Evaluation of analysis increments using sensitivity calculations

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1. Introduction

The use of adjoint integrations has provided a new tool of evaluating the quality of initial conditions for numerical integrations. At ECMWF calculations of the adjoint sensitivity of forecast errors to initial conditions has become part of the operational suite. The first step of a minimization procedure provides the gradient of the day-2 forecast errors with respect to initial conditions, this will be simply called sensitivity (Rabier et al., 1996). Further steps of minimizing the day-2 forecast errors improve the estimate of errors in the initial conditions (Klinker et al., 1998). The fact that these error estimates project onto the leading singular vectors, similar to the sensitivity, justifies to call them "key analysis errors".

The correction of the analysis using the sensitivity or the key analysis errors has shown to improve the quality of the forward model integration substantially. This is true for the short and for the medium range as well. The ability to improve the forecast skill significantly by modifying the initial conditions naturally leads to the question whether these corrections contain any information about the quality of the analysis increments. Objections against this interpretation are normally raised by speculating that the minimization of forecast errors compensates model errors as well, like errors in the parameterization and errors in the dynamical part of the model. More research is needed to identify to what extent errors in the parameterization project onto fast growing modes, whereas errors in the dynamics are likely to be relatively small. If we assume that changing the initial conditions would partly compensate model errors, then we should see at least some reduction of systematic errors in the forward integrations. However, the sensitivity integrations started from modified initial conditions using the key analysis errors do not show an impact on systematic errors. It seems therefore that the key analysis errors and the sensitivity are mainly correcting analysis errors.

2. Analysis increments and key analysis errors

On the basis that the adjoint sensitivity provides corrections of the analysis in the right direction, the sensitivity or key analysis errors can be seen as a correction to the analysis increment. The question here arises whether there is any correlation between analysis increments and the key analysis errors. Or in other words: is there any correlation between forecast errors arising from problems in initial conditions and analysis increments?

The Hovmoeller diagram of temperature analysis increments around 700 hPa (Fig. 1) shows that the update of the first guess has a large systematic part. In particular over the summer time North American continent the analysis has to compensate a significant warm bias of the model. As the formulation of the variational analysis is based on the assumption of unbiased background fields it is no surprise that the model bias has a detrimental impact on the quality of the analysis as measured from the forecast skill. A 3D-Var data assimilation experiment has shown that subtracting the model bias from the background field improves the quality of the forecasts.

Comparing key analysis errors and increments in form of an Hovmoeller diagram for the summer season (Fig.1 and Fig. 2) it is obvious that the interpretation of the key analysis errors as a correction to the increments is very difficult. One important reason has to be seen in the different nature of increments and adjoint integration output. Whereas the increments project onto the full space of possible evolutions, the sensitivity and key analysis errors project strongly onto the unstable subspace. The same can be seen from the geographical distribution of the standard deviation of key analysis errors and increments. It seems therefore necessary to apply a filter to the analysis increments that would enable a fair comparison between the two quantities, the analysis increments and sensitivity fields.

It has been shown by Gelaro et al (1997) that the sensitivity can be constructed by using singular vectors as well. Though the T42-based singular vector sensitivity is somewhat smoother than the T63 adjoint sensitivity, the major features are very much alike. Forward integrations from the singular vector based sensitivities show a similar gain in skill as obtained from integrations based on modified analyses using the adjoint sensitivity. On the basis that the adjoint sensitivity can be substituted by the singular vector based sensitivity it has been decided to use the singular vectors as filter for analysis increments. By projecting analysis increments onto singular vectors at initial time a comparison with the sensitivity becomes more meaningful. We have to keep in mind that the results of this comparison apply to the unstable subspace only. However, this is not a very restricting condition as model integrations with full and projected increments have shown that the projected first guess increments describe a large part of the time evolution of the complete increments.

For a period of 3 months (June-July-August 1998) various statistics for analysis increments and sensitivity have been calculated. Unlike the comparison between key analysis errors and full analysis increments, the projected analysis increments have maximum values in the same areas as the sensitivity (Fig. 3). Further calculations include the covariances and correlations between projected increments and the sensitivity (Fig.4). The predominantly negative values for both, the correlation and covariances, indicate that in most areas, especially over land, the temperature increment at model level 23 (close to 700hPa) would be corrected by the sensitivity in the way to reduce the distance from the first guess. This is a fairly general result for all levels and parameters, in particular for the surface pressure. The fact that the increments in the unstable subspace are too large would imply to reduce the background error in the analysis. This result seems to be in agreement with present model tests (Communication with A. Simmons) that show how larger background errors in the analysis have a detrimental impact on forecast performance.

