Latest Results on the Assimilation of GPSRO data at the Met Office and ECMWF

By Michael Rennie

Met Office
Exeter United Kingdom

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Thanks to Sean Healy (ECMWF), Carlo Buontempo (Met Office) and Dave Offiler (Met Office)

Overview

Met Office:

1. Current operational status
2. Some data monitoring results
3. Forecast impact experiment results
4. Future developments

ECMWF:

5. Some recent results

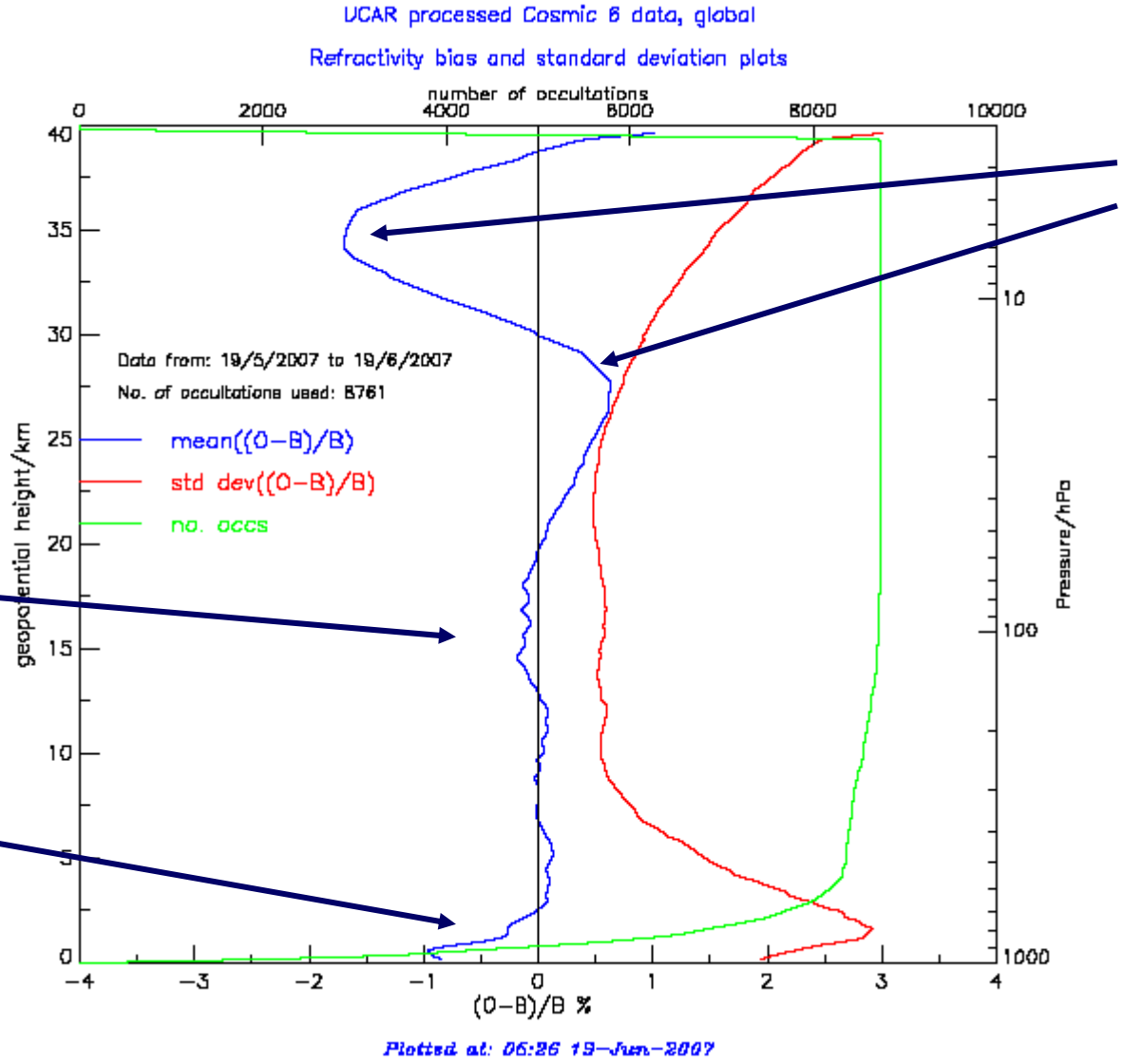
1. Met Office operational status of GPSRO

- Assimilate with local **1D refractivity operator** (see Healy et al 2005):
  - Global model, N320L50, 4D-Var, ~40 km resolution, 50 levels, top ~ 0.1 hPa
  - **Three R matrices**: low, middle and high lats
  - **Vertical correlations** modelled by exponential decay with height separation with scale height 3.3 km
  - Reject data outside 4-27 km
  - Process ref profiles in 1D-Var for QC
  - Currently use **4 COSMIC** sats (2,3,5 and 6) around 100-200 occs per cycle at moment
- RO was **withdrawn** from operations twice:
  - Firstly due to problem with refractivity observations (November 06). First assimilated CHAMP and GRACE-A from Sept 06.
  - Secondly on assumption RO (4 COSMIC) led to failure of model (Jun 07). However **NOT true**.
- Went **operational** for the third time with four COSMIC satellites on 14th August.

2. Data monitoring

- Plots based on observation – background statistics. Background is a 6 hour global model forecast.
- O-B statistics show **similar** general behaviour **for all** data sources.
- However **some differences** are evident between UCAR and GFZ **processing**.
- COSMIC satellites have very **similar mean** of (O-B/B) distributions, but **differing spread** around mean
- Can see sample of plots at GRAS SAF: http://monitoring.grassaf.org

Typical refractivity O-B stats. COSMIC 6, global monthly average



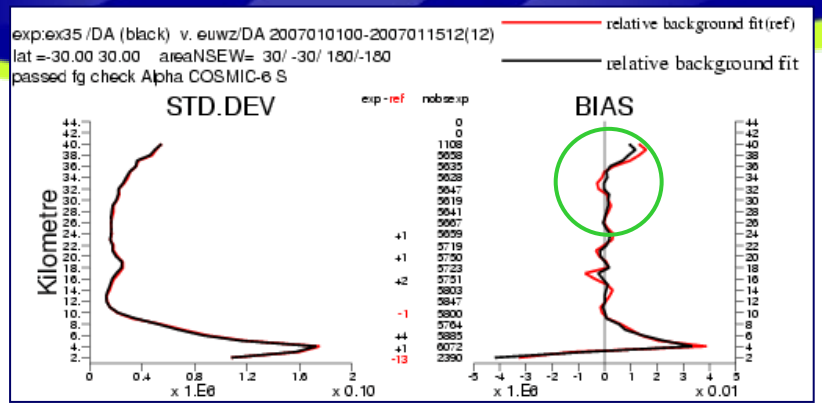
MO model bias

Low lat tropopause

Known negative bias

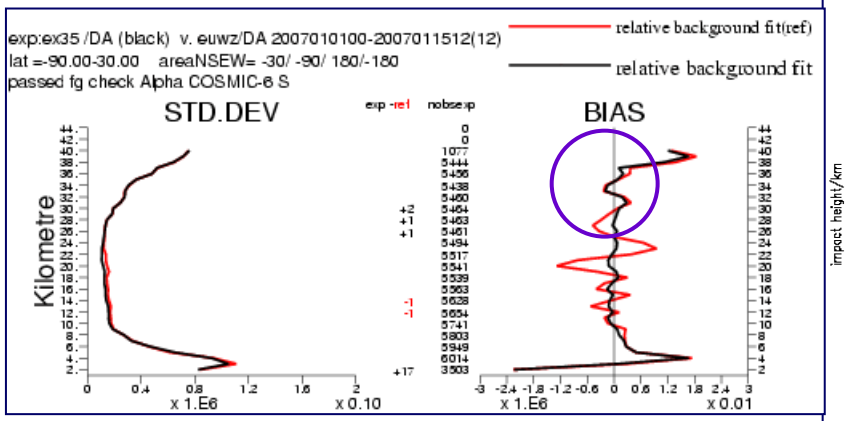
Met Office ECMWF bending angle comparison

TR

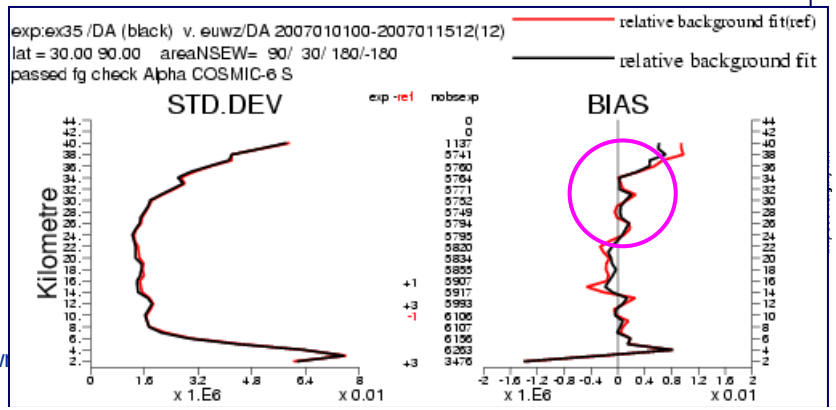


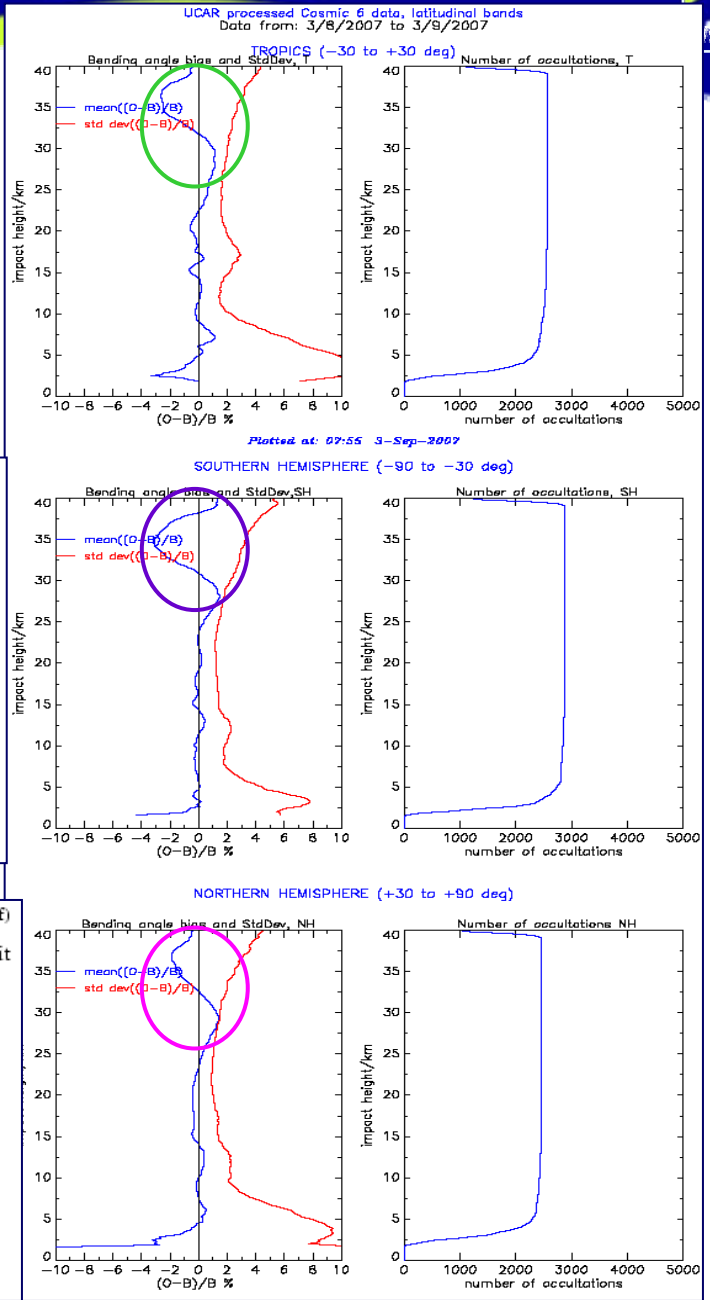
ECMWF

SH



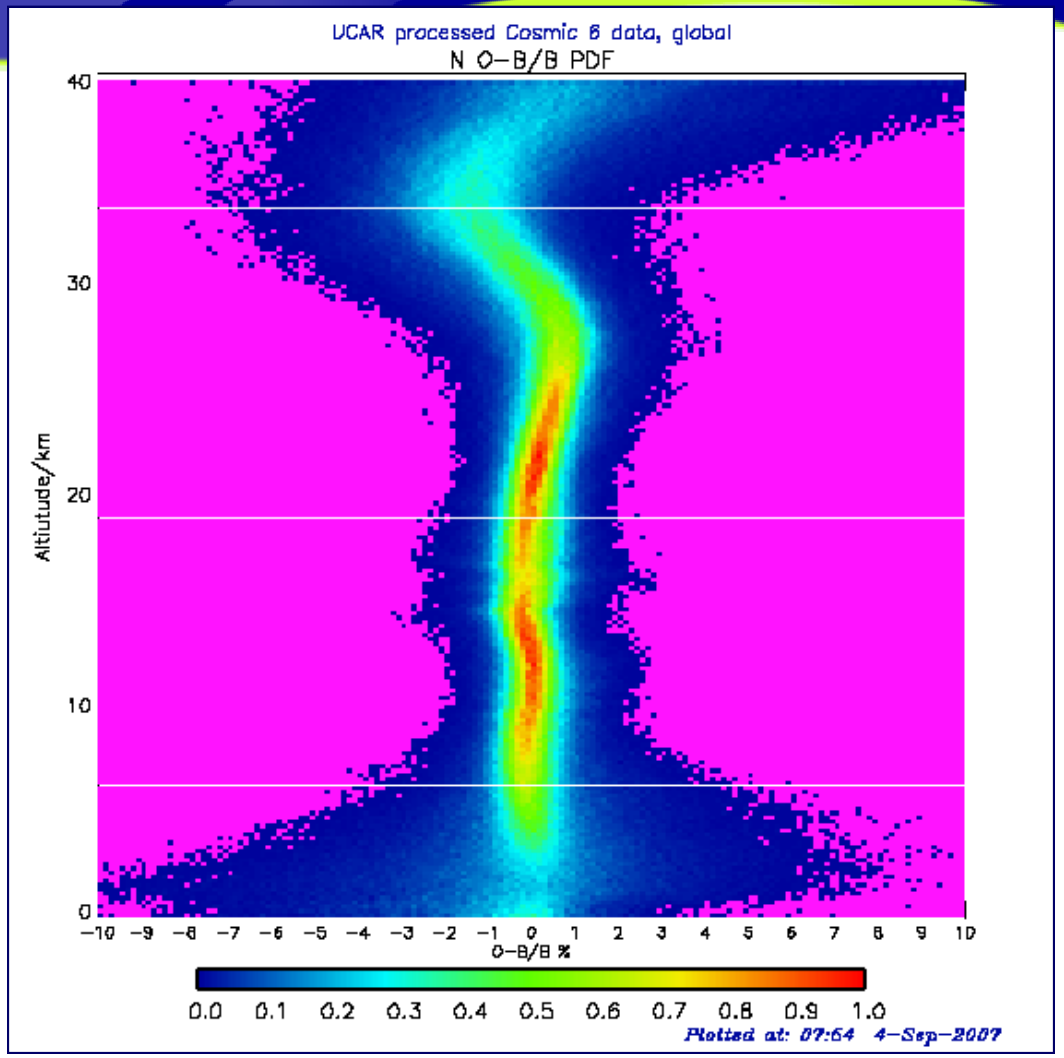
NH





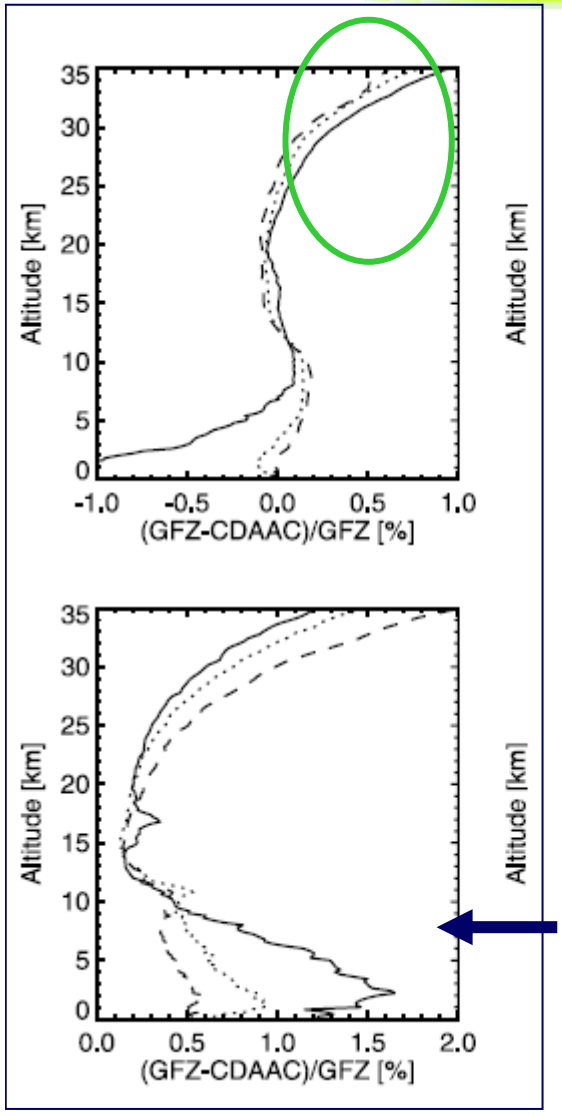
Met Office

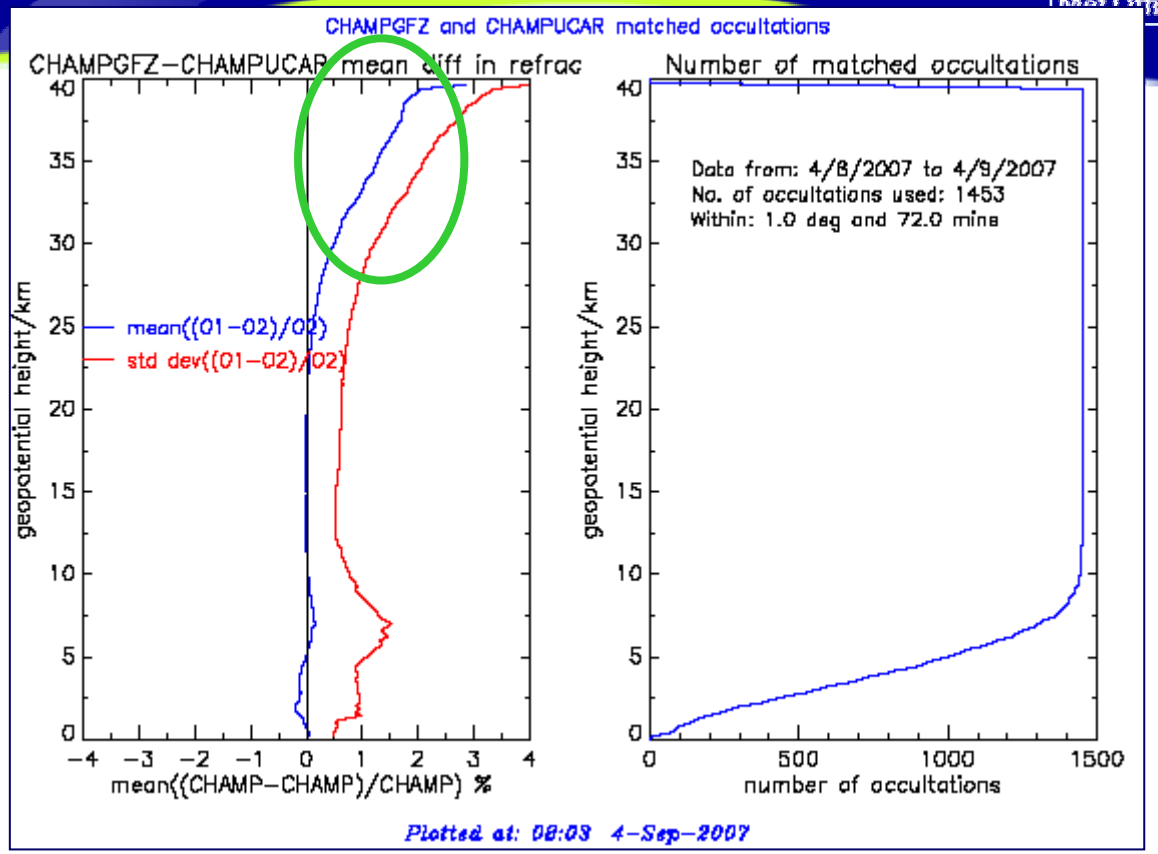
Refractivity O-B/B distributions. 1 month's data



COSMIC 6/UCAR

Refractivity processing differences?





