TECHNICAL MEMORANDUM

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North Atlantic network studies using the ECMWF analysis system

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ABSTRACT

This paper summarises the statistical network studies which have been carried out at ECMWF in 1985 to prepare for the Operational WWW System Evaluation for North Atlantic (OWSE-NA) which is to take place in 1987-88.

The main purpose of this paper is to help plan the deployment of the new observing systems over the North Atlantic in 1986-87-88. Some possible configurations for the future North Atlantic observing network have been simulated and tested using the analysis error standard deviation calculated in the ECMWF analysis scheme.

As this type of study has been carried out in two other centres (Offenbach and Paris), it has been a good opportunity to compare some specific properties of the three different assimilation systems: the data used, the statistical sets and the ability to perform network studies.

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1. INTRODUCTION

Several important changes are expected to occur before 1990 in the present North Atlantic observing network: some weather ships will be removed, some mobile ships will be able to make soundings (ASAP system), and some buoys and ASDAR systems will be deployed.

The purpose of the Operational WWW System Evaluation for the North Atlantic (OWSE-NA) for 1987-88 is to test all the operational aspects of the deployment of new observing systems like ASAP, ASDAR and buoys. A variety of committees and groups have been set up by the World Meteorological Organisation to prepare and carry out the OWSE-NA. The Scientific Evaluation Group (SEG) is responsible for all the evaluation aspects of the OWSE: evaluating the quality and impact of the new observations immediately after their deployment (mainly in 1987 and 1988), performing design studies before the deployment in order to evaluate the "potential impact" of new observations, and providing some guidelines to the people in charge of the deployment. The Scientific Evaluation Group is chaired by A. Gilchrist.

The network studies presented here are part of the work of the SEG work, as are similar studies carried out in Offenbach and Paris. These statistical network studies consist of setting up several realistic observation configurations for the future North Atlantic network, and then testing each of them in an Optimum Interpolation (OI) analysis scheme: in particular the OI scheme provides the analysis error standard deviation field which gives an estimate of the quality of the analysis.

The preliminary work which has been done to prepare the network studies has been described in details in another SEG paper, Pailleux and Pierrard (1985). This paper documents the assumptions which have been made about the different observing systems, the way the configurations have been set up, the preparation of the simulated data, the period chosen for the tests and the specification of the results to be calculated. All this information will be summarised in Section 2.1. It must be stressed that the present network studies have been set up using information available in May 1985, and that several things have changed since that date, especially in the commitments of the different countries for deploying ASAP and ASDAR systems.

The network studies carried out by the SEG are continuations of a preliminary study made in 1984, Pailleux (1984). Its main conclusion can be summarised as follows: taking into account the normal routes of ASAP ships and their passive periods, at least 4 ASAP ships are needed to replace the fixed weather ship R without any detrimental effect on the analysis error standard deviation.

2. DESCRIPTION OF THE PRESENT NETWORK STUDIES

2.1 General description

This study is mainly concerned with ASAPs: we investigate different scenarios with various numbers of ASAP ships, making different assumptions for the shipping routes over the Northern Atlantic; up to 17 ASAP ships are used in the scenarios. Some routes are sure to be used in the deployment as the countries have made commitments, but other routes have been specified by the SEG (see Pailleux and Pierrard, 1985). Most of the ships are merchant ships (e.g.: French ships between France and Martinique - British or Finnish ships between the Channel and North America), though it is possible that two of them will be German patrol vessels (which stay in the open ocean for a long time before returning to port). The routes and the geographical positions which have been assumed for the different ships are described in Pailleux and Pierrard (1985).

The network configurations which are investigated are the following:

B = present configuration + ASDARs
I = B - weather ship R + 9 ASAPs
J = B - weather ship R + 13 ASAPs
K = B - weather ship R + 13 ASAPs (different assumptions about routes).
L = B - weather ship R + 17 ASAPs

The "present configuration" corresponds to all the observations available in the ECMWF archives (very late cut-off time). A similar study has been made by A. Kaestner with the early cut-off time of the German operational analysis. The same simulated ASDAR data have been used in all the configurations: the ASDAR data coverage corresponds more or less to the FGGE ASDAR scenario. The reasons for choosing the other configurations are as follows:

- B is very similar to the FGGE configuration.
- I is the "minimum OWSE configuration" (configuration likely to occur at the beginning of 1987).
- J and K represent two "mean configurations" which could occur before the end of 1988 if all the present deployment commitments are honoured. K is similar to J except that 2 ASAP systems are moved from the routes Scotland/Saint-Lawrence and Channel/Boston to the routes Channel/West-Indies and Gibraltar/Boston in order to fill some data coverage gaps in the southern part of the area.

- L is an optimistic configuration which assumes a high level of development of the ASAP system, which will probably not be reached before 1990.

The configurations are called B, I, J, K, L, instead of A, B, C,... for historical reasons: A, C, D,.. correspond to configurations that have been envisaged at one stage but are no longer applicable.

Due to the rapid evolution of the deployment plans in the different countries, the present configurations B, I, J, K and L are not completely applicable either. For example the assumed ASDAR development is probably much too optimistic; we now know that the ASDAR programme will suffer a considerable delay. As a second example the route Helsinki/New York which has been assumed for the Finnish ASAP system will not be used, but the Finnish ASAP system will be on a British ship operating between the Channel and Boston. Therefore the tested configurations must be considered as examples of what could happen given the information available in June 1985.

This last point is not crucial as the main thing to look at in our study is the improvement in the North Atlantic network due to an increase of the number of ASAP soundings. The ASDARs and buoys would have had a marginal impact in the present study using a three-dimensional analysis system, as they are single level observations. Moreover the FGGE ASDAR distribution has been evaluated in previous Observing System Experiments (Baede et al., 1985) and some Observing System Simulation Experiments have been carried out for the North Atlantic by Kaestner (1982) for buoys.

The principle of the network study consists of using an operational optimum interpolation analysis scheme. All the data corresponding to one configuration are introduced into the analysis, then we examine the analysis error standard deviation calculated in the OI analysis. It must be stressed that the actual values of the observations do not matter for this kind of statistical study: the analysis error which is examined depends only on the position of the observations and on statistics about the observation error and 6h forecast error.

The network study has been made at ECMWF for the period 1 June 1985, 00Z to 4 June 1985, 00Z using all the observations present in the ECMWF archives for that period. Five complete assimilation experiments have been carried for that period (13 six-hour assimilation cycles), one experiment for each of the configurations. For the simulated ASAPs and ASDARs, the geographical locations worked out in Pailleux and Pierrard (1985) have been used, and the observed values have been derived by interpolating the operational ECMWF analysis to the simulated observation points: the observed value does not matter for the computation of the analysis error standard deviation, and by taking observed data equal to the operational analysis, the simulated observations are always accepted by the analysis and we avoid any rejection problems.

The analysis error is used in the assimilation to derive the forecast error of the next cycle (6 hours later), which is then used to derive the following analysis error standard deviation Ea: this is the reason the five assimilation experiments have to remain completely independent.

This study concentrates on the examination of the analysis error fields for the geopotential height at 200, 500 and 1000 hPa. The normalised analysis error Ea/Ep has been examined as well: it is always between 0 and 1 (100%):

Ea/Ep = 0 would mean "perfect analysis",

Ea/Ep = 100% would mean that the "analysis is as bad as the 6-hour forecast first guess" (occurs when no data are available to perform the analysis).

The analysis error standard deviation and the normalised analysis error have been examined for the seven 00Z and 12Z analyses during the period of the experiment: the 06Z and 18Z analyses are less interesting to look at as it was assumed that the ASAP systems were working only at 00Z and 12Z.

The same study has been carried out by the French Meteorological Service (M.C. Pierrard, personal communication) using exactly the same period and data, allowing a direct comparison of the results and also of the two assimilation systems (French and ECMWF). However 4 days is too short for a comprehensive ASAP study, as it takes about two weeks to examine all the observation distributions (this is about the time needed by a ship to perform a return trip over the North Atlantic). The simulated ASAP observations have been worked out for a 15 day period by Pailleux and Pierrard (1985), and the German Meteorological Service (A. Kaestner) has used those to make a network study of B, J and K over the 15 days; this will provide a good basis for validating all the other comparisons made between 1 and 4 June 1985. Moreover all the data coverage maps including the simulated ASAPs can be examined over the 15-day period.

2.2 Some remarks on the performance of network studies

● In the OI theory, the calculation of the analysis error standard deviation is probably the least reliable part of the computation. Consequently we have to be careful when using this analysis error to estimate the quality of an observation network or of an analysis: this problem has been discussed by Cats (1984) and Rinne and Jarvenoja (1984).

- In practice the importance of observations is considerably increased in situations with severe weather conditions. This will never be taken into account in a network study because of the statistical nature of the analysis error we look at.

- Observing System Simulation Experiments (OSSEs) are a better alternative to network studies, because they do take into account special cases with severe meteorological conditions. But they are more difficult to set up, especially because of the difficulty of getting realistic simulated data. The present North Atlantic network studies are actually the "spare experiments" which have been decided because of the impossibility of producing results from OSSEs in time.

- The quantity 1-Ea/Ep is a measure of the improvement brought about by the observations to the 6h forecast first guess. The better the 6h forecast, the smaller this improvement is expected to be. So we have the paradox that the best assimilation systems give the smallest amplitude in the signal we look at in the network study. Moreover, the forecast error is generally prescribed in an empirical way in the current data assimilation systems: the larger the prescribed forecast error, the larger the improvement 1-Ea/Ep due to the data.

3. SOME PROPERTIES OF THE ECMWF ANALYSIS SYSTEM

The ECMWF operational analysis system is a global three-dimensional multivariate OI scheme which is described in Lorenc (1981). Here we point out some properties of this scheme which are of interest for the results of the network studies.

3.1 Box technique

Instead of performing the analysis grid point by grid point, the globe is split in latitude/longitude boxes which are about 670 km in size. A large volume of data (up to 255) is selected to analyse that box, and a large correlation matrix is set up to analyse all the grid points and all the variables in that volume. The analysis error standard deviation is evaluated only at the centre of the analysis boxes, that means on a very crude grid (about a 6-degree mesh).

Then for each analysis box, the data selection and the matrix computation are performed twice, first for the data checking then for the normal analysis. The data selection in less extensive in the data checking mode than in the main analysis mode. Since the analysis error standard deviation is calculated at the data checking step (i.e. the first step), it does not take into account the advantages of the extensive data selection algorithm.

3.2 Analysis in one slab or in three slabs

When the total number of data available to analyse one box is small enough, the analysis is performed in one slab: all the variables at all levels are analysed with the same data set from the surface to the stratosphere. But as soon as the total number of data exceeds a specified limit, the analysis is performed in 3 slabs:

- the data from 1000 to 700 hPa are used to analyse the bottom slab (sometimes from 1000 to 500 hPa);

- the data from 700 to 150 hPa are used to analyse the middle slab (sometimes from 850 to 100 hPa);

- the data from 150 to 10 hPa are used to analyse the upper slab (sometimes from 200 to 10 hPa).

A smooth transition in insured at the slab boundaries to avoid vertical discontinuities in the analysis.

In this study, it turned out that for some boxes the addition of extra simulated soundings was enough to get the total number of the data above the "1 slab/3 slab" limit. For example, if the total number were just below the limit in configuration B and just above in configuration I, then the analysis error standard deviation at, let us say 500 hPa, is derived with less data in configuration I than in configuration B!

In order to see to what extent this property has interfered with the present study, the number of boxes analysed in one slab has been put in Table 1 for each main-hour analysis and each configuration: the changes in the numbers of "1 slab" boxes is small when moving from one configuration to another, but they are sufficient to affect the scores derived from the analysis errors. Therefore Table 1 must be kept in mind when we look at the results: we can see for example that on 1 June, 00Z, the configurations I, J, K and L have all been analysed with 456 "1 slab boxes", which means that the comparison is perfectly clean, while 462 boxes have been analysed in one slab in configuration B, which means that we have to be cautious when comparing B with the other configurations for that analysis set.

	B	I	J	K	L
1 June 00Z	462	456	456	456	456
1 June 12Z	484	483	483	482	481
2 June 00Z	503	502	501	503	502
2 June 12Z	729	728	728	727	726
3 June 00Z	552	551	551	548	???
3 June 12Z	660	660	659	656	655
4 June 00Z	466	462	461	457	456

Table 1: Number of analysis boxes analysed in 1 slab for the different dates and the 5 configurations. Total Number of boxes = 1146.

3.3 The ECMWF analysis error is not the OI error

The OI analysis error variance is calculated from the OI equations:

$$\mathrm{Var(Eoi)} = \mathrm{Var(Ep)} - W^T . C$$

where Var(Ep) is the variance of the forecast error, $W^T.C$ is the dot product of the weight vector W by the vector C containing the covariances between the analysed quantity and all the data used in the analysis.

Since May 1984 the analysis error variance produced by the ECMWF analysis has been changed to:

$$\mathrm{Var(Ea)} = \mathrm{Min}\ (\mathrm{Var(Eoi)}+\mathrm{Var(Emin)},\mathrm{Var(Ep)})$$

All the prescribed statistics, including Var(Ep), have also been changed as well in May 1984: Var(Ep) has been considerably reduced.

Let us call Eois, Eps, Eas and Emins the error standard deviations, that is the square roots of the respective variances. Emins represents the standard deviation of the error coming from unresolved scales and non-optimal statistics: we can call it "minimum analysis error" (see Lönnberg and Shaw, 1984 for more details). As an example Emins is 6m for the 500 hPa geopotential height, which means that the analysis error standard deviation Ea can never be smaller that 6m.

Eoi represents the quality of the synoptic scale analysis (excluding the scales not resolved by the grid), and can be very close to zero in a data dense area: at least it tends to zero when the number of data becomes infinite. It is the quantity which has been examined in the French and German network studies; it is also the quantity which was used in the ECMWF system before May 1984: see the network studies carried out by Cats (1984).

