TECHNICAL MEMORANDUM

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On the quality of FGGE data and some remarks on the ECMWF data assimilation scheme

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1. INTRODUCTION

The ECMWF data assimilation system has been utilized to perform Observing System Experiments with FGGE Level II-b data. In one experiment the impact of satellite wind data on global analyses and forecasts has been studied and a second experiment was devoted to study the impact of aircraft data. One important part of these experiments was a manual monitoring of the various analysis and forecast charts, produced with and without certain data subsets. By this manual monitoring it was possible to highlight some data quality problems as well as some data assimilation problems. The purpose of this paper is to describe these problems. It is hoped that the content of this paper will help data producers to improve data quality as well as to give ECMWF some ideas of improving it's data assimilation system. The fact that this paper is concerned with "problems and weaknesses" should not hide the fact that the authors are greatly impressed by the ability of the ECMWF data assimilation system to produce global analyses of high quality and consistency. A description of the ECMWF data assimilation system is available in Larsen, Lorenc and Rutherford (1977).

2. QUALITY CONTROL OF DATA

One general weakness of the ECMWF analysis system is present in the quality control of observational data coming from the same data source with a great likelihood of having highly correlated errors. Some of these data are treated as if the errors are completely independent, which may give the result that erroneous data are supporting each other and therefore not rejected by the "analysis check". In this section some examples of such quality control applications with a bad outcome are presented and some ideas for the improvement of the quality control procedures are also given.

2.1 Examples of cloud wind observations with too low wind speeds

For several situations we noticed that analyzed wind-velocities in the subtropical jetstream were much weaker when satellite wind observations were utilized for the analysis compared to when these data were excluded from the analysis. The differences mainly seem to occur over land areas of Europe and Asia. The differences were found to originate from satellite wind reports in the close vicinity. Though these satellite wind reports were associated with larger assumed observational errors than the radiosonde and aircraft data, the impact became significant due to the large number of these reports. Several examples of suspect wind speeds in satellite wind reports are contained in Figure 1. For this case, the analyzed 200 mb wind speed was approximately 10 m/s larger over Sicily and central Italy when satellite wind reports were not used.

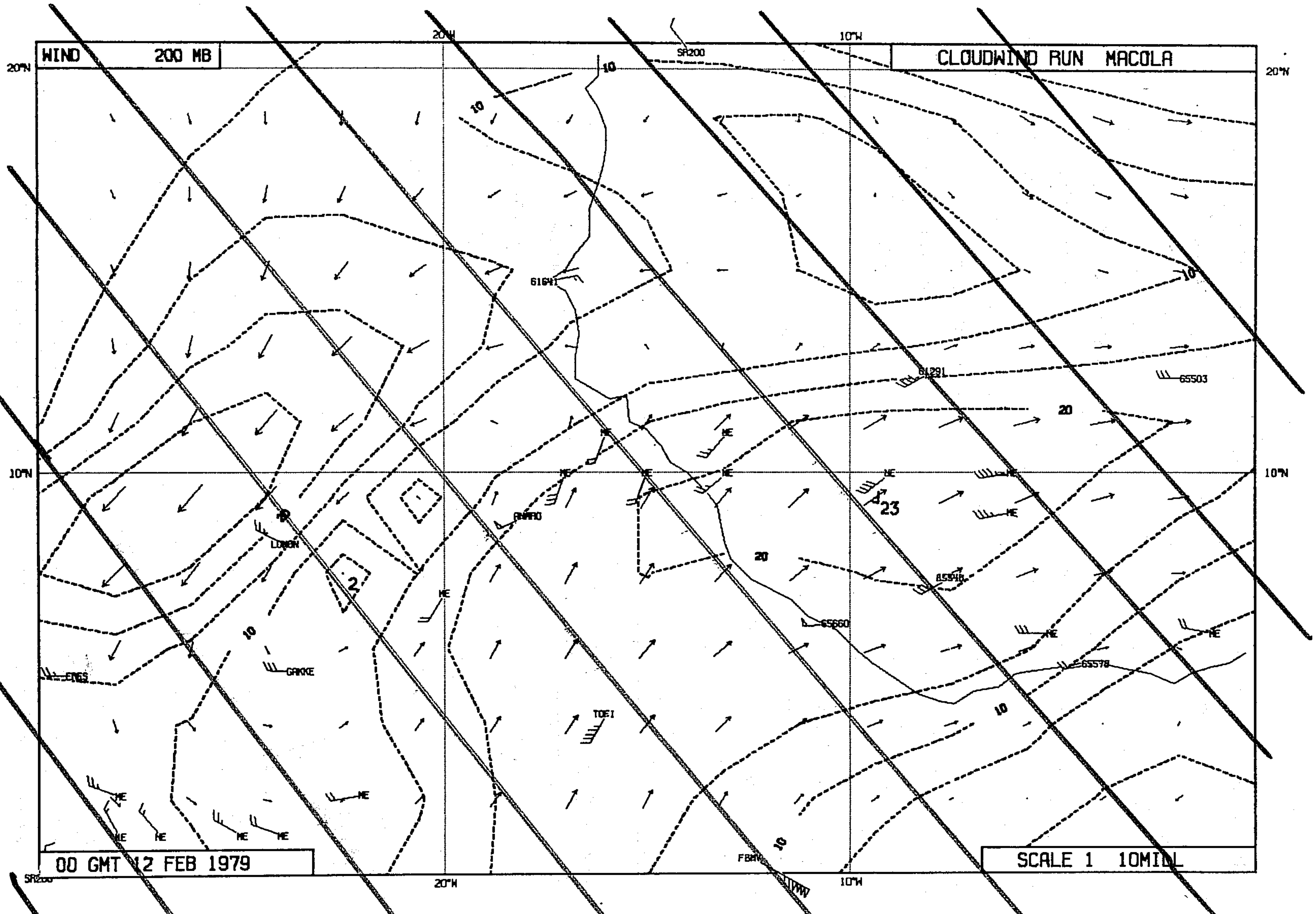


Fig. 1 200 mb wind speed analysis for 12 February 1979 00 GMT over the Mediterranean Sea. Examples of bad cloud wind observations are included.
(ME: Meteosat; WI: GOES Indian Ocean winds produced by Wisconsin University).

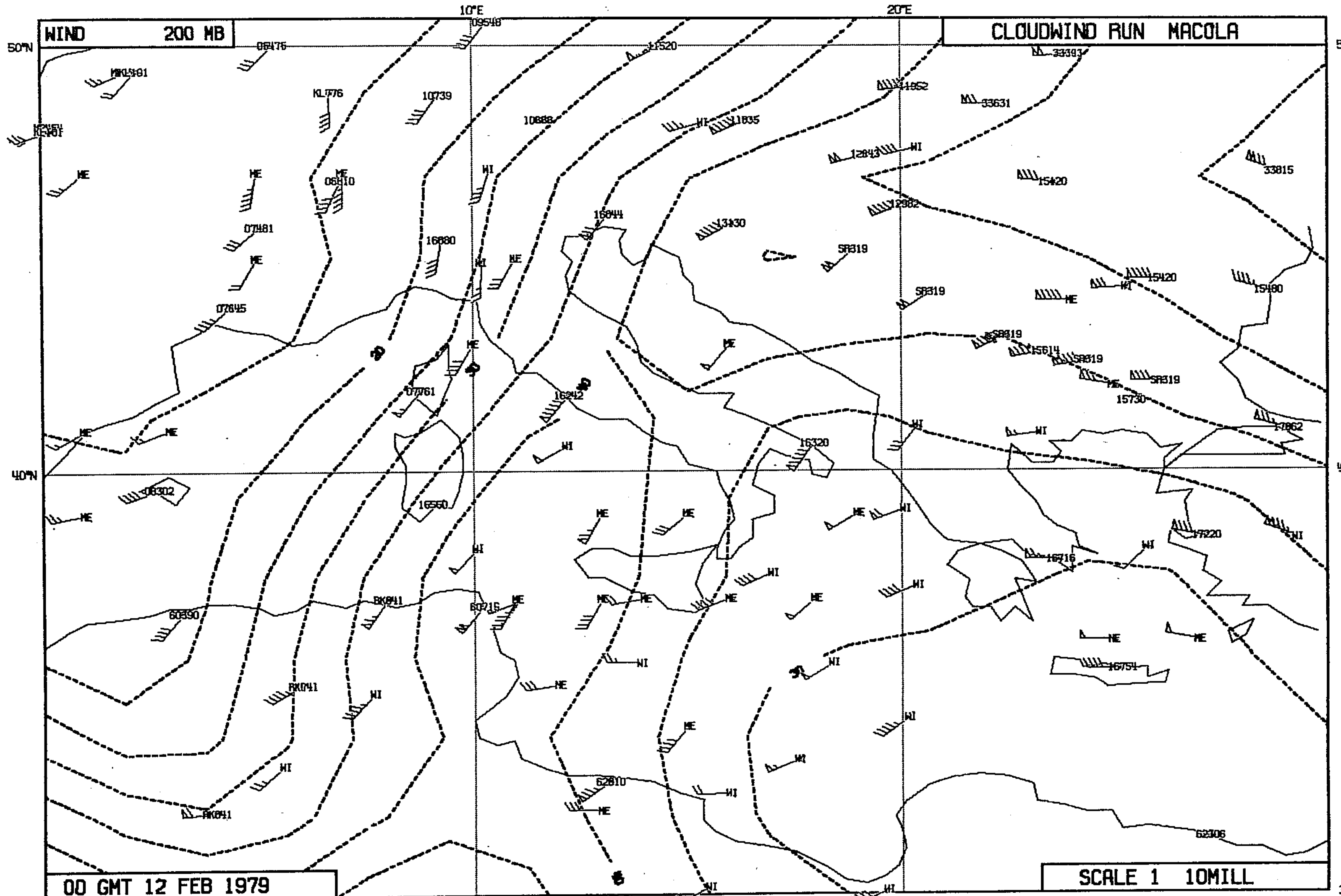


Fig. 1 200 mb wind speed analysis for 00 GMT 12 February 1979 over the Mediterranean Sea. Examples of bad cloud wind observations are included (ME:METEOSAT, WI:GOES Indian Ocean winds produced by Wisconsin University).

For the case illustrated in Figure 1, it is not difficult to judge that the satellite wind speeds are too low. It should therefore be possible to construct a quality control scheme which rejects erroneous data in cases like this. A more difficult case to handle is presented in Figures 2-3 which show 250 mb wind speed analyses over Iran, Pakistan and India for 7 February 1979 00GMT and 06GMT. At 00GMT the analyses with and without satellite wind data are rather similar in the southern part of the maps, while in the northern part of the maps some bad satellite wind reports have influenced the "cloudwind" analysis. At 00GMT there are other data available which indicate that the satellite wind reports are bad. At 06GMT (Figure 3), however, less data are available and a serious analysis error of about 40 m/s is introduced into the "cloudwind" analysis by some bad satellite wind reports. This error, introduced mainly at 06GMT, remained in the analyses through several subsequent analysis cycles.

Similar errors in the analysis of the subtropical jetstream occured several times during the period of the satellite wind observing system experiment (6-19 February 1979). The errors are clearly reflected in the mean difference field between the 200mb wind analyses with and without satellite wind data, the mean value being taken over the complete experiment period (Figure 4).

