TECHNICAL MEMORANDUM

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The impact of North Atlantic tempship radiosonde data on the ECMWF analysis and forecast

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Abstract

Around 1984, a practical exercise was set up by the World Meteorological Organisation (WMO), in order to study, design, implement and evaluate a network of in-situ observations over the North-Atlantic. This exercise is called OWSE-NA: Operational WWW System Evaluation for the North Atlantic. It took into account the existing observing systems to start with, such as Oceanic Weather Ships (OWS), satellite and aircraft observations. The major component of the OWSE-NA was the deployment of some radiosonde systems on board several mobile ships. These systems are called ASAPs: Automated Shipborne Aerological Program.

1987 and 1988 were the two years of intensive evaluation within the OWSE-NA: ASAP systems were deployed and monitored by several meteorological centres (with feedback to the instrument providers). Some impact studies were carried out. The results obtained from monitoring and numerical experiments in 1987 and 1988 are reported in the Scientific Evaluation Group report on OWSE-NA (1989).

The purpose of the present paper is to report more recent Observing System Experiments (OSEs) performed in the period (September 1989 - January 1990), in order to test the impact of the North Atlantic radiosonde network on the ECMWF analysis and forecast. Similar experiments have been carried out in at least two other centres, the UK Met Office in Bracknell and the Deutscher Wetterdienst (DWD) in Offenbach, with strong coordination between the three centres.

1. INTRODUCTION

Some important changes have occurred since 1985 in the North Atlantic observing network: one weather ship (the French one in fixed position "R") has been removed; some merchant ships are now making soundings (Automated Shipborne Aerological Program - ASAP); some buoys have been deployed. Inside the World Meteorological Organization (WMO), these changes have been coordinated through the project called "Operational WWW System Evaluation for North Atlantic" (OWSE-NA).

During the planning phase of the project (1984-86), some network studies were performed in order to help plan the deployment of the new observing systems. The network studies were addressing mainly the question of the shipping routes to choose for deploying ASAPs, and the air routes to choose for deploying automatic aircraft measurements on planes (called ASDAR). They were performed by ECMWF, DMN (French Weather Service in Paris) and DWD (German Weather Service in Offenbach) and are summarized in the SEG report (1989). More details about the network studies performed with the ECMWF operational analysis are given in Pailleux (1986). As the ASDAR project failed, no ASDAR system was actually deployed over North Atlantic, and the new upper air observations were reduced to ASAPs.

During the period 1986-88, several ASAPs were deployed. They were monitored in different centres, and especially at ECMWF where a monthly report, dedicated to the OWSE-NA, was produced by the Meteorological Operations Section. Feedback of the monitoring results to those in charge of the ASAP deployment and of the instruments led progressively to improvement in the availability and the quality of the ASAP soundings. Some parallel data assimilations and forecasts were also run in 1987-88 to evaluate the impact of the new North Atlantic observations and to compare it to the impact of other important observations such as satellite data. These impact studies demonstrated some positive impact of the new North Atlantic observations, but the signal was very weak partly because both the availability and the quality of the new ASAPs were below expectation. The 1987-88 impact studies are also summarized in the SEG report (1989). At ECMWF, the main parallel assimilation (without the new North Atlantic systems) was performed on the period 10-20 March 1988 with ten experimental forecasts to be compared to operational forecasts. Eight forecast experiments were completely neutral in terms of impact; one of them showed a small positive impact of North Atlantic systems; another one showed a small negative signal which was traced back to some biased TEMP SHIPs (soundings made from a ship).

At the beginning of 1989 (end of the official evaluation period of the OWSE-NA), it was clear that further improvements of the North Atlantic radiosonde network were possible. Some improvements did occur in 1989, and a new detailed investigation of the North Atlantic ASAP availability and quality was performed in Autumn 1989 (Strauss, pers. comm., and Graham, pers. comm.). A status report on the North Atlantic radiosonde network, as it was at the end of 1989, is available (Pailleux, 1990). One important conclusion of this status report is that "since summer 1989, the ASAP system has reached a normal reliability". This is the main incentive for running other impact studies on recent periods (after Summer 89) which may show more conclusive results than the ones run in 1987-88 when the ASAP deployment was not finished.

Section 2 summarizes the evolution of the North Atlantic observing network during the last few years and the situation as it is at the end of 1989 and the beginning of 1990. The rest of this paper is dedicated to impact studies performed on the North Atlantic TEMP SHIP observations. The principle of these studies is described in section 3. The longest study covers a one-week period from 9 to 15 September 1989, chosen at random desregarding the meteorological situation (section 4). The same impact study has been performed on two specific cases already selected and studied at the UK Met Office, Graham and Hall (pers. comm.): the first one is the sudden deepening of a low over Ireland and UK on 27-28 October 1989 (section 5); the second one is a severe storm which hit the South of England on 25 January 1990 (section 6).

2. EVOLUTION OF THE NORTH ATLANTIC NETWORK UNTIL THE END OF 1989

The important aspect of the evolution of the observing network is related to deployment of ASAPs, to Oceanic Weather Ships (OWS) and other mobile ships making soundings: all of them are transmitting soundings coded in TEMP SHIP code. At the beginning of 1986, the French stopped operating the weather ship "R" and deployed ASAP systems on four merchant ships on routes between France and Martinique: the four call signs of the ships are FNOR, FNOU, FNPH and FNRS. A Finnish ASAP was also deployed on a British ship (VSBV3) between the Channel and Saint-Lawrence at the same time. The other ASAP systems were deployed progressively between 1986 and 1989. They are British, German or Danish. Some German ships are research vessels which may stay in the open ocean for several weeks (good data coverage) before staying in port, also for a long period, without reporting. Also there are several mobile ships, making TEMP SHIPs over North Atlantic outside the OWSE-NA program, most of them being Russian; the routine monitoring showed that both their availability and their quality are irregular.

There was a continuous improvement of the radiosonde network over North Atlantic between 1985 and 1989, due to a large variety of practical things, such as:

- more ASAPs being deployed;
- telecommunication problems being monitored and solved: (e.g. difficulties with the transmission through METEOSAT; mistakes in the call sign);
- improvement of the observation practices (e.g. at the beginning, many ASAPs were hit by geopotential height bias due to inappropriate barometer used for ground references);
- improvement of the observation practices also on some island stations, the best example being Bermuda (report in the SEG report - 1989).

At the end of 1989, there are 12 to 14 ASAPs operating in the North Atlantic, contributing to the equivalent of more than "4 radiosonde stations full time" (full time meaning one station making two soundings per day: 0000 UTC and 1200 UTC). This means that on average each ASAP system is operational between 30 or 40% of the time, the rest of the time the ship is in port, or the report does not reach the GTS in time. This ASAP network, together with the three weather ships (C, L and M), and also with some other ships making soundings outside the ASAP program, produces a radiosonde data coverage over North Atlantic which is much better than it used to be before the OWSE-NA. More details about the availability and the quality of each system can be found in Pailleux (1990). Concerning the aircraft reports, very little has changed during the OWSE-NA because of the failure of the ASDAR program. The

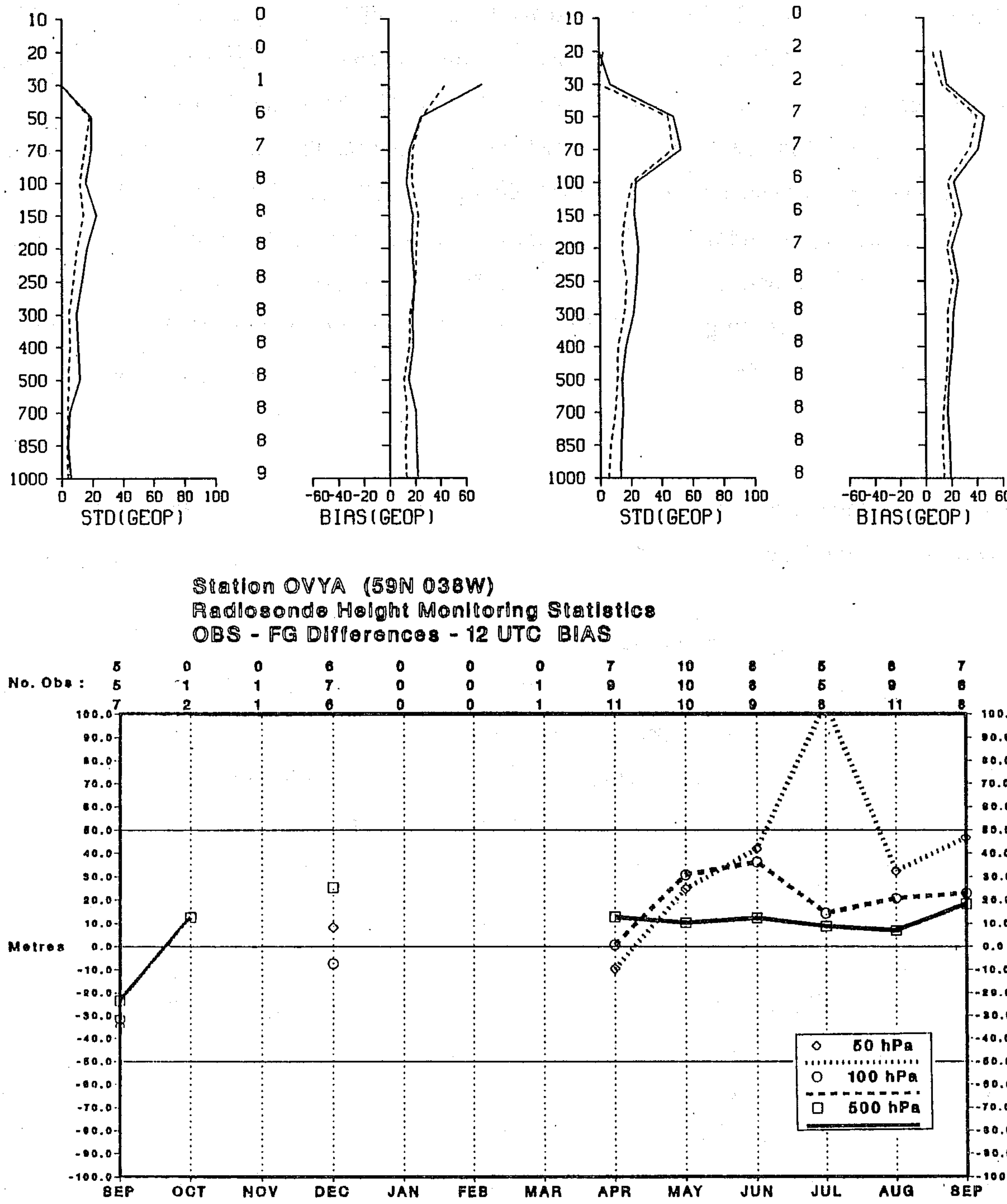


Fig. 1 Example of radiosonde monitoring statistics for ASAP ship OVYA. Top: September 1989 statistics showing the standard deviation and the mean of the departures "observation minus guess", for the geopotential height in metres, at all standard levels. The two left diagrams are for 0000 UTC, the two right diagrams for 1200 UTC. Note the positive bias (about 20 m) almost constant on the vertical. Bottom: Evolution of the monthly mean differences "observations minus guess" for the geopotential height at three difference levels (500, 100 and 50 hPa), on the period (September 88 - September 89). Note that the regular availability is only for the period April to September 89.

buoy network has been significantly improved over the North Atlantic, especially near Greenland and Iceland, and to the North West of the Azores.

Fig. 1 is an example of standard monitoring material (as produced at ECMWF by the Meteorological Operations Section) investigating the performance of the Danish ASAP OVYA in September 1989. The height observation is compared to the ECMWF first guess (6 h forecast) at each standard level; the average and the standard deviation of the differences are computed for the reports of September 1989, and plotted. The bias diagrams of the top part show a bias of +20 m in the monthly mean "observation-guess" which starts at the bottom, and is constant up to 100 hPa. Apart from this bias problem, OVYA looks good. The bottom part of Fig. 1 shows that OVYA started reporting regularly in April 1989. This bias is the typical "youth mistake" mentioned before (wrong reference pressure) which hit several ASAP systems, and it is not surprising to find it in September 1989 on the 5 month old ASAP OVYA. More recent discussions seem to indicate that this particular problem has been solved, and this is confirmed by ECMWF monitoring results obtained in Spring 1990 (Strauss and Radford, pers. comm.). The example of OVYA is an illustration of the standard process "deployment - monitoring - feedback - correction", which appears to be useful in many cases.

3. PRINCIPLE OF THE IMPACT STUDIES FOR NORTH ATLANTIC TEMP SHIPs

The impact of some North Atlantic radiosondes on analyses and forecasts has been studied in the past by several groups, generally using operational Numerical Weather Prediction (NWP) models. Some experiments carried out at the beginning of the eighties are reported in Gilchrist (1982). The impact found by several groups in the past was occasional and limited to some particular synoptic features. It was almost impossible to demonstrate any impact on the large scales, presumably because the area where the radiosonde observations were removed was too small, possibly also because of intrinsic limitations of some limited area models which were used in these Observing System Experiments (OSEs).

For the experiments reported in the present paper, the operational ECMWF system has been used in the state it was on the different periods we investigated. So, the September 89 system has been used for studying the September period, the October 89 system to study the October period, the January 90 system to study the January period. Actually only one operational change was made in the ECMWF analysis between September 89 and January 90 (it concerns the quality control of cloud winds and was made in November), and no change was made in the forecast model. The operational analyses and forecasts have been used as main control; the operational analysis has also been used as verification analysis throughout the impact studies.

The model is a global spectral model with 19 levels in the vertical and a T106 horizontal resolution. The analysis is a 3D multivariate Optimum Interpolation (OI) using all data types, including TOVS, cloud winds and aircraft reports which are the main other sources of upper-air information, in addition to the radiosondes (see Lorenc, 1981).

The impact studies were all performed by carrying out an assimilation which is parallel to the operational one, in which all the TEMP SHIP reports have been removed over the area (20°N-70°N, 80°W-10°E). So we are looking at the impact of all the TEMP SHIPs: OWSs, ASAPs and other TEMP SHIPs. The land radiosonde observations such as the stations from the Azores, Greenland and Bermuda have been kept in the parallel assimilation, as well as the surface observations from all the ships and the buoys. For the parallel assimilation (called "No North Atlantic TEMP SHIP"), 6-day forecasts have been run from 1200 UTC almost every day, and compared to the operational forecasts. The results have been evaluated by comparing the analysis and forecast maps, plotting difference maps between the two parallel runs, and producing the Northern Hemisphere scores for all the forecasts.