Similar result to von Engeln:

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L22705,

- Difference between CHAMP GFZ and CHAMP UCAR
- ~ 2% at 40 km

Vertical correlation in refractivity O-B/B. 1 month's data

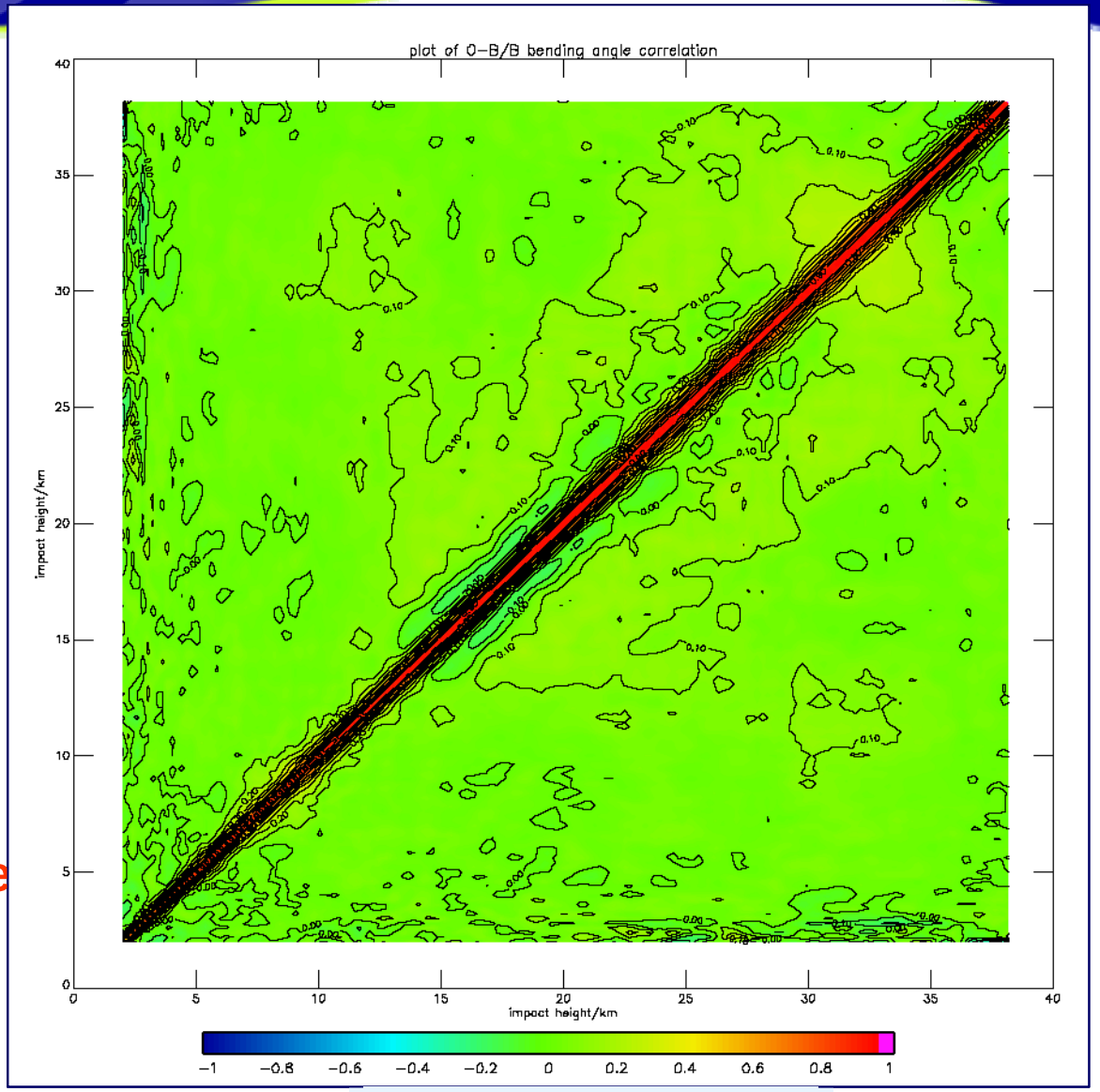
covariance

$$\sigma_{ij} = \langle x_i x_j \rangle - \langle x_i \rangle \langle x_j \rangle$$

$$r = \frac{\sigma_{ij}}{\sigma_i \sigma_j}$$

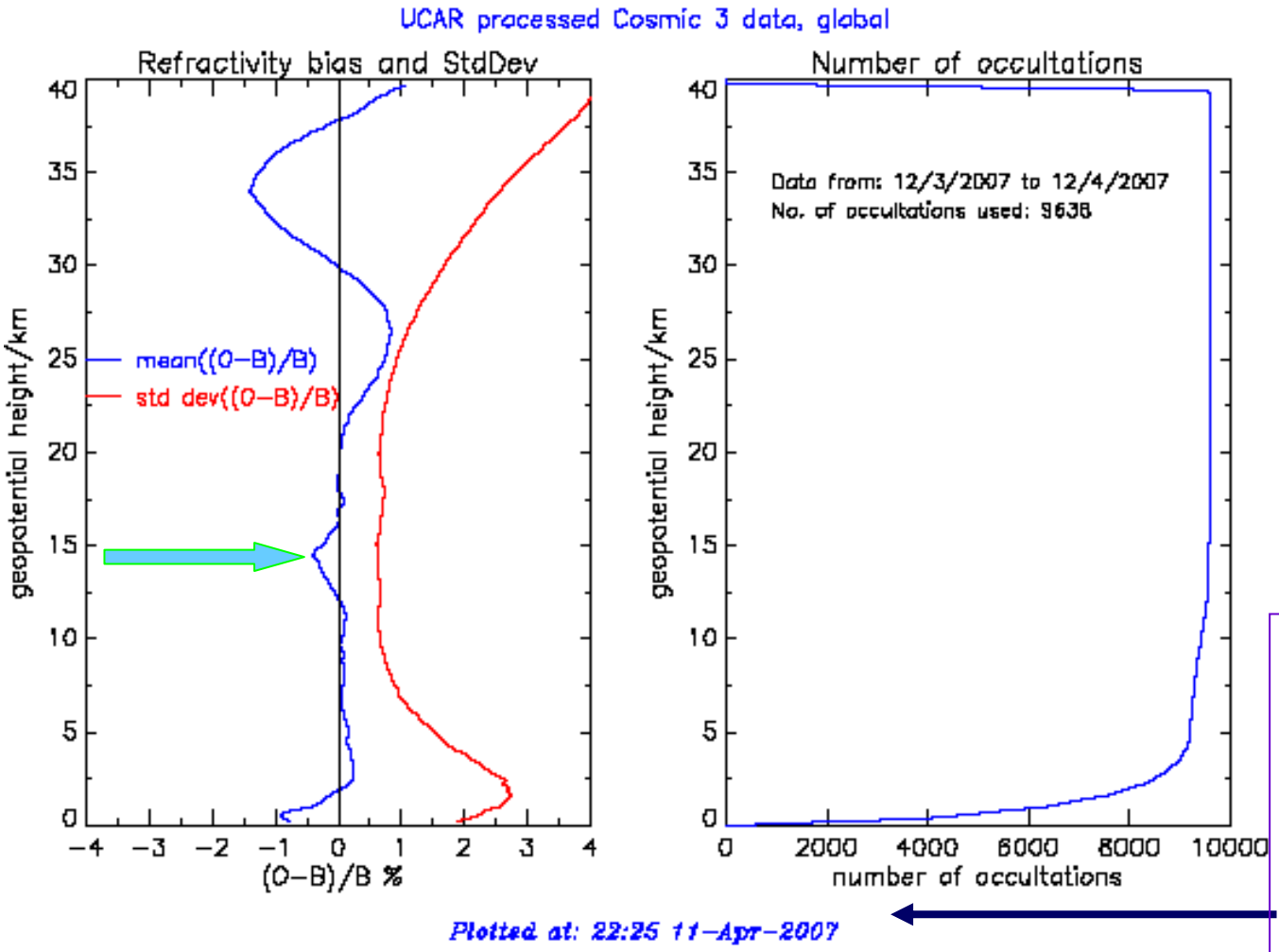
correlation coefficient

Correlation in bending angle



CHAMP/GFZ

Reduction of ref bias with COSMIC assimilation



Improvement around altitude of expected peak impact of RO ~ 100 hPa

Monthly average prior to this date. GPSRO assimilated from 15th May.

3. Forecast impact experiment details

- Month-long trials for **two seasons**:
  - Winter (27th Nov-27th Dec) 2006
  - Summer (24th May-24th Jun) 2007
- 4D-Var, N216L50, all other operational observations for the period of the trial were assimilated.
- **COSMIC only** for Winter period, used **all GPSRO** (including CHAMP and GRACE-A) in Summer period.

Experiment details

- Winter trials:
  - **COSMICx4:** 4 COSMIC sats (2,3,5 and 6) vs no GPSRO
  - **COSMICx6:** 6 COSMIC sats vs no GPSRO
  - **LatR:** Latitude dependent +more conservative errors above 10 km vs old global R matrix
  - **No_low:** No lower cut-off vs 4 km cut-off
  - **No_up:** No upper cut-off vs 27 km cut-off
  - The last three all used 6 COSMIC satellites

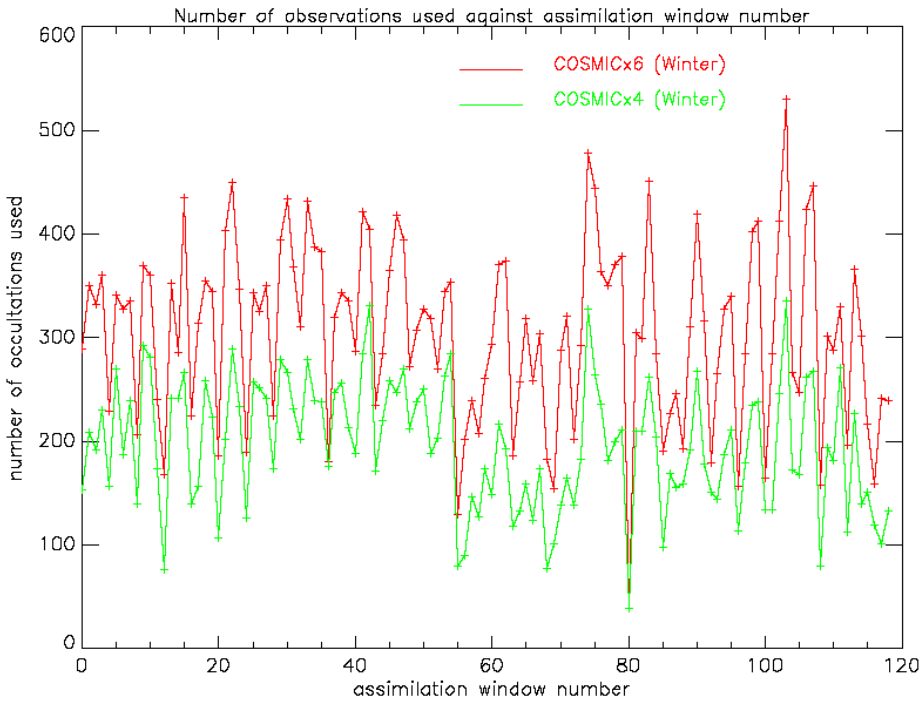
- Summer trials:
  - **All_GPSRO:** COSMIC + CHAMP + GRACE-A vs no GPSRO
  - **COSMICx4:** 4 COSMIC sats (2,3,5 and 6) vs no GPSRO

- Use 4 -27 km cut-off to **avoid negative biases** at low altitudes and the **a priori climatology** that is used in deriving **refractivity** at high altitudes.

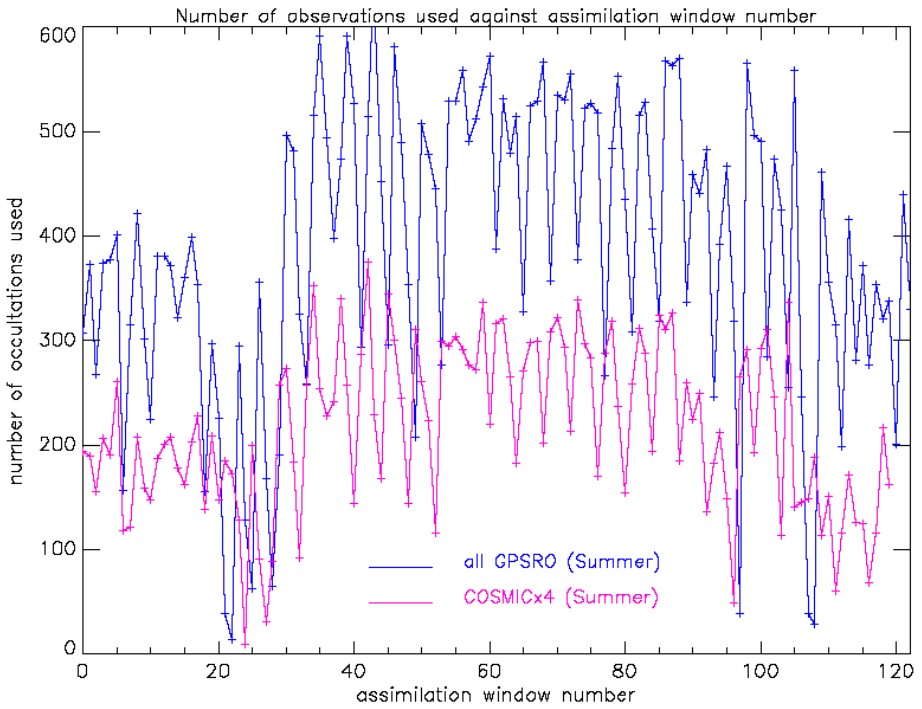
- In practice the large errors used at top and bottom may mean this approach is **too cautious** given some impact at low alts can be gained.

Number of occultations used in the trials

Winter 06

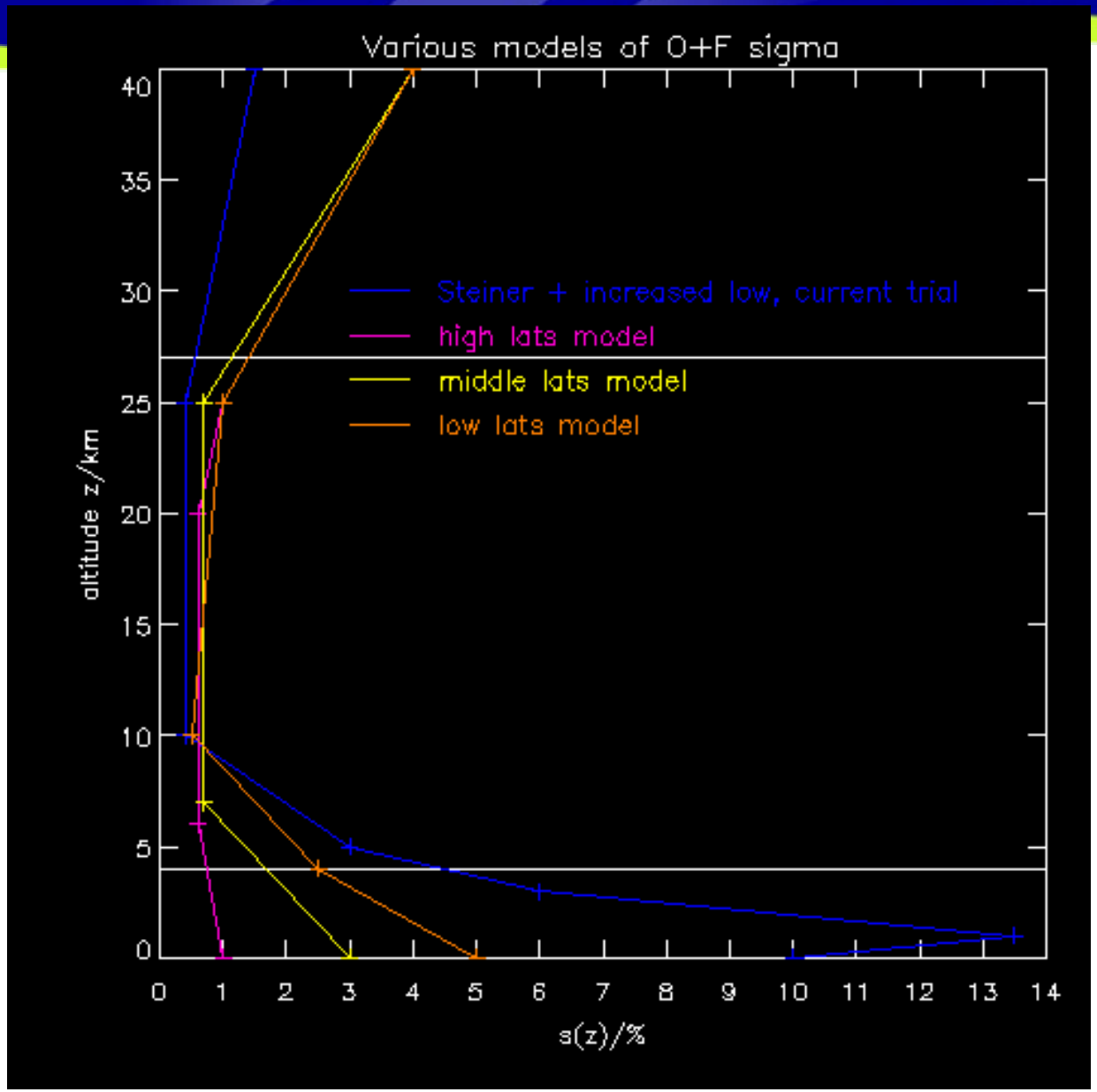


Summer 07



Current operations use ~100-200 occs per 6 hour cycle using 4 COSMICs

Obs + Forward model errors: lat R trial



- Blue are **old** standard error values.
- The others are the three **latitudinal band** errors now used operationally
- New errors follow O-B stats closely, therefore **over-estimates**

With old global R matrix

- GPSRO gave:
  - Very large proportion of the cost function
  - Larger than ATOVS and the temperature observations from radiosondes.
  - The penalty too large for the forecast improvements
- Indicated that the errors for GPSRO were too small:
  - fitting RO disproportionately
  - Large analysis increments in potential temperature at level 30 (~18 km)

With new R matrices (latR)

- Errors ~doubled over 10 km altitude but reduced below 10 km:
  - Penalty in VAR was reduced by ~10 %, suggesting the increase in the errors above 10 km was very significant
  - new errors were thought to be conservative in that they follow O-B standard deviation for each latitude band.
  - Lower errors below 10 km led to improvement in fields around 500 hPa (~ 5km) and below.

