Assimilation of GPS radio occultation measurements at ECMWF

Sean Healy

Outline

- Bending angle or refractivity assimilation.
- The ROPP 1D bending angle observation operator.
- Impact in a simplified NWP assimilation system.
- Vertically correlated bending angle errors.
- Current work on ROPP 2D bending angle operators.
- Measurements from the GRAS instrument on Metop-A.
- Summary.

Bending angle or refractivity assimilation?

- The choice depends on the height of the NWP model top. Both approaches require extrapolation:

  – refractivity: extrapolate the observed bending angles
  – bending angle: extrapolate the NWP fields

- If NWP model goes up to ~55/60 km, bending angle is probably best. **E.g**, ECMWF model goes up to 80 km. The bending above the model top for a ray with a tangent height at 40 km is ~ 0.05 microradians.

- If NWP model top is 35 km or below, probably refractivity is the best option, but you have to remember that the upper level refractivity values contain climatology information.

Statistical Optimization

- The bending angles used in the Abel transform are the weighted average of the observed values and bending angle values **simulated** with a climatology or NWP model (eg, MSIS, CIRA or ECMWF!).

Simulated BA's

Observed BA's

$$\hat{\boldsymbol{\alpha}} = \boldsymbol{\alpha}_{\mathbf{b}} + \mathbf{B}(\mathbf{B}+\mathbf{O})^{-1}(\boldsymbol{\alpha}-\boldsymbol{\alpha}_{\mathbf{b}})$$

Error cov. matrix for simulated BA's

Error cov. matrix for observed BA's

statistically optimized bending angle.

$$N(x) = 10^6\left[\exp\left(\frac{1}{\pi}\int_x^{\infty}\frac{\hat{\alpha}(a)}{\left(a^2-x^2\right)}da\right)-1\right]$$

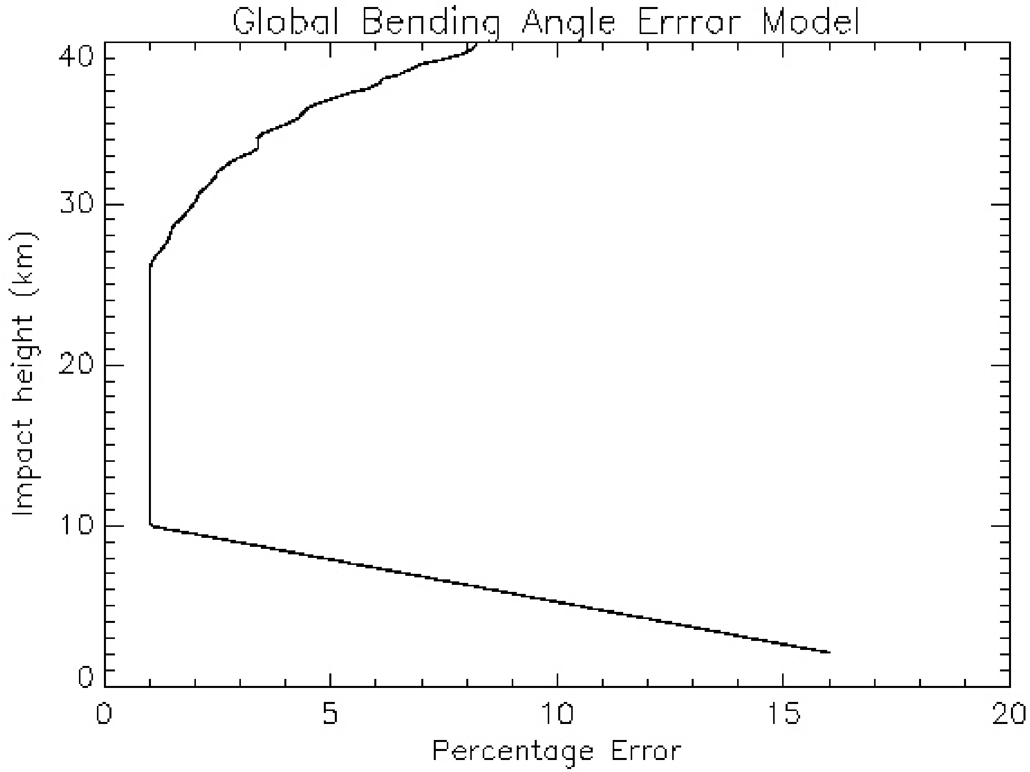
Operational assimilation at ECMWF with the ROPP 1D bending angle operator

- We assimilate bending angles with a 1D operator. We ignore the 2D nature of the measurement and integrate

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

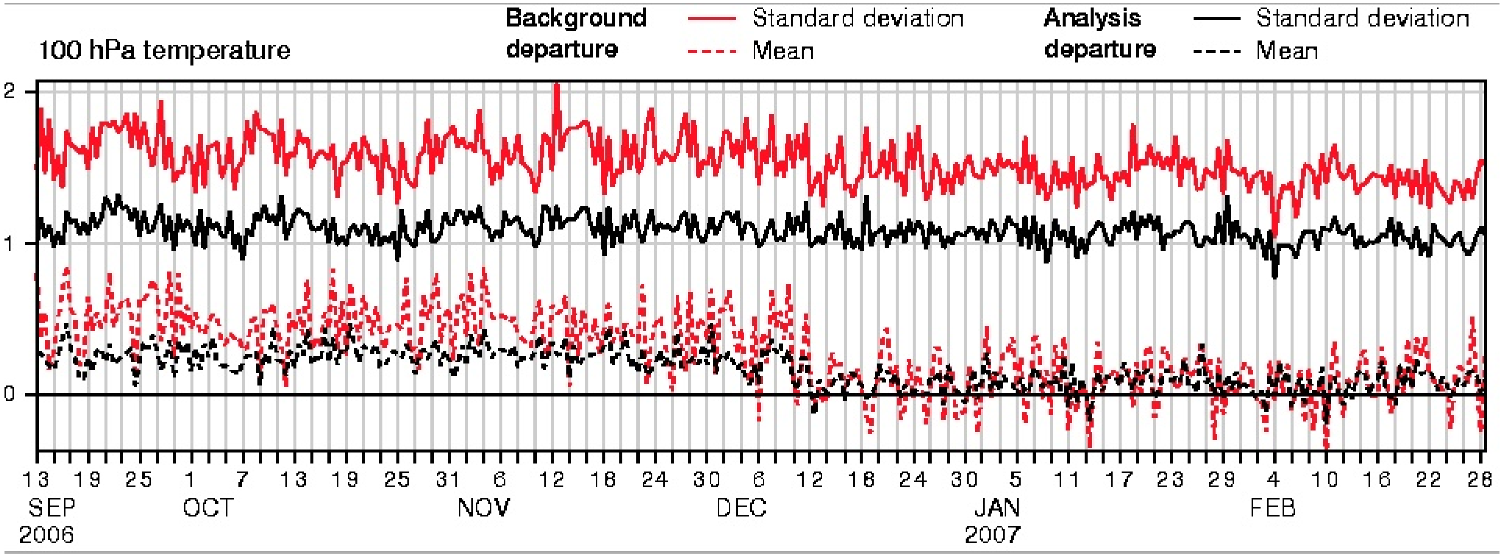
- The forward model is quite simple:
  - evaluate geopotential heights of model levels
  - convert geopotential height to geometric height and radius values
  - evaluate the refractivity, N, on model levels from P,T and Q
  - integrate, assuming refractivity varies exponentially between model levels.
  - solution given in terms of the Gaussian error function.

Assumed observation errors (Global)



We ignore vertical correlations. We now assimilate bending angles from surface to 40 km, with a **~ 200 m vertical separation (no vertical thinning!)**.

Operational short-range forecast fit to radiosonde temperature measurements (100 hPa, SH)



ECMWF started assimilating GPSRO data operationally on December 12, 2006.

Clear improvement in the bias in operational fit to radiosonde temperature measurements.

