Assessing the impact of GPS radio occultation measurements in ERA5

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Background

GPS radio occultation (GPS-RO) measurements have been routinely assimilated into numerical weather prediction (NWP) systems since 2006. They complement the information provided by satellite radiances because:

- GPS-RO measurements have good vertical resolution.
- GPS-RO can be assimilated without bias correction. Therefore, they "*anchor*" the satellite radiance bias correction scheme.
- The measurements are globally distributed.

GPS-RO is now a key observing system for reanalyses. The number of these measurements increased by an order of magnitude in 2006 – from around 200 profiles per day to more than 2000 profiles – with the launch of the six COSMIC/FORMOSAT-3 satellites.

The consistency of the global temperature reanalyses in the stratosphere has improved significantly since 2006 as a result of the active assimilation of the GPS-RO measurements. See Figure 1.

The COSMIC GPS-RO measurements also play an important role in constraining the cold lower/middle stratospheric temperature biases in ERA5, as shown in Figure 2.

A number of low resolution ERA5 experiments have been performed to investigate the GPS-RO impact, and compare it with the impact of AMSU-A channel 14.

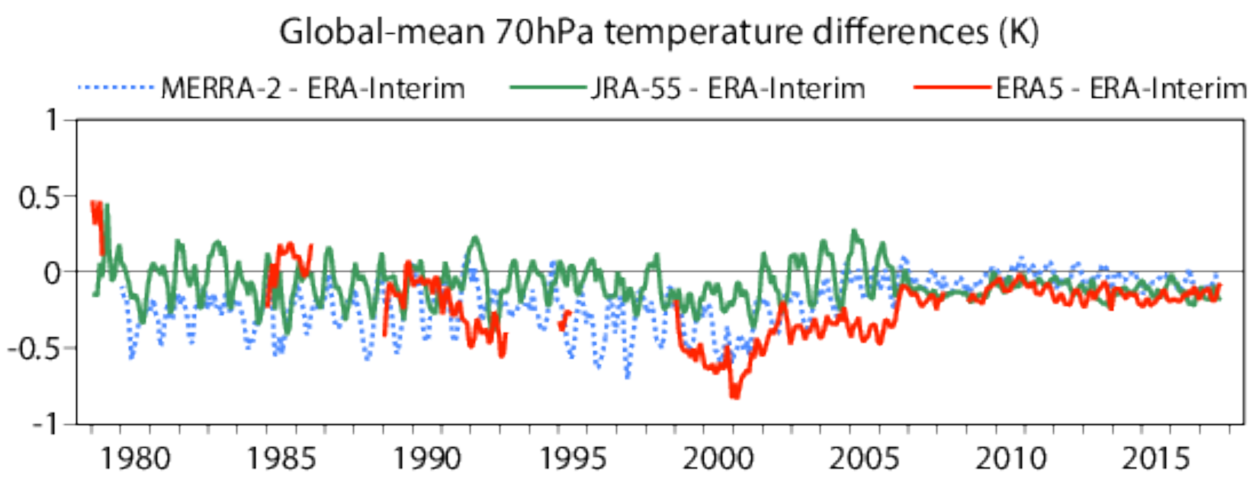

Figure 1

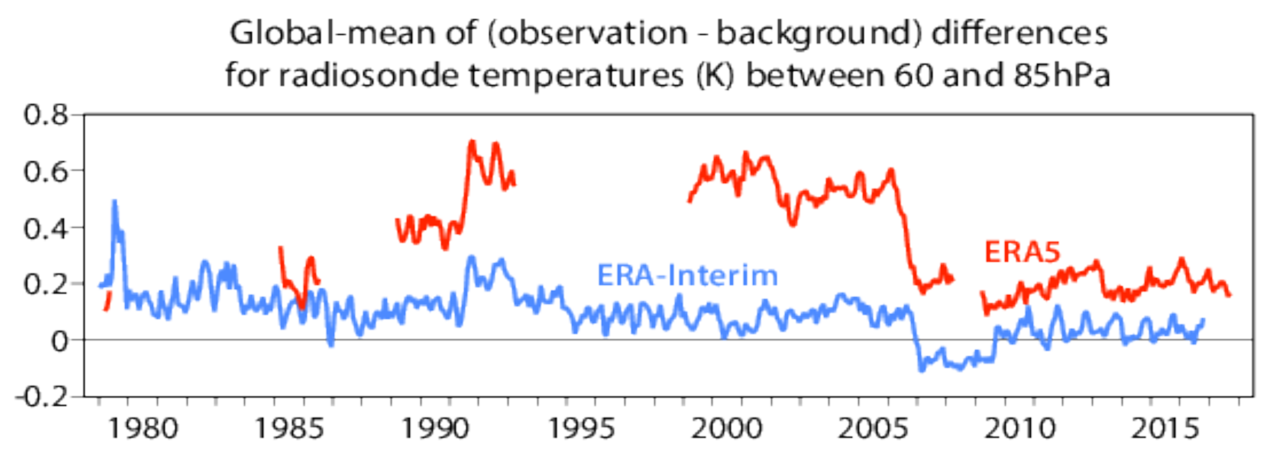

Figure 2

Low resolution experiments in ERA5

The experiments are performed at T159, for the period Jan 1- June 30, 2011. All aircraft temperature measurements and satellite radiances are blacklisted, **except** AMSU-A channel 14, which is assimilated without bias correction. Experiments include:

- **REF**: The reference experiment, including all conventional data, AMSU-A channel 14, and GPS-RO bending angles.
- **NoRO**: REF but GPS-RO is blacklisted.
- **NoCH14**: REF but AMSU-A channel 14 is blacklisted.

Figure 3: GPS-RO generally warms the vertical interval between 200 to 10 hPa, reducing the known biases in ERA5 (Figure 2). **Figure 4**: AMSU-A channel 14 is correcting large model biases (> 4K) near 1 hPa.

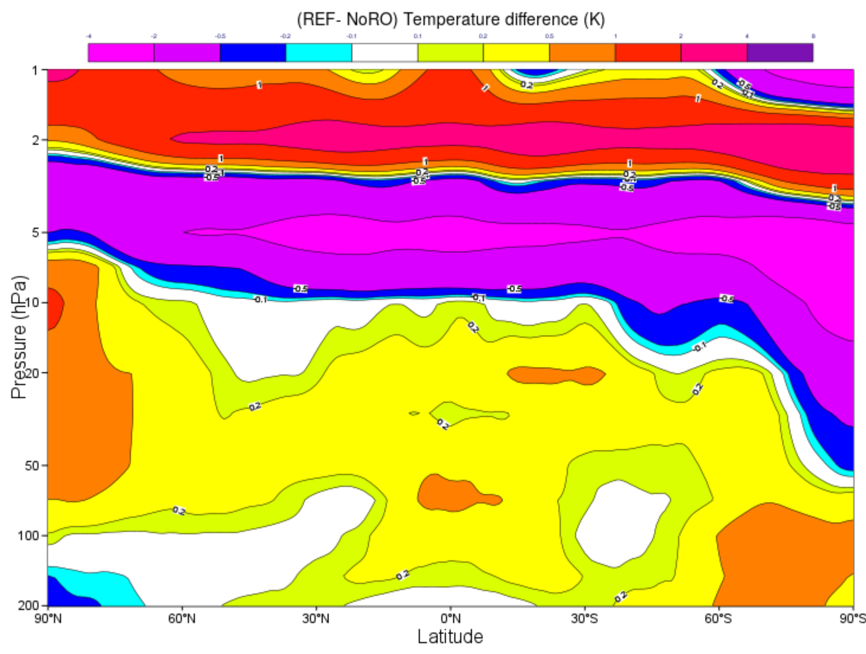

Figure 3: The zonally averaged (REF-NoRO) temperature differences (April-May, 2011).

