RESEARCH DEPARTMENT
MEMORANDUM

ECMWF

To:	DR, HMetDiv, HMetAppS, RD division and Section Heads
Copy:	DA and MetOps Sections
From:	Patricia de Rosnay, Anne Fouilloux, Drasko Vasiljevic, Lars Isaksen and Jean-Noël Thépaut
Date:	November 5, 2012 File: RD33
Subject:	**Two-metre temperature data assimilation issue in winter 2011-2012 in IFS cycle 37r3**

1 Introduction

The Daily Report for 5 March 2012 noted a warm bias in the two-metre temperature forecast over Finland. After investigations by the Data Assimilation Section it was found that the delayed cut-off analysis was unexpectedly different from the early delivery analysis and it was affected by a large positive bias in two-metre temperature over Finland. Further investigations revealed a global scale issue in the delayed cut-off screen level parameters analysis, that was identified to be related to a bug in the Observation Data Base (ODB) used for surface conventional data in IFS cycle 37r3. The bug was dramatically amplified from 08 February 2012 when the GPS ground data was re-introduced in passive mode in the operational analysis (after a several months without GPS ground data in), leading to a spurious warm bias at high latitude. The bug was not due to the GPS data, it was only exacerbated when additional passive data, in this case GPS data, was present in the surface ODB, leading to observation array overwriting in the delayed cut-off screen level parameter analysis.

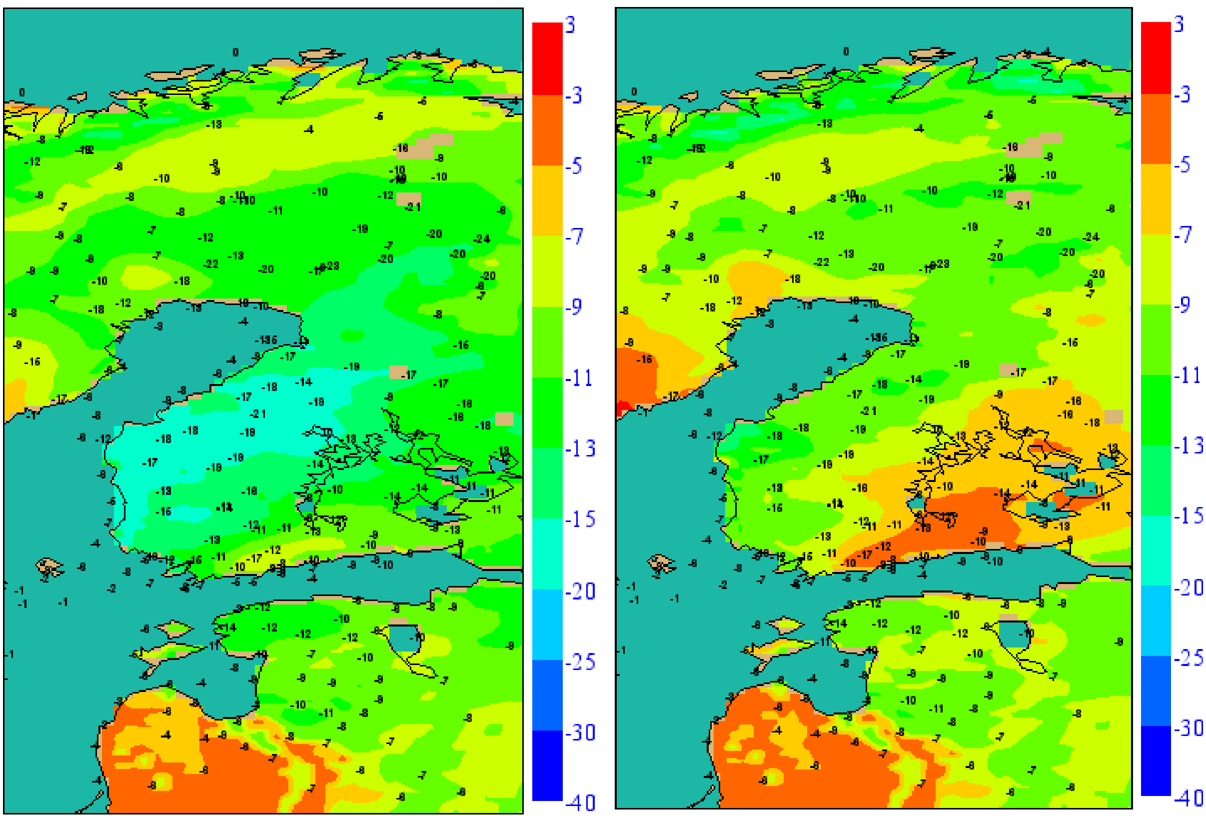
- The first action was to suspend GPS extraction on 09 March 2012. Although it did not fix the bug itself, it stopped the bug amplification and immediately led to much more realistic two-metre temperature analysis fields.
- The second action was to find and fix the conventional surface data ODB bug. The bug fix was introduced in operations with IFS cycle 37r3 on 20 March 2012.

The bug fix implemented on 20 March 2012 was supported by results from two T1279 research experiments conducted to (i) reproduce the bug and validate the bug fix using consistent IFS versions, (ii) evaluate the impact of the ODB bug on the operational forecasts for the most affected period, from 09 February to 08 March 2012. Preliminary results of these investigations were presented at the OD/RD meeting on 20 March 2012.

This memorandum documents the screen level analysis issue summarised above. Detailed technical description of the problem in the conventional surface data base and how it was solved is included. The effects of the bug on the operational two-metre parameters analysis in the Boreal winter 2011-2012 are presented together with the impact on surface variable analyses and forecasts in February-March 2012. This bug and the fact that it remained unnoticed for several weeks resulted from a series of 'unfortunate' events that revealed some weaknesses in our system. So, beyond the bug fix implemented on 20 March 2012, we give perspectives of improvements required in our system (e.g. conventional observations monitoring) for near-future implementation.

2 Two metre temperature warm bias over Finland

Figure 1 shows the operational two-metre temperature analysis on 06 March 2012 at 00UTC, from the early delivery analysis (DA) on the left and from the delayed cut-off analysis (DCDA) on the right. The DA analysis is used to initialise the 10-day forecast, while DCDA is the core analysis that propagates the information from one cycle to the next and provides initial conditions for the first guess forecast used in the early delivery system. The DA and DCDA two-metre temperature analyses are expected to be very similar since they rely on the same model first guess and SYNOP reports used in the analysis do not differ much between the early delivery and delayed cut-off streams, because of the excellent timeliness of conventional observations. However, this figure shows that the DA and DCDA two-metre temperature analyses were drastically different on 06 March 2012. The DA analysis (left) was still in relatively good agreement with the SYNOP observations (black numbers) in the northern part of the area. However it showed a warm bias in the coastal area in southern Finland, as well as in Estonia. The DCDA analysis on the right panel was clearly affected by a very large warm bias over the entire Finland. The warm bias was particularly large in the south of the country and in Estonia, with differences with observations larger than 10 Celsius in many locations. Such large differences between the DA and DCDA analyses clearly showed that the two-metre temperature analysis results were affected by a major problem.



(a) Early delivery (DA)

(b) Delayed cut-off (DCDA)

Figure 1: Two-metre temperature analysis (in Celsius) at 00UTC on 06 March 2012 for the operational high resolution (a) early delivery analysis and (b) delayed cut-off analysis. SYNOP observations are also reported on the maps (black numbers).

3 Evidence of a screen level parameters analysis issue in DCDA

Figure 2 shows the time evolution of the root mean square (RMS) first guess departure computed at global scale for DA and DCDA screen level temperature and relative humidity analyses, at 00UTC, from November 2011 to April 2012. It shows that:

- DCDA and DA two-metre analyses started to differ (by approximately 0.5 K in temperature and 1% in relative humidity) on 15 November 2011 when IFS cycle 37r3 was implemented in operations.
- The problem was amplified significantly from 08 February 2012 when the GPS ground based data was re-introduced for passive monitoring.
- Both the two-metre temperature (T2m) and relative humidity (RH2m) analyses were affected by the bug, with very large global mean first guess departures RMS (more than 3K for the two-metre temperature analysis and more than 15% for the relative humidity) from 08 February to 08 March 2012.
- Removing the GPS data from 9 March 2012 stopped the bug amplification and brought it back to the level before 08 February 2012.
- The fix introduced in operations in IFS cycle 37r3 on 20 March effectively solved the issue in the DCDA analysis.

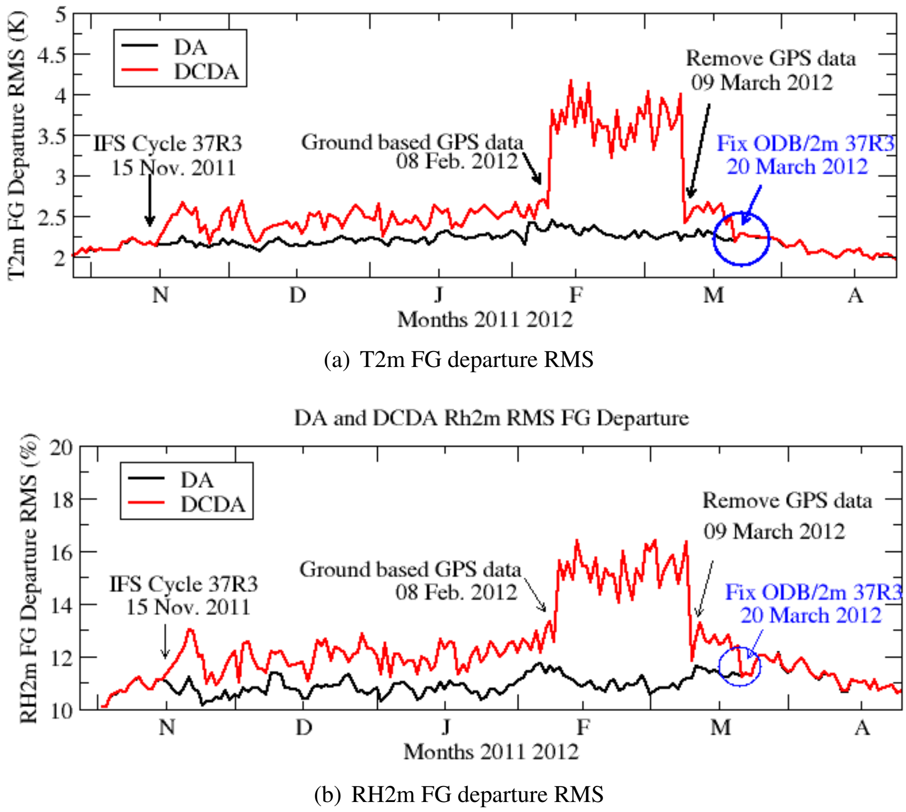


Figure 2: First guess departure (observations minus model) RMS, for the operational high resolution DA (black) and DCDA (red) analyses, at 00UTC, for November 2011 to April 2012, for (a) the two-metre analysis and (b) the two-metre relative humidity.

4 Bug in the ODB for surface conventional data

The GPS ground based data was re-introduced on 08 February 2012 in the ODB for monitoring purpose. GPS data was passively (i.e. not assimilated) re-introduced and this data is not used in the two-metre analyses in any manner. So the GPS data was not expected to affect screen level parameters data assimilation results. Since it is a conventional data it was together with the SYNOP data in the conventional data ODB that is used by the surface analyses tasks.

Figure 3 shows the DCDA ODB content in two-metre temperature data together with the ODB content as decoded by the surface analysis on 06 March 2012 at 00UTC, for Tropics and for high latitudes in the northern hemisphere. This figure clearly shows that the 00UTC DCDA two-metre temperature analysis read spurious values from the surface conventional ODB. It shows that observations randomly distributed around the globe were used in the surface analysis, leading to use in general too cold temperature values in the tropics and too warm temperature values at high latitude. Basically, completely wrong observations of two metre temperature and relative humidity were used in operations in the 00UTC DCDA screen level parameters analyses from 08 February to 08 March 2012.

It is interesting to notice that the problem concerned only the 00UTC DCDA analysis. The 12UTC DCDA was not affected by such errors in the ODB decoding, nor the DA analyses at 00UTC and 12UTC (not shown).

