Tuning of Nudging of Surface Pressure Observations

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1 Motivation

For the December 1999 storms and a small number of other severe storm events, the nudging was not able to correct efficiently for the large errors conveyed to the LM through the lateral boundaries. This resulted in significant and sometimes large errors e.g. in the surface pressure field of the LM analyses and very-short to short range forecasts in the environs of these cyclones. It indicated that the surface pressure observational information was not assimilated sufficiently when the dynamic forcing was very strong. Therefore, refinements such as the inclusion of observed pressure tendencies in the quality control thresholds and the introduction of a spatial consistency check for surface pressure data have already been introduced in 2000 and 2001. Furthermore, the quality weights for pressure data from reports with large absolute observed pressure tendencies is increased to enhance the influence of such data. Despite some improvement, however, the forcing of the pressure nudging obviously remained too weak in these cases with a very strong dynamic forcing. This motivated the tuning experiments presented here with a view to a general increase of the nudging coefficient for surface pressure data.

There is also some theoretical justification to choose a greater value for the nudging coefficient for this type of data than for other data. This is related to the fact that for multiple observations, the individual (spatial, temporal, and quality) weight w_k given to an observation at a target grid point is complemented by a relative weight

$$W_k \quad = \quad \frac{w_k}{\sum_j w_j} \cdot w_k \tag{1}$$

where the sum is over all observations influencing a certain target grid point. This simple approach is designed to improve the gradients of the analysed fields (Benjamin and Seaman, 1985) and has been widely used in nudging schemes. However, it has the adverse property to tend to reduce the total weight and effective forcing of the nudging in data-dense areas. For instance, for a single observation with individual weight 1 at the target grid point coinciding with the observation location, the total weight at that point is also 1 (because $\sum_k W_k = w_k$). However, if the observation is surrounded by four other observations with the same observation increment such that their individual (spatial) weight w_k is 0.25 at the target grid point, then the total weight $\sum_k W_k$ related to all observations together will be reduced from 1 to about 0.625. Thus, the total forcing of the nudging is reduced, and the resulting effective e-folding decay time of the relaxation is almost doubled. This effect prevails particularly with the surface pressure nudging where a target grid point is usually influenced by many observations from the relatively dense European synoptic surface station network.

2 Investigated Modifications and Impact on Upper-Air Verification

The experiments performed for the storm cases indicate that (at least within certain bounds) the larger the coefficient the better the simulated surface pressure fields. However, the scores in the upper-air wind verification tend to degrade in some cases. This, and the theoretical considerations above applied to the typical data density within the LM domain suggest that doubling the coefficient to a value of $12 \cdot 10^{-4} s^{-1}$ should be a good choice.

This has been applied in parallel assimilation and forecast cycle experiments with 3 daily forecasts from 0, 12, and 18 UTC, and compared to the reference version with a nudging coefficient of $6 \cdot 10^{-4} s^{-1}$. Two 6-day periods have been verified. Period I from 29-10-2000 to 4-11-2000 was characterized by the occurence of several pronounced mesoscale cyclones within the LM domain, whereas period II from 19-12-2000 to 25-12-2000 was anticyclonic with some low stratus and south- to southeasterly winds over Germany and environs. In the subsequent plots for period I, only the radiosondes of the northwestern part of the LM