4. STUDY OF THE PERIOD 9-15 SEPTEMBER 1989

4.1 Description of the situation

A data assimilation has been run for the period (9 September 0000 UTC - 15 September 1200 UTC) without North Atlantic TEMP SHIPs (see section 3 for details), and compared to the operational assimilation. Six 6 day forecasts have been run from the "No North Atlantic TEMP SHIPs" assimilation, starting every day from the 1200 UTC analysis, 10 to 15 September. These forecasts have then been compared to the corresponding operational forecasts.

This one week period was not chosen because of the meteorological situation. Two other reasons led to this choice:

(i) There was a "No SATEM" experiment already available at ECMWF, starting on 9 September, 0000 UTC (Illari, 1990). So it was a good opportunity to compare the impact of North Atlantic radiosondes with the impact of SATEMs (or TOVS) which are another major component of the North Atlantic observing system.

(ii) The detailed monitoring (see section 2) showed that both the availability and the quality of the observations submitted to the impact study were good in this particular period.

Regarding the meteorological situation, this period can be considered as chosen at random. At the beginning of the period, the eastern part of the Atlantic and the western part of Europe was affected by a ridge, and the dying cyclone "GABRIELLE" was stationary near the American coast. On the 13th, GABRIELLE was caught in the midlatitude western flow near Newfoundland, and crossed the Atlantic in two days. Reactivated twice by polar air coming from North Canada, then from Greenland, it deepens quickly leading to about 970 hPa at the centre of the low to the North West of Ireland (the place where there was a strong anticyclone on the 9th).

One typical radiosonde data coverage for this period is presented in Fig. 2. The TEMP SHIPs removed from the experimental assimilation are marked by a square for OWSs and by a circle for the mobile ships (ASAPs or non ASAPs). In this particular case there are nine radiosonde observations less in the experimental analysis than in the operational analysis. Table 1 gives the complete list of TEMP SHIPs which are discarded from the experimental analysis from 0000 UTC on the 12th to 0000 UTC on the 13th, together with their geographical positions. At 0600 UTC and 1800 UTC, the OWSs L and M are normally the only TEMP SHIPs reporting over the Atlantic area. At 00 and 12 UTC it is about 10 TEMP SHIPs reporting in the area. Note that some observations (marked with a "*" in Table 1) are duplicated in the observation file presented to the analysis. This duplication problem appeared 11 times in the

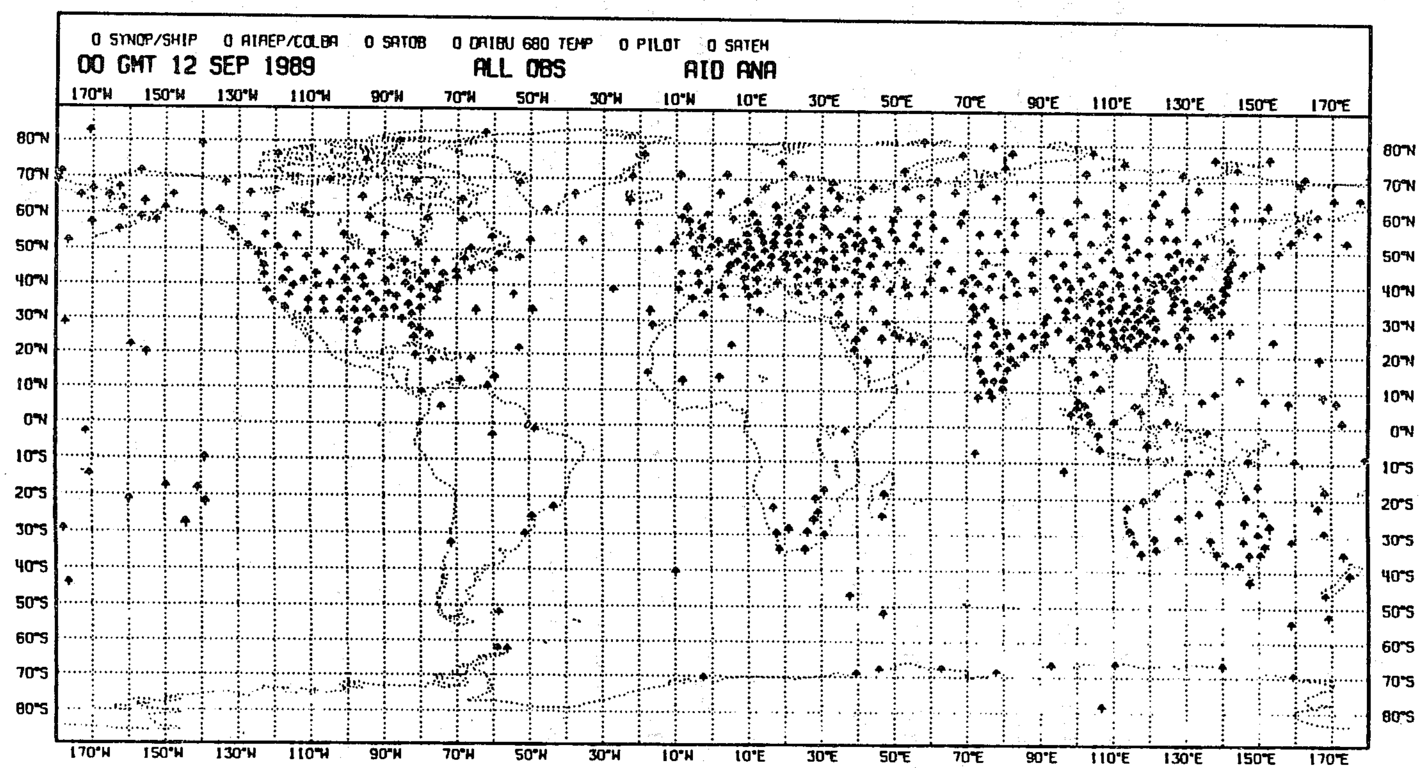


Fig. 2 Global data coverage map for radiosonde observations on 12 September 1989, 0000 UTC. In the North Atlantic area, the Ocean Weather Ships are indicated by a square and the mobile SHIPs by a circle.

12/9/89 00Z			
LATITUDE / LONGITUDE	66.00	2.20	
LATITUDE / LONGITUDE	59.20	-8.30	
LATITUDE / LONGITUDE	57.40	-20.10	
LATITUDE / LONGITUDE	52.60	-49.90	
LATITUDE / LONGITUDE	52.70	-35.50	
LATITUDE / LONGITUDE	50.00	-14.50	
LATITUDE / LONGITUDE	37.10	-54.40	
LATITUDE / LONGITUDE	32.60	-49.20	
LATITUDE / LONGITUDE	21.50	-52.80	
12/9/89 06Z			
LATITUDE / LONGITUDE	66.10	2.30	
LATITUDE / LONGITUDE	57.10	-20.20	
12/9/89 12Z			
LATITUDE / LONGITUDE	66.00	2.10	
LATITUDE / LONGITUDE	60.40	2.00	*
LATITUDE / LONGITUDE	60.40	2.00	*
LATITUDE / LONGITUDE	59.30	-2.10	
LATITUDE / LONGITUDE	58.30	2.30	
LATITUDE / LONGITUDE	57.00	-20.30	
LATITUDE / LONGITUDE	53.60	2.80	*
LATITUDE / LONGITUDE	53.60	2.80	*
LATITUDE / LONGITUDE	53.20	-44.20	
LATITUDE / LONGITUDE	52.70	-35.50	
LATITUDE / LONGITUDE	50.00	-19.00	
LATITUDE / LONGITUDE	38.10	-50.80	
LATITUDE / LONGITUDE	35.30	-46.80	
LATITUDE / LONGITUDE	31.00	-41.00	
12/9/89 18Z			
LATITUDE / LONGITUDE	66.00	2.00	
LATITUDE / LONGITUDE	57.10	-20.10	
13/9/89 00Z			
LATITUDE / LONGITUDE	66.10	2.10	
LATITUDE / LONGITUDE	58.30	3.00	
LATITUDE / LONGITUDE	57.10	-19.90	
LATITUDE / LONGITUDE	53.50	-37.60	
LATITUDE / LONGITUDE	52.70	-35.50	
LATITUDE / LONGITUDE	49.70	-23.00	
LATITUDE / LONGITUDE	39.20	-46.80	
LATITUDE / LONGITUDE	37.50	-43.20	

Table 1 Geographical positions of all the North Atlantic TEMP SHIPs from 12 September 0000 UTC to 13 September 0000 UTC, in 1989. They are the ones which have been removed from the assimilation in the impact study. The TEMP SHIPs marked "*" have been duplicated because of a call sign problem.

experimental period (9-15 September). It was traced back to some TEMP SHIPs received twice from the GTS, one of them having a corrupted call sign or no call sign at all (Silvester, pers. comm.). In this case the decoding is not able to detect that it is a genuine duplicate, and the same radiosonde observation is then presented twice to the analysis which assumes they are independent observations, and gives then an excessive weighting factor to the duplicated observation. This problem was detected for the first time when running this impact study, a specific test has been implemented in the operational analysis to treat it, but only in April 1990. However, it is believed that this occasional excessive weighting in the OI analysis does not affect significantly the results of the impact study for this particular period. In order to make the task of the data processing centres easier, it is recommended to all those making or transmitting OWSE-NA observations that they make sure the messages are transmitted with the full and correct call sign.

4.2 Impact of the North Atlantic TEMP SHIPs on the analysis

Fig. 3 shows a sequence of initialized analysis difference maps "No North Atlantic TEMP-SHIP - Operations" for 500 hPa geopotential height for a 24 h period starting on 12 September 0000 UTC. Outside the North Atlantic area the differences are reduced to a noisy signal which is the indirect impact of North Atlantic TEMP SHIPs through spectral fit, normal mode initialization and different first guesses. The order of magnitude of this noise is 1 m for the 500 hPa geopotential height. On the North Atlantic area the order of magnitude of the differences is 10 m. A maximum of +26 m is noted at the position of ship L on 12 September 0000 UTC: this is actually the maximum difference at 500 hPa between the two analysis sets on the total period 9-15 September.

The synoptic features which are analysed differently with and without TEMP SHIPs are very rare. However, in Fig. 4, we can see a small but significant difference on the analysis of cyclone GABRIELLE in the middle of the Atlantic, on 14 September 1200 UTC. The position of the low is the same in the operational and the "No North Atlantic TEMP SHIP" analyses. However, the operational analysis is 2 hPa deeper with a stronger pressure gradient to the South of GABRIELLE. The 850 hPa temperature field shows also a slightly more intense development of the cyclogenesis as the warm advection to the South-East of the low is a little more pronounced. (Check for example the position of isotherm +14°C). Although no absolute truth is available to tell exactly which analysis is better, a subjective evaluation of the cyclogenesis seems to indicate that in reality the low is more pronounced than in both analyses presented in Fig. 4: the operational analysis is then likely to be better, showing a small positive impact of the North Atlantic TEMP SHIPs on the development of GABRIELLE.

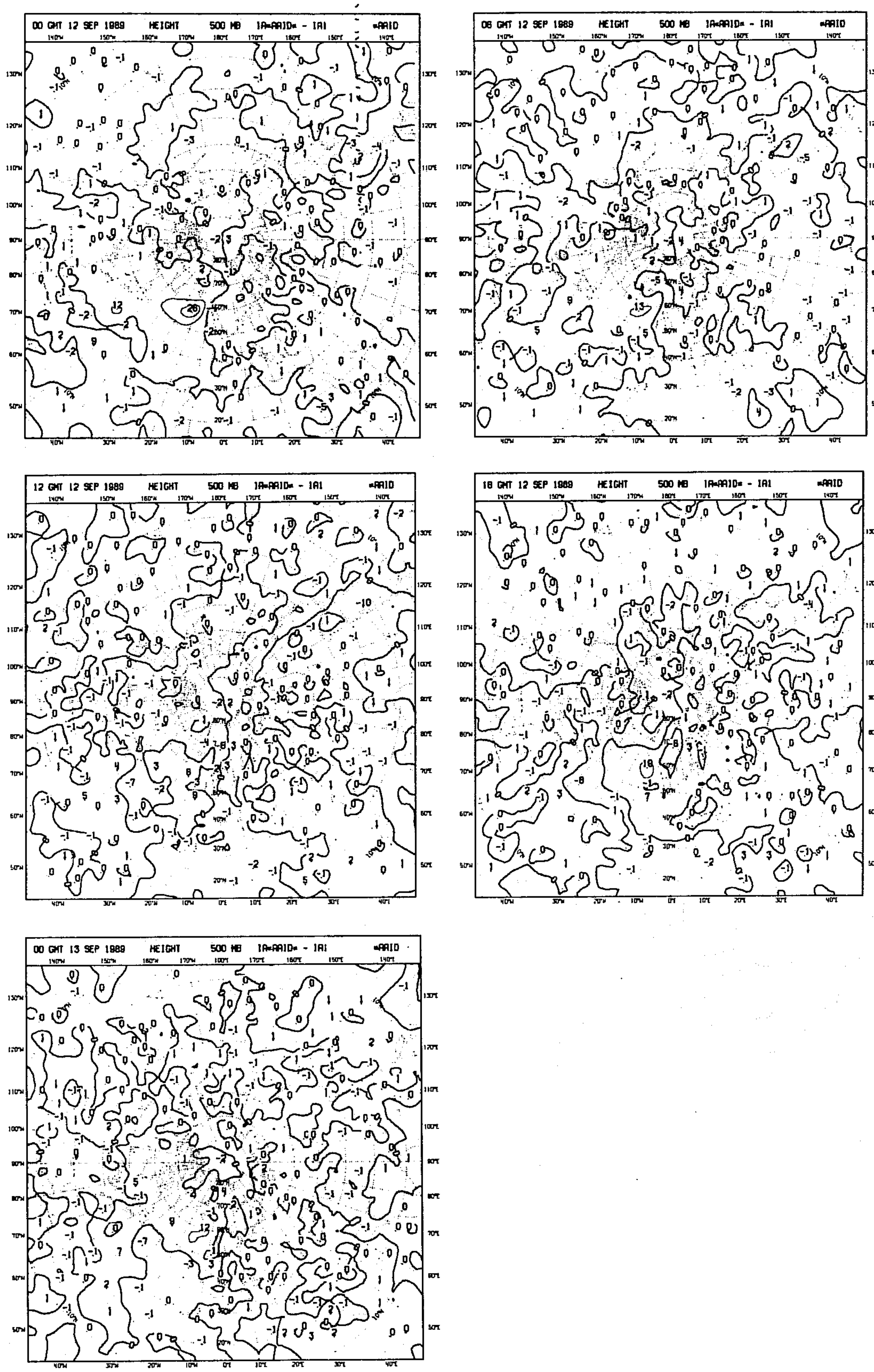


Fig. 3 **500 hPa geopotential height analysis difference maps between "No North Atlantic TEMP-SHIP" and operational assimilations from 12 September 0000 UTC to 13 September 0000 UTC, in 1989. Left column is for 00 and 1200 UTC. Right column for 0600 and 1800 UTC. Contour interval: 10 m. Extremes plotted in metres. Outside the Atlantic area the differences are due to spectral fit, normal mode initialisation and different first guess.**

