TECHNICAL MEMORANDUM

325

EUCOS impact study

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December 2000

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen

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Abstract

In this paper the possibility of having a different observation network over Europe is examined in terms of impact on the analysis and forecast. The active radiosonde stations are reduced and same more aircraft data are distributed via GTS to the meteorological centres. Some radiosonde stations are transmitting also information at 06 and 18 UTC. The impact on the short and medium range forecast is very small; the benefit of having more radiosonde data is mainly over North and South-West of Europe. The extra aircraft observations have some impact on South-East Europe and on the short range forecast. However, during EUCOS period sensitive areas where errors are fast growing were more located over the North Pacific than over Europe. A further investigation by using Limited Area Model is recommended in order to investigate the impact in the very short range forecast and at small horizontal scale.

1. Introduction

The main goal of the EUCOS programme is to define an optimum European ground-based observing system supporting the short range weather forecast over Europe. Because of the high density coverage of radiosonde stations over Europe and in particular central Europe, a primary question arises on the possibility of reducing the operating radiosonde network and using a different observational system. Some network scenarios have been proposed by the EUCOS Scientific Advisory Team and by the EUMENET Programme Board on Observation and their evaluation with respect to the forecast performance over Europe is required. The EUCOS special observational campaign took place from 20 September to 14 November 1999, 27 radiosonde stations uniformly distributed (~500 km spacing) over the national territories of EUMETNET were activated four times per day (00, 06, 12 and 18 UTC) supplying wind, temperature and humidity measurements up to above the tropopause. The observational network also has been complemented by 116 AMDAR platform providing wind and temperature profiles below the tropopause. This paper illustrates the impact on the short and medium range forecast over Europe of assimilating less radiosonde and more aircraft vertical profiles. In Section 2, a description of the experiments performed is given. Results are shown in section 3. Preliminary conclusions are drawn in section 4.

2. Experiments

Three assimilation experiments have been performed using different numbers of radiosonde and aircraft observations. A 4D-Var assimilation system (*Rabier et al.*,1999, *Mahfouf and Rabier*, 1999) has been used. It employs a high-resolution model with full physical parametrizations at T319 spectral truncation using a linear grid and 60 vertical levels for comparing the observations with the atmospheric state. 4D-Var uses a lower resolution model at T63 to minimize the distance between the observations and the background field (6-hour forecast) and a simplified physics package (*Mahfouf*, 1999).This version of the assimilation system has been operational at ECMWF since 12 October 1999. In Table 1 are shown the experiment configurations in terms of observations used in the assimilation.

Exp	N. of TEMP	N. of AMDAR
S1	Control	Control
S2	-36	Control
S3	-36	+116

Table 1: Number and type of observations blacklisted in the experiments performed

S1 is the reference experiment which uses the same radiosonde and aircraft data as before the EUCOS campaign.

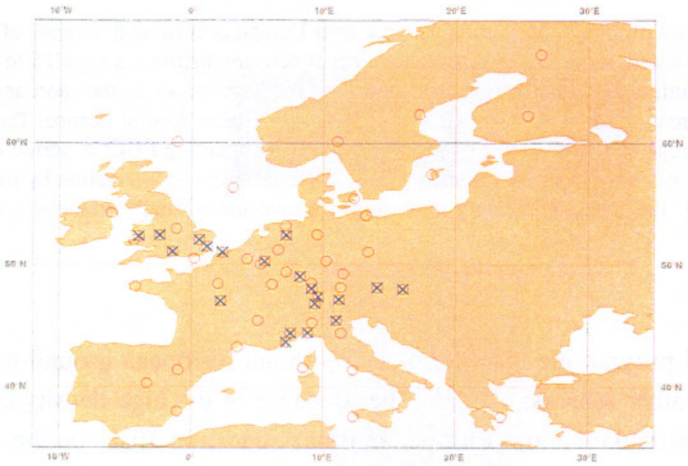

Figure 1: Blacklisted EUCOS radiosonde stations: Red dots in S2 and S3 experiments, blue crosses in S1