The main difference between the 00UTC DCDA and the three others screen level parameters analysis lies in the use of the national networks snow data. Since IFS cycle 36r4 the surface conventional ODB includes additional snow data that were made available from national snow networks from some of Member States (started with Sweden). The national snow data is available daily at 06UTC, so it is present only in the 00UTC DCDA ODB which spans 21UTC to 09UTC. The additional snow data is a new report type (16025) and it does not contain the ODB level column. It was used from 29 March 2011 in operations IFS cycle 36r4 and in the esuite in IFS 37r2 (de Rosnay et al. , 2011). The use of the national network snow data was extensively tested before implementation and it was not affecting the screen level parameters analysis tasks in IFS cycles 36r4 and 37r2 (as shown by Figure 1) that were used in operations before IFS cycle 37r3.

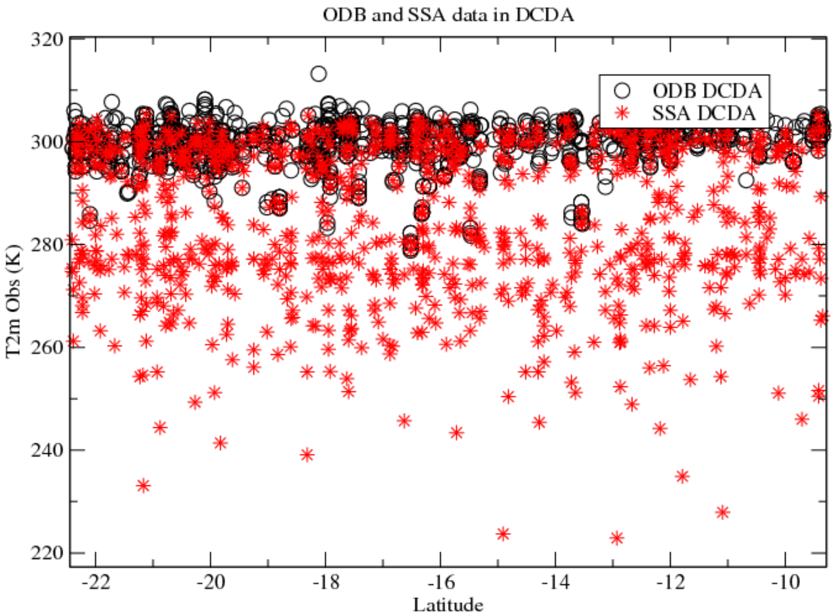
The ODB used for conventional surface observations contains various report types. The surface analysis sql requests were not selective, mainly based on obstype (SYNOP, DRIBU and TEMP for screen level analysis and SYNOP for the snow analysis). So, a range of not needed reportypes were actually extracted from the sql requests. This was not an issue until IFS cycle 37r2 because the surface analysis Fortran part was selecting further the requested variable number to be used in the analysis.

In IFS cycle 37r3 the ODB was restructured and the level column used in the surface ODB was moved to conv_body. So, the screen level parameters sql request which was mixing a variety of obstypes (SYNOP, DRIBU and TEMP) was not any longer compatible with the new structure of the ODB because it was mixing data with and without (national network snow snow data) level. The problem only concerned the DCDA 00UTC sql request because the additional snow data is not present in the DA 00UTC, DA 12UTC and DCDA 12UTC ODBs.

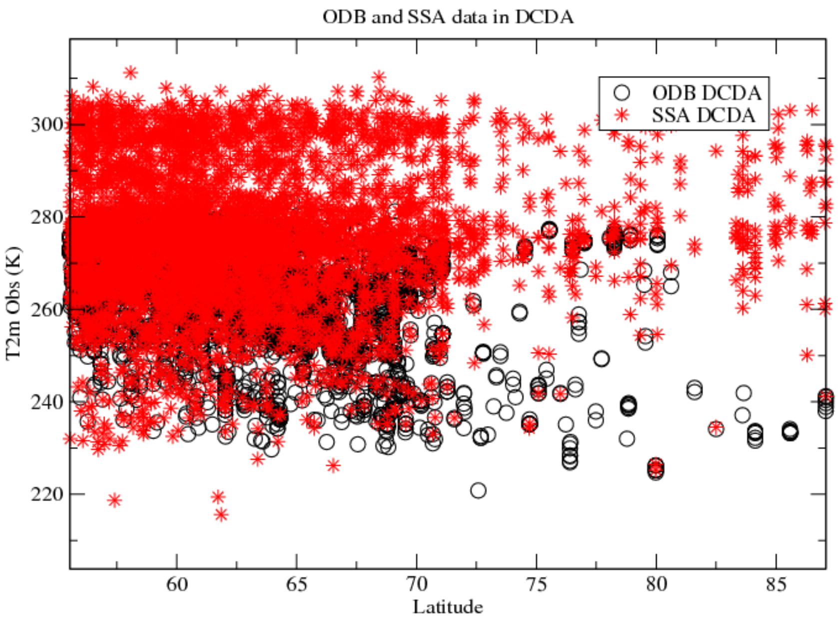
The consequence of this bug was that the ODB sql request used in the IFS did not return the right observations for the 00UTC DCDA analysis. And as shown in Figure 1, the overwriting problem was dramatically amplified when the data volume became larger, as it happened when passively adding the GPS ground data in the conventional ODB from 08 February to 08 March 2012.

5 Fixes and RD experiments

On 09 March the extraction of GPS ground data was suspended to stop the dramatic bias in DCDA two-meter temperature analysis. It had an immediate effect on the DCDA two-meter temperature issue as shown in Figure 2, with global DCDA RMS first guess departure reducing to values close to 2.5 Celsius, similar to values



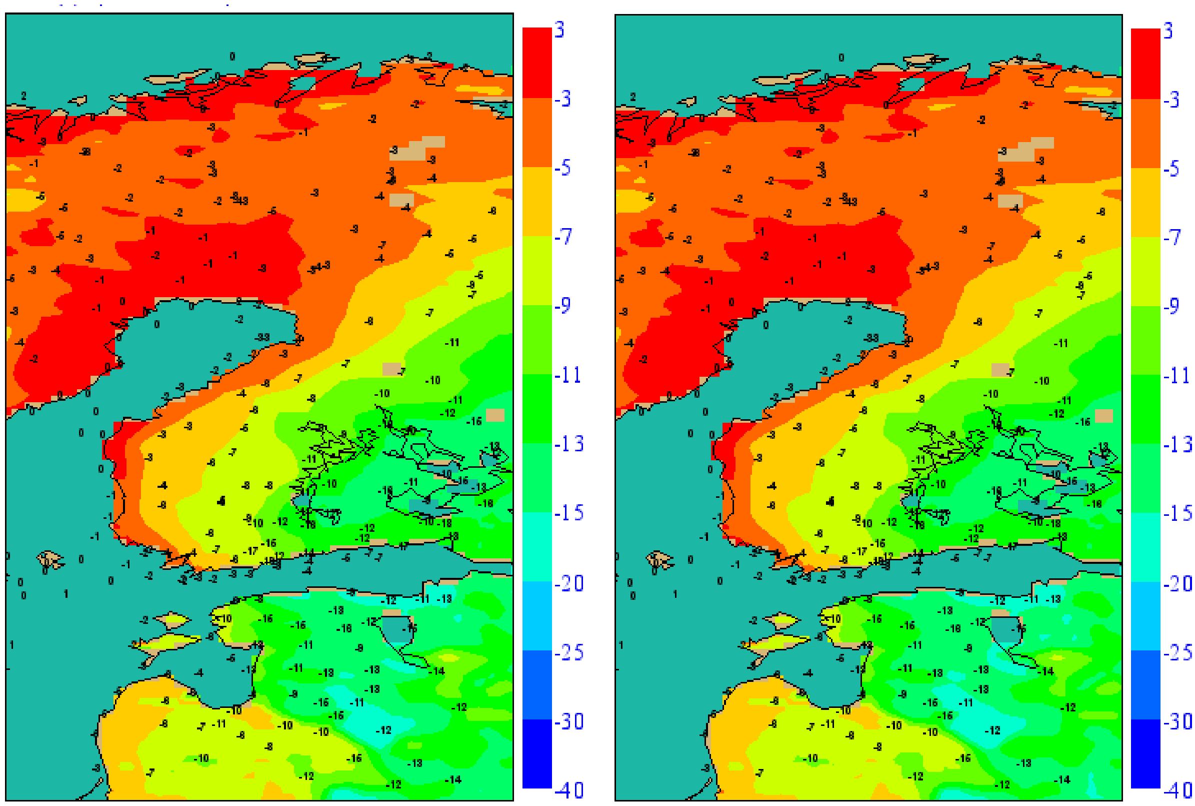
(a) Tropics



(b) High latitudes (NH)

Figure 3: Two-metre temperature observations in the DCDA ODB (black circles) and used in the surface analysis (red crosses), for (a) tropics and (b) high latitudes in the northern hemisphere, on 06 march 2012 at 00UTC.

before 08 February 2012. Figure 4 shows the DA and DCDA two-metre temperature analyses for Finland at 00UTC on 09 March 2012 after the passive GPS ground data were removed in DCDA. It shows that the DA and DCDA analyses are consistent, with a much reduced bias in DCDA compared previous days (shown in Figure 2).



(a) Early delivery (DA)

(b) Delayed cut-off (DCDA)

Figure 4: Two-metre temperature analysis (in Celsius) at 00UTC on 09 March 2012 for the operational high resolution (a) early delivery analysis and (b) the delayed cut-off analysis. SYNOP observations are also reported on the maps (black numbers).

The fix introduced on-the-fly on 20 March in IFS cycle 37r3 consisted of excluding reportype 16025 (additional snow data) from the sql request used for the screen level parameters analysis (ssa_robhdr_2m.sql and ssa_robody_2m.sql). In addition modsurf and orography not relevant for surface conventional data were also removed from the sql request. This fix prevented the sql request from using the additional snow data which is not compatible with the screen level data in the new ODB structure.

The bug also affected the suite used to produce the H-SAF SM-DAS-2 product which was at that time in pre-operational phase for EUMETSAT (`http://www.ecmwf.int/research/EUMETSAT_projects/SAF/HSAF/ecmwf-hsaf/`). SM-DAS-2 production is based on continuous RD experiments using up to date IFS cycles as in operations. The IFS cycle 37r3 bug fix was introduced on 14 March 2012 in the branch dap_CY37R3_smdas2_op1 for the experiment fmwt which was producing SM-DAS-2.

As for the 37r3 fix, the ODB ssa sql requests were modified in the fix introduced in 38r1, with modsurf and orography removed and the two-meter analysis not getting the additional snow data which is not compatible, from 37r3, to be read together with screen level data. Whereas for the fix in 37r3 we excluded the reportype 16025 from the screen level parameters requests, for 38r1 the fix (branch dap_CY38R1_fix_sql_odb_t2m),

instead of excluding reportype 16025, selects the list of reportypes to keep for the 2m analysis. A set of experiments (not shown here) validated the fact that the bug fixes introduced in 37r3 and in 38r1 are bit-identical. The point of the modification introduced in 38r1 is to prevent a similar bug from happening again in the future when new reportypes are included in the conventional ODB. For the upper air data reportypes the request specifies the short list of varno needed by the surface analysis, so we do not get the entire vertical profile which is not used anyway in the surface analysis. ctxinitdb.F90 was modified to allow the use of varno in the ssa_robody_2m.sql.
The bug fix implementation was supported by the results from two RD experiments, conducted with IFS cycle 37r3 in early delivery at T1279 for 08 February to 09 march 2012 to reproduce the bug (fnsb) and to test the bug fix (fnsf, dap_CY37R3_fix_sql_odb_t2m). Both experiments included the most recent fix on Jc that was introduced in operations 06 March 2012 to solve a SYNOP rejection issue (Fisher , 2012). Results of these experiments are presented, together with operational results before and after the bug fix, in the following section.

