Recent progress in the application of GPSRO data at the Met Office

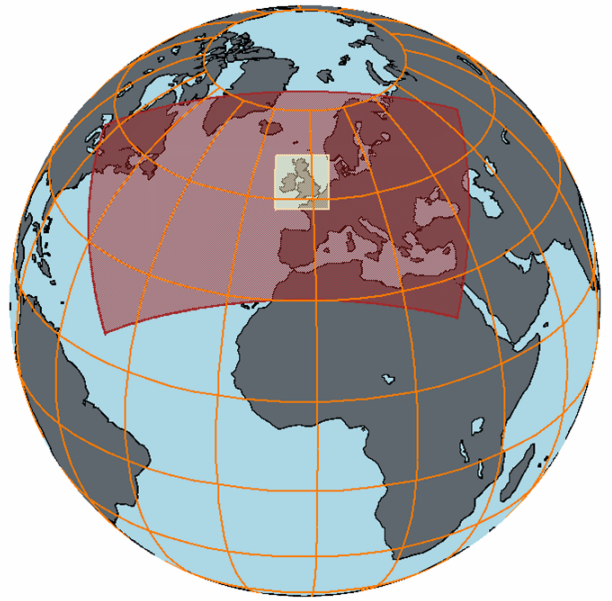
Michael Rennie, OPAC 2010 Workshop, 07/09/10

Outline

1. Status at the Met Office
2. Monitoring GPSRO data
3. Extra QC for bending angle assimilation
4. Bending angle up to 60 km to improve model biases

1. Status at Met Office

- **Assimilate bending angle (400-500 occs per 6 hours):**
  - COSMIC (profile bottom-40 km), ~56% of occs
  - GRAS (10-40 km), ~40%
  - GRACE-A (profile bottom-40 km), ~4%

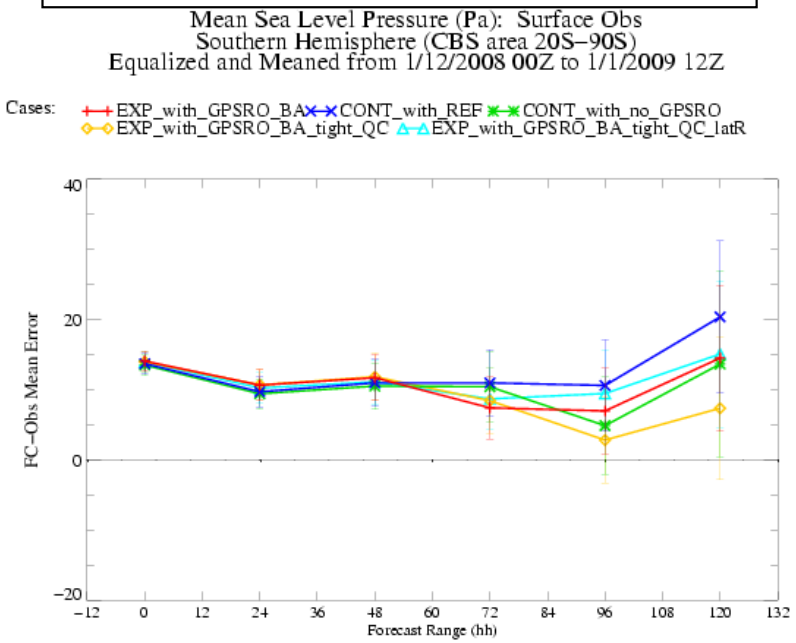


- **Into:**
  - **Global model** (~25 km horizontal resolution, 84 km model top, 70 vertical levels)
  - **NAE** (North Atlantic and European) model (12 km, horizontal, 84 km model top, 70 vertical levels)
  - **Crisis Area Models**

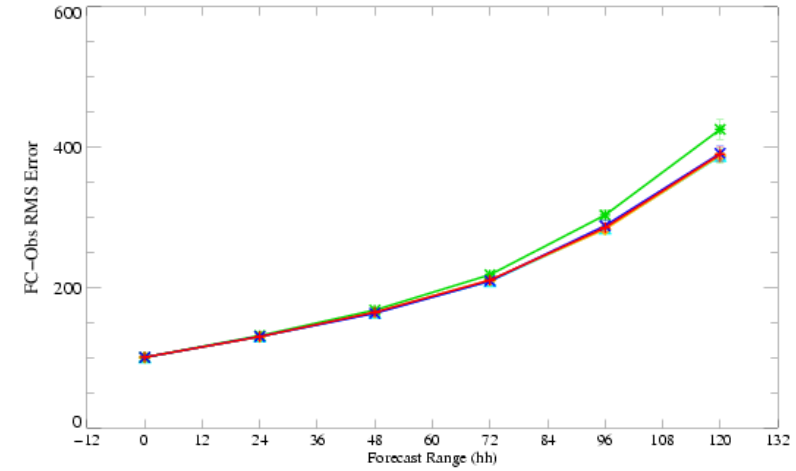
- **GPSRO important component of observing system:**
  - OSEs: 1-2 points on the NWP index (out of ~140) – a weighted RMS based skill score.
  - Impact similar to IASI (IR sounder) in magnitude (in 2007).
  - Useful diagnosing model problems with: high vertical resolution; low bias; only ob type to use pressure state vector above surface.

