

Impact of NOAA15 and NOAA16 ATOVS AMSU-A radiance data in the DMI-HIRLAM 3D-VAR data assimilation system

– November and December 2003

Bjarne Amstrup

Danish Meteorological Institute

Lyngbyvej 100, DK-2100 Copenhagen Ø

e-mail: bja@dmi.dk

1. Introduction

Several impact studies with the DMI-HIRLAM analysis and forecasting system have shown a positive – or initially a neutral – impact when using ATOVS (Advanced TIROS (Television Infra-Red Observation Satellite) Operational Vertical Sounder) AMSU-A (Advanced Microwave Sounding Unit-A) brightness temperatures with data from NOAA16 (National Oceanic and Atmospheric Administration) alone or a combination of data from NOAA16 and NOAA17 ((Amstrup, 2001; Schyberg *et al.*, 2003; Amstrup, 2002; Amstrup, 2003; Amstrup and Mogensen, 2004)). Accordingly, this type of observational data has been used operationally at DMI since December 2002 after a long period of using the data in the pre-operational suite. However, only two months after the data from NOAA17 ATOVS AMSU-A became operational September 2nd 2003, the instrument failed completely. Initially, at DMI we were not able to properly process the NOAA15 AMSU-A level 1c output from AAPP (ATOVS and AVHRR Processing Package) from the locally DMI received stations. However, after the failure of the NOAA17 AMSU-A1 instrument NOAA15 ATOVS AMSU-A brightness temperature data became very interesting again since some data have been available via the EARS (EUMETSAT ATOVS Retransmission Service) service. Furthermore, after looking into the problems encountered earlier with NOAA15 locally received data we found a solution. Before the start of EARS the data used at DMI were data received locally from Smidsbjerg and Sdr. Strømfjord (Kangerlussuaq) antennas and further processed with the AAPP package (see <http://www.eumetsat.de/en/index.html>): The raw (level 0) data received are processed in 3 steps to level 1c (geo-referenced and calibrated temperatures and albedo) data. The resulting level 1c data, containing brightness temperatures for the 15 AMSU-A channels, are then further processed separately from AAPP to the standard BUFR-format ((WMO, 1995)).

Two experiments have been made: 1) a five week period (denoted 200311/extended November 2003) from October 27th to November 30th 2003 for which 3 runs were made, one without AMSU-A data (labeled NoA), one including NOAA16 AMSU-A data (labeled WiA16) and one including both NOAA15 and NOAA16 AMSU-A data (labeled WiA1516); and 2) a month (denoted 200312) for which two runs were made, one without AMSU-A data (labeled NoA) and one including both NOAA15 and NOAA16 AMSU-A data (labeled WiA). The NOAA16 data consists of locally received data as well as EARS data whereas NOAA15 data is data

from EARS only in these runs.

2. The ATOVS AMSU-A usage in HIRLAM 3D-VAR

The radiative forward model presently used for calculating brightness temperatures is based on RTTOV-7 (Radiative Transfer model for TOVS, release 7), available from the Numerical Weather Prediction SAF (Satellite Application Facility) (see <http://www.metoffice.com/research/interproj/nwpsaf/index.html>, Saunders *et al.*, 1999 and Matricardi *et al.*, 2004).

At present a diagonal observation error covariance matrix is used. The values for NOAA15 as well as for NOAA16 (and NOAA17) are 900 K^2 for channels 1 to 3, 90 K^2 for channel 4, 0.35 K^2 for channels 5 to 8, 0.70 K^2 for channel 9 and 1.40 K^2 for channel 10. The values for channels 1 to 3 should be sufficiently high to minimize the use of data for these channels. The values for channels 9 and 10 are higher than for the channels 5 to 8 because the response function for these channels do have nonnegligible amplitudes above the vertical limit of the DMI-HIRLAM models, 10 hPa. Climate values are at present used in the radiation transfer model for levels above the vertical limit of the model. It may be considered to use values from the ECMWF model and/or to extend the model upwards for this instead.

Data is presently rejected over land and ice, and a cloud clearing based on the total cloud liquid water content is made since the effect of precipitable particles is not modeled in the radiative transfer model. The data are subsequently thinned to 0.9° for NOAA15 and NOAA16 data separately.

For bias-correction a Harris-Kelly ((Harris and Kelly, 2001)) scheme with 7 predictors from the background model (model first guess) is used. The initial examination that was done for NOAA16 data ((Schyberg *et al.*, 2003)) showed that the scatter of the difference between observed and modeled brightness temperature varied significantly as a function of latitude. It was therefore decided to have separate bias correction coefficients for three latitude bands: 1) up to 50°N , 2) between 50°N and 65°N , and 3) north of 65°N . With these limits, the number of observations were approximately the same in the three areas – except for the northern band depending on the time of the year due to different ice coverage for different seasons.

