Implementation of ALADIN 4DVAR prototype at EARS and HMS

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Introduction

The topic studied is of major interest in numerical weather prediction (NWP), where the initial state of the atmosphere is needed to compute the forecasts. The procedure of creating initial condition is quite complex: information provided by meteorological observations, latest forecasts and knowledge of the atmospheric properties is to be combined in an optimal way to provide the state of the atmosphere with a minimal error variance. This is than called "analysis" and serves as a starting point of forecast computations. The present technique, operational at Hungarian Meteorological Service (HMS) and in an experimental phase at Environmental Agency of Slovenia (EARS), is 3DVAR (three dimensional variational assimilation). This scheme is very efficient for the assimilation of observations measured at regular analysis times (e.g. every 6 hours). The scheme uses all observations as if they were made exactly at the analysis time. The possible mismatch of actual measurement time and analysis time introduces an error for frequent, continuous or irregular observations. 4DVAR (four dimensional variational data assimilation) can be seen as a time extension of 3DVAR, which allows observations to enter the model at more accurate time. Also 4DVAR enables a flow dependent representation of the background errors in the analysis through the time propagation of the Jb normalized model state (term $\mathbf{HBH}^T$ in the BLUE equation). The 4DVAR minimization is much more complex and costly compared to 3DVAR because it needs a forward and backward model forecast for the period of time window (typically 6 hours) in each iteration step. To do this, some linear approximations of the full model and its adjoint are used.

Implementation of 4DVAR prototype

A prototype 4DVAR system of the ALADIN model has been set up first in France and then in Sweden, which was adapted to the Slovenian computer platform during my stay. Our starting point was the Slovenian quasi-operational 3DVAR system, which was then completed with the following elements (both at EARS and HMS locally). All the work was done under the SMS environment:

- Preparation of observations in time-slots: this prepares the use of observations for 4DVAR where they are grouped in 1 hour slots from –0:30 min to +0:30 min. This means that in case of a 6 hour assimilation window we group the observations in 7 time-slots

- 4D screening: this enables the computation of obs-model differences for each time-slot according to a 4D model trajectory as well as the quality control of observations.
- Interpolation of the 4D model trajectory to a low resolution model geometry: this step is needed to enable a cheaper (in CPU) 4D variational minimization
- 4D variational minimization: this step provides the increment of the initial field itself by combining the 4D model trajectory with the observations continuous in time. This is the most demanding part of the 4DVAR assimilation in terms of CPU and computer memory as it includes about 15 integration of the model (its linear and adjoint version) for 6 hours.

•Interpolation of the fields from low to high resolution using FullPos. A correction to the FullPos code had to be applied, with help from Norwegian meteorological institute. This step involves transformation of low resolution analysis and low resolution (truncated) first guess

•Trajectory run: it updates the observational departures with respect to model state after the low resolution minimization so the observations are compared again to more realistic model state. It also adds the low resolution increments to the first guess at high resolution.

•Surface blending: after the low resolution minimization, surface and soil fields are copied from the first guess. This is dome in order to avoid the impact of simplified forward and backward integrations on those fields.

•Outer loops: using the steps described above, it was possible to repeat minimizations at low resolution, each followed by the trajectory run. The benefit having more outer loops is expected from the re-linearizations of the model trajectory used in the minimization step.

