TECHNICAL MEMORANDUM

454

Early-delivery Suite

J. Haseler

Research Department

December 2004

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

ECMWF
Shinfield Park
Reading
RG2 9AX
United Kingdom

Series: Technical Memoranda

A full list of ECMWF Publications can be found on our web site under:
http://www.ecmwf.int/publications/

Abstract

The early-delivery suite is a reorganisation of the data assimilation system in order to make the ECMWF operational products available earlier. In particular, it makes the 0000 UTC products available before the end of the working day, even in the easternmost Member States where local summer time is three hours ahead of Universal Time. Following extensive pre-operational testing, it became the ECMWF operational data assimilation system on 29 June 2004.

1. Introduction

ECMWF has had a four-dimensional variational data assimilation scheme since November 1997 (Rabier et al. 2000, Mahfouf et al. 2000, Klinker et al. 2000). The observation time-window was increased from six to twelve hours in September 2000 (Bouttier 2001).

Figure 1 shows the original 12-hour 4D-Var data assimilation configuration, which was operational from September 2000 until June 2004. The 0000 UTC analysis uses observations from the time window 1501 - 0300 UTC. On reception at ECMWF, the observations are stored in the Reports Data Base. At 0745 UTC, the first family of extraction tasks takes the observations for the period 1501 - 2100 UTC from the Reports Data Base and prepares input files for the analysis. At 0800 UTC, the second family of extraction tasks prepares the input analysis observation files for the period 2101 - 0300 UTC. Any observations that arrive after the relevant extraction task has run are not used by the analysis. The three-hour forecast from the previous day's 1200 UTC analysis provides the first guess at 1500 UTC for the start of the 0000 UTC 12-hour assimilation window.

Within the 0000 UTC cycle, separate surface analyses, of sea-surface temperature, 2-metre temperature, 2-metre relative humidity, snow and soil moisture, are done at 1800 UTC and 0000 UTC. The six and twelve hour forecasts from the previous day's 1200 UTC analysis provide the first guess fields for these surface analyses.

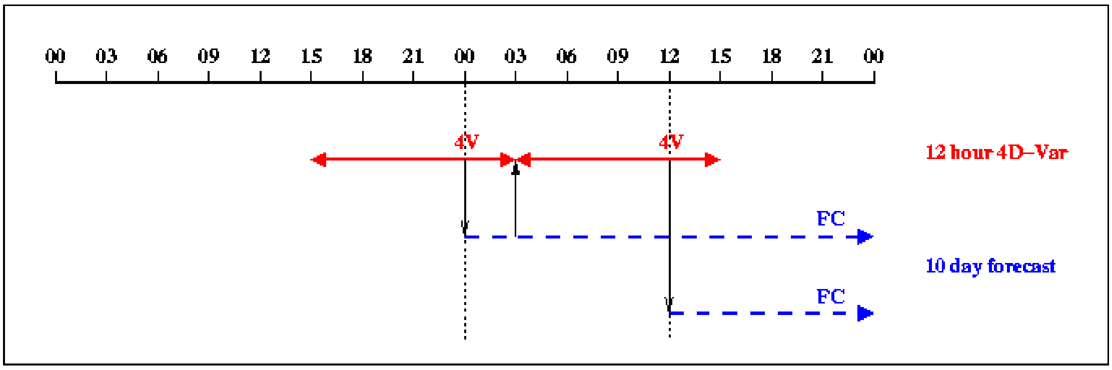

Figure 1 Organisation of the original 12-hour 4D-Var data assimilation suite, operational from September 2000 until June 2004

The 1200 UTC analysis uses observations from the time window 0301 - 1500 UTC. The extraction tasks for observations for the periods 0301 - 0900 UTC and 0901 - 1500 UTC are run at 1900 and 1915 UTC respectively. The three-hour forecast from the 0000 UTC analysis provides the first guess at 0300 UTC for the start of the 1200 UTC 12-hour assimilation window. The six and twelve hour forecasts from the 0000 UTC analysis provide the first guess fields for the 0600 and 1200 UTC surface analyses.

Ten day forecasts are run from the analyses at 0000 UTC and 1200 UTC.

Figure 2 shows the first early-delivery configuration. The 12-hour 4D-Var analysis is run with an observation window that is shifted forwards by six hours with respect to the original configuration. The 0000 UTC analysis now uses observations in the time window 2101 - 0900 UTC, while the 1200 UTC analysis uses observations in the window 0901 - 2100 UTC. These analyses are run with a delayed-cut-off time, in order to use the maximum possible number of observations. The extraction tasks for observations in the periods 2101 - 0300 UTC and 0301 - 0900 UTC are run at 1345 and 1400 UTC respectively, while the extraction tasks for observations in the periods 0901 - 1500 UTC and 1501 - 2100 UTC are run at 0145 and 0200 UTC. The first guess for the 0000 UTC analysis is the nine-hour forecast from the previous day’s 1200 UTC delayed-cut-off analysis. The twelve- and eighteen-hour forecasts from the 1200 UTC delayed-cut-off analysis provide first guess fields for the 0000 and 0600 UTC surface analyses. The first guess for the 1200 UTC analysis is the nine-hour forecast from the 0000 UTC delayed-cut-off analysis. The twelve and eighteen hour forecasts from the 0000 UTC delayed-cut-off analysis provide first guess fields for the 1200 and 1800 UTC surface analyses. It is these 12-hour 4D-Var delayed-cut-off assimilations that propagate information forwards from day to day. There is no loss of observational information compared with the original 12-hour 4D-Var data assimilation configuration.

The early-delivery analyses do not propagate information from cycle to cycle. Each analysis is reinitialized with the best available model fields from the delayed-cut-off assimilation. The 0000 UTC early-delivery analysis is a 6-hour 4D-Var analysis that uses observations in the time window 2101 - 0300 UTC. The cut-off time is 0400 UTC, and any observations that arrive after this time are not used by the early-delivery analysis. However, if they arrive by 1400 UTC, they can still be used by the delayed-cut-off 12-hour 4D-Var 0000 UTC analysis. The first guess for the 0000 UTC early-delivery analysis is the nine-hour forecast from the previous day’s 1200 UTC delayed-cut-off 12-hour 4D-Var analysis.

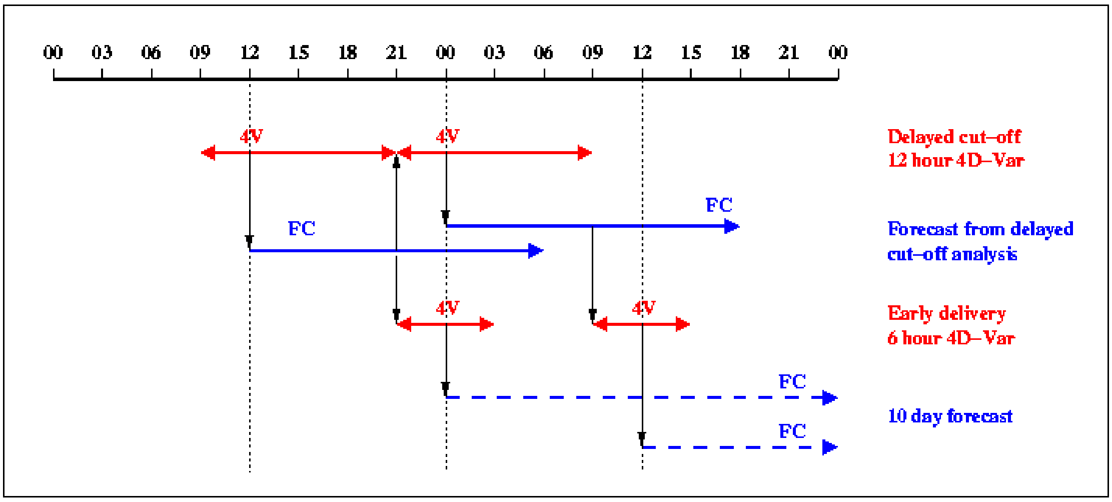

Figure 2 The first early-delivery configuration, implemented in June 2004

The early-delivery 1200 UTC analysis is a 6-hour 4D-Var analysis that uses observations in the time window 0901 - 1500 UTC, with a cut-off time of 1600 UTC. Its first guess is the nine-hour forecast from the delayed-cut-off 12-hour 4D-Var 0000 UTC analysis.

Ten-day forecasts are run from the early-delivery analyses at 0000 and 1200 UTC.

As well as the observations that are actively used by the analysis, there are also some that are passed passively through the system. Statistics of departures from the first guess and analysis are gathered for the passive observations, but they are not used by the analysis. This is useful, for example, for monitoring the quality of new observation types prior to their operational use. All observation monitoring is done in the delayed-cut-off 12-hour 4D-Var analyses, and no passive data needs to be input to the early-delivery analyses.

The early-delivery configuration as described above became the operational data assimilation system on 29 June 2004. All the experimentation described in this Technical Memorandum was run with this configuration. However, after operational implementation, it was realized that information was being lost from the coupled wave analyses. The 0000 UTC delayed-cut-off analysis produces analysed wave fields at 0000 and 0600 UTC. Observations from 2101 - 0300 UTC are used to make the 0000 UTC wave analysis and observations from 0301 - 0900 UTC are used to make the 0600 UTC wave analysis. Because the delayed-cut-off forecast starts from the 0000 or 1200 UTC analysis, the information from wave observations in the ranges 0301 - 0900 UTC and 1501 - 2100 UTC is not propagated forwards in time. To solve this problem, a second early-delivery configuration was devised. Instead of starting from the 0000 and 1200 UTC analyses, the delayed-cut-off forecasts now start from the 0600 and 1800 UTC analyses. The operational data assimilation system was changed to this configuration on 28 September 2004.

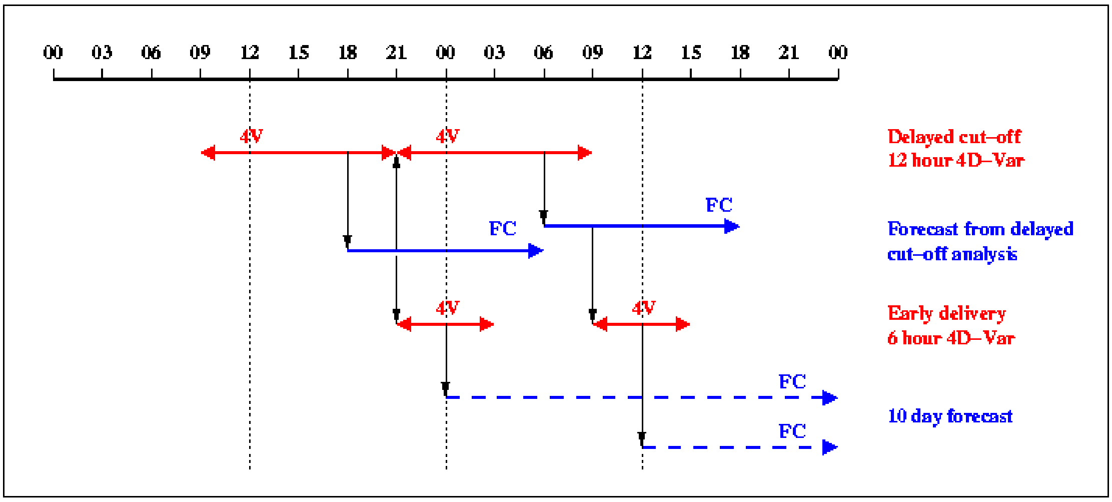

Figure 3 The second early-delivery configuration, implemented in September 2004

2. Operational Schedule

Figure 4 shows the operational schedule for the 0000 UTC suite with the original data assimilation scheme. The suite begins at 0800 UTC with the extraction of the observations, followed by the 12-hour 4D-Var analysis. When the analysis completes, at about 0930 UTC, the ten-day forecast and the Ensemble Prediction Scheme (EPS) are triggered to start. Dissemination of the forecast is scheduled between 1115 (day 1) and 1245 UTC (day 10). The EPS dissemination is scheduled between 1335 (day 0) and 1415 UTC (day 10).

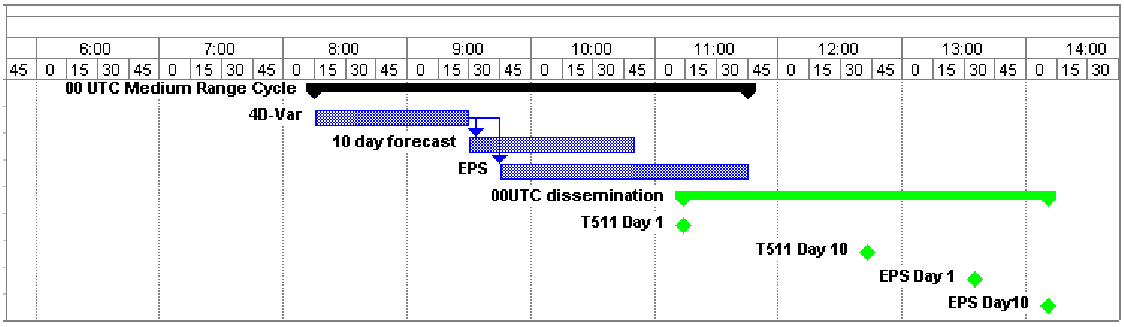

Figure 4 Operational schedule for 0000 UTC suite with original data assimilation scheme

Figure 5 shows the operational schedule for the 0000 UTC early-delivery suite. Observations are extracted four hours earlier, at 0400 UTC, and there is a further saving of about 30 minutes compared with the original data assimilation scheme because the analysis is now 6-hour 4D-Var rather than 12-hour 4D-Var. The forecast dissemination is scheduled between 0715 (day 1) and 0845 UTC (day 10), while the EPS dissemination is scheduled between 0935 (day 0) and 1015 UTC (day 10).

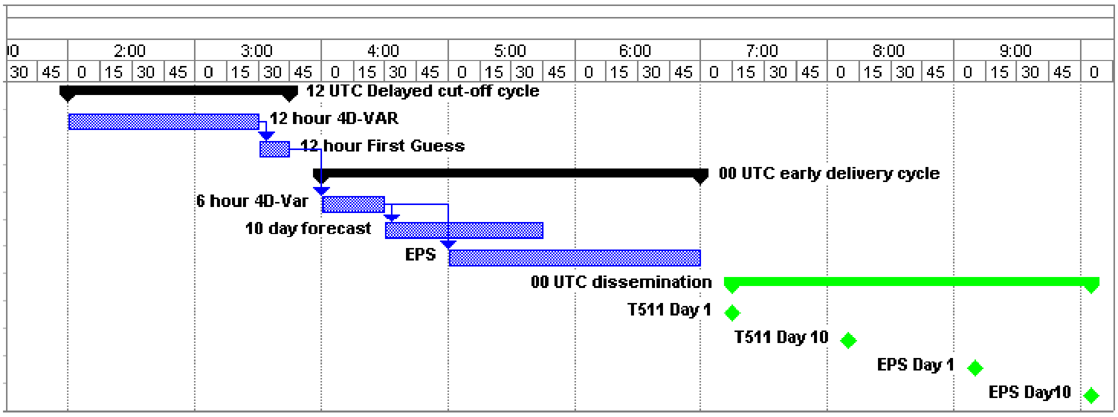

Figure 5 Operational schedule for 0000 UTC early-delivery suite

Table 1 sets out the dissemination times for the original and early-delivery suites at 0000 UTC and 1200 UTC. Products from the 0000 UTC early-delivery suite are made available four hours earlier than before, while the 1200 UTC products are available 3¼ hours earlier.

		Original Suite (UTC)	**Early-delivery Suite (UTC)**
0000 UTC	Deterministic forecast, day 1	1115	0715
	Deterministic forecast, day 10	1245	0845
	EPS, day 0	1335	0935
	EPS, day 10	1415	1015
1200 UTC	Deterministic forecast, day 1	2230	1915
	Deterministic forecast, day 10	0000	2045
	EPS, day 0	0050	2135
	EPS, day 10	0130	2215

Table 1 Dissemination times (UTC) for the original and early-delivery suites

3. Experimentation

The early-delivery system has been extensively tested during 2003 and 2004, and its impact on the quality of the forecasts is essentially neutral. Combined scores are presented below for the following periods:

1 February – 18 June 2004	(139 days)
12 October –30 November 2003	(50 days)
1 September –30 September 2003	(30 days)
1 June –7 August 2003	(68 days)
17 January –27 February 2003	(42 days)

The scores for February - June 2004 have been taken from the pre-operational testing of the early-delivery system, while the scores for the earlier periods have been taken from Research Department experiments. Forecasts from the early-delivery analyses are compared with forecasts from control analyses with the original 12-hour 4D-Var configuration. The control forecasts are taken from either the operational suite or the pre-operational testing of the same software release as the corresponding early-delivery experiment.

Figures 6 and 7 show the anomaly correlation for the 500 hPa geopotential-height forecast error for the Northern and Southern Hemisphere extratropics, averaged over 329 days, for the forecasts from the early-delivery analyses (red) and the control analyses (blue). The curves overlap almost entirely, demonstrating equivalent performance.

Figure 8 shows the anomaly correlation for the 1000 hPa geopotential height forecast error for Europe, averaged over 329 days, for the forecasts from the early-delivery analyses (red) and the control analyses (blue). Again, the impact of the early-delivery scheme is shown to be neutral.

