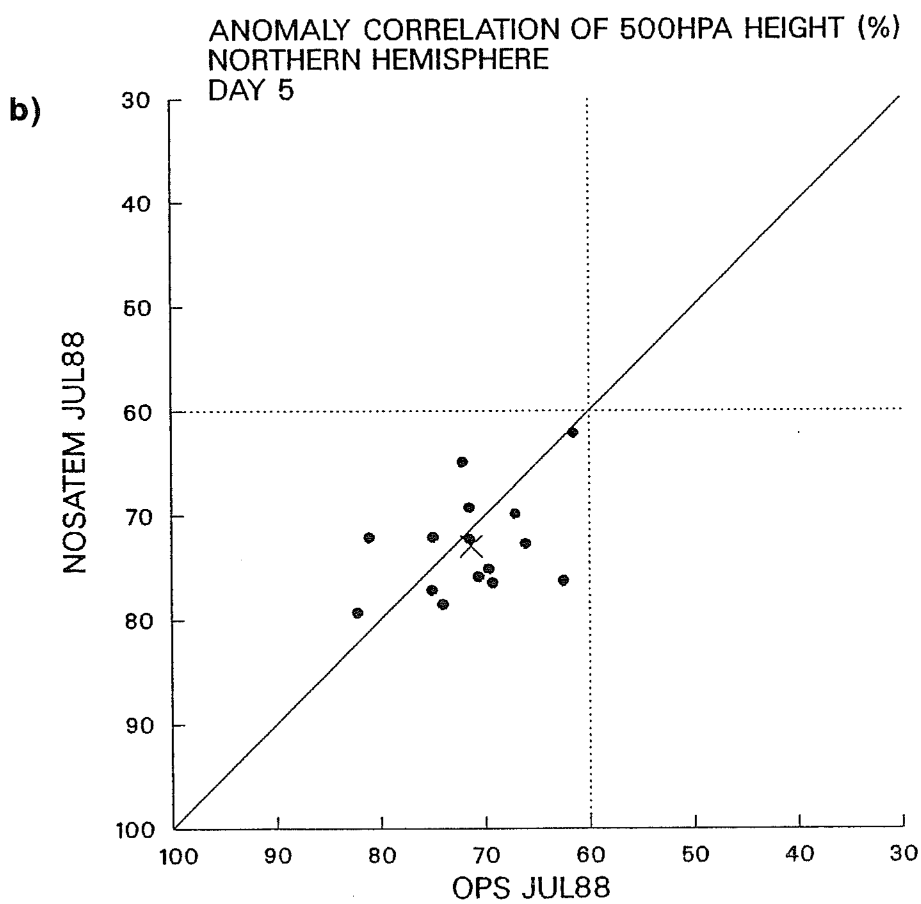


Fig. 2 Scatter diagrams of OPS versus NOSATEM forecast scores for day 5. (a) is with the July-87 system and (b) is with the July-88 system.

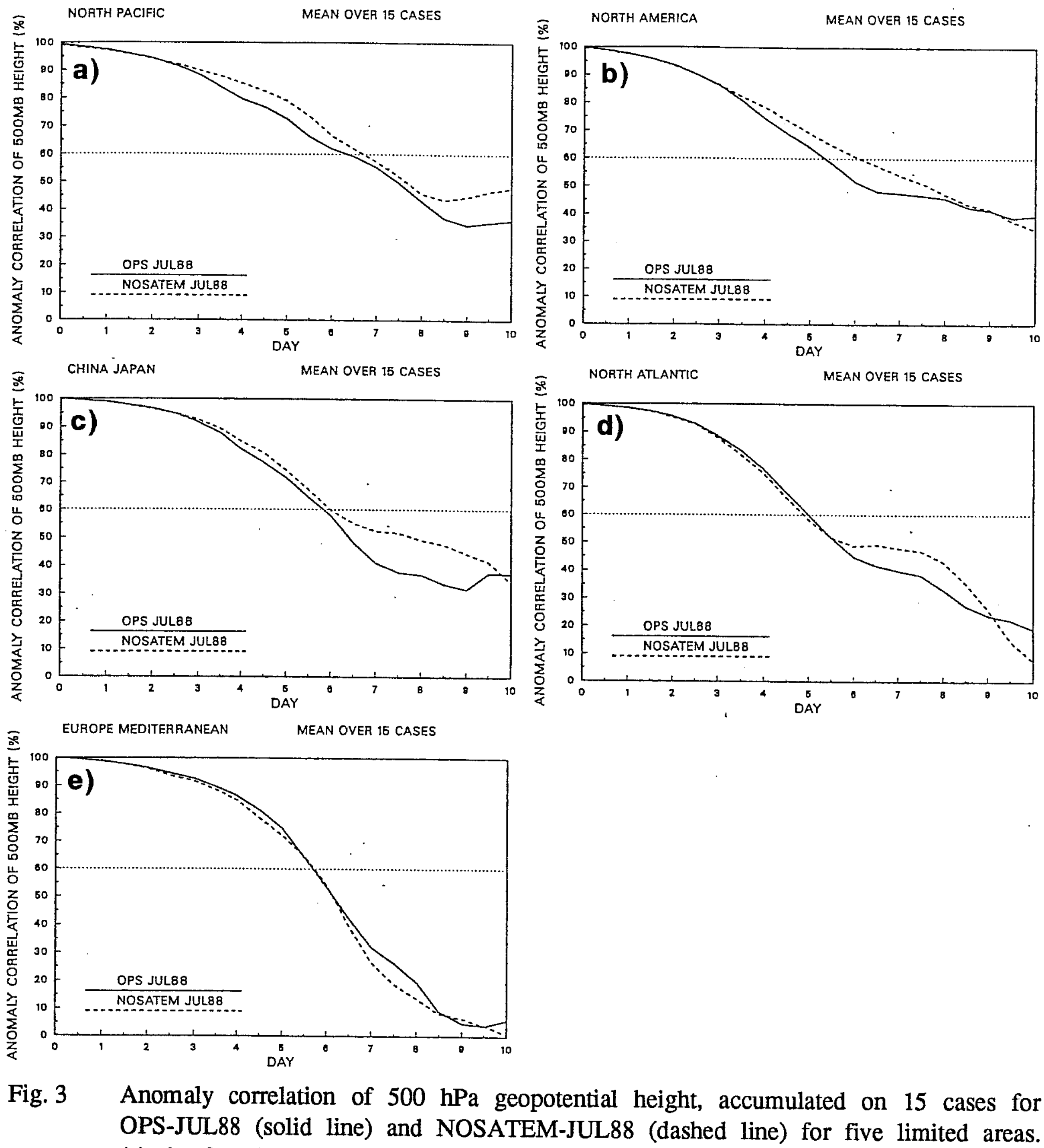


Fig. 3 Anomaly correlation of 500 hPa geopotential height, accumulated on 15 cases for OPS-JUL88 (solid line) and NOSATEM-JUL88 (dashed line) for five limited areas. (a) is for the North Pacific, (b) is North America, (c) is China/Japan, (d) is North Atlantic and (e) is Europe and the Mediterranean.

period, due to the presence of an anomalous circulation in the stratosphere over Europe and Asia.

4. SYNOPTIC CASE STUDIES

We had particular interest in studying further the case which showed a negative impact of satellite data in the 1988 system. By tracing forecast errors back in time it was found that the problems often originated from the eastern part of the North Pacific which is a large area with few conventional observations. A priori one would assume that the satellite information would be most valuable in this region. The polar front was active in this area with waves developing over the ocean and moving towards North America.

