Study of spatially varying flow-dependent background error variances in ALADIN implementation outside Météo-France II

Antonín Bučánek
antonin.bucanek@chmi.cz

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Contents

1 Introduction

It would be nice to have data assimilation algorithm with nonhomogeneous and flow dependent background errors. One simple solution could be done in ALADIN[1] 3DVAR scheme where grid-point background error standard deviations will be used to introduce nonhomogenity and potentially flow dependency.

The increments of the state vector are changed to the control variable during minimization of the cost function to achieve better convergence. The variable change involve a normalization by the background error standard deviations (stde). By default normalization is done in the spectral space where the control variable increments are scaled by the averaged standard deviations ($\sigma_b(lev)$ is one number per vertical level). When normalization is done in the grid-point space, background error standard deviations could depend on their geographical position. This will introduce demanded nonhomogenity in the specification of background errors.

Strajnar [2008] have adapted ARPEGE[2] code for ALADIN and showed the potential for use of the grid-point σ_b maps. Mohamed Zied Sassi was invited to Prague for period of 23. 9.–18. 10. 2013 to revise the status of usage of the grid-point σ_b maps in ALADIN. To find out if there is necessary workaround to be able to run the σ_b maps outside Meteo-France. To investigate variability of the AEARP[3] maps of background error standard deviations, their implication to the analysis and the forecast. This report complements Sassi [2013] with more technical issues and few academic tests.

Section 2 is focusing on the implementation of the normalization by the grid-point σ_b maps. Variability of σ_b maps computed by AEARP maps of are examined in section 3. Section 4 is devoted to constant σ_b maps which are used in order to verify correctness of their implementation. Single observation experiments are studied in section 5 with artificial σ_b maps. Comments to full observation experiment are in section 6.

1.1 ALADIN setup

A short description of the model version used in the study:

- ALADIN cycle 36t1ope (ALARO-0 with 3MT),
- LACE/CE domain (540×432 grid points, linear truncation E269x215, $\Delta x \sim 4.7$ km),
- 87 vertical levels, mean orography,
- time step 180 s, 3h coupling interval,
- ensemble based B matrix.

2 Technical Implementation

The grid-point σ_b maps are used when LSPFCE = .F. in namelist NAMJG. It is expected that the grid-point σ_b's are stored in the grib file called *errgrib*. The errgrib file could have latlon or Gaussian grid. In case of latlon grid default value of the key LSBLATLONG should be changed to true in namelist NAMJG (LSBLATLONG = .T.). At least vorticity stde (σ_b^{ζ}) or wind stde have to be present in errgrib. If only vorticity stde is provided in ergrib, unbalanced divergence ($\sigma_b^{\eta_u}$), unbalanced temperature and logarithm of surface pressure ($\sigma_b^{T_u}$, $\sigma_b^{lnps_u}$) are set to values of spectral stde computed from B matrix. But unbalanced specific humidity stde ($\sigma_b^{q_u}$) is computed by an empirical formula [Rabier et al., 1998]. This formula is designed for full humidity field as in case of ARPEGE, where humidity is uni-variate.

[1]is the limited area model and Aire Limitée, Adaptation Dynamique, Development International

[2]Action de recherche petite echelle grande echelle, which means research project on small and large scales

[3]Assimilation ensemble ARPEGE

Diagnostics of our B matrix shows that unbalanced part of humidity field is about 80 % of total humidity field, so one can use the formula knowing potential problems. Use of the empirical formula is avoided when humidity $\sigma_b^{q_u}$ is set to constant in errgrib and LRDQERR = .T. is set in namelist NAMJG. After that $\sigma_b^{q_u}$ equals to spectral value computed from B matrix.

The errgrib files computed by AEARP[4] are stored in Meteo-France on machine cougar:

- `/home/m/mxpt/mxpt001/arpege/oper/assim/$YYYY/$MM/$DD/r$NT/errgribvor` ,
- `/home/m/mxpt/mxpt001/arpege/oper/assim/$YYYY/$MM/$DD/r$NT/errgrib_scr` ,

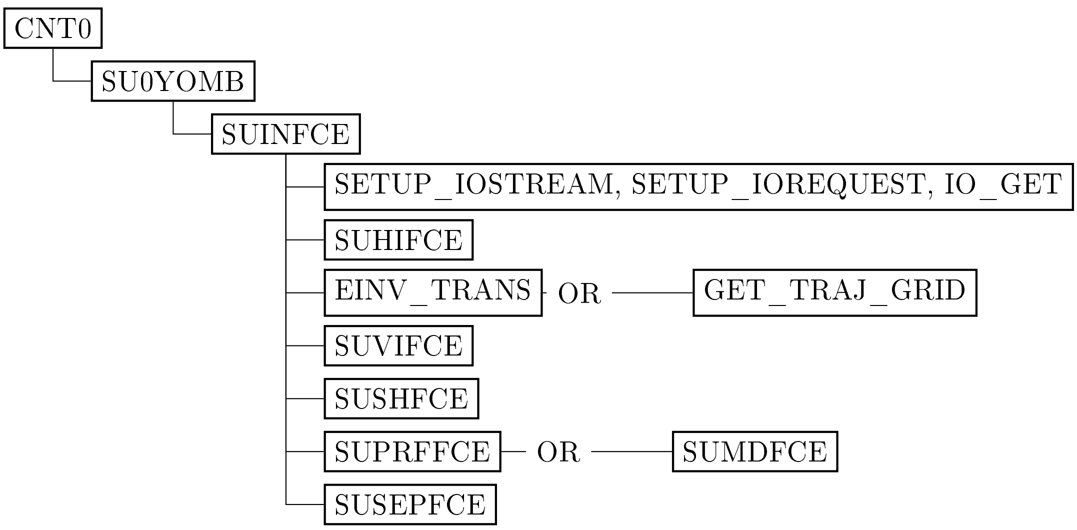
errgribvor is used in minimization and errgrib_scr is used in screening. Both files must be renamed to *errgrib* before execution of screening or minimization. The file errgribvor contains σ_b^{ζ}, $\sigma_b^{\eta_u}$, $\sigma_b^{T_u}$, $\sigma_b^{lnps_u}$, σ_b^{q} in Gaussian grid over the globe. And errgrib_scr contains background error standard deviations of 10 m wind components, 2 m temperature and relative humidity, logarithm of surface pressure, 27 brightness temperatures, total column water vapor and wind components, temperature, relative humidity, specific humidity, geopotential on model levels. Care should be taken to errgribs, errgrib_scr is valid +6 h to the date of the file, errgribvor is valid +3 h to the date of the file, in fact errgribvor contain +6 h forecast from −3 h to the date of the file.