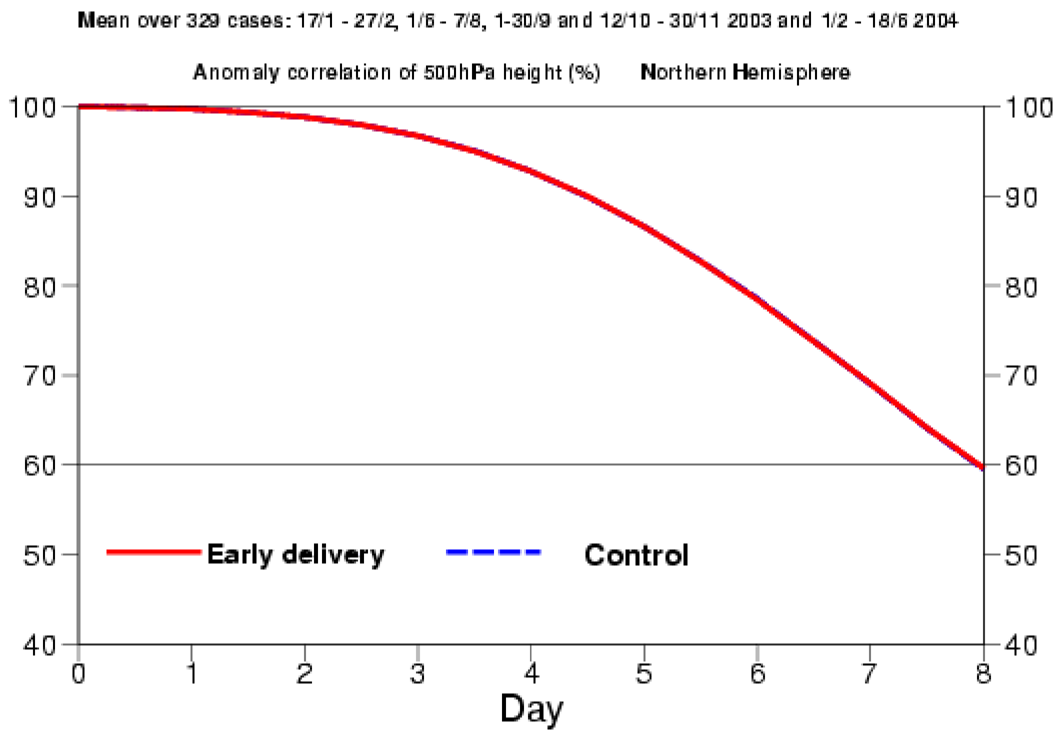

Figure 6 Anomaly correlation of the 500 hPa geopotential-height forecast error for the Northern Hemisphere extratropics, averaged over 329 days, for the forecasts from the early-delivery analyses (red) and the control analyses (blue).

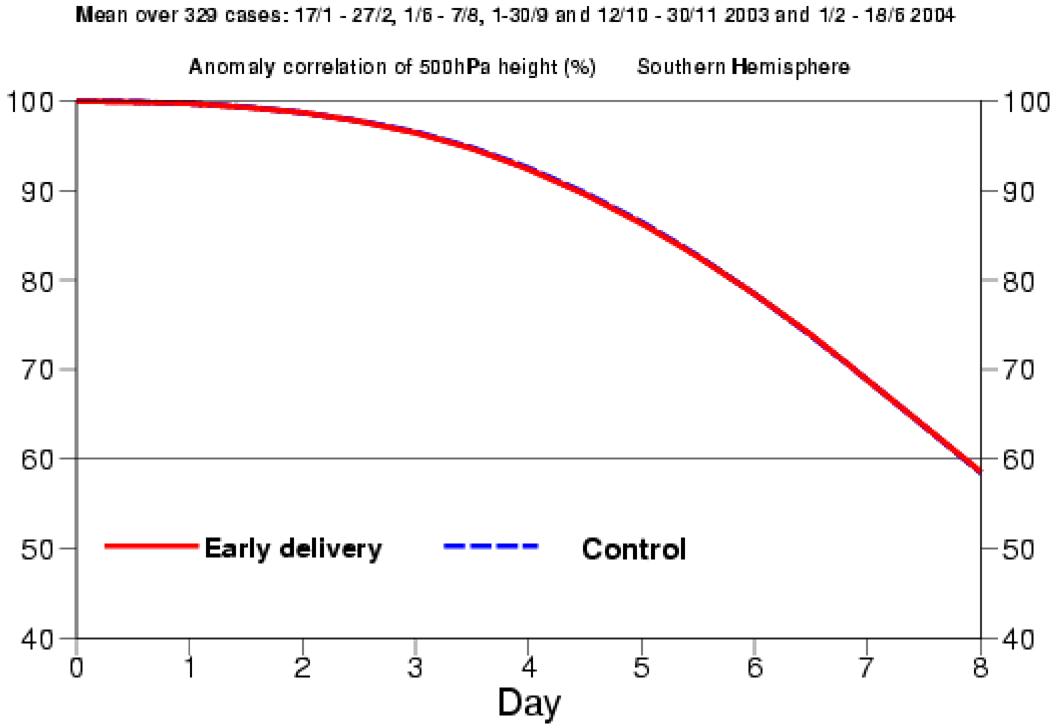

Figure 7 Anomaly correlation of the 500 hPa geopotential-height forecast error for the Southern Hemisphere extratropics, averaged over 329 days, for the forecasts from the early-delivery analyses (red) and the control analyses (blue)

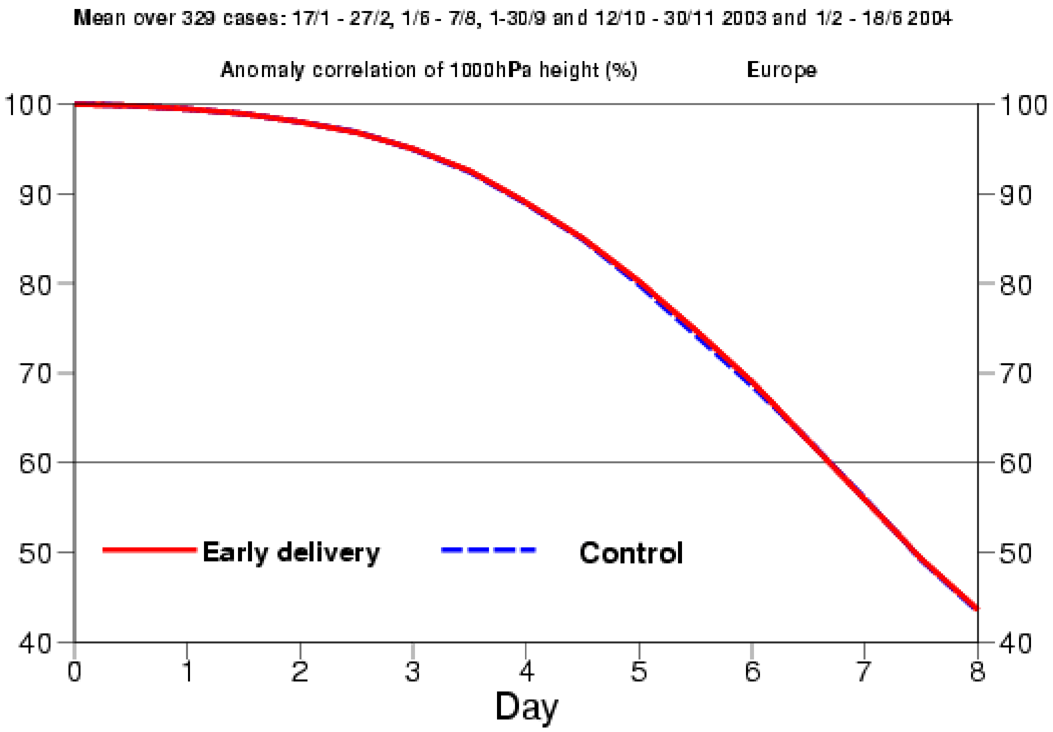

Figure 8 Anomaly correlation of the 1000 hPa geopotential-height forecast error for Europe, averaged over 329 days, for the forecasts from the early-delivery analyses (red) and the control analyses (blue)

3.1 Observation cut-off time

A set of early-delivery experiments was run for September 2003, to investigate the effect of the observation cut-off time on the quality of the subsequent forecasts. Starting from the same delayed-cut-off shifted-window 12-hour 4D-Var assimilation, three different early-delivery experiments were run. For the 6-hour 4D-Var analyses for 0000 UTC, with observations in the time window 2101 - 0300 UTC, the first experiment used only those observations that had been received by 0400 UTC, the second used observations that had been received by 0600 UTC and the third used observations that had been received by 0800 UTC.

Figure 9 shows the anomaly correlation for the 500 hPa geopotential-height forecast error for the Northern Hemisphere extratropics, averaged over 30 days from 1 September 2003, for the ten-day forecasts from the 0000 UTC early-delivery analyses with an observation cut-off time of 0400 UTC (red), 0600 UTC (blue) and 0800 UTC (green), and for the control forecasts (brown).

In these experiments, use of the observations that arrived after 0400 UTC gave no significant gain in forecast quality. Accordingly, all subsequent early-delivery experimentation was run with an observation cut-off time of 0400 UTC for the 0000 UTC analysis and 1600 UTC for the 1200 UTC analysis. Note that in all four experiments, the propagation of information from cycle to cycle was performed by exactly the same delayed-cut-off assimilation.

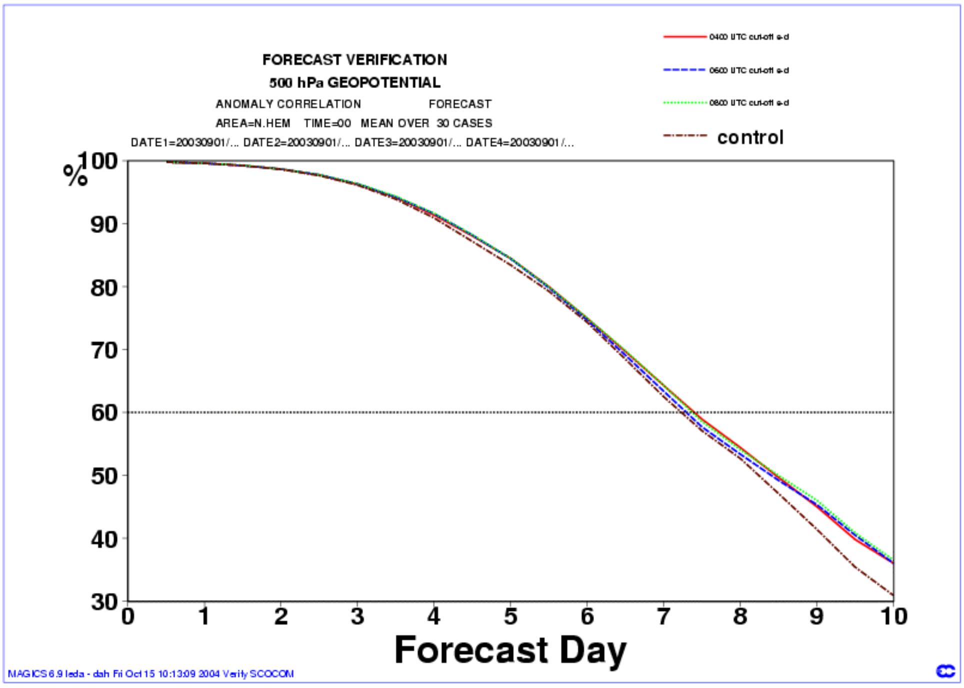

Figure 9 Anomaly correlation for the 500 hPa geopotential-height forecast error for the Northern Hemisphere extratropics, averaged over 30 days from 0000 UTC 1 September 2003, for the forecasts from the early-delivery analysis with an observation cut-off time of 0400 UTC (red), 0600 UTC (blue) and 0800 UTC (green) and for the control forecasts (brown). All four experiments were based on exactly the same delayed-cut-off cycling.

3.2 Delayed-cut-off observations

In the early experimentation, the shifted-window 12-hour 4D-Var data assimilation used the observations that had been presented to the operational suite. Observations for the intervals 0301 - 0900 UTC and 0901 - 1500 UTC had been extracted from the Reports Data Base at 1900 and 1915 UTC respectively and observations for 1501 - 2100 UTC and 2101 - 0300 UTC had been extracted at 0745 and 0800 UTC respectively. Since the start of December 2003, a separate delayed-cut-off (STREAM=DCDA) set of observations has also been saved, with observations from 0901 - 1500 UTC and 1501 - 2100 UTC extracted at 0145 and 0200 UTC respectively and observations from 2101 - 0300 UTC and 0301 - 0900 UTC extracted at 1345 and 1400 UTC respectively. These are the same extraction times as are now used for the delayed-cut-off observation stream in the operational early-delivery suite. The delayed-cut-off observation stream has more late-arriving data than the old operational suite for the periods 2101 - 0300 UTC and 0901 - 1500 UTC, and fewer late-arriving data for the periods 0301 - 0900 UTC and 1501 - 2100 UTC.

Two early-delivery experiments were run for February and March 2004. One used the operational observations in its shifted-window 12-hour 4D-Var assimilation and the other used the new delayed-cut-off observation stream. The quality of the forecasts from the early-delivery analyses in the two experiments was compared. In the Southern Hemisphere, at all levels, there was a small improvement in the early-delivery forecast scores when the delayed-cut-off observation stream was used for the shifted-window 12-hour 4D-Var analyses. The Southern Hemisphere 500 hPa geopotential-height scores are shown in Figure 10. In the Northern Hemisphere, changing the shifted-window 12-hour 4D-Var assimilation observation stream had no impact on the quality of the forecasts from the early-delivery analyses. Over the two- month period, the experiment with the new delayed-cut-off stream used 0.1% more TEMP winds and 1% more AMSU-A brightness-temperature data than the experiment with the operational observations.

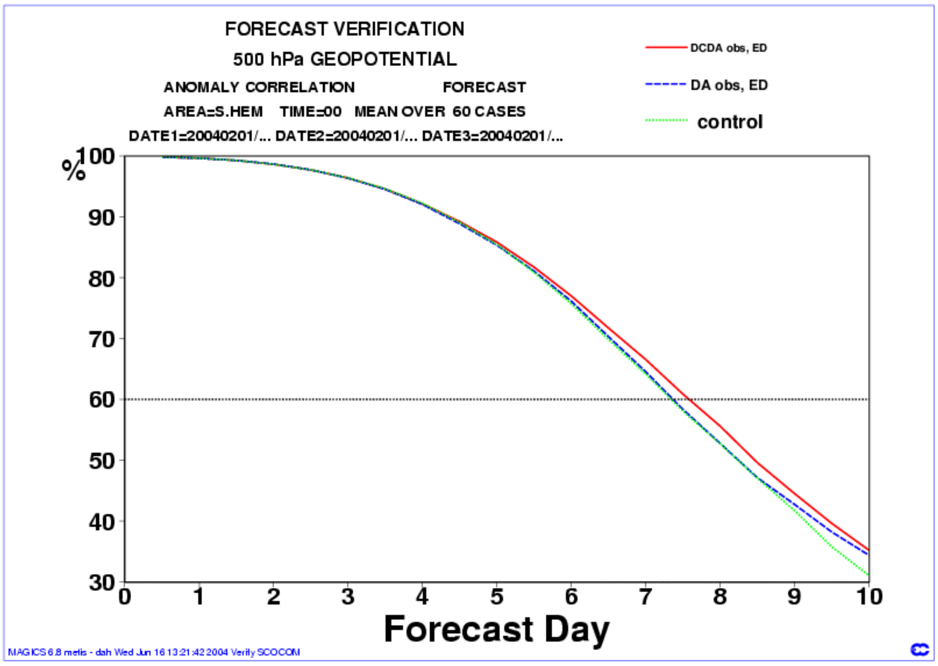

Figure 10 Anomaly correlation for the 500 hPa geopotential-height forecast error for the Southern Hemisphere extratropics, averaged over 60 days from 0000 UTC 1 February 2004, for the forecasts from the early-delivery analyses (red and blue) and the control analyses (green). In the red experiment, the shifted window 12-hour 4D-Var analyses used the delayed-cut-off observation stream, while in the blue experiment the operational observations were used.

4. Data Coverage

The extraction of the observations for the 0000 UTC early-delivery analysis is done at 0400 UTC. For the 0000 UTC analysis on 25 March 2004, which uses observations for the time interval 2101 UTC 24 March - 0300 UTC 25 March 2004, the table below shows which observations arrived early enough to be used by the early-delivery analysis, i.e. before 0401 UTC, and which were used by the operational analysis but arrived too late to be used by the early-delivery analysis, i.e. they were received between 0401 and 0800 UTC. (As long as the observations arrive by 13:45, they are still used by the delayed-cut-off analysis, even if they arrive too late to be used by the early-delivery analysis.)

Observation Type	Number of reports received before 0401 UTC	Number of reports received 0401 - 0800 UTC
SYNOP	13243	323
SHIP	1396	34
Aircraft	52219	239
BUOY	2785	708
TEMP	541	35
PILOT	278	8
Profilers	583	42
ATOVS/AMSU-A	254520	63445
ATOVS/AMSU-B	1705625	487260
ATOVS/SSU and MSU	4	0
ATOVS/HIRS	440017	126560
AIRS	65546	15081
Geostationary radiances	730763	24900
SSM/I	986496	0
Scatterometer	353394	143226
AMV	216465	46047

Table 2 Observations for the timeslot 2101 UTC 24 March - 0300 UTC 25 March 2004, showing the number of reports for each observation type which were received before 0401 UTC (i.e. early enough to be used by the early-delivery analysis) and the number received between 0401 and 0800 UTC (i.e. early enough for the old operational analysis, but too late for the early-delivery analysis)

Data coverage plots for the time window 2101 UTC 24 March - 0300 UTC 25 March 2004, showing the geographical coverage of the on-time and late observations for various observation types, are presented in an Annex to this document. There are no plots for SSM/I data or ERS-2 scatterometer reports, since all observations of these types arrived early enough to be included in the early-delivery analysis.