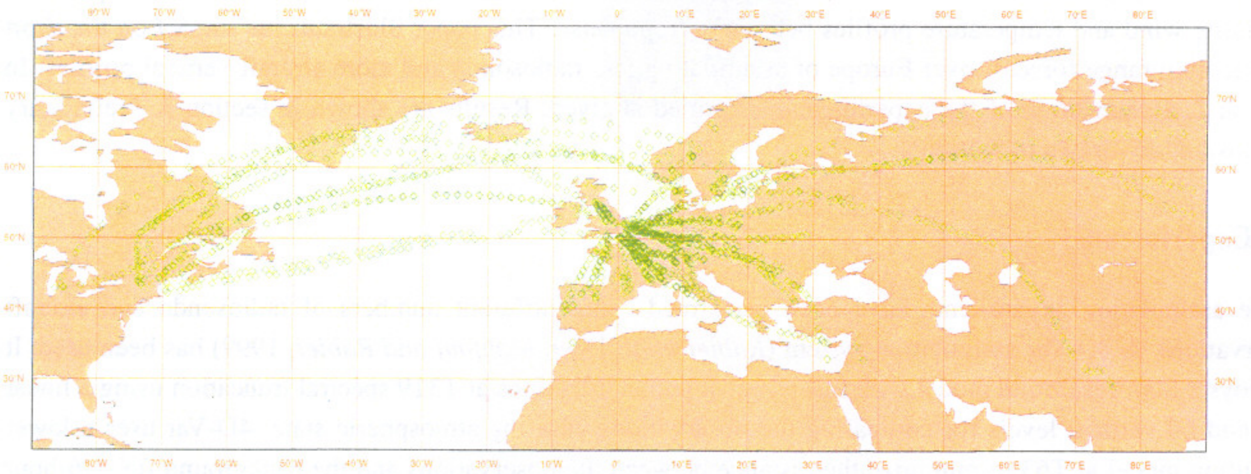

Figure 2: Typical daily data coverage of activated AMDAR data in S3 (green boxes)

In the S2 and S3 experiments, there are 36 radiosonde stations not used with respect to S1, and in S3 there are 116 more AMDAR platforms used than in S1and S2. In Fig 1, the S2 and S3 blacklisted stations during the EUCOS campaign are shown in red dots and the superimposed blue crosses are the radiosondes blacklisted in S1. The daily data coverage of the AMDAR observations assimilated in S3 is shown in Fig 2. The assimilation experiments have been performed for the full EUCOS period, 20 September - 14 November 1999 and the (hereafter named) operations, are the experimental suite up to the 12 October and the operational suite afterwards, when it became effectively operational.

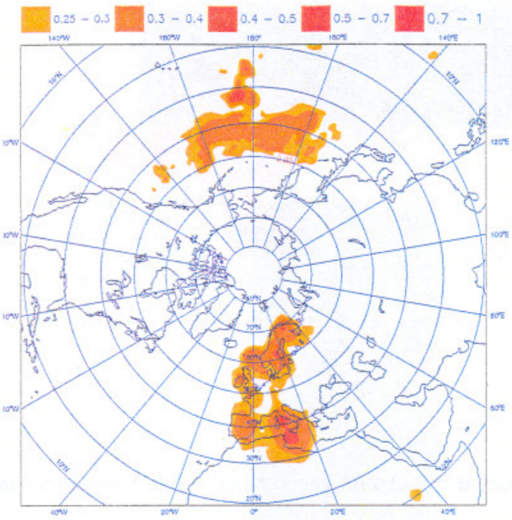

Figure 3: RMS of the analysis differences at 250 hPa for geopotential height between S1 and S2. Contours are in dam.

3. Results

The analysis and forecast comparisons between S1 and S2 would establish the impact of assimilating less vertical profiles of temperature, wind and humidity over Europe whilst by comparing S2 with S3 the impact of the extra AMDAR data can be shown. Results are presented for the full EUCOS period.

4. RMS analysis differences.

The root mean square (rms) of the analysis differences at 250 hPa for the geopotential height between S1 and S2 is depicted in Fig 3. The largest impact of the additional radiosonde observations in S1 is over North Europe and South-West Europe (5 m). Over the North Pacific where the atmospheric flow is more unstable, the analysis differences are mainly due to the rejection applied by the variational quality control (*Järvinen and Undén,* 1997; *Andersson and Järvinen,* 1999) (VarQC); small differences in the background field can result in having a different number and type of observations used in the analysis. Fig 4 shows the 250 hPa geopotential height of the rms analysis differences between S3 and S2, the largest impact is over Siberia (7 m) where some extra AMDAR were assimilated (Fig 2) and the observational coverage is not dense (in the North Atlantic there is little effect because of the already existing aircraft network). Similar difference patterns are depicted to a lesser extent at 500 hPa (S1 versus S2 and S3 versus S2) (not shown). The rms of the analysis differences at 250 hPa for the geopotential height between S3 and S1 is shown in Fig 5. The two figures (Fig 4 and 5)

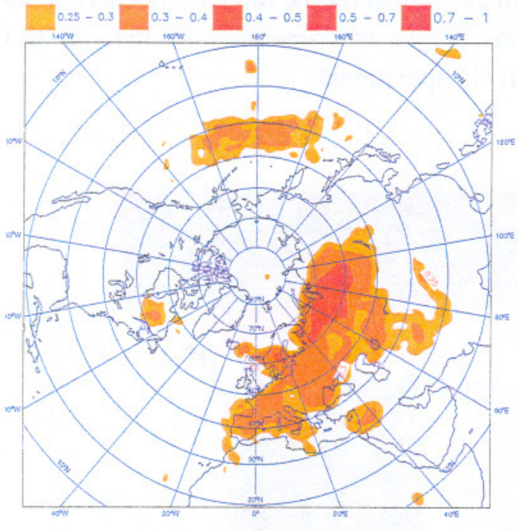

Figure 4: RMS of the analysis differences at 250 hPa for geopotential height between S3 and S2. Contours are in dam.