GPSRO's impact

- Generally see **reduction** in **bias** and **RMSE** in fit to observations of:
  - Temp, GPH, RH, wind speed, surface obs
- Similar effects to Healy et al 2005 (using CHAMP).
- Using lower cut-off gives small improvement at lowest levels in temp and RH
- Can **assess impact** by looking at the **reduction in RMSE** of fields at different forecast ranges and areas.

Zone	Field	Pressure level	Forecast range
NH, SH, Trop	PMSL, T, H, RH, W,	850, 700, 500, 250, 100, 50	24, 48, 72, 96, 120, 144

COSMIC Winter results summary

Test-control	COSMICx4	COSMICx6	latR	No_low	No_up
RMS diff obs	12 % 88 % 0 %	21 % 79 % 0 %	7 % 92 % 1 %	4 % 96 % 0 %	0 % 100 % 0 %
RMS diff analysis	13 % 82 % 5 %	17 % 74 % 9 %	19 % 81 % 0 %	1 % 98 % 1 %	0 % 100 % 0 %

RMS diff <-2 %, improvement

-2 %<RMS diff <+2%, neutral

RMS diff > +2 %, degradation

For COSMICx6 about 80 % of the good scores were in SH

Best score was a 10 % reduction in RMSE wrt obs for: Temp, 250 hPa, SH, T+24

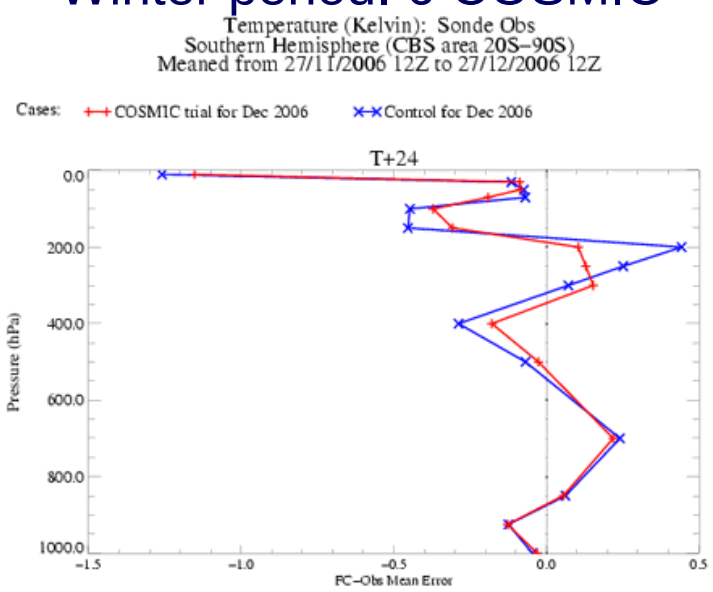
Summer period results summary

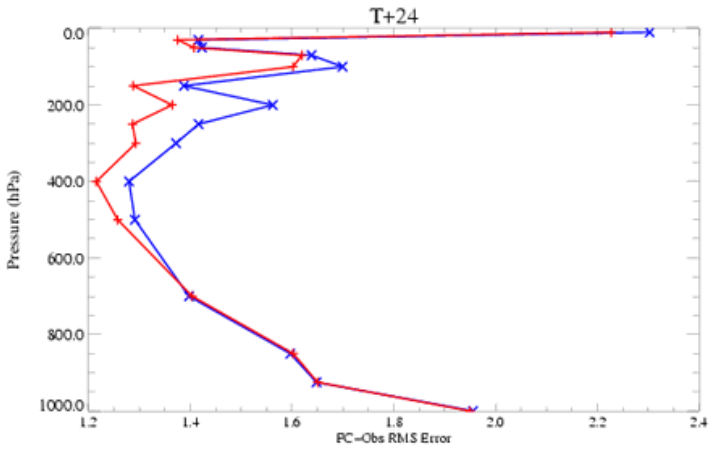
Test-control	COSMICx4	All_GPSRO	
RMS diff obs	5 % 95 % 0 %	7 % 93 % 0 %	
RMS diff analysis	11 % 87 % 2 %	14 % 82 % 4 %	

- Impact similar to winter trial
- But smaller in magnitude

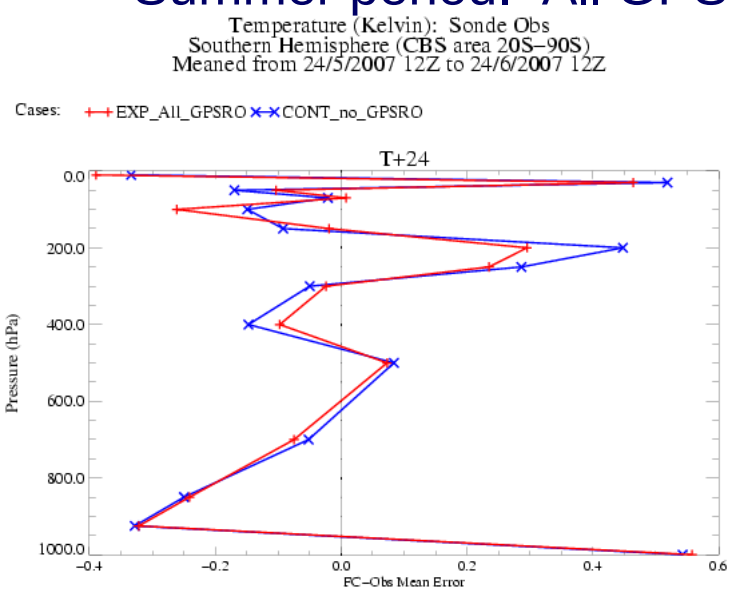
Vertical profile of T wrt radiosondes. Southern Hemisphere T+24

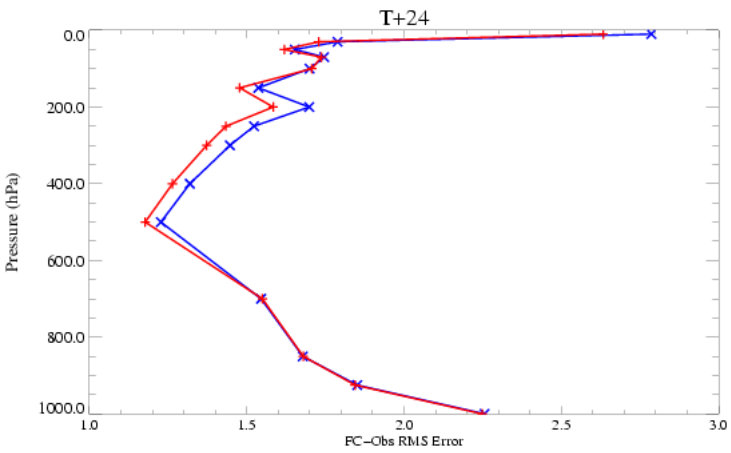
Winter period. 6 COSMIC





Summer period. All GPSRO



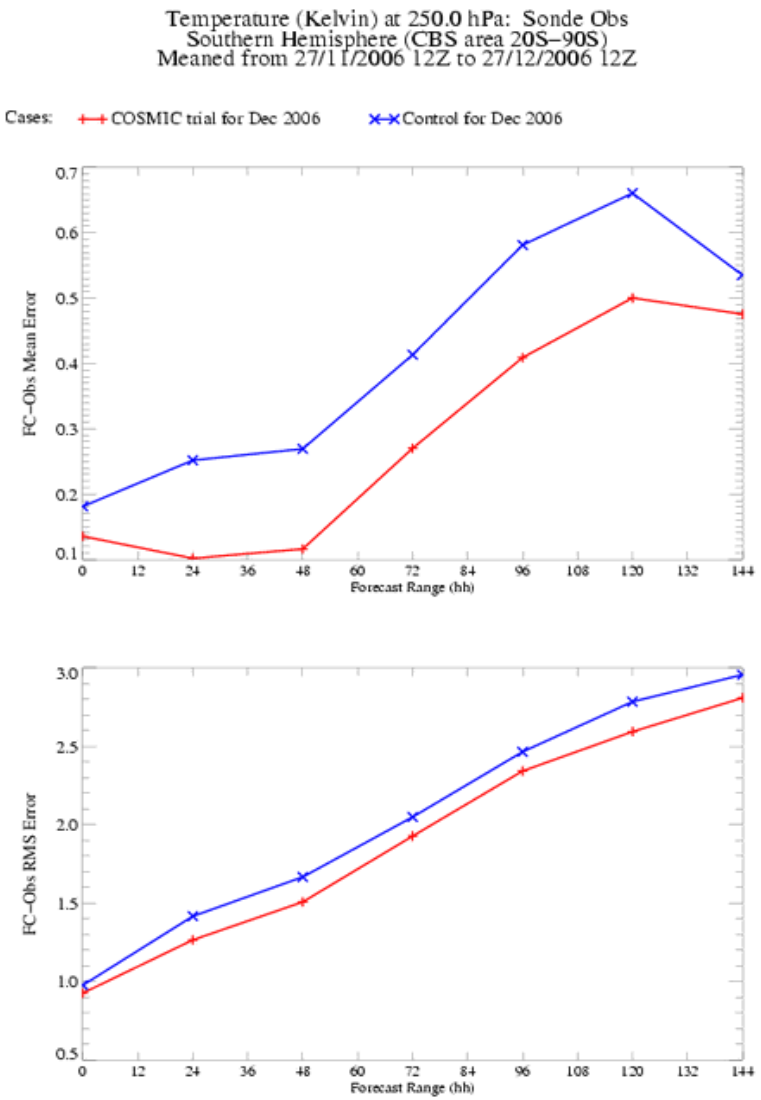


Mean error

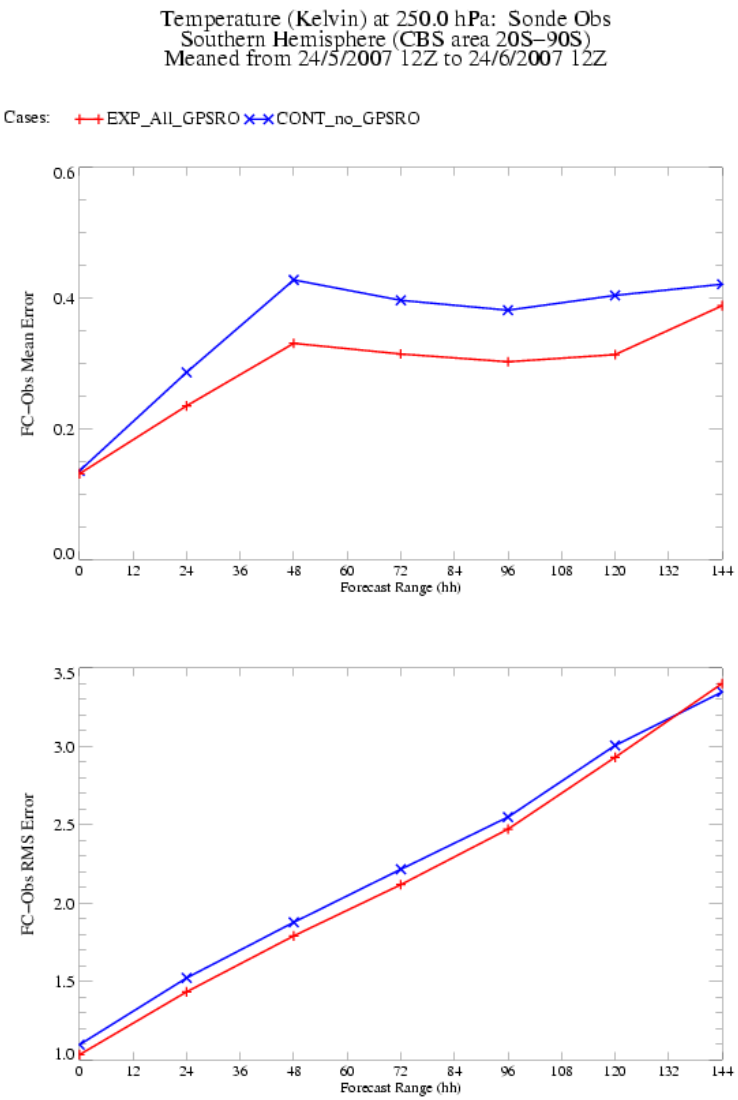
RMSE

Bias and RMS as function of forecast range. Temp, 250 hPa, SH.

Winter period. 6 COSMIC



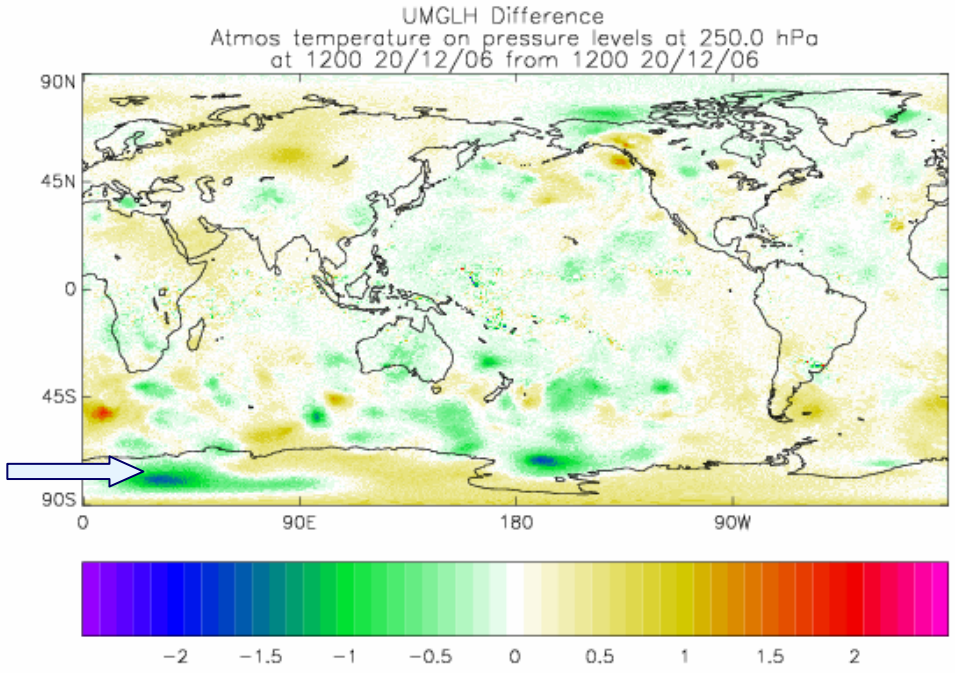
Summer period. All GPSRO



Summary of trials

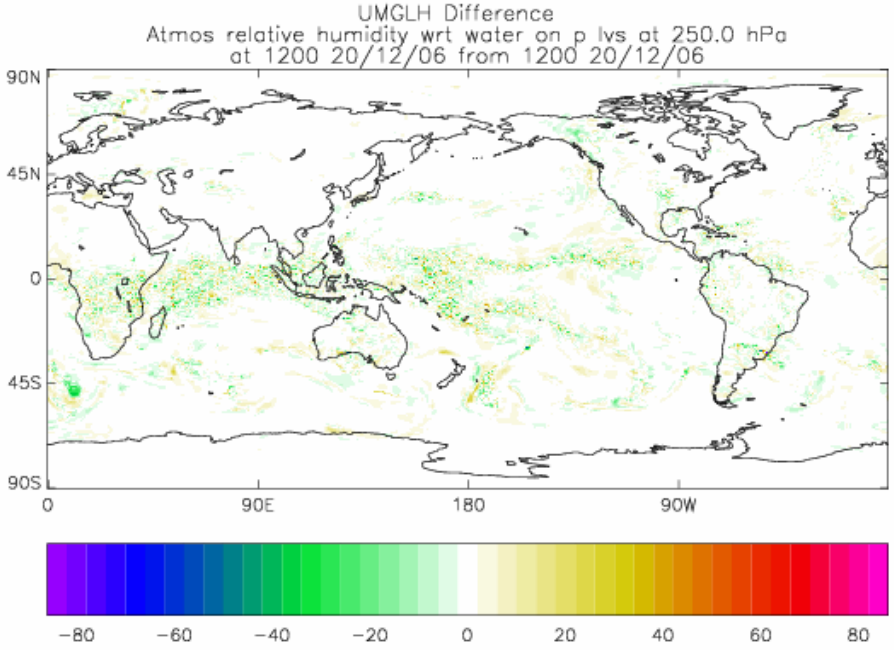
- Winter trial gave **good results** especially with the combination of 6 COSMICs and new errors
- **SH** impact much **greater** than TR or NH
- Summer trial was disappointing in comparison to Winter given the extra data used.
- Could be a **sampling issue** i.e. trials not long enough. Or perhaps a **seasonal difference**. Scores are a little better in each hemisphere's summer season.
- In same summer period **IASI** is giving **stronger positive impact** than all GPSRO and **ASCAT** is giving **weaker impact** than all GPSRO.

Example increments at 250 hPa (~10 km). Winter trial



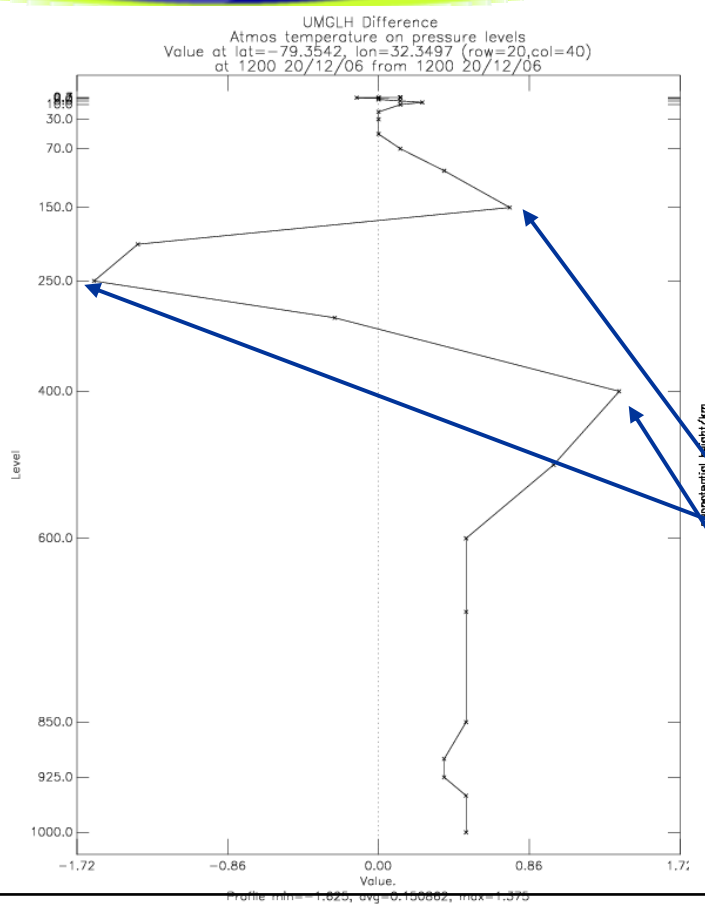
Temp (K)

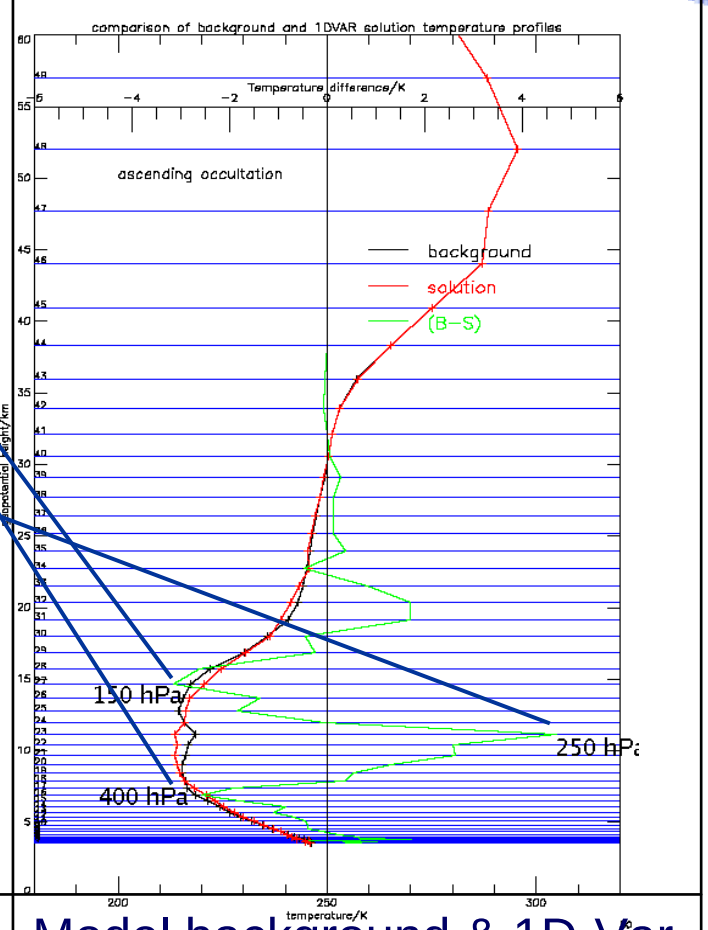
Relative humidity (%)



Plots of (exp – control) in analysis increments of temp and RH at 250 hPa.