5. Observation Departure Statistics

Statistics of the departures of observations from the background field and the analysis are presented for a three-week period at the beginning of February 2004. Statistics for both the delayed-cut-off 12-hour 4D-Var and the early-delivery analysis are compared with a control analysis, which has the original 12-hour 4D-Var configuration. Due to the changed window geometry, the delayed-cut-off 12-hour 4D-Var experiment has more late arriving data at 0000 and 1200 UTC, and fewer data at the end of its observation windows, at 0600 and 1800 UTC. Total numbers of observations presented to the delayed-cut-off and the control analyses over the three-week period are similar. The totals for the delayed-cut-off 12-hour 4D-Var and the control assimilation are within 0.5% for radiosondes, AIREPs, profilers, SYNOPs, AMV winds and scatterometer data and within 1% for geostationary radiances and DMSP data. There are 1% extra data from the NOAA polar orbiting satellites, 2% less dropsonde data and 3% less DRIBU reports in the delayed-cut-off 12-hour 4D-Var compared with the control assimilation.

The observation statistics for the 6-hour 4D-Var early-delivery analyses are accumulated for the three weeks over two six-hour intervals, 2101 - 0300 UTC and 0901 - 1500 UTC. The statistics for the control 12-hour 4D-Var analyses are accumulated over two twelve-hour intervals, 1501 - 0300 UTC and 0301 - 1500 UTC. For an observation type that reports evenly over the data assimilation window, and where all the observations arrive before the early-delivery cut-off time, the total number of observations accumulated for the 6-hour 4D-Var early-delivery analysis statistics should be approximately 50% of the total accumulated for the 12-hour 4D-Var control analysis statistics. For TEMPs, where most of the observations report at 0000 UTC or 1200 UTC and most arrive promptly, the proportion accumulated for the early-delivery statistics is significantly greater than 50%. For AIREPs, where the observations are distributed fairly evenly in time, but some arrive after the cut-off time, the proportion accumulated is less than 50%.

5.1 Used AIREP 'u' Winds

Figure 11 shows the standard deviation and the bias for the AIREP east-west (u) component winds which were used by the analysis in the Northern Hemisphere extra-tropics (north of 20ºN) for the delayed-cut-off 12-hour 4D-Var (black) and the control (red). The departures from the background field are shown with a solid line, while a dotted line is used for the departures from the analysis. Over the three-week period, 1,612,502 AIREP u winds were used by the delayed-cut-off 12-hour 4D-Var, and 1,610,327 were used by the original analysis, a 0.13% difference. The observations are distributed evenly in time and the impact of shifting the assimilation window by six hours is seen to be neutral.

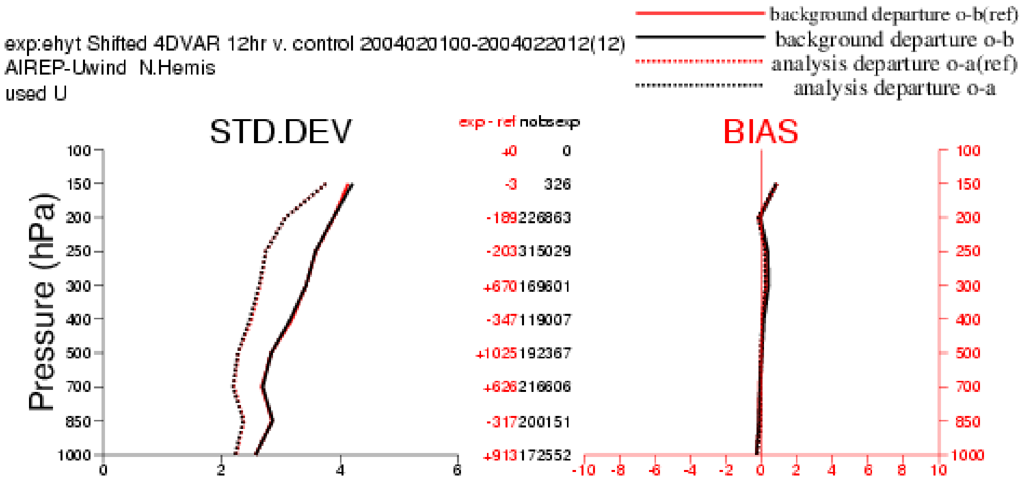

Figure 11 Standard deviation (left) and bias (right) for the departures of used AIREP u-wind components in the Northern Hemisphere extratropics from the background (solid) and analysis (dotted) for delayed-cut-off 12-hour 4D-Var (black) and control (red), accumulated over the period 0000 UTC 1 February 2004 - 1200 UTC 20 February 2004

Figure 12 shows the standard deviation and the bias for the AIREP u winds which were used by the analysis in the Northern Hemisphere extratropics for the early-delivery analysis (black) and the control (red). The standard deviation of the departure from the background field is smaller for the early-delivery system than for the control above 700 hPa, while the standard deviation of the departure from the analysis is smaller for the early-delivery at all levels. Bouttier (2001) showed that the distance of the analysis from the observations is greater for 12-hour 4D-Var than for 6-hour 4D-Var. Since the early-delivery analysis uses 6-hour 4D-Var and the control analysis uses 12-hour 4D-Var, this may explain the closer fit of the early-delivery analyses to the observations. The early delivery analyses used 49% fewer AIREP u winds than the control analyses in the Northern Hemisphere and 63% fewer in the Southern Hemisphere. (It should be emphasised that observations that arrive too late to be used by the early-delivery analysis are not lost, since they are included in the delayed-cut-off cycling component of the suite.)

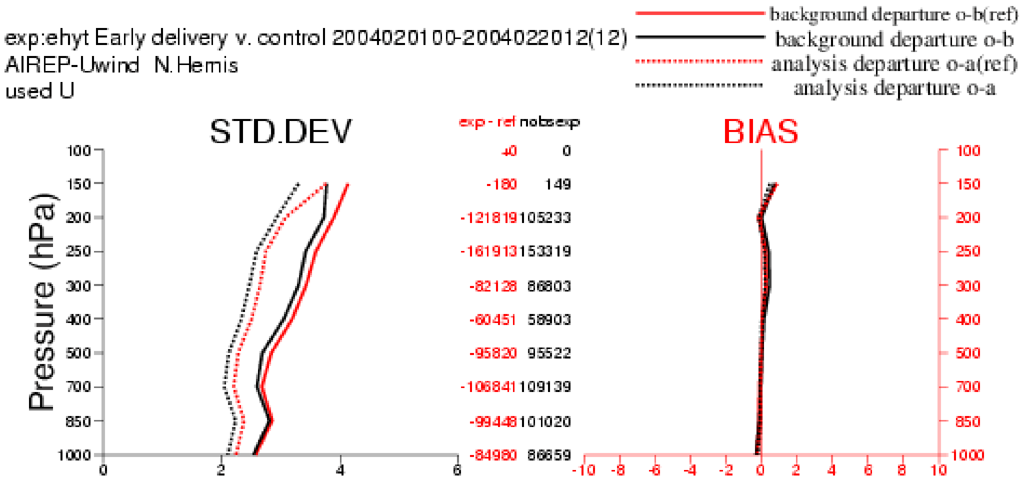

Figure 12 Standard deviation (left) and bias (right) for the departures of used AIREP u-wind components in the Northern Hemisphere extratropics from the background (solid) and analysis (dotted) for the early-delivery (black) and control (red), accumulated over the period 0000 UTC 1 February - 1200 UTC 20 February 2004

5.2 Used TEMP ‘u’ Winds

Figure 13 shows the standard deviation and the bias for the TEMP u winds that were used by the analyses in the Northern Hemisphere extratropics for the delayed-cut-off 12-hour 4D-Var (black) and the control (red). The standard deviation of the departure from the background field is smaller for the delayed-cut-off 12-hour 4D-Var than for the control in the region 500 - 200 hPa, while the standard deviation of the departure from the analysis is smaller for the delayed-cut-off 12-hour 4D-Var in the region 1000 - 150 hPa. The explanation for this is that the background-error standard deviation for component wind increases most rapidly with time in the upper troposphere, as shown by Jrvinen (2001). In the delayed-cut-off 12-hour 4D-Var, the TEMP reports, with an observation time of 0000 or 1200 UTC, are used three hours after the start of the background forecast, rather than nine hours in the control analysis. The departure statistics indicate the analysis is able to draw more closely to the TEMP u winds if they are used closer to the start of the 4D-Var window when the background errors are smaller.

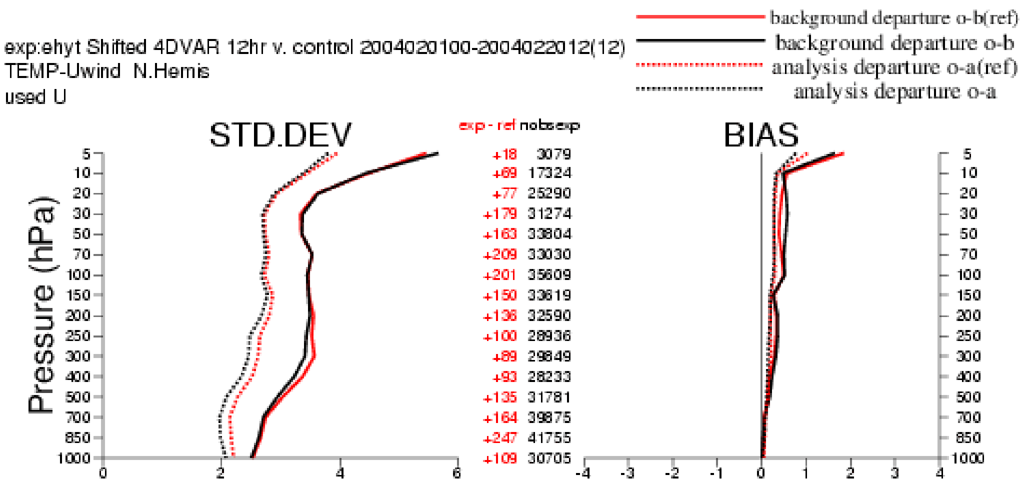

Figure 13 Standard deviation (left) and bias (right) for the departures of used TEMP u-wind components in the Northern Hemisphere extratropics from the background (solid) and analysis (dotted) for delayed-cut-off 12-hour 4D-Var (black) and control (red), accumulated over the period 0000 UTC 1 February - 1200 UTC 20 February 2004

Figure 14 shows the standard deviation and the bias for the TEMP u winds that were used by the analysis in the Northern Hemisphere extratropics for the early-delivery analysis (black) and the control (red). The standard deviation of the departure from the background field is smaller for the early-delivery system than for the control in the region 500 - 200 hPa, while the standard deviation of the departure from the analysis is smaller for the early-delivery in the region 1000 - 50 hPa.

During this three-week period, 17% fewer TEMP u winds were used in the Northern Hemisphere extratropics by the early-delivery 6-hour 4D-Var analyses than by the control 12-hour 4D-Var analyses. (Again, it should be noted that any late-arriving TEMP reports were not lost, since they were still used by the delayed-cut-off analysis.)

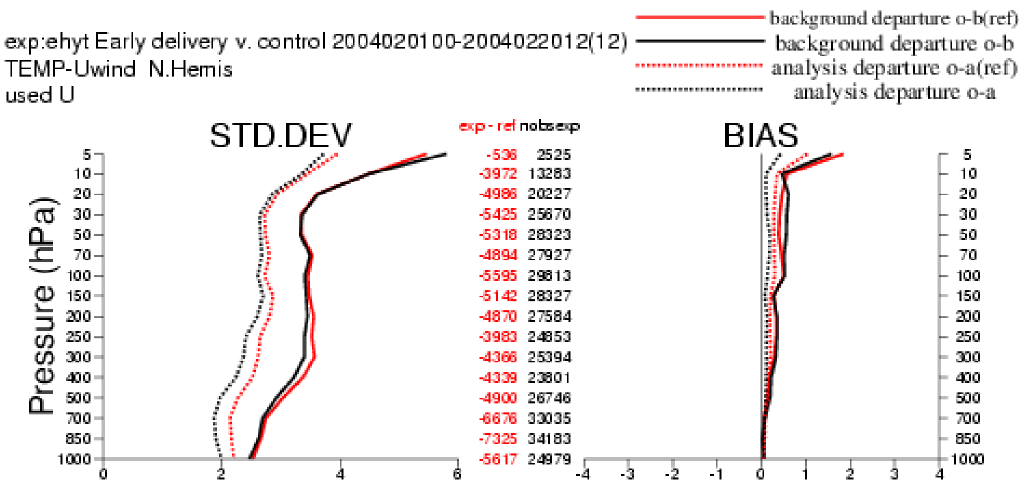

Figure 14 Standard deviation (left) and bias (right) for the departures of used TEMP u-wind components in the Northern Hemisphere extratropics from the background (solid) and analysis (dotted) for the early-delivery (black) and control (red), accumulated over the period 0000 UTC 1 February - 1200 UTC 20 February 2004

5.3 Used NOAA Brightness Temperatures

Overall, there were 1.1% more used brightness-temperature observations from NOAA polar-orbiting satellites for the delayed-cut-off 12-hour 4D-Var analyses than for the control analyses, with more data from NOAA-16 and NOAA-17, and slightly fewer data from NOAA-15, AQUA and AIRS. The early-delivery analyses used 62% fewer brightness-temperature observations than the control analyses.

Figure 15 shows the standard deviation and bias for the NOAA-16 AMSU-A brightness temperatures that were used by the analysis in the Northern Hemisphere extratropics for the early-delivery analysis (black) and the control (red). The early-delivery analysis has a larger bias for channels 12-14, reaching -0.6 K for the departure of the channel-14 brightness temperatures from the background field, compared with 0.1 K for the control. The standard deviation is of similar magnitude for the early-delivery analysis and the control, reaching 1.4 K for the departure of channel 14 from the background field, and 0.8 K for the departure from the analysis. In the tropics and the Southern Hemisphere extratropics, the early-delivery analyses have a smaller bias than the control analyses, while the standard deviation is neutral. The delayed-cut-off 12-hour 4D-Var analyses also show an increase in bias for NOAA-16 AMSU-A channels 12-14 in the Northern Hemisphere extratropics, but with the smaller magnitude of -0.4 K. AQUA AMSU-A brightness temperatures show the same signal as NOAA-16 AMSU-A. Channel 14 of NOAA-15 AMSU-A is blacklisted, but channel 13 hints at the same signal, though with reduced magnitude.

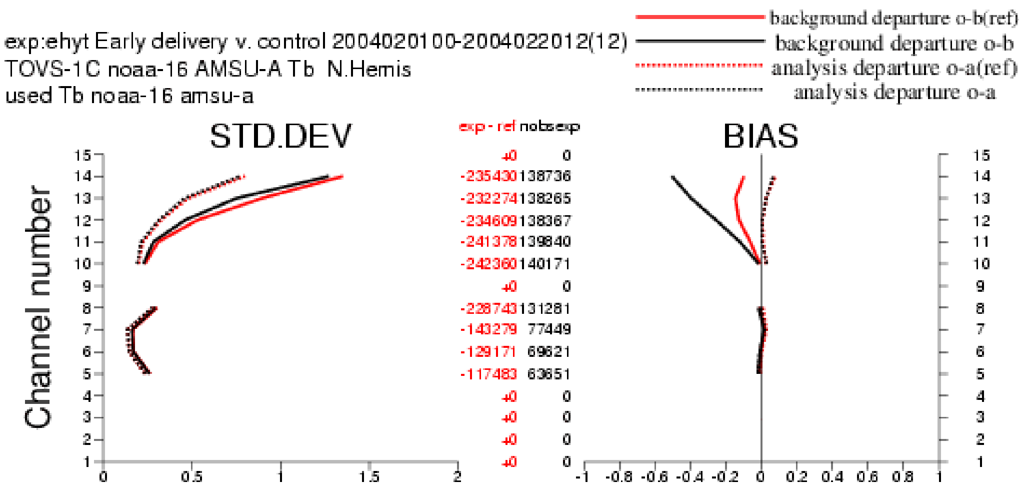

Figure 15 Standard deviation (left) and bias (right) for the departures of used NOAA-16 AMSU-A brightness temperatures in the Northern Hemisphere extratropics from the background (solid) and analysis (dotted) for the early-delivery (black) and control (red), accumulated over the period 0000 UTC 1 February - 1200 UTC 20 February 2004

6. Case Studies

The 329 days of experimentation presented in Section 3 demonstrate that, averaged over a long period, the early-delivery system has a neutral impact on forecast scores. Concern was expressed that the short observation cut-off time might degrade the forecasts of rapidly developing systems. Three historic rapidly developing storm cases were rerun, with a control data assimilation system and an early-delivery data assimilation system. They were the 'Danish Storm' of early December 1999, and the two European 'Christmas Storms' of late December 1999. The evolution of Hurricane Isabel was also investigated. This developed during September 2003 and was already included in the 329 days of early-delivery experimentation described above.

The European storms caused widespread damage and claimed many lives. With reference to the first of the Christmas Storms, it was pointed out that the ECMWF operational analyses of the time failed to capture the full amplitude of the observed extreme pressure fall and surface wind speeds (Wernli et al. 2002). Despite this, the forecasts from the early-delivery and control assimilations are compared here with the operational ECMWF analyses, since this study is limited to a subjective comparison of forecast quality rather than a detailed investigation of analysis performance.