Assimilation experiments in a simplified NWP system

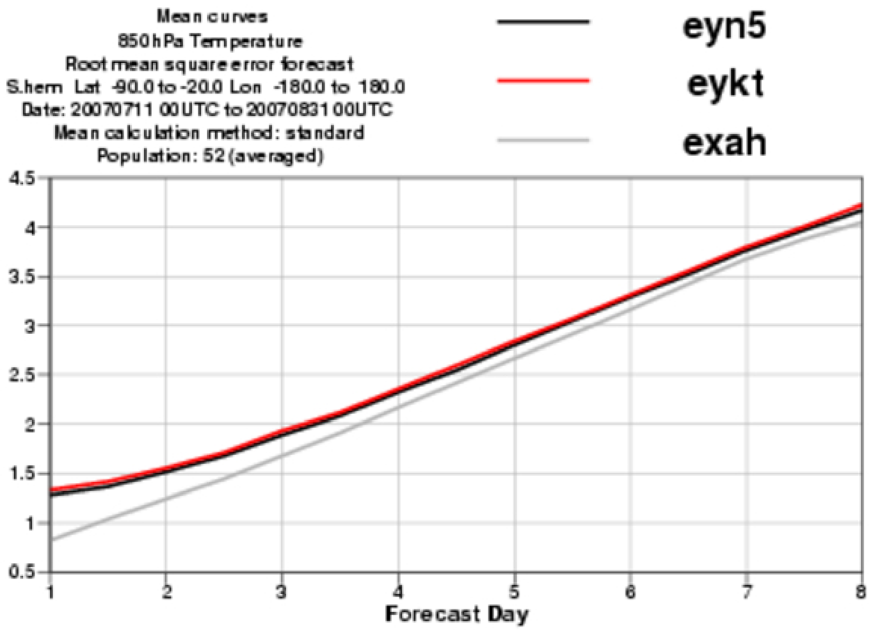
- GPSRO was not available for the set of **Observing System Experiments (OSE's)** reported in ECMWF Newsletter 113 designed to assess the impact of space component of the Global Observing System.

- Interest in how GPSRO would perform in such a system.

- **Interaction with the Variational Bias Correction (VarBC) of satellite radiances will be discussed by Dick Dee in his reanalysis talk**.

Experiments in a simplified NWP system

- Period: June 15^{th} to August 31^{st}, 2007.
- T511 Cy32r3. **VarBC on**.
- **Baseline *(red curves)***: Assimilates all conventional measurements + AMSU-A and MHS instruments from the METOP-A satellite.
- **COSMIC *(black curves)*:** As baseline, but with all COSMIC measurements assimilated.
- **Control *(grey curves)*:** All observations used in operations, including IASI (Experiment run by Andrew Collard).


