3D-VAR data assimilation experiments for the double-nested limited area model ALADIN/Hungary

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1 Introduction

Data assimilation is an analysis technique by which the observational meteorological data are merged together with a dynamical model of the atmosphere in order to obtain as much as possible an accurate and consistent description of the atmospheric state. An assimilation process takes into account all the available information, i.e. the meteorological observations, the background (in the form of an a priori estimation of the atmospheric state), the error statistics of these two types of information, the physical laws governing the atmospheric flow. In the frame of the numerical weather prediction, this estimation of the atmosphere, the so-called "*analysis*", represents the initial state of the model. So, to produce a good forecast, a good description of the initial conditions is necessary.

The variational assimilation consists in minimizing a cost-function, which measures the departures of the analysis from the background information, and from the observations. The adjoint model allows the computation of the gradient of the cost-function to be minimized with respect to the initial conditions of the model, at the beginning of the assimilating period. In practice, the initial point of the minimization, or *first-guess*, is taken equal to the background. There is a difference between the terms *background* (which is used in the definition of the cost-function) and *first-guess* (which is used to initiate the minimization procedure). (Le Dimet and Talagrand, 1986).

In the 3D-VAR experiments the choice of the first-guess is important. For the global models, the first-guess is always the 6h forecast from the previous model integration. For the mesoscale models, different possibilities can be chosen:

- the 6h forecast from the previous model run, which contains the small scales information;
- the analysis provided by the global model, which contains the large scales information;
- the mixture of the first two files, made by a procedure called "*blending*", which takes the fine-mesh information from the limited area model, and the information from the analysis of the global model (from planetary scales).

All the experiments were performed with 3D-VAR data assimilation scheme for a *double-nested limited area model*. This means that the boundary conditions of the model are provided by another limited area model, which has a bigger domain, and a lower resolution. At his turn, this limited area model, which is only "simple-nested", is driven by a global model. The idea of the double-nested models is to get a fine scale resolution in the area of interest, and to analyze better the physical process from the smaller scales.

ALADIN/Hungary is a *double-nested limited area model*, with 8 km resolution, which is coupled with ALADIN/LACE, a limited area model, with 12 km resolution. The boundary conditions for ALADIN/LACE are provided by ARPEGE, a global model.

Because of the fine resolution and of the noise produced by the interpolation from the global geometry to the one of the limited domain, the ALADIN model is using the initialization to provide a filtered state valid at the initial time, starting from the analysis. A digital filter initialization (DFI) is applied on both analysis of the global model and forecast (or first-guess) of the limited area model, on the final grid of the mesoscale model, but at a lower resolution. The difference between the filtered fields provides a blending large-scale increment, which is added on the final grid, i.e. at the full resolution, to the forecast of the limited area model. So the role of the DFI is to filter out the global analysis increments at the smaller scales. Digital filter initialization ensures an "implicit and smooth" transition function to blend the spectra of the coupled models (Giard, 2001).

It was found that the classical DFI might destroy some useful signals of the 3D-VAR increments (Dziedzic, 2000). Therefore, another initialization method was proposed to test, namely the incremental digital filter initialization (IDFI), when it is assumed that the first-guess is already balanced and the analysis increment (the difference between the analysis and the first-guess) should be filtered.

Working with a double-nested limited area model, the aim of the experiments was to find out how the choice of the first-guess could influence the results, and which one is the best option, what initialization method is better to be used, and generally, to get an idea about the best possible strategy of the 3D-VAR data assimilation scheme for ALADIN/Hungary model.

The paper is organized as follows. After a description of the experiments performed with 3D-VAR scheme in section 2, the results are presented in section 3. Conclusions and discussion follow in section 4.

It is noted that this report is a summary of the work made in Budapest to the Hungarian Meteorological Service, during my first ALATNET stay, between November 2001-May 2002.

2 3D-VAR experiments

The 3D-VAR data assimilation scheme from the ALADIN/Hungary model is using an incremental procedure (it is called incremental, following ARPEGE notion; but it is not incremental, because for ALADIN model, there is no difference between high and low resolution increments). So first, the differences between the background field and the observations are calculated at full resolution of the forecast. Then, the analysis increments are estimated using the observation increments. Afterwards, these increments are used to update the background field in order to create the analysis.

The 3D-VAR procedure finds the analysis increments by minimizing the cost-function given by:

$$J(x) = J_b(x) + J_o(x) + J_c(x) \tag{1}$$

where

- The background term ($J_b(x)$) measures the fit of the analysis to the background (usually, the 6h forecast).
- The observation term ($J_o(x)$) measures the fit of the differences between the observation and the analysis increment.

- The constraint term ($J_c(x)$) measures the fit of the analysis increment to a set of dynamical constraints. (Derber and Bouttier, 1999).

At the moment for the ALADIN model only the observation and the background terms from the expression of the cost-function are defined, which can be written as:

$$J(x) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}(\mathbf{Hx} - \mathbf{y})^T \mathbf{O}^{-1}(\mathbf{Hx} - \mathbf{y}) \tag{2}$$

where $\mathbf{x}$ is the control variable, $\mathbf{y}$, the vector containing the observations, $\mathbf{x}_b$ is the background field, $\mathbf{H}$ is the observation operator (who works between the observation space and the model space), $\mathbf{B}$ is the background error covariance matrix and $\mathbf{O}$ is the observation error covariance matrix.

For the observation term of the cost function ($J_o(x)$) only SYNOP and TEMP observations were considered, and the standard NMC statistics for the background term ($J_b(x)$). The NMC (National Meteorological Center, now is called National Centers for Environmental Prediction) method estimates the background error statistics using a set of differences between forecasts valid at the same time, but at different ranges (usually 36h - 12h differences) (Parrish and Derber, 1992). This method was used first for the global model (ARPEGE), and then it was adapted for the high-resolution limited area model (Berre, 2000). These statistics are used as the background error covariance matrix ($\mathbf{B}$) in the 3D-VAR scheme to compute the background term. The observation error covariance matrix ($\mathbf{O}$) contains errors in the observation process (instrumental errors), errors in the design of the operator $\mathbf{H}$, and representativeness errors.

One week period, between 25.02.2002 - 02.03.2002, was selected for the 3D-VAR experiments with ALADIN/Hungary model. Different first-guesses and initialization methods were tested. The steps performed in the 3D-VAR cycling are: first, the preparation of the observational data making the conversion from one format (netcdf) to another (CMAFOC), followed by a screening procedure, which calculates the high resolution departures and makes the quality control of the observations. Then the variational analysis (3D-VAR) is performed, using the first-guess, the observation file prepared by the screening, and the classical (standard) background error statistics file. Because the 3D-VAR data assimilation scheme is acting for the upper-air meteorological fields, after the variational analysis step, the optimal interpolation analysis (CANARI) is applied for the surface variables. Finally the first-guess is obtained for the next cycling step. After 3D-VAR cycling, the model is integrated to obtain the forecast (Široká and Horányi, 1999).

In these experiments, two coupling strategies were applied: time-consistency and space-consistency. The time-consistency coupling means that the lateral boundary data are coming from the same run of the coupling model, thus the information is consistent in time (contain consistent time tendency information). The initial file is the 3D-VAR analysis, and the first two lateral boundary conditions (LBC) files are coming from the ALADIN/LACE model. The space-consistency coupling means that the first two LBC files are not coming from the same integration of the model. The first LBC file is identical with the initial file, which is 3D-VAR analysis. Thus the information is consistent in space (Široká [1], 2001).

As LBC files for the first-guess, in cycling, and for the forecast, in production, three types of files were available:

- the operational ALADIN/LACE LBC files, provided twice per day, used also for the operational integration of ALADIN/Hungary model (in dynamical adaptation);

- the ALADIN/LACE files from the assimilation cycle (the analysis and the first-guess), provided four times per day;

- the ARPEGE files from the assimilation cycle (the analysis and the first-guess), provided four times per day.

The first set of experiments was performed using in cycling, the first-guess (6h forecast from the previous integration) obtained with ALADIN/LACE LBC files from the assimilation cycle, in time/space consistency, without any initialization, and in production, the operational ALADIN/LACE LBC files were used for 24h forecast, with digital filter initialization. For simplicity, the names of the experiments from this set are "*time*", when time-consistency technique was used, and "*space*" for space-consistency.

As it was mention before, after the first tests with 3D-VAR scheme for a limited area model with digital filter initialization, it was proposed to test the incremental digital filter initialization. This initialization method was tried in Prague for ALADIN/LACE model, by Široká and Bölöni (Široká [2], 2001; Bölöni, 2001) and it seems that the results show better forecasts. In our experiments, this initialization method was tested, to see if the results of the double-nested model have the same improvement with IDFI, as for the simple-nested model.

The second set of experiments is similar with the first one, except that incremental digital filter initialization was used in cycling. Here the names of the experiments are "*time_idfi*" for time-consistency technique, and "*space_idfi*" for space consistency.

The third set of experiments was made to see the implications of the double-nesting on the 3D-VAR results. It was realized using in cycling, the first-guess (6h forecast from the previous integration) obtained with ALADIN/LACE, respectively ARPEGE LBC files (from the assimilation cycle), in space-consistency, without initialization, with "Moroccan" solution. This means that in cycling, the initial and the first LBC files are 3D-VAR analysis, and the second LBC file is ALADIN/LACE, respectively ARPEGE analysis. In production, the initial and the first LBC files are 3D-VAR analysis, and the second LBC file is 6h forecast of ALADIN/LACE, respectively ARPEGE models. In production the integration is made only for 6h, with digital filter initialization. The names of the experiments are "*LACE*" and "*ARPEGE*".

As evaluation tools for all experiments, the objective scores were used, e.g. the statistical measures (RMSE, BIAS), echkevo scores, ectoplasm plots, and also for a subjective evaluation, maps of mean sea level pressure increments and with the representation of different fields (e.g. temperature, geopotential, relative humidity, vertical velocity).

3 Results

In this chapter, the most important results of the three sets of experiments are presented.

3.1 Verification

The statistical measures (RMSE, BIAS) are used as indicators of the extent at which model prediction match observations. These objective scores are calculated as a temporal and spatial average over all the stations and along the given time interval, for the forecast of the model using 3D-VAR scheme, and also for the operational forecast (as reference). The compared fields are the temperature, geopotential, zonal and meridional wind, relative humidity, direction and intensity of the wind.

The verification was made against SYNOP and TEMP observations, for the period 25.02.2002 - 02.03.2002. The scores are plotted as vertical profiles (from the surface to 400 hPa) for the forecast time (00h, 06h, 24h), and as time-evolution for 24h at the standard levels.

The scores of the first set of experiments were compared to the scores of the operational forecast, and one can see that:

- At the time 00h, the analysis with 3D-VAR scheme is better than dynamical adaptation, so it is getting closer to the observations, for all the fields. An important improvement is for relative humidity (Figure 1). The scores for temperature and geopotential are closer. Also for wind there is an improvement especially for the upper levels (Figure 2). At the surface the scores are near of those of the operational forecast, except for relative humidity. But this improvement shows only that the analysis is closer to the observations, which is expected.

- After 6h forecast, the improvement from the initial time is lost. For some levels the forecast with 3D-VAR is better, but for others, no. The forecasts of the temperature, geopotential and wind direction with 3D-VAR scheme are close to those of the operational forecast. The wind and relative humidity have some irregular profiles, with better results for some levels, but not at all levels (Figures 3, 4). So, starting from a better analysis, the results with 3D-VAR scheme for different levels are worse than in dynamical adaptation.

- After 24h forecast, the scores are similar with those in dynamical adaptation, with small variations near of the surface (not shown). This means that the information is coming mainly from the LBC files, as for the operational forecast, and the effect of the observational data assimilated at the beginning of the forecast period is negligible.

- One explanation of the loss of improvement is that for 3D-VAR forecast, the same TEMP observations are used, as for the global model ARPEGE. So the new information is coming only from SYNOP data, which is not very helpful, because 3D-VAR is acting for upper-air. In the future, also other types of data

(AMDAR, ATOVS) will be used, and an improvement of the 3D-VAR results is expected.

- Comparing the profiles of the forecast with 3D-VAR, when time and space consistency coupling techniques were used, one can see that the time-consistency strategy shows better results, but the difference is not so big. It is surprising, because for ALADIN/LACE model, the space-consistency was chosen as the best coupling technique. For the next stay, it will follow to investigate the two coupling strategies, for some interesting meteorological situations, with a front passing through the domain.

One remark has to be done: the big values of the wind at 1000 hPa are due to some problems in the quality control of the observational data, and the signal is not physical.

The next vertical profiles were plotted for the operational forecast and using 3D-VAR scheme, when the same coupling technique was applied, with and without incremental digital filter initialization in cycling.

- At the moment 00h, the shapes for temperature and geopotential fields are very close. Also the differences for relative humidity (Figure 5) and wind (not shown) are small, maybe with a little improvement when no initialization was used. But this difference appears because of the IDFI, which is getting the analysis a little far away from the observations.

- After 6h, the scores are similar for all the fields (not shown).

- We can see that there is no need to apply IDFI in cycling, because the initial fields provided by ALADIN/LACE model are in balance. IDFI is useful for the simple-nested limited area model (ALADIN/LACE) because the noise made by the transformation from the global geometry to the limited domain one's is stronger.

The forecast obtained from the third set of experiments is compared to the 3D-VAR results using the operational ALADIN/LACE LBC files in production (from the first set), with the same coupling strategy (space-consistency).

- At the time 00h, the scores for temperature are similar. For geopotential, the 3D-VAR analysis with ARPEGE LBC files is slightly better. The relative humidity is improved with ALADIN/LACE LBC files (from assimilation cycle), for upper levels, and the analysis of the wind, using ARPEGE LBC files shows better scores, but the difference is not so big (Figures 6, 7).

- After 6h integration, the shapes for temperature are very close. The scores for the forecast with ARPEGE LBC files are better for geopotential. For relative humidity, the 3D-VAR forecast with operational ALADIN/LACE LBC files in production is better for the upper levels. For wind, one can say that 3D-VAR forecast with ARPEGE LBC files has a small improvement than the others (not shown).

- So, the choice of the second LBC file in cycling (analysis or 6h forecast) when space-consistency strategy is used, is important. Comparing the scores from *space* and *LACE* experiments, we can conclude that using the "Moroccan" solution, the forecast is looking slightly better. Also the choice of the lateral boundary conditions (from the global model or limited area model) is important. So using ARPEGE LBC files, the forecast seems to have better results, than with ALADIN/LACE LBC files. From the next stay, we plan more experiments with ALADIN/LACE and ARPEGE LBC files from the assimilation cycle, for a longer forecast (not only for 6h), being able to have all the files in real-time.

3.2 Echkevo

Other information about the balance properties of the fields can be obtained from the echkevo scores. The echkevo program computes the time evolution of the fields at different levels for the selected points on the domain.