6 Results

6.1 Time series of DCDA and DA analyses

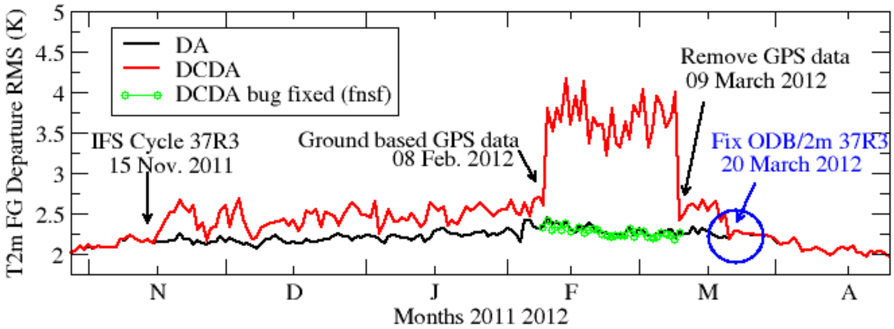
Figures 5 shows the time evolution from November to April 2012 of the screen level parameters analysis at 00UTC for the operational DCDA and DA analyses and for the DCDA analysis of the RD experiment fnsf that includes the 37r3 bug fix. It shows that the bug fix effectively solves the issue in the DCDA analysis, even when the GPS data is extracted from 08 February to 09 March. Figure 6 shows the operational time series of DA and DCDA T2m analysis at 00UTC from January 2011 to September 2012. It shows that the problem started on 15 November 2011 when IFS cycle 37r3 was implemented. The bug was amplified from 08 February to 08 March 2012 when the GPS data was extracted for monitoring. The bug was fixed on 20 March 2012, with consistent DA and DCDA screen level parameters analysis since then.

6.2 Spatial differences between DCDA and DA analyses

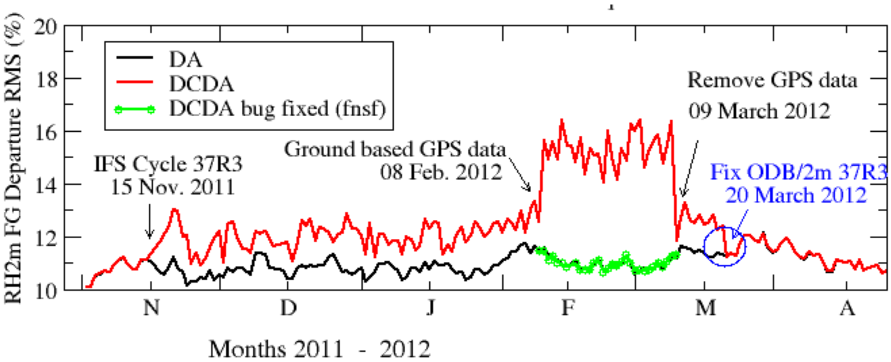
Figure 7 presents maps of DCDA minus DA T2m analysis at 00UTC for different dates. On 14 November (Figure 7(a)) with IFS cycle 37r2, DCDA and DA were in very good agreement. Only a few points, corresponding to late observation used in DCDA only, were different compared to DA. As soon as 37r3 was implemented (Figure 7(b)), DCDA started to differ from DA with patchy differences due to a limited number of observations overwriting.

The bug amplification due to GPS data extraction (09 February to 08 March), is clearly illustrated in Figure 7(d) by very large differences between DCDA and DA T2m analyses. Although the pattern of the differences is relatively patchy due to the use of randomly overwritten observations, a general large positive bias of DCDA at high latitudes and a tendency to have cold bias in the tropics is shown, as expected from Figure 2. Note that the quality control used in the surface analysis, based on first-guess departure check, prevents from using observations that differ by more than 7.5 K or (33% for RH2m) compared to the first guess, so the use of wrong data in the analysis was, to some extend, slightly limited by the quality control. However Figure 7(d) shows that the bug effect on the T2m DCDA analysis was very large. The last two panels of Figure 7 (e,f) show the immediate impact on the DCDA T2m analysis field of the GPS data extraction suspension and the bug fix implementation, respectively.

Figure 8 shows monthly mean (for 09 February-08 March 2012) difference between DCDA and DA T2m

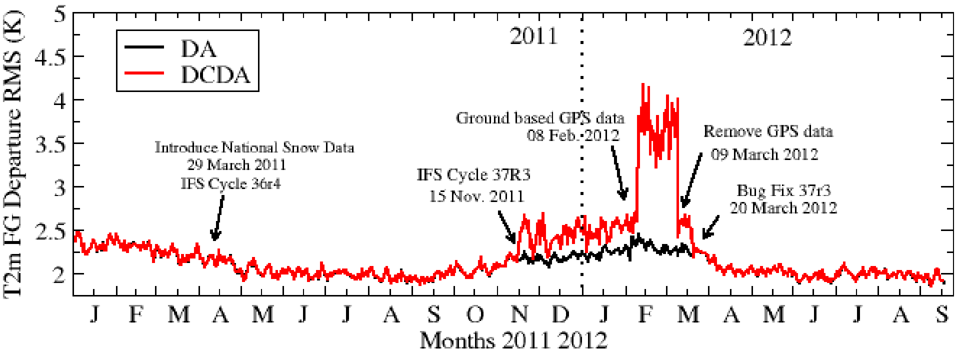


(a) T2m FG departure RMS



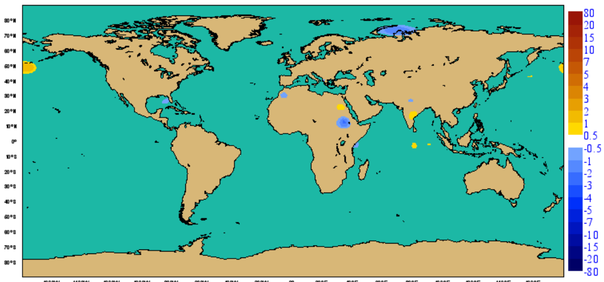
(b) RH2m FG departure RMS

Figure 5: As in Figure 1: first guess departure (observations minus model) RMS, for the DA (black) and DCDA (red) analyses, at 00UTC, for November 2011 to April 2012, for the operational high resolution (a) two-metre analysis and (b) two-metre relative humidity. In addition the bug fixed T1279 RD experiment (fnsf) DCDA analysis is represented in green, showing that the bug fix affectively solves the screen level parameters DCDA analysis issue.

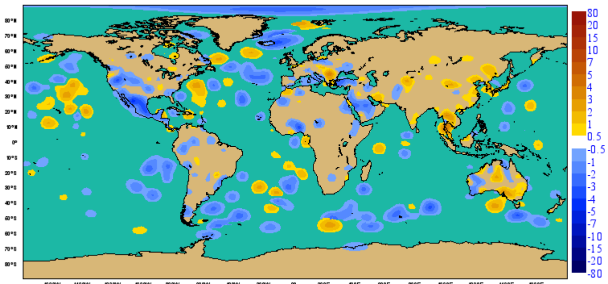


(a) T2m FG departure RMS for 2011-2012

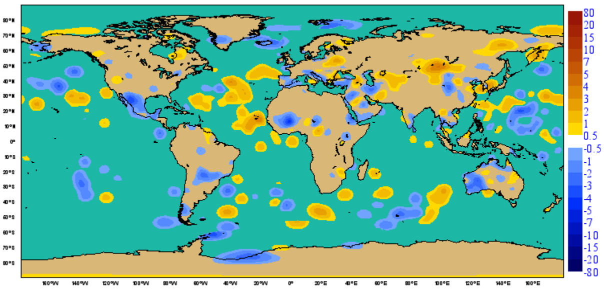
Figure 6: First guess departure (observations minus model) RMS, for the DA (black) and DCDA (red) analyses, at 00UTC, for 2011-2012, for the operational high resolution suite.



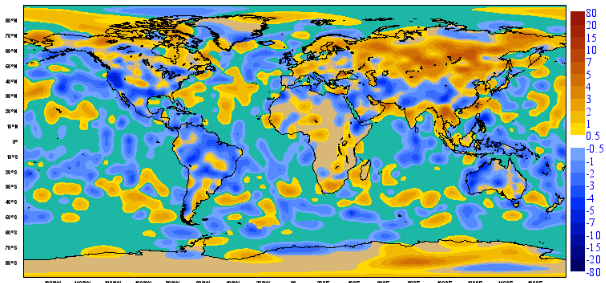
(a) 14 November 2011 (37r2)



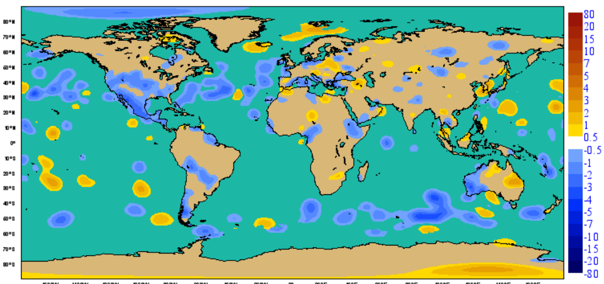
(b) 16 November 2011 (37r3 with bug)



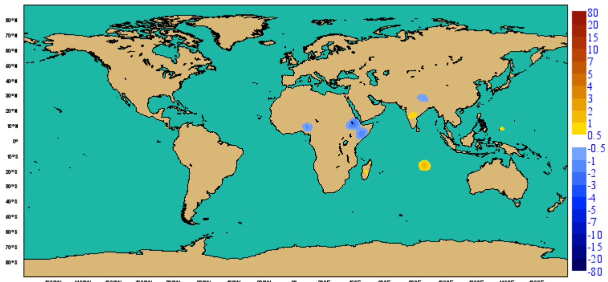
(c) 08 February 2012 (37r3 with bug)



(d) 09 February 2012 (37r3 with bug + GPS)

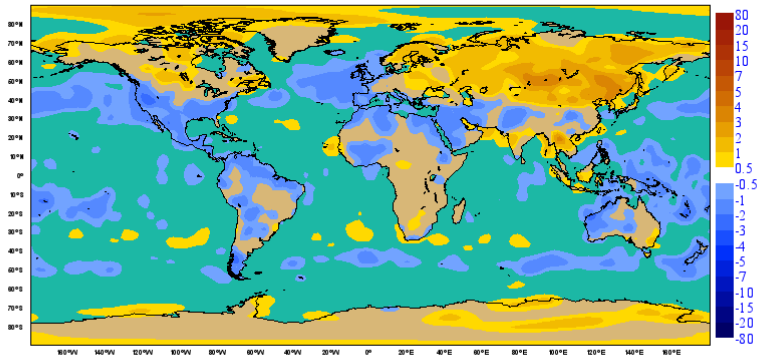


(e) 09 March 2012 (37r3 with bug, GPS removed)

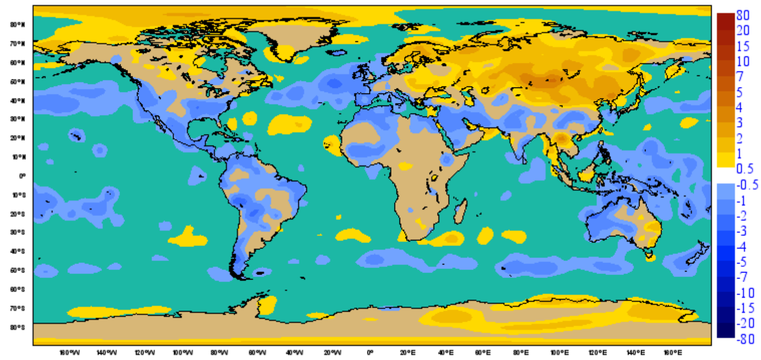


(f) 21 March 2012 (37r3 fixed)

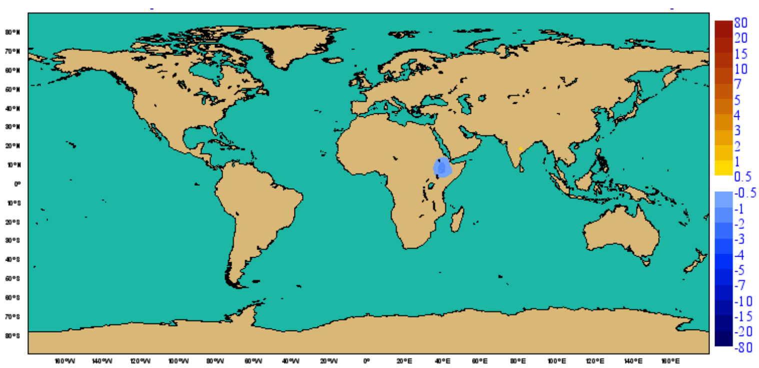
Figure 7: Difference between DCDA and DA two-metre temperature analyses (in K) on (a) 14 November 2011 when 37r2 was still used in operations, (b) 16 November after 37r3 was implemented in operations, (c) on 08 February with 37r3 just before the GPS data started to be used, (d) on 09 February 2012 with 37r3 after the GPS data extraction started, (e) on 10 March 2012 after the extraction of GPS data was suspended and (f) on 21 March 2012 a day after the bug fix was implemented in operations.