One of best examples of impact. MSLP in SH, Dec 2008

Vs. surface obs



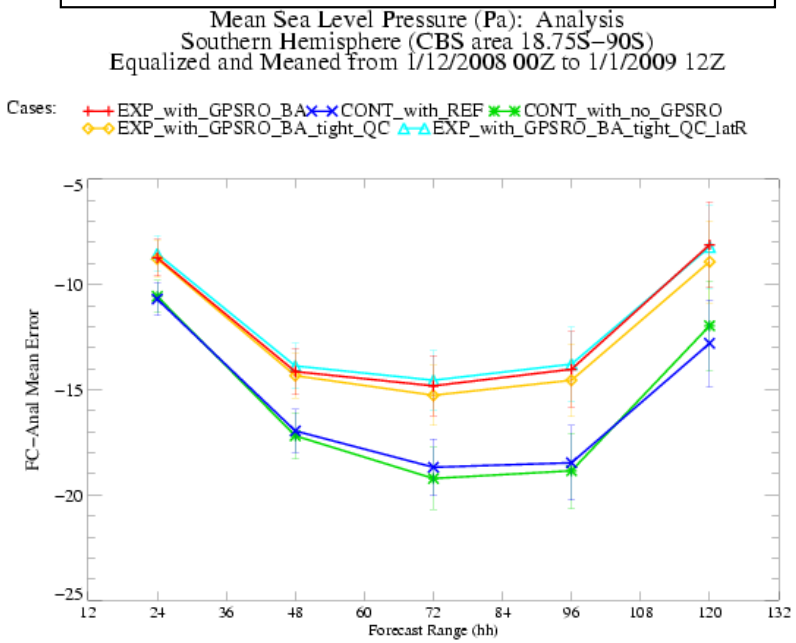
Mean error

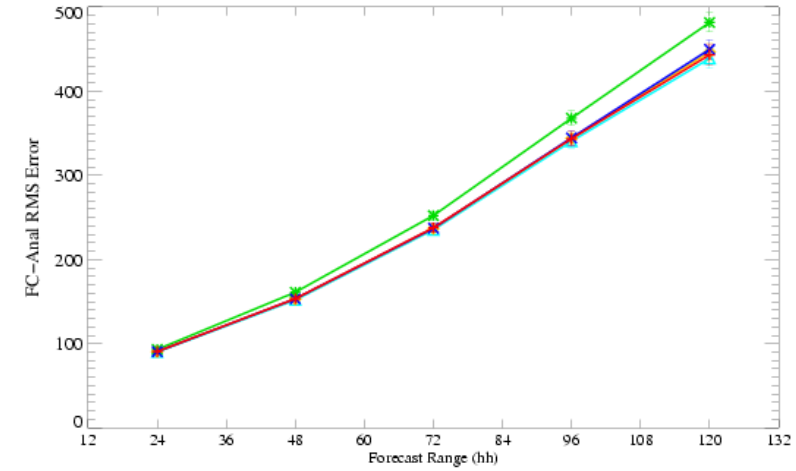


RMS error

68% error bars calculated using $S/(n-1)^{1/2}$

Vs. analyses

