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Brief summary of my thesis: Study of AMDAR data in NWP model ALADIN

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Thesis characteristic

Title: Study of AMDAR data in NWP model ALADIN
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Abstract: The impact of assimilation (using 3D-Var method) of aircraft measurements on forecasts of the numerical model ALADIN is studied in the present work. Methods of measuring several meteorological parameters by aircrafts and their recording to AMDAR message are shown. So called BLUE equation for production of an analysis (the best assessment of the state of atmosphere represented by a numerical model) is deduced. The equivalence between the BLUE equation and a minimization of the quadratic functional used by 3D-Var is shown. Essential steps of integrating meteorological measurements to assimilation procedure are outlined. The process of assimilation used in Czech Hydrometeorological Institute is shown and the results of aircraft measurements assimilation are presented.

Keywords: analysis, 3D-Var, AMDAR, asimilation

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Introduction

Original abstract of my diploma thesis is quite self explaining (page 2). Only shame is that the thesis is in czech. This paper is concerned only about setup of experiments, used verification methods and obtained results.

CHAPTER 1

Set experiments and verification methods

LAM model ALADIN was used for experiments. Experimental domain was "LACE". One step of assimilation cycle was produced by surface assimilation of 2 m temperature

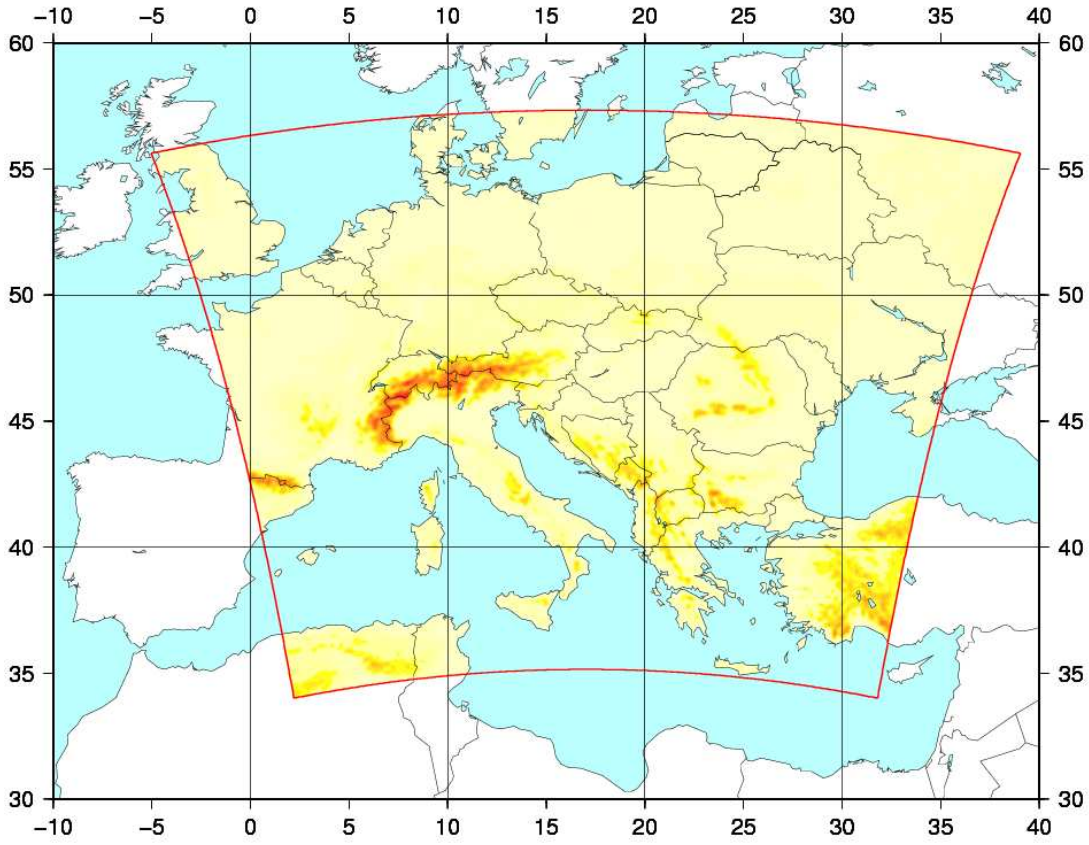

Figure 1.1: Experimental domain "LACE" with orography

2 m humidity (Surface Canari [1]) followed by spectral blending of ALADIN guess (6h prediction of previous run of ALADIN) and ARPEGE analysis, both valid to the same time. Spectral blending [2] is preceding 3D-VAR assimilation of upper air fields. Surface Canari, Blending and 3D-Var were repeating every 6 hour. Every 12 hour was produced forecast for 48 hours (00 UTC 12 UTC).

Experimental period was 25. 3. 2008 – 19. 4. 2008. There was set 4 experiments, 3 testing, one reference. Names are:

DREF reference experiment using observations from SYNOP, TEMP reports for 3D-Var assimilation. Assimilation window is set to 3 hours (±1.5 h). Type of observation will be discussed later.

DT01 experiment uses observations from AMDAR, SYNOP, TEMP reports. Assimilation window was also 3 hours. So this experiment has the same setup as reference but uses AMDAR observations.

DT00 also uses AMDAR, SYNOP, TEMP reports. But assimilation window is only 1 hour (±0.5 h). This setup has better utilizations of observations in time than **DT01** but less of observations due to shorter assimilation window.

DT04 this experiment uses only AMDAR and SYNOP reports with 3 hour assimilation window. It is simulating situation where TEMP reports will not be available.

Type of observation used from SYNOP, TEMP, AMDAR reports was:

SYNOP only geopotential was used

TEMP temperature, u,v components of wind, specific humidity were used

AMDAR temperature, u,v components of wind were used

Numbers of observations from AMDAR reports vary during day. Minimum is 00 UTC and maximum around midday as shown on figure 1.2. There you can see that amount of observation suddenly increased after 1 April. This problem was probably caused by technical problems of observation delivery. You can notice that number of active observation was around 3000 during day hour and around 100 values at 00 UTC on figure 1.2, amount of observation was almost the same for every variable in experiments **DT01**, **DT04**, **DREF** only experiment **DT00** has less of observation from AMDAR reports, approximately 3 times less. This figure also shows decreased standard deviation after analysis.

1.1 Verification methods

Objective verification was made on geopotential, relative humidity, temperature, wind speed and direction. First day of verification period was left to "warm up" of 3D-Var.

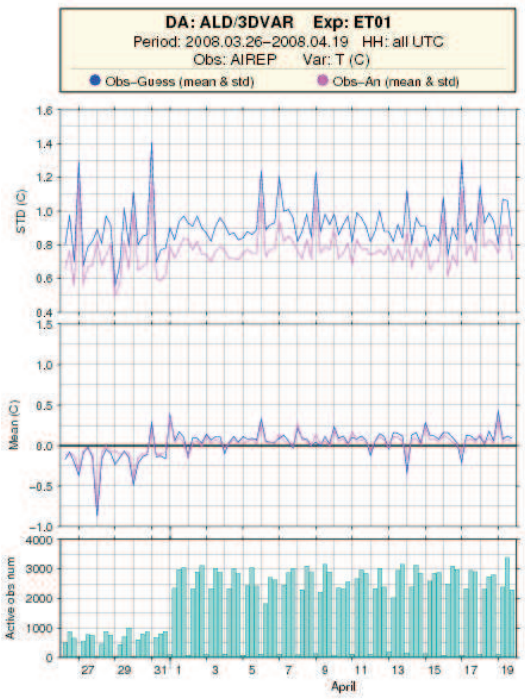

Figure 1.2: Shows numbers of active observations of temperature from AMDAR reports, mean difference of temperature between observations and guess (surface Canari and Blending) and mean difference of temperature between observations and analysis. Figure also shows standard deviation of mean differences

There was two main verification method. First: ALADIN forecast was compared with observation from TEMP, SYNOP reports. Second: comparison of ALADIN forecast of upper air fields with IFS (ECMWF) analysis interpolated to ALADIN domain (only in 00 UTC and 12 UTC). Upper air fields are used for verification because ALADIN and IFS has completely different surface scheme. For both methods were computed $\overline{RMSE}$ - mean of root mean square error over verification period, $\overline{BIAS}$ mean deviation of model to observation over verification period and confidence intervals as kind of significance test.

$$\overline{RMSE} = \frac{1}{Na}\sum_{j=1}^{Na}\left[\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(F_i - O_i\right)^2}\right]_j . \tag{1.1}$$

$$\overline{BIAS} = \frac{1}{Na\,N}\sum_{j=1}^{Na}\sum_{i=1}^{N}\left(F_{i,j} - O_{i,j}\right). \tag{1.2}$$

Where O indicates observation of verified variable, F is model forecast valid to the same time as observation interpolated to place of observation. i denote index of observation point. N is number of observation valid in the same time. Na is number of days

of verification, j is index of verification day. $\overline{RMSE}$, $\overline{BIAS}$ were computed for 15 vertical levels and 8 time ranges.

1.1.1 Confidence intervals

Confidence intervals were constructed for mean value of difference between test and reference experiment on confidence level 95 %. Construction of confidence intervals is equivalent to T-test of mean value. Difference of test and reference experiment is denoted x. Estimate of mean value is $\overline{x}$ and mean value is denoted μ. Nul hypothesis is H_0: $\mu = 0$. Random variable τ will be evaluated. τ has Student distribution where degree of freedom is n-1, n - number of elements used to evaluate estimate of mean value, [3].

$$\tau = \frac{\overline{x} - \mu}{s}\sqrt{n} \ . \tag{1.3}$$

Sample standard deviation of x is denoted s (note: $s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$). Hypothesis H_0 is refused when $|\tau| > t_p$, where t_p denotes relevant quantile of Student distribution. Confidence level 95 % is reached when $t_{0.975}$. Hypothesis is refused when:

$$\begin{aligned} \text{for} \qquad \overline{x} > 0 \qquad &\Longrightarrow \qquad \frac{\overline{x} - 0}{s}\sqrt{n} > t_{0.975} \ , \\ &\text{or} \qquad \overline{x} - t_{0.975}\frac{s}{\sqrt{n}} > 0 \ . \end{aligned}$$

Value of expression $\overline{x} - t_{0.975}\frac{s}{\sqrt{n}}$ is also nearer bound of confidence interval to zero for positive $\overline{x}$. Hypothesis $\mu = 0$ is refused if estimate of mean value with its confidence interval lies above zero. So mean value μ is positive on confidence level 95 %.

$$\begin{aligned} \text{for} \qquad \overline{x} < 0 \qquad &\Longrightarrow \qquad \frac{\overline{x} - 0}{s}\sqrt{n} < -t_{0.975} \ , \\ &\text{or} \qquad \overline{x} + t_{0.975}\frac{s}{\sqrt{n}} < 0 \ . \end{aligned}$$

Again value of expression $\overline{x} + t_{0.975}\frac{s}{\sqrt{n}}$ is nearer bound of confidence interval to zero for negative $\overline{x}$. Now hypothesis is refused when $\overline{x}$ and its confidence interval is less than zero. So μ is negative on confidence level 95 %. With this test is shown which time ranges and pressure level is significant improvement or degradation. It will be shown by tables.

CHAPTER 2

Obtained results

Verification will be presented by vertical cross-section of difference between test and reference experiment for verified variable. Light red areas in figures are negative. Because interval of isolines aren't denoted in figures:

- geopotential interval of isolines is 0.2 dynamical meter [1],
- relative humidity isolines are every 1 %,
- temperature isolines interval is 0.1 K,
- wind speed has isoline every 0.2 m/s .

Percentage cross-section has isolines every 0.5 %. Table of significance test is attached to figures. Green cells with + sign denote significant improvement. Red cells with - sign denote significant degradation. Cell without color no significant result.

Experiment reminder:

DREF reference experiment, window 3 hours (±1.5 h), SYNOP, TEMP,

DT01 AMDAR, SYNOP, TEMP, window 3 hours,

DT00 AMDAR, SYNOP, TEMP, window 1 hour,

DT04 AMDAR, SYNOP, window 3 hours.

As could be expected night (00 UTC) start of forecasts of all experiment had consistent result with reference (there is no visual prove attached). Only 12 UTC start was some changes.

2.1 Experiment DT01

Summary: verification against observation from TEMP reports shows rather negative results on the other hand verification against analysis from ECMWF is more positive. Both verification show significantly degradated ALADIN zero hour forecasts of geopotential between 30–150 hPa, and improved forecasts in lower troposphere. For relative humidity wasn't detect bigger influence of observation from AMDAR reports. $\overline{RMSE}$ of temperature is improved against analysis from ECMWF, maximal improvement is 4.5 % but against observation from TEMP reports there is degradation about 2 %. Wind speed has also contradictory results. This contradictory results could be caused by dependence of reference experiment analysis (and forecast) on observation from TEMP reports. It is assimilating only TEMP reports so it might be nearer to TEMP obseration in prediction at least at 0 hour. Improvement of wind speed is in maximum 7 % when verified against ECMWF analysis.