6.1 The Danish Storm of December 1999

A deep low passed across Denmark and Southern Sweden at the beginning of December 1999. According to the ECMWF operational analysis at the time (cycle 21r4, t319, 60 levels), at 1200 UTC 3 December 1999, there was a low of 964 hPa over the North Sea to the west of Denmark. At 1800 UTC 3 December, the low had deepened to 958 hPa. It was centred over Denmark and had a very sharp gradient to the south and west. At 0000 UTC 4 December, the low was centred over south-east Sweden, with a minimum pressure of 960 hPa. The lowest pressure actually recorded was 953 hPa at 1800 UTC near the east coast of Jutland (Ulbrich et al. 2001). Figure 16 shows the operational mean sea-level pressure analyses of the storm at these three times.

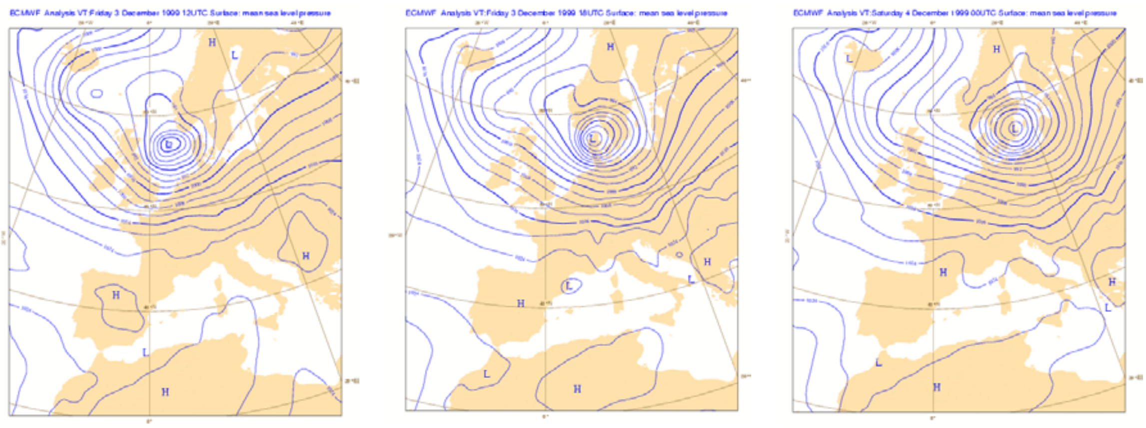

Figure 16 The operational analyses of mean sea-level pressure at 1200 UTC 3 December 1999 (left), 1800 UTC 3 December 1999 (centre) and 0000 UTC 4 December 1999 (right)

Both the early-delivery system and the control gave excellent 30-hour forecasts of the Danish Storm. The 30-hour forecast from the early-delivery analysis at 1200 UTC 2 December 1999 had a central pressure of 958 hPa, while the forecast from the control analysis had a central pressure of 961 hPa. Figure 17 shows the mean sea-level pressure fields for the 54-hour forecasts from the analyses at 1200 UTC 1 December 1999, together with the verifying operational analysis at 1800 UTC 3 December 1999. Both systems positioned the low correctly but underestimated its depth. The forecast from the early-delivery analysis (centre) had a minimum pressure of 965 hPa, the forecast from the control analysis (right) had a minimum pressure of 966 hPa, while the operational analysis (left) had a minimum pressure of 958 hPa.

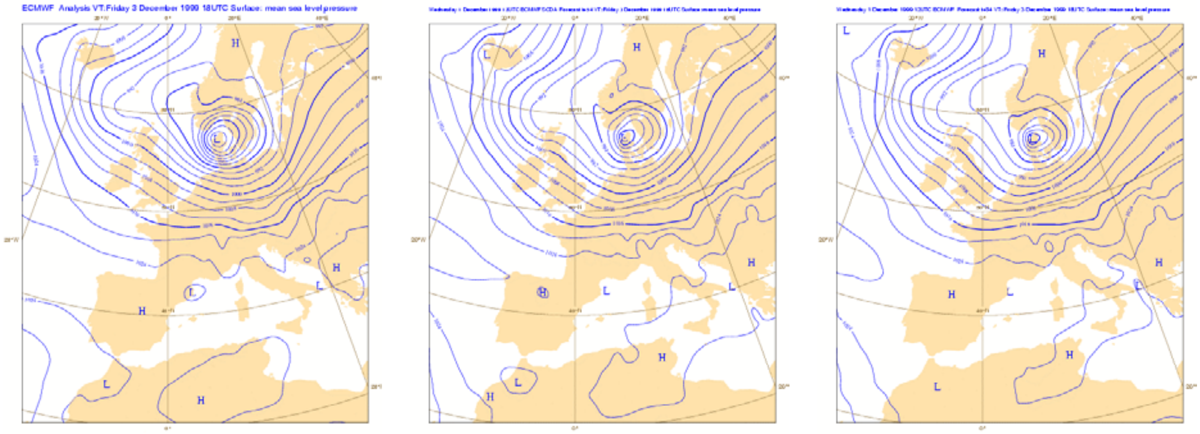

Figure 17 Mean sea-level pressure at 1800 UTC 3 December 1999 for the operational analysis (left), the 54-hour forecast from the early-delivery analysis (centre) and the 54-hour forecast from the control analysis (right)

For the 78-hour forecasts from the analyses of 1200 UTC 30 November 1999, both systems seriously underestimated the depth of the low. With the early-delivery system, the central pressure was 978 hPa and the low was displaced slightly to the south east. With the control system, the central pressure was 975 hPa and the low was displaced a little to the south west, but it did develop a region of tight gradients to the south and west of the centre which was missing in the early-delivery system.

For the 102-hour forecasts from the analyses of 1200 UTC 29 November 1999, the early-delivery system had a slack low of 986 hPa in the North Sea to the west of Denmark, while the control had a deep low of 969 hPa off the east coast of Scotland.

Figure 18 shows the 126-hour forecasts from the analyses at 1200 UTC 28 November 1999. The early-delivery system (centre) had a weak low of 978 hPa at approximately the correct position, while the control forecast (right) had a deep low of 957 hPa off the north-east tip of Scotland.

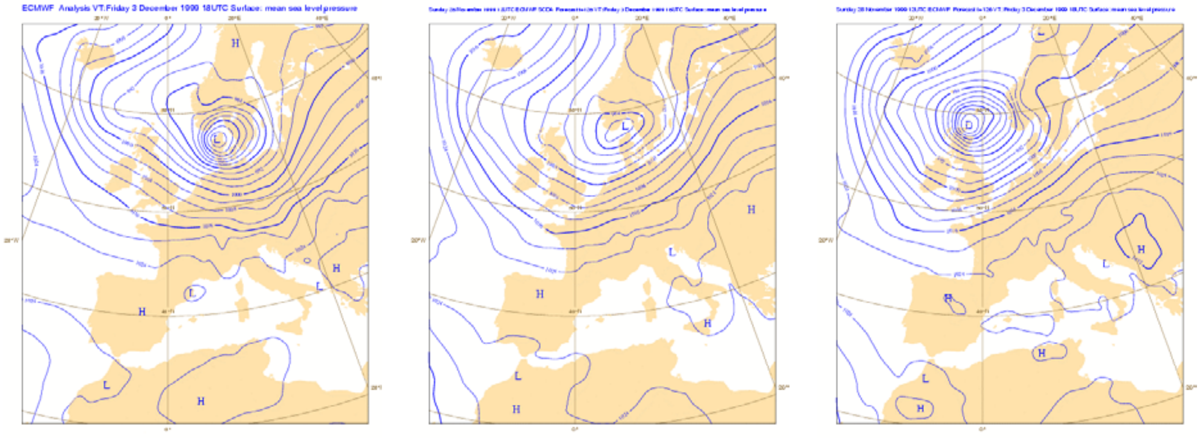

Figure 18 Mean sea-level pressure at 1800 UTC 3 December 1999 for the operational analysis (left), the 126 hour forecast from the early-delivery analysis (centre) and the 126 hour forecast from the control analysis (right)

In conclusion, for the final 2½ days, the early-delivery and control systems gave forecasts of similar quality for the Danish Storm. For the forecasts beyond four days, the control system gave a better indication of severe weather, but the early-delivery system was more accurate in its positioning of the low.

6.2 The First Christmas Storm of December 1999

An intense and explosively-developing storm passed swiftly and destructively across Northern France on 26 December 1999, and went on to cause further extensive damage in Southern Germany and Switzerland. It was referred to as 'T1' by Météo-France and 'Lothar' by Deutscher Wetterdienst. In the six hours to 0000 UTC 26 December 1999, it moved 700 km across the Atlantic to a position of 49N 7W, where it had a central pressure of 984 hPa (Baleste et al. 2001). In the following six hours, it deepened explosively. At 0600 UTC it was close to Rouen, with a central pressure of 962 hPa. Behind the low, the pressure rose rapidly, with recorded increases of 10 hPa in 15 minutes. The low then began to fill, and at 1200 UTC it was positioned over Germany with a central pressure of 974 hPa. A maximum wind speed of 48 m/sec was reported at Orly, and wind speeds in excess of 40 m/sec were reported from Caen, Chartres, Nancy, Strasbourg, Basel and Zürich.

In the following series of diagrams, mean sea-level pressure fields are presented, with the ECMWF operational analysis on the left, the forecast from the early-delivery analysis in the centre and the forecast from the control analysis on the right. Figure 19 shows the 60-hour forecasts from the analyses of 1200 UTC 23 December 1999, with the verifying analysis at 0000 UTC 26 December 1999. The analysed low of 984 hPa to the west of the French coast was missed by both forecasts.

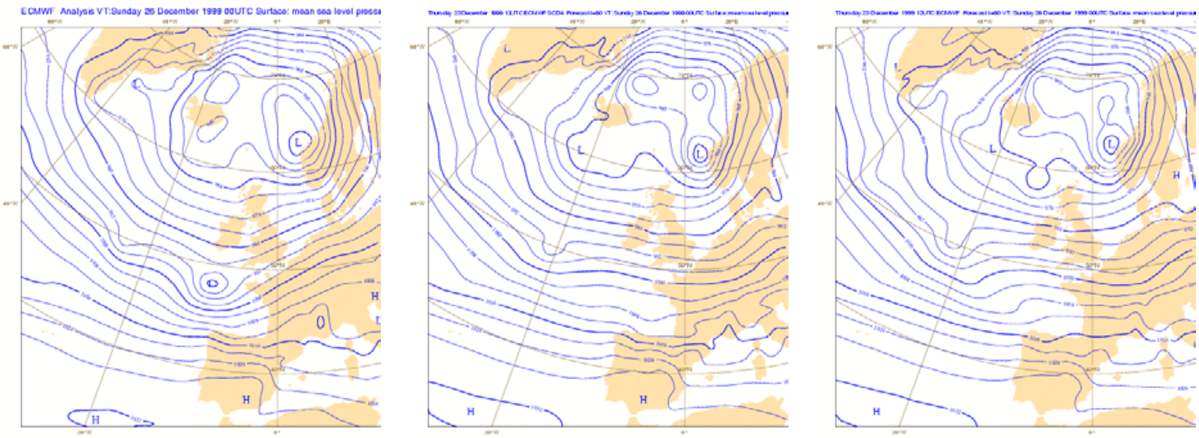

Figure 19 Mean sea-level pressure at 0000 UTC 26 December 1999 for the operational analysis (left), the 60-hour forecast from the early-delivery analysis of 1200 UTC 23 December (centre) and the 60-hour forecast from the control analysis (right)

Figure 20 shows the 72-hour forecasts from the analyses of 1200 UTC 23 December 1999 and the verifying analysis at 0000 UTC 26 December 1999. Both forecasts incorrectly developed a low pressure area over the Irish Sea region. In the operational analysis, the first French storm had tracked across Northern France and was now depicted as a sharp trough over Western Germany.

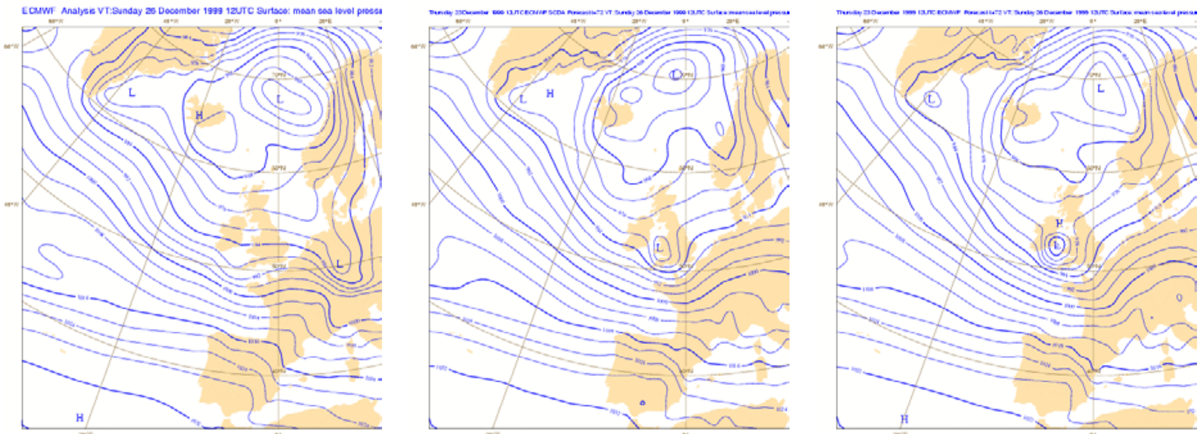

Figure 20 Mean sea-level pressure at 1200 UTC 26 December 1999 for the operational analysis (left), the 72-hour forecast from the early-delivery analysis of 1200 UTC 23 December (centre) and the 72-hour forecast from the control analysis (right)

In the 108-hour forecasts from the analyses of 1200 UTC 23 December 1999, both systems failed to develop the second Christmas Storm, which was a deep low of 972 hPa in the Paris region.

At 0000 UTC 26 December 1999, both 36-hour forecasts from the analyses of 1200 UTC 24 December failed to develop the closed low of 984 hPa to the west of the French coast. The forecast from the control analysis generated a trough of 996 hPa in approximately the correct position. The early-delivery experiment missed this development completely.

For the 48-hour forecasts from the analyses of 1200 UTC 24 December 1999, both systems incorrectly generated a low over the Irish Sea region. The control forecast had a hint of the trough over Western Germany, but without the tight gradients of the analysis. The forecast from the early-delivery analysis missed the trough completely. In the 84-hour forecasts from the analyses of 1200 UTC 24 December 1999, both systems failed to generate the deep low in the Paris region.

Figure 21 shows the 24-hour forecasts from the analyses of 1200 UTC 25 December 1999. The forecast from the control analysis gave a good representation of the storm over Germany. The forecast from the early-delivery analysis was still unable to predict the storm properly.

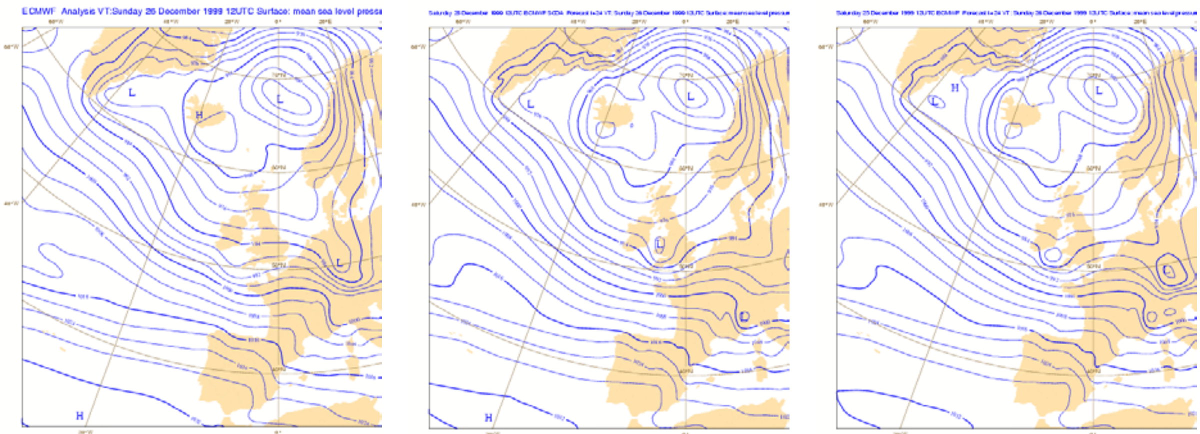

Figure 21 Mean sea-level pressure at 1200 UTC 26 December 1999 for the operational analysis (left), the 24-hour forecast from the early-delivery analysis of 1200 UTC 25 December (centre) and the 24-hour forecast from the control analysis (right)

6.3 The Second Christmas Storm of December 1999

The second Christmas Storm began to form in the afternoon of 26 December 1999 and moved swiftly eastwards across the Atlantic. It was referred to as ‘T2’ by Météo-France and ‘Martin’ by Deutscher Wetterdienst. At 1800 UTC 26 December, it was located at 43N 33W with a central pressure of 1002 hPa (Pearce et al. 2001). At 0000 UTC 27 December, the Brest radiosonde recorded an exceptionally high wind speed of 147 m/sec at a height of about 8000m, giving an indication of the strength of the jet stream overhead. The low started to deepen explosively, and its central pressure dropped by about 25 hPa between 0600 and 1500 UTC. At 1800 UTC it was just to the north of Nantes with a minimum pressure of 964 hPa. It then began to fill, and at 0000 UTC 28 December, it was located at 48N 5E with a central pressure of 972 hPa. There were damaging winds in western and southern France, northern Spain and the western Mediterranean. A maximum wind speed of 54 m/sec was reported at Royan, and wind speeds in excess of 40 m/sec were reported from Limoges, Clermont-Ferrand, Bordeaux, Cognac, La Rochelle and Cap Ferret (Baleste et al. 2001).