Until November 2003 the bias correction coefficients for NOAA16 data were based on data from the full month of April 2002. New bias coefficients used in this study are based on 7.5 months of data from 2003. The bias coefficients used for NOAA15 are based on 5 months of data from June to November 2003, made available to DMI from SMHI.

Further details concerning assimilation of ATOVS data in the HIRLAM 3D-VAR system can be found in Schyberg *et al.* (2003).

3. Experimental setup

The operational data-assimilation system for DMI-HIRLAM has since the end of September 2000 been a 3D-VAR analysis scheme (Gustafsson *et al.*, 2001; Lindskog *et al.*, 2001) and a forecast model (based on reference version 5.x with some local modifications). The DMI system is documented in Sass *et al.* (2002) and the upgrade in December 2002 is documented in Amstrup *et al.* (2003).

The version used here is the HIRLAM 3D-VAR 6.0 OpenMP version for NEC. The observation window covers a 3 h span around the analysis time (00, 03, 06, 09, 12, 15, 18, 21 UTC) except for a 6 h span around the analysis times 06 UTC and 18 UTC before the long forecasts starting from these. A standard observation set is used including synoptic observations, ship observations, (drifting and moored) buoys, pilot balloons, radiosonde data and aircraft data. The runs with these observation types is denoted NoA (No ATOVS). The runs including NOAA16 and NOAA15 AMSU-A brightness temperature data is denoted WiA1516 and WiA, respectively, for the extended November 2003 period and the December 2003 period. The run using NOAA16 AMSU-A brightness temperature in the extended 003 period is denoted WiA16.

The basic model applied in the present OSE study is DMI-HIRLAM-G including the changes made in December 2002. Furthermore, the resolution of ECMWF sst- and ice-fields has been increased to 0.5° instead of 1.0° . The horizontal resolution of DMI-HIRLAM-G is 0.45° , the number of vertical levels 40, the number of grid points is 190×202 , the dynamics time step is 150 s, the physics time step is 450 s and the lateral boundary values are updated every 3 hours from ECMWF (the so called “frames” boundaries) 00 UTC, 06 UTC, 12 UTC or 18 UTC forecasts. Long (48 hour) forecasts are made at the four major SYNOP hours (00, 06, 12 and 18 UTC).

Twice a day (at 00 UTC and 12 UTC reassimilation cycles) the DMI-HIRLAM-G model is restarted from fresh ECMWF analyses using an analysis increment method.

4. Results

The results are compared in different ways. A standard observation verification where forecast results are compared to standard SYNOP and radiosonde observations using an EWGLAM (European Working Group on Limited Area Model) station list is done and the results are shown and commented upon in section 4.1. Results of forecasted 12 h precipitation against observations from SYNOP stations at 06 UTC and 18 UTC are given in terms of standard contingency tables as well as equitable threat scores are given in section 4.2.

4.1. Observation verification

Figure 1 shows results from obs-verification of the three runs in the extended November 2003 period. In general NoA has the worse root mean square (rms) error scores. The rms scores are more similar for WiA16 and WiA1516 but WiA1516 has better scores than WiA16 for more parameters than WiA16 has better scores than WiA1516. The bias scores are in general similar for the three runs except for the height scores for which NoA has the worse scores and for mslp for which NoA has the better scores. With respect to the inter comparison between WiA16 and WiA1516, WiA1516 has marginal better bias scores than WiA15 for some parameters. So the conclusion with respect to the obs-verification for the extended November 2003 period is that it is better to include NOAA AMSU-A data and that it is better to include data from two satellites than to include data from only one satellite. (This is also in accordance with results seen at other centers).

Figure 2 shows the results from obs-verification of the two runs in the December 2003 period. The tendencies from the extended November 2003 period are the same in this period with the run (WiA) including NOAA AMSU-A data having the better rms scores. WiA has also better bias scores than NoA for some parameters with ms1p as an exception.

Obs-verification of the vertical structure of temperature and geopotential height is illustrated in Figures 3 and 4 for November 2003 and December 2003, respectively. The figures show rms scores of temperature for the run including all AMSU-A data (upper left) and differences in rms scores between this run and the NoA run (upper right) at analysis time and for the 12, 24 and 36 hour forecasts as a function of pressure in the given period. The lower part of the figures shows the same except for geopotential height in stead of temperature. For both periods the run including AMSU-A data has better scores than the run without AMSU-A data both for temperature and for geopotential height.