For our experiments, three days were chosen, at the beginning (25.02.2002), at the middle (28.02.2002), and at the end (02.03.2002) of the period, and also, several positions relative to the domain. Here the selected points in (x,y) coordinates are written:

◇ [5, 5] - a point in the coupling zone (bottom-left corner of the domain),

◇ [22, 52] - a point over the mountains,

◇ [51, 61] - a point over the mountains,

◇ [90, 70] - a point in the middle of the domain,

◇ [138, 93] - a point over the mountains,

◇ [170, 120] - a point in the upper-right corner of the domain.

In these days, and for these points, the time evolution of the mean sea level pressure was checked during the 6h forecast in production. In all pictures (Figures 8-10), the evolution of the mean sea level pressure from the operational forecast (in dynamical adaptation) is represented as reference.

- Comparing the echkevo scores for the operational forecast and using 3D-VAR data assimilation scheme (with time and space consistency coupling technique), one can see that the fields are in balance. For the points above a significant orography, the scores with 3D-VAR scheme are almost identical (Figure 8).

- Figure 9 shows the scores for the 3D-VAR forecast with time-consistency strategy, when different initialization methods were used (with DFI in production and no initialization in cycling, without initialization in production and in cycling, with DFI in production and with IDFI in cycling). The plots confirm again that the digital filter initialization reduces the noise from the analysis.

- The incremental digital filter initialization was tested in ALADIN/LACE blending procedure, and the results are good (Bölöni, 2001). But ALADIN/Hungary model, being coupled with ALADIN/LACE, is using the files after the blending procedure, thus the fields are already in balance, and the effect of the IDFI in cycling is almost negligible. One can see that the curves of the time evolution of the mean sea level pressure are almost the same, whether the IDFI was used in cycling or not.

- Also the curves for the *LACE* and *ARPEGE* experiments are homogenous, which indicates that the fields are in balance (Figure 10).

- So, the main conclusions from these echkevo scores are that the fields are in balance and the initialization with the incremental digital filter is useless for a double-nested limited area model.

3.3 Ectoplasm

Ectoplasm software permits to compute the spectral energy on ellipses for the spectral fields. The whole spectrum of the fields was computed for the same days as for echkevo, on the first-guess, on the variational analyzed state and on the initialized state. The objective of these plots was to find out the active part of the spectrum, at which step of the procedure appears, and how big it is.

In Figures 11, 12, the spectral energy is shown for divergence of the 3D-VAR forecast in time and space-consistency, for the model levels 16 (representing the free atmosphere) and 23 (representing the planetary boundary layer). For the large scales (with the wave-numbers between 1 and 10) the spectrum of the first-guess is very close to the initialized state (*DFI analysis*), which is expected. For the wave-numbers between 10 and 66 (small scales), the first-guess and the 3D-VAR analyzed state are almost identical. The step that modifies the most the spectrum of the divergence is the initialization. For the level 16, the spectrum of the initialized state differs to the one of the variational analyzed state at small scales (between 10 and 66), and for the level 23, the wave-numbers interval is between 10 and 40. After the wave-number 40, all three curves are identical.

The shapes from Figures 11, 12 are similar with those for divergence of the forecast from *LACE* and *ARPEGE* experiments (not shown). It will be interesting to study the spectral energy for some extreme cases (fronts passing through the domain, etc.).

3.4 Maps of increments

As another evaluation procedure we have drawn the maps with the mean sea level pressure increments, for three chosen days (the same as for echkevo), and for the next experiments with 3D-VAR scheme: in time and space-consistency (from the first set), and with ALADIN/LACE and ARPEGE LBC files (from the third set).

In Figures 13, 14, the next increments are plotted:

- 3D-VAR analysis - first-guess

- DFI analysis - 3D-VAR analysis
- DFI analysis - first-guess

Comparing Figures 13, 14 the smallest increments are in *ARPEGE* and *time* experiments. The biggest increments were found in *space* experiment. The differences between increments are around 0.2 - 0.5 hPa. Maybe the increments from the *ARPEGE* experiment look more homogeneous and structured. The differences in the final states are very small for all four experiments.

Looking on the first three rows of the figures, we see that DFI strongly modifies the 3D-VAR analysis, as identified by the ectoplasm results.

3.5 Plots

A subjective evaluation was made, using maps with the representation of different fields of the DFI analysis at 500 hPa: temperature and geopotential, relative humidity, vertical velocity. The fields were plotted for the same days as the echkevo scores, and the maps were organized such as one column represents one type of experiment: *time*, *space*, *LACE* and *ARPEGE* (Figures 15, 16). As reference for these fields, the results of the operational analysis were plotted (Figure 17).

Looking on the maps, the differences for the experiments with 3D-VAR data assimilation scheme are not visible, especially for temperature and geopotential. Also the scores of the verification show very close values. Compared to the operational forecast, the most significant differences are for relative humidity and vertical velocity, over the mountain region. These results confirm the previous conclusions that for the time being we cannot choose a winner between these four experiments.

4 Conclusions

In this paper, the experiments performed with 3D-VAR data assimilation scheme for a double-nested limited area model ALADIN/Hungary were described. Different coupling techniques (time/space consistency), lateral boundary conditions files (from ALADIN/LACE or ARPEGE models), initialization methods in cycling (incremental digital filter initialization, no initialization), coupling methods (analysis or 6h forecast as the second LBC file in cycling) were tested.

After all these experiments, we can conclude that the 3D-VAR forecast for ALADIN/Hungary model didn't show an important improvement compared to the dynamical adaptation, as it was expected, even if at the initial time the fields are better represented. We try to explain further some of the possible reasons.

The new information for the assimilation cycle is provided only by the surface data. In the upper-air, the same TEMP data were used for the global model. As it was mentioned before, future experiments using other types of data (AMDAR, ATOVS) are expected to improve the 3D-VAR results.

The error statistics have also influence on the results. The standard statistics, being computed as a difference between forecasts valid at the same time, but at different ranges, are typical for large scale phenomena, which were analyzed already by the global model. So, the small scale information has also to be provided through the first-guess, not only having high-resolution observations.

For ALADIN/LACE model, the results show an improvement when the lagged statistics were used. The lagged constant coupling method is similar with the classical one, with the difference that the shorter forecast (from 12h) is recomputed using the same boundary information, as for the longer forecast (from 36h). Thus the effects coming from the boundary data containing large scale influence are diminished (Horányi and Bölöni, 2001). These lagged statistics will be tried also in the next stay for the double-nested limited area model.

Comparing the two coupling techniques, one can say that, the time-consistency seems to give a better forecast so far. The smallest increments are found in the *ARPEGE* and *time* experiments, but the echkevo scores show similarity of the results. So we cannot conclude that the time-consistency is the best coupling strategy for the double-nested limited area model. These coupling strategies will be investigated for some interesting meteorological situations.

The incremental digital filter initialization in cycling had not such a good impact on the forecast, because the fields are already in balance. So, in the 3D-VAR cycling for a double-nested limited area model, there is no need to use an initialization method.

From the last set of experiments, it can be seen that the choice of the second LBC file in cycling (analysis or 6h forecast) is important, when space-consistency strategy is used. So, the "Moroccan" solution is a good option as coupling method. Also it seems that it will be better to use in the future the lateral boundary conditions files from the global model. The difference of the resolution between the double-nested and the simple-nested models is not too big, so the LBC files bring more information from the small scales, and less from the large scales. However it remains to investigate the results of the 3D-VAR scheme with "Moroccan" solution for some extreme meteorological situations.

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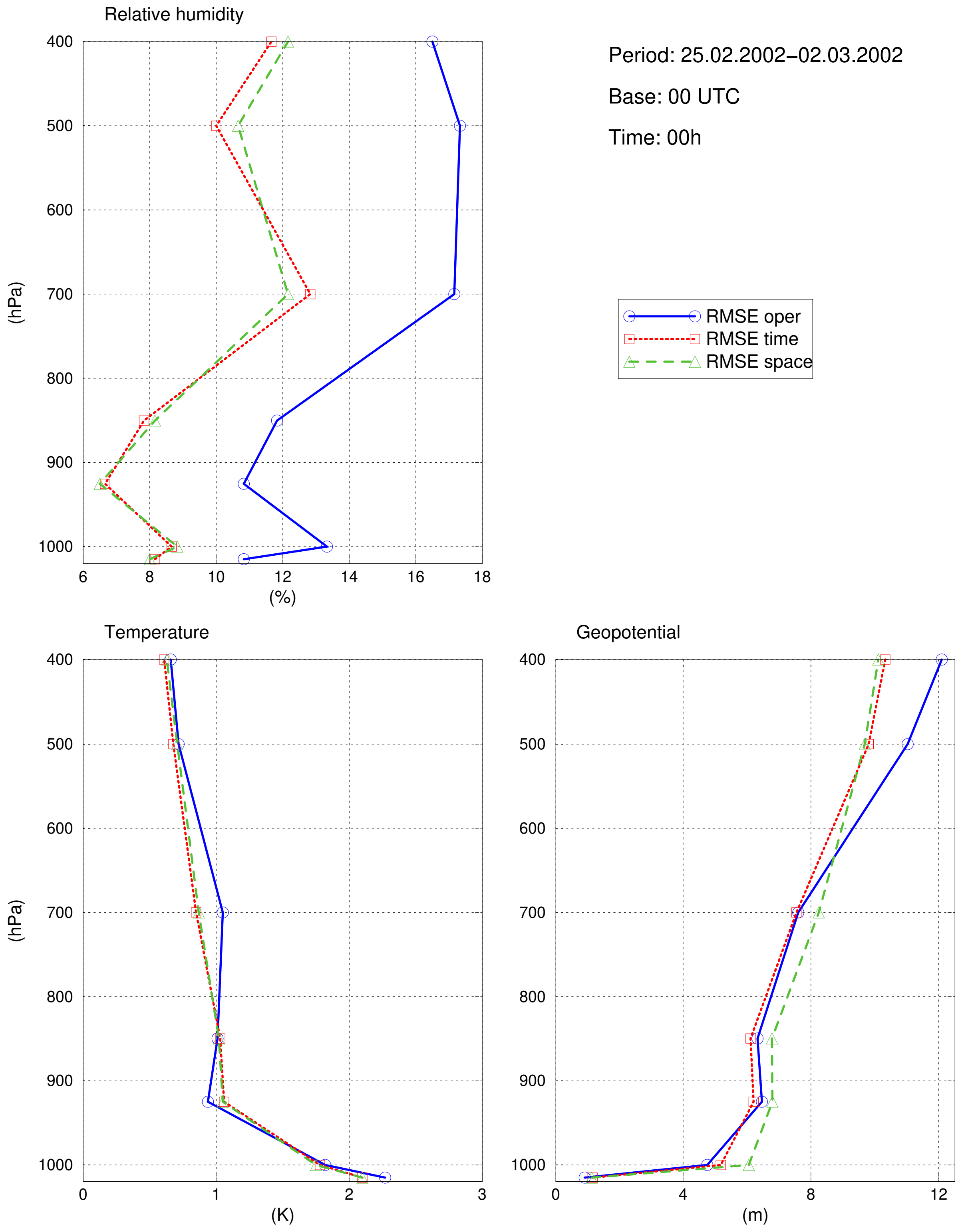

Figure 1: the vertical profile of RMSE for the operational analysis (*oper*), and using 3D-VAR scheme in time-consistency (*time*), and space-consistency (*space*) for the relative humidity, temperature, geopotential

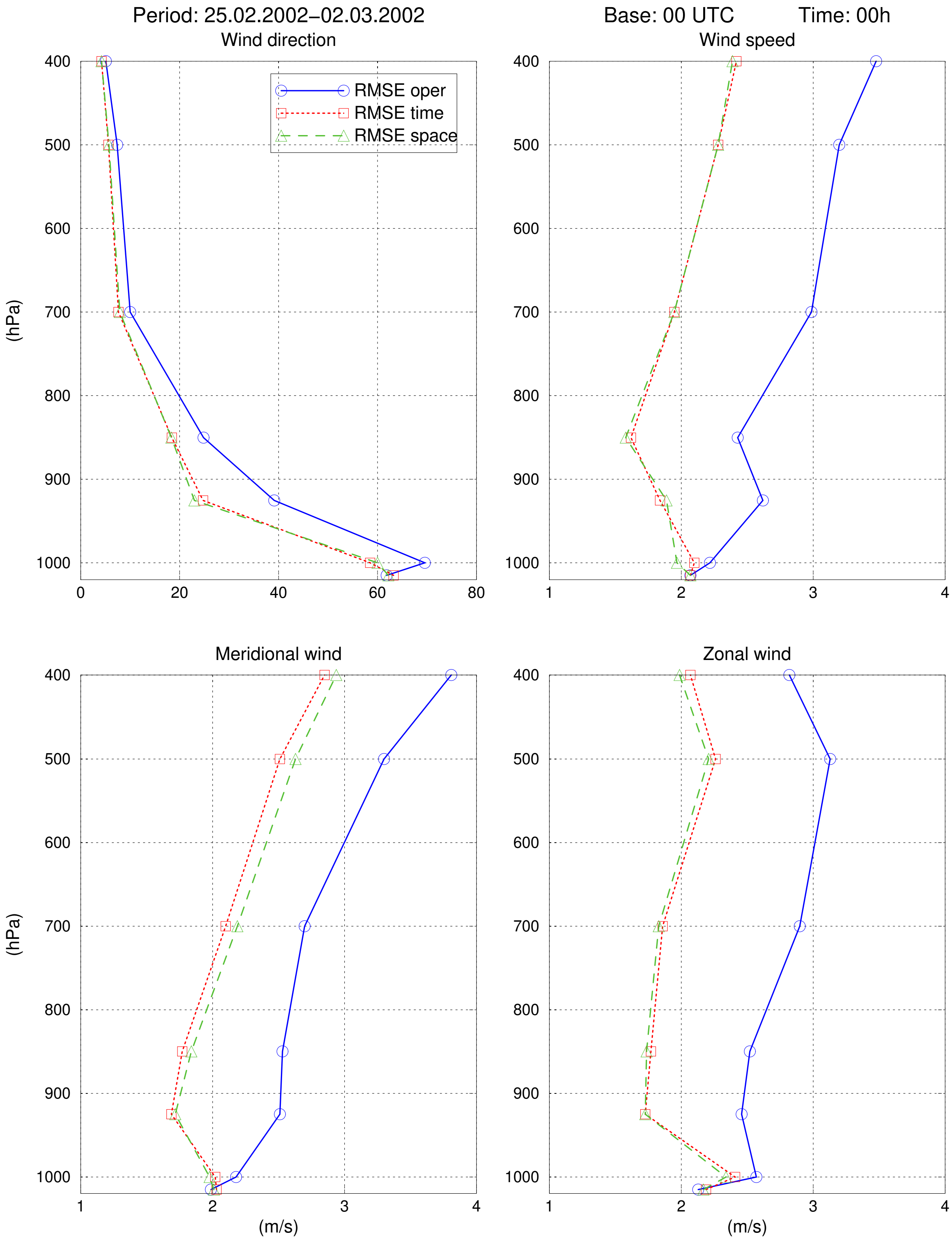

Figure 2: the vertical profile of RMSE for the operational analysis (*oper*), and using 3D-VAR scheme in time-consistency (*time*), and space-consistency (*space*) for meridional and zonal wind, and for the direction and speed of the wind