Verification of 00 UTC and 12 UTC starts of forecast together gets the same structure of cross-section as start at 12 UTC. Amplitude of changes is smaller with less significant points.

[1] In following text will be expressed dyn. m and relation to SI units is: 1 dyn. m= $\frac{1}{10}$ m^2s^{-2}.

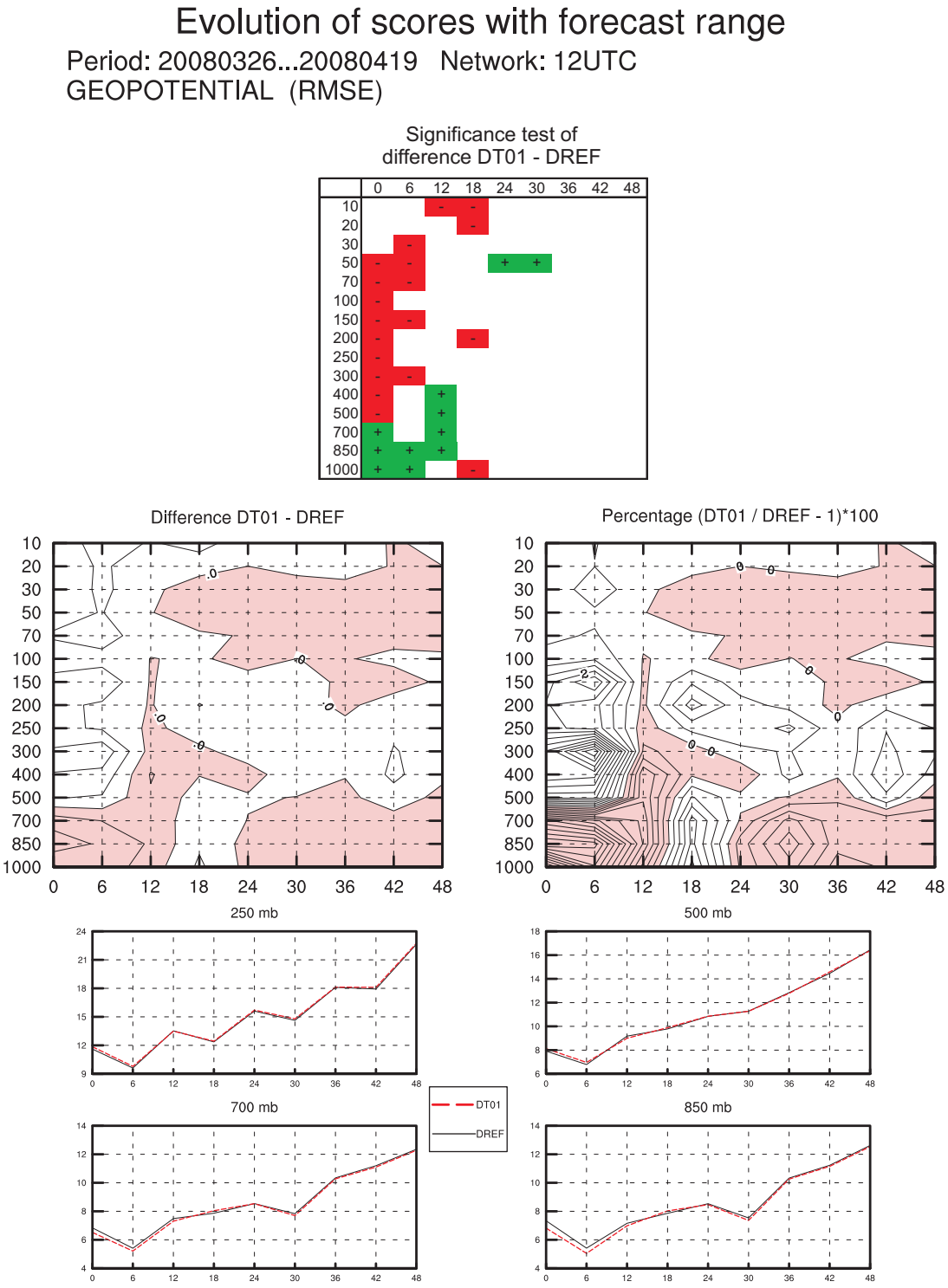

Figure 2.1: Verification $\overline{RMSE}$ of geopotential against observation from TEMP reports for experiment **DT01**. Start of forecast was 12 UTC.

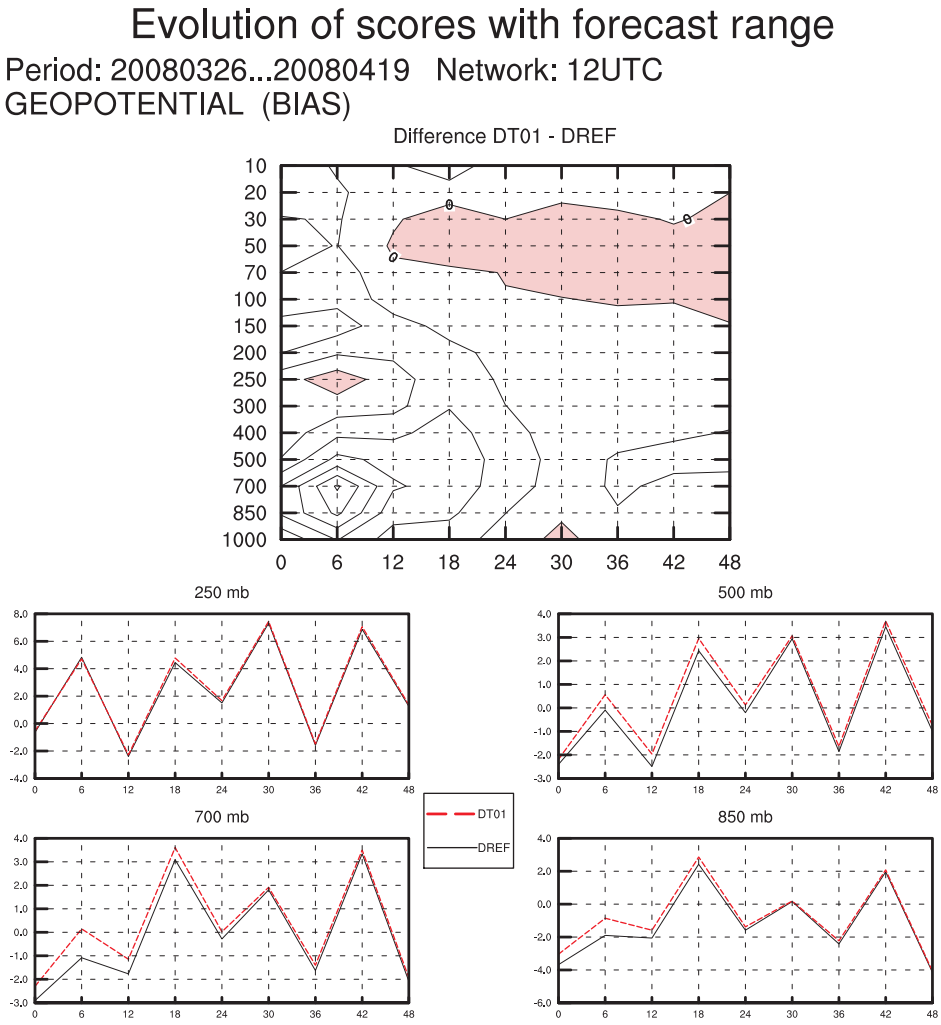

Figure 2.2: Verification of systematic error of geopotential for experiment **DT01** against observation from TEMP. Start 12 UTC.

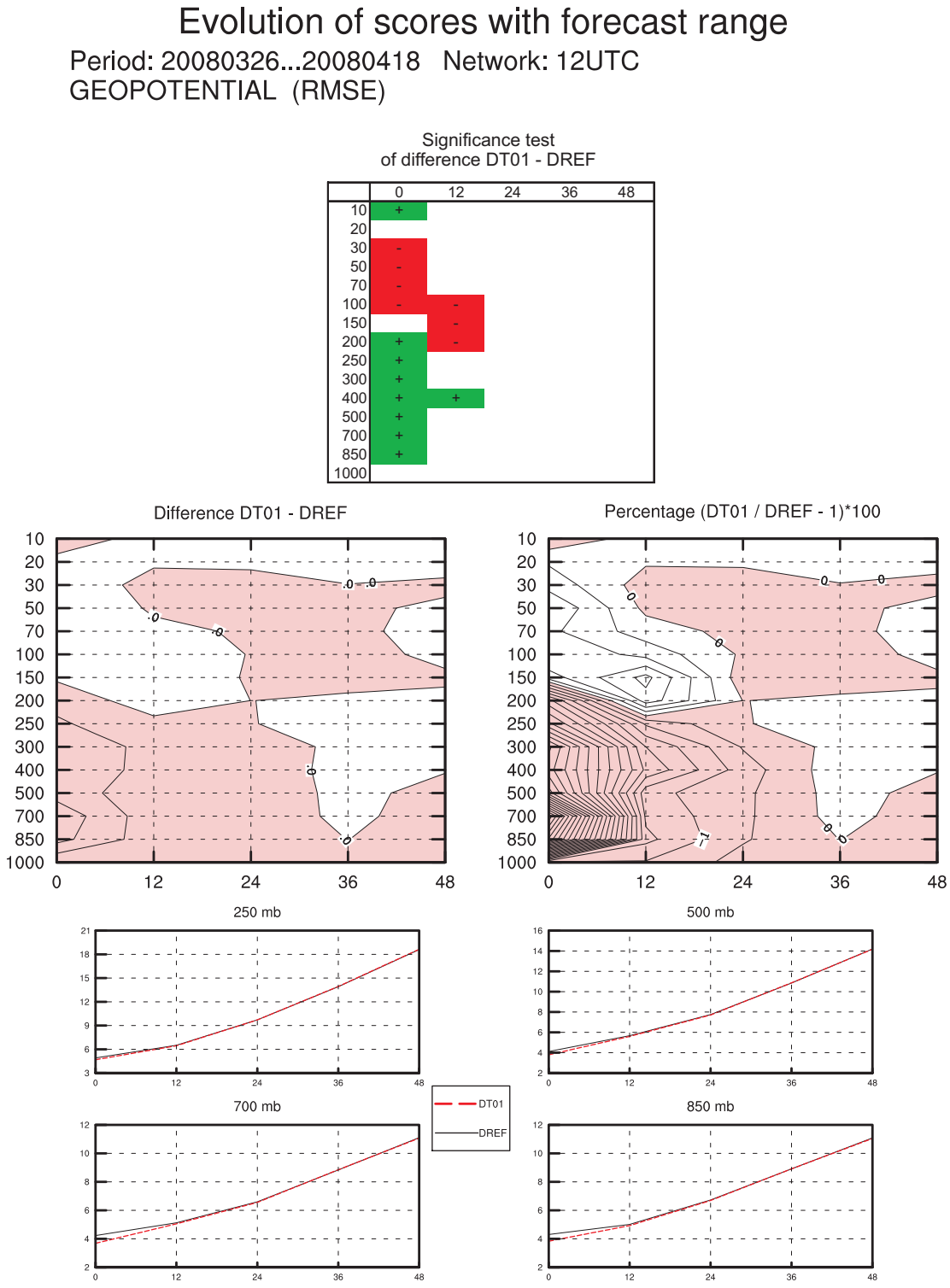

Figure 2.3: Verification $\overline{RMSE}$ geopotential against analysis from ECMWF for experiment **DT01**. Start of forecast - 12 UTC.