4.2. Precipitation verification

The equitable threat score (ETS) measures the fraction of observed and/or forecast events that were correctly predicted, adjusted for hits associated with random change (see, e.g. http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html). By use of the following table

| | observed | |
|-------------------|----------|-------|
| | no event | event |
| forecast no event | A | B |
| forecast event | C | D |

we have $ETS = (D - \text{chance}) / (B + C + D - \text{chance})$ with $\text{chance} = (C + D) * (A + B) / (A + B + C + D)$. Termed in a different way ETS is defined as: $ETS = (R - \text{chance}) / (T - \text{chance})$ where R is the total number of observed **and** forecasted events, T is total number of events observed **or** forecasted and chance is given by $\text{chance} = F * O / N$ where F is number of forecasted events, O the number of observed events and N is the total number of events plus non-events. The ETS score is between $-1/3$ and 1, 1 being the perfect score and 0 indicating no skill.

Table 1 shows the results by use of a Danish station list (29 stations) and an EWGLAM station list, respectively, for the model runs. Results for 6-18 h, 18-30 h and for 18-30 h are given for limits of very low precipitation amounts (0.3 mm/12 h), low precipitation amounts (1.5 mm/12 h) and for larger precipitation amounts (5 mm/12 h). No conclusion can be based on these results with respect to forecasts of precipitation since most of the scores are comparable and if they are not comparable it varies a lot which version has the better or worse score.

Tables 2 and 3 show contingency tables of precipitation accumulated over 12 hours (from 6 to 18 hour forecasts, 18 to 30 hour forecasts, and 30 to 42 hour forecasts) for the extended November 2003 period and the December 2003 period, respectively. The numbers in these tables are obtained by counting the number of observed and predicted precipitation amounts in each of five classes for the EWGLAM stations that do report 12 hours accumulated precipitation. The five precipitation classes are (precipitation amounts in mm): $P1 < 0.2$,

Table 1: Equitable threat scores (ETS) for the model runs. ETS1 is for a limit of 0.3 mm/12 h, ETS2 is for a limit of 1.5 mm/12 h and ETS3 is for a limit of 5.0 mm/12 h. The best score is marked with a bold font if the score is at least 0.01 higher than the second best. The worst score (in the November period) is marked with red font if the score is at least 0.01 lower than the second best.

| Danish stations 200311 | | | | | | | | | |
|------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | 6–18 h | | | 18–30 h | | | 30–42 h | | |
| model | ETS1 | ETS2 | ETS3 | ETS1 | ETS2 | ETS3 | ETS1 | ETS2 | ETS3 |
| NoA | 0.435 | 0.435 | 0.338 | 0.349 | 0.333 | 0.214 | 0.326 | 0.235 | 0.143 |
| WiA16 | 0.413 | 0.409 | 0.298 | 0.342 | 0.349 | 0.212 | 0.337 | 0.282 | 0.155 |
| WiA1516 | 0.429 | 0.404 | 0.267 | 0.329 | 0.329 | 0.198 | 0.341 | 0.272 | 0.208 |
| Danish stations 200312 | | | | | | | | | |
| NoA | 0.375 | 0.407 | 0.481 | 0.314 | 0.330 | 0.401 | 0.227 | 0.319 | 0.325 |
| WiA | 0.368 | 0.424 | 0.443 | 0.297 | 0.332 | 0.329 | 0.241 | 0.310 | 0.316 |
| EWGLAM stations 200311 | | | | | | | | | |
| NoA | 0.379 | 0.413 | 0.368 | 0.338 | 0.361 | 0.301 | 0.299 | 0.312 | 0.255 |
| WiA16 | 0.378 | 0.418 | 0.363 | 0.338 | 0.371 | 0.304 | 0.308 | 0.330 | 0.267 |
| WiA1516 | 0.380 | 0.422 | 0.361 | 0.336 | 0.371 | 0.308 | 0.308 | 0.322 | 0.249 |
| EWGLAM stations 200312 | | | | | | | | | |
| NoA | 0.370 | 0.438 | 0.362 | 0.327 | 0.395 | 0.320 | 0.300 | 0.356 | 0.275 |
| WiA | 0.375 | 0.444 | 0.356 | 0.332 | 0.402 | 0.315 | 0.311 | 0.366 | 0.286 |

$0.2 \leq P2 < 1.0$, $1.0 \leq P3 < 5$, $5 \leq P4 < 10$ and $P5 \geq 10$. P is either F (forecast) or O (observation) in the tables. The “sum” rows and columns are the sums of the numbers in the given observation classes or forecast classes, respectively. Note that the observed values are uncorrected values. Thus, small observed precipitation values are most likely underestimated. As for the ETS scores it is hard to make any conclusion based on these tables. It may, however, be noted that WiA has the better diagonal score for the 3 given forecast ranges for December 2003 and that WiA has smaller numbers in the outer diagonal (the O1/F5 and O5/F1 elements) than NoA.

5. Conclusion

Based on standard verification scores there is a clear positive impact from using NOAA AMSU-A brightness temperatures in the DMI-HIRLAM data assimilation system.

Based on the results from the extended November 2003 period and a short period of including these data in the pre-operational suite, NOAA15 AMSU-A brightness temperatures were added to the observational data used in the DMI-HIRLAM operational suite December 3rd 2003.

