MEASURES OF THE INCREMENTAL DIGITAL FILTERS' EFFECTS ON THE ALADIN 3D-VAR ANALYSIS AND THEIR SENSITIVITY TO BACKGROUND ERROR VARIANCES

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Abstract: The main idea has been to investigate the sensitivity of the ALADIN 3D-Var analysis and its imbalance to the prescribed forecast error variance for unbalanced divergence. We expect that the observed divergence features to be better analyzed in a mesoscale model when a large variance for unbalanced divergence, which is the main part of divergence, is prescribed. On the other hand, the level of noise in the analysis is likely to become more important when a large divergence variance is used. This is related to the fact that divergence can be connected with spurious inertia-gravity waves, which can create noise. It has been found that the analysis sensitivity and its imbalance with respect to the variances of other meteorological parameters are also important.

Key words: 3D-VAR, variance, analysis, initialization, incremental

1. INTRODUCTION

First, we have been interested to study the following possible duality: the divergent part of the wind becomes more important in the small scales and therefore it would be better to analyze faithfully divergence in a mesoscale analysis, but divergence is also classically associated with inertia-gravity waves and therefore with noise.

On the one hand, we expect that the observed divergence features to be better analyzed when a large variance for unbalanced divergence, which is the main part of divergence (see Derber and Bouttier, 1999, and Berre, 2000), is prescribed. This is especially important in mesoscales, for which the divergent part of the wind is likely to become more important (compared to the rotational part of the wind). We have realized during the work that the analysis sensitivity and its imbalance with respect to the variances of other meteorological parameters (such as vorticity and unbalanced surface pressure – temperature) were also important and that some diagnostics on the relative effect of Digital Filter Initialization (DFI) (Lynch et. al., 1992, and Lynch *et al.*, 1997) were needed.

On the other hand, the level of noise in the analysis is likely to become more important when a large divergence variance is used. This is related to the fact that divergence can be connected with spurious inertia-gravity waves, which can create noise. This aspect is classically studied by plotting the time evolution of the horizontal average of the absolute surface pressure tendency, which is a measure of noise. Another possible indicator is the amplitude of the initialization increment, which should be as small as possible in comparison with the analysis increment (Daley, 1991, page 28). Therefore, it is interesting to study how the level of noise varies with the prescribed variances for unbalanced divergence and other meteorological parameters used in sensitivity experiments.

2. DATA AND METHODS

Using the ALADIN 6-hour forecast as a first guess field and the observations, a 3D-Var ALADIN analysis (the configuration *e131*) was performed over the ALADIN-France integration domain on 28.12.2000 12UTC. Cycle 13 of the ALADIN model (Bubnova et al., 1993, and Radnoti et al., 1995) and the mesoscale statistics (i.e. the lagged NMC statistics, Široka *et al*., 2003) were used.

First, the reference value *REDNMC* = *1.0* was used for the scaling factor for the background error variances of all control variables (unbalanced divergence, vorticity and unbalanced surface pressure - temperature).

The analysis increment was obtained by subtracting the first guess from the 3D-Var analysis field:

$$\underset{\text{analysis increment}}{\underset{\downarrow}{\delta x^{a}}} = \underset{\text{not initialized analysis}}{\underset{\downarrow}{x^{ani}}} - \underset{\text{not initialized first guess}}{\underset{\downarrow}{x^{fgni}}}$$

The spectral energy of the analysis increment was calculated for the following fields: temperature, kinetic energy, vorticity and divergence. Three model levels were chosen: one near the surface (level 31), one around the 500 hPa pressure level (level 18) and one in the stratosphere (level 7).

Some features of the analysis increments such as vertical dependence and sensitivity with respect to the variances for unbalanced divergence, vorticity and unbalanced surface pressure – temperature were studied. In order to do this, six values (*0.0, 0.5, 0.9, 1.0, 1.5* and *2.0*) of the *REDNMC* scaling factor for the variances were chosen.