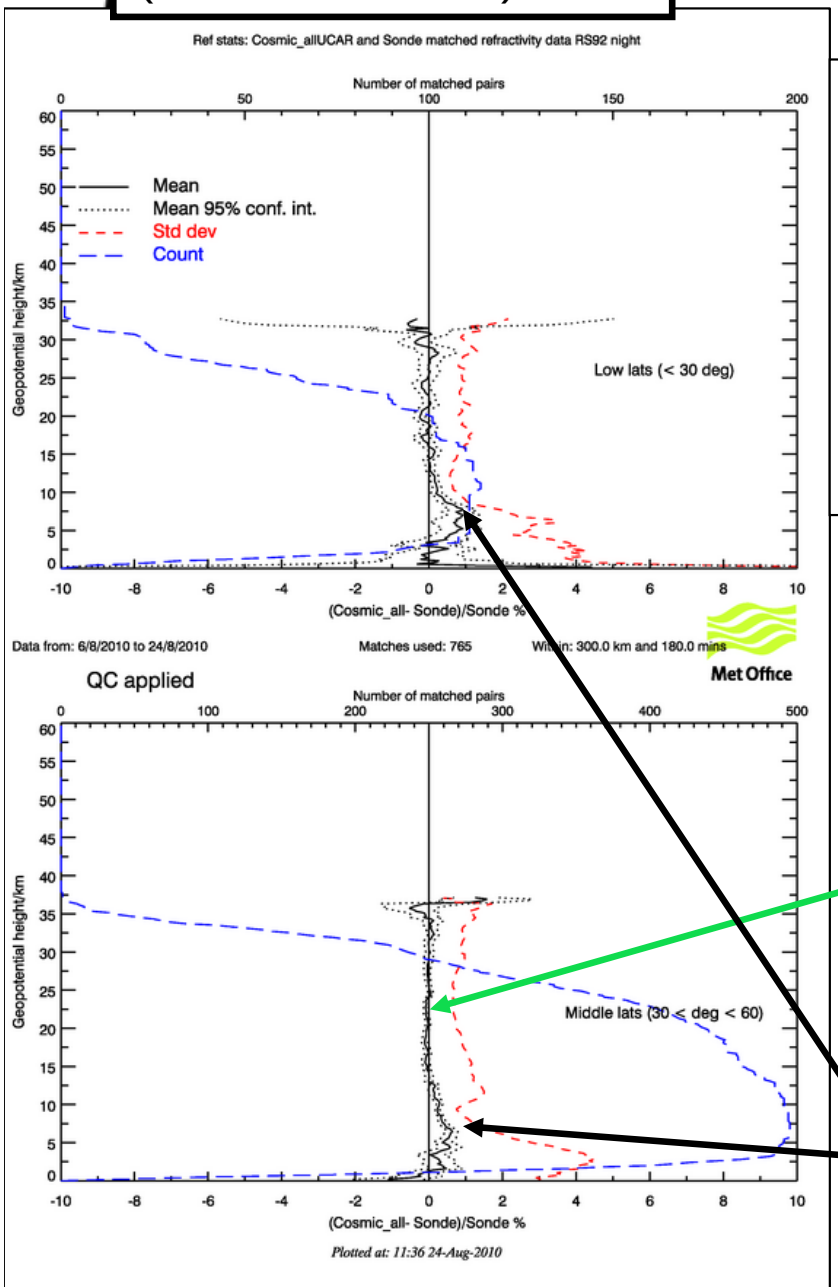




68% error bars calculated using $S/(n-1)^{1/2}$

2. Monitoring

Vaisala RS92:
(COSMIC - RS92)/RS92

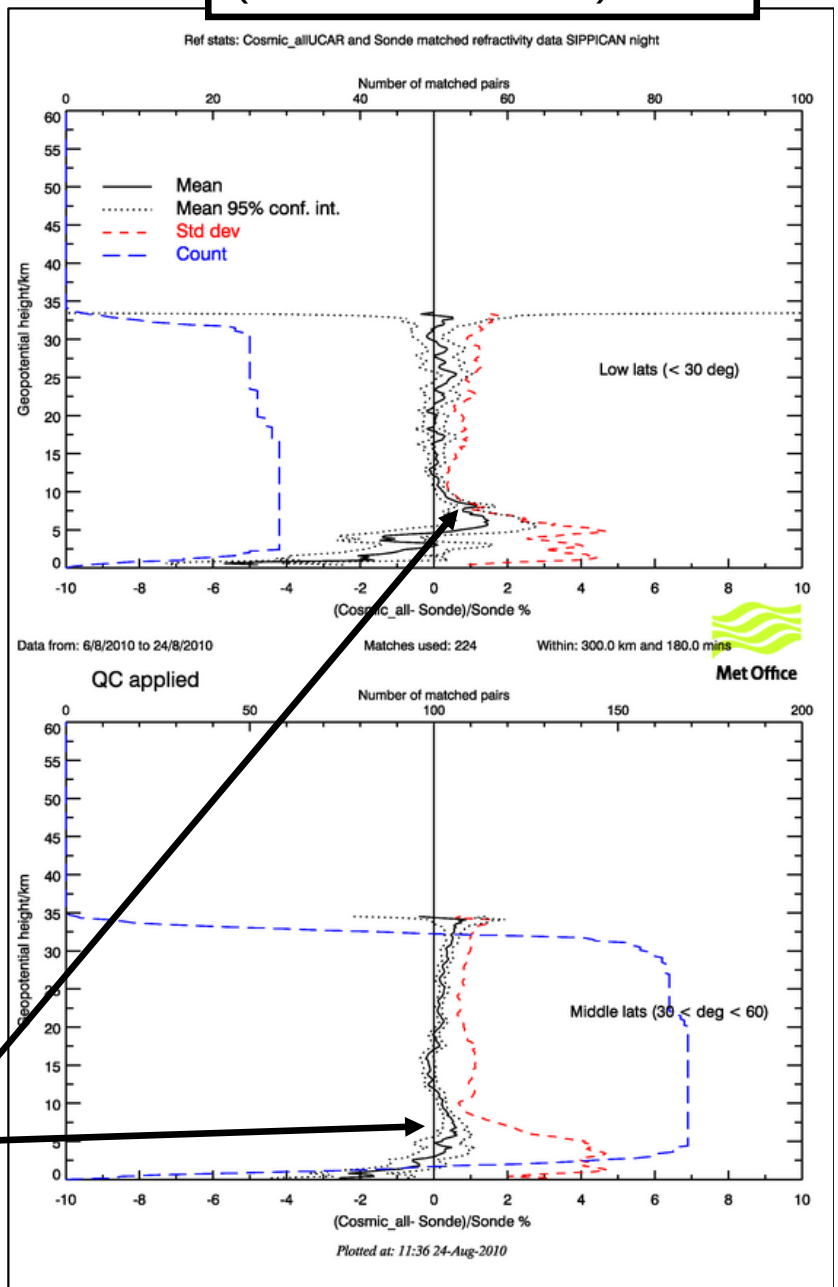


Co-located COSMIC and radiosonde refractivity (3 hrs, 300 km)