Sampling cases in the summer according to forecast quality over Europe at day-4 shows that the cases of poor scores are associated with a positive correlation of projected increments and sensitivity over the Atlantic. From this result, which has been confirmed by the same statistics for autumn 1998, one would have to conclude that the background errors in the analysis over the Atlantic are too small for sensitive cases which are frequently fast growing baroclinic systems.

3. Summary

This study has shown that the sensitivity calculations at ECMWF can be used to assess the quality of the analysis increments in the unstable subspace. For 2 seasons (JJA and SON) correlation statistics of projected analysis increments and sensitivity of day-2 model errors to initial conditions have been calculated. By stratifying the data according to good and bad forecast performance over Europe the results suggest that the increments over the Atlantic are too small. This can be interpreted as a sign of too small background errors over the rather data sparse areas of the Oceans. Over continents this study would suggest that analysis increments are too large.

References

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Klinker, E., Rabier, F. and Gelaro, R., 1998: Estimation of key analysis errors using the adjoint technique. Q. J. R. Meteorol. Soc., 124,1909-1933.

Rabier, F., Klinker,E., Courtier, P and Hollingsworth, A., 1996: Sensitivity of forecast errors to initial conditions. Q. J. R. Meteorol. Soc. 122,121-150

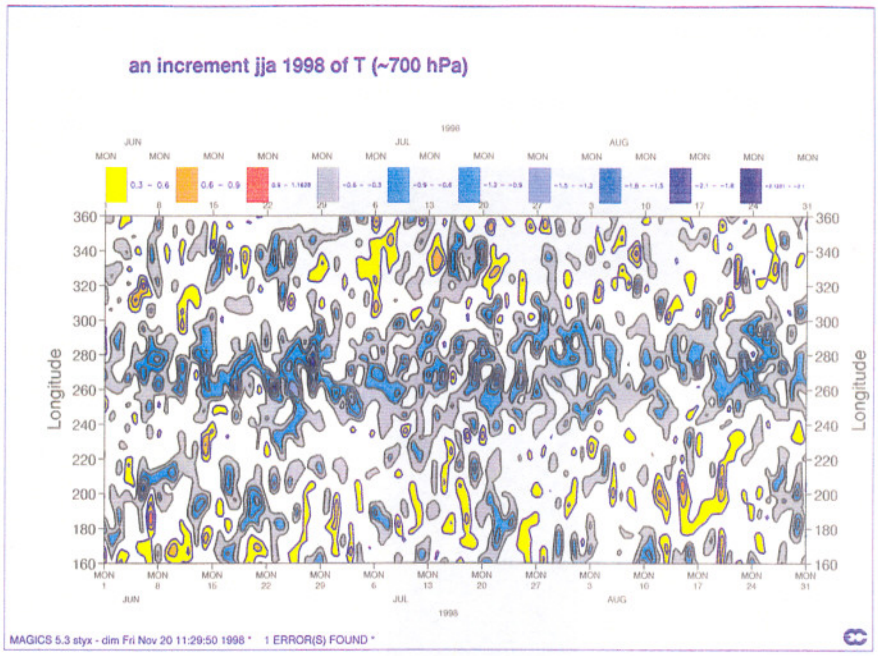


Fig. 1: Hovmoeller diagram of temperature analysis increments for the summer 1998 at model level 23 (~700 hPa).