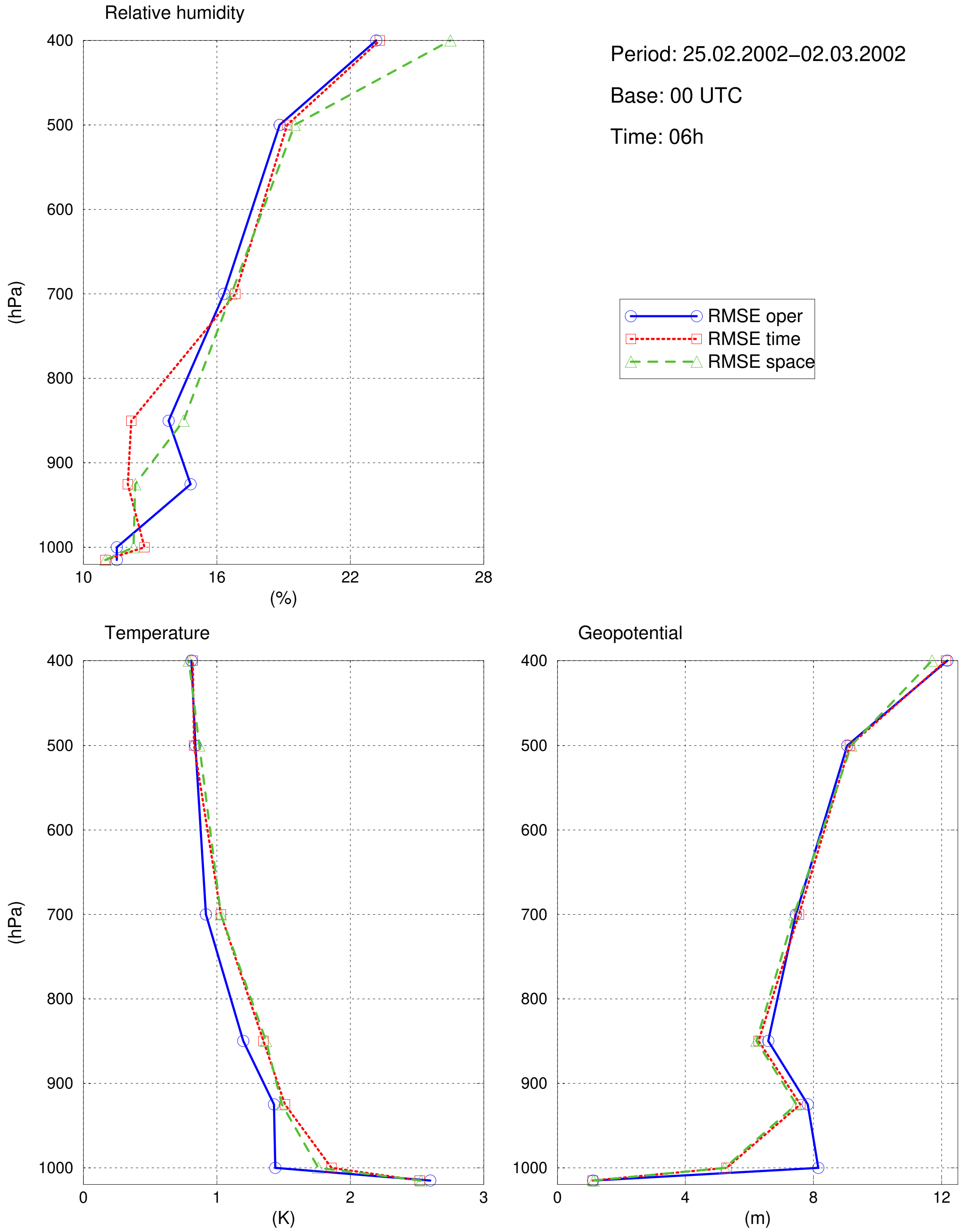

Figure 3: the same as Figure 1, but after 6h integration

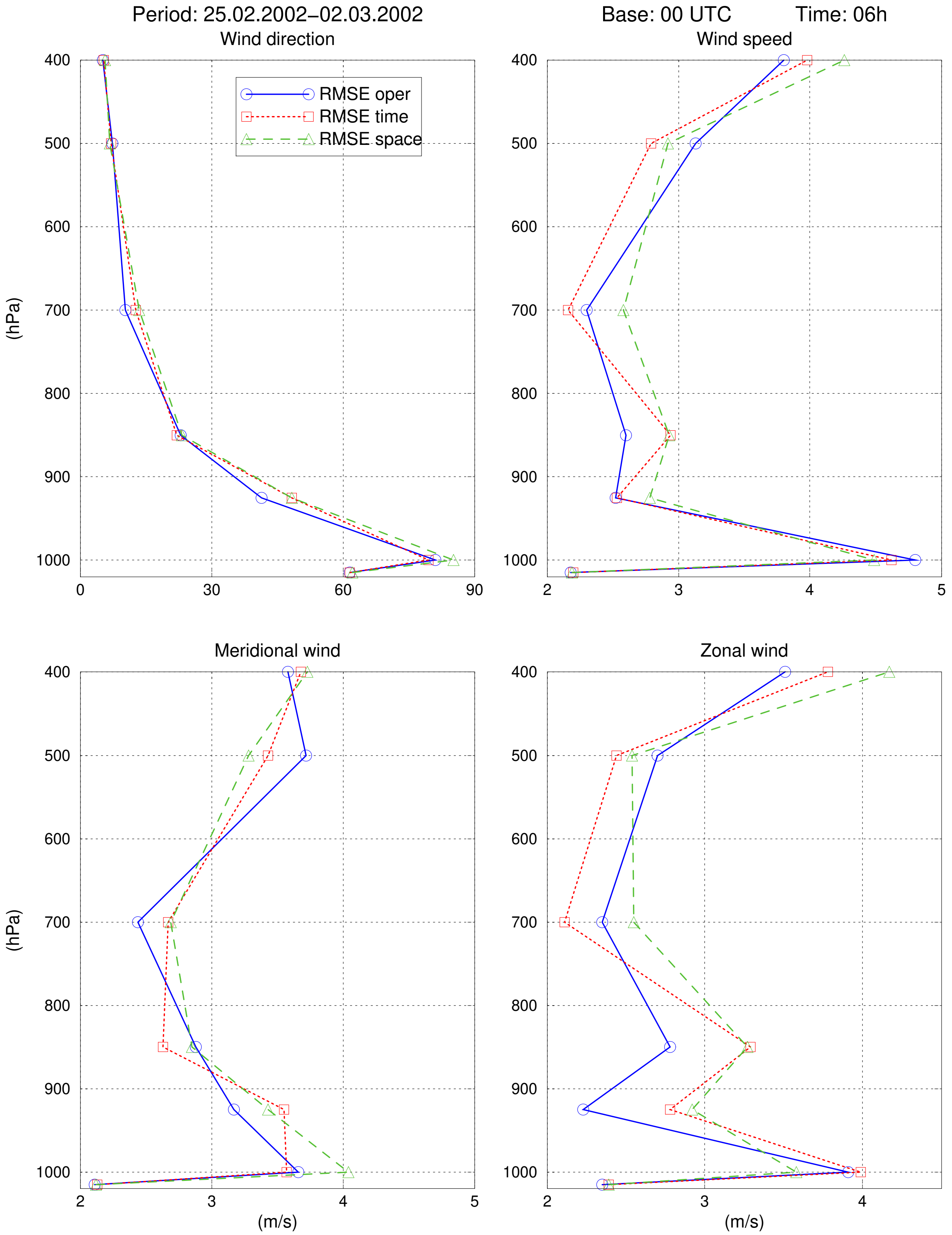

Figure 4: the same as Figure 2, but after 6h integration

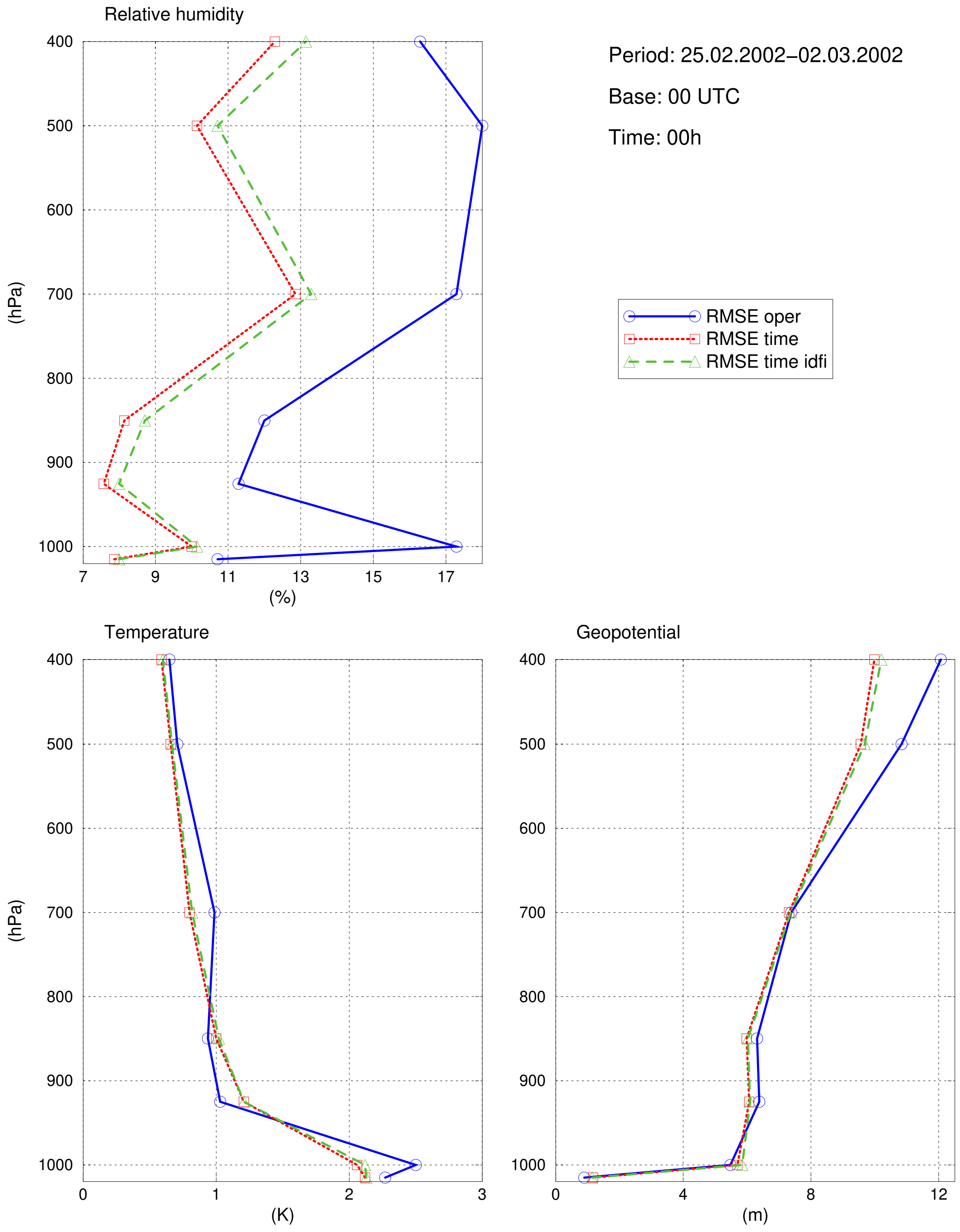

Figure 5: the vertical profile of RMSE for the operational analysis (*oper*), and using 3D-VAR scheme in time-consistency (*time*), and time-consistency with IDFI (*time_idfi*) for relative humidity, temperature, geopotential

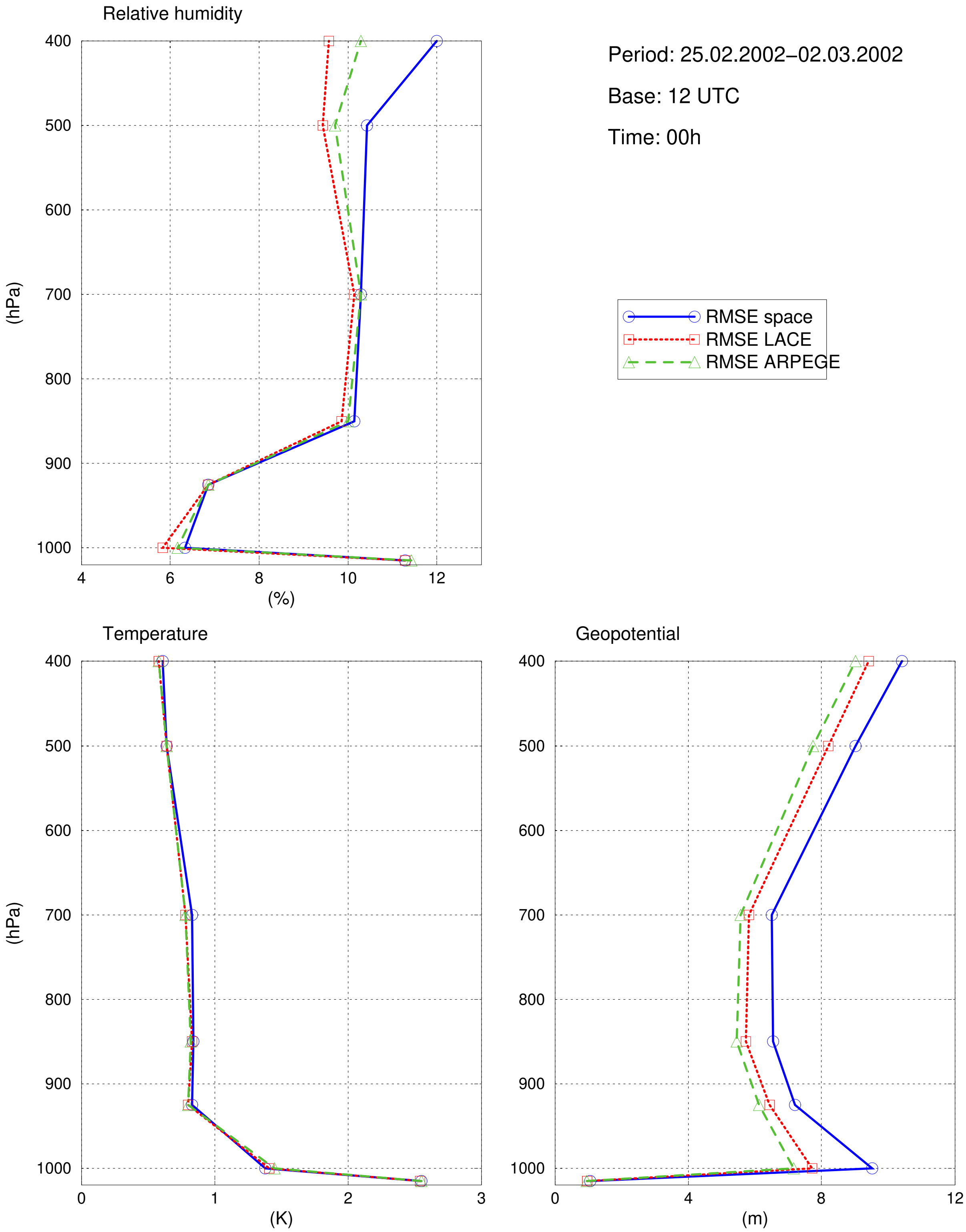

Figure 6: the vertical profile of RMSE for the analyses using 3D-VAR scheme in space-consistency (*space*), with ALADIN/LACE (*LACE*) and ARPEGE files (*ARPEGE*) for relative humidity, temperature, geopotential