The systematic errors of satellite wind reports with too low wind velocities have also been confirmed by comparison with colocated radiosonde data in a study by Pailleux and Henniant (1981). Figure 5 shows a histogram of wind velocities of colocated satellite wind reports and radiosonde reports. Observe that almost all wind-velocities above 100 m/s are missing in the satellite wind reports.

2.2 An example of bad aircraft winds

Figure 6 shows an aircraft flight (KL833) going from India to Indonesia on 9 November 1979 0GMT. The wind directions of the observations are obviously all wrong (180° error for every observation); but as these observations support each other in the data assimilation tests, they have been used in the analysis.

The eastern flow which is established between India and Indonesia is then destroyed in the analysis. Moreover, the analysis is bad in a large area over the Indian Ocean, down to 10°S. See, for example, the southern crossequatorial flow by 80°E which is probably due to the bad aircraft data and to the u-v correlation function which is used in the analysis.

Figure 7 also gives the control analysis (without aircraft observations) over the same area.

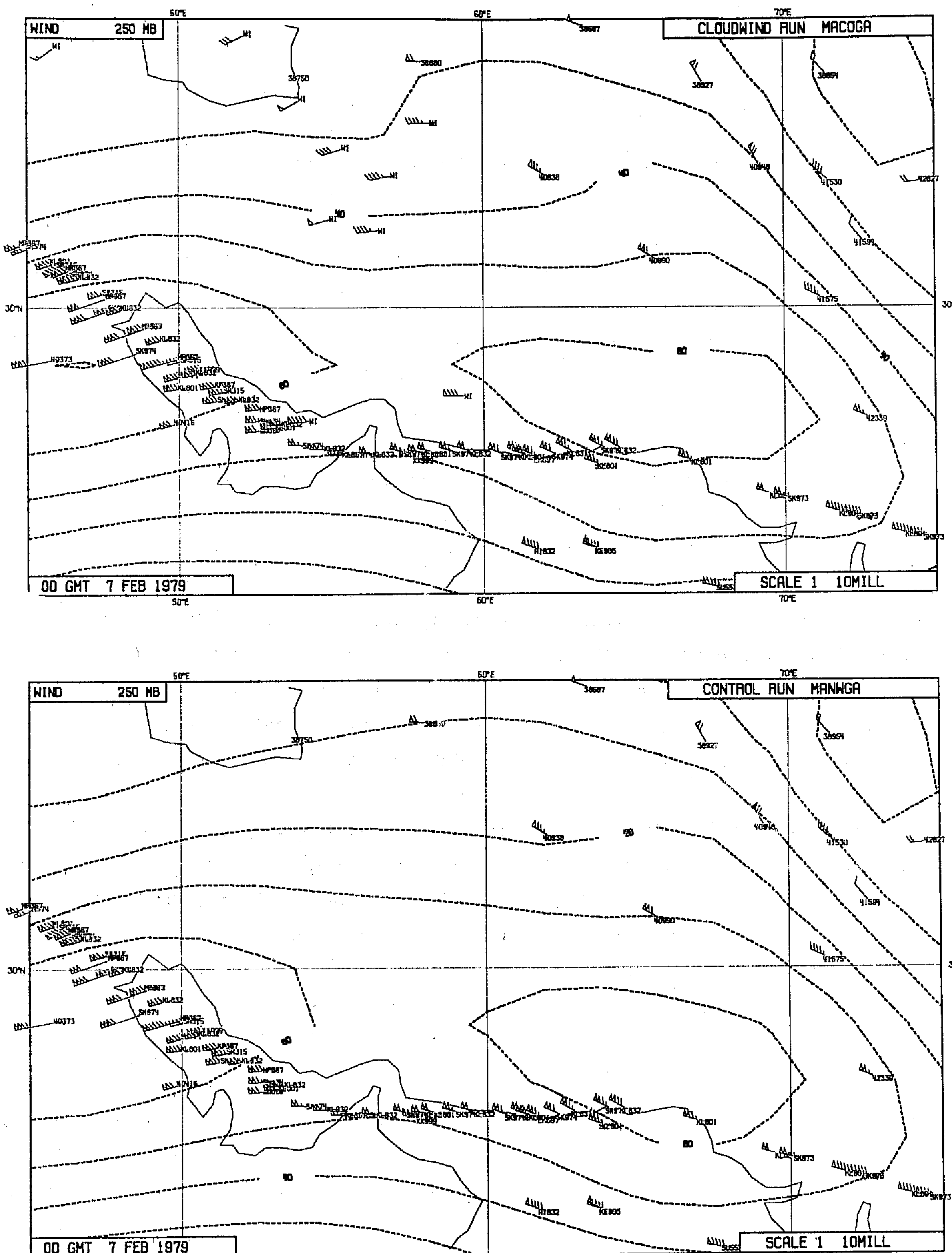


Fig. 2. 250mb wind speed analyses for 7 February 1979 00 GMT over Iran and neighbouring areas. Cloud wind: top; control: bottom.

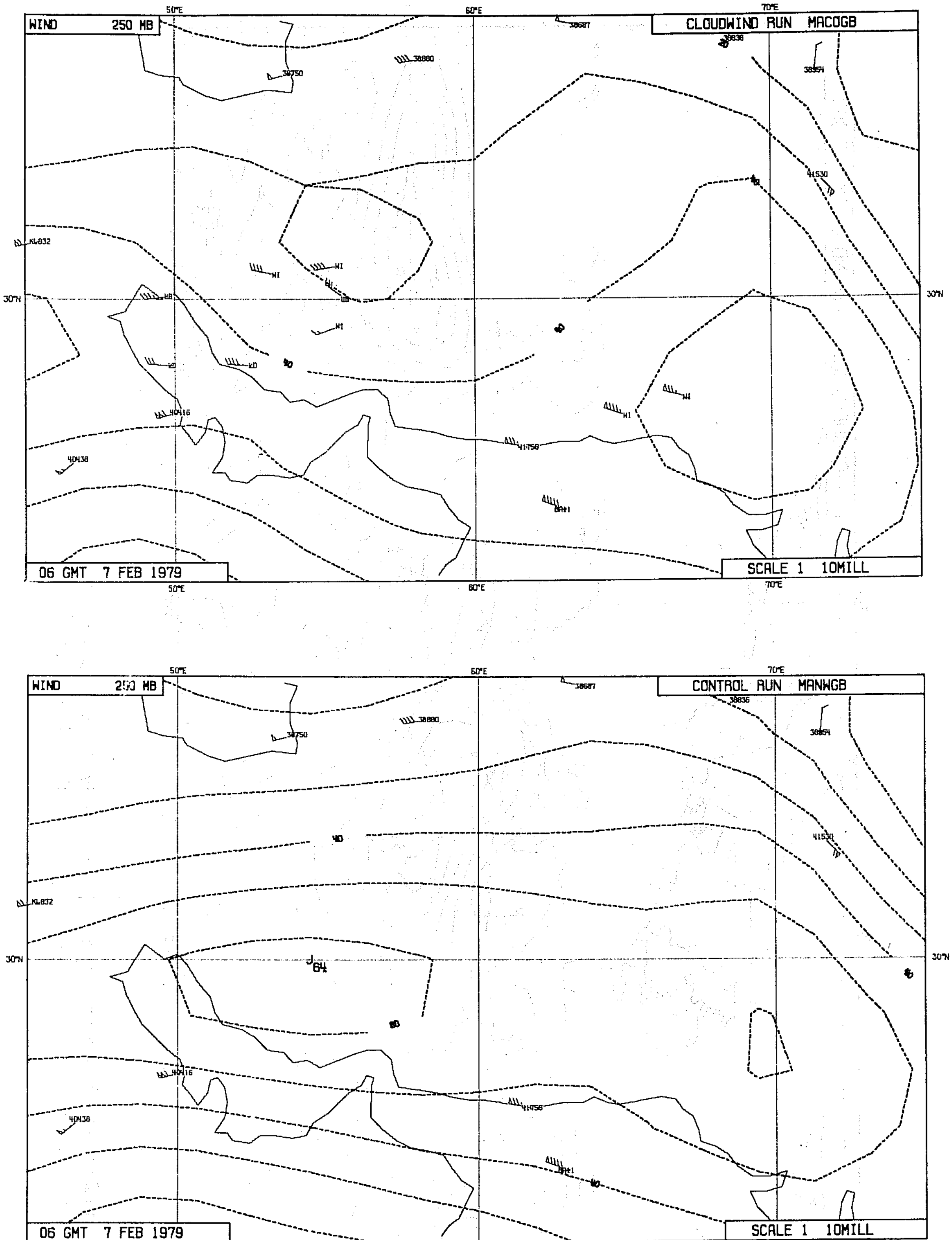


Fig. 3. 250 mb wind speed analyses for 7 February 1979 6 GMT over Iran and neighbouring areas. Cloud wind: top; control: bottom. (LD: GOES Indian Ocean winds produced by LMD).

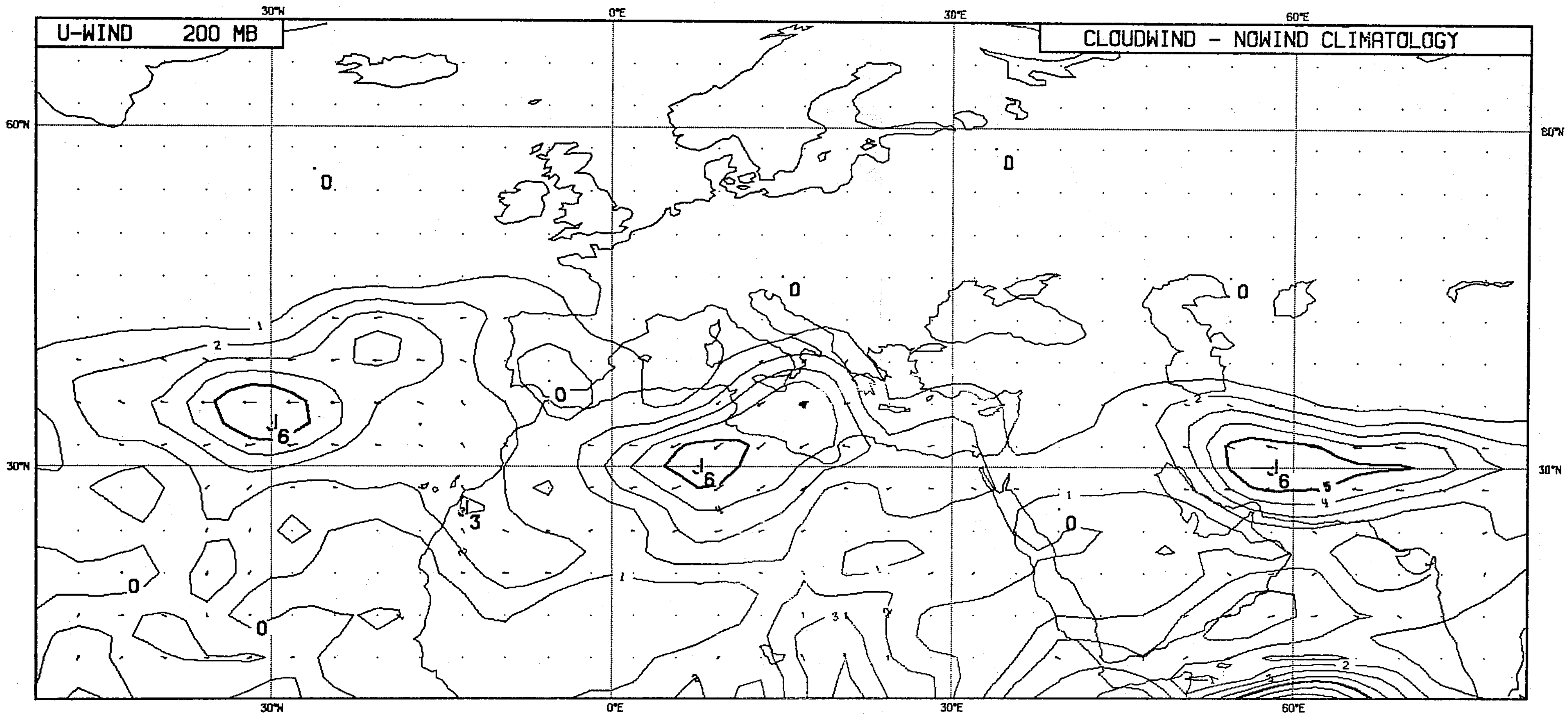


Fig. 4. Difference between mean 200 mb winds from the cloud wind and control analyses. Averaging period: 7 - 19 February 1979.