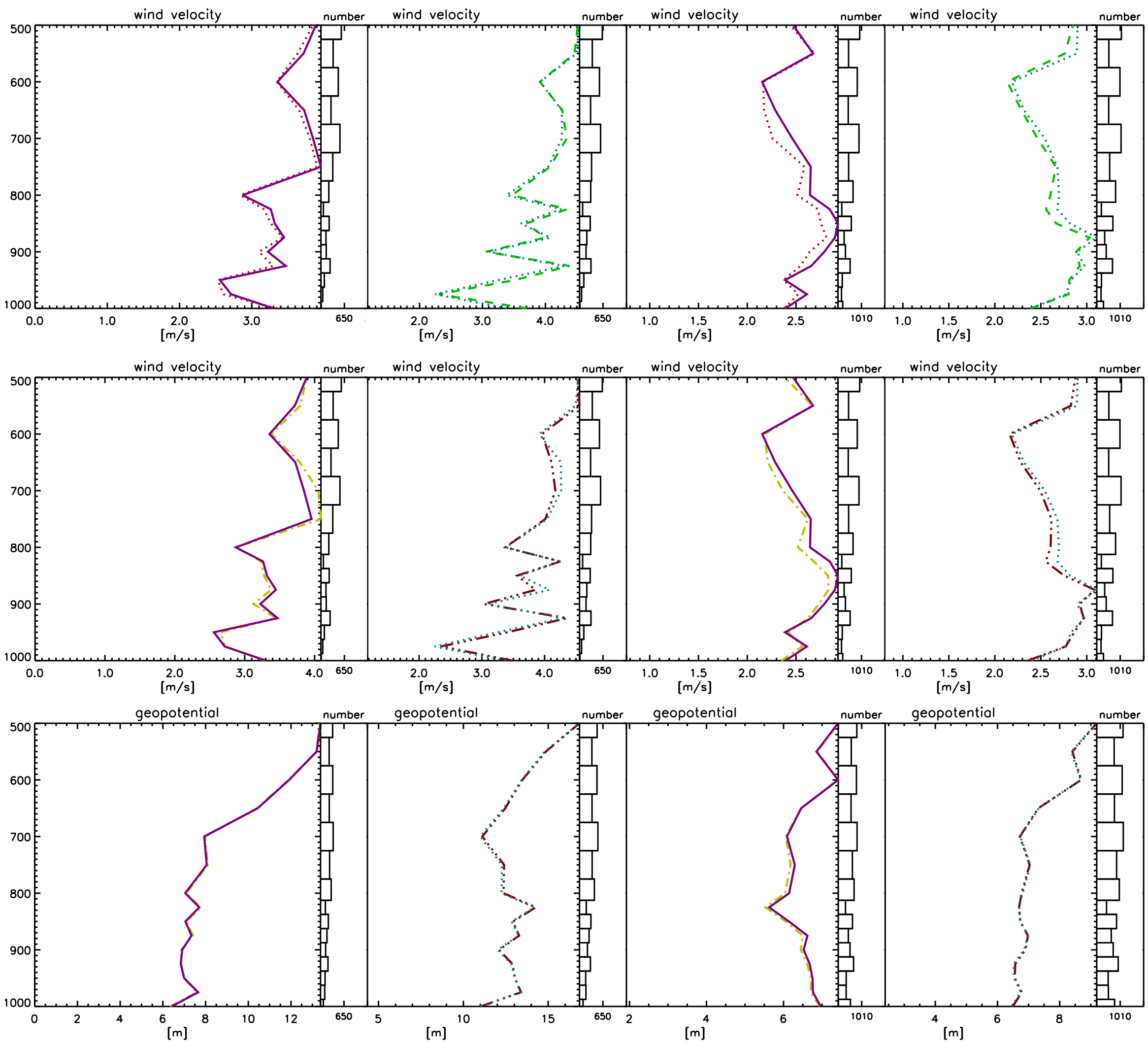

Figure 1: Upper-air verification against radiosonde data (TEMP and PILOT) between 1000 and 500 hPa for forecasts from continuous assimilation and forecast cycle experiments for period I from 29 October, 6 UTC, to 4 November 2000, 0 UTC, and period II from 19 December, 12 UTC, to 25 December 2000, 0 UTC. For this verification, only the radiosondes from the 'northwestern area' of the LM domain, i.e. north of 50 degrees latitude and west of 10 degrees longitude, are used for period I, and for period II, only those from the 'inner domain' are used, which excludes the outermost 60 grid rows (ca. 420 km) of the total LM domain. The upper 2 rows of panels show vertical profiles of rms errors of wind speed, the bottom row of geopotential. From left to right, the panels show the 6-hour forecasts for period I, the 12-hour forecasts for period I, the 6-hour forecasts for period II, resp. the 12-hour forecasts for period II. Red dotted lines (6-hour forecasts) and green dashed lines (12-hour forecasts): reference version; purple solid line and bluish green dotted lines: version with nudging coefficient for surface pressure enhanced to $12 \cdot 10^{-4} s^{-1}$; yellow dash-dotted and brown dot-dash-dotted lines: new version with enhanced nudging coefficient for surface pressure and with modified geostrophic wind correction.

domain are used for the verification. That area covers the tracks of the cyclone centres. The results from the verification on the whole LM domain are similar execpt that the differences between the versions compared are smaller.

Figure 1 (left panels) shows that there is a deterioration of the wind (speed) which is small and limited to the first 6 forecast hours in period I but significant both at +6h and +12h forecast time in period II. Therefore, a number of further tuning experiments have been performed with respect to the corrections that are related to the surface pressure nudging. Decreasing the top level of the temperature correction from 400 hPa to 500 hPa does not improve the forecasts, while increasing that level to 250 hPa has a negative impact. Different versions have been tested with respect to the fraction of the geostrophic wind increments that is added to the model wind field. Moderately decreasing the geostrophic wind correction tends to improve period II and at the same time degrade period I.

