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Forecast sensitivity to observation error variance

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Forecast sensitivity to observation error variance

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An overview of the latest developed diagnostic tool for observation usage and impact is presented. The tool consists on calculating the sensitivity of the short-range forecast error with respect to the assigned observation error variances by using the adjoint version of the assimilation and forecast model. This sensitivity is compared with the influence of the same observations in the assimilation process and their related contribution to the forecast error is also assessed. The results indicate that a reduction of the error variances for all observation types, except radiosondes and polar atmospheric motion vectors, would potentially reduce the 24-hour forecast error. In particular, a sensitivity experiment with reduced error variance for radio occultation observations shows, on average, a smaller mean 24- and 48-hour forecast difference with respect to aircraft and radiosonde measurements.

Background

The ECMWF four-dimensional variational system (4D-Var) handles a large variety of both space and surface-based meteorological observations (more than 30 million a day) and combines the observations with the prior (or background) information on the atmospheric state. Being able to assess the contribution of each observation to the analysis is amongst one of the most challenging diagnostics in data assimilation and numerical weather prediction. Methods have been developed to measure the observational influence in data assimilation schemes (see *Cardinali et al.*, 2004 and the references therein). The two key parameters are the Degree of Freedom for Signal (DFS), which quantifies how many atmospheric state elements are determined by the observations, and the Observation Influence (OI) which is the DFS divided by the number of observations (*OI*=0 indicates that background information dominates whereas *OI*=1 indicates that the observations totally dominate).

These techniques show how the influence is partitioned between the observation and the background or pseudo-observation during the assimilation procedure. They therefore provide an indication of the robustness of the fit between model and observations, and indicate the necessity for some refinement of the assigned accuracies in the assimilation system.

For the forecast, adjoint-based techniques are able to characterize the forecast impact of every measurement (see *Cardinali*, 2009 and the references therein). The technique computes the variation of the forecast error due to the assimilated data – this is known as the Forecast Error Contribution (FEC). In particular, the forecast error is measured by a scalar function of the model parameters, namely wind, temperature, humidity and surface pressure that are more or less directly related to the observable quantities. In general, the adjoint methodology can be used to estimate the sensitivity of a forecast not only to observations but also to any parameter used in the assimilation system. In particular, the sensitivity with respect the observation error variance offers guidance to variances tuning beneficial to short-range forecast (*Daescu & Langland*, 2012 and reference therein). This is quantified by FSR (Forecast Sensitivity to the observation error covariance matrix R) in such a way that positive (negative) values indicate that for a specific type of observation a decrease (increase) in the corresponding observation error variance will be of benefit.

Assessment of the ECMWF system performance

Analysis and forecast experiments using the ECMWF 4D-Var system have been performed for June 2011 to assess the impact of observations on the analysis and forecast. Figure 1a shows the DFS of all the assimilated observations.

- Microwave radiances from AMSU-A together with infrared radiances from IASI are the most informative data type, each providing 21% of the total observational information for the analysis; infrared radiances from AIRS follow with 16%.
- The information content of AIREPs (aircraft) at 9% is the largest amongst conventional observations, followed at about 4% by TEMPs (radiosondes) and in situ surface pressure SYNOP observations.
- Noticeable is the 7% contribution of GPS radio occultation (GPS-RO) data which is fourth in the satellite ranking.

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The 24-hour forecast error contribution (FEC) of all the observing system components is shown in Figure 1b.

- The largest contribution in decreasing the forecast error is provided by AMSU-A radiances (~21%); data from IASI, AIRS, GPS-RO and AIREPs provide 10% of the forecast error reduction followed by TEMPs and SYNOPs (5%). All the other observation types each contribute up to 3%.
- Atmospheric Motion Vectors (AMVs) from all the various platforms (MODIS, Meteosat and GOES) make a useful contribution to the 24-hour error reduction (6%).

Comparing Figure 1a with Figure 1b is clear that the impact of the observations (by observation type) on the analysis (DFS) is quite similar to their impact on the forecast as measured by the forecast error (FEC) reduction. For some observation types the DFS is larger than the FEC (e.g. IASI and AIRS). This impact loss can predominantly depend on either the observation quality or biases in the model that will prevent the analysis changes affecting the short-range forecast thereby increasing the 24-hour forecast error.

In Figure 1c, the sensitivity with respect to the observations error variance (FSR) is shown for the observation types. The positive sensitivities indicate that a reduction in error variance should decrease the 24-hour forecast error whilst a higher error variance should be applied for observations with negative sensitivity. According to Figure 1c, all the variances should be deflated apart for TEMPs and AMVs from MODIS and Meteosat. An alternative interpretation of Figure 1c is that the background error variances are in general too small and increasing their size should be beneficial for the short-range forecast.