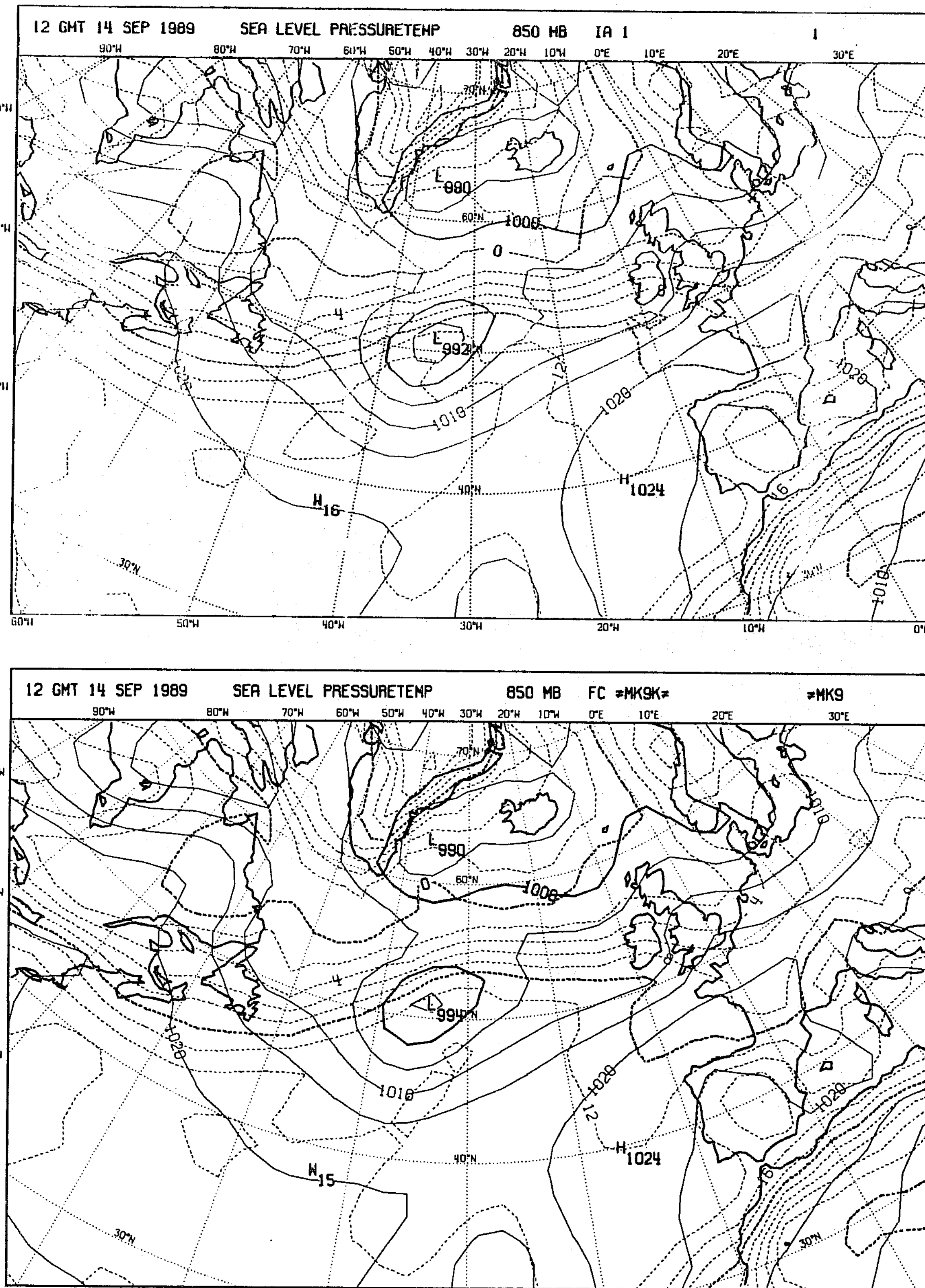


Fig. 4 Mean sea level pressure and 850 hPa temperature analysis maps for 14 September 1989, 1200 UTC. Top: Operational analysis; bottom: "No Temp-Ship analysis". The low in the middle of the Atlantic was previously tropical cyclone "GABRIELLE".

4.3 Impact of the North Atlantic TEMP SHIPs on the forecast

The synoptic evaluation of the six pairs of forecasts did not show any significant difference in the forecasts starting from the 10th, 11th and 15th. The biggest synoptic difference was observed in the forecast starting from the 12th. Fig. 5 shows the pair of 2 day forecasts starting from the 12th and verifying on the 14th, 1200 UTC (maps discussed in 4.2). The position of cyclone GABRIELLE is wrong by about 500 km in the 2 day forecast performed without TEMP SHIPs, while it is almost correct in the operational forecast (note however that both forecasts are not deep enough by about 10 hPa). Also over Ireland, and to the North-West of Ireland there is a spurious cyclogenesis in both forecasts, but worse in the forecast without TEMP SHIPs (check for example the horizontal pressure gradient over Ireland in Fig. 5). The same difference with a smaller amplitude is observed over Ireland in the 1 day forecast starting from the 13th (not shown), confirming the importance of North Atlantic radiosondes for describing and forecasting synoptic and small scale features. Let us note also that the operational forecasts starting from the 12th and the 13th are very bad from day 3 onwards (much below the average quality of the ECMWF model), and the two synoptic features mentioned before were forecasted in a completely wrong way at days 4, 5 and 6 over Scandinavia, as mentioned by the Swedish Weather Service (Undén and Radford, pers. comm.). Some differences between forecasts with and without TEMP SHIPs exist from day 3 onwards, but these differences cannot be judged in terms of impact, because both forecasts are too far from the reality. It can still be concluded that not only are the North Atlantic TEMP SHIPs not to be blamed for this bad episode in the forecast quality, but also they helped in preventing the forecast quality from being degraded too quickly.

The impact of the North Atlantic TEMP SHIPs on the development of GABRIELLE is also visible on the forecast starting from the 14th. Fig. 6 shows the pair of 1 day forecasts valid on the 15th, 1200 UTC, and the verification analysis. The centre of GABRIELLE is again better forecast in the operational forecast, although it is less significant than on the 2-day forecast for the 14th.

The Northern Hemisphere scores (not shown) do not show any difference between the operational and "No North Atlantic TEMP SHIPs" forecasts, on any of the six experiments which have been run. The differences described before, although significant, are confined to scales which are too small to affect the Northern Hemisphere scores.

4.4 Comparison with the impact of TOVS data

As an assimilation without TOVS data has been run on a period starting on the 9th 0000 UTC, it is also possible to evaluate the impact of TOVS data and to compare it with the impact of North Atlantic TEMP

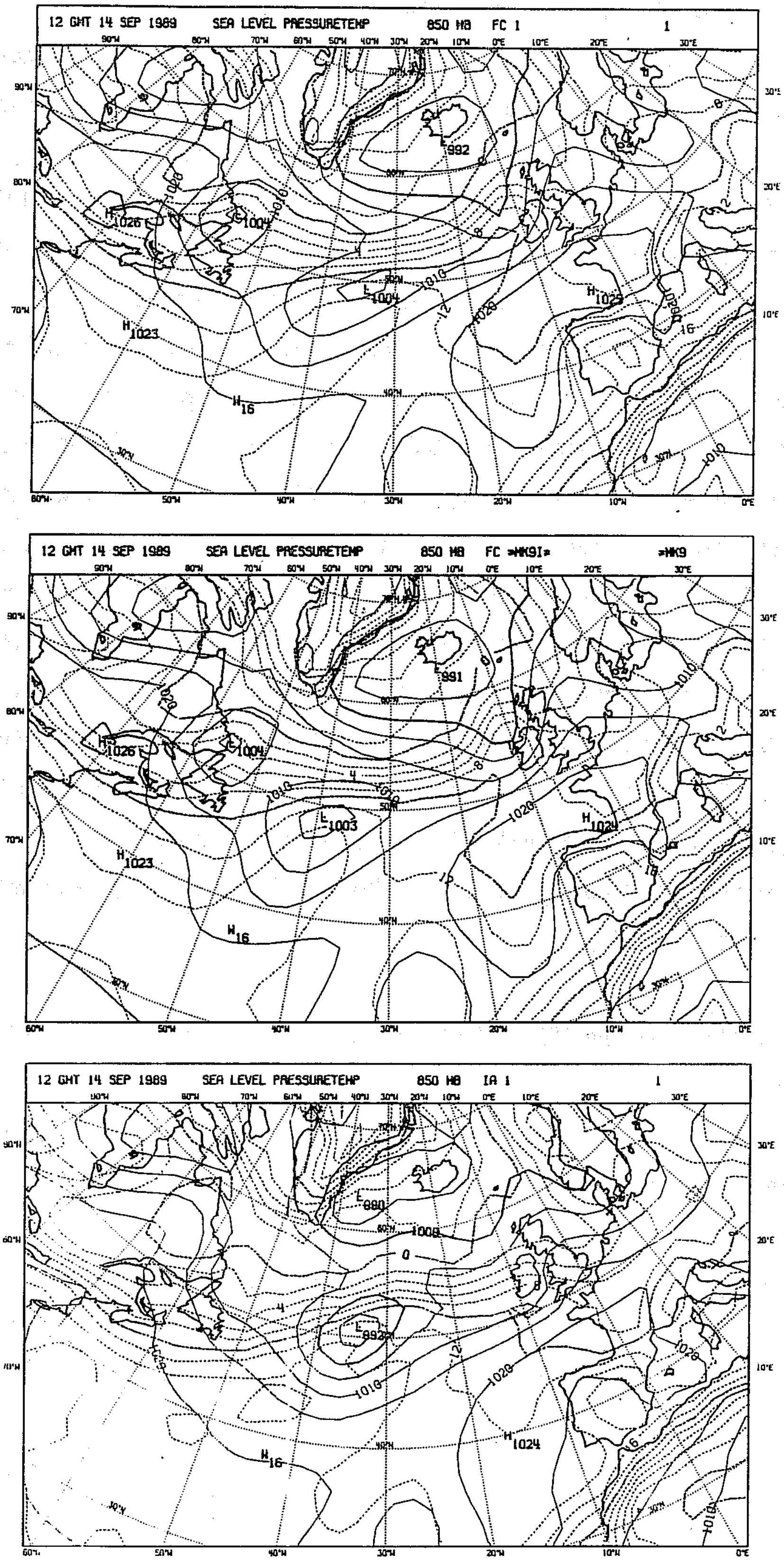


Fig. 5 Mean sea level pressure and 850 hPa temperature maps for the 48 h operational forecast (top) and the 48 h "No North Atlantic TEMP-SHIP" forecast (middle) run on 12 September 1989, 1200 UTC. The bottom map is the verification analysis (14 September, 1200 UTC), same as Fig. 4 (top) on which the arrows marked "O" and "NT" show the forecast error in the position of "GABRIELLE", for operations and "No TEMP-SHIP" respectively.

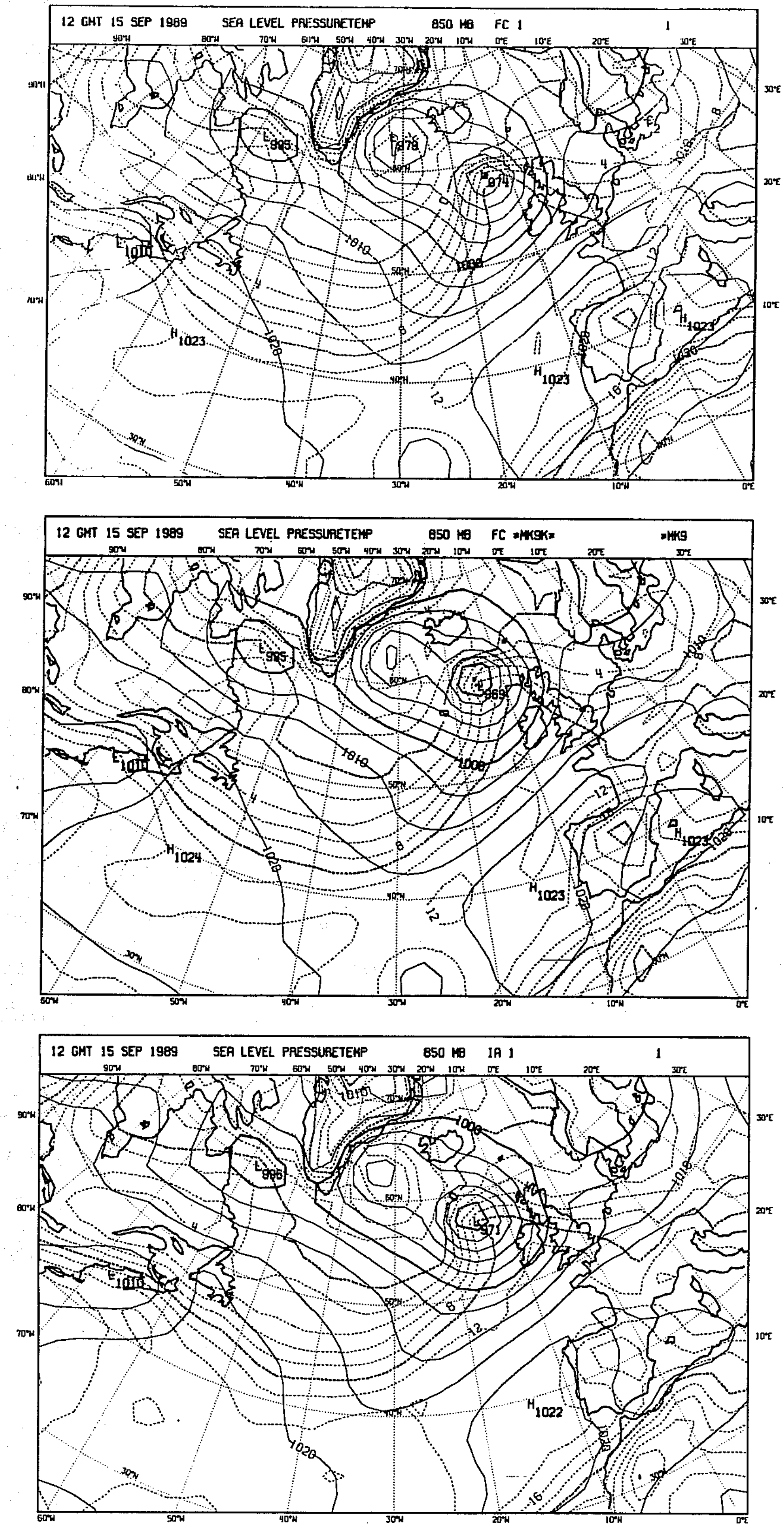


Fig. 6 Mean sea level pressure and 850 hPa temperature maps for the 24 h operational forecast (top) and the 24 h "No TEMP-SHIP" forecast (middle) run on 14 September 1989, 1200 UTC. The bottom map is the verification analysis (15 September, 1200 UTC), on which the arrows marked "O" and "NT" show the forecast error in the position of "GABRIELLE" for operations and "No North Atlantic TEMP-SHIP" respectively.

