A new formulation of WRFDA analysis control variables

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1. Introduction

Background error covariance matrix **B** plays a crucial role in data assimilation. It ensures a balance preserving transfer of observational information to the unobserved parts of a computational domain. Storage and manipulation require reduction of the number of its non-null entries. In general, reduction is ensured via an appropriate diagonalization procedure resulting in a necessity of storing exclusively matrix diagonal terms, alongside the diagonalizing transformation, so that full form of the matrix could be restored whenever required. This transformation has usually some physical foundations and reflects balance expected to be found in nature. Frequently, however, it is identified by means of statistical analysis performed on a time series of model outputs (NMC method).
Consequently, definition of control variables for variational data assimilation is based on splitting model variables into balanced and unbalanced contributions. A balanced field represents a fraction of the full field, which can be explained by the means of other control variables. A correlation scheme allowing identification of the balanced fields exists in WRFDA but it does not account for any link between moisture and other control variables. Consequently, incorporating moisture observations in data assimilation procedure modifies exclusively moisture field. Conversely, observations other than humidity do not impact moisture field. To remedy this flaw we report here an attempt of introducing a correlation between moisture and the remaining control variables

2. New correlation scheme

In view of building a fully multivariate **B** matrix, a construction of new balanced fields has been undertaken following the ideas presented in (Berre, 2000). The most important modifications with respect to it refer to a necessity of transferring the correlation scheme developed for a spectral model into a framework of a grid-point model (WRFDA). Furthermore, an adaptation of the correlation scheme to WRFDA model and control variables is required.

The balanced fields are constructed via linear regressions with the previously introduced control variables. The corresponding unbalanced fields arise from full fields once the balanced parts have been subtracted. The indices (i,j) run over the horizontal directions, whereas k and l over vertical levels whose number equals to N_k.

Balanced velocity potential is given by

$$\chi_b(i,j,k) = \alpha_{\psi\chi}(i,j,k) * \psi(i,j,k).$$

Balanced temperature and balanced surface pressure read respectively

$$T_b(i,j,k) = \sum_{l=1}^{N_k} \alpha_{\psi T}(i,j,k,l) * \psi(i,j,l)$$
$$+\sum_{l=1}^{N_k} \alpha_{\chi_u T}(i,j,k,l) * \chi_u(i,j,l)$$

and

$$ps(i,j) = \sum_{l=1}^{N_k} \alpha_{\psi ps}(i,j,l) * \psi(i,j,l)$$
$$+\sum_{l=1}^{N_k} \alpha_{\chi_u ps}(i,j,l) * \chi_u(i,j,l)$$

where unbalanced velocity potential is defined as

$$\chi_u(i,j,k) = \chi(i,j,k) - \chi_b(i,j,k).$$

Finally, balanced relative humidity accounts for all previously introduced variables and is given by

$$Q_b(i,j,k) = \sum_{l=1}^{N_k} \alpha_{\psi Q}(i,j,k,l) * \psi(i,j,l) +$$
$$+ \sum_{l=1}^{N_k} \alpha_{\chi_u Q}(i,j,k,l) * \chi_u(i,j,l) +$$
$$+ \sum_{l=1}^{N_k} \alpha_{T_u Q}(i,j,k,l) * T_u(i,j,l) +$$
$$+ \sum_{l=1}^{N_k} \alpha_{ps_u Q}(i,j,l) * ps_u(i,j)$$

where unbalanced temperature and unbalanced surface pressure are respectively defined as

$$T_u(i,j,k) = T(i,j,k) - T_b(i,j,k)$$

and

$$ps_u(i,j) = ps(i,j) - ps_b(i,j).$$

Consequently, the control variables of the new formulation are ψ, χ_u, T_u, ps_u and rh_u. With respect to the original formulation, the first two remained unchanged, the definition of T_u and ps_u has been modified and rh_u has been introduced.