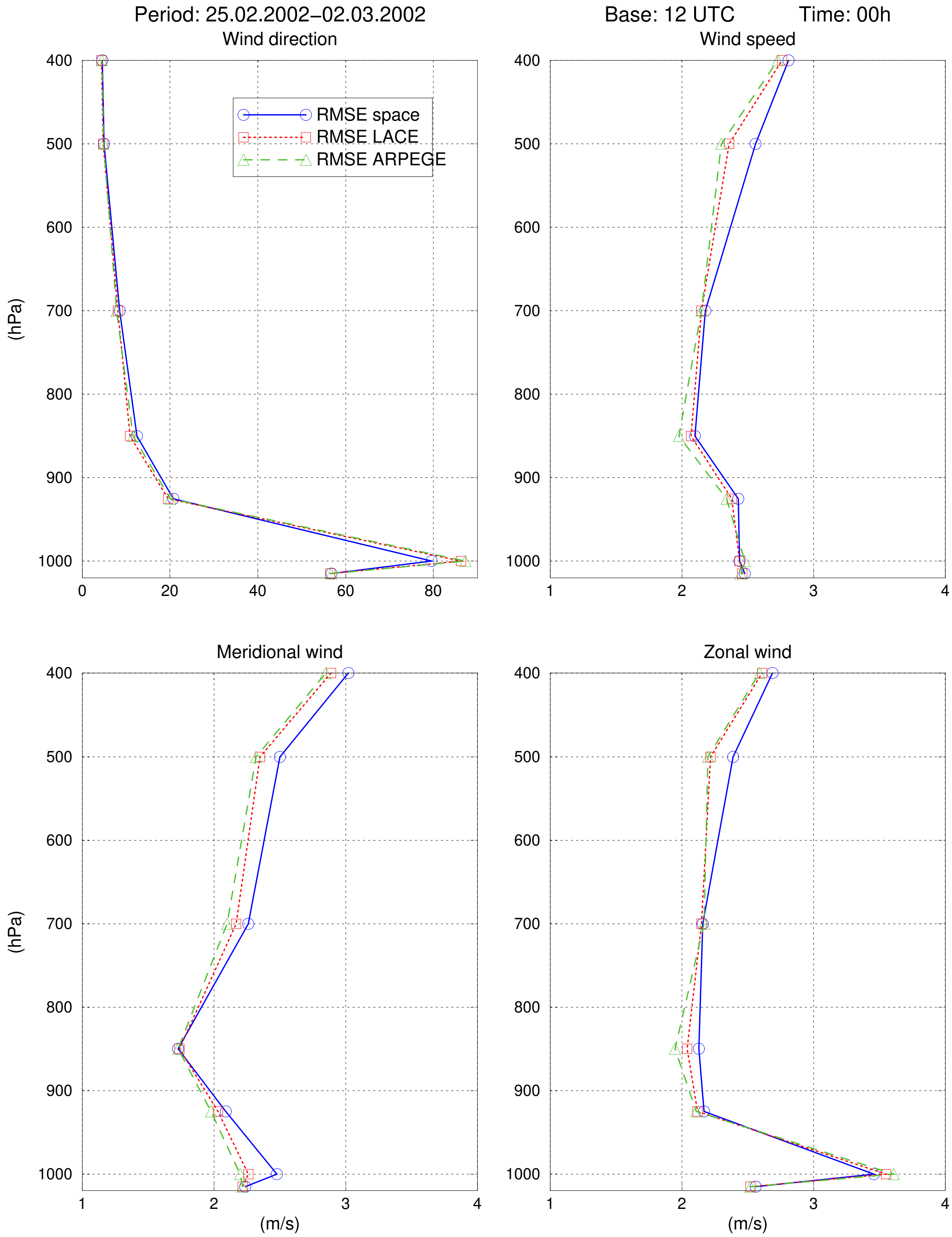

Figure 7: the vertical profile of RMSE for the analyses using 3D-VAR scheme in space-consistency (*space*), with ALADIN/LACE (*LACE*) and ARPEGE files (*ARPEGE*) for meridional and zonal wind, the direction and speed of the wind

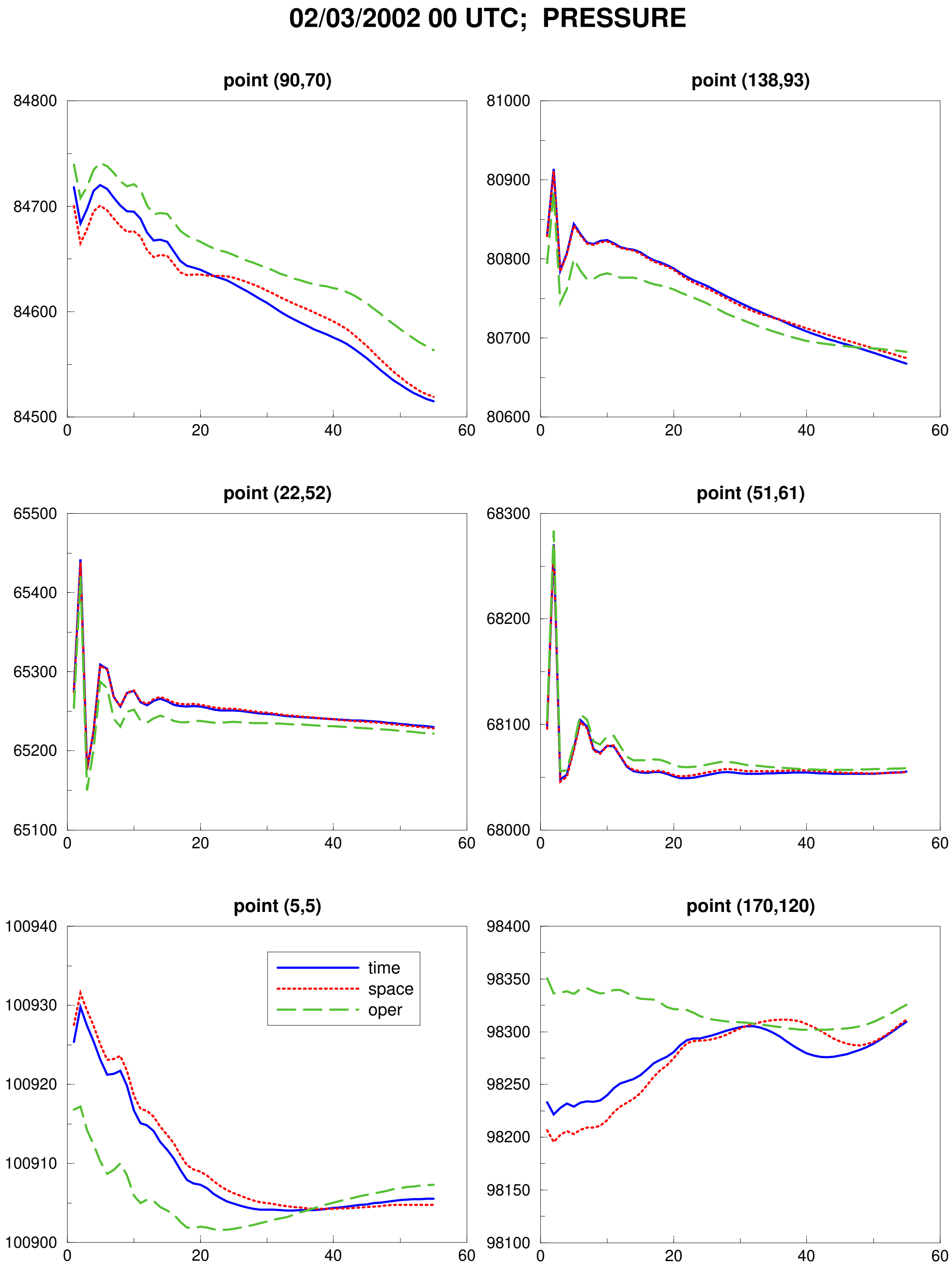

Figure 8: the echkevo scores for six different points, for the operational forecast ($oper$), and using 3D-VAR scheme in time-consistency ($time$), and space-consistency ($space$)

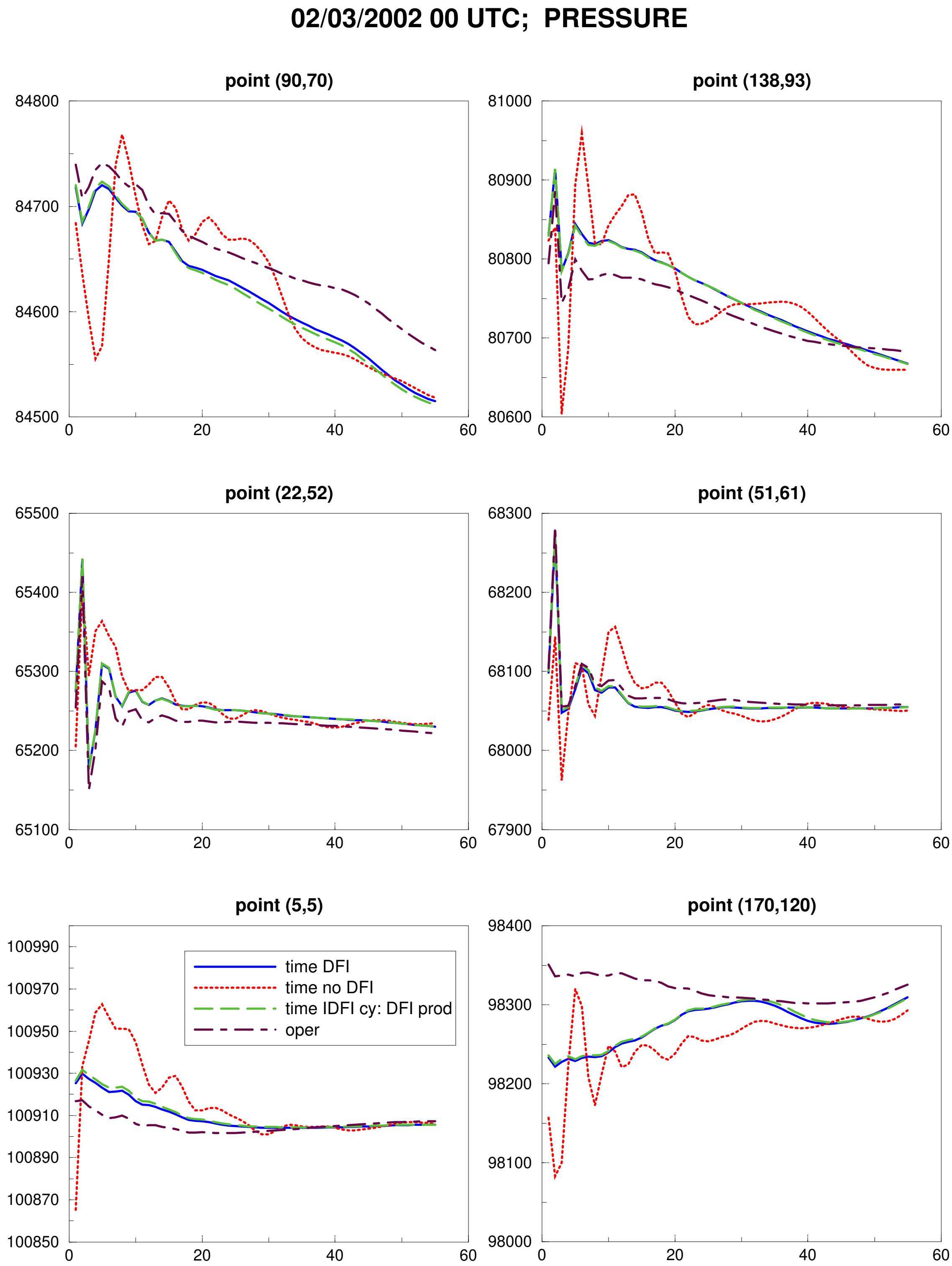

Figure 9: the echkevo scores for the operational forecast (*oper*), and using 3D-VAR scheme in time-consistency with DFI in production (*time DFI*), time-consistency without DFI in production (*time no DFI*), time-consistency with IDFI in cycling and DFI in production (*time IDFI cy; DFI prod*)

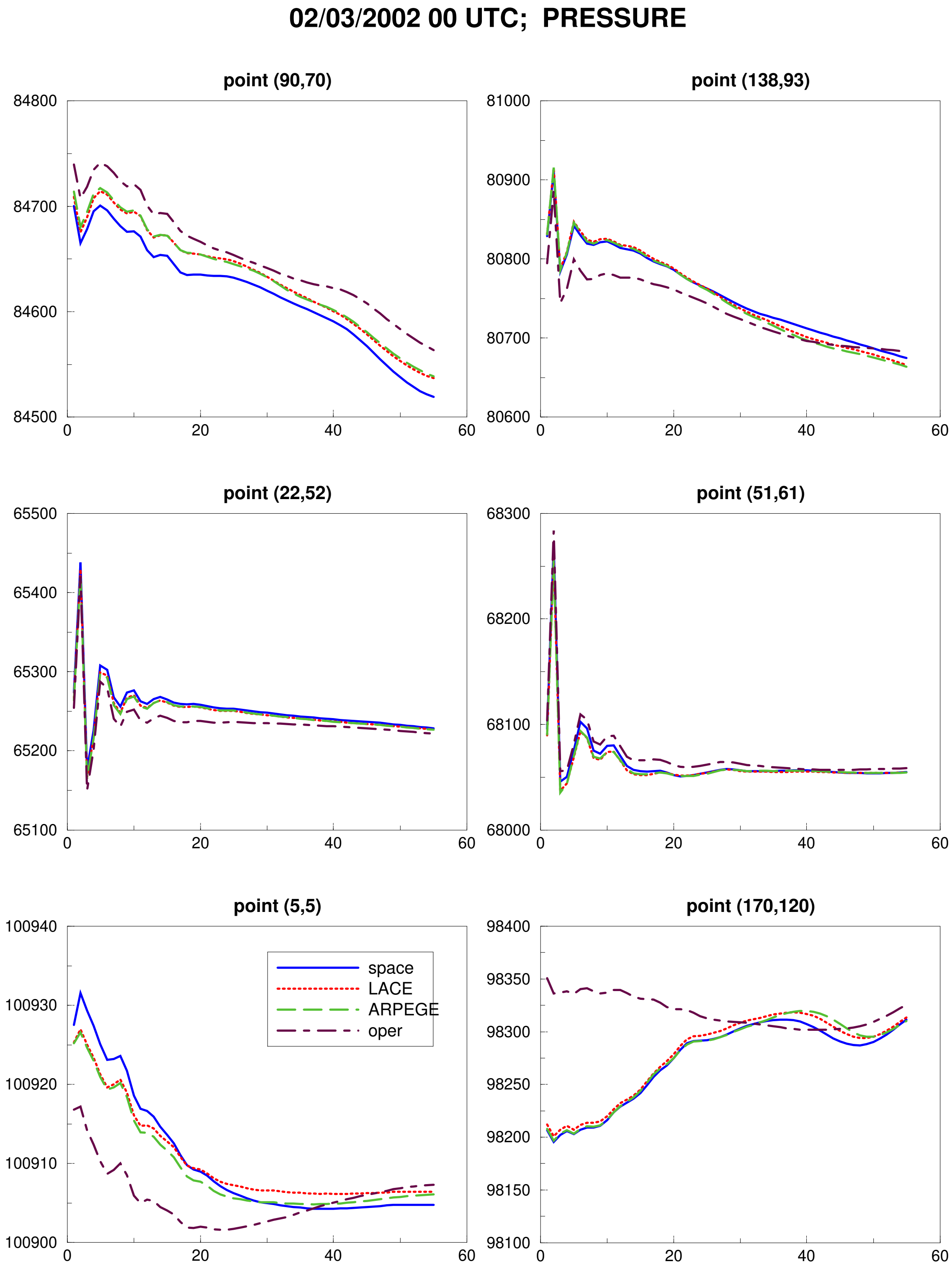

Figure 10: the echkevo scores for six different points, for the operational forecast (*oper*), and using 3D-VAR scheme in space-consistency (*space*), with ALADIN/LACE (*LACE*), and ARPEGE files (*ARPEGE*)