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Table 2: Contingency tables for November 2003. NoA did not include ATOVS AMSU-A data, WiA16 included NOAA16 ATOVS AMSU-A data, and WiA1516 included NOAA15 and NOAA16 ATOVS AMSU-A data. EWGLAM station list.

| NoA 200311 (6-18 h forecasts) | | | | | | | NoA 200311 (18-30 h forecasts) | | | | | | |
|--|-------------|------------|-------------|------------|------------|-------|--|-------------|------------|-------------|------------|------------|-------|
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 9203 | 532 | 138 | 14 | 10 | 9897 | F1 | 8836 | 492 | 153 | 28 | 14 | 9523 |
| F2 | 2490 | 823 | 447 | 66 | 27 | 3853 | F2 | 2569 | 775 | 457 | 77 | 36 | 3914 |
| F3 | 831 | 633 | 1047 | 300 | 128 | 2939 | F3 | 1069 | 688 | 992 | 316 | 133 | 3198 |
| F4 | 65 | 50 | 222 | 247 | 167 | 751 | F4 | 102 | 72 | 237 | 207 | 148 | 766 |
| F5 | 18 | 14 | 42 | 78 | 122 | 274 | F5 | 31 | 25 | 57 | 77 | 123 | 313 |
| sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 | sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 |
| %FO | 73 | 40 | 55 | 35 | 27 | 65 | %FO | 70 | 38 | 52 | 29 | 27 | 62 |
| WiA1516 200311 (6-18 h forecasts) | | | | | | | WiA1516 200311 (18-30 h forecasts) | | | | | | |
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 9135 | 526 | 128 | 15 | 15 | 9819 | F1 | 8806 | 494 | 154 | 28 | 13 | 9495 |
| F2 | 2535 | 816 | 464 | 57 | 21 | 3893 | F2 | 2620 | 781 | 458 | 67 | 29 | 3955 |
| F3 | 857 | 636 | 1037 | 329 | 114 | 2973 | F3 | 1052 | 688 | 996 | 326 | 146 | 3208 |
| F4 | 66 | 55 | 225 | 239 | 168 | 753 | F4 | 102 | 69 | 239 | 214 | 124 | 748 |
| F5 | 14 | 19 | 42 | 65 | 136 | 276 | F5 | 27 | 20 | 49 | 70 | 142 | 308 |
| sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 | sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 |
| %FO | 72 | 40 | 55 | 34 | 30 | 64 | %FO | 70 | 38 | 53 | 30 | 31 | 62 |
| WiA 200311 (6-18 h forecasts) | | | | | | | WiA16 200311 (18-30 h forecasts) | | | | | | |
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 9158 | 520 | 131 | 20 | 12 | 9841 | F1 | 8863 | 503 | 156 | 28 | 14 | 9564 |
| F2 | 2520 | 823 | 461 | 62 | 27 | 3893 | F2 | 2562 | 766 | 426 | 74 | 28 | 3856 |
| F3 | 852 | 637 | 1034 | 310 | 114 | 2947 | F3 | 1048 | 690 | 1039 | 326 | 135 | 3238 |
| F4 | 63 | 54 | 232 | 234 | 156 | 739 | F4 | 107 | 75 | 218 | 207 | 144 | 751 |
| F5 | 14 | 18 | 38 | 79 | 145 | 294 | F5 | 27 | 18 | 57 | 70 | 133 | 305 |
| sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 | sum | 12607 | 2052 | 1896 | 705 | 454 | 17714 |
| %FO | 73 | 40 | 55 | 33 | 32 | 64 | %FO | 70 | 37 | 55 | 29 | 29 | 62 |

Table 3: Contingency tables for December 2003. NoA did not include ATOVS AMSU-A data, WiA included NOAA15 and NOAA16 ATOVS AMSU-A data. EWGLAM station list.