Mean curves
850hPa Temperature
Root mean square error forecast
S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
Date: 20070711 00UTC to 20070831 00UTC
Mean calculation method: standard
Population: 52 (averaged)
eyn5
eykt
exah
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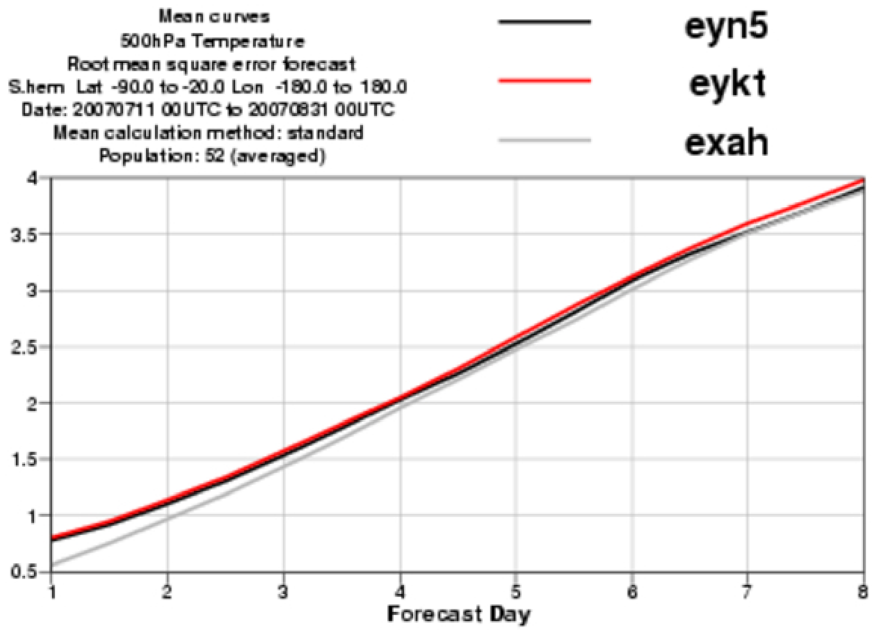
Forecast Day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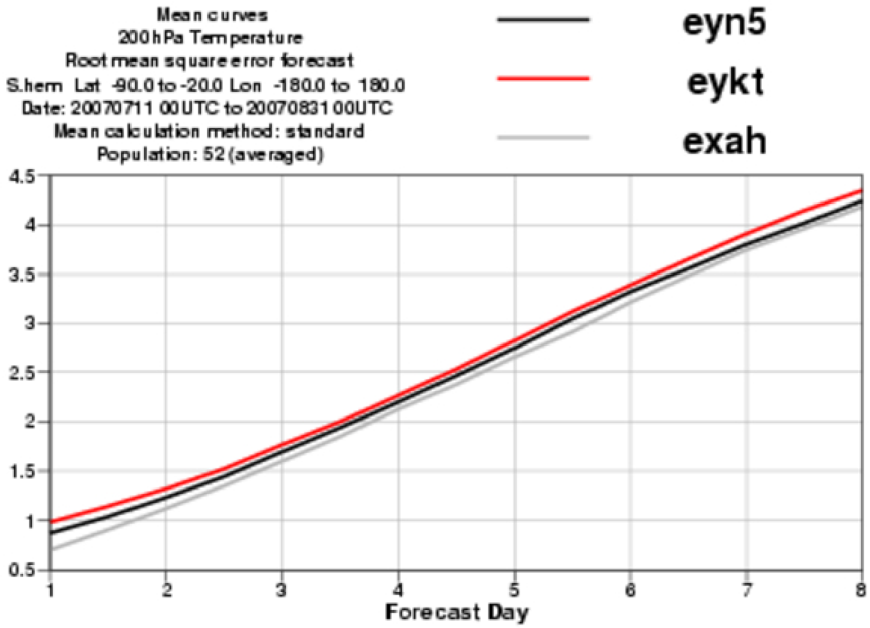
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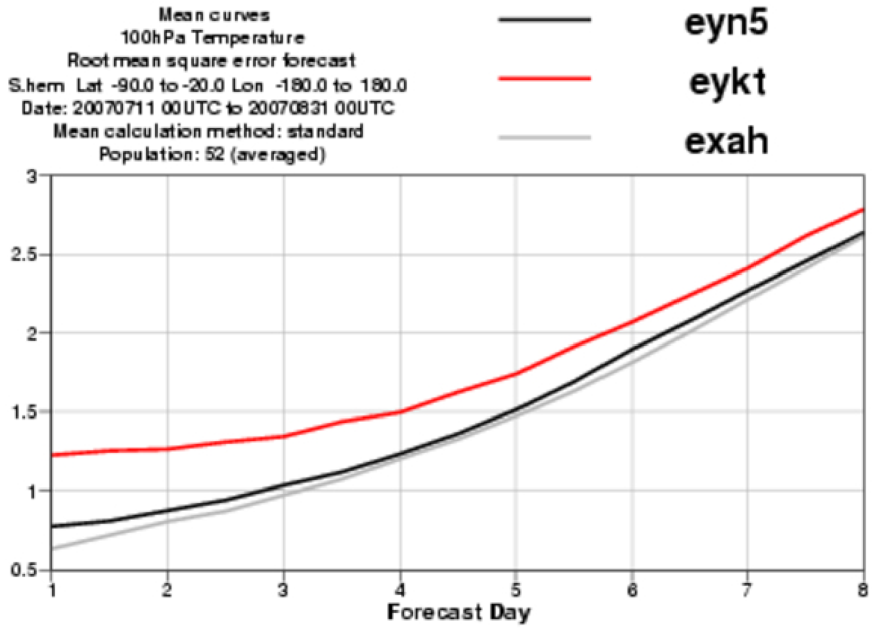
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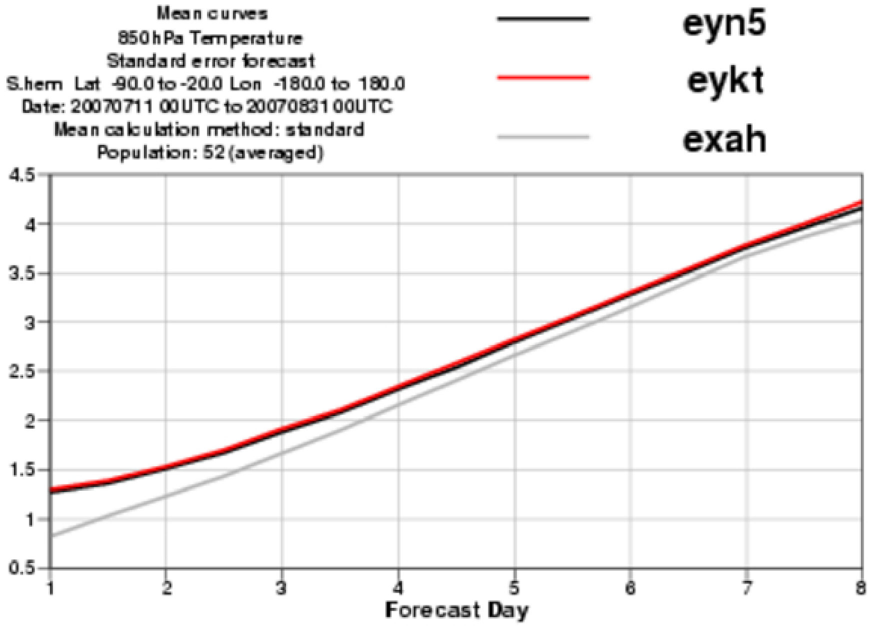
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Standard error forecast
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Date: 20070711 00UTC to 20070831 00UTC
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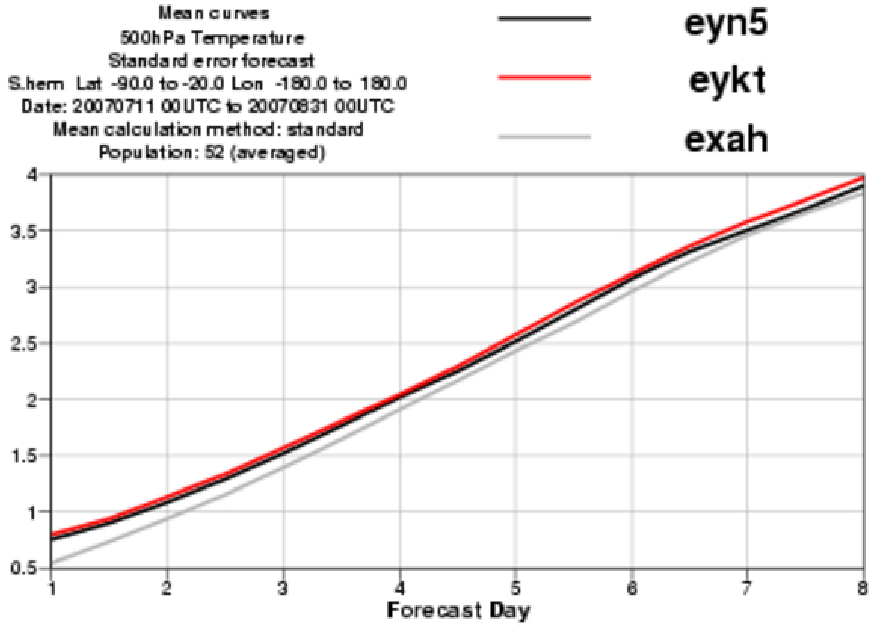
Forecast Day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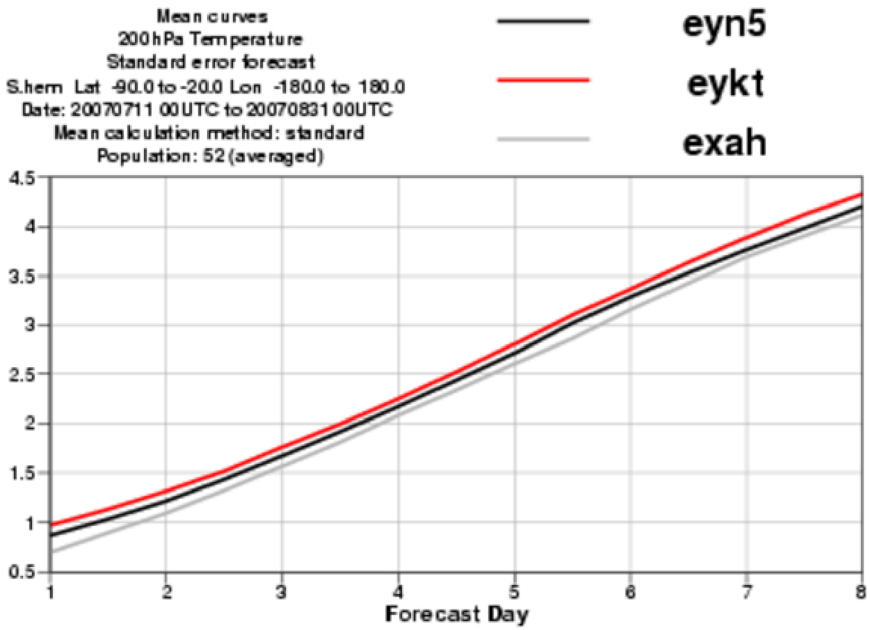
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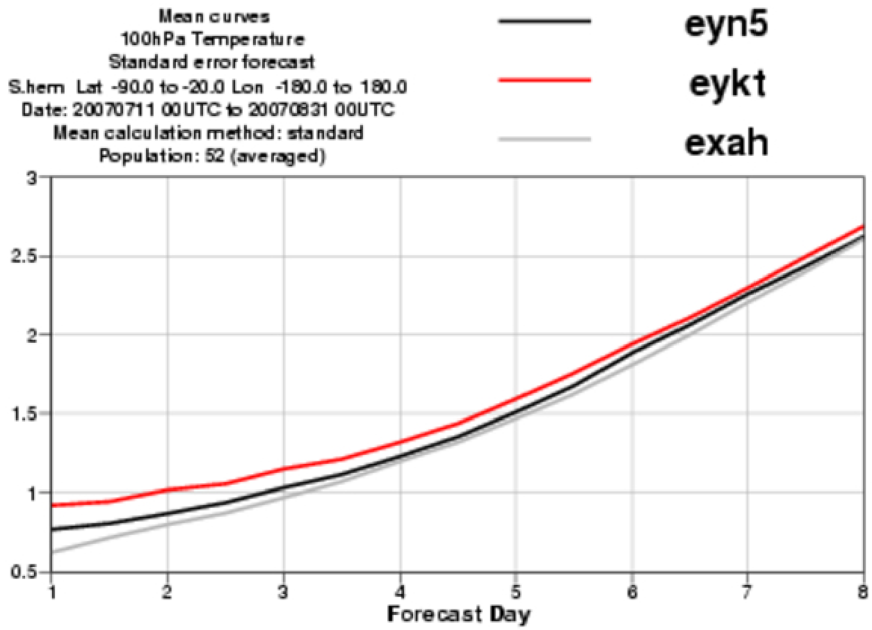
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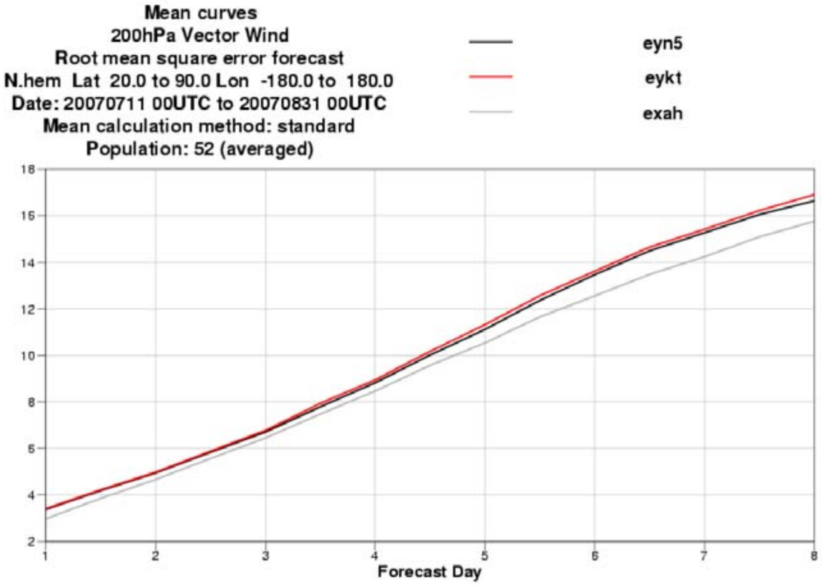
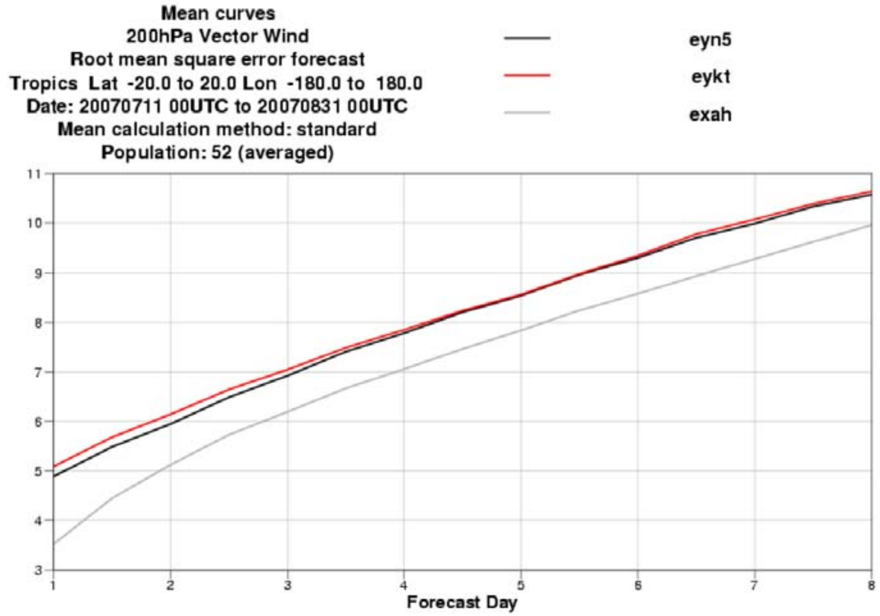
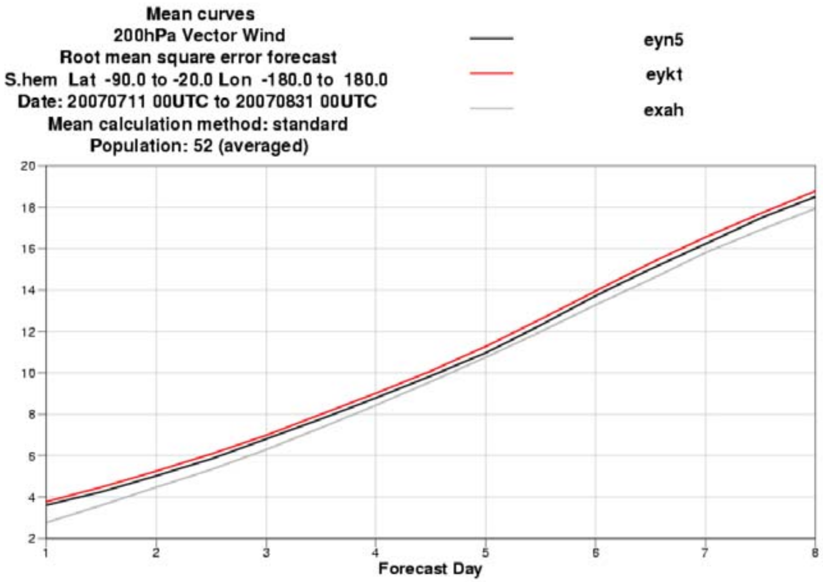
Forecast Day