In the North East Pacific the NOSATEM-JUL88 and the OPS-JUL88 analyses differ mainly in the lower troposphere. The general impression is that the NOSATEM atmosphere is livelier in many respects. At 500 hPa, the waves in the temperature field usually appear to be more amplified, and there is usually stronger warm and cold air advection in the NOSATEM analyses. As an example, in Fig 4 the cold and warm air advection at 500 hPa are indicated by dots plotted on the intersections between height contours and temperature contours. The cold front near 40° North, 150° West is clearly more active in the NOSATEM analyses. The frontal waves are also more developed in the NOSATEM assimilation at 850 hPa. The fronts are often sharper in the active parts along the front and there is an accompanying difference in the surface pressure fields. Figs 5a and b show the analyses of 1 February 1987, 12 UTC, Figs 5c and d are the 48 hour forecasts and Fig 5e is the verifying operational analysis of 3 February 1987, 12 UTC. The strong development in the NOSATEM forecast started near (170°W, 38°N) in the analysis and the 48-hour forecast verifies well, although the centre is too deep. The OPS-JUL88 forecast intensified too late and maintained a spurious double structure in the 48-hour forecast.

The NOSATEM-JUL88 forecasts do not verify better than OPS-JUL88 in the North Pacific in the short range, however after day 3 they are superior. Synoptic examination of the analyses showed that the satellite data are often warmer than the first-guess on the cold side of a front and colder on the warm side. This effect has been noted by Gallimore and Johnson (1986) in a study of SATEM data from 1979, and is consistently found also in the present study. The use of SATEMs in frontal regions weakens the horizontal temperature gradient and therefore reduces the strength of the polar-front jet near the front. The air-mass dependent biases (and poorly estimated tropospheric static stability) in the baroclinic zones degrade the large scale features of the SATEM analyses, and thereby degrade the skill in the medium range forecasts.

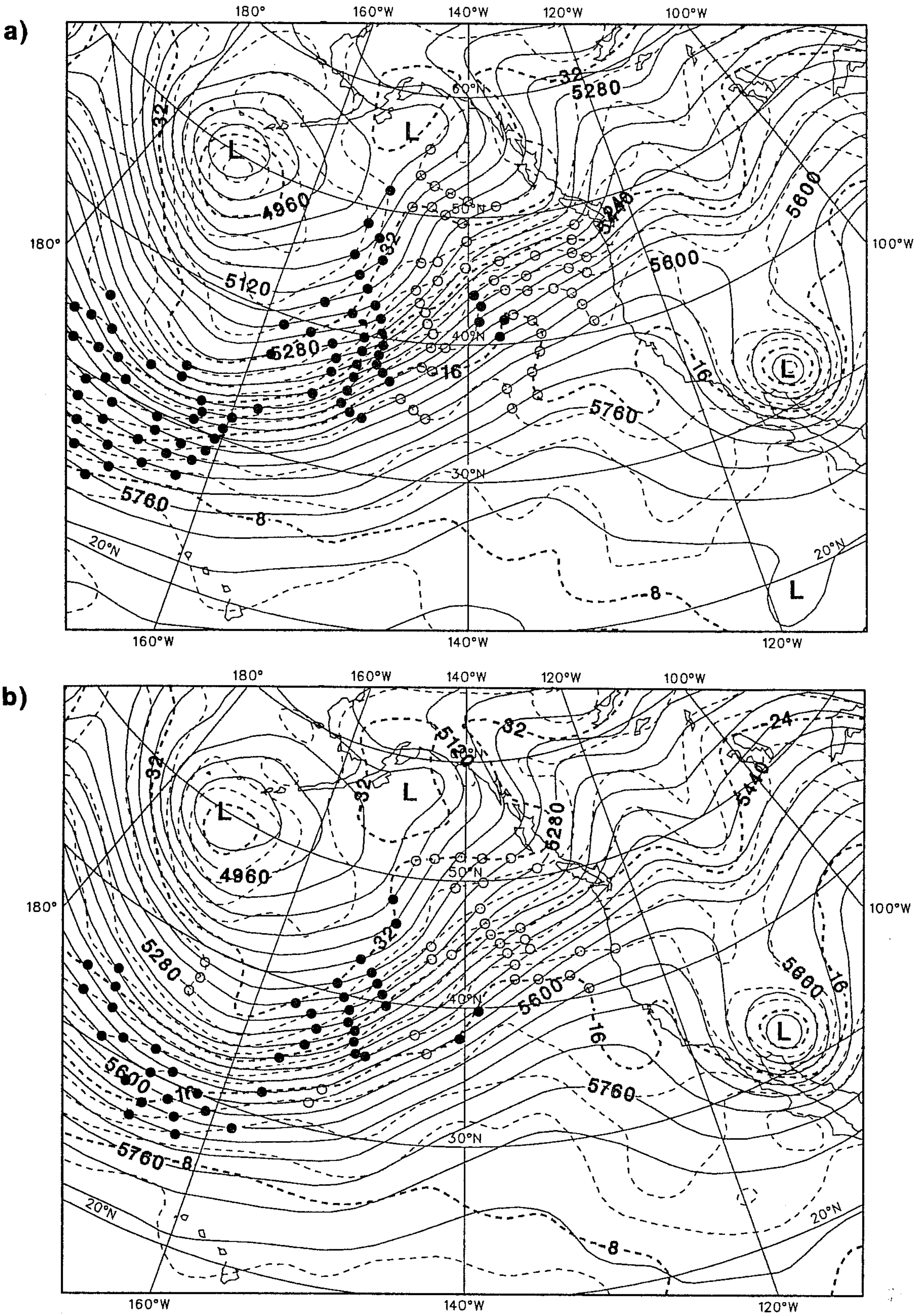


Fig. 4 Analyzed 500 hPa geopotential height (full lines) and temperature (dashed) 31 January 1987, 12 UTC. The markers in the intersections between height contours and temperature contours indicate temperature advection, full circles for cold and open circles for warm air advection. (a) is OPS-July 88 and (b) is NOSATEM.