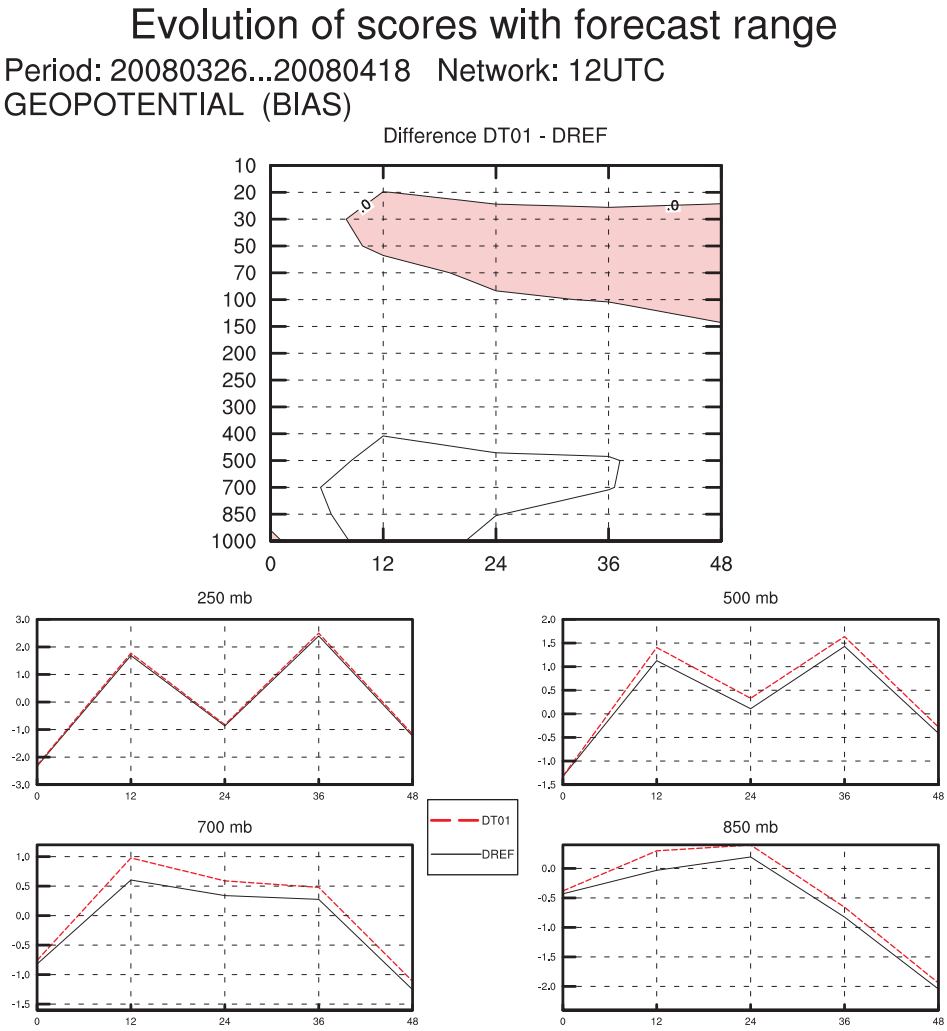

Figure 2.4: Verification of systematic error of geopotential for experiment **DT01** against analysis from ECMWF. Forecast start is 12 UTC.

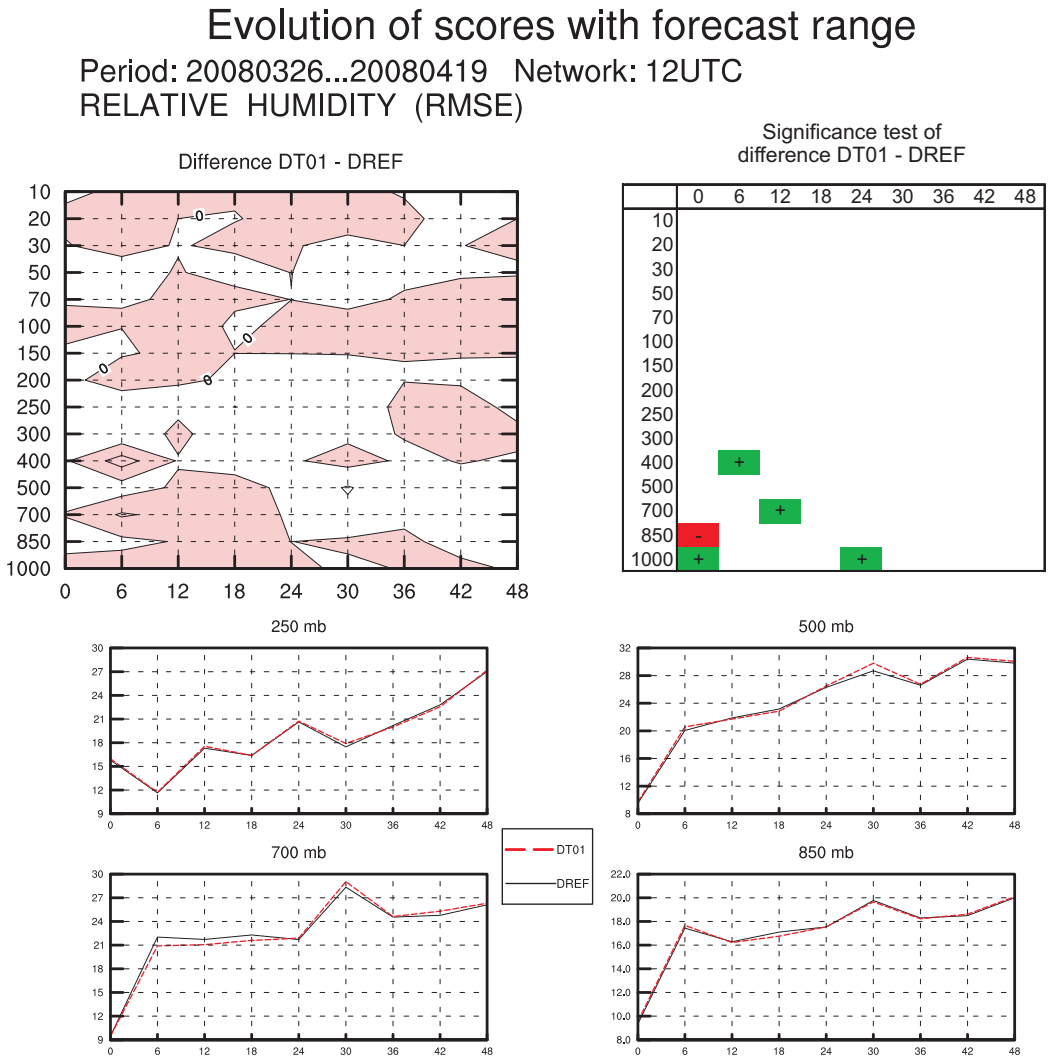

Figure 2.5: Verification $\overline{RMSE}$ of relative humidity for experiment **DT01** against observation from TEMP reports. Start of forecasts 12 UTC.

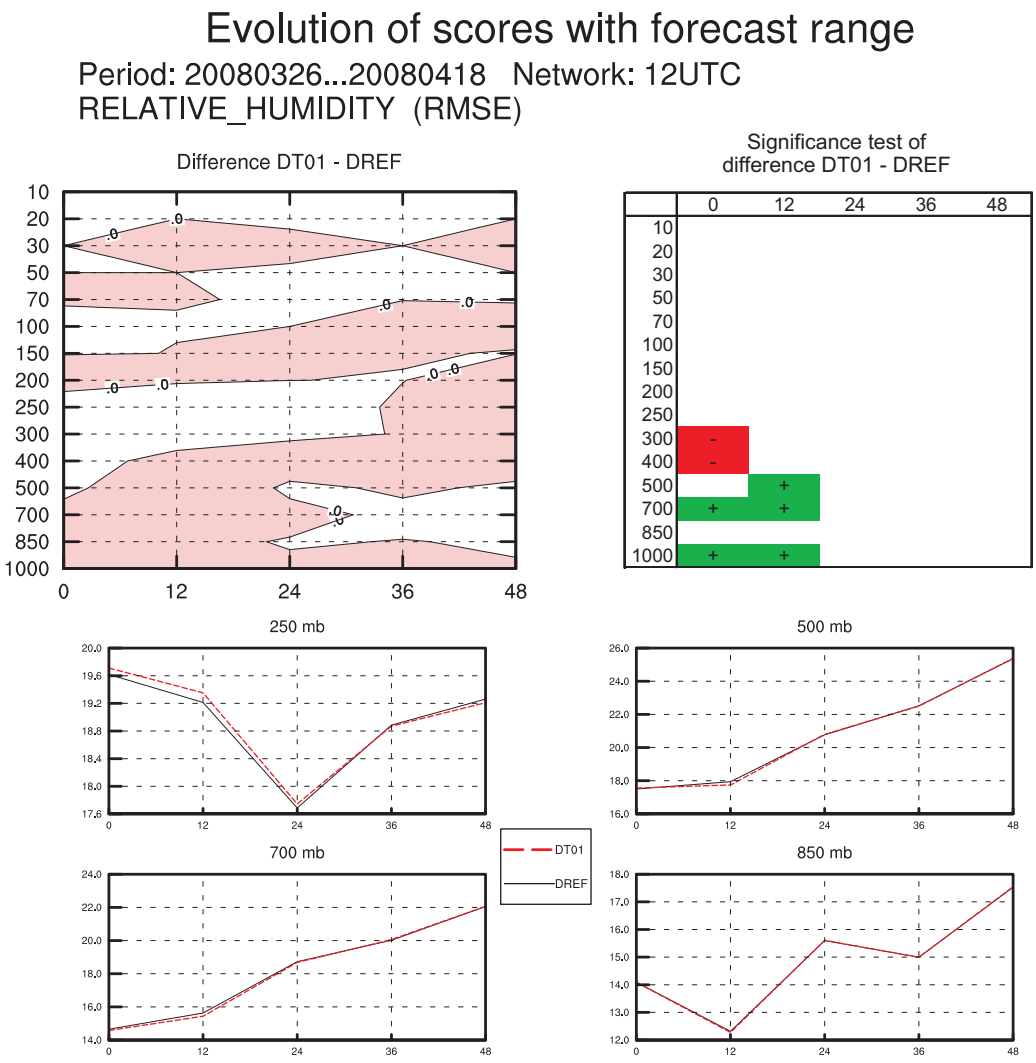

Figure 2.6: Verification $\overline{RMSE}$ of relative humidity for experiment **DT01** against analysis from ECMWF. Start 12 UTC.

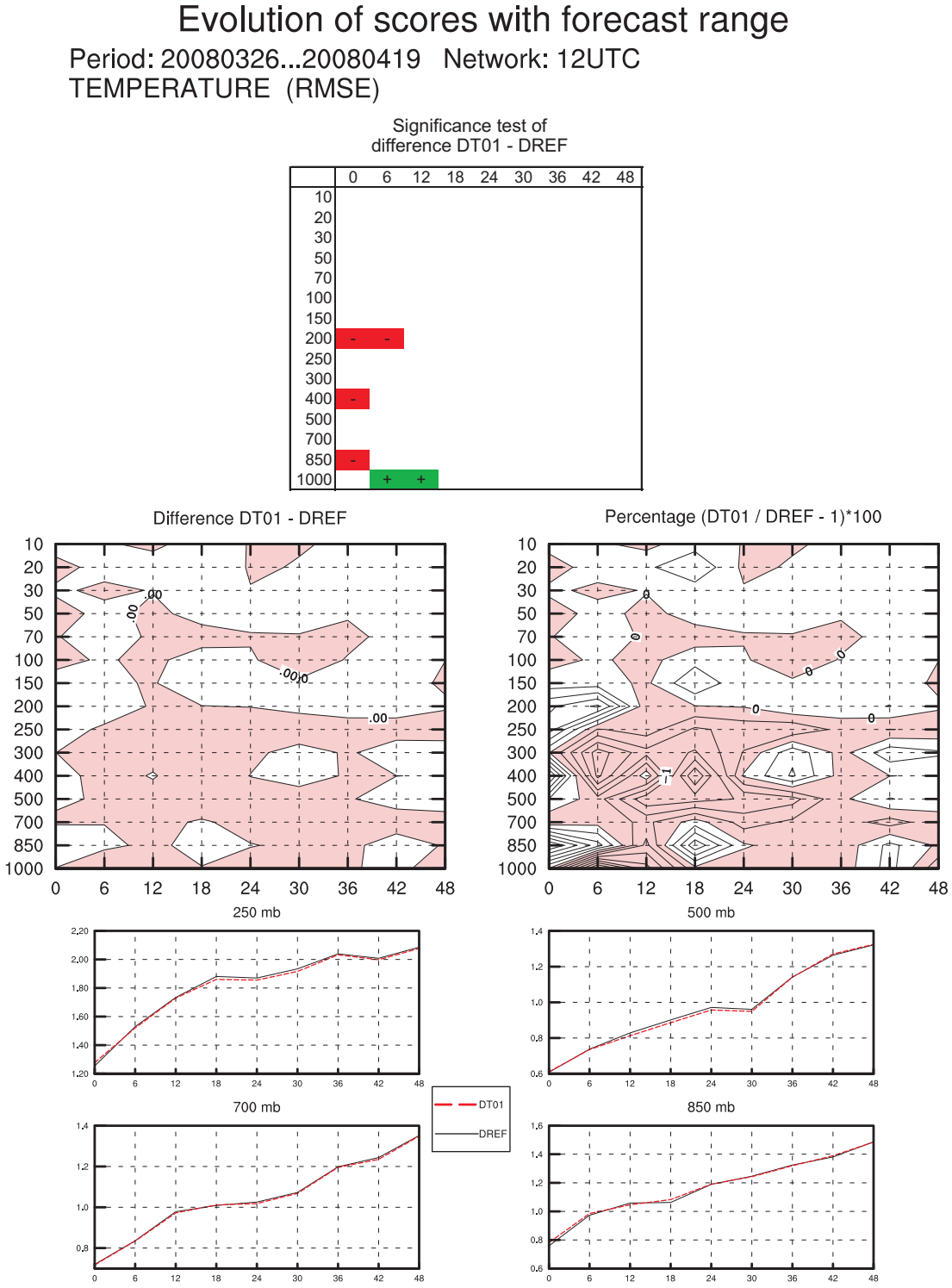

Figure 2.7: Verification $\overline{RMSE}$ of temperature for experiment **DT01** against observation from TEMP reports. START 12 UTC.