Eas is the main quantity which has been examined in the present network study, it is supposed to describe the analysis error at all scales. It always lies between Emins and Eps: for the 500 hPa geopotential height, Emins is 6m and Eps around 13m, so the range of variation for Eas is small between the analysis without data and the "perfect analysis". Consequently the analysis error maps produced in this study are very smooth, at least much smoother than the maps produced by Cats (1984), and by the French and German studies.

3.4 Calculation of Eps from Eas

At the beginning of each analysis cycle Eps has to be calculated and given as input to the OI equations. The computation of Eps involves several statistics about climatology and forecast errors coming from different sources which depend on the latitude and season. It involves also the analysis error standard deviation Eas of the previous cycle (6 hours before) which is directly related to the data coverage. The full details of the computation of Eps are given in Lönnberg and Shaw (1984).

The addition of new data is expected to reduce the analysis error Eas, then to reduce the forecast error Eps of the next assimilation cycle, and so on. This is the reason why it is interesting to perform the network studies in full data assimilation experiments including several cycles. It also provides an opportunity to examine the extent to which the addition of new data in the analysis reduces the forecast error Eps through the computation of the analysis error. Fig. 1 shows the 500 hPa geopotential height forecast error Eps on 4 June 00Z (after 13 assimilation cycles) for configurations B and L

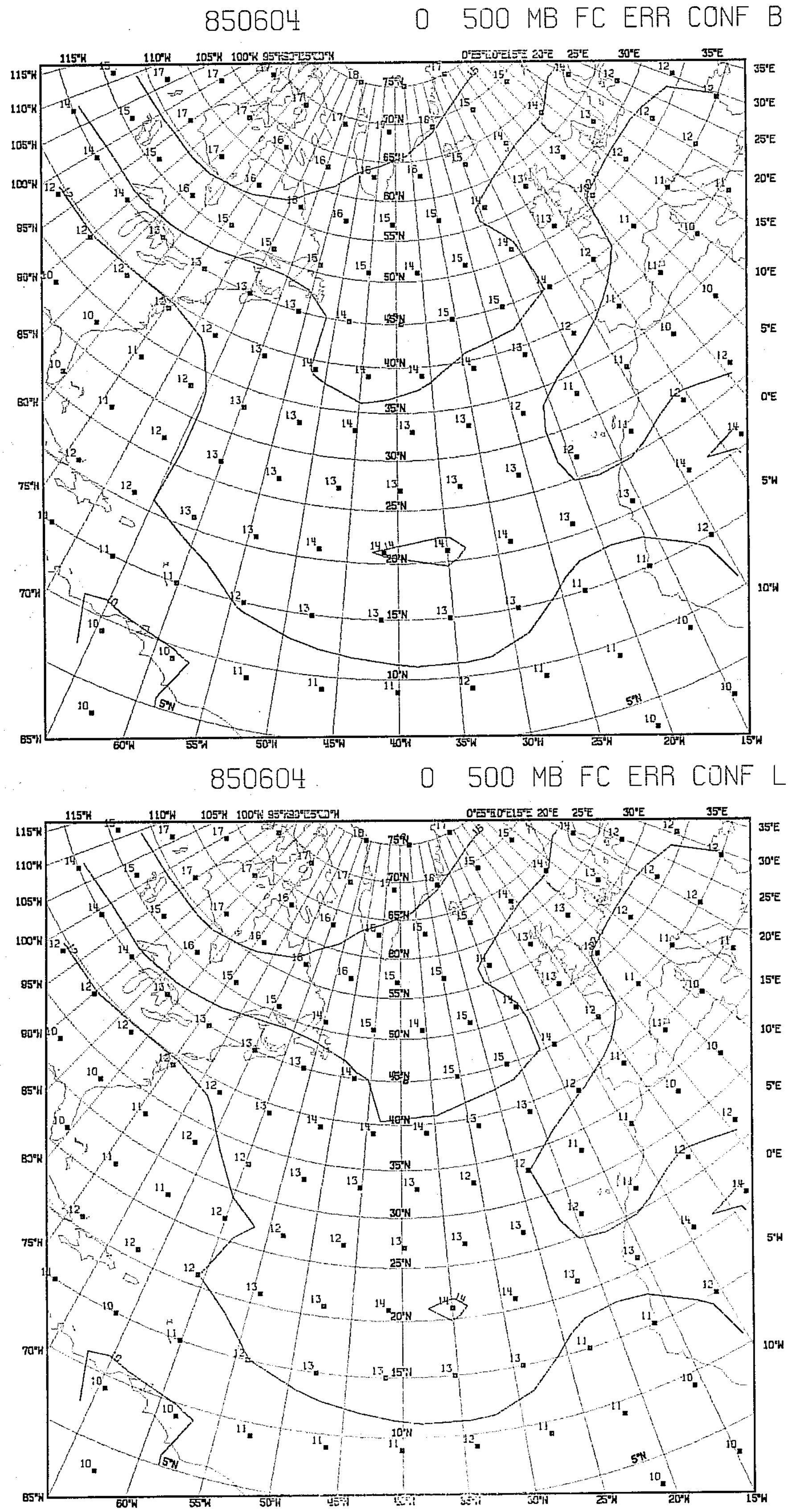


Fig. 1 500 hPa geopotential height forecast error (in meters) used in the OI analysis on 4 June 00Z.
Top: configuration B - Bottom: configuration L.

(L = B - weather ship R + 17 ASAPs): the differences have the expected sign, but the maps are very close to each other. This means that the algorithm used to derive the forecast error Eps at each analysis cycle is relatively insensitive to the addition of new data in the analysis.

3.5 Performance of the system in network studies

The main consequence of the properties described in Sections 3.1 to 3.4 is that the analysis error fields and forecast error fields are very smooth. This is obviously good for the OI itself, as the horizontal gradient of the forecast error is assumed to be zero in the OI theory, but the amplitude of the signal we are looking at is then expected to be small. The error fields are also given on a 6-degree grid, and no improvement in smaller scales can be described through these fields. International comparisons of statistics used in different OI analysis systems have been carried out recently; they show that the mean value of forecast errors used by ECMWF is generally smaller than the values used in other centres. The ECMWF and German forecast errors are actually comparable, and the French one is about 25% larger. The 1 slab/3 slab algorithm could be a serious weakness for network studies as it can give misleading results.

Keeping in mind all these aspects, we will now try to extract from the ECMWF analysis error the signal of a simulated ASAP deployment, and compare it with that found in other studies.

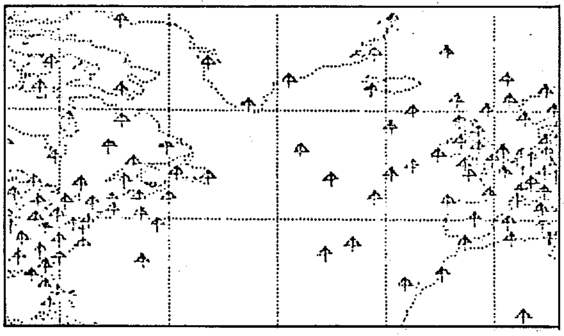
4. GENERAL COMPARISON OF THE DIFFERENT CONFIGURATIONS

4.1 ASAP data coverage (from simulated observations)

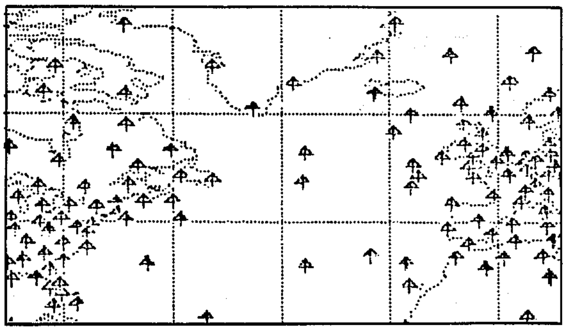
One important factor for the ASAP system is the percentage of active periods: an active period is when the ship is at sea and makes soundings whereas a passive period is when the ship is in the port or too close to the coast. This percentage can be worked out directly from the simulated locations of the 17 ASAP ships on a 15-day period (Pailleux and Pierrard, 1985) and is found to be 63%: this may be a little too optimistic as 2 ships out of 17 are assumed to be "Research Vessels" and to make soundings 100% of the time; also no long inactive period (such as repairs etc.) has been taken into account in that evaluation. Roughly, we can say that an ASAP system over the North Atlantic is 60% efficient compared to a radiosonde station making soundings every day at 00Z and 12Z: this factor is a mean value and depends on the shipping route.

For configuration J (one which could be close to real situation by the end of 1988 - 13 ASAPs), Fig. 2 shows the radiosonde data coverage maps from 1 June, 00Z to 4 June, 00Z, every 12 hours. The simulated ASAPs have been plotted on the maps as well as the normal radiosondes. Note that the Azores station is missing during the whole period except on 4 June, 00Z, but its absence must not be considered as detrimental for the network study as it is a perfect illustration of what happens all the time in reality. Moreover, most of the operational analyses (except at ECMWF) are run with a short cut-off time so that a part of the operational observations is always missing.

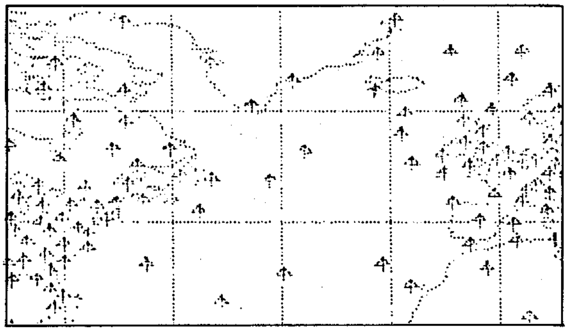
In Fig. 2, we can see that there is always a reasonable number of radiosondes over the North-Atlantic, which was not the case in the simulations made in Pailleux (1984) with only 4 or even 8 ASAPs. However we are still far from a uniform data coverage at the synoptic scale: there is for example a large gap around (40N, 45W) on 1 June and an even larger gap around (40N, 30W) on 3 June.



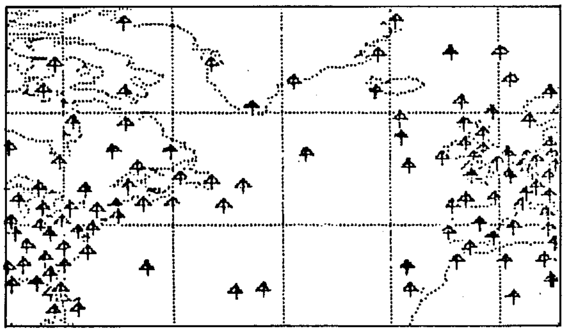
1 JUNE 00Z



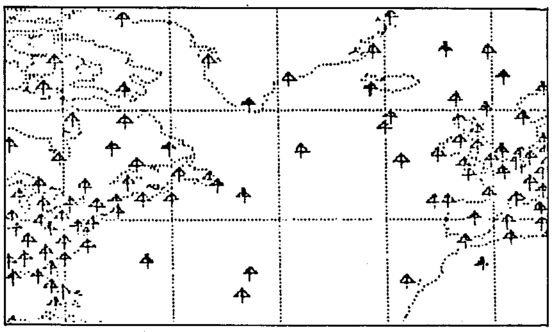
1 JUNE 12Z



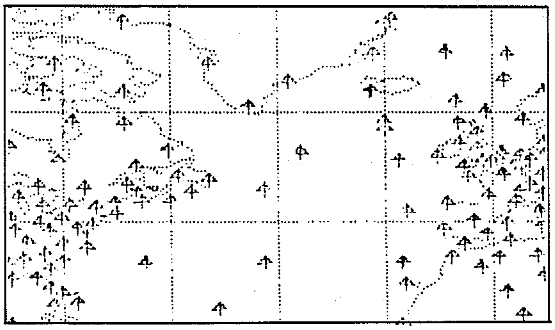
2 JUNE 00Z



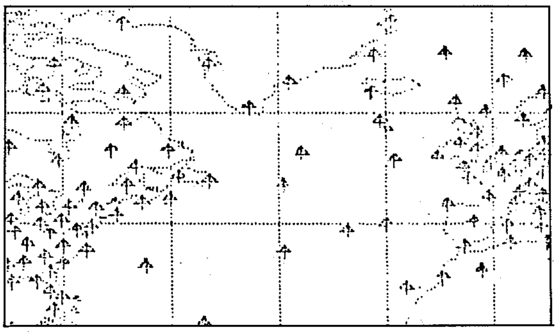
2 JUNE 12Z



3 JUNE 00Z



3 JUNE 12Z



4 JUNE 00Z

Fig. 2 Radiosonde data coverage maps for configuration J from 1 June 00Z to 4 June 1985 00Z.