Profile of increments

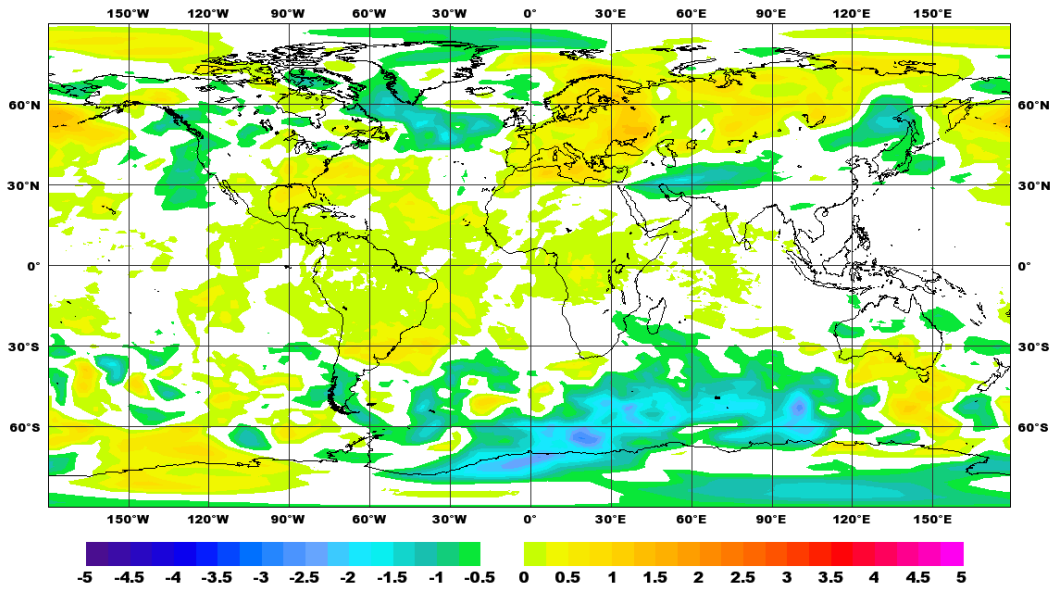


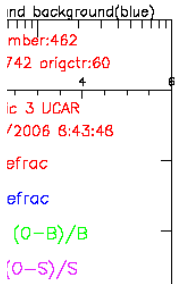


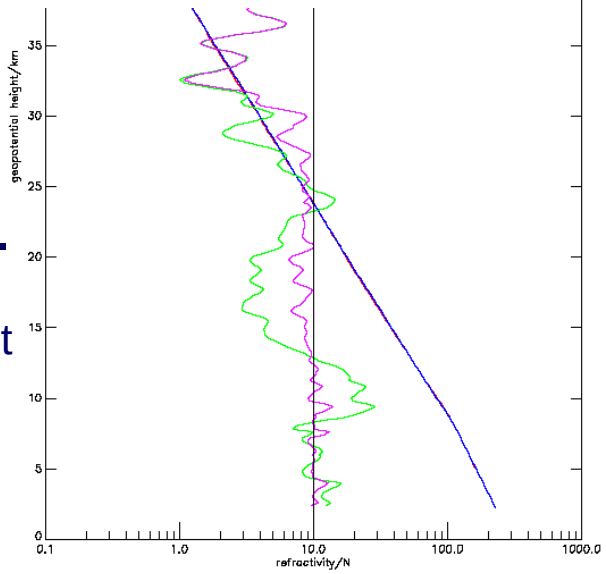
Analysis increments (exp-control) in temperature vs pressure. (at lat=-79, lon=33)

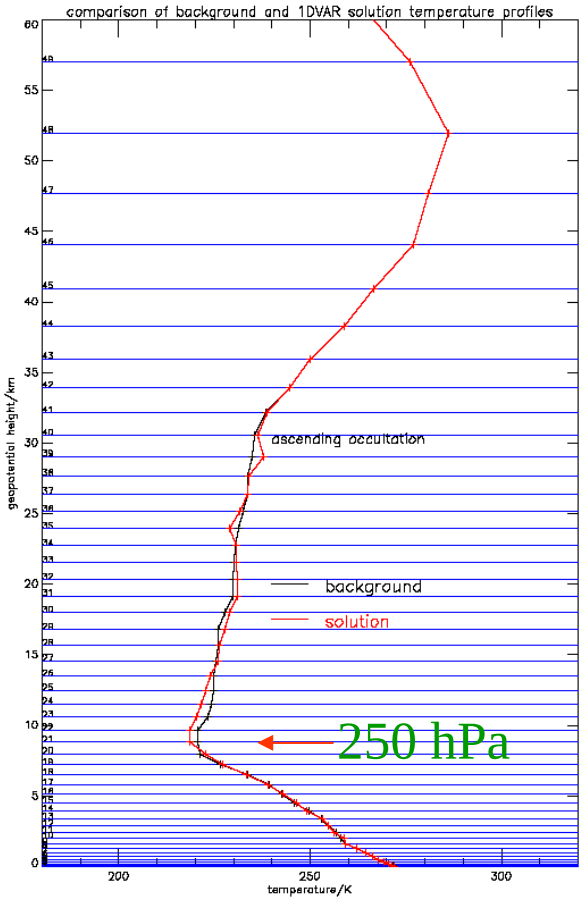
Model background & 1D-Var solution temperature profiles for the COSMIC 1 occultation (at lat=-79, lon=33)

Mean diffs in Temp (COSMICx6- no GPSRO). Winter trial





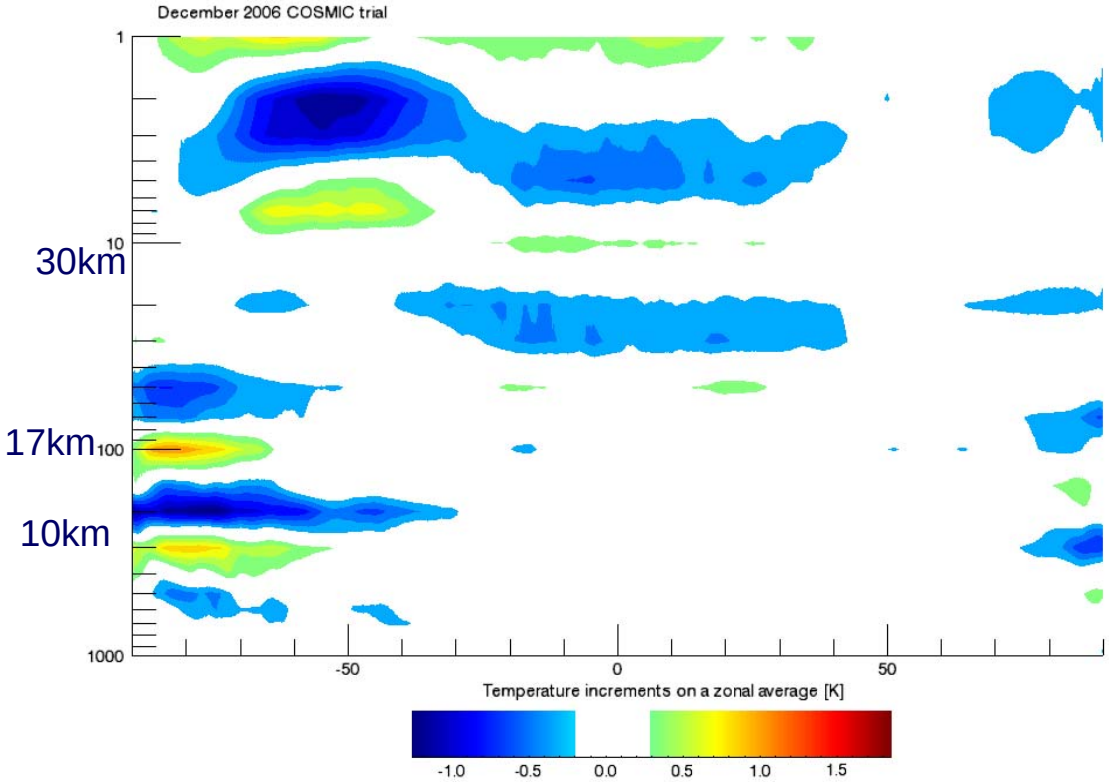




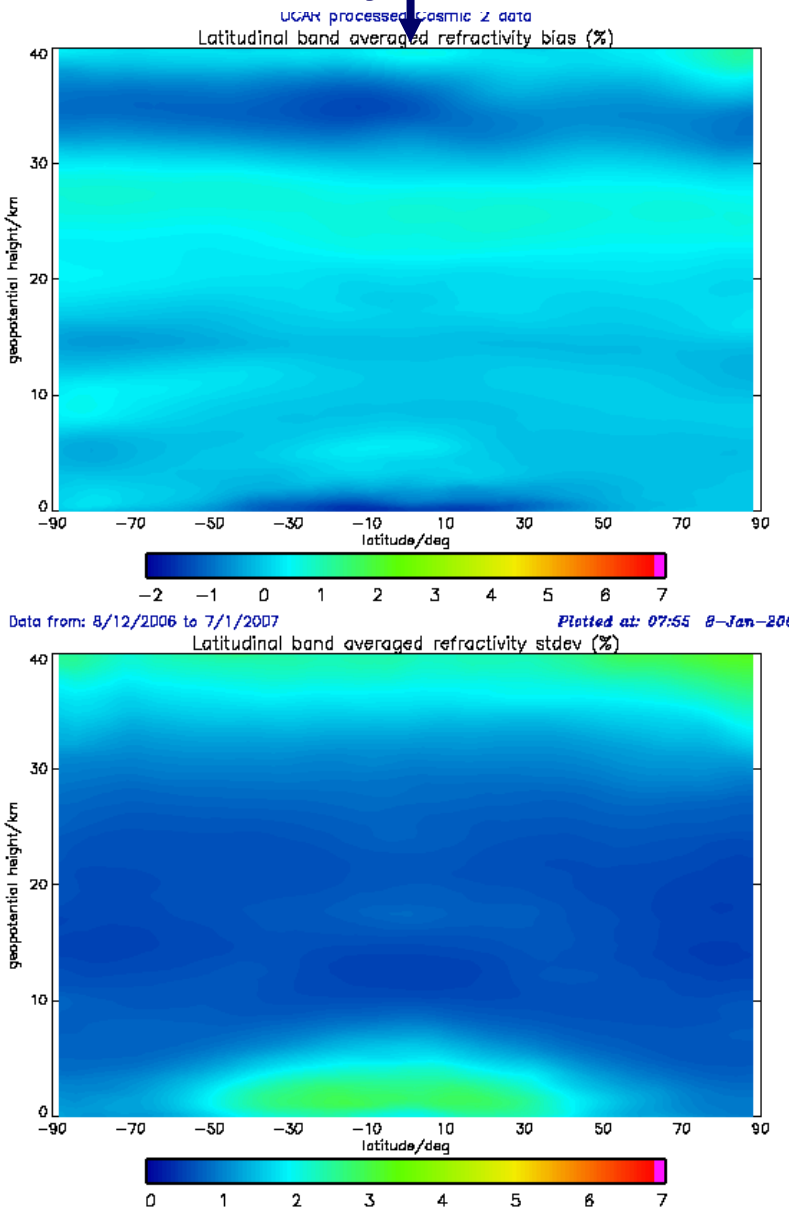
- GPSRO causing cooling over Antarctica at 250hPa. 1D-Var solution to right supports this (1st Dec, -64 deg lat).

Zonal temp diffs (COSMIC –no GPSRO) and O-B stats

one 24 hr forecast



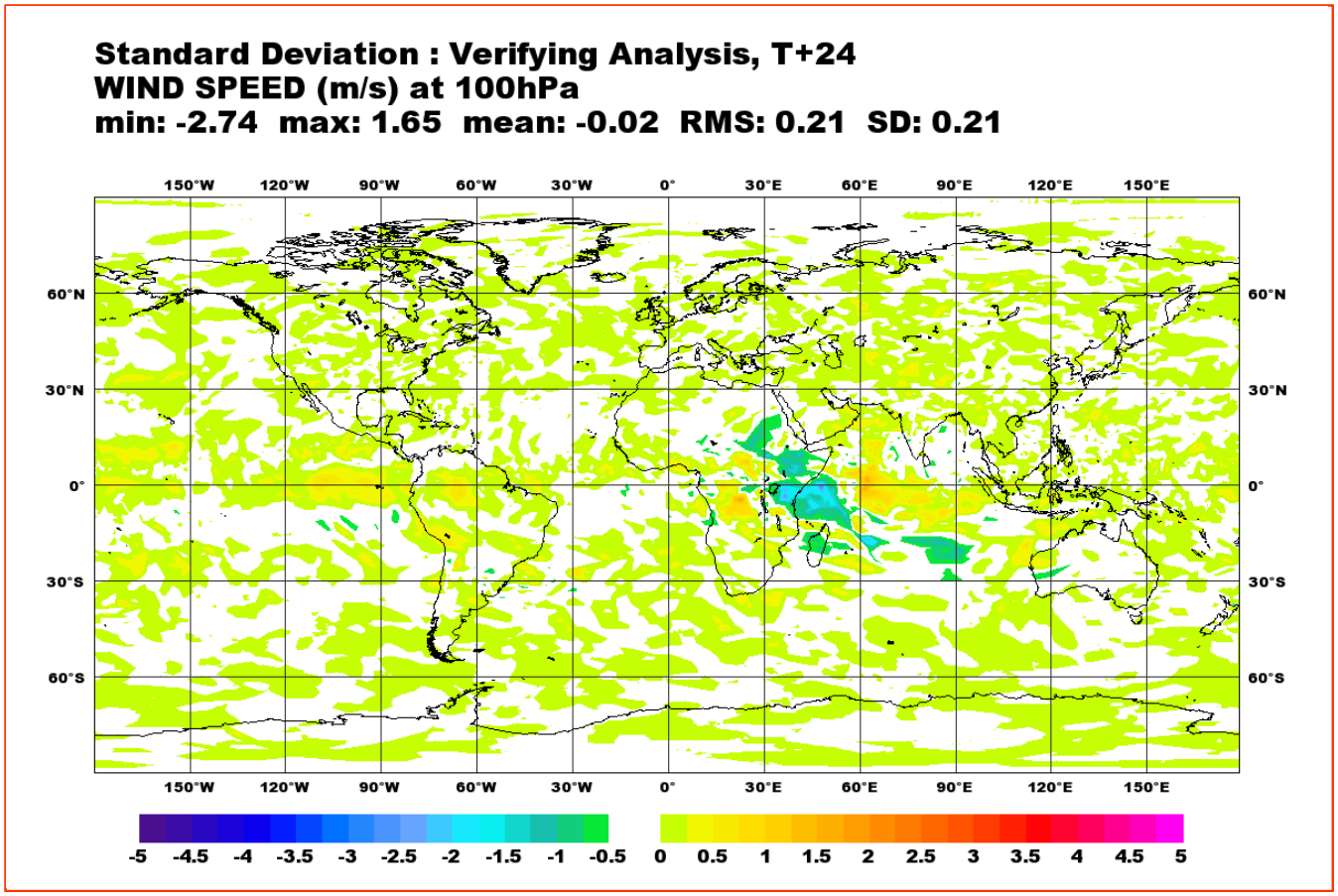
Monthly mean



- Signs that RO is removing model biases

All_GPSRO summer trial 100 hPa (~16 km) mean temp difference

Cooling tropopause feature over tropical Africa. Many convective features at the time.

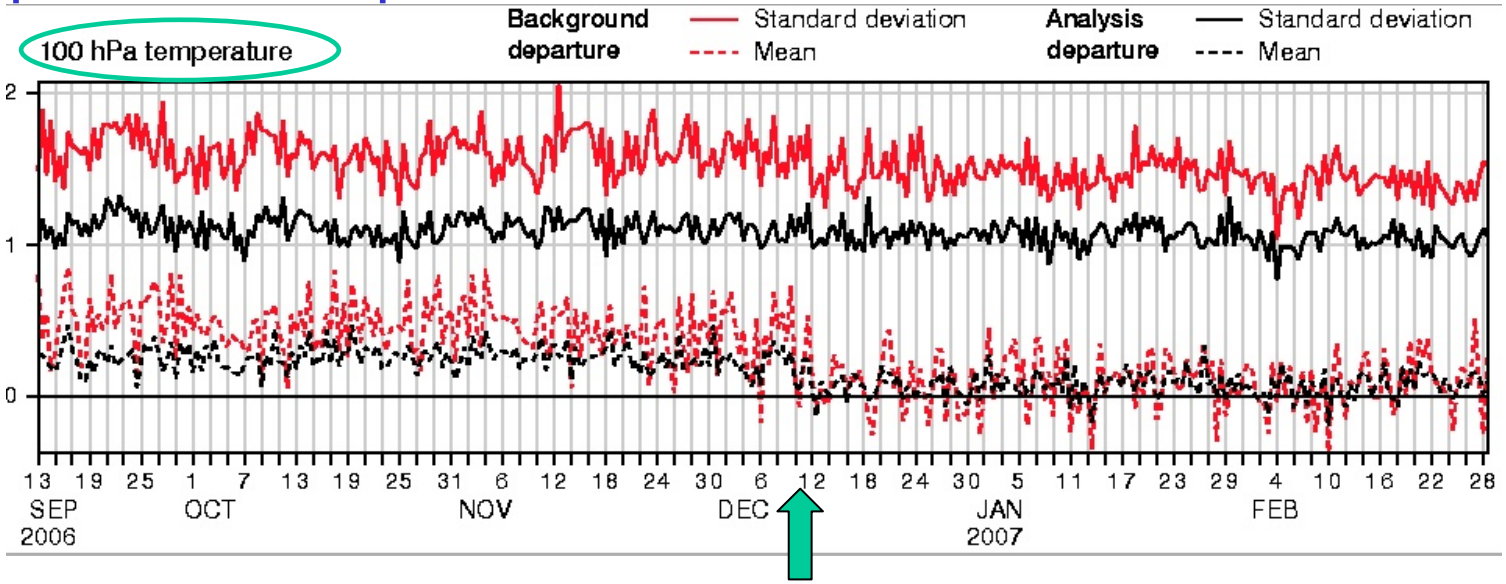


4. Future developments

- Continue to analyse summer trial results: reasons for smaller impact. Run with smaller errors >10km.
- Start using all 6 COSMIC + CHAMP+GRACE-A + GRAS data.
- Optimise error characteristics for 1D refractivity operator.
- Optimise cut-off heights. Perhaps variable errors/cut-offs to cope with high moisture profiles.
- Run experiments with GRAS SAF 1D bending angle operator
- Investigate biases between GPSRO and other observation types to potentially maximise GPSRO's impact.