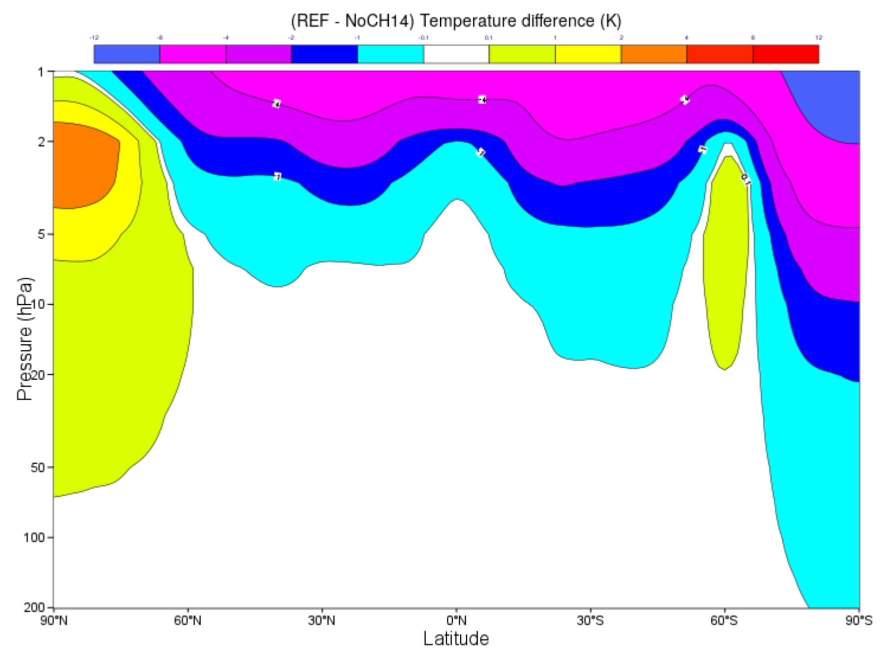

Figure 4: The zonally averaged (REF-NoCH14) temperature differences (April-May, 2011).

The GPS-RO "null-space"

Channel 14 is correcting large stratospheric temperature biases in the southern polar region (Figure 5). This temperature bias does not produce a large signal in bending angle space (Figure 6). There are two reasons for this:

- The bending angle signal-to-noise falls exponentially above ~10 hPa (32 km). The assumed bending angle uncertainty values at impact heights of 40 km and 50 km are typically 5 % and 20 %, respectively. Compare with the biases shown in Figure 6.
- GPS-RO struggles to constrain temperature biases that increase gradually with height, *if they do not change the density as function of height significantly*. Specifically, a temperature perturbation that grows exponentially with the density scale height H, say $\delta T \propto e^{z/H}$, is difficult to constrain with GPS-RO.

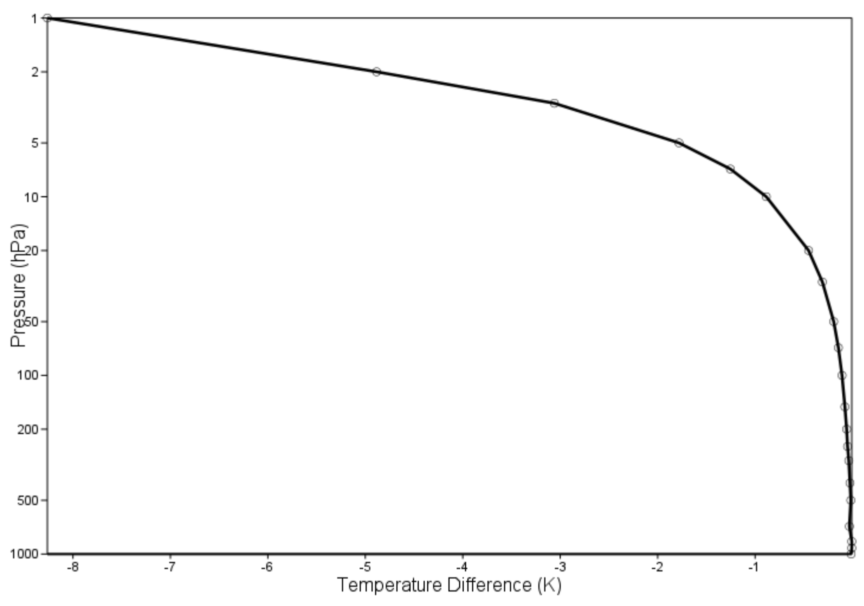

Figure 5: Mean (REF-NoCH14) temperature differences for the South Polar region (lat < -65 S).