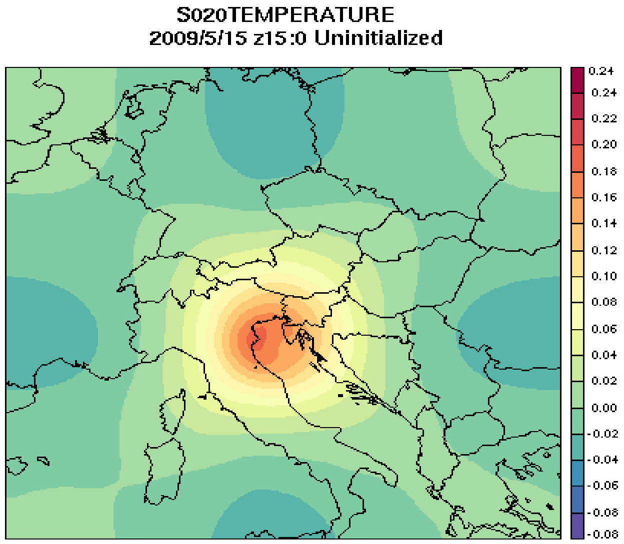
Study of observation increments

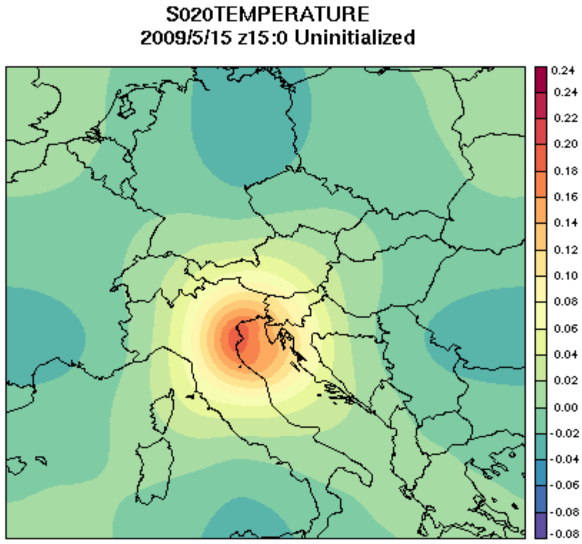
The system was tested mostly using 1 observation because of the time constraint (minimization is much quicker as only 1 iteration is needed). After that, the system was tested also using a complete set of aircraft (AMDAR) observations. Still using the 4DVAR prototype at EARS, some experiments were carried out remotely to validate 4DVAR algorithm at low and high resolutions compared to 3DVAR. In a single observation experiment we used one radiosounde observation of temperature above Ljubljana (at around 500 hPa). The experiment was carried out with minimizations at high (4.4 km) and low (13.2 km) resolution.

- Comparison of minimizations at different resolutions showed some small differences in shape, magnitudes and position of analysis increment. The choice resolution affected mainly the low level moisture fields.
- Comparison to 3DVAR showed increased anisotrophy of 4DVAR analysis increment and differences in magnitude and correlation lengths of the analysis increments.

- In single observation 4DVAR experiments the problem of biperiodic increments seems to be even more annoying than in 3DVAR
- A test with all currently available observations from OPLACE was carried out, in order to confirm that the code and scripts work for all types of data and to assess the time constraints..