5. ECMWF results

Operational implementation of GPSRO, Dec 12, 2006



Clear improvement in time series for operations compared to radiosondes. This set-up was fairly neutral in troposhpere but positive for stratosphere T scores.

Operational implementation represented a quite conservative use of data. **No data below 4 km**, **no rising occultations**.

Next set of experiments to **investigate increased use** of the data.

NB. Using the GRAS SAF 1d bending angle forward operator

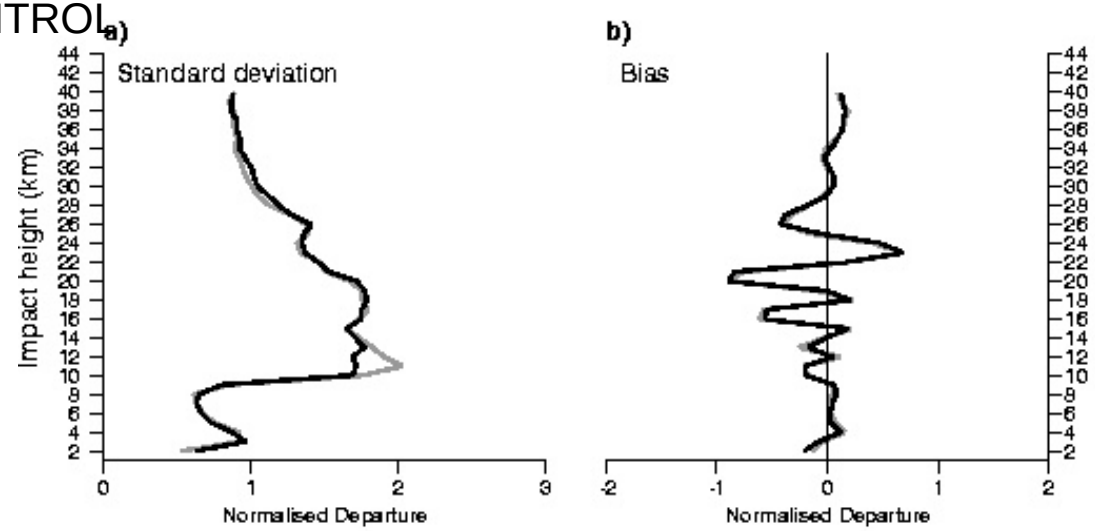
ECMWF

Increased use of the GPSRO data

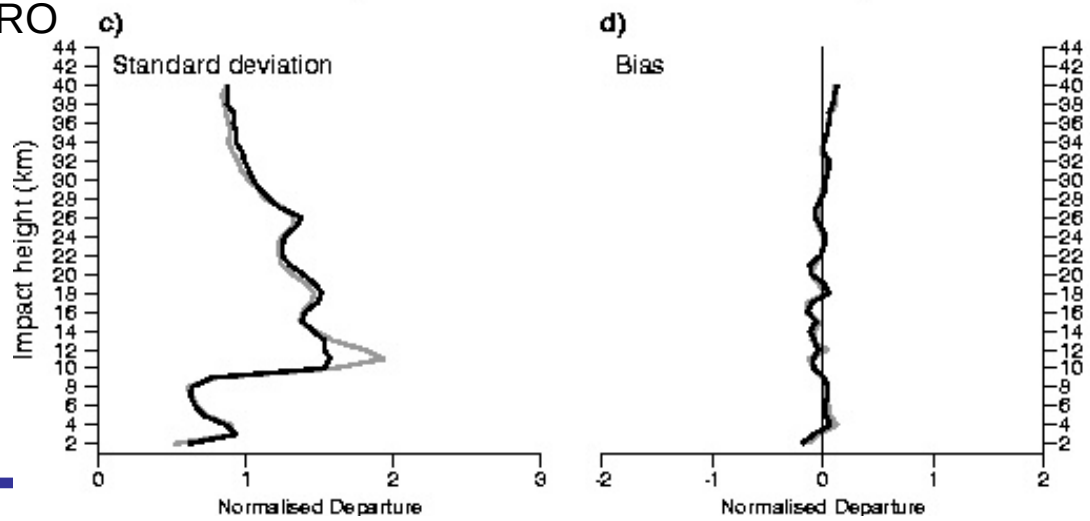
- Experimental period 15 Dec, 2007 to 28 Feb, 2007.
- Removed blacklisting of measurements below 4 km and rising occultations.
- Compared this experiment with NO GPSRO control (GPSRO passive).

O-B bending angle statistics for rising and setting occultations (eg, SH, COSMIC-3)

CONTROL



GPSRO



BLACK = setting

GREY = rising

The only significant differences are near 10 km. This is a transition height in the processing.

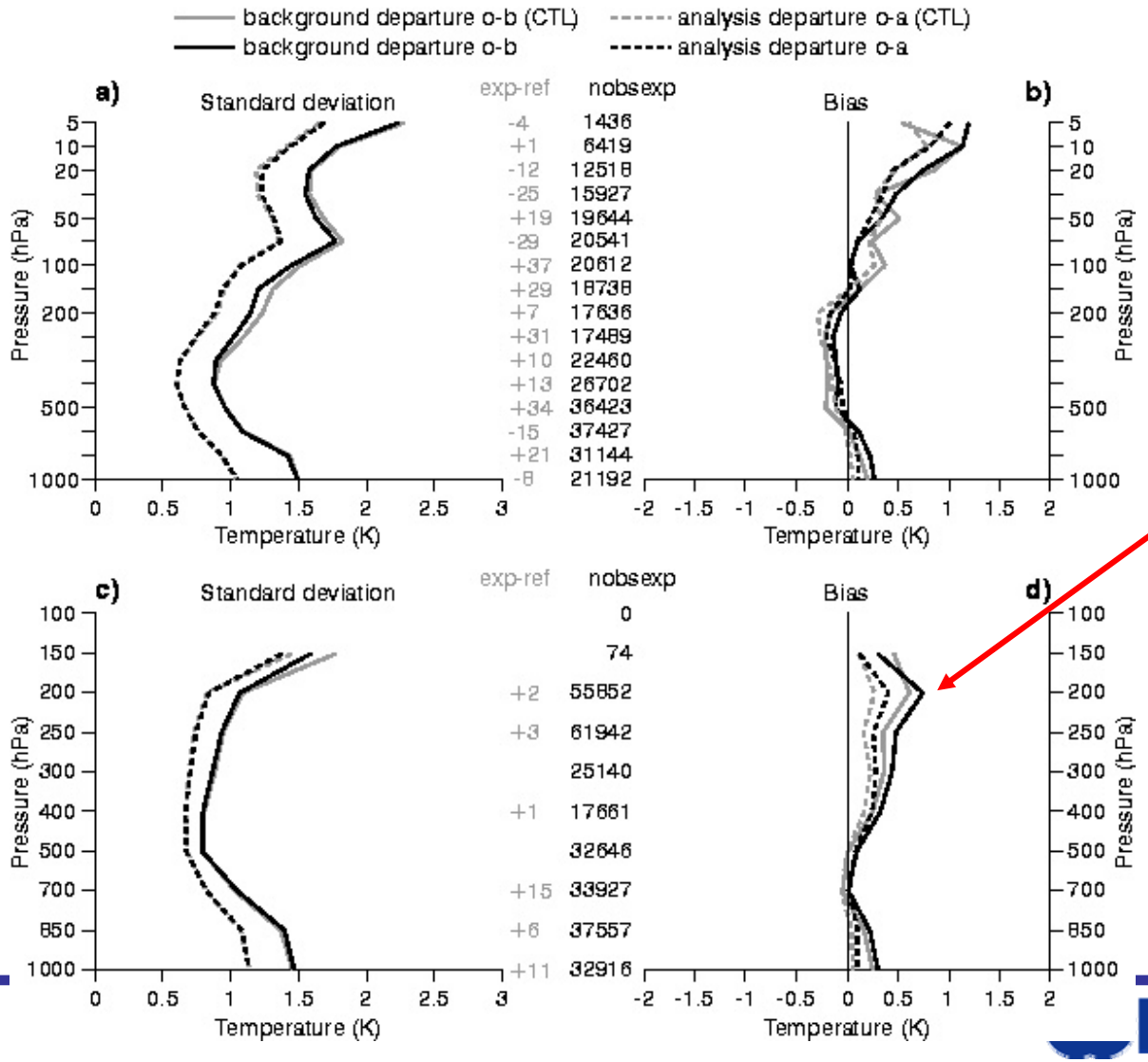
Above 10 km = Phase-lock-loop
Below 10 km = Open-loop.

ECMWF

Obstat radiosonde and aircraft statistics (SH)

Radiosonde

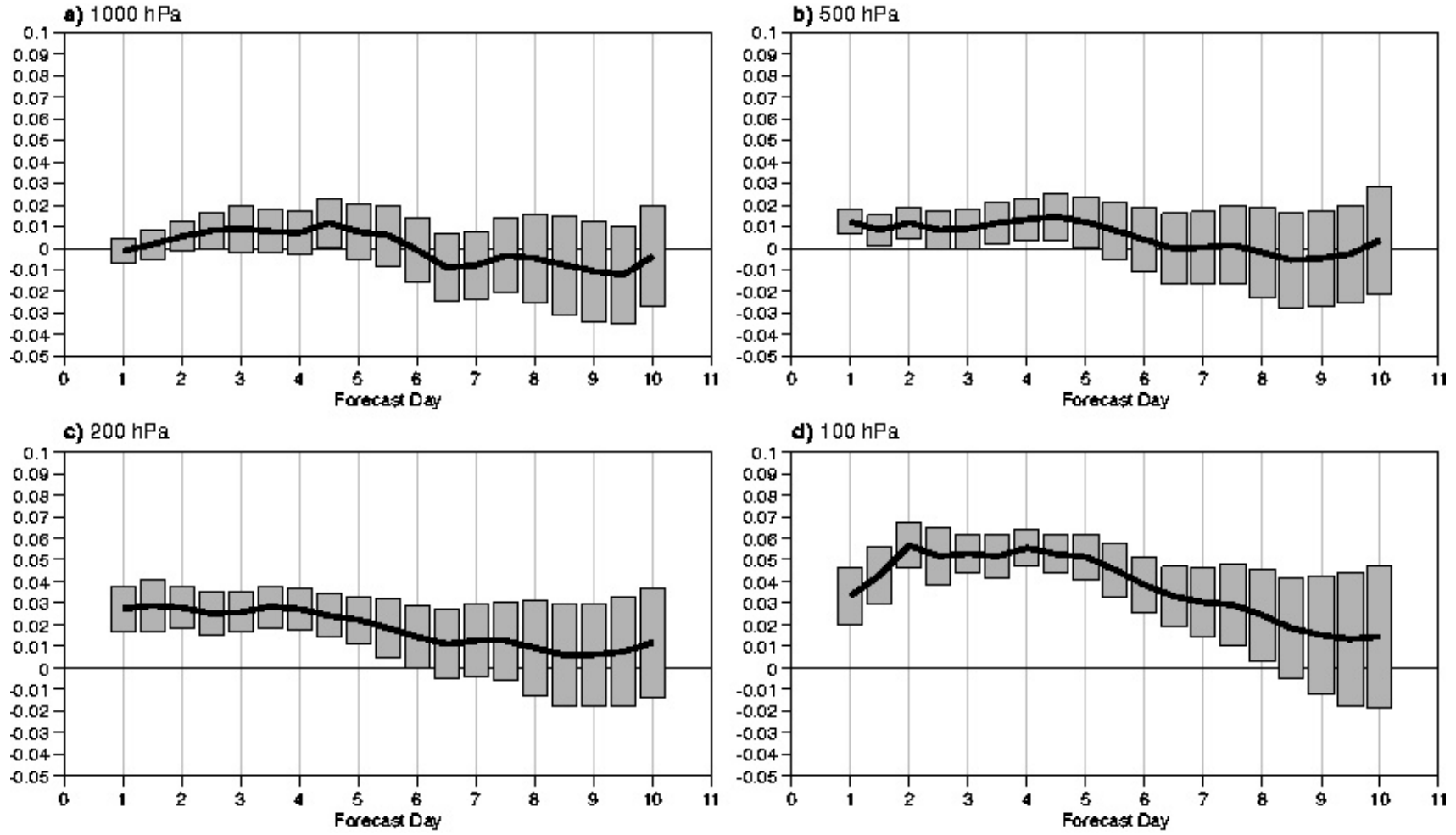
Aircraft



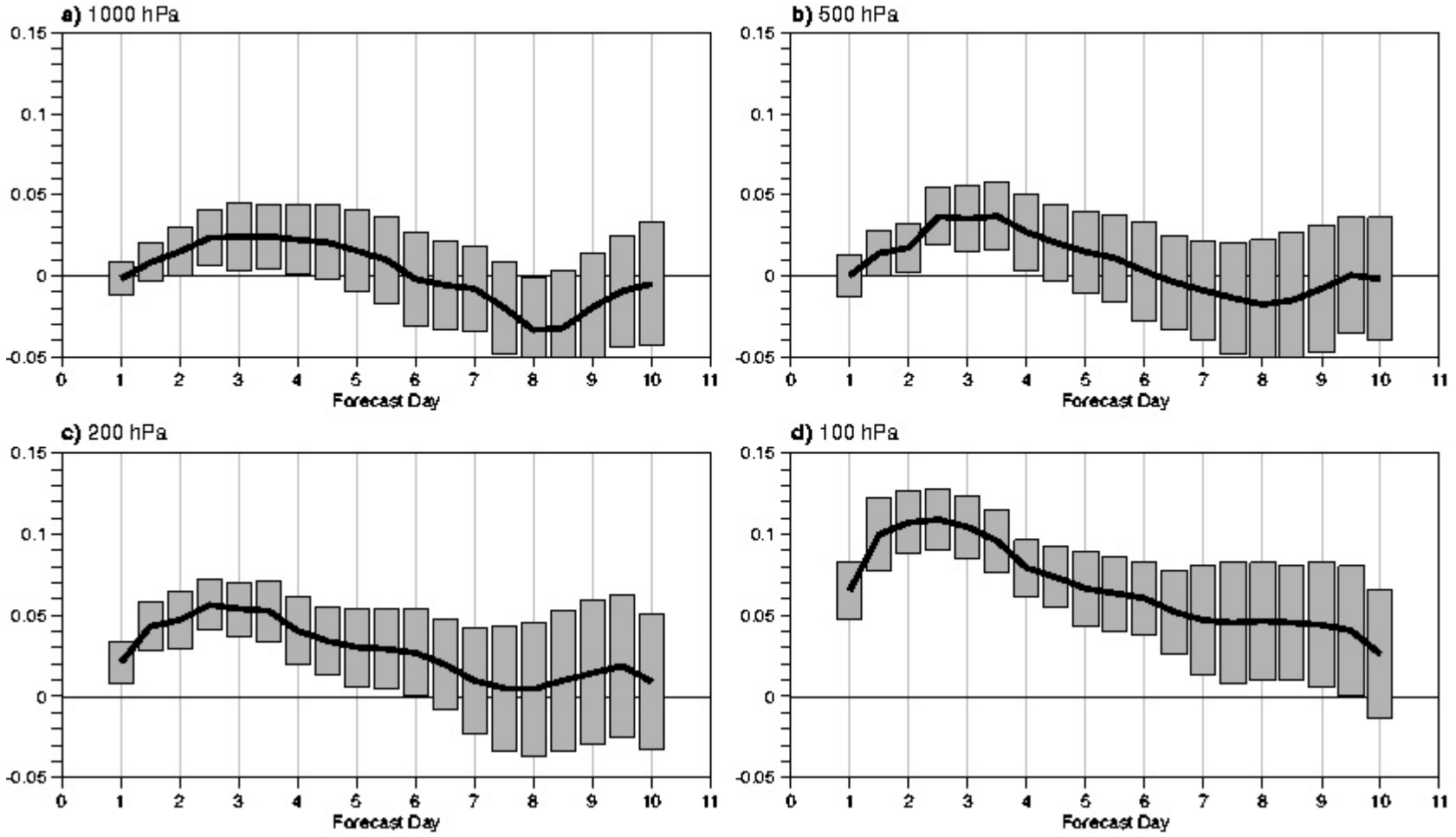
Aircraft thought to be biased warm

Fractional reduction in RMS height errors (NH)

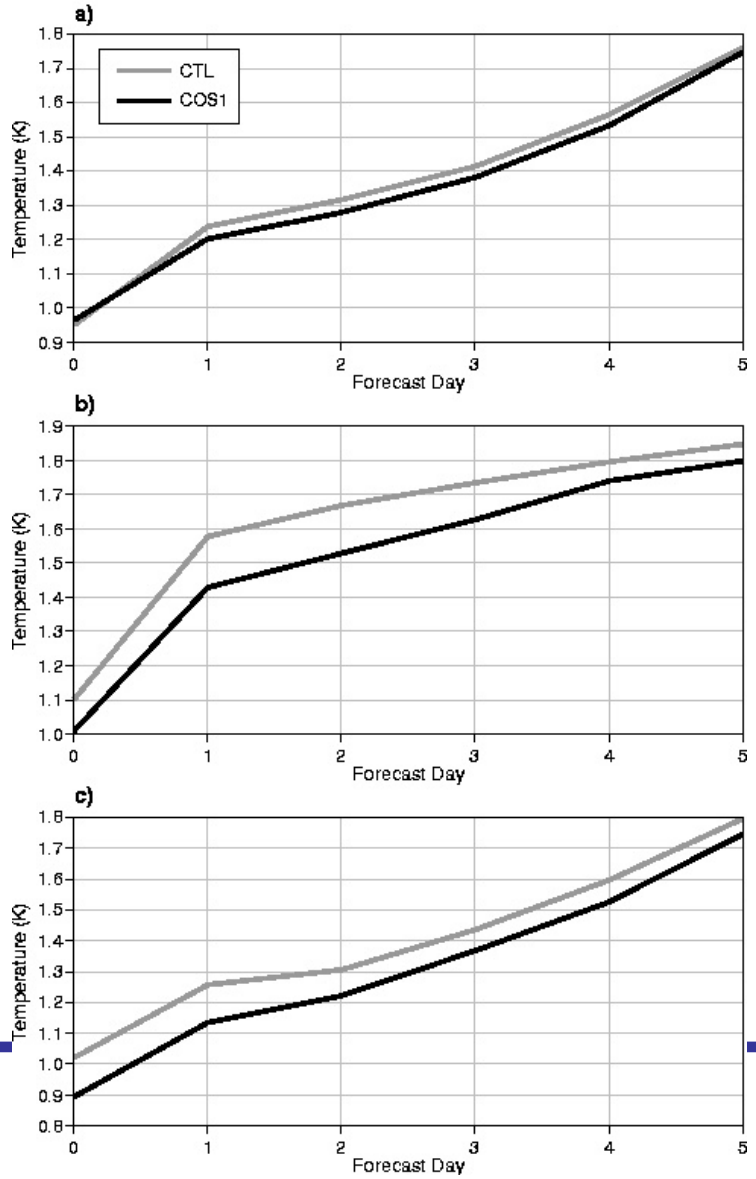
(RMS_control - RMS_gpsro)/RMS_control with 95% confidence error bars



