TECHNICAL MEMORANDUM

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High-frequency AMDAR data – a European aircraft data collection trial and impact assessment

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Abstract

In an effort to optimize the benefit and the value-for-money of the European AMDAR programme (E-AMDAR), EUCOS has developed a data collection strategy limiting the number of aircraft data to one profile (ascent or decent) per three hours per airport. Telecommunication expense associated with the AMDAR data collection can thus be redirected from the busiest airports in Europe to the more remote locations served by the E-AMDAR programme. A data collection trial experiment was initiated by EUCOS to test the effectiveness of the proposed strategy. In two 6-week special observing periods, one in spring and one in the autumn of 2003, as much as practically possible of all the high-frequency AMDAR data (HF-AMDAR) were collected in near-real time. These enhanced sets of European AMDAR data were used by the ECMWF operational system. At a later time the EUCOS-proposed data selection rules were applied to the HF_AMDAR data sets, and the resulting reduced data sets (RQ-AMDAR) with about 50% less data were made available. ECMWF conducted data assimilation experiments to assess the relative analysis and forecast impact of RQ with respect to HF, in its operational Numerical Weather Prediction system. Comparisons between HF and RQ show a 60-70% reduction in the number of used profiling data in the vicinity of airports and used in-flight data over the North Atlantic.

In the Central European area, the analysis is quite insensitive to the RQ reduction in data collection. Larger differences are found in Eastern Europe, over the European Seas and coastal regions, and Scandinavia. For Central Europe it is quite clear that the AMDAR collection can safely be reduced, given the present level of data redundancy in that area, as shown by information content analysis. Our results lend some support to EUCOS proposed data collection strategy, showing that its implementation will lead to a more uniform, and largely sufficient data coverage, at a lesser cost, with only very minor degradation in NWP performance. The data reduction should be limited to Central Europe profiling AMDAR, whereas elsewhere in Europe and at flight level, efforts should be made to maintain high AMDAR data coverage, and to further extend it in the future.

1. Introduction

1.1 The E-AMDAR programme

In recent years the number and the coverage of aircraft data has increased very significantly - in particular the automated ACARS[1] and AMDAR[2] systems (WMO 1996). The collection and distribution of European AMDAR data is managed through the E-AMDAR programme of EUCOS[3] (see www.eumetnet.eu.org). The objectives of E-AMDAR are to maximise the efficiency/cost ratio of implementing AMDAR systems for EUMETNET's participating national weather services by reducing duplication in the use of resources and seeking to meet requirements in the most cost-effective manner. The requirements are to provide:

- ascent/descent measurements as a complement and potential substitute for radiosondes on the territory of EUMETNET Members at over 140 European airports, 35 of which should provide at least 3 hourly profiles during the day time.
- measurements from data sparse areas having an incidence on short range forecasts in Europe, to be adjusted as necessary according to the results of the EUCOS design studies (routes from Europe to North Africa, South America and Canada, over Siberia and the Arctic).

Figure 1 shows the recent 4.5-year evolution of the number of E-AMDAR data used in ECMWF's operational system (January 2000 to June 2004). The numbers have increased by a factor five from 4,000 to 20,000 per day in this period, due to several factors: a general increase in the number of E-AMDAR equipped aircraft, enhanced data collection, and changes in the data usage (thinning, data selection and

[1] Aircraft Communication Addressing and Reporting System
[2] Aircraft Meteorological Data Relay
[3] The EUMETNET (The Network of European Meteorological Services) Composite Observing System

quality control) in the data assimilation system. The sudden increase in January 2002 in Figure 1 is due to an important change in the aircraft data selection criteria at ECMWF that allowed many more of the data to be used (Cardinali et al. 2003). The current data selection algorithm thins data from each flight independently to one observation per 60 km for flight-level data, and one observation per model level for ascent and descent data. The two peaks in 2003 represent the two EUCOS special observing periods that are the subject of this report.

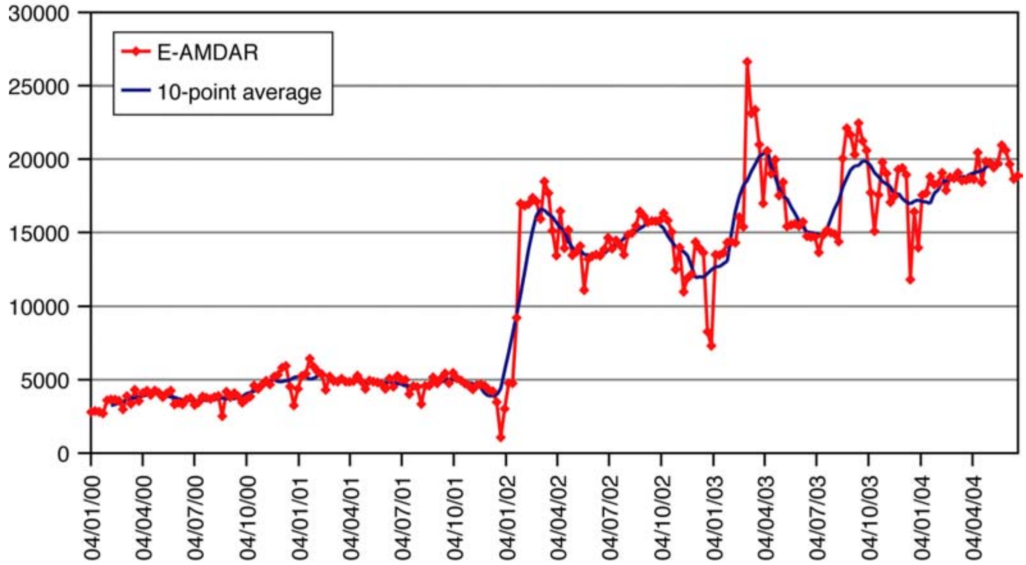

Figure 1 Time series of 24-hour data counts for E-AMDAR data used in ECMWF's operational data assimilation system, January 2000 to June 2004, in red sampling every seven days (Tuesdays, 2100-2059 UTC, thus avoiding the weekly variations). The blue curve shows the running 10-point average.

1.2 NWP impact of aircraft data

Globally the number of aircraft reports currently (November 2004) received at ECMWF is in excess of 150,000 per day providing point measurements of wind and temperature. The data are irregularly distributed over the globe with dense concentrations over the United States, Europe and along the main inter-continental air traffic routes[4]. AMDAR reports are often produced at the specified frequency of one report per seven minutes at cruise level, with additional reports at wind maxima. Ascent reporting is at 10 hPa intervals vertically for the first 100 hPa in the lower part of the profile and every 50 hPa above that layer to top of climb (near 20,000 feet) with the reverse applying during the descent phase. The AMDAR system thus provides altitude data roughly every 70-100 km along the flight path as well as detailed profiles in the near vicinity of airports.