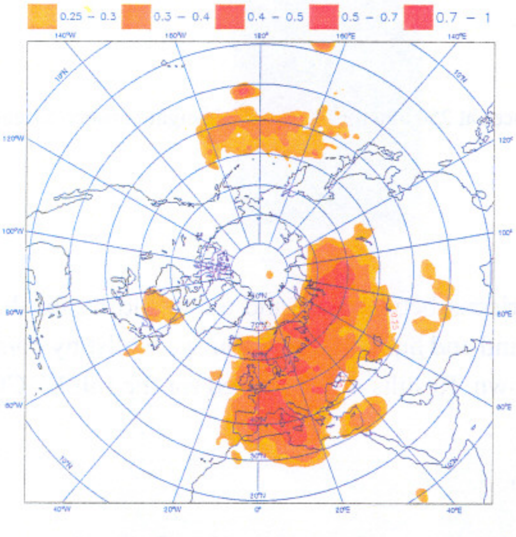

Figure 5: RMS of the analysis differences at 250 hPa for geopotential height between S3 and S1. Contours are in dam.

exhibit a similar shape (as expected) with larger differences (2 m) in some areas over Europe at the location of the radiosonde stations that have been blacklisted in S2 and S3 but used in S1.

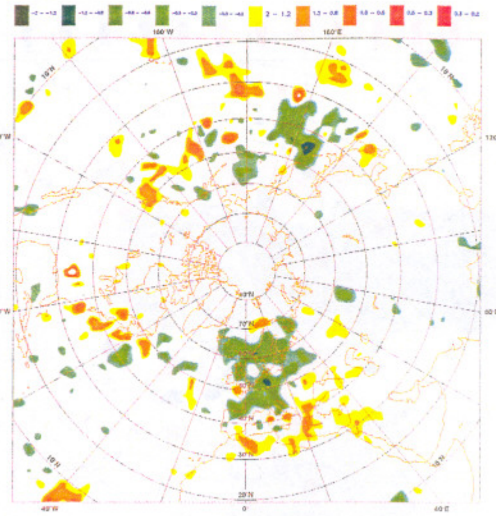

Figure 6: RMS of the analysis increment differences at 250 hPa for geopotential height between S1 and S2. Contours are in metres.

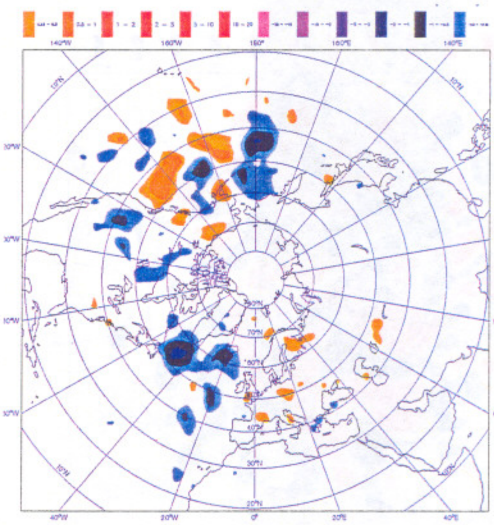

Figure 7: 48-hour RMS forecast error differences for geopotential height at 250 hPa between S2 and S1. Yellow (blue) contours indicate smaller (larger) error in S1. Contours are in dam.

5. RMS differences of analysis increments

The analysis increments are computed by subtracting the background field from the analysis. Small rms analysis increments are a sign of consistency of the short range forecast with the observations. Fig 6 shows the 250 hPa geopotential height differences between the rms of the analysis increments in S1 and S2. Positive differences are in yellow and negative ones are in green. S1 provides smaller increments over Europe (up to -

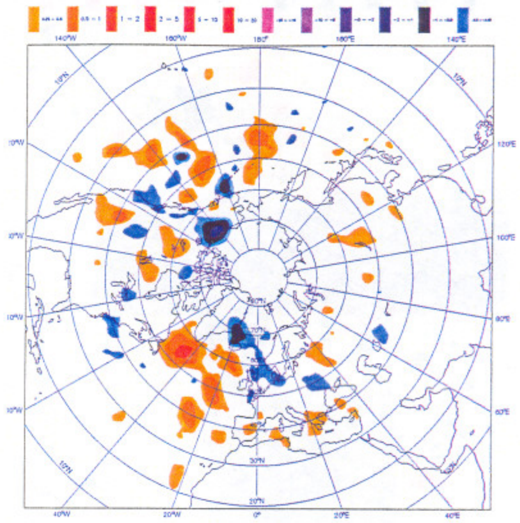

Figure 8: 48-hour RMS forecast error differences for geopotential height at 250 hPa between S1 and S3. Yellow (blue) contours indicate smaller (larger) error in S3. Contours are in dam

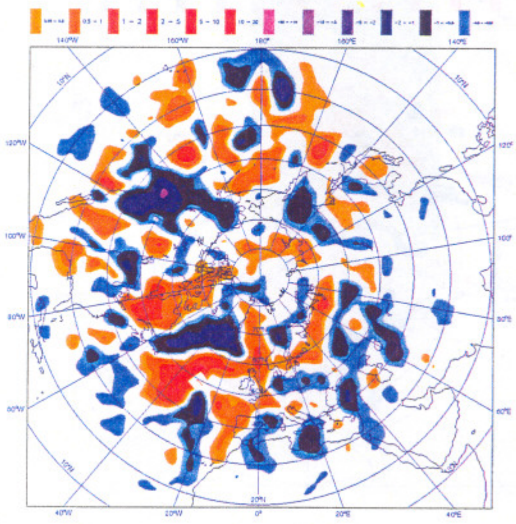

Figure 9: 120-hour RMS forecast error differences for geopotential height at 250 hPa between S2 and S1. Yellow (blue) contours indicate smaller (larger) error in S1. Contours are in dam.