Fractional reduction in RMS height errors (SH)



100 hPa Temperature against radiosondes



nh

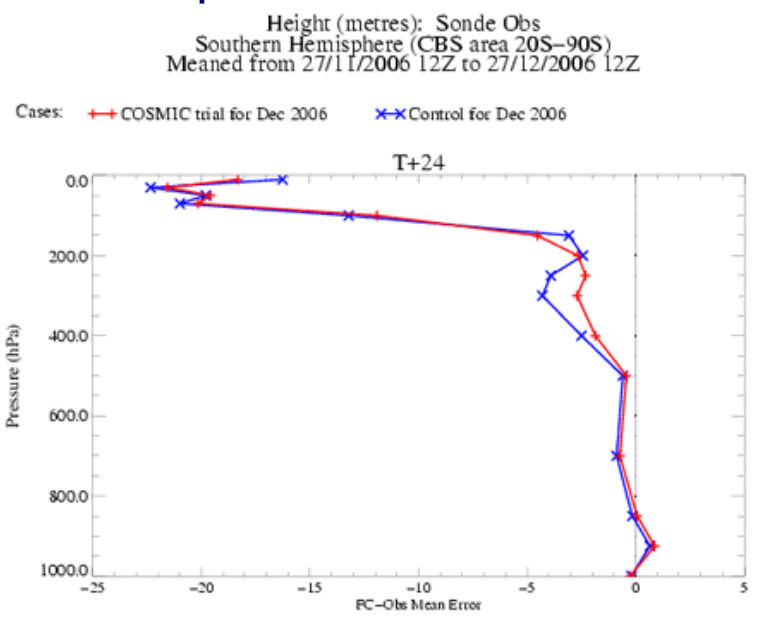
tr

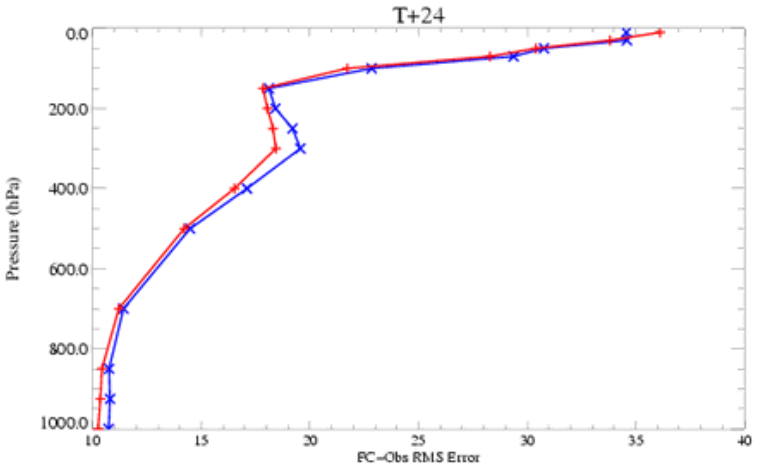
sh

Questions & Answers

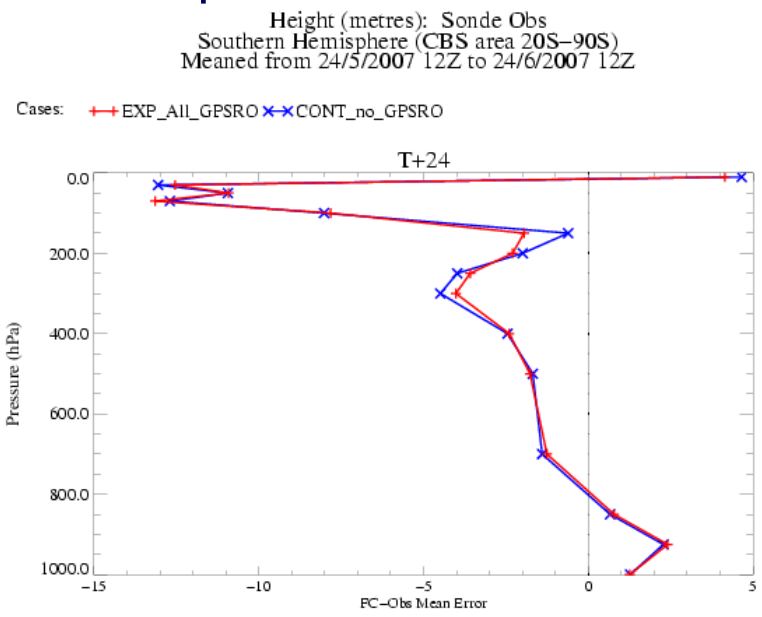
Vertical profile of GPH wrt radiosondes. SH T+24