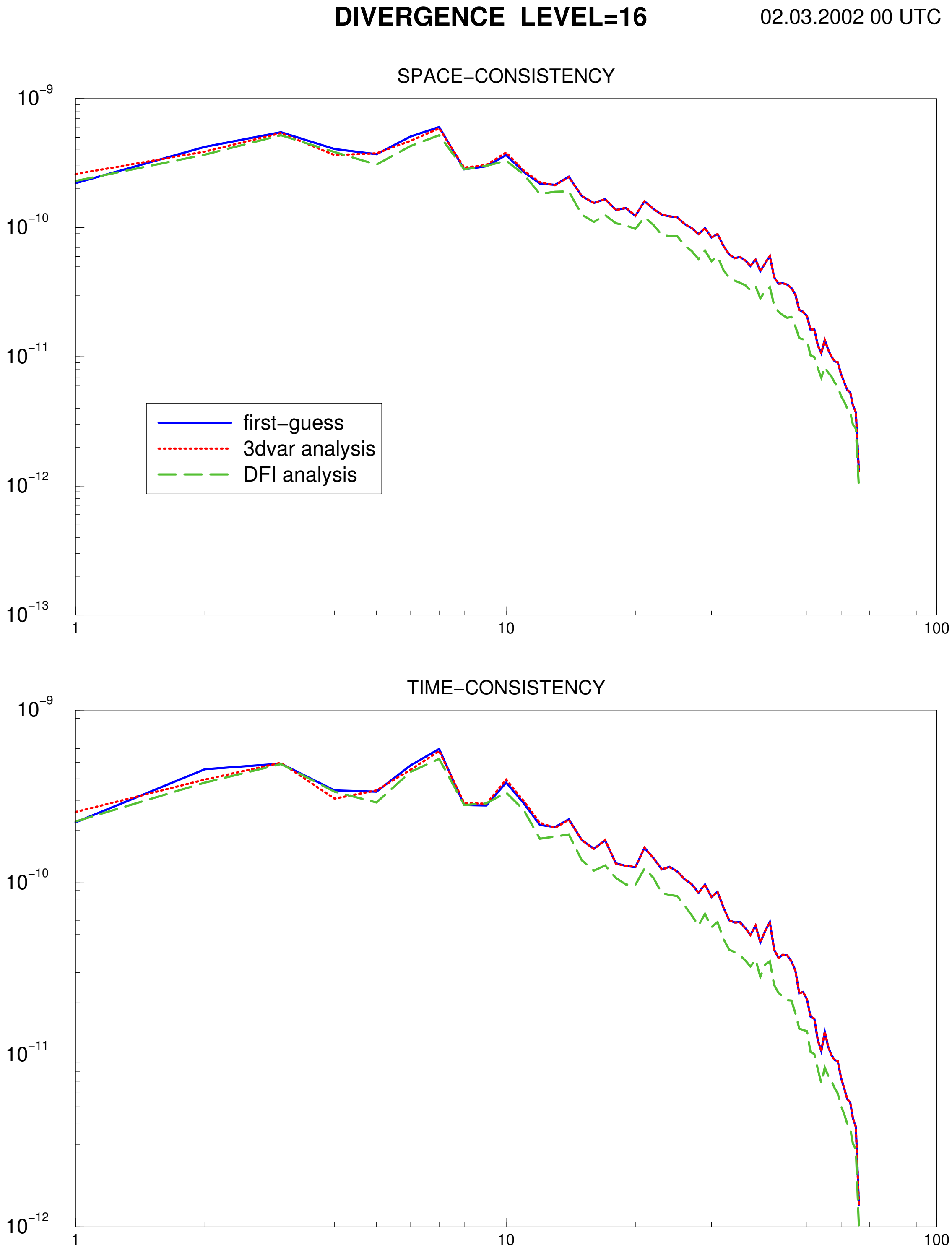

Figure 11: the spectral energy for divergence of the analyses with 3D-VAR scheme in time and space consistency on the first-guess (*first-guess*), on the variational analyzed state (*3dvar analysis*), and on the initialized state (*DFI analysis*), for the model level 16

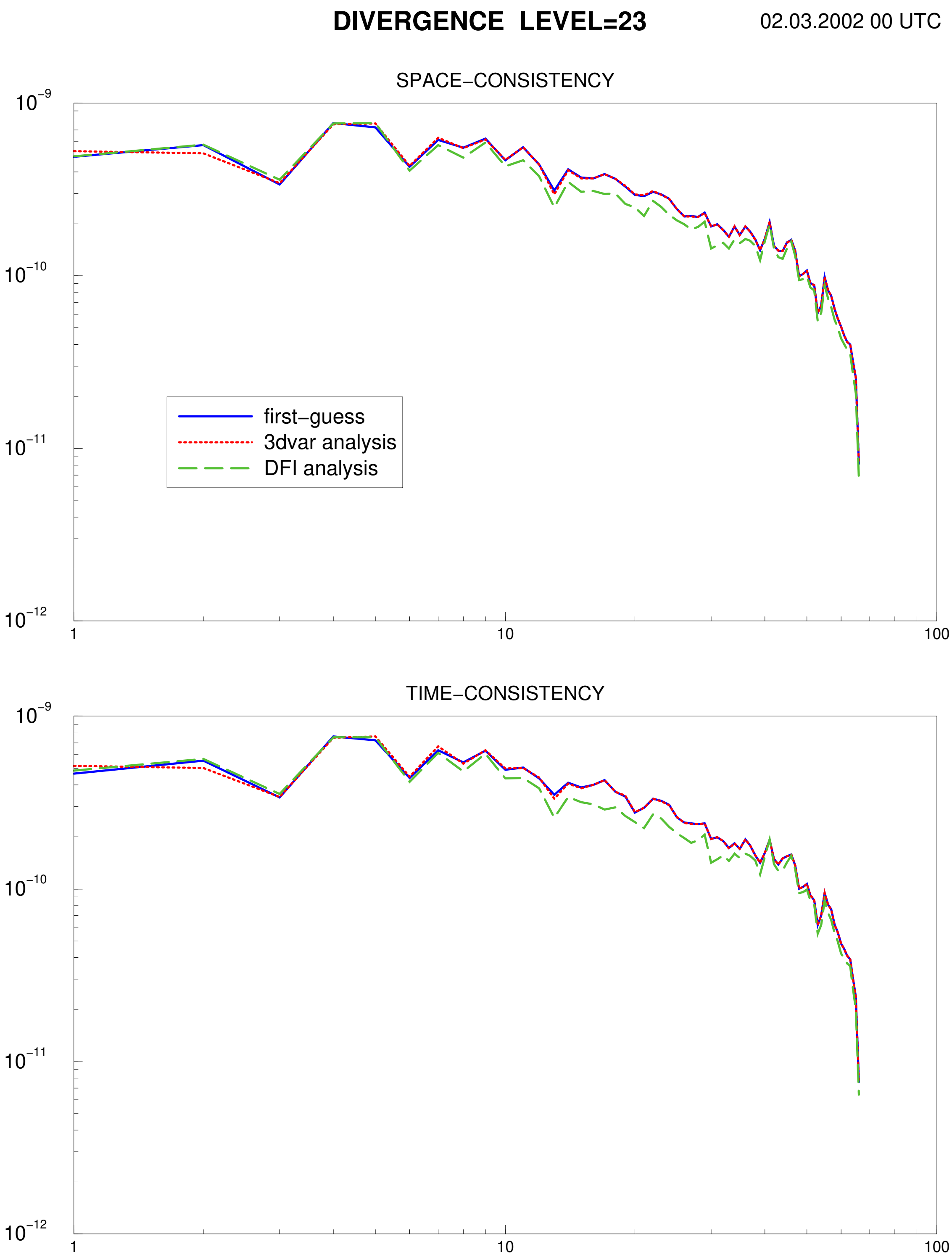

Figure 12: the same as Figure 11, but for the model level 23

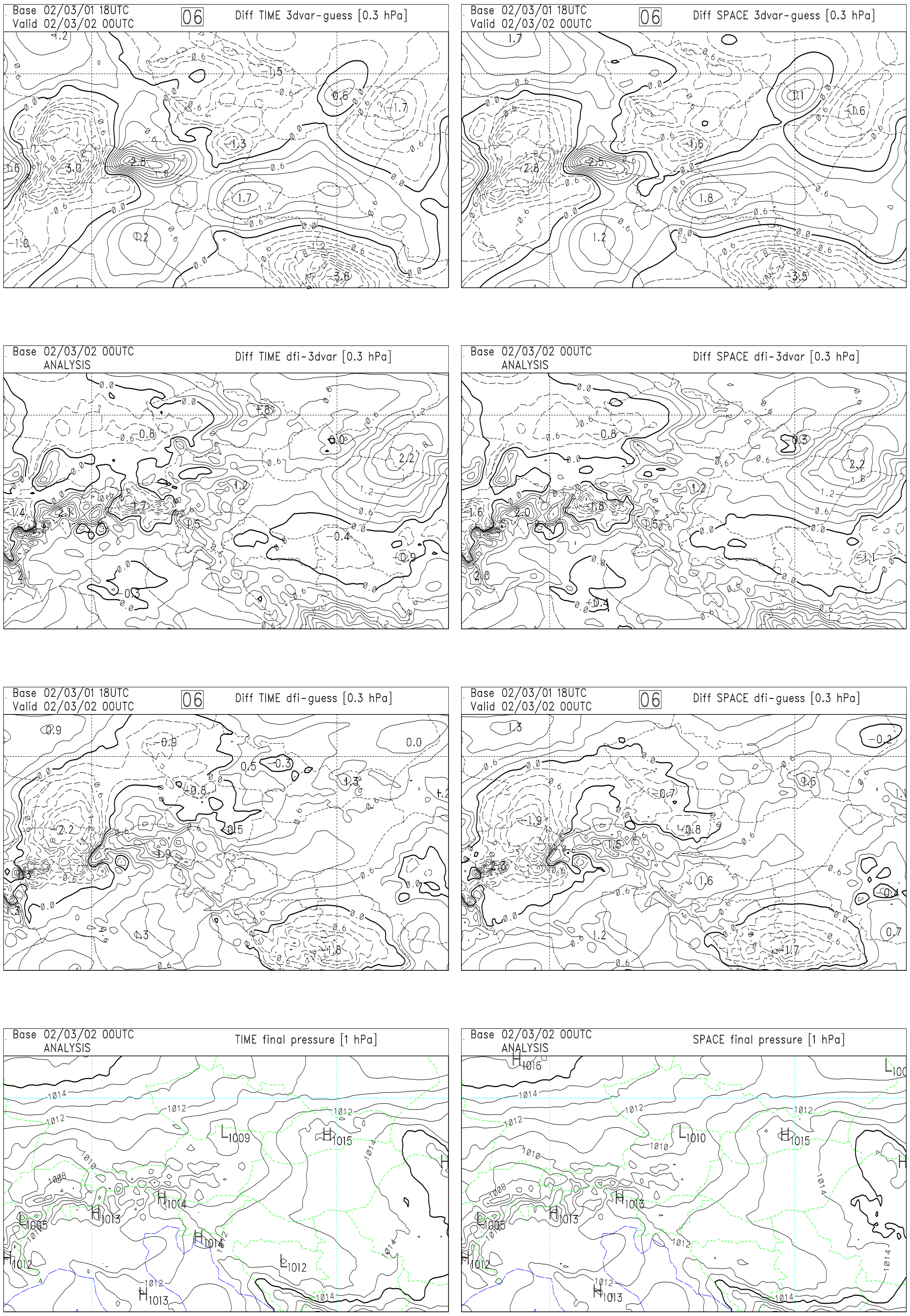

Figure 13: the mean sea level pressure increments and the final state, for the analyses with 3D-VAR in time (left column) and space-consistency (right column), for 02.03.2002, 00 UTC