1.2m) with the exception of some parts of the Mediterranean sea (up to +0.8 m). Similar results are obtained at 500 hPa. A similar pattern is shown when comparing the rms of the analysis increments in S3 and S2. S3 gives a consistent background improvement (up to 1.2 m) over Europe, over the North Atlantic and over Siberia (not shown).

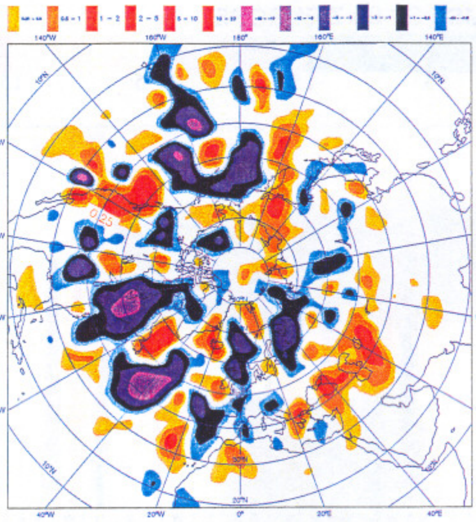

Figure 10: 120-hour RMS forecast error differences for geopotential height at 250 hPa between S1 and S3. Yellow (blue) contours indicate smaller (larger) error in S3. Contours are in dam

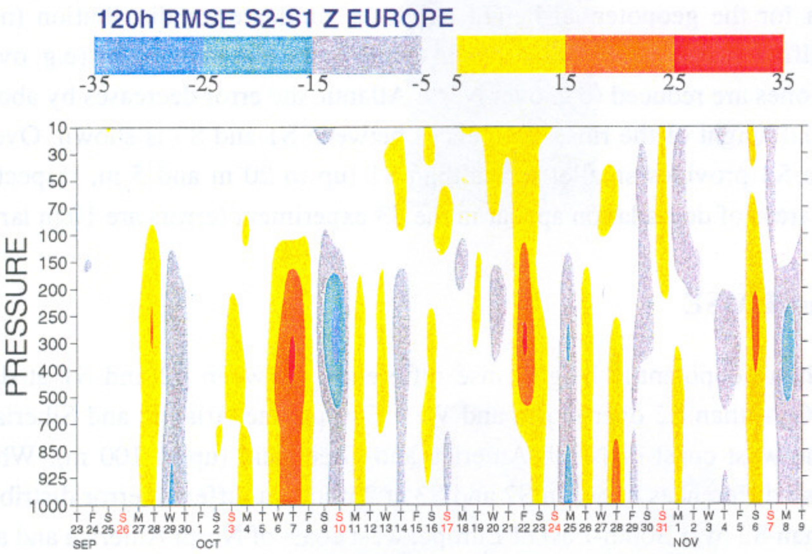

Figure 11: Cross section of 120-hour RMS forecast error differences for geopotential height averaged over Europe between S2 and S1. Yellow (blue) contours indicate larger (smaller) error in S1. Contours are in metres.

6. 48-hour forecast RMSE

The rms error of the 48-hour forecast has been computed for three experiments. Differences between S2 and S1 give a small positive impact of S1 with respect to S2 over Europe. In Fig 7, the 250 hPa geopotential height of the rmse differences between S2 and S1 is shown. Yellow (blue) shading indicates smaller (larger) errors in S1 than S2. After 48 hours, larger errors in S1 than S2 are in the Central Pacific, North America and North

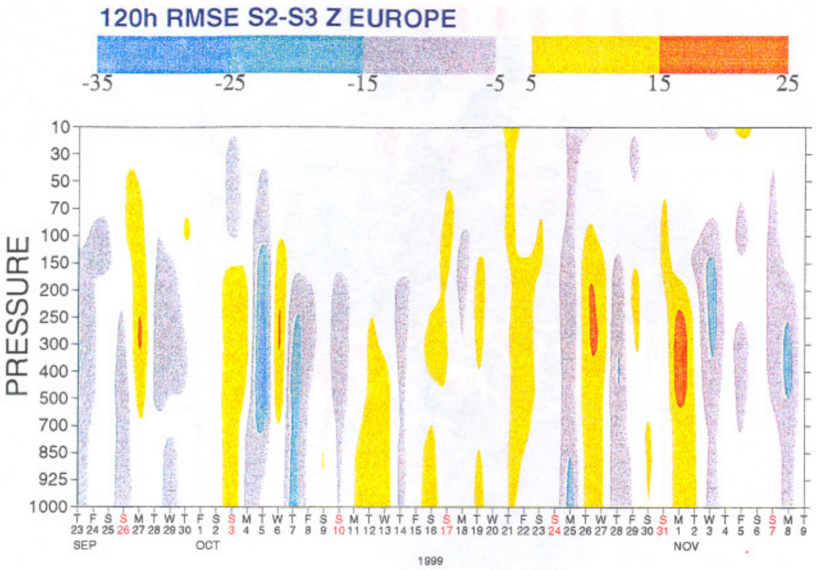

Figure 12: Cross section of 120-hour RMS forecast error differences for geopotential height averaged over Europe between S2 and S3. Yellow (blue) contours indicate larger (smaller) error in S3. Contours are in metres.