The DFI increments for analysis and first guess were calculated as follows:

$$\underset{\text{full DFI increment for the analysis}}{\underset{\downarrow}{\delta x^{Ia}}} = \underset{\text{initialized analysis}}{\underset{\downarrow}{x^{ai}}} - \underset{\text{not initialized analysis}}{\underset{\downarrow}{x^{ani}}}$$

$$\underset{\text{full DFI increment for the first guess}}{\underset{\downarrow}{\delta x^{Ifg}}} = \underset{\text{initialized first guess}}{\underset{\downarrow}{x^{fgi}}} - \underset{\text{not initialized first guess}}{\underset{\downarrow}{x^{fgni}}}$$

We have calculated the incremental DFI increment by subtracting the initialization increment for the first guess from the initialization increment for the analysis:

$$\underset{\text{incremental DFI increment}}{\underset{\downarrow}{\delta x^{II}}} = \underset{\text{full DFI increment for the analysis}}{\underset{\downarrow}{\delta x^{Ia}}} - \underset{\text{full DFI increment for the first guess}}{\underset{\downarrow}{\delta x^{Ifg}}}$$

The need to apply DFI in an incremental way, which had been identified in previous studies (Dziedzic, 2000), has also been investigated in this study.

At the end, we have obtained the final analysis increment as the sum of the analysis increment and the incremental initialization increment:

$$\underset{\text{the final analysis increment}}{\underset{\downarrow}{\delta x^{II,a}}} = \underset{\text{initialized analysis}}{\underset{\downarrow}{x^{ai}}} - \underset{\text{initialized first guess}}{\underset{\downarrow}{x^{fgi}}} =$$

$$= \underset{\text{the analysis increment}}{\underset{\downarrow}{\delta x^{a}}} + \underset{\text{incremental DFI increment}}{\underset{\downarrow}{\delta x^{II}}}$$

In order to investigate the relative effect of incremental initialization in comparison with the analysis effect, we have calculated three ratios:

$$r_1 = \frac{\left\| \delta x^{II} \right\|^2}{\left\| \delta x^{a} \right\|^2}$$

↓
ideally should be close to 0
(smaller than 1)

$$r_2 = \frac{\left\| \delta x^{II} \right\|^2}{\left\| \delta x^{II,a} \right\|^2}$$

↓
ideally should be close to 0
(smaller than 1)

$$r_3 = \frac{\left\| \delta x^{II,a} \right\|^2}{\left\| \delta x^{a} \right\|^2}$$

↓
ideally should be close to 1

These three ratios have been calculated for temperature, kinetic energy, vorticity and divergence, at the same three above-mentioned levels. Also, we have evaluated the sensitivity of these ratios with the scaling factor for the variances of control variables.

The effect of using large scales statistics (i.e. standard NMC statistics, Parrish and Derber, 1992) in the 3D-Var analysis has also been investigated. A 3D-Var analysis has been performed using large scale statistics for the reference case with all scaling factors equal to 1.0.

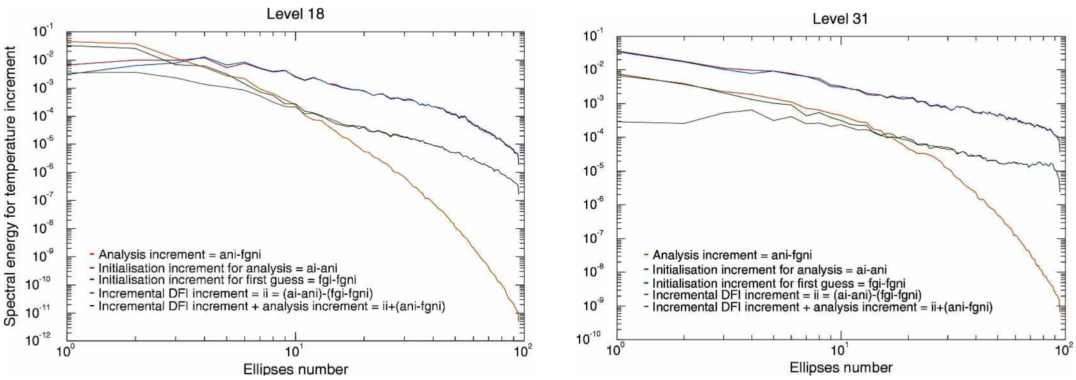
The time evolution of the model area average of the absolute surface pressure tendency, which is a measure of the level of noise, and its sensitivity with respect to the prescribed variances for unbalanced divergence, vorticity and unbalanced surface pressure - temperature have been analized.

