Improved structure functions for 3D-VAR

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1 Background

The background error correlations, usually referred to as structure functions, of a data assimilation system determine how the information from the observations are distributed horizontally and vertically. The structure functions also determine how the observation information is distributed between different model variables. The structure functions are supposed to represent the correlations of the errors of the background state, which is a short range forecast, in the case of HIRLAM 3-6 hours.

Usually the structure functions are estimated from differences of forecasts at different ranges, but valid at the same time. This is the so-called NMC-method (Parrish and Derber, 1992). An interesting alternative is to derive the forecast error covariances from ensemble assimilation experiments (Houtekamer *et al*., 1996) by perturbing, for example, observations and forecast model parameterisations. Furthermore, regardless of whether the NMC-method or ensemble assimilation is used, the balances between the different model variables may be formulated in terms of an analytical balance (Gustafsson *et al*., 2001) or a more advanced statistical balance formulation (Berre, 2000). Advantages of statistical balance in the HIRLAM formulation: Scale and latitude dependent geostrophy, boundary layer friction, moisture effects are represented. It should be mentioned that the geostrophy-formulation of the analytical balance is very poor close to the equator.

The structure functions used in the current HIRLAM reference system are based on statistics accumulated on differences between SMHI (Swedish Meteorological and Hydrological Institute) +24 h and +48 h operational HIRLAM forecasts. They use an analytical balance. The operational SMHI HIRLAM was applied with a resolution of 0.4^{o} x 0.4^{o} in the horizontal and with 31 vertical levels. The data set covers the period 1 December 1997 through 28 February 1998.

The NMC-method applied to differences between +24 h and +48 h forecasts has been observed to provide too broad background error correlation structures. Furthermore, since the HIRLAM reference model is currently run with 40 vertical levels, a vertical interpolation of the structure functions is carried out.

The purpose of the present work was to generate new, sharper structure functions, with an improved realism of the balance description, using statistical balance. The new ones should furthermore be based on data from 40 vertical levels.

2 Newly generated structure functions

Two sets of new structure functions were generated:

- The NMC-method was applied on 4 months (August-November 2004) of SMHI operational forecast differences (36 h-12 h). The operational forecast model was run with 22 km horizontal resolution and 40 vertical levels. A statistical balance formulation was used.

- The forecast differences were taken from 2 weeks of 6 h forecasts (18 -31 October 2000). These were from an ensemble assimilation experiment. It was carried out at 22 km horizontal resolution and with 40 vertical levels. There were 10 members plus a control in the ensemble assimilation experiment (using perturbed observations and perturbed lateral boundaries from a similar experiment at ECMWF). When calculating structure function statistics the members were combined (co-1,1-2,2-3,.....,9-10,10-co) to give 154 cases. Again a statistical balance formulation was used.

The old and the new structure functions are illustrated in Figure 1 and 2. Figure 1 shows the horizontal impact of one single surface pressure observation 5 hPa less than the corresponding background equivalent on the surface pressure and low level wind fields. With the new structure functions, using a statistical balance, the frictional inflow associated with the low level cyclonic circulation is represented. The horizontal scales of the increments are significantly smaller in the case of ensemble based structure functions. Figure 2 illustrates that also the vertical scales are more confined in the case of ensemble based structure functions.