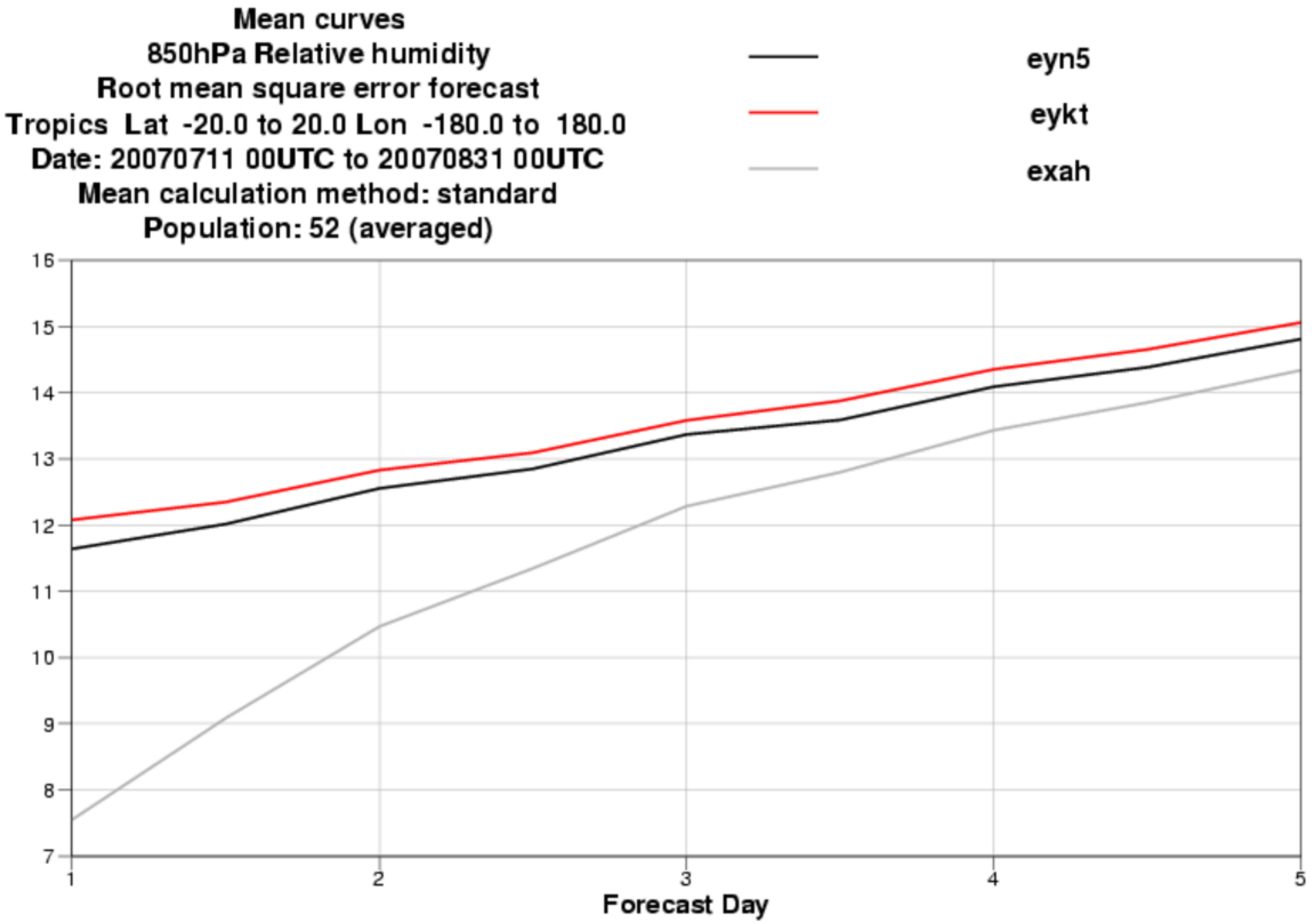
Winds (200 hPa)







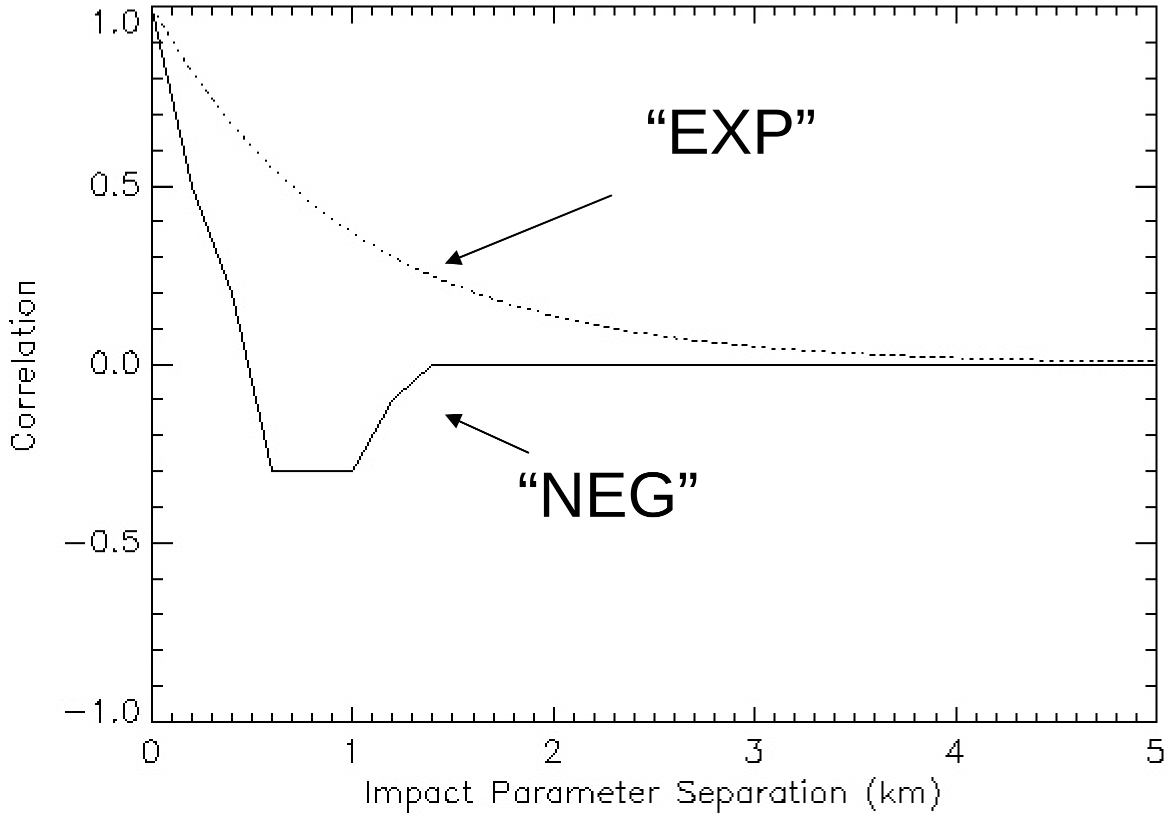
Humidity information (Tropics, 850 hPa)