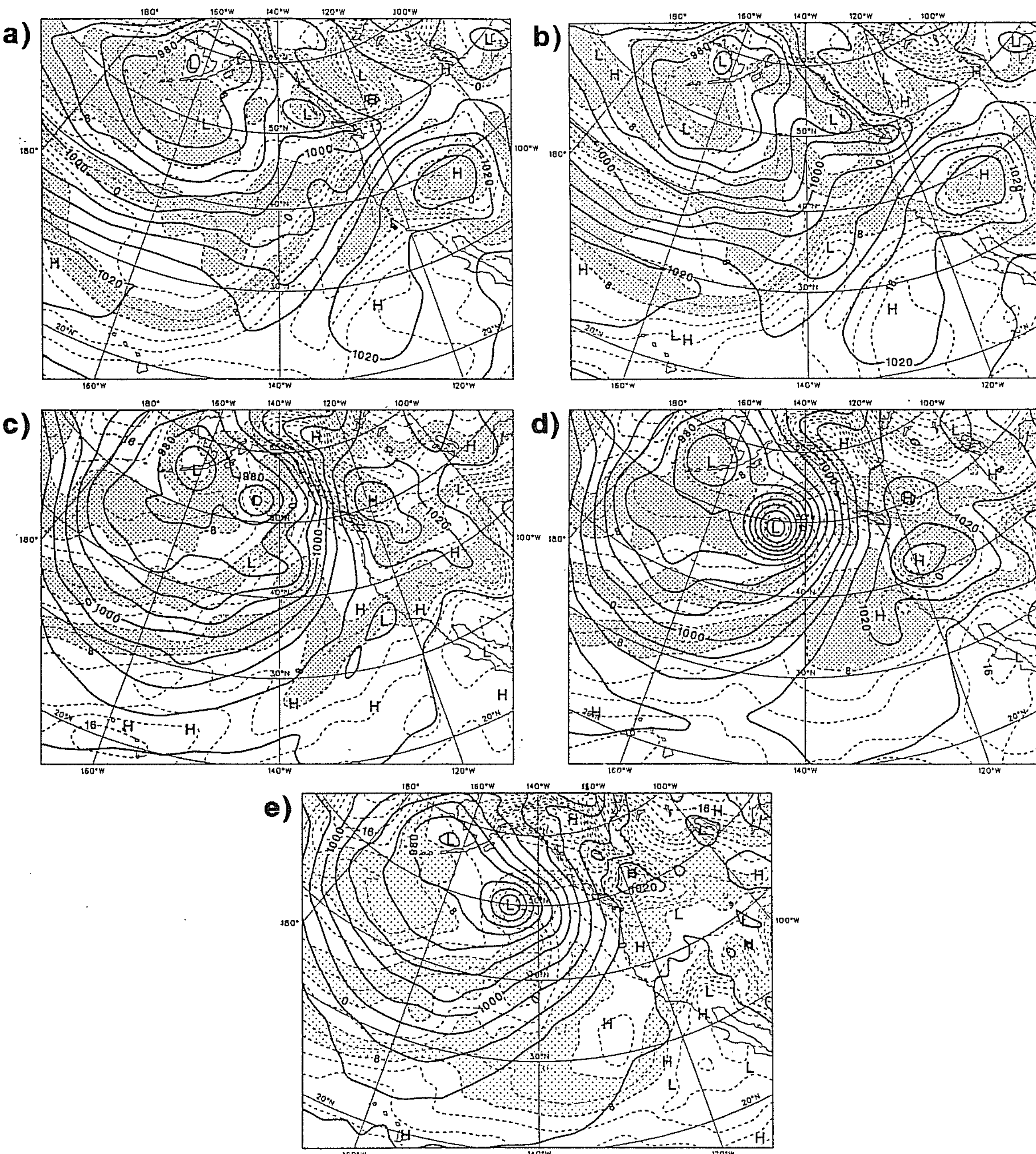


Fig. 5 Mean sea level pressure (hPa, full lines) and 850 hPa temperature (K, dashed lines and shaded in intervals of 4K) in the eastern North Pacific. (a) is the OPS-July 88 analysis at 1 February 1987, 12 UTC and (b) is the corresponding NOSATEM analysis. (c) is the 48-hour forecast from the analysis in (a) and (d) is the corresponding NOSATEM forecast. (e) is the verification analysis for 870203 12 UTC.

5. GEOGRAPHICAL BIASES IN THE SATEM DATA IN FEBRUARY 1987

The synoptic biases noted in the statistical SATEM retrievals were most severe in outbreaks of cold continental air over the warmer oceans to the east of Asia and N America. An example of this retrieval problem is shown in Fig. 6 off the coast of North America. The 1000-700 hPa field shows a strong cold air current being directed to the east of Canada until 45°W and then towards the north. The departures, SATOB minus first guess, are all positive in this region and there is a corresponding compensation in the 500-300 hPa layer. In these areas we shall show that the background field for the analysis (i.e. the first-guess) is rather accurate, as the short range forecast which provides the first-guess has the benefit of good data coverage upstream. Verifications of the first-guess against island stations just off these coasts shows negligible bias in the first-guess.

We noticed that biases of one sign in the SATEM data for the 1000-700 layer were usually accompanied by biases of the opposite sign in the 300-500 layer. It is therefore interesting to study the mean differences between the SATEM data and the first-guess, averaged over the period of our experiment, for an index S defined as follows:

$$S = T_V(1000\text{-}700) - T_V(500\text{-}300)$$

where T_V is layer-mean virtual temperature. The parameter S gives a measure of overall tropospheric static stability. The theory of baroclinic instability indicates that the static stability has a key role in determining the growth rate of synoptic disturbances. We may therefore expect that errors in the data affecting static stability, if not trapped by the quality control procedures, can have a serious effect on the forecasts.

5.1 Biases between SATEM data and the First-guess

The average bias and standard deviation of the SATEM minus first-guess differences have been calculated for the static stability index for the period 30 January to 14 February and are shown in Figs 7a-d, for NOAA-10. Results for NOAA-9 have very similar characteristics (see Appendix). Off the east coasts of N America and Asia most of the SATEM reports are cloudy retrievals, and the retrievals show large biases of up to 3K over the Gulf Stream and 8K over the Kuroshio (Fig 7b). These biases arise because the SATEM reports are, on average, warmer than the first-guess at the lower level and colder than the guess at the upper level in these areas.

By contrast, the retrievals show biases of opposite sign in S in mid-latitudes on the eastern sides of the Atlantic and Pacific Oceans. In these areas of predominantly warm a)

b)