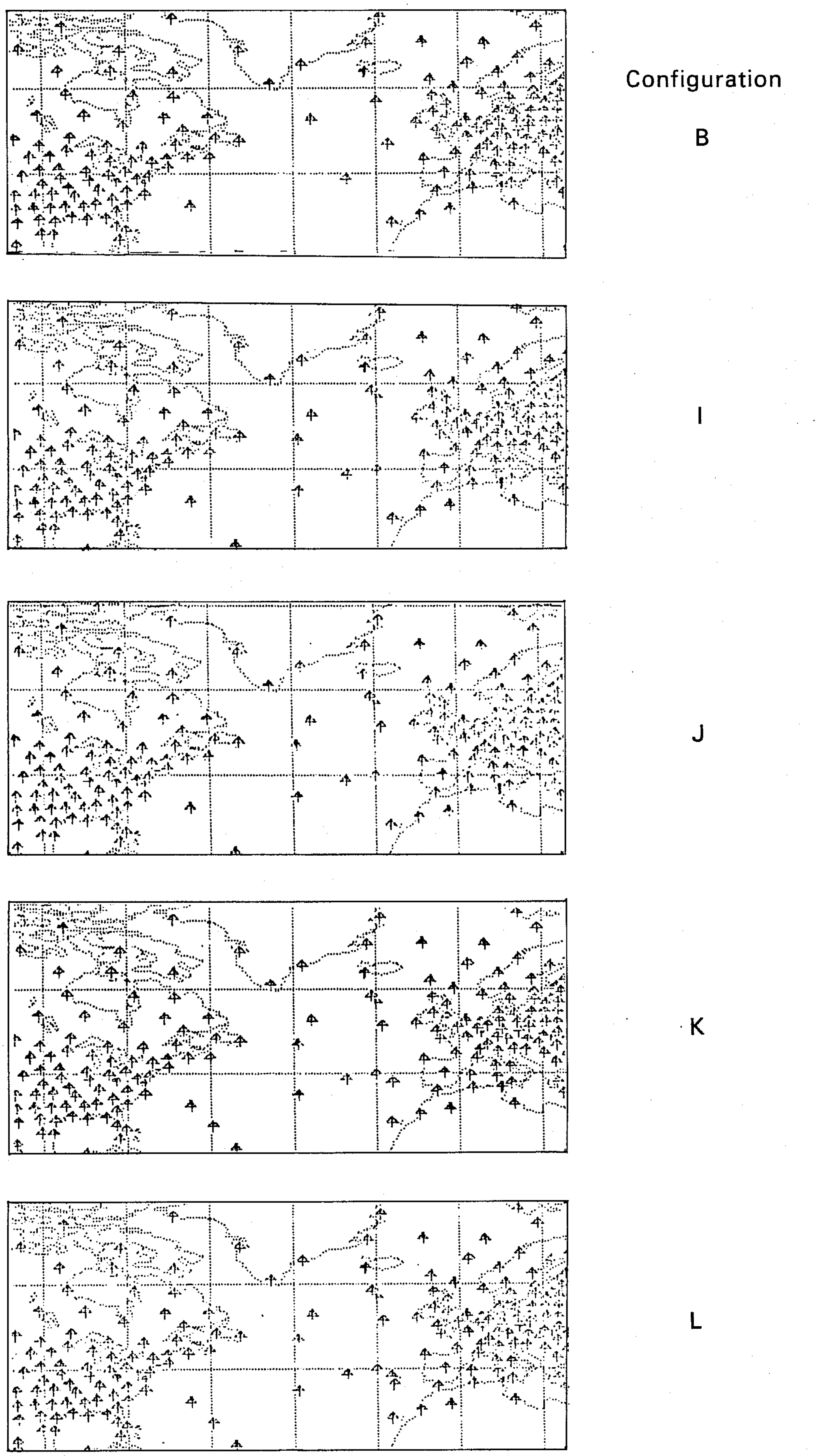


Fig. 3 Radiosonde data coverage maps on 4 June 1985 00Z, for different configurations.

Fig. 3 gives an indication of the differences between configurations B, I, J, K and L based on one single case, 4 June 00Z (the one with the Azores radiosonde present). It shows, for example, that the big gap existing in B (present configuration) to the east of Bermuda can be considerably reduced by deploying ASAPs on southern shipping routes, as assumed in configurations K and L. There are three ASAPs more in L than in K, which does not appear immediately by comparing the two maps: the reason is that in L two ASAPs are very close to each other near Boston, as are two others between the Azores and Gibraltar. This will not be exceptional in reality: it is difficult to avoid and it obviously reduces the overall impact of the ASAP network. On the other hand it may be good for quality control of the ASAPs especially at the early stage of the implementation.

4.2 Examination of the error maps

The analysis error maps (Eas) and the normalised analysis error maps (Eas/Eps) have been examined throughout the period at 200, 500 and 1000 hPa. Fig. 4 shows these maps for configuration B and for two cases: 00Z on 1 June and 2 June: the values have been plotted at the centre of the analysis boxes. The maps are very smooth for the reasons explained in Section 3. On 2 June the values at 500 hPa vary from 7m (over Europe and North America) to 15m in the middle of the Atlantic. The normalised analysis maps show more or less the same features as the analysis error maps, except that the areas with no data at all are more apparent. The analysis error is larger on 2 June than on 1 June because of a lack of satellite data: on 2 June there is no satellite data at all to the east of 40W, which explains for example the large area with Eas/Eps = 100%. It does not mean that there is no data at all in this area, but only that we do not manage to get an analysis error smaller than the forecast error through the algorithm described in Section 3.

Fig. 5 shows the analysis error on 2 June 00Z (the one with a poor satellite data coverage) for the different configurations B, I, J, K and L. It indicates the improvement in the analysis obtained by respectively 9, 13, 13 and 17 ASAPs. Compare especially J and K which have the same number of ASAPs.

The maps at 200 hPa (not shown) are very similar to the 500 hPa maps, except that we can see the impact of the ASDARs (which are included in all configurations) and the ASAP signal is slightly smaller because of that. No useful information can be extracted from the surface maps.

5. TIME AVERAGED ERROR MAPS FOR THE DIFFERENT CONFIGURATIONS

The analysis error maps (unnormalised Eas, and normalised Eas/Eps) have been averaged on all the 00 and 12Z analyses, that is 7 analysis times. The average has been made on the variances, which is the only additive quantity. Figs. 6 to 15 show the averaged error maps and the normalised analysis error for the configurations: they give an indication of the potential impact of the ASAP system over the whole period, which is more reliable than the specific cases given in Figs. 4 to 5.

The large area in the middle of the Atlantic, with Eas larger than 12m in configuration B, is considerably reduced by the addition of the 9 ASAPs in configuration I. However, just to the west of the Bay of Biscay the analysis error is larger in I than in B for four different analysis boxes. It is difficult to find out what part is due to the removal of weather ship R

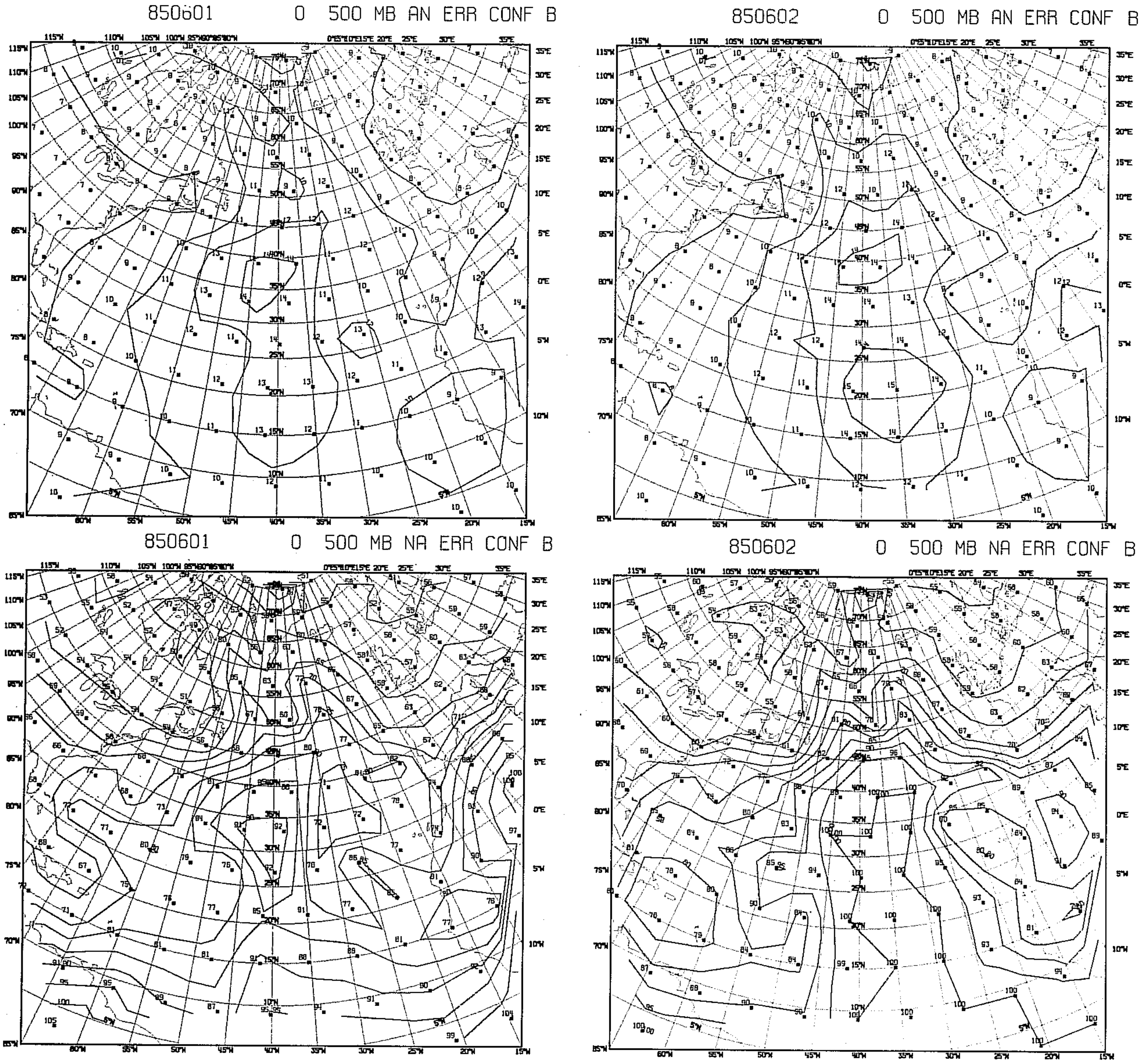


Fig. 4 500 hPa analysis error maps for configuration B.
Left column: 1 June 00Z - Right: 2 June 00Z
Top: analysis error in meters
Bottom: normalised analysis error (in %)

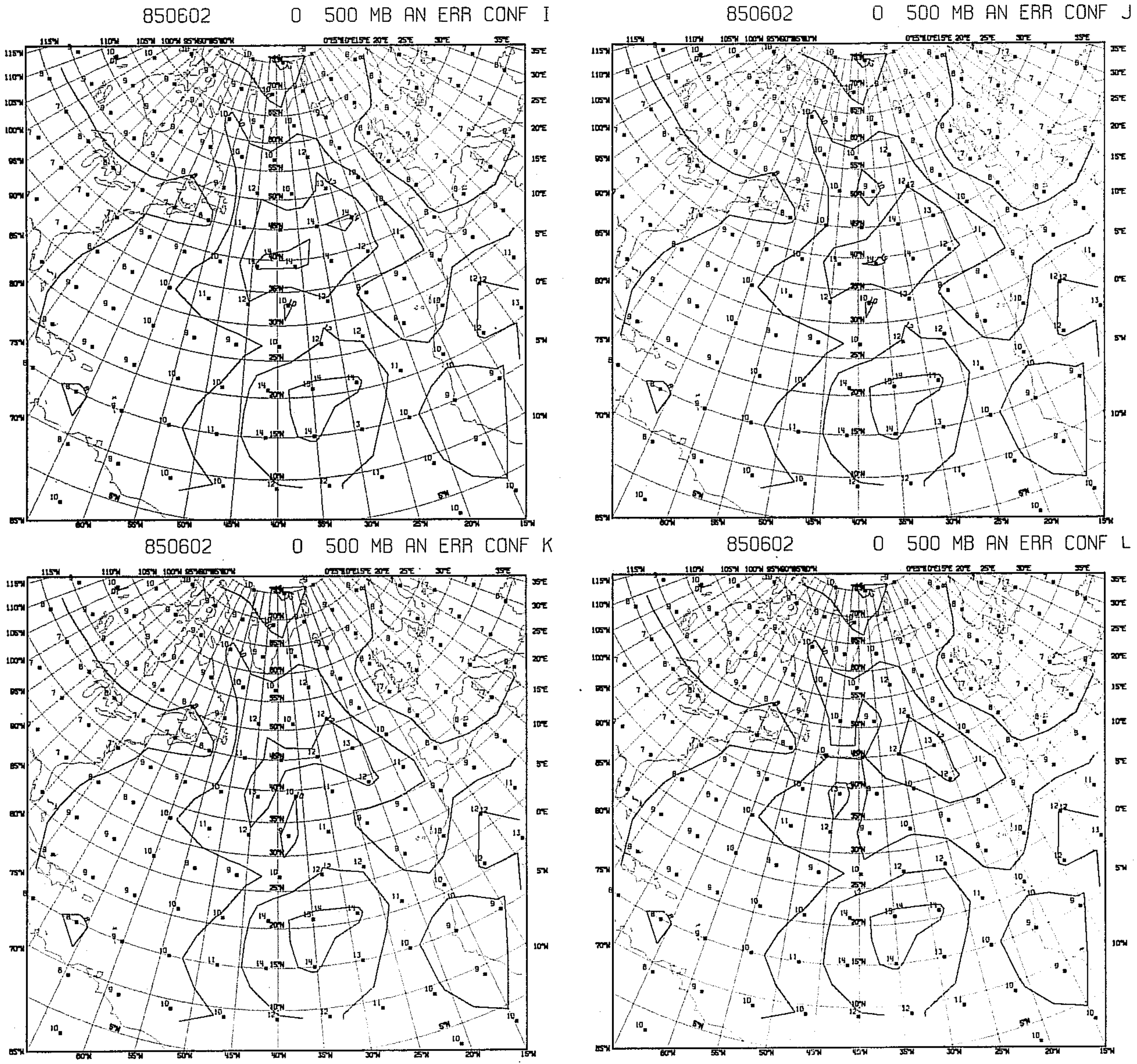


Fig. 5 500 hPa analysis error maps on 2 June 00Z for configurations I,J,K and L. (The same map for B is on Fig. 4).