Atlantic (up to 20 m) whilst a smaller errors are in Europe (up to 5 m) and North Asia. Comparisons between S2 and S3 at 250 hPa for the geopotential height exhibit a similar error distribution (not shown) but the positive areas are amplified (error in S3 smaller than in S2) in space and in intensity (e.g. over Europe up to 10 m) whilst the negative ones are reduced (e.g. over North Atlantic the error decreases by about 10 m). In Fig 8, the 250 hPa geopotential height of the rmse differences between S1 and S3 is shown. Over the Atlantic and the Mediterranean area S3 provides smaller errors than S1 (up to 20 m and 5 m, respectively) whilst over North of Europe some areas of degradation appear in the S3 experiment (errors are 10 m larger in S3 than S1).

7. 120-hour forecast RMSE

Fig 9 shows the 250 hPa geopotential height rmse differences between S2 and S1 at day 5: S1 provides smaller errors, up to 50 m, than S2 over North and West Europe, the Atlantic and Siberia; larger errors are mainly located over the west coast of North America and Greenland (up to 100 m). When comparing the geopotential height rmse differences between S2 and S3 at 250 hPa a different error distribution is displayed, S3 has smaller errors than S2 over South-East of Europe, west coast of North America and a small region over the Pacific and the Atlantic ocean (not shown). Over North and West Europe S3 provides larger error than S2 whilst S1 gives smaller errors than S2. In Fig10 is shown the 250 hPa geopotential height rmse differences between S1 and S3 at day 5. In general, S1 is performing better than S3 over the North Atlantic and Europe (errors are up to 20 m smaller). On the South-East of Europe there is still (with respect to the day 2) a region where S3 provides smaller errors than S1 (up to 20m). The 5-day forecast rmse on a vertical cross section (from 1000 to 10 hPa) averaged over Europe has been computed for the three experiments and the full EUCOS period. Fig 11 shows the differences between S2 and S1, yellow (blue) contours indicate S1 has smaller (larger) mean error than S2. The starting date of the 5-day forecast is on the x-axis and pressure levels on the y-axis, contours are in metres. The map shows 2 cases where the error in S1 experiment is 35 m smaller than S2 and only one case where it is larger. In general, both assimilation experiments provide a not systematic impact on the 5-day forecast performance over Europe, only in very few cases S1 is better than S2.

Comparisons between S2 and S3 are shown in fig 12; S3 is performing slightly worse than S2, and once more there is not a persistent negative or positive impact between the two experiments. In order to understand whether differences in rmse are significant or not, a paired comparison test has been performed for Europe.The T-test tests the null hypothesis that the mean of the population sampled is zero. The population sample is the rmse differences between the experiments: S2-S1 and S2-S3 for the independent events. The T-

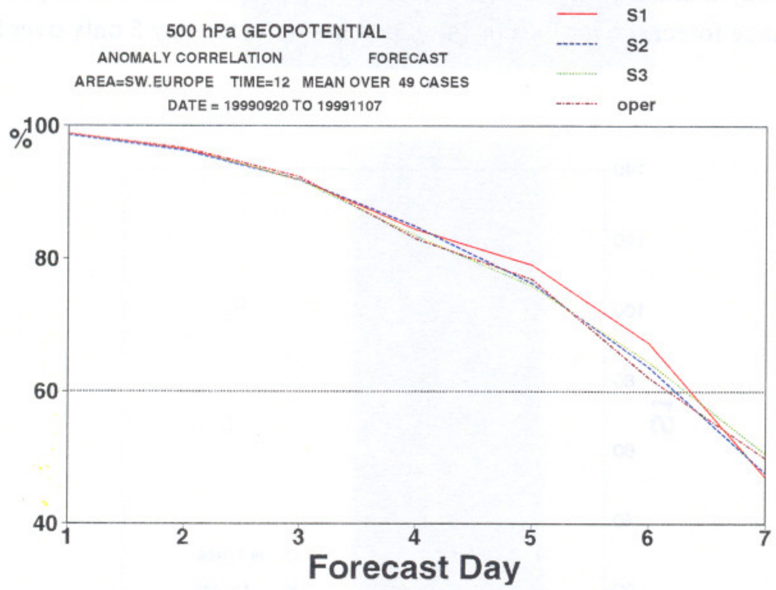

Figure 13: 500 hPa geopotential anomaly correlation for South-West Europe verified against the own analysis for S1 (red), S2 (blue), S3 (green) and operations (brown).

test indicates that S1 is better than S2 at the 10% level on 5 and 6-day forecast (1000 and 500 hPa) whilst it is worse than S2 on the 4-day forecast (500 and 200 hPa). S3 is better than S2 at the 10% level on the 1-day forecast and it is worse at the 1% level on the 4-day forecast (1000 and 500 hPa). However, the T-test results should be taken with caution because the test assumes that errors are uncorrelated between forecasts which it is not always true.

