ASSIMILATION OF GRAS GPS RADIO OCCULTATION MEASUREMENTS AT ECMWF

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Abstract

GPS radio occultation bending angle profiles are assimilated from the GRAS instrument on MetOP-A and the COSMIC constellation, using a one-dimensional observation operator. The GRAS measurements have a good impact, relative to a no GPS radio occultation control. However, the COSMIC measurements provide a better constraint of stratospheric temperature biases.

It is shown that a recent modification of the COSMIC processing has led to much better consistency between the GRAS and COSMIC mean departure statistics in the stratosphere. Furthermore, it is demonstrated that the remaining bias can be partially attributed to biased aircraft temperature measurements.

INTRODUCTION

GPS radio occultation (GPSRO) measurements are now routinely used in operational numerical weather prediction. They are a valuable component of the global observing system because they can be assimilated without bias correction and they have superior vertical resolution to satellite radiance measurements. The former means that they provide “anchor points” for the bias correction of radiance measurements, and the latter means that the GPSRO measurements can detect forecast errors that are in the null-space of other measurements.

ECMWF began operationally assimilating GPSRO measurements from the COSMIC constellation of six satellites (Anthes *et al*., 2008) on December 12, 2006 and from the GRAS instrument on MetOP-A (Luntama *et al*., 2008) on May 10, 2008. COSMIC provides around 2000 bending angle profiles per day and GRAS around 650 per day. Recent adjoint based forecast sensitivity calculations by Cardinali (2009) have shown that the GPSRO measurements now make a significant contribution to the reduction of the 24 hour forecast errors in the ECMWF system. In this work we have compared the forecast impact of GRAS and COSMIC measurements. We have also investigated how the consistency has improved as a result of recent COSMIC processing changes, and the causes of the remaining bending angle biases.

OBSERVATION OPERATOR

The GPSRO measurements are assimilated as bending angle profiles using a one-dimensional observation operator. This simulates bending angle as a function of impact parameter by evaluating the following integral (Kursinski *et al*.,1997):

$$\alpha(a) = -2a \int_a^{\infty} \frac{d(\ln n)/dx}{\sqrt{x^2 - a^2}}\, dx$$

where a is the impact parameter, n is the refractive index derived from the NWP model and $x = nr$ is the refractive index-radius product. This model ignores the two-dimensional nature of the measurement and only extracts NWP information at a single location. The operator used at ECMWF (Healy and Thépaut, 2006) is part of the GRAS SAF Radio Occultation Processing Package (ROPP), and the source code can be downloaded from "http://www.grassaf.org/software.php".

FORECAST IMPACT EXPERIMENTS

Three forecast impact experiments have been performed. The control experiment (CTL) uses all the observations that are assimilated at ECMWF except the GPSRO measurements. The GRAS experiment is the same as CTL except that the GRAS measurements are also assimilated. Similarly, the COSMIC experiment is the same as CTL except COSMIC measurements are also assimilated. The GRAS and COSMIC measurements are assimilated assuming the same observation error model. The standard deviation of the assumed error falls linearly with impact height (impact parameter minus radius of curvature) from 20 % at 0 km impact height to 1 % at 10 km. The error above 10 km is maximum of either 1 % or 3 microradians. The 3 microradian threshold usually occurs around 30 km. COSMIC measurements are assimilated from the surface up to 50 km, whilst GRAS measurements are assimilated between 8 km and 50 km in the northern and southern hemispheres, and between 10 km and 50 km in the tropics. As noted COSMIC typically provides 2000 profiles per day, whereas GRAS provides 650 profiles per day. The experiments cover the period June 1 to July 31, 2008.