2.1 Setup of grid-point stde maps in screening

The routine INIFGER reads a errgrib (errgrib_scr) file for screening then the routine GEFGER horizontally and vertically interpolates errgrib fields to observation points and writes background errors to ODB.

2.2 Setup of grid-point stde maps in minimization

There are almost no changes in initialization of grid-point σ_b maps in minimization since work of Strajnar [2008] (cy36t1). Text of this paragraph will follow Strajnar's report.



Grid-point σ_b maps are initialized in routine SUINFCE. Reading of errgrib file is done by routines: IO_GET, SETUP_IOSTREAM, SETUP_IOREQUEST. Then σ_b's are horizontally and vertically interpolated from input grid to the ALADIN geometry by SUHIFCE, SUVIFCE. GET_TRAJ_GRID or EINV_TRANS reads background fields in order to be used in computation of humidity background

[4]error files are calculated in routine `arp/var/sujbvarens.F90`, additional spatial filtering is needed to avoid noise in case of small ensemble size

errors (LRDQERR = .F.). This is followed by insertion of spectral values of stde computed from B matrix to variables that are missing in errgrib file except specific humidity standard deviations computed by the empirical formula in SUSHFCE [Rabier et al., 1998].
Mean profiles $\langle\sigma_b(\text{var}, \text{lev})\rangle$ of grid-point background error standard deviations are computed in SUPRFFCE:

$$\langle\sigma_b(var, lev)\rangle = \sqrt{\sum_{i=1}^{NGPTOT} \frac{1}{NGPTOT}\, \sigma_b^2(i, var, lev)}, \tag{1}$$

where $NGPTOT$ is number of grid-points in the ALADIN geometry, var stays for variable, lev for level and i is index of grid-point. If LCFCE = .T. then SUMDFCE is called and horizontally constant background errors are used, grid-point σ_b's equal to spectral average of stde prescribed in B matrix. Unfortunately there is a bug and the result is not the same as for spectral case (LSPFCE = .T.) because there is a division of vorticity and divergence by map factor in SUSEPFCE. Optionally, if ALADIN has L3DBGERR = .F. then SUMDFCE calculates vertically averaged horizontal pattern of background error for vorticity. It means the same pattern for all vertical levels.

$$patt(i) = \sqrt{\frac{\sum\limits_{lev=1}^{NLEV}\left[\sigma_b^{\zeta}(i, lev)\right]^2}{\frac{1}{NGPTOT}\sum\limits_{i=1}^{NGPTOT}\sum\limits_{lev=1}^{NLEV}\left[\sigma_b^{\zeta}(i, lev)\right]^2}}. \tag{2}$$

Last step is routine SUSEPFCE where grid-point background error standard deviations are usually normalized by mean profiles and multiplied by spectral stde (σ_{SP}) computed from B matrix (eq. 3) but there are two other options (b, c).

$$\widetilde{\sigma_b}(i, var, lev) = \underbrace{\frac{\sigma_b(i, var, lev)}{\langle\sigma_b(var, lev)\rangle}}_{\text{scaling factor}}\, \sigma_{SP}(var, lev), \qquad \text{where} \tag{3}$$

$$\sigma_{SP}(var, lev) = REDNMC\sqrt{\sum_{kstar}\sigma_{SP}^2(kstar, var, lev)}, \tag{4}$$

where $kstar$ is norm of total wave number vector and $\widetilde{\sigma_b}(i, var, lev)$ is resulting grid-point standard deviation error which would be applied during minimization. It means that mean value of grid-point stde $\langle\widetilde{\sigma_b}(i, var, lev)\rangle$ over domain equals prescribed value from B matrix.

(b) When "unbalanced specific humidity" is read from errgrib file (LRDQERR = .T.) and LREDNMCQ = .T. then

$$\widetilde{\sigma_b}(i, q_u, lev) = \sigma_b(i, q_u, lev) * \text{REDNMC\_Q} \tag{5}$$

and the other variables are determined by eq. 3.

(c) In case of L3DBGERR = .F. :

$$\widetilde{\sigma_b}(i, var, lev) = patt(i) * \sigma_{SP}(var, lev). \tag{6}$$

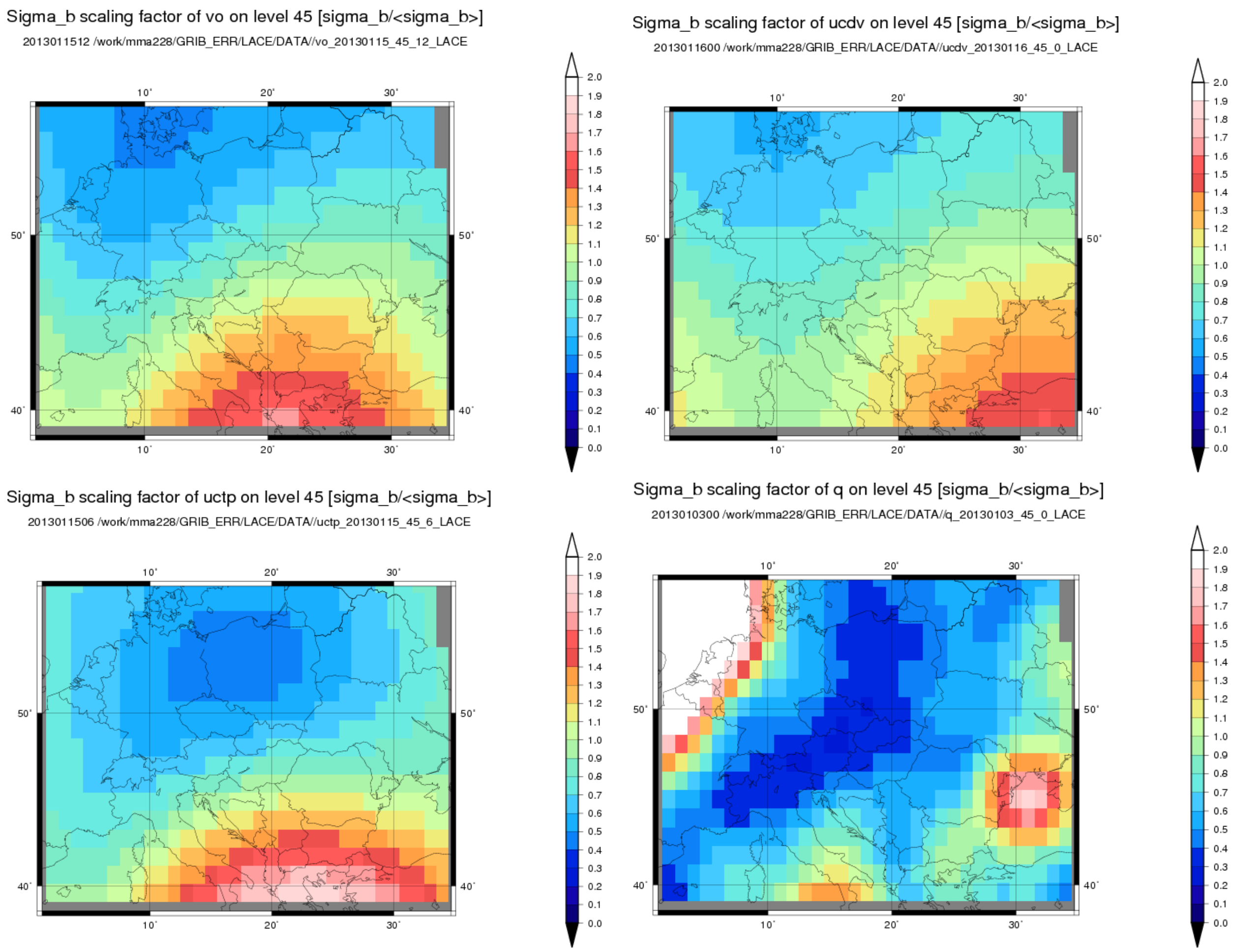
Finally map factor is applied on vorticity and divergence at the end of SUSEPFCE. Application of map factor should be fixed for cases where it is not necessary i.e. when LCFCE = .T. .