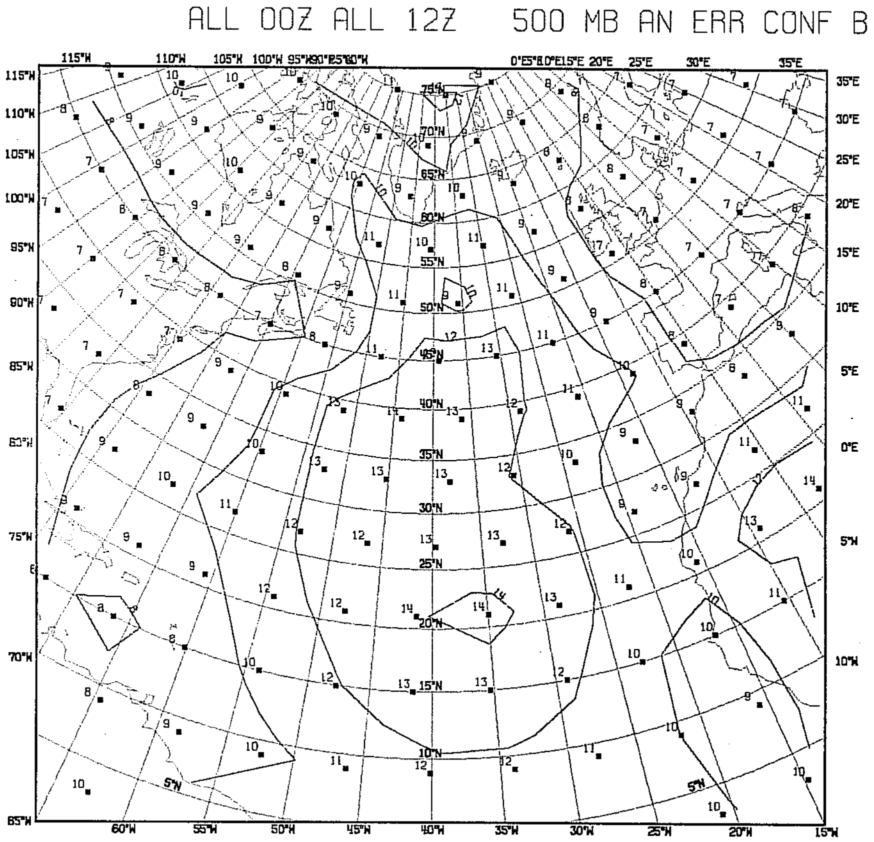


Fig. 6 500 hPa analyses error standard deviation map (meters), averaged in the period (1 June 00Z - 4 June 00Z). Configuration B.

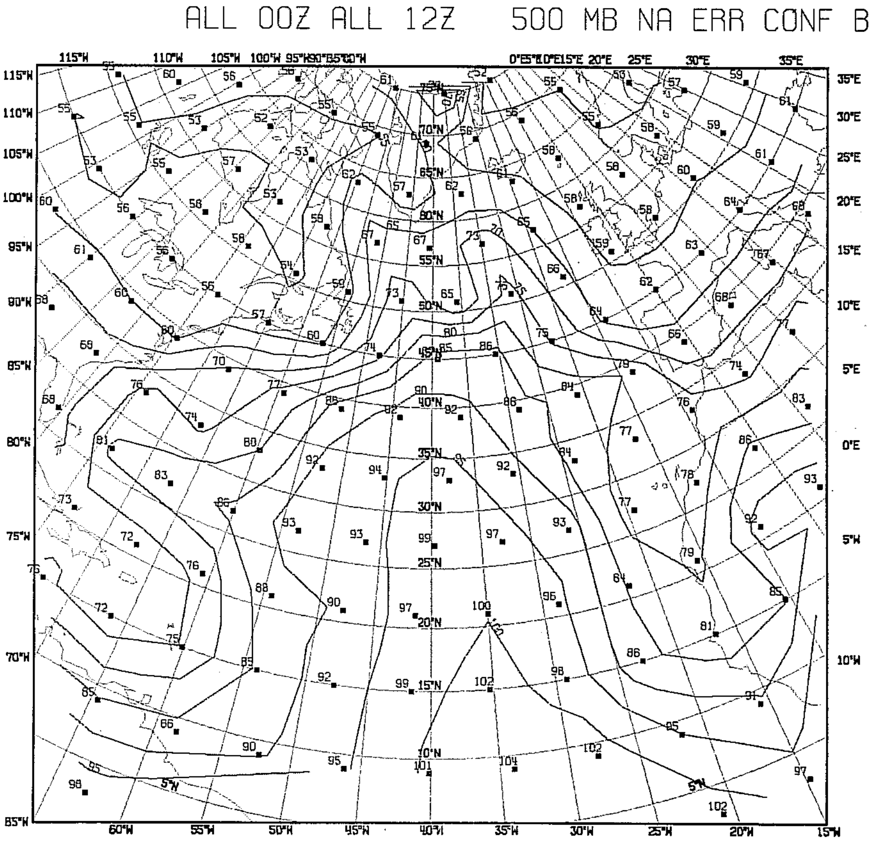


Fig. 7 500 hPa normalised analysis error map (%), averaged in the period (1 June 00Z - 4 June 00Z). Configuration B.

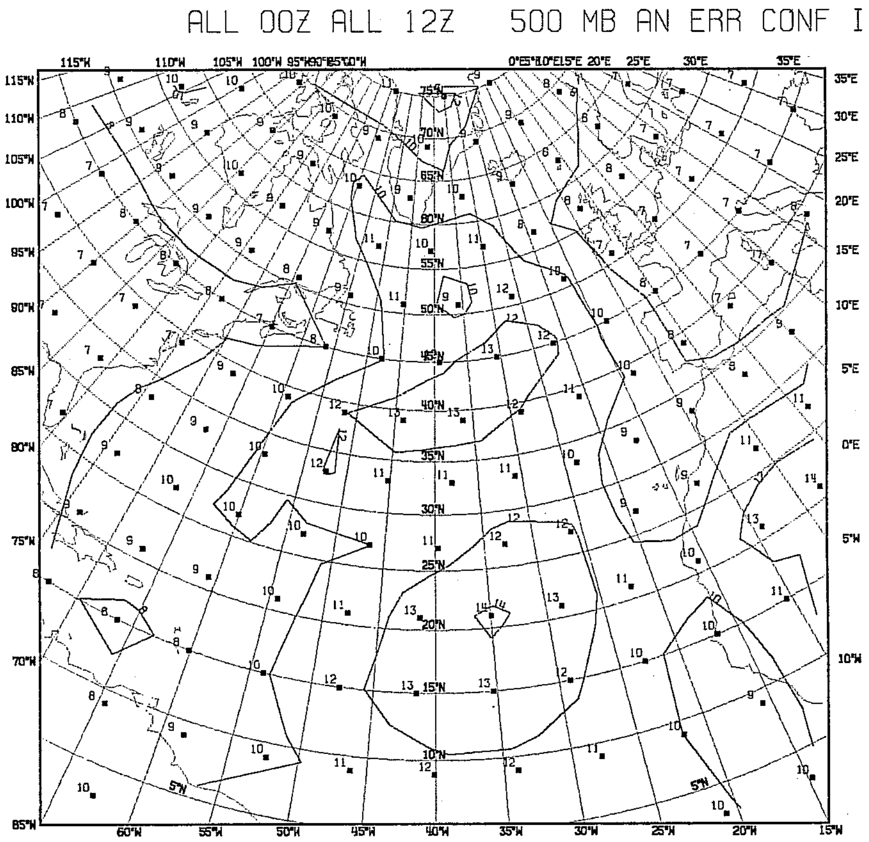


Fig. 8 As Fig. 6 but for configuration I.

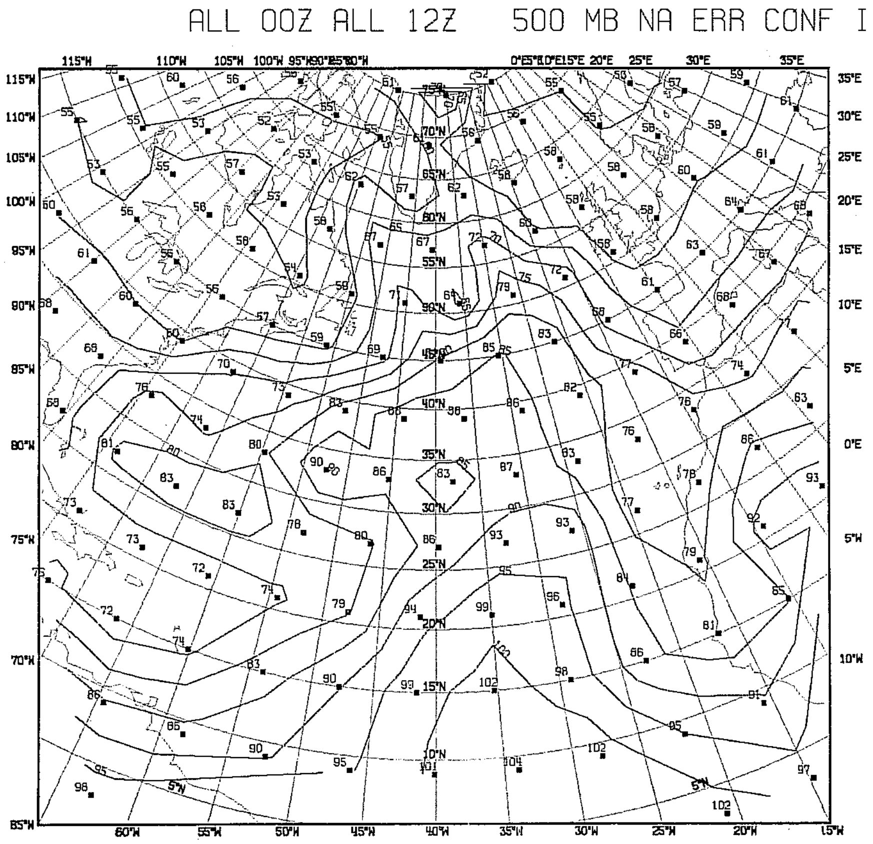


Fig. 9 As Fig. 7 but for configuration I.

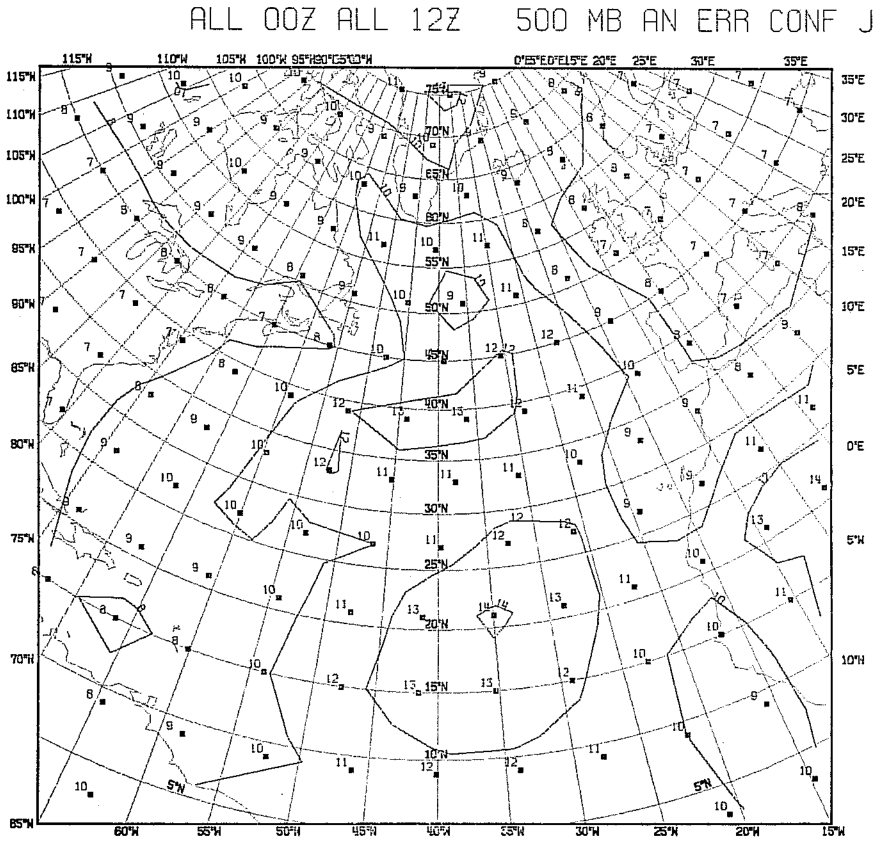


Fig. 10 As Fig. 6 but for configuration J.