(a) Oper



(b) RD bug reproduce (fnsb)



(c) RD bug fix (fnsf)

Figure 8: Difference between DCDA and DA two-metre temperature analyses (in K) averaged for 09 February to 08 March 2012, for (a) the operational high resolution suite and the RD high resolution experiments that (b) reproduce the bug (fnsb), (c) includes the bug fix (fnsf).

analyses for the operational high resolution analysis and for the RD experiments fnsb and fnsf. It shows that the experiment fnsb reproduces the bug while fnsf effectively fixes the bug, even during this period for which the GPS data was extracted and therefore present in the conventional ODB. Monthly mean map makes it clear that the bug led to a positive T2m bias in DCDA at high latitude, in particular in northern Europe, Siberia and China. America, Spain Italy and West Australia was affected by a negative bias in the DCDA T2m.

6.3 Impact of the bug on the early delivery analysis and forecasts

Two-metre temperature and relative humidity are diagnostic variables, so their analyses have no direct impact on the forecast. However the two-metre temperature analysis is used in the analyses of snow temperature soil temperature and soil moisture (the latter also uses the relative humidity analysis), which are all prognostic variables. These variables are then used as initial conditions for the first guess short forecasts that propagate them from one cycle to the next. The short forecasts are used as background for both the DA and DCDA analyses. So, the DCDA screen level parameters analysis does have an (indirect) influence on the DA analysis, and therefore on the 10-day forecast, through its influence on the first guess forecasts initial conditions of soil moisture, snow temperature and soil temperature.

Figures 9 to 16 show the impact of the bug on the early delivery (DA) analyses for soil moisture, soil temperature and snow temperature and snow density for three weeks between 16 February and 08 March 2012. They are based on the two high resolution RD experiments fnsb and fnsf that reproduce and fix the bug, respectively. The first week after the introduction of GPS data, from 09 to 15 February is not shown since the DA analysis was only slightly affected. As expected the propagation of the bug effects from DA to DCDA took several weeks due to the indirect link between DCDA screen level parameters and DA surface prognostic variables. These figures show that already in the second week, (16-22 February), the DA analysis of surface variables was affected. They show the propagation of the bug effects from DCDA to DA through the last three weeks of the four weeks period for which the bug was amplified by the presence of GPS data in the ODB.

The DA soil moisture analysis (Figures 9, 10 and 11) was rapidly affected in Africa and America in the first two layers, on the second week after the GPS data were introduced (and also, to a less extend, on the first week, not shown). In some areas, such as in Australia the bug had an impact on soil moisture on the third week with amplification on week 4. Soil moisture in the third layer was also affected by the bug, whereas there was no impact of the bug on the fourth layer soil moisture (not shown).
In northern latitudes at this period of the year (Boreal winter) soil moisture analysis is not very active because of a weak coupling between soil moisture and atmosphere. So, there is no impact of the bug on soil moisture. However soil temperature and snow temperature analyses are active in winter time and they rely on two-metre temperature analysis increments. So, at high latitude the bug in the ODB that affected the DCDA two-metre temperature analysis mainly had an impact on the prognostic soil and snow temperature initialisation (Figures 12 to 16). The overestimated T2m in DCDA led to overestimated soil temperature, snow temperature and snow density in the DA analysis. Strongest impact of the bug on surface temperature and snow density was as expected obtained in the fourth week after GPS data introduction (from 02 to 08 march 2012). Figure 17 shows a relatively limited impact of the bug on the DA T2m and snow depth analyses.
Figures 18, and 19 show the bug impact (fnsb-fnsf) on the 24h forecasts of soil moisture and soil temperature. They show that the bug has an impact on the forecast surface variables which is consistent with the impact obtained for the DA analysis. The impact is consistent throughout the forecast range until day 10 (not shown). Figure 20 shows the impact on snow density and T2m 24h forecasts. The impact of the bug is of limited amplitude for T2m, mainly located in Siberia. Figure 21 shows the forecast impact on T2m and on snow density over Europe. It confirms that although the bug had an impact on the snow density forecast in northern Europe,

it did not much affect the T2m forecast over Europe.
Figure 22 presents the impact of the bug fix on the 1000HPa geopotential height and temperature forecasts for the northern hemisphere, southern hemisphere, tropics and Europe. It shows that the fix has a neutral to slightly positive impact in the northern hemisphere. It is neutral in Europe, so the bug had a limited impact on the atmospheric scores.

7 Summary and perspective

IFS cycle 37r3 had a bug in the ODB that affected the screen level parameters (T2m and RH2m) delayed cut-off analyses (DCDA) at 00UTC (so, at 00UTC and at 06UTC). The bug was introduced in operations on 15 November 2011 (IFS cycle 37r3 implementation). It was amplified from 08 February to 09 March 2012 by the passive introduction of the GPS data in the conventional surface ODB. On 09 March the GPS data extraction was suspended, so the bug amplification stopped. On 20 March 2012 the bug fix was implemented on-the-fly in 37r3.
Research experiments showed that the bug affected the delayed cut-off two-metre parameters analysis. From 08 February to 08 March 2012 it also had an impact on the early delivery (DA) analyses of surface variables, particularly strong for snow density and soil temperature which were overestimated in most of the northern latitudes, as well as on soil moisture in the first three layers in Australia and in South Africa. The 10-day forecasts, initialised from the DA analysis were also affected (from 08 February to 09 March 2012), mainly by a positive bias in snow density and soil temperature. However the T2m early delivery analysis and forecasts were not very sensitive to the bug and over Europe experiments with and without the bug presented very similar results. So, the bug was dramatic in DCDA, but since it affected diagnostic variables that are only indirectly linked to the forecasts through their use in surface prognostic variable analysis, it remained of limited amplitude in DA and it did not significantly affect the forecasts.

The series of events that made possible such a bug to happen and to remain unnoticed for several months revealed several weaknesses in our system:

- The new ODB developed for implementation in 37r3, was tested with IFS cycle 37r1 for which the additional snow data was not in the release (it was in IFS 37r2 release). This is because IFS 37r1 was not an operational cycle. So, in the future it is crucial to clarify which perforce branch is the current operational one to be used as the basis for technical developments, to ensure that RD perform tests with the current operational branch.

- The sql requests used in the IFS did not fail, although the requests were not compatible with the data requested for the new ODB structure. It should have failed, but instead delivered spurious data values. As a comparison the Linux stations sql requests returned empty data for the same ODB and same sql requests. On the long term, this should be fixed in the ODB used in the IFS.

- The bug was amplified by the introduction of the passive GPS data in the conventional surface ODB. Tests with the new data did not allow to easily detect the issue because the IFS is not bit-reproducible when additional conventional data is added. A fix will be introduced in IFS cycle 39r1 to ensure the sequence number of the data already present in the ODB is not modified when new data is added. This will allow bit-reproducible experiments when passive data is introduced in the surface conventional ODB.

- The bug remained unnoticed because we don't have any monitoring of the conventional surface observations. Simple monitoring figures, such as the one shown in Figures 1 and 6 that compare DA and DCDA analyses, would have allowed to spot the bug immediately after IFS 37r3 implementation in November

2011. It is crucial to develop and to implement surface conventional observations monitoring. This is ongoing for implementation in IFS cycle 39r1.

Acknowledgements

Thanks to FMI and to Ivan Tsonevsky for reporting on two-metre temperature warm bias over Finland.

References

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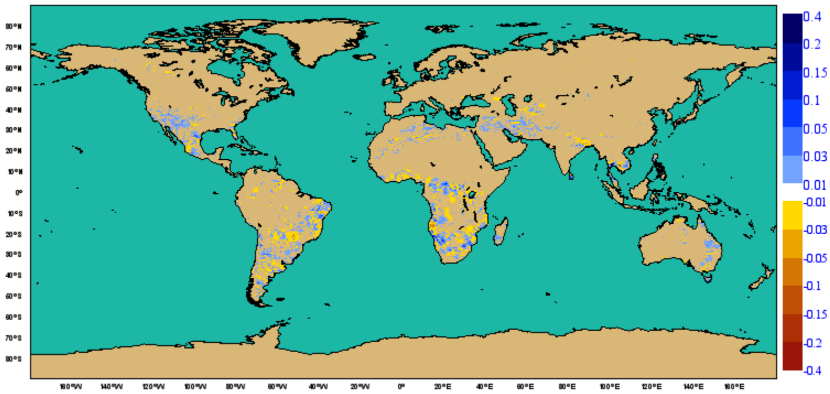
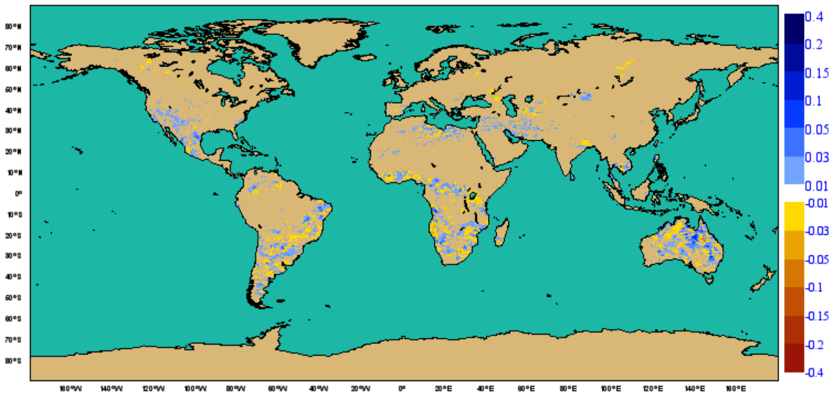
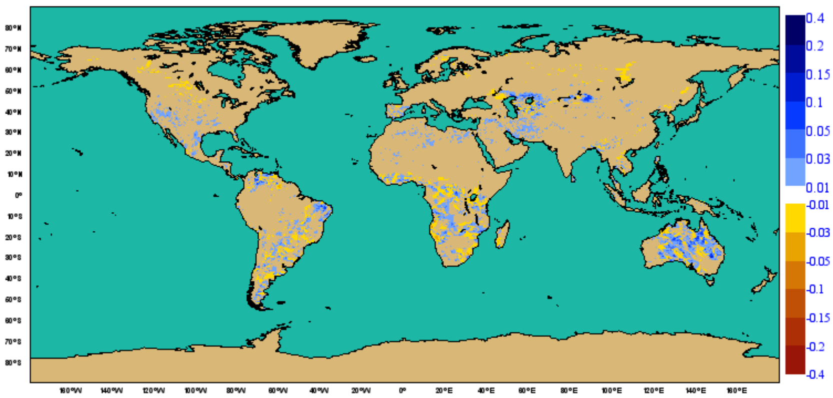
de Rosnay, P., Dragosavac, M., Isaksen, L., Andersson, E. and Haseler, J., 2011: Use of new snow data from Sweden in IFS cycle 36r4 *ECMWF Research Memorandum, R48.3/PdR/1139, 28 March 2011*