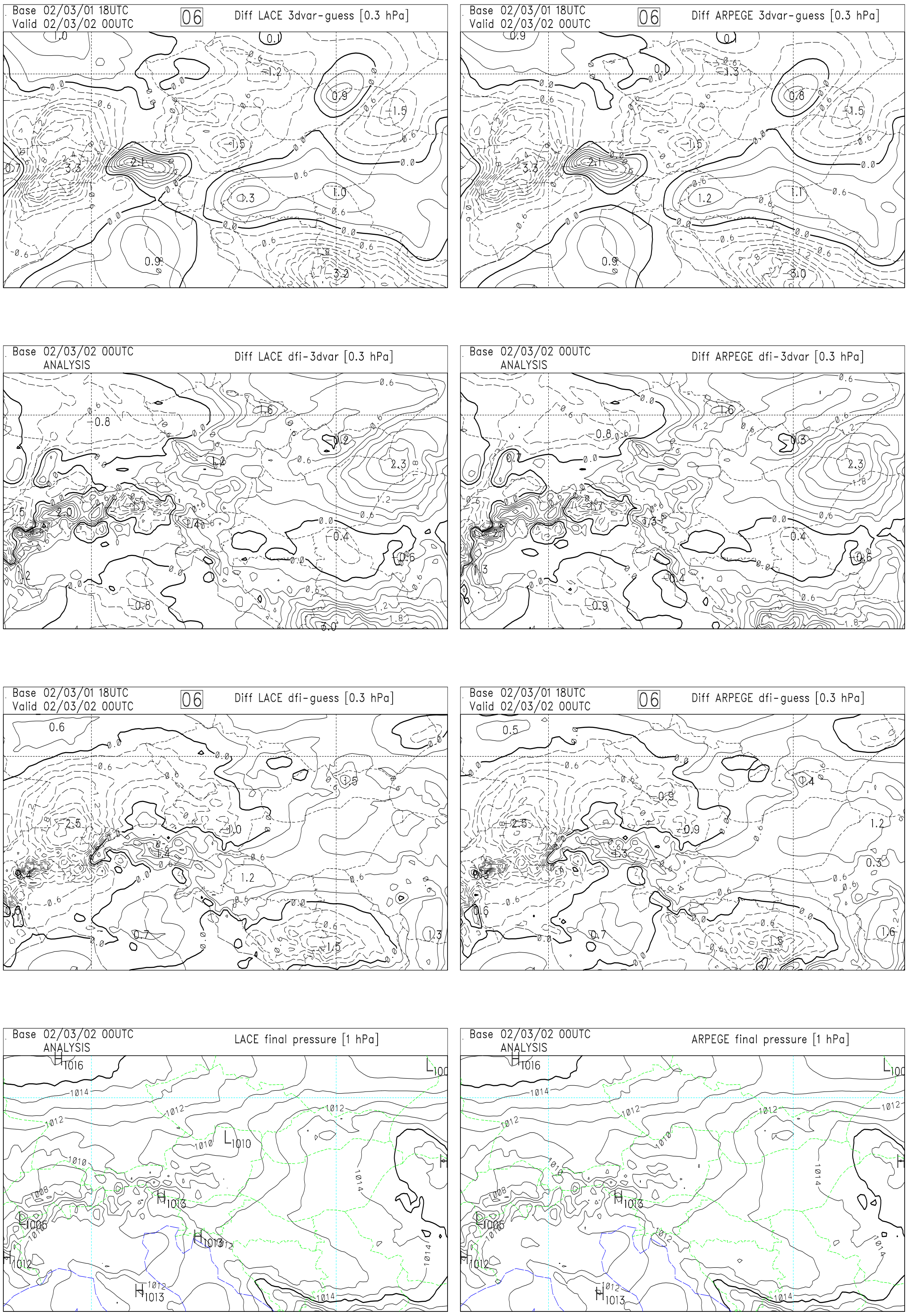

Figure 14: the mean sea level pressure increments and the final state, for the analyses with 3D-VAR with ALADIN/LACE (left column) and ARPEGE files (right column), for 02.03.2002, 00 UTC

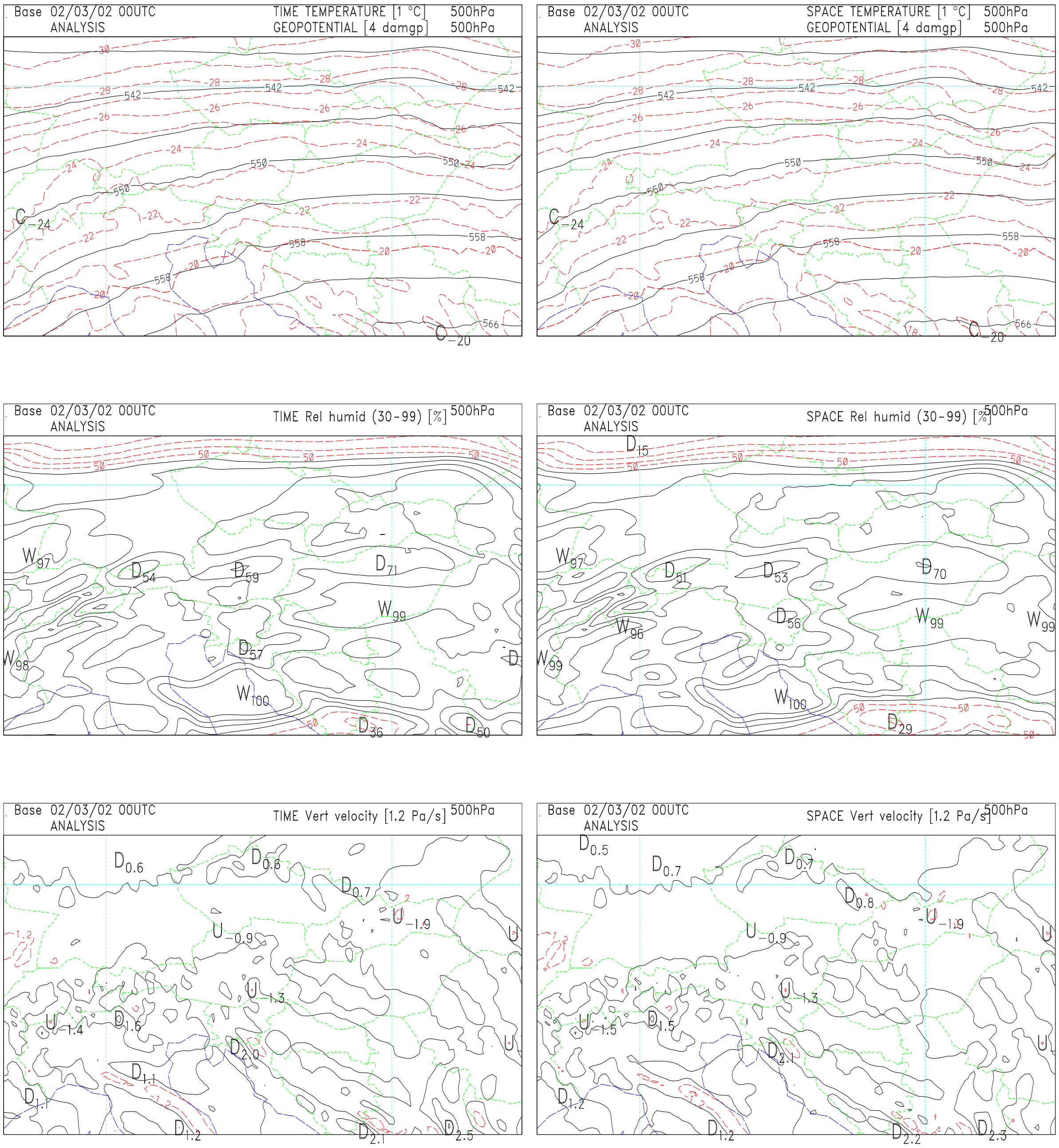

Figure 15: the analyses of temperature and geopotential, relative humidity and vertical velocity fields at 500 hPa, in time (left column) and space-consistency (right column), for 02.03.2002, 00 UTC

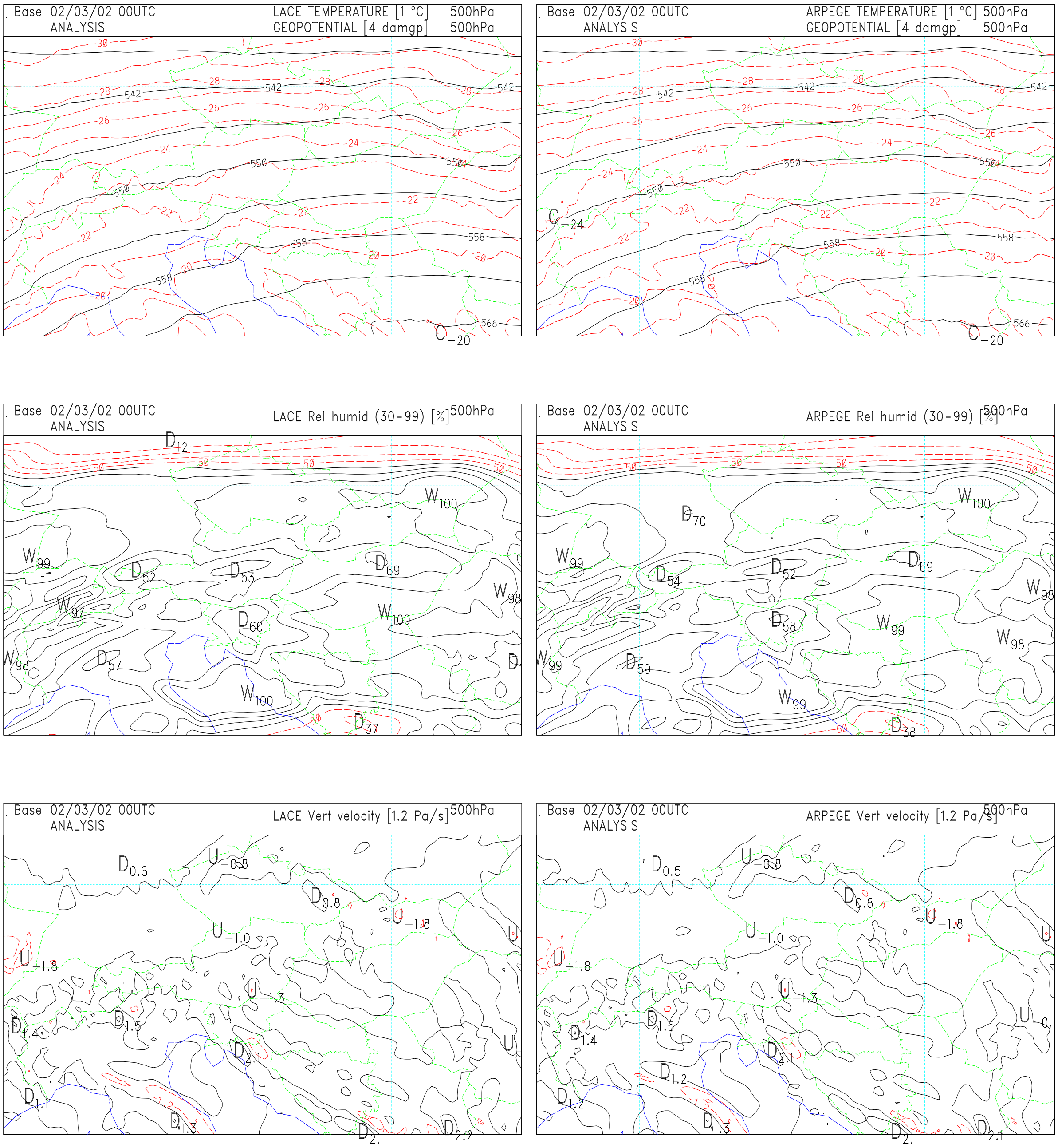

Figure 16: the analyses of temperature and geopotential, relative humidity and vertical velocity fields at 500 hPa, with ALADIN/LACE (left column) and ARPEGE files (right column), for 02.03.2002, 00 UTC

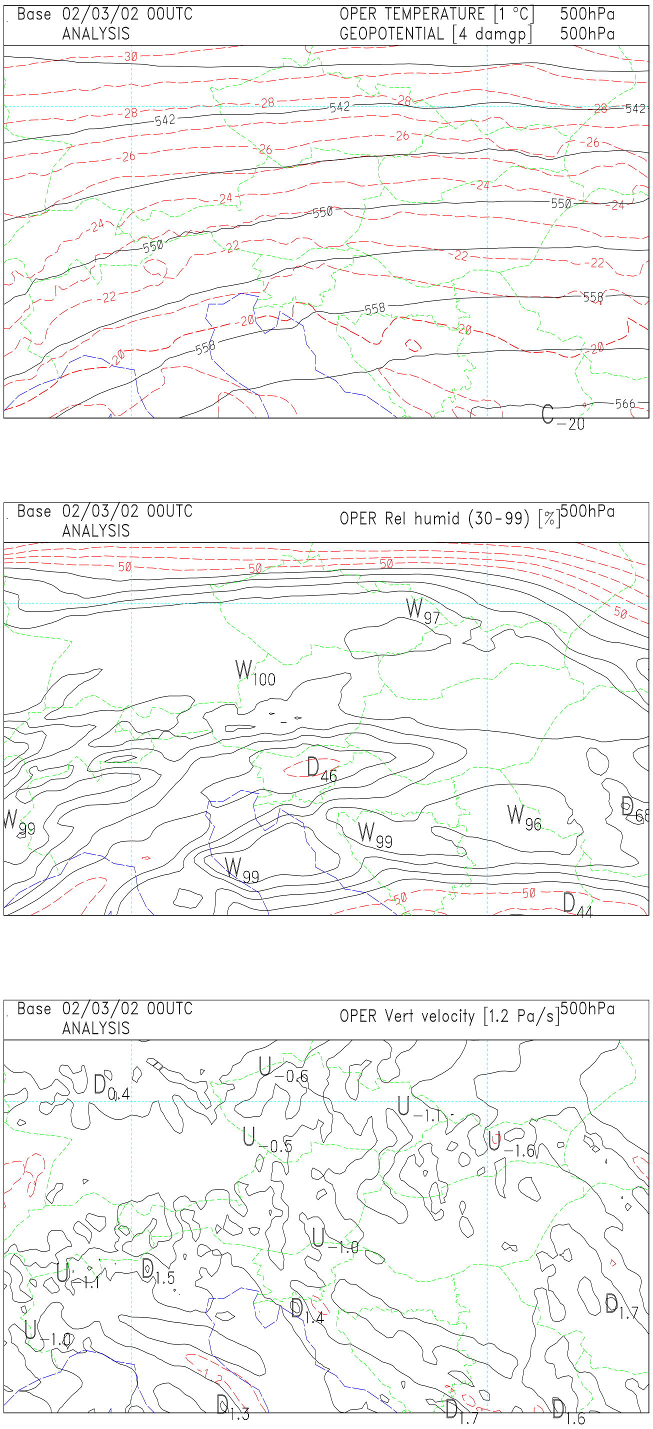

Figure 17: the analyses of temperature and geopotential, relative humidity and vertical velocity fields at 500 hPa, from the operational forecast, for 02.03.2002, 00 UTC

6 Additional corrections

6.1 3D-VAR experiments

This part in my report was added after I discovered that I had a mistake in my scripts, when I performed the experiments described before. In cycling, when I made the 6h integration for the first-guess, I always used digital filter initialization. So the correct description of the experiments is:

- the first set of experiments was performed using in cycling, ALADIN/LACE files from the assimilation cycle as lateral boundary conditions (LBC) for the first-guess (6h forecast from the previous integration), in time/space consistency, with digital filter initialization. In production, the operational ALADIN/LACE files were used as LBC for 24h forecast, with digital filter initialization.

- the third set of experiments was realized using ALADIN/LACE, respectively ARPEGE files (from the assimilation cycle) as LBC, in cycling and in production, and as coupling method, "Moroccan" solution. For the first-guess (6h forecast from the previous integration), space-consistency coupling technique and digital filter initialization were applied. In production the integration was made only for 6h forecast, with digital filter initialization.

So after that, I rerun the second type of experiments, with different initialization methods, to see which is the best choice for 3D-VAR data assimilation scheme.

The new experiments were realized for the same period (25.02.2002 - 02.03.2002) applying for the first-guess (in cycling) digital filter initialization, incremental digital filter initialization, and without any initialization. ALADIN/LACE files from the assimilation cycle, were used as LBC in cycling, and operational ALADIN/LACE LBC files in production. The verification was made for the analysis and 6h forecast from production. The scores of the operational model (in dynamical adaptation) were plotted as reference.