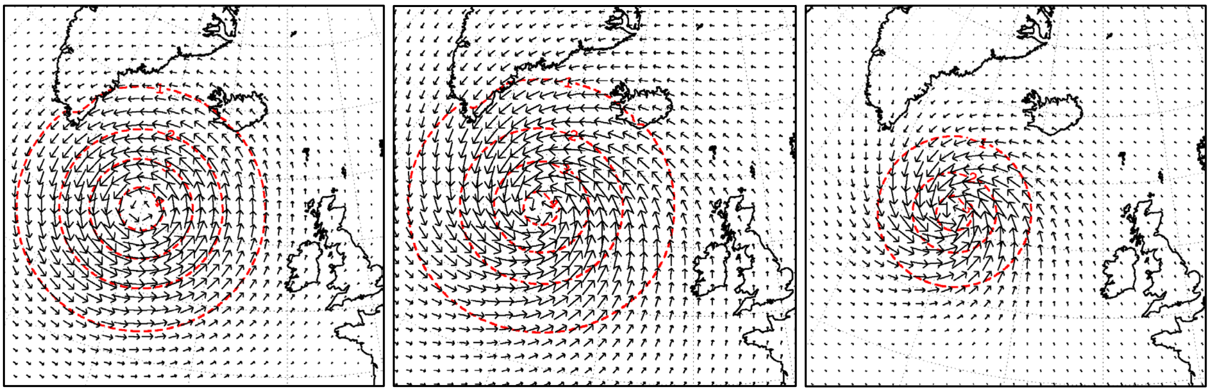

Figure 1. Impact of one single surface pressure observation 5 hPa less than the corresponding background equivalent. Red isolines represents surface pressure increments and black arrows winds at the lowest model level. Left is for reference structure functions (using analytical balance), middle for new NMC-based (using statistical balance) and right for ensemble based (using statistical balance).

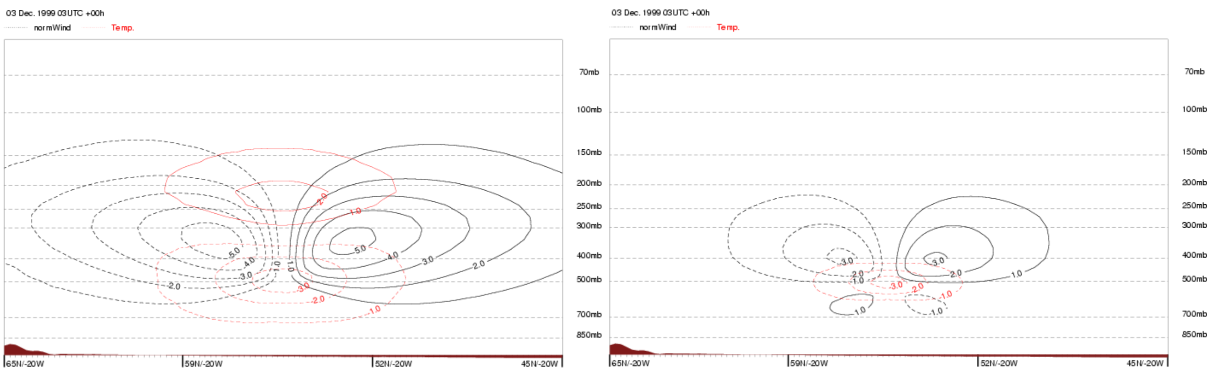

Figure 2. Impact of one single temperature observation at 500 hPa and 5 K less than the corresponding background equivalent. Red isolines represents temperature increments and black wind speed increments. Left is for new NMC-based structure functions (using statistical balance) and right for ensemble based (using statistical balance).

3 Assimilation experiments

Three parallel assimilation and forecast experiments have been carried out over the SMHI operational domain illustrated in Figure 3**.** An horizontal resolution of 22 km and 40 vertical levels were used. Analyses ad forecasts up to 48 h were carried out 4 times a day for the period 1 June -5 July, 2005, using hirlam.6.4.0. Reference settings were used except for the domain and for that ECMWF forecasts were used as lateral boundaries. The structure functions used in the three parallel runs were as follows:

- Reference structure functions using analytical balance (f3d)
- NMC-method and statistical balance (sbq)
- Ensemble assimilation and statistical balance (sbe)

It should be mentioned that in the two parallel runs using statistical balance an index field was used for representing horizontal background error variations. The magnitude of the horizontally averaged background error standard deviations were similar for the three experiments.