| NoA 200312 (6-18 h forecasts) | | | | | | | WiA 200312 (6-18 h forecasts) | | | | | | |
|--|-------------|------------|-------------|------------|------------|-------|--|-------------|------------|-------------|------------|------------|-------|
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 8264 | 323 | 93 | 11 | 4 | 8695 | F1 | 8315 | 324 | 90 | 8 | 3 | 8740 |
| F2 | 2991 | 876 | 352 | 55 | 17 | 4291 | F2 | 2956 | 869 | 341 | 57 | 16 | 4239 |
| F3 | 1074 | 875 | 1350 | 377 | 122 | 3798 | F3 | 1050 | 884 | 1359 | 381 | 129 | 3803 |
| F4 | 85 | 86 | 379 | 321 | 164 | 1035 | F4 | 95 | 76 | 366 | 315 | 154 | 1006 |
| F5 | 20 | 15 | 83 | 114 | 211 | 443 | F5 | 18 | 22 | 101 | 117 | 216 | 474 |
| sum | 12434 | 2175 | 2257 | 878 | 518 | 18262 | sum | 12434 | 2175 | 2257 | 878 | 518 | 18262 |
| %FO | 66 | 40 | 60 | 37 | 41 | 60 | %FO | 67 | 40 | 60 | 36 | 42 | 61 |
| NoA 200312 (18-30 h forecasts) | | | | | | | WiA 200312 (18-30 h forecasts) | | | | | | |
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 7807 | 321 | 115 | 18 | 5 | 8266 | F1 | 7913 | 312 | 119 | 20 | 2 | 8366 |
| F2 | 3209 | 825 | 355 | 77 | 26 | 4492 | F2 | 3116 | 840 | 348 | 68 | 23 | 4395 |
| F3 | 1256 | 905 | 1281 | 363 | 138 | 3943 | F3 | 1260 | 897 | 1268 | 379 | 142 | 3946 |
| F4 | 116 | 97 | 403 | 291 | 149 | 1056 | F4 | 111 | 106 | 395 | 288 | 150 | 1050 |
| F5 | 45 | 27 | 103 | 129 | 200 | 504 | F5 | 34 | 20 | 127 | 123 | 201 | 505 |
| sum | 12433 | 2175 | 2257 | 878 | 518 | 18261 | sum | 12434 | 2175 | 2257 | 878 | 518 | 18262 |
| %FO | 63 | 38 | 57 | 33 | 39 | 57 | %FO | 64 | 39 | 56 | 33 | 39 | 58 |
| NoA 200312 (30-42 h forecasts) | | | | | | | WiA 200312 (30-42 h forecasts) | | | | | | |
| $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum | $\frac{\text{obs} \rightarrow}{\downarrow \text{for}}$ | O1 | O2 | O3 | O4 | O5 | sum |
| F1 | 7577 | 342 | 143 | 29 | 12 | 8103 | F1 | 7673 | 342 | 143 | 30 | 7 | 8195 |
| F2 | 3251 | 769 | 367 | 84 | 27 | 4498 | F2 | 3196 | 764 | 372 | 81 | 26 | 4439 |
| F3 | 1416 | 882 | 1234 | 363 | 162 | 4057 | F3 | 1370 | 913 | 1261 | 389 | 152 | 4085 |
| F4 | 140 | 152 | 383 | 286 | 145 | 1106 | F4 | 147 | 126 | 335 | 266 | 151 | 1025 |
| F5 | 50 | 30 | 130 | 116 | 172 | 498 | F5 | 48 | 30 | 146 | 112 | 182 | 518 |
| sum | 12434 | 2175 | 2257 | 878 | 518 | 18262 | sum | 12434 | 2175 | 2257 | 878 | 518 | 18262 |
| %FO | 61 | 35 | 55 | 33 | 33 | 55 | %FO | 62 | 35 | 56 | 30 | 35 | 56 |