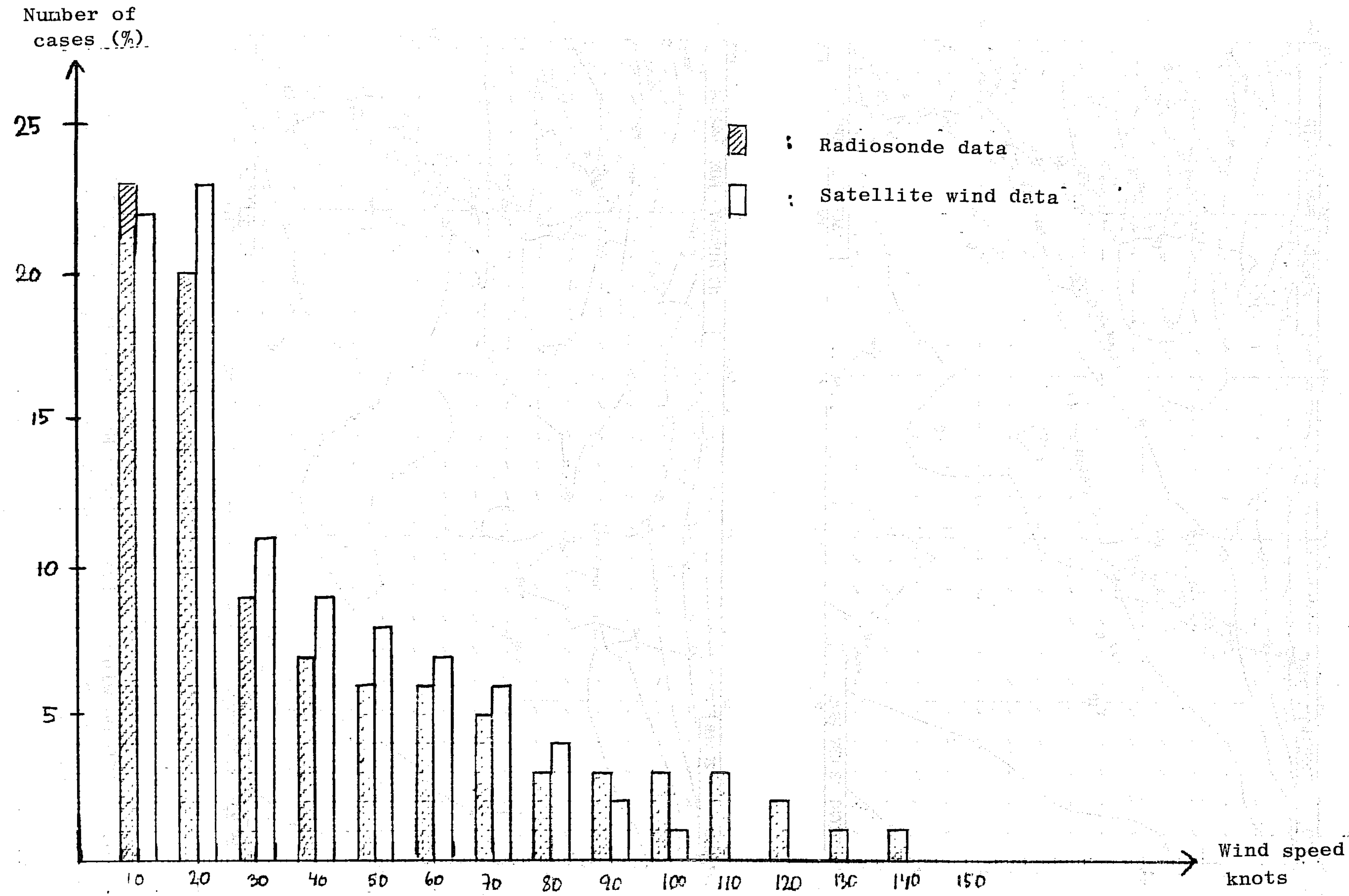
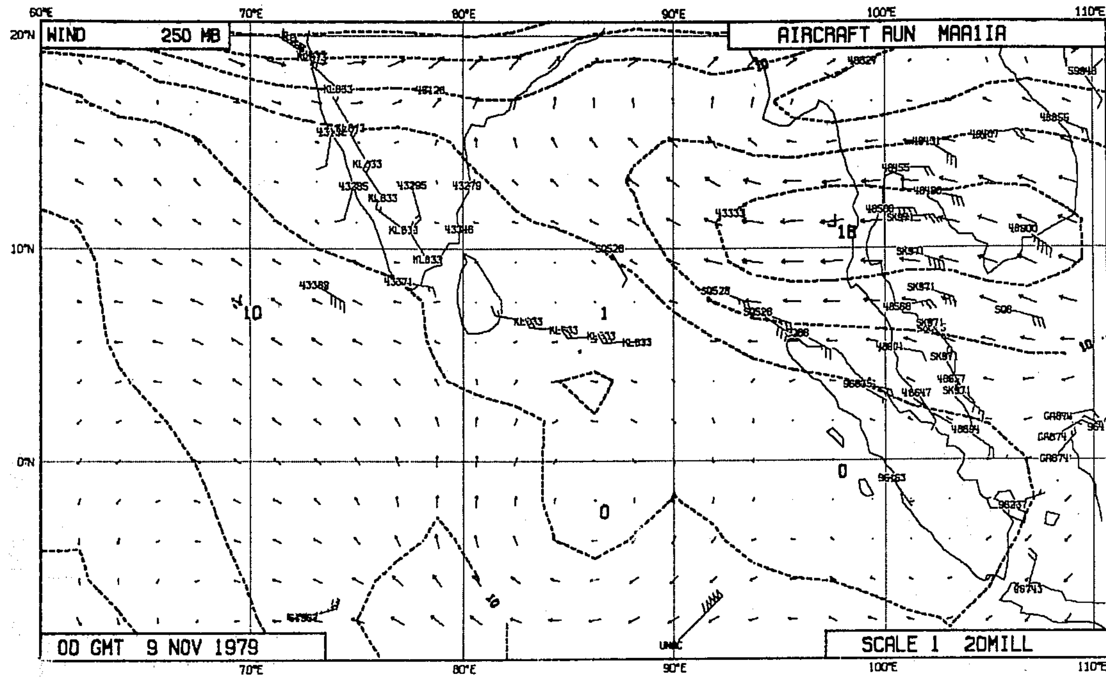


Fig. 5. Statistical distribution of wind speeds from colocated radiosonde and satellite wind reports. Approximately 4000 pairs of comparison from the period 1 November 1980 until 31 January 1981 are included.



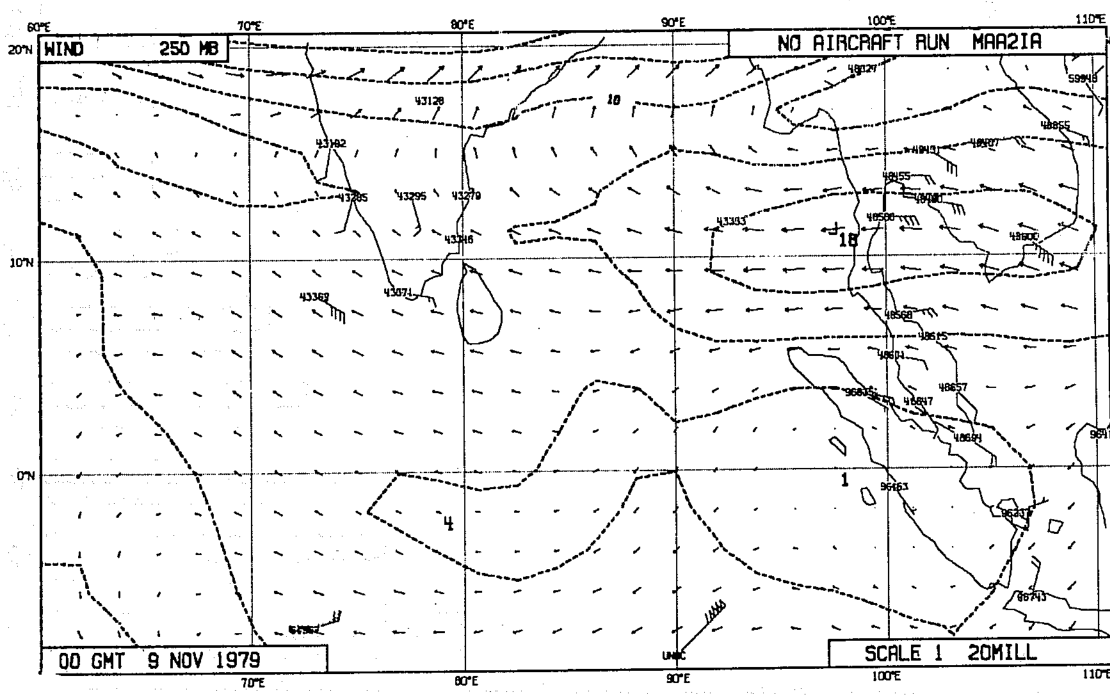


Fig. 6. 250 mb wind analyses for 9 November 1979 00 GMT over the Indian Ocean. Aircraft analysis: top; Control analysis: bottom.