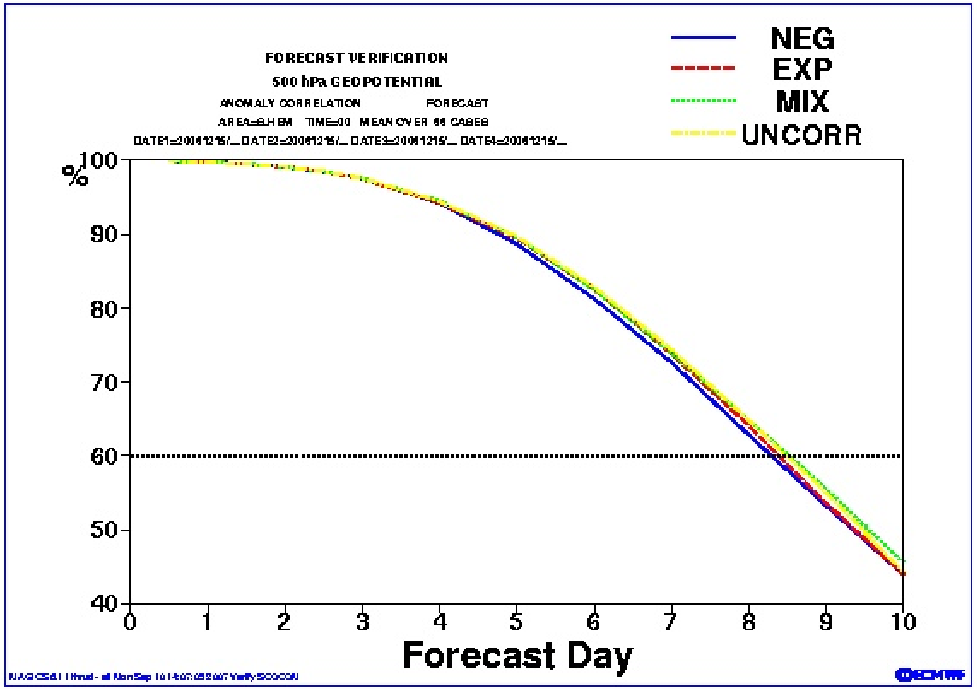
The improvement with COSMIC is significant at the 95% level.

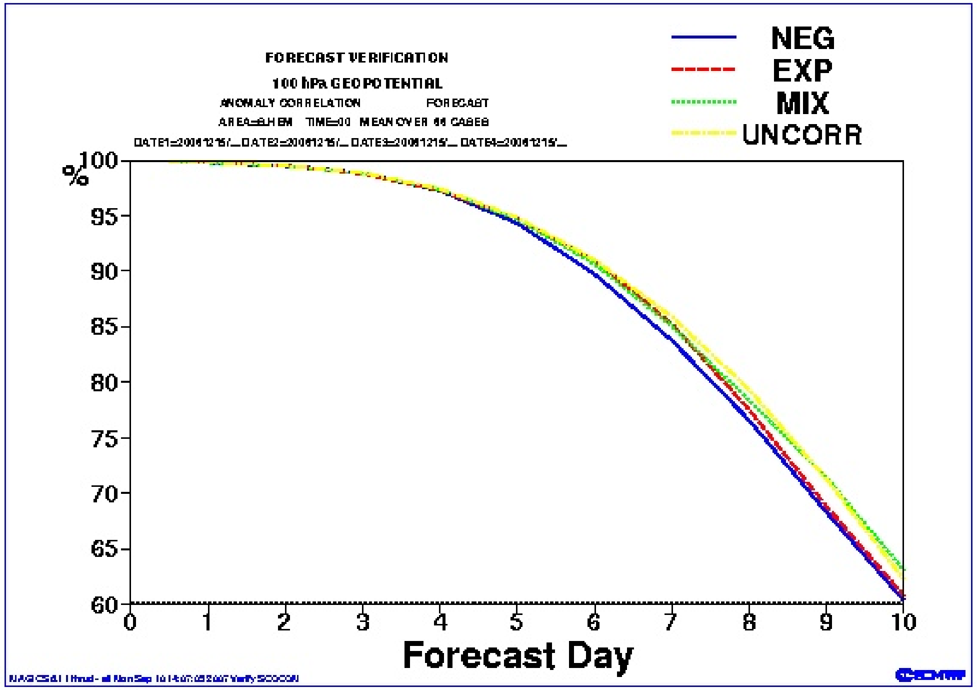
Vertically correlated observation errors

- Based on a branch provided by Andrew Collard.
- The main difficulty is choosing a realistic correlation matrix.
- Processing of the observations would suggest –ve correlations, but its not clear whether this is appropriate in the lower troposphere, where forward model/representation errors may dominate.
- Investigated 3 correlation models. The choice is a bit *ad-hoc*, but informed by work by Steiner et al, Poli et al and Syndergaard .



“MIX” assumes the “NEG” model below 10 km and the a slightly narrower exponential model above 10 km.

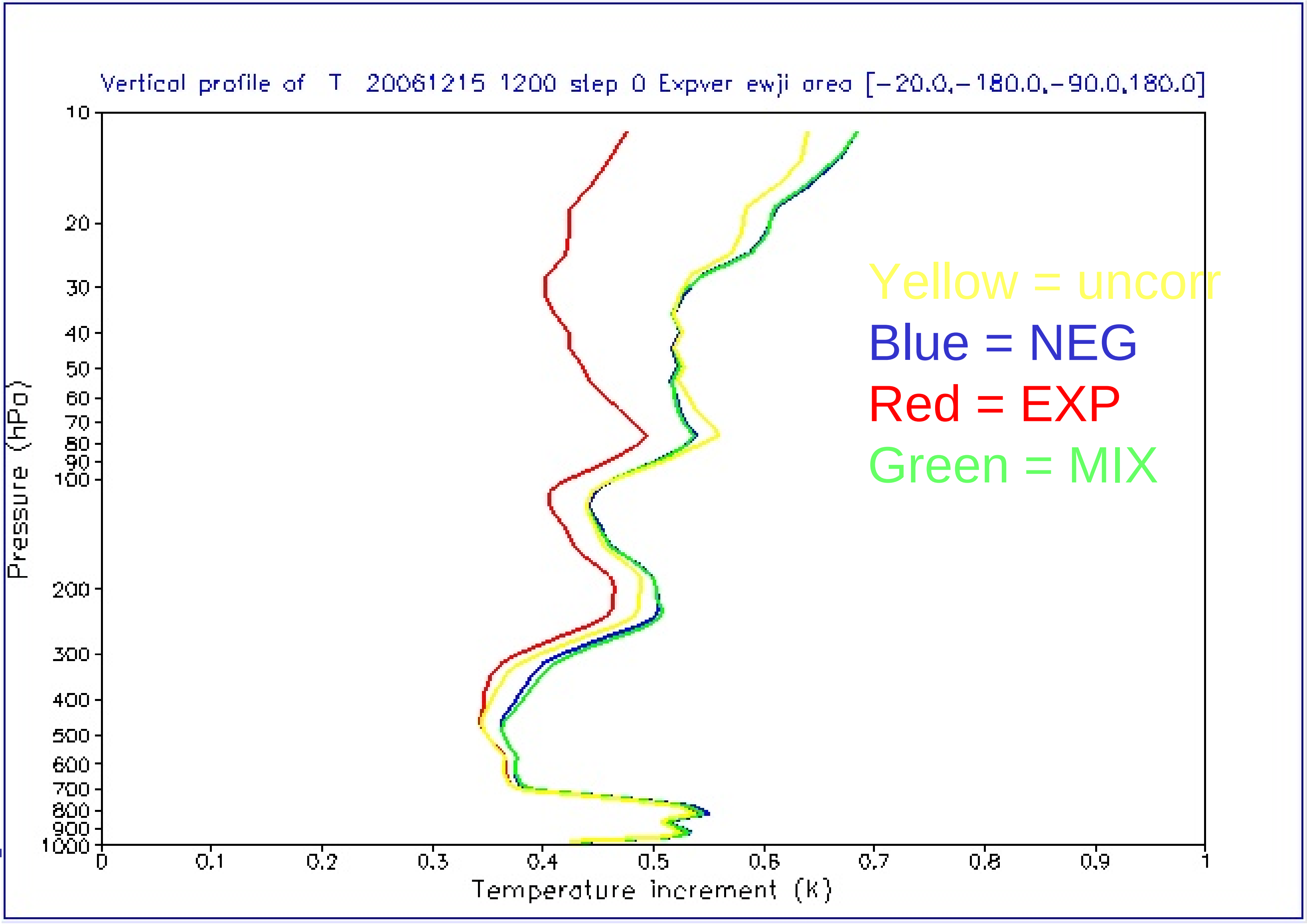




It is difficult to find a correlation model that improves on the uncorrelated case.