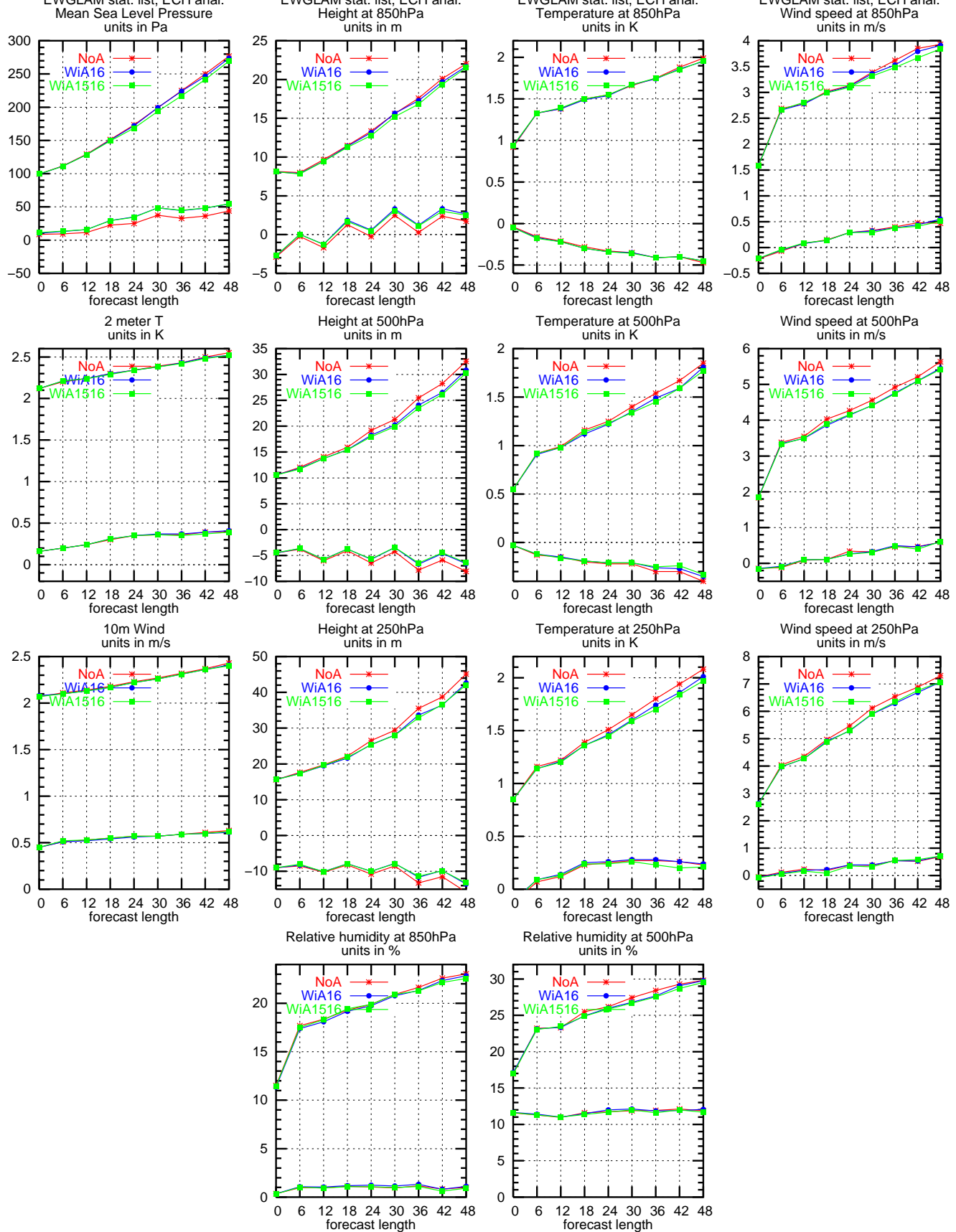


Figure 1: Obs-verification of results from November 2003. NoA is the run excluding AMSU-A data, WiA16 is the run including NOAA16 AMSU-A data only, and WiA1516 is the run including NOAA15 and NOAA16 AMSU-A data. EWGLAM station list.

