
GPS radio occultation assimilation research at ECMWF

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Background

- **ECMWF has not performed any Observing System Simulation Experiments (OSSE's)**, but a set of Observing System Experiments (OSEs) looking systematically at the sensitivity to GPSRO observation number are about to start.
- **So why am I here?** I will present results from selected OSE's (or forecast impact experiments) performed over the past year, looking at the impact of GPSRO measurements and seeing how they interact with other observing systems.
- It is hoped that these results will help point to areas of interest that can be investigated further with the OSSE's.



Outline

- Assimilation of GPSRO measurements at ECMWF
- Comparing the impact of COSMIC and GRAS measurements.
- Impact of revised COSMIC data, where a processing change has improved the consistency between COSMIC and GRAS measurements. GPSRO fighting with biased aircraft temperature measurements.
- Water vapour information derived from GPSRO measurements.
- Surface pressure information derived from GPSRO measurements. NWP system performance when all surface pressure observations are blacklisted.
- New results from Carla Cardinali (ECMWF) with an adjoint based data assimilation tool that estimates the relative importance of all the observing systems. (Good news for GPSRO!)
- Summary



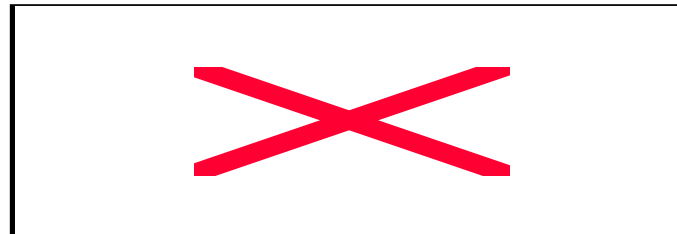
Bending angle assimilation

- We assimilate bending angle profiles with a 1D observation operator. (We are still testing the 2D operator.)
- This has the advantage that **climatology is not introduced through the “statistical optimization” processing step**, so we can use the data higher up.
- In operations we now assimilate COSMIC measurements from the surface up to 50 km. We assume an observation error of 3 microradians above 30 km.



Operational assimilation at ECMWF with the ROPP 1D bending angle operator

- Ignore the 2D nature of the measurement and integrate

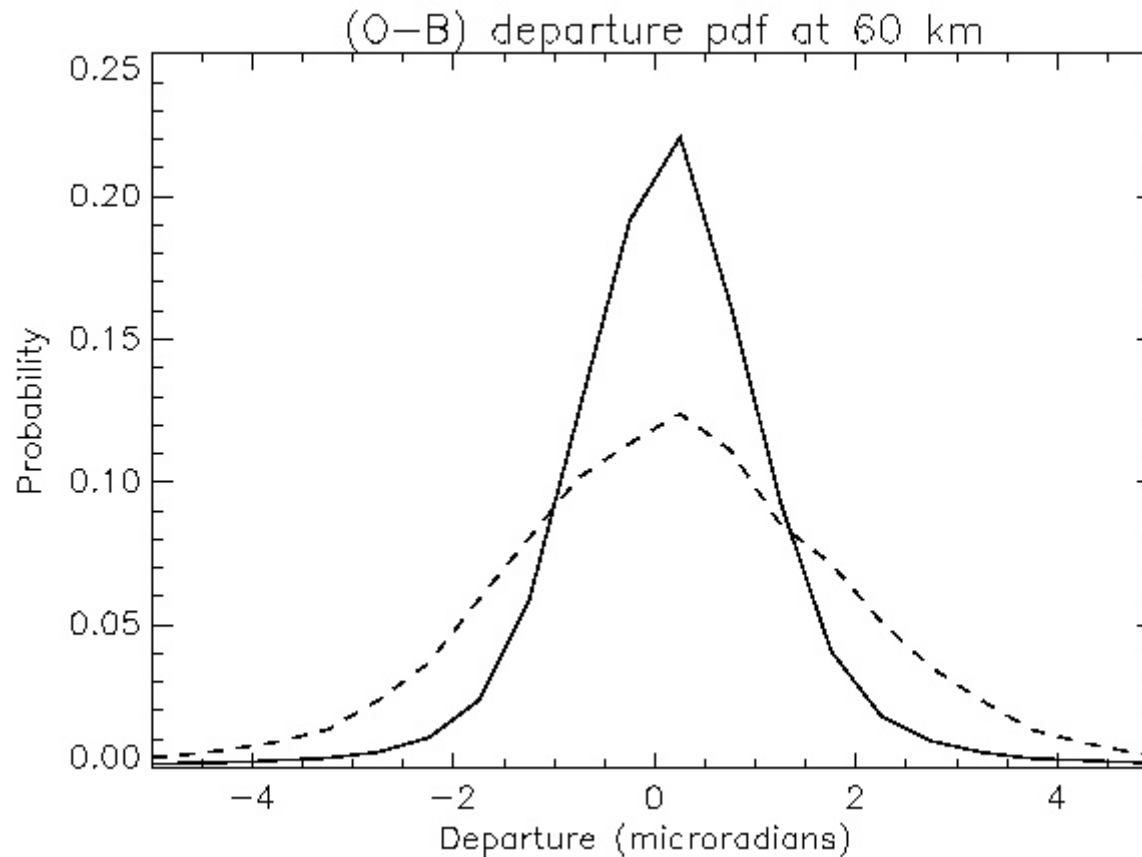


- The forward model is quite simple and not computationally expensive:
 - evaluate geopotential heights of model levels
 - convert geopotential height to geometric height and radius values
 - evaluate the refractivity, N , on model levels from P , T and Q
 - integrate, assuming refractivity varies exponentially between model levels.
 - solution given in terms of the Gaussian error function.