Very small bias

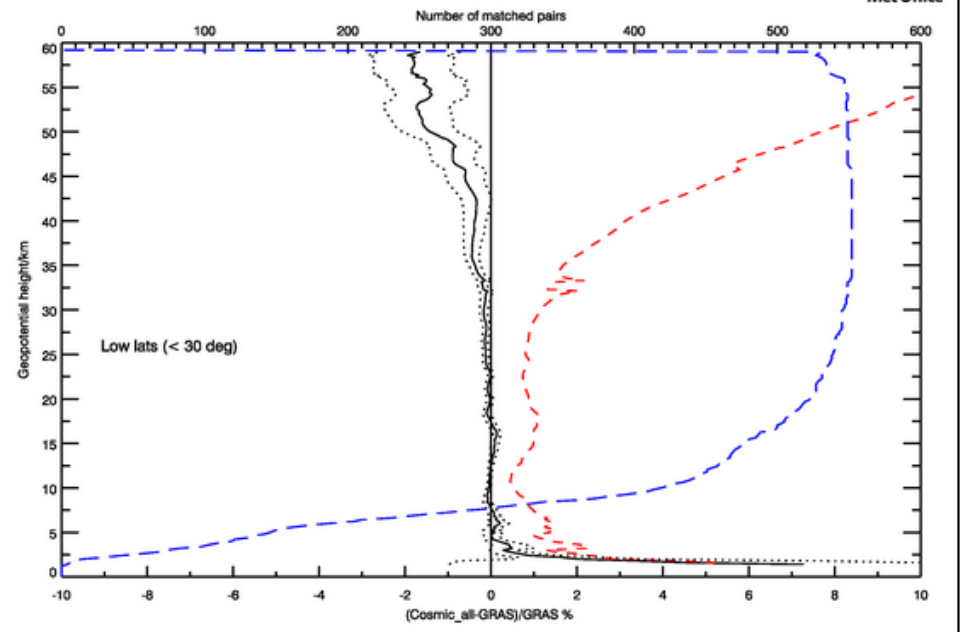
Sonde's understimate humidity

SIPPICAN (USA):
(COSMIC – SIPP)/SIPP



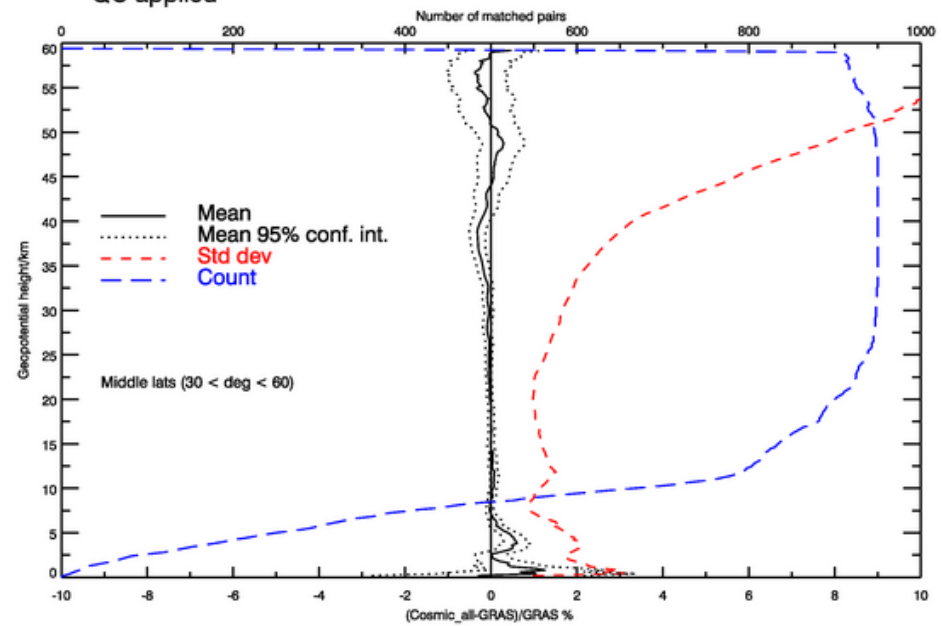
COSMIC and GRAS co-located stats (3hrs, 300 km)