Figures





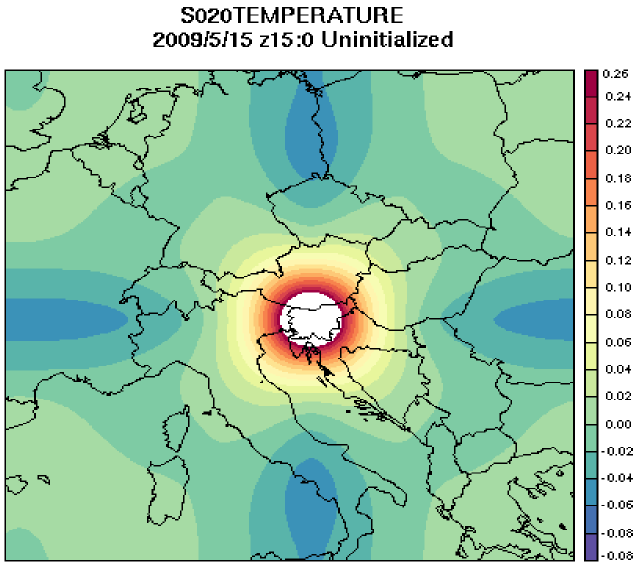
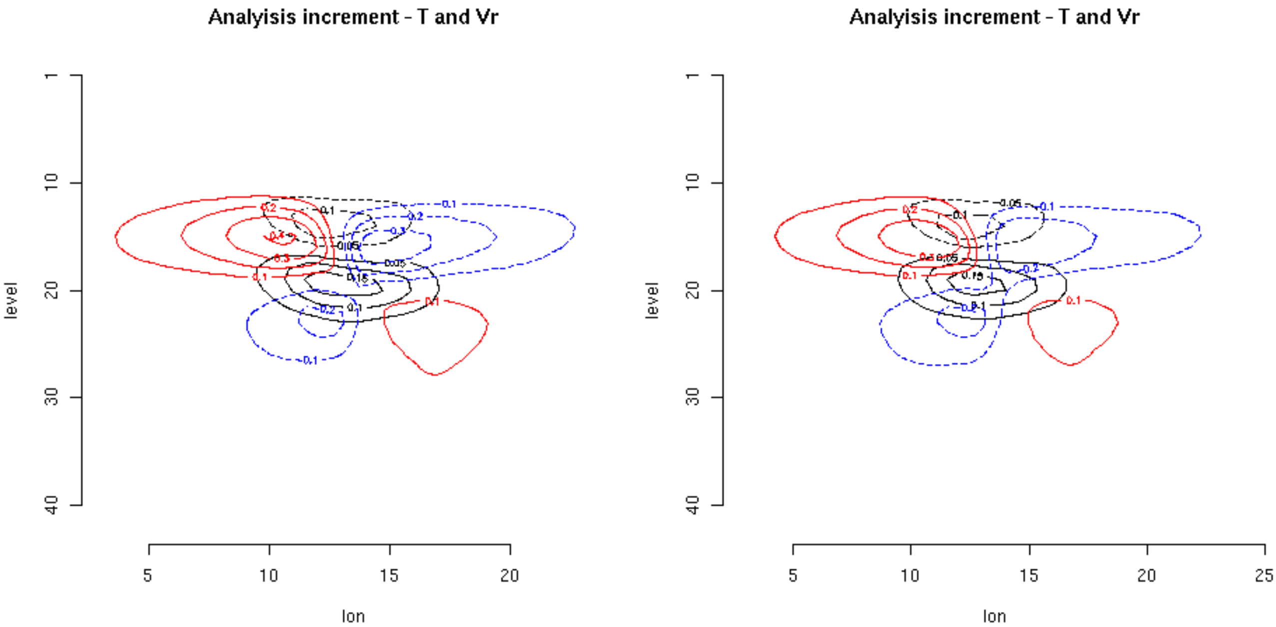


Figure 1: Temperature analysis increments at observation level (~500 hPa) Observatioonal time window is 6h and observation is in the middle of the time window (18 UTC.) The results are shown at the beginning of the time window (15 UTC). Upper left: 4DVAR minimization at low resolution (13.2 km), right: 4DVAR minimization at high resolution (4.4 km), bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).