SHIPs, especially regarding the synoptic features described before. As mentioned before no impact of TEMP SHIPs was found on the forecast starting on the 11th. Fig. 7 and 8 are showing the operational and "No SATEM" forecasts starting on the 11th 1200 UTC, together with the corresponding verification analyses. Fig. 7 shows the 3 day forecasts, valid on the 14th, and Fig. 8 the 5 day forecasts, valid on the 16th. It is clear that at day 3 the TOVS have a negative impact on the structure of GABRIELLE: the "No SATEM" forecast gives a somewhat better position for the centre of the low, with also a better minimum value (994 hPa against 999 hPa for the minimum). At day 5 we have an opposite signal with the "No SATEM" forecast developing a spurious anticyclone in the middle of the Atlantic and blocking the development of another low to the East of Newfoundland. The operational forecast is also wrong on this particular feature, but still not as bad as the "No SATEM" forecast.

In other words, an example of positive impact of SATEMs and an example of negative impact are found for one single case: 11 September 1989, 1200 UTC. The negative impact is affecting the cyclone GABRIELLE at day 3, the positive impact is on a somewhat larger scale feature at day 5.

The forecast starting on the 12th shows even better that the TOVS can be a "double-edged weapon" (see Fig. 9). At day 2, the strength of cyclone GABRIELLE in the middle of the Atlantic is better in the "No SATEM" run than in the operational one (negative impact!), although its position is worse (positive impact!). This tendency of the TOVS data to weaken the weather systems of this scale has been observed almost consistently in this September period. It is also in agreement with the results given in Andersson et al. (1991) and Kelly et al. (1991), and it is probably inherent to the specific properties of SATEM retrieved data, such as their inability to reproduce sharp horizontal gradients, particularly in cloudy areas.

Altogether the synoptic impact of TOVS on North Atlantic and Europe can be rated as neutral on this set of four experiments, which does not mean that the differences "operations" - "No SATEM" are small. Indeed the forecast differences are generally larger than the differences "operations" - "No North Atlantic TEMP SHIP". They can be rated as neutral because some differences are showing some degradation of the forecasts, others are showing some improvement of the forecast due to the SATEMs; and also beyond day 3, some significant differences are just showing two different versions of bad forecasts (different but equally bad).

This is especially true for the forecasts starting on the 12th and 13th of September, when the operational forecast was very bad over the North of Europe (final evolution of cyclone GABRIELLE). By removing the TOVS, one fails to improve the operational forecast. However the operational and "No SATEM"

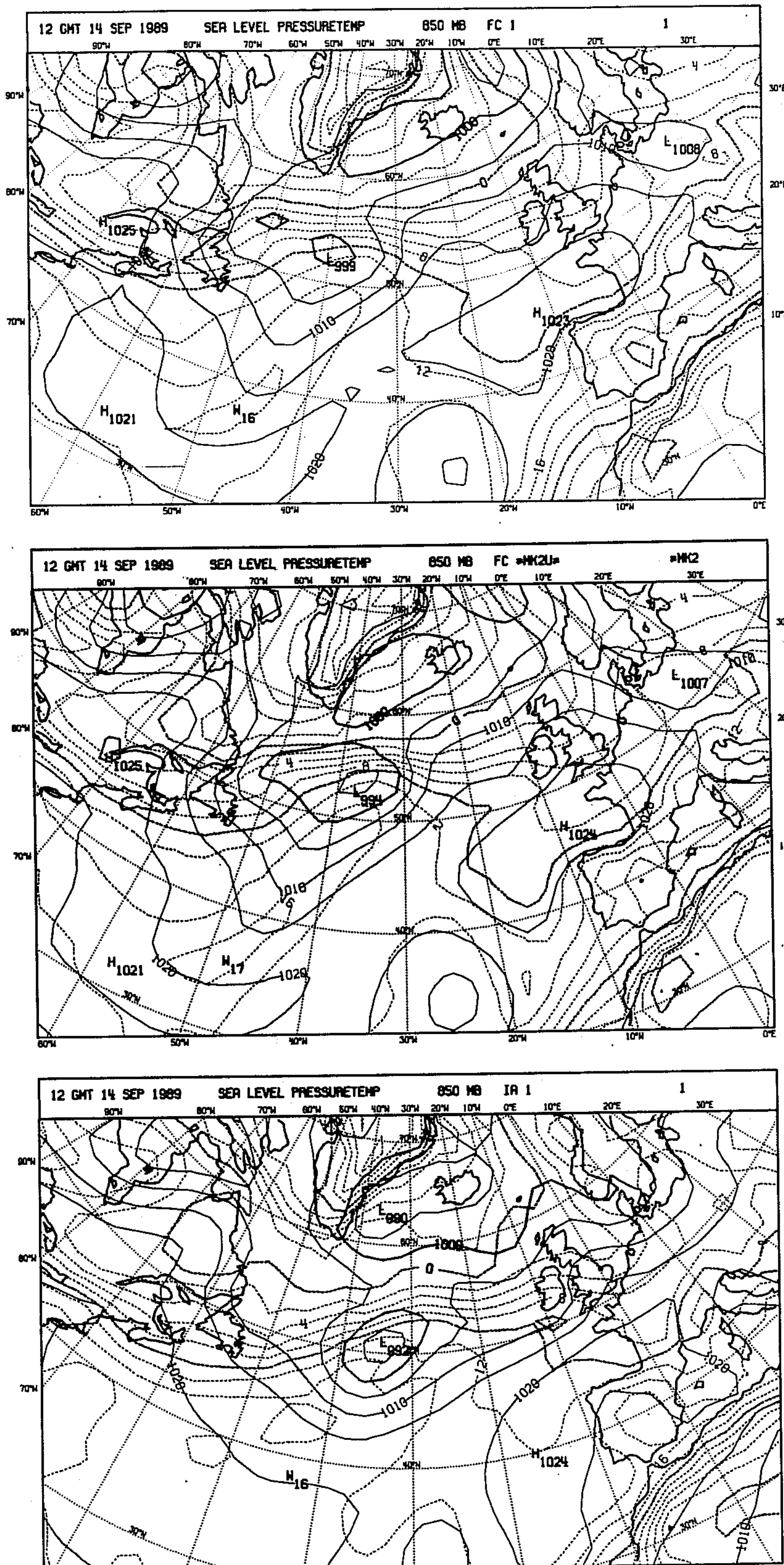


Fig. 7 Mean sea level pressure and 850 hPa temperature maps for the 72 h operational forecast (top) and the 72 h "No SATEM" forecast (middle) run on 11 September 1989, 1200 UTC. The bottom map is the verification analysis (14 September, 1200 UTC), same as Fig. 4 (top) on which the arrows marked "O" and "NT" show the forecast error in the position of "GABRIELLE", for operations and "No SATEM" respectively. The corresponding "No North Atlantic TEMP SHIP" forecast is identical to operations on this case (not shown).

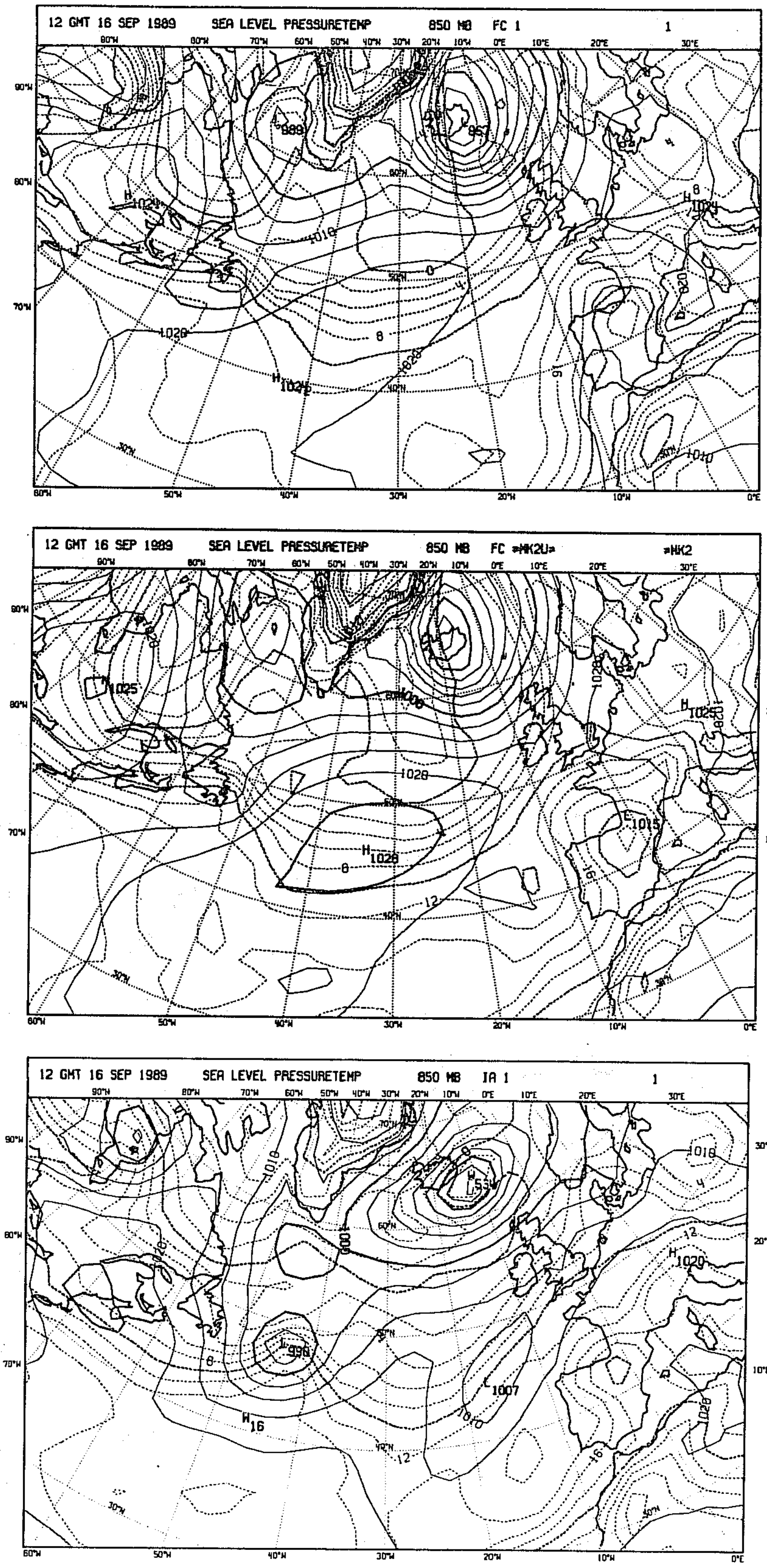


Fig. 8 Mean sea level pressure and 850 hPa temperature maps for the 120 h operational forecast (top) and the 120 h "No SATEM" (middle) run on 11 September 1989, 1200 UTC (same forecasts as Fig. 7). The bottom map is the verification analysis (16 September, 1200 UTC). Note the spurious anticyclone in the middle of Atlantic in the "No SATEM" forecast, a little better in the operational forecast.

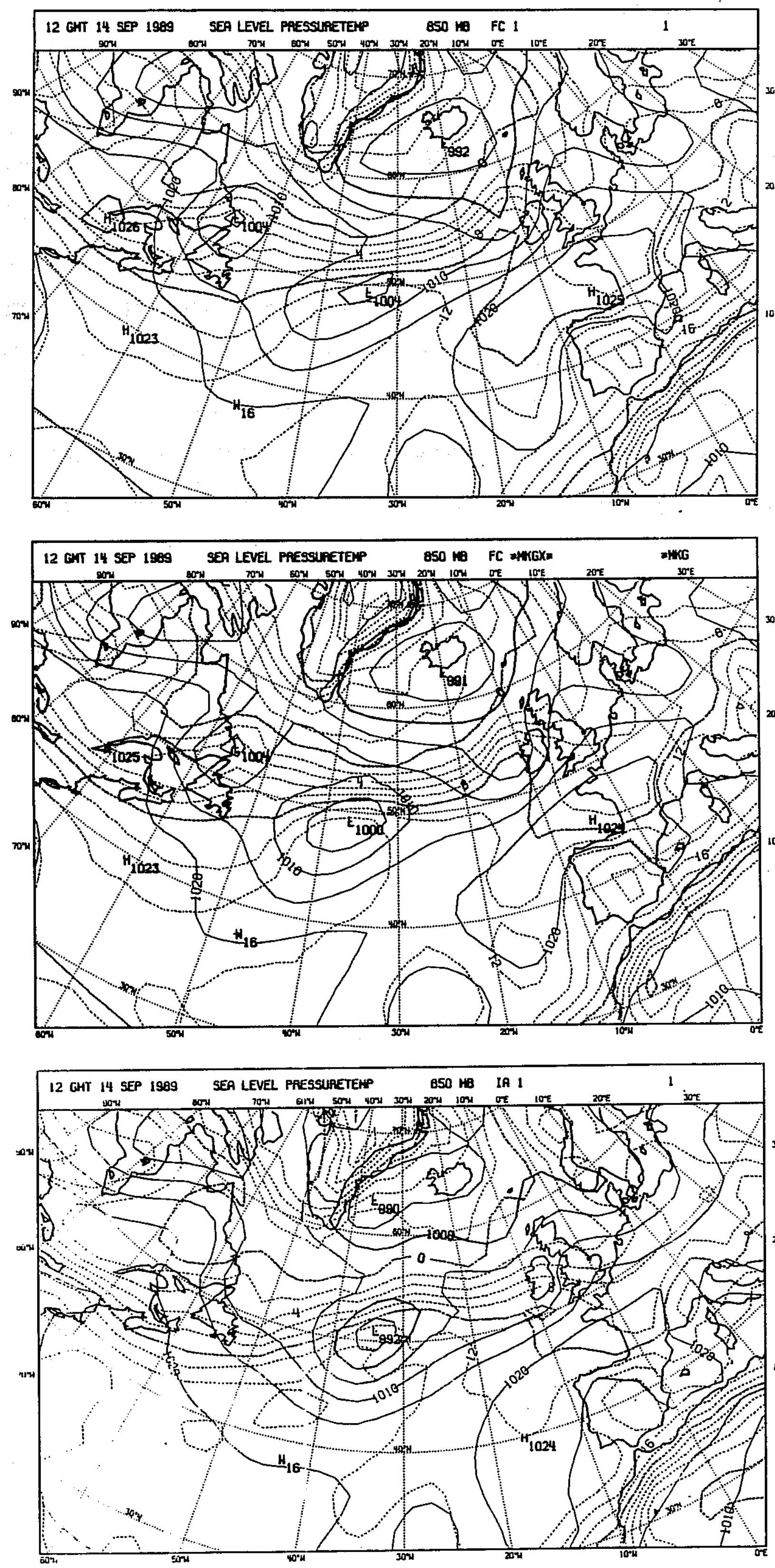


Fig. 9 Mean sea level pressure and 850 hPa temperature maps for the 48 h operational forecast (top) and the 48 h "No SATEM" forecast (middle) run on 12 September 1989, 1200 UTC. The bottom map is the verification analysis (14 September, 1200 UTC) on which the arrows marked "O" and "NS" show the forecast error in the position of "GABRIELLE", for operations and "No SATEM" respectively. Fig. 9 is similar to Fig. 5 except the "No SATEM" forecast (middle) replaces the "No North Atlantic TEMP SHIP" forecast.

forecasts are significantly different from days 3 to 5, which tells us that the forecast model was particularly sensitive to changes in the initial data on this particular period.

