Influence of observations on the operational ECMWF system

Reprinted from ECMWF Newsletter Number 76

Introduction

The global meteorological observing system is extremely expensive and in the present economic climate conventional observations such as radiosondes are beginning to be severely reduced. At the same time improved satellite systems are becoming available. The operational observing network, which uses both conventional and satellite measurements, influences how accurately the initial atmospheric state can be prescribed and therefore to a large extent the resulting forecast accuracy. There is therefore an urgent need to investigate the importance of different observing systems on Numerical Weather Prediction performance.

In this work we quantify through Observing System Experiments (OSEs), the contribution made by the main ground-based and satellite-based operational systems to medium range forecasting. In an OSE the impact of a specified observing system is assessed by comparing extended data assimilation and regular forecasts based on the total operational system with those generated excluding the particular observing system under investigation. The value of a new or experimental observing system can be assessed in a similar manner.

In a previous study Kelly et al. (1993) performed a series of OSE's using the then operational ECMWF system based on optimal interpolation (Lorenc; 1981). They used a baseline observing system consisting only of in-situ data, comprising radiosondes, aireps, synops, ships and buoys. OSEs were used to assess the impact of adding satellite derived temperature and humidity information (SATEMs) only, cloud motion winds (SATOBs) only, and SATEMs plus SATOBs to the baseline system. They found that adding SATEMs or SATOBs alone improved the forcast, but that adding both SATEMs and SATOBs gave less improvement than adding just one of those observing systems. These unsatisfactory results triggered an appraisal of the use of data in the O/I system and helped motivate the decision to develop a 3D-Var system which could analyse the Tiros Operational Vertical Sounder (TOVS) radiances directly, together with all other data. The purpose of this paper is to repeat and extend the earlier experiments, but this time using the 3D-Var assimilation system which became operational in early 1996. These new results, described in subsequent sections, demonstrate that the main observing systems are contributing in important ways to medium range forecasts in the Northern Hemisphere, in the Tropics, and in the Southern Hemisphere.

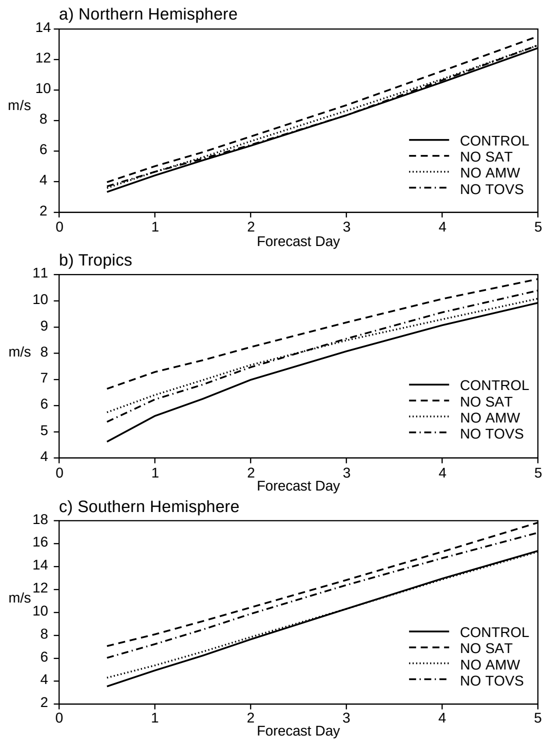

Fig. 1 a) Satellite OSE 200hPa Vector Wind Root Mean Square Forecast for a)Northern Hemisphere, b) Tropics, c) Southern Hemisphere.

Experiment design

Two series of Observing System Experiments (OSEs) were run for periods in December 1996 and February 1997. These experiments used the operational system of the 15th May 1997, which includes a revision to the background cost function of the variational analysis (Andersson et al. ; 1994, 1996), (Bouttier; 1997). In earlier experiments (Kelly et al.; 1993) problems were revealed with the use of SATEMs in the Northern Hemisphere (Kelly and Pailleux; 1988) and as a consequence these satellite data were removed from the Northern Hemisphere and Tropics until the introduction of 1D-Var (Eyre et al.; 1993). The interpretation of OSE's is not always straight-forward. The value of an observing system is most easily demonstrated when an energetic event seen only by one observing system occurs in the area being observed. A case study demonstrating this is included.