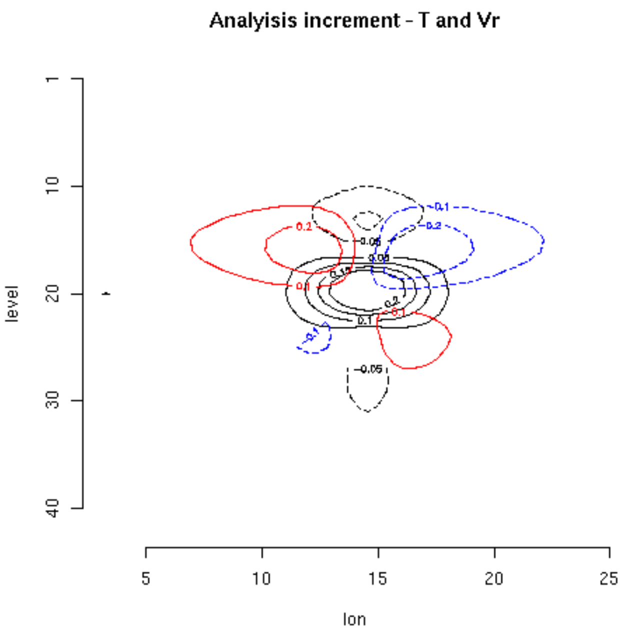
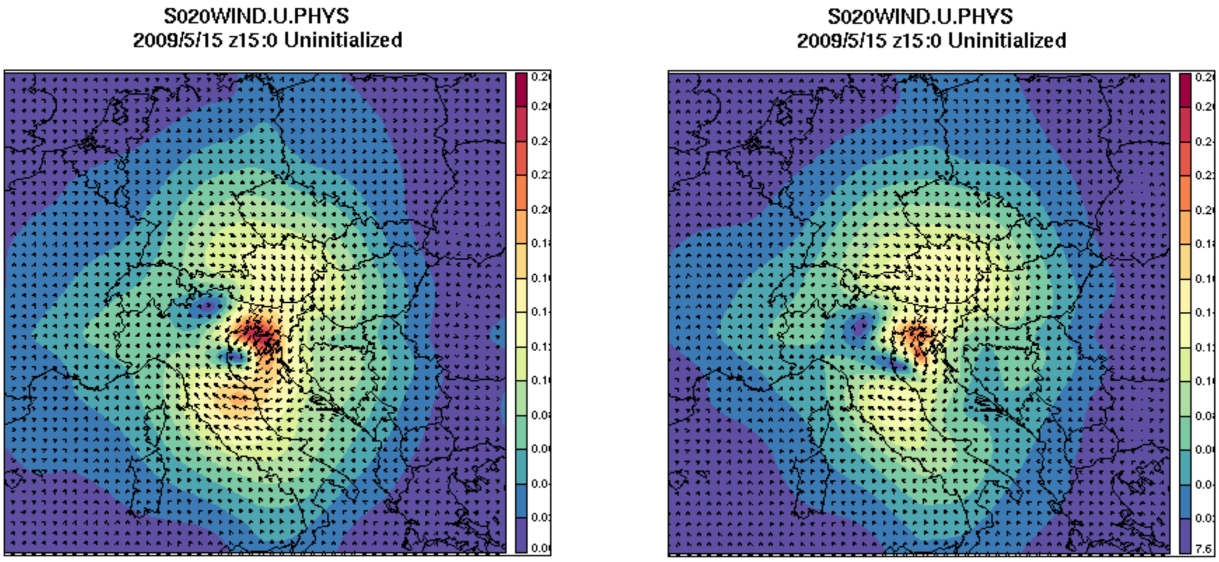


Figure 2: Vertical cross-sections of temperature analysis increments (black contours) and radial winds (red and blue contours). Upper left: 4DVAR minimization(13.2 km), upper right: 4DVAR minimization(4.4 km) bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).



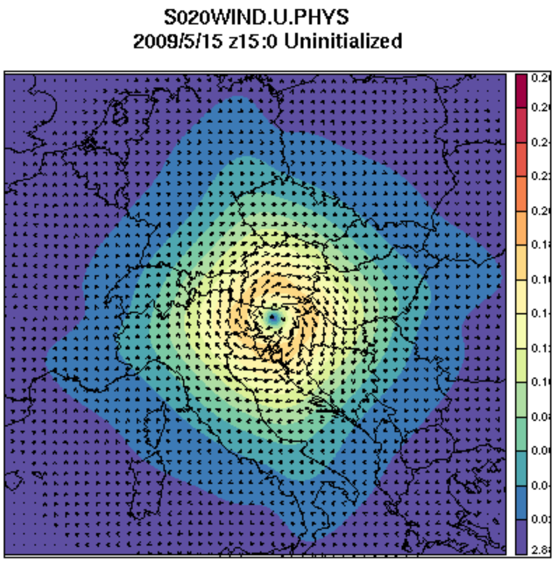
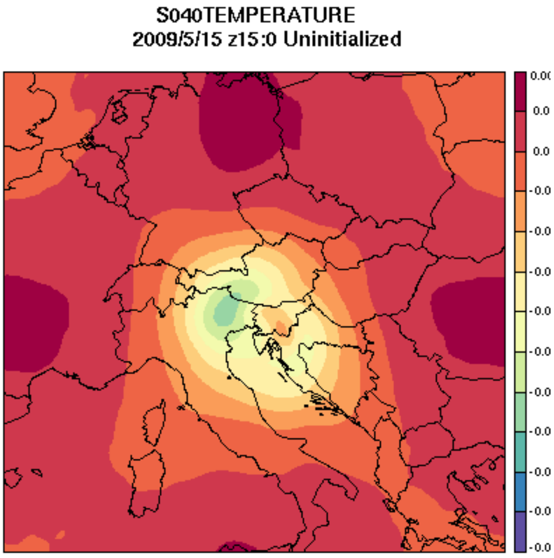
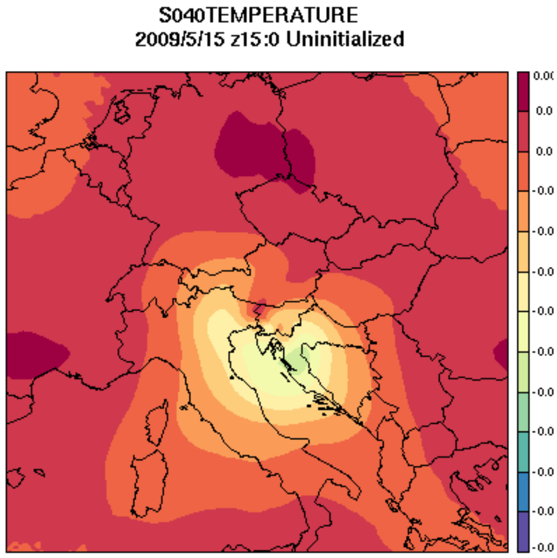