Comparison of GRAS and COSMIC-4 bending angle departures

- Both COSMIC and GRAS are now being assimilated operationally. Noise characteristics of GRAS measurements are better.



(Jan 2009
Global, from
operations)



Forecast impact

- We have compared the impact of GRAS and COSMIC, for experiments covering June-July, 2008.
- GRAS measurements are only assimilated above 8 km, COSMIC used to the surface.
- ~1800-2000 COSMIC measurements, compared with 650 GRAS.
- In general, COSMIC appears to do a better job constraining the stratospheric biases.





Verification against radiosondes

Standard deviation of the errors

Mean errors

More than one GPSRO instrument is needed to constrain stratospheric biases.
How many needed?

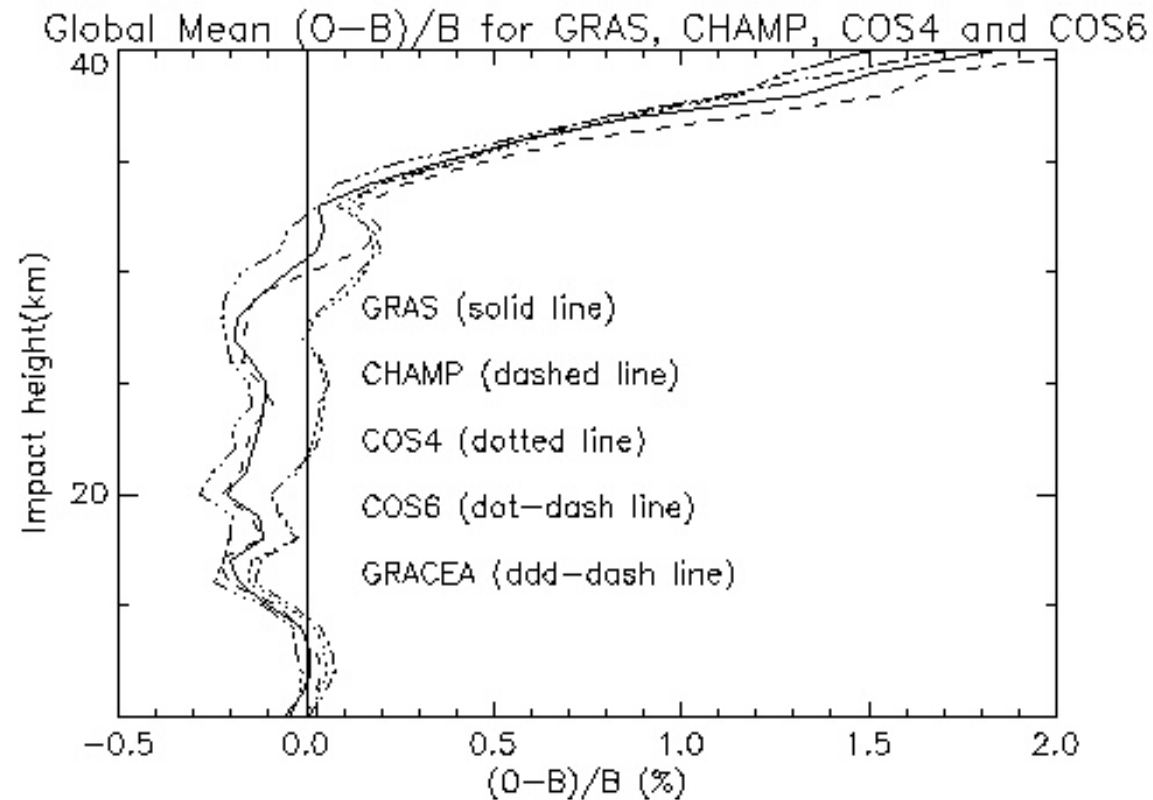


GRAS-COSMIC departure differences

- At the ECMWF GRAS SAF workshop (2008) we noted that the mean departures from COSMIC differed from those of GRAS, CHAMP and GRACE-A.
- The COSMIC departures were in better agreement with ECMWF and it was expected that the problem was with the GRAS processing.
- However, Christian Marquardt (EUMETSAT) demonstrated at the January AMS meeting that the problem was caused by the smoothing of the phase delays at UCAR.
- UCAR have proposed modifications to their processing and have made the data available to the NWP centres.



Bending angle statistics 30 Days up to Sept 24, 2008



“Structural uncertainty” causing differences in mean fit?