Having a look at the RMSE scores for the 00 UTC (Figures 18, 19), one can see that for analysis the curves are almost identical for temperature, geopotential, and wind direction, no matter what initialization method was used. For relative humidity, wind speed, meridional and zonal wind, the IDFI have worse scores, and with DFI and no initialization, the shapes are similar, showing a small improvement.

After 6h integration, again for temperature, geopotential, wind direction, and moreover for relative humidity, the RMSE scores are the same, for all three initialization methods. Small differences appear for wind speed, meridional and zonal wind, when the DFI gives better results, and the shapes when IDFI and no initialization was used, are almost the same (Figures 20, 21).

The conclusion based only on these scores, would be that the incremental digital filter initialization seems to be the worst option, and between DFI and no initialization, we can choose the DFI, but the difference is not so big.

The echkevo scores were plotted for the same days and points as before, but the time evolution of the mean sea level pressure was checked during the 6h forecast in cycling for the 3D-VAR experiments in time-consistency with different initialization methods (Figures 22, 23). One can see large oscillations for the points over the mountains, when DFI was used. For the other points the shapes are rather smooth, compared to those with IDFI and no initialization, which look more irregular.

These scores emphasize that for 3D-VAR experiments we have to use digital filter initialization in cycling.

Figure 24 shows the echkevo scores, when the time evolution of the mean sea level pressure was checked during the 6h forecast in production, for the operational forecast and using 3D-VAR scheme with different initialization methods in cycling and in production. The figure is the same as Figure 9, only that this is the correct one. So it can be seen that the fields are in balance, when DFI was used in production (for the operational model, and also with 3D-VAR scheme). Without initialization, the noise appears especially for the first time-steps. This confirms that we need to apply digital filter initialization also in production.

6.2 Final conclusions

After these new experiments with 3D-VAR scheme for the double-nested limited area model ALADIN/Hungary it was shown that the digital filter initialization must be used in cycling for the first-guess, and in production, for the forecast.

According to this conclusion, we can say that the other two sets of experiments (the first and the third one's) were performed correctly. So the conclusions are the same as before, except the one referring to the initialization method.

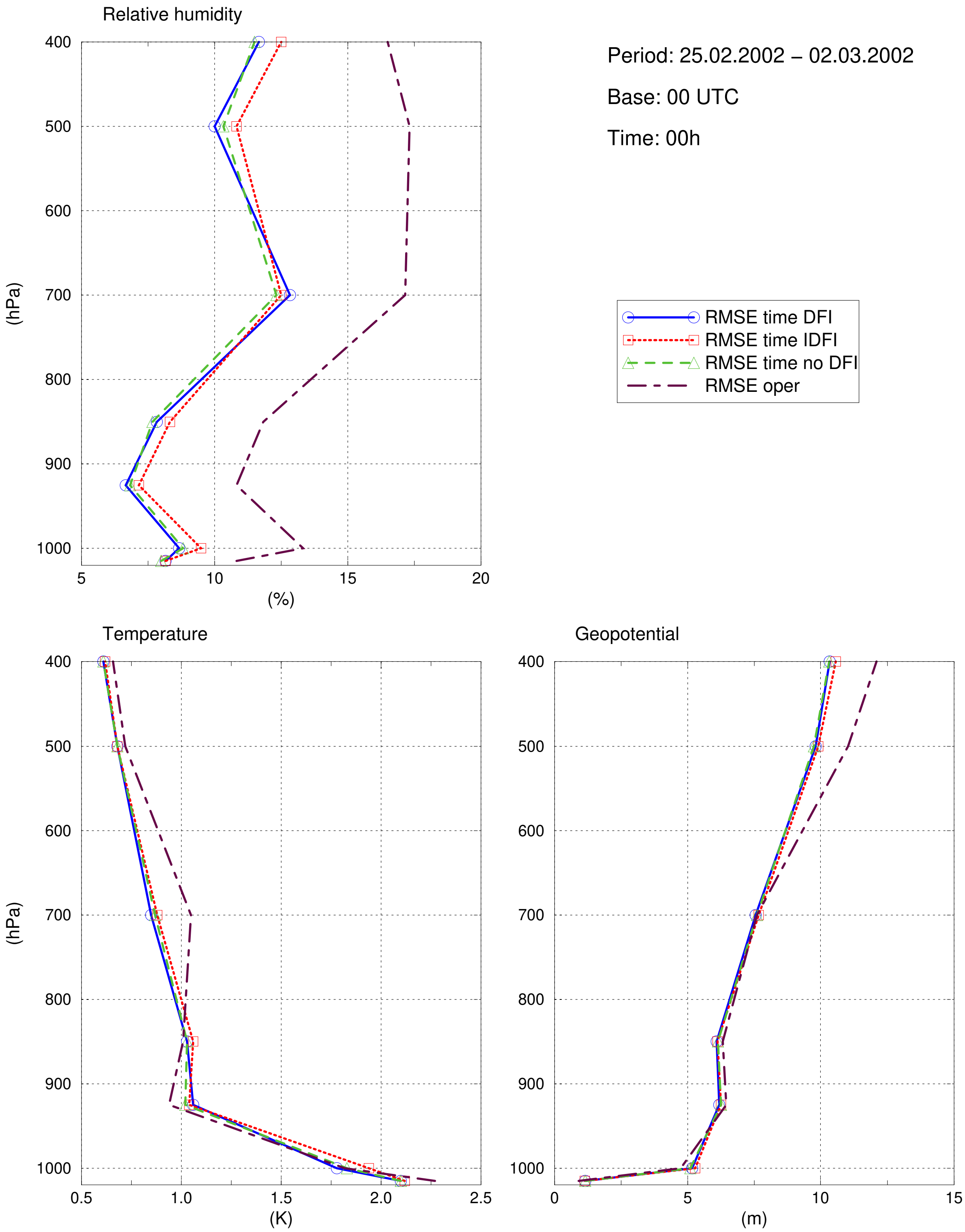

Figure 18: the vertical profile of RMSE for the operational analysis (*oper*), and using 3D-VAR scheme in time-consistency with DFI (*time DFI*), time-consistency with IDFI (*time_idfi*), and time-consistency without initialization (*time no DFI*), for relative humidity, temperature, geopotential

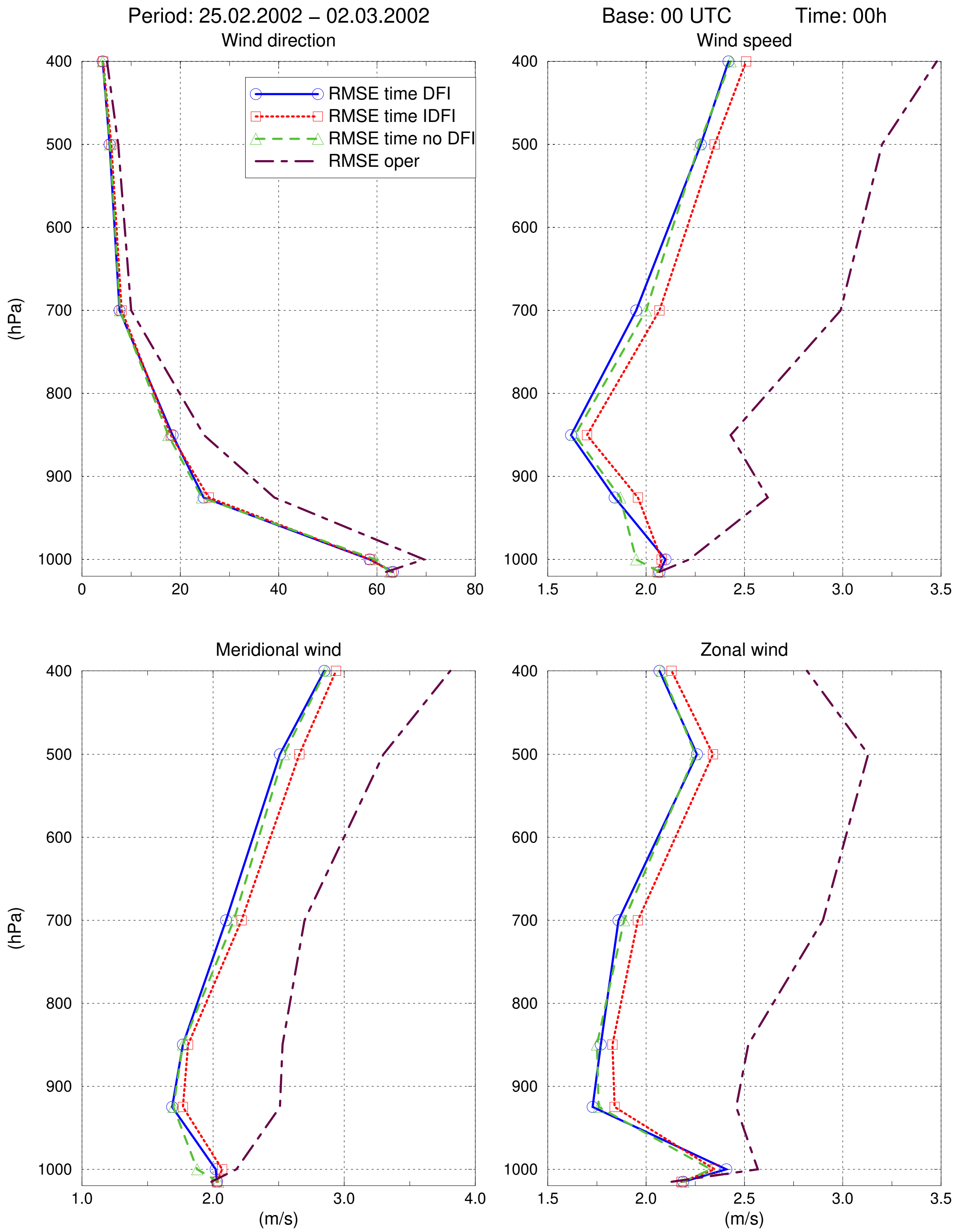

Figure 19: the vertical profile of RMSE for the operational analysis (*oper*), and using 3D-VAR scheme in time-consistency with DFI (*time DFI*), time-consistency with IDFI (*time_idfi*), and time-consistency without initialization (*time no DFI*), for meridional and zonal wind, the direction and speed of the wind