Figure 22 shows the 60-hour forecasts from the analyses of 1200 UTC 25 December 1999 and the verifying analysis at 0000 UTC 28 December 1999. The operational analysis had a low of 972 hPa in the Paris region. The forecast from the early-delivery analysis had a low of 976 hPa with a very tight gradient to the west, but positioned too far west. The forecast from the control analysis had a low of 984 hPa, again too far to the west.

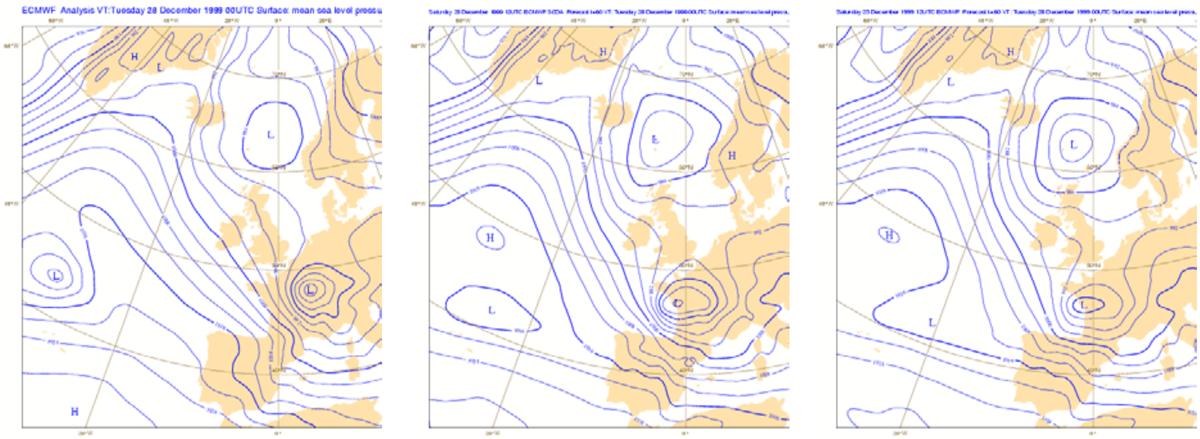

Figure 22 Mean sea-level pressure at 0000 UTC 28 December 1999 for the operational analysis (left), the 60-hour forecast from the early-delivery analysis of 1200 UTC 25 December 1999 (centre) and the 60-hour forecast from the control analysis (right)

Figure 23 shows the 24-hour forecasts from the analyses of 1200 UTC 26 December 1999 and the verifying analysis at 1200 UTC 27 December 1999. The operational analysis had a low of 984 hPa at 47N 4W. The forecast from the control analysis had a low of 988 hPa at 49N 18W. The forecast from the early-delivery analysis had a low of 996 hPa at 48N 17W.

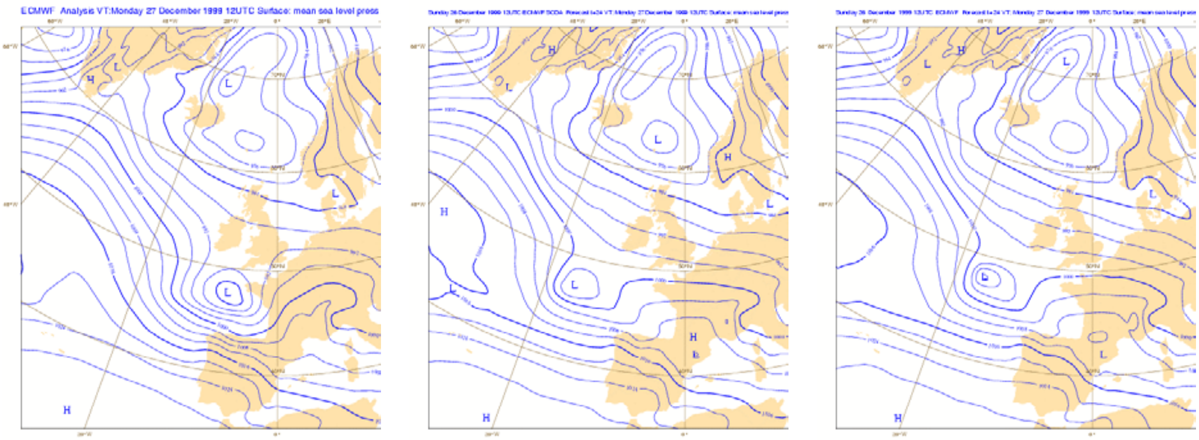

Figure 23 Mean sea-level pressure at 1200 UTC 27 December 1999 for the operational analysis (left), the 24-hour forecast from the early-delivery analysis of 1200 UTC 26 December 1999 (centre) and the 24-hour forecast from the control analysis (right)

Figure 24 shows the 36-hour forecasts from the analyses of 1200 UTC 26 December 1999 and the verifying analysis at 0000 UTC 28 December 1999. The operational analysis had a low of 972 hPa. The forecast from the control analysis had a low of 980 hPa, while the forecast from the early-delivery analysis has a low of 988 hPa. Both forecasts positioned the low too far to the west.

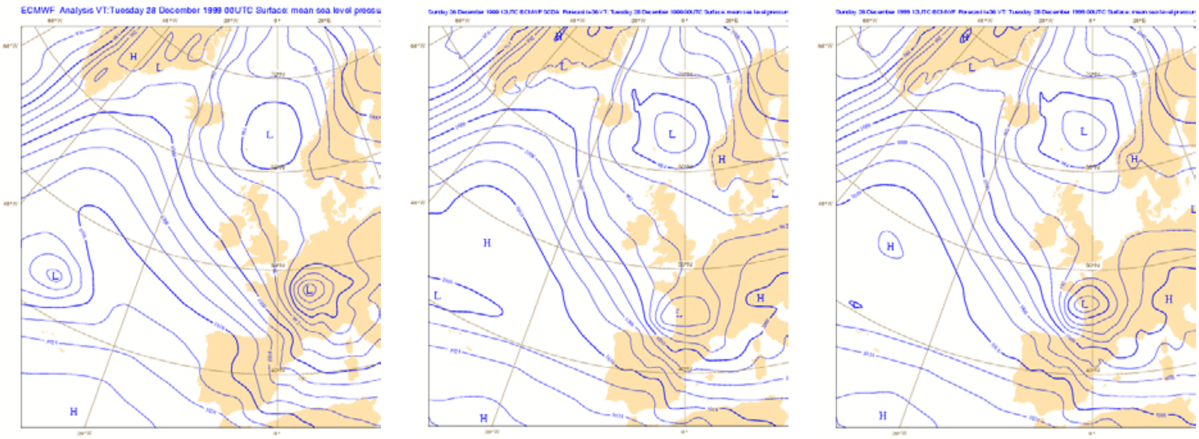

Figure 24 Mean sea-level pressure at 0000 UTC 28 December 1999 for the operational analysis (left), the 36-hour forecast from the early-delivery analysis of 1200 UTC 26 December 1999 (centre) and the 36-hour forecast from the control analysis (right)

Figure 25 shows the 12-hour forecasts from the analyses of 1200 UTC 27 December 1999 and the verifying analysis at 0000 UTC 28 December 1999. Both forecasts finally managed to predict the storm well, but only the early-delivery forecast would have been available early enough to be of any use.

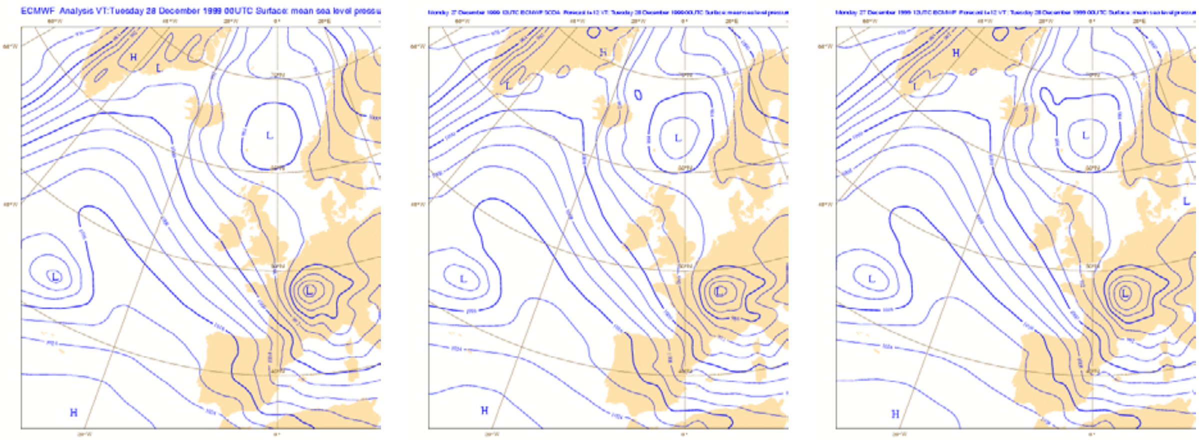

Figure 25 Mean sea-level pressure at 0000 UTC 28 December 1999 for the operational analysis (left), the 12-hour forecast from the early-delivery analysis of 1200 UTC 27 December 1999 (centre) and the 12-hour forecast from the control analysis (right)

6.4 Hurricane Isabel

Hurricane Isabel made a landfall near Ocracoke Island on the Outer Banks of North Carolina at 1700 UTC 18 September 2003. The 9-day forecasts verifying at 0000 UTC 19 September 2003 were poor for both the early-delivery system and the control. The 8-day forecasts verifying at the same time were excellent for both systems. Figure 26 shows the mean sea-level pressure and 10-metre wind at 0000 UTC 19 September 2003 for the control analysis (left), the 8-day forecast from the early-delivery analysis at 0000 UTC 11 September 2003 (centre) and the 8-day forecast from the control analysis (right).

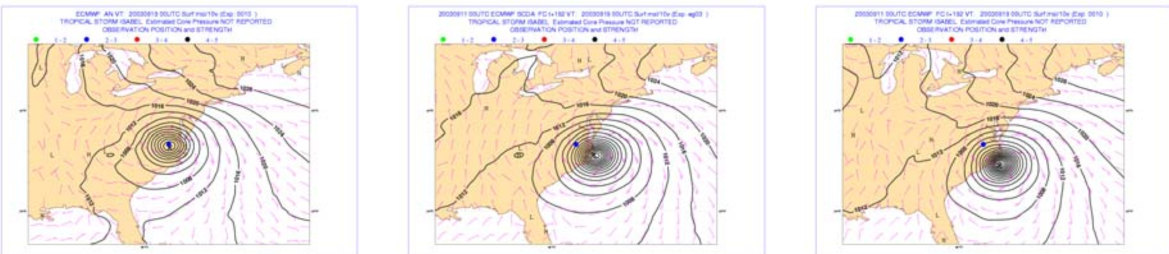

Figure 26 Mean sea-level pressure and 10m wind at 0000 UTC 19 September 2003 for the control analysis (left), the 8-day forecast from the early-delivery analysis (centre) and the 8-day forecast from the control analysis (right)

Figure 27 shows the 7-day forecasts verifying at 0000 UTC 19 September 2003, with the forecast from the early-delivery analysis giving better guidance than the control forecast. The control analysis is on the left, the 7-day forecast from the early-delivery analysis of 0000 UTC 12 September 2003 is in the centre and the 7-day forecast from the control analysis is on the right.

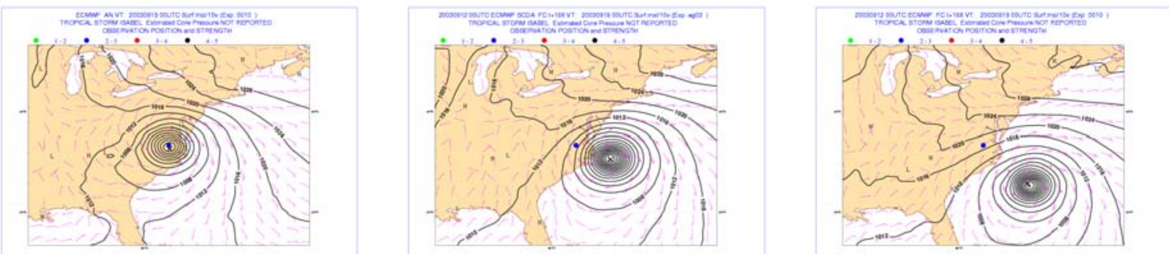

Figure 27 Mean sea-level pressure and 10m wind at 0000 UTC 19 September 2003 for the control analysis (left), the 7-day forecast from the early-delivery analysis (centre) and the 7-day forecast from the control analysis (right)

Figure 28 shows the mean sea-level pressure and 10 metre wind fields and the Regional Specialized Meteorological Centre (RSMC) tropical cyclone report of Isabel's position for the early-delivery analysis of 0000 UTC 12 September 2003 (left) and the control analysis (right). These were the starting-point analyses for the forecasts shown in Figure 27 above.

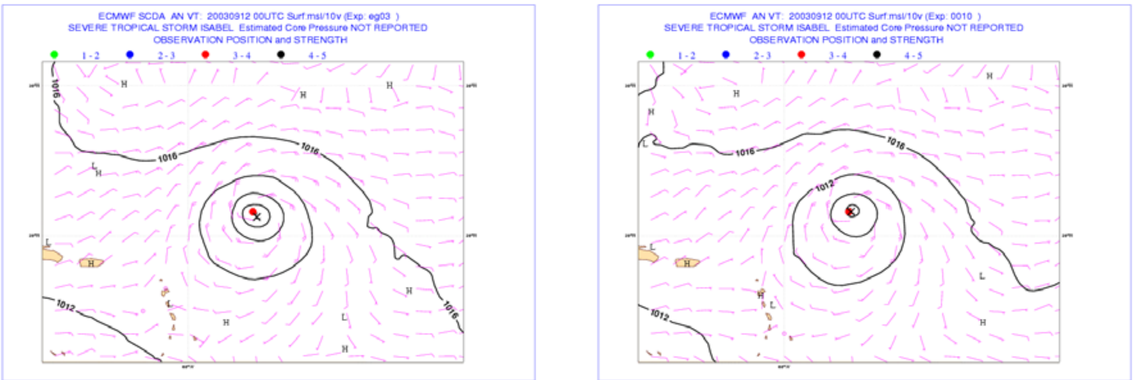

Figure 28 Mean sea-level pressure, 10m wind and reported tropical cyclone position at 0000 UTC 12 September 2003 for the early-delivery analysis (left) and the control analysis (right)

For most of the lifetime of Hurricane Isabel, the early-delivery and control analyses appeared to be of comparable quality. The single exception to this was at 0000 UTC 14 September 2003, when the early-delivery analysis was worse than the control analysis. The first guess for the early-delivery analysis predicted that Isabel's centre was too weak and too far to the west. The analysis then further weakened the storm centre, without being able to move it back far enough to the east. More of the dropsonde winds were rejected by the early-delivery analysis than by the control analysis.

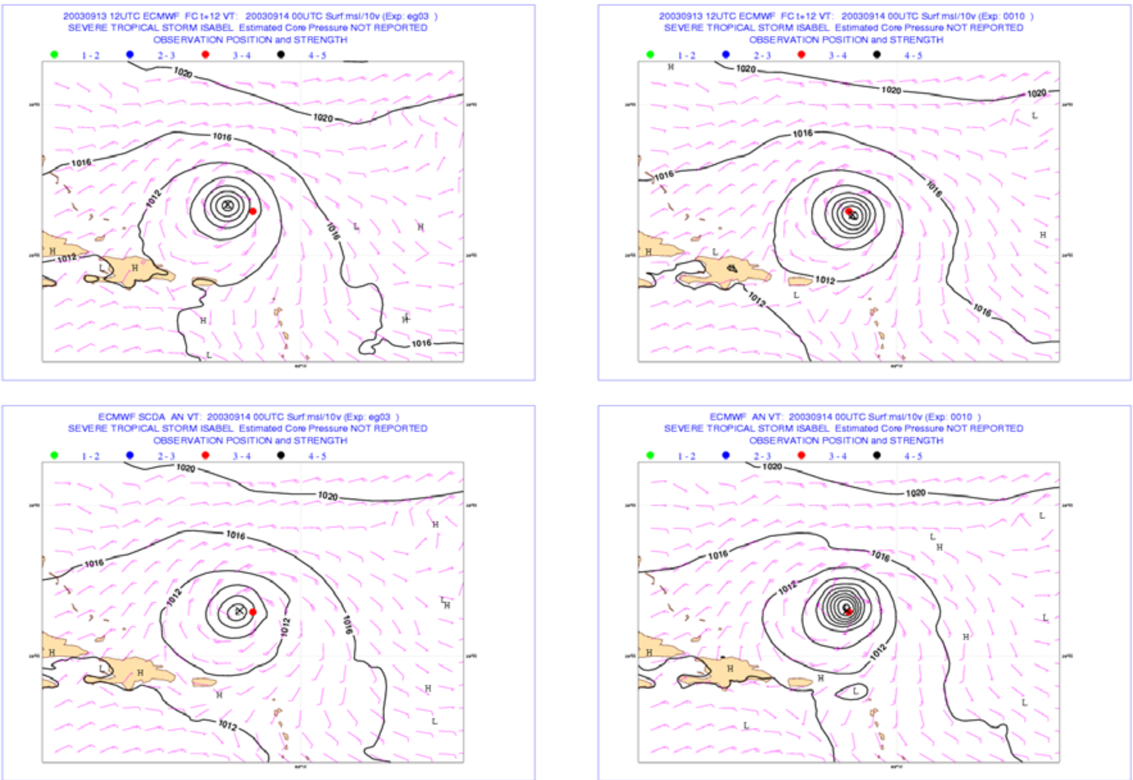

Figure 29 Mean sea-level pressure, 10m wind and reported tropical cyclone position at 0000 UTC 14 September 2003 for the early-delivery first guess (top left), early-delivery analysis (bottom left), control first guess (top right) and control analysis (bottom right)

Despite the poorer analysis, Figure 30 shows that the resulting 5-day forecast of Isabel's landfall was comparable with the control forecast.