REF (COSMIC - GRAS)/GRAS

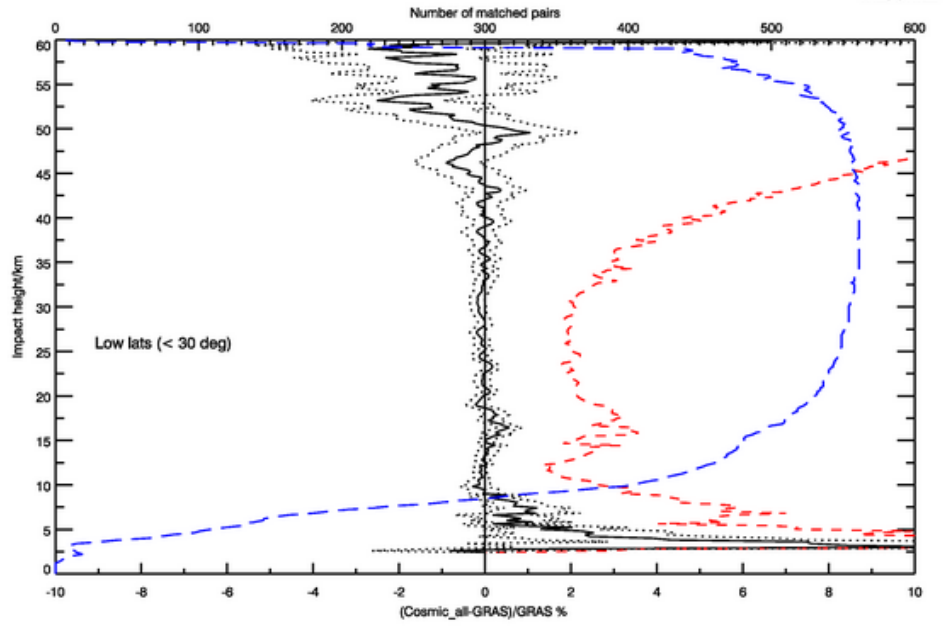


Data from: 6/8/2010 to 24/8/2010 Matches used: 2253 Within: 300.0 km and 180.0 mins

QC applied



BA (COSMIC - GRAS)/GRAS



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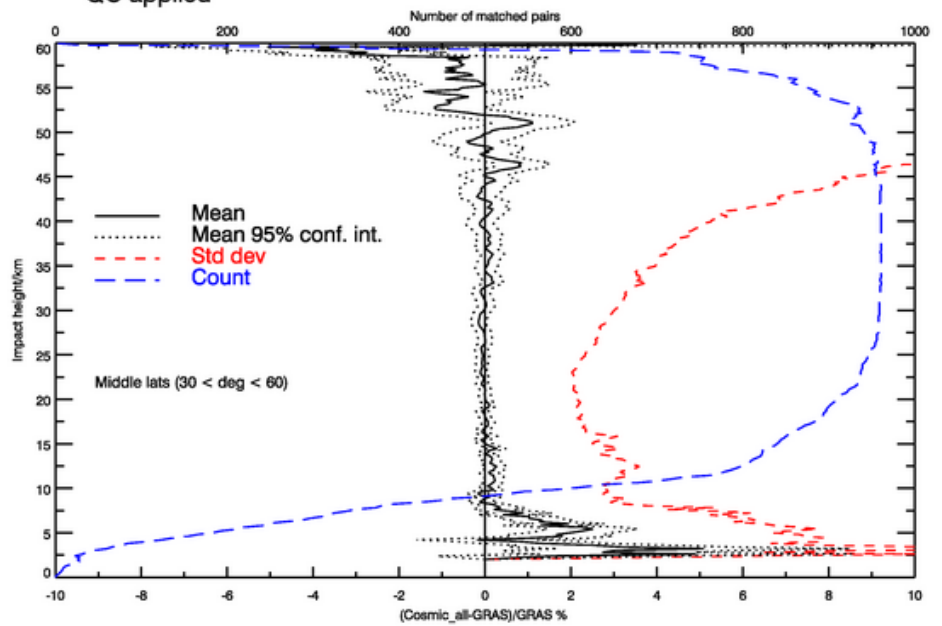
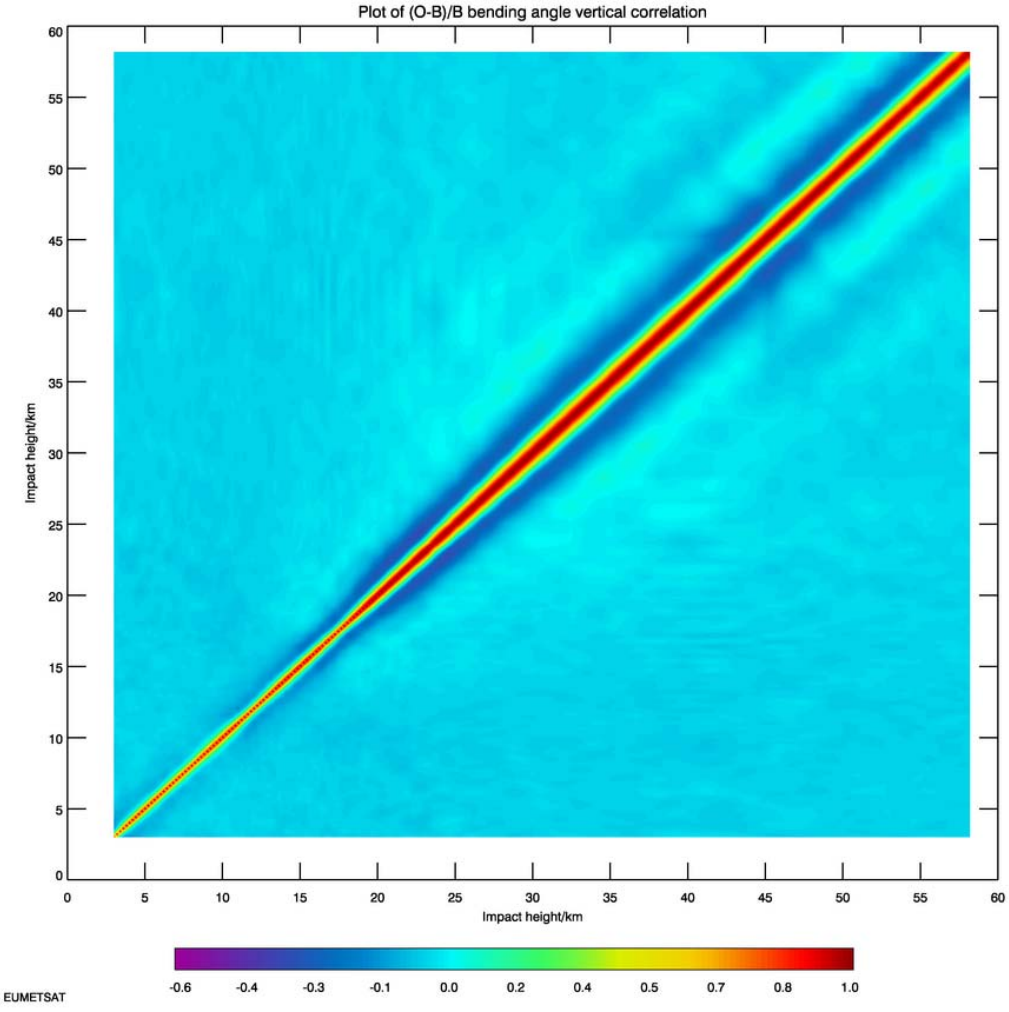