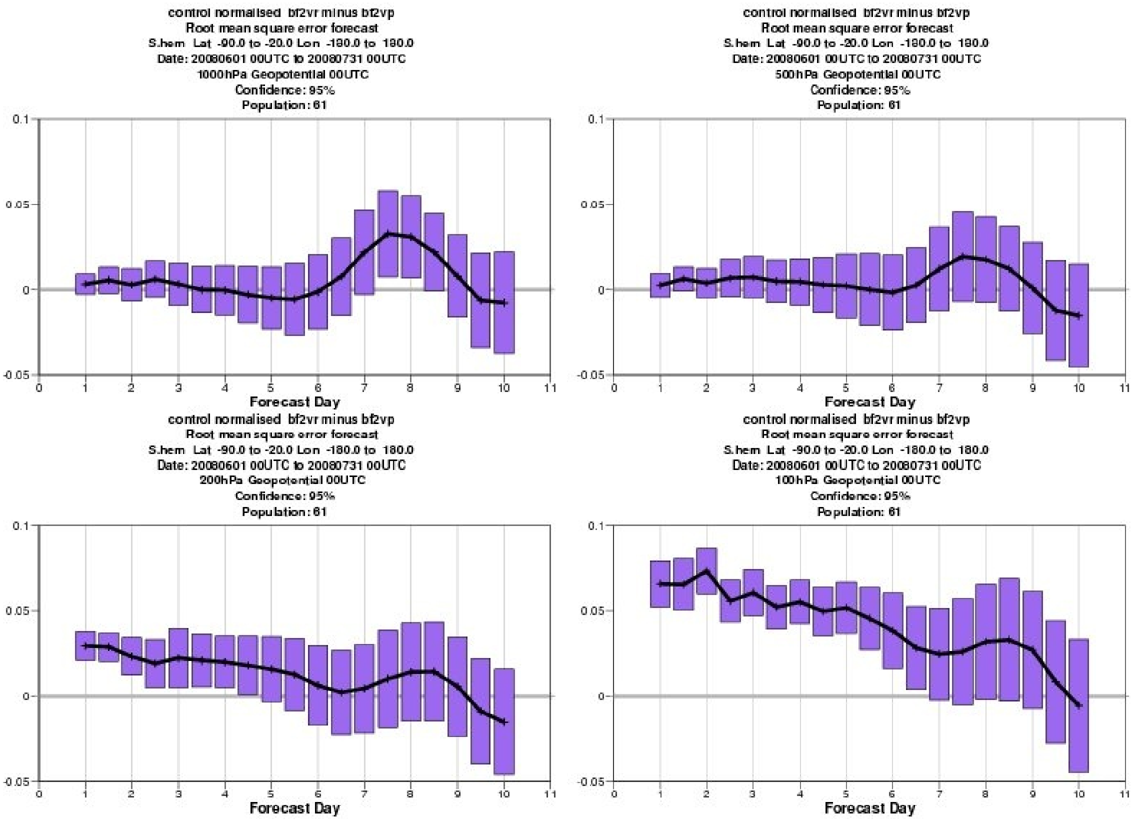


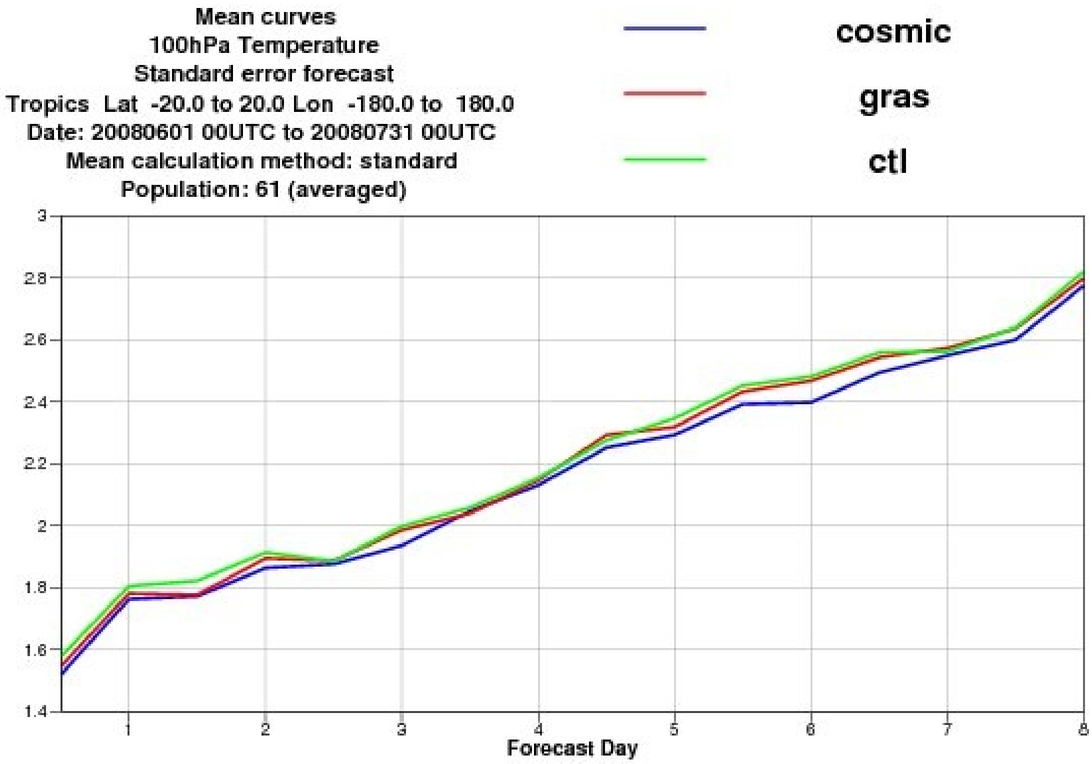
Figure 1: **The fractional reduction in RMS geopotential height (1-RMS(GRAS)/RMS(CTL)) errors at 1000, 500, 200 and 100 hPa. A positive value indicates a positive impact. The error bars indicate the 95 % confidence interval.**