The overall Northern Hemisphere impact of TOVS is given on the four anomaly correlation diagrams of Fig. 10. They show a small positive impact of TOVS on each of the four cases. This result is somewhat different from the one obtained with the July 1988 version of the ECMWF system (see Andersson et al., 1991 where, out of 15 cases, there were slightly more cases of negative impact than cases of positive impact. The September 1989 version of the ECMWF system achieves a better use of SATEM data than before, which could be attributed to the tightening of the quality control performed in January 1989 and documented in Kelly et al. (1991). Also the scores of Fig. 10 put together with an example like the 5-day forecast of Fig. 8, are a strong indication that the SATEM data are needed over the oceans for the analysis and the forecast of the larger scales.

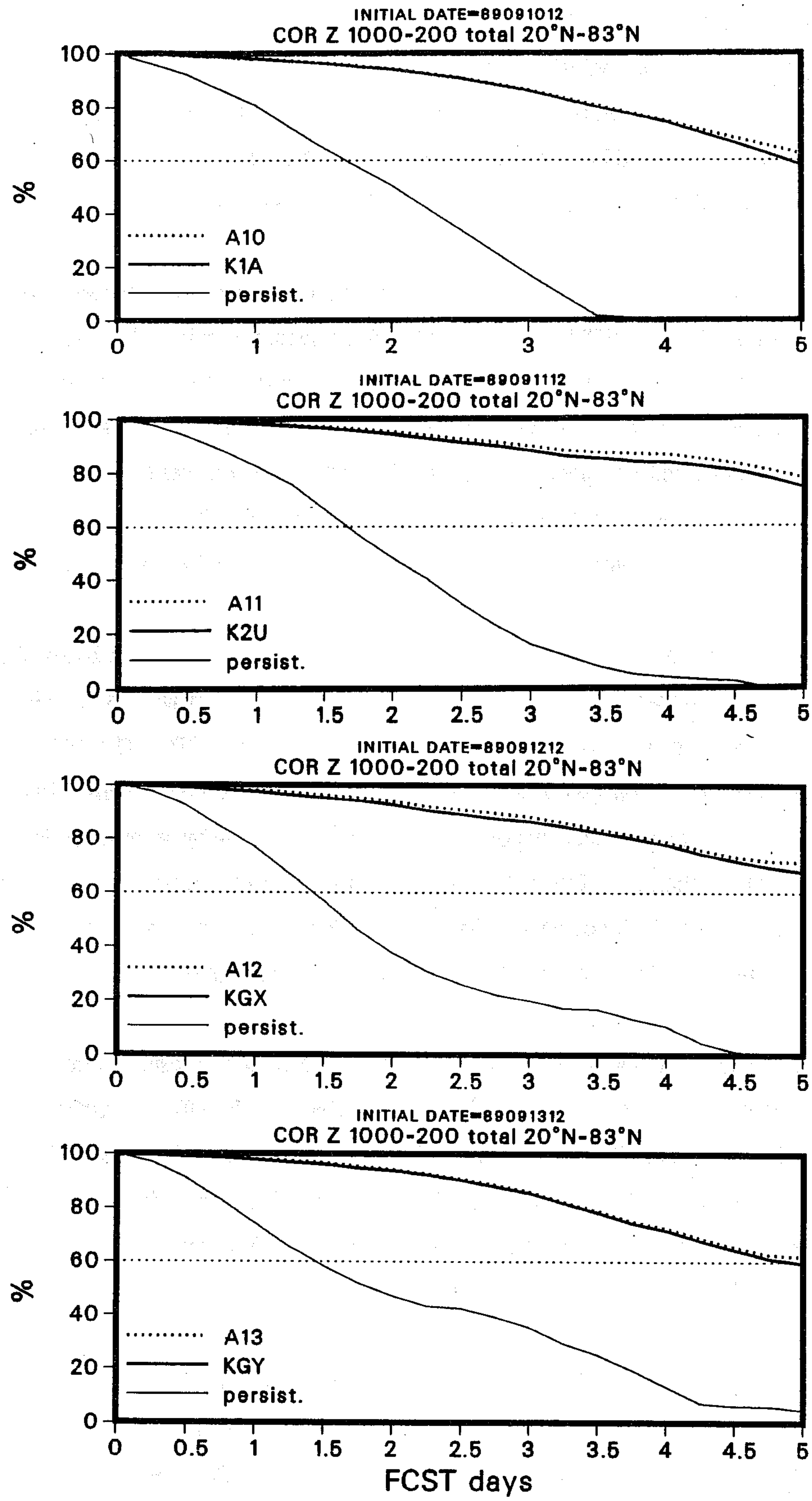


Fig. 10 Northern hemisphere forecast anomaly correlations comparing operational forecast (dotted lines) and No SATEM forecasts (full lines) on four consecutive days of September 1989. The forecast range is plotted on the horizontal axis until day 5. The field considered is the averaged geopotential height from 1000 to 200 hPa. The cases are from the 10th of September (top) to the 13th of September (bottom).

5. STUDY OF THE PERIOD 24-28 OCTOBER 1989

5.1 Description of the meteorological situation

This situation has been studied at ECMWF after a study made at the UK Met Office, Graham (1990), showing that the forecast of the sudden deepening of a low over the British Islands on the 27th and 28th of October 1989 was sensitive to the North Atlantic TEMP SHIP observations.

Fig. 11a, b, c and d shows the chronological evolution of the meteorological situation from the 25th, 1200 UTC to the 28th, 1200 UTC (ECMWF initialized analysis sequence, with a 24 h time interval). On the 25th and 26th, a weak low is moving slowly to the North from the West of Gibraltar, and a trough is developing to the South of Greenland, moving eastward. On the 27th the two systems meet to the South West of Ireland and a quick cyclogenesis occurs; the system then crosses the British Isles. On the 28th 1200 UTC, the pressure is about 975 hPa at the centre of the low situated over the East coast of Ireland, and a strong pressure gradient can be observed to the South of Ireland and over Cornwall.

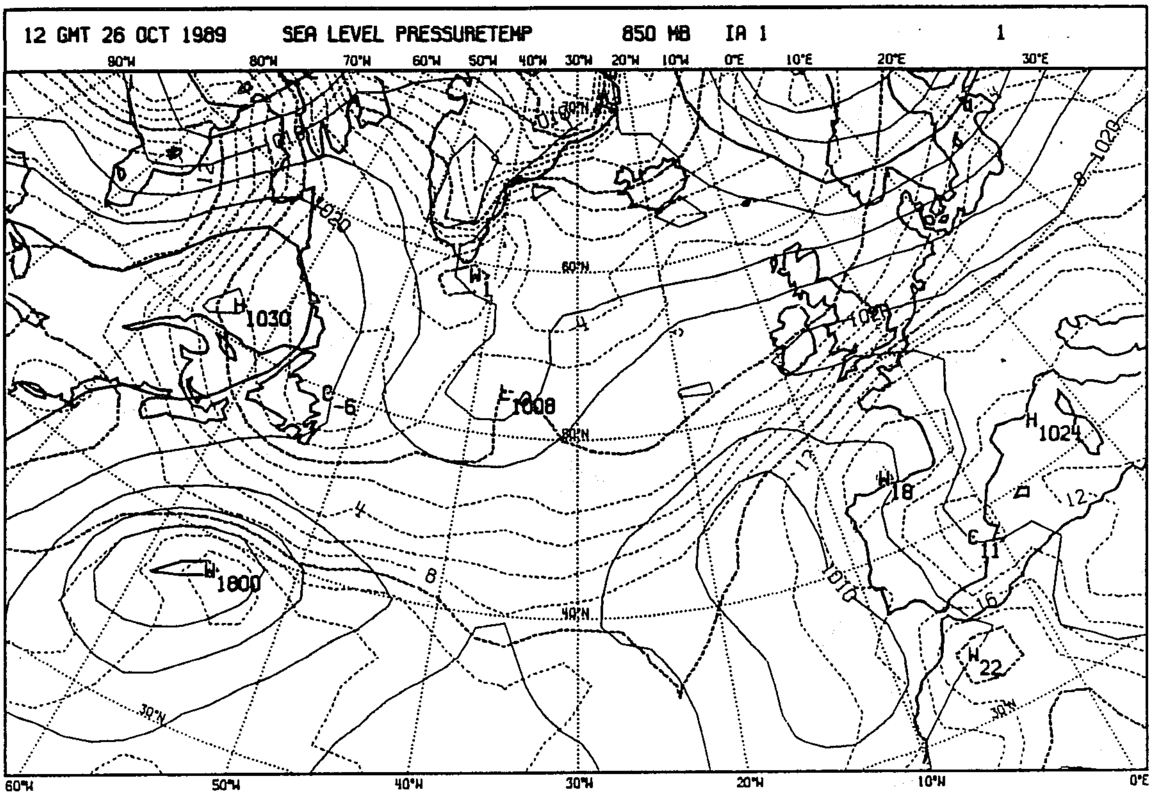
In the UK Met Office experiment (Graham, 1990), it was shown that the North Atlantic TEMP SHIP observations had a positive impact on the forecast of this particular low as it was on the 28th. This was found consistently in several short range forecasts valid for the 28th, 1200 UTC. The 48 h forecast from the 26th was the one showing the biggest positive impact of North Atlantic TEMP SHIPs; in the 48 h "No North Atlantic TEMP SHIP" experiment, the position of the low was wrong by several hundred kilometres (over the North Sea rather than over Ireland) whereas the operational forecast was much better. This could be related to a high availability of ASAPs (and other radiosonde observations) near the critical area where the "West Portugal" system meets the "South Greenland" system (see Fig. 12).

When this particular experiment was set up at ECMWF, the UK Met Office results were known, and the main goal was to see whether or not the positive impact obtained by the UK Met Office global model could be reproduced by the ECMWF model. The "No North Atlantic TEMP SHIP assimilation" was run on a 3 day period, 24 October, 1200 UTC, to 27 October, 1200 UTC (like for the UK Met Office), following the technical specifications mentioned before. Three 6 day forecasts were run from 1200 UTC on the 25th, 26th and 27th, and compared to operational forecasts.

5.2 Impact of the North Atlantic TEMP SHIPs on the analysis and the forecast

The positive impact obtained by the UK Met Office on the forecasts valid for 28 October, 1200 UTC (low over the British Isles) cannot be reproduced by the ECMWF model. The operational and "No North Atlantic TEMP SHIP" forecasts valid for 28 October, 1200 UTC, are close to each other (not shown).

(a)



(b)