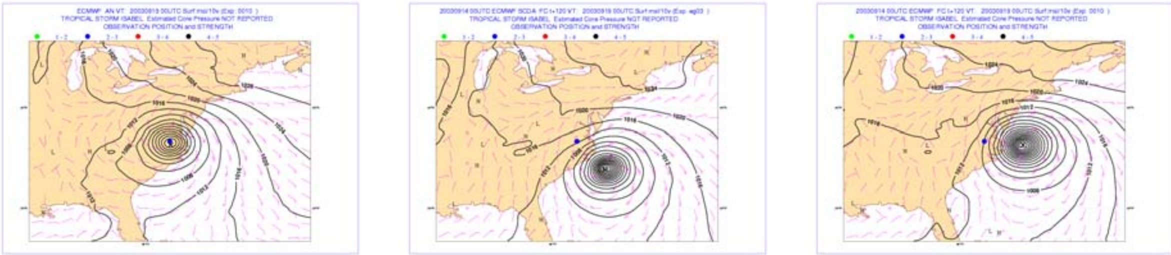

Figure 30 Mean sea-level pressure and 10m wind at 0000 UTC 19 September 2003 for the control analysis (left), 5-day forecast from the early-delivery analysis (centre) and 5-day forecast from the control analysis (right)

The 1 to 4 day forecasts of the landfall of Hurricane Isabel were very good for both systems.

6.5 Summary

The early-delivery system had an essentially neutral impact on the Danish Storm and the excellent forecasts of Hurricane Isabel were also excellent with the early-delivery system. However, the poor forecasts of the two Christmas storms were even worse with the early-delivery system. Especially bad were the 24-hour forecast of the first storm and the 36-hour forecast of the second storm. The early-delivery experiments were then repeated with an eight-hour observation cut-off time instead of the original four-hour cut-off time, but inclusion of late-arriving observations did not give any significant improvement in the quality of the forecasts. The control and delayed-cut-off 12-hour 4D-Var assimilations had been running independently for a month before the Christmas storm period and the first-guess fields presented to the control and early-delivery assimilations were not identical. The Christmas Storm sequence, with its very unstable conditions and explosively developing storms, has always proved to be a very difficult period for the ECMWF data assimilation and forecast system to predict correctly.

7. Future Developments

There are various plans for more timely reception of satellite data. ECMWF has started to use EUMETSAT ATOVS Retransmission Service (EARS) data. Ground stations download and process ATOVS data as the NOAA polar-orbiting satellites pass overhead, and the information is posted on the GTS by EUMETSAT within 30 minutes. The EARS data currently cover Europe and the North Atlantic, and there are plans to extend the cover to the whole of the Northern Hemisphere. MetOp, the first European polar-orbiting weather satellite, is scheduled to be launched in 2005. Although initially the data will be available 2¼ hours after observation time, there are plans to provide it more quickly. By 2010, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) is planned to replace the current NOAA satellites, and its processed data should also be available within 30 minutes. Faster reception of satellite data may make it possible to further reduce the observation cut-off time of the early-delivery data assimilation.

By providing the best possible first guess from the delayed-cut-off 12-hour 4D-Var analyses, it has proved to be possible to perform 4-hour cut-off analyses without any significant reduction in forecast quality. As a result, the early-delivery suite became the operational data assimilation system on 29 June 2004, and the

ECMWF forecast products are now available up to four hours sooner than with the previous operational schedule.

Acknowledgements

I would like to thank David Burridge for his support of this project from its inception through to its operational implementation. I would also like to thank Erik Andersson, Adrian Simmons, Lars Isaksen, Milan Dragosavac, Manuel Fuentes, Alfred Hostadler and Antonio Garcia-Mendez for help, advice and software.

References

Baleste, M.-C., Brunet, H., Mougel, A., Coiffier, J., Bourdette, N. and Bessemoulin, P., 2001: Les tempêtes exceptionnelles de Noël 1999. In *Phénomènes remarquables,* 7, Météo-France, Toulouse, France.

Bouttier, F., 2001: The Development of 12-hourly 4D-Var. ECMWF Tech. Memo. 348

Järvinen, H., 2001: Temporal evolution of innovation and residual statistics in the ECMWF variational data assimilation systems. *Tellus*, **53A**, 333-347.

Klinker, E., Rabier, F., Kelly, G. and Mahfouf, J.F., 2000: The ECMWF operational implementation of four-dimensional variational assimilation. Part III: Experimental results and diagnostics with operational configuration. *Q. J. R. Meteorol. Soc*., **126**, 1191-1216.

Mahfouf, J.F. and Rabier, F., 2000: The ECMWF operational implementation of four-dimensional variational assimilation. Part II: Experimental results with improved physics. *Q. J. R. Meteorol. Soc*., **126**, 1171-1190.

Pearce, R., Lloyd, D. and McConnell, D., 2001: The post-Christmas 'French' storms of 1999. *Weather*, **56**, 81-91.

Rabier, F., Järvinen, H., Klinker, E., Mahfouf, J.F. and Simmons, A., 2000: The ECMWF operational implementation of four-dimensional variational assimilation. Part I: Experimental results with simplified physics. *Q. J. R. Meteorol. Soc*., **126**, 1143-1170.

Ulbrich, U., Fink, A. H., Klawa, M. and Pinto, J. G., 2001: Three extreme storms over Europe in December 1999. *Weather*, **56**, 70-80.

Annex: Observation Data Coverage Plots

Data coverage plots for the time window 2101 UTC 24 March - 0300 UTC 25 March 2004, showing the geographical coverage of the on-time and late observations for various observation types, are presented in Figures A.1 - A.22. There are no plots for SSM/I data or ERS-2 scatterometer reports, since all observations of these types arrived early enough to be included in the early-delivery analysis. (As long as the observations arrive by 1345 UTC, they are still used by the delayed-cut-off analysis, even if they arrive too late to be used by the early-delivery analysis.)

TEMP Reports

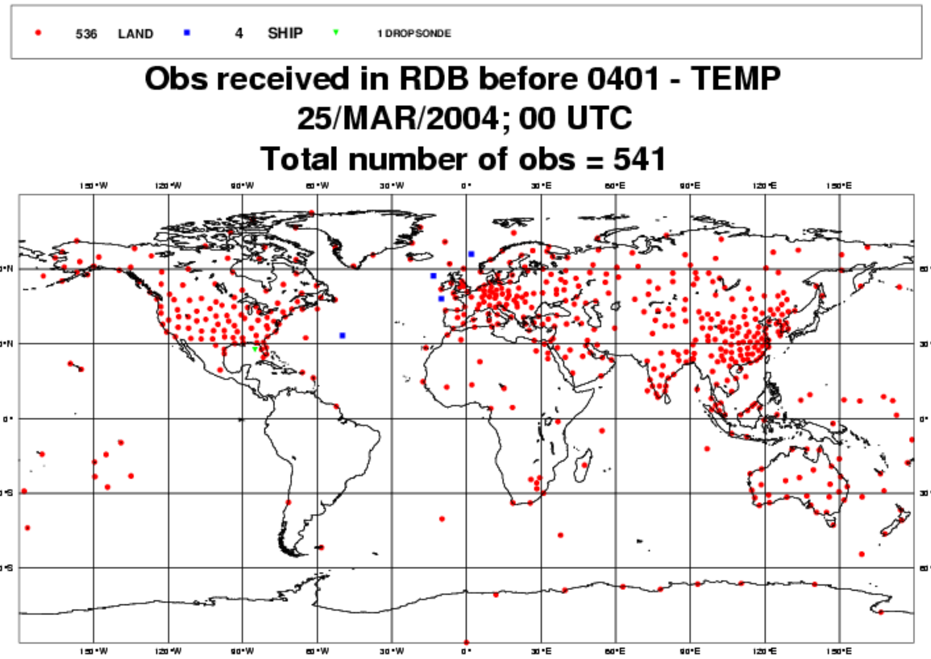

Figure A. 1 TEMP reports for land (red) and ship (blue) for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

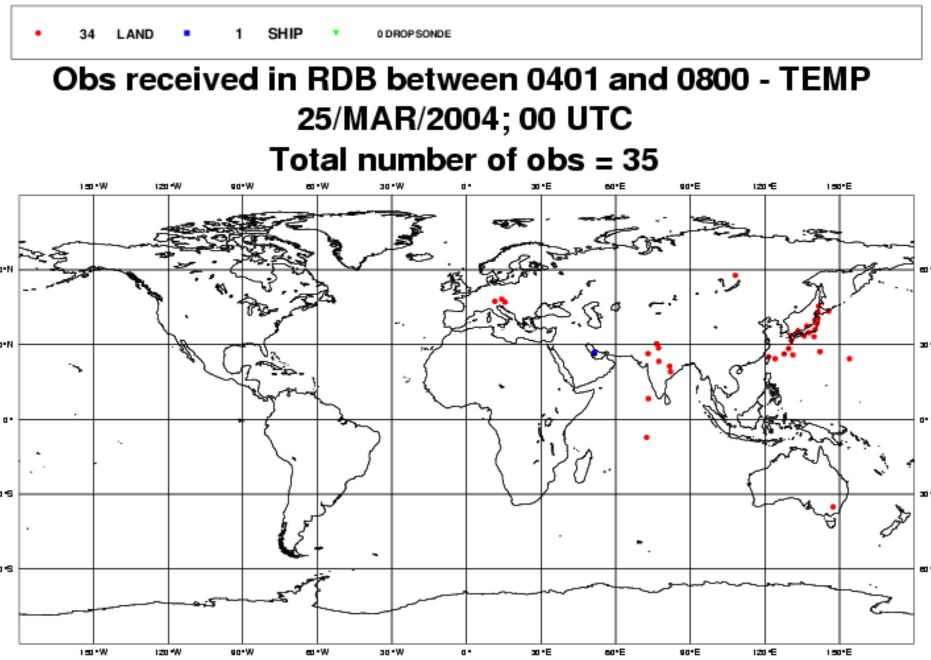

Figure A. 2 TEMP reports for land (red) and ship (blue) for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

Pilot and Wind Profiler Reports

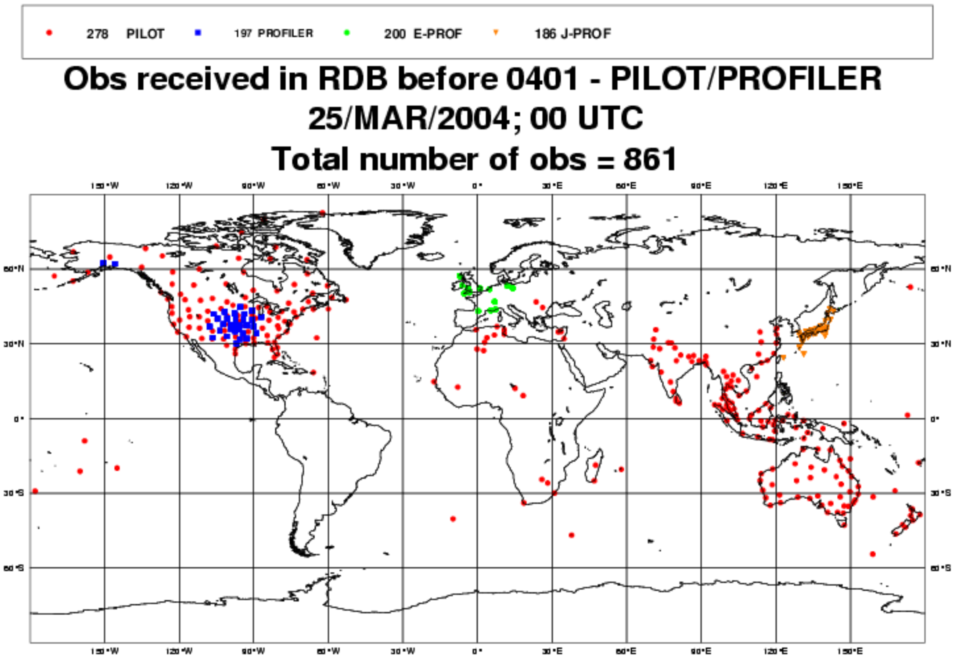

Figure A.3 PILOT (red) and Profiler (blue/green/orange) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

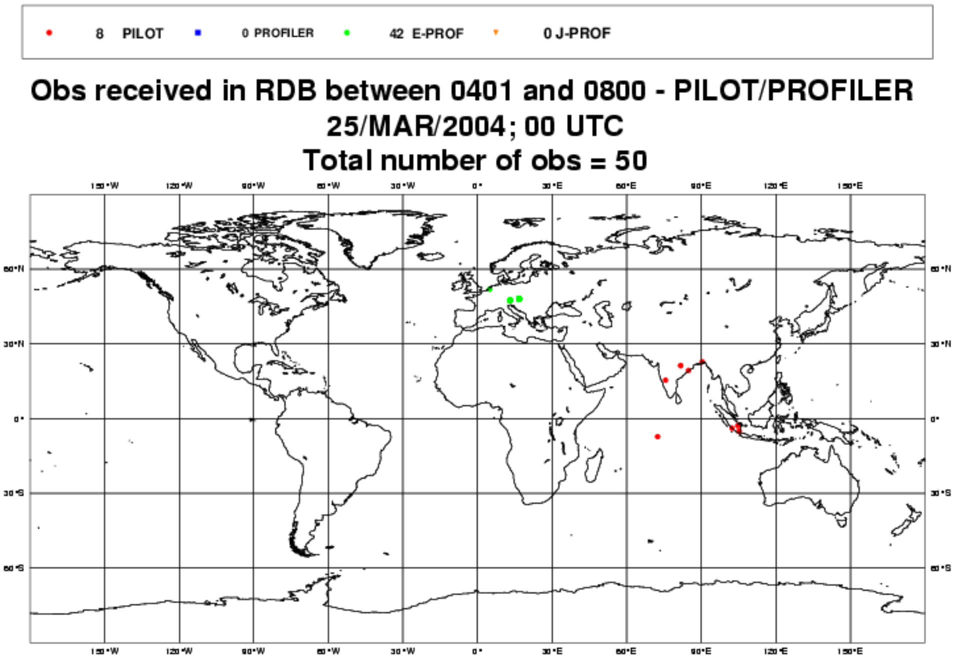

Figure A.4 PILOT (red) and Profiler (blue/green/orange) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

SYNOP and SHIP Reports

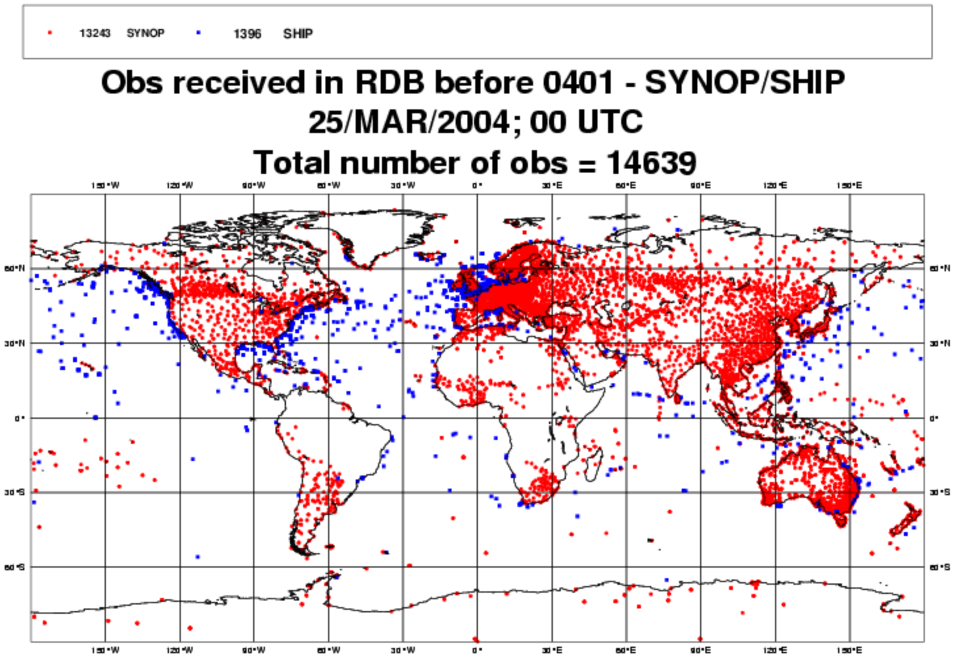

Figure A.5 SYNOP (red) and SHIP (blue) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