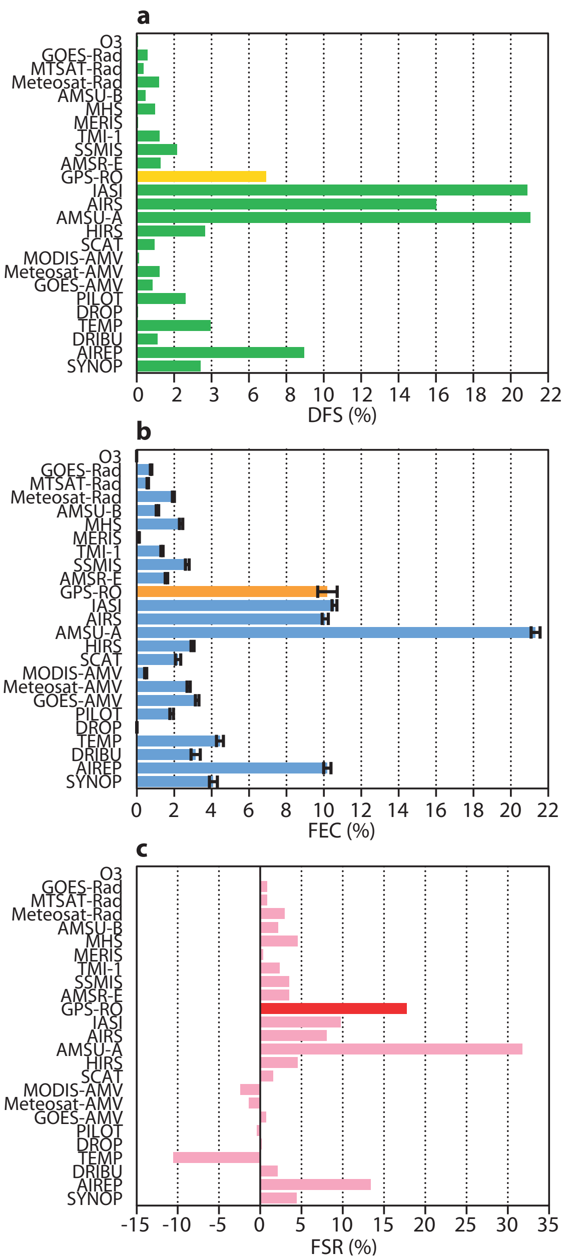

Figure 1 Total amount of (a) DFS, (b) FEC and (c) FSR for all assimilated observation types for June 2011.

GPS-RO case study

In the ECMWF system, the GPS-RO data provides 7% of DFS (Figure 1a) and 10% of FEC (Figure 1b). The GPS-RO measurements mainly provide temperature information in the upper-troposphere and lower/middle stratosphere. The GPS-RO measurements complement the information provided by satellite radiances because they have superior vertical resolution, and they can be assimilated without bias correction in the NWP model.

The assumed GPS-RO observation error standard deviation (i.e. square root of the observation error variance) used in the assimilation of the data at ECMWF varies as a function of the impact height z, which is defined as impact parameter minus the 'radius of curvature', where the radius of curvature is the radius of the best spherical fit to the Earth at the location of the observation. The assumed standard deviation of the bending angle errors, is 20% of the observed value at $z = 0$ km impact height, falling linearly with impact height to 1% at 10 km. Above 10 km, the error is assumed to be 1% of the observed value, until this reaches the lower limit of 3 microradians. Given the high observation accuracy, the mean GPS-RO observation influence in the analysis is also high, contributing half to the DFS with the other half coming from the relatively high number of assimilated observations.