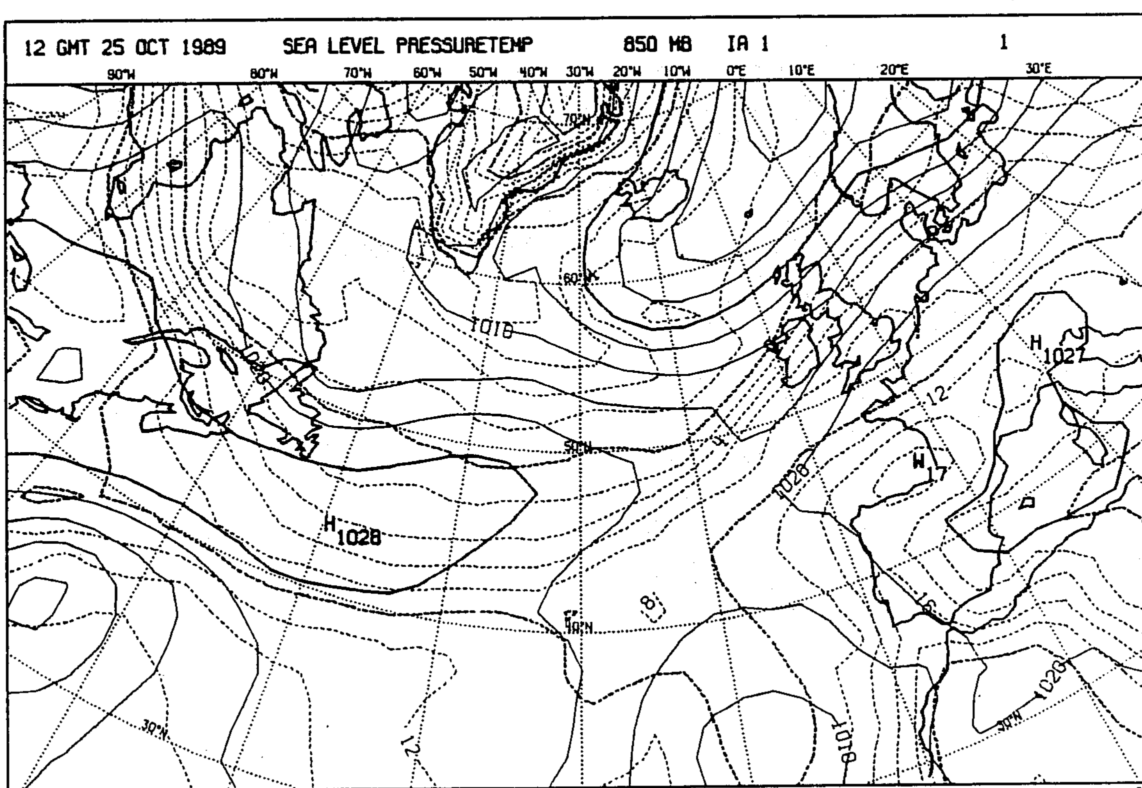
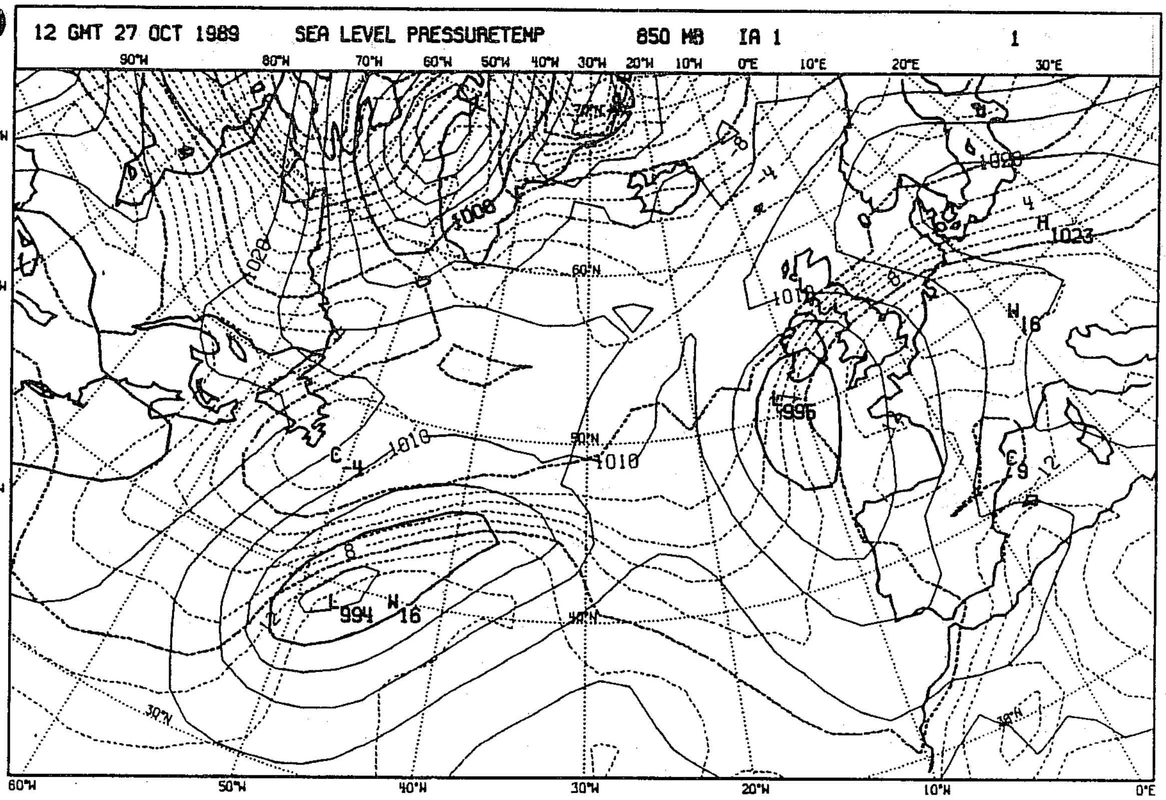


Fig. 11a/b Initialised analysis maps for 25 October 1989, 1200 UTC to 28 October 1989, 1200 UTC, for mean sea level pressure and 850 hPa temperature.

a) 25 October 1989, 1200 UTC.

b) 26 October 1989, 1200 UTC.

(c)



(d)

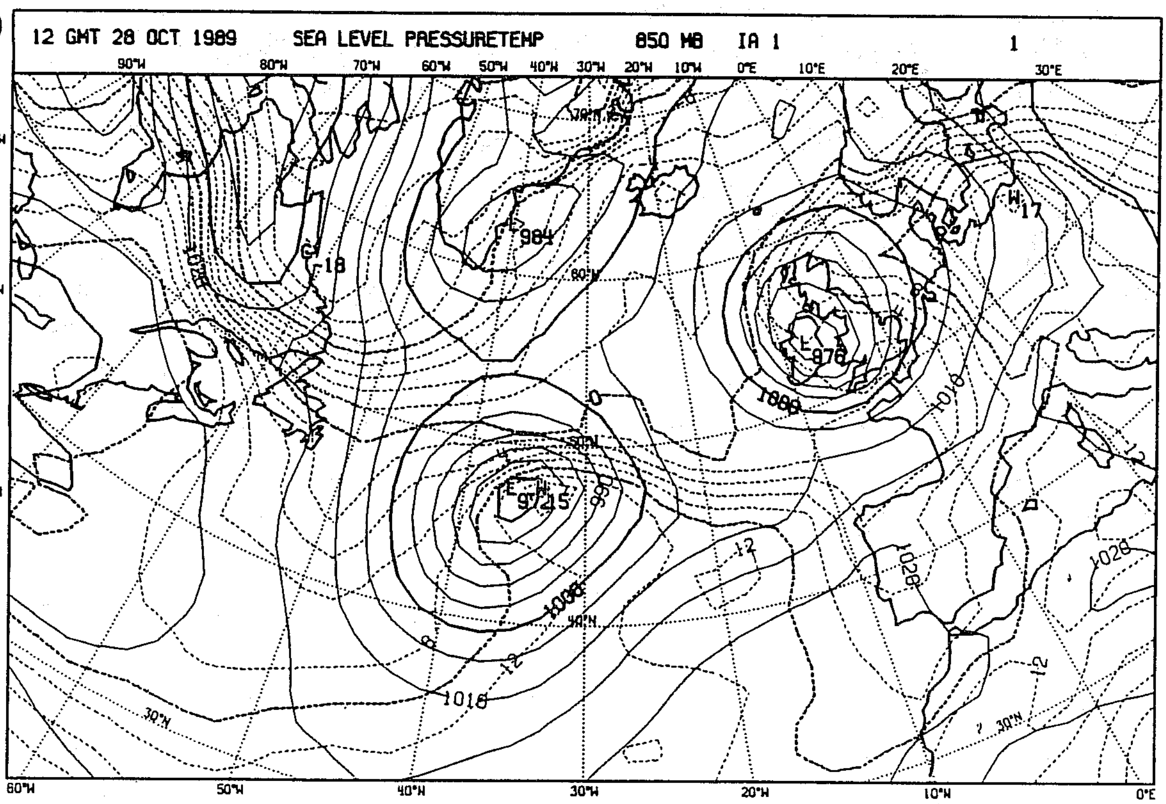


Fig. 11c/d Initialised analysis maps for 25 October 1989, 1200 UTC to 28 October 1989, 1200 UTC, for mean sea level pressure and 850 hPa temperature.

c) 27 October 1989, 1200 UTC.

d) 28 October 1989, 1200 UTC.

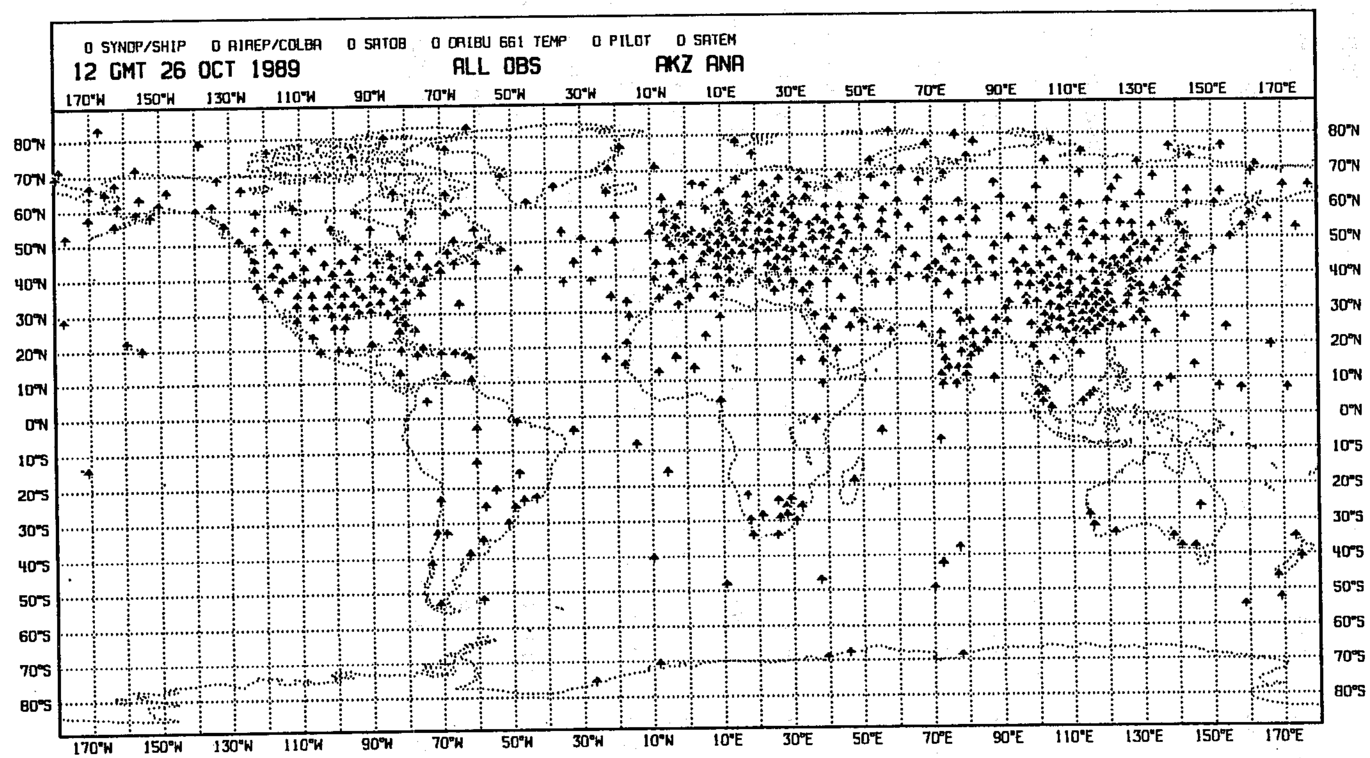


Fig. 12 Global data coverage map for radiosonde observations on 26 October 1989, 1200 UTC. In the North Atlantic area, the Ocean Weather Ships are indicated by a square and the other ships by a circle.

They are also close to the UK Met Office operational forecast, whereas the UK Met Office "No North Atlantic TEMP SHIP" forecast is significantly worse. It is not clear why the absence of these North Atlantic observations is substantially degrading the UK Met Office forecast and not affecting the ECMWF forecast.

The detailed examination of the ECMWF forecasts beyond day 3 did not show any impact. Although some differences can be noted on the maps, the forecast of the important systems (especially the one which is over the British Isles on the 28th) is too bad in both forecasts to allow the possibility of judging these differences.

The 24 h pair of forecasts run from the 26th show a slight advantage of the operational forecast on the one without TEMP SHIPs, regarding another system in the middle Atlantic (see Fig. 13). The "No North Atlantic TEMP SHIP" forecast has a tendency to create a cut-off low by (45°N, 35°W) with a 995 hPa minimum which exists neither in the operational forecast nor in the verification analysis.

The forecast pair run from the 26th is also the only one (in all the cases studied in this paper) where a positive impact of North Atlantic TEMP SHIPs could be detected on the Northern Hemisphere scores: see the anomaly correlation diagrams presented in Fig. 14. A signal can be detected on these diagrams as early as 36 h in the forecast range and is affecting all the wave numbers. However, most of the impact visible on the score diagrams cannot be interpreted in terms of significant synoptic differences, except the small impact shown at day 1 on Fig. 13. In particular the substantial difference in terms of score performance at days 4, 5 and 6 seems to be related to features which are badly predicted anyway (with or without TEMP SHIPs). This is the expression of the small significance of the Northern Hemisphere standard scores for a study like the present one related to some TEMP SHIPs in one particular area.

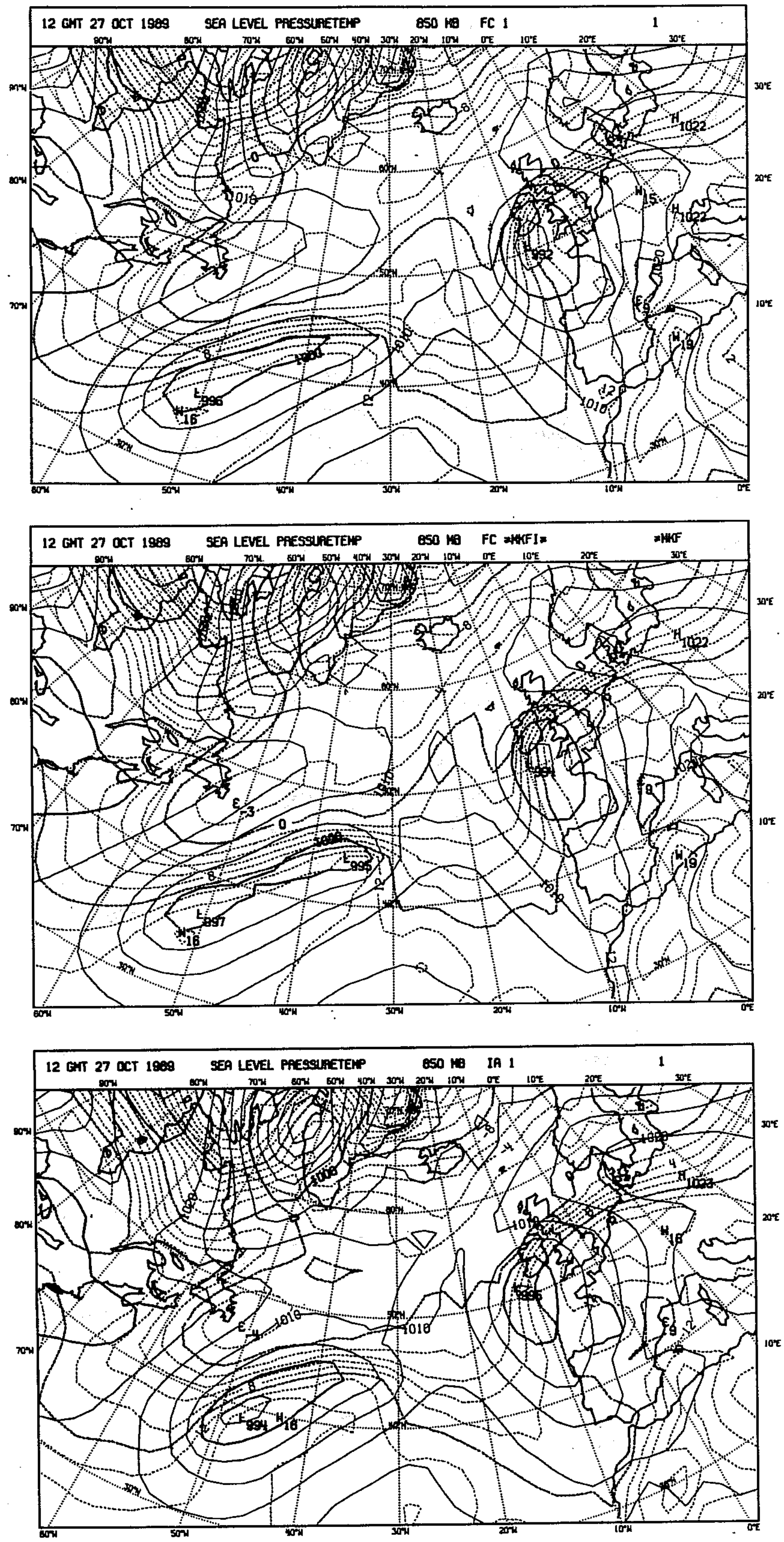


Fig. 13 Mean sea level pressure and 850 hPa temperature maps for the 24 h operational forecast (top) and the 24 h "No North Atlantic TEMP SHIP" forecast (middle) run on 26 October 1989, 1200 UTC. The bottom map is the verification analysis (27 October, 1200 UTC).