The new OSE experiments systematically removed the following observing systems from the full operational system:

- ♦ Satellite clear radiance data from the TOVS satellites (NOTOVS),
- ♦ Geostationary Atmospheric Motion Winds (AMWs) from cloud and water vapour (NOAMW),
- ♦ Radiosonde wind, temperature and humidity data (NORAOB),
- ♦ Aircraft winds and temperatures (NOAIREP),
- ♦ The combined removal of both a. and b. (NOSAT).

All of these experiments have been compared to the full operational system (CONTROL).

The results are grouped into two sections, first the satellite measurements and second the conventional upper-air measurements. All verification statistics use the operational ECMWF analysis. Similar results were obtained were obtained for the two periods, 5th to 20th December 1996 and 1st to 14th February 1997, therefore the two experiments have been combined to give a 29 day set of forecast scores.

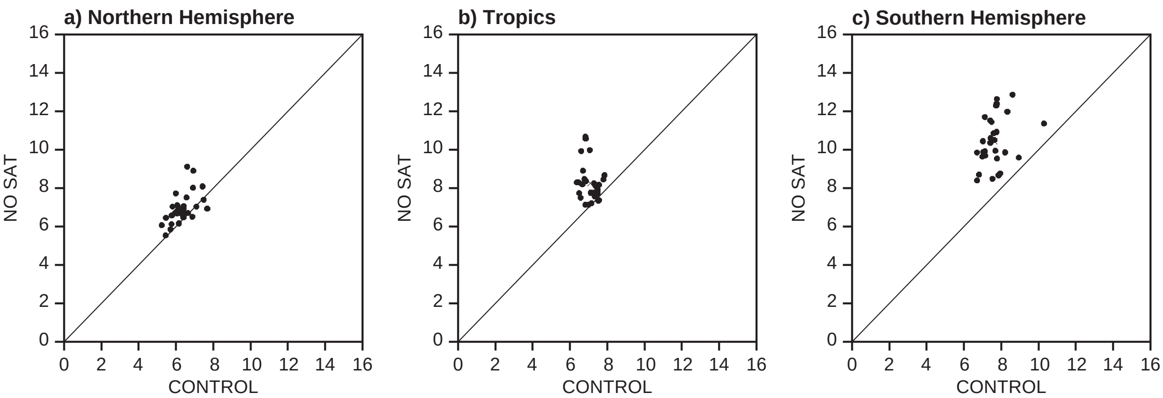

Fig. 2 a) Satellite OSE (control v NOSAT) 200hPa Vector Wind Root Mean Square 48 hour-forecast scatter plots for a) Northern Hemisphere, b) Tropics, c) Southern Hemisphere.

Results

Satellite OSEs

A series of four experiments have been included:

- ♦ CONTROL ♦ NOTOVS
- ♦ NOAMW ♦ NOSAT

The ERS scatterometer has been included in all experiments. Its impact will be discussed in a future article.

Forecast wind impact at 200 hPa

Aviation forecasts which use upper level winds are a major output product of NWP and the impact of satellite data on the upper level winds is illustrated. Figure 1 shows the overall impact of satellite data and it varies in the short range from 1/3 of a day in the Northern Hemisphere , to 1 1/2 days in both the Tropics and the Southern Hemisphere. AMWs have most value in the Tropics but give a significant improvement in the Northern Hemisphere. TOVS have a significant impact in the Tropics and large impact in the Southern Hemisphere.

The scatter of these forecast wind rms error for the NOSAT v CONTROL at day two is shown in Figure 2. Almost all forecasts are positive for the CONTROL . In all cases the CONTROL gives a smaller rms error and the largest deterioration in the NOSAT forecast varies from 2 m/s in the Northern Hemisphere to 5 m/s in the Tropics.