(a) SM1 AN, 16-22 February 2012

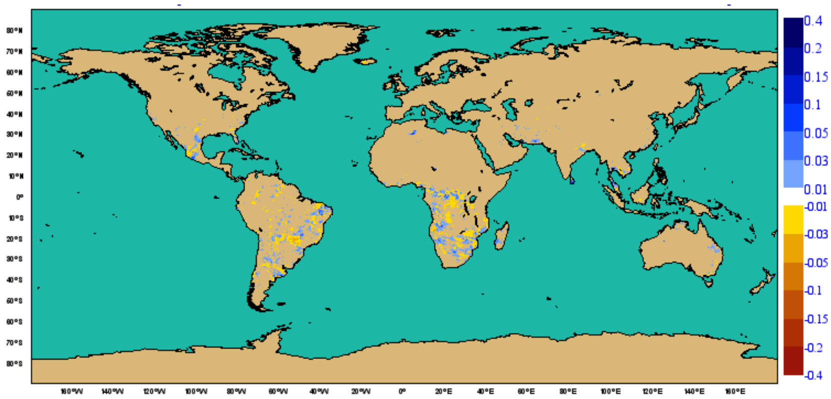


(b) SM1 AN, 23 February - 01 March 2012

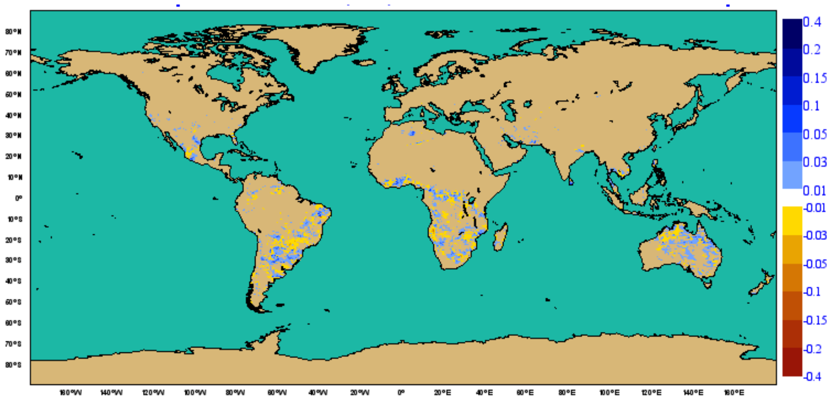


(c) SM1 AN, 02-08- March 2012

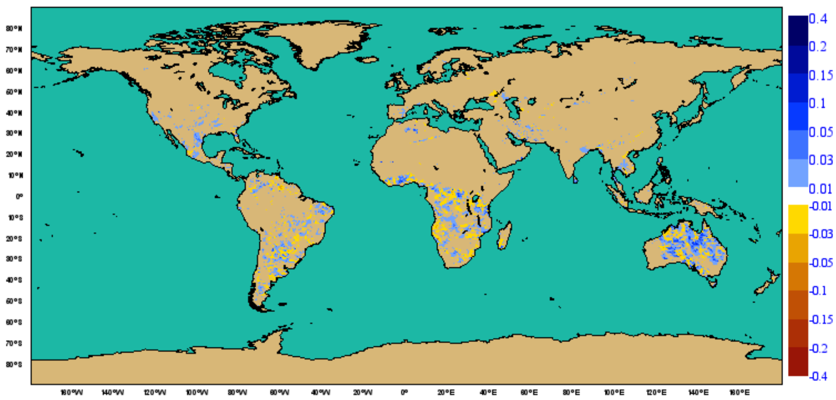
Figure 9: **Difference in DA soil moisture (in $m^3.m^{-3}$) analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **first soil layer (0-7 cm)**. *Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) SM2 AN, 16-22 February 2012

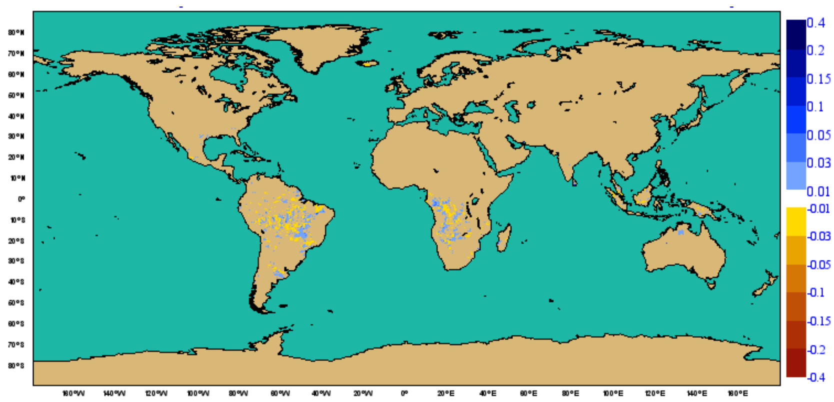


(b) SM2 AN, 23 February - 01 March 2012

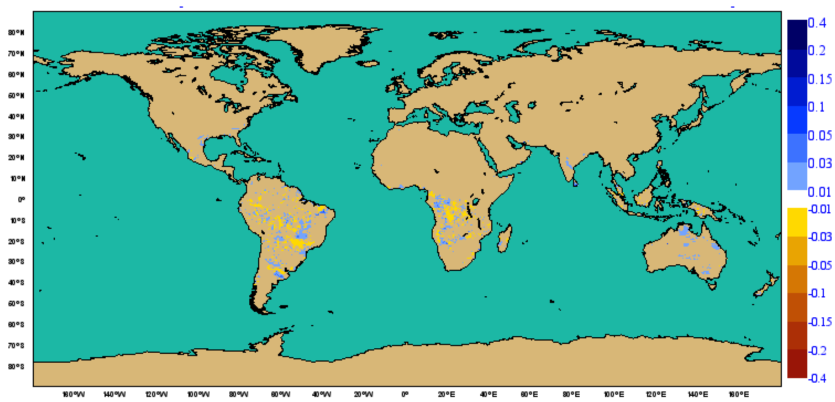


(c) SM2 AN, 02-08- March 2012

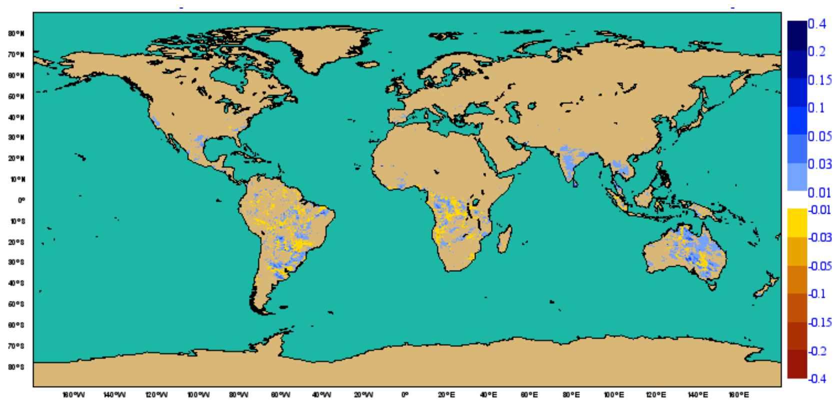
Figure 10: **Difference in DA soil moisture (in m^3.m^{-3}) analysis** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **second soil layer (7-28 cm)**. *Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) SM3 AN, 16-22 February 2012

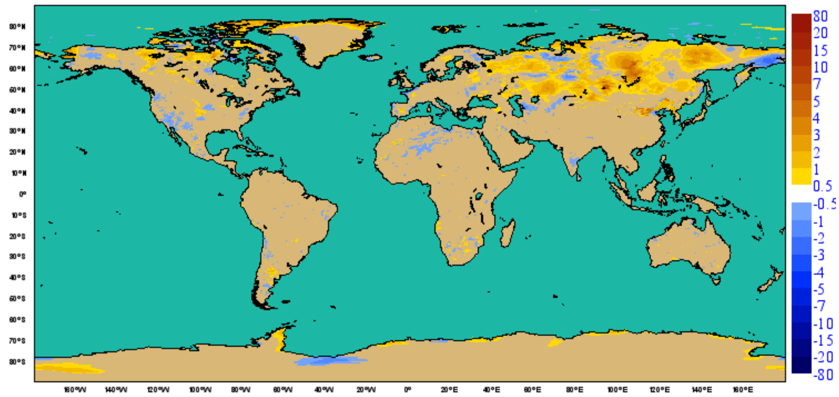


(b) SM3 AN, 23 February - 01 March 2012

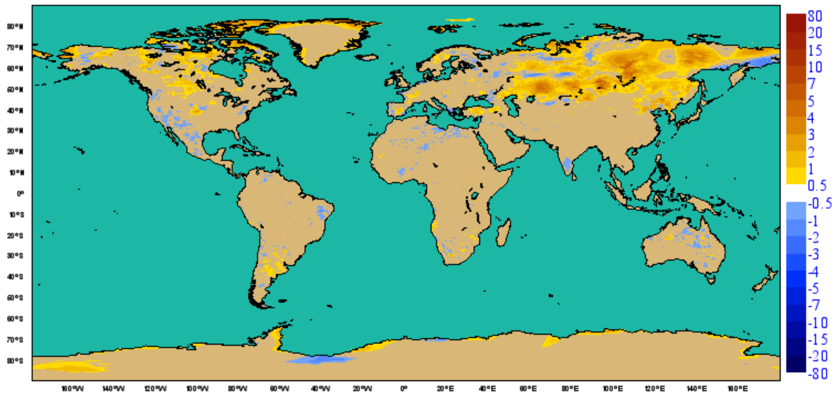


(c) SM3 AN, 02-08- March 2012

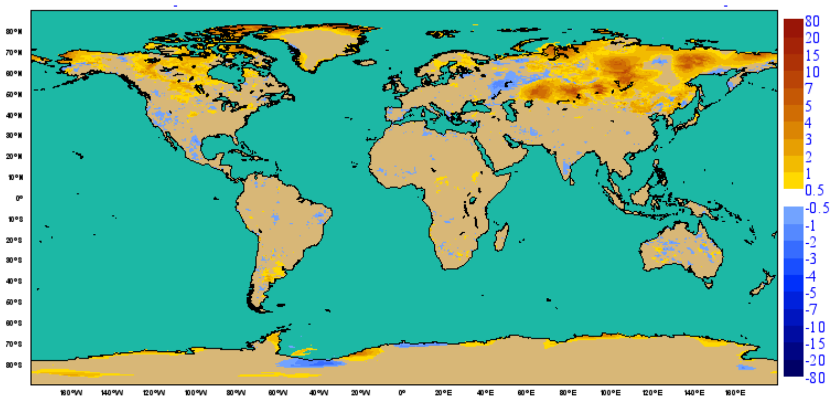
Figure 11: **Difference in DA soil moisture ($m^3.m^{-3}$) analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **third soil layer (28-100 cm)**. *Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) Soil Temp1 AN, 16-22 February 2012

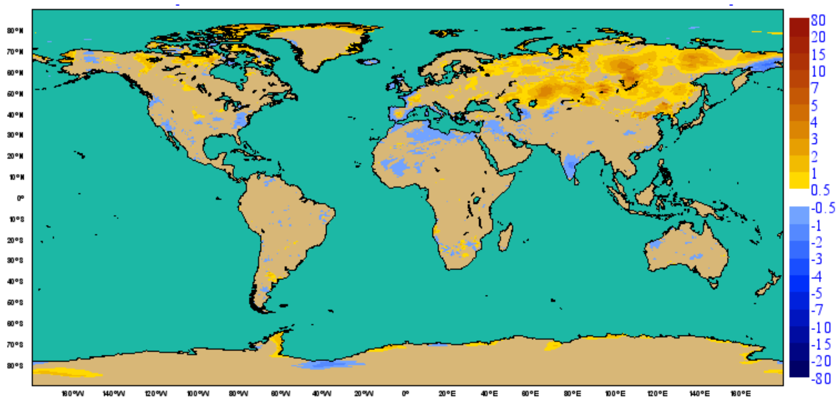


(b) Soil Temp1 AN, 23 February - 01 March 2012

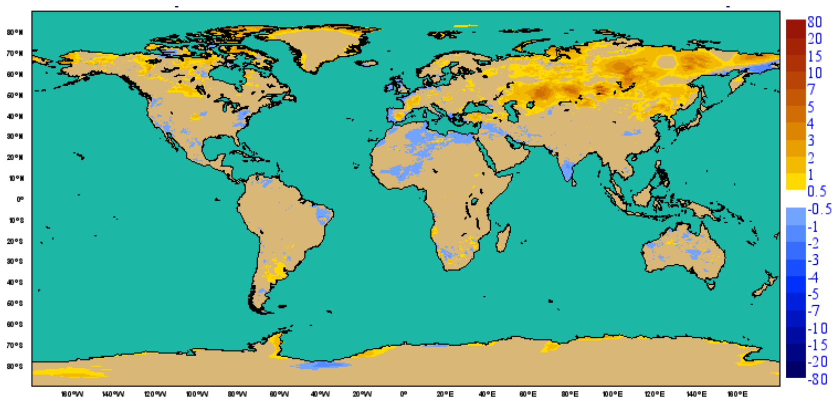


(c) Soil Temp1 AN, 02-08- March 2012

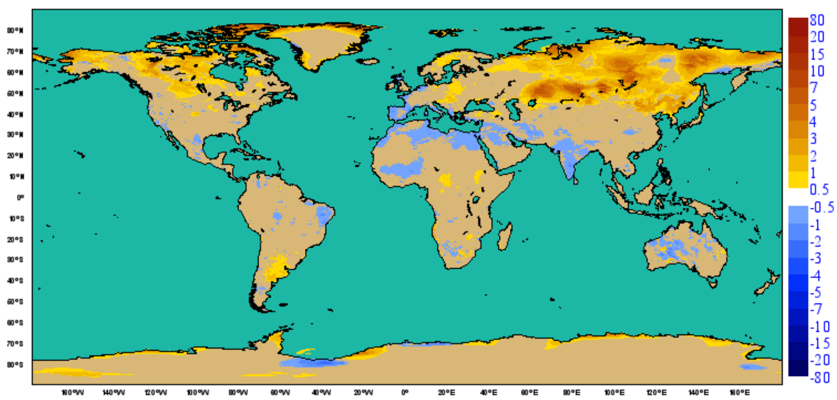
Figure 12: **Difference in DA soil temperature (in K) analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **surface soil layer (0-7 cm)***. Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) Soil Temp2 AN, 16-22 February 2012