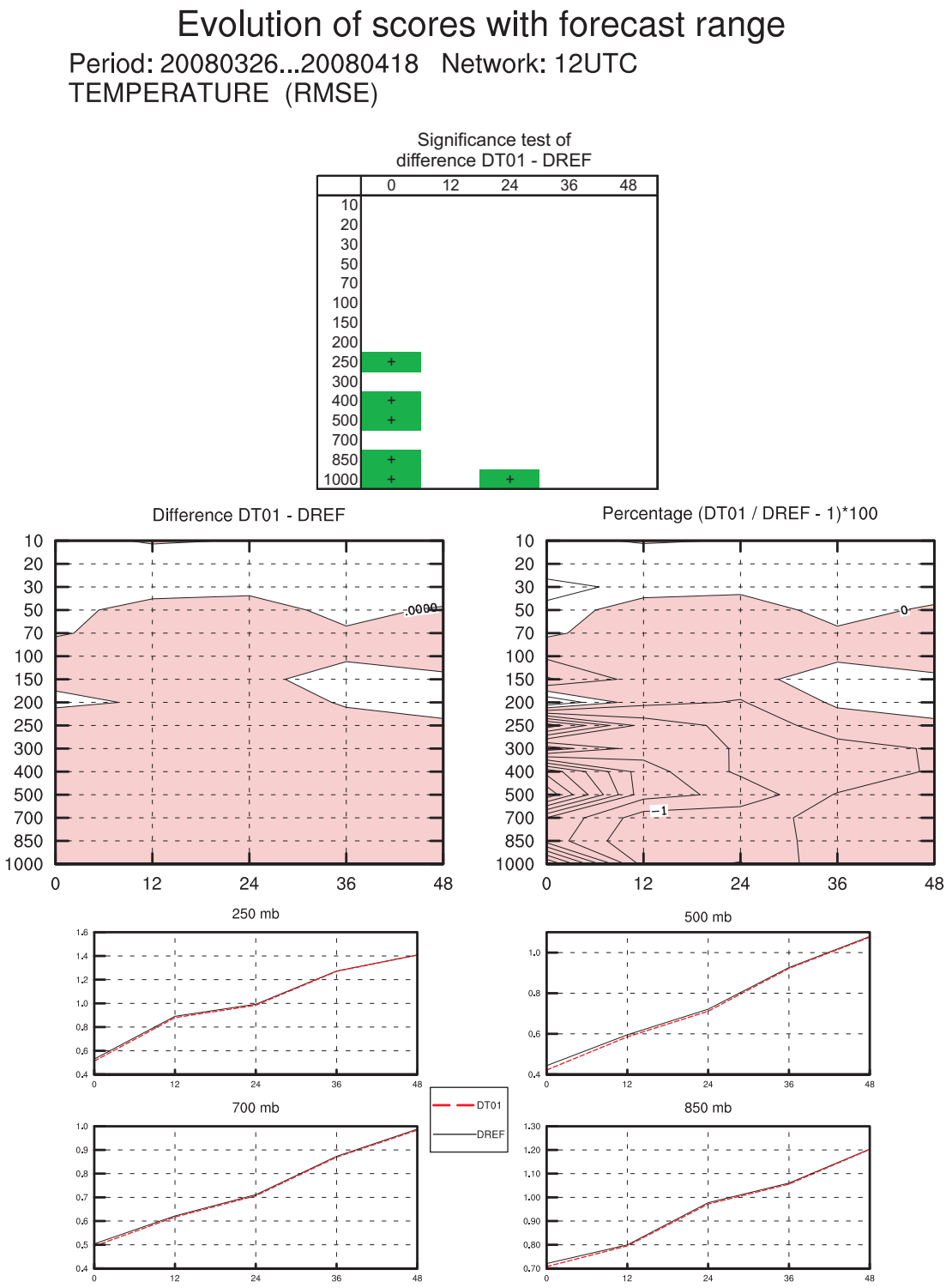

Figure 2.8: Verification $\overline{RMSE}$ of temperature for experiment **DT01** against analysis from ECMWF. 12 UTC.

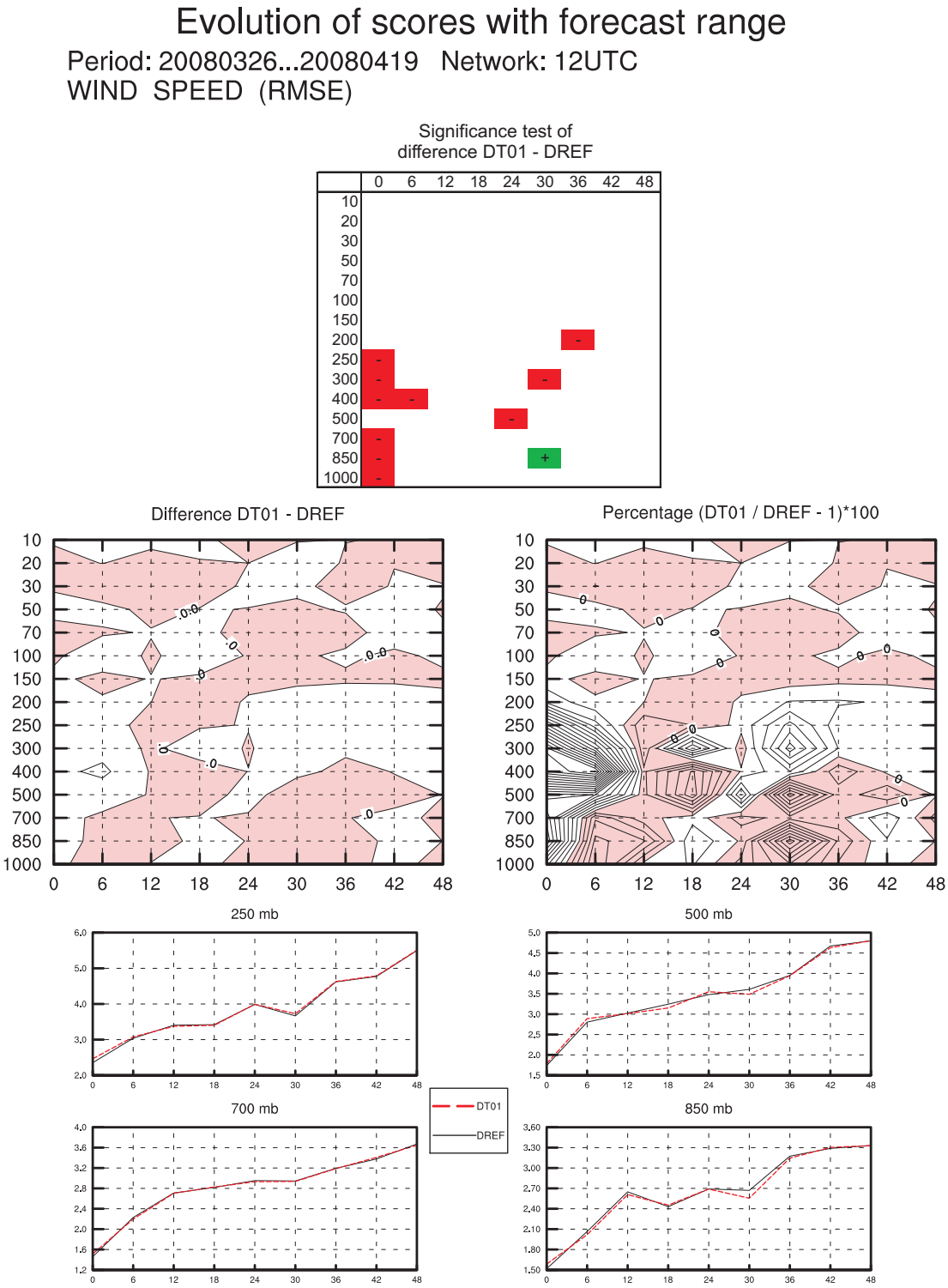

Figure 2.9: Verification $\overline{RMSE}$ of wind speed for experiment **DT01** against observation from TEMP reports. Forecast start is 12 UTC.

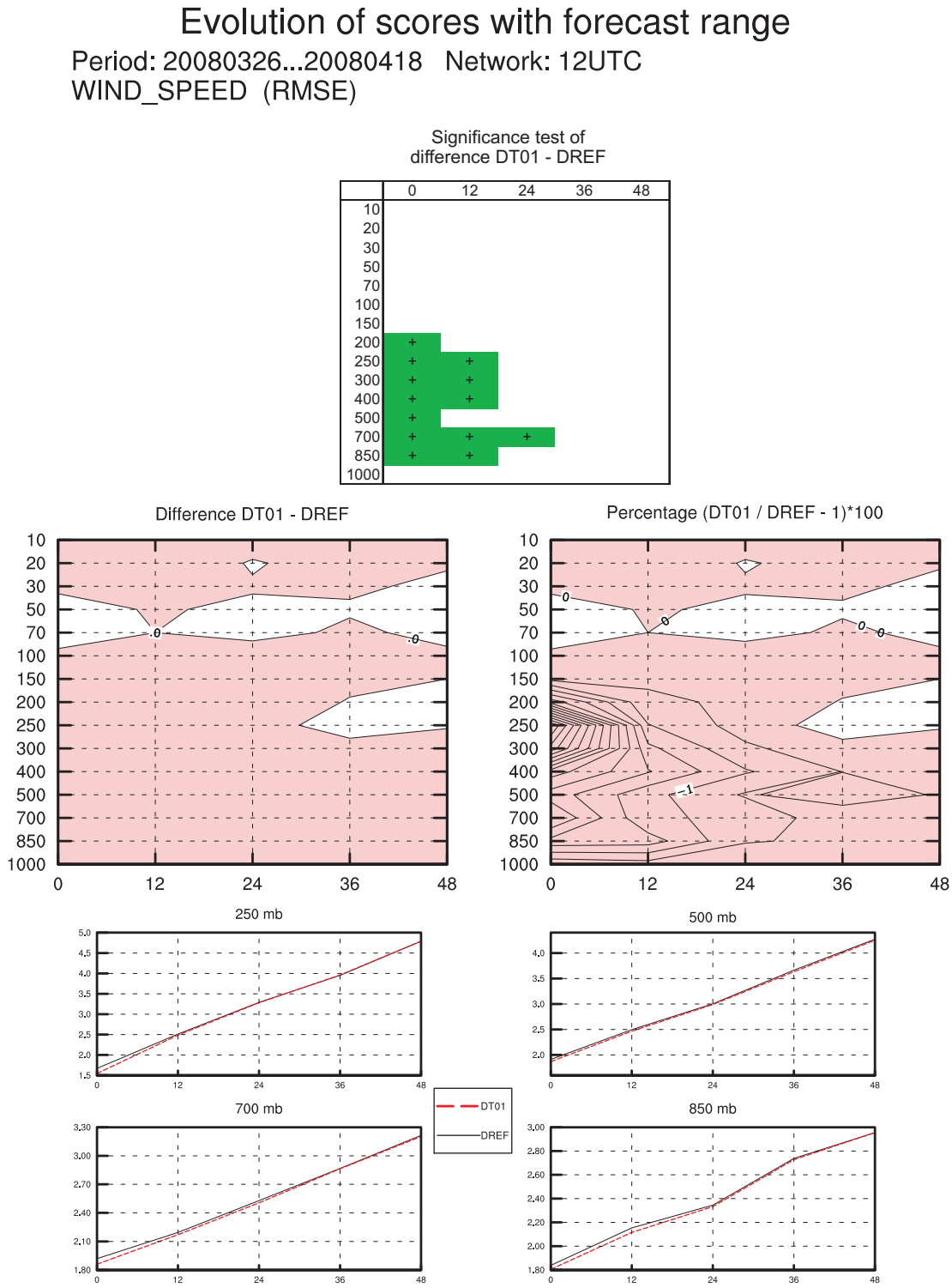

Figure 2.10: Verification $\overline{RMSE}$ of wind speed for experiment **DT01** against analysis from ECMWF. Start of forecast is 12 UTC.

2.2 Experiment DT00

Summary: Experiment **DT00** has smaller amplitude of changes and less statistically significant points than **DT01**. But if we compare numbers of significantly improved and degradated points we find out that **DT00** has better ratio. **DT00** has increased number of statistically significant points in verification of $\overline{RMSE}$ of wind speed against analysis from ECMWF with comparison **DT01**. This is probably due to better time location of observations.