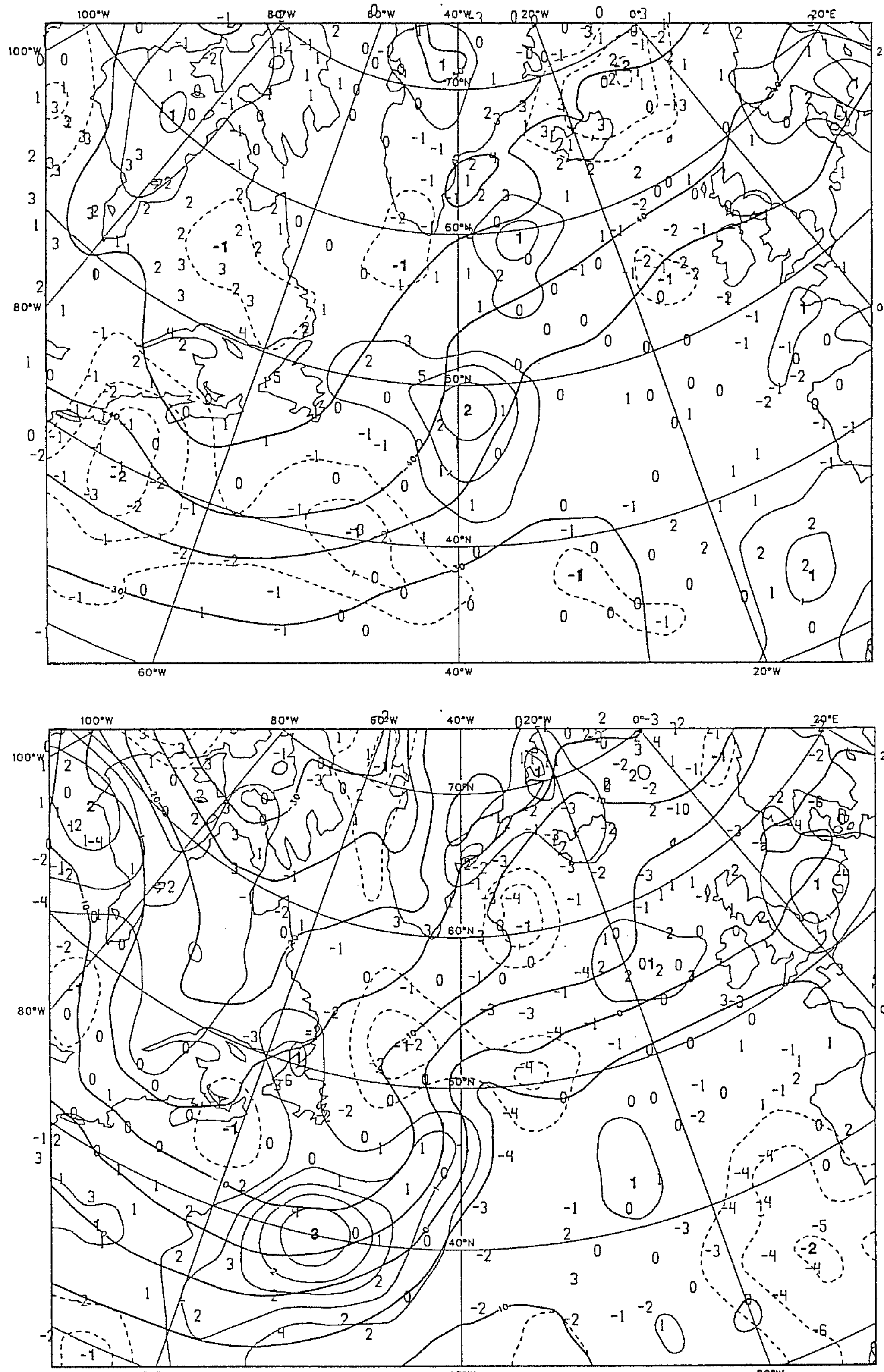


Fig. 6 Observed SATEM layer-mean temperature deviations from first guess in K, 870206-12 UTC, for the North Atlantic. The first-guess field (OPS-JUL88 is contoured with an interval of 5K (solid lines). Also contoured (thin lines) is the analysis increment with an interval of 0.5K : thin full lines are positive (AN-FG) and dashed are negative. (a) is 1000-700 hPa, (b) is 500-300 hPa.

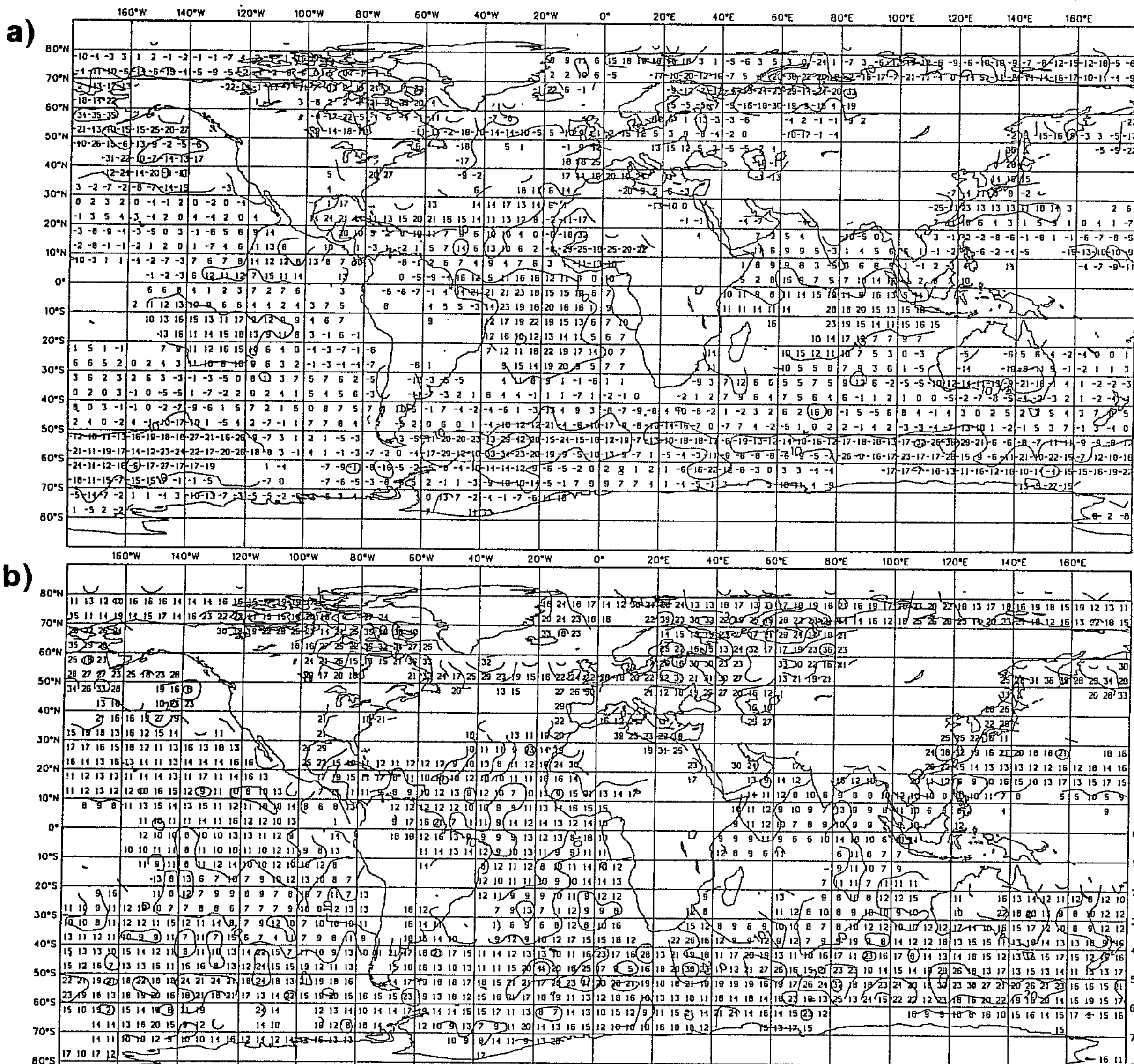


Fig. 7 (a) is bias of stability index (S) for NOAA-10 Clear Soundings, February 87. (Bias = observation minus first-guess, averaged over the studied 15-day period in February 1987). (b) is standard deviation. (c) and (d) are like (a) and (b) respectively but for MSU soundings.

c)

d)