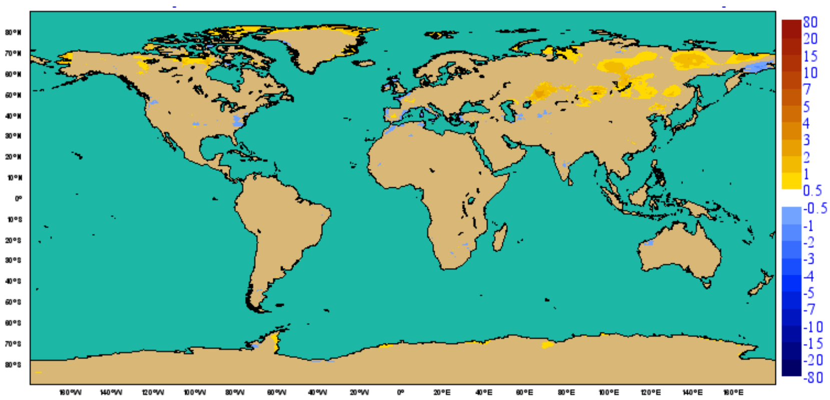


(b) Soil Temp2 AN, 23 February - 01 March 2012

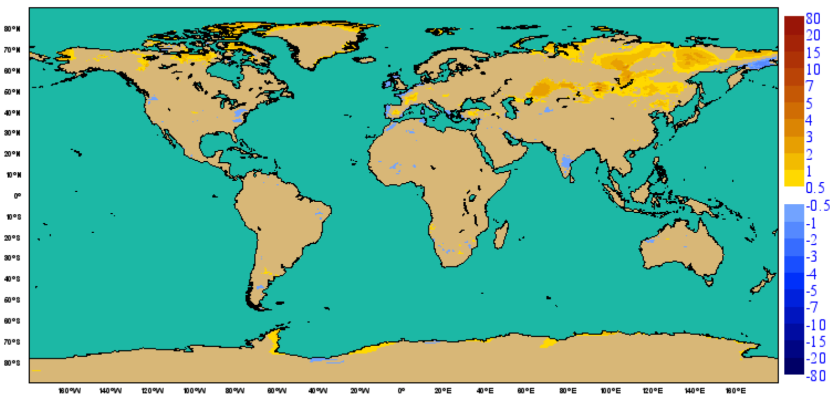


(c) Soil Temp2 AN, 02-08- March 2012

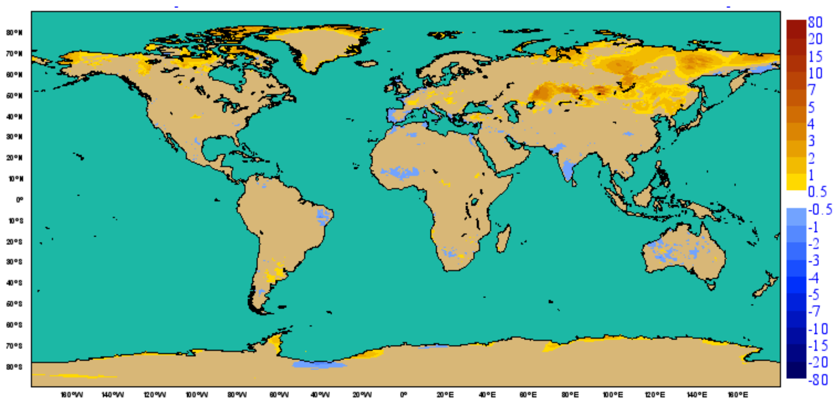
Figure 13: **Difference in DA soil temperature (in K) analysis** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **second soil layer (7-28 cm)**. *Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) Soil Temp3 AN, 16-22 February 2012

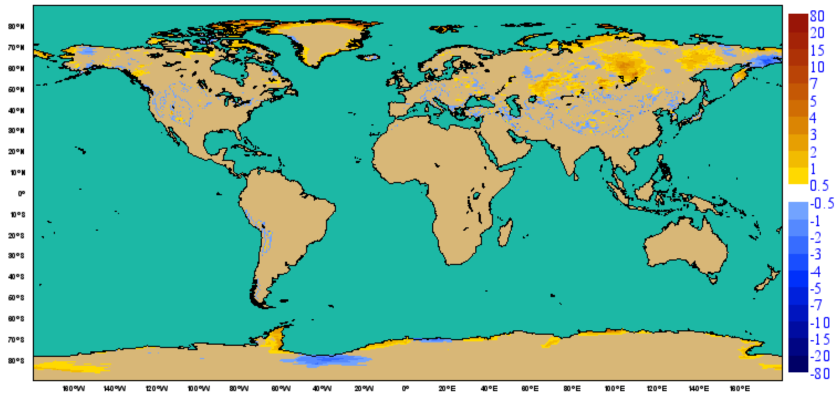


(b) Soil Temp3 AN, 23 February - 01 March 2012

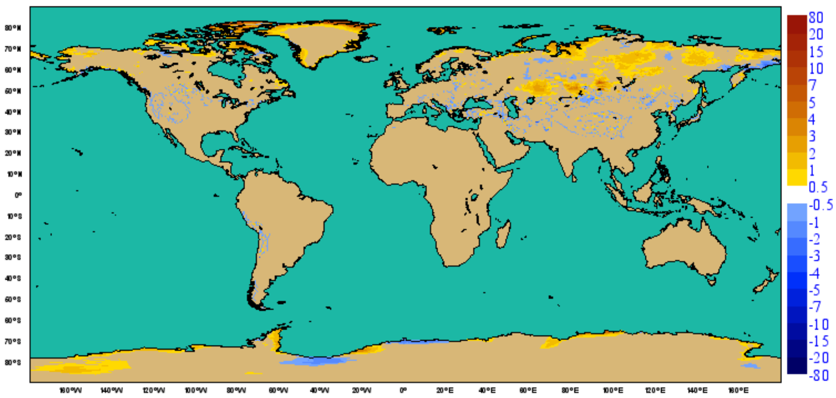


(c) Soil Temp3 AN, 02-08- March 2012

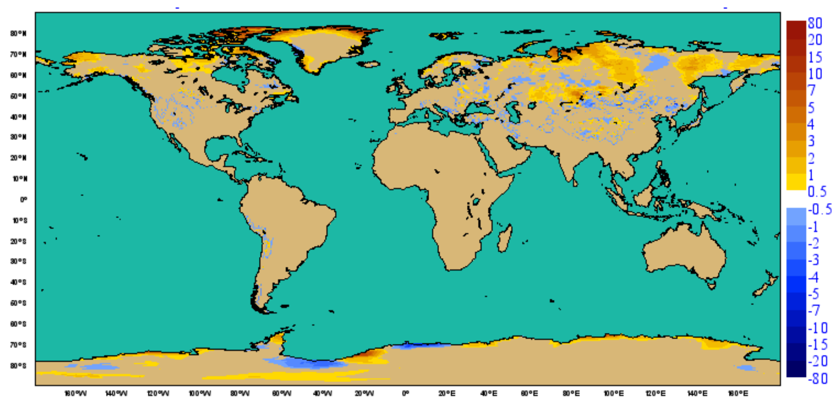
Figure 14: **Difference in DA soil temperature (K) analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for the* **third soil layer (28-100cm)***. Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) Snow Temp AN, 16-22 February 2012

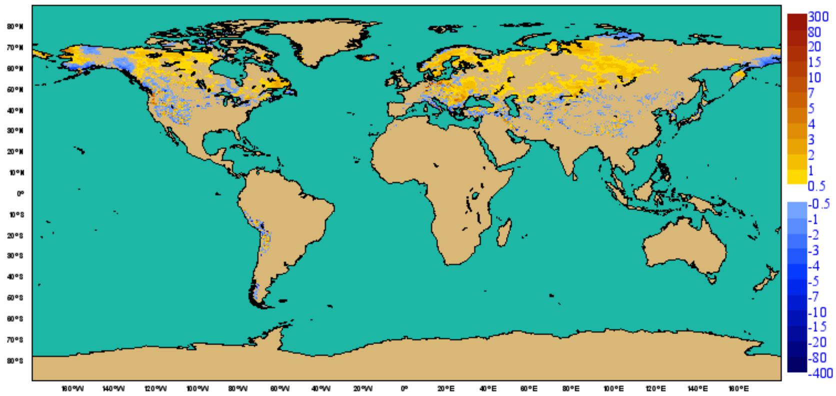


(b) Snow Temp AN, 23 February - 01 March 2012

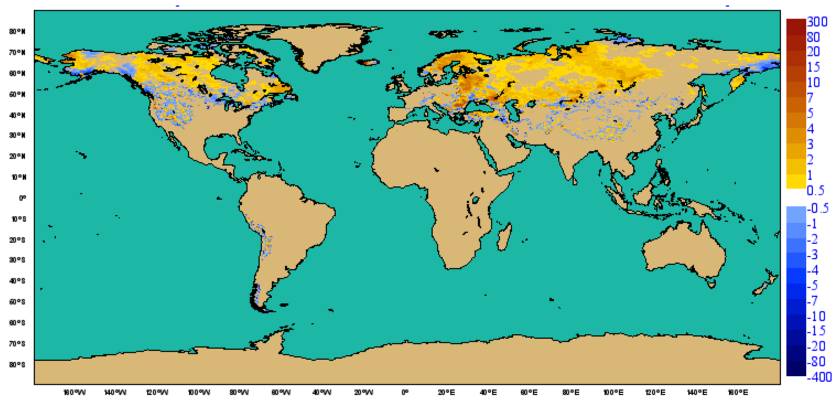


(c) Snow Temp AN, 02-08- March 2012

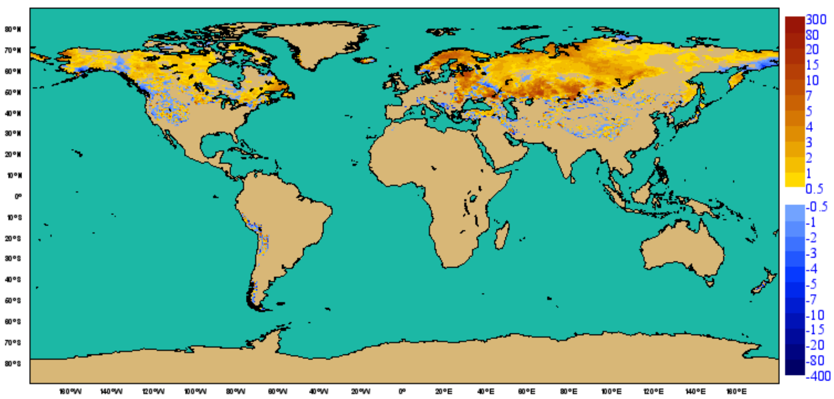
Figure 15: **Difference in DA snow analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for* **snow temperature (K)**. *Maps are weekly averaged from (a) 16 to 22 February 2012, (b) 23 February to 01 March 2012 and (c) 02 to 08 march 2012.*