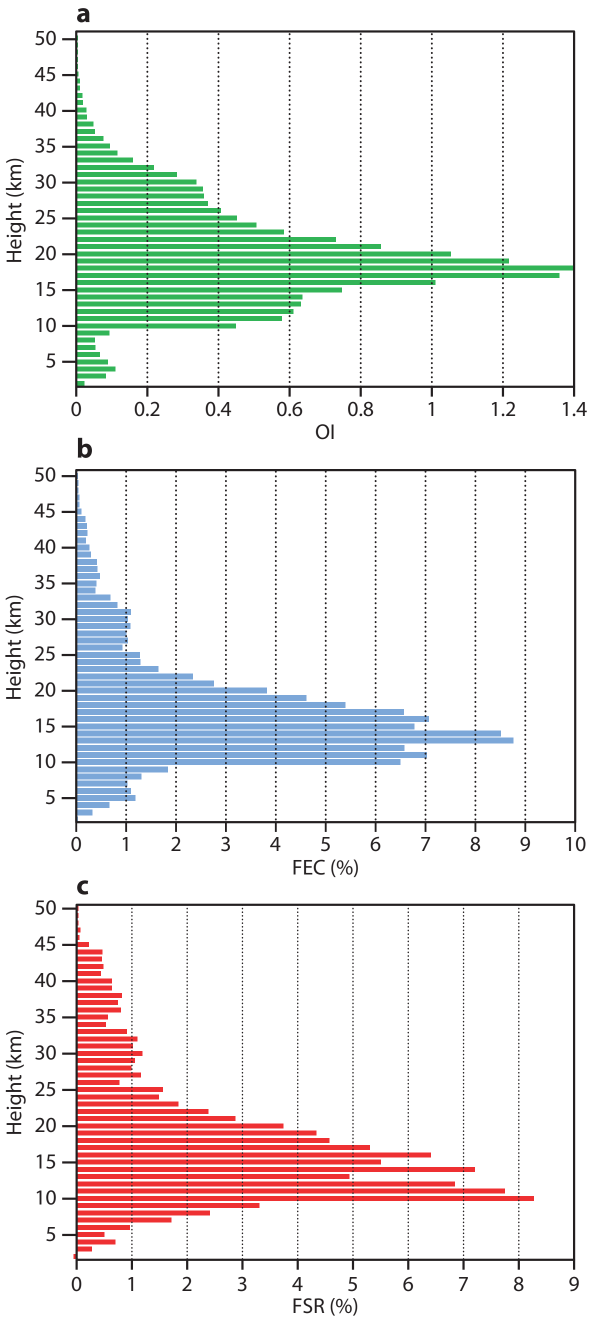

Figure 2 (a) Mean OI, (b) total FEC and (c) FSR for GPS-RO observations as a function of height for June 2011.

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Figure 2a shows the mean Observation Influence (OI) of GPS-RO data with respect to the height. The largest OI is in the troposphere and the low stratosphere where the largest forecast error reduction is also found. The number of measurement per level is the same. These profiles are consistent with earlier studies of information content using 1D-Var (e.g. *Healy & Eyre*, 2000), and reflect the large weight given to the observations between 10–30 km. At these levels the largest forecast error reduction is also observed as indicated in Figure 2b).

Figure 2c shows GPS-RO observations sensitivity to the observation error variance. Generally, a reduction of the variances is suggested for all vertical levels and in particular between 10 and 30 km. It is interesting to note that the FSR computation suggests reducing the assumed errors mostly in the layer where the weight given to the GPS-RO is already very large.

Figure 3 shows the geographical distribution of the forecast error reduction due to GPS-RO data (Figure 3a) and the forecast sensitivity to the GPS-RO observation error variance (Figure 3b) averaged between 12 and 20 km for June 2011.

The mean forecast impact of GPS-RO is larger over the tropics than in the extra-tropic (Figure 3a blue contour) but in general, apart from a few areas of degradation close to the poles, the GPS-RO observations decrease the 24-hour forecast error everywhere. As can be seen from Figure 3b, the largest signal for observation error variance reduction is also in the tropics (yellow-red contours).