To begin with, we illustrate contributions of the balanced fields to their full counterparts. They have been computed for a tropical domain, which covers the Western hemisphere and is spanned between 30S and 30N, Fig. 2. Balanced velocity potential is practically absent from full velocity potential field, Fig.1. There is, however, a non-negligeable contribution of the balanced temperature and surface pressure to their respective full fields. It is far more pronounced than for the original **B**, where balanced field fraction amounted to at most 5% for temperature and 7% for surface pressure. One can also observe a substantial fraction of balanced relative humidity within its full field.

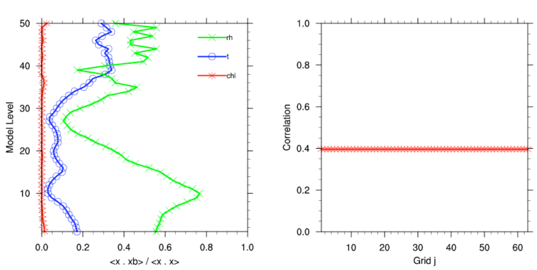

Figure 1 Contribution of the balanced fields (χ, T, rh in the LHS figure and ps in the RHS one) to full fields computed for a tropical domain illustrated in Fig.2.

3. Single observation test

Continuing with the tropical domain, a series of single observation tests has been performed. In the first place they illustrate a fully multivariate nature of the newly built **B** matrix. Indeed, the results shown in Fig.2 present an impact of moisture observation on velocity components, temperature and humidity. The increments are homogeneous in case of mass fields and some twist, most probably owing to incorporation of velocity potential in the correlation scheme, can be observed for velocity fields.

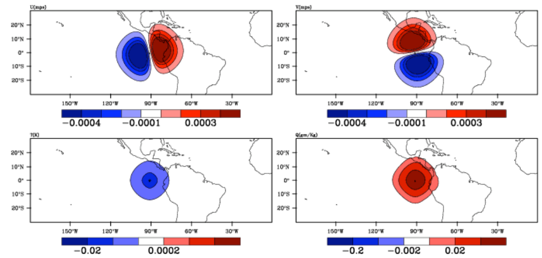

Figure 2 Single observation test for a tropical domain. An increment of Q=1 g kg^{-1} has been placed in the center of the domain. The resulting increments for U, V, T and Q are shown in these four panels.

4. Case study

Next, a comparison of data assimilation results obtained with the original and the newly built **B** matrix shall be presented. The thoroughly studied and well-documented Katrina hurricane has been considered as an appropriate case study. Assimilation experiments have been performed in a 12km resolution domain covering the Caribbean and the US.

In the first place, all the available conventional measurements have been assimilated during 6-hourly cycled 3D-Var. The experiment has been initiated with NCEP's FNL analysis at 00:00 on 21 August and lasted until 18:00 UTC on 31 August 2005. With the exception of the first background state, each of them has been constituted by a valid 6-hour forecast issued from an analysis obtained for a previous assimilation window.

Using a criterion of minimal pressure, the analysis fields have been scrutinized in order to produce hurricane's track. The tracks produced for both formulations of the **B** matrix have been compared to the best Katrina track (Knabb et al., 2005).

For the original formulation of the **B** matrix the localization of the track of the hurricane is only possible starting from 12:00 UTC on 26 August 2005. It appears earlier, at 06:00 UTC on 24 August 2005, for the experiment with the newly built **B** matrix. Initially, it is, however, substantially shifted towards north-east with respect to the best hurricane track.