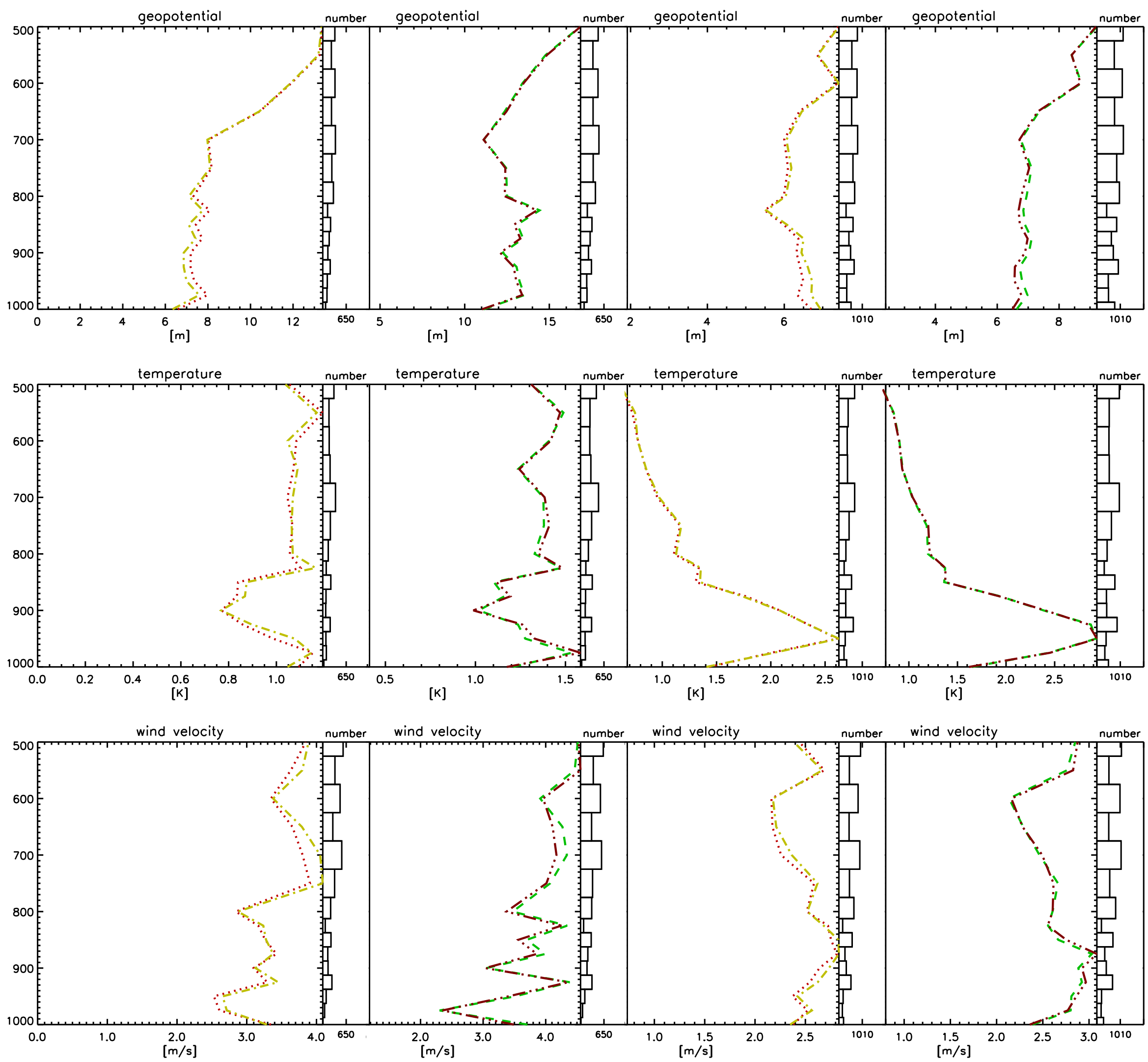

Figure 2: Upper-air verification as in Fig. 1. From left to right, the panels show the 6-hour forecasts for period I, the 12-hour forecasts for period I, the 6-hour forecasts for period II, resp. the 12-hour forecasts for period II. From top to bottom, the panels show the rms errors of geopotential, temperature, and wind speed. Red dotted lines (6-hour forecasts) and green dashed lines (12-hour forecasts): reference version; yellow dash-dotted and brown dot-dash-dotted lines: new version with enhanced nudging coefficient for surface pressure and with modified geostrophic wind correction.

As a result of these tuning experiment, the following modifications on the geostrophic wind correction have been finally adopted for the new version:

- The general factor applied to the geostrophic wind increments is decreased from a fixed value of 0.5 to a pressure-dependent value which varies linearly in pressure between 0.3 at 1000 hPa and 0.5 at the top of the correction, i.e. at 400 hPa.
- The thickness of the layer above the ground, where an additional reduction factor is applied which ranges from 1 at the top of the layer to zero at the ground, is reduced from 100 hPa to 50 hPa.
  Together with the first modification, this results in a slight increase of the correction within the lowest 50 hPa and a decrease further above with repect to the old version.
- The overall upper limit for the absolute value of the wind correction is increased from $\Delta t_h \cdot 2.5\, m/s$ to $\Delta t_h \cdot 20\, m/s$, , where Δt_h is the model integration timestep in hours. This tends to enhance the wind correction in the presence of large pressure errors, i.e. mainly in period I.

These modifications improve the winds (Figure 1, centre colum panels) in both periods at all forecast times except for the deterioration around 700 hPa at +6h in period I. The impact on geopotential (Figure 1, right panels) is neutral to slightly positive in period II.

Compared to the reference version (Figure 2), the negative impact on the wind in period II has been greatly reduced at +6h and almost eliminated later on. In period I, it is enhanced above 750 hPa at +6h, however at +12h, there is a small positive impact now. For temperature, the impact is slightly negative in period I and neutral in period II, whereas for geopotential, it is positive except at +6h in period II. Overall, the upper-air fields appear to be slightly degraded at +6h and slightly improved at +12h and later on.

Finally, it is noted that in period II, both the increase of the nudging coefficient and the changes to the geostrophic wind correction tend to contribute to an altogether (very) small positive impact on the prediction of the cloud cover of low stratus.

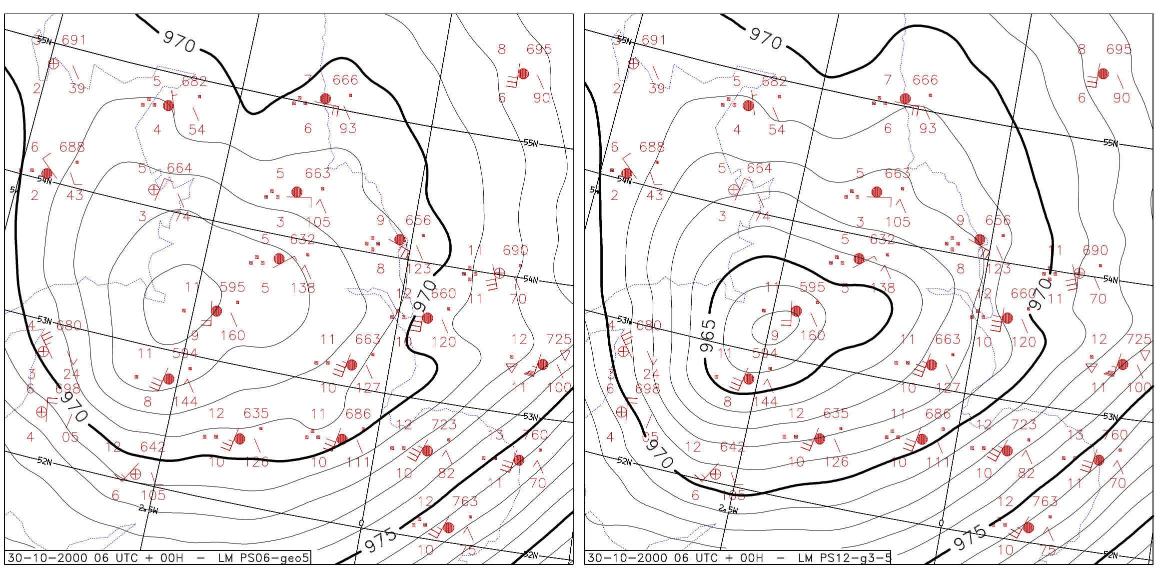

Figure 3: Mean sea level pressure of LM analyses (contours) and surface observation reports valid for 30 October 2000, 6 UTC. Left panel: reference version; right panel: new version with enhanced nudging coefficient for surface pressure and with modified geostrophic wind correction.