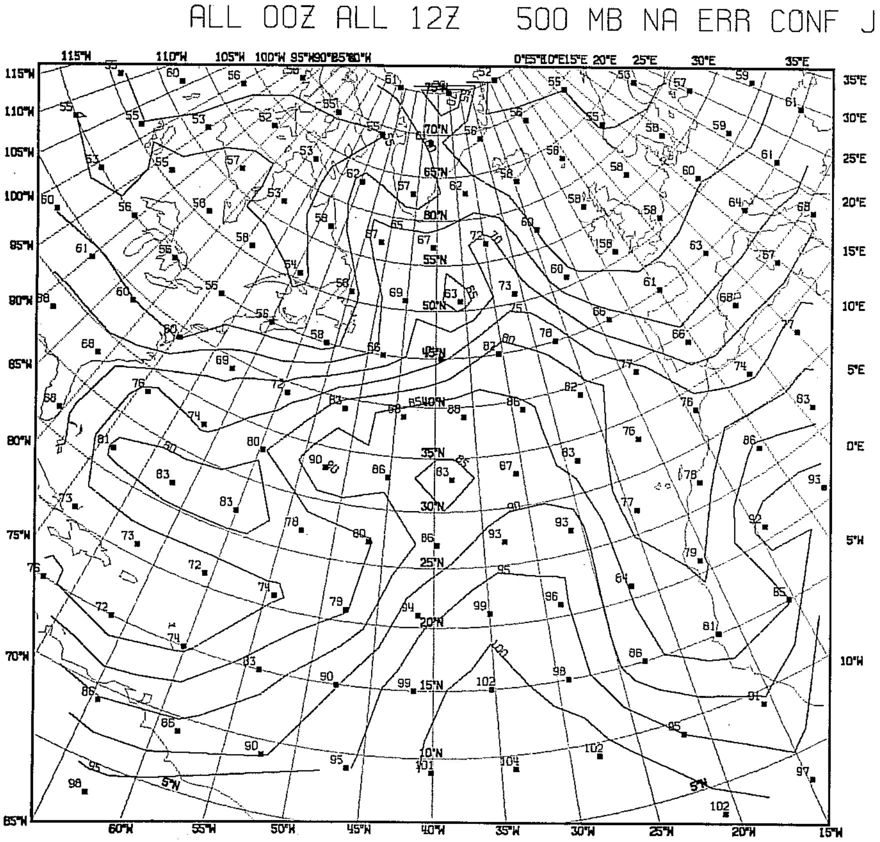


Fig. 11 As Fig. 7 but for configuration J.

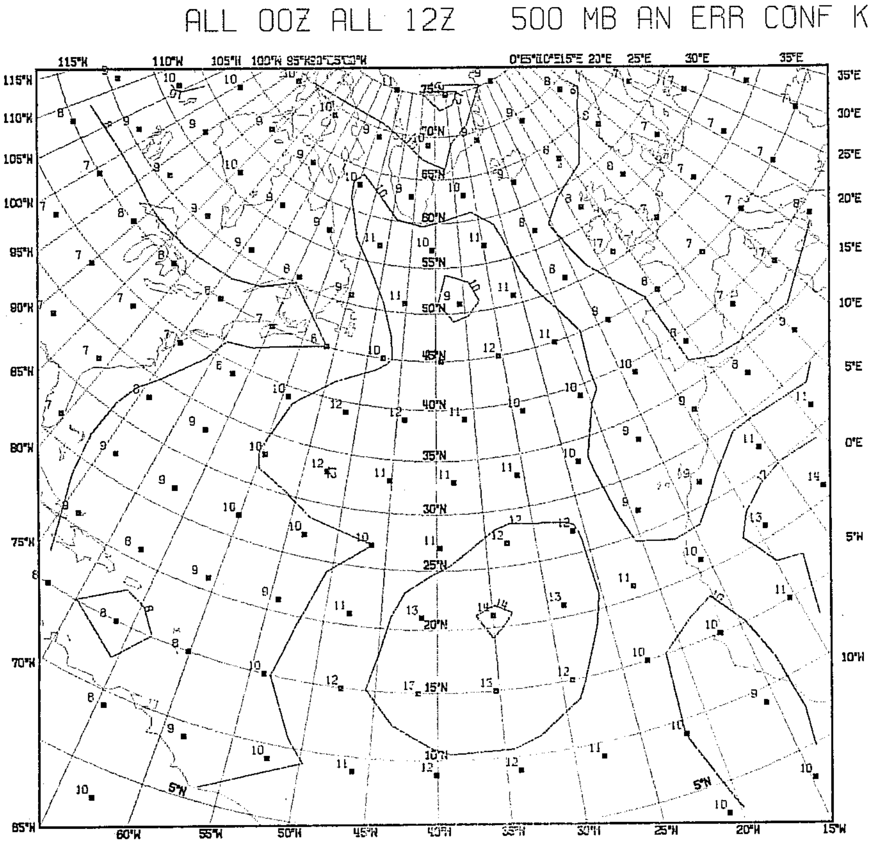


Fig. 12 As Fig. 6 but for configuration K.

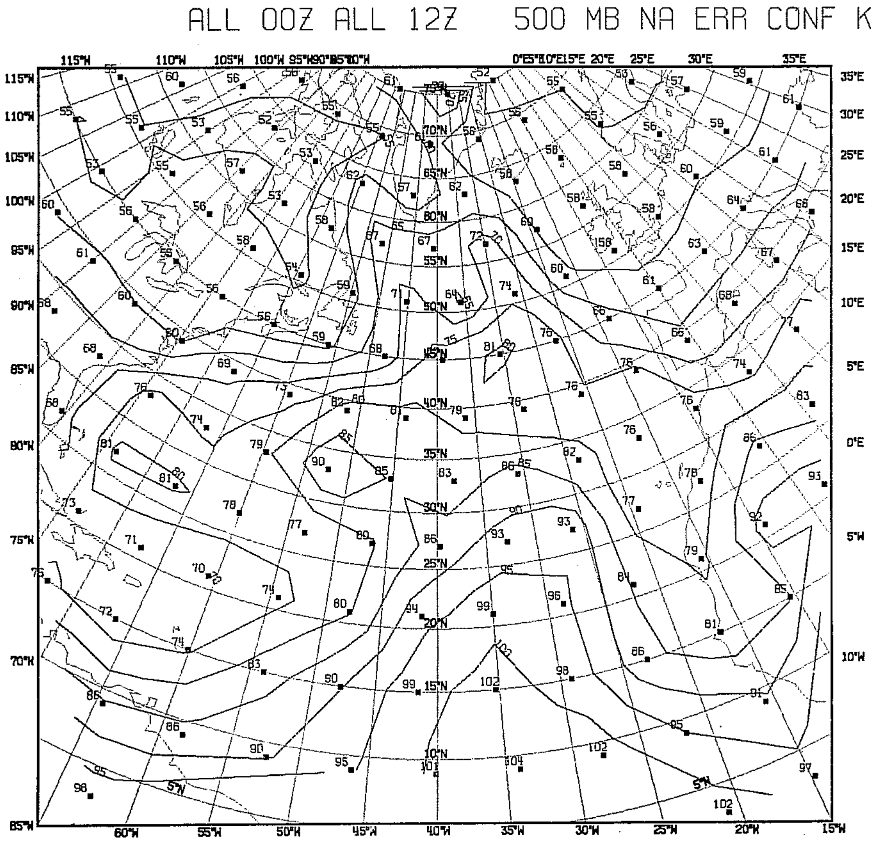


Fig. 13 As Fig. 7 but for configuration K.

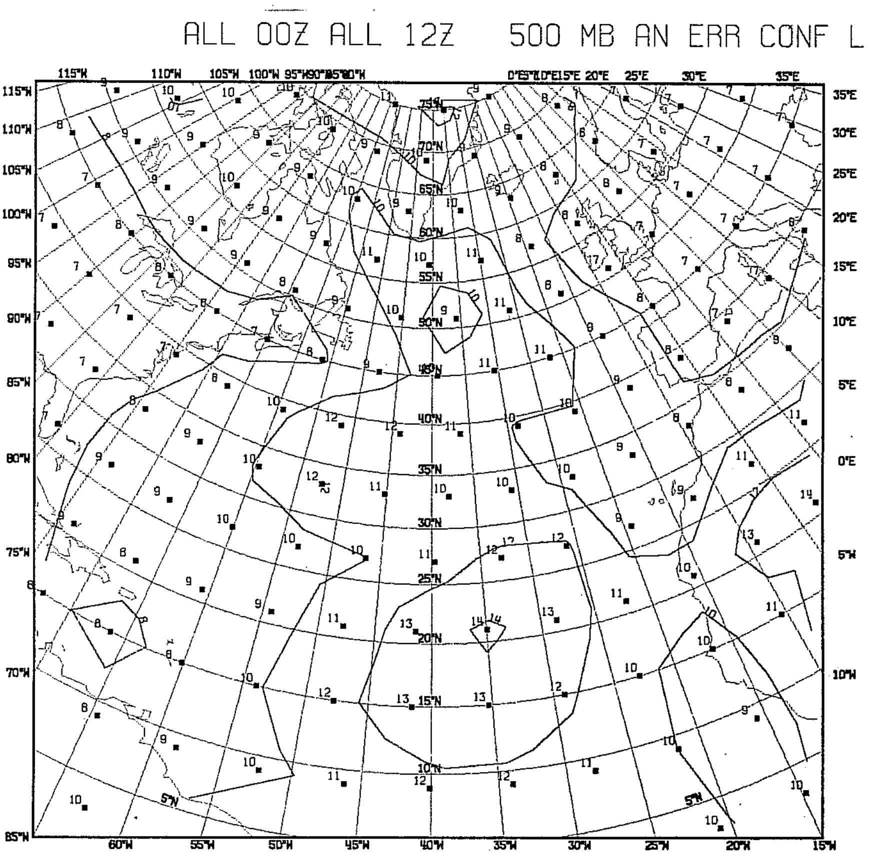


Fig. 14 As Fig. 6 but for configuration L.

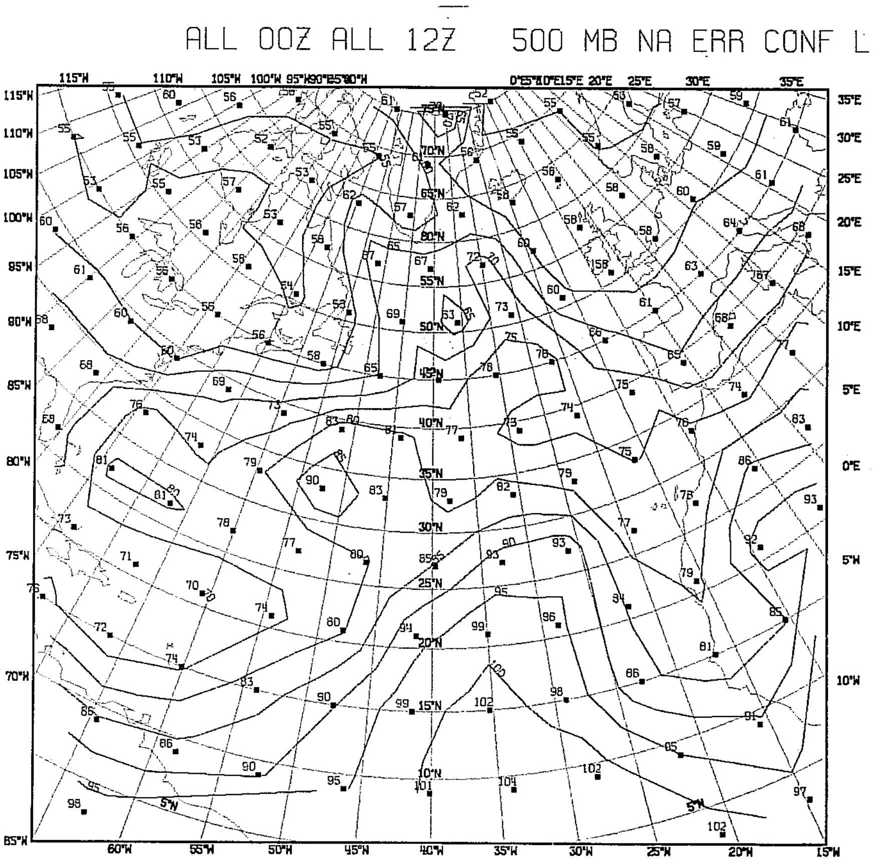


Fig. 15 As Fig. 7 but for configuration L.

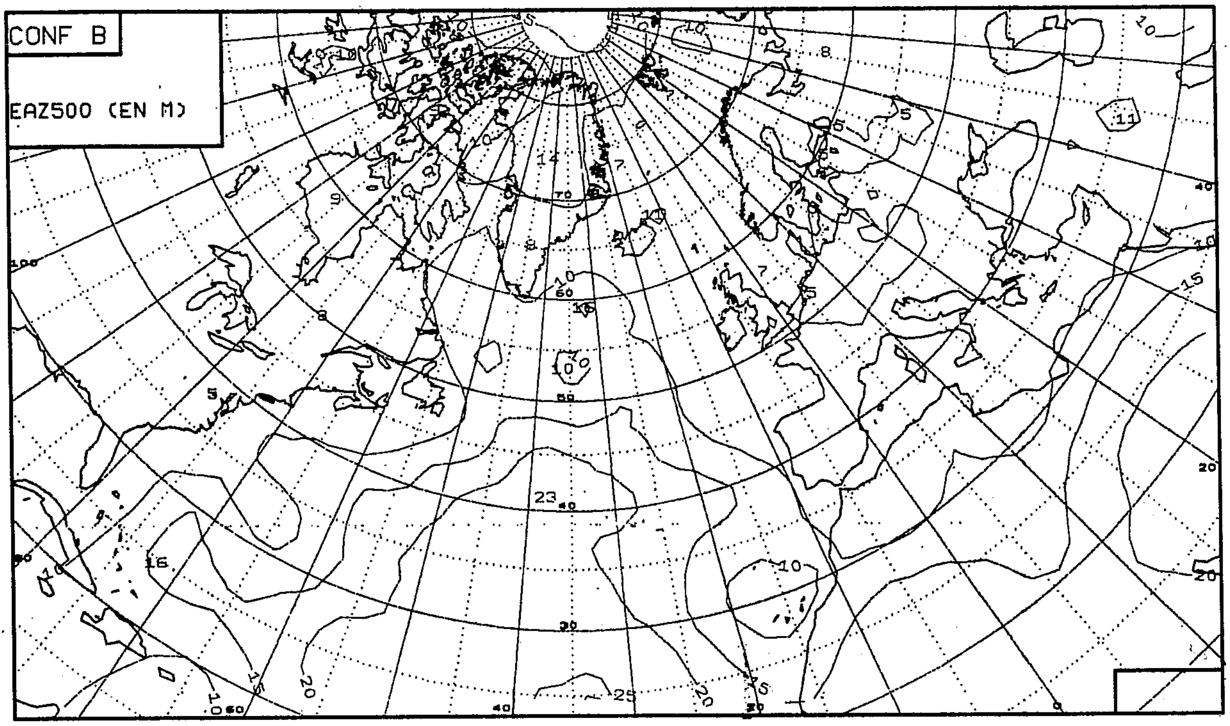


Fig. 16 Average of analysis error standard deviation E_{as} at 500 hPa for configuration B. Result of the French study (M.C. Pierrard).