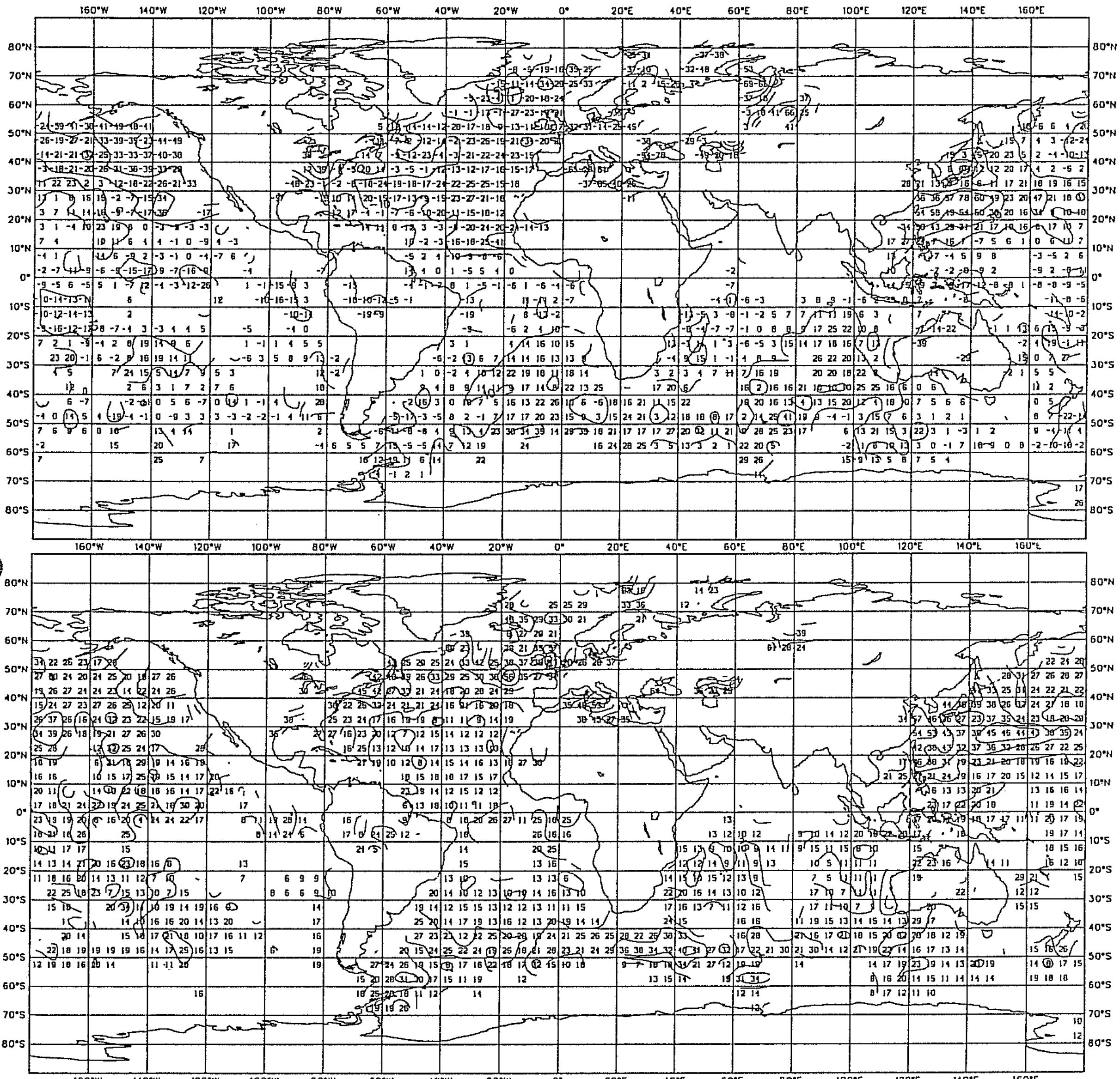


Fig. 7 Continued.

low-level advection, the negative bias in S arises because the retrievals are cold relative to the first-guess at the lower level, and warm relative to the first-guess at the upper level.

In mid-latitudes the biases in the clear soundings are generally smaller than the biases in the cloudy soundings. However, in the sub-tropics, there are biases in excess of -2K in the clear retrievals along 30° North in the eastern North Pacific, and off the coast of west Africa. Since the first-guess is fairly accurate as we shall show shortly, these biases are quite large.

Figs 7c-d show the standard deviation of the SATEM minus guess differences for the period of the experiment. There are extensive areas where the standard deviation exceeds 3K for both clear and cloudy retrievals. The standard deviations are as large as 5 or 6K over the Gulf Stream and the Kuroshio. Oort (1983) shows that the standard deviation of the daily temperature in these latter areas is 6 to 7K at both 850 and 500 hPa. Since the first-guess is rather accurate, a standard deviation of 6K for the difference between SATEM and first-guess for the parameter S indicates that the SATEM data in these areas has hardly more information than a climatological estimate.

In equatorial regions Oort shows that the variability of temperature in the troposphere is of order 1K, so that biases or standard deviations of order 1K in the SATEM minus first-guess values for S are again indicative that the SATEM data have only a little more information than climatology. The clear soundings have rather little bias in S relative to the first-guess in equatorial regions (Fig 7a), but do have standard deviations of between 1 and 1.5K which indicates that the information content relative to climatology is low. The cloudy soundings have biases in S, relative to the first-guess, of between 1 and 1.5K, and standard deviations between 1 and 2K. Thus the information content of the cloudy retrievals is low also in equatorial regions.

5.2 Validation of the First-guess as a Reference Standard

We have implicitly used the first-guess as a reference standard to obtain a global overview of the performance of the SATEM data. To justify this approach we now validate the first-guess against radiosonde data.

5.2.1 North Atlantic

Fig 8a shows a scatter plot of the value of S as observed at the three Atlantic weather ships (C, L and M) plotted against the corresponding first-guess value of S. Reports are only plotted when the reported surface pressure is 1000 hPa or more. The range of variation of S in the plotted reports is about 12K and the maximum deviation of order 2K. This indicates that the first-guess for S is rather accurate.

Fig 8b shows the corresponding scatter plot for the SATEM value of S plotted against the first-guess value of S in the north Atlantic, (50-68°N, 40°W-5°E). As already seen in Figs 7c-d, the standard deviation of the SATEM minus first-guess differences is of order 3K, with many differences in excess of 10K. There are differences in the collocation method between Fig 8a and Fig 8b. In both cases the first-guess is interpolated spatially to the observation position. However the first-guess is always valid at the same time as the radiosonde report, but the SATEM report may differ from the first-guess in its valid time by up to three hours. Despite this timing difference, the much larger scatter in Fig 8b than in Fig 8a can hardly be attributed to differences in the collocation method.

Many of the SATEM reports in the Atlantic must have been in error, but only a small percentage of the bad data was rejected (as indicated by the hollow circles).

5.2.2 The Area South of Japan

Turning to the Asian region, Fig 8c shows a scatter plot for S of first-guess against radiosonde data from five stations along the south coast of Japan. The scatter is slightly higher than at the Atlantic weather ships; the largest deviation is about 4.5K.

Fig 8d shows the corresponding plot for the SATEM data in the same area (25-35°N, 130-140°E). The scatter in the SATEM data is much larger, with differences of up to 15K. There is also clear evidence of a marked positive bias in the SATEM values of S. The first-guess is much more accurate than the SATEM data in this area. Much of the worst data was rejected, but the quality control should be much tighter.

5.2.3 Central Pacific

To evaluate the first-guess in the sub-tropical North Pacific, Fig 8e shows a scatter plot of the first-guess for S against the radiosondes at Midway Island and at Hawaii. The typical scatter is about 2K, with largest deviations of order 4K. Fig 8f shows the corresponding scatter plot for the SATEM data in the area (19-29°N, 155-180°W). Even in this data sparse area the SATEM data are noisier than the first-guess.