3 Impact on Surface Pressure

The statistical benefit on surface pressure found during the first forecast hours almost disappears after +6h. However, the benefit can be significant in individual storm cases. For the 30 October 2000 cyclone (Figure 3), of which the central pressure decreased by 15 hPa between 0 UTC to 6 UTC and by another 15 hPa until 12 UTC, the central pressure error in the 6 UTC analysis is reduced from 7 hPa to 4 hPa. At 12 UTC, it is reduced from about 5 hPa to 1 hPa in the analysis and from 13 hPa to 11 hPa in the 6-hour forecast with very short cut-off time (where all observations are used from the synoptic time itself, i.e. from 6 UTC, but no observations from later on, i.e. from 7 UTC or 8 UTC). Furthermore, the shape of the isobars appears to be more realistic.

For the (3 December) 1999 Danish storm (Figure 5 to Figure 7), the analysis errors at 6 UTC and at 9 UTC are reduced by 2 hPa to about 3 hPa resp. 2 hPa. For the forecasts

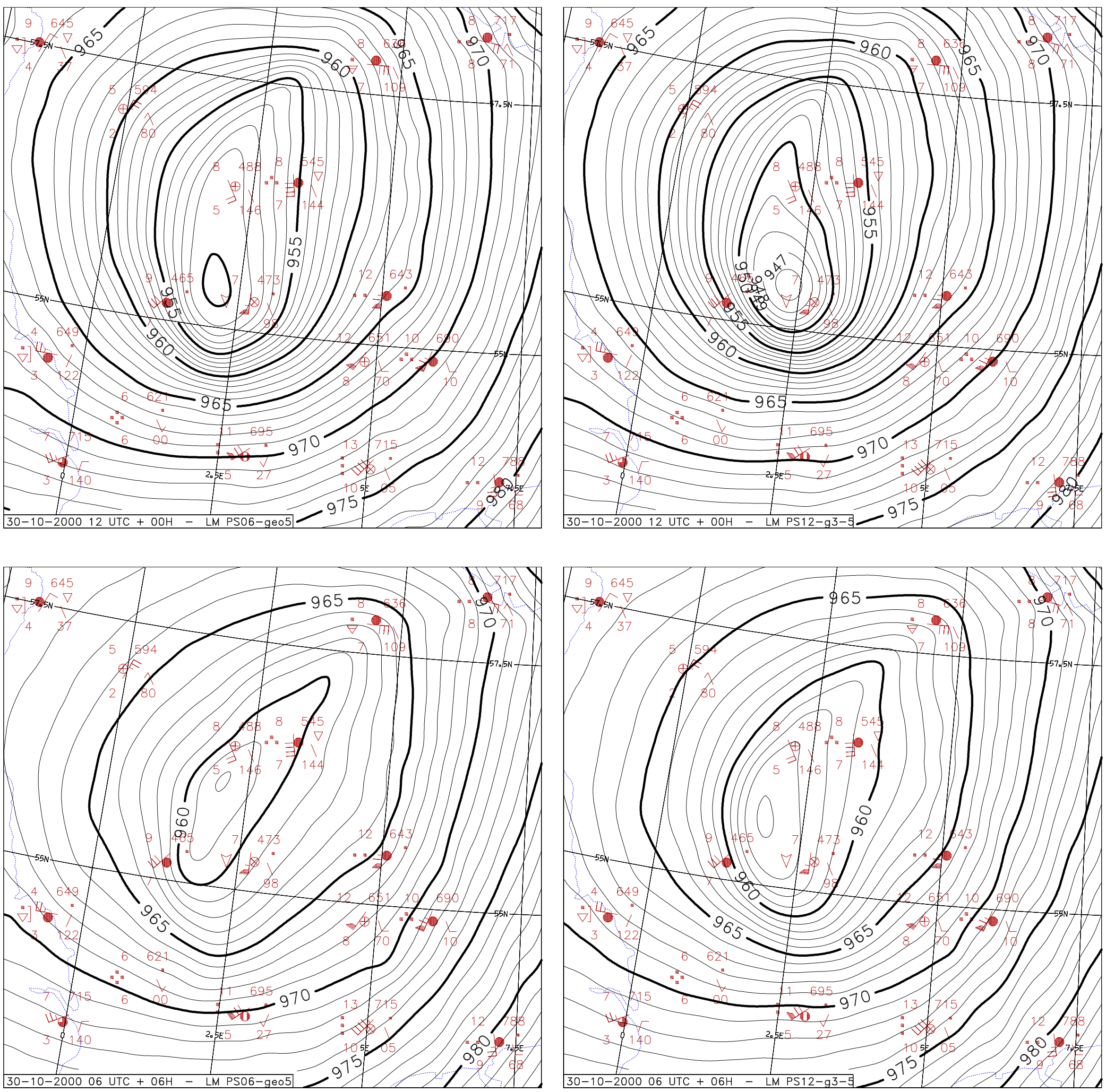

Figure 4: Mean sea level pressure of LM runs (contours) and surface observation reports valid for 30 October 2000, 12 UTC. Left panels: reference version; right panels: new version with enhanced nudging coefficient for surface pressure ($12 \cdot 10^{-4} s^{-1}$) and with modified geostrophic wind correction. Upper panels: LM analyses; lower panels: 6-hour forecasts with short cut-off time.