2.3 Application of grid-point stde maps in minimization

Usage of grid-point σ_b maps is nicely written in Strajnar [2008]:

> Prescribed background errors are used inside minimization, more exactly in the variable change from control to model space (routine CHAVARIN). After accounting for correlations and before solving balance relationships, the control variable increments are multiplied by grid point standard deviations of background error. This is done inside routine CVARGPTL, in the subroutine EJGNRGGI in the case of Aladin. (At this stage, an option LEVARGP=.TRUE. (which is not the default value) is also provided for zeroing the increments in I+E zones in order to prevent the bi-periodic structures to affect the opposite side of limited area domain. The background errors are multiplied by a weighting function which is falling from one to zero throughout the I zone, becoming equal zero in the E zone.)

Figure 1: Scaling factor for vorticity stde (vo), for unbalanced divergence (ucdv), for unbalanced temperature (uctp) and specific humidity (q), level 45 ($\sim$ 550 hPa). Scaling factors are valid for different dates.



3 Errgrib and its variability

The question was whether errgrib fields have sufficient variability to be used in minimization. Scaling factor (see eq. 3) for the ALADIN geometry was plotted to investigate day to day change of all variables inside errgrib on different levels. Situations on level 45 ($\sim 550\,\text{hPa}$) with the most pronounced variability are shown on the figure 1. One can see quite course spatial resolution of scaling factors. It is due to resolution of AEARP and number of its members. One could think about ALADIN stde maps which would have better resolution but it would require to setup an ALADIN ensemble in high resolution. Without any further knowledge about behavior of σ_b's in minimization one would say that scaling factors are really different from identity (represented by value 1.0). To avoid premature conclusions scaling factors were investigated in particular grid-point (Prague). They show quite reasonable change from one day to the other (see the figure 2). More details could be found in Sassi [2013]. We have concluded that it is worth to test grid-point σ_b maps in ALADIN 3DVAR.

Figure 2: Scaling factor in grid-point representing Prague. Scaling factor for vorticity stde (vo), for unbalanced divergence (ucdv), for unbalanced temperature (uctp) and specific humidity (q) are plotted on level 45 ($\sim$ 550 hPa).

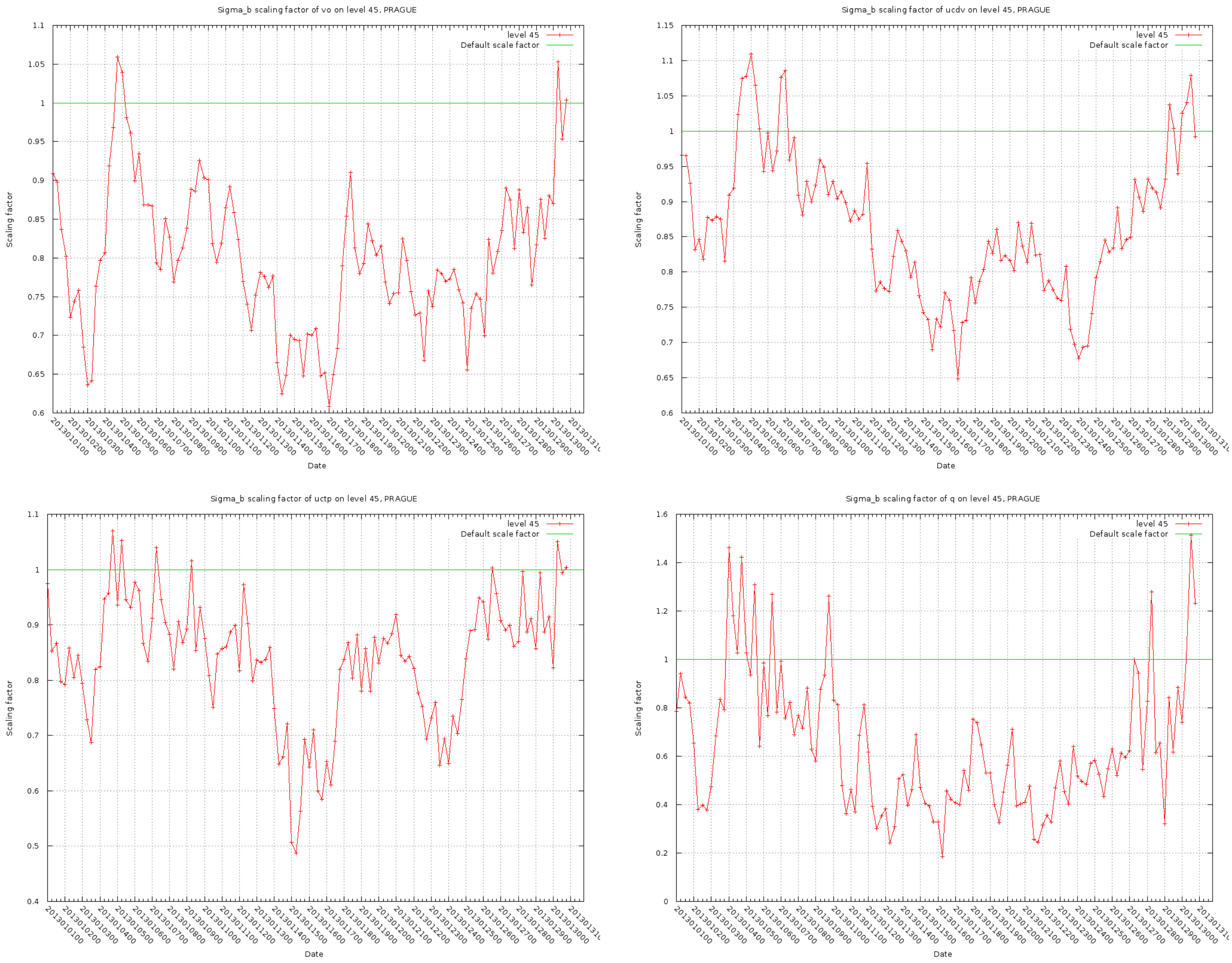
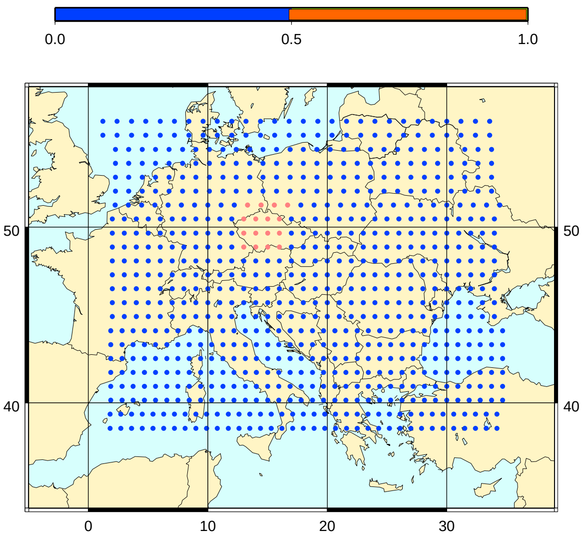