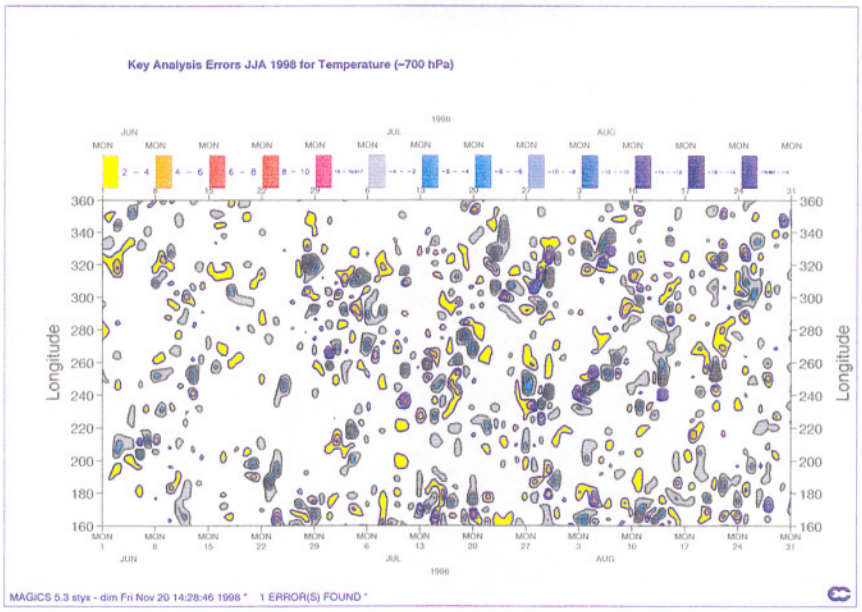


Fig. 2: Hovmoeller diagram of key analysis errors of temperature for the summer 1998 at model level 23 (~700hPa)