starting at these two analysis times with very short cut-off time, the reduction of the central pressure errors are as follows: at 18 UTC from 10 hPa to 9 hPa (+12h) resp. from 7 hPa to 4 hPa (+9h), at 21 UTC from 12 hPa to 8 hPa (+15h) resp. from 8 hPa to 4 hPa (+12h), at 0 UTC (not shown) from 10 hPa to 6 hPa (+18h) resp. from 6 hPa to 3 hPa (+15h). In most cases, this comes along with a moderate improvement of the centre position and a more realistic shape of the central part of the cyclone. For the 26 February 2002 cyclone (Figure 8), finally, the pressure error is reduced in the analysis at 0 UTC at a very early stage from about 7 hPa to 5 hPa. In the subsequent forecast (with operational cut-off), the errors decrease with increasing forecast time, and at 15 UTC, the central pressure error of less than 2 hPa is reduced by almost 1 hPa, and the fit to almost all observations is improved.

The modification of the geostrophic wind correction has a limited impact on the pressure field in these storm cases. Apart from the analyses shown in Figure 9 where the improvement in one case and deterioration in the other case is up to almost 1 hPa, the (more often negative)

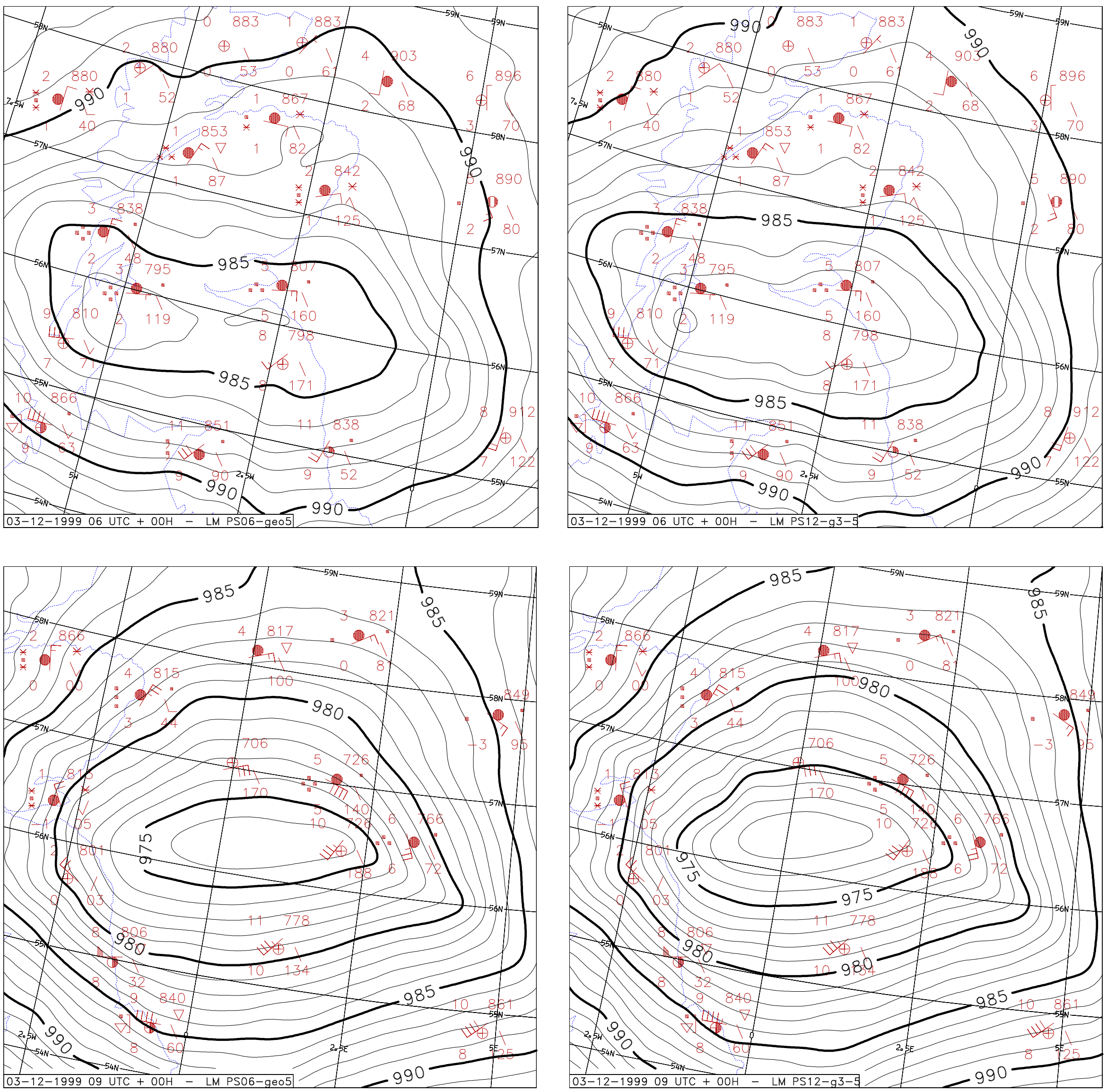

Figure 5: Mean sea level pressure of LM runs (contours) and surface observation reports valid for 3 December 1999. Left panels: reference version; right panels: new version with enhanced nudging coefficient for surface pressure ($12 \cdot 10^{-4} s^{-1}$) and with modified geostrophic wind correction.
Upper panels: LM analyses valid for 6 UTC; lower panels: LM analyses valid for 9 UTC.

impact both in the analyses or forecasts is between 0 and 0.5 hPa everywhere.