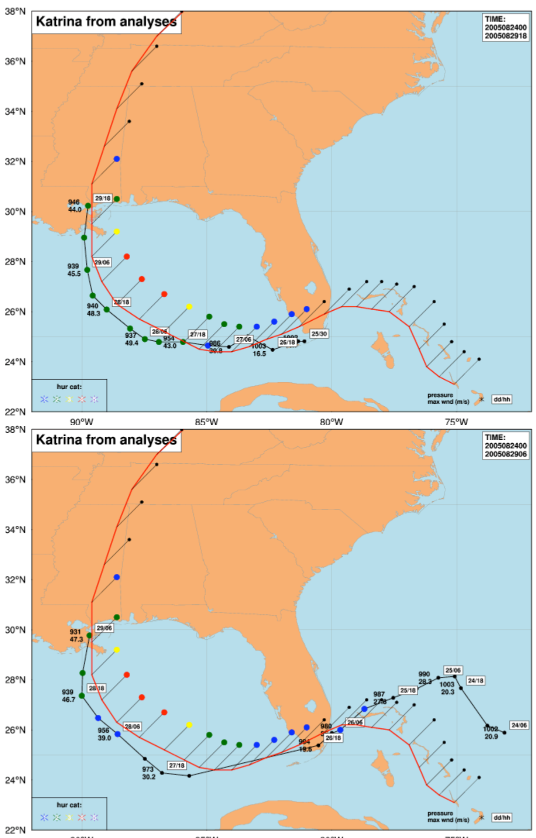

Figure 3 Comparison of tracks (black – data assimilation experiments, red – best track) extracted from analysis fields for the Katrina hurricane. Data assimilation experiments performed with the original (top) and newly built (bottom) background error covariance matrix.

In the second place, some of the analyses have been used as initial conditions for long-term, 72-hour, forecasts. Hurricane tracks shown in Fig. 4 have been initialized at 00:00 UTC between 26 and 28 August 2005 for both experiments. It is easily noticeable that in order to obtain a reasonable forecast of the hurricane track, one must wait until 00:00 UTC on 27 August 2009 for the original **B**, and until 00:00 UTC on 28 August 2009 for the newly built **B**.

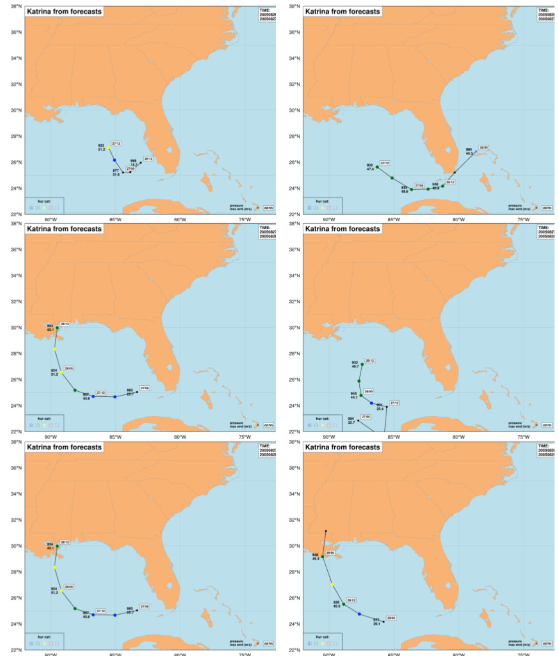

Figure 4 Hurricane tracking from 72-h forecasts initialized at 00:00 on 26, 27, and 28 August 2005 for the newly built (RHS column) and the original (LHS column) **B**.

Finally, we discuss verification against observations of the analyses and forecasts produced in both experiments. In Fig.5 we compare vertical profiles of the analysis root mean square error (RMSE) for U, V, T and Q. Smaller values of the RMSE have been found for the experiments performed with the original **B** matrix. The discrepancies are most striking for moisture Q in the lowest levels of the atmosphere and for U and V velocity components in the vicinity of the tropopause.

RMSE for the 6-hour analysis time series averaged over the surface of the domain and covering the period between 00:00 UTC on 21 August and 18:00 UTC on 31 August 2005 is shown in Fig.6. In case of U, V and T both experiments show similar results. For Q and ps, however, the original **B** outperforms the modified one. Similarly, in Fig.7, 12-hour forecast surface-averaged RMSE is shown. Here again, most pronounced discrepancies can be spotted for Q and ps. This tendency is also present in longer, up to 72-hour, forecasts.