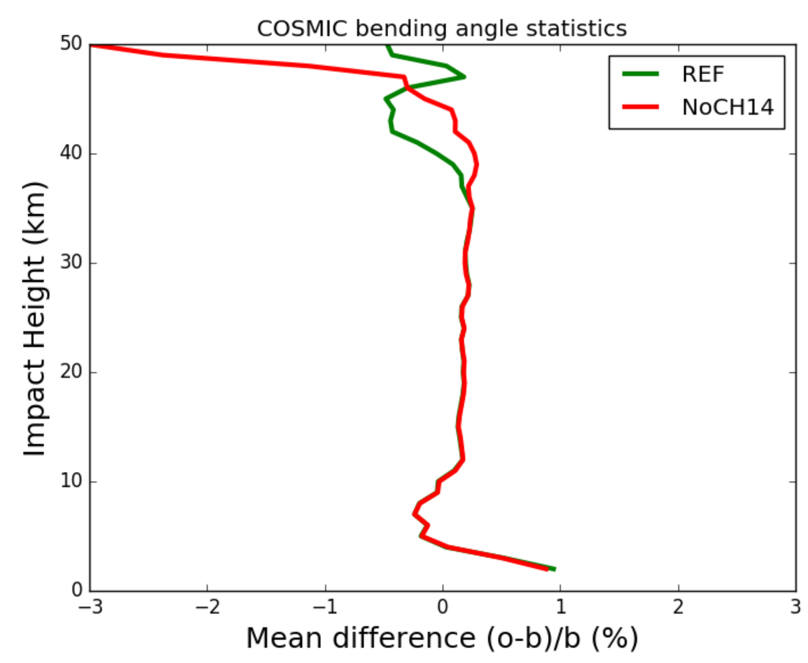

Figure 6: The COSMIC bending angle (o-b) statistics for the South Polar region.

Testing GPS/MET data in ERA5

GPS/MET was the original "proof-of-concept" GPS-RO mission from 1995-1997. We have tested data reprocessed by UCAR. See:

http://www.cosmic.ucar.edu/data.html

- **Prime-time GPS/MET data**: Limited GPS/MET test periods where Anti-Spoofing (AS) encryption is **OFF** (*as present day*).
- **AS-ON**: Anti-spoofing encryption on. (*Not used during proof-of-concept*)
- Although the AS-ON data is clearly noisier (Figure 7), it can be assimilated into the reanalysis system. We have tested Dec. 23, 1996 – Jan. 13, 1997. Assimilating the GPS/MET data improves the fit to radiosonde temperature measurements above 300 hPa (Figure 8).
- **More work is required to *recover* all the available GPS/MET data.**