In order to obtain the evolution of the absolute surface pressure tendency, a 12-hour forecast of the ALADIN model (configuration *e001*) has been performed. Firstly, the level of noise for the reference case with all scaling factors for variances equal to 1.0 has been investigated. The ALADIN 12-hour integration has been performed starting from three different initial states: not initialized first guess (*fgni*), not initialized 3D-Var analysis (*ani*) and the final analysis (not initialized first guess plus the analysis increment and the incremental DFI increment, noted by *fgni+ii+(ani-fgni)*). The lateral boundary conditions have been provided by the global model ARPEGE (Courtier et al., 1991) at every three hours, the first coupling field being the ARPEGE analysis and the next ones being ARPEGE forecasts.

3. RESULTS

By plotting the spectral energy of the analysis increment as a function of the wave number (which is related to the horizontal scale) at the three levels (7, 18 and 31), it can be observed that, for all four chosen fields (temperature, kinetic energy, vorticity and divergence), the spectral energy of the analysis increment in the small scales grows higher when going to low levels (as can be seen in figure 1 for temperature). It means that there are more small scale features at low levels, in accordance with what is represented by the background error covariance matrix.

In order to study the impact of different scaling factors for variances, we have plotted the spectral energy of the analysis increment (summed over all wave



a) b)

Fig. 1. The spectral energy for temperature increments at levels 18 (a) and 31 (b)

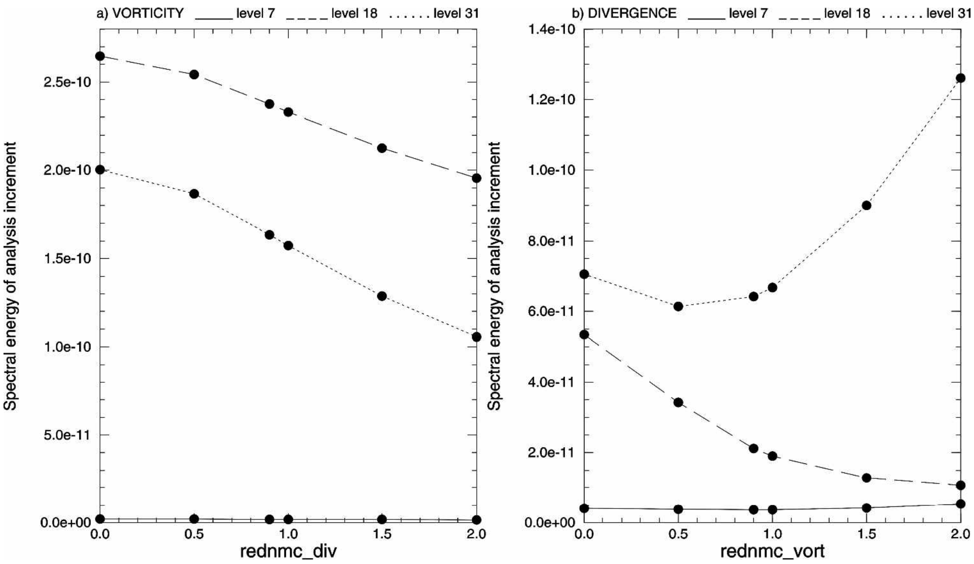


Fig. 2. The spectral energy of the analysis increment:
a) for vorticity as function of the scaling factor for unbalanced divergence variance
b) for divergence as function of the scaling factor for vorticity variance

numbers) as a function of *REDNMC* scaling factor for unbalanced divergence, vorticity and unbalanced surface pressure - temperature variances. In figure 2 can be observed that when the scaling factor for unbalanced divergence variance increases, the analysis increment for vorticity decreases at both levels 18 and 31, and when the scaling factor for vorticity variance increases, the analysis increment for divergence decreases at level 18. It means that the variances of unbalanced divergence and vorticity control the partition of the wind analysis increment between vorticity and divergence at level 18. This is in accordance with the opposite evolutions of the rotational and divergent eigen-values when the ratio ν from figures 3a and 3b of Unden (1989) increases. In contrast, at level 31, when the scaling factor for vorticity variance increases, the analysis increment for divergence increases. This is consistent with the positive coupling between vorticity and divergence at low levels due to the surface friction (Derber and Bouttier, 1999).