Figure 3: Errgrib grid-point net. Orange color shows grid-points with non zero value of σ_b whereas blue points have $\sigma_b = 0$. Shown pattern is used for all vertical levels.



4 Constant errbrib

Constant errgrib was created in order to verify that grid-point σ_b's do what we expect according to the code (see section 2.2). Quick and easy way to create constant errgrib is to use Grib-api (`grib_set -d 1.0 errgrib errgribnew`). We were expecting identity to reference but our expectation were not fulfilled. Difference was too larger against computation in spectral space, which could not be done by rounding errors. After division by map factor in SUSEPFCE vorticity and divergence are no more constant and we are not able to receive identity against computation in spectral space. It seems that division is introduced to convert vorticity (divergence) to reduced vorticity (divergence) which is used in spectral computation. When division by map factor was suppressed there were almost no difference between use of grid-point σ_b's and spectral ones (difference around 10^{-14}). Another option is to insert square of map factor instead of constant to field of vorticity and divergence in errgrib, this approach was not tested.

5 Single observation experiment

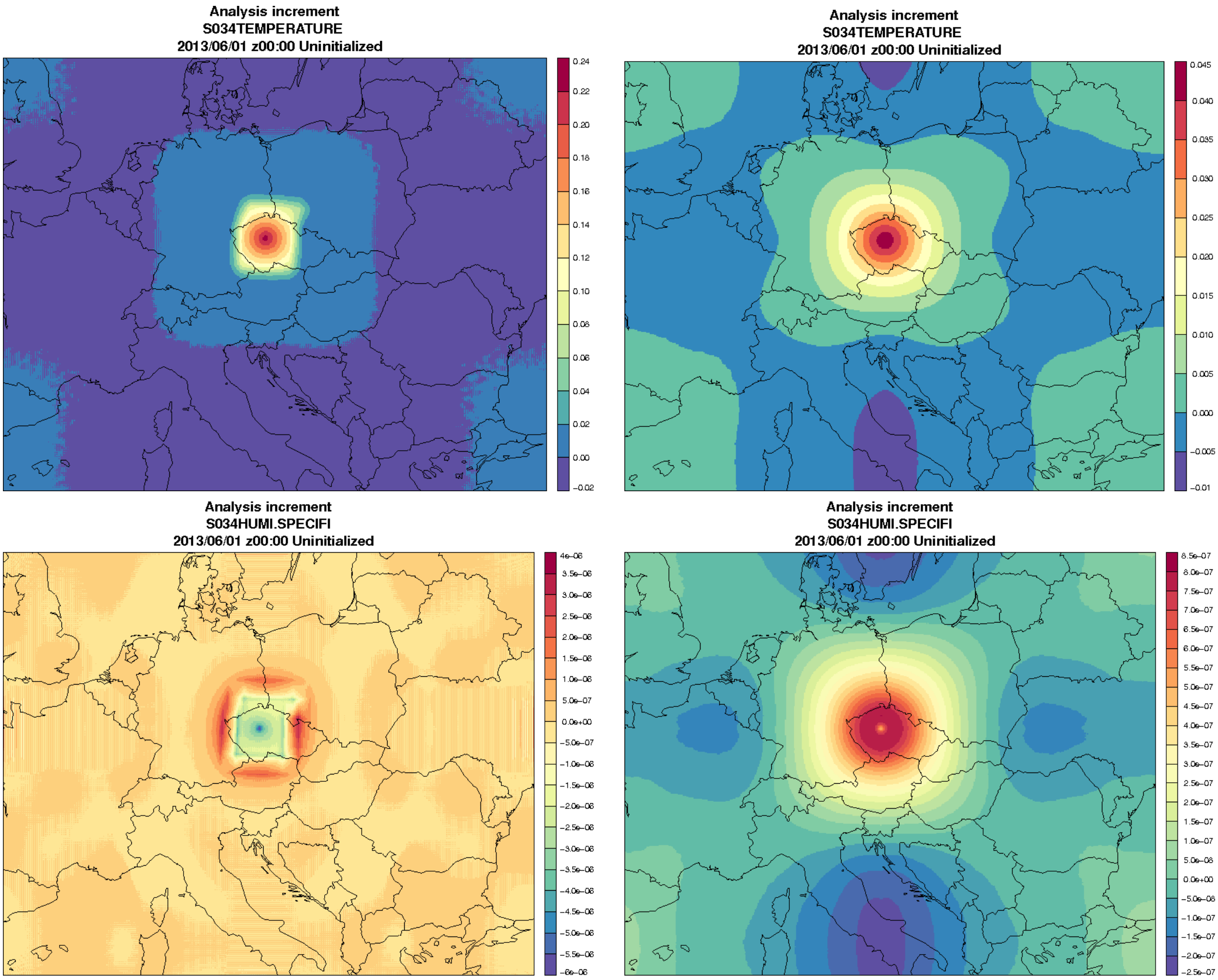
Single observation of temperature at 500 hPa near Prague was used to test different setup of errgrib file. Single observation experiment with errgrib computed by AEARP is presented in Sassi [2013], whereas here we will focus more on artificial errgribs. All experiments presented here have suppressed division by map factor in SUSEPFCE.