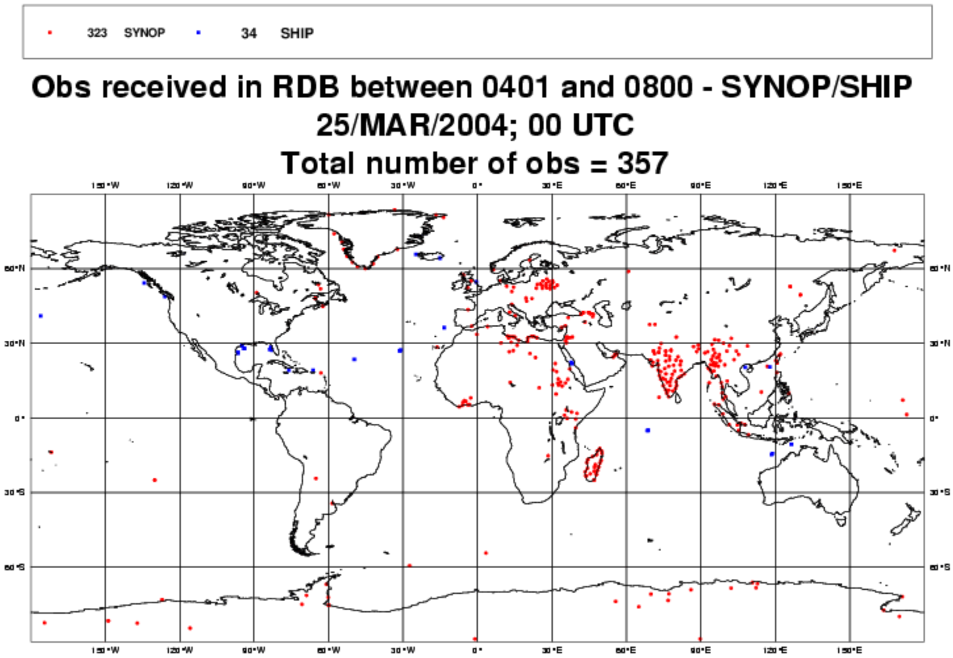

Figure A.6 SYNOP (red) and SHIP (blue) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

Aircraft Reports

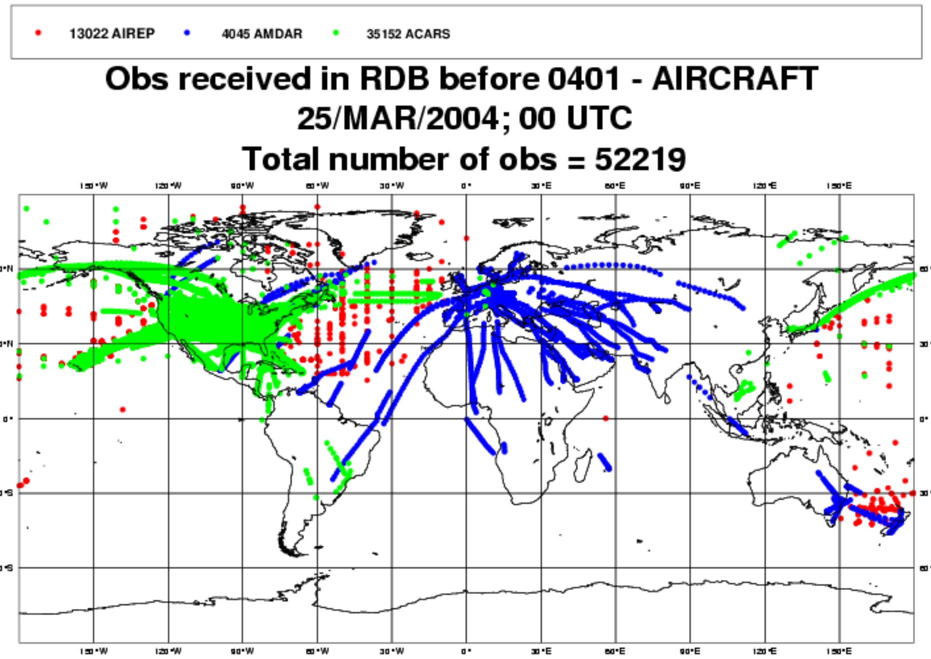

Figure A.7 AIREP (red), AMDAR (blue) and ACARS (green) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

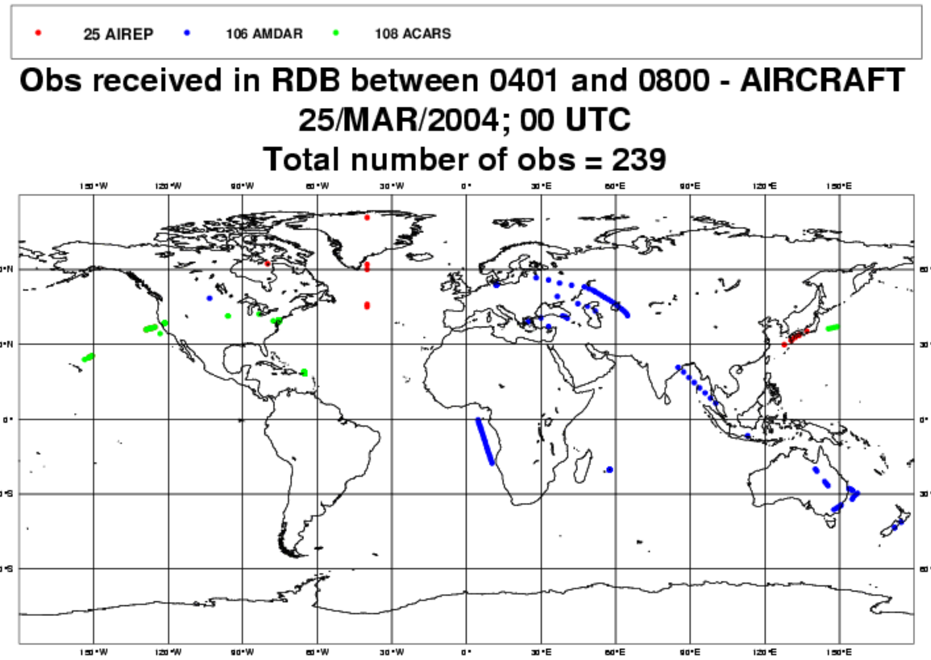

Figure A.8 AIREP (red), AMDAR (blue) and ACARS (green) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

DRIBU Reports

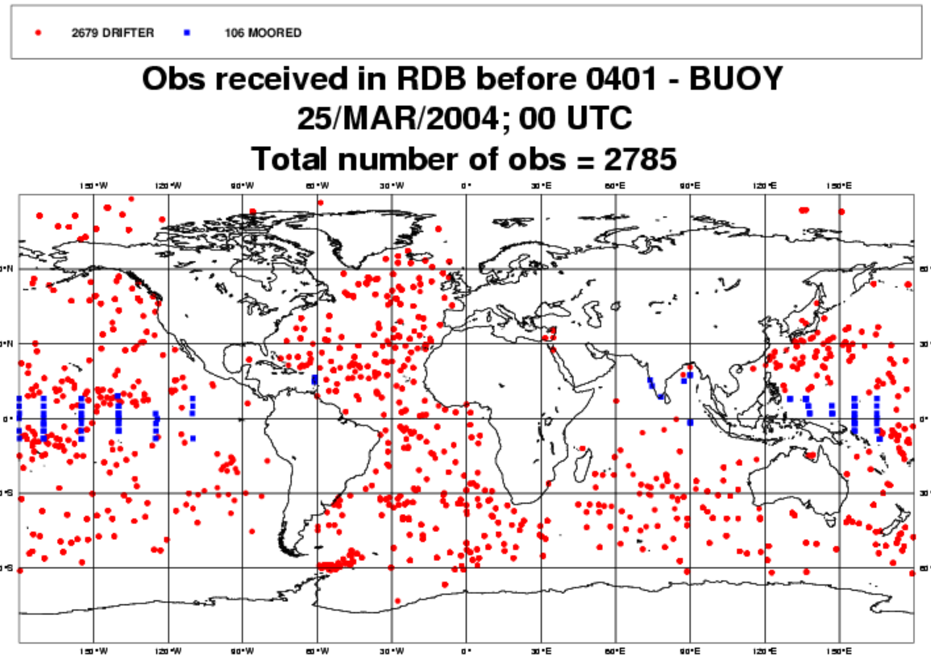

Figure A.9 Drifting (red) and moored (blue) BUOY reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

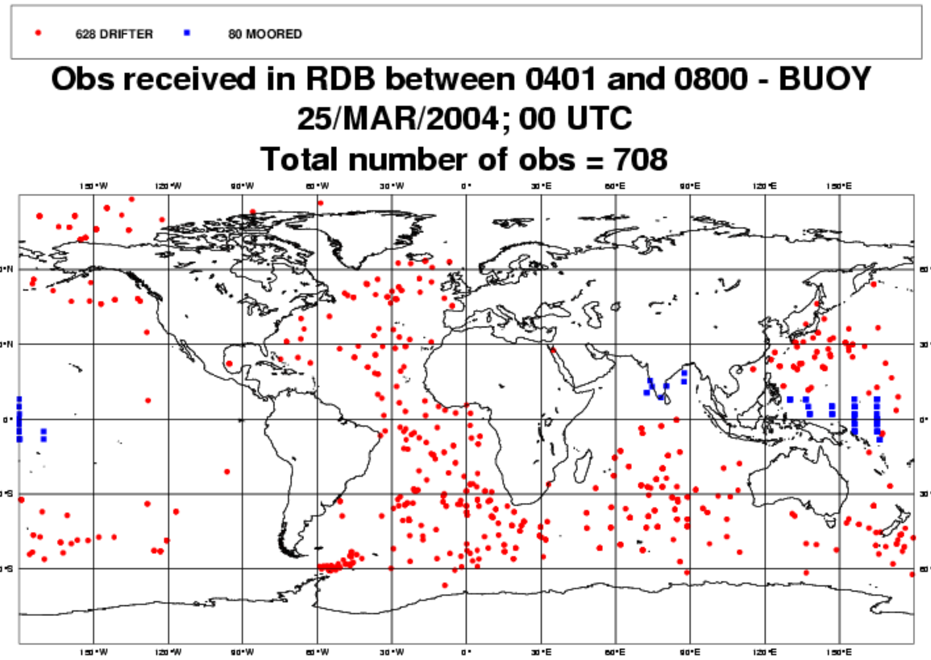

Figure A.10 Drifting (red) and moored (blue) BUOY reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

Scatterometer Reports

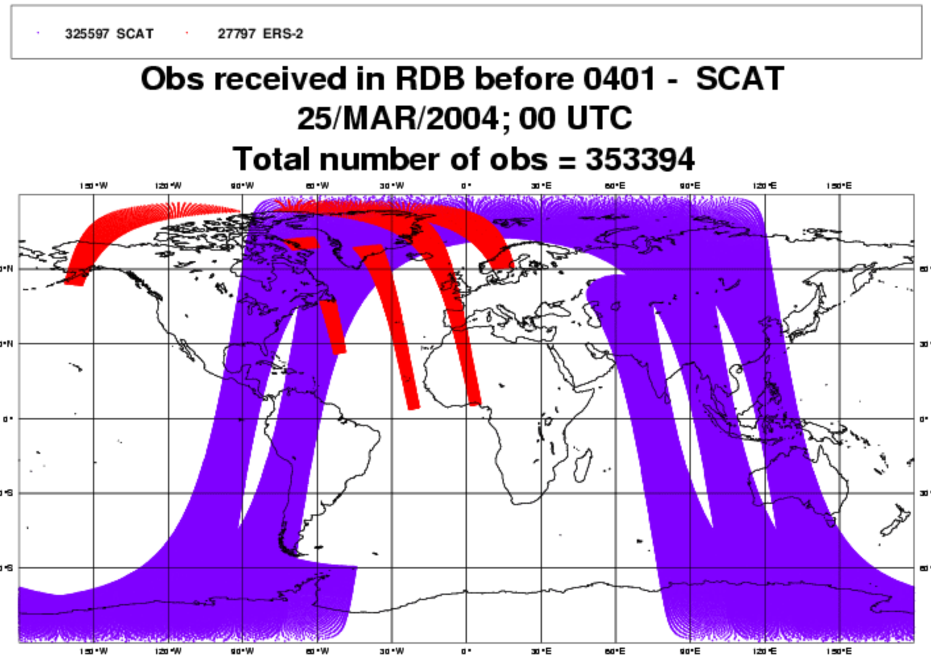

Figure A.11 ERS-2 (red) and QuikScat (purple) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

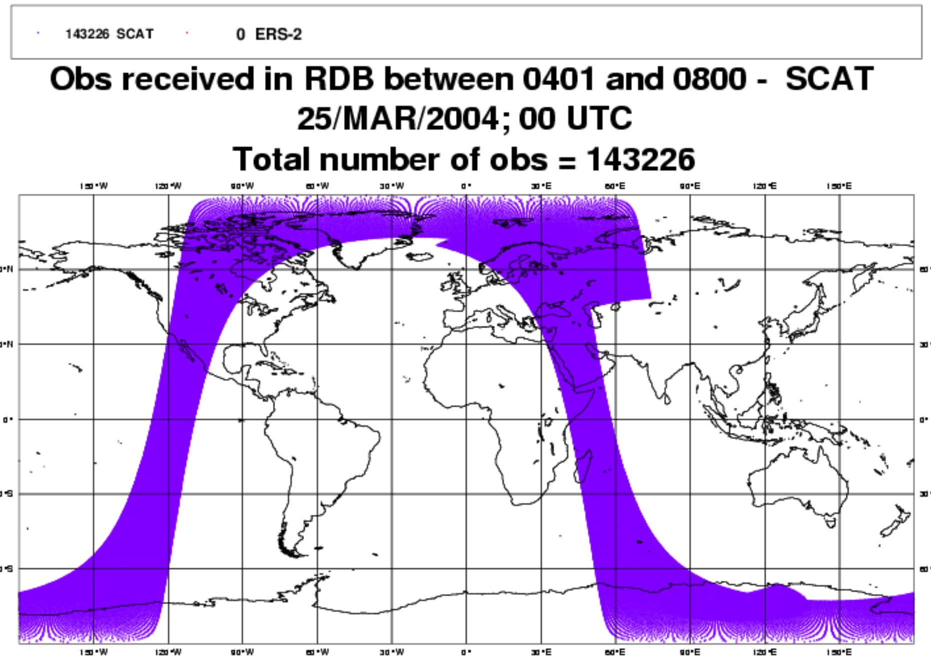

Figure A.12 ERS-2 (red) andQuikScat (purple) reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

Atmospheric Motion Vector (AMV) Reports

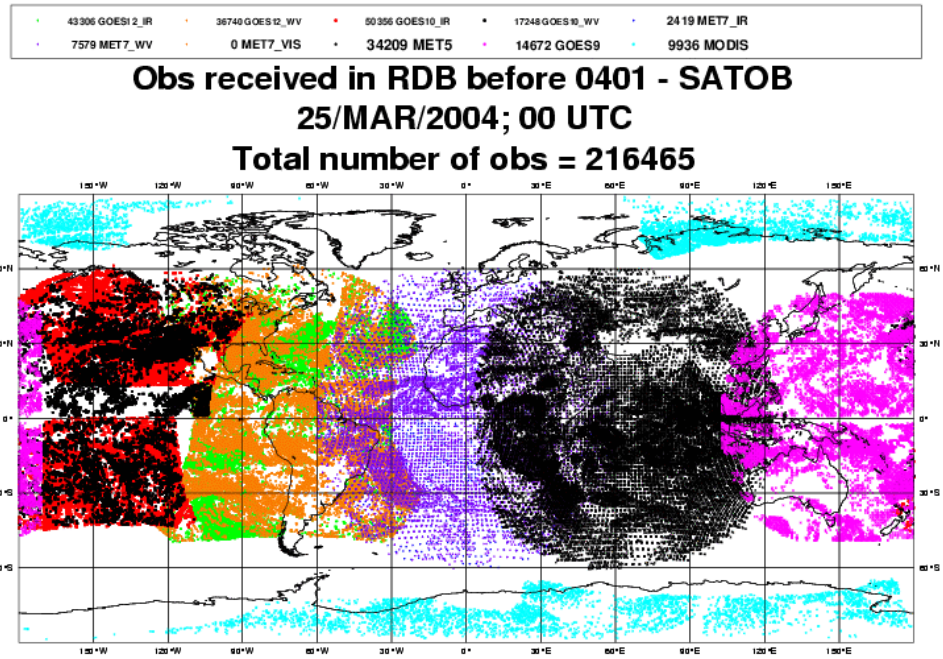

Figure A.13 AMV reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

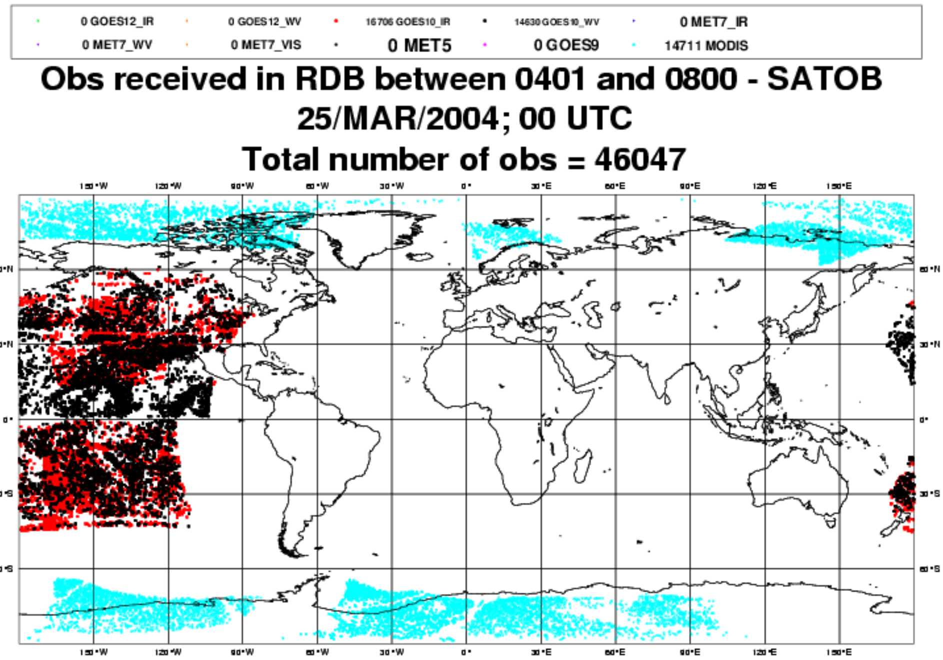

Figure A.14 AMV reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC

ATOV/AMSU-A Reports

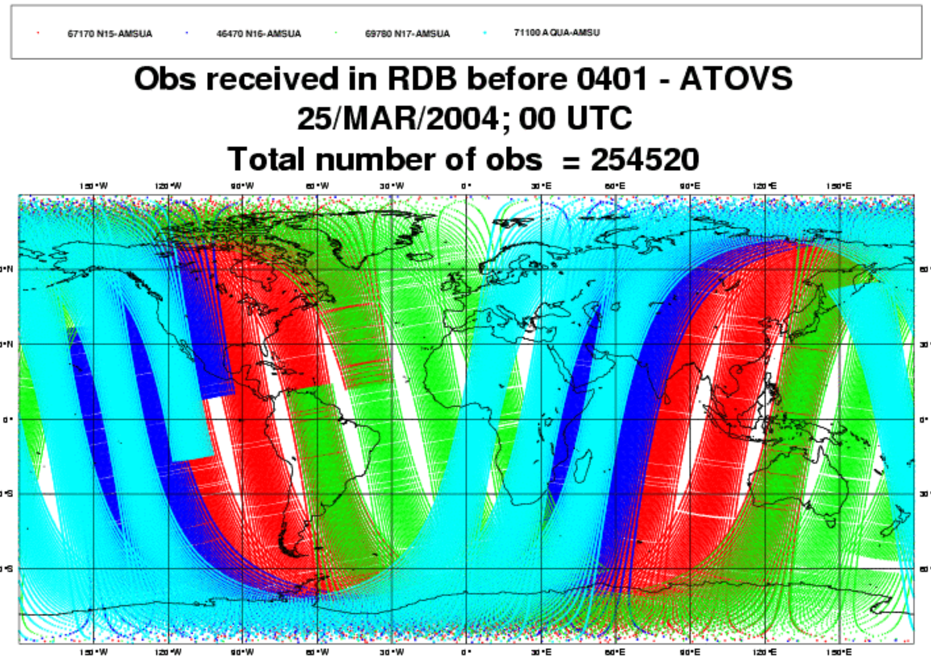

Figure A.15 ATOVS/AMSU-A reports from NOAA 15 (red), NOAA 16 (blue), NOAA 17 (green) and AQUA (cyan), for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