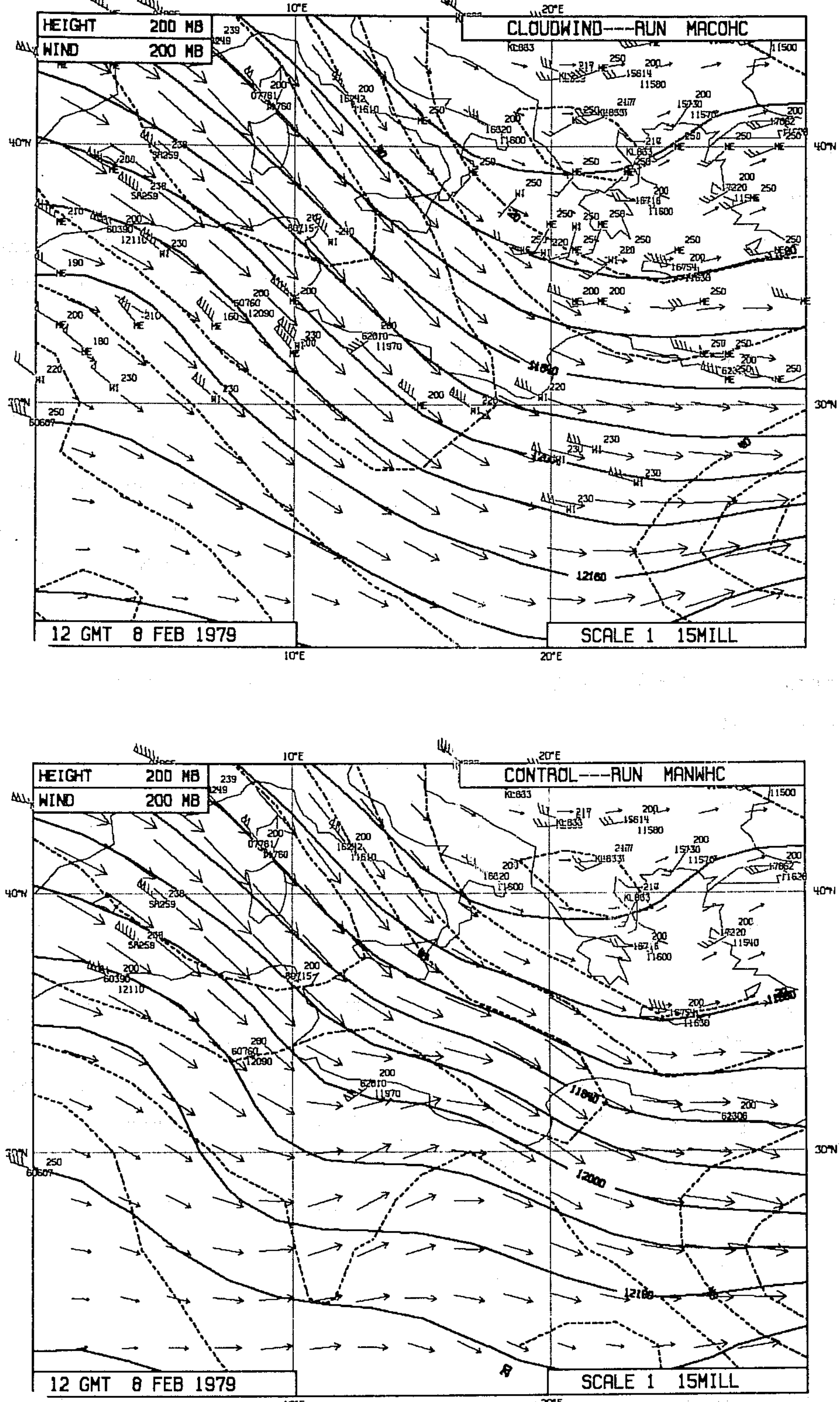


Fig. 7. 200 mb wind and geopotential analyses for 8 February 1979 12 GMT over Northern Africa. Cloud wind analysis: top; Control analysis: bottom.

2.3 Problems in the quality control of radiosonde data

In the ECMWF analysis scheme (see Lorenc, A., 1980), data are subject to quality control in three steps. The final of these steps is the "analysis check" in which the observed values are compared with a preliminary interpolation of neighbouring data to the position of the observation to be checked. As regards "analysis check" of radiosonde data from a certain level, data from other levels of the same report as well as data from other reports in the vicinity are utilized. The main argument for using reference data from the same report is that single-level errors are supposed to be the most frequent for radiosonde reports. However, there also occur radiosonde reports which are internally consistent but contain some systematic errors throughout the reports. Examples of such errors are:

- An error of 100 gpm has been added to the geopotential height at all levels.

- Wind speed was reported in knots instead of m/s.

- The temperature profile is consistently too warm or too cold. (This type of error occurs very often).

The present ECMWF "analysis check" has difficulties to reject data with errors of this kind since data from the different levels support each other. One example is given in Figure 7. In the analysis without cloud wind data, a bad radiosonde report from the Libyan station 62010 was accepted since it was internally consistent, and a strange ridge was created over Libya in the analysis. In the analysis with cloud wind data, however, the information content from surrounding data was large enough and the data from radiosonde station 62010 were rejected.

A conclusion from this and other similar cases is that the ECMWF "analysis check" of radiosonde data seems to rely too much on data from other levels of the same radiosonde reports. It seems necessary to consider development of more refined algorithms for "analysis check" (see section 2.4).

2.4 Suggestions for improved quality control during the analysis

The cases which have been described are all examples of bad observations which are accepted by the analysis scheme because they support each other. In the data checking cloud winds and ASDAR are checked one by one as if they were independent. Specifically, ASDAR wind observations are checked against interpolated values calculated with the ASDAR wind observations of the same flight. In the same way, when cloud wind observations are checked, the cloud winds of the same fleet are used. This checking technique is obviously dangerous as big errors can affect the whole fleet or the whole flight without destroying the internal consistency of the fleet or the flight. This problem occurs in the checking of radiosonde data too, but a vertical correlation between observation errors at different levels is then assumed, which reduces the bad impact of this weakness.

The problem could be reduced by the following procedure (a): When an observation A^o is checked against an interpolated value A^i in the final test of the analysis scheme, we should use only other observations which are completely independent of A^o to calculate A^i. So, in the final check, when a radiosonde observation is checked, the other observations of the same radiosonde should not be used; for an ASDAR report the observations of the same flight should not be used; for a cloud wind observation the observations of the same fleet should not be used, etc.

This modification is certainly difficult to implement in the present ECMWF analysis program because of the box technique; it would be much easier to do it in a scheme using a local data selection for each analyzed point.

The quality control would probably be improved by the single modification (a), but in some cases (a) could have a negative impact. For example, if a radiosonde report contains an error on a single level and if the data on this level is no longer checked against data from the other levels, then it may be accepted. So it would be wise to perform data checking in several steps. The first step could consist only in checking the internal consistency of each data set: vertical consistency of a sounding by the usual methods, internal consistency of an ASDAR flight by looking at the spatial continuity of the observed wind, etc. The results of this internal consistency checking should be kept by using some flags.

Then, after the final checking (i.e. comparison of observed values against the interpolated values), the complete results of quality control for a data set could be stored in a table. For example, in the case of a radiosonde sounding, this table would contain indications on the quality of each observed parameter as well as the internal consistency of the sounding. Then the final decision (rejection or not rejection) could be taken globally, it could be:

- rejection of the complete sounding (or complete flight, or complete fleet ...) if many parameters are suspect even if the internal consistency is good.

- rejection of some individual parameters which are suspect and destroy the internal consistency of the sounding.

- to keep the whole sounding, if it is consistent and if most of the observed parameters are not suspect.

The detailed procedure must be determined by some experiments; some ideas suggested by Gandin (1971) might be used.

3. DATA SELECTION

In the ECMWF analysis system and its box technique, all the data are used, even if the redundancy of the observations is very large. If the data quality control was working perfectly, this redundancy would never have any bad consequence except the computing time of the program. However, in the cases 2.1 and 2.2 mentioned in section 2, the analyzed fields fit the redundant and bad observations very well, while some good independent radiosonde data are available and are probably used with a very small weight.

So, as the quality control tests will never be perfect, it seems reasonable to make a selection among the observations, each time many redundant data are available. Moreover, it would be wise to delete all the satellite data in the areas where many radiosondes are available.

4. STATISTICS

The statistical values which are used in the analysis scheme are representative of the mean spatial structure of the meteorological fields. As always in statistical methods, these statistics are not good to handle some specific cases. Some examples are given in which the assumed statistics for observation and forecast errors are not realistic enough to give a good description of the meteorological situations.

4.1 RMS of observational errors

In the present operational ECMWF analysis system the assumed RMS observation error is 8 m/s for SATOBS (except for HIMAWARI) and 6 m/s for aircraft and radiosonde winds for levels 300, 250 and 200 mb. An error of 8 m/s is too small a value for SATOBS when we have the underestimated strong winds noted in 2.1. Moreover, in the examples given in Figs. 1 and 2, where we have many cloud winds and a small number of radiosondes, the weights which are given to the different observations are completely unrealistic.

As 6 m/s seems to be a rather large value for aircraft reports and radiosonde reports, the observational wind errors have been reduced to run an observing system experiment on aircraft data (June 1981). The statistics have been changed in the following way:

	Operations RMS		New values (for aircraft experiment)	
	RS-AIDS-ASDAR	AIREP	RS-AIDS-ASDAR	AIREP
1000	2 m/s	7 m/s	1.8 m/s	5.2 m/s
850	2	7	1.8	5.2
700	3	8	2.5	5.5
500	4	8	3.0	5.5
400	5	8	3.5	5.5
300	6	8	4.0	6
250	6	8	4.0	6
200	6	8	4.0	6
150	6	8	4.0	6
100	6	8	4.0	6

The evaluation of the first analyses done with the new RMS errors seems to indicate a positive impact of this modification and a good fitting of upper-air data to the analyses. If these values had been used in the analyses given in Figs. 1 and 2, the bad impact of weak SATOBS over Italy and Iran would have been less significant. It seems that this modification should be put into the operations after a study of its impact on the rejection tests. The final test in the quality control is a comparison of wind increments with a quantity proportional to $\sqrt{\overline{\varepsilon u^{p2}} + \overline{\varepsilon u^{o2}}}$ the reduction of $\overline{\varepsilon u^{o2}}$ gives an increase of the number of rejected winds.

As it seems realistic to assume that the wind error is larger for strong winds, it might be interesting to do experiments in which the RMS wind error would increase with the observed wind speed itself.

4.2 Horizontal correlation functions

The ECMWF statistical interpolation scheme is based on non-divergent corrections to a first-guess field, and for the analysis of the stream function a Gaussian isotropic autocorrelation function is utilized. With the present operational functions, correlations for the wind components are negative at a distance of about 850 km in a direction normal to the wind components. A general criticism is that these autocorrelation functions are based on statistics for middle and high latitude streamfunction characteristics and they are probably less representative for the tropical regions.

One example of a poor 200 mb wind analysis from the data assimilation run with satellite wind data is given in Fig. 8 (12 February 1979 00 GMT, detail west of Africa). Some reports from tropical wind observing ships, which were not utilized for the analysis, have also been plotted in the figure. Note the large discrepancies between these ship reports and the analysis and also note the strong analyzed north-easterly flow at 10°N 25°W. This strong flow developed in the analysed fields during several analysis cycles with the aid of satellite wind reports in the south-westerly flow at approximately 5°N 20°W and by extrapolation with autocorrelation functions described above. As a result, the analysis without satellite winds was much better than the analysis with satellite winds in the actual area for 12 February 1979 00 GMT. The effect of the Gaussian correlation function is also clearly illustrated by taking the difference of two analyses with and without certain observations but with the same first guess field. Fig. 9 is the difference between the two analyses with and without aircraft data which were discussed in section 2.2. In this case, some bad aircraft reports over the Bay of Bengal introduce corrections with the shape of middle and high latitude disturbances.