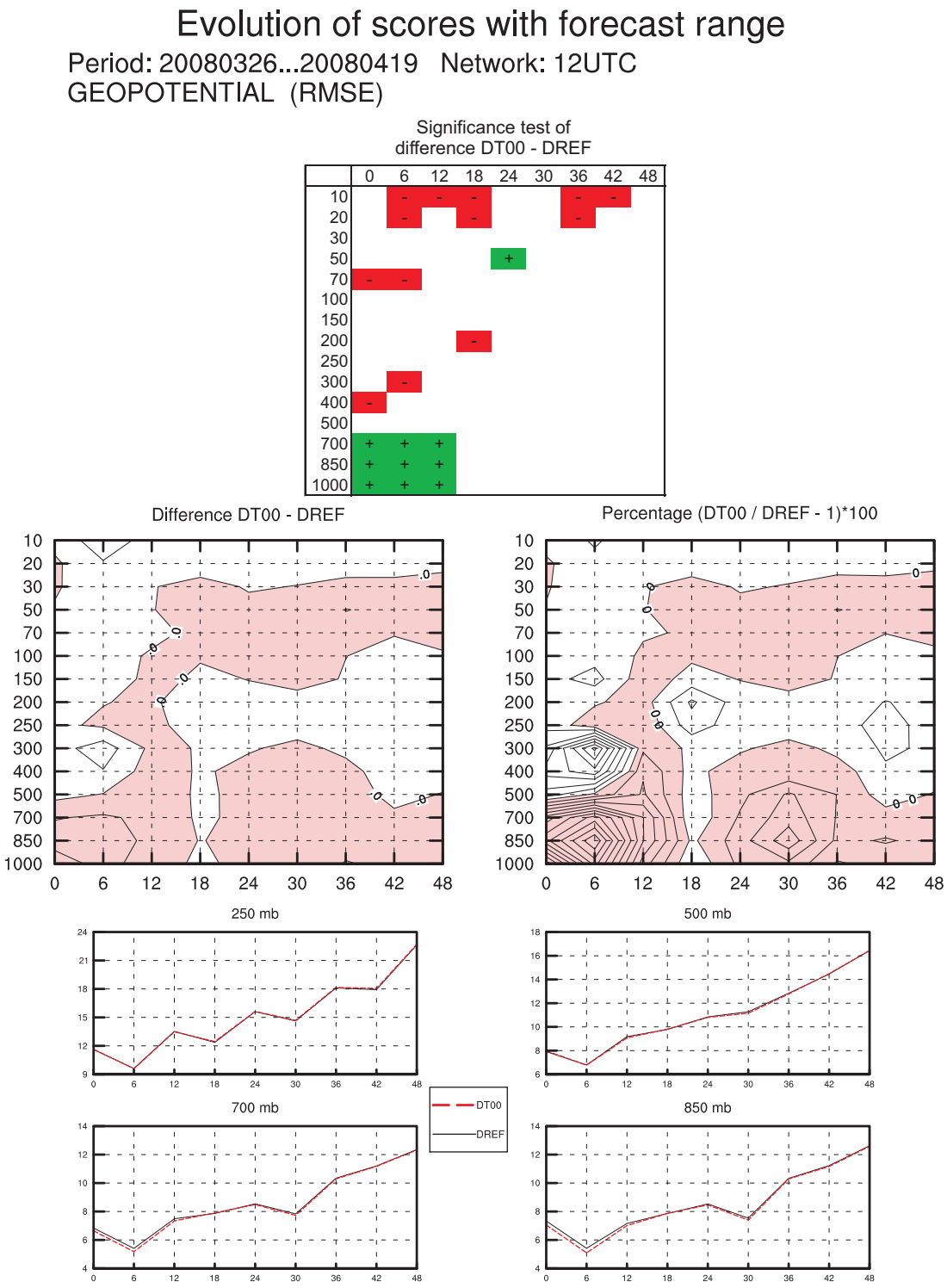

Figure 2.11: Verification $\overline{RMSE}$ of geopotential for experiment **DT00** against observation from TEMP reports. Start 12 UTC

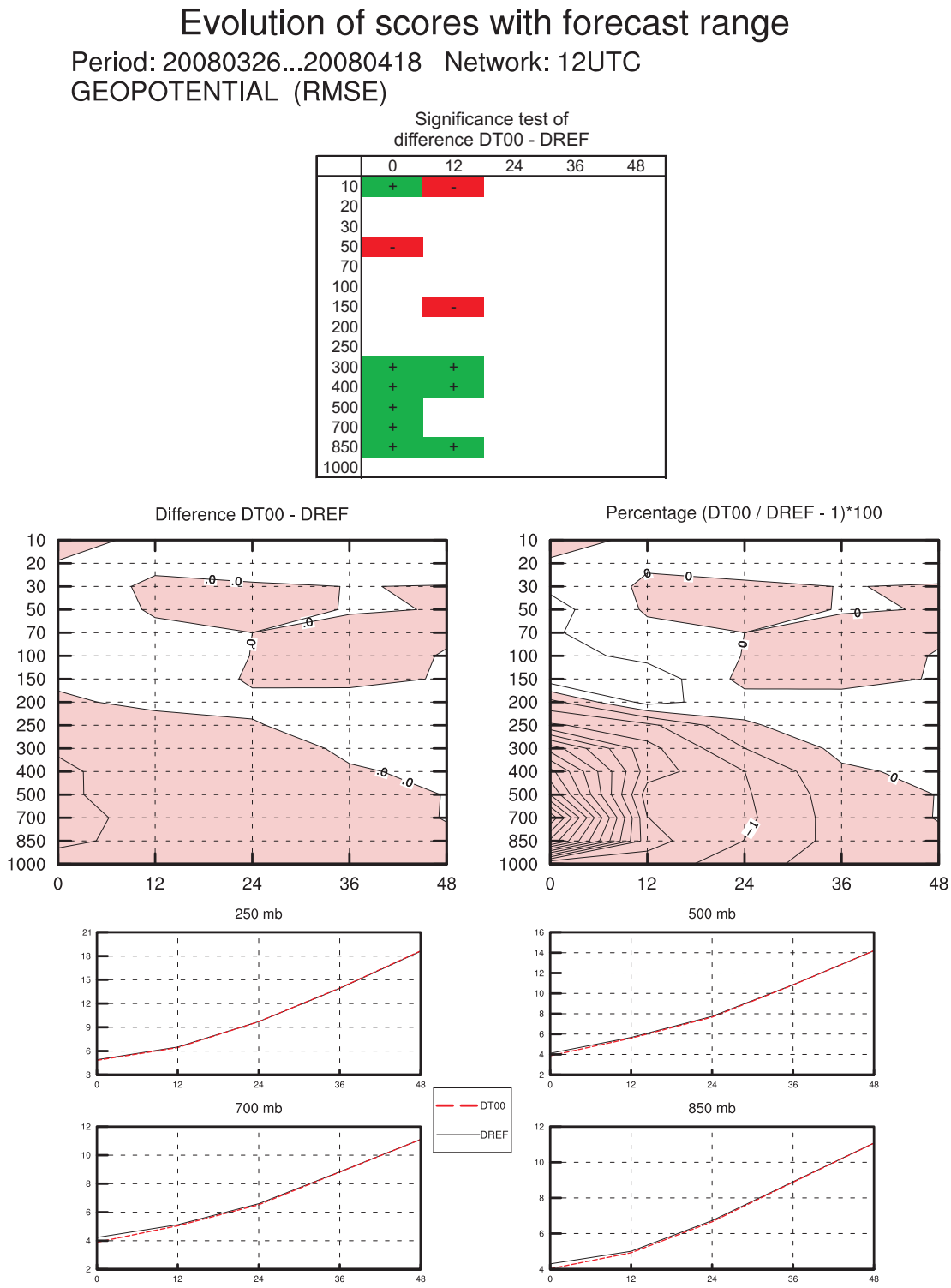

Figure 2.12: Verification $\overline{RMSE}$ of geopotential against analysis from ECMWF for experiment **DT00**. Start 12 UTC.

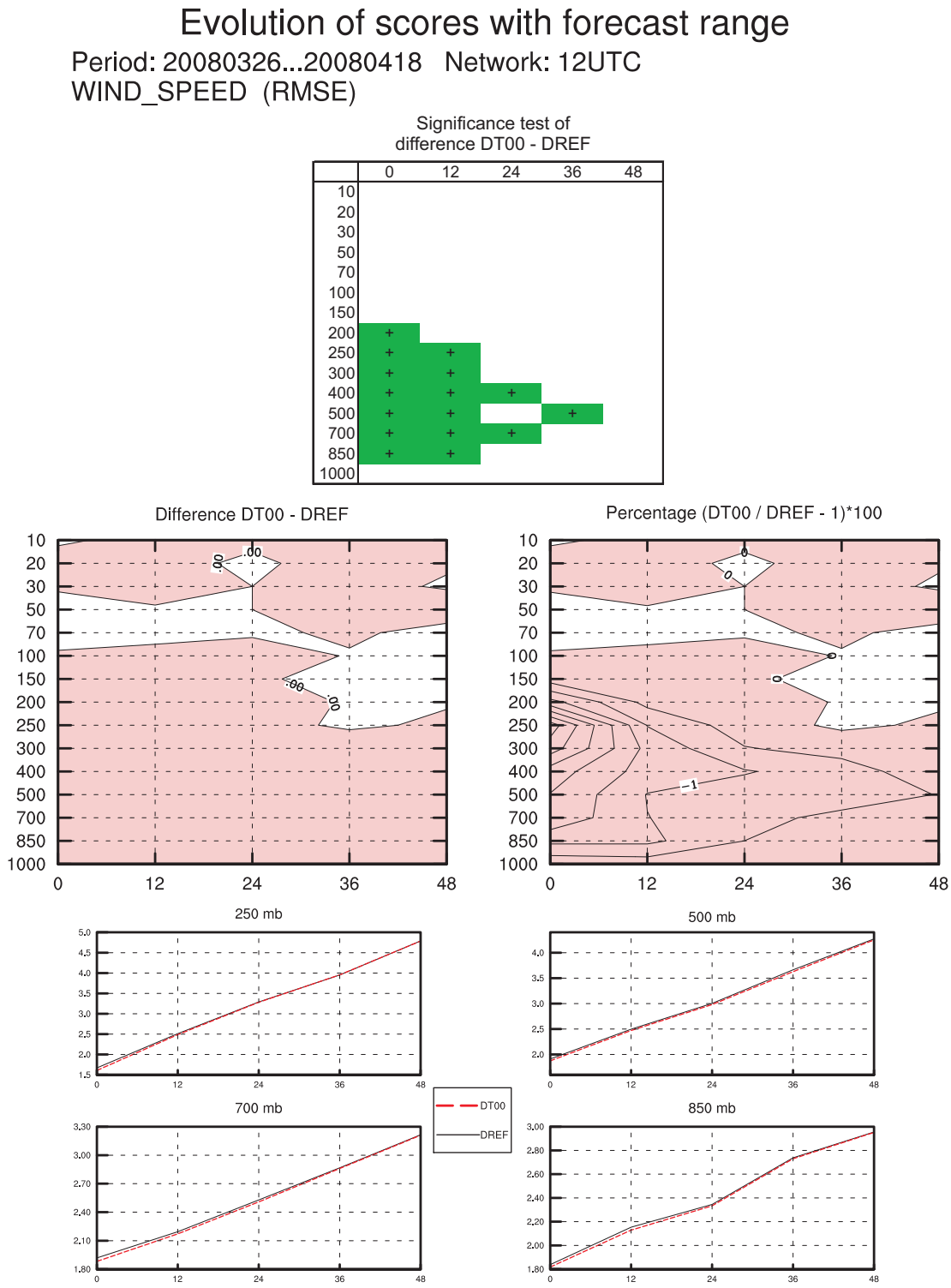

Figure 2.13: Verification $\overline{RMSE}$ of wind speed for experiment **DT00** against analysis ECMWF. Start 12 UTC.

2.3 Experiment DT04

This experiment is simulating situation when observation from TEMP reports are not available. Start of forecast at 00 UTC is almost ALADIN without 3D-Var because of a few observation from AMDAR reports (proximately 100 values). Results show mainly degradation as was expected, see figure 2.14, 2.15. Only figure 2.15 shows improvement of wind speed through all time ranges when verified against ECMWF analysis. This improvement shows that ALADIN without assimilation could have better results in high atmosphere against ECMWF analysis.

Forecast starting at 12 UTC has degradation almost in all statistically significant points when verified against observation from TEMP reports. Verification against ECMWF analysis shows that wind speed has improvement. Assimilation of observation from TEMP reports could not be completely substitute by observation from AMDAR reports for rest of verified variables.