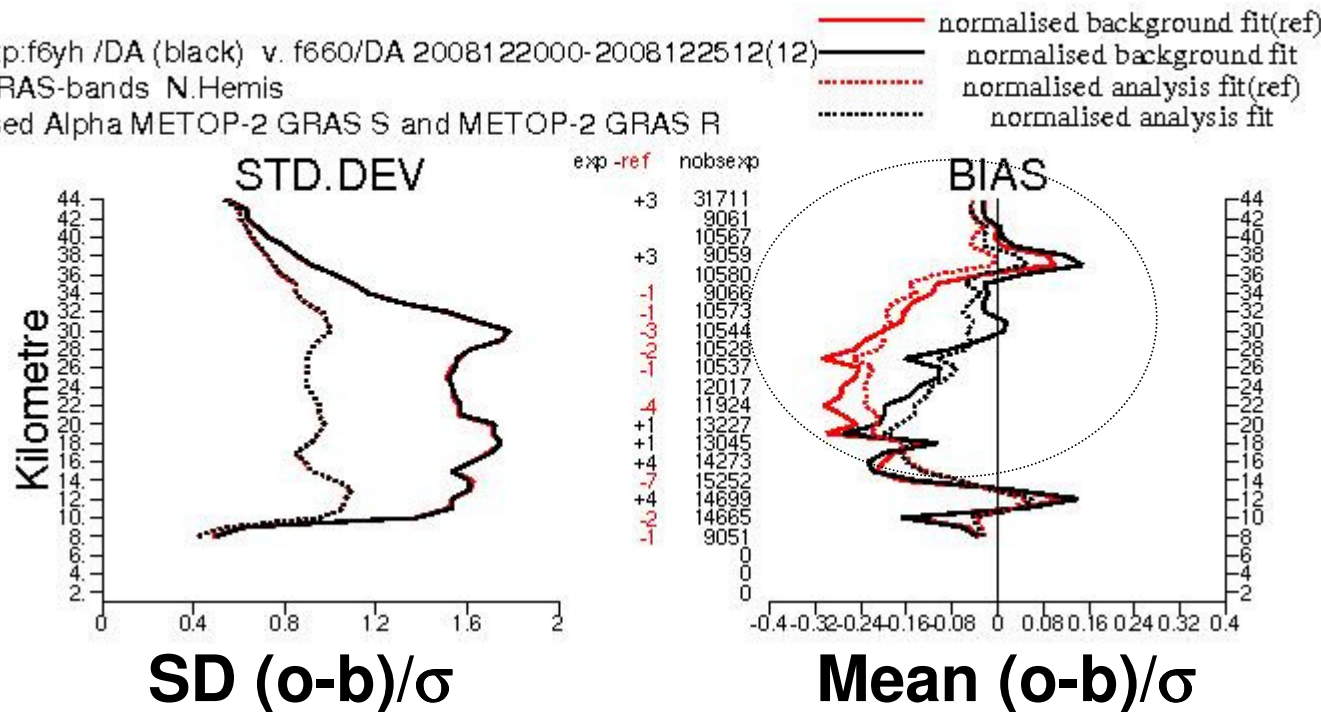


Experiments with Modified COSMIC data

Nov - Dec 08 and Jan 09

- The COSMIC processing changes have **improved the GRAS departures considerably, indicating much better consistency between the data.**

exp: f6yh /DA (black) v. f660/DA 2008122000-2008122512(12)
 RAS-bands N.Hemis
 sed Alpha METOP-2 GRAS S and METOP-2 GRAS R