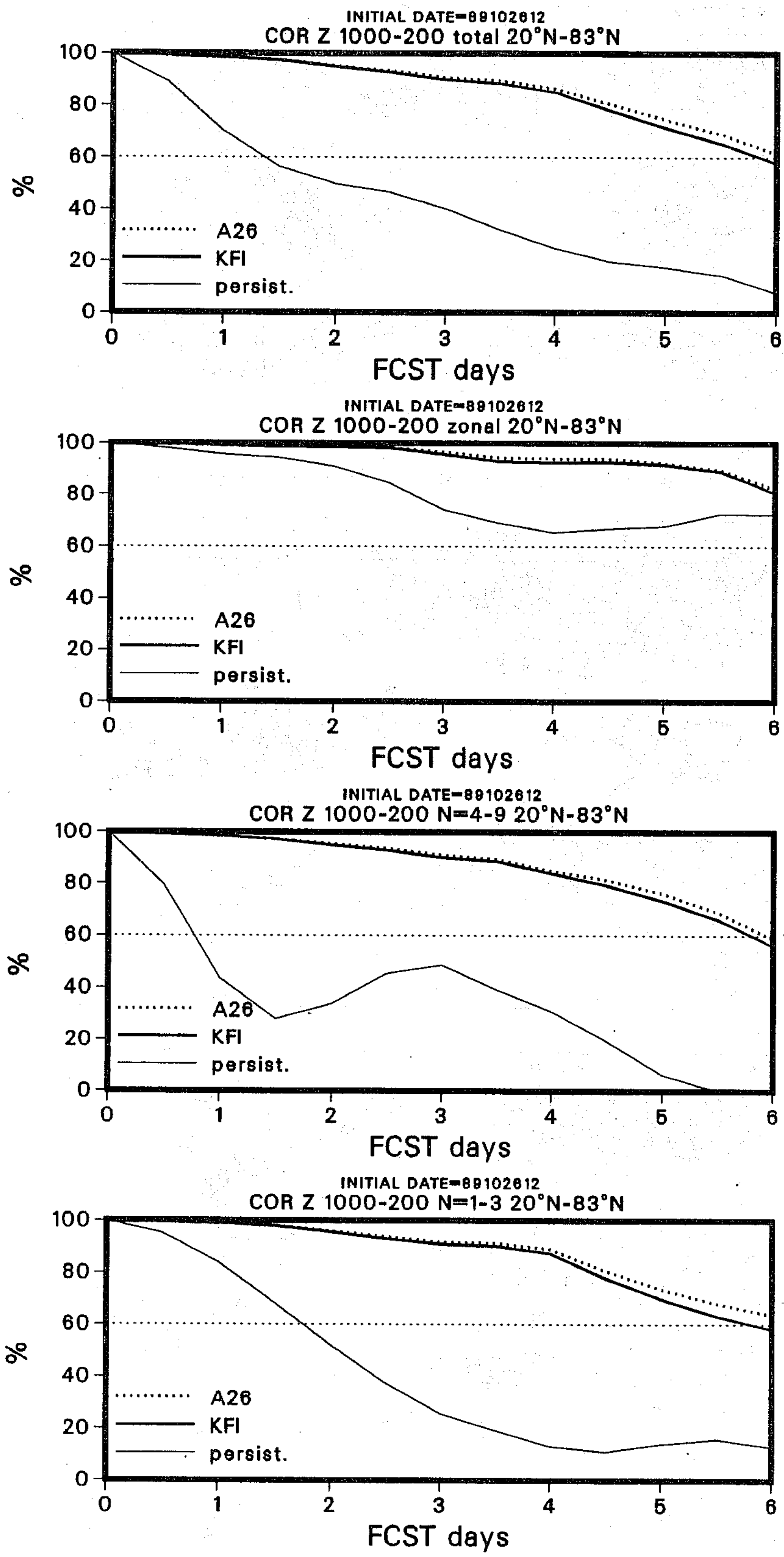


Fig. 14 Forecast error anomaly correlation for Northern hemisphere, comparing operation forecast (dotted line) with "No North Atlantic TEMP SHIP" forecast (full line) on 26 October 1989, 1200 UTC.

From top to bottom the different diagrams show: total field, zonal mean, synoptic waves, long waves. The variable considered is the geopotential height averaged from 1000 to 200 hPa.

6. STUDY OF THE STORM OF 25 JANUARY 1990

6.1 Description of the meteorological situation

On 25 January 1990, Ireland and the UK were hit by a strong storm with extreme gales producing a lot of damage and killing several people. On 24 January, 1200 UTC, this storm was starting to develop in the Atlantic, where a low just below 1000 hPa could be found at (50°N, 37°W) between weather ship C and the ASAP ONDA. Fig. 15 shows the evolution of this storm between the 24th and the 25th, 1200 UTC. On the 25th, 1200 UTC, the low was over the South of Scotland, with a minimum of 955 hPa in the ECMWF operational analysis (951 hPa in a UK Met Office analysis with a higher resolution). The storm then moved towards the North Sea and Denmark. On the 26th, 0000 UTC, the low was centred just to the West of Jutland.

Like in the October case, a study by the UK Met Office, Heming (1990) showed a positive impact of the North Atlantic TEMP SHIPs on the forecast of this storm (forecasts valid on the 25th). The main purpose when setting up the ECMWF experiment was again to check if this positive impact could be reproduced with the ECMWF data assimilation and forecast system. This time the limited area fine mesh model was used in the UK Met Office study. This study also highlighted the special role of weather Ship C and ASAP ONDA.

At ECMWF, a short assimilation with "No North Atlantic TEMP SHIPs" was run: three assimilation cycles, 0000, 0600 and 1200 UTC, on the 24th. Then a 6 day forecast was run from this assimilation. All the details of this "No North Atlantic TEMP SHIP" assimilation are identical to the ones described before.

6.2 Impact of the North Atlantic TEMP SHIPs on the analysis and forecast

When investigating the impact of the North Atlantic radiosondes on the analysis, special attention was given to ASAP ONDA on 24 January. It appeared that the call sign problem mentioned before (see section 4.1) was affecting Ship ONDA which was used twice in the 1200 UTC analysis (and even three times in the 0000 UTC analysis!). Because of the crucial position of Ship ONDA on the 24th, just to the South of the developing storm, a new control assimilation has been run, similar to operations but removing the duplicates of ONDA. This experiment is called "clean operations" hereafter. This particular fix has been introduced operationally at ECMWF in Spring 1990.

Fig. 16 shows the impact of the North Atlantic TEMP SHIPs on the analysis of 24 January, 1200 UTC (top map), as well as the impact of inappropriate use of ASAP ONDA (bottom map). The bottom map

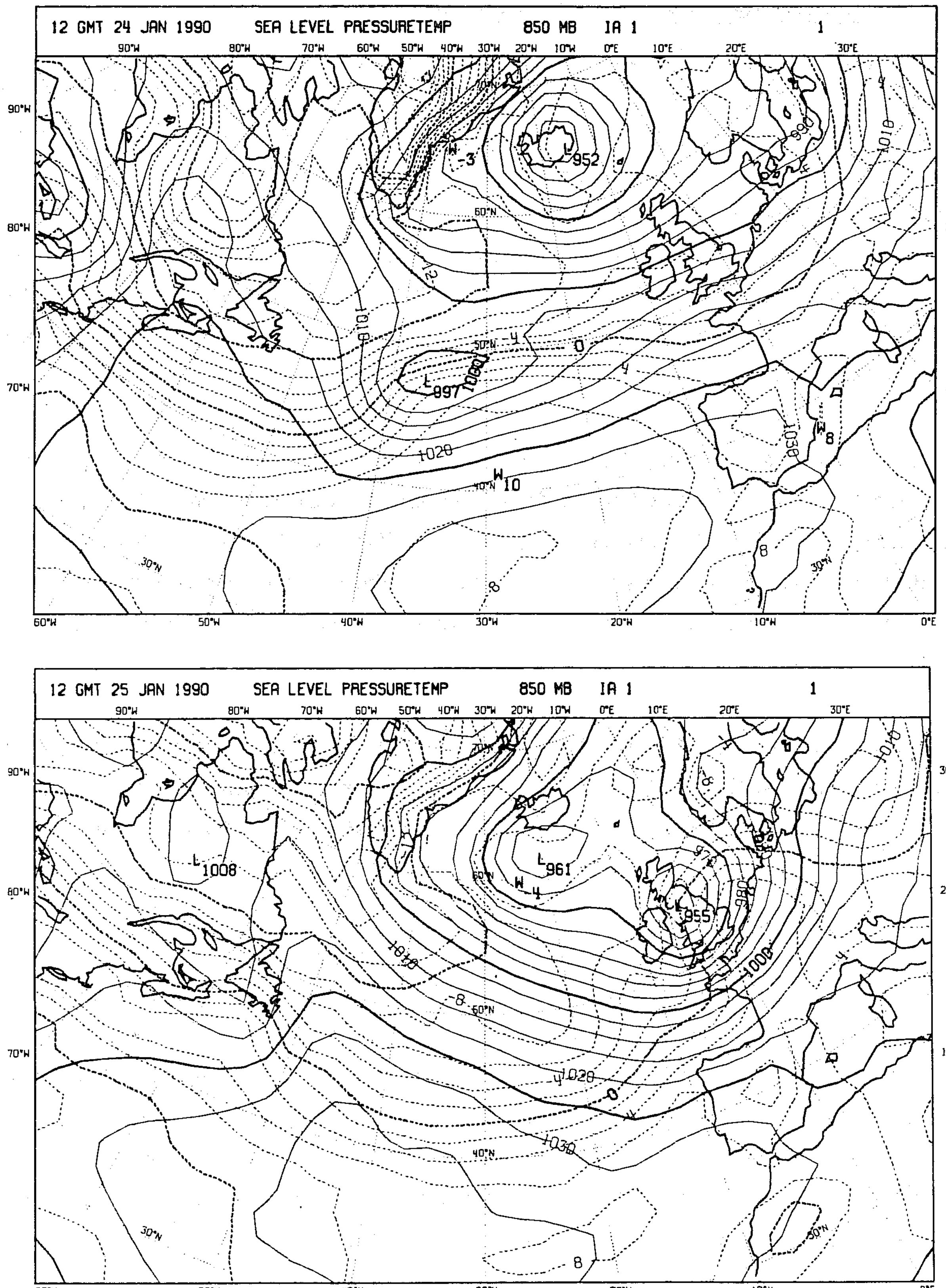
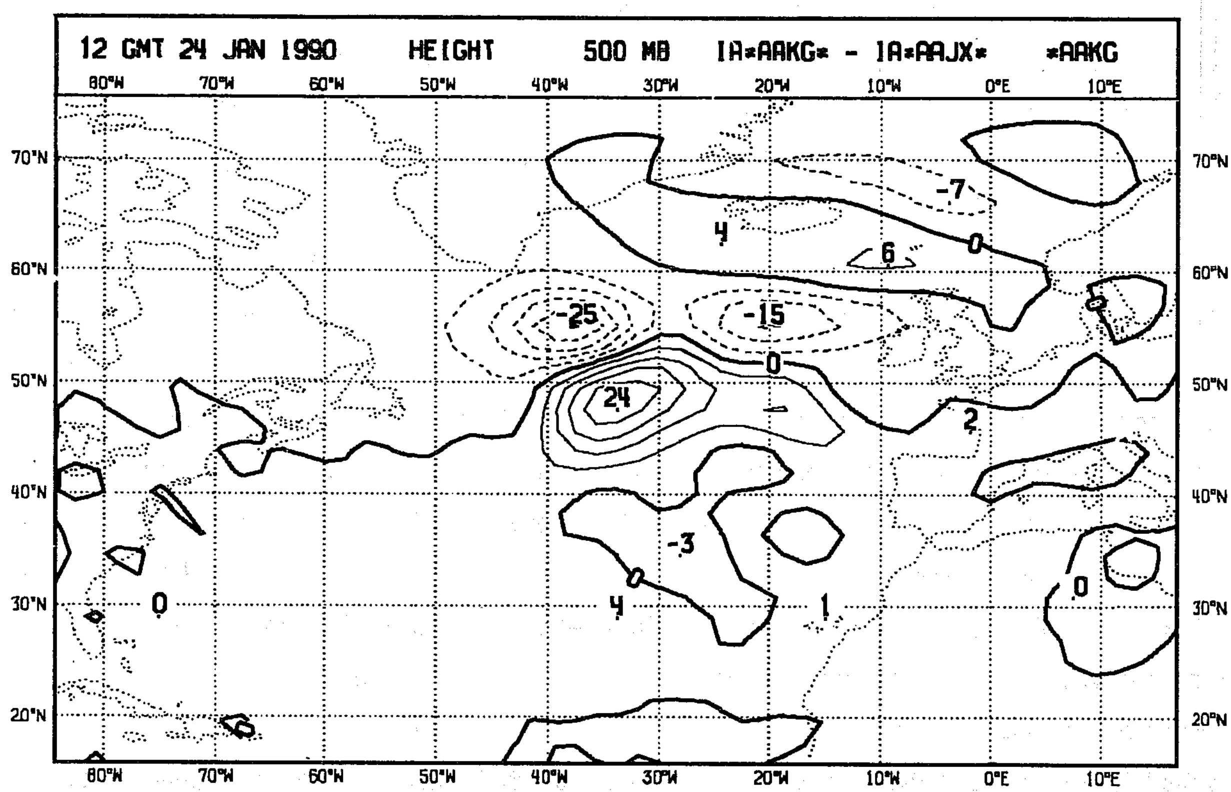


Fig. 15 Mean sea level pressure and 850 hPa temperature analysis maps for 24 January 1990, 1200 UTC (top) and 25 January 1990, 1200 UTC (bottom). On 24 January the positions of ships C and ONDA are marked C and O. On the map for the 25th, the position of th centre of the storm given by the 24 h forecasts (from the 24th) are marked "1" for operational forecast, and "2" for No North Atlantic TEMP SHIP forecast.