*see more at http://monitoring.grassaf.org

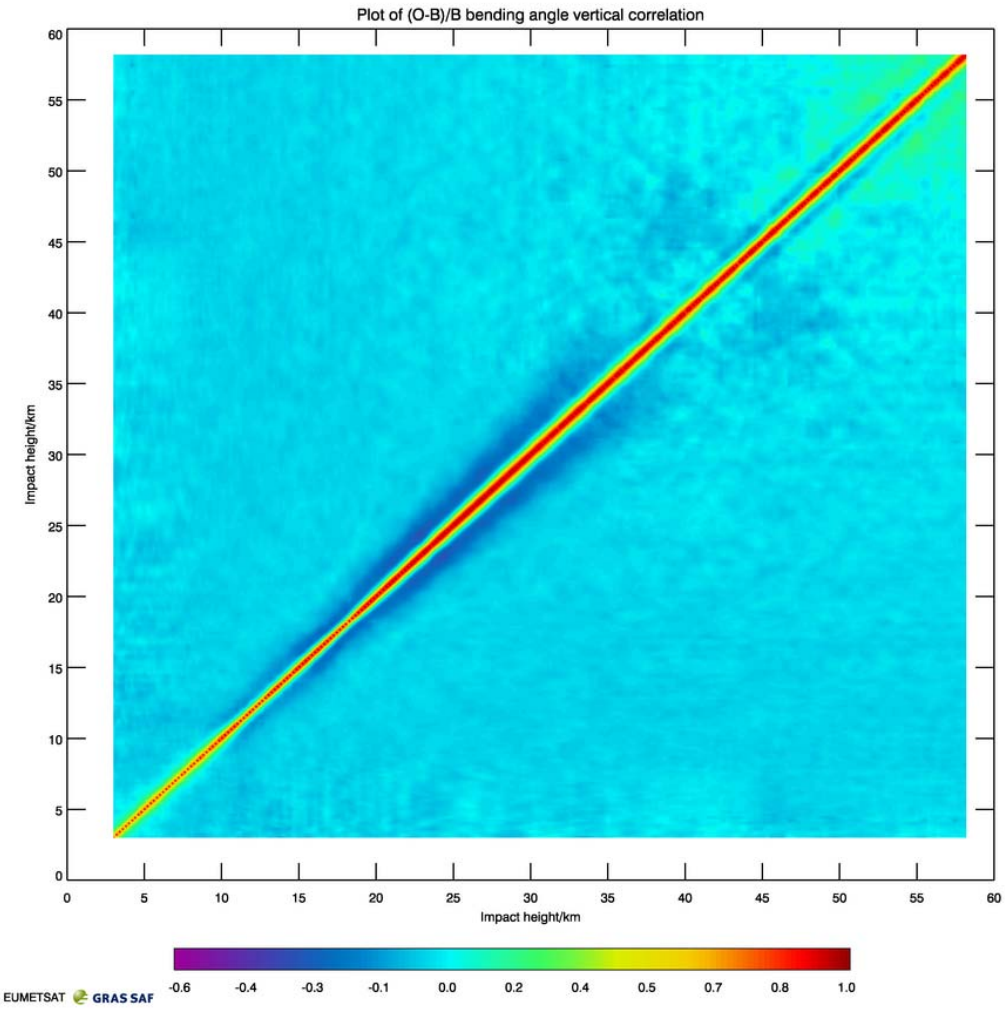
Met Office

GRAS and COSMIC BA agree well in terms of bias, but BA vertical correlations are quite different
•Different vertical smoothing/filters?

COSMIC BA (O-B)/B vertical correlation



GRAS BA (O-B)/B vertical correlation



3. Extra QC for bending angle (BA)

- BA used in global model since Mar 2010.
- 1D forward model:

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

  - Algorithm by Sean Healy (ECMWF). UKMO implementation described in ***Rennie, M. P., 2010: The impact of GPS radio occultation assimilation at the Met Office (QJRMS)***
  - Available in ROPP (http://grassaf.org/). Successfully adopted by the Naval Research Laboratory (Monterey, USA) also.