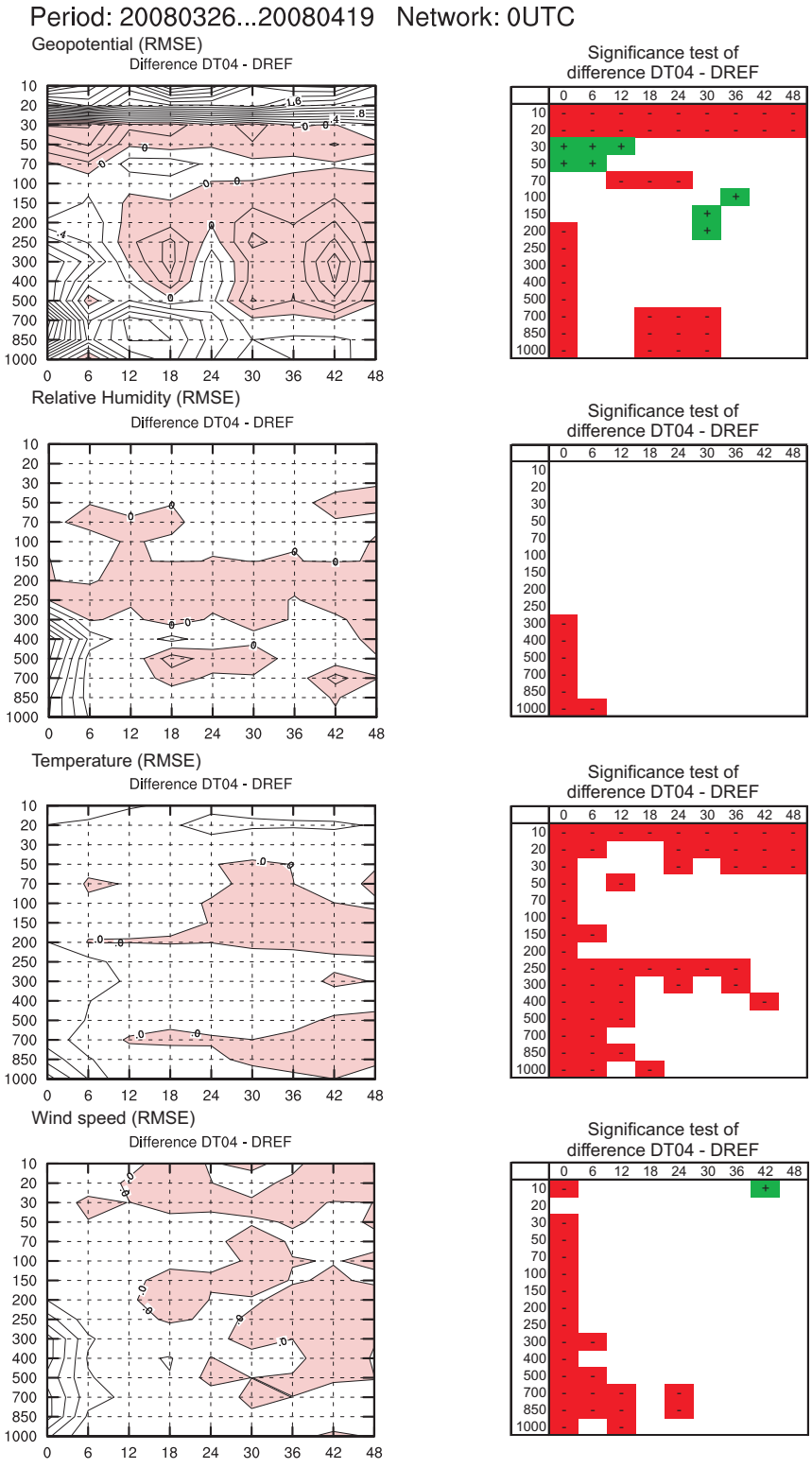

Figure 2.14: Verification of $\overline{RMSE}$ of all verified variables against observation from TEMP reports for experiment **DT04**. Start of forecasts is 00 UTC.

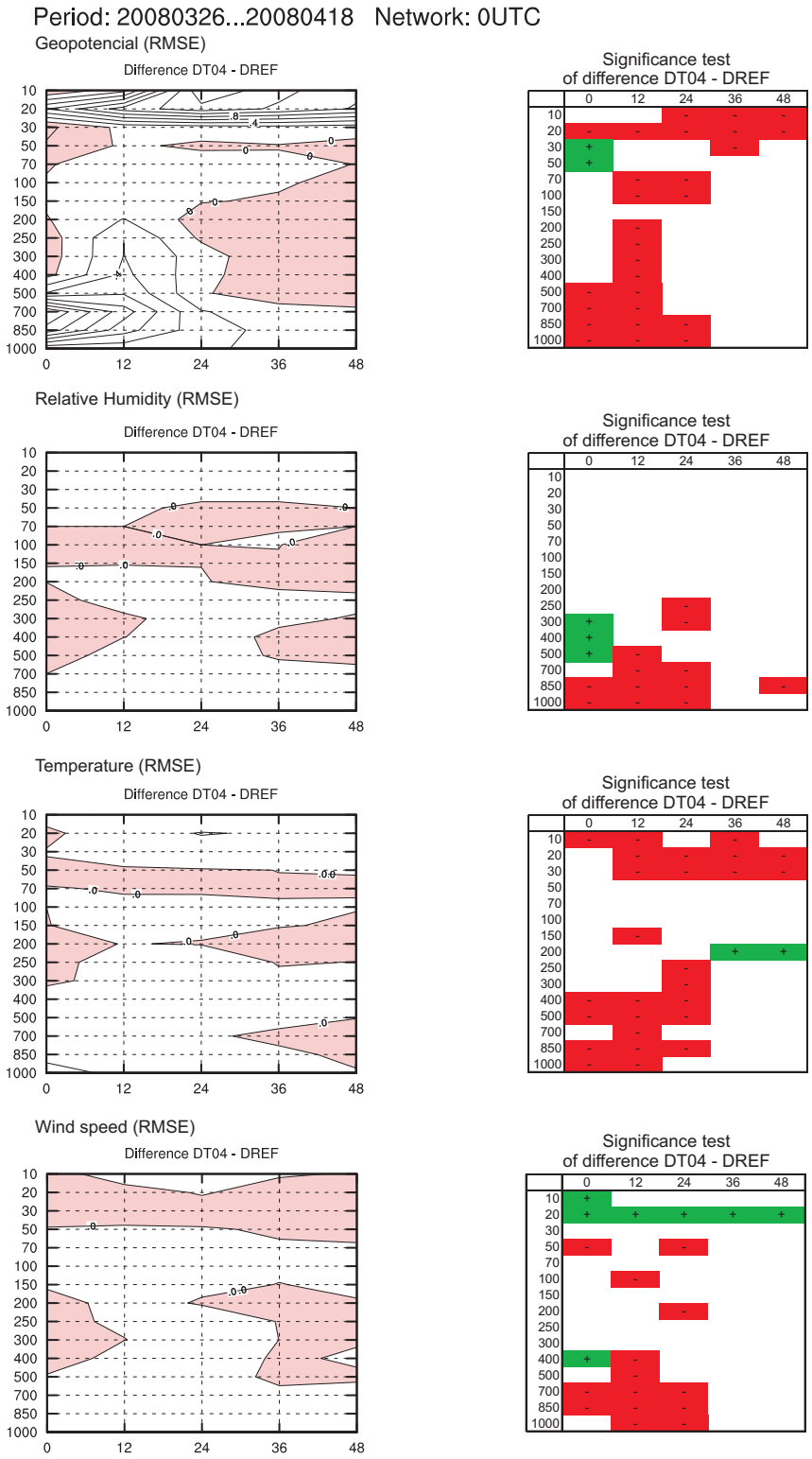

Figure 2.15: Verification of $\overline{RMSE}$ of all verified variables against analysis from ECMWF for experiment **DT04**. Start of forecasts is 00 UTC.

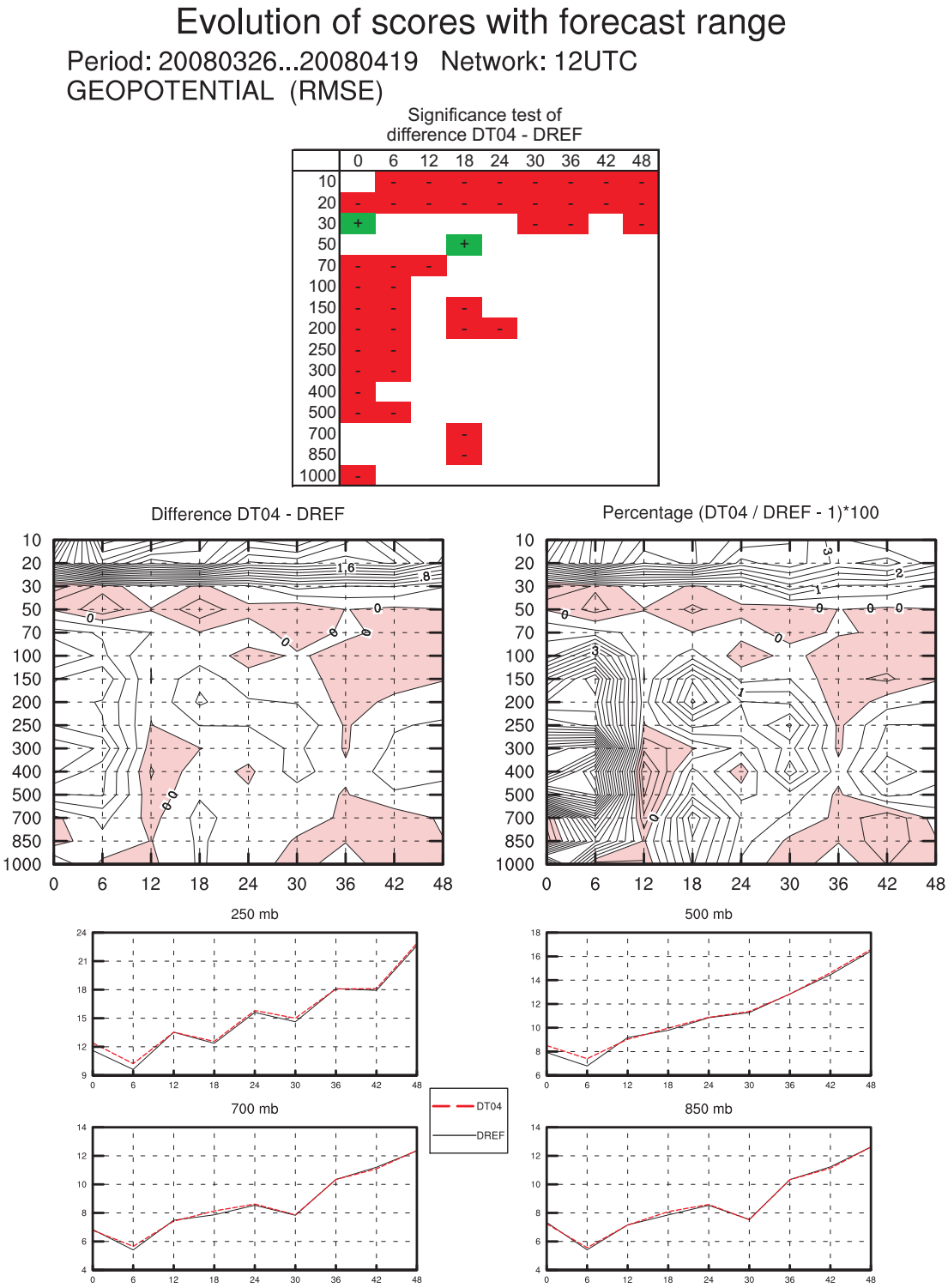

Figure 2.16: Verification of $\overline{RMSE}$ of geopotential against observation from TEMP reports for experiment **DT04**. Start 12 UTC.