8. Anomaly correlation score

The 7-day anomaly correlation score for the three experiments has been computed against radiosonde observations and the corresponding analysis. Results in both cases show very little impact at every vertical level and over different regions. S2 has a minor positive impact with respect to S1 and S3 in North America (not shown), whilst S1 is performing slightly better over Europe. In Fig 13 the 500 hPa geopotential height anomaly correlation for South-West Europe clarifies for which area of Europe S1 is performing better. The ECMWF operational suite (brown dash line) using all the EUCOS observations is not performing better than S1.

9. Comparisons between S1 and S3

In general, very little forecast impact is found between the experiments S1 and S3 on the short and medium range over the Northern Hemisphere. The only significant impact is over Europe at 500 hPa on the 5-day forecast with S3 worse than S1 at the 10% level (Fig 14). The scatter plot shows that S3 provides a much larger error in 8 cases out of 49. Two of these cases are presented in paragraph 4. The rmse differences between S1 and S3 at day 2 and 5 (Fig 8 and 10, respectively) indicates that S3 is performing slightly better than S1 on the short range forecast over Europe but it persists up to the day 5 only over South-East of Europe.

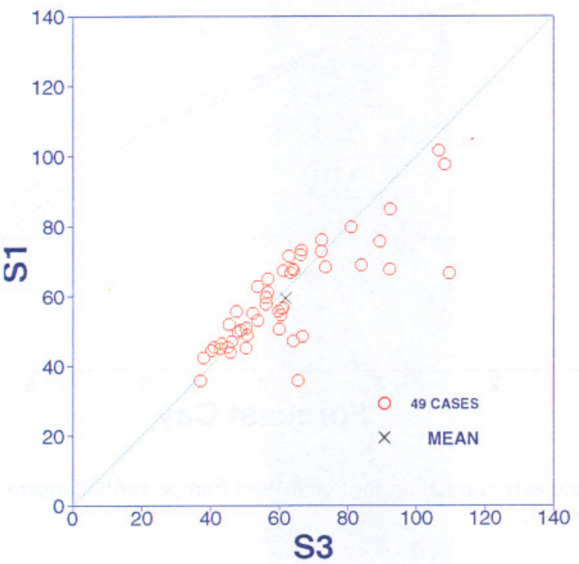

Figure 14: 500 hPa geopotential height rmse scatter plot of 5-day forecast over Europe of S1 versus S3. Number of cases 49. Errors are in meter

10. Cases study

In this paragraph some cases of interest during the EUCOS period are presented. In general, the synoptic maps of the 3 and 5-day forecast for the S1, S2, S3 experiments and operation have not shown many differences with respect to the verifying operational analysis. The rmse experiments differences (e.g Fig 11 and 12 for 5-day forecast) are not corresponding to significant changes of the forecasted synoptic situations.

In the first week of October, the Figs 11,12 show S1 having smaller errors than S2 and S3. On the 5 October, a WV satellite image from GOES-8 (not shown) indicates a confluence zone (East coast of North America) of a polar and tropical jet. The geopotential and wind increments map at 200 hPa is shown in Fig 15. The increments are due to the single level (~250hPa) temperature and wind observations from the extra EUCOS AMDAR data. The observations have increased the anticyclonic vorticity field. The geopotential height sensitivity map (computed operationally) at 500 hPa valid for the 5 October indicates the East coast of North America as a potential region of fast growing error (not shown). The forecast error tracking is spotting the

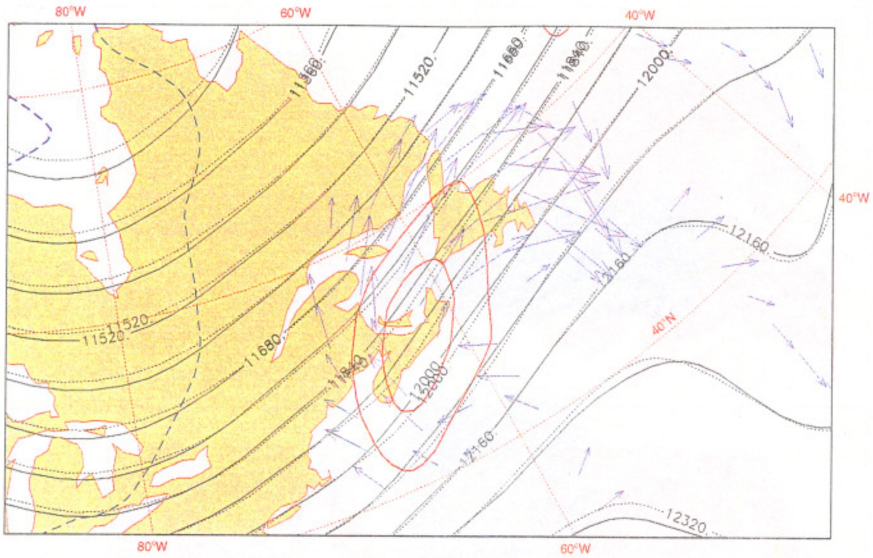

Figure 15: 200 hPa operational wind and geopotential height increments valid on 991005 at 12 UTC. Positive height increments are in red (solid line) and negative in blue (dash line). Contours every 10m. The wind vectors unit are $5ms^{-1}$. Solid black line is the geopotential analysis field and dot line is the first guess field. Contours every 80 m.