In summary, it seems necessary to thoroughly review the selection of autocorrelation functions for the wind analysis and possibly use autocorrelation functions which are dependent on latitude as well as season.

5. VERTICAL INTERPOLATION AND INITIALIZATION

During the Observing System Experiment which is aimed at studying the impact of satellite wind data, numerical forecasts up to Day 10 were computed for 4 situations. For each situation, one forecast ("cloudwind") was based on initial data including satellite wind observations and a second forecast ("Control") was based on initial data, excluding the satellite wind reports. The fourth of these forecast experiments gave the unexpected result that the "Control" forecast was significantly better than the "cloudwind" forecast over the North Atlantic Ocean for the time range 2-6 days. A closer examination of this forecast experiment revealed that the cause for the differences between the two forecast runs was rather to be found in the data assimilation system than in the quality of the available satellite wind data.

The large differences between the two forecast runs over the Northern Atlantic Ocean were traced back to originate from small-scale differences between the initial temperature analyses over the Eastern Pacific Ocean. To show this, difference maps between the 500 mb geopotential forecasts ("cloudwind"-"Control") and difference maps between 700 mb temperature forecasts are presented in Fig.10. During the first 24 hours of the forecast integrations, the initial temperature

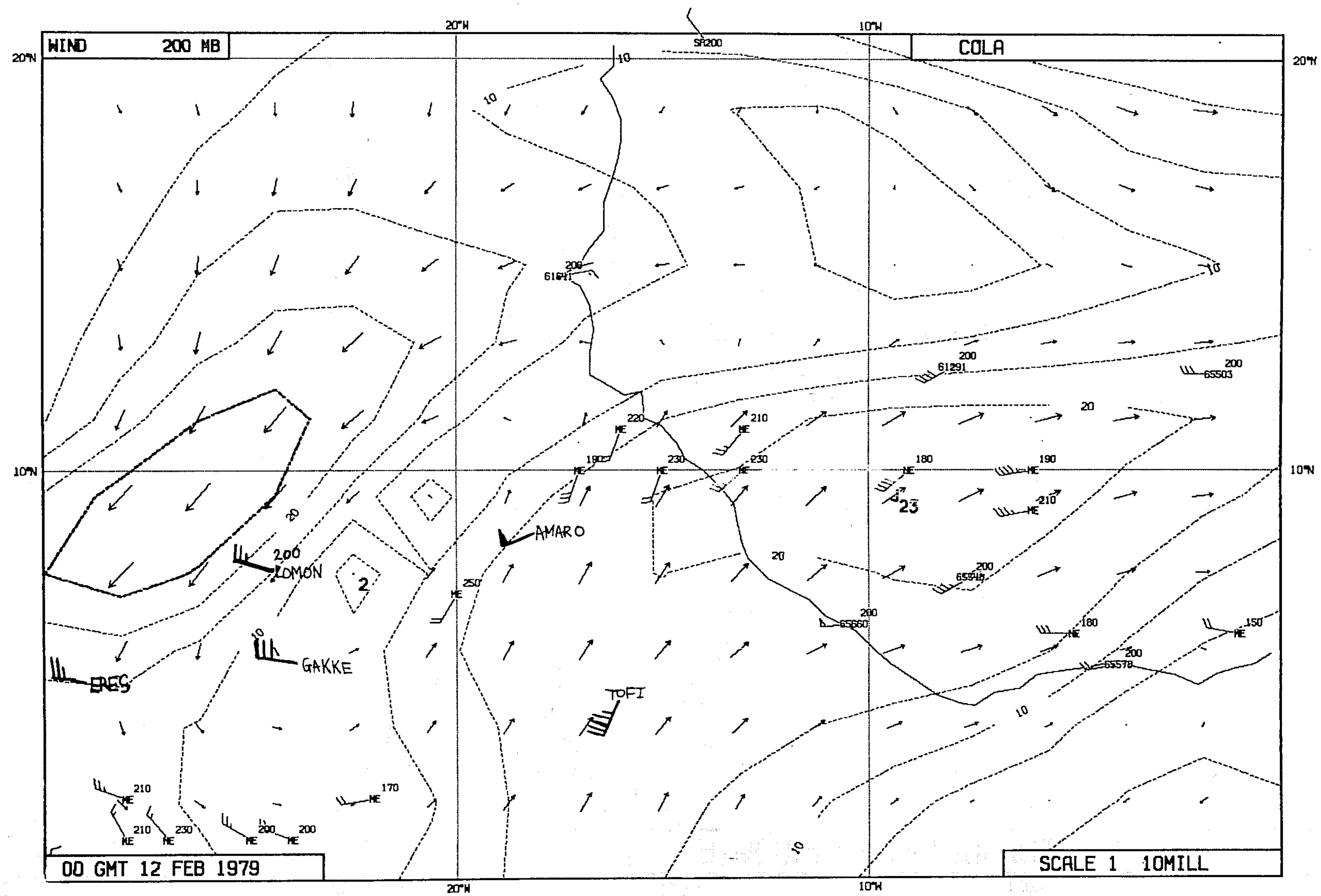


Fig. 8. 200 mb wind analysis for 12 February 1979 00 GMT over Western Africa and the Atlantic Ocean from the cloudwinds assimilation run. Special tropical observing ship data were not used for the analysis.

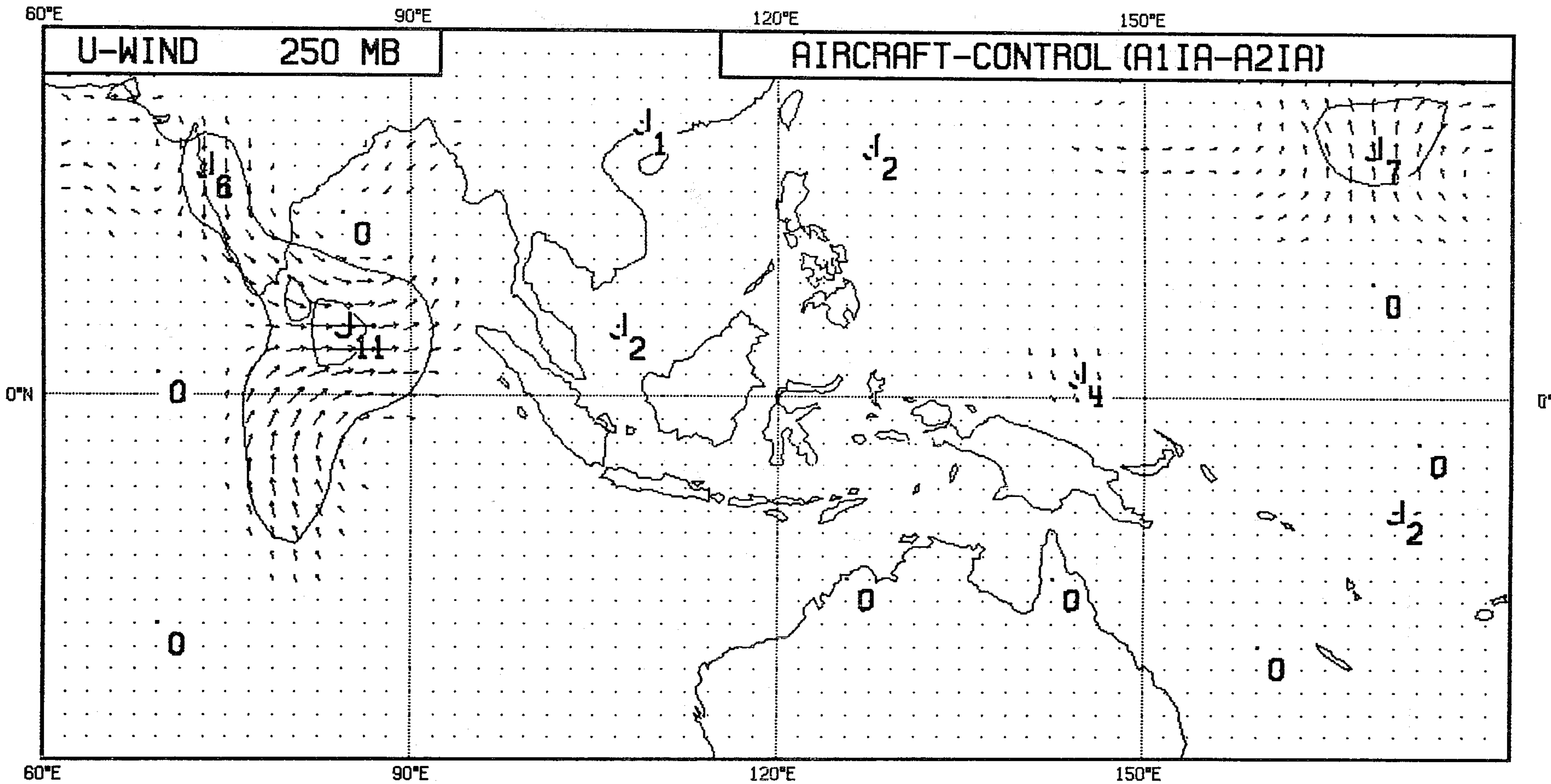


Fig. 9. Difference between 250 mb wind analyses with and without aircraft data for 9 November 1979 00 GMT over South East Asia and Australia.