Figure 3: Wind analysis increments at the level ob temperature observation. Upper left: 4DVAR minimization(13.2 km), upper right: 4DVAR minimization(4.4 km) bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).





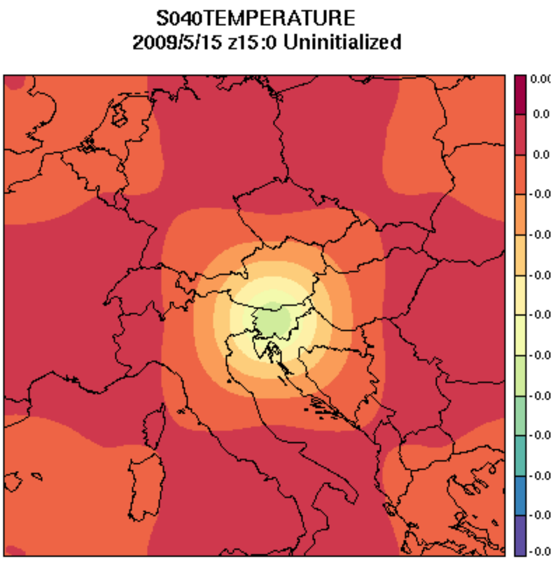
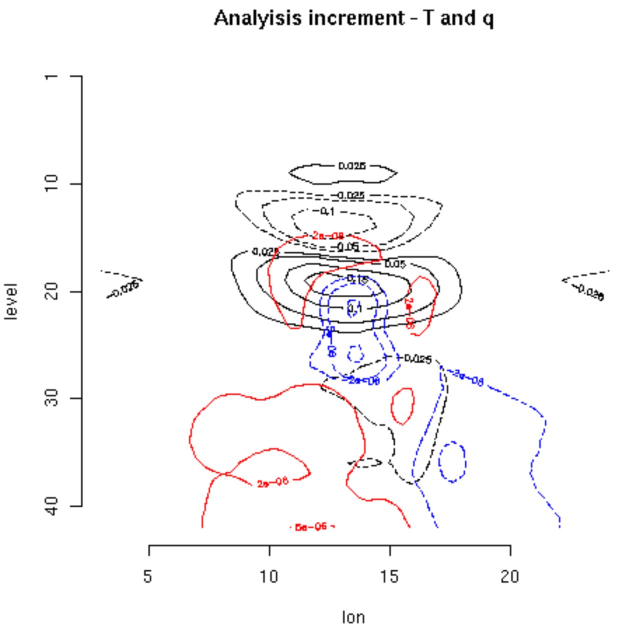
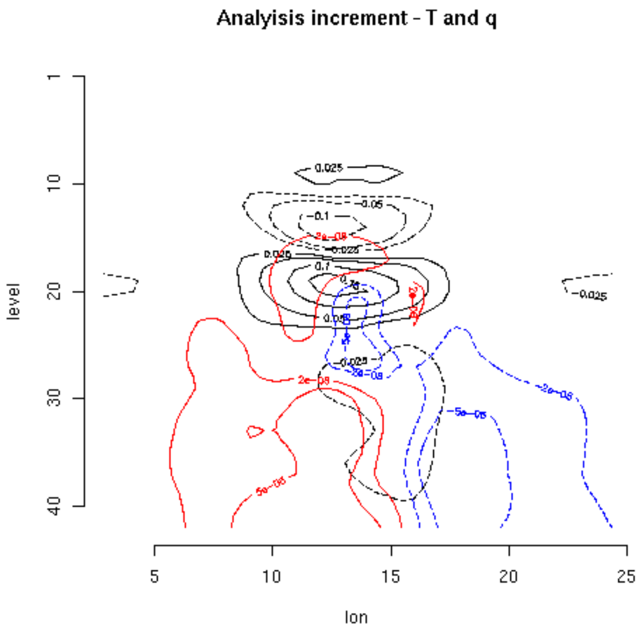