Substantial benefit in global and regional NWP of the aircraft data has been demonstrated in several studies (Rukhovets et al. 1998; Cardinali et al. 2003; Kelly et al. 2004). As an example we show in Figure 2 the day-2 forecast impact from a recent observing system experiment (OSE) by Kelly et al. (2004). The yellow shading indicates where withholding aircraft data has degraded forecast skill, that is increased the rms of forecast error. In these experiments all available aircraft data had been removed from the assimilation. There is clear positive impact of using the data on the day-2 forecast over the North Pacific, North America, North Atlantic and Europe.

[4] Up-to-date data coverage maps are available at www.ecmwf.int.

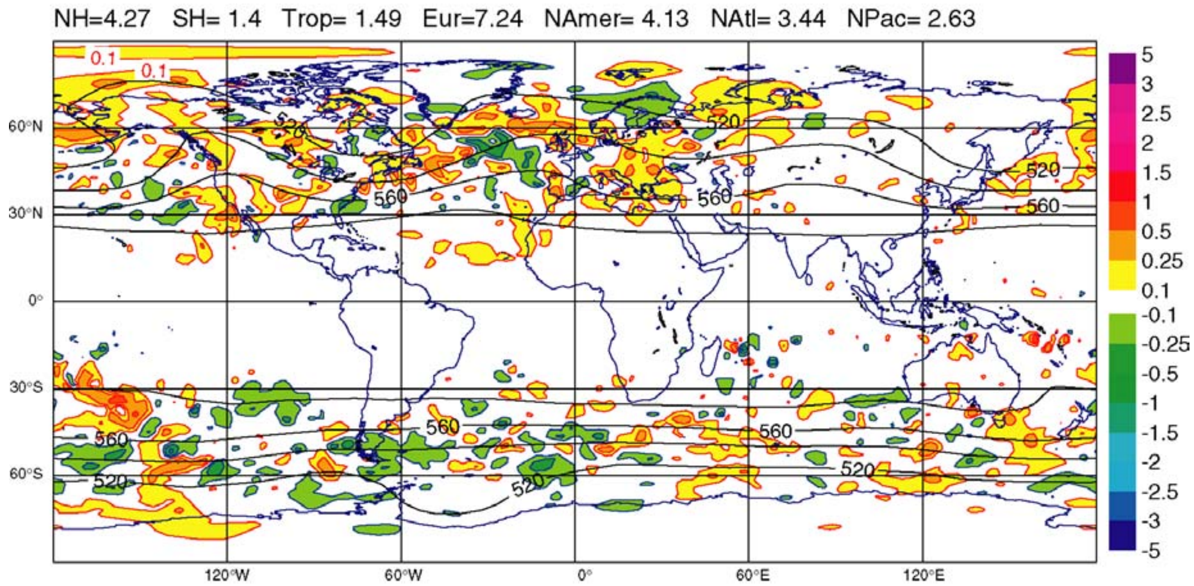

Figure 2 Day-2 forecast impact from withdrawing all aircraft data from the ECMWF data assimilation system, in the period 20021212-20030209, in terms of rms of 500 hPa geopotential height error. Shading starts at +-0.1 dam, with yellow (green) shading indicating larger (smaller) without aircraft data. Area-integrated values in m^2s^{-2} are given in the legend. (Data provided by Graeme Kelly, ECMWF, see also Kelly et al. 2004). Black contours show the mean analysed 500 hPa geopotential (interval 40 dam).

2. The high-frequency AMDAR observing system experiment

2.1 Study objectives

There are telecommunications costs associated with the collection of the aircraft data. In order to optimize efficiency and value for money, the E-AMDAR programme has implemented the mechanisms required to configure the data collection on a flight-by-flight basis, in collaboration with each of the collaborating fleet operators. The normal procedures in 2003 would seek to collect less of the data from flights on the most frequent routes, in favour of flights from the less well-covered areas. It is an objective of the E-AMDAR programme to optimize the fleet-configuration with respect to the other components of the European observing system. The last EUCOS observing system experiment (OSE) was conducted in 1999. This demonstrated that 830 AMDAR profiles per day compensated for a reduction in the European upper-air network to approximately 40 stations (Cardinali 2000). This became the basis for the EUCOS upper-air network design.

In the present OSE the objectives are to investigate the relative benefit derived from:

- European AMDAR profiles captured where possible at up to ½ hour frequency (otherwise as E-AMDAR fleet coverage allows) together with the associated level flight data. This configuration will be referred to as HF_AMDAR in the following.
- AMDAR coverage according to the current EUCOS requirement, this being 3-hourly profiles (and associated flight-level data) from airports spaced every 250 km. This will be referred to as RQ_AMDAR in the following.

2.2 The special observing periods datasets

To enable the OSE two special observing periods (SOP) were organized and conducted. The SOPs were each run for 6 weeks: Spring 20030305-20030416 and Autumn 20030820-20030830. During the SOP the fleet-configurations of the participating airlines (Air France, British Airways, Lufthansa and SAS) were modified to provide data more frequently, to a maximum of once every 60 minutes (in most cases) over a predetermined list of airports. By default the associated en-route data was also reported. The SOP data were transmitted to the meteorological community in the usual way, via the GTS .

The resulting change in exchanged data volumes is illustrated in Figure 3. The normal operational data counts of received E-AMDAR data runs at approximately 20,000 to 22,000 per 24-hours. During the SOPs this number increased by typically 10,000, thus exceeding 30,000. A reduced data set (RQ_AMDAR), corresponding to the current EUCOS requirement was generated some months after the SOP and was delivered to those weather centres that had expressed an interest in carrying out impact assessments (OSEs). The associated data counts are also shown in Figure 3 and we can see that the numbers, around 15,000 per 24-hours, are approximately half of HF_AMDAR, and some 25% less than normal E_AMDAR operations.

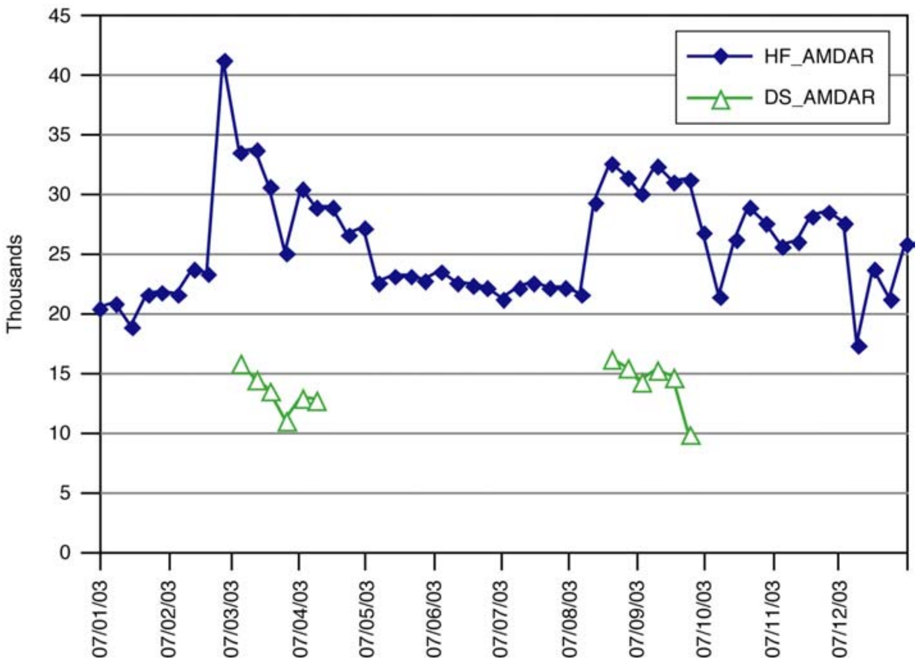

Figure 3 Time series of 24-hour data counts, for E-AMDAR data received at ECMWF, sampling every seven days (Tuesdays, 2100-2059 UTC, thus avoiding the weekly variations) for operations (blue) and the RQ_AMDAR experiments. The high-frequency data collection during the two 6-week test periods (20030305-20030416 and 20030820-20040930) is clearly visible.