(a) Snow Density AN, 16-22 February 2012

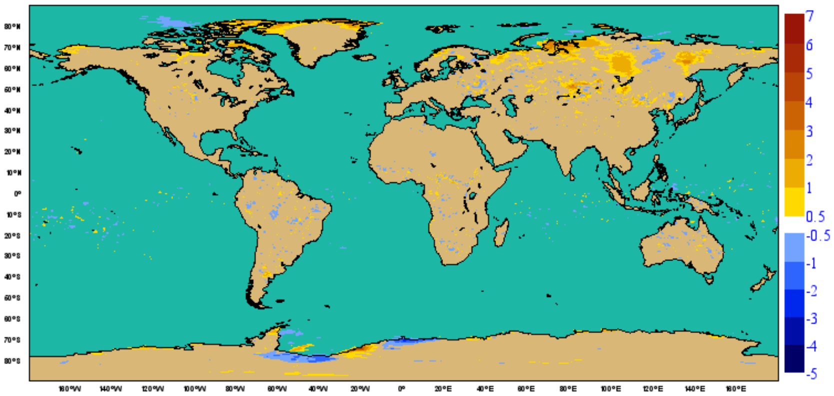


(b) Snow Density AN, 23 February - 01 March 2012

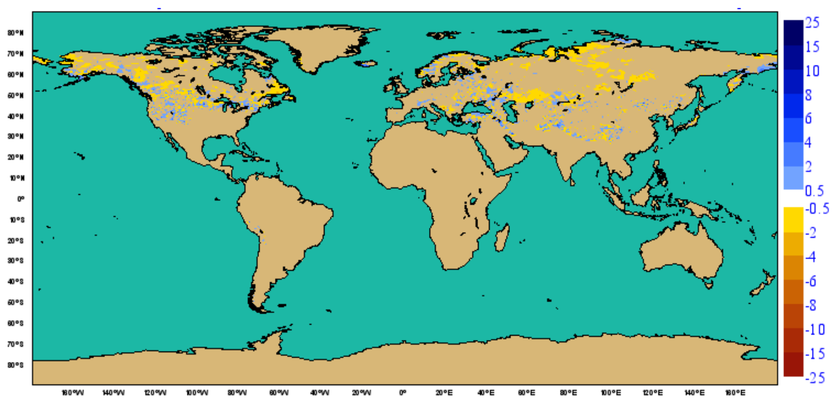


(c) Snow Density AN, 02-08- March 2012

Figure 16: **Difference in DA snow analysis** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis on* **snow density (Kg/m^3)***. Maps are weekly averaged from (a) 09 to 15 February 2012, (b) 16 to 22 February 2012, (c) 23 February to 01 March 2012 and (d) 02 to 08 march 2012.*

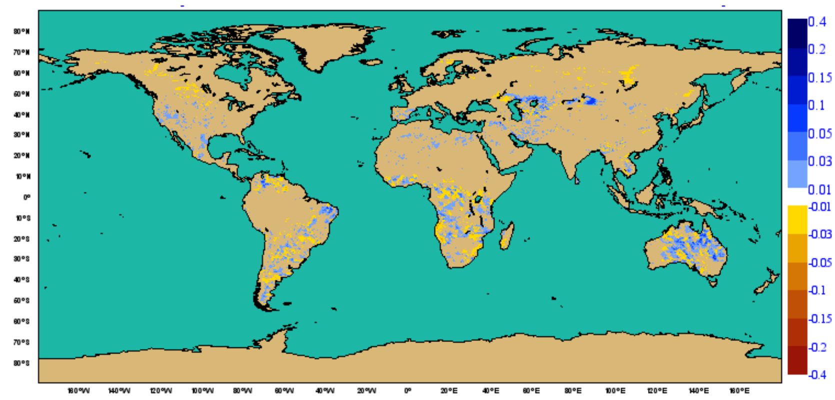


(a) T2m AN, 02-08- March 2012

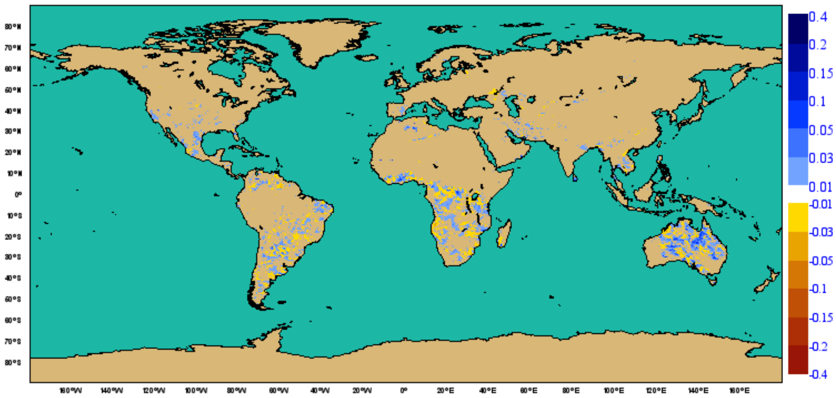


(b) Snow Depth AN, 02-08- March 2012

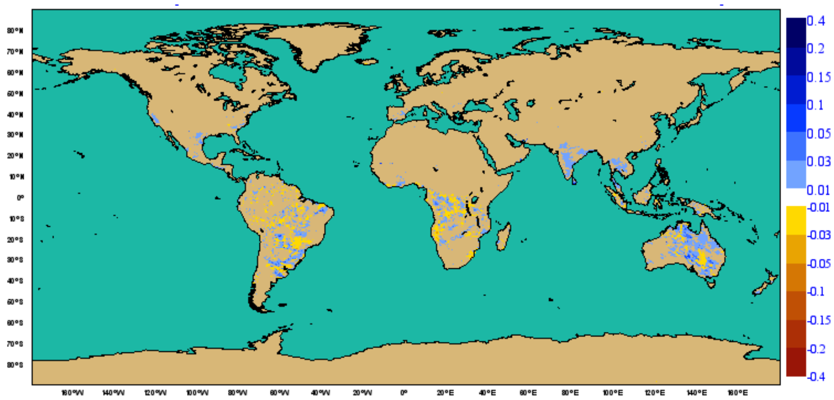
Figure 17: **Difference in DA analyses** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis for* **(a) T2m analysis (in K) and (b) snow depth analysis (in cm)***. Maps are weekly averaged from 02 to 08 march 2012.*



(a) SM1 FC24, 02-08- March 2012

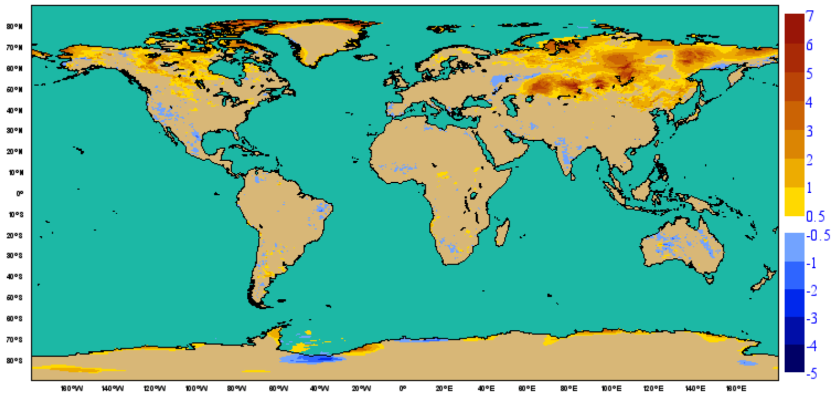


(b) SM2 FC24, 02-08- March 2012

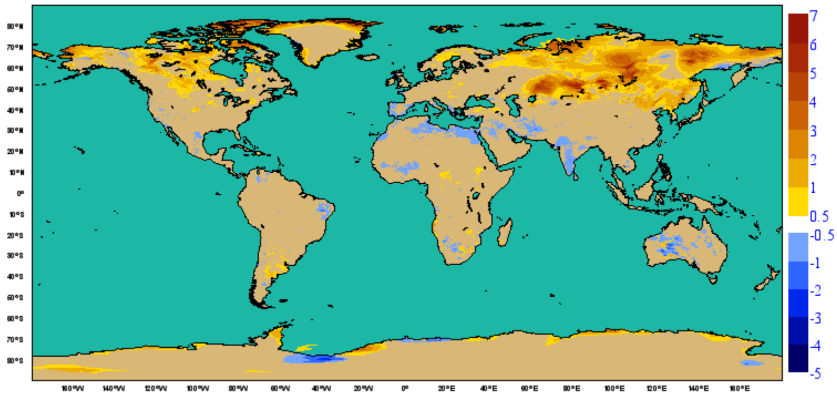


(c) SM3 FC24, 02-08- March 2012

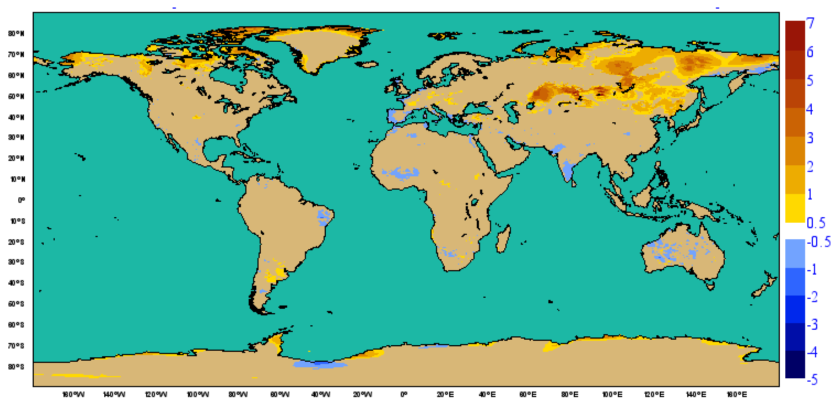
Figure 18: **Difference in soil moisture ($m^3.m^{-3}$) 24h forecasts** *between fnsb (bug) and fnsf (bug fix), for (a) the surface layer (0-7 cm). (b) the second soil layer (7-28 cm) and (c) the third soil layer (12-100 cm), showing the impact of the bug on the early delivery analysis. Maps are weekly averaged from 02 to 08 march 2012.*



(a) Soil Temp1 FC24, 02-08- March 2012

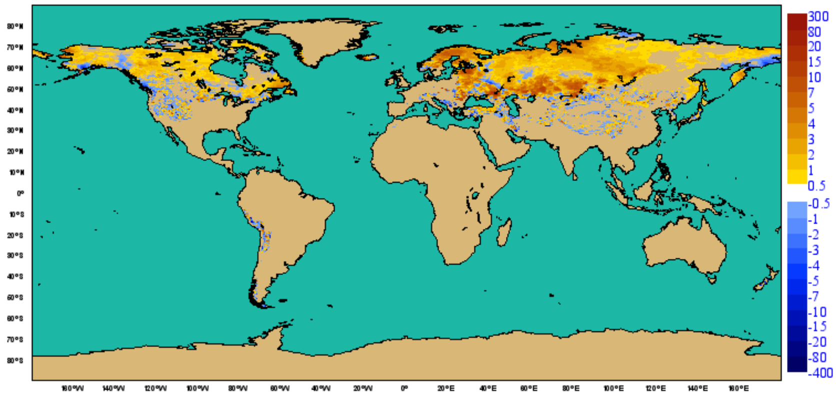


(b) Soil Temp2 FC24, 02-08- March 2012

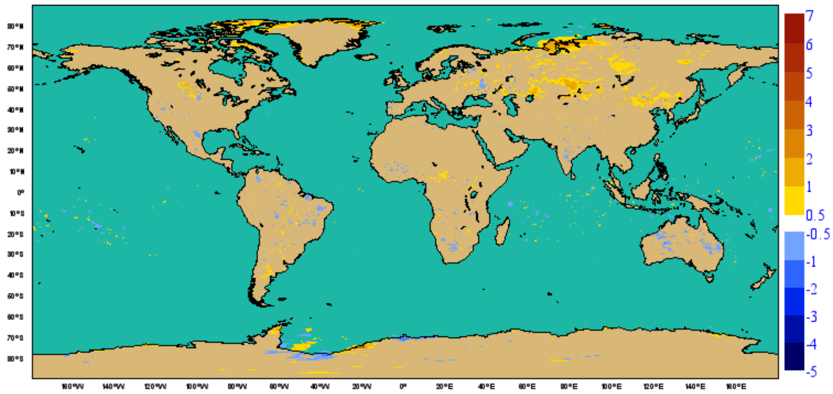


(c) Soil Temp3 FC24, 02-08- March 2012

Figure 19: **Difference in soil temperature (K) 24h forecasts** *between fnsb (bug) and fnsf (bug fix), for (a) the surface layer (0-7 cm). (b) the second soil layer (7-28 cm) and (c) the third soil layer (12-100 cm), showing the impact of the bug on the early delivery analysis. Maps are weekly averaged from 02 to 08 march 2012.*