5.2.4 Discussion

The results just discussed justify the use of the first-guess as a reference standard for an overview of the performance of the SATEM data in the Northern Hemisphere sub-tropics and extra-tropics. The first-guess is much less biased than the SATEM data. The scatter

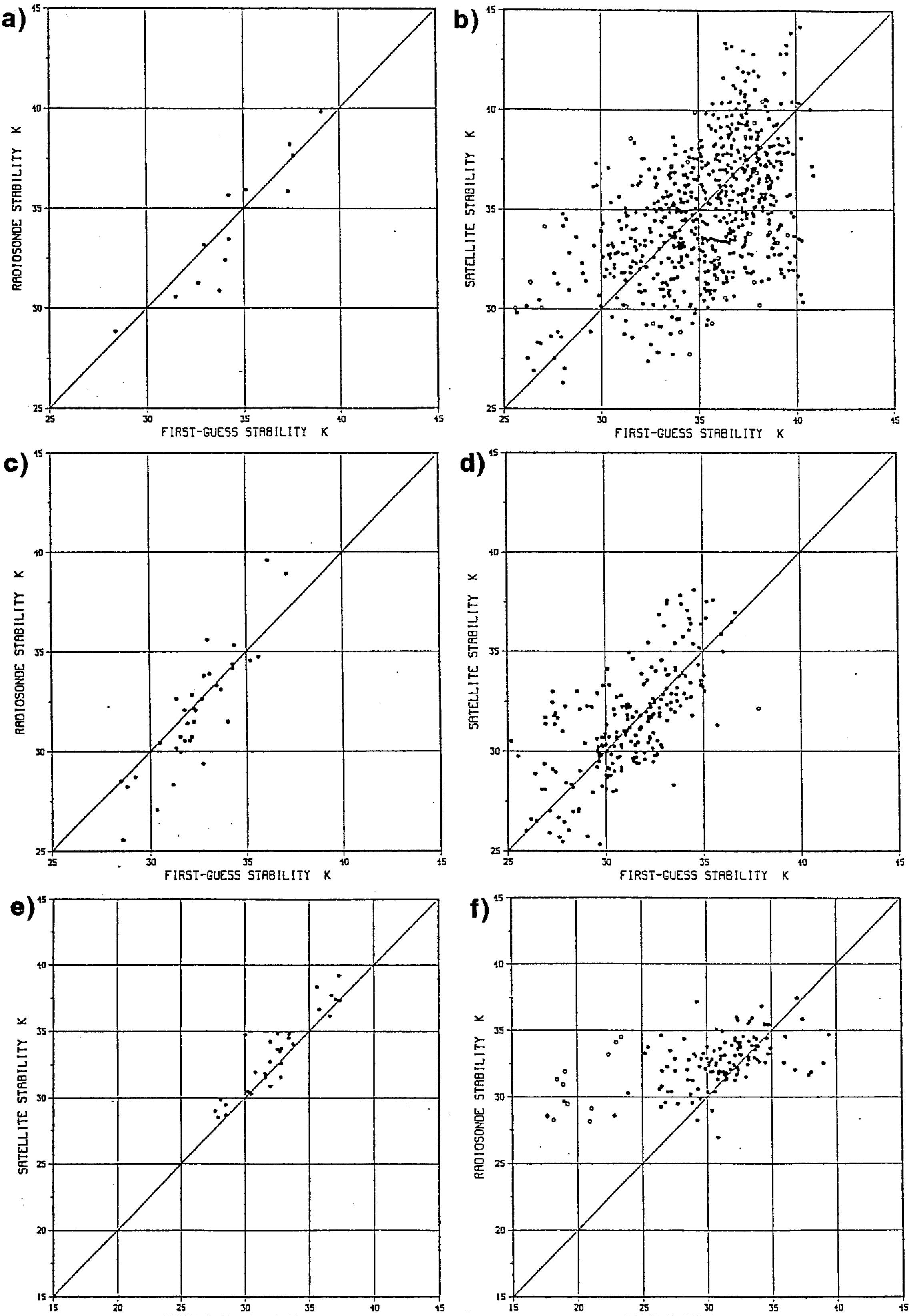


Fig. 8 Scatter diagram comparing the stability index (S) of the first-guess (horizontal axis) with radiosondes (vertical axis), left, and with NOAA-10 SATEMs, right, for a 15-day period in February 1987. (a) and (b) are in the North Atlantic, (c) and (d) are for Midway and Hawaii, (e) and (f) are for the Southern part of Japan.

of the first-guess relative to radiosonde data is also less than the scatter of the SATEM data relative to the first-guess. In short, the first-guess is more accurate than the SATEM data for a quantity like S.

The satellite data should be better at measuring average temperatures over thick layers (say 1000-300 hPa) than measuring a gross static stability over the 1000-300 hPa layer. However studies (not shown) indicate that the first-guess for the 1000-300 hPa layer-mean temperature, in the areas just discussed, is more accurate than the SATEM data.

Furthermore, comparing the first-guess accuracy (as measured against radiosondes) in data assimilations with and without SATEM data gives a direct measure of the value of SATEM data in the assimilation. The deviation of the first guess from reliable radiosondes along the west coasts of North America and Europe reflects the quality of up-stream satellite soundings. Table 1 presents statistics of this quantity for those and some other regions based on 23 observation times (00 and 12 UTC) within the 15-day period. Again, it appears that NOSATEM performs as well as OPS-JUL88 in the Atlantic and in the North Pacific areas whereas the SATEMs are very important in the Southern Hemisphere.

	OPS-JUL88		NOSATEM		
	Bias	SD	Bias	SD	Number
W America	7.3	19.9	-5.2	20.5	109
W Europe	-3.9	14.7	-2.8	14.6	364
E of Argentina	7.6	25.0	3.5	34.1	103
S of New Zealand	0.0	20.2	-16.9	28.9	59

Table 1. First guess quality as compared with radiosondes. 00 and 12TC 31 January to 14 February 1987, 500 hPa geopotential in metres.

6. SUMMARY OF THE IMPACT OF SATEMs WITH THE 1988 SYSTEM

The observing system experiment reported in this paper evaluated the impact of the operational 250 km statistical SATEM retrievals produced by NESDIS from TOVS data during the period from 30 January to 14 February 1987. The parallel assimilations were performed with the July 88 ECMWF operational assimilation system. We found the following results from the impact study:

a) Positive and large impact in the Southern Hemisphere;

b) Negative impact in the Northern Hemisphere, with large variations from case to case.

The earlier OSE performed by Kelly and Pailleux (1988) on the same period but using the July 1987 assimilation system found a neutral impact in the Northern Hemisphere. The model and analysis developments implemented between July 87 and July 88 led to forecast improvements whether or not SATEM data were used. Improvements were larger in the NOSATEM context. Consequently the neutral impact of SATEM data with the 1987 system became a negative impact with the 1988 system.

Rodgers (1976) defined the information content of an observing system as the logarithm of the ratio of volumes of the uncertainty ellipses before and after the measurement. The volume of the uncertainty ellipse is proportional to the determinant of the corresponding error covariance matrix. Suppose the error covariance of the first-guess is $\underline{\underline{E}}_p$, that the error covariance of the measurements is $\underline{\underline{E}}_o$, and that the two are combined in an optimal way, so that the posterior error covariance $\underline{\underline{E}}_a$ is given by

$$\underline{\underline{E}}_a^{-1} = \underline{\underline{E}}_p^{-1} + \underline{\underline{E}}_o^{-1}$$

Then the information content of the data is proportional to

$$\ln\,[\det(\underline{\underline{E}}_p)/\det(\underline{\underline{E}}_a)]$$

If $\underline{\underline{E}}_o$ becomes substantially larger than $\underline{\underline{E}}_p$, i.e. if the observations become substantially less accurate than the first-guess, then their information content decreases to zero, although it remains positive. However, the argument that data always have positive information content, however noisy they may be, ignores an important feature of the estimation problem in meteorology. The penalty for believing an erroneous observation in a meteorological context can be very heavy, because of the unstable nature of the atmosphere. If one is dealing with data which is noisier than the first-guess, then one needs very effective quality control procedures which will prevent one accepting observations which are too far from the first-guess, even if their error is nevertheless within the range of expected error for the observing system.