The geographic distribution of the data density for the two SOP data sets is illustrated for flight-level and profiling data in Figure 4 and Figure 5, respectively. The plots show data counts between 0900 and 1459 UTC accumulated over the 42-day Spring SOP. We see a strong concentration of data over continental Europe, with good coverage extending over the Eastern Atlantic and parts of Siberia. The RQ_AMDAR density is substantially reduced in all areas, over mainland Europe, and also over the now less well-covered Atlantic and Siberian areas.

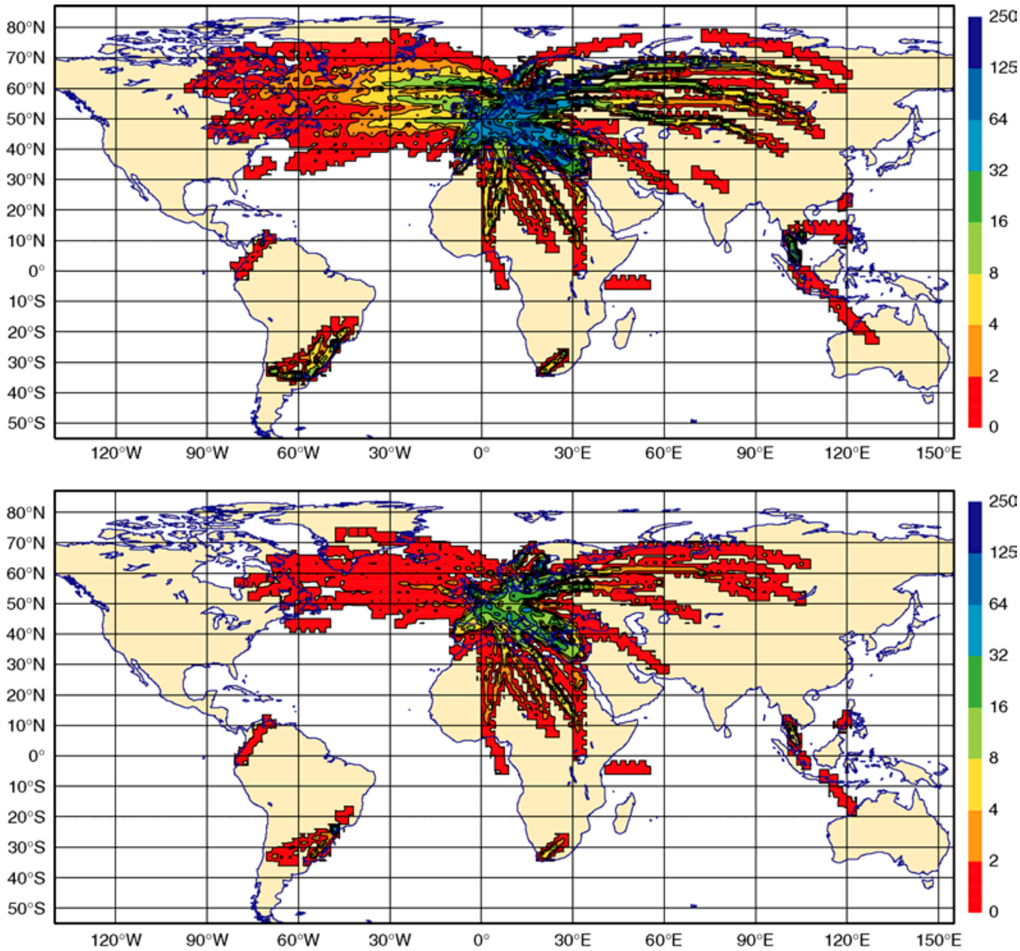

Figure 4 Data density for HF_AMDAR (top) and RQ_AMDAR (lower panel) in the layer 150-250 hPa. The contouring (legend) is in terms of number of received data per 1x1 degree latitude-longitude box, counting European AMDAR data 0900-1459 UTC each day in the 42-day period 20030305-20030416.

For the profiling data (Figure 5, showing 450-550 hPa) we see that the RQ_AMDAR selection has had the intended effect, reducing the coverage at Europe's busiest airports, while maintaining most of the E-AMDAR data from the less frequently served airports. The result is a more even data density.

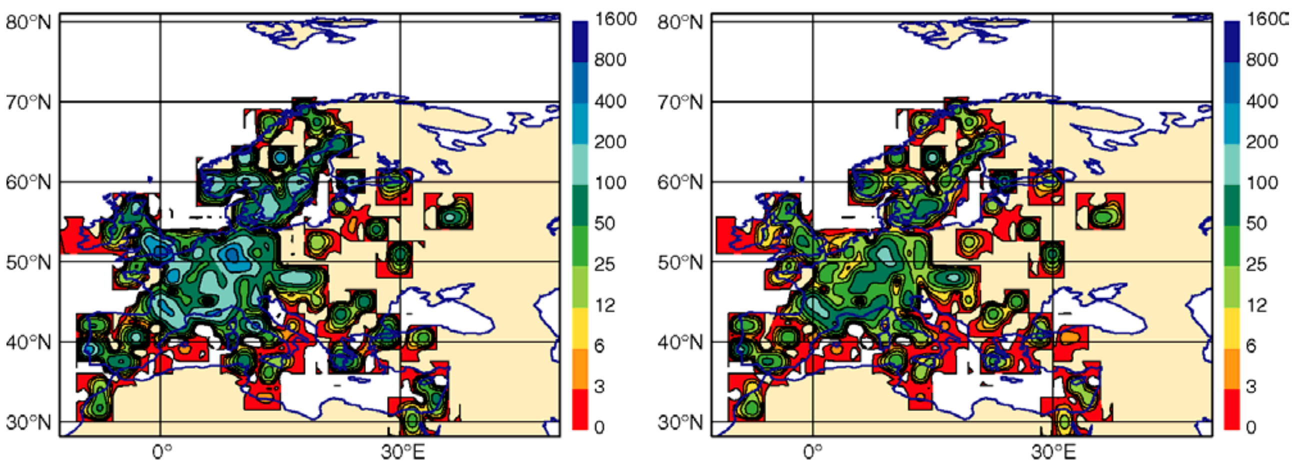

Figure 5 Data density for HF_AMDAR (left) and RQ_AMDAR (right panel) in the layer 450-550 hPa (right). Otherwise like Figure 4.