Noise normalised
GRAS Departures

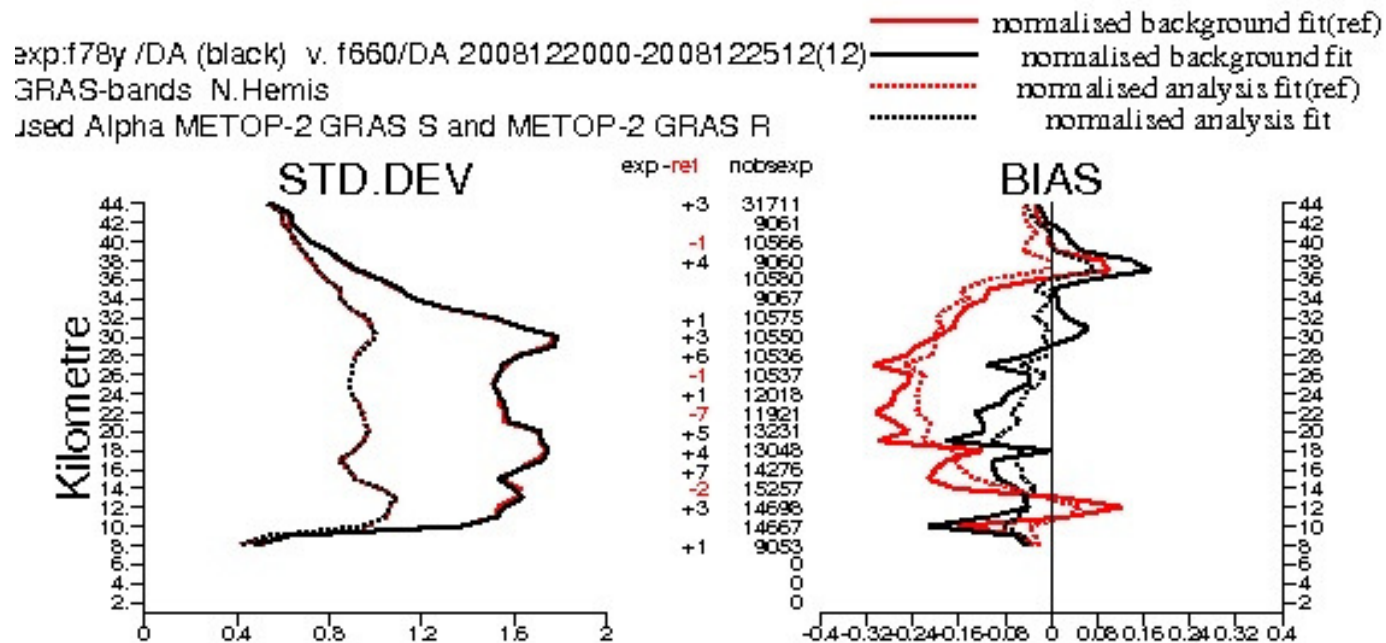
Red = with oper. COSMIC

Black = with new COSMIC



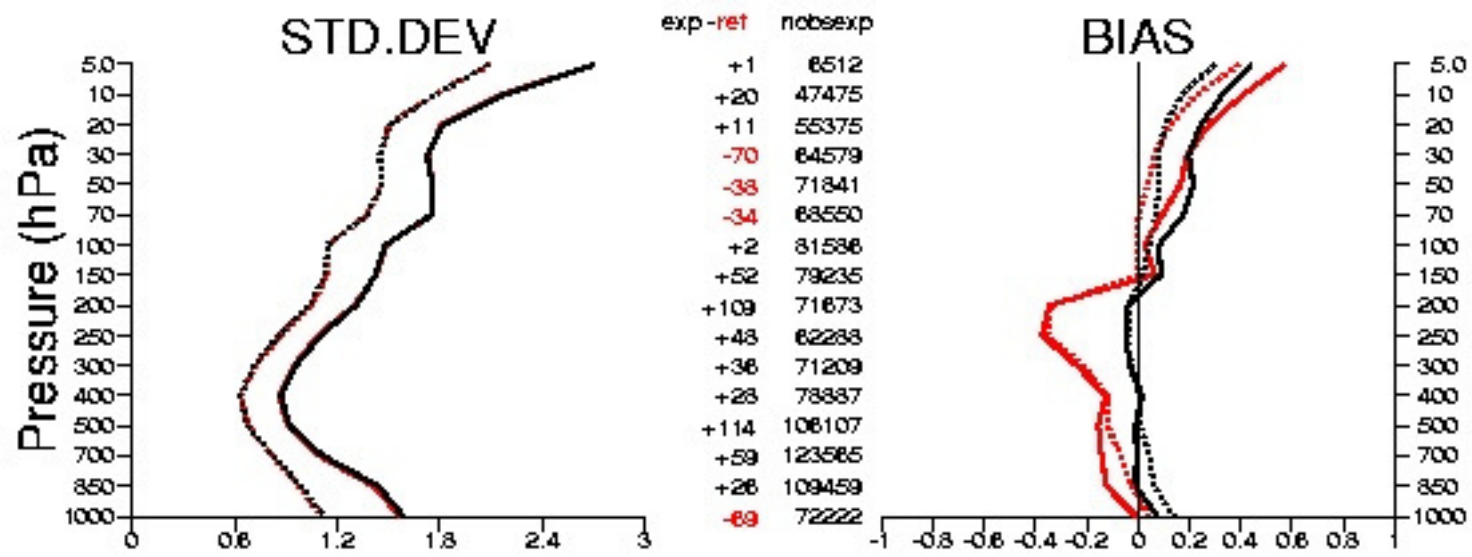
But why are bending angles biased –ve in the stratosphere?

- Partly caused by aircraft temperature measurements that are biased warm. They bias the forecasts/analyses warm. When I blacklist the aircraft temperatures GRAS departures get even better!



Fit to radiosonde temperature measurements with new COSMIC data when aircraft T blacklisted (NH)

exp:f78y /DA (black) v. f660/DA 2008120100-2008123112(12)
 TEMP-T N.Hemis
 used T



Red = operational COSMIC
 Black = new COSMIC + no aircraft T

In NH too few GRAS and COSMIC measurements to correct the bias introduced by the aircraft T values!



Water vapour information from GPSRO Experiment in a simplified NWP system

- Period: June 15th to August 31st, 2007.
- T511, Cy32r3, 12h incremental 4D-Var.
- **CONTROL**: Assimilates all conventional measurements + AMSU-A and MHS instruments from the METOP-A satellite.
- **COSMIC**: As control, but with all COSMIC measurements assimilated.
- **OPERATIONS (32r2)**: but T511 and inc. 4D-Var.



Humidity information (Tropics, 850 hPa)



The improvement with COSMIC (black line) is significant at the 95% level.



COSMIC vs NO GPSRO (~full system)



Water vapour

- COSMIC is improving the water vapour at 850 hPa, but the improvement is relatively small. Further, the results with the full system suggests most of the water vapour information comes from other observations.
- Is this because the COSMIC data numbers are too low? Or are we not giving COSMIC enough weight? 2D operators?
- It will be interesting to see how the OSSE water vapour results scale as the data number increases.