Detailed synoptic and statistical study of the analyses show that the SATEM data usually have larger errors than the first-guess, even over the mid-oceans of the Northern Hemisphere. The SATEM data also have considerable biases which are air-mass dependent, and so have strong regional variations. The increased scatter of the forecast scores comparing OPS and NOSATEM is much bigger in the JUL88 context than in the JUL87 context, which confirms that the analysis/forecast system has become more sensitive to the data, and to errors in the data. The quality control of SATEMs needs to be improved. Work in this area is reported in Kelly et al. (1989).

We have seen several examples where the forecast (and presumably therefore the analysis) of weather systems have been adversely affected by the use of SATEM data which should have been rejected, particulary in the baroclinic zones. The typical synoptic manifestations of air-mass dependent biases in the SATEM data include the weakening of frontal structures, and the associated jet streams and baroclinic zones. Similar effects have been reported by Gallimore and Johnson (1986) in an impact study with the GLA system using 1979 SATEM data.

The SATEM OSE reported here is part of a larger set of satellite experiments which have been performed at ECMWF on the period 30 January to 14 February 1987. This period was initially chosen because of the meteorological situation and the availability of two satellites, NOAA-9 and NOAA-10. In addition, complete sets of raw radiances, cloud-cleared radiances and TOVS soundings were kindly provided by NESDIS. The report by Flobert et al. (1989) describes observing system experiments in which the 3I retrieval system (Chédin et al., 1985) is used to generate the retrievals during this period. The report by Zhang et al. (1989) describes observing system experiments on humidity data in this period.

Kelly et al. (1989) report on new quality control procedures to identify and eliminate the worst of the SATEM data. In the medium-term, experiments combining retrievals and assimilation, are being considered with the retrieval methods from the Oxford and Wisconsin groups, and will hopefully help to decide whether or not it is an advantage for global assimilation to incorporate also the satellite retrieval in operational mode.

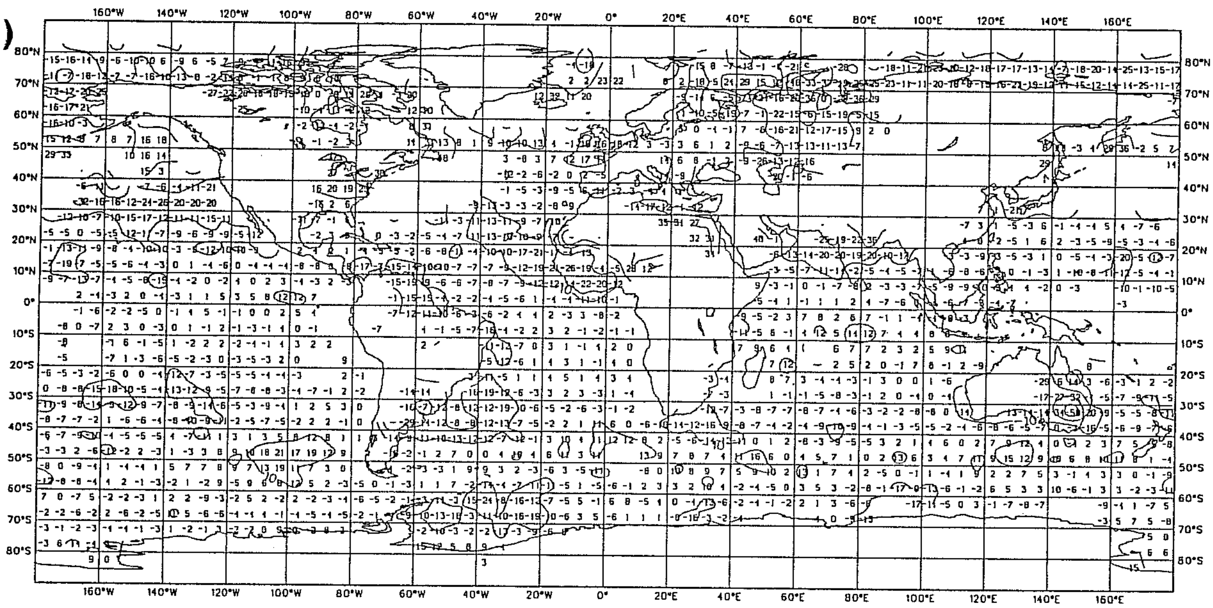
In the slightly longer term, the research in data assimilation is now converging towards using something which is as close as possible to the genuine observed quantity, rather than interfaces. SATEMs are actually a 'sub-optimal' interface between the satellite retrieval scheme and the analysis scheme. The integrated approach (using radiances directly) is easier to achieve in the context of a variational analysis scheme than in the traditional OI analysis.

A fundamental problem with SATEMs is the lack of vertical resolution in the satellite radiance measurements and this is more true of cloudy regions and in particular, in mid-latitude fronts. The microwave channels of the MSU instrument contain the only infmation in the troposphere and this is not enough to resolve fine vertical temperature structures in these active areas.

Appendix

This appendix contains similar plots of Bias and Standard deviation of stability index (s) for NOAA-9 Figs A ((a), (b) (c) and (d)). There is general agreement between both NOAA-9 and NOAA-10, however, in some local areas NOAA-9 appears to have smaller deviations than NOAA-10 in particular in the North Pacific.

a)



b)

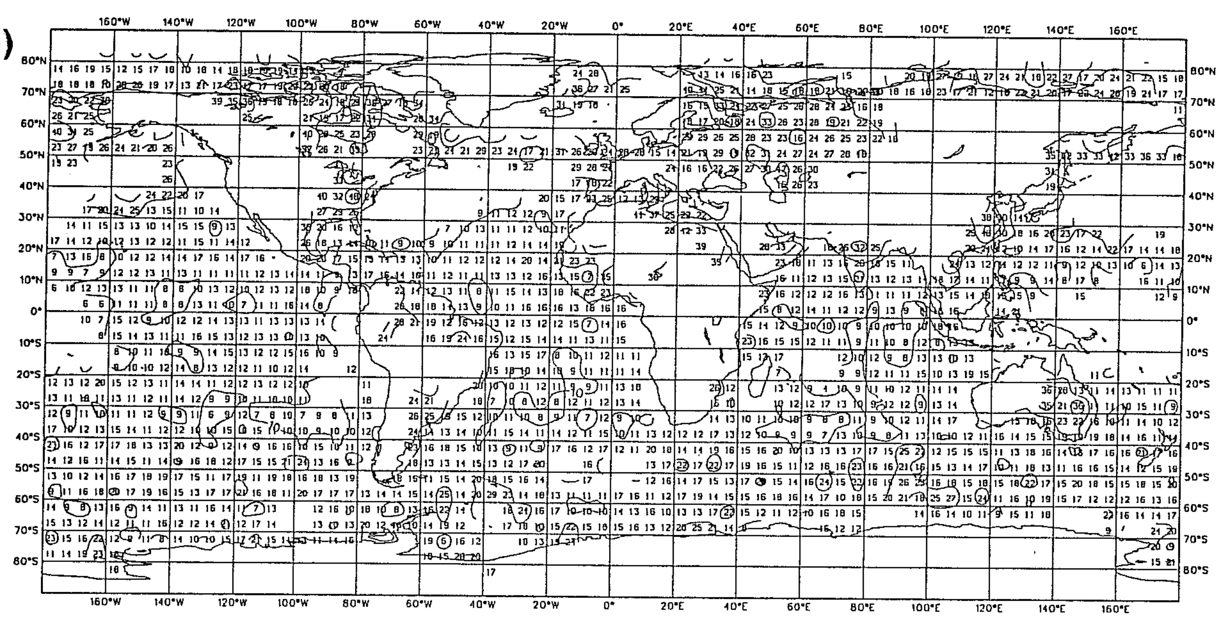


Fig. A1 (a) is bias of stability index (S) for NOAA-9 Clear Soundings, February 87. (Bias = observation minus first-guess, averaged over the studied 15-day period in February 1987). (b) is standard deviation. (c) and (d) are like (a) and (b) respectively but for MSU soundings.