3. The ECMWF data assimilation system

The ECMWF data assimilation system is a 4D-Var scheme (Rabier et al. 2000). One of the strengths of 4D-Var is its ability to assimilate frequent data, as demonstrated by Järvinen et al. (1999), Andersson et al. (2001) and Cardinali et al. (2003). All available observations within a 12-hour period are used simultaneously (Bouttier 2001) in one global estimation problem. The observations are compared with a short-range forecast on a half-hourly basis. The differences between observations and a short-range forecast are analysed to obtain a corrected model state (the analysis), which evolves during the 12-hour assimilation period in better agreement with the observations. The short-range forecast and the comparison with observations is carried out at full resolution, currently T511 spectral truncation (40 km), whereas the analysis increments are evaluated at T159 (120 km). The vertical domain extends from the surface to 0.1 hPa and is discretised on 60 model levels.

3.1 The 4D-Var scheme

The scheme uses a wide variety of meteorological observations (as outlined in Courtier et al. 1998) from both conventional and satellite instruments. Global data within a 12-hour period (the so-called assimilation window) running from 03 to 15 UTC and from 15 to 03 the following day were used simultaneously in the version of 4D-Var used for this study. For further details on the incremental formulation of 4D-Var we refer to Courtier et al. (1994), and for details on AMDAR data usage and quality control see Cardinali et al. (2003).

3.2 Aircraft data usage

AMDAR and ACARS provide automated reports of wind and temperature measurements with an accuracy comparable to that of radiosondes: 1-2 m/s for wind and 0.7-1.2 K for temperature (Benjamin et al. 1999; WMO 1996). The assumed observation errors have been reduced in many operational forecast centres (e.g. Dalby and Berney, 1999) to reflect the increased quality of the observations. At ECMWF aircraft observation errors were reduced by about 30% in 1999 as part of a general revision of the assimilation scheme at the time.

At ECMWF many data types are thinned before use to avoid potential imbalances between data types with very different densities. Moreover, the effects of error correlation for certain data types are reduced by means of data thinning (Bormann et al. 2002; Liu and Rabier 2002). For aircraft data the observation error correlation is thought to be very small, enabling the data to be used at a resolution similar to that of the assimilating model. Aircraft data are thinned along-track considering one flight at a time (Järvinen and Undén 1997; Cardinali et al. 2003), i.e. where there are several flights in an area, the data from different flights will be used as mutually independent measurements.

3.3 Data assimilation experiments in the two SOPs

The operational data assimilation system used the HF_AMDAR data set as received at ECMWF via the GTS. Two data assimilation experiments were run: one for the Spring SOP and one for the Autumn SOP, in order to assess the analysis and forecast impact of using the reduced coverage RQ_AMDAR dataset instead of HF_AMDAR. The spring experiment used the 25r5 version of the forecasting system and the autumn experiment used the 26r1 version , to enable clean comparison between the experiment and operations in both periods. The assimilation experiments will be referred to as RQ and HF in the following.

The distribution of used data is illustrated in Figure 6 for the spring experiment. The effect of the data thinning and redundancy checks of the assimilation system is to even out the data density somewhat. The difference between the HF and RQ assimilations in terms of used AMDAR data is therefore not as marked as is in terms of received data (c.f. Figure 5). There is nevertheless a significant difference in numbers: overall the used profiling E-AMDAR data are reduced by about 60%-70% and similarly for the flight-level data in both spring and autumn.

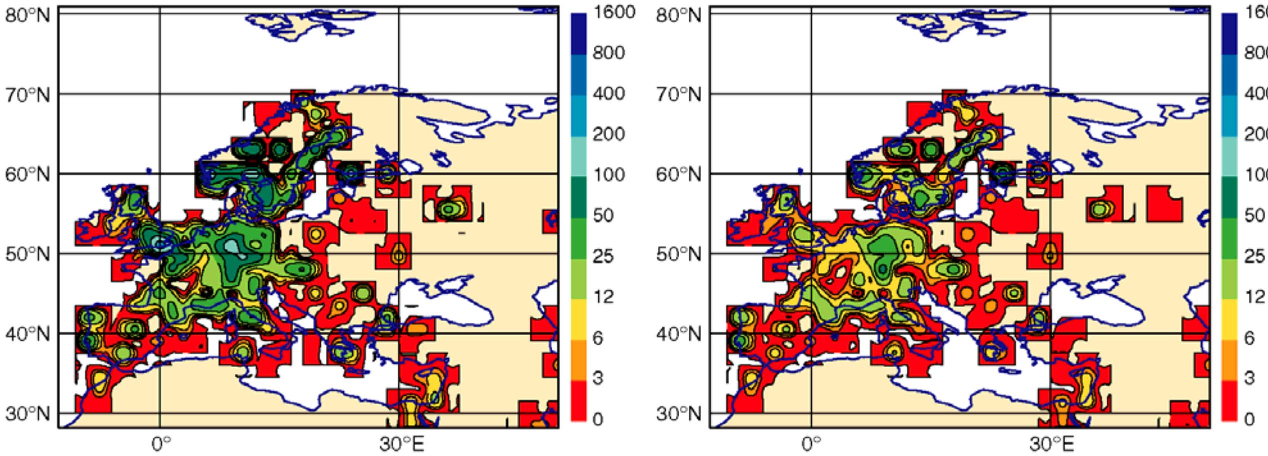

Figure 6 Data density for AMDAR data used in data assimilation for the layer 450-550 hPa in the seven-day period 20030820-2100 to 20030827-2059 UTC, for the HF (left) and the RQ (right) data assimilation experiments. The colour shading (legend) shows number of data per 1x1 degree latitude longitude box in the seven-day period.

Due to a technical error some AMDAR data in the Australian region were wrongly omitted from the RQ experiment. This has significantly reduced the number of AMDAR profiles assimilated at Sydney and Melbourne and other major airports in the region. In-flight data from routes within Australia, between Australia and New Zealand, and Southeast Asia were also affected. In the evaluation below we therefore ignore any Southern Hemisphere and Tropical differences between HF and RQ. We consider it entirely safe to assume that the E-AMDAR impact in the Northern Hemisphere is largely unaffected by the unintended differences in the Australian region.

4. Impact assessment

The impact of implementing the proposed EUCOS data selection strategy for E-AMDAR data has been assessed by comparing the results obtained from the RQ and HF assimilation experiments in terms of analysis increments, analysis differences, information content in the analysis and forecast impact. The impact is evaluated with respect to the prevailing weather situation in the study periods.

Figure 7 shows the average weather situation in two experiment periods, spring (left) and autumn (right), in terms of mean-sea level pressure (contoured) and upper troposphere wind speed (colour shaded). In spring an anticyclone covered much of Western and Central Europe providing settled conditions. The North Atlantic cyclone track was displaced to the north, to Scandinavia. In the autumn period, a westerly flow brought a succession of weather systems from the Atlantic to the British Isles, the North Sea and southern Scandinavia. Western and Central Europe was again under the influence of an extensive anti-cycle providing settled conditions.