same area as a region of initial evolution of the 5-day forecast error over the North East of Europe (not shown). Fig 16 shows a 5-day forecast of the 500 hPa geopotential height over Europe for all the experiments. From the top to the bottom panel and from the left to the right hand-side are the verifying operational analysis, S1, S2, S3 and operational forecast, respectively. The differences among the 5-day forecast experiments are on the position and intensity of the low over the North-East of Europe. In particular, S3 and operational forecasts show a less deep trough (omega pattern). The extra AMDAR data over the East coast of North America have moved the jet position slightly northwards (Fig 15); these observations were in good agreement with SATOB, PILOT and TEMP wind observations in the same area, nevertheless the 5-day forecast over Europe has been degraded.

A similar case occurred on the 22 October; among all the experiments the best 5-day forecast over Europe is performed by S1. S1 shows a better 500 hPa forecasted ridge over the North-West of Europe and a better low over the South-West coast of Europe (not shown). Some operational geopotential analysis increments are created at 200 hPa on the 22nd of October at 12 UTC, South of Greenland, by the extra AMDAR data. The forecast error tracking indicates that the initial error is trapped on the evolving trough over the East Atlantic (Fig 17). There is no clear indication that the AMDAR data were of doubtful quality. Unfortunately no other types of data were in that region apart from few other AIREPs (from a different flight) which agreed with the AMDAR observations.

In the first week of November the general circulation was characterized by the evolution of a blocking situation over the Western edge of the continent with a cut-off low over the South of Europe. Fig 18 shows the operational geopotential and wind increments at 500 hPa to be mainly located over England, the North of France and the North sea for the 6 November 1999, 12UTC. The increments are due to some radiosonde stations that were blacklisted in the experiments S2 and S3. The operational sensitivity map indicates the area susceptible to analysis errors (Fig 19). Superimposed at the field are the radiosonde stations blacklisted in S2

Figure 16: 500 hPa geopotential height for the operational verifying analysis on the 991010 at 12 UTC (left-hand, top panel), 5-day forecast of S1, S2, S3 and operations from the top to the bottom panel. Contours every 10 dam.

and S3 but used in S1 (black open circle). At day 5, S1 and the operations can depict the cut-off low better than S2 and S3 (not shown). The assimilation of the observations from all the stations over the Atlantic border (Brest, Aberporth, Hillsborough, Herstmonceux, Nottingham Watnall and Ekofisk) have been very important in this particular meteorological situation.

For these three cases, one more experiment has been performed (S1 12-hourly) in which the measurements at 06 and 18 UTC for the radiosonde stations reporting 6-hourly (special EUCOS observations) have been blacklisted. The differences between S1 and S1 12-hourly are negligible, even in the 991106 case where the extra radiosonde stations have been found important for the 5-day forecast.