Surface pressure information derived from GPSRO measurements

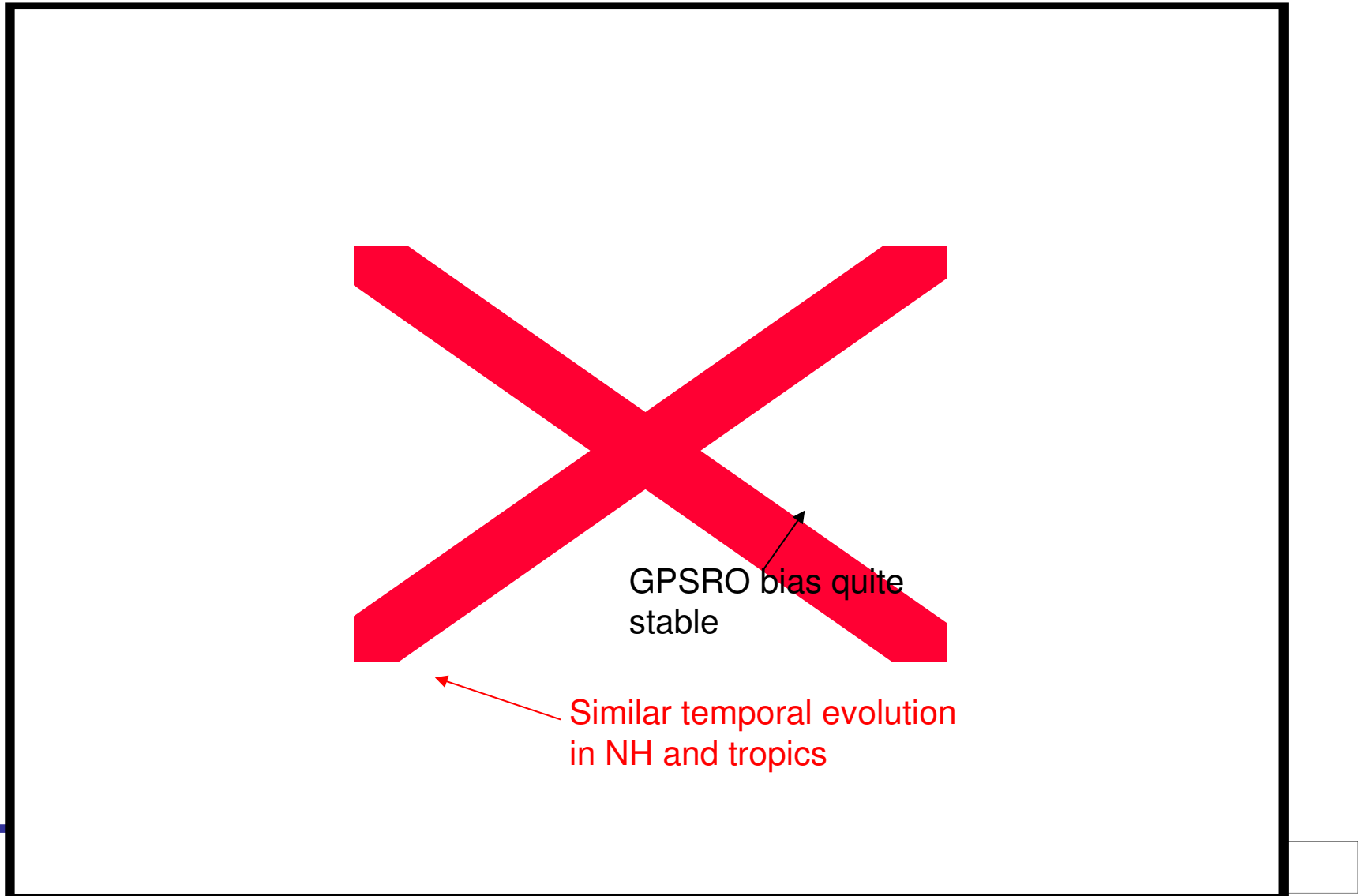
- The integration of the hydrostatic equation is part of the GPSRO observation operator because the bending angle and refractivity values are given as a function of a height co-ordinate.
- 1D-Var information content studies (Healy and Eyre, 2000) suggest that it should be possible to derive useful surface pressure information from the GPSRO measurements.
- We have recently performed experiments **where all surface pressure information is blacklisted** to see if COSMIC and GRAS can constrain the surface pressure field.
- Period June-July, 2009. **Verified against ECMWF operations.**







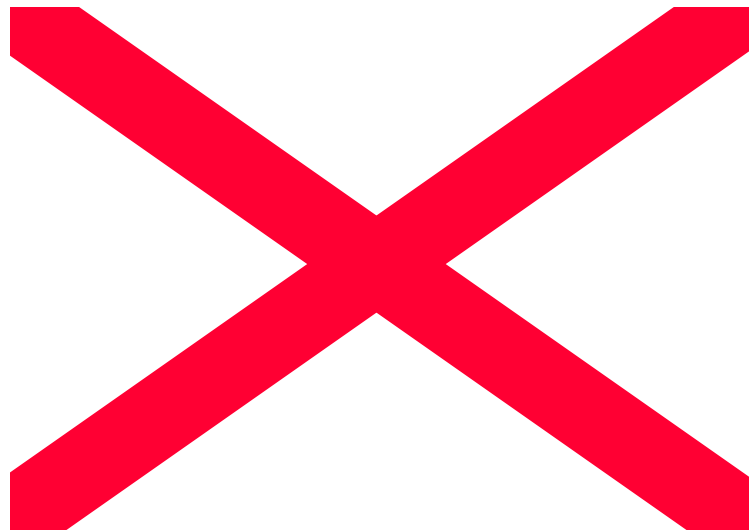
Southern Hemisphere results (24 hour mean error)