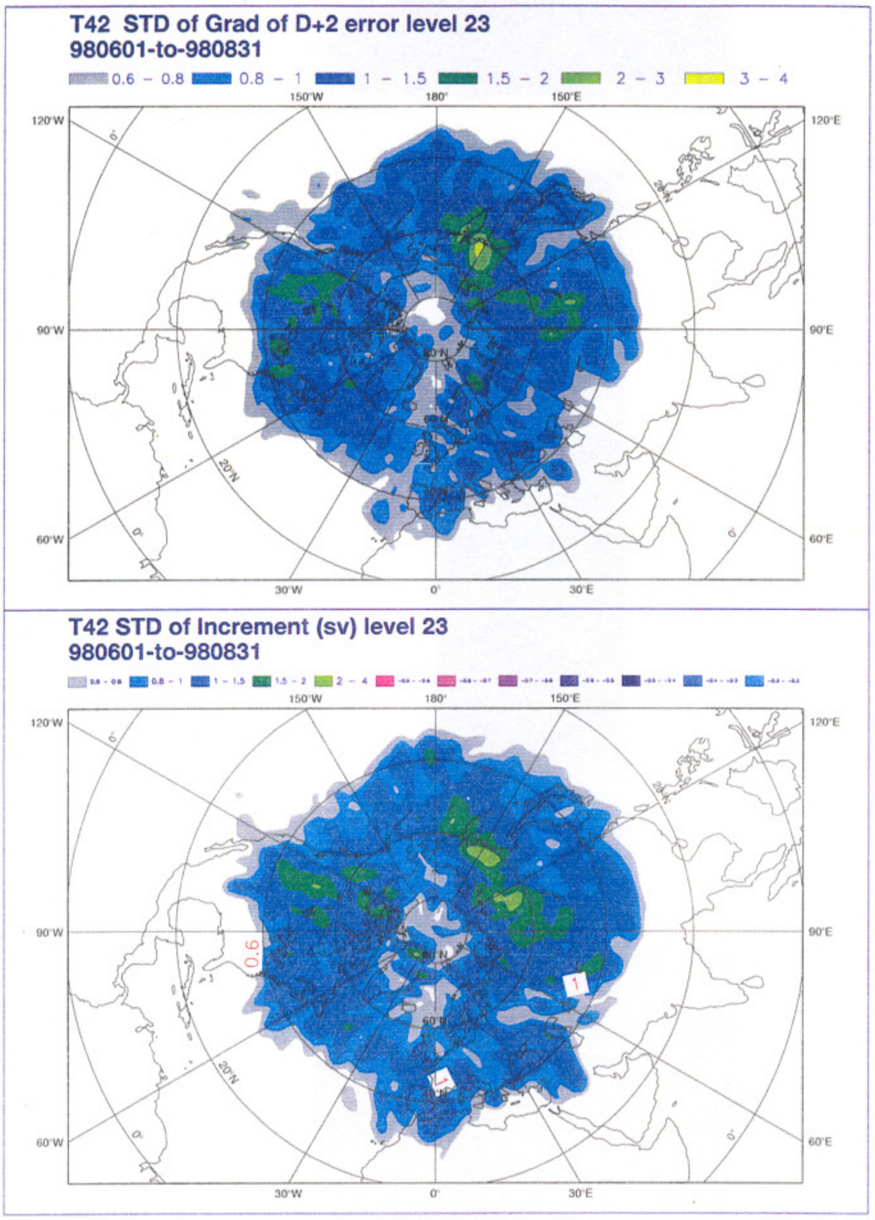
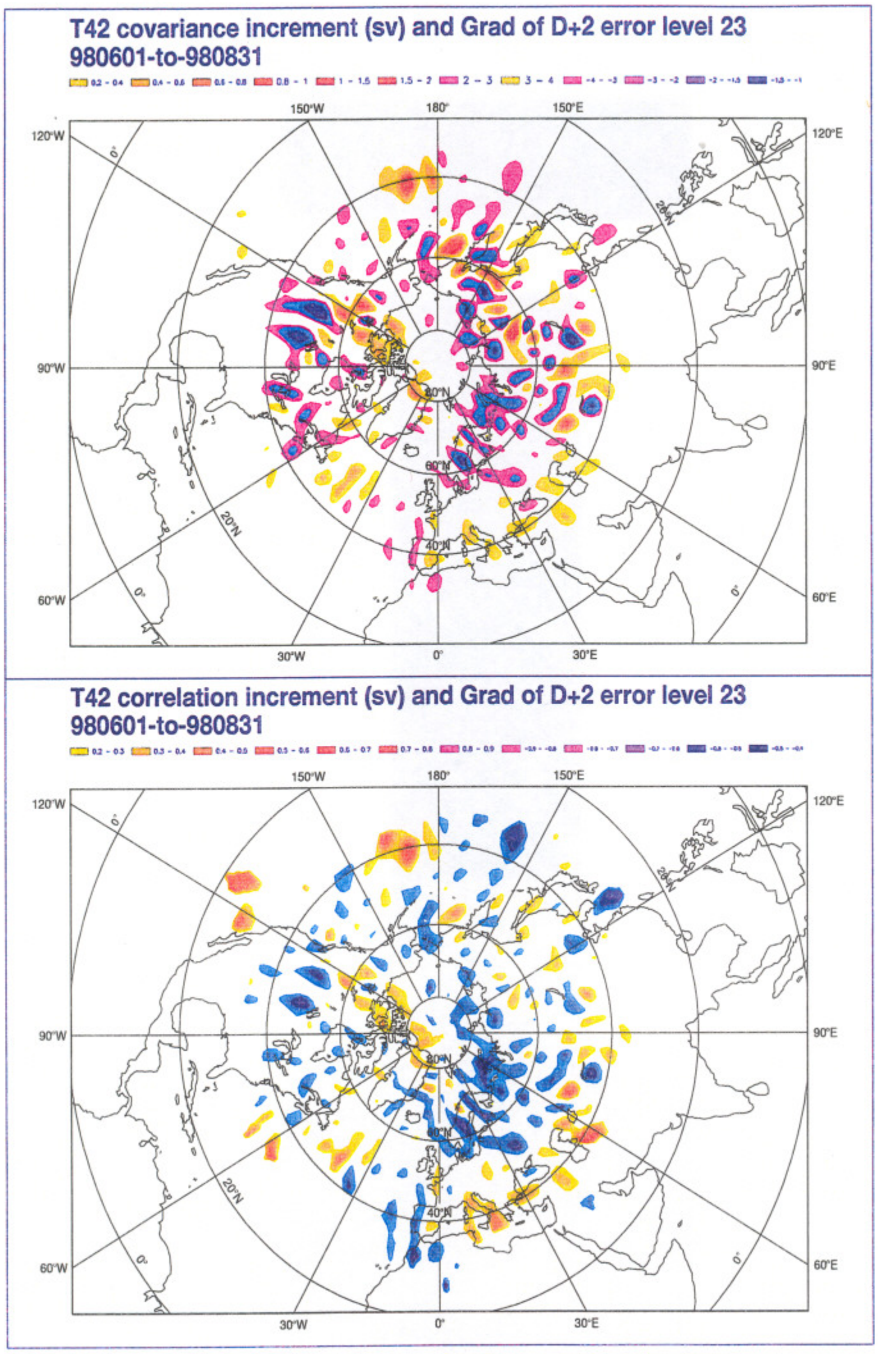