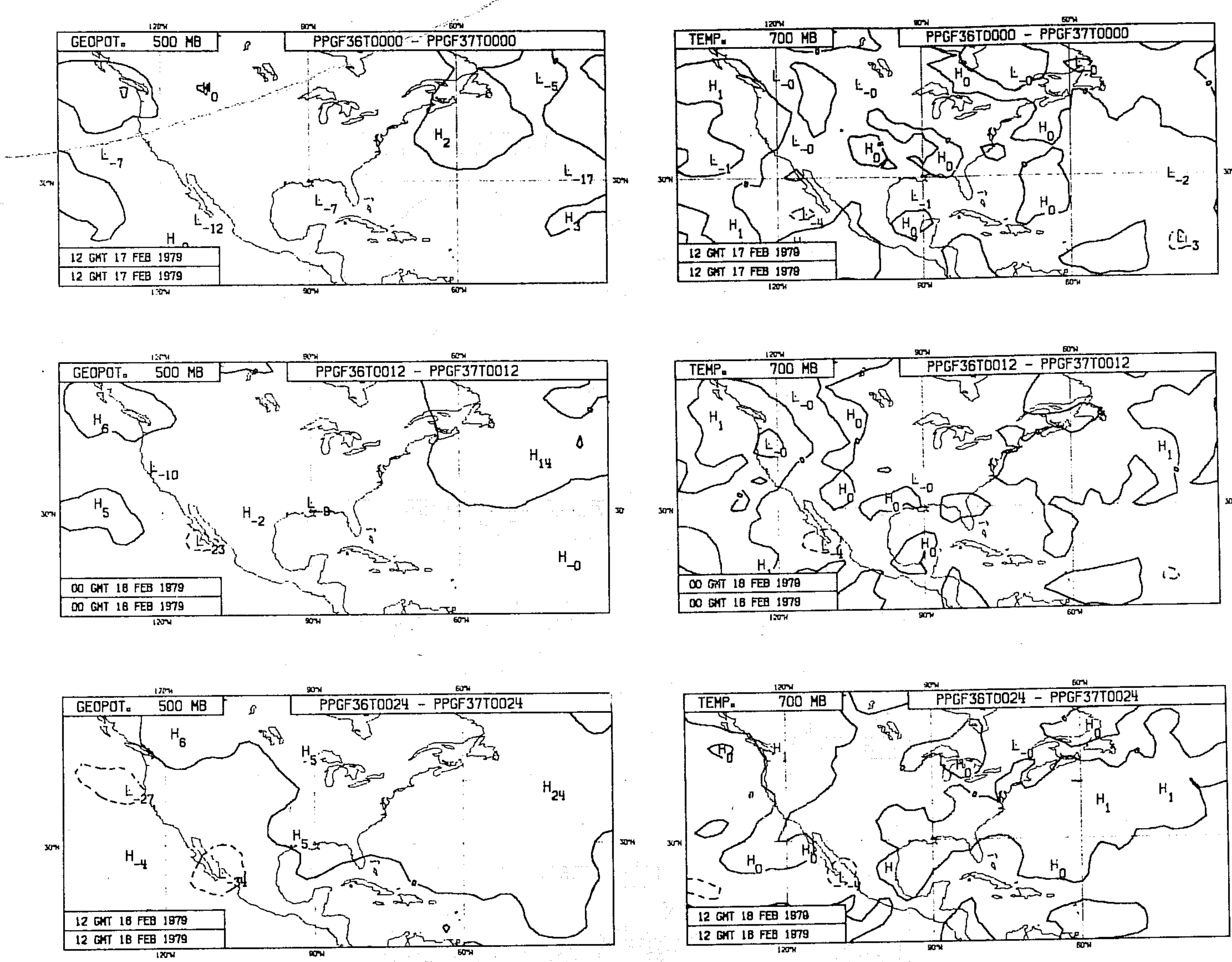


Fig. 10a. Differences between forecasts based on analyses with and without cloud wind data for 17 February 12 GMT over the Northern America and surrounding ocean areas.
500 mb geopotential height: left; 700 mb temperature: right
Initial analyses: top; 12h forecast: middle; 24h forecast: bottom.

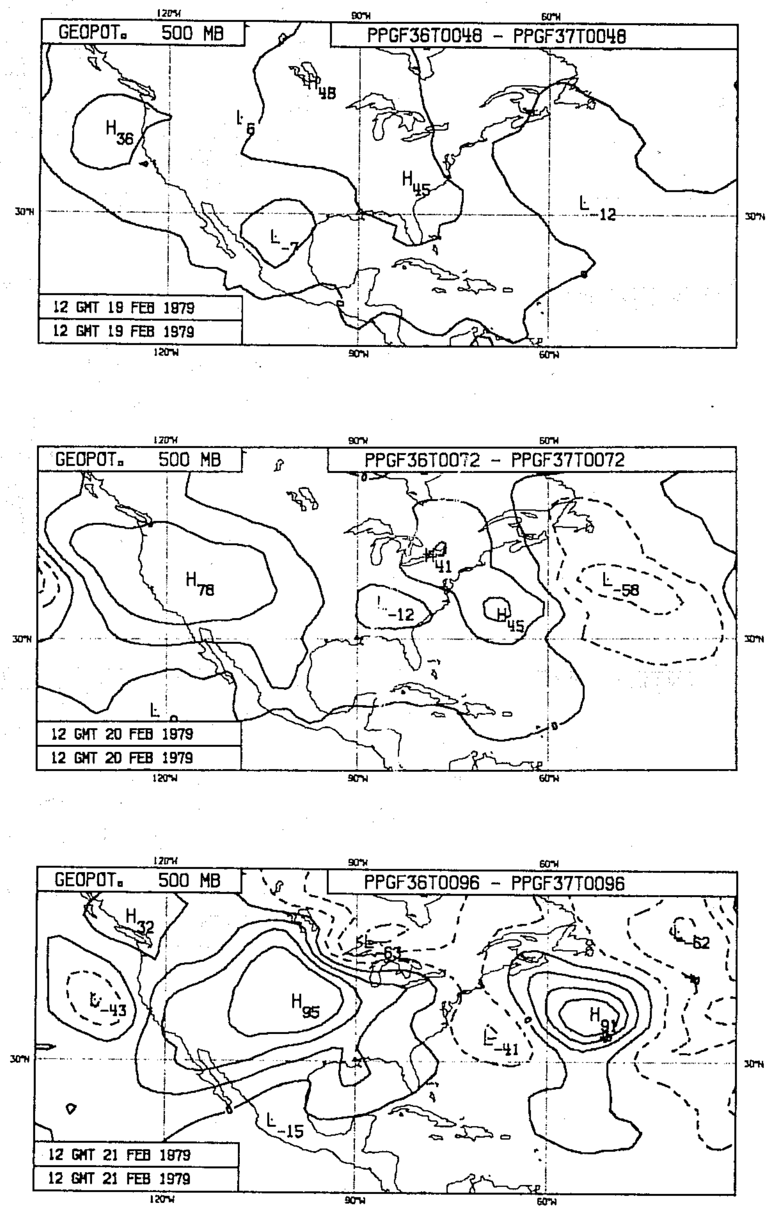


Fig. 10b. Difference between 500 mb geopotential forecasts based on analyses with and without cloud wind data for 17 February 12 GMT over North America and the surrounding ocean areas. Day 2: top; Day 3: middle; day 4: bottom.

difference ($-4^{\circ}C$ at $22^{\circ}N$ $114^{\circ}W$ and 700 mb) is advected eastwards to the Mexican coast. Then this "difference wave" starts to interact with the general mid-latitude westerlies over the North American continent. During Day 1 to Day 4 of the forecasts, the difference wave rapidly amplifies and moves from the middle of the North American continent to the middle of the North Atlantic Ocean. At Day 4 there is a difference of the order 100 gpm between the two forecast runs at $40^{\circ}N$ $50^{\circ}W$. The difference maps in Fig. 10 clearly illustrate that small differences in initial data can cause very large differences in the forecast results.

The next question to answer is why these small-scale differences occur in the temperature analyses over the Pacific Ocean. This question will be explored in section 5.1 below.

In section 5.2 another problem concerning observed imbalances between the mass-field and the wind-field will be discussed. Both these problems are related to the initialization procedures and to the vertical interpolation of data between pressure and σ-levels.

5.1 Small-scale temperature variations not present in the geopotential thicknesses

In the ECMWF data assimilation system, temperatures are not directly analyzed but derived from the first-guess temperature fields on σ-levels and the analyzed geopotential increments on pressure levels. The number of σ-levels in the lower troposphere is larger than the number of pressure levels of the analysis scheme. Due to this difference in the number of levels, small-scale vertical variations in the temperatures on the σ-levels may be preserved from the first guess fields to the analysis fields (on σ-levels). Generally, this is the main objective of the incremental vertical interpolation technique. On the other hand, a drawback of the method is that also unrealistic, small-scale vertical variations may be preserved in the σ-level fields during several analysis cycles.

For the case with small-scale temperature variations discussed above (17 February 1979 12 GMT), it was found that the analyzed thickness fields on pressure levels were almost identical for the two assimialtion runs with and without satellite wind data. It was also confirmed that these thickness analyses were in good agreement with a large number of satellite thickness observations (TIROS-N) in the area of interest. As was pointed out above, however, the differences between the temperature fields from the two assimilation runs contained some small-scale variations with an amplitude of $1-4^{\circ}C$. The hydrostatic balance constrains the temperature differences to have opposite signs on some σ-levels since the thicknesses are almost identical. This is also confirmed in Fig. 11 which contains maps of the differences between the 700 mb temperatures and the differences between the 850 mb temperatures from the two data assimilation runs (These temperatures were obtained by cubic spline interpolation from the temperatures on the σ-levels).

It is thus quite clear that the small-scale temperature variations originate from the first guess temperature fields on σ-levels and not from any observed data from the 17 February 1979 12 GMT. First guess field cross-sections along 114°W (Fig. 12) confirm the large differences between the first guess temperature and humidity fields in the two assimilation runs. Note especially the layer close to 600 mb between 0°N and 15°N in the first guess fields from the "control" data assimilation run. The temperature profile is almost unstable, the relative humidity is close to 100% and the radiative cooling is of the order of 6°C per day. Also note the shift in the position of the trade wind maxima when satellite-wind data are not utilized.

One likely explanation for the existence of these small-scale variations in the temperature fields is as follows. Assimilation of various data sets of variable quality will always create some small-scale variations in the analyzed fields without any significant relation to the physical features of interest. If then the forecast model includes sophisticated physical parameterization schemes, the model may react too sensitively to the small-scale variations in the initial fields and the amplitudes of these may even grow. In the example above it is most likely the radiative cooling in the forecast model which contributes to the creation of the large differences between the temperature fields from the two assimilation runs. Probably also other factors contribute to the creation of the large differences. These factors could include the vertical correlations which are used in the multivariate analysis scheme as well as the vertical cubic spline interpolation of first guess geopotential fields from σ-levels to pressure levels.

5.2 Imbalances in first guess and initialized fields

The ECMWF multivariate statistical interpolation scheme is based on the assumption that the first guess wind and mass fields obey a reasonable balance. Analysis increments, in approximative geostrophic balance outside the tropics, are added to the first guess fields. If the first guess fields are not in balance, the multivariate analysis will still produce increments which are balanced and, thus, the resulting analyzed fields will not be in balance.