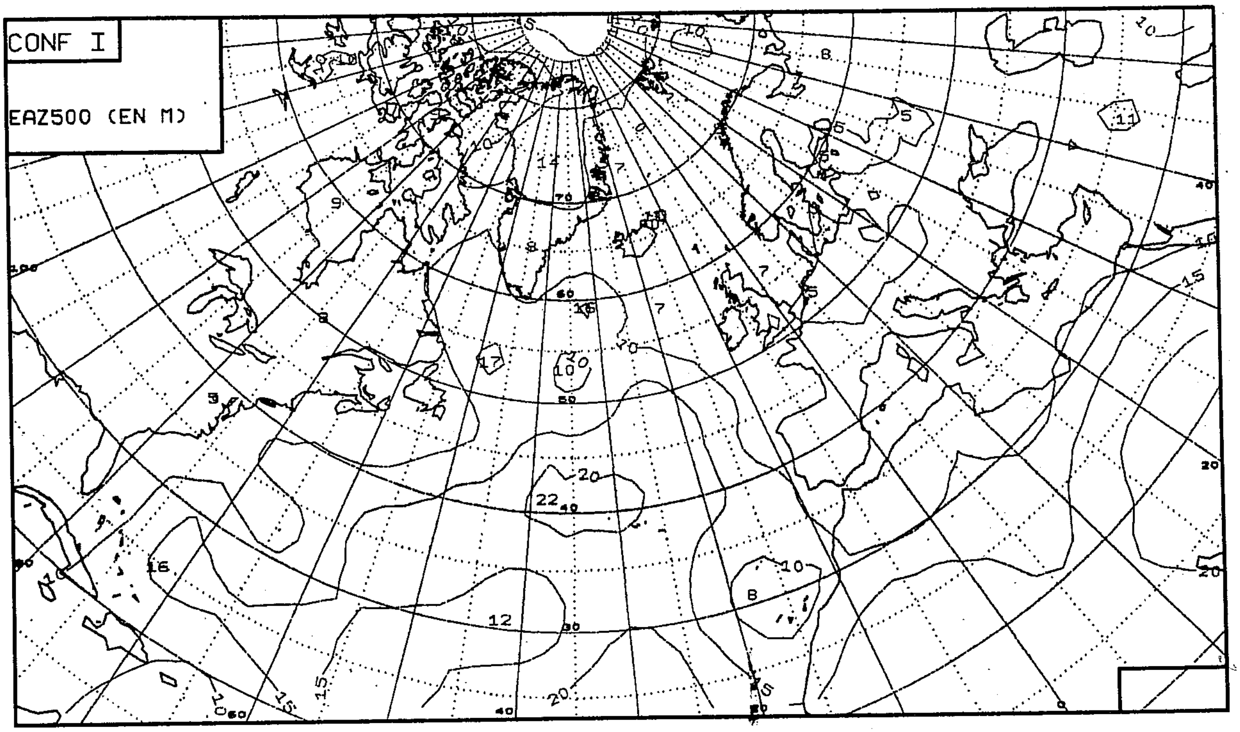


Fig. 17 Same as Fig. 16 for configuration I (French Study).

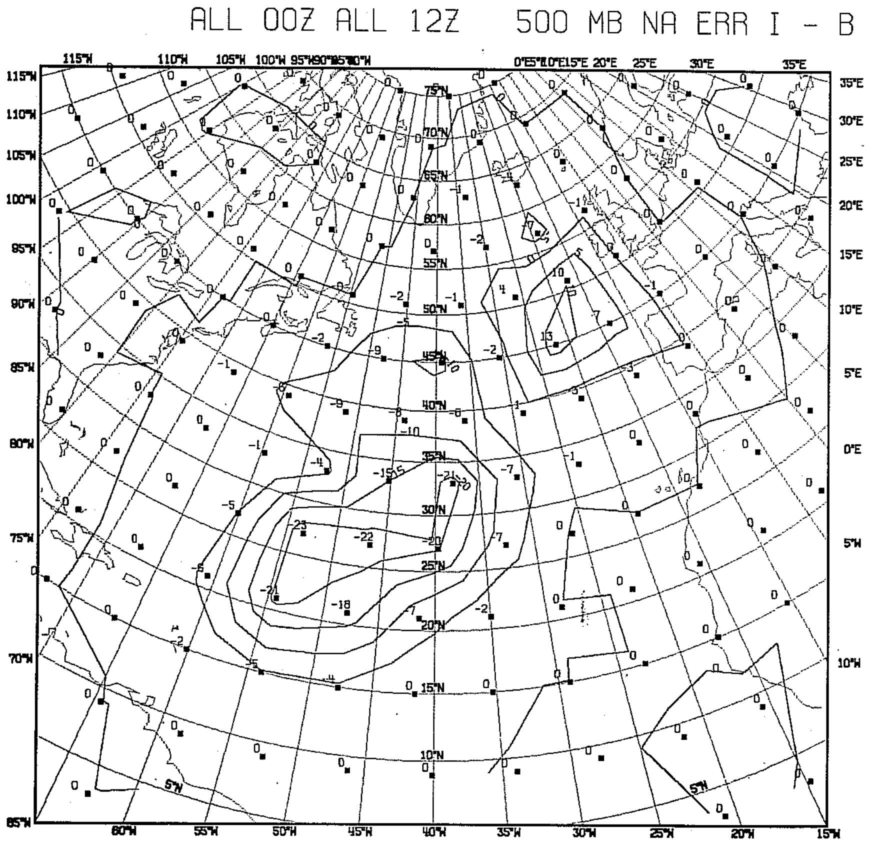


Fig. 18 500 hPa analysis error difference between two configurations (in decimeters).
Configuration I - Configuration B
Negative values means E_{as} lower in I than in B
Averaged field on the period (1 June 00Z, 4 June 00Z).

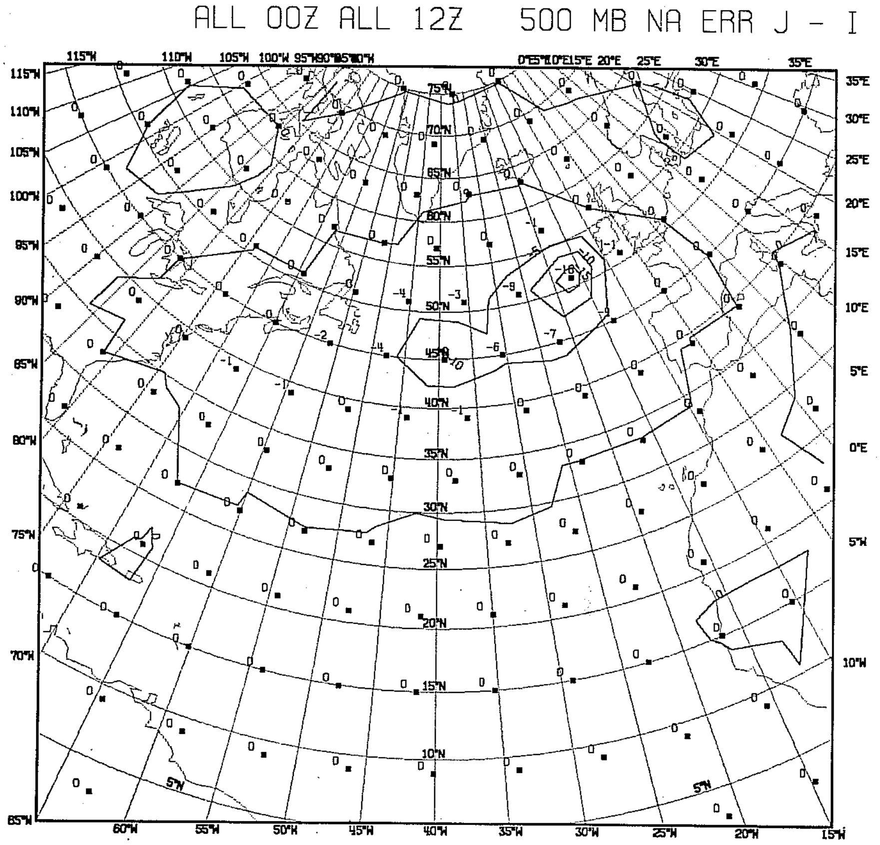


Fig. 19 Same for configuration J - configuration I.

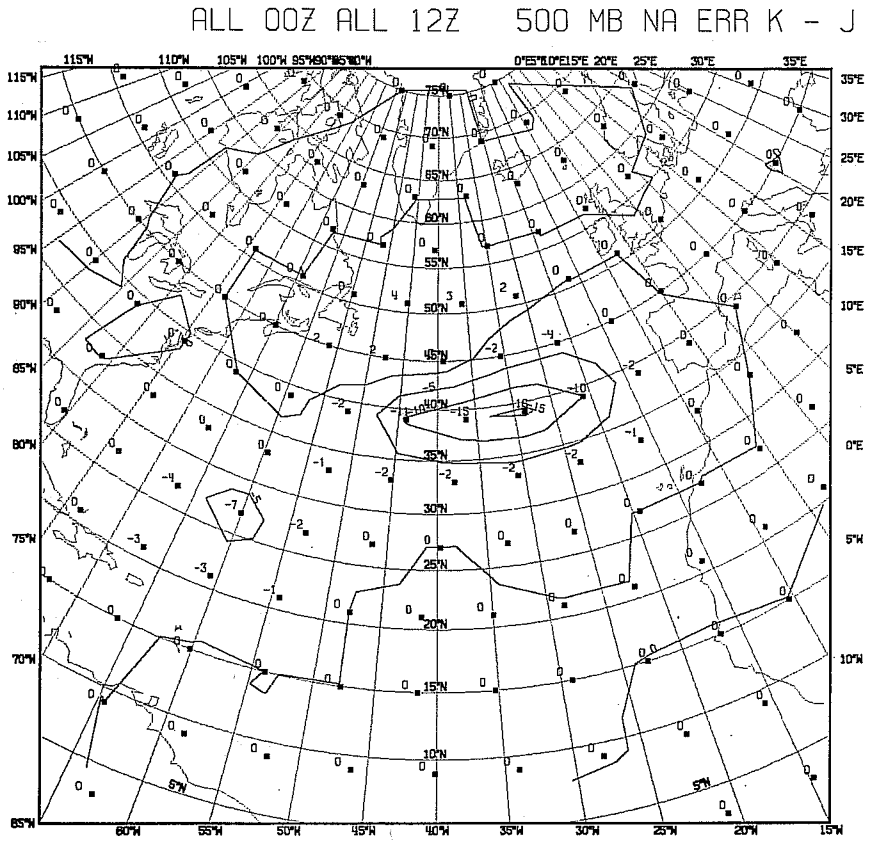


Fig. 20 Same for configuration K - configuration J.

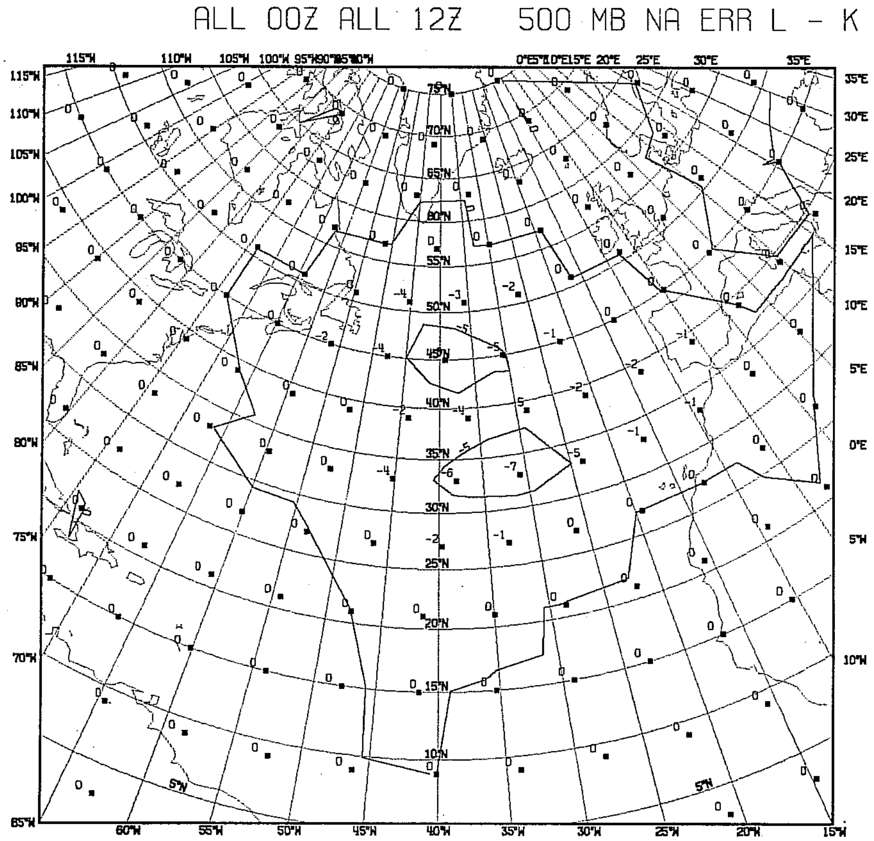


Fig. 21 Same for configuration L - configuration K.

and what part is due to the "1 slab/3 slab" problem in the ECMWF data assimilation system (see Section 3). The part due to the disappearance of weather ship R must be large as the ASAP ships which could have replaced it are in port, or are improving the analysis near West Indies. This is confirmed by the similar results coming out of the French study: they show a somewhat larger analysis error in I than in B in the same area (the French data-selection scheme does not have the 1 slab/3 slab problem) - see Figs. 16 and 17.