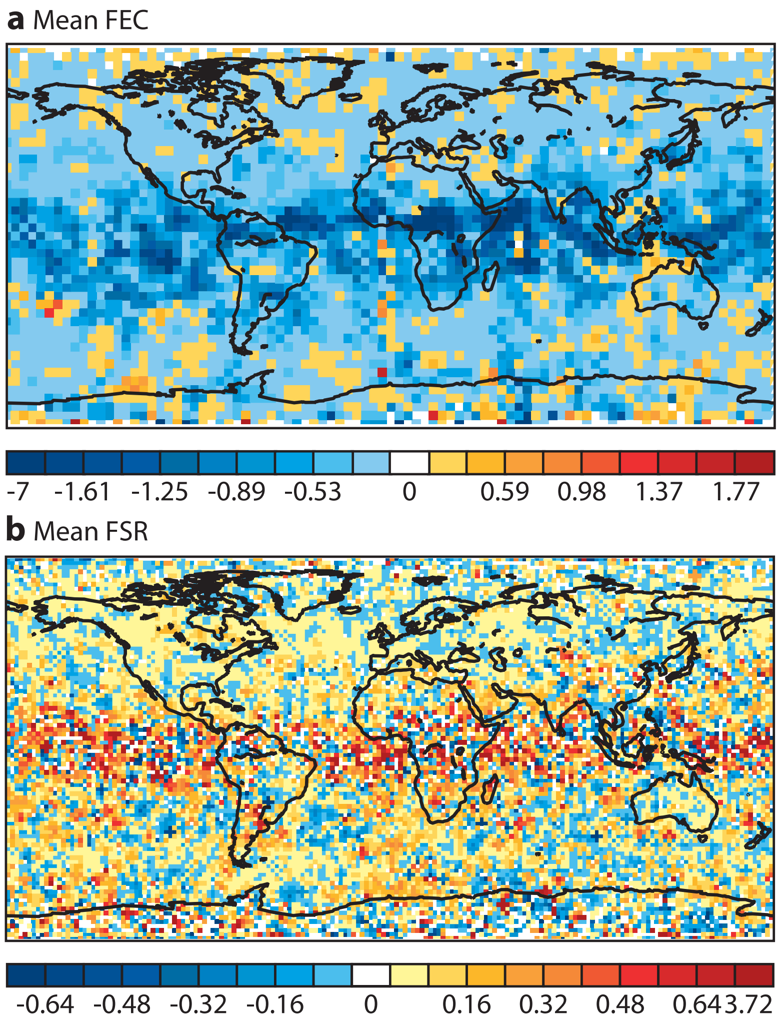

Figure 3 GPS-RO (a) mean FEC and (b) mean FSR from 12 to 30 km for June 2011. For (a) positive (negative) values indicate an increase (decrease) of forecast error. For (b) positive (negative) values indicate that a decrease (increase) of the observation error variances would improve the 24-hour forecast error.

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An analysis sensitivity experiment (*Half-Sigma*) has been performed by reducing the GPS-RO error variance as indicated by the study of the forecast sensitivity to error variance (i.e. between 10 to 30 km the error standard deviation has been halved). In terms of observation fit, the performance of *Half-Sigma* has been compared with that of the control (*CNTR*) experiment which contains the operational assigned variances.

Figure 4 shows the mean forecast differences with respect to radiosonde observations of 24-hour and 48-hour forecasts for *CNTR* and *Half-Sigma* and for the zonal wind component (panel a), meridional wind component (panel b) and temperature (panel c). For *Half-Sigma* there is a mean improvement with respect to the radiosonde fit, especially for the 48-hour forecast at every level. The best improvement occurs in the high troposphere and lower stratosphere and for both wind components. When compared with the aircraft observations a larger mean forecast difference reduction is noticed in *Half-Sigma* than in *CNTR* for the 48-hour forecast for the troposphere for the zonal component of the wind in the tropics (Figure 5a) and the southern hemisphere (Figure 5b).

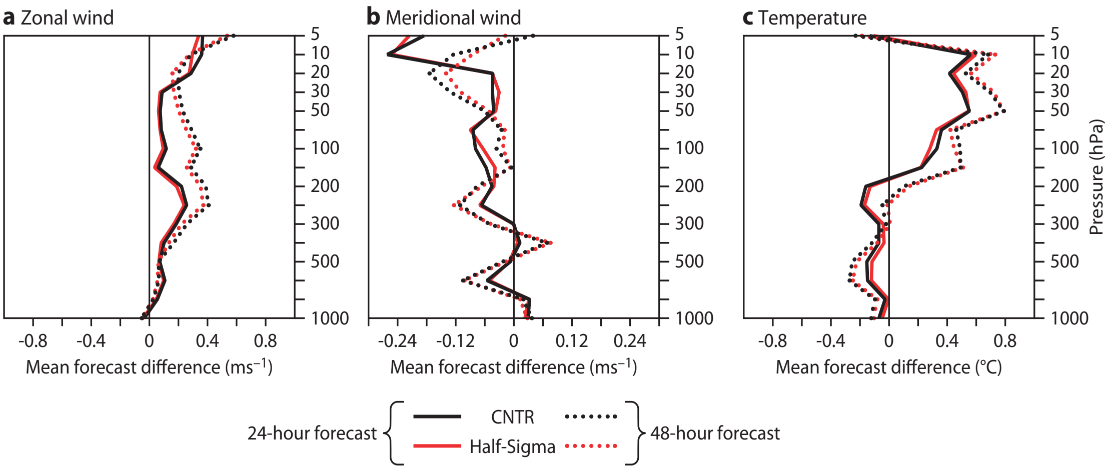

Figure 4 Mean forecast differences with respect to radiosonde observations for (a) zonal wind component, (b) meridional wind component and (c) temperature in the northern hemisphere for 24-hour (solid line) and 48-hour (dotted line) forecasts for CNTR (black) and Half-Sigma (red) for June 2011.