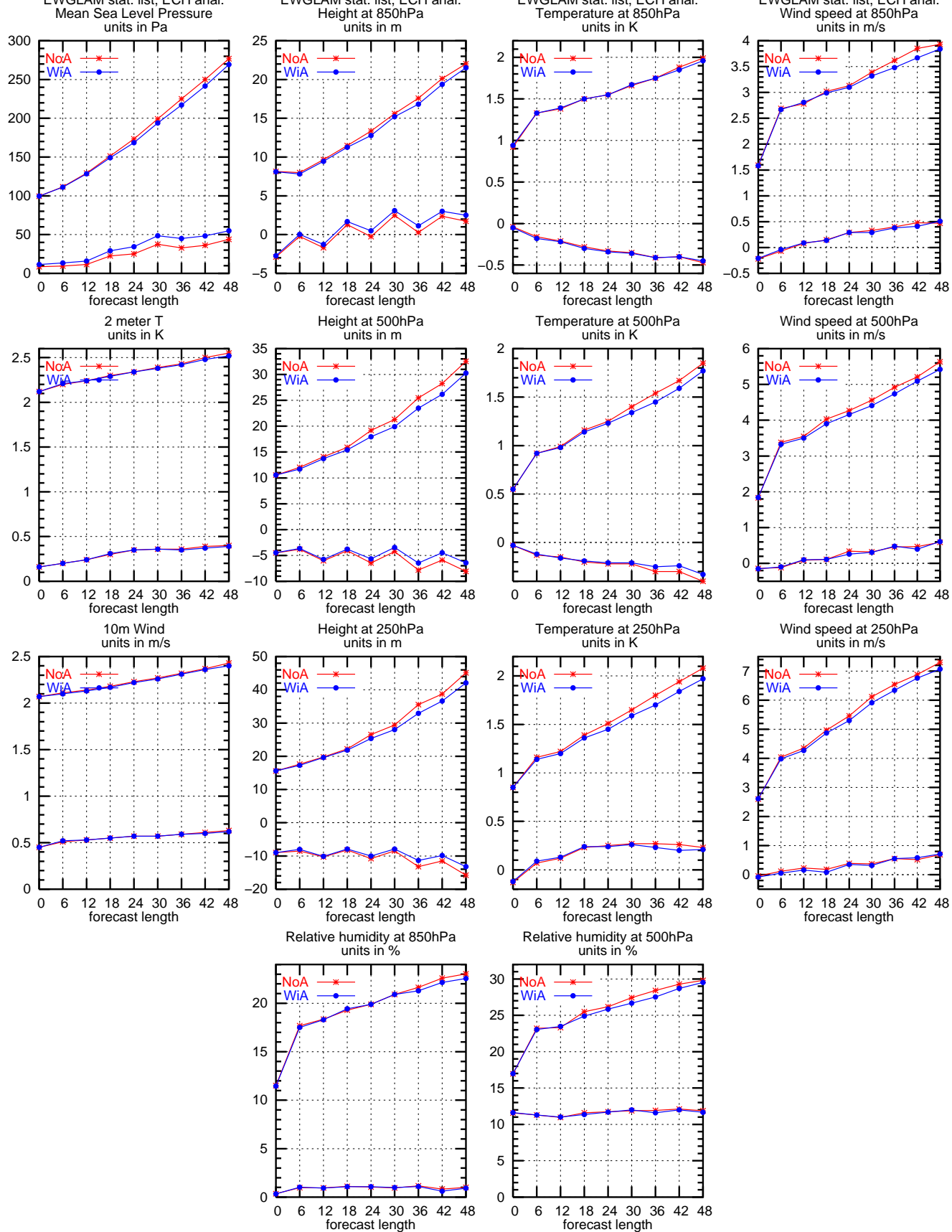


Figure 2: Obs-verification of results from November 2003. NoA is the run excluding AMSU-A data and WiA includes NOAA15 and NOAA16 AMSU-A data. EWGLAM station list.

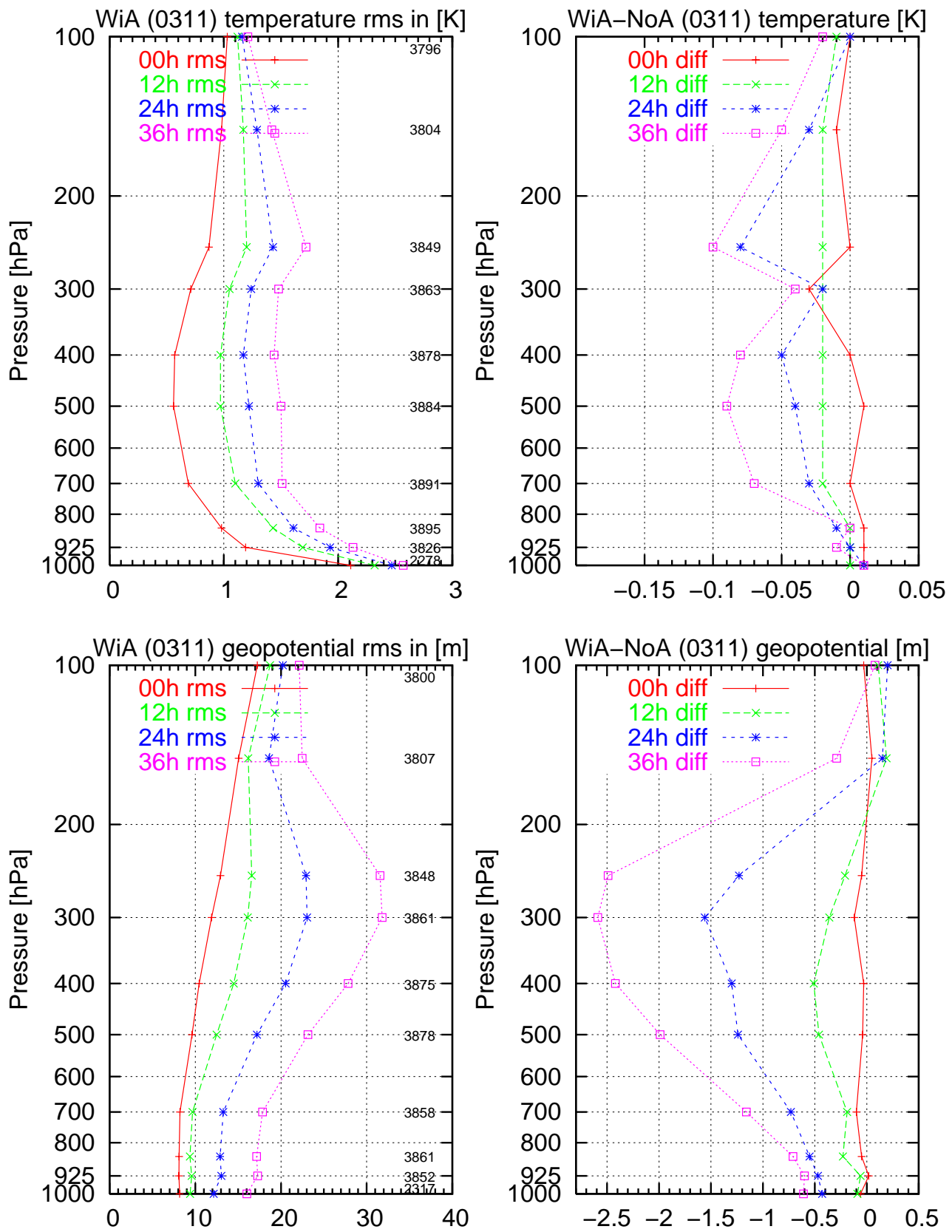


Figure 3: Rms scores for WiA1516 (left, denoted WiA in the labels) and differences in rms-scores between WiA and NoA (right) at analysis time and for the 12, 24 and 36 hour forecasts as a function of pressure in the November 2003 period. Top row is for temperature and bottom row is geopotential. Positive values in the difference plots where NoA has better rms-scores.