The rate at which analysis errors grow and evolve into forecast errors, on time scales of a few days, is largely determined by baroclinic instability. A useful indication of where such growth is likely to occur, and where it will be most rapid, is given by the Eady index (using the definition of Hoskins and Valdez 1990), shown for both periods in Figure 8. We can see that in the spring period the atmospheric conditions are such that error growth is most likely to occur in the Northern and Western Atlantic, and Scandinavia, and much less so in the western and southwestern parts of Europe. In the autumn period (right) the Eady index shows maxima in an area covering Scotland, Iceland and southern Norway, and an area extending eastward from Greece, associated with the subtropical jet. These areas can be considered the most ‘sensitive regions’ in the current study periods.

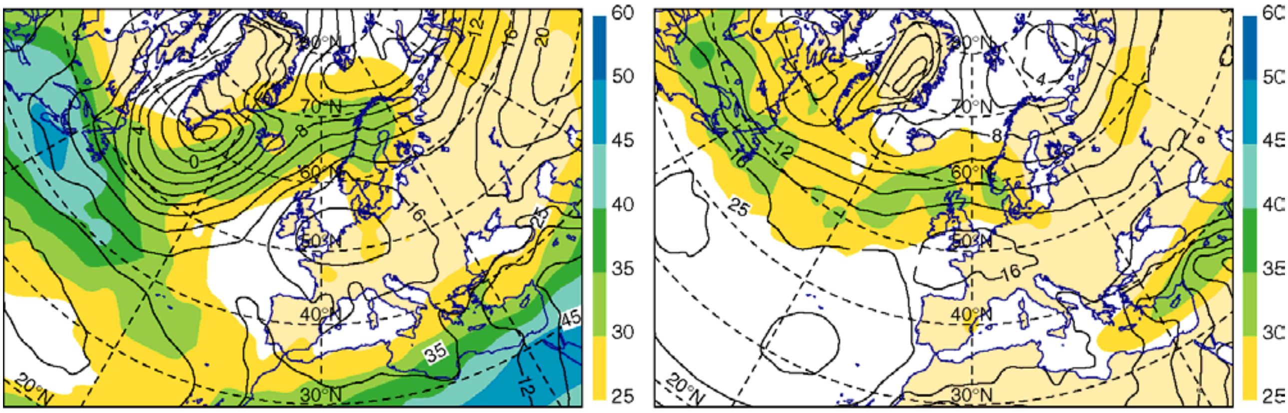

Figure 7 Average 1000 hPa geopotential height (contoured with interval 2 dam), and 250 hPa wind speed (shaded, see legend), for the two experimental periods: spring 20030305-20030416 (left) and autumn 20030820-20030930 (right). The contouring corresponds to approximately 2.5 hPa in terms of mean sea level pressure.

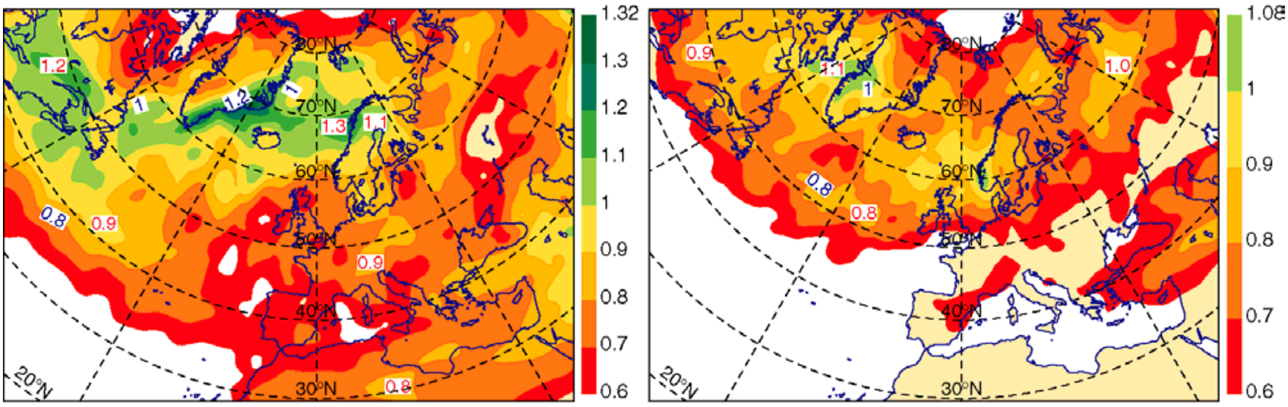

Figure 8 RMS of Eady index for the two experimental periods: spring 20030305-20030416 (left) and autumn 20030820-20030930 (right). The contour interval is 0.2 with colour shading (legend). The Eady index indicates how rapidly perturbations, such as analysis errors and analysis differences, grow and develop into forecast errors.

4.1 Analysis impact

Analysis differences between RQ and HF can be expected where there is difference in density of used data (Figure 6), and in particular where the atmospheric conditions are such that differences will grow over time (c.f. Figure 8). Differences will be small where the assimilation is accurate due to good availability of observations, and/or the atmospheric conditions are relatively stable. Figure 9 shows that the differences in both periods are very small over much of Central Europe (yellow shading) and Iberia. Differences are larger near some of the E-AMDAR data clusters in Eastern Europe, in the Mediterranean region, Portugal, western France, Ireland, and in particular Scandinavia and the Norwegian Sea. The latter feature correlates well with sensitive regions in Figure 8, as do the tendency for larger differences in the Eastern Mediterranean (Spring), western Mediterranean (Autumn) and the Black Sea and the Baltic.

From these maps it appears that for Central Europe the analysis is quite insensitive to changes in E-AMDAR data collection and density, whereas larger analysis impact tends to occur over surrounding European Seas and coastal areas, and Eastern and Northern Europe. Corresponding plots for wind and temperature analysis differences give similar indication (not shown).