The GRAS experiment performs well relative to the no GPSRO CTL. Figure 1 shows the fractional improvement in the Root-Mean-Square (RMS) height errors in the southern hemisphere at 1000, 500, 200 and 100 hPa. Each experiment is verified against its own analysis. A positive value indicates a positive impact, and it is evident that the results are broadly neutral at 1000 hPa and 500 hPa, but clearly positive at 200 hPa and 100 hPa, which is consistent with the blacklisting and basic information content of the measurements. These are very encouraging results. However, it is also clear that the 650 GRAS profiles per day are unable to constrain the stratospheric temperature biases as well as the 2000 COSMIC profiles. Figure 2 shows the mean and standard deviation of the temperature forecast errors at 100 hPa in the tropics, verified against radiosonde temperature observations. It is evident that the GRAS measurements reduce both the mean and standard deviation of the error, but the COSMIC results are superior. For example, the mean error at 12 hours is ~1K in the CTL experiment, but this is reduced to just below -0.8 K when the GRAS measurements are introduced. In the COSMIC experiment the mean error is less than -0.5 K. These results indicate that a single instrument is not sufficient to constrain stratospheric, biases and they reinforce the need for a constellation of GPSRO instruments.

REVISION OF THE COSMIC PROCESSING

As noted earlier, one of the strengths of GPSRO measurements is that they can be assimilated without bias correction. In addition, ideally, the error and bias characteristics should not be instrument dependent, meaning that GPSRO measurements are potentially well suited for generating long time series for climate trend detection. However, routine operational monitoring of GRAS and COSMIC measurements has shown that the bias characteristics in the stratosphere are different (von Engeln 2006; Healy 2008). Figure 3 shows vertical profiles of GRAS, COSMIC-4 and COSMIC-6 (o-b)/b departures in the northern hemisphere, averaged for December 2008. The GRAS data are processed at EUMETSAT and the COSMIC measurements at the University Corporation for Atmospheric Research (UCAR). In general, there is good consistency amongst the COSMIC instruments, but the GRAS departures in the stratosphere tend to be of order 0.2 % smaller. It is also noteworthy that the GRAS departure statistics agree with CHAMP and GRACE-A measurements. Given that COSMIC departures are less biased with respect to ECMWF, it was originally assumed that the error would be in the GRAS processing. However, Christian Marquardt *et al.* (2009) demonstrated at the January 2009 AMS Meeting that differences could be attributed to different smoothing algorithms applied to the phase delay data. As a consequence, the COSMIC processing was modified, and a dataset for the period November 2008 to January 2009 was made available to the NWP centres for testing. Figure 4 shows the (o-b)/b departure statistics for December 2008 for an experiment using the revised data. The improved consistency in the departure statistics is striking. As expected the COSMIC are now biased negative, but the GRAS biases above 20 km have also been reduced. This is an interesting result because it shows that bending angle profiles from different instruments now have very similar bias properties, indicating that it should be possible to derive accurate time series from multiple instruments. Note that the change in the operational processing of COSMIC measurements was made on October 12, 2009.