Figure 4: Low level temperature increments. Upper left: 4DVAR minimization(13.2 km), upper right: 4DVAR minimization(4.4 km) bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).





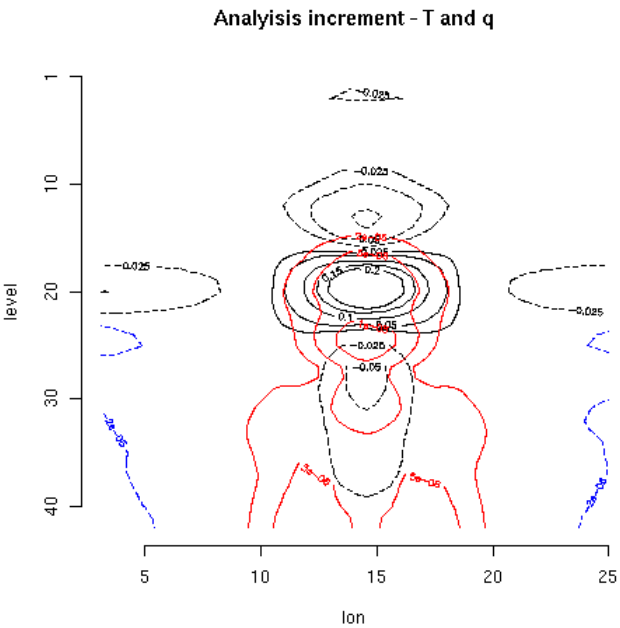
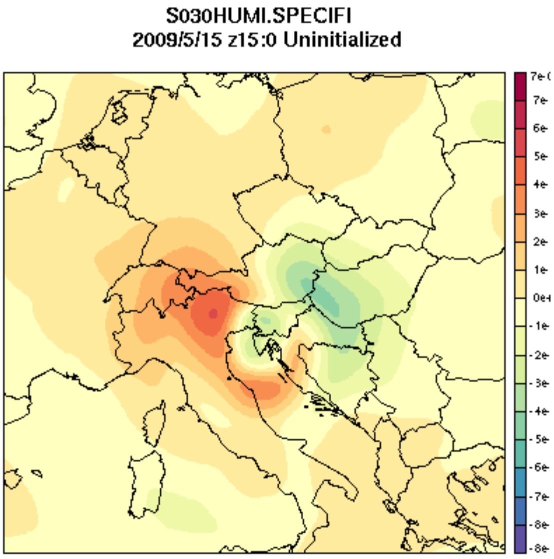
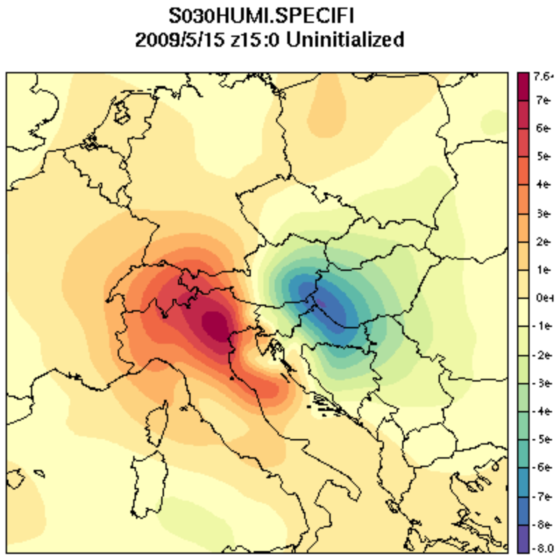


Figure 5: Vertical cross-sections of temperature analysis increments (black contours) and relative humidity (red and blue contours). Upper left: 4DVAR minimization(13.2 km), upper right: 4DVAR minimization(4.4 km) bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).