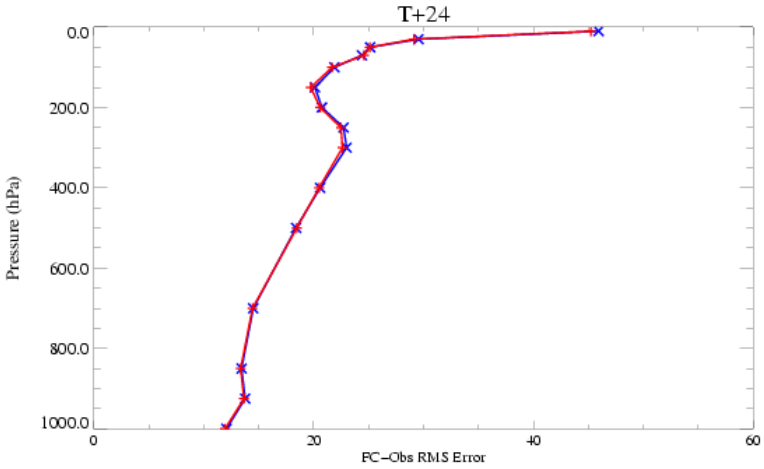
Winter period. 6 COSMIC





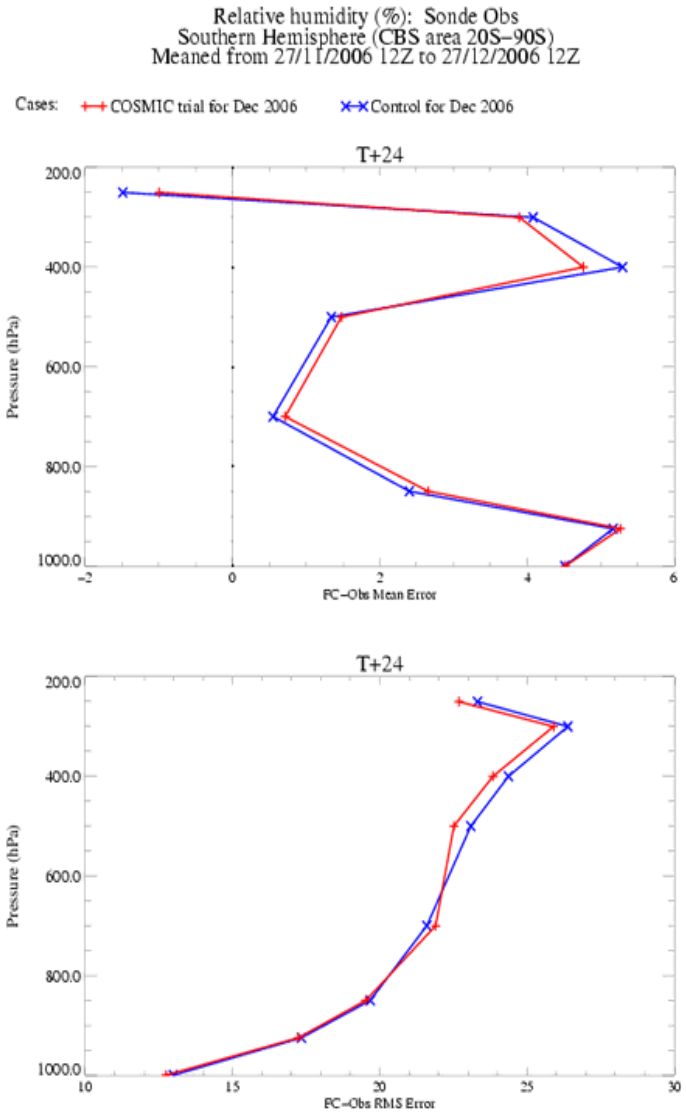
Summer period. All GPSRO



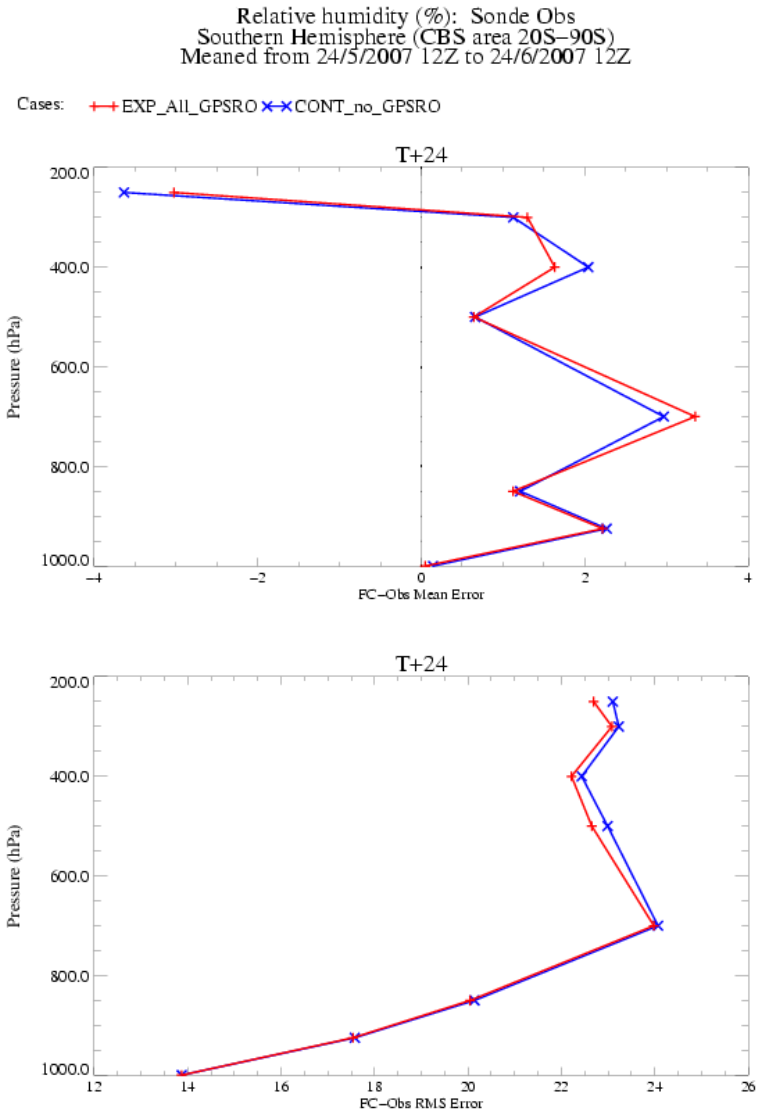


Profile of Relative Humidity wrt radiosondes

Winter period. 6 COSMIC

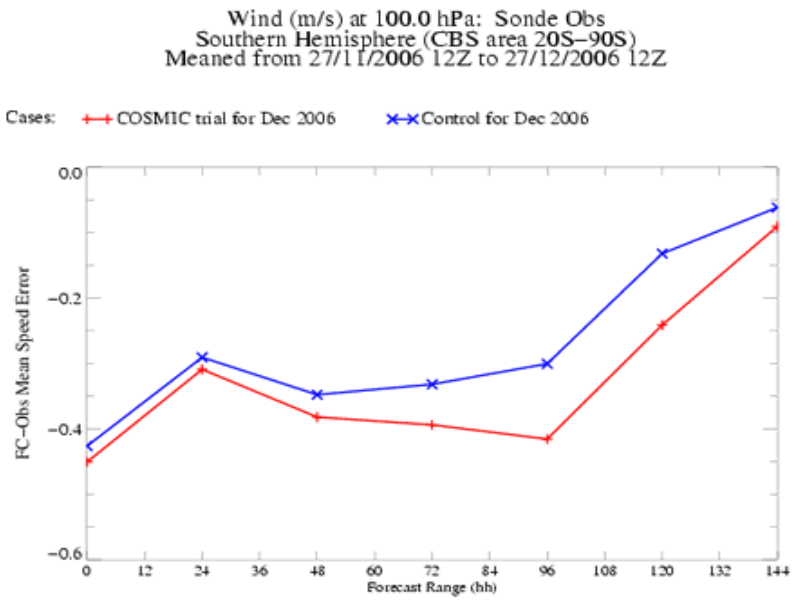


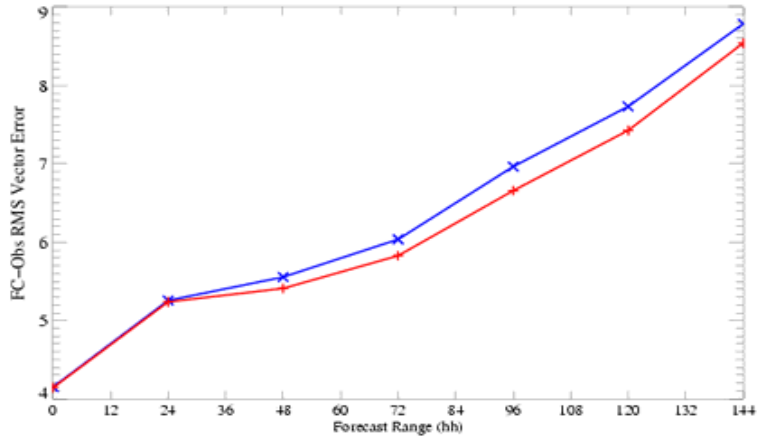
Summer period. All GPSRO



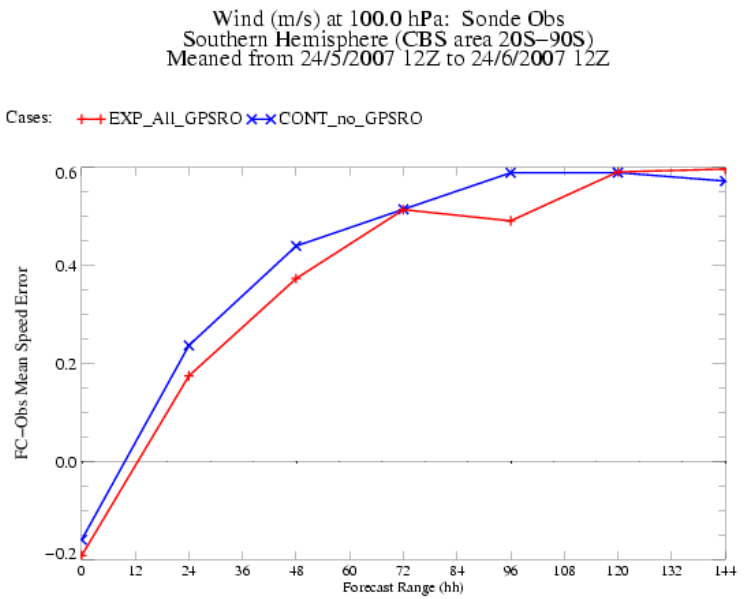
Wind speed, 100 hPa, SH

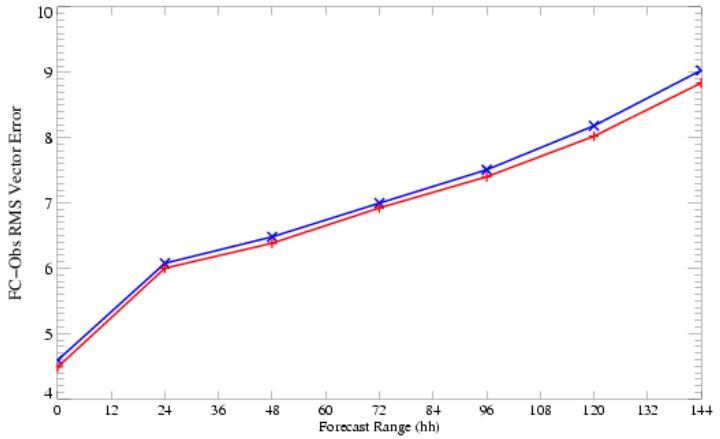
Winter period. 6 COSMIC





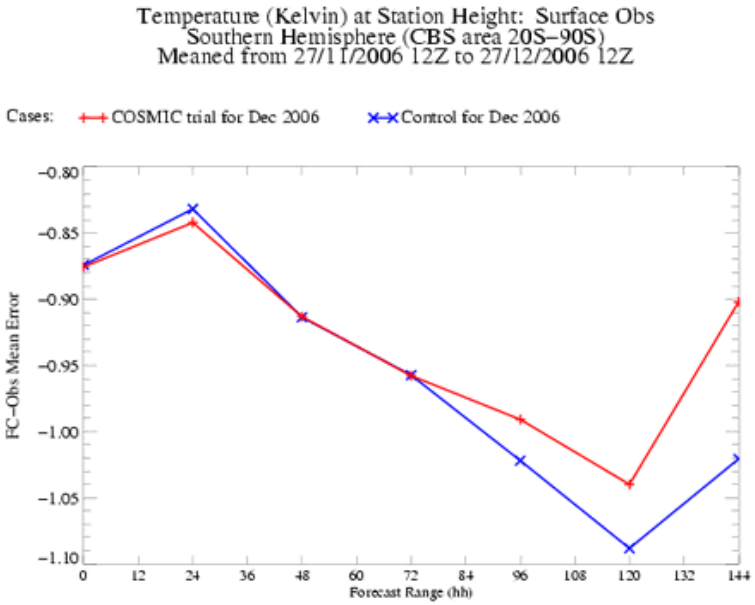
Summer period. All GPSRO

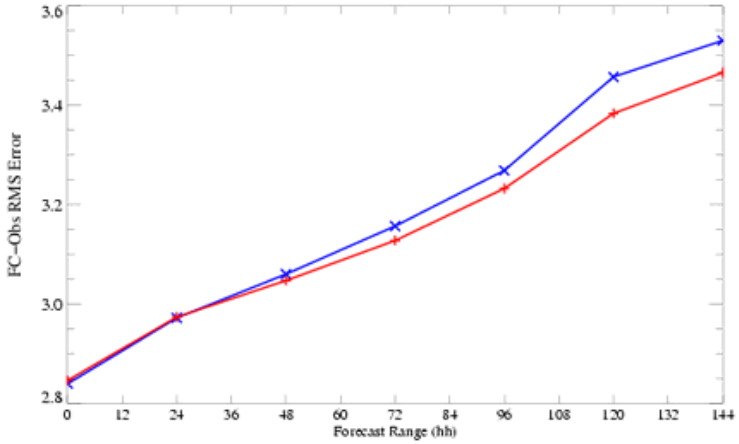




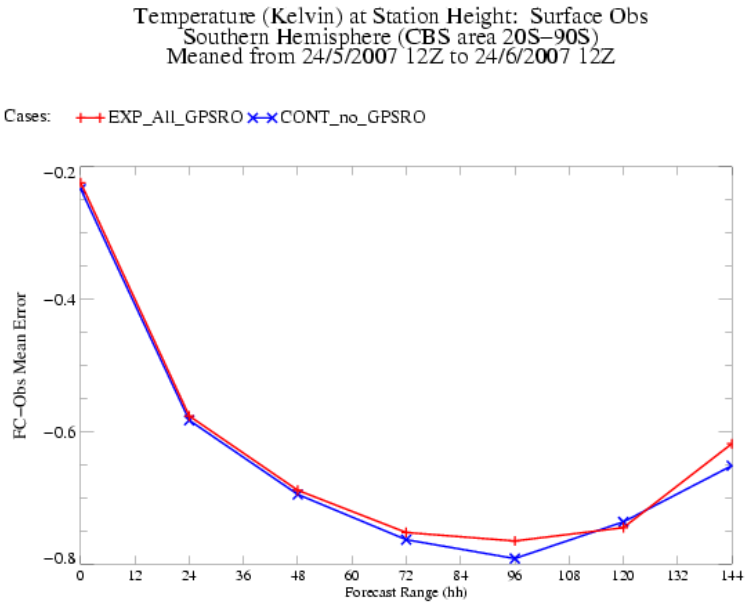
Surface obs. Temp at station height

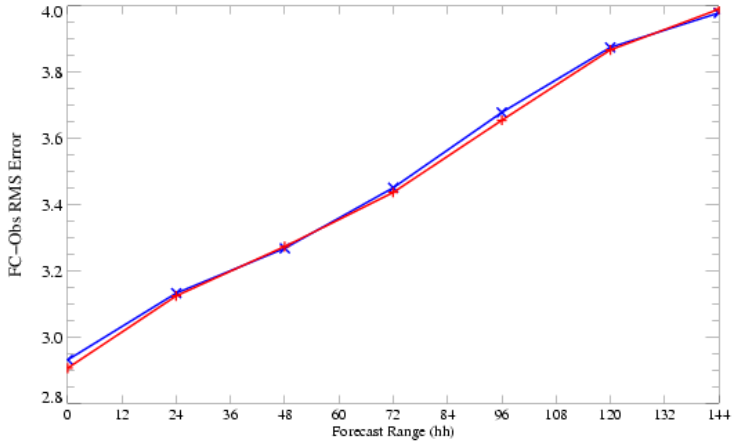
Winter period. 6 COSMIC





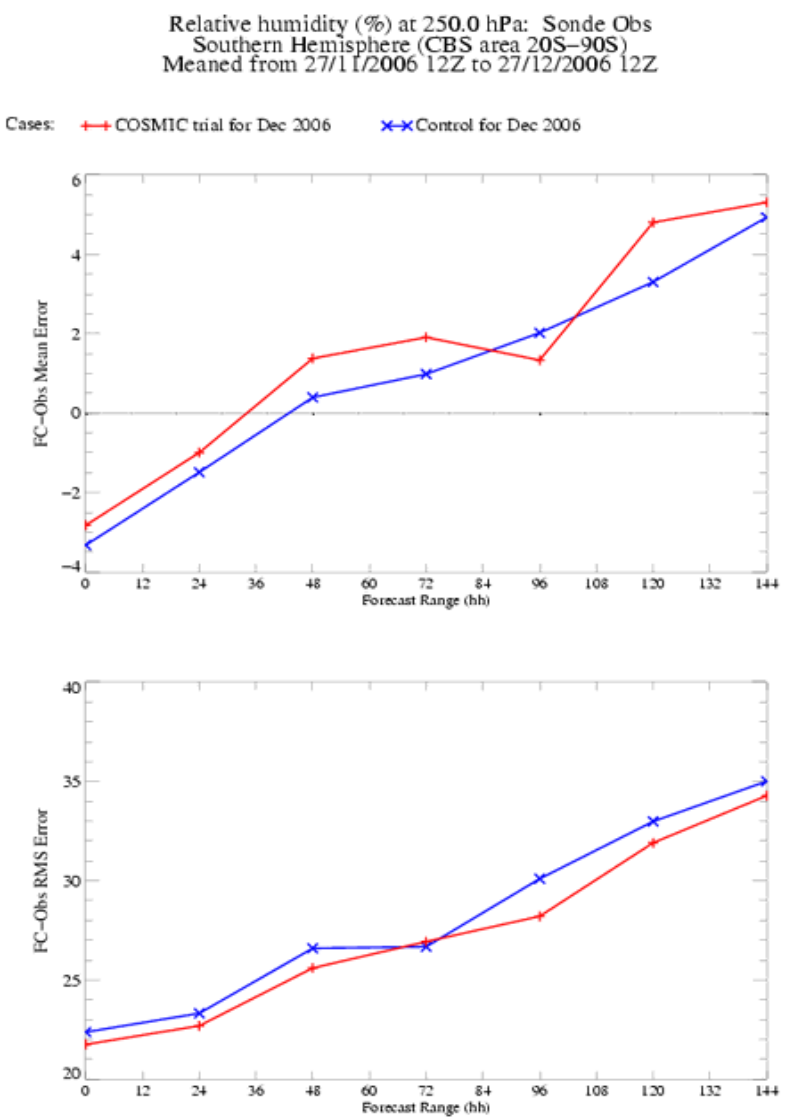
Summer period. All GPSRO



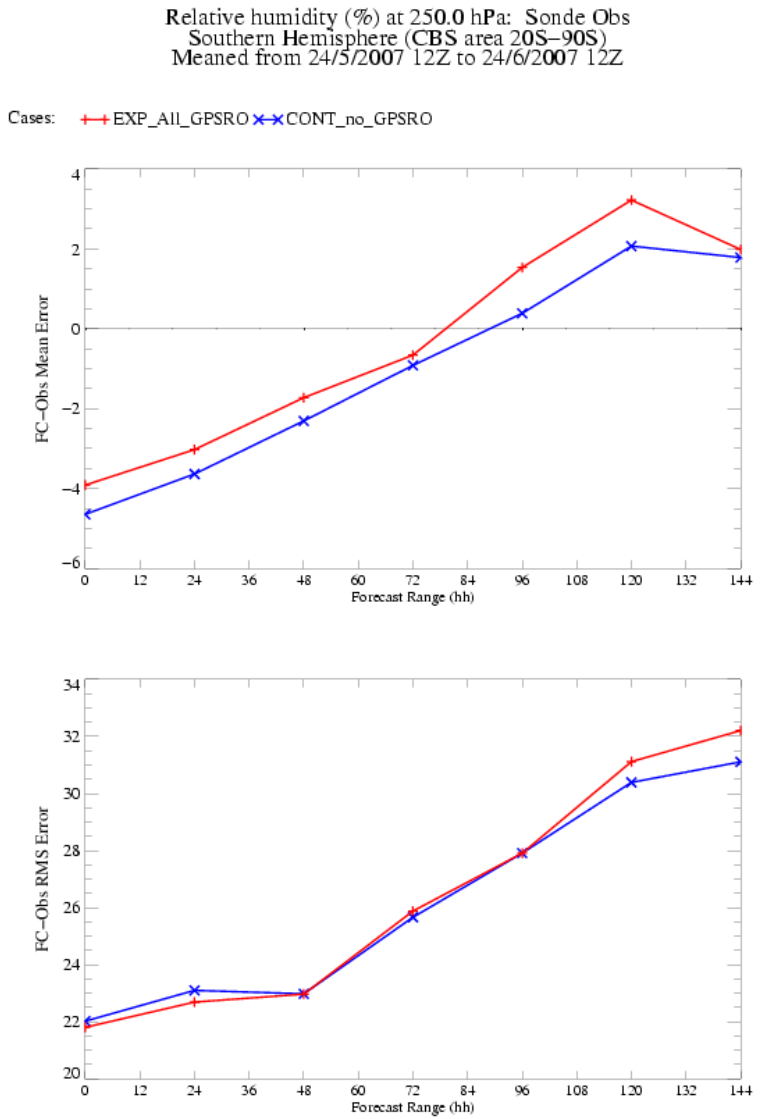


Relative Humidity, 250 hPa, SH

Winter period. 6 COSMIC

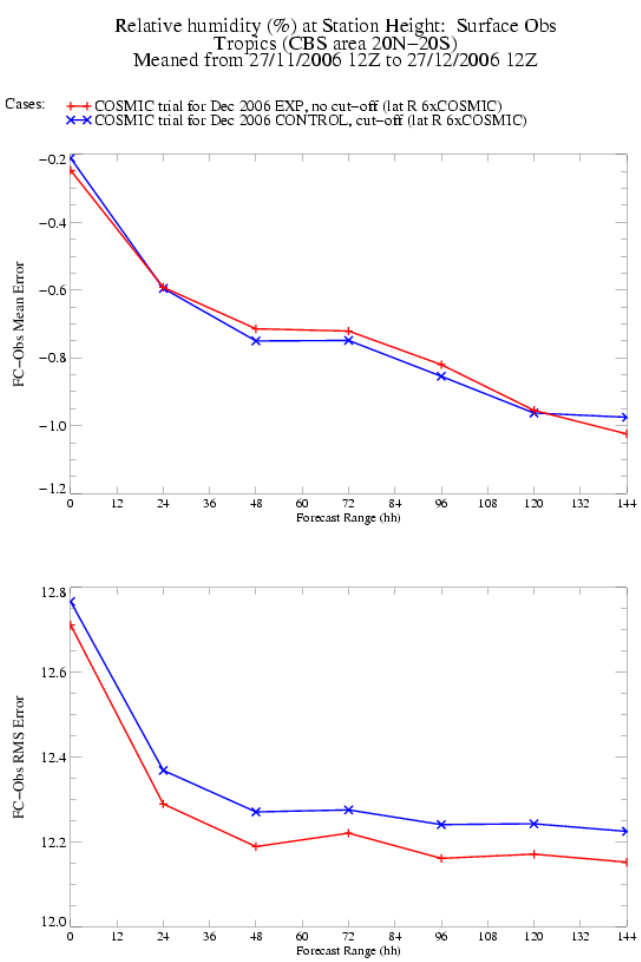


Summer period. All GPSRO

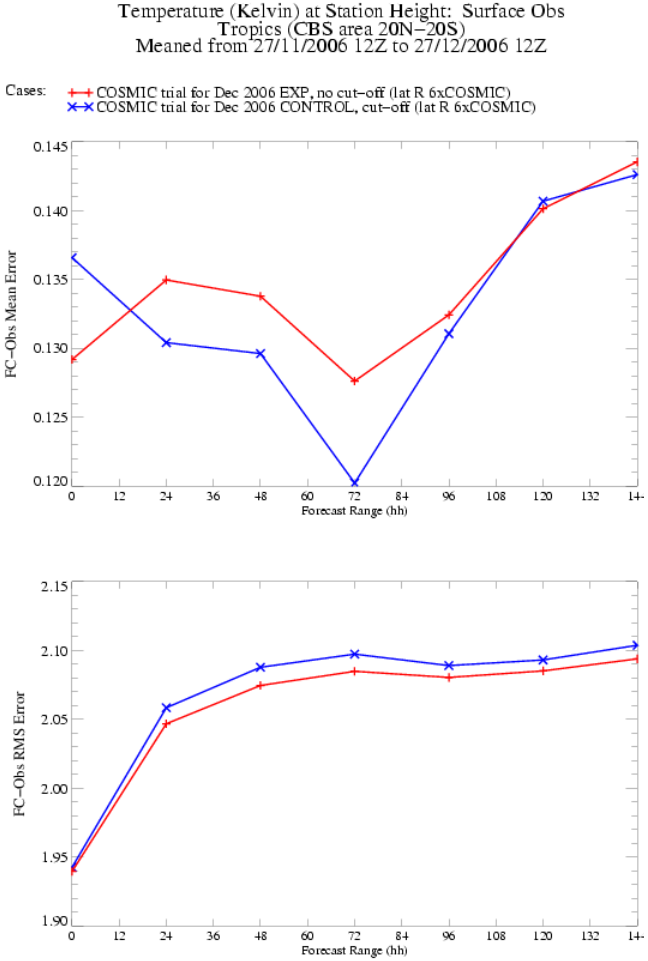


No lower cut-off trial with new errors in Winter

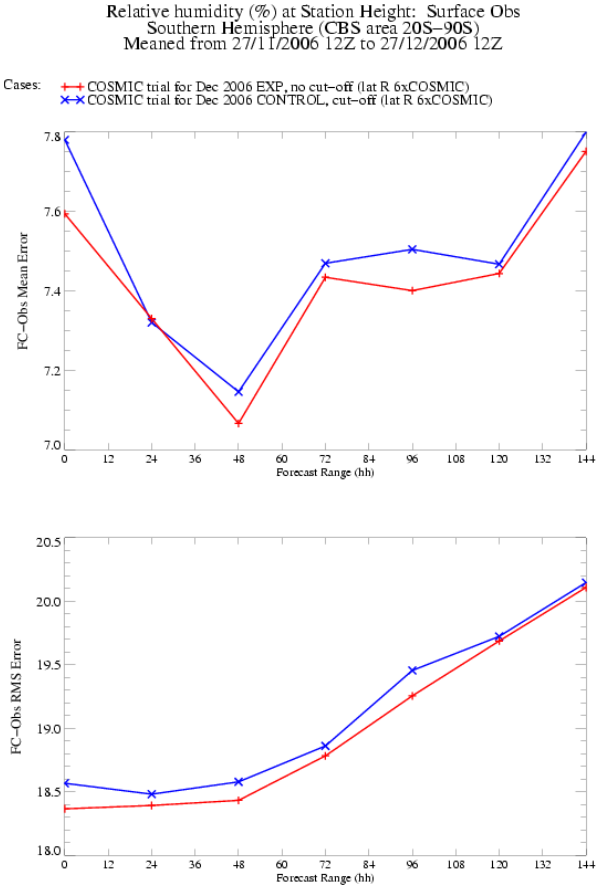
Tropics RH at surface



Tropics T at surface



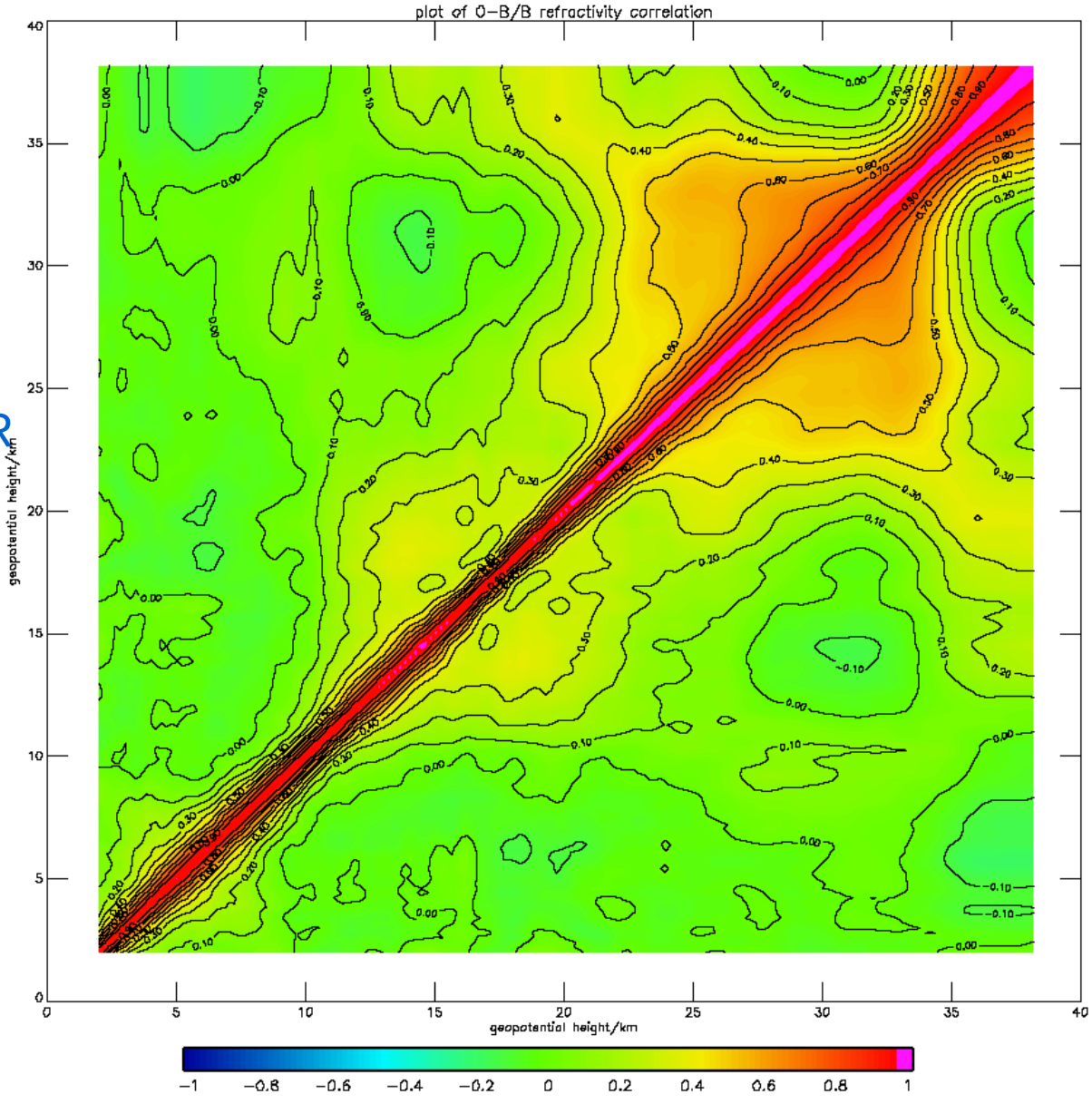
SH RH at surface



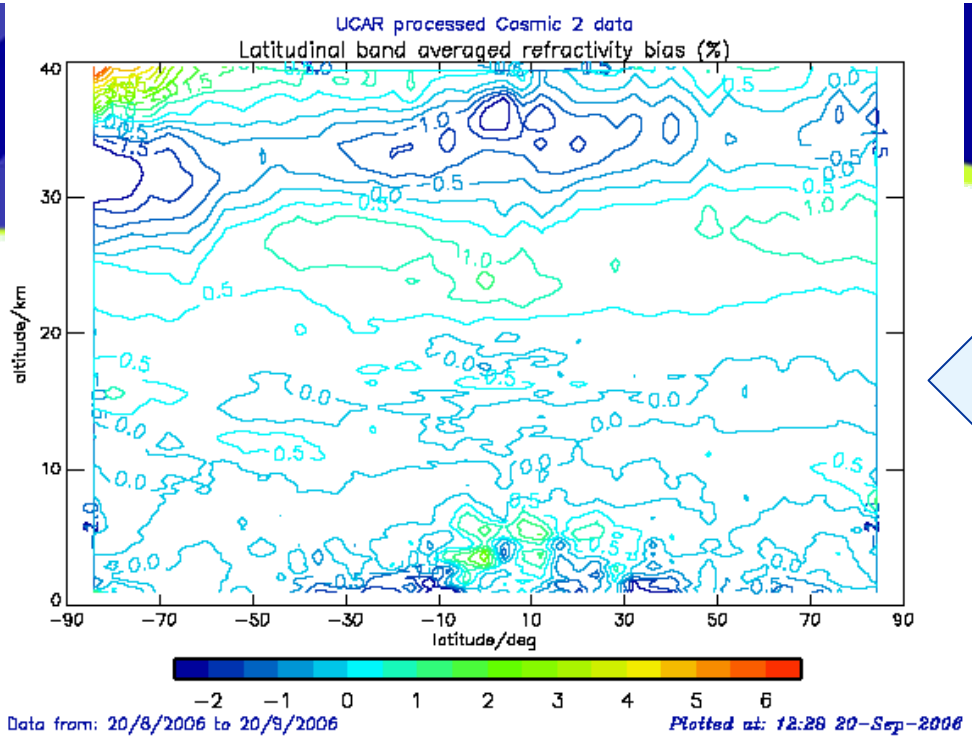
Contd.