The NEG correlation model produces a degradation. The –ve correlations appear to increase the magnitude of the temperature increments in the troposphere.

RMS T increments (SH)



GPSRO forward model development (ROPP v2.0)

1D operator: We evaluate the integral

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

$$x = nr$$

u where the refractive index is derived from the NWP profile information extracted from **a single location** in the horizontal.

2D operator: we solve the bending angle using the NWP profile information extracted at a **series of equally spaced locations** in the 2D “occultation plane”.

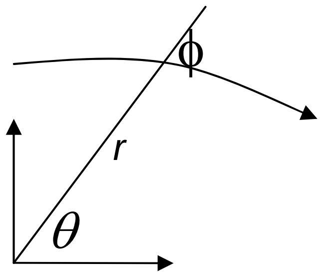
2D Ray-tracer

For the ray path in the troposphere we solve

$$\frac{dr}{ds} = \cos\phi$$

$$\frac{d\theta}{ds} = \frac{\sin\phi}{r}$$

$$\frac{d\phi}{ds} = -\sin\phi\left[\frac{1}{r} + \left(\frac{\partial n}{\partial r}\right)_\theta\right]$$



We then switch to a 1D method to calculate the bending for the ray path above ~ 10 km.

Still some approximations

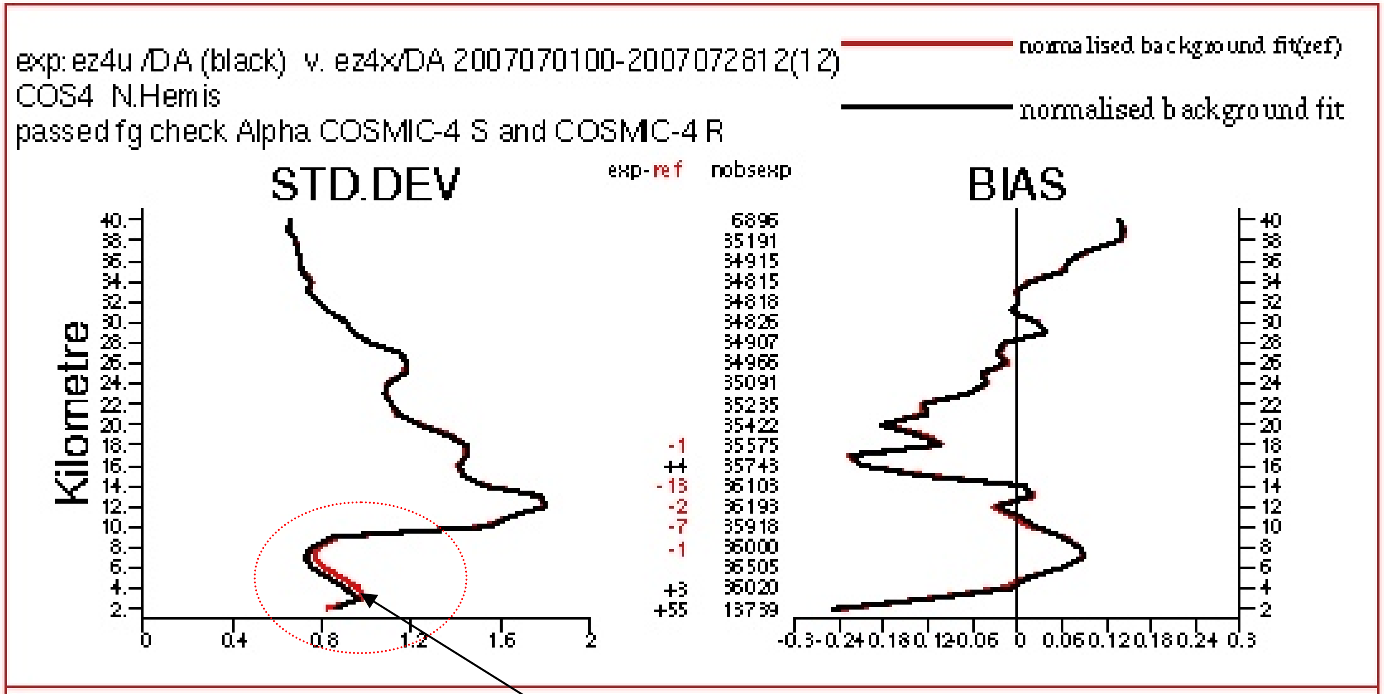
We neglect tangent point drift! A 2D plane is constructed using the azimuthal angle defined in the BUFR file.The 2D plane contains **31 profiles separated by 40km**.

Central profile = “occultation point”.

1) calculate the bending from the tangent point along the path towards the LEO
2) Calculate the bending from the tangent point along the path towards the GPS.
3) Add these bending angles together to get the total bending.

The height of the tangent point (starting point of the 2D ray path) is estimated from the “derived impact parameter” – i.e., the value given in the data file. Currently testing a correction for this problem.