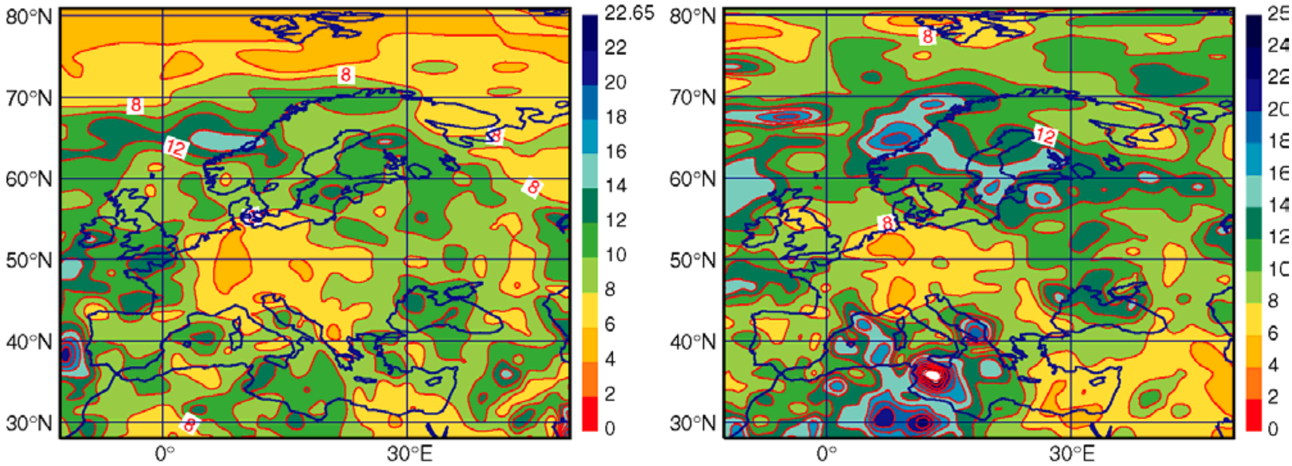

Figure 9 Rms of analysis difference in terms of 700 hPa geopotential height (m^2s^{-2}) for the two experimental periods: spring 20030305-20030416 (left) and autumn 20030820-20030930 (right). The contour interval is 2.0 m^2s^{-2}.

North-south cross sections over Europe (Figure 10) show the difference (RQ minus HF) in rms of analysis increments, in terms of geoptotential height at pressure levels. Red contours show increased analysis increments in the RQ assimilation that used fewer E-AMDAR observations. We see that RQ generally has larger increments at the 150-400 hPa levels. In the case that less data lead to increased increments it is a clear indication that the assimilation is degraded, i.e. the misfit between the background and used data has increased, at these levels. The opposite case (blue contours), i.e. smaller increments when less data area used, does however not necessarily imply improved analyses - it can also be an indication that background errors that were detected in HF have remained undetected in the RQ assimilation. This would appear to be the case in some parts of the mid and lower troposphere in these experiments.

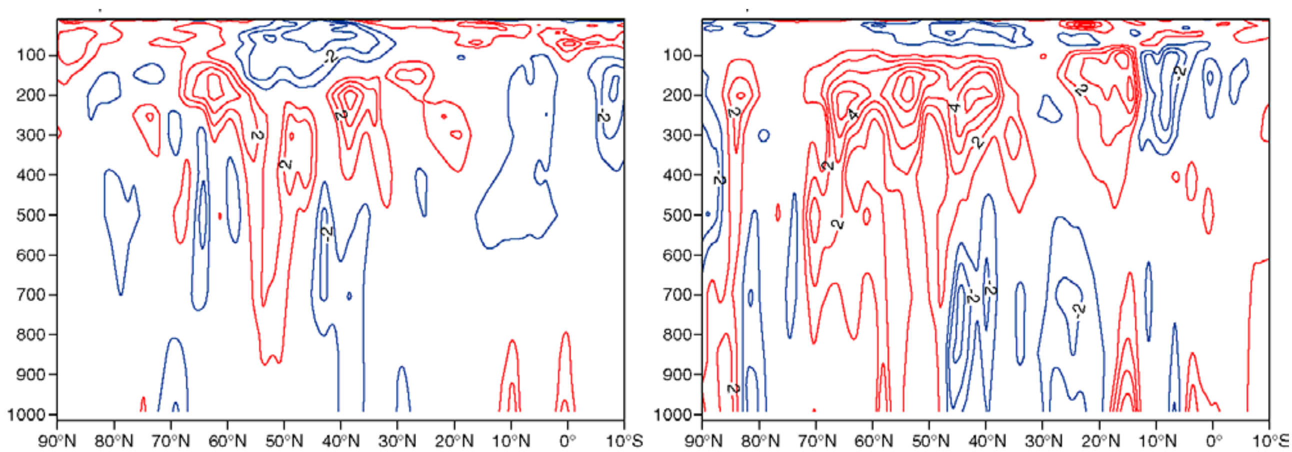

Figure 10 North-south cross section, zonally averaged over the European region (12.5° W to 42.5° E), showing difference in rms of analysis increments in terms of geopotential on pressure levels (contour interval is 1.0 m^2s^{-2}), for the spring period (left) and autumn (right). Red (positive) contours indicate that increments are larger in the RQ than in the HF experiment, with the opposite shown in blue.

4.2 Information content

Recently, methods have been developed that enable calculation of the information content provided by the data in the 4D-Var analysis (Cardinali et al. 2004; Fisher 2003). Cardinali et al. (2004) found that AIREP globally contribute approximately 7% of the observational information to the analysis, which is comparable to that of the radiosonde observing system (8%) and larger than that of the SYNOP network of surface stations (3%), for example. Information content is here measured in terms of degrees of freedom for signal (DFS) (Rodgers 1976; 1996; 2004; Rabier et al. 2002). Individual data, in a data dense, location each contribute relatively little in terms of DFS, whereas isolated data that are accurate with respect to the analysis background information are associated with high DFS.

We have investigated the E-AMDAR information content in the RQ and HF analyses for 20030826. This date corresponds to the first data point in the autumn RQ data series in Table 1, which has a typical difference in data counts with respect to HF. The E-AMDAR information content has been calculated separately for flight-level data (pressure < 300 hPa) in an area over the North Atlantic (30-65°N, 10-60°W), and for profiling data (pressure > 300 hPa) in three areas in Central Europe (40-54°N, 0-15°E), Northern Europe (54-70°N, 4-30°E) and Eastern Europe (30-60°N, 20-40°E).

Table 1 Information content (degrees of freedom for signal, DFS) and data counts for E-AMDAR data in four specific areas as defined in the text, 20030826 accumulated for the 00 and 12 UTC analysis cycles, thus based on data from 15:00 on the 25th to 14:59 UTC on the 26th of August 2003.

Area	Data Counts		Information Content		Information Content per observation	
	HF	RQ	HF	RQ	HF	RQ
North Atlantic, flight level	1638	508	540.8	193.7	0.33	0.38
Central Europe, profiling	22346	8091	3358.6	1269.5	0.15	0.16
Northern Europe, profiling	14281	4645	2629.8	939.1	0.18	0.20
Eastern Europe, profiling	3599	2182	678.2	401.1	0.19	0.18

We can see that in the Eastern European area RQ has used approximately 2/3 of the HF data, whereas in the other three areas it has used only about 1/3 of HF data. The information content per observation is markedly higher for the North Atlantic flight-level data than for the European profiling data, with Central area showing the smallest value. These values are consistent with the data coverage in the four areas. The RQ data selection has retained more of the most valuable data (from the information-content point of view) in the North Atlantic area, whereas in the other three areas the change in information content per observation is small.

4.3 Forecast impact

The forecast impact has been evaluated in terms of objective scores such as rms (root mean square) of forecast error and anomaly correlation, for wind, temperature and geopotential at pressure levels, for a number of geographical areas and forecast ranges, using operational analyses as reference. Averaging over each 6-week SOP the impact is very small in terms of these traditional large-scale measures of forecast skill. As an example, we show in Figure 11 the rms of 500 hPa geopotential forecast error for the European area for both periods. There is no visible difference in forecast performance between HF (blue line) and RQ (red).