By plotting the spectral energy of the initialization increment for analysis as function of the wave number, at the three aforementioned levels, we have seen that, for all four chosen fields (temperature, kinetic energy, vorticity and divergence), the spectral energy of the initialization increment for analysis is stronger than the analysis increment, with an exception at level 18 in the large scales. This feature is illustrated in figure 1 for temperature increments at model levels 18 and 31. For all chosen fields and at all three levels, the initialization increment for first guess was very close to the initialization increment for analysis. These two features have led us to conclude that the DFI is working mostly on the information coming from the first guess. This conclusion has indicated that the DFI should be applied in an incremental way.

The incremental initialization increment is lower than the analysis increment in the large scales, but it becomes higher than the analysis increment in the small scales (see figure 1). This thing is valid for all chosen fields at all three levels. A possible interpretation may be that DFI is attenuating some noise in the large scales, and that in the small scales it is transferring some information from the observed large scales to the not observed small scales (i.e. adjusting small scales in order to become consistent with the modified large scales from the point of view of the model balance). At the end, we have obtained the final analysis increment as the sum of the incremental initialization increment and the analysis increment. In figure 1, it can be seen that the final analysis increment remains closer to the analysis increment in the large scales, but it follows the incremental initialization increment in the small scales. This means that, for temperature, the analysis has a stronger effect in the large scales, while the initialization is playing an important role especially in the small scales.

We have used the ratio between the spectral energy of the incremental DFI increment (summed over all wave numbers) and the spectral energy of the analysis increment (summed over all wave numbers) to study the relative effect of incremental DFI compared to the analysis. Ideally, this ratio should be as small as possible, in order to have less noise in the 3D-VAR analysis. In order to see what kind of sensitivity exists with respect to the variances of the control variables, we have plotted the ratios for temperature, kinetic energy, divergence and vorticity as a function of scaling factors. We have observed the following: not so much sensitivity with respect to unbalanced surface pressure - temperature variance, a bit more sensitivity with respect to unbalanced divergence variance and higher sensitivity with respect to vorticity variance. A possible explanation for the higher sensitivity with respect to vorticity variance, in comparison with the unbalanced surface pressure – temperature and unbalanced divergence variances, could be the fact that the vorticity variance determines the variances of rotational wind and balanced surface pressure – temperature, which are the main parts of the wind and surface pressure – temperature variances, and which mostly determine thus the analysis increment amplitude.

Figure 3 shows that for temperature at level 31 the ratio becomes smaller when a low variance is used for vorticity and when a high variance is used for unbalanced surface pressure - temperature and for unbalanced divergence. This may be somewhat consistent with the increased importance of divergence at low levels.

Figure 4 presents the three different ratios *r1, r2* and *r3* used to diagnose the relative effect of incremental DFI