Forecast height impact at 500 hPa

Figure 3 shows the performance of the Operational ECMWF Forecast Model. The scores calculated are for 500hPa geopotential height anomaly correlation. The NOSAT experiment shows a negative impact in all areas. This is an important finding, as it is often suggested that it is not possible to demonstrate the impact of satellite data, especially in the Northern Hemisphere. This result comprises both the effect of AMWs and also of TOVS clear radiance data. In the case of AMWs there is a positive impact in the Northern hemisphere which must be largely influenced by the Tropics where the bulk of the data is found. TOVS data however has only a small impact in the Northern Hemisphere, its main impact being in the Southern Hemisphere where it improves the medium range forecast by up to 1 1/2 days. In the presence of TOVS data then the AMWs provide little additional benefit in the Southern Hemisphere. If TOVS data is not present then the AMWs have a positive impact.

Conventional upper air OSEs

The experiments included in this group are:

- CONTROL which uses all data,
- NORAOB which excludes both radiosonde winds, temperatures and humidy data,
- NOAIREP which excludes both aircraft wind and temperature observations.

For the purposes of comparison the NOAMW experiment will also be considered in this group in order to assess the relative importance of the AIREP and AMW wind observing systems.

Forecast wind impact at 200 hPa

The impact on the 200 hPa winds is shown in Figure 4. As for the satellite system experiments, all verification is based on the ECMWF operational analysis.

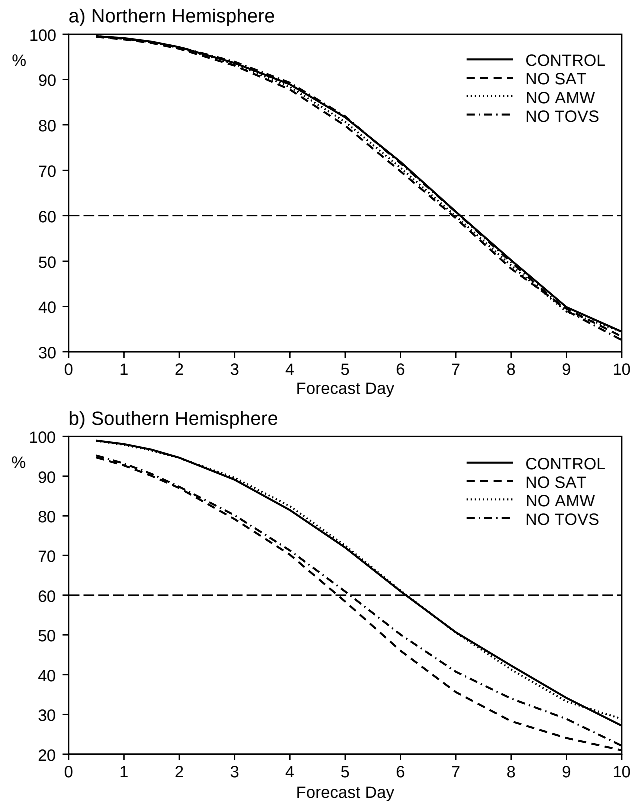

Fig. 3 Satellite OSE 500hPa Anomaly Correlation Forecast for a) Northern Hemisphere, b) Southern Hemisphere.

In the Northern Hemispheric the scores are dominated by the radiosondes, with their exclusion (NORAOB) the forecast accuracy is reduced by one day. The AMWs and AIREPs have a lesser effect and both have about equal weight, each degrading the forecast by 1/3 of a day if omitted.

In the Tropics, Radiosondes and AMWs have comparable impact of about 2/3 of a day. Removing the AIREPs has a smaller but still negative impact. Currently there are few Radiosondes in the Tropics and this number is being reduced. Sych a reduction will adversely affect forecast skill.

As seen previously TOVS data dominates the forecast impact in the Southern Hemisphere. Removing when degrades the forecast skill by around 1 1/2 days. Excluding the Radiosonde data in this region reduced the forecast skill about 1/3 of a day and AMW's and AIREP's have only a small impact.