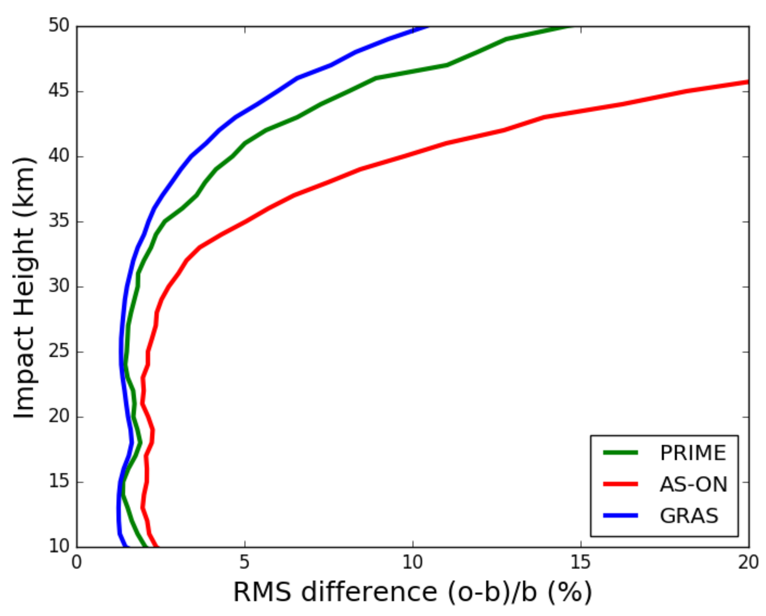

Figure 7: Global GPS/MET and operational GRAS bending angle statistics for reference.

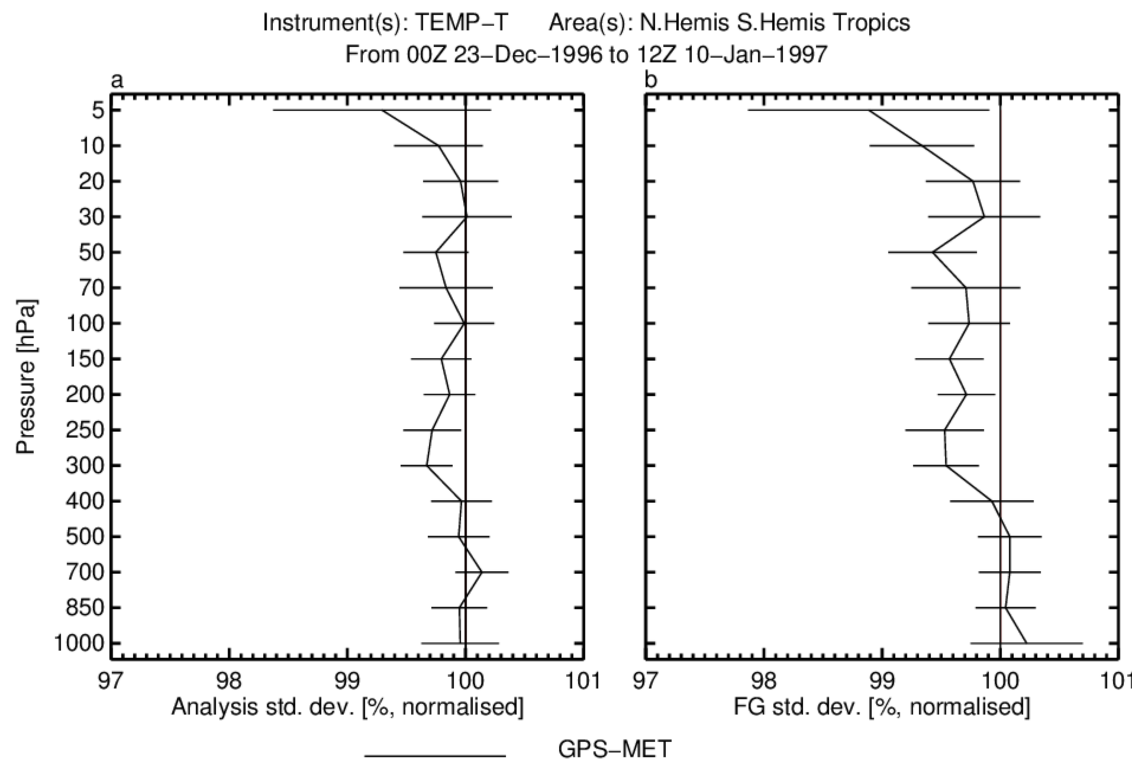

Figure 8: The percentage reduction in the first-guess (FG) and analysis departure statistics for radiosonde temperature measurements, as a result of assimilating GPS/MET AS-ON data.