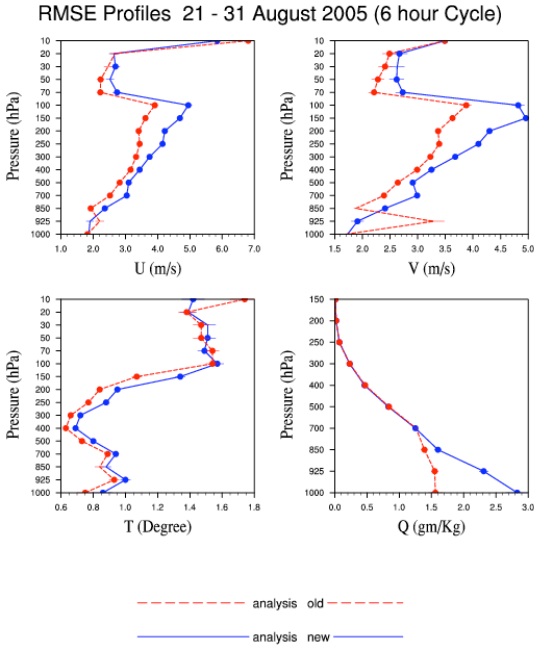

Figure 5 Time- and level-wise averaged profiles of the analysis RMSE for U, V, T and Q. Results obtained with the original (red) and modified (blue) **B** matrix are compared.

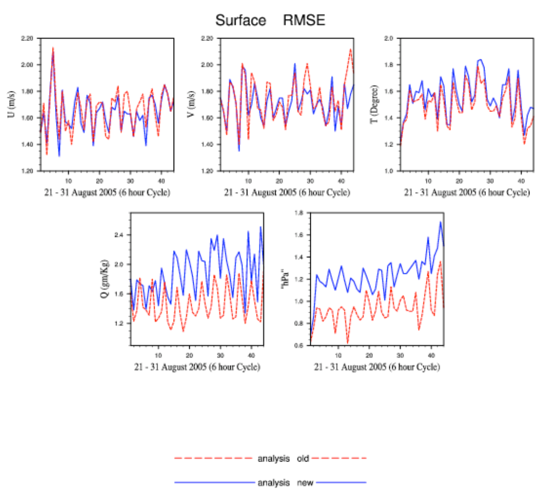

Figure 6 Surface-averaged analysis time series of the RMSE for U, V, T, Q and ps. The original **B** results are shown in red and the modified **B** in blue.

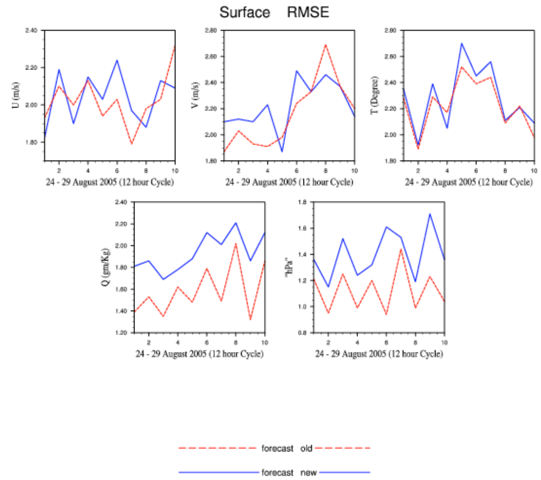

Figure 7 Surface-averaged 12-hour forecast time series of the RMSE for U, V, T, Q and ps. Red curve represents the original and the blue curve the modified **B** matrix.

5. Summary

Fully multivariate background error covariance matrix has been implemented in WRFDA, in view of improving data assimilation quality in tropical regions. Consequently, WRFDA control variables have been redefined. In particular a link between moisture and wind, as well as between moisture and other mass fields have been incorporated. A considerable contribution of the newly introduced balanced mass fields to their full counterparts has been observed for a tropical domain. In particular, an enhancement with respect to the original **B** formulation could have been noticed for temperature and surface pressure. Fully multivariate character of the modified **B** has also been illustrated via single observation tests.

The impact of the new **B** formulation has been then tested for the Katrina hurricane case. However, no improvement in the quality of data assimilation results has been observed. Some degradation even has been encountered, especially for moisture and surface pressure fields. Further investigations aiming at improving our understanding of these results are necessary. They shall follow two paths. Deeper analysis of the verification results on the one hand and additional case studies on the other hand.

References:

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