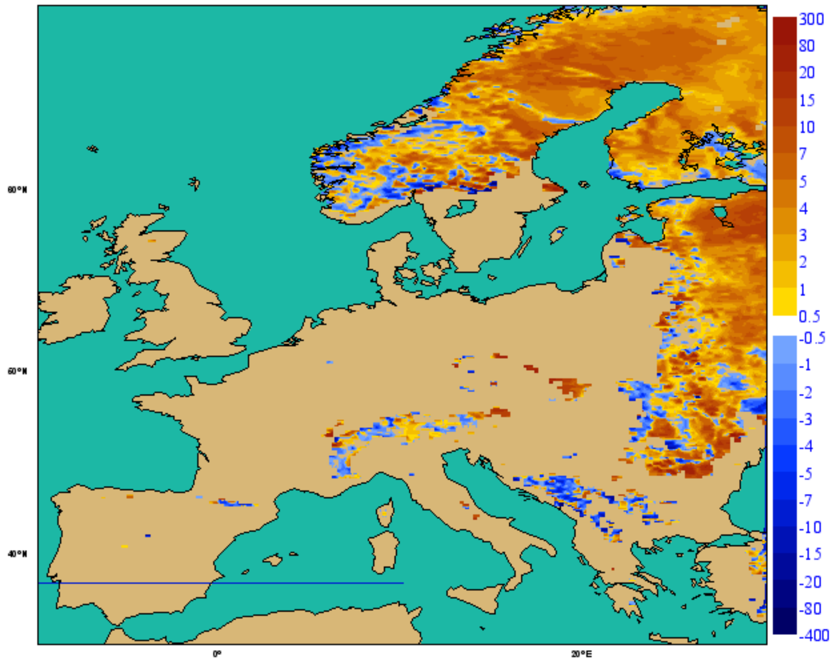


(a) Snow Density FC24, 02-08- March 2012

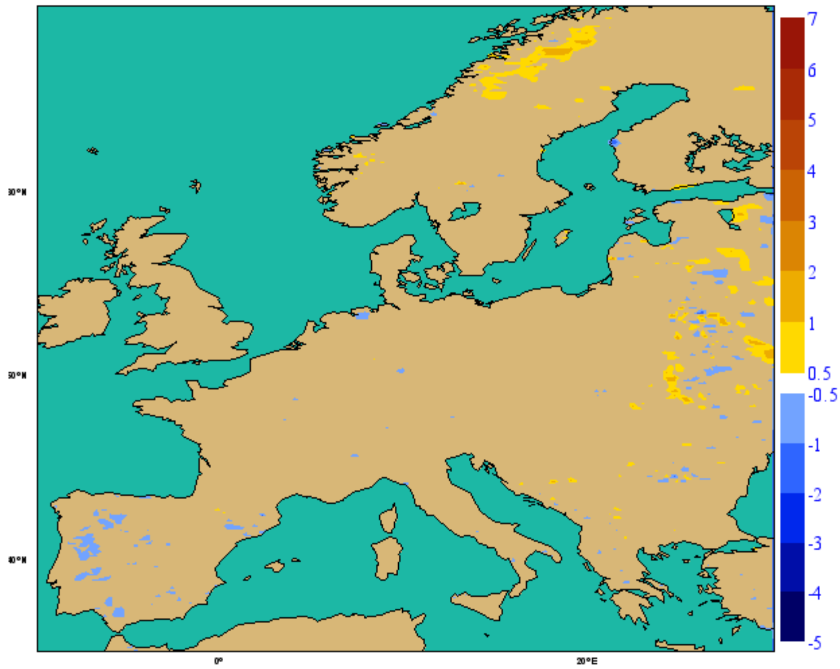


(b) T2m FC24, 02-08- March 2012

Figure 20: **Difference in snow density (Kg/m^3) and T2m (K) 24h forecasts** *between fnsb (bug) and fnsf (bug fix), showing the impact of the bug on the early delivery analysis. Maps are weekly averaged from 02 to 08 march 2012.*

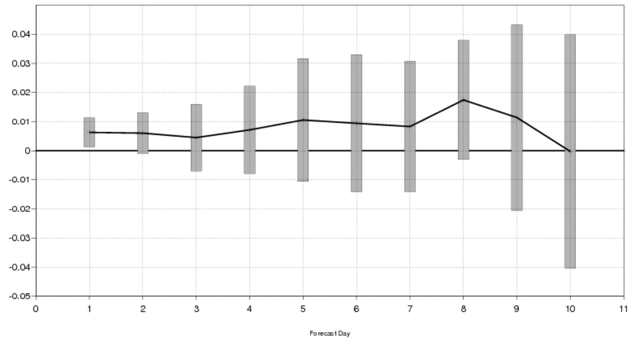


(a) Snow Density FC24, 02-08- March 2012

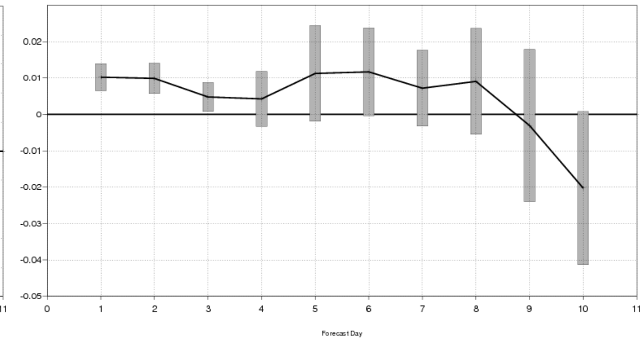


(b) T2m FC24, 02-08- March 2012

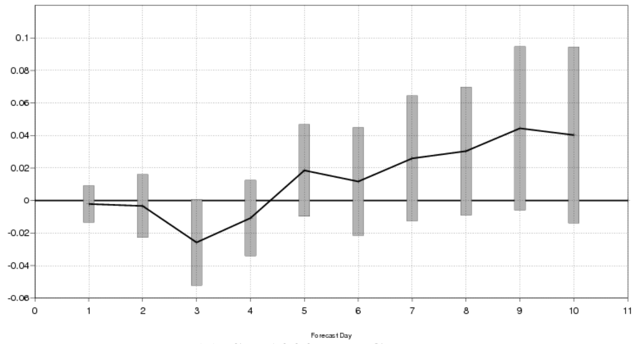
Figure 21: **Difference in snow density (Kg/m^3) and T2m (K) 24h forecast** *between fnsb (bug) and fnsf (bug fix) over Europe, showing the impact of the bug on the early delivery analysis. Maps are weekly averaged from 02 to 08 march 2012.*



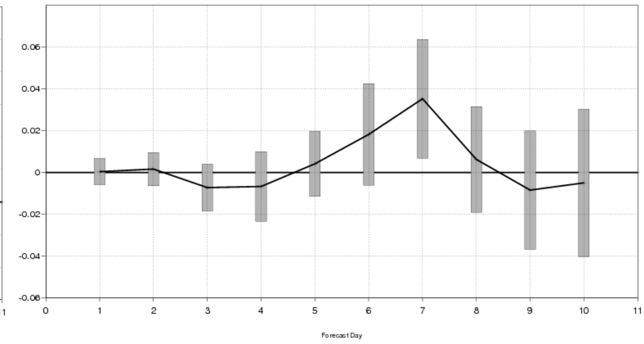
(a) NH 1000 HPa Geopot



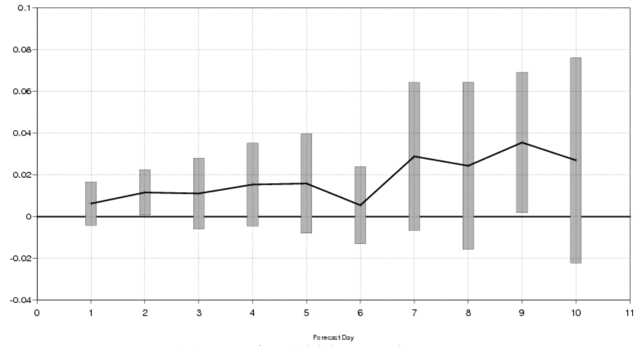
(b) NF 1000 HPa Temp



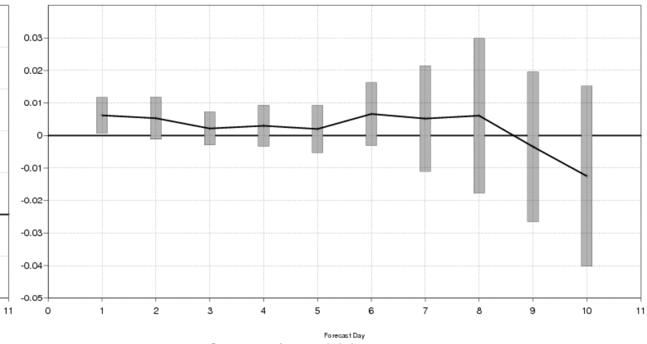
(c) SH 1000 HPa Geopot



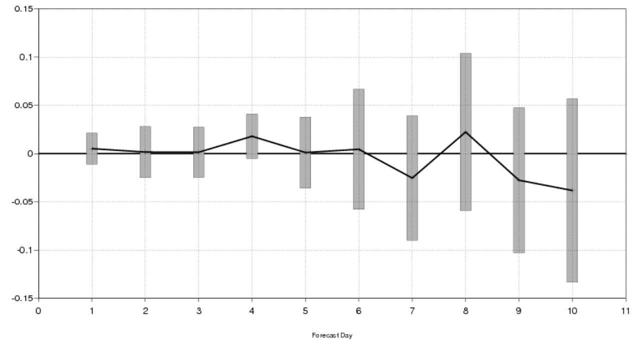
(d) SF 1000 HPa Temp



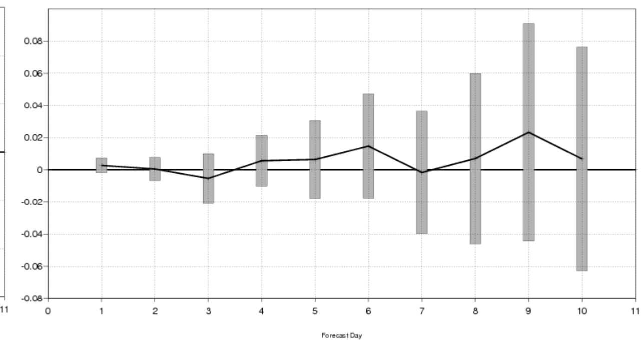
(e) Tropics 1000 HPa Geopot



(f) Tropics 1000 HPa Temp



(g) Europe 1000 HPa Geopot



(h) Europe 1000 HPa Temp

Figure 22: Impact of the bug fix on the 1000HPa geopotential height and temperature forecasts RMS scores from 08 February to 09 March 2012. Positive values indicate that the bug fixed experiment improved the forecast compared to the experiment that reproduces the bug.