(O-B)/sigma_o stats



Black = 2D

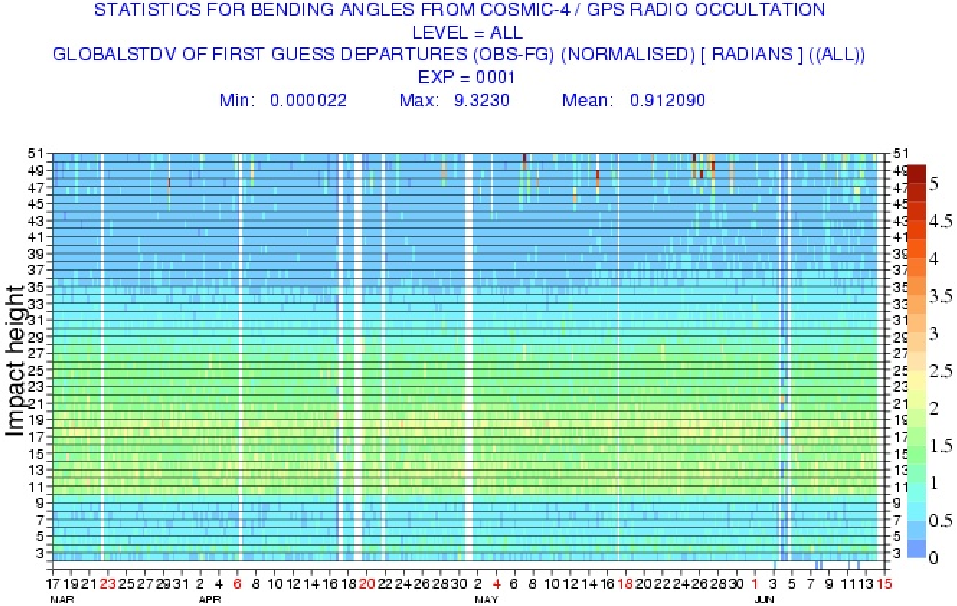
Red = 1D

O-B's have been
Reduced by ~7%

GRAS on MetOP-A

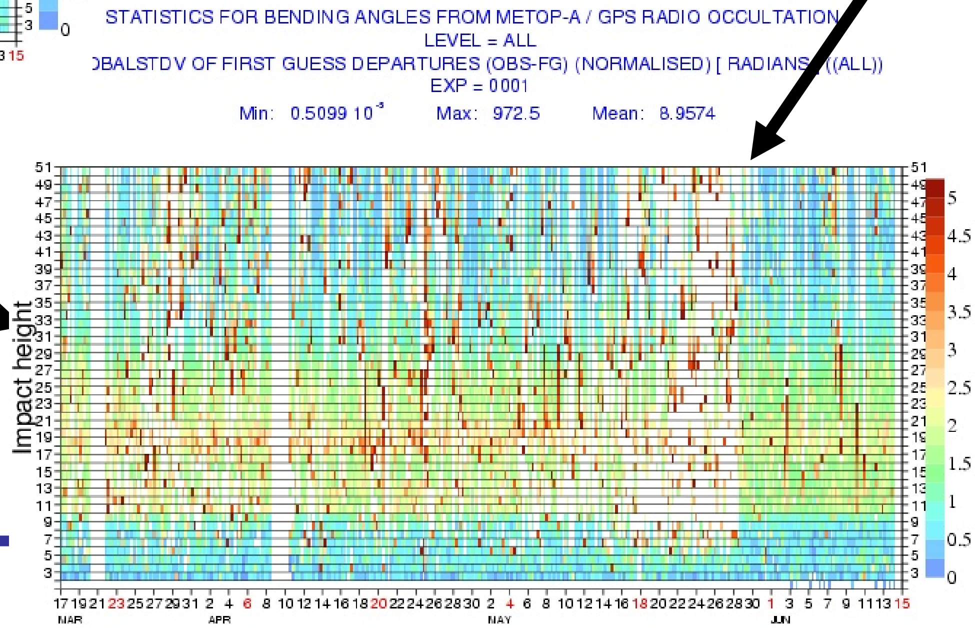
- GRAS was declared preoperational on February 21 (2008) and operational on April 17 (2008).
- ECMWF started monitoring GRAS in operations on February 25.
- Forecast impact experiment: Feb 25 to April 17, 2008. Cy32r3, T511, 12 hour incremental 4D-Var.
- Blacklist the measurements in the lower/mid troposphere because GRAS is not processed with open loop or wave optics retrieval method.
- GRAS provides around 650 occultations per day.

GRAS SAF monitoring: (o-b)/sigma_o



COSMIC-4

PPF 2.11

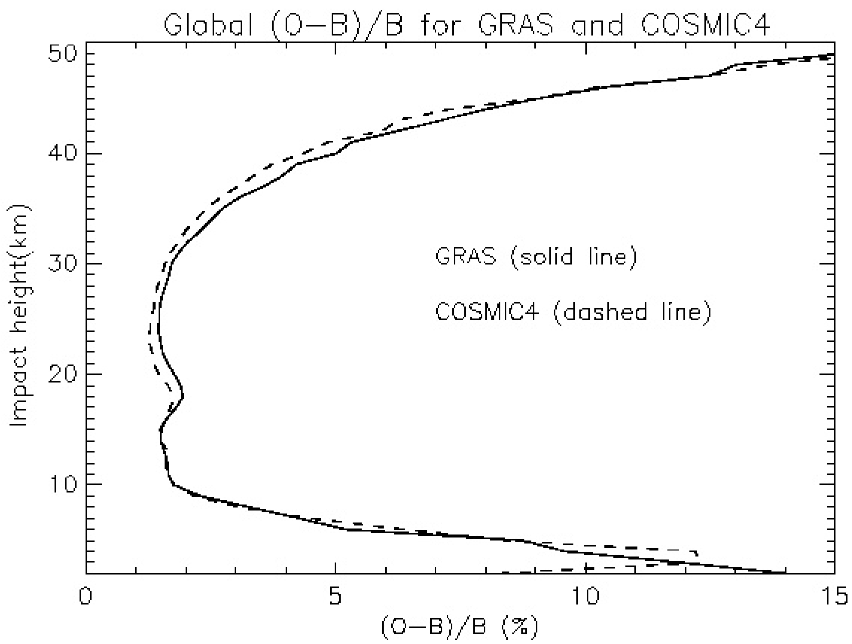


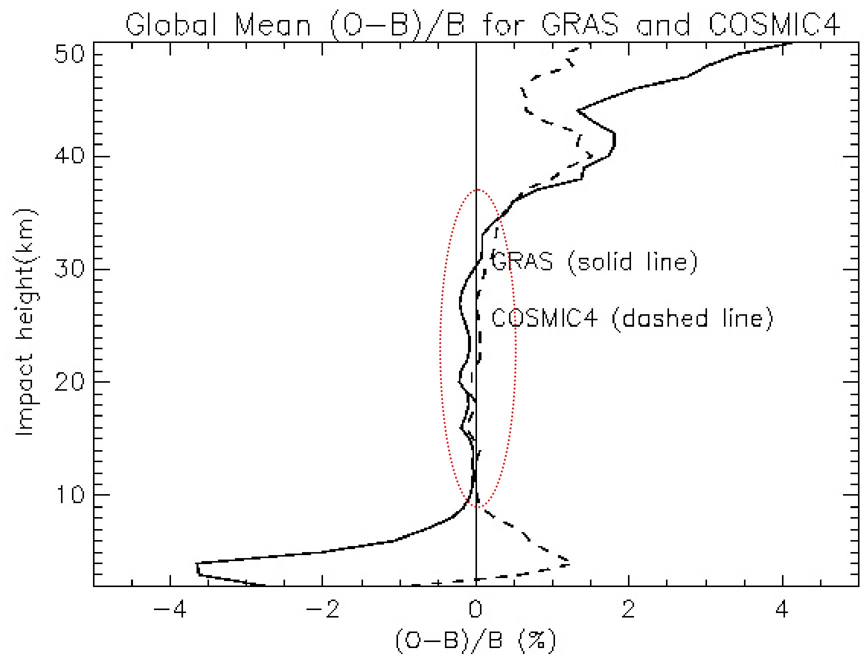
The GRAS statistics are Being corrupted by ~1% of very poor quality data.

This is being caught by the first guess check

GRAS

Comparison with COSMIC-4
(O-B)/B statistics (June 1 – 14, 2008)