4 Conclusion

The substantial and significant improvements of the analyzed and predicted pressure fields in several mesoscale cyclonic severe storm cases and the near-neutral impact in the upper-air verification for two 6-day assimilation and forecast cycles suggest the operational introduction of the modifications. These consist of doubling the nudging coefficient for surface pressure to $12 \cdot 10^{-4} s^{-1}$ and of the changes to the geostrophic wind correction as mentioned above.

5 References

Benjamin, S.G., N.L. Nelson, 1985: A simple scheme for objective analysis in curved flow. *Mon. Wea. Rev.* **113**, 1184 - 1198.

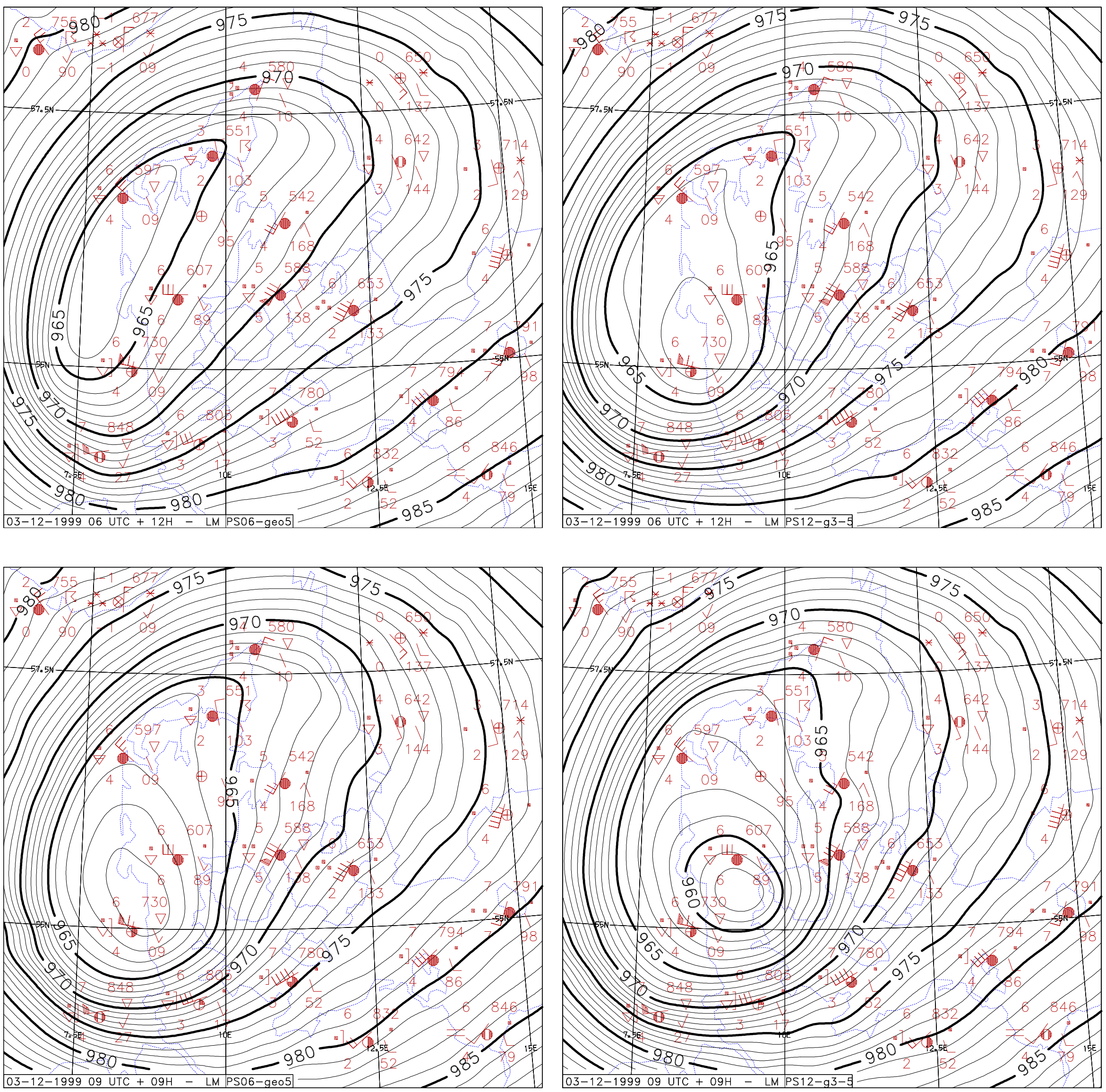

Figure 6: As Fig. 5 but upper panels: 12-hour forecasts (with short cut-off time for observations) valid for 18 UTC; and lower panels: 9-hour forecasts (with short cut-off time) valid for 18 UTC.