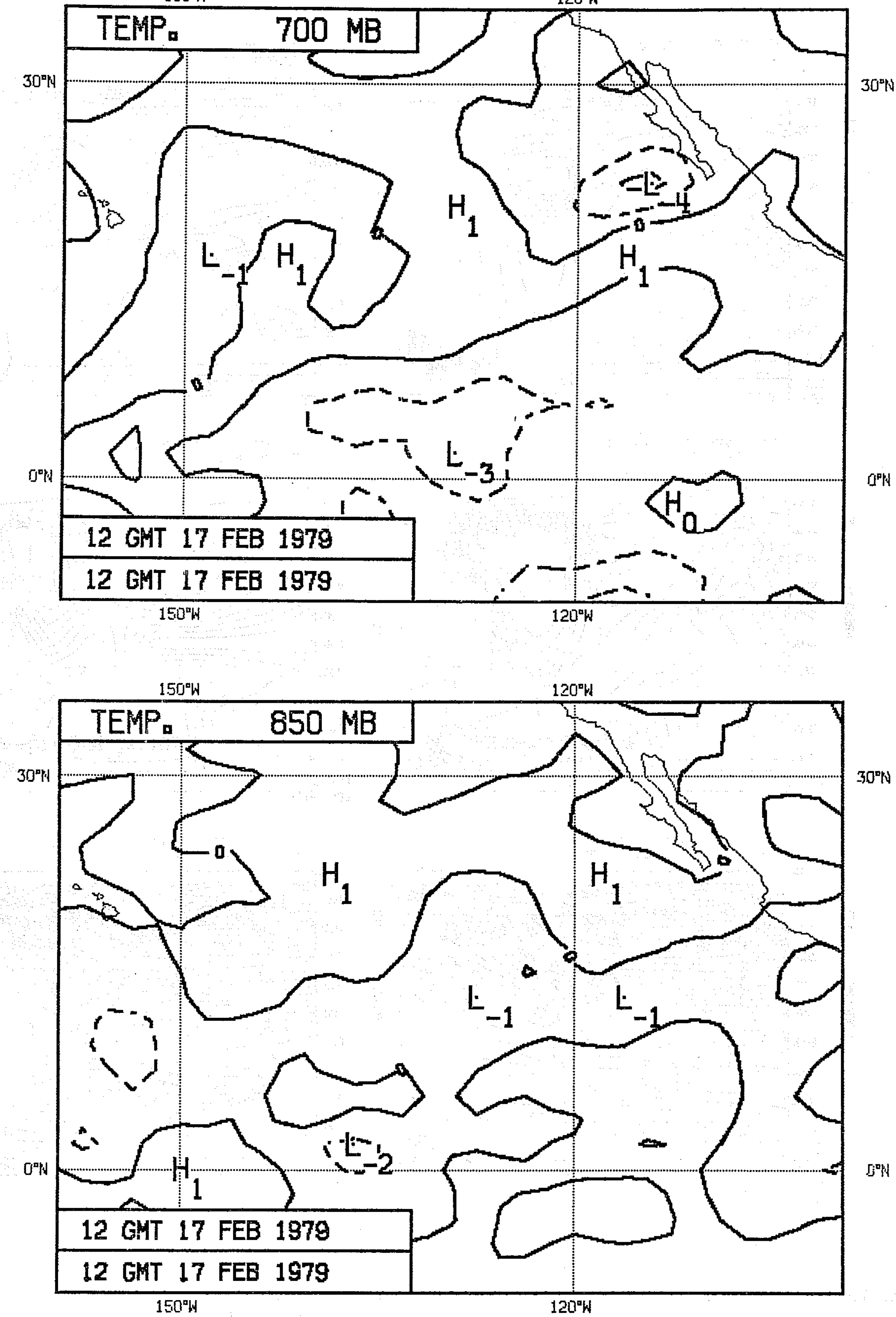


Fig. 11 Differences between initialized temperature fields with and without cloud wind data for 17 February 1979 12 GMT over the Eastern Pacific Ocean. 700 mb: top; 850 mb: bottom.

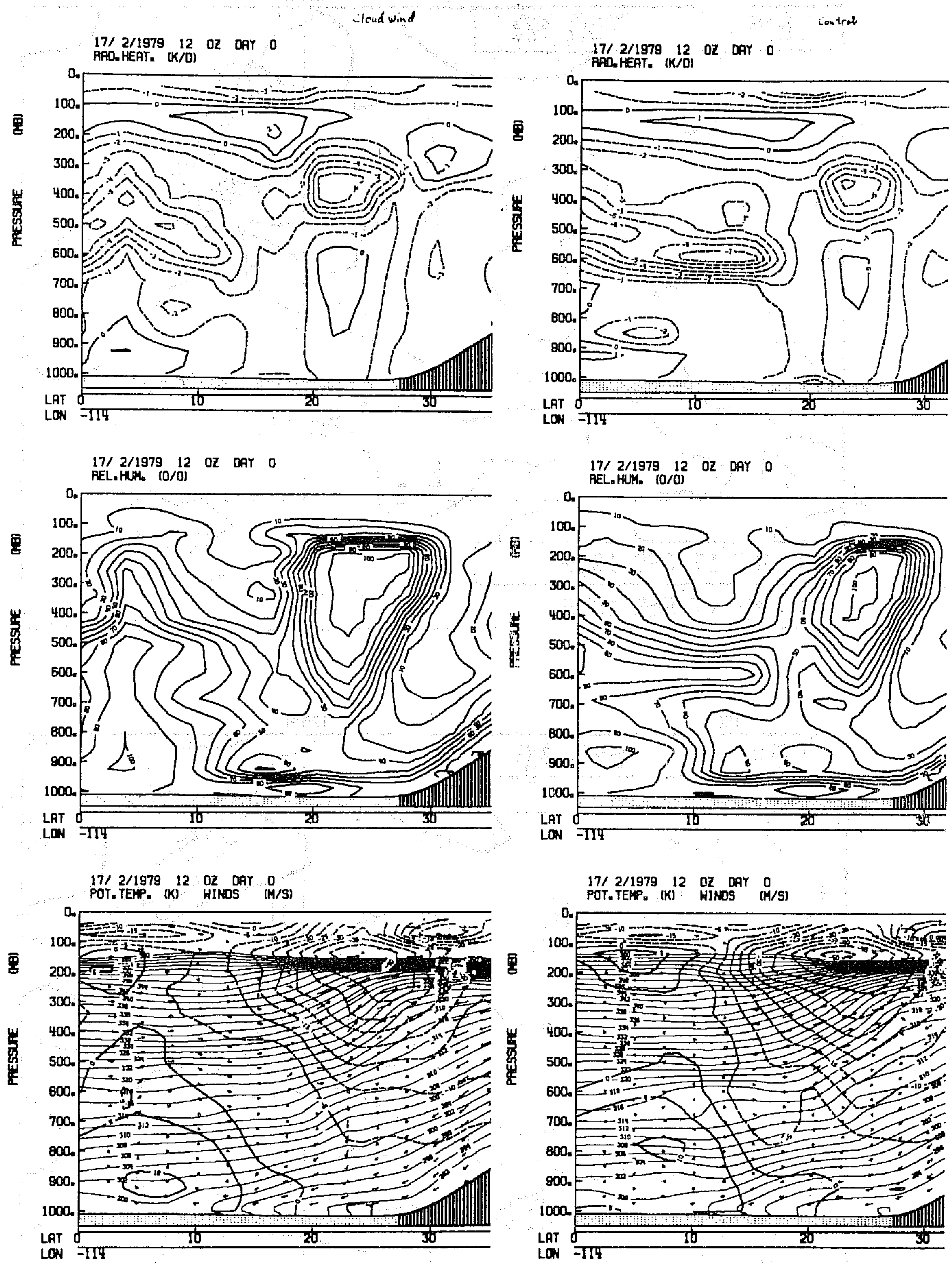
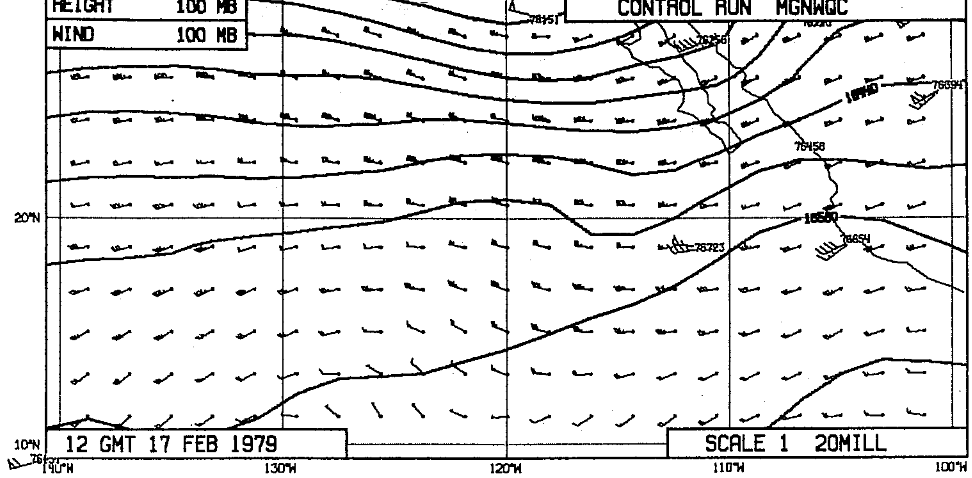


Fig. 12. Cross-sections along 114W of first-guess fields on σ levels for potential temperature, wind, relative humidity and radiative heating valid for 17 February 1979 12 GMT. Cloud wind first-guess fields: left; control (first-guess fields: right.



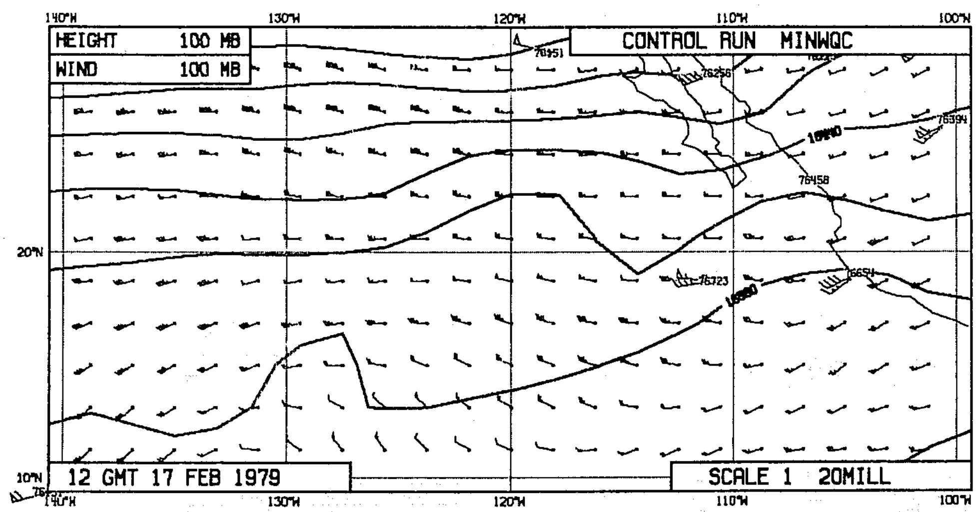


Fig. 13. 100 mb wind and geopotential height for 17 February 1979 12 GMT over the Eastern Pacific Ocean. First guess fields: top; initial analysis: bottom. Both maps are from the assimilation run without cloud wind data.