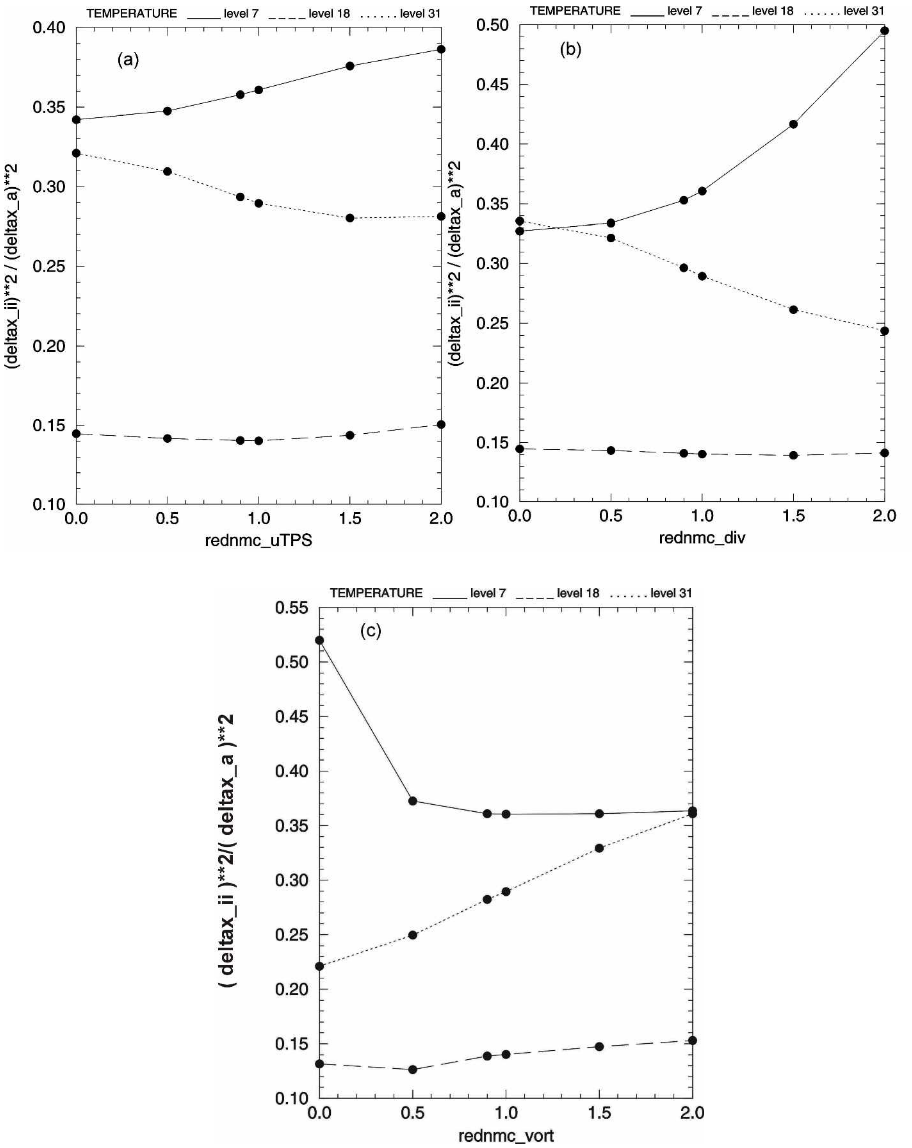


Fig. 3. The ratio between the spectral energy of the incremental DFI increment (summed over all wave numbers) and the spectral energy of the analysis increment (summed over all wave numbers) for temperature at levels 1, 18 and 31 as function of the scaling factors for unbalanced surface pressure – temperature (a), unbalanced divergence (b) and vorticity (c)

compared to the analysis effect as a function of wave number, for temperature increments at level 31. Looking at the reference case (all REDNMC = 1.0), it can be observed that, for all three ratios, the condition of being as small as possible (for *r1* and *r2*) or close to 1 (for *r3*) is valid only in the large scales.

In fact, through these three different diagnostics, we can see the same features, namely that the analysis has a stronger effect in the large scales, while the initialization becomes more important in the small scales.

We have observed in more detail the temperature increments at level 31 and we have seen that, when we have reduced the scaling factor for vorticity variance to 0.0, the analysis increment has not been decreased so much, and the final analysis