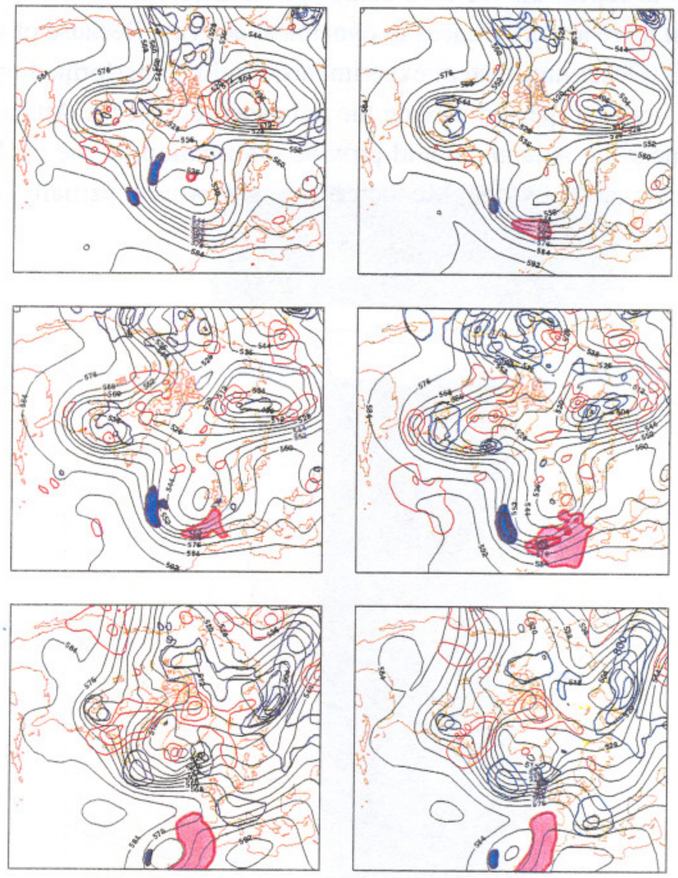

Figure 17: 500 hPa 5-day forecast geopotential height error track. Forecast step is 12, 24, 36, 48, 108, 120 hours from the top to the bottom panel and from the left to the right hand. The solid black line is the forecast field (contours every 8 dam). Positive error contours are in red and negative in blue. The errors track is shadow in red (positive) and blue (negative).

11. Conclusion

Assimilation and forecast experiments have been performed in order to investigate the impact of different observation-network configurations. In general, only a very small impact has been noticed either by reducing the radiosonde network or by increasing the AMDAR data.

The benefit of having more radiosonde data (S1) is mainly over North and South-West Europe, likely due to the stations on the Atlantic coasts. The extra AMDAR observations have some impact on South-East Europe on the short range forecast. However, a map of key sensitivity analysis (*Rabie*r et al., 1996) for the 2 months of the EUCOS period shows that the most sensitive areas where errors are fast growing were not located over Europe but mainly over the North Pacific and the North-East Atlantic oceans (not shown) which could have compromised the significance of the results.

A meaningful impact over the continental Europe could probably be seen in the very short range forecast and at small horizontal scale that suggests a further investigation on the EUCOS period by using Limited Area Models.

An ideal solution would be to repeat the EUCOS campaign in different seasons (winter: January-February; summer: July-August) when there are differences in dynamical activity. Because of the difficulty of repeating such a campaign some OSE (Observing system experiments) could be performed by reducing the number of radiosonde stations over central Europe and leaving the radiosondes over the Atlantic and the Mediterranean borders. The observations near the Atlantic would provide information on the cyclones developed over the ocean and the measurements near by the Mediterranean sea would partially compensate the lack of information over the North Africa continent.

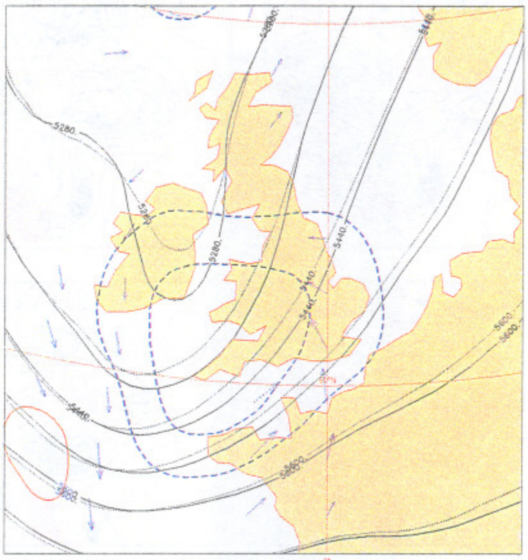

Figure 18: 500 hPa operational wind and geopotential height increments valid on 991106 at 12 UTC. Positive height increme are in red (solid line) and negative in blue (dash line). Contours every 10m. The wind vectors unit are 5ms^{-1}. Solid black line is t geopotential analysis field and dot line is the first guess field. Contours every 80 m.

On the full EUCOS period, a few cases have been selected and the performance of the three experiments investigated. S1 has been found to provide a better 5-day forecast with respect to S2 and S3. The EUCOS AMDAR data have been found to slightly degrade the quality of the forecast despite being in agreement with other observation types. A possible explanation of the forecast deterioration could be the assumption of uncorrelated observation error which is possibly untrue for high frequency and close reports. In some synoptic situations (Atlantic blocking) to assimilate more radiosonde data over the Atlantic borders has been found to benefit the 5-day forecast.

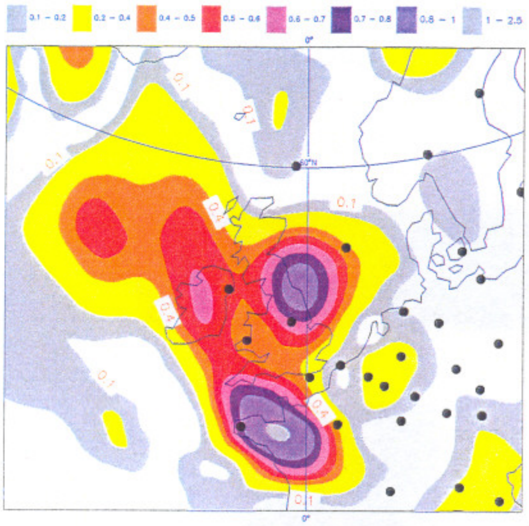

Figure 19: Key sensitivity analysis valid for 991106 for the 500 hPa geopotential height

Acknowledgements

I am grateful to Ernst Klinker for the time spent in discussion with me and to Antonio Garcìa Mèndez for providing all the information available on the EUCOS observations.

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