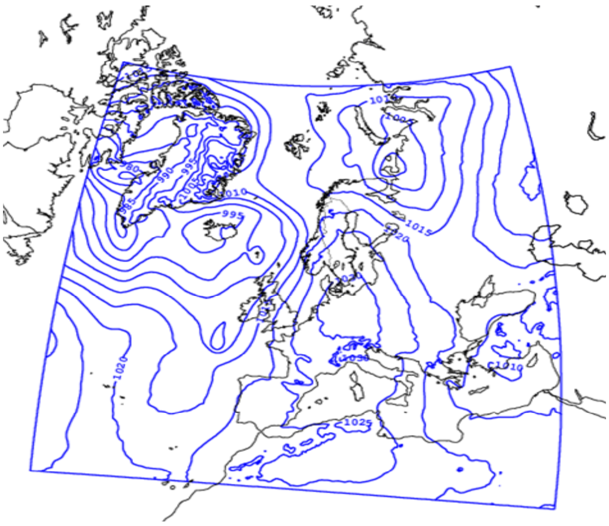

Figure 3. Illustration of model domain

The forecasts of three parallel runs of the one month period have been verified against observations. The results are presented as rms (root mean square) error, standard deviation and bias, as function of forecast length for different meteorological parameters. Figure 4 is for mean sea level pressure forecasts and Figure 5 for wind speed and temperature forecasts at the 700 and 300 hPa forecasts. In terms of rms and standard deviations the forecasts based on assimilation with a statistical balance within the structure functions are better for all parameters. The scores of the two different runs using a statistical balance (with NMC or ensemble method) are however rather similar.

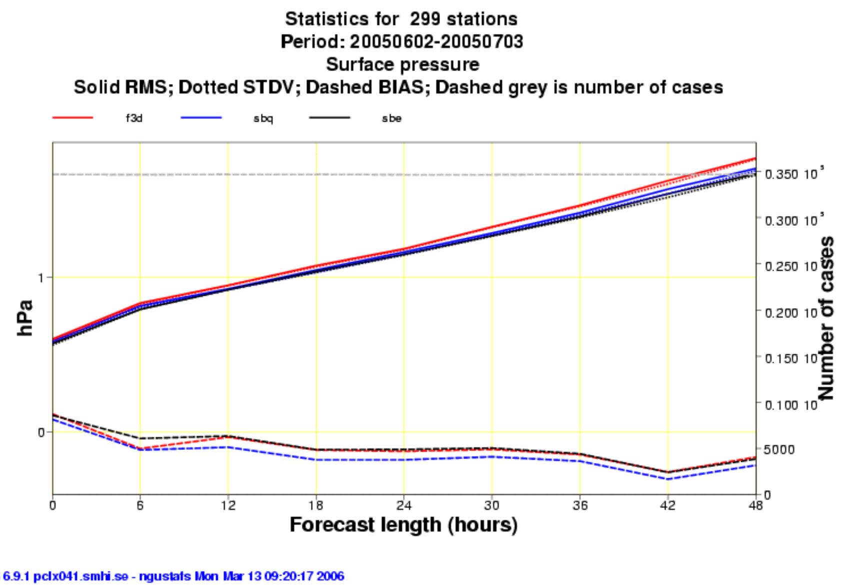

Figure 4. Rms, standard deviation and bias of Mean Sea Level Pressure forecasts (hPa) as function of forecast length (h). Red lines are for reference structure functions, blue for new NMC-based using statistical balance and black for new ensemble based using statistical balance.