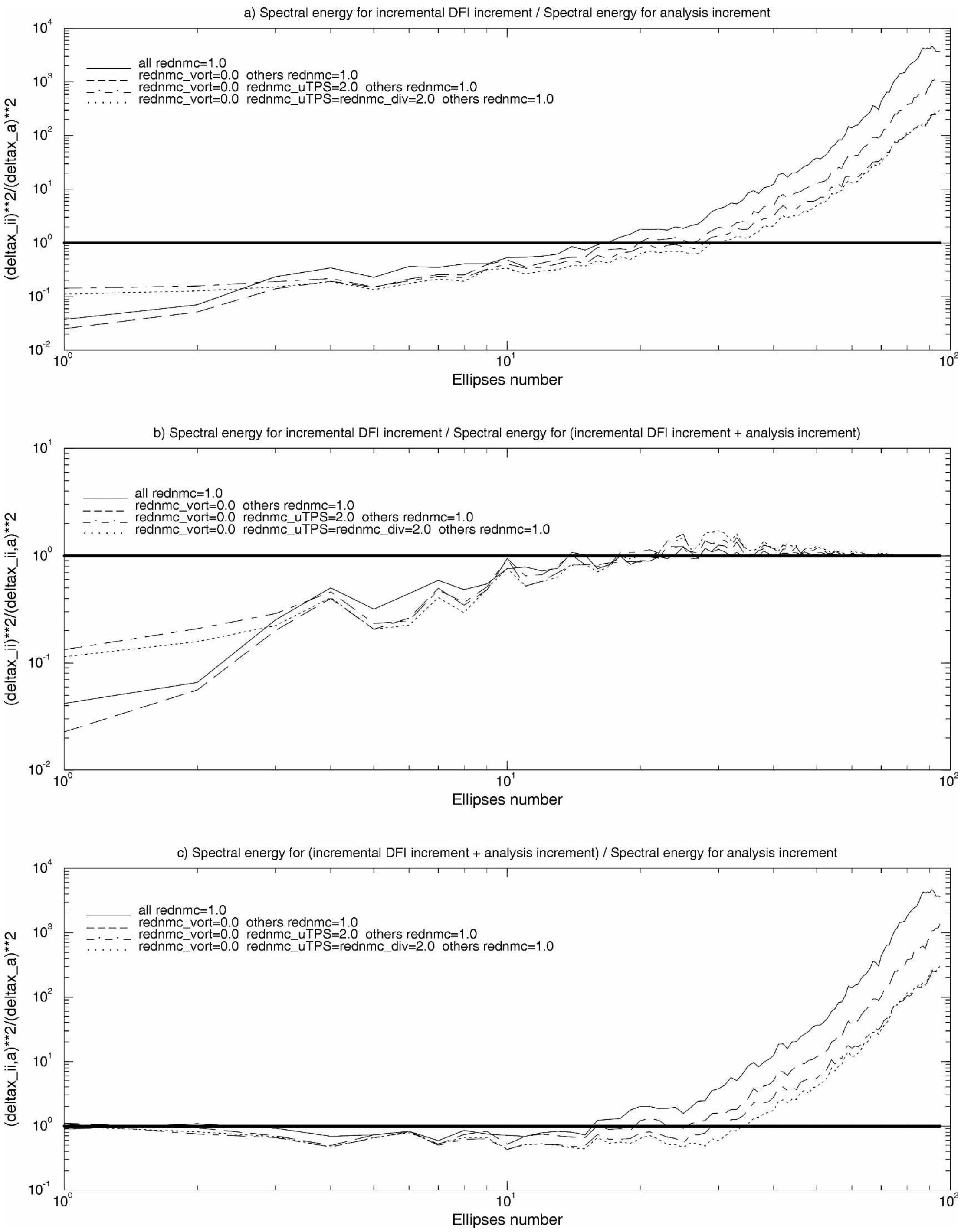


Fig. 4. The ratios r1 (a), r2 (b) and r3 (c) as function of the wave number, for different scaling factor values for variances of the control variables

increment becomes smoother than in the reference case with all scaling factors equal to 1.0. By increasing the scaling factors for variances of unbalanced divergence and unbalanced surface pressure - temperature to 2.0, we have increased the analysis increment, but the final analysis increment is still smoother than in the reference case.

The three ratios presented in figure 4 illustrate also the fact that the last case with the scaling factor for vorticity variance equal to 0.0 and the scaling factors for unbalanced divergence and unbalanced surface pressure - temperature variances equal to 2.0 is the best. In the large scales, the three ratios for all four presented cases have reasonable values. In the small scales, the ratios for the last case are the smallest, compared to the other three cases, even if they remain quite high. In conclusion, one can say that for temperature at level 31 it is beneficial to have a small variance for vorticity and large variances for unbalanced divergence and unbalanced surface pressure - temperature.

The effect of using large scale statistics in the 3D-Var analysis has also been investigated. By comparing the two 3D-Var analysis obtained using the mesoscale and large scale statistics (for the reference case with all REDNMC=1.0), we have seen that the analysis increment for the case of large scale statistics has more energy in the large scales, but it remains similar to the analysis increment obtained using mesoscale statistics in the small scale.