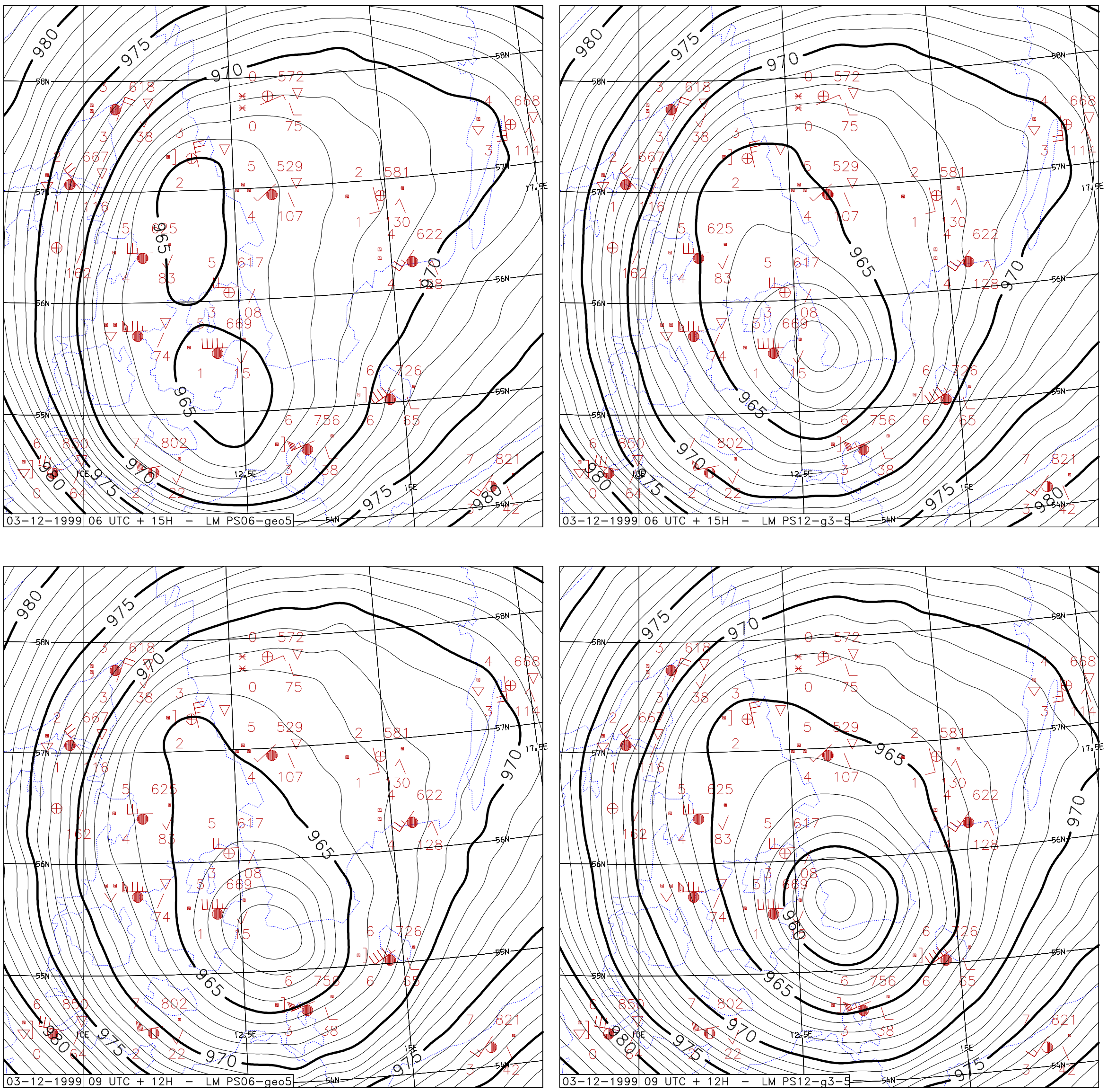

Figure 7: As Fig. 5 but upper panels: 15-hour forecasts valid for 21 TC; and lower panels: 12-hour forecasts valid for 21 UTC.