We have investigated possible reasons for the negative bias in the stratospheric bending angle departures. An experiment using the revised COSMIC data was conducted with aircraft temperature measurements blacklisted. Aircraft temperature measurements are known to be biased warm (Ballish and Kumar, 2008), and they lead to cold forecast and analysis biases with respect to radiosonde measurements in the troposphere, peaking near 200 hPa at ~-0.4 K. Although very few aircraft temperature measurements are assimilated above 200 hPa, they will clearly influence the height of model levels above this level. Simulated GPSRO bending angles are sensitive to the pressure, temperature and humidity values on the model levels, and also the height of these levels. A troposphere that is biased warm, will bias the simulated stratospheric bending angles high. Figure 5 shows the GRAS, COSMIC-4 and COSMIC-6 bending angle departures in the northern hemisphere using the new COSMIC data when aircraft temperatures are blacklisted. It is clear that removing the aircraft temperature measurements improves the GPSRO departure statistics considerably, and they are generally less than -0.1%. ECMWF intends to introduce a bias correction of aircraft temperature measurements in the near future.



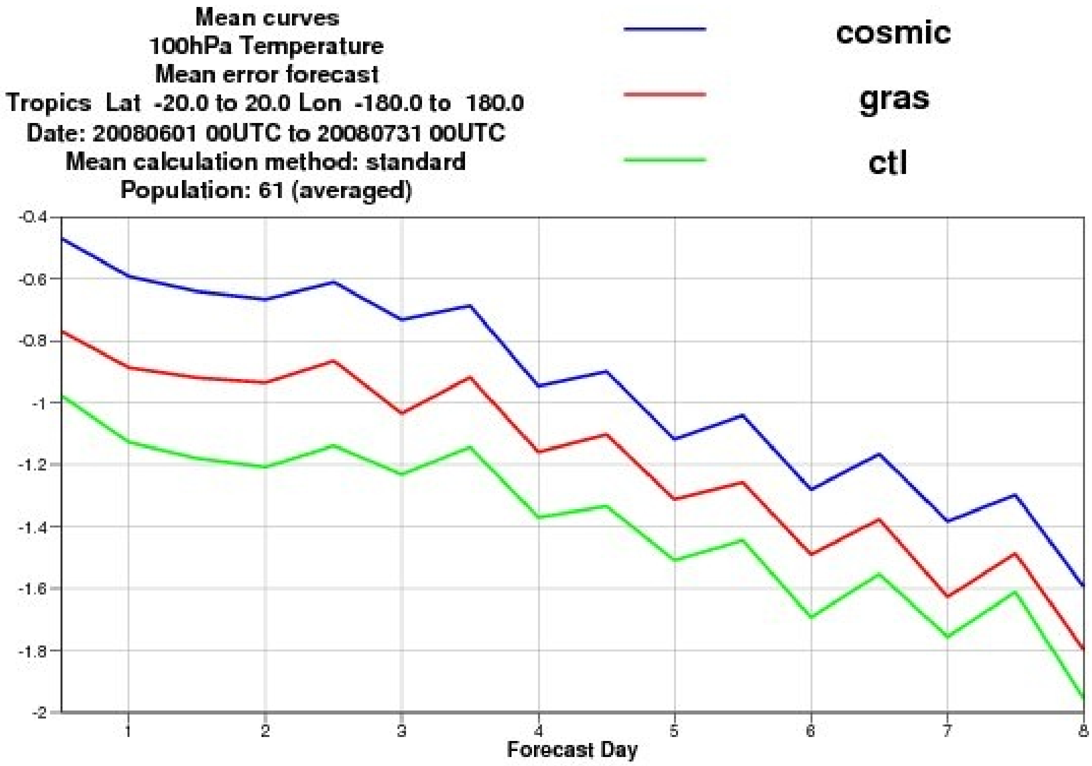


Figure 2: **The mean and standard deviation of the temperature forecast errors at 100 hPa in the tropics, verified against radiosonde temperature measurements.**