The time evolution of the model area average of absolute surface pressure tendency, which is a measure of the level of noise, shows that there is an increase of the level of noise every 3 hours, immediately after the couplings, but the first peak is the highest (see figure 5). This is probably a problem of inconsistence between ALADIN first guess and ARPEGE analysis (used as boundary condition). The 3D-VAR analysis introduces some noise (especially during the first 3 hours), but the incremental DFI is able to reduce the most important part of it (as it can be seen from figure 5).

By analyzing the sensitivity of the level of noise with respect to the three scaling factors for unbalanced divergence, vorticity and unbalanced surface pressure - temperature variances, it appears that the noise introduced by the analysis is much more sensitive to the vorticity variance.

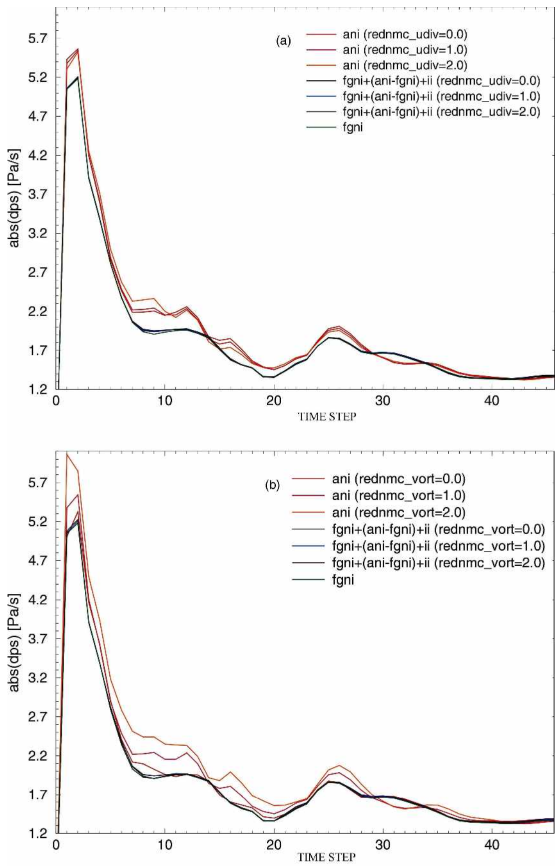


Fig. 5. The time evolution of the model area average of absolute surface pressure tendency for different values of the scalling factors for unbalanced divergence **(a)** and vorticity **(b)** variances. On the figure, 46 time steps correspond to a 6-hour forecast range (the integration time step is about 470 s)

In fact, we could see the same kind of sensitivity from the ratios of increments.

4. CONCLUSIONS

First, we have seen that it is necessary to apply DFI in an incremental way.

The scale dependence of the incremental DFI effect shows that it is much more important in the small scales, while the analysis effect is stronger in the large scales.

We could see a higher sensitivity of the incremental DFI effect with respect to the vorticity variance than to the unbalanced divergence and unbalanced surface pressure - temperature variances, according to the amplitude of incremental DFI increment, the three discussed ratios and the absolute surface pressure tendency evolution.

For temperature at level 31 we have observed quite different spectral sensitivities of the analysis increment, incremental DFI increment and final analysis increment, depending on the control variables.

By setting the scaling factor for vorticity variance to 0.0 and increasing the scaling factors for unbalanced divergence and unbalanced surface pressure - temperature variances to 2.0, the relative effect of DFI can be partially reduced, but it still remains quite strong in the small scales.

These preliminary conclusions have been obtained only from a single 3D-Var experiment. In the future, it will be interesting to repeat this study for other experiments, and not only for background error statistics computed with the NMC method, but also for background error statistics computed with the ensemble method (Ştefãnescu and Berre, 2004). The sensitivity with respect to height and scale dependent scalling factors could be studied too. Also, it would be interesting to use space and flow dependent scalling factors.

In order to decrease the relative effect of initialization on the analysis in the small scales, one may try to adjust the DFI itself, instead of modifying the background error variances.

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