Several artificial errgribs were prepared with common area where values are different from zero (the figure 3). Prepared pattern is inserted to all vertical levels. Obtained results are split to following two subsections.

5.1 Errgrib with constant values over small area

Unbalanced temperature is preset to 1 in the area shown on the figure 3 and the rest of the domain is filled with zeros. It implies that the scaling factor inside the orange area is ~ 7.58 whereas 0 outside. The other parameters are kept constant. The figure 4 shows the experiment with depicted errgrib and the reference experiment where no errgrib was used. The analysis increments are negligible outside the area as was expected. The analysis increments inside the area are roughly 7 times larger than the analysis increments in the reference experiment. The result confirm our expectation and convince to test further.

Figure 4: Comparison of the experiment with the artificial errgrib to the reference experiment without errgrib. Temperature and specific humidity of the experiment with the constant values in the small area of errgrib are in the left column. Reference experiment is in the right column. Level 34 is approximately equivalent to 500 hPa. REDNMC = 1 in both experiments. The figures have different scales!

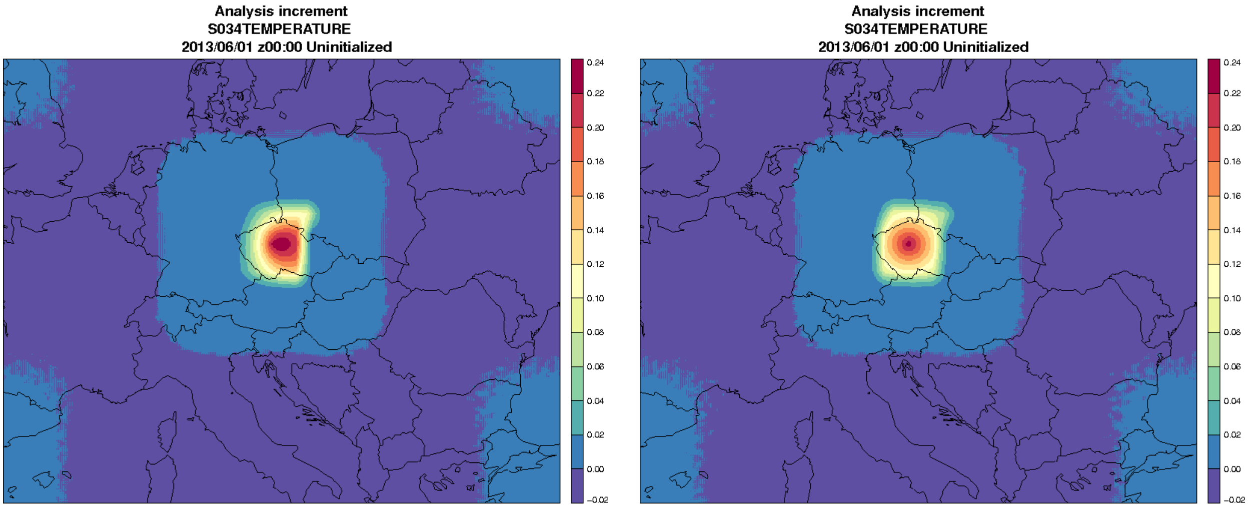


5.2 Errgrib with linearly increasing values over small area

The experiment should verify possibility to make analysis increments larger on the east side of the area. Values in the errgrib field of unbalanced temperature are linearly increasing from zero on the west side to one on the east side of the area. Whereas zero values are outside the area. The other parameters are kept constant in errgrib. The analysis increments are compared on the figure 5 when constant and linearly increasing σ_b's are used inside the area. The increased values of the analysis increments could be observed in the east side of the area. This experiment confirm that analysis increments could be strongly influenced by maps of σ_b although the errgrib file used shows rather extreme scenario.

Two more errgribs were prepared with linearly increasing values in vorticity and unbalanced hu-

Figure 5: Comparison of analyses increments. The left figure shows analysis increment when errgrib values were linearly increasing inside the area. The right figure show analysis increment when errgrib values were constant inside the area.



midity inside the area (the other variables are constant). If a single observation of temperature is assimilated and the errgrib with increasing values is used in humidity the final analysis equals the reference experiment computed completely in the spectral space. It seemed quite surprising that no difference was observed at least in humidity. But it satisfies the equation for cost function and its gradient (see appendix A).

When linearly increasing values of vorticity are set in the area of errgrib, resulting analysis increments are larger then in case where linearly increasing values of temperature are used (see the figure 6). It is not easy to estimate analysis increments for comparison of these two cases and to find their pseudo-analytical solution. But one should keep in mind that vorticity σ_b map influences temperature in comparable amount as temperature σ_b map itself.

6 Full observation experiment

A case study using AEARP errgribs has been computed over the period of severe floods in Czech Republic (from 1st to 5th June 2013), see Sassi [2013]. REDNMC and SIGMAO_COEF have been set to the value 1. All the analyses have been done in simplified framework which means no digital filter initialization, no surface analysis and no assimilation cycle were run. The first guess was the first coupling file downscaled to the ALADIN resolution. Only conventional observations were assimilated. Verification was made against TEMP and SYNOP observations and shows rather neutral results.

BlendVAR experiment using sigma_b maps within full assimilation cycle was run on slightly longer period, 21. 5.–10. 6. 2013. First production started on 26. 5. due to 5-day warm-up. SYNOP, TEMP, AMDAR, AMV observations were included and AEARP sigma_b maps were used for all variables. We tuned REDNMC (1.7) and SIGMAO_COEF (0.67) according to Desroziers et al. [2005]. Setup of reference experiment was the same, just sigma_b maps were not used. Verification showed rather neutral results against TEMP, SYNOP observations and against ECMWF analyses (see figure 7, 8).

On the 1st of June 2013 there were extreme precipitation rates in Czech Republic, we were curious how experiment with sigma_b maps competes operation setup. Frequency bias for categorical forecasts and Fraction skill score [Mittermaier and Roberts, 2010] were computed for precipitations cumulated in 24 h (the best score is one in both cases). Figure 9 shows clear skill improvement in both BlendVAR options against operational setup for this particular day, but it is not clear if sigma_b maps leads to better forecast.