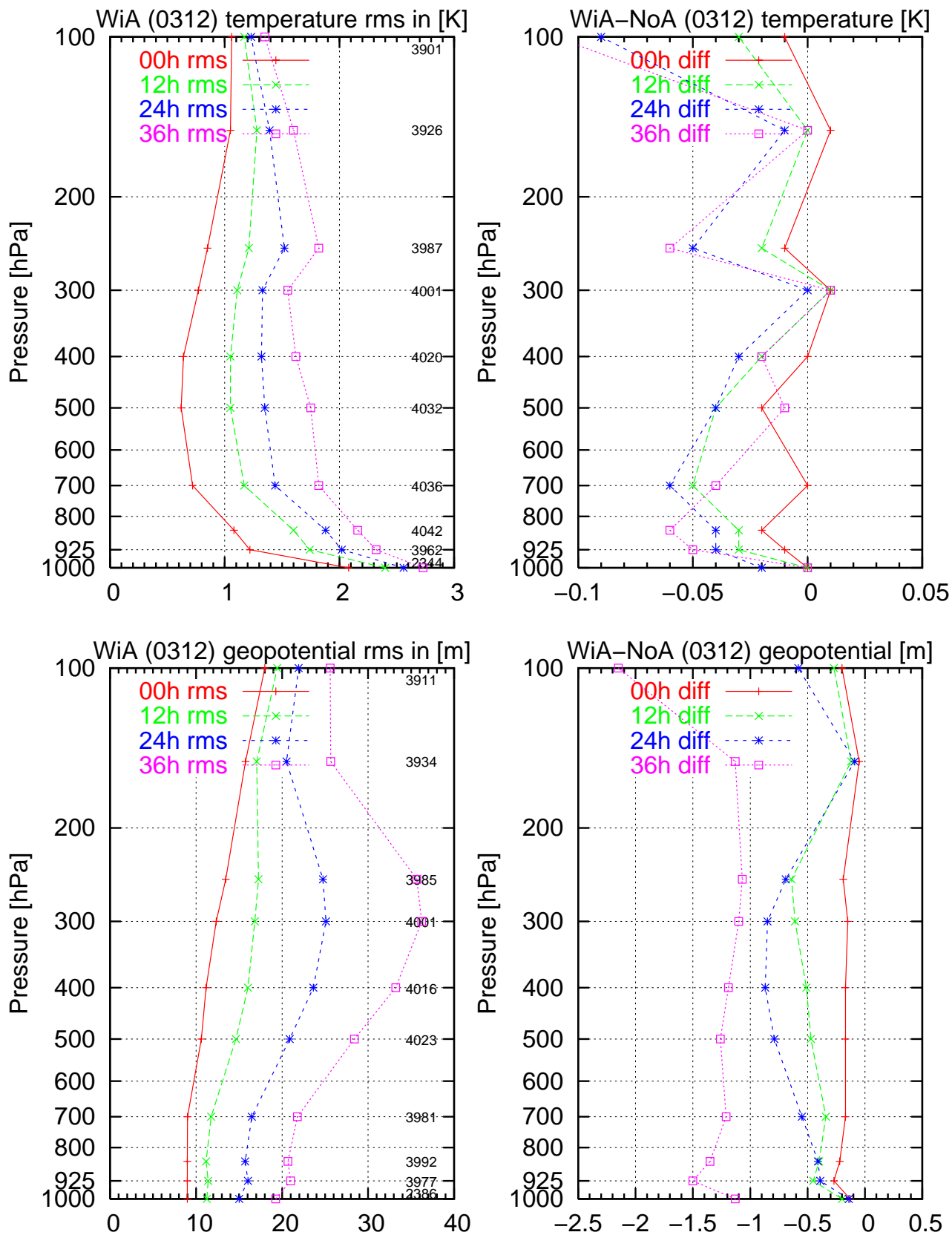


Figure 4: Rms scores for WiA (run using both NOAA15 and NOAA16 AMSU-A data, left) and differences in rms-scores between WiA and NoA (the run excluding NOAA data, right) at analysis time and for the 12, 24 and 36 hour forecasts as a function of pressure in the December 2003 period. Top row is for temperature and bottom row is geopotential. Positive values in the difference plots where NoA has better rms-scores.