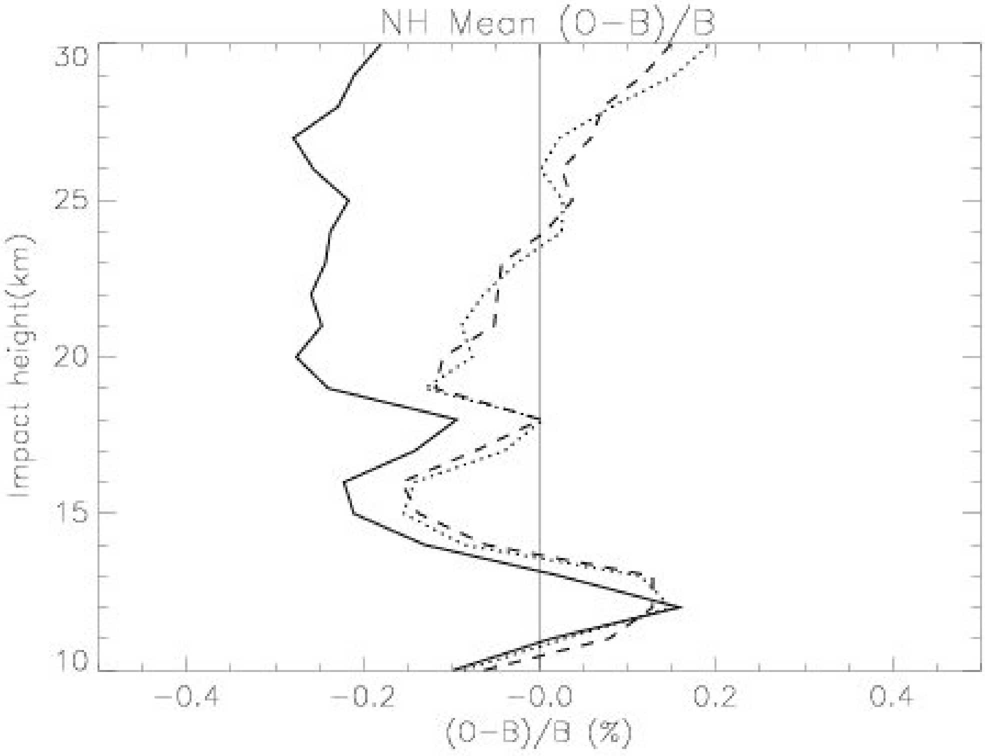


Figure 3: **The mean (O-B)/B departures in the northern hemisphere for GRAS (solid), COSMIC-4 (dotted) and COSMIC-6 (dashed). The statistics cover the period December 1 - 31, 2009 and use the operational measurements at that time.**