- **BA vs. REF:** modest improvement of +0.4 in NWP index (overall RO impact 1-2 points).
- Other benefits of BA:
  - Use GPSRO higher without assimilating a priori climatology.
  - Smaller vertical error correlations – can assume diagonal R.

A problem with BA in VAR

- Tangent-linear (TL) approx. used in VAR for updates in forward modelled observation (saves computational cost):

$$\mathbf{y}_n = H(\mathbf{x}_b) + \frac{\partial H(\mathbf{x}_b)}{\partial \mathbf{x}_b}(\mathbf{x}_n - \mathbf{x}_b) = \mathbf{y}_b + \mathbf{H}(\mathbf{x}_n - \mathbf{x}_b)$$

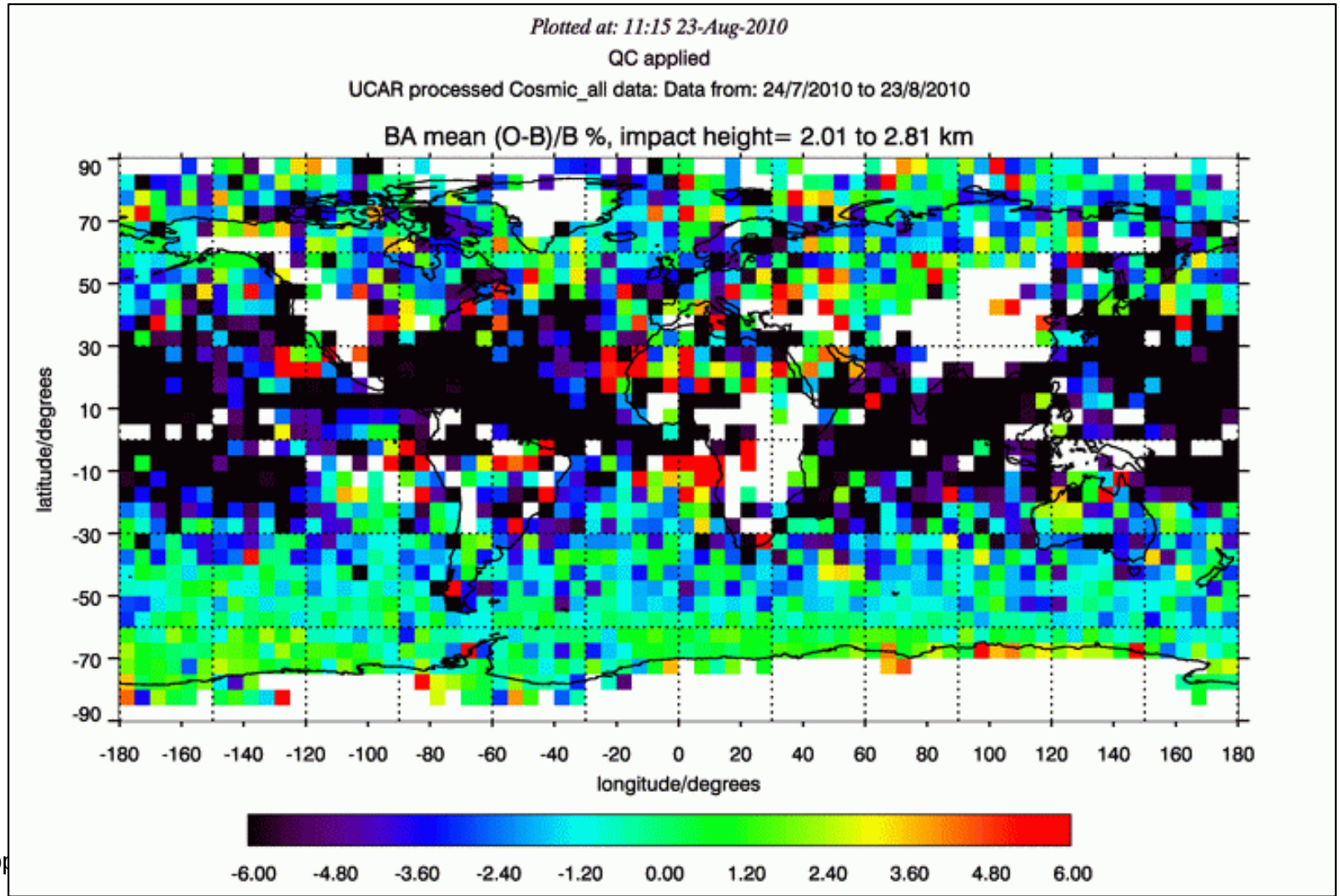
- However, BA operator too ***non-linear*** when prior model state has ***approaching-ducting*** refractivity vertical gradients
  - Derivative of *H* wrt specific humidity becomes very large.
  - TL updates created negative BA (unphysical).