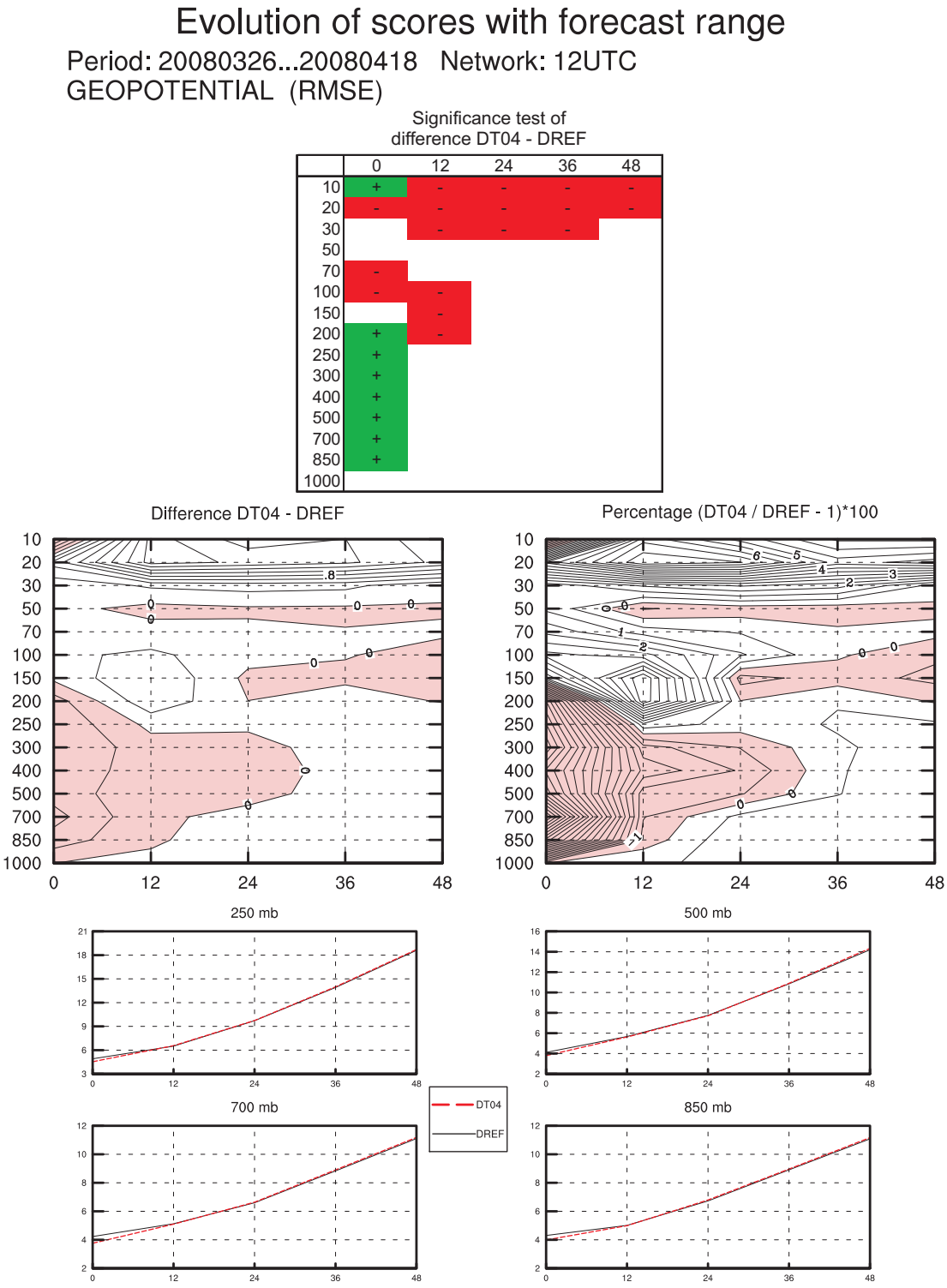

Figure 2.17: Verification of $\overline{RMSE}$ of geopotential against analysis from ECMWF for experiment **DT04**. Start 12 UTC.

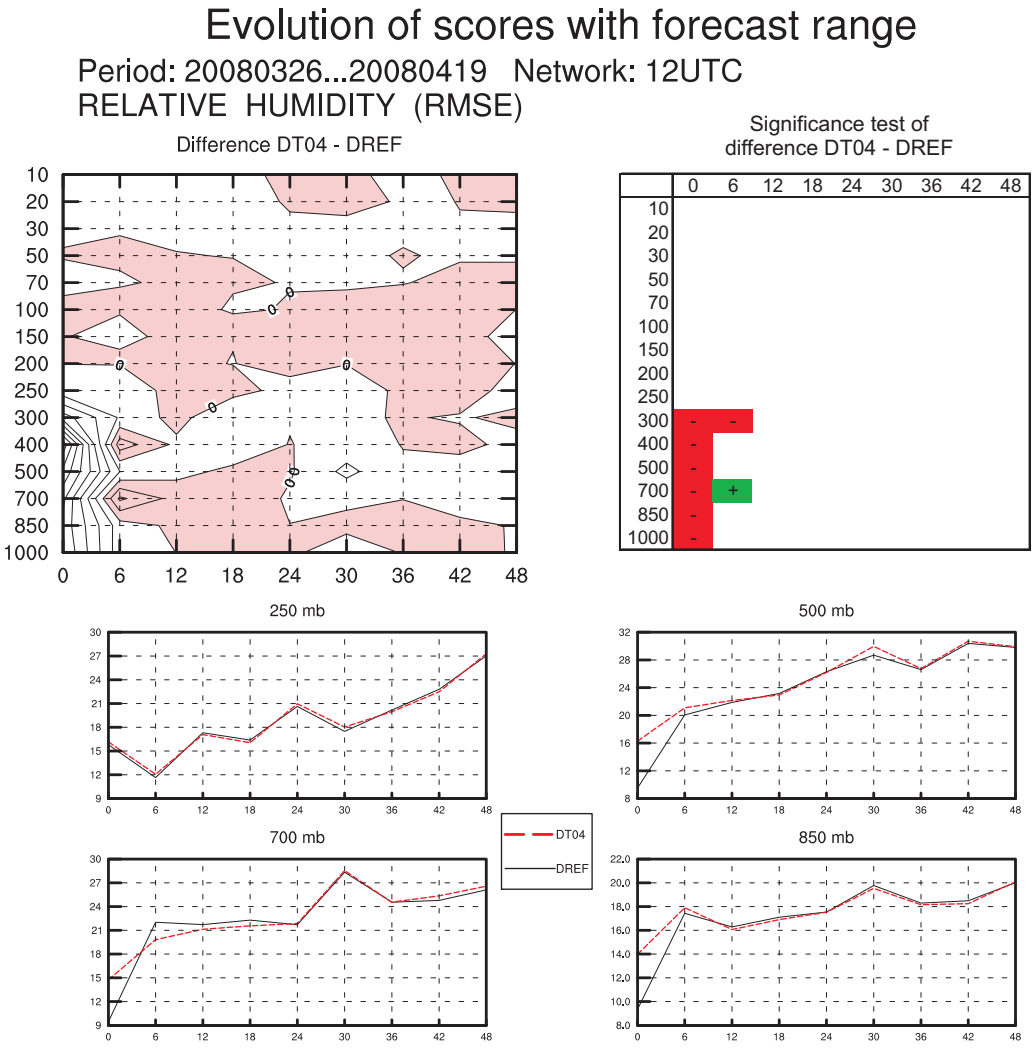

Figure 2.18: Verification of $\overline{RMSE}$ of relative humidity for experiment **DT04** against observation from TEMP reports. Start of forecasts 12 UTC.

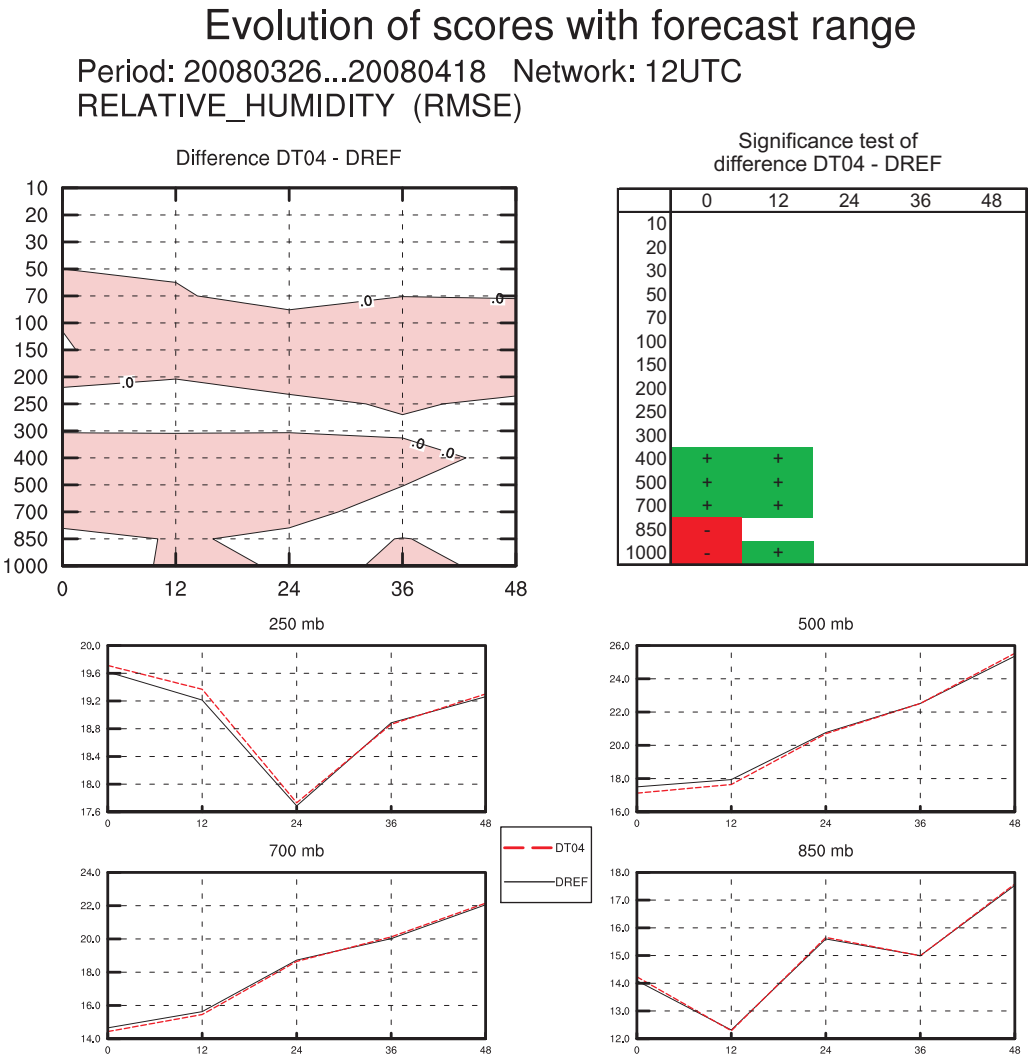

Figure 2.19: Verification of $\overline{RMSE}$ of relaive humidity for experiment **DT04** against analysis from ECMWF. Forecasts start is 12 UTC.

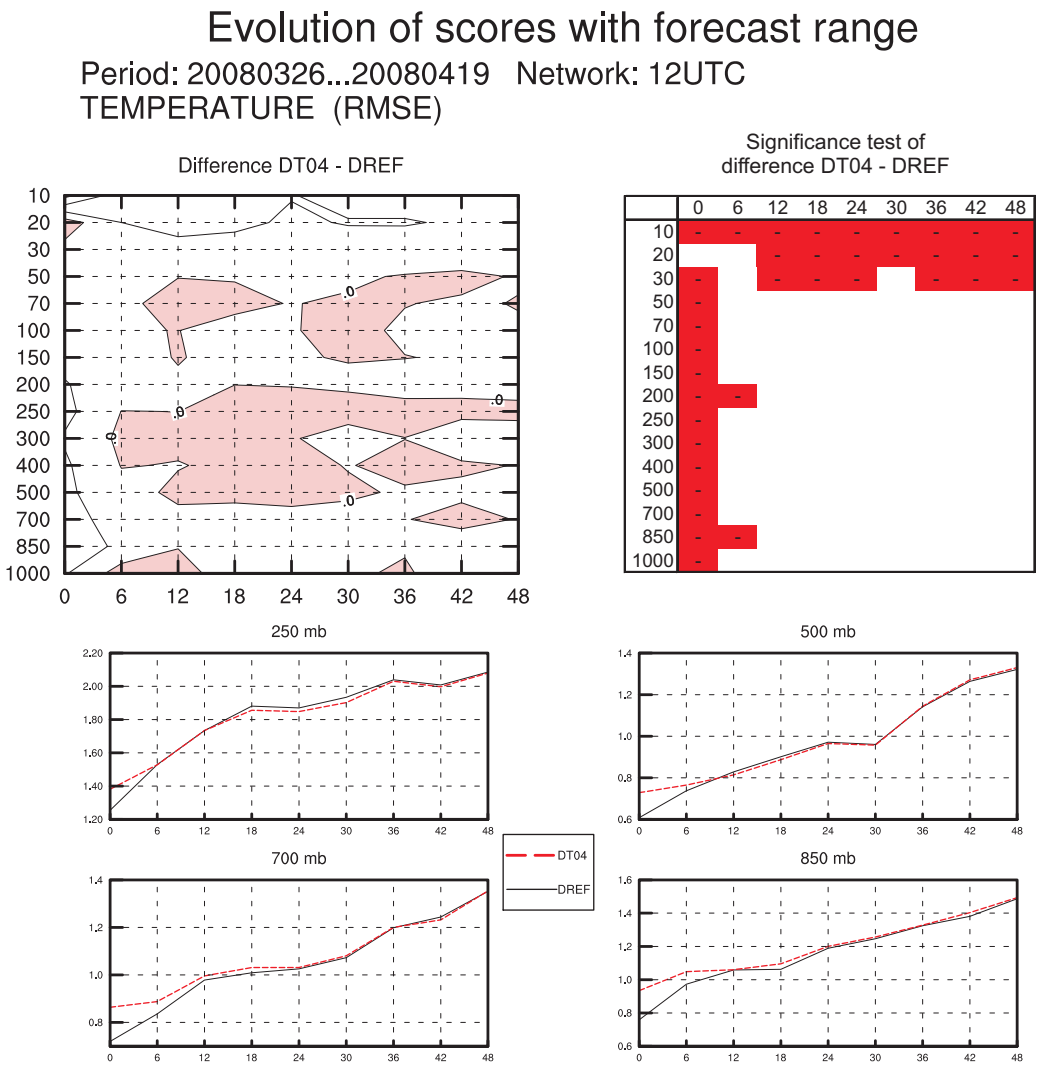

Figure 2.20: Verification of $\overline{RMSE}$ of temperature for experiment **DT04** against observation from TEMP reports. 12 UTC.