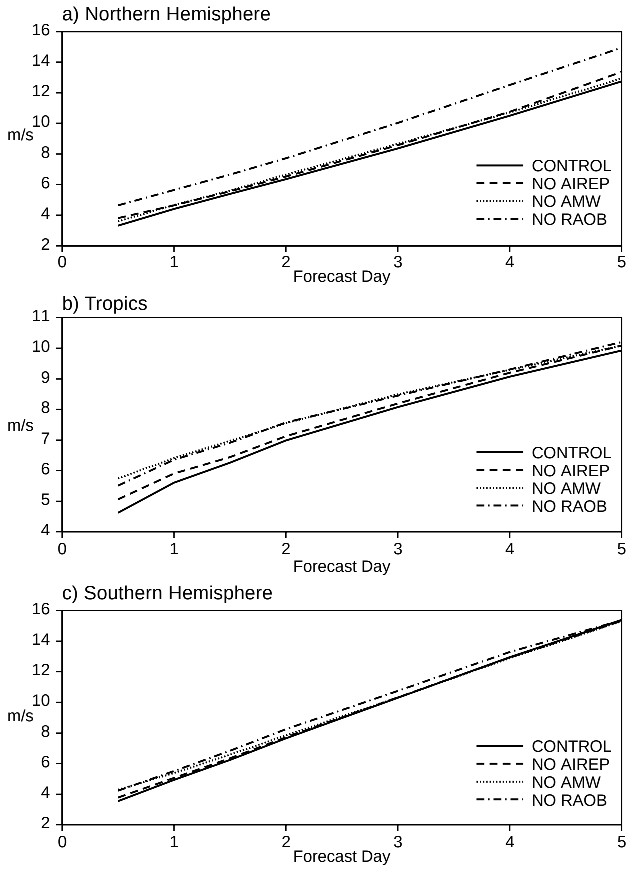

Fig. 4 a) Conventional Upper Air OSE 200hPa Vector Wind Root Mean Square Forecast for a) Northern Hemisphere, b) for Tropics, c) Southern Hemisphere.

Scatter plots are shown for NORAOB v CONTROL 48 hour forecasts (Figure 5) and almost all points in the three regions show a negative impact due to the exclusion of Radiosondes. The largest radiosonde impact is in the Northern Hemisphere and has a magnitude of about 3 m/s.

Forecast height impact

Figure 6. shows the 500 hPa anomaly correlation scores In the Northern Hemisphere the forecast accuracy is dominated by the radiosondes without which the five day forecast skill is reduced by about 1 day. The Radiosondes have less impact in the Southern Hemisphere. The influence of AMWs and AIREPs is somewhat smaller but still positive.

Synoptic case

After the discussion of objective scores it is of interest to look at the synoptic impact. A case has been selected during the February experiment in which strong cyclogenesis occurred in the North Atlantic. The base date of this situation is 12 UTC on the 10th of February 1997. As discussed, the OSE experiments which have the most impact are NORAOB and NOSAT and forecasts from these have been compared with the control and the verifying operational analysis.

The 48 hour forecasts and the verifying analysis are shown in Figure 7. Large errors are clearly seen in both the NORAOB and NOSAT south of Newfoundland. Both of these forecasts fail to deepen the low pressure system which is captured well in the control. In order to capture this development both the radiosonde and satellite observations are required. Another region in which the NORAOB experiment is further degraded in comparison with the remaining experiments is in the complex low pressure system extending from the mid-Atlantic, over Scotland and to East of the Baltic. In this experiment the system is much weaker in intensity than the control or NOSAT. The low pressure system in this complex near Scotland is also poorly forecast.

Moving to the 96 hour forecasts, shown in Figure 8, the low pressure system south of Newfoundland at day two has moved north-west and deepened. The control forecast provides the best representation of this low pressure system. It deepens the low considerably more than the other experiments even though its central pressure is too high and its position has a two-degree error. The complex low pressure seen in the 48 hour forecast has now developed into four main low