CHAMP/UCAR

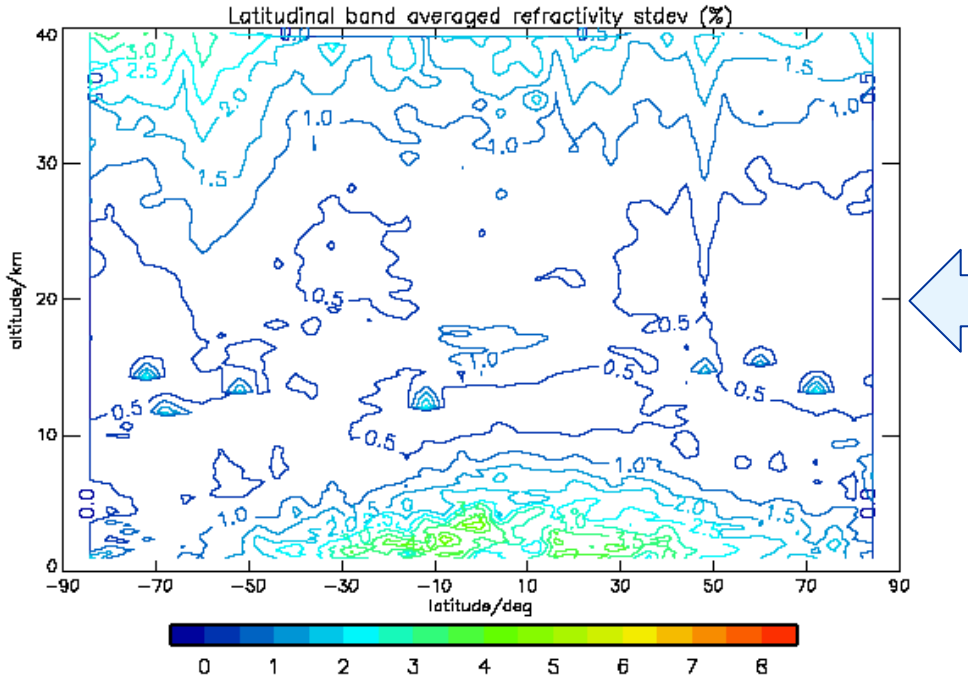
More in common with COSMIC 6



- Zonal averaging.
- Month average.
- Almost a year's data.
- COSMIC 2

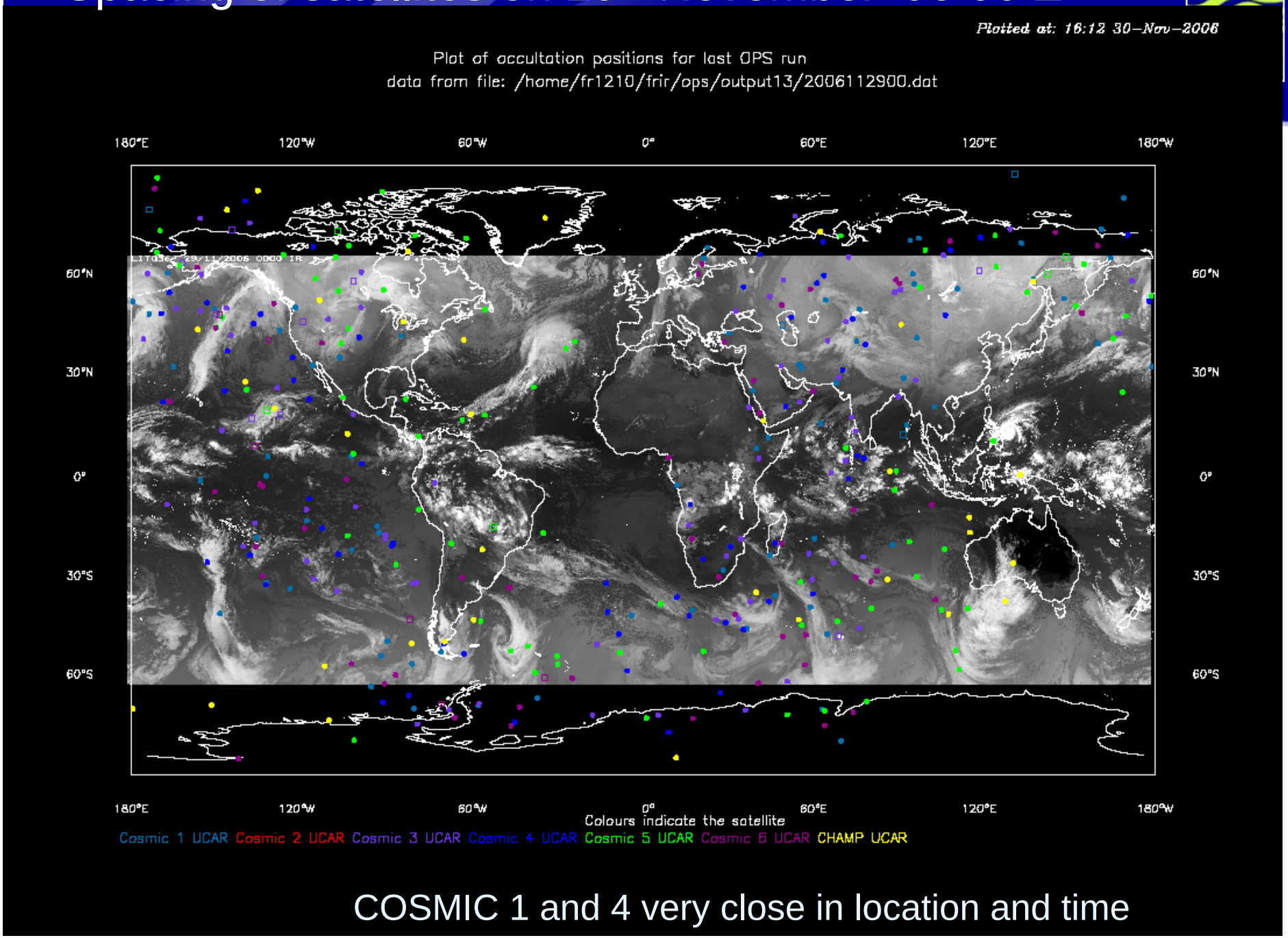


Ref O-B/B zonal mean



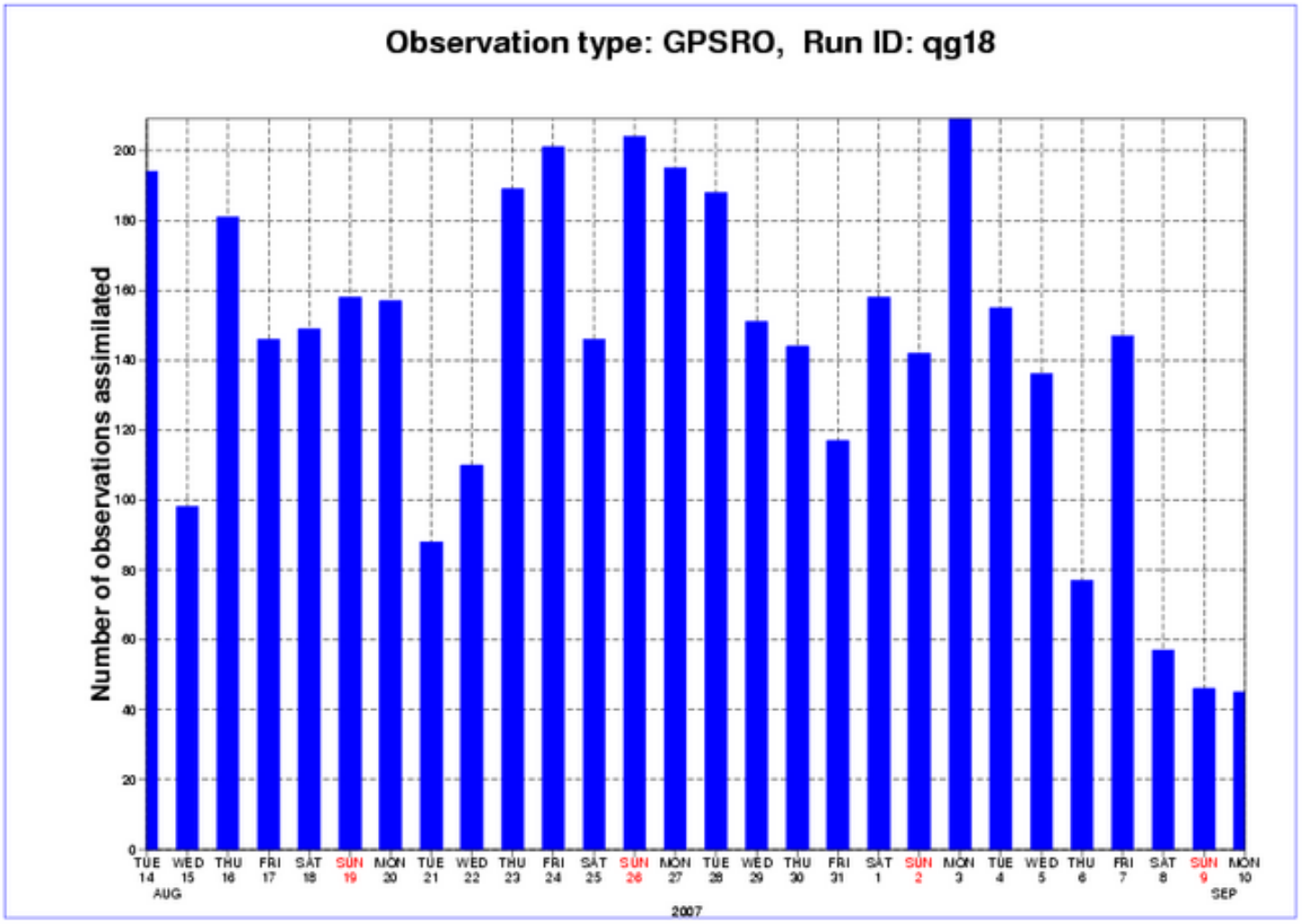
Ref O-B/B Zonal standard deviation

Spacing of satellites on 29th November '06 00 Z



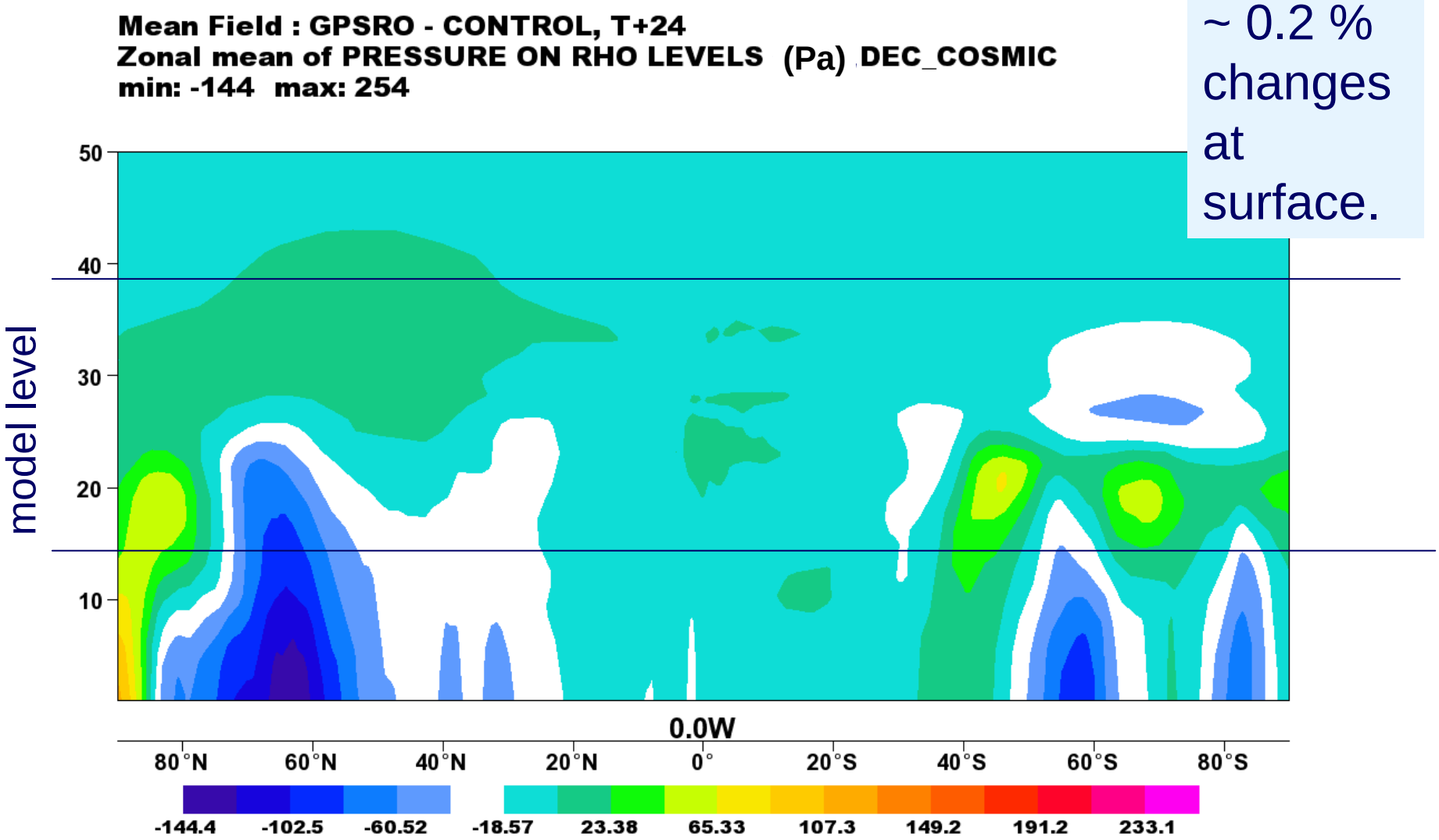
COSMIC 1 and 4 very close in location and time

Number obs used operationally. e.g. 18Z run



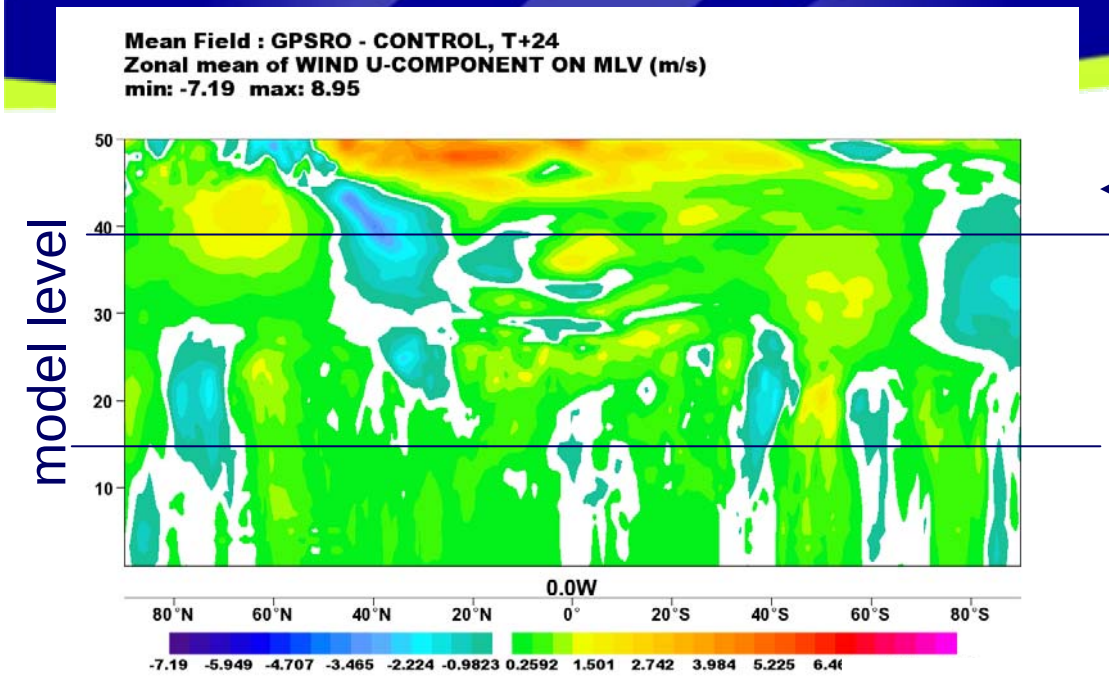
- ~ 700 radiosondes per 18Z cycle
- ~ 20-25 k ATOVS per 18Z cycle

Mean differences in pressure. Zonal average. Winter COSMICx6 (old errors)



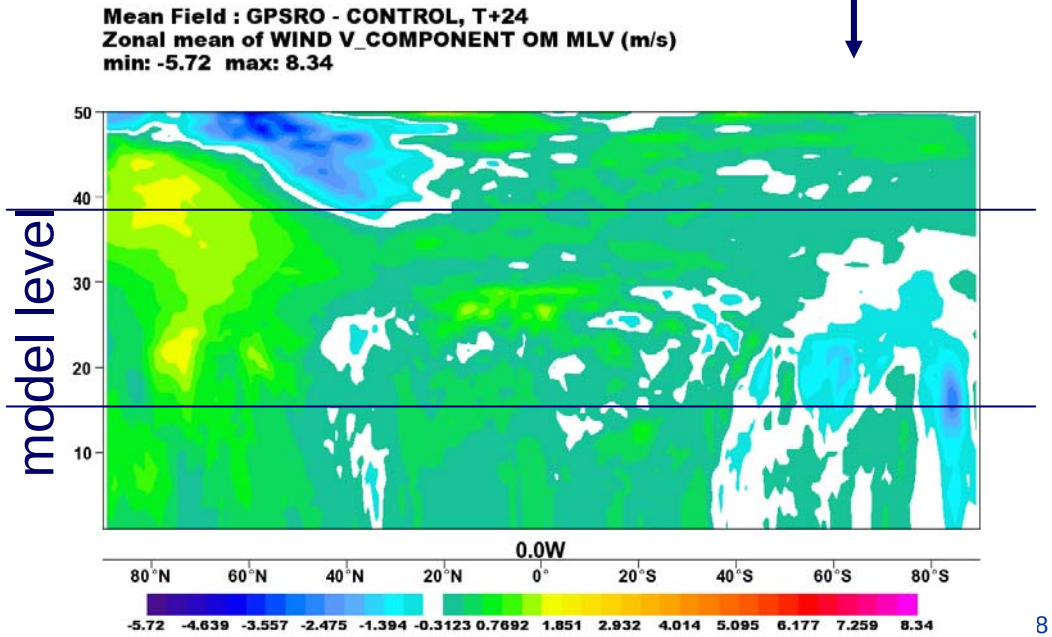
~ 0.2 % changes at surface.

Diffs in zonal average wind fields. Winter COMSICx6



← u component
i.e. east-west

v component
i.e. north-south ↓



- The change from **old to latR** errors **reversed** many of the features seen.
- Very sensitive to size of errors >10km

Review of Met Office results

- Met Office operational with 4 COSMIC sats
- O-B stats similar for all sats. Bias between UCAR & GFZ above ~25 km
- COSMIC reduces both bias and RMS error in the UTLS for T,GPH,RH and wind speed
- Dominated by improvements in SH
- Improvements made with lat dependent errors
- Improvement seen using no lower cut-off
- Model bias reduced with RO assimilation