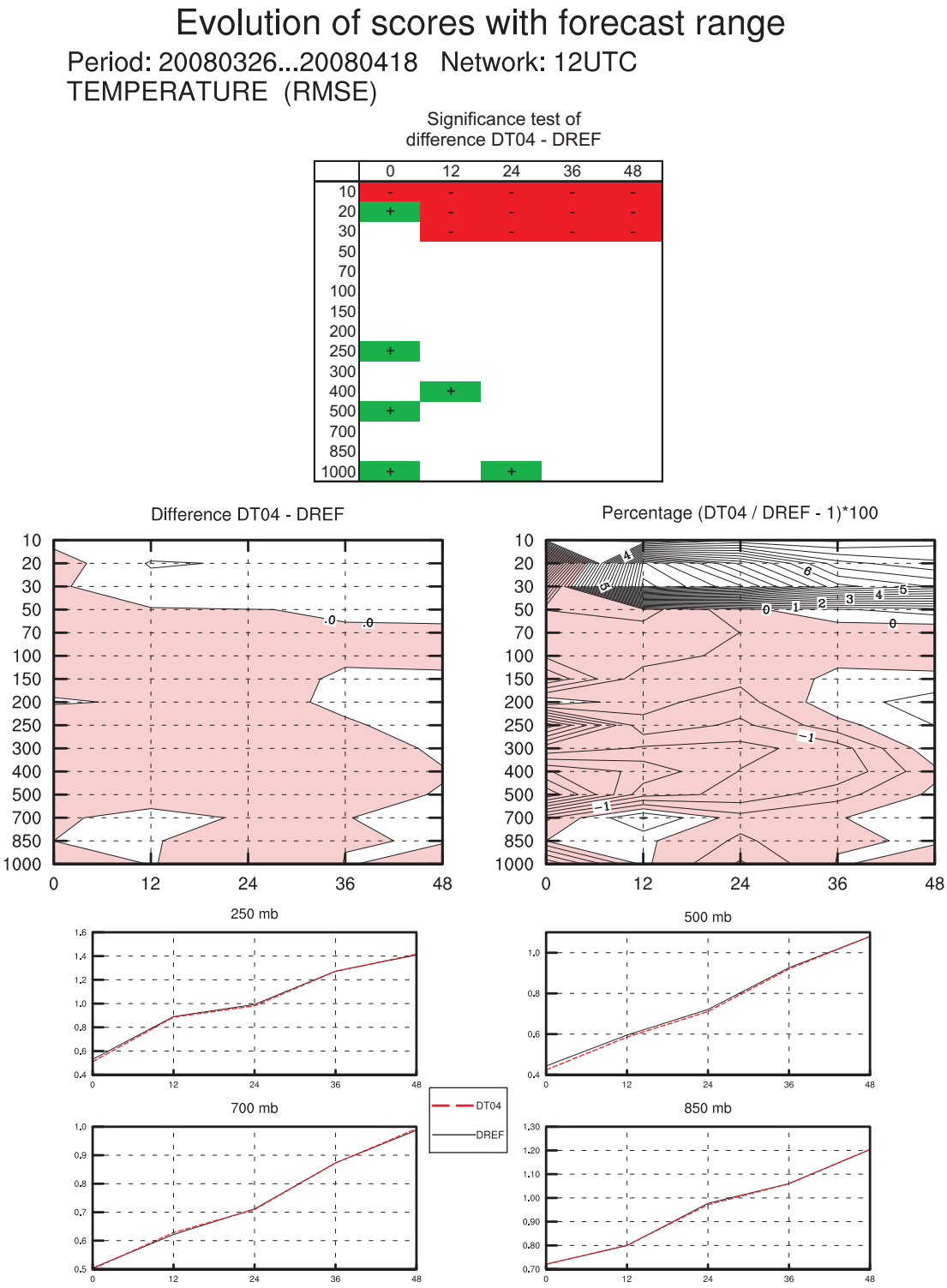

Figure 2.21: Verification of $\overline{RMSE}$ of temperature for experiment **DT04** against analysis from ECMWF. Start 12 UTC.

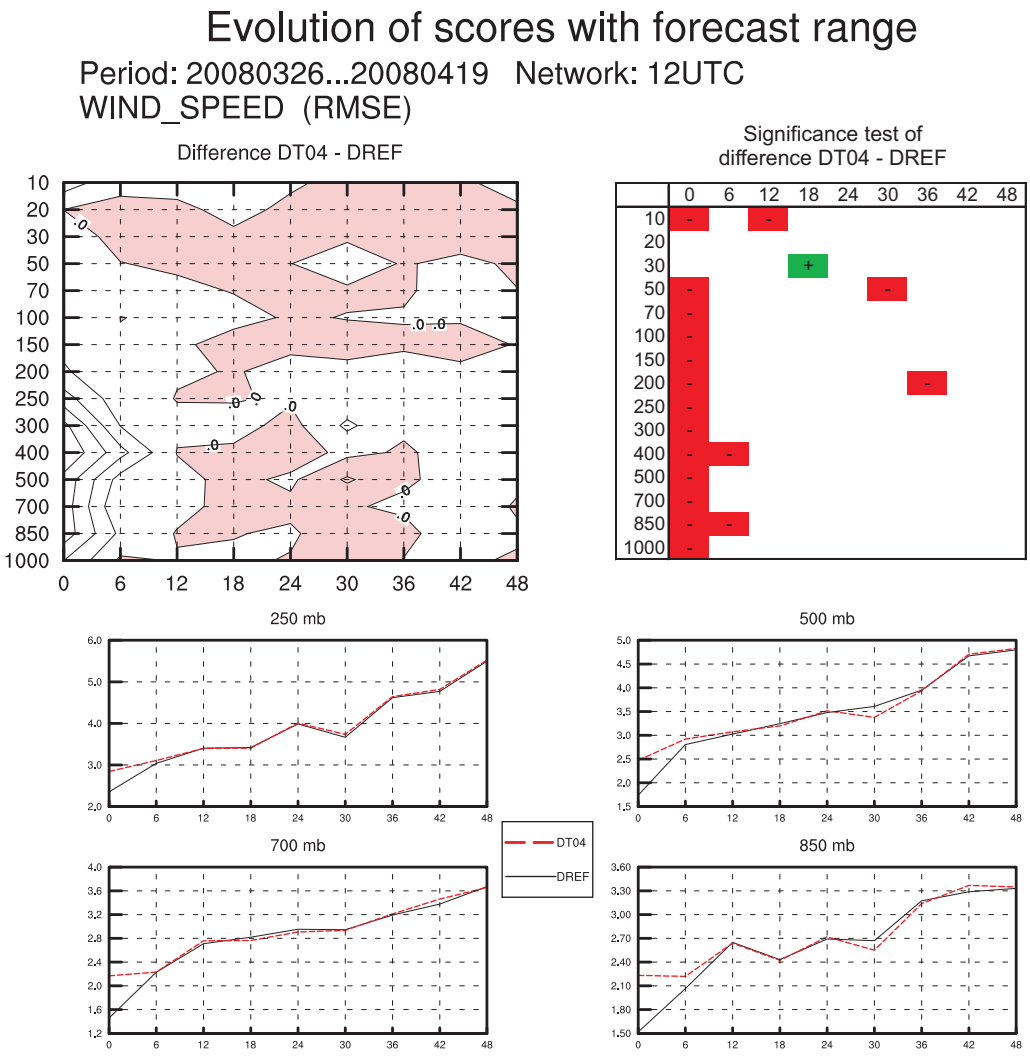

Figure 2.22: Verification of $\overline{RMSE}$ of wind speed for experiment **DT04** against observation from TEMP reports. Start of forecasts is 12 UTC.

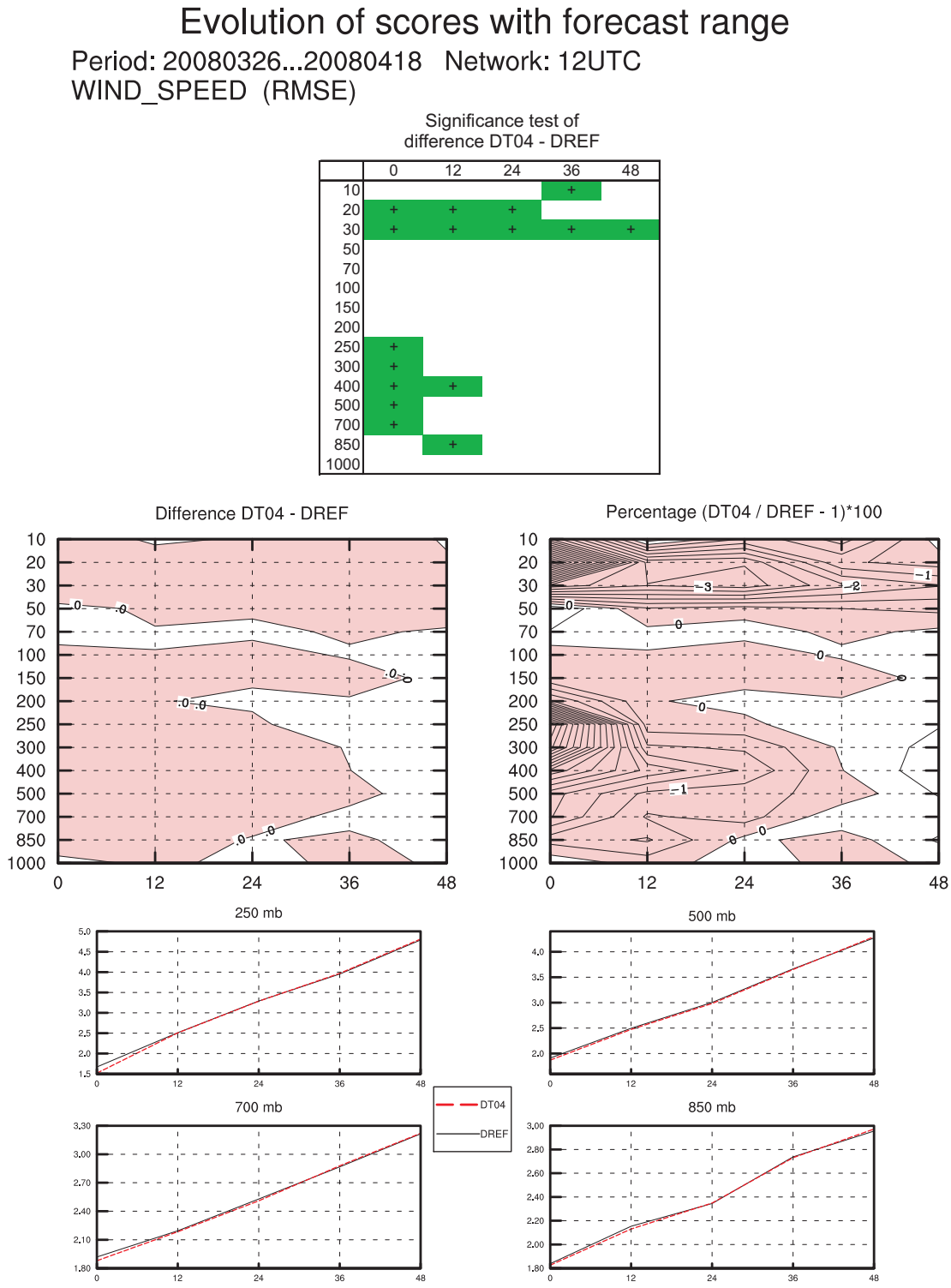

Figure 2.23: Verification of $\overline{RMSE}$ of wind speed for experiment **DT04** against analysis from ECMWF. Forecasts begin at 12 UTC.

Conclusion

Verification of upper air parameters against observation from TEMP reports was done approximately in 100 points at times 00 and 12 UTC and approx. in 20 points at times 6 and 18 UTC (this numbers fluctuated). On the other hand verification against analysis from ECMWF was done in all grid points (approximately in 85 000 points). If we look on numbers of verified point, verification against analysis should have bigger weight. Experiment **DT01** has absolute value of improvement higher than **DT00** but has also more significantly degradated points than **DT00**. So experiment **DT00** is better than **DT01** if we count numbers of degradated points. Assimilation of AMDAR reports has mainly positive influence when verified against analysis from ECMWF. But changes are generally very small and for effective use improvement should be better. Experiment **DT04** showed unsubstitutable role of observation from TEMP reports in higher levels of atmosphere.

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