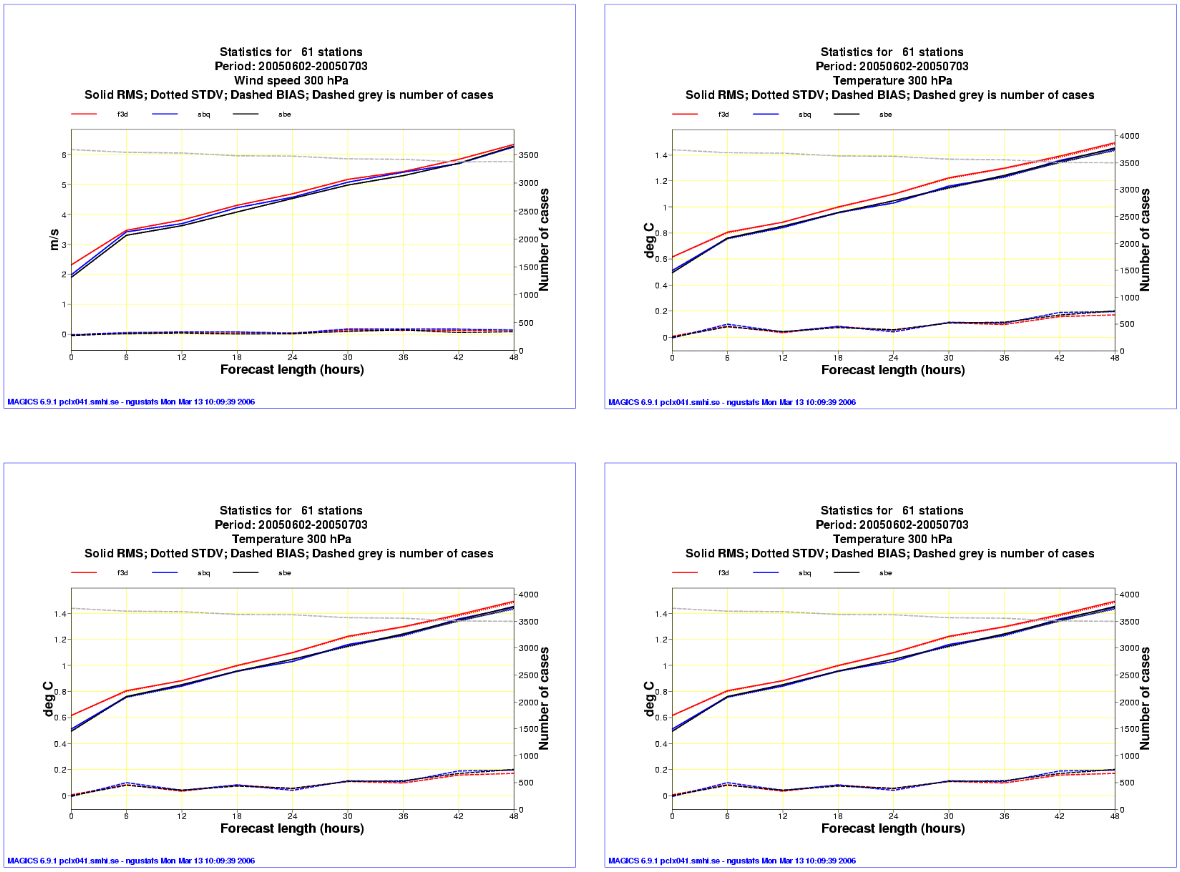

Figure 5. Rms, standard deviation and bias of Wind speed (m/s) and temperature (K) forecasts as function of forecast length (h). Upper left: 300 hPa wind speeds. Lower left: 700 hPa wind speeds. Upper right: 300 hPa temperatures. Lower right: 700 hPa temperatures. Red lines are for reference structure functions, blue for new NMC-based using statistical balance and black for new ensemble based using statistical balance.

4 Concluding Remarks

Two new sets of new structure functions have been generated using the NMC-method and ensemble assimilation, respectively, and with an statistical balance. The application of the new structure functions in the HIRLAM system results in improved forecast verification scores. The assimilation experiments carried out here were using 3D-VAR, but the new, improved structure functions should also improve 4D-VAR. There were no significant difference in forecast quality between the runs using the new NMC-based and the new ensemble based structure functions.

When utilising structure functions based on statistical balance one should not use structure functions generated on an area smaller than the one on which the assimilation is carried out on. This can lead to spurious assimilation increments due to extrapolation of correlation spectra. Ideally the structure functions should be calculated on the same model domain and resolution as the one used in the assimilation.

5 References

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