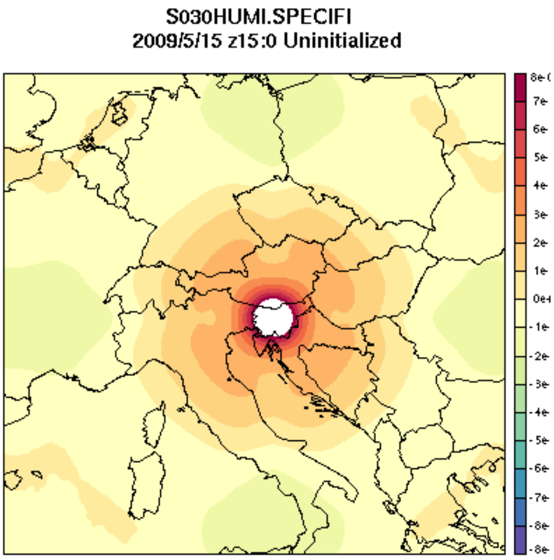


Figure 6: Lower troposphere humidity increments. Upper left: 4DVAR minimization(13.2 km), upper right: 4DVAR minimization(4.4 km) bottom: 3DVAR at 4.4 km using the same initial obs-guess departure (1 K).

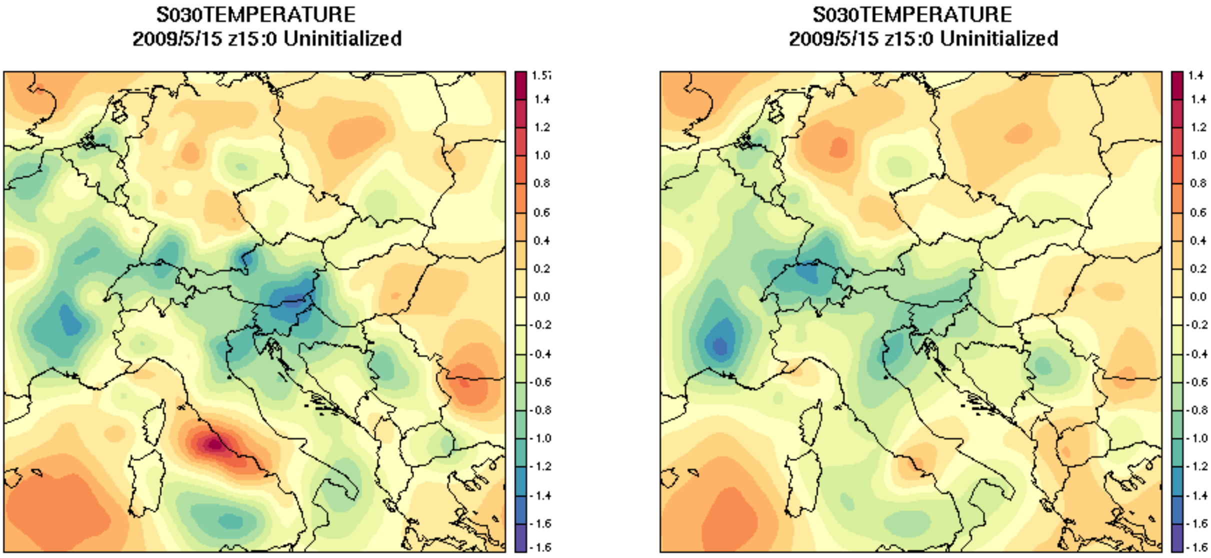


Figure 7: Full observation (all obs. available from OPLACE) temperature increments in the lower troposphere. Left: 4DVAR minimization(13.2 km) after 20 iterations, right: 4DVAR minimization(4.4 km) after 10 iterations with CONGRAD minimizer.