The 4 extra ASAPs which are in configuration J but not I reduce the analysis error in the north eastern area and remove completely the bad impact of the loss of weather ship R. It is striking that the improvement between J and K is larger, especially along the 40N parallel: and the cost of that improvement is very cheap: no extra ASAPs to deploy, just the decision to use (even to a small extent) routes like Gibraltar-Boston or Channel-West Indies. Going from K to L leads to another improvement, which means that even with 13 ASAPs well deployed the analysis error is still far from the analysis error of data dense areas.

The different improvements obtained by changing the configuration from B to I, from I to J, from J to K, and from K to L, are shown on Figs. 18 to 21: differences in decimetres between the time averaged analysis error of two configurations (negative values means reduction of the analysis error, that is improvement). Positive values in, let us say, I - B, means that I is worse than B; actually the only significant positive area (larger than 0.5m) is in the difference map I - B (dotted area near weather ship R).

6. SPACE AVERAGED ERRORS USED AS QUALITY SCORES

The analysis error fields have been averaged over the two Atlantic areas shown on Fig. 22: the choice of these areas is somewhat arbitrary. However region 1 is rather small, contains no land at all except the Azores, and is important for short-range forecasts; region 2 is much larger, includes some land and a part of the tropics.

For each 00Z and 12Z analysis from our experimental period, the analysis error (normalised and unnormalised) has been space-averaged over the two verification regions (again the mean values have been computed on the variances). This gives a day to day variability of the performance of the different configurations on seven main consecutive analyses. The scores are gathered in Tables 2 to 7 for the levels 200, 500 and 1000 hPa. The time evolution of these scores for the analysis error at 200 and 500 hPa for region 1 are also shown on Fig. 23. All these scores have to be considered keeping in mind the "1 slab/3 slab" problem, and looking at Table 1 giving the number of boxes analysed in 1 slab for each analysis.

From Fig. 23 and Tables 2 to 7, we get the following results:

- The overall impact of simulated ASAPs is small: the Eas difference between the two extreme configurations B and L is about 1m. This is due to the properties of the ECMWF data assimilation system which have been described in Section 3, and it should not matter too much as the interesting feature is not the amplitude of Eas, but the relative values of the different configurations.

- Putting the configurations in order from the best to the worst we get the expected order L, K, J, I, B, except that B is slightly better than J for

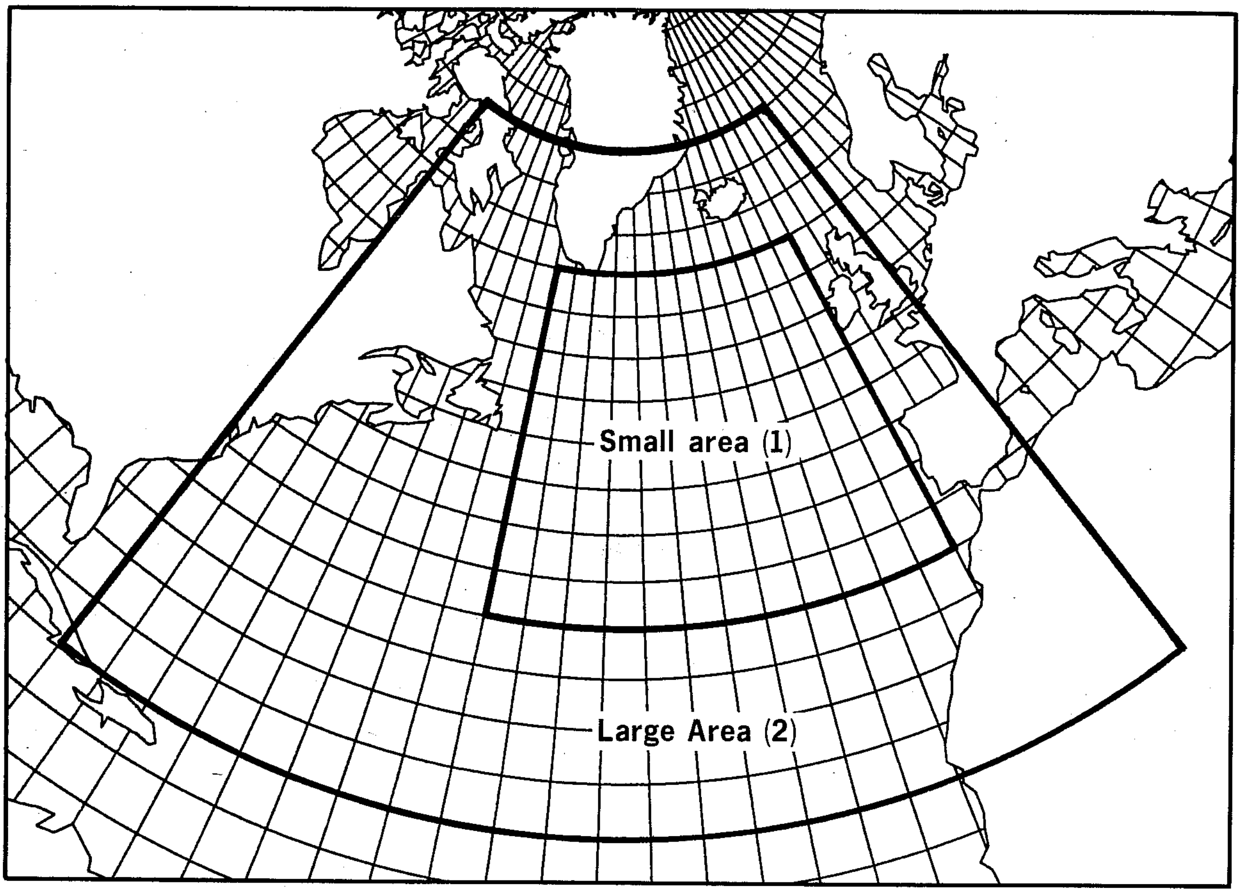


Fig. 22 Atlantic areas used to calculate the analysis of scores (E_{as} 500 hP geopotential height).

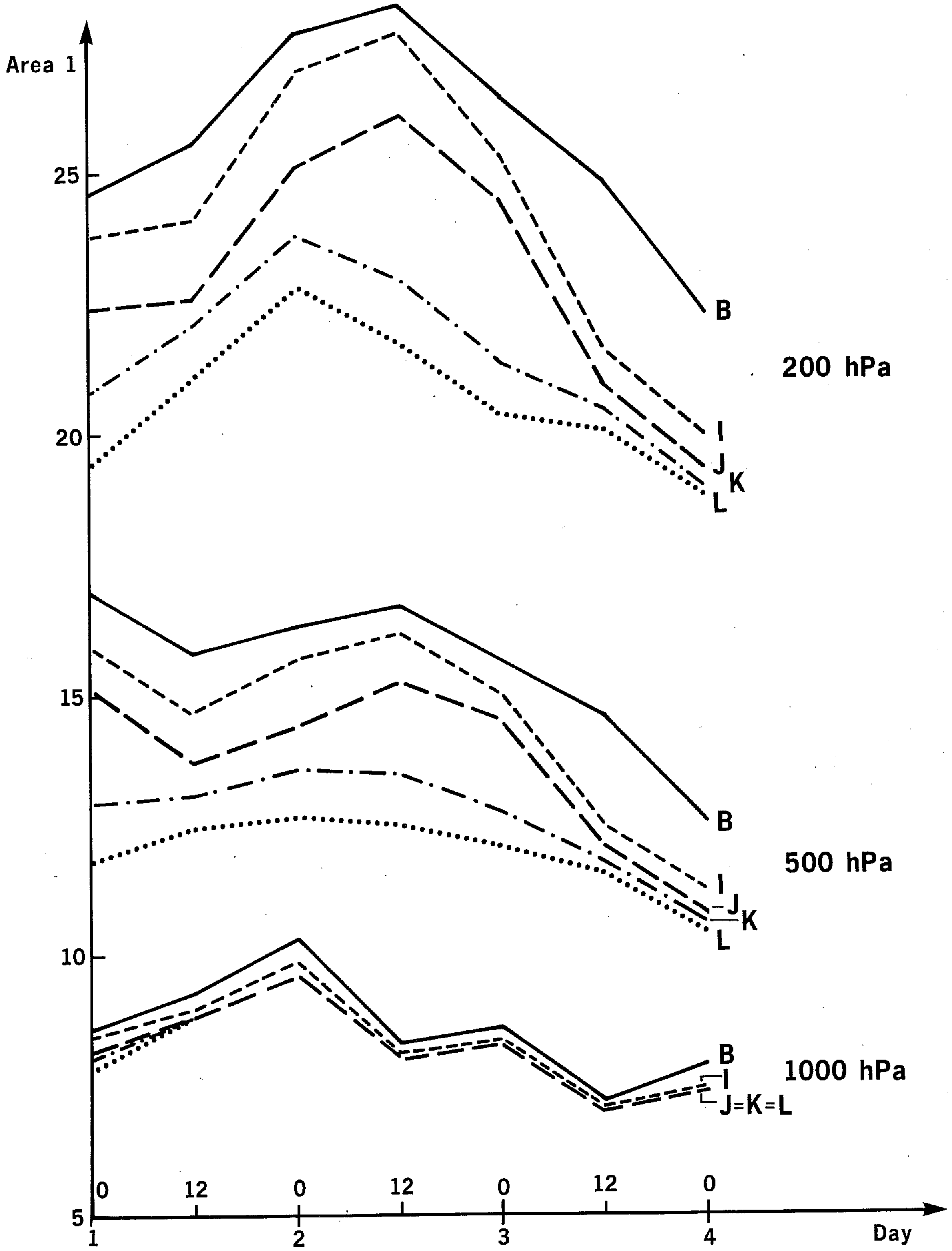


Fig. 24 Average of analysis error standard deviation E_{as} over area 1 at 1000, 500 and 200 hPa for 00 and 12Z analyses Result of the French study (M.C. Pierrard).

REGION 1 200 mb

(35N - 60N , 50W - 10W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	14.3	14.0	13.3	13.2	12.8
1 June 12Z	13.1	12.9	12.5	12.4	12.1
2 June 00Z	15.1	15.3	14.7	14.3	13.9
2 June 12Z	14.0	14.1	13.7	13.4	13.1
3 June 00Z	14.7	14.8	14.5	13.8	13.6
3 June 12Z	13.5	12.8	12.7	12.6	12.5
4 June 00Z	13.8	13.4	13.1	13.0	12.9

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	65	63	60	60	58
1 June 12Z	63	62	61	61	60
2 June 00Z	74	75	72	71	69
2 June 12Z	67	68	66	65	64
3 June 00Z	72	72	71	68	67
3 June 12Z	65	62	61	61	61
4 June 00Z	67	65	64	64	63

Table 2

REGION 1 500 mb

(35N - 60N , 50W - 10W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	11.1	10.9	10.4	10.2	9.8
1 June 12Z	10.5	10.4	9.9	9.8	9.5
2 June 00Z	11.7	11.8	11.2	11.0	10.6
2 June 12Z	11.1	11.2	10.9	10.5	10.2
3 June 00Z	11.6	11.7	11.4	10.8	10.7
3 June 12Z	10.8	10.2	10.0	10.0	9.9
4 June 00Z	10.4	10.0	9.8	9.7	9.6

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	73	72	68	67	65
1 June 12Z	73	72	70	69	68
2 June 00Z	83	84	81	79	76
2 June 12Z	77	78	76	73	72
3 June 00Z	82	82	81	77	76
3 June 12Z	75	71	70	70	70
4 June 00Z	73	71	69	69	69

Table 3

REGION 1 1000 mb

(35N - 60N , 50W - 10W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	7.6	7.5	7.4	7.4	7.4
1 June 12Z	7.1	7.1	7.0	7.0	7.0
2 June 00Z	7.6	7.5	7.5	7.5	7.4
2 June 12Z	7.2	7.1	7.1	7.1	7.1
3 June 00Z	7.5	7.4	7.4	7.4	7.4
3 June 12Z	7.0	7.0	7.0	7.0	7.0
4 June 00Z	7.7	7.4	7.4	7.4	7.4

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	64	64	63	63	63
1 June 12Z	64	64	64	64	65
2 June 00Z	70	70	69	70	70
2 June 12Z	64	64	64	64	65
3 June 00Z	68	68	68	68	69
3 June 12Z	63	63	63	64	64
4 June 00Z	70	68	68	68	68

Table 4

REGION 2 200 mb

(20N - 70N , 75W - 0W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	13.6	13.4	13.2	13.2	13.0
1 June 12Z	13.3	13.0	12.8	12.8	12.7
2 June 00Z	13.8	13.6	13.4	13.3	13.1
2 June 12Z	13.7	13.4	13.3	13.2	13.1
3 June 00Z	13.9	13.7	13.6	13.4	13.3
3 June 12Z	13.8	13.1	13.1	13.0	12.9
4 June 00Z	13.3	13.0	12.9	12.8	12.8

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	60	59	58	58	57
1 June 12Z	63	61	61	61	60
2 June 00Z	67	66	65	64	64
2 June 12Z	64	63	63	62	62
3 June 00Z	66	66	65	64	64
3 June 12Z	65	62	62	62	61
4 June 00Z	64	62	62	62	62

Table 5

REGION 2 500 mb

(20N - 70N , 75W - 0W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	10.4	10.2	10.1	10.0	9.8
1 June 12Z	10.0	9.7	9.6	9.5	9.4
2 June 00Z	10.5	10.2	10.1	10.0	9.8
2 June 12Z	10.3	10.1	10.0	9.9	9.8
3 June 00Z	10.6	10.4	10.3	10.1	10.0
3 June 12Z	10.3	9.8	9.8	9.7	9.7
4 June 00Z	10.0	9.7	9.7	9.6	9.6