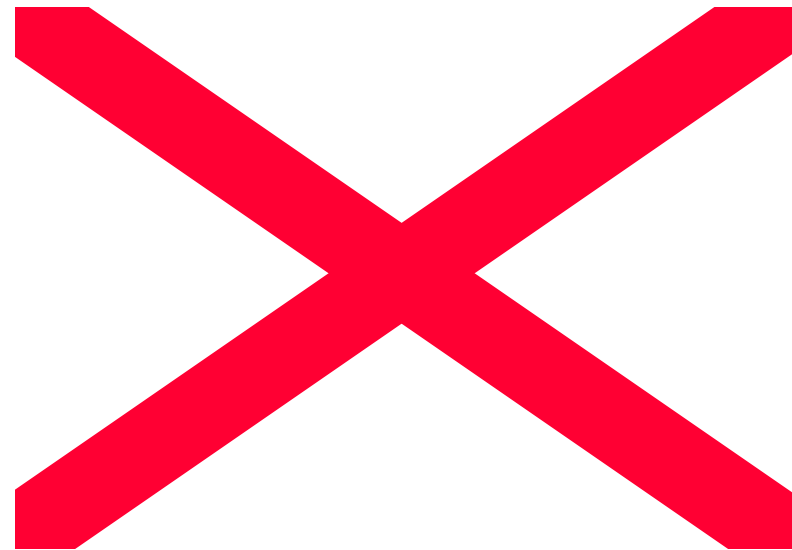
SH – sigma of 24 Hour error



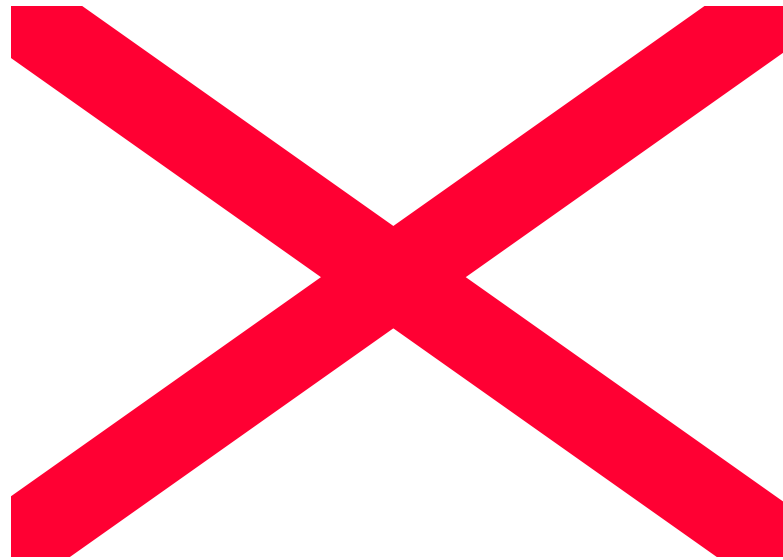
NH Mean Error



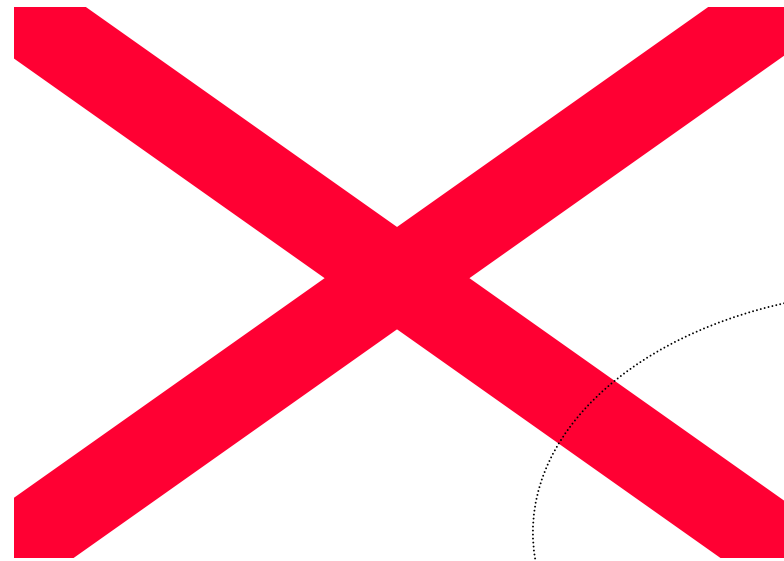
NH 24H sigma



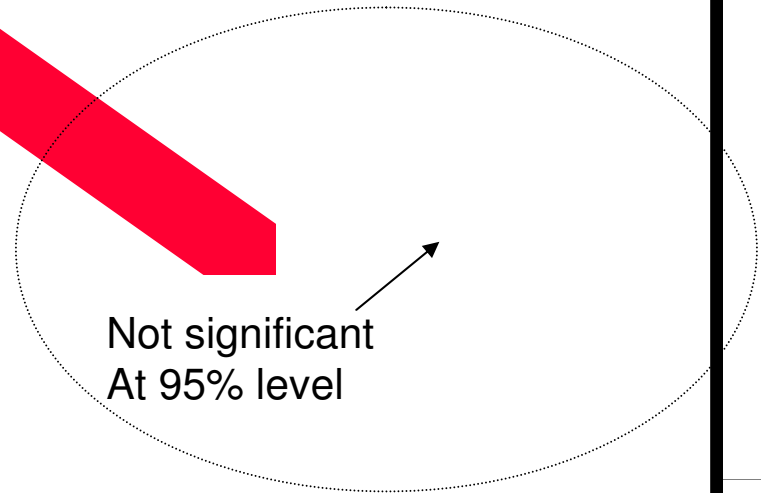
500Z height score (SH)



500Z Height Score (NH)



Not significant
At 95% level



Surface pressure work summary

- Evolution of the surface pressure bias is very different when GPSRO is assimilated. GPSRO experiment seems to have quite a stable bias, but why is it biased at all?
- Some indication that GPSRO measurements are reducing the random errors, particularly in the SH, but still larger than in Control. Could we do better with more GPSRO data?
- Ps measurements do not seem to have a very big impact on 500Z scores in the SH at the medium range when GPSRO assimilated.