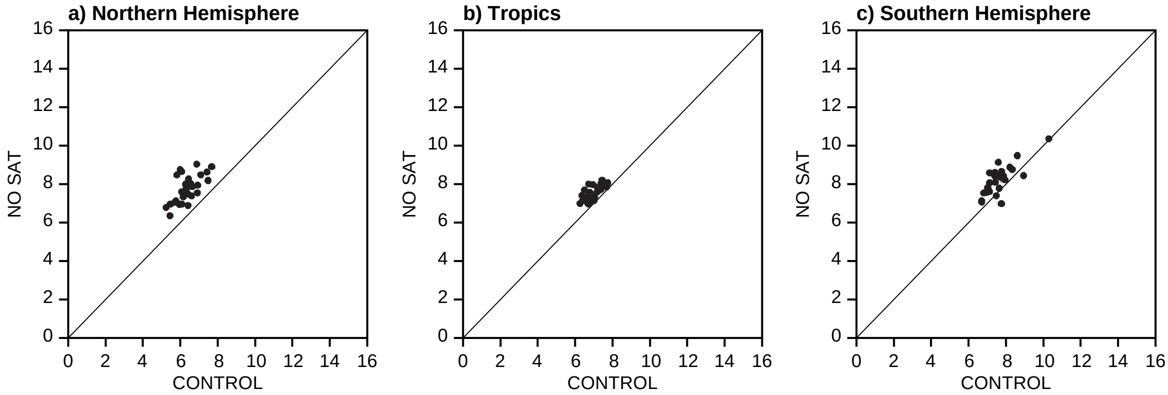

Fig. 5 Conventional Upper Air OSE (control v NORAOB) 200hPa Vector Wind Root Mean Square Forecast scatter plots for a) Northern Hemisphere, b) Tropics, c) Southern Hemisphere.

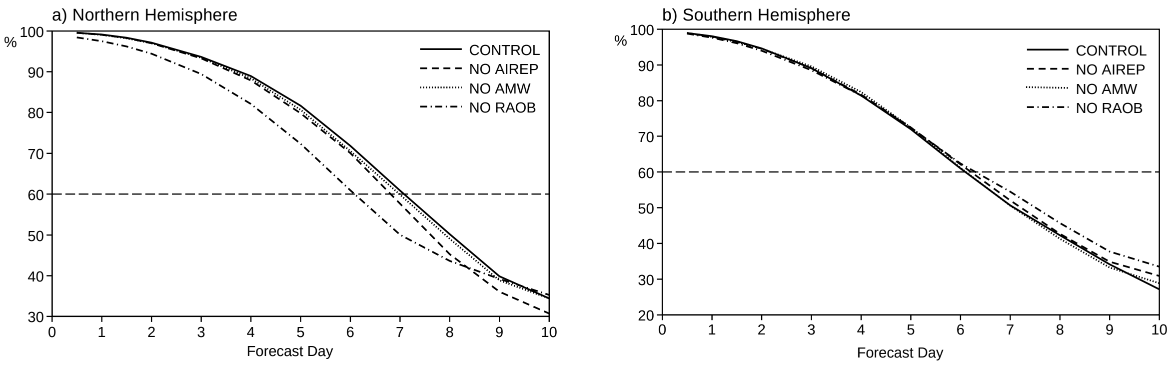

Fig. 6 Conventional Upper Air OSE 500hPa Anomaly Correlation Forecast for a) Northern Hemisphere, b) Conventional, c) Southern Hemisphere.

pressure systems. Large errors in the NORAOB forecast are evident providing a poor forecast for Europe. The NOSAT forecast is a little better but there is a large error in the system south of Ireland. In comparison the control forecast develops this low pressure system very well.

Conclusions and recommendations.

In general the results obtained in this set of experiments are encouraging. The current operational 3D-Var system has been shown to benefit from the assimilation of both satellite data and conventional observations and broadly speaking its performance in each of the Northern Hemisphere, the Tropics and the Southern Hemisphere is satisfactory. It is clear that in some regions there is a degree of redundancy in the current observing system but this is necessary to provide coverage in the event of occasional failures in parts of the observing system. However the inclusion of each data type almost always improves the forecast system which was not invariably the case in the past.

The satellite OSE's show that AMWs have a positive impact particularly in the Northern Hemisphere and the Tropics. High space and time resolution AMWs are now being produced and their impact should be tested. Alternatively, the TOVS clear radiances provides benefits in the Southern Hemisphere and the Tropics but have only a small impact in the Northern Hemisphere. In this region the Radiosonde network is particularly important in improving forecast accuracy.