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	69	68	67	66	65
1 June 12Z	70	69	68	68	67
2 June 00Z	76	74	73	73	72
2 June 12Z	72	71	70	70	69
3 June 00Z	76	75	74	73	72
3 June 12Z	72	70	69	69	69
4 June 00Z	72	70	70	69	69

Table 6

REGION 2 1000 mb

(20N - 70N , 75W - 0W)

Analysis Error Standard Deviation (metres)

	B	I	J	K	L
1 June 00Z	7.4	7.3	7.3	7.3	7.3
1 June 12Z	7.2	7.1	7.1	7.1	7.1
2 June 00Z	7.5	7.4	7.4	7.4	7.4
2 June 12Z	7.3	7.3	7.3	7.3	7.3
3 June 00Z	7.5	7.5	7.5	7.4	7.4
3 June 12Z	7.2	7.2	7.2	7.2	7.2
4 June 00Z	7.4	7.3	7.3	7.3	7.3

Normalised Analysis Error (%)

	B	I	J	K	L
1 June 00Z	62	61	61	61	61
1 June 12Z	64	64	64	64	64
2 June 00Z	68	68	68	68	68
2 June 12Z	65	65	65	65	65
3 June 00Z	68	68	68	68	68
3 June 12Z	64	64	64	64	64
4 June 00Z	67	67	67	67	67

Table 7

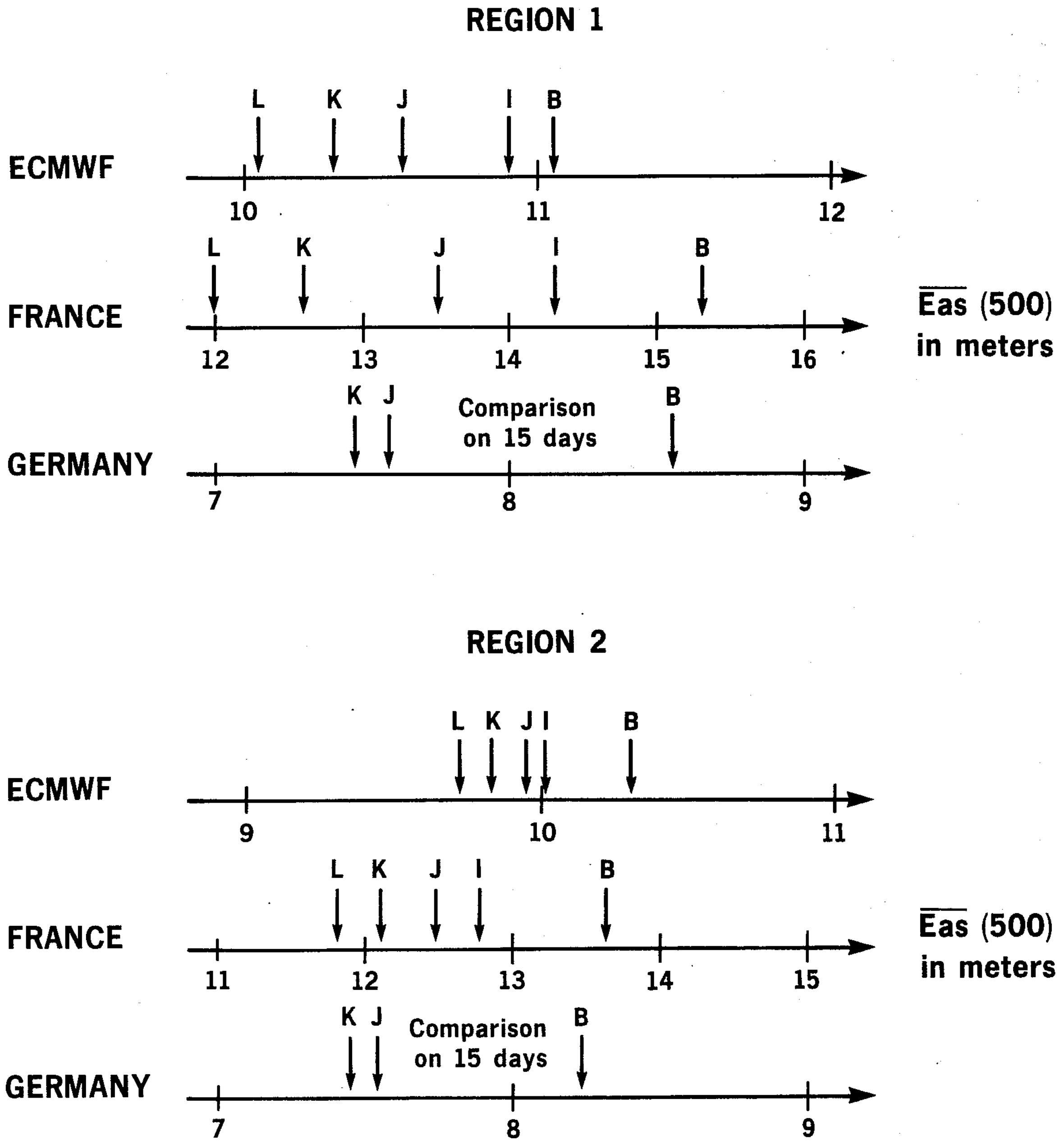


Fig. 25 Quality scores for configurations B,I,J,K and L obtained by averaging the 500 hPa analysis error in time, and in space on the two different regions of Fig. 22.
Results are given from the ECMWF, French and German studies. The time period used is:
(1 June 00Z - 4 June 00Z) for ECMWF
(1 June 12Z - 4 June 12Z) for France
15 days for Germany

analysis has been carried out without any satellite data (the TOVS are available in Reading but not in Paris). Again note the importance of satellite data.

- The French study has been initiated by a cold start on 1 June, 00Z, so this analysis time cannot be compared with the ECMWF results.

- I is always better than B in the French study, even if the quality of the two configurations is very similar from 2 June, 00Z to 3 June, 00Z. This gives an idea of the impact of the "1 slab/3 slab" problem in the ECMWF study.

In order to summarise the previous scores, Eas has been averaged both in space and time: in space on the two different areas mentioned before, in time on the seven main-hour analyses from 1 June 00Z to 4 June 00Z. These scores are given on Fig. 25 for the 500 hPa geopotential height (similar scores for other levels can be easily worked out from Tables 2 to 7).

The scores from the French and the German network studies are also shown to provide a direct comparison. The analysis error Eas is reduced by 10% to 15% (mean value over region 1), by going from the present configuration B to the "mean OWSE" configuration J, both in the French and German studies. The corresponding reduction is only 5% in the ECMWF system (we have already discussed the reasons why the amplitude of the signal is so small in the ECMWF system). Apart from this last point the results are consistent, and, when they are different due to the "1 slab/3 slab" problem, the relative performance of the different configurations as they appear in the French results is probably more reliable.

Finally the diagrams plotted on Fig. 25 are directly comparable to the results given in Pailleux (1984).

7. CONCLUSIONS AND RECOMMENDATIONS

The main conclusions are to be addressed to the WMO groups in charge of the OWSE-NA. However some interesting remarks can be made about the tool which has been used to carry out the network studies, i.e. the ECMWF data assimilation system.

7.1 Conclusions and recommendations related to the OWSE-NA

(a) Over the North Atlantic an ASAP system is available about 60% of the time. For the rest of the time the ships are in port or too close to the coast. This value is of course a mean value and depends on the shipping route.

(b) With 13 ASAPs and 2 weather ships (C and L, but R removed), the quality of the data coverage is almost stationary in time. This means that there is always a reasonable number of ships in the open ocean to make useful soundings. However there are still big gaps in the data coverage at the synoptic scale and the location of these gaps varying from one day to another.

(c) The study of the analysis error standard deviation Eas (as it comes out from an OI analysis program) shows a continuous improvement in the analysis when the number of ASAPs increases from 0 to 9, then to 13, and finally to 17. This indicates that even with 17 ASAPs we are far from the quality of data dense areas (Europe - North America), and there is still room to improve the analysis.

(d) An improvement which is as large (and sometimes even larger) is obtained in the network study between configurations J and K, two configurations with 13 ASAPs each, just by moving 2 ASAP ships to different routes. Therefore it is recommended that at least two or three ASAPs should be deployed on routes like Boston/Gibraltar or Channel/Jamaica. Putting more than 50% of the ASAPs on routes between the Channel and North America should be avoided. For 1988 the target should be a configuration not too far from K (rather than J), assuming that L is too optimistic and not realistic.

(e) The configuration I with 9 ASAPs, but no weather ship R, is obviously better than the present configuration B if we look at the whole North Atlantic (see Fig. 18). However, in the area of the present weather ship R, the analysis error Eas is still larger in configuration I than in B. It is only when we reach configuration J (with 13 ASAPs) that the disappearance of weather ship R is completely compensated, even locally.

(f) In the longer term (after the OWSE years), the weather ships C and L may disappear as well, which has not been taken into account in this study. Then the problem may become different: to put the ASAPs on routes where the latitude is as high as possible. We have to remember that the centre of the Atlantic, around 55N, is a very active meteorological area.

(g) The meteorological activity of the different regions has not been taken into account in this study, except to a small extent through the forecast error standard deviation used in the analysis system. But this forecast error field is too smooth to describe properly the areas of intense meteorological activities.

(h) In this study, it has been assumed that the soundings were made at 00 and 12Z by each ASAP system. There is still a large possibility of improving the analysis by making soundings at 06 and 18Z as well.

(i) The importance of satellite data has been demonstrated by comparing different situations, some with a good satellite data coverage, and some with a bad data coverage. The availability of satellite data is probably at least as crucial for the OWSE-NA than any decision related to the deployment of ASAPs or ASDARs.

7.2 Remarks on the ECMWF assimilation system

(a) The analysis and forecast error standard deviations (Eas and Eps), are smooth fields. This is obviously a good property for the analysis itself as the OI equations do not take into account the horizontal variations of the forecast errors. But it reduces the amplitude of the signal coming out of network studies.

(b) Eas is never very low because it is computed in such a way that it is always larger than a prescribed "minimum analysis error" (small scales, not optimal structure functions). It is never very large either, because Eps is generally small compared to other analysis systems.

(c) Following this last point, there are two reasons why Eps is generally smaller than in other systems. First the ECMWF 6h forecast is generally better. Then, in some other systems, Eps is increased artificially compared to the values resulting of statistical computations against observations, in order to tune the OI analysis on situations when the first guess is bad (the only important work of the analysis is to correct the 6h forecast when it is bad!).

(d) The "1 slab/3 slab" algorithm is a serious weakness for network studies. But the new analysis system which will become operational in 1986 will remove this difficulty, as the analysis will always be performed in 2 slabs.

(e) The field Eps which is set up at each analysis cycle should be dependant on the data used in previous cycles through Eas. But in reality Eps is not very sensitive to the addition of new data only.

(f) Because of properties (a) to (e) and also of the coarse grid used to represent Eas and Eps, the ECMWF analysis system is not very suitable for carrying out network studies on a limited area like the North Atlantic. The reason is obvious: this analysis system has been tuned to produce global analyses which are as good as possible, not to produce results for North Atlantic network studies. Moreover the way the experiments have been run (five independent global assimilation suites) is very expensive, even if it is cheaper than OSSEs. However, it is striking that several conclusions have been derived for the potential impact of ASAPs, conclusions which are more or less confirmed by other network studies made with other analysis systems.

ACKNOWLEDGEMENTS

The author is very grateful to Marie-Claire Pierrard (Paris) and to Andreas Kaestner (Offenbach) who performed similar studies allowing interesting comparisons of the results and of the analysis systems.

Marie-Claire Pierrard has also carried out all the handling of the ECMWF analysis archives in order to produce the simulated observation files (which have been used in both French and ECMWF studies).

All the error maps have been plotted using "JPP" (Johannes's Plotting Package); the author is very grateful to Johannes Andersen for this software.

REFERENCES

Baede, A.P.M., S. Uppala and P. Kållberg, 1985: Impact of aircraft wind data on ECMWF analyses and forecasts during the FGGE period, 8-17 November 1979. ECMWF Technical Report No 47.

Cats, G., 1984: On the use of the optimum interpolation estimate of the analysis error in the evaluation of observation system experiments. ECMWF internal paper (April 1984).

Kaestner, A., 1982: Observing System Simulation Experiment on drifting buoy system in the Atlantic. Proceedings of the JSC study conference on Observing System Experiments - Exeter, 19-22 April 1982. - GARP report N4, November 1982.

Lönnberg, P., and D. Shaw, 1984: ECMWF data assimilation - scientific documentation. ECMWF Research Manual 1 (Met Bulletin M1.5/11).

Lönnberg, P., and D. Shaw, 1984: Data selection and quality control in the ECMWF analysis system. ECMWF Workshop on Use and Quality Control of Meteorological Observations, 6-9 November 1984, ECMWF, Reading, U.K., 225-254.

Lorenc, A.C., 1981: A global three-dimensional multivariate statistical interpolation scheme. Mon.Wea.Rev., <u>109</u>, 701 -721.

Pailleux, J., 1984: Testing the North Atlantic observing network using different analysis schemes. ECMWF Seminar on Data Assimilation Systems and Observing System Experiments with Particular Emphasis on FGGE, 3-7 September 1984, ECMWF, Reading, U.K., 327-344.

Pailleux, J., and M.C. Pierrard, 1985: North Atlantic OWSE - Network studies needed for the preparation of the experiment. Working paper of the SEG.

Rinne, J., and S. Jarvenoja, 1984: Random analysis error of 500 mb height analysis for the FGGE year. Mon.Wea.Rev., <u>112</u>, 1389-1397.