Forecast Error Sensitivity to Observation (FSO)

Carla Cardinali (ECMWF)

- Data assimilation scientists have developed adjoint based tools to estimate how observation types contribute to the reduction of a 24 hour forecast error. See ECMWF workshop presentations.
http://www.ecmwf.int/newsevents/meetings/workshops/2009/Diagnostics_DA_System_Performance/index.html
- Carla Cardinali has recently completed this type of calculation for the ECMWF system and GPSRO has performed well.



Forecast sensitivity to observation: Equations (slides from Carla)

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J}{\partial \mathbf{x}_a}$$

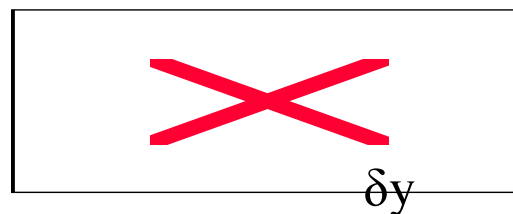
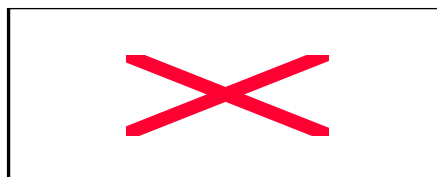
J is a measure of the forecast error

Analysis solution

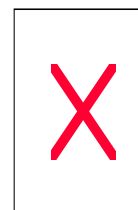
$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

Analysis sensitivity to observation and background

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T$$



Forecast error sensitivity to the analysis

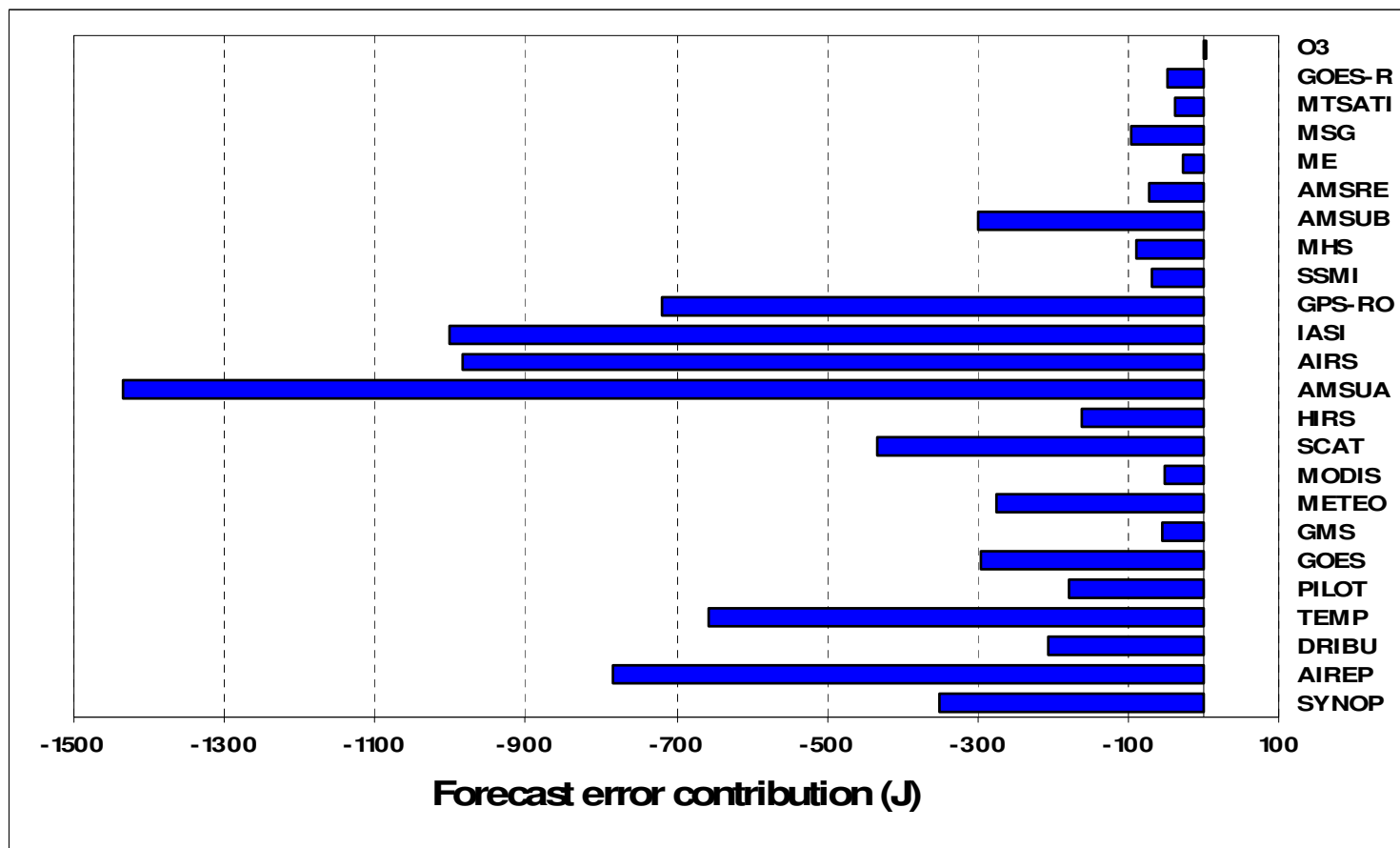


Rabier F, *et al.* 1996.