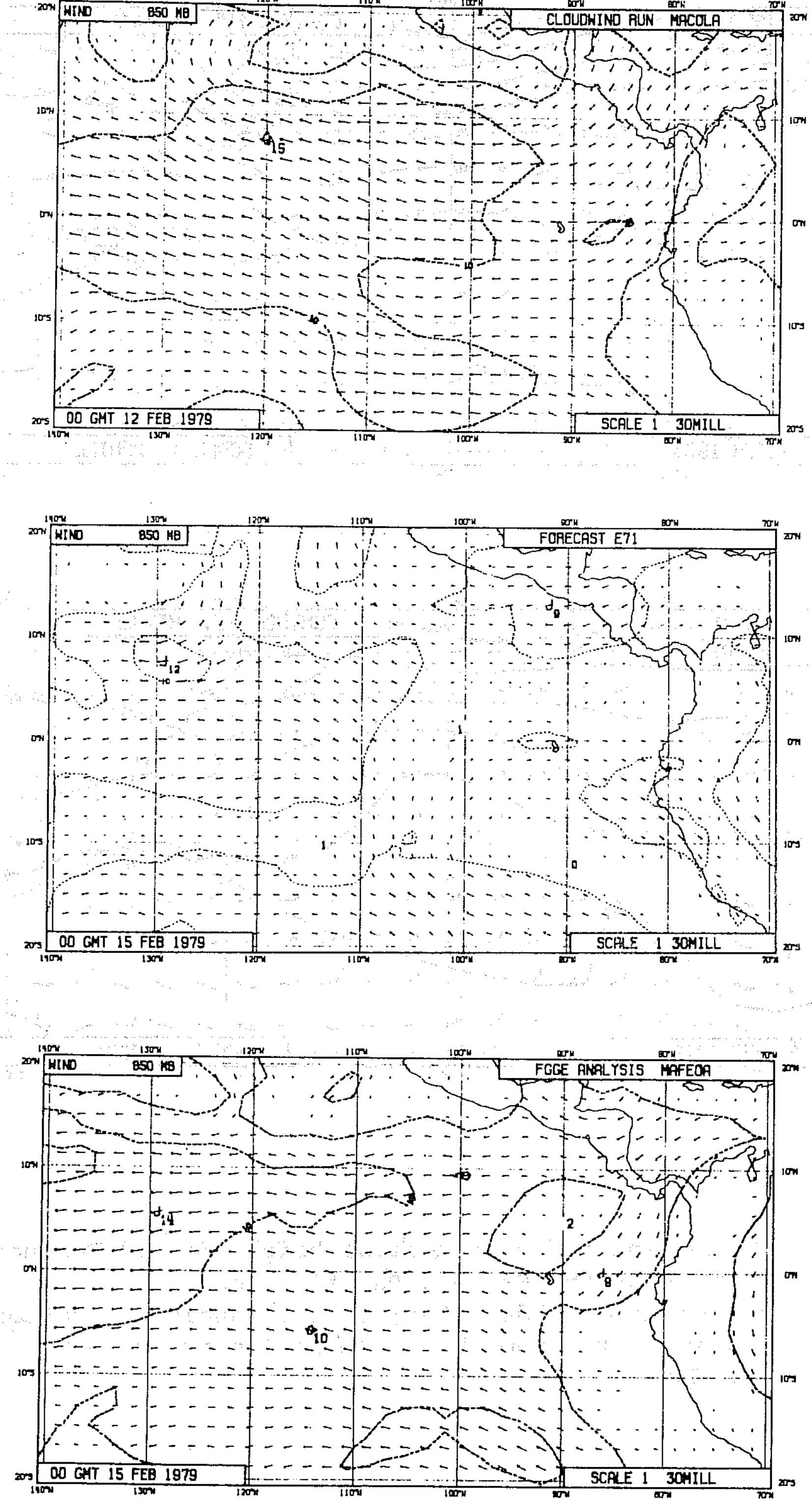


Fig. 14 850 mb wind analyses and forecasts over the Eastern Tropical Pacific Ocean.
Initial analysis for 12 February 1979 00GMT: top;
Day 3 forecast valid at 15 February 1979 00GMT: middle;
Verification analysis for 15 February 1979 00GMT: bottom.

An example of a poorly balanced 100 mb first guess field is given in Fig. 13 (top). The example in the figure is taken from the data assimilation run without satellite wind data on 17 February 1979 12 GMT. Observe the mass field wave at 22°N 115°W for which the corresponding wave does not appear in the wind field. In general, the 100 mb wind field and the 100 mb mass field should be in reasonable geostrophic balance at 22°N. After the analysis and after the initialization, the imbalance has not been removed but rather amplified (Fig. 13 bottom).

Possible explanations for the imbalance in Fig. 13 are:

- Some spurious gravity wave oscillations are still present in the forecast fields after 6 hours of integration. It should be noted that the utilized data assimilation scheme was unable to produce noise-free analyses in the upper stratosphere due to an initial deficiency in the vertical incremental interpolation routine.

- Because of the tropopause, the vertical interpolation of geopotentials from σ- to pressure levels results in small-scale fluctuations which are not created during the corresponding vertical interpolation of the wind field. (Both maps were produced by cubic spline interpolation from original data on σ-levels).

Reasons for the noticed imbalance have not been further explored. Disregarding the explanation, it does not seem appropriate to start the analysis computations with first guess fields not in balance on pressure levels as those in Fig. 13.

6. DEFICIENCIES IN THE FORECAST MODEL

During the evaluation of global forecasts which has been done within the framework of the observing system experiment on cloud winds, some systematic deficiencies of the forecast model have been noted. The description of the model can be found in Burridge and Haseler (1977).

6.1 Circulation inside the tropics

A statistical evaluation of the forecasts on an equatorial area (15°S-15°N) shows that forecasts are rather poor inside the tropics. A synoptic evaluation confirms the inability of the present model to handle some aspects of the tropical circulation.

Fig. 14 gives the 850 mb wind analysis over the Pacific Ocean, near Peru for 12 February 0 GMT, and the 3-day forecast obtained from this analysis. The verification analysis, for 15 February 0 GMT is also given. While the real circulation remains very stable, the trade-winds tend to disappear in the forecast. As a result, the 3-day forecast given by the model is much worse than persistence!

6.2 Overdevelopments of storms

Fig. 15 shows 3-day forecasts over the Atlantic Ocean valid for 18 February 1979 0 GMT which have been run on initial data from the OSE on cloud winds. Three maps are presented:

- One showing the 3-day forecast for sea level pressure using all the data ("cloud-wind" run).
- A second one showing the 3-day forecast using all the data except cloud winds (control run).
- The verification analysis.

Both forecasts show a very strong storm which developed very quickly. The value at the centre of the low is:

- 962 mb in the cloud wind forecast
- 953 mb in the control forecast
- 982 mb in the verification analysis.

The pressure in the centre of the low is much too deep in both forecasts, it seems that there is a tendency in the model to overestimate the development of some storms. Moreover, the difference in the centre of the low is rather large (9 mb) since no significant difference has been found between the cloud wind and control analyses in the initial situation (at least by checking the surface and 500mb maps).

In summary, it seems that the forecast model is very sensitivie to slight random differences in the initial analyses, which is also confirmed by the study done in paragraph 5.1.

7. CONCLUSIONS AND RECOMMENDATIONS

Several problems of data quality and of data assimilation techniques have been described and discussed in the previous sections of this report. In summary we would like to suggest the following actions to be taken:

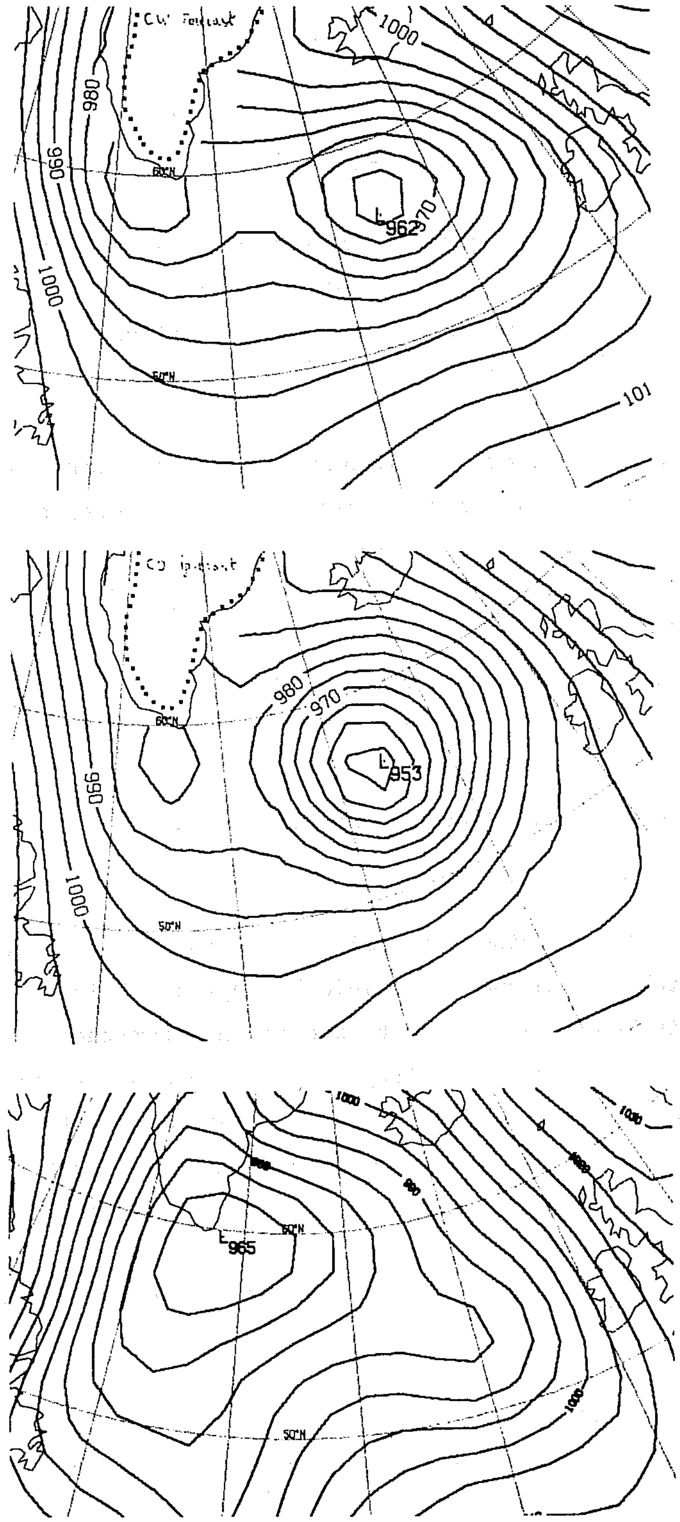


Fig. 15 Sea-level pressure forecasts and verification analysis valid for 18 February 1979 00GMT over the Northern Atlantic area.
3 day forecast from analyses with cloud wind data: top;
3 day forecast from analyses without cloud wind data: middle;
Verification analysis: bottom.

(A) With reference to satellite data producers

(A1) Satellite wind data producers should thoroughly examine the reasons for the occurrence of satellite wind reports with too low wind speeds. If possible, corrective actions should be taken to improve the production of future satellite wind data.

(A2) Satellite data producers should have access to reference information such as short-range numerical forecasts, radiosonde- and aircraft reports in order to perform quality control of produced data.

(A3) Satellite data producers should put high priority on producing data in areas without any other observations.

(B) With reference to the international meteorological community

(B1) Future codes for sending meteorological data over the Global Telecommunication Sustem should include "group" (or "fleet") identifiers to indicate which reports are coming from the same data source with a higher probability of having dependent errors. For example, it would be interesting to indicate what are the cloud winds which have been produced in the same fleet and assigned to the same pressure level, in the SATOB code.

(C) With reference to improvements of the ECMWF data assimilation system

(C1) Quality control procedures, which can also handle large errors with spatial dependency, should be developed.

(C2) Observation error statistics as well as forecast error statistics, utilized by the analysis system, should be thoroughly reviewed. Especially, the mathematical form of correlation functions for wind analysis in the tropics should be studied.

(C3) The possibility of not selecting lower quality data for analysis in areas with reasonable density of high quality data should be studied.

(C4) Reasons for the development of spurious small-scale features in the first guess fields should be studied.

(C5) Reasons for the observed imbalance between the 100 mb wind- and mass fields should be studied.

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