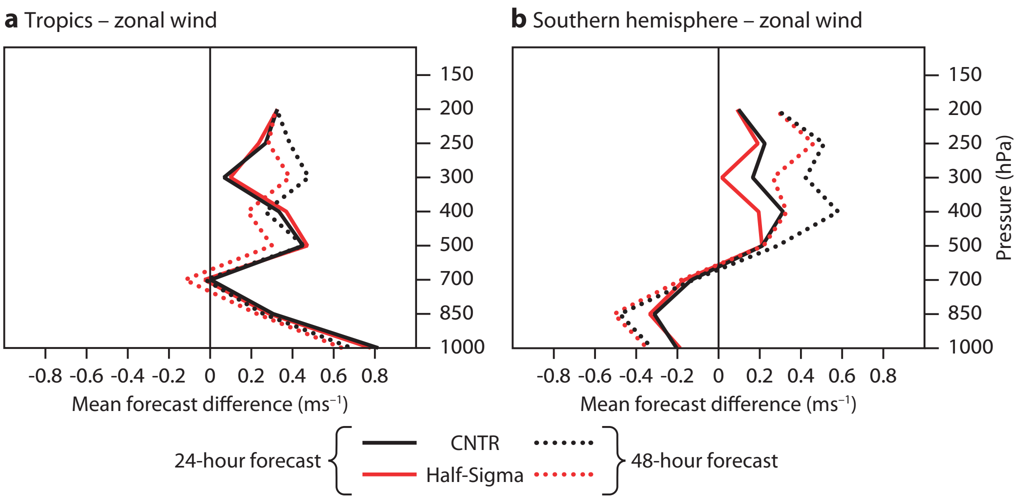

Figure 5 Mean forecast differences with respect to aircraft observations for zonal wind component in (a) the tropics and (b) southern hemisphere for 24-hour (solid line) and 48-hour (dotted line) forecasts for CNTR (black) and Half-Sigma (red) for June 2011.

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Outlook

The largest contribution in the analysis as measured by the DFS and in the forecast as measured by FEC is provided by microwave sounder radiances (AMSU-A) followed by the infrared sounder radiances (IASI and AIRS) from the instruments that mainly provide information on temperature and humidity. For microwave satellite humidity information, SSMIS (microwave imager), MHS (microwave sounder) and AMSR-E (microwave imager) instruments are, in decreasing order, contributing to the reduction in forecast error. Of all the conventional observations, AIREPs and TEMPs provide the largest contribution.

The forecast sensitivity to the observation variance suggests that if there is a reduction in the observation error variances for all the observation types, except TEMPs and AMVs, the 24-hour forecast error will decrease. The fifth largest impact either in the analysis or in the forecast is provided by GPS-RO data, with the largest contribution coming from the heights between 12 and 20 km. The forecast sensitivity to the observation error variance suggests that the GPS-RO error variance should be reduced leading to a decrease in the forecast error. Interestingly, the suggested reduced variances are mostly in the layer where the weight given to the GPS-RO is already quite large.

A first attempt to decrease the GPS-RO observation error variances has been made and some improvement in terms of a smaller mean forecast difference with respect to conventional (aircraft and radiosonde) observations has been found. However, a different measure of forecast error reduction due to the revision of the observation error accuracy must be considered. Also more experimentation is needed to fully exploit the benefits and understand the limitations of the FSR tool. A revision of the observation error variances for all the assimilated observations at ECMWF, as indicated by the forecast sensitivity tool, is planned for implementation in 2013.

Further reading

Cardinali, C., S. Pezzulli & **E. Andersson,** 2004: Influence matrix diagnostics of a data assimilation system. *Q. J. R. Meteorol. Soc.*, **130**, 2767–2786.

Cardinali, C., 2009: Monitoring the forecast impact on the short-range forecast. *Q. J. R. Meteorol. Soc.*, **135**, 239–250.

Daescu, D. & **R.H. Langland,** 2012: Error covariance sensitivity and impact estimation with adjoint 4D-Var: theoretical aspect and first application to NAVDAS-AR. *Q. J. R. Meteorol. Soc.*, doi:10.1002/qj.1943.

Healy, S.B. & **J.R. Eyre,** 2000: Retrieving temperature, water vapour and surface pressure information from refractive–index profiles derived by radio occultation: A simulation study. *Q. J. R. Meteorol. Soc.*, **126**, 1661–1683.