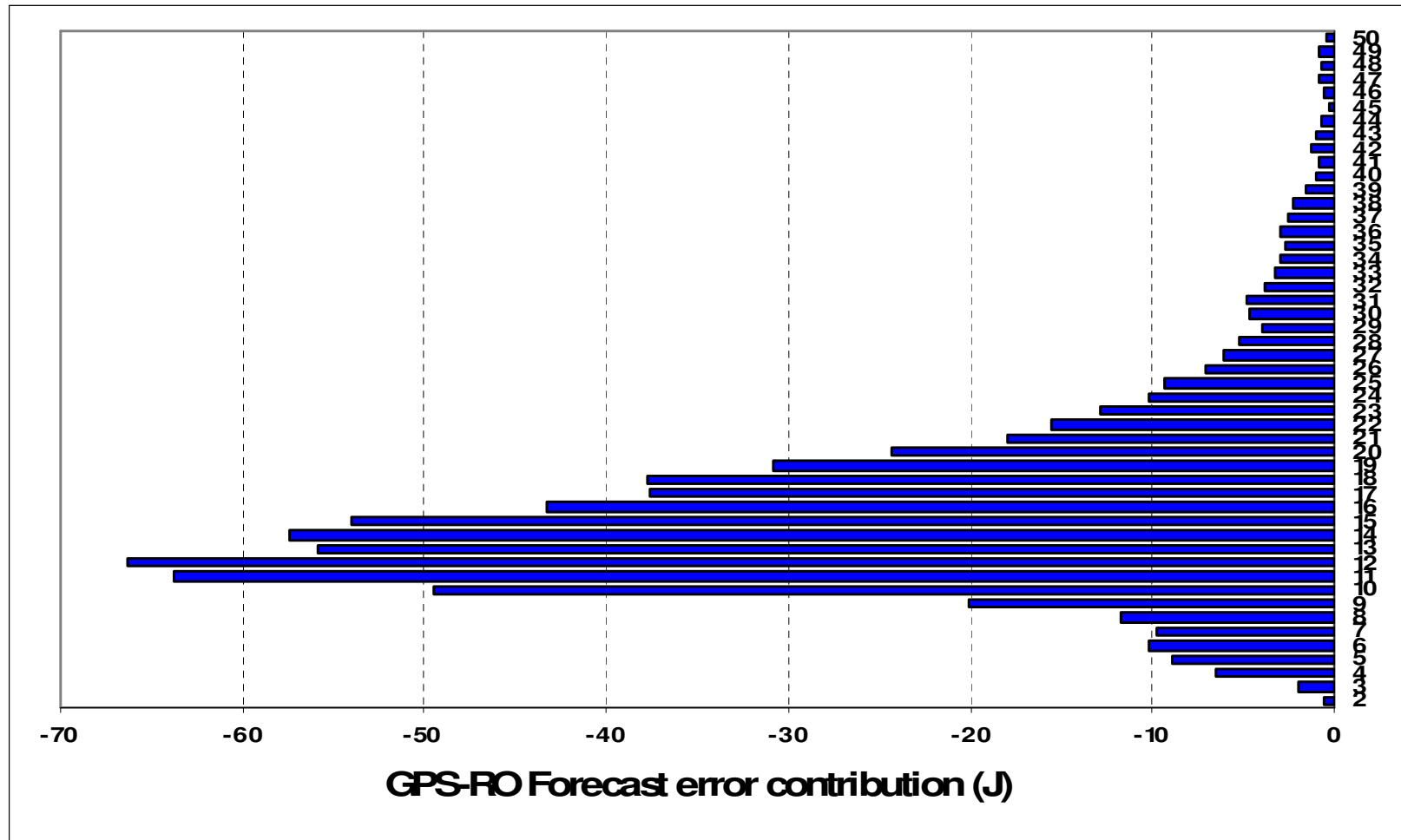
The tool provides information on the observation type, subtype, variable and level responsible for the forecast error variation



FSO Results



Heights where GPSRO contribute most to error reduction



Summary

- Outlined recent impact experiments at ECMWF.
- One instrument not sufficient to constrain stratospheric temp. biases.
- The new COSMIC data are clearly more consistent with GRAS. Part of the –ve stratospheric bending angle bias is attributable to the assimilation of biased aircraft temperatures at ECMWF. GPSRO + radiosondes are fighting the biased aircraft temperatures!
- Some water vapour information in simplified experiments, but results suggest most of the information is from other sources (SSM/I, AIRS). Will this improve if GPSRO numbers increase or better operators are used?
- Surface pressure results are interesting: some indications that GPSRO measurements provide useful information in the SH.
- GPSRO measurements are performing well in adjoint based forecast error sensitivity tests. They are now clearly a very important component of the observing system.



Some issues

- GPSRO measurement anchor the radiance bias correction. How is this handled in the OSSE's?
- The GRAS SAF Radio Occultation Processing Package is available for download. From December 1, this will include 2D bending angle operators. Try these operators in the OSSE's.