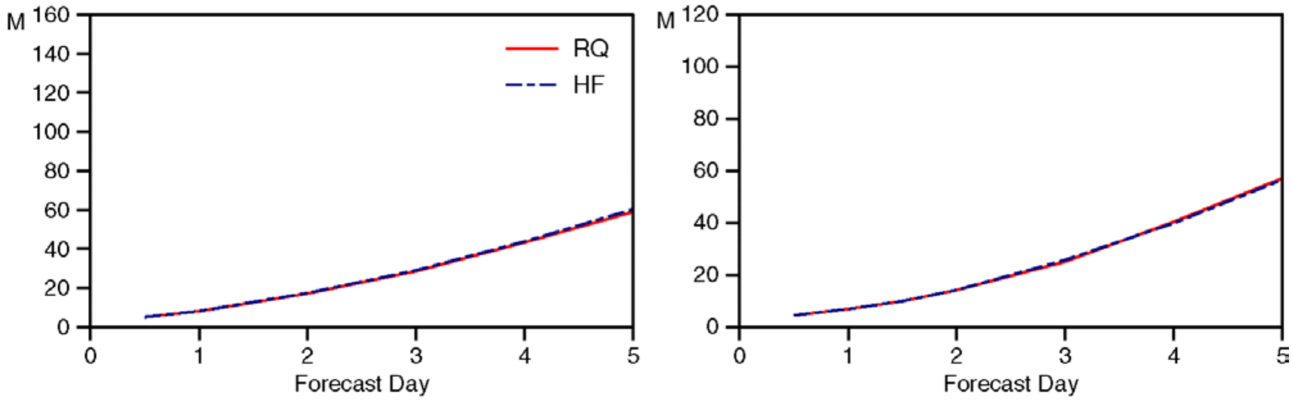

Figure 11 Average RMS 500 hPa geopotential forecast error for RQ (red) and HF (dashed blue) assimilation experiments for the Spring-period (left) and autumn (right), for the first 5 days of forecasts issued from 12 UTC analyses. The curves overlap indicating essentially equivalent forecast performance.

Small forecast performance differences can nevertheless be significant if they occur consistently in the test sample. Statistical significance tests have been performed on a set of objective forecast performance scores to test which of the (small) score differences between HF and RQ are significant in the sense that they are unlikely to have occurred purely by chance. The result is presented in Table 2 and Table 3 for the spring and autumn SOPs, respectively. Only those score differences that are significant at the 95 % level, or higher are listed. We can see that several results in the very short range are significant, and that in most cases RQ is found to perform worse than HF, as might be expected as RQ used less data.

Many of the significant results are for the shortest forecast range, that is, for the 24-hour range. Corresponding maps showing the difference in rms of 24-hour forecast error for each SOP in terms of 500 hPa geopotential and 200 hPa vector wind are shown in Figure 12 and Figure 13, respectively. In the top panel of Figure 12 there is indication that increased errors (yellow) in RQ in E. Asia (significant at the 99% level) emanate from Eastern Europe, spreading eastwards across parts of Asia. The error reduction over the North Atlantic is not classified as significant according to the criteria applied in Table 2. The increased errors over Asia interact with the subtropical jet (bold arrows in Figure 13) and amplify in the strongly baroclinic zone northeast of Japan. The error propagation from Europe, across Asia to Japan cannot have occurred just within the 24-hour forecast, but rather through cycling of the assimilation system over periods of several days. The slight degradation may have its origin in reduced coverage of profiling data in Eastern Europe, and/or in the reduction of flight-level data in the routes across Siberia.

In the autumn period (lower panels) there is very little indication of degradation at 500 hPa, other than over the N. Pacific (significant at 98%) east of Japan. It that period it seems plausible that the errors have propagated on a more southerly route, perhaps originating in the Eastern Mediterranean and Black Sea region (c.f. Figure 8 and Figure 9). The small error increase in 200 hPa winds over Europe (Figure 13 lower panel) is significant at the 99% level, and could be an indication that the in-flight data over Europe have been too much reduced in RQ.

Table 2 Significant objective forecast scores computed for the spring period, listing scores with significance > 95% that RQ assimilation performs worse or better (shaded) than HF, amongst level=(500, 200), score=rms, range=(24, 48, 72, 96) hours, parameter=(Z, VW), area=[N. Hem, Europe, N. America, E. Asia, N. Atlantic, N. Pacific), satisfying conditions on serial independence within the sample.

Score	FC range	Area	Significance
500 hPa Z	24	E. Asia	Worse at 99%
	72	N. Atlantic	Worse at 95%
200 hPa Z	24	N. America	Worse at 95%
	96	N. Pacific	Worse at 95%
500 hPa VW	24	N. Pacific	Worse at 99%
		E. Asia	Worse at 95%
	48	N. Hem	Better at 99%
		N. Pacific	Better at 95%
200 hPa VW	24	N. Hem	Worse at 99%
		Europe	Worse at 95%
		N. Pacific	Worse at 95%
		N. America	Worse at 99%
		N. Atlantic	Worse at 99%
	48	N. Hem	Worse at 95%

Table 3 As Table 1, but for Autumn period.

Score	FC range	Area	Significance
500 hPa Z	24	N. Pacific	Worse at 98%
	96	N. Pacific	Better at 95%
200 hPa Z	24	Europe	Worse at 99%
500 hPa VW	24	N. Atlantic	Worse at 99%
		E. Asia	Worse at 99%
	96	E. Asia	Worse at 99%
200 hPa VW	24	N.Hem	Worse at 99%
		Europe	Worse at 99%
		N. Pacific	Worse at 99%
	72	N. America	Worse at 99%