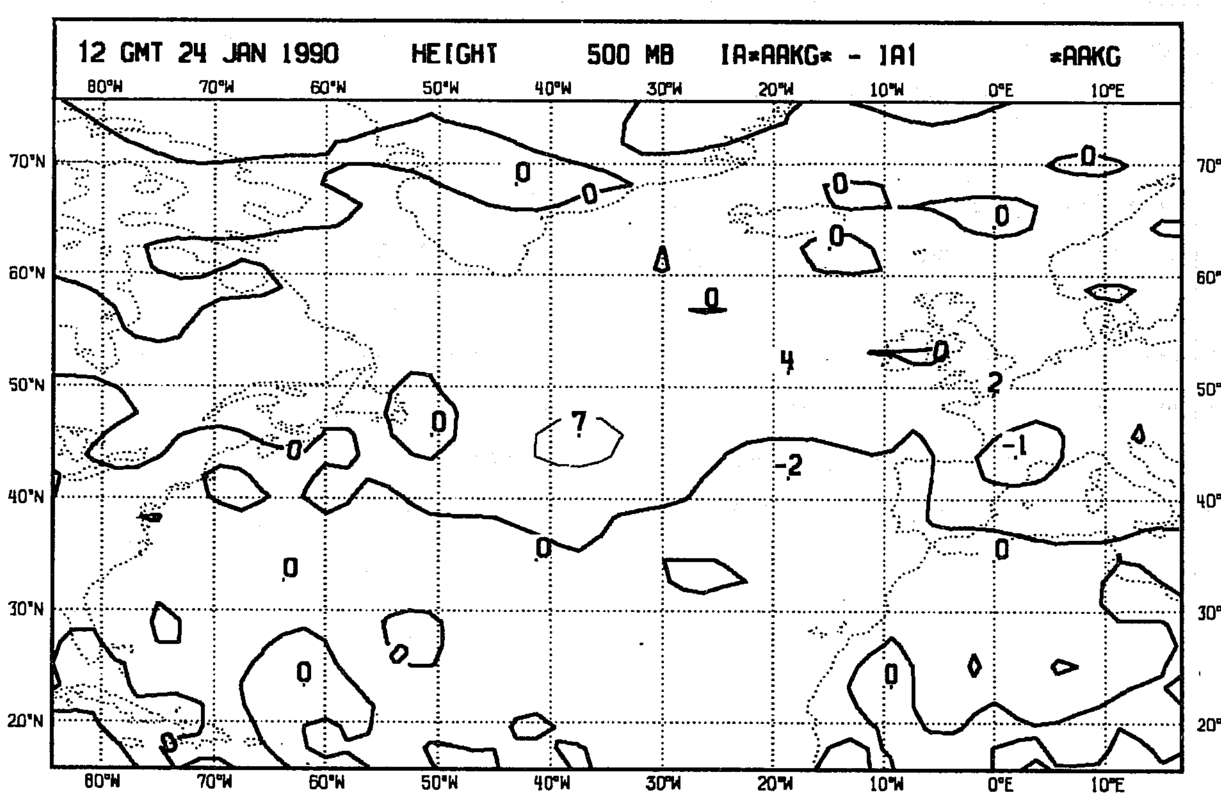


Fig. 16 500 hPa geopotential height anomalies difference maps for 24 January 1990, 1200 UTC.
Top: "Clean Operations" - "No North Atlantic TEMP SHIP"
Bottom: "Clean Operations" - "Operations".
The top map shows the impact of North Atlantic TEMP-SHIPs on the analysis. The bottom map shows the impact of a proper treatment of duplicates which avoids to use ONDA twice (as in operations).

shows a maximum difference of 7 metres for the 500 hPa geopotential height, at the location of Ship ONDA, between "clean operations" and operations, leading one to think that the duplication problem has only a small impact. The 500 hPa difference map "clean operations - No North Atlantic TEMP SHIP" shows a wave pattern with a 25 m amplitude in the storm area.

Fig. 17 shows three 24 h forecasts from the three parallel assimilations, all valid for the 25th, 1200 UTC, when the storm was hitting England: operations, clean operations and "No North Atlantic TEMP SHIP". These forecasts have to be compared with the verification analysis of Fig. 15 (bottom). Let us note that the three forecasts are good in the sense that they all catch the storm development on the 24 h period, although none of them is deep enough. "Operations" and "clean operations" are almost identical, confirming the small impact of the call sign problem, even in this extreme case. There are some differences between the operational forecast and the forecast with no TEMP SHIP regarding the strength of the storm and its exact position. The "No North Atlantic TEMPSHIP" storm is weaker by a few hectopascals, and also its exact position is shifted to the East, over the North Sea, compared to its exact position over Scotland (see Fig. 15 bottom). This type of positive impact is similar to the one obtained by the UK Met Office study, although its magnitude is much smaller. It is also confirmed by the 36 h forecast maps (not shown) for 26 January, 0000 UTC, where the low is approaching Denmark: again the operational forecast is deeper by 5 hPa, and the position is too far East in the run without TEMP SHIPs, somewhat better in the operational forecast.

Finally, as in all the previous cases except on 26 October 1989, no significant impact was found on the Northern hemisphere scores. No significant synoptic impact could be identified beyond day 2 either.

The main message coming out from this study of the January storm is the importance of in-situ data to describe properly the analysis of extreme features, over the Atlantic, and their short-range forecast especially when these features are small scale and likely not to be described by current satellite data. This result is coming consistently from the studies done at ECMWF and in the UK Met Office, with different amplitudes: the response of the UK Met Office model is bigger (no straightforward explanation).

7. CONCLUSION

In the context of the OWSE-NA, data assimilation and forecast experiments (coordinated by the SEG) have been run at ECMWF to investigate the impact of the North Atlantic TEMP SHIP observations on the analysis and the forecast. These experiments have been run on three different periods, a one week period in September 1989 chosen at random from the meteorological point of view, and two shorter

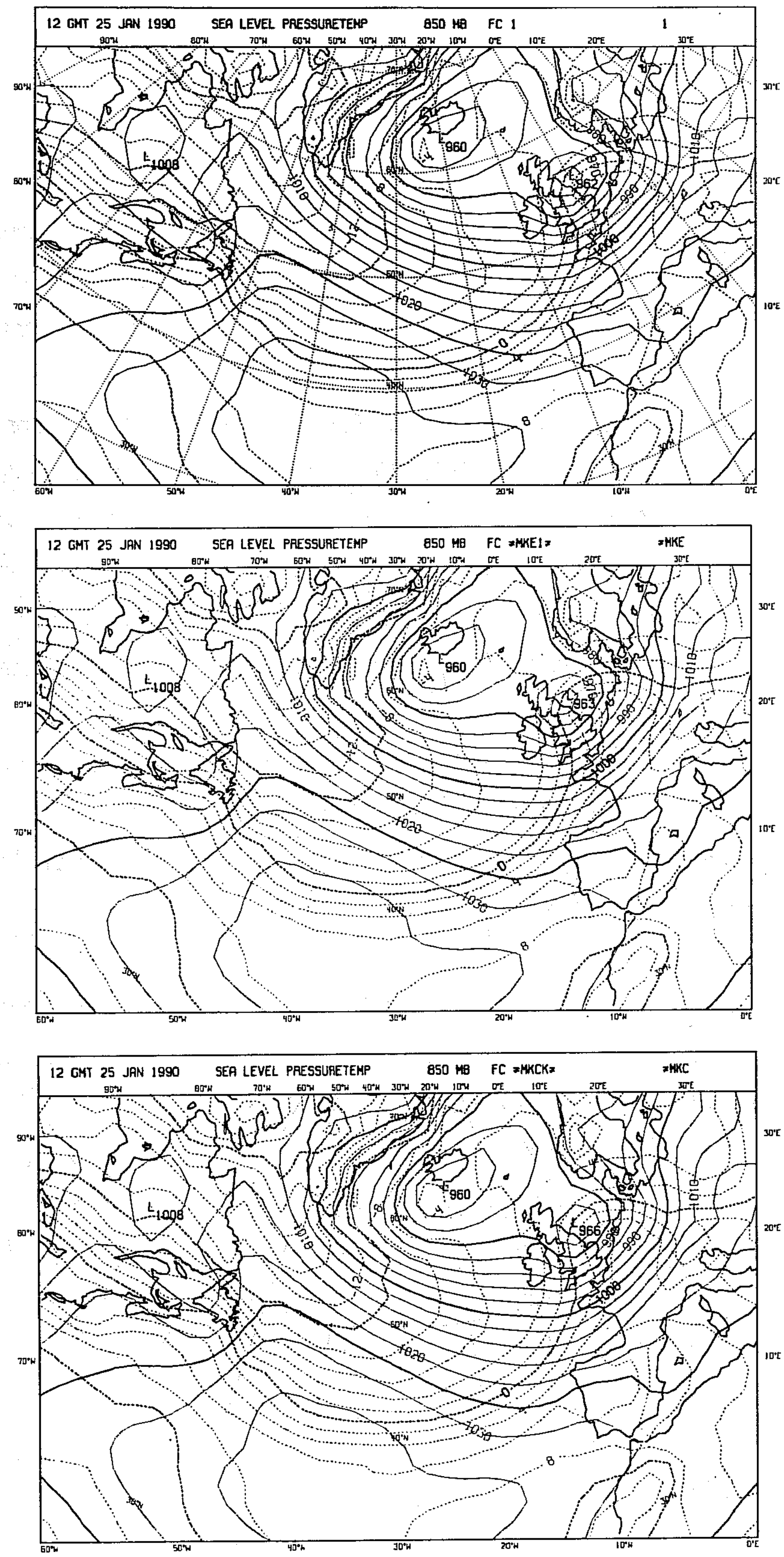


Fig. 17 Mean sea level pressure and 850 hPa temperature maps for the 24 h operational forecast (top), the 24 h "clean operations" (middle) and the 24 h "No North Atlantic TEMP SHIP" forecast (bottom) run on 24 January 1990, 1200 UTC. The verification analysis for 25 January, 1200 UTC is given on Figure 15 bottom, where the respective positions of the storm over England are marked.

specific cases selected by the UK Met Office because of particular weather systems.

The one week period of September 1989 showed some modest positive impact of the North Atlantic TEMP SHIPs on two particular synoptic systems up to day 2, one of these systems being the dying tropical cyclone GABRIELLE. Out of 6 forecasts run on this period, three of them did not show any synoptic impact at all, two showed a very small positive impact, and one (from 12 September, 12 UTC) showed a somewhat significant impact of the North Atlantic TEMP SHIPs. The parallel study done in the UK Met Office seems to confirm these results, with differences in the details (Graham, pers. comm.).

The first specific case was a 3 day period in October 1989, with particular attention on the development of a low over Great Britain on the 28th. The ECMWF experiment fails to reproduce the positive impact obtained by the UK Met Office global model on this particular system. It still shows some (much smaller) positive impact on another system in the middle of the Atlantic, and also, the Northern hemisphere anomaly correlations show in one case (26 October) what would be called a "glorious positive impact" by some score assessors (unfortunately impossible to interpret in synoptic terms)!

The second specific case is the storm which hit the British Isles on 25 January 1990. A substantial impact of the North Atlantic TEMP SHIPs on the position and strength of this storm at day 1 was obtained in the UK Met Office limited area model. The ECMWF experiment manages to reproduce the same kind of impact but with a much smaller amplitude.

Altogether ten pairs of forecasts (with and without TEMP SHIPs) have been run. Five of them can be rated as "completely neutral". In the remaining five, three of them showed a very modest positive impact of the observations, and two of them a significant positive impact up to 48 hours. Let us note that no negative impact has been found, confirming that the quality of the observations is good on average (as indicated by routine monitoring) and that the North Atlantic radiosonde network has reached the "adult age". No significant synoptic impact could be detected beyond day 3, because when differences appear, they affect systems which are badly predicted in both forecasts. Also, except in one case showing a positive impact, the Northern Hemisphere scores never showed any significant impact.

These results confirm the ones documented in Gilchrist (1982) where it is stated that the impact of North Atlantic radiosondes is visible mainly in the small and synoptic features. They also confirm the importance of radiosonde information in a data sparse area like the North Atlantic, by describing accurately the three dimensional structure in temperature and wind of some particular weather systems.

On the period 9-13 September a "No SATEM" assimilation and four "No-SATEM" forecasts were also run and compared to the operational and "No North Atlantic TEMP SHIP" runs. Each of the four cases shows a small positive impact of the SATEM data on the Northern hemisphere scores (result which is different compared to previous OSEs at ECMWF) and a large positive impact on the Southern hemisphere (like in all the previous OSEs). The subjective impact on the synoptic features of the North Atlantic and Europe is neutral on average with some positive and negative aspects. The negative aspects are rather concentrated in small scales important for strong weather systems, where it is clear that the current satellite products cannot replace in-situ data such as TEMP SHIPs.

Finally the present paper should be read together with the documentation of similar experiments performed in the UK Met Office and the Deutscher Wetterdienst.

Acknowledgements

This study has been performed with the (direct or indirect) collaboration of several people, some inside, some outside ECMWF.

Inside ECMWF, I am grateful to the Met Ops Section (especially B. Strauss, A. Radford and K. Silvester) for their constant monitoring support. They were also always able to answer any particular observation problem with an amazing accuracy. Thanks also to L. Illari who ran the beginning of the "No SATEM" experiments for the September period, and to P. Undén who provided the means for removing of the spurious duplicates, and to J. Eyre who checked the manuscript, providing useful comments.

Outside ECMWF, all the members of the SEG (who initiated this study) should be mentioned. Finally this study was done in constant collaboration with R. Graham (UK Met Office) who did first a lot of preliminary studies to select the periods, and then ran the same type of experiments with the UK Met Office global model. Thanks also to C. Hall and J. Heming for their study of the January case.

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