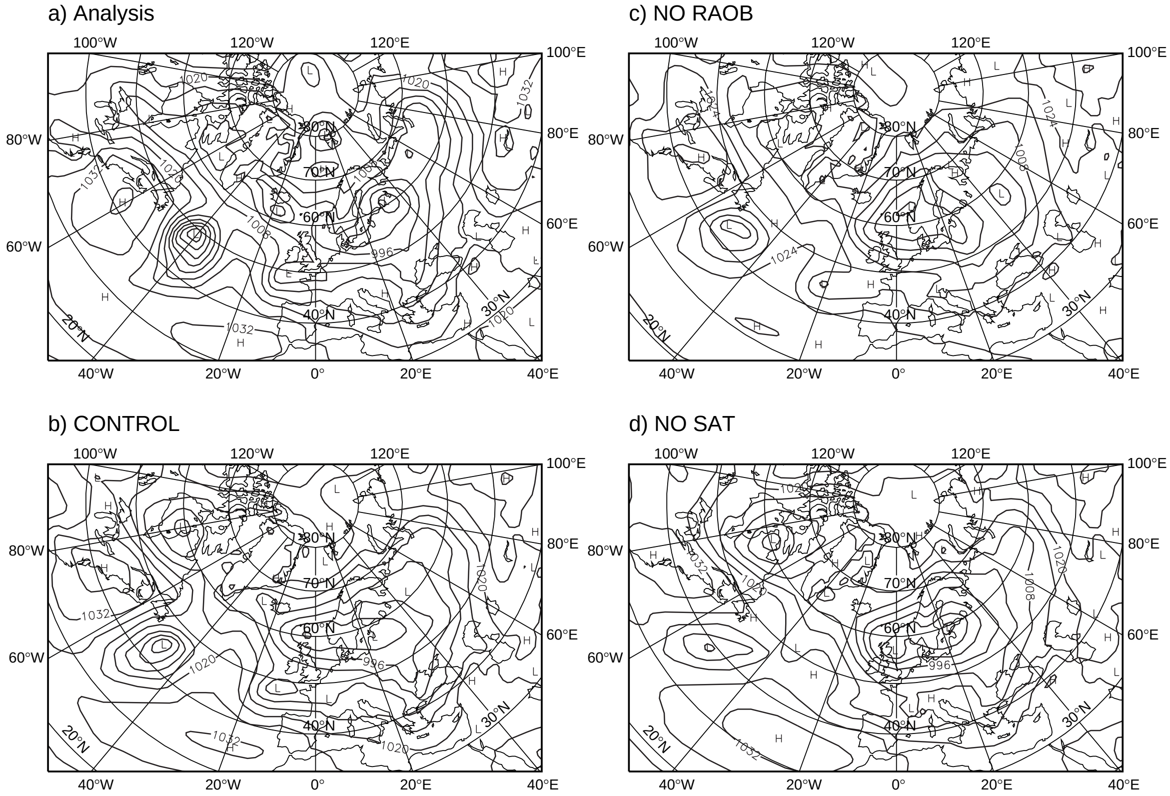

Fig. 7 MSL fields at 12 UTC 12/2/97 for a) analysis, b) 48-hour froecast for control experiment, c) 48 hour forecast for 'NORAOB' experiment, d) 48 hour forecast for 'NOSAT' experiment.