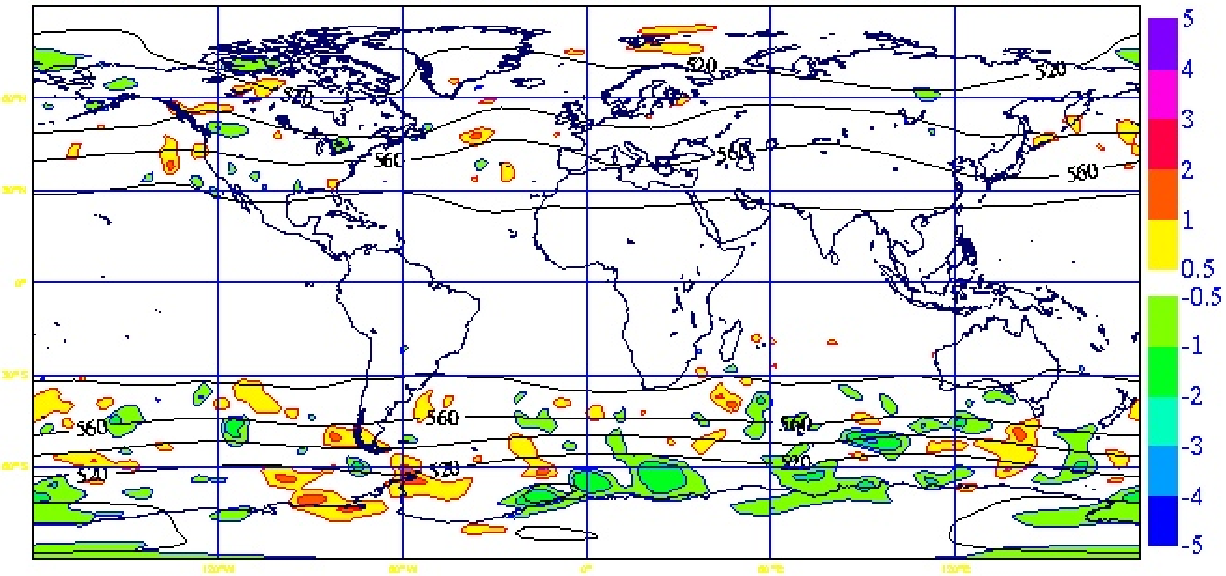
Standard deviation

Mean

From operations: passed first guess check

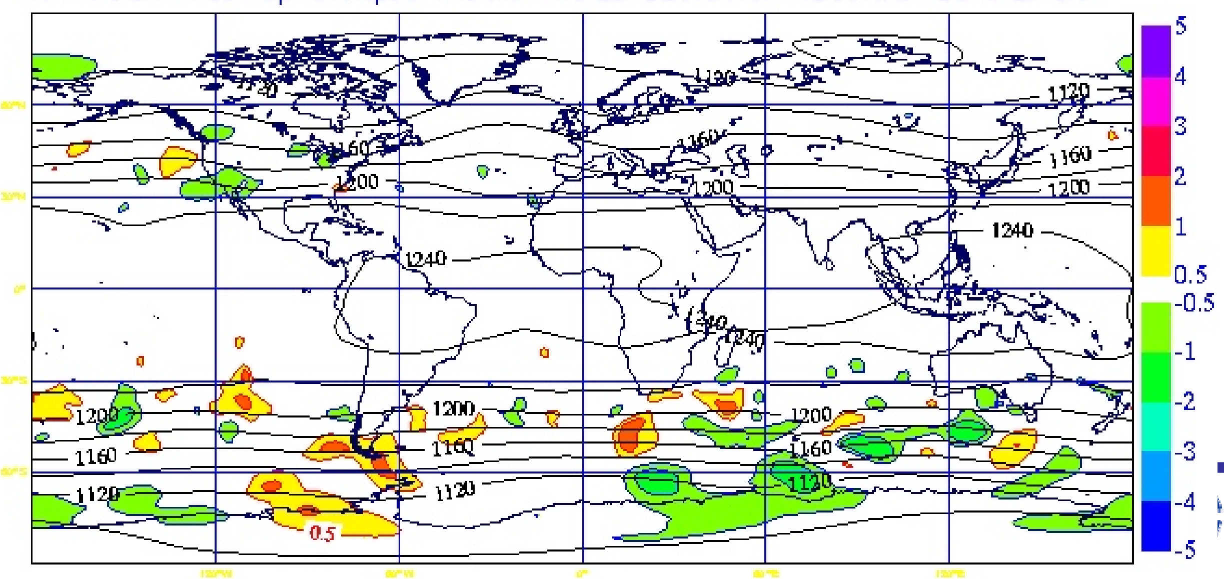
Z500

Diff in RMS of fc-Error: RMS(fc_ezxb - an_ezxb) - RMS(fc_ezy7 - an_ezy7)
Lev=500, Par=Z, fcDate=20080225-20080412 0Z, Step=120
NH=-0.08 SH= -2.01 Trop= 0Npole=1.61Nml=-0.36 Eur=5.36 NAmer= -9.75 NAtl= -1.53 NPac= 7.25

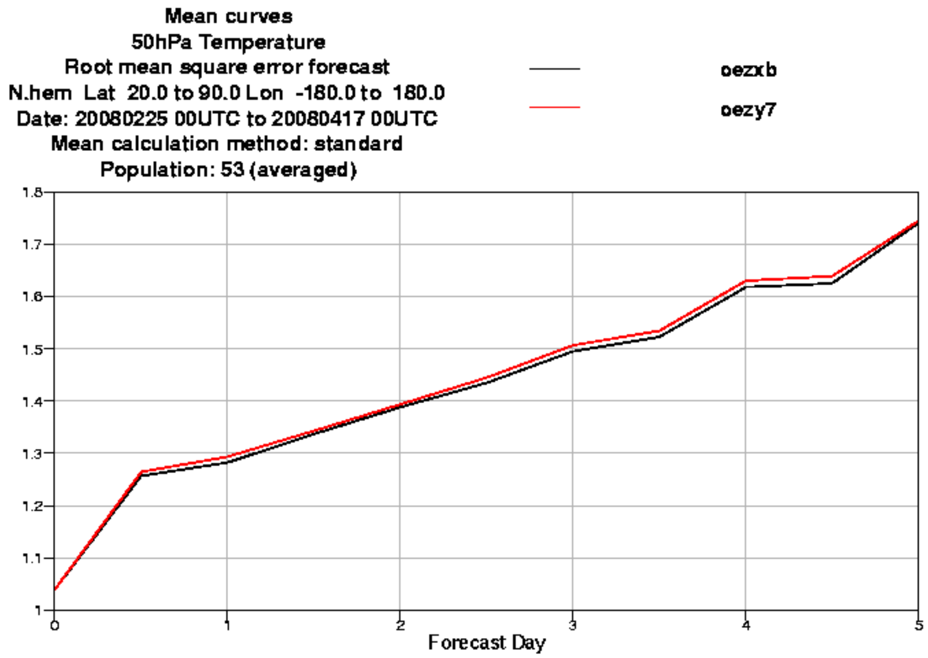


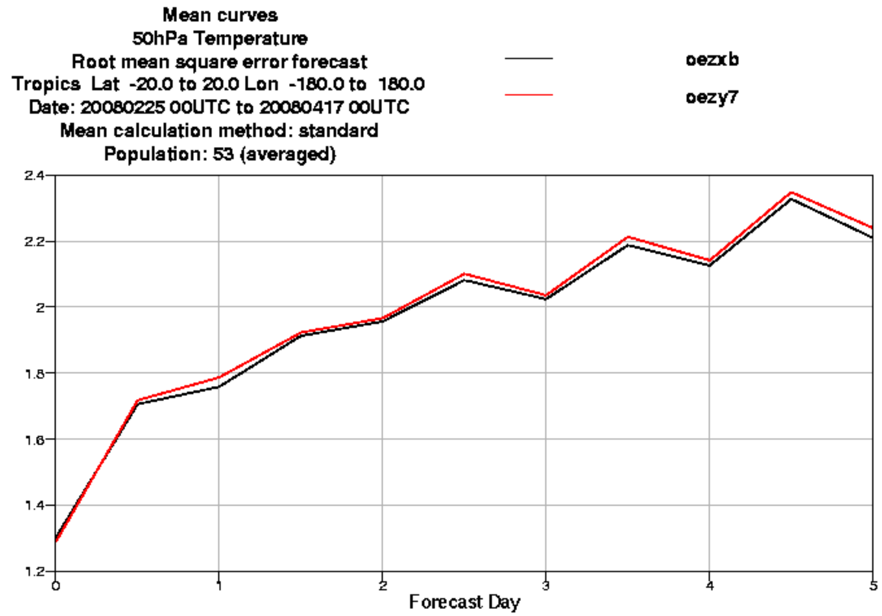
Z200

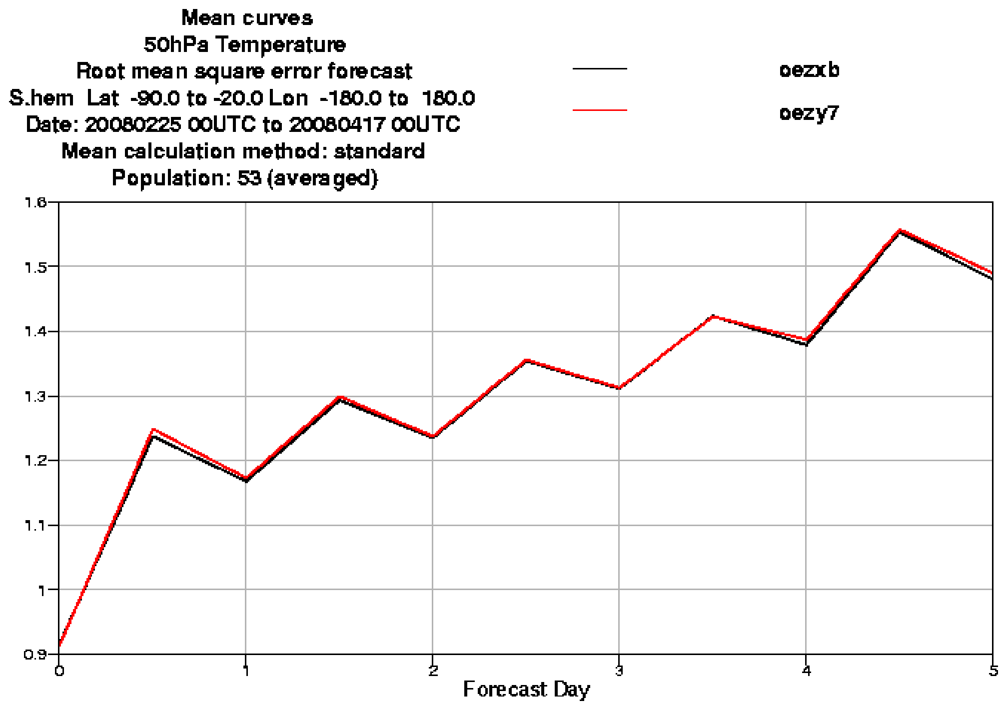
Diff in RMS of fc-Error: RMS(fc_ezxb - an_ezxb) - RMS(fc_ezy7 - an_ezy7)
Lev=200, Par=Z, fcDate=20080225-20080412 0Z, Step=120
NH=-1.3 SH= -1.59 Trop= 0.77Npole=1.45Nml=-1.75 Eur=2.28 NAmer= -12.38 NAtl= -2.5 NPac= 3.64



ECMWF







Verification against radiosondes, T50. Improvement in NH is significant.

ECMWF

Summary

- Discussed assimilation options and described the ROPP 1D bending angle operator.
- Presented results in a simplified NWP system. COSMIC has a big impact on the stratospheric temperatures and some impact on lower level humidity. However, it is clear that other measurement are providing the bulk of the humidity information.
- Experiments including correlations. Not very successful with the negative correlations.
- Outlined current work on 2D operators. Need to look at a few case studies.
- First results with GRAS. Difference in bias characteristics for 10 to 30 km between GRAS/CHAMP and GRACE-A and COSMIC measurements.