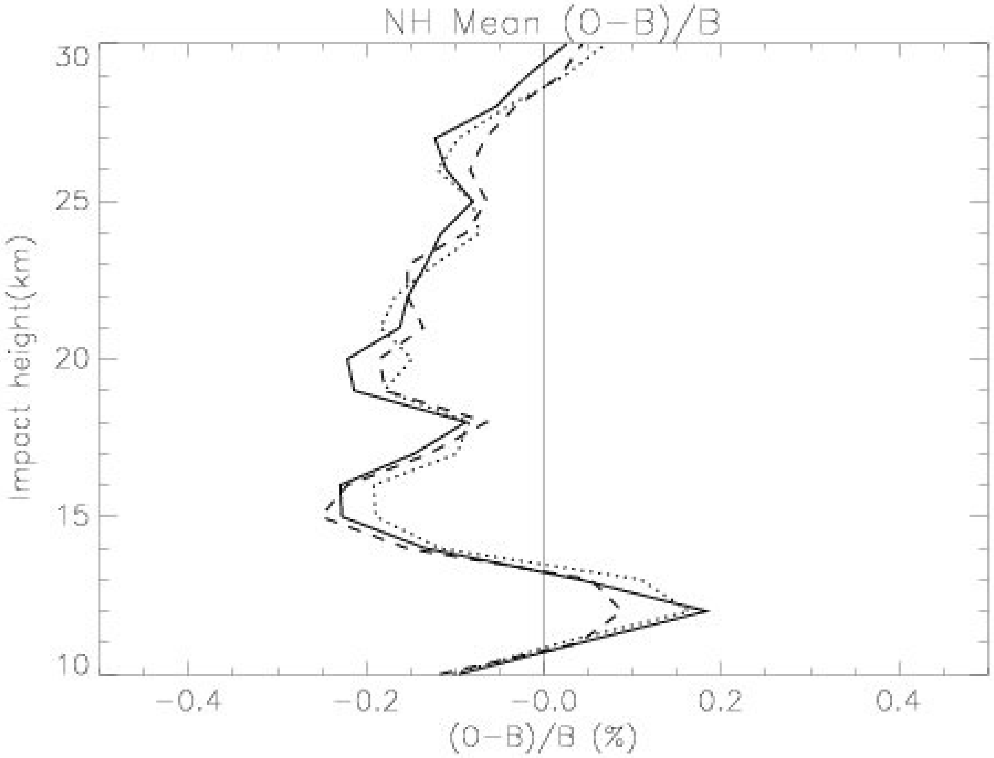


Figure 4: **As Figure 3, but using the revised COSMIC data.**

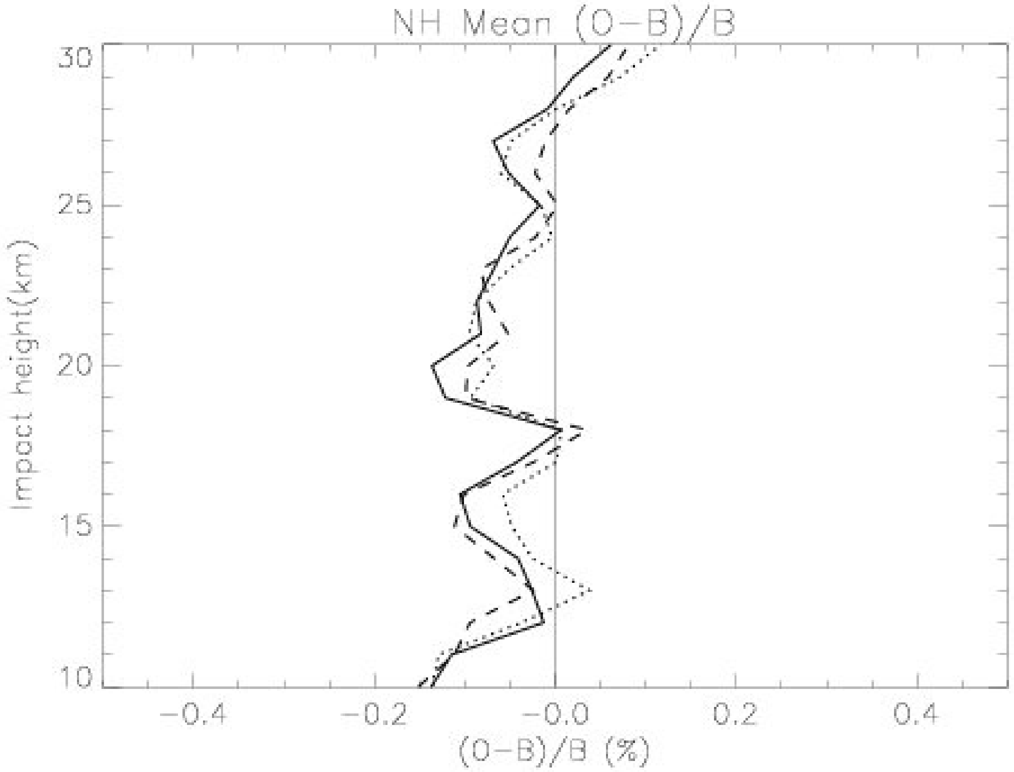


Figure 4: **As Figure 3, but using the revised COSMIC data and blacklisting aircraft temperature measurements.**

SUMMARY

The GRAS instrument has a clear positive impact relative to a no GPSRO control. However, comparisons against an experiment where COSMIC measurements are assimilated suggest that more than one instrument is required to constrain stratospheric temperature biases.

The revision of the COSMIC processing at UCAR has led to far better consistency between the GRAS and COSMIC mean departure statistics. The remaining negative bias in the stratosphere is at least partly attributable to biases in the ECMWF analyses and forecasts caused by the assimilation of biased aircraft temperature measurements.

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