7 Conclusion

A few technical problems raised during investigation of usage of grid-point σ_b maps in ALADIN. Handling of specific humidity is not strait forward in ALADIN because it is not univariate as in AEARP. Errors of unbalanced part of specific humidity estimated by empirical formula or read from errgrib should be overestimated in some sense because both options are related to total humidity field. But, these errors are used only in normalized form to scale errors read from B matrix, one could expect that geographical dependence of balanced and unbalanced humidity errors is similar. One cannot be sure that geographical dependence of errors is similar for AEARP and ALADIN, so far we cannot compare because generation of σ_b maps by ALADIN ensemble is not yet prepared.

If humidity is missing in errbrib file the empirical formula is taken instead, in ALADIN it would be better to read humidity sigma_b from B matrix by default and the empirical formula should be under a key. Humidity sigma_b can be read from B matrix when you follow the instructions in section 2.

There are bugs in application of map factor. Particularly when key LCFCE=.T., or when only vorticity is present in errgrib so divergence is read from B matrix and then map factor is wrongly applied to divergence. And finally it is surprising that division by map factor is at the end of SUSEPFCE, it would make more sense to divide vorticity and divergence by map factor after their interpolation to ALADIN geometry to have them in reduced form for all other computations especially when there are nonlinearities.

There is still a problem, which was not mentioned before, related mainly to AROME. Meier et al. [2013] reported that algorithm is not working properly when humidity is held in grid-point space. Apendix B shows solution for this bug.

After resolving technical problems single observation experiments with artificial errgrib where run. Section 5 shows that σ_b maps can strongly influence resulting analysis in expected way. While simplified and full observation experiment shows neutral verification scores (see section 6). Because σ_b maps computed by AEARP have not lead to improved forecast so far, it brought an idea of their generation by ALADIN ensemble, but it would be computationally demanding and not feasible in CHMI operational environment.

Appendices

A Independence of analysis increments on a humidity stde map

I would like to show why the analysis in the section 5.2, when the σ_b map of unbalanced humidity and a single observation of temperature were used, equals to the reference analysis. The equation 7 shows decomposition of the B matrix to the series of the operators, their description can be found in Fisher [2007]. We will focus on the operator $\mathbf{K}$ which explains our question. $\mathbf{K}^{-1}$ is used to remove correlations between model variables. Both $\mathbf{K}$ and $\mathbf{K}^{-1}$ are lower triangular matrices (eq. 12). $\mathbf{K}$ appears in the variable change from the control variable χ to the analysis increment δx (eq. 8), in the cost function (eq. 9) and in the gradient of the cost function (eq. 10, 11). The cost function and its gradient are written with respect to the control variable χ as it is done in the model ALADIN. The most right term in the gradient equation 11 shows multiplication of the observation departure from the model variables in the model space (vector $\mathbf{v}$) with transposition of operator $\mathbf{K}$. Because only a single observation of temperature is used, the vector $\mathbf{v}$ has only non zero temperature elements. Then $\mathbf{K}^T\mathbf{v}$ has zero elements in "humidity part". The operator $\mathbf{U}$, among others, contains the application of the σ_b maps to the decorrelated variables. The application of the σ_b map to zero "humidity" elements leads to zeros and therefore there is no reason why χ should contain non zero elements in "humidity part". The variable change from the control variable to the analysis increment is $\mathbf{KU}$, because "humidity elements" are zeros, the final humidity elements are determined by linear combination of vorticity, unbalanced divergence, unbalanced temperature and logarithm of unbalanced surface pressure. It means that humidity increment should be the same as in case where no σ_b maps are used.

$$\mathbf{B}^{\frac{1}{2}} = \mathbf{K} \underbrace{\left(\mathbf{FSF}^{-1}\mathbf{DVW}\right)}_{\mathbf{U}} \tag{7}$$

$$\delta x = \mathbf{B}^{\frac{1}{2}}\chi \tag{8}$$

$$J(\chi) = \frac{1}{2}\chi^T\chi + \frac{1}{2}\left[\mathbf{y} - H(\mathbf{x_b}) - \mathbf{HB}^{\frac{1}{2}}\chi\right]^T \mathbf{R}^{-1}\left[\mathbf{y} - H(\mathbf{x_b}) - \mathbf{HB}^{\frac{1}{2}}\chi\right] \tag{9}$$

$$\nabla J(\chi) = \chi + \mathbf{B}^{\frac{T}{2}}\mathbf{H}^T\mathbf{R}^{-1}\left[\mathbf{y} - H(\mathbf{x_b}) - \mathbf{HB}^{\frac{1}{2}}\chi\right] \tag{10}$$

$$\nabla J(\chi) = \chi + \mathbf{U}^T\mathbf{K}^T \underbrace{\mathbf{H}^T\mathbf{R}^{-1}\left[\mathbf{y} - H(\mathbf{x_b}) - \mathbf{HB}^{\frac{1}{2}}\chi\right]}_{\mathbf{v}} \tag{11}$$

$$\mathbf{K} = \begin{pmatrix} \mathbf{1} & 0 & 0 & 0 \\ \mathbf{L} & \mathbf{1} & 0 & 0 \\ \mathbf{M} & \mathbf{N} & \mathbf{1} & 0 \\ \mathbf{O} & \mathbf{P} & \mathbf{Q} & \mathbf{1} \end{pmatrix} \quad \mathbf{K}^T = \begin{pmatrix} \mathbf{1} & \mathbf{L}^T & \mathbf{M}^T & \mathbf{O}^T \\ 0 & \mathbf{1} & \mathbf{N}^T & \mathbf{P}^T \\ 0 & 0 & \mathbf{1} & \mathbf{Q}^T \\ 0 & 0 & 0 & \mathbf{1} \end{pmatrix} \quad \mathbf{v} = \begin{pmatrix} \zeta \\ \eta \\ T \\ q \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ T \\ 0 \end{pmatrix} \tag{12}$$

B Bug in AROME 3DVAR with LSPFCE=.FALSE.

The problem appears when humidity is held in grid-point space and LSPFCE=.F. (Sigma_b maps are used). Humidity behaves as univariate because balance computation is held in spectral space and appropriate buffer SPJB is not filled with humidity field. I propose to adapt routines jbtomodel.F90 and jbtomodelad.F90 in which humidity needs be transformed to spectral space and filled to "SPJB" buffer. Repaired versions of these routines for cycle 36 could be found on RCLACE forum:
`http://www.rclace.eu/forum/viewtopic.php?f=30&t=365`

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Figure 6: Comparison of the analyses increment for single observation of temperature. Linearly increasing values of σ_b are used inside the small area. They were applied to the vorticity (the left column) and to the temperature (right column). Wind increments are not zero in the right column but they are smaller than the scale used for comparison.