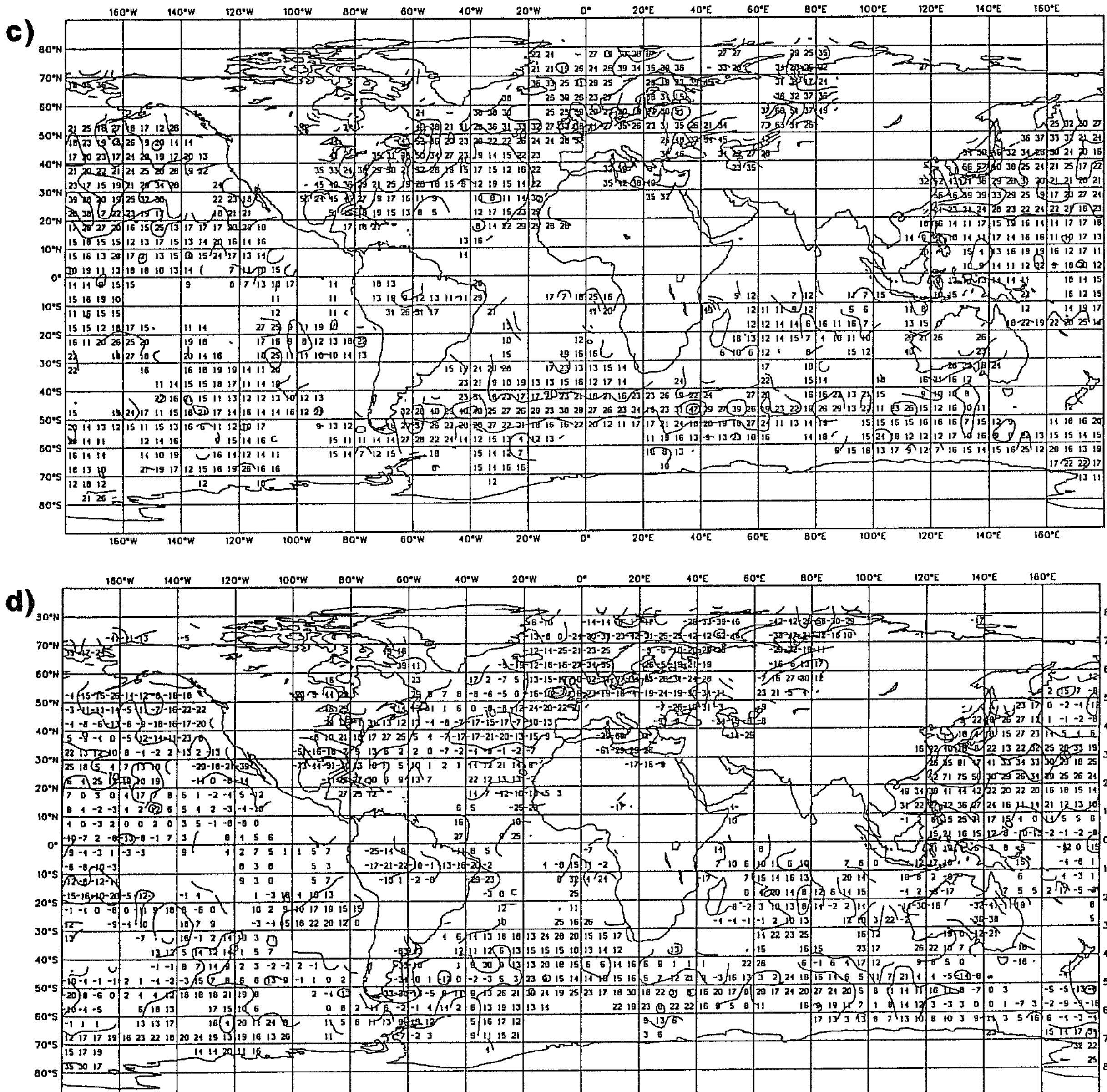


Fig. A1 Continued.

References

Daley, R., 1985: The analysis of synoptic scale divergence by a statistical interpolation scheme. Mon.Wea.Rev., 113, 1066-1079.

Durand, Y., 1985: The use of satellite data in French high resolution analysis. Proceedings of the ECMWF Workshop on high resolution analysis. Reading, June 1985.

Chédin, A., N.A. Scott, C. Wahiche and P. Mouliner, 1985: The Improved Initialisation Inversion method: a high resolution physical method for temperature retrievals from the TIROS-N series. J.Clim.Appl.Meteor., 24, 128-143.

Flobert, J-F., E. Andersson, A. Chédin, G. Kelly, J. Pailleux and N. Scott, 1989: Data assimilation and forecast experiments at ECMWF using the "3I" inversion scheme for satellite soundings. ECMWF Techn.Memo. 156.

Gallimore R.G. and D.R.Johnson, 1986: A case study of GWE satellite data impact on GLA assimilation analysis of two ocean cyclones. Mon.Wea.Rev., 114, 2016-2032.

Gilchrist, A., 1982: JHSC Study Conference on observing systems experiments. Exeter, 19-22 April 1982. GARP report No.4 on numerical experimentation programme.

Hollingsworth, A. and P. Lönnberg, 1989: The verification of objective analyses: Diagnostics of analysis system performance. Met.Atm.Phys., 40, 3-27.

Kelly, G., E. Andersson, P. Lönnberg, J. Pailleux and Z. Zhang, 1989: Quality control of NESDIS physical retrievals of satellite data. ECMWF Tech.Memo. 158.

Kelly, G. and J. Pailleux, 1988: Use of satellite vertical sounder data in the ECMWF analysis system. ECMWF Tech.Memo. No. 143.

Lönnberg, P., 1988: Developments in the ECMWF analysis system. Proceedings of the ECMWF Seminar on data assimilation and the use of satellite data. Reading, September 1988.

Miller, M.J., 1988: The sensitivity of systematic errors of the ECMWF forecast model to parametrized processes. Proceedings of the CAS/JSC workshop on systematic errors in models of the atmosphere, Toronto, Canada, 19-23 September 1988. WMO/TD No.273, 289-296.

Oort, A.H., 1983: Global atmospheric circulation statistics, 1958-1973. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Professional Paper 14.

Reale et al., 1986: Higher resolution operational satellite retrieval. Proceedings of the second Conference on Satellite/Remote Sensing and Applications, Williamsburg 13-16 May 1986. Published by the American Meteorological Society.

Rodgers, C.D., 1976: Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev.Geoph.Space.Phys. Vol.14, No.4, 609-624.

Undén, P., 1989: Tropical data assimilation and analysis of divergence. To appear in Mon.Wea.Rev.

Uppala, S., A. Hollingsworth, S. Tibaldi and P. Kållberg, 1984: Results from two recent observing system experiments at ECMWF. Proceedings of the ECMWF seminar/workshop on data assimilation systems and observing system experiments, Reading 3-11 September 1984, Vol.1, 165-202.

Zhang, Z., J. Pailleux and G. Kelly, 1989: Evaluation and development of the ECMWF humidity analysis. ECMWF Tech.Memo. 160.