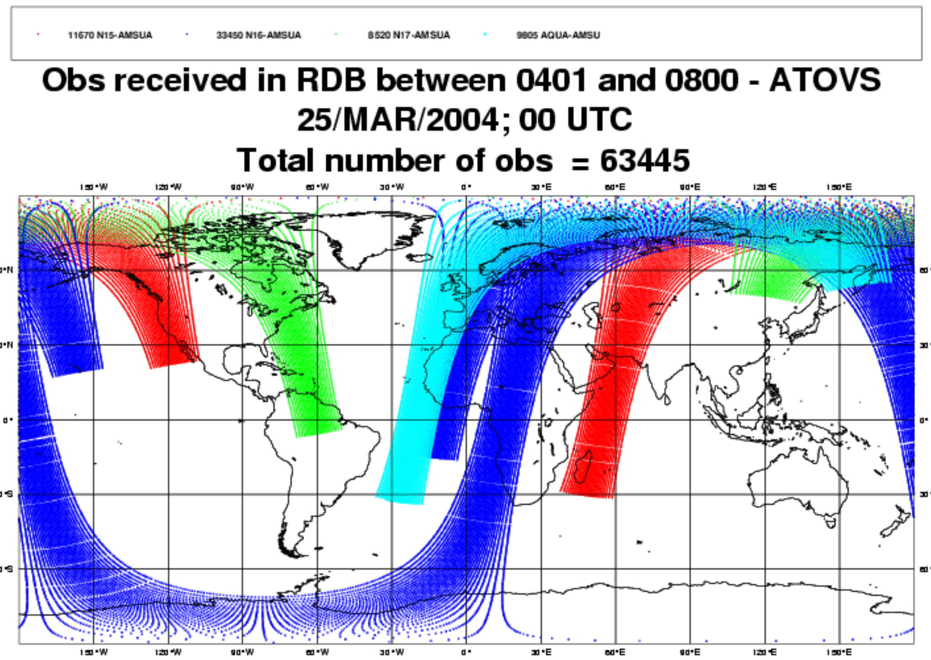

Figure A.16 ATOVS/AMSU-A reports from NOAA 15 (red), NOAA 16 (blue), NOAA 17 (green) and AQUA (cyan), for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC.

Geostationary Radiance Reports

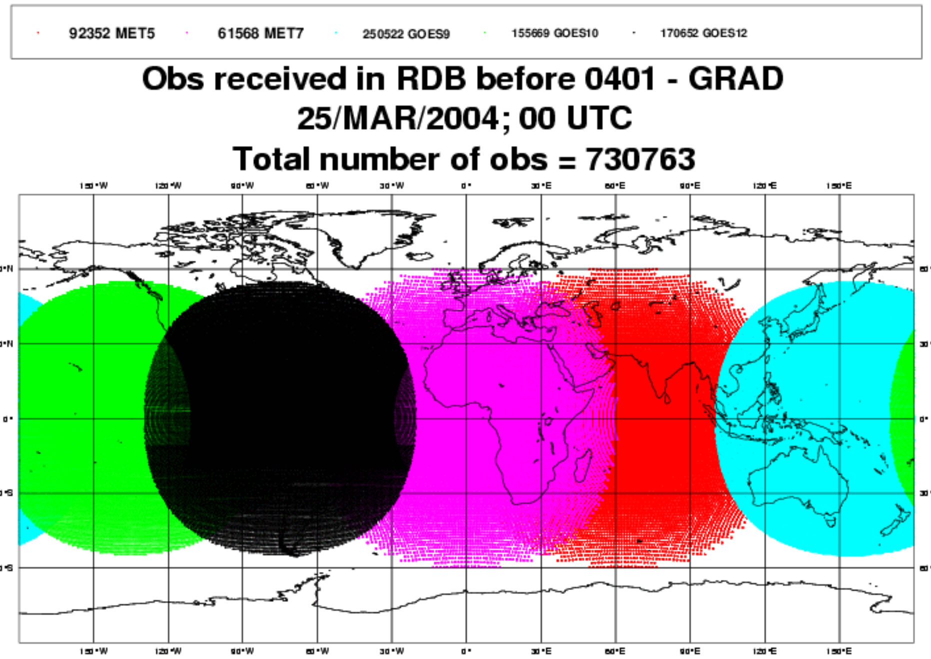

Figure A.17 Radiance reports from Meteosat-5 (red), Meteosat-7 (pink), GOES-9 (cyan), GOES-10 (green) and GOES-12 (black), for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

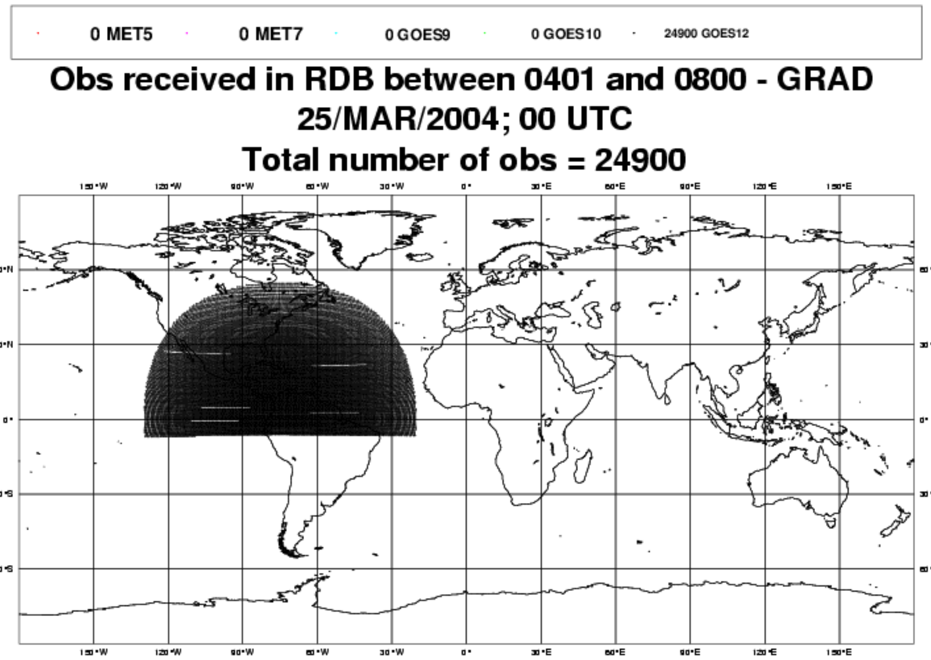

Figure A.18 Geostationary radiance reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC.

AIRS Reports

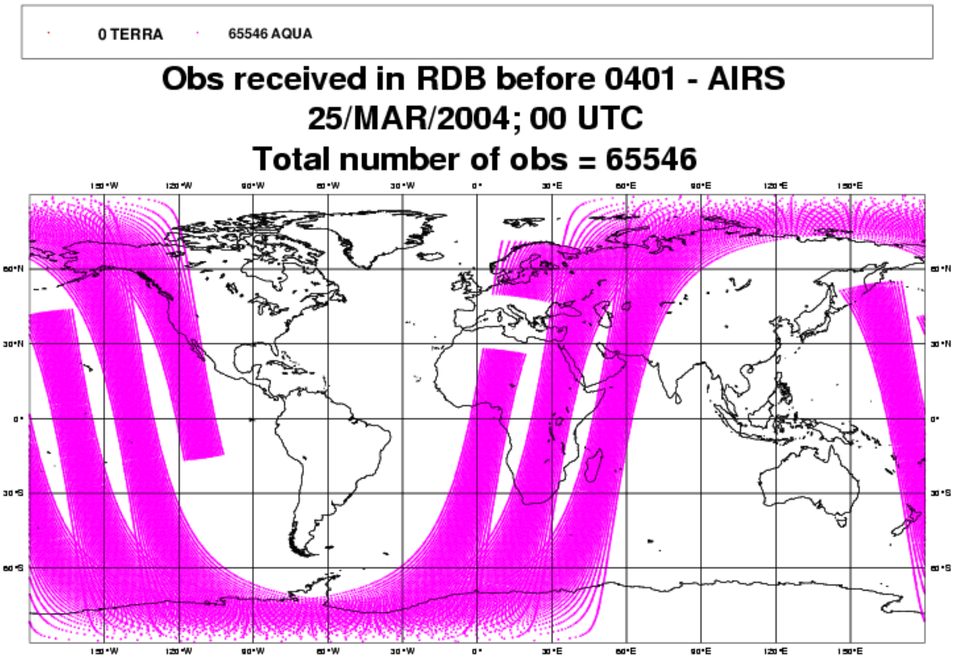

Figure A.19 AIRS reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

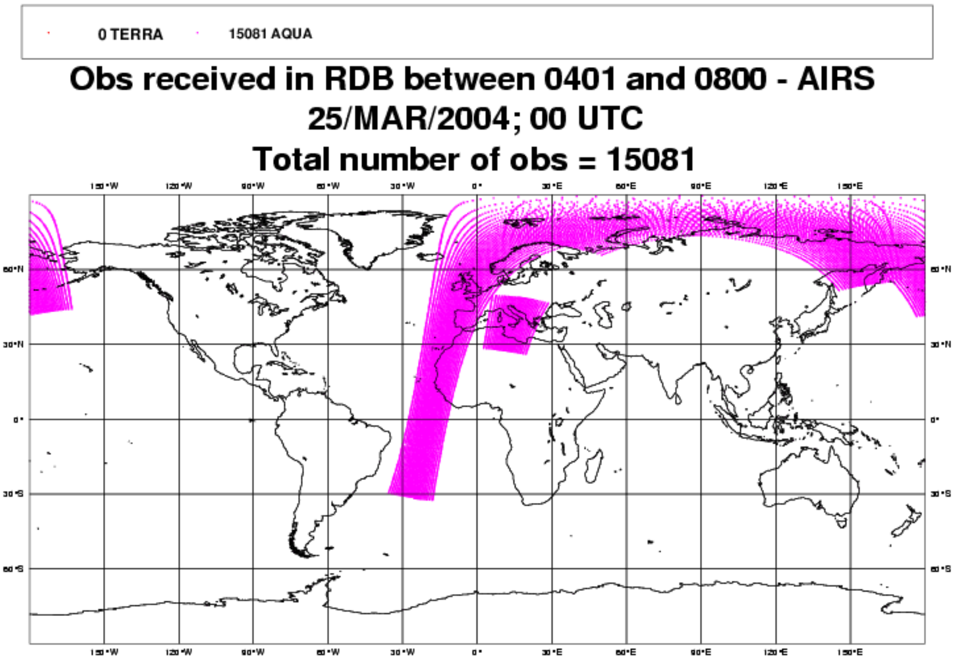

Figure A.20 AIRS reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC.

Ozone Reports

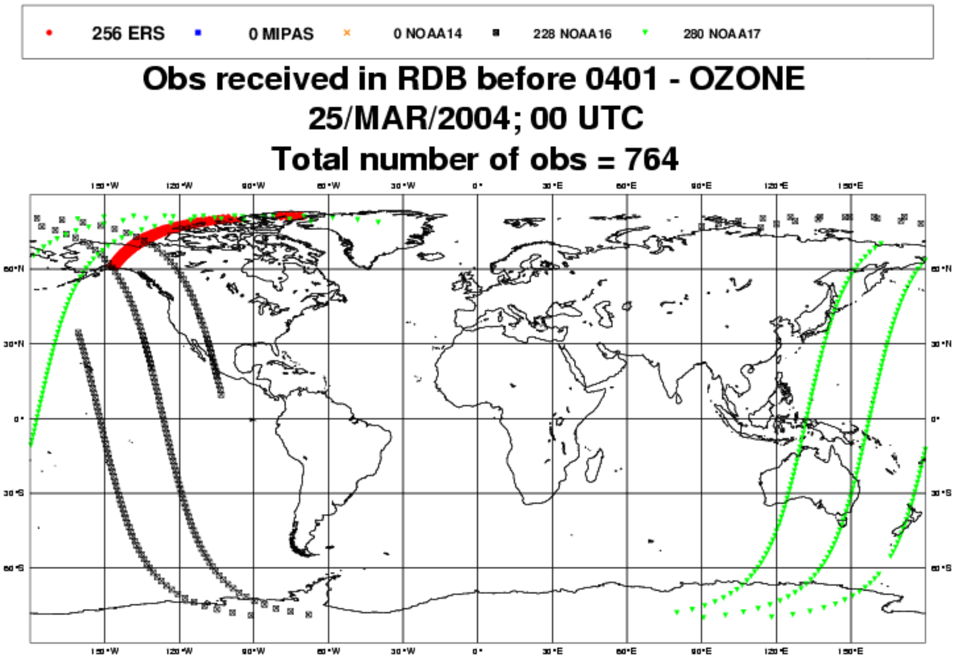

Figure A.21 Ozone reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received by 0400 UTC

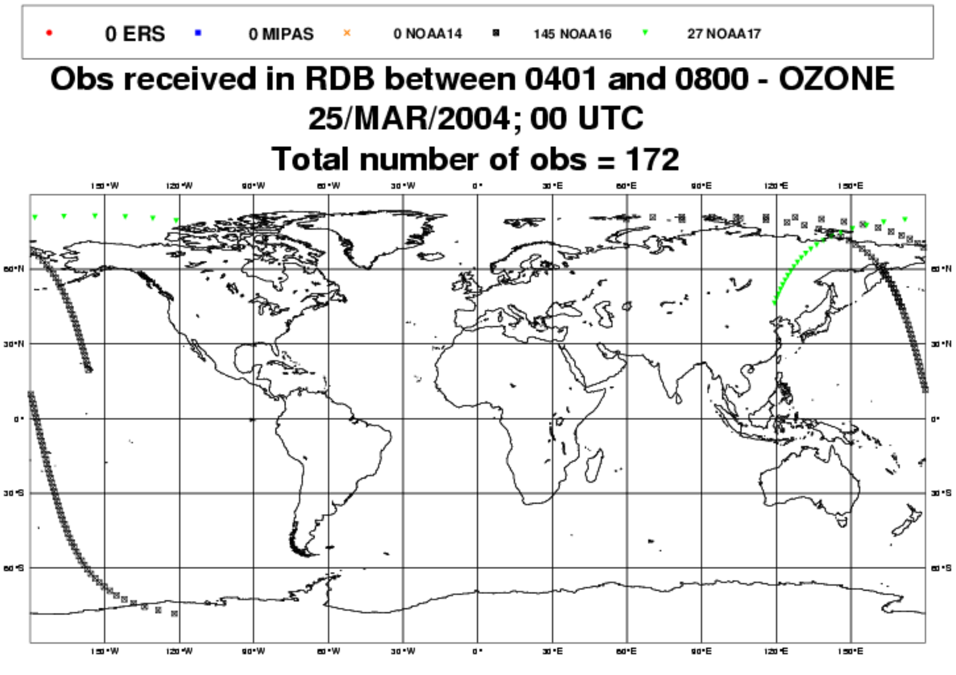

Figure A.22 Ozone reports for the period 2101 UTC 24 March - 0300 UTC 25 March 2004 which were received between 0401 and 0800 UTC.