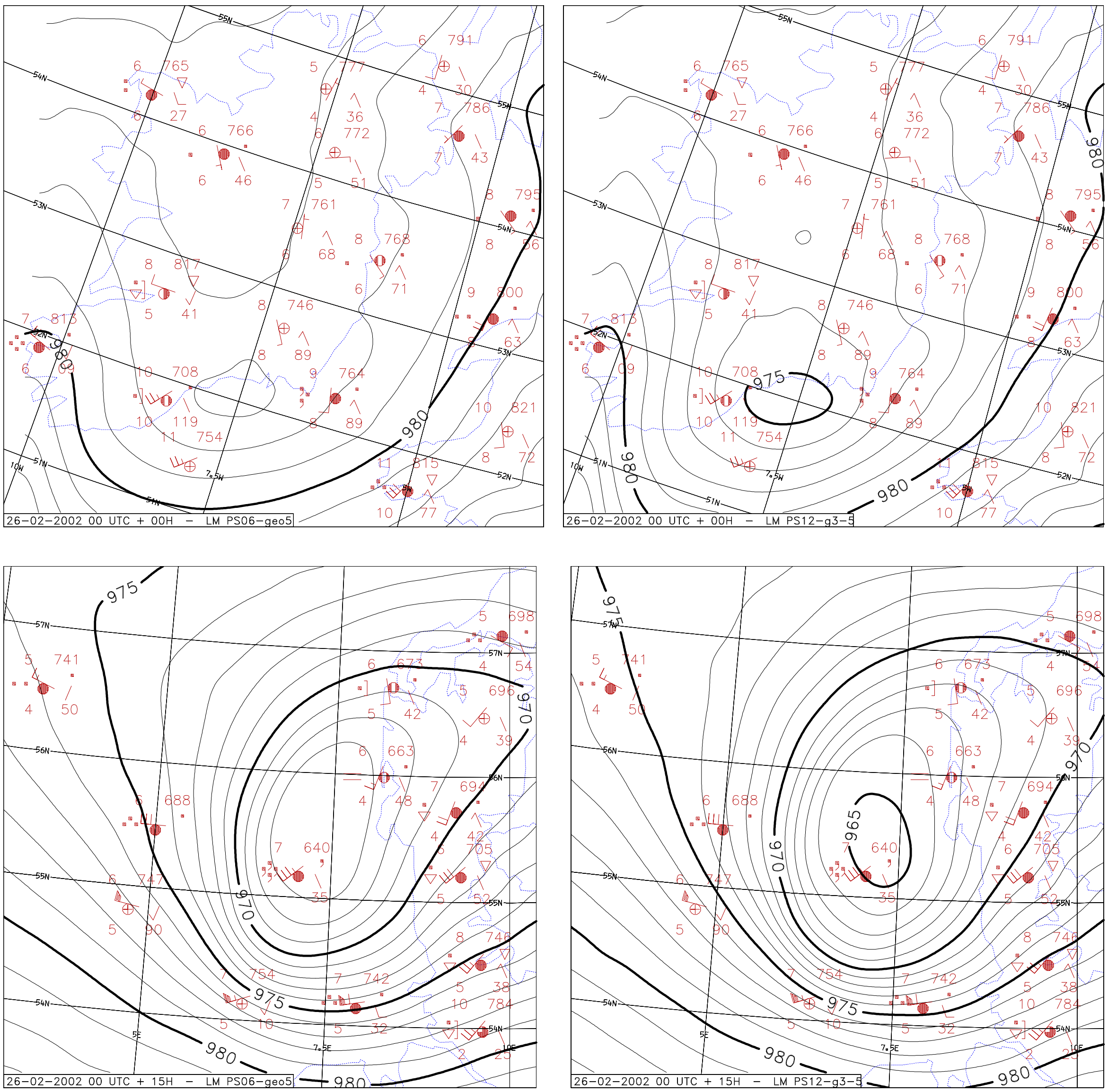

Figure 8: Mean sea level pressure of LM runs (contours) and surface observation reports valid for 26 February 2002. Left panels: reference version; right panels: new version with enhanced nudging coefficient for surface pressure ($12 \cdot 10^{-4} s^{-1}$) and with modified geostrophic wind correction. Upper panels: analyses valid for 0 UTC; lower panels: 15-hour forecasts valid for 15 UTC.

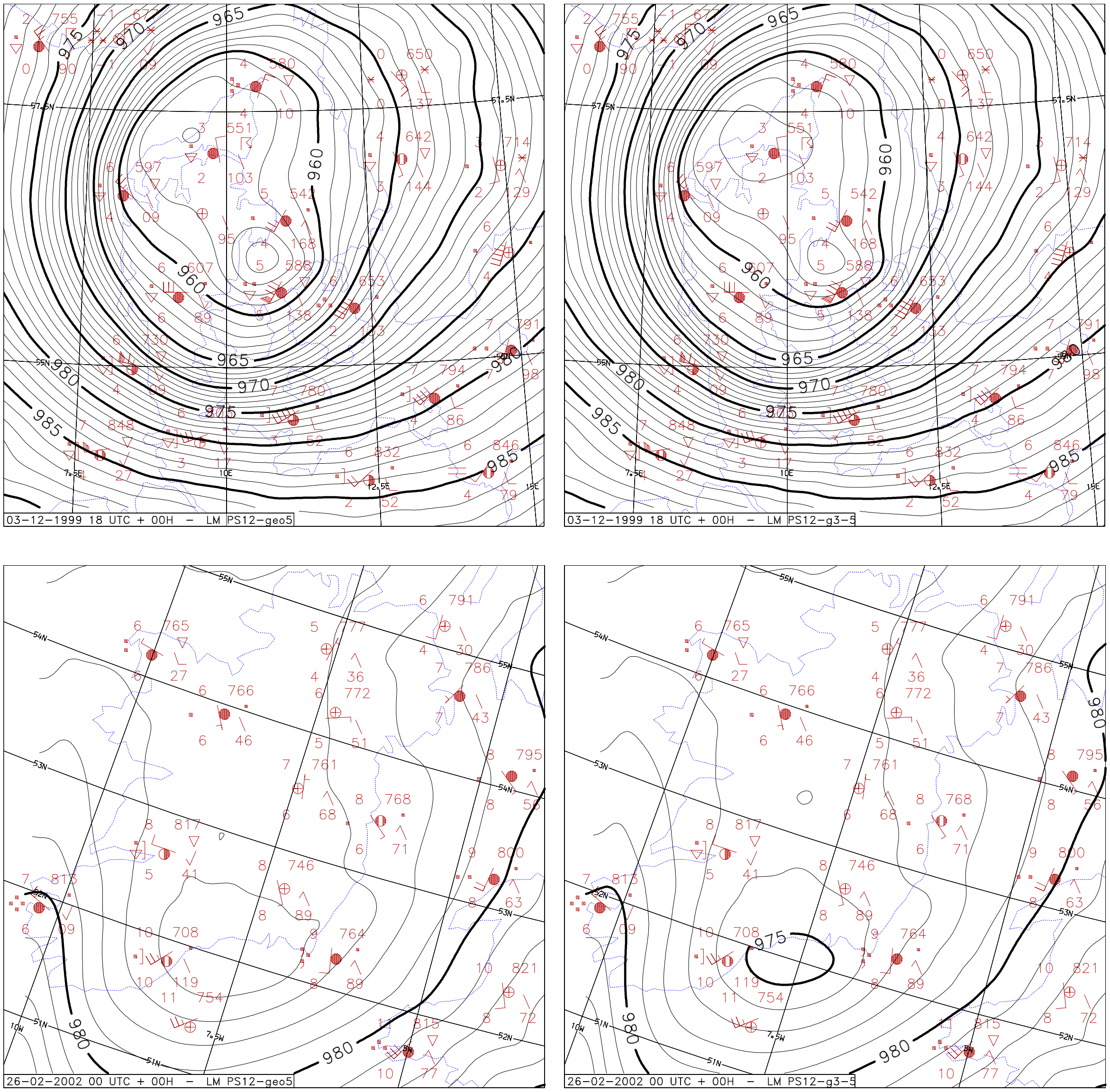

Figure 9: Mean sea level pressure of LM analyses (contours) and surface observation reports. Left panels: control version with enhanced nudging coefficient for surface pressure ($12 \cdot 10^{-4}s^{-1}$); right panels: new version, i.e. as control version but with modified geostrophic wind correction. Upper panels: analyses valid for 3 December 1999, 18 UTC; lower panels: analyses valid for 26 February 2002, 0 UTC.