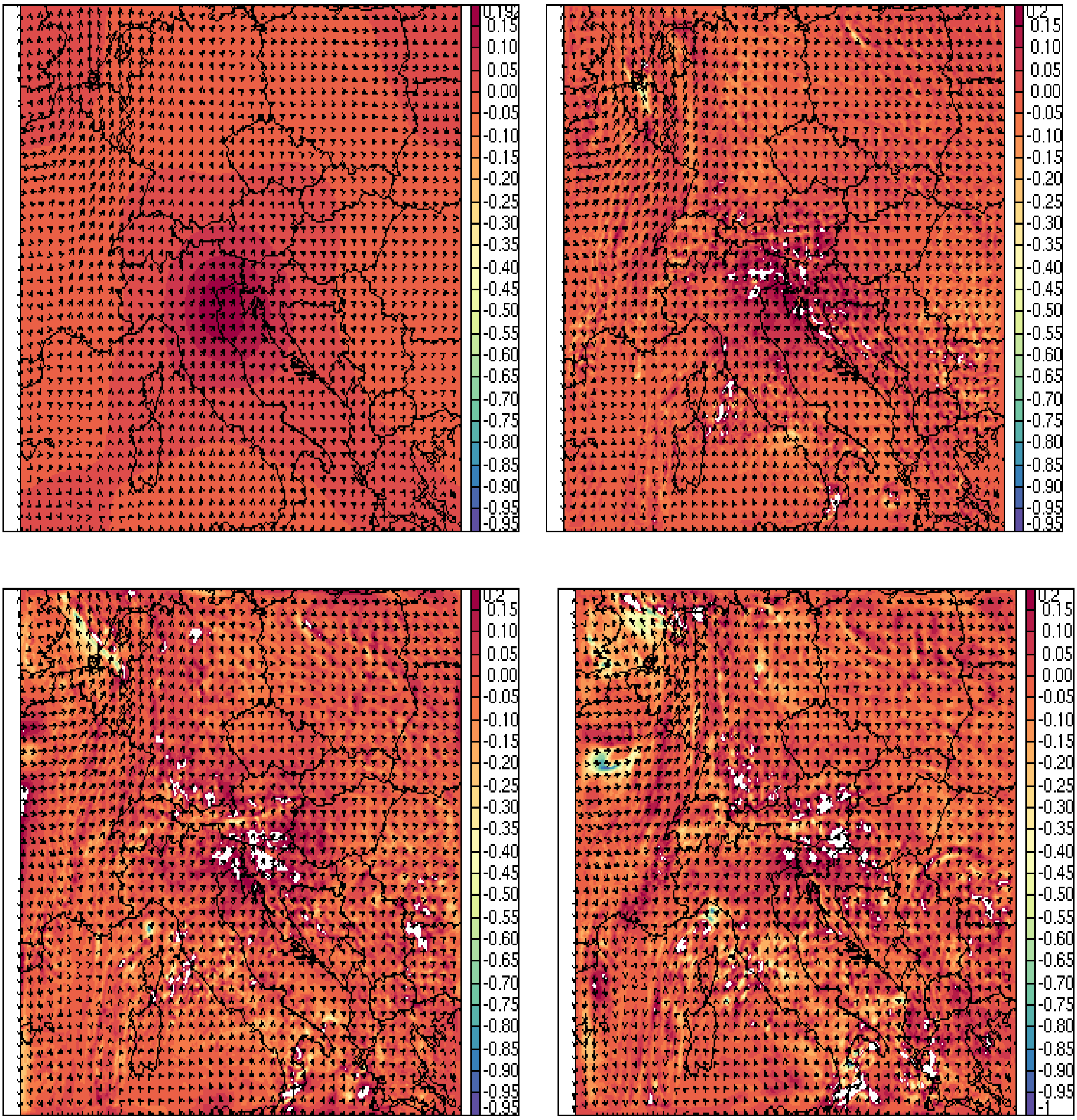


Figure 8: Propagation of single observation temperature increment on the full resolution over the assimilation window (DFI used). Initial increment (upper left), +2 h forecast (upper right), +4 h forecast (bottom left), +6 h forecast (bottom right).