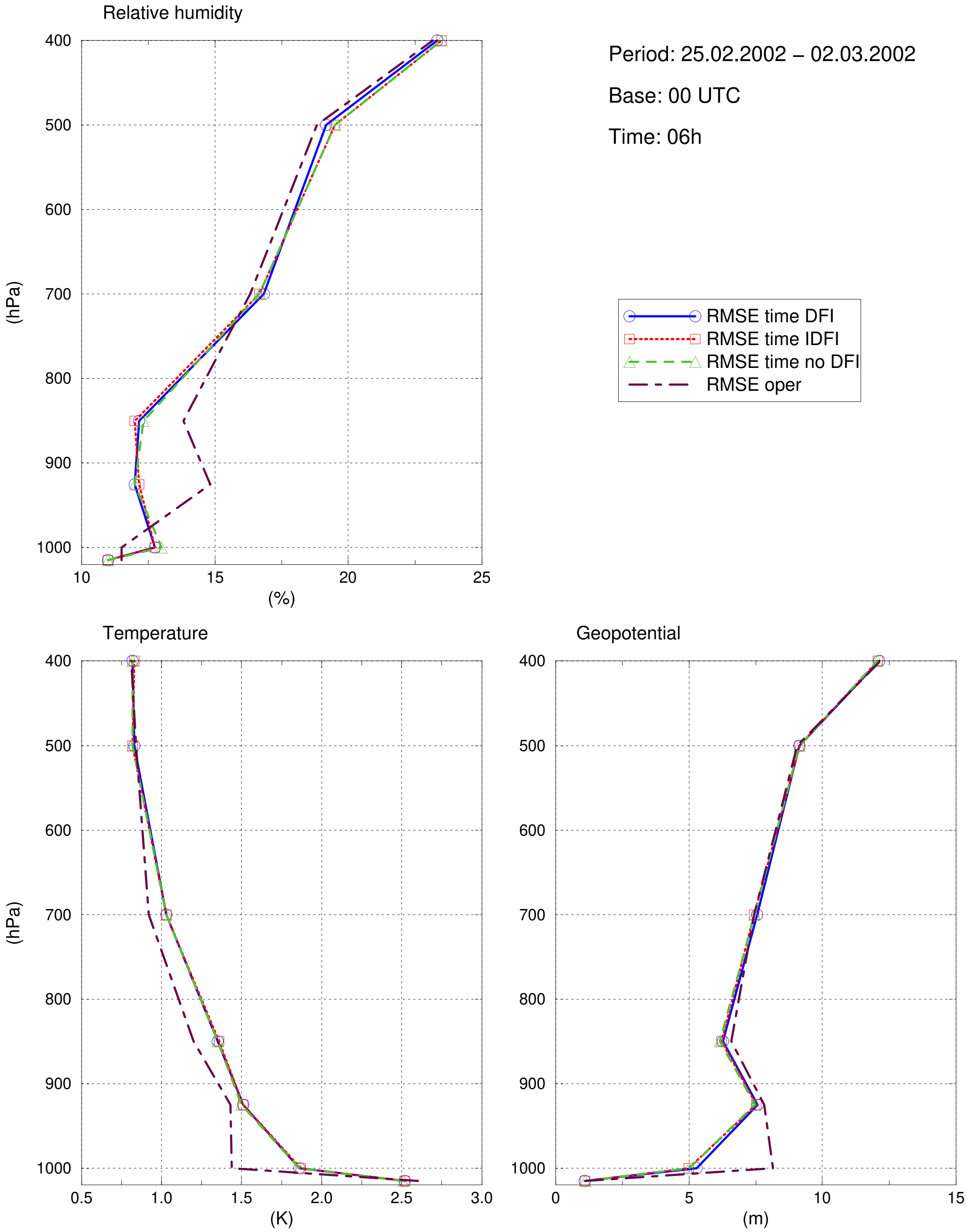

Figure 20: the same as Figure 18, but after 6h integration

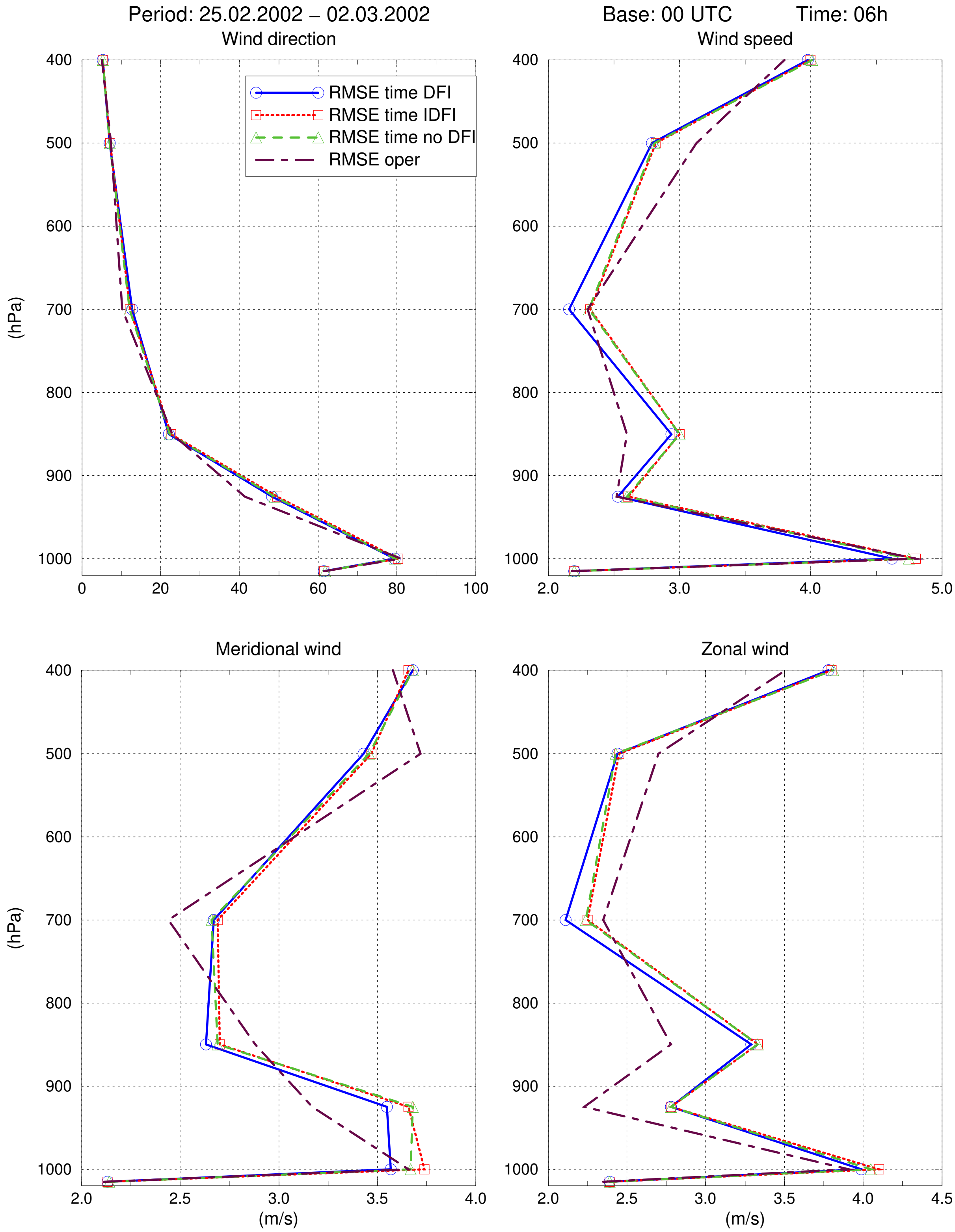

Figure 21: the same as Figure 19, but after 6h integration

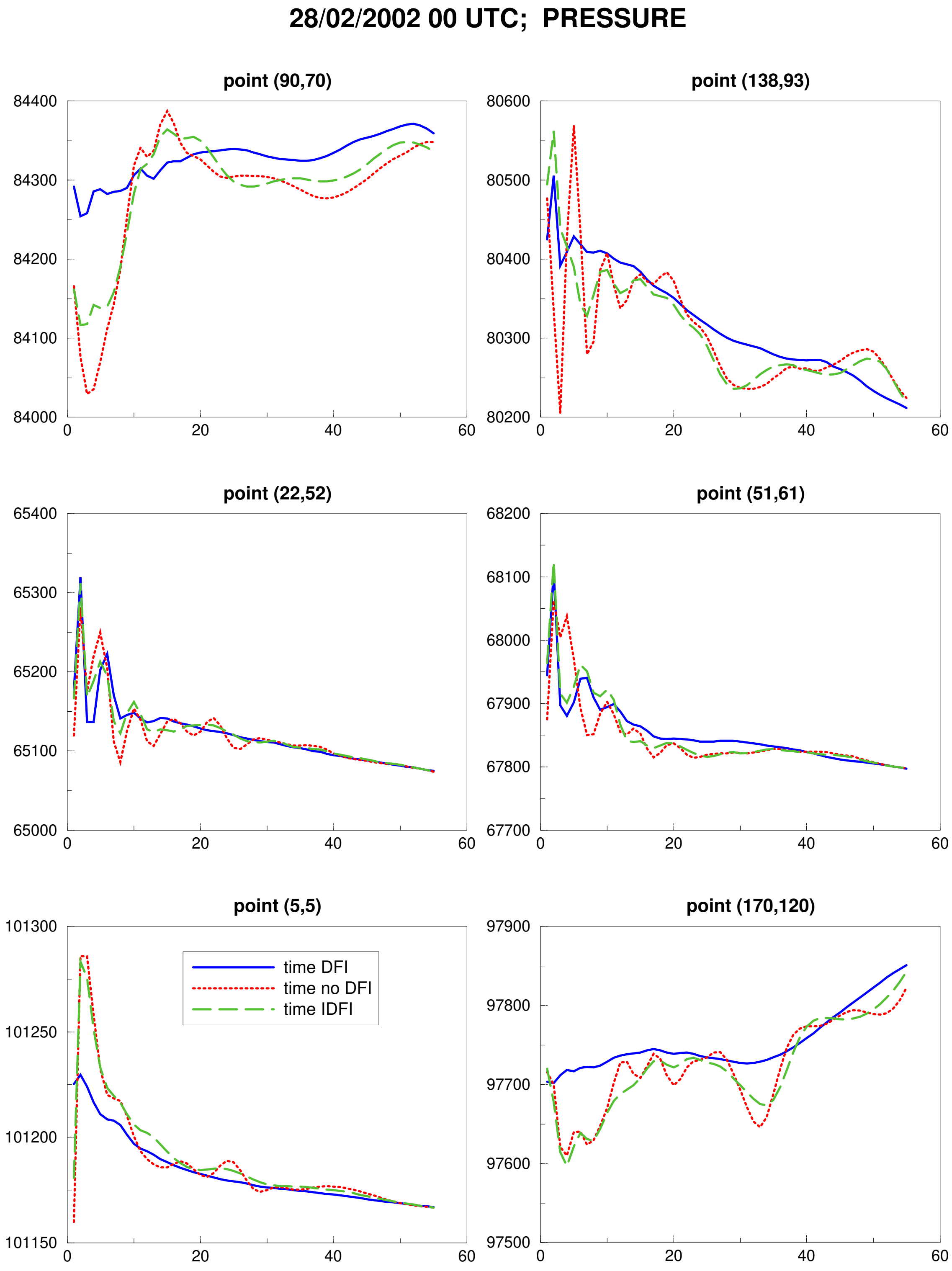

Figure 22: the echkevo scores for six different points, for the forecast using 3D-VAR scheme in time-consistency with DFI in cycling (*time DFI*), time-consistency without initialization in cycling (*time no DFI*), time-consistency with IDFI in cycling (*time IDFI*)

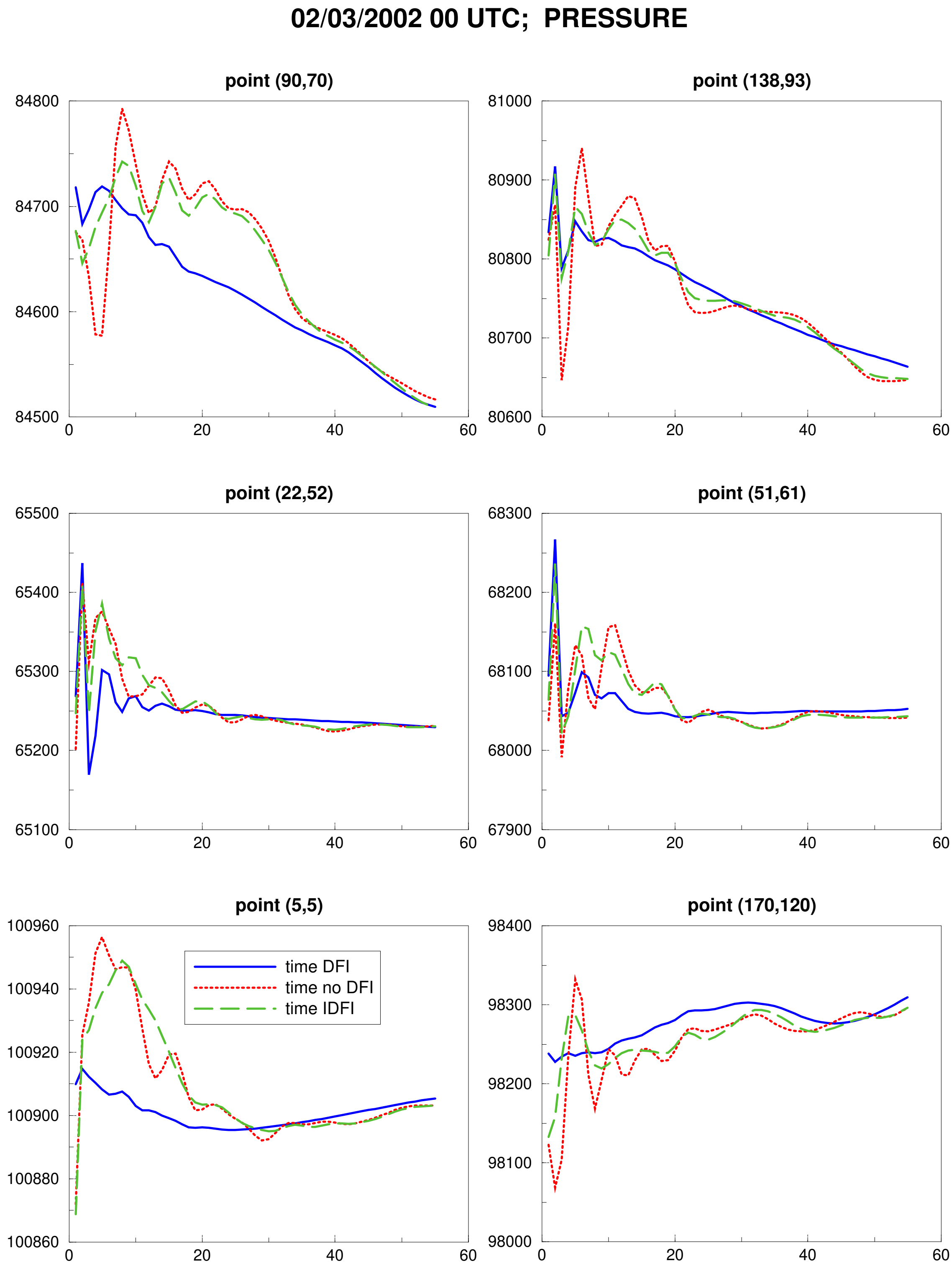

Figure 23: the echkevo scores for six different points, for the forecast using 3D-VAR scheme in time-consistency with DFI in cycling (*time DFI*), time-consistency without initialization in cycling (*time no DFI*), time-consistency with IDFI in cycling (*time IDFI*)

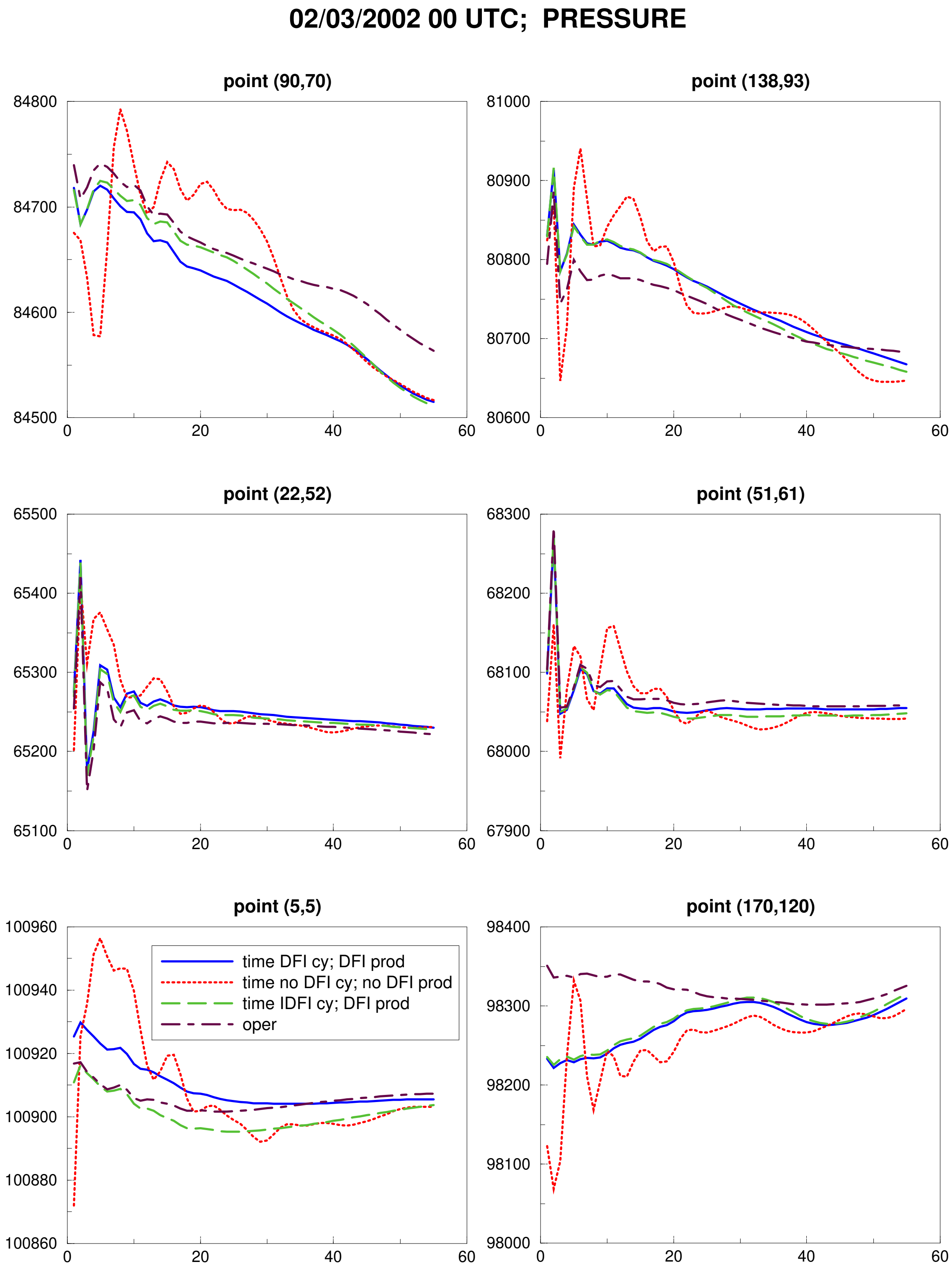

Figure 24: the echkevo scores for the operational forecast (*oper*), and using 3D-VAR scheme in time-consistency with DFI in cycling and production (*time DFI cy; DFI prod*), time-consistency without initialization in cycling and production (*time no DFI cy; no DFI prod*), time-consistency with IDFI in cycling and DFI in production (*time IDFI cy; DFI prod*)

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