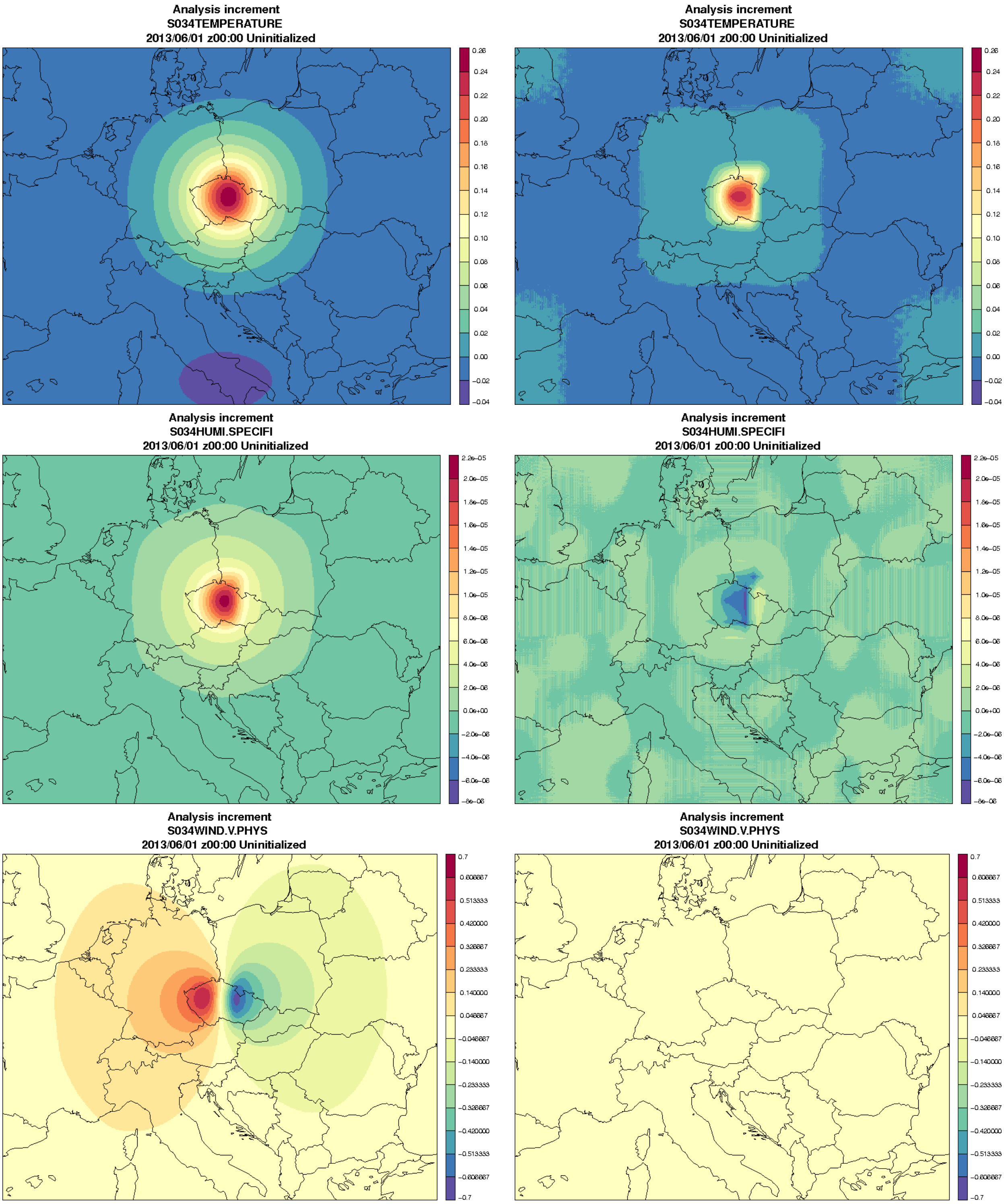
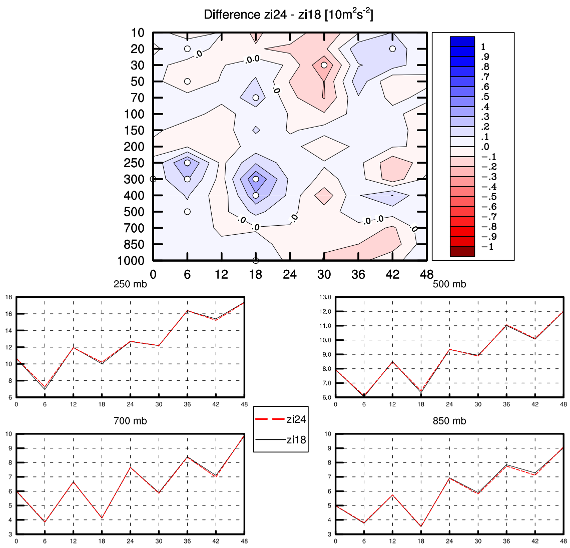
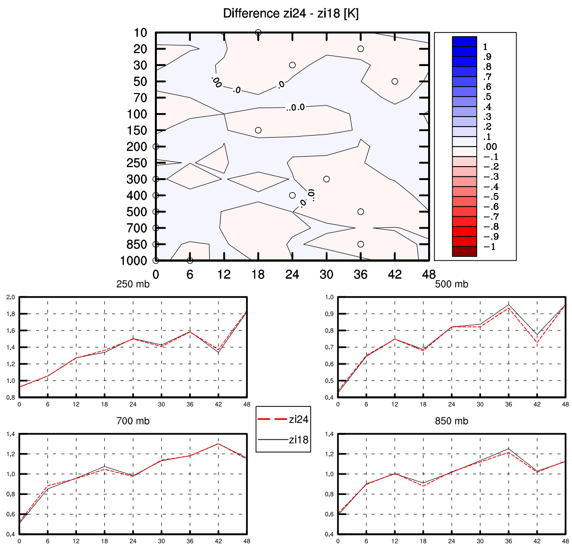


Figure 7: RMSE of experiment with assimilation cycle (zi24) compared to reference experiment (zi18). Verification was done against TEMP observations. Small circles show statistically significant difference.