Fig. 3: Standard deviation of sensitivity (top panel) and projected analysis increments (bottom panel) for temperature at model level 23 for summer 1998



T42 covariance increment (sv) and Grad of D+2 error level 23
980601-to-980831

T42 correlation increment (sv) and Grad of D+2 error level 23
980601-to-980831

Fig.4: Covariances (top panel) and correlation (Bottom panel) of sensitivity and projected analysis increments for temperature at model level 23 for summer 1998

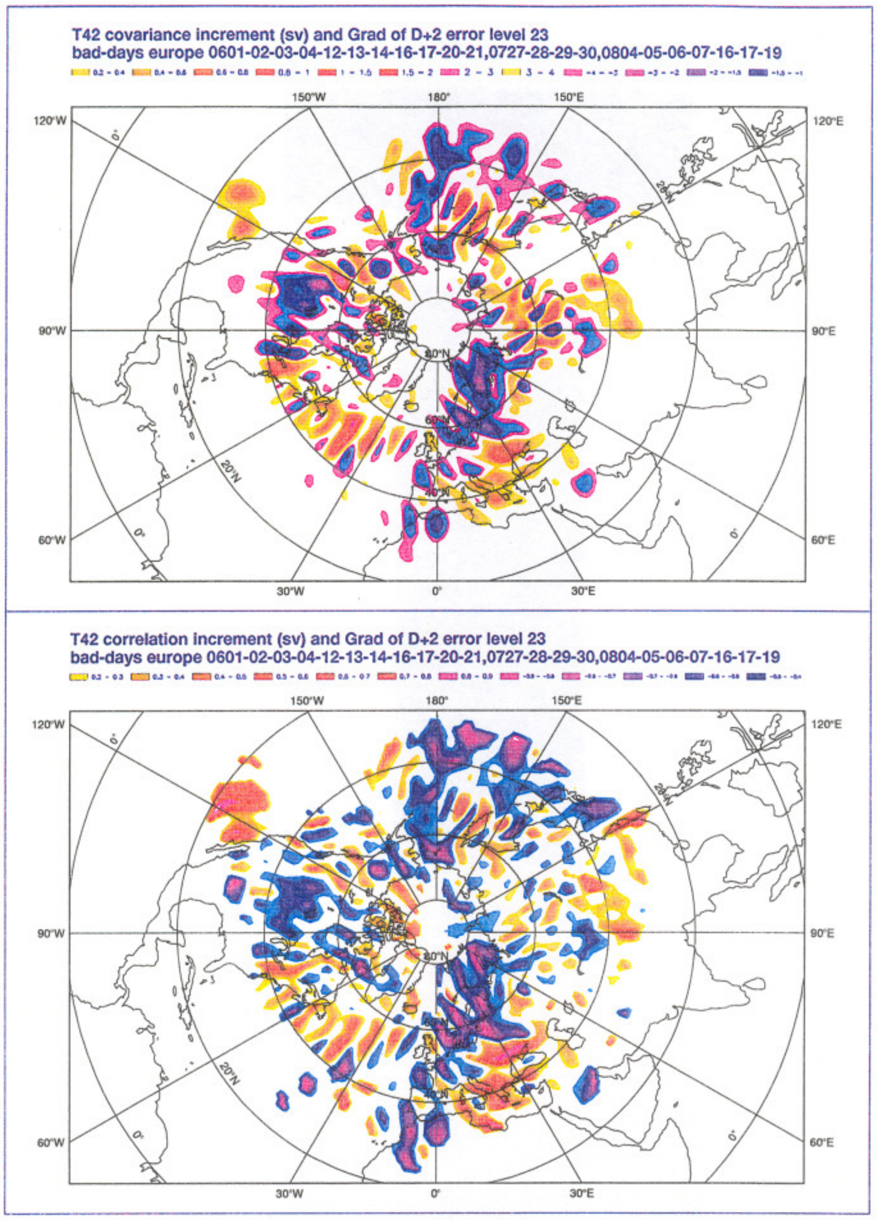


Fig. 5: Covariances and correlation of sensitivity and projected analysis increments for temperature at model level 23 for cases of poor forecast performance over Europe in Summer 1998