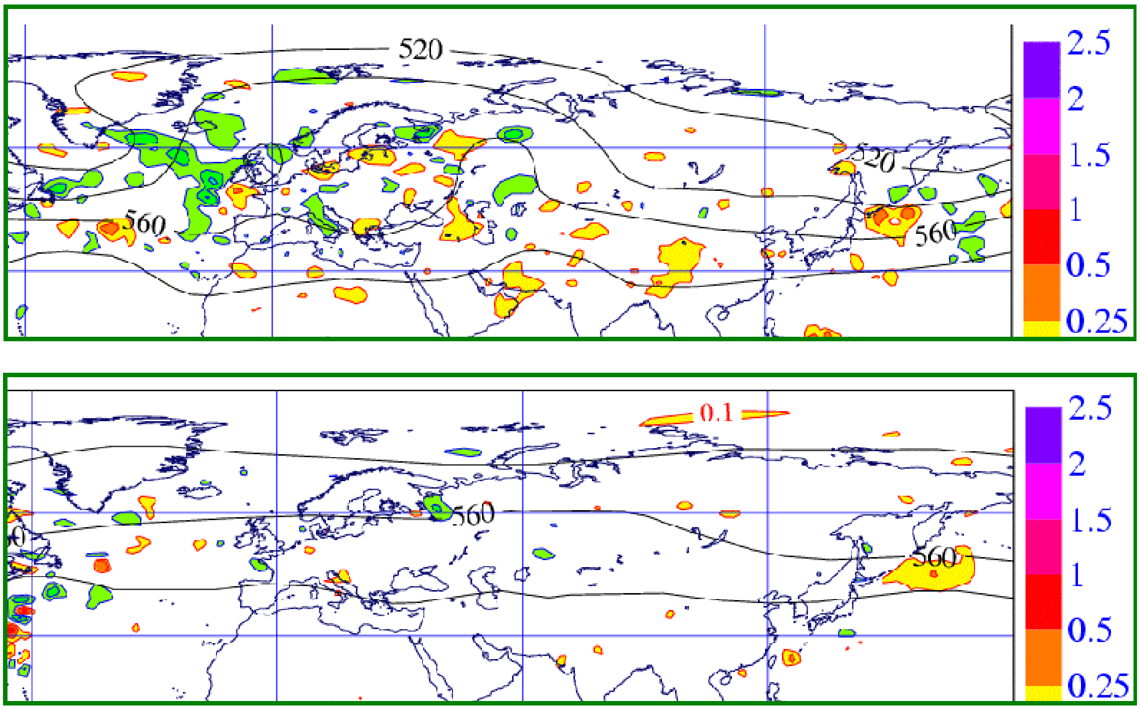

Figure 12 Difference in rms of 24-hour forecast error (RQ minus HF), in terms of 500 hPa geopotential height, for the spring period (top) and autumn (lower panel). Shading starts at +-0.1 dam, with yellow (green) shading indicating larger (smaller) with reduced numbers of aircraft data. Black contours show the mean analysed 500 hPa geopotential (interval 40 dam).

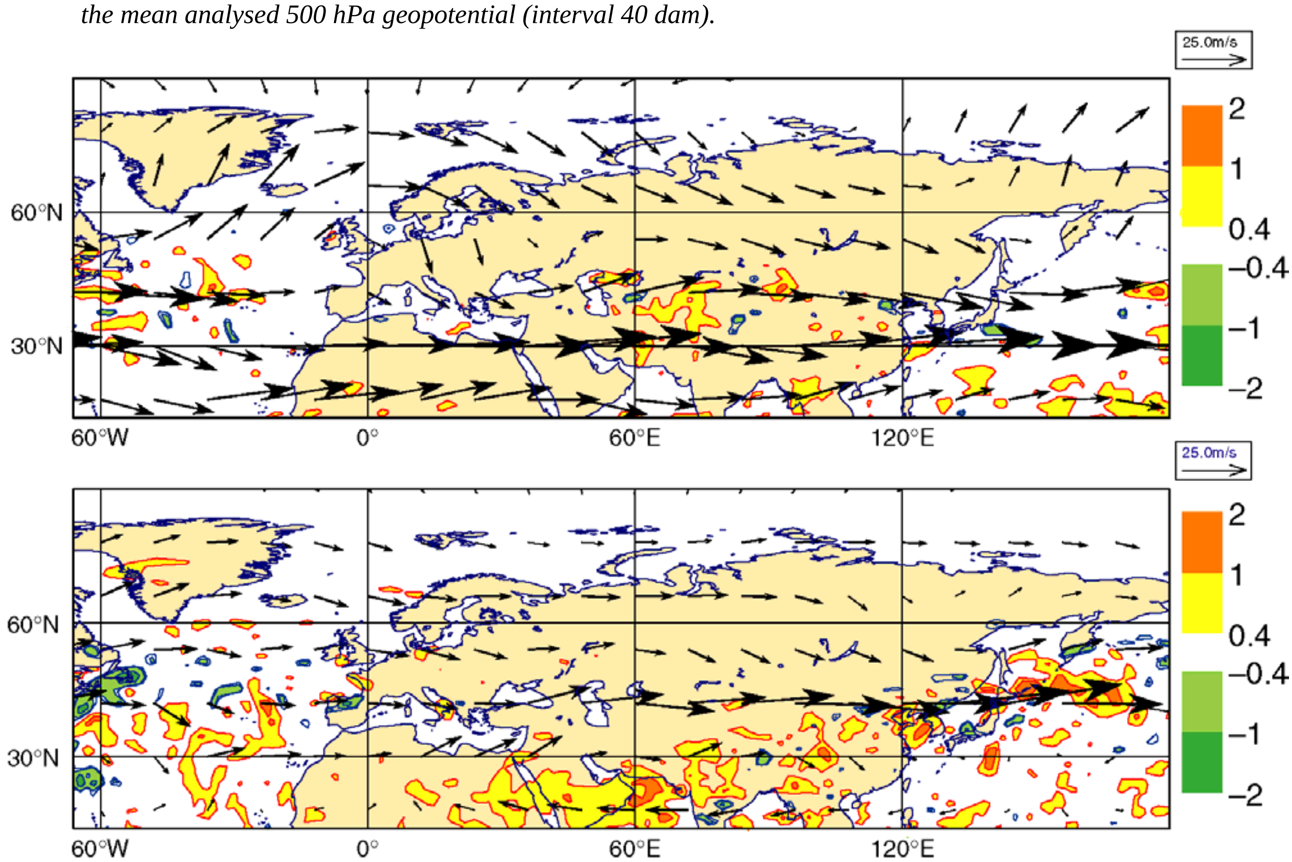

Figure 13 Difference in rms of 24-hour forecast error (RQ minus HF), in terms of 200 hPa vector wind (shaded), for the spring period (top) and autumn period (lower panel). Shading starts at +-0.4 ms^{-1}, with yellow (green) shading indicating larger (smaller) error with reduced numbers of aircraft data. Black arrows show the mean analysed 200 hPa wind vectors (with unit vector indicating 25 ms^{-1}).

5. Conclusions

Data assimilation experiments have been conducted to assess the relative analysis and forecast impact of RQ with respect to HF, in ECMWF's operational Numerical Weather Prediction system. RQ corresponds to the proposed EUCOS requirement for aircraft data collection within the E-AMDAR programme, whereas HF corresponds to the maximum achievable data collection, within two 6-week special observing periods. Comparisons between HF and RQ show a 60-70% reduction in RQ in the number of used profiling data in the vicinity of airports and in used in-flight data over the North Atlantic.

In the Central European area, the analysis is quite insensitive to the RQ reduction in data collection. Larger differences are found in Eastern Europe, over the European Seas and coastal regions, and Scandinavia. For Central Europe it is quite clear that the AMDAR collection can safely be reduced, given the present level of data redundancy in that area, as shown by information content analysis. Our results lend some support to EUCOS proposed data collection strategy, showing that its implementation will lead to a more uniform, and largely sufficient data coverage, at a lesser cost, with only very minor degradation in NWP performance. The data reduction should be limited to Central Europe profiling AMDAR, whereas elsewhere in Europe and at flight level, efforts should be made to maintain high AMDAR data coverage, and to further extended it in the future.

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