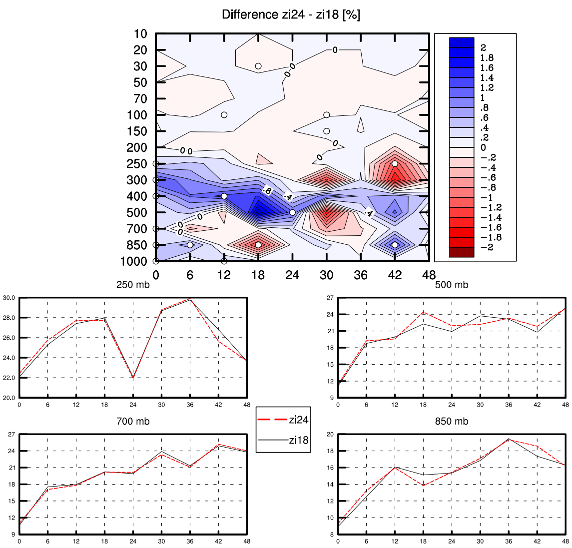
(a) Geopotential



(b) Temperature



(c) Relative humidity



(d) Wind speed

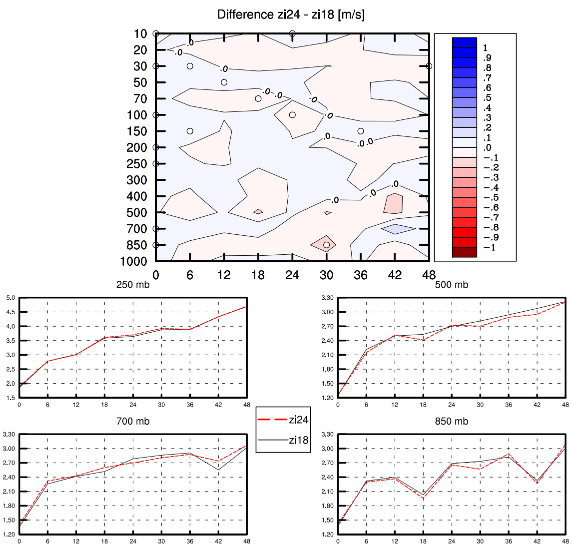
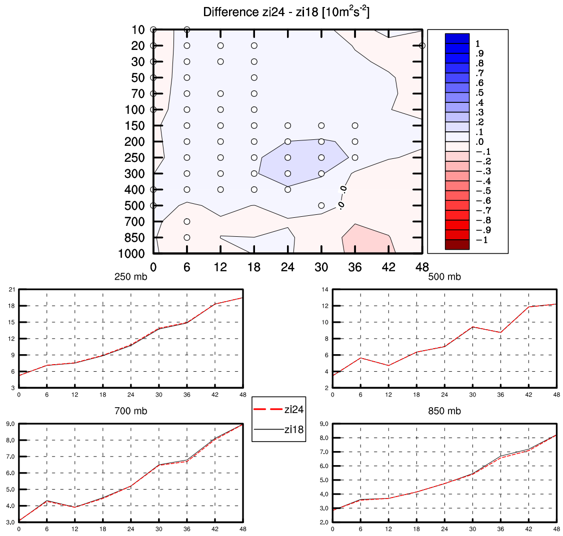
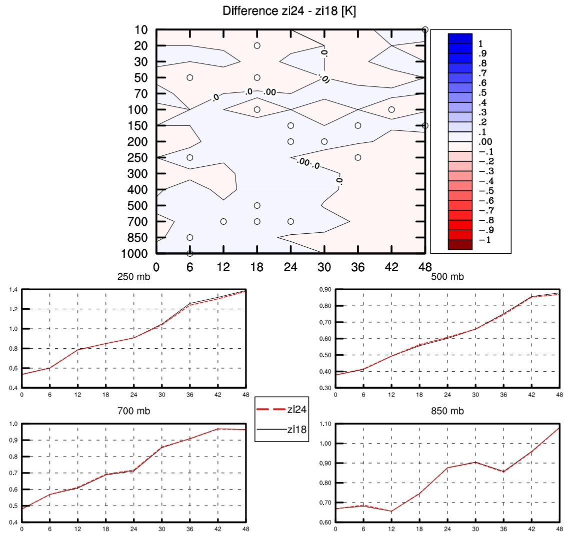


Figure 8: RMSE of experiment with assimilation cycle (zi24) compared to reference experiment (zi18). Verification was done against ECMWF analyses. Small circles show statistically significant difference.

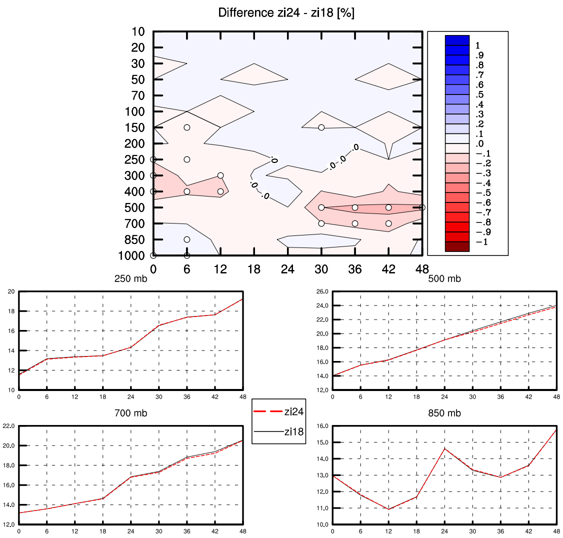
(a) Geopotential



(b) Temperature



(c) Relative humidity



(d) Wind speed

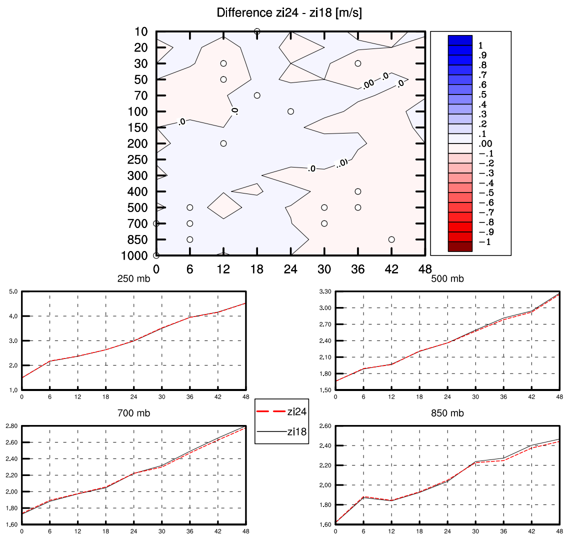


Figure 9: Frequency bias and fraction skill score for forecast on 1. 6. 2013 06 UTC, VAR denotes reference experiment (zi18), VARerrgrib is experiment with sigma_b maps (zi24) and oper_op8 is experiment with operational setup.