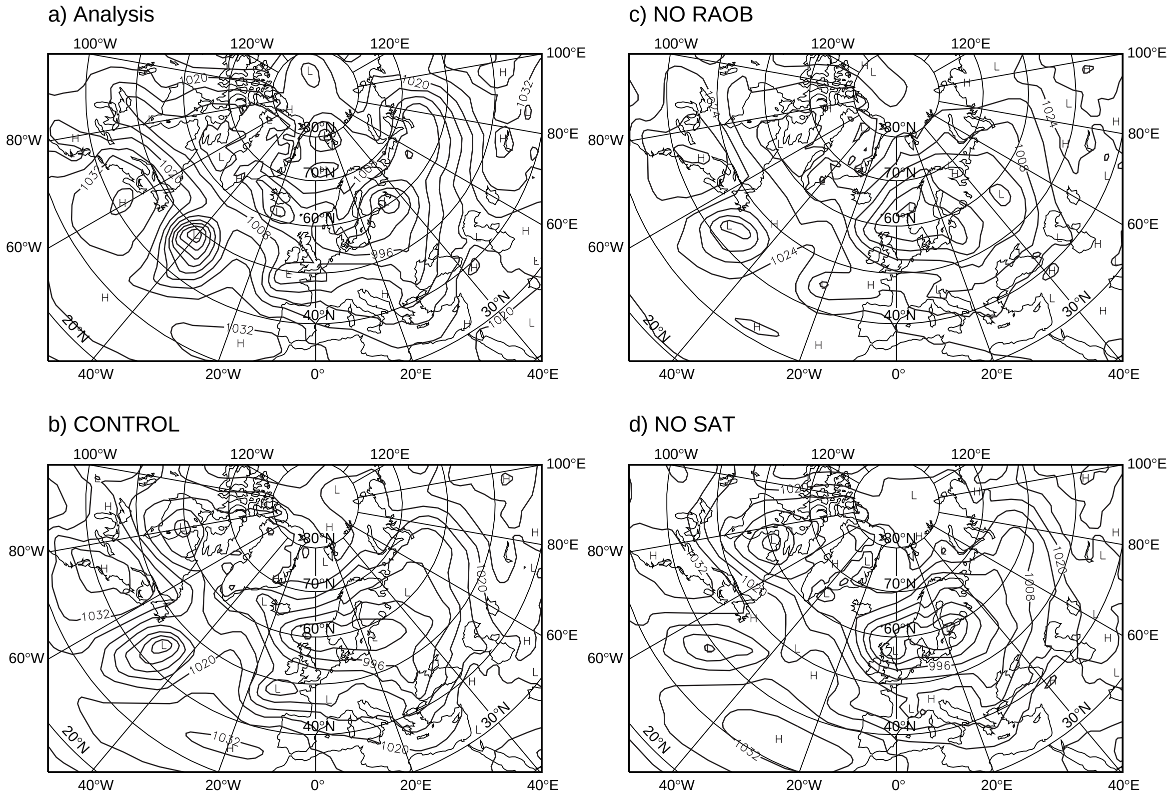

Fig. 8 Same as Fig. 7 but for the 96-hour forecast valid at 12 UTC 14/2/97.

However if the current trend to reduce this network continues it will soon result in a reduction in forcast accuracy. The large impact of TOVS in the Southern Hemisphere suggests that increasing the use of TOVS in the Northern Hemisphere could become a priority with the continuing decline of the Radiosonde network. Finally, TOVS data provided a large postivie impact on the Tropical winds, a result which has not been reported from previous experiments.

Graeme Kelly.

References

Andersson E., J. Haseler, P. Undén, P. Courtier, G. Kelly, D. Vasiljevic, C. Brankovic, C. Cardina, C. Gaffard, A. Hollingsworth, C. Jakob, P. Janssen, E. Klinker, A. Lanzinger, M. Miller, F. Rabier, A. Simmons, B. Strauss, J-N. Thépaut and Pedro Viterbo. 1996:The ECMWF implementation of three dimensional variational assimilation (3D-Var). Part III: Experimental results, accepted to .*Q. J. R. Meteorol. Soc.*.

Andersson E., J. Pailleux, J-N. Thépaut, J.R. Eyre, A.P. McNally, G.A. Kelly and P.Courtier, 1994: Use of cloud-cleared radiances in three/four-dimensional variational data assimilation. *Q. J. R. Meteorol. Soc.,* **120**, 627-653.

Bouttier F., Derber D. and Fisher M. The 1997 revision of the J_b term in 3D/4D-Var. ECMWF Tech. Memo. No. 238.

Eyre, J.R., G.A. Kelly, A.P. McNally, E. Andersson and A. Persson, 1993: Assimilation of TOVS radiance information through one-dimensional variational analysis. *Q. J. R. Meteorol. Soc.,* **119**, 1427-1463.

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

Kelly, G.A., J. Pailleux, F. Rabier and J-N Thepaut. 1993:Observing System Experiments made with the ECMWF System. World Weather Watch Tech. Report.16. WMO/TD No. 594.

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