- Led to irregular convergence in 4D-Var – needed method to avoid sharp gradients:
  - Calculate the model REF vertical gradient, and reject data below the height where gradient reaches a threshold.
  - <= -80 1/km (N units) was found to suffice.
- OSE show impact of new QC is neutral.

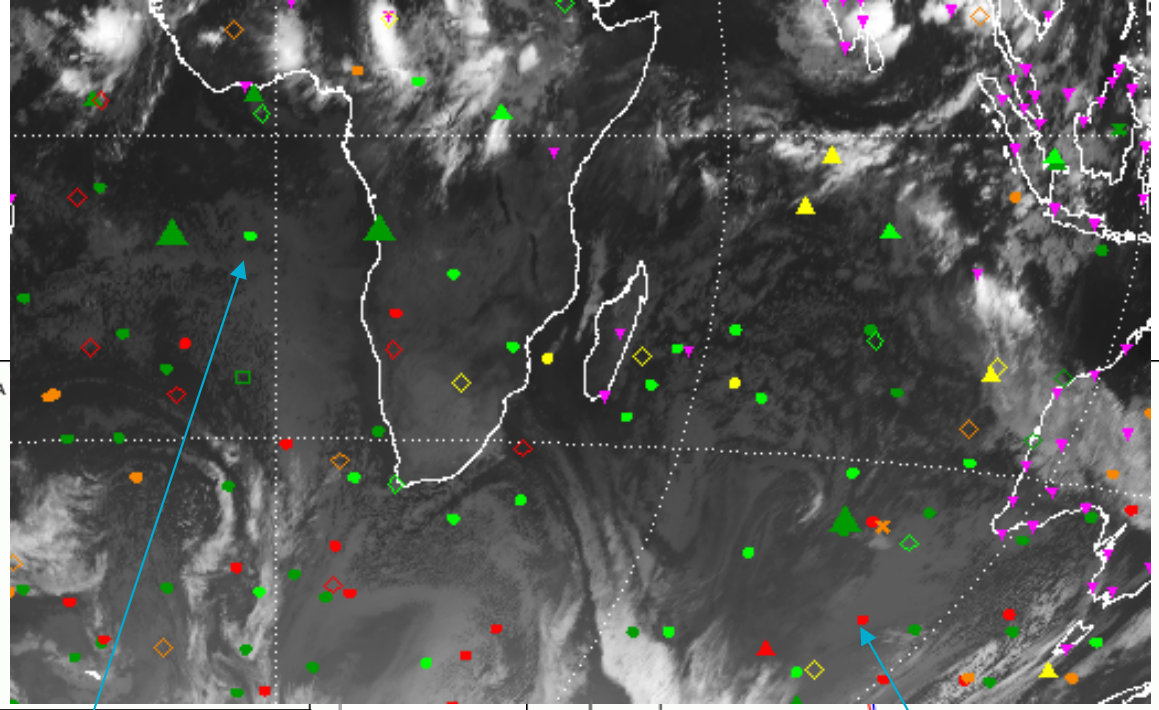
- Problem exacerbated by -ve bias in BA in lower troposphere (also in REF)
  - Seen in trade-wind inversion regions (Sc areas).
  - large O-B departures cause larger d**x** for TL update:

$$\mathbf{y}_n = \mathbf{y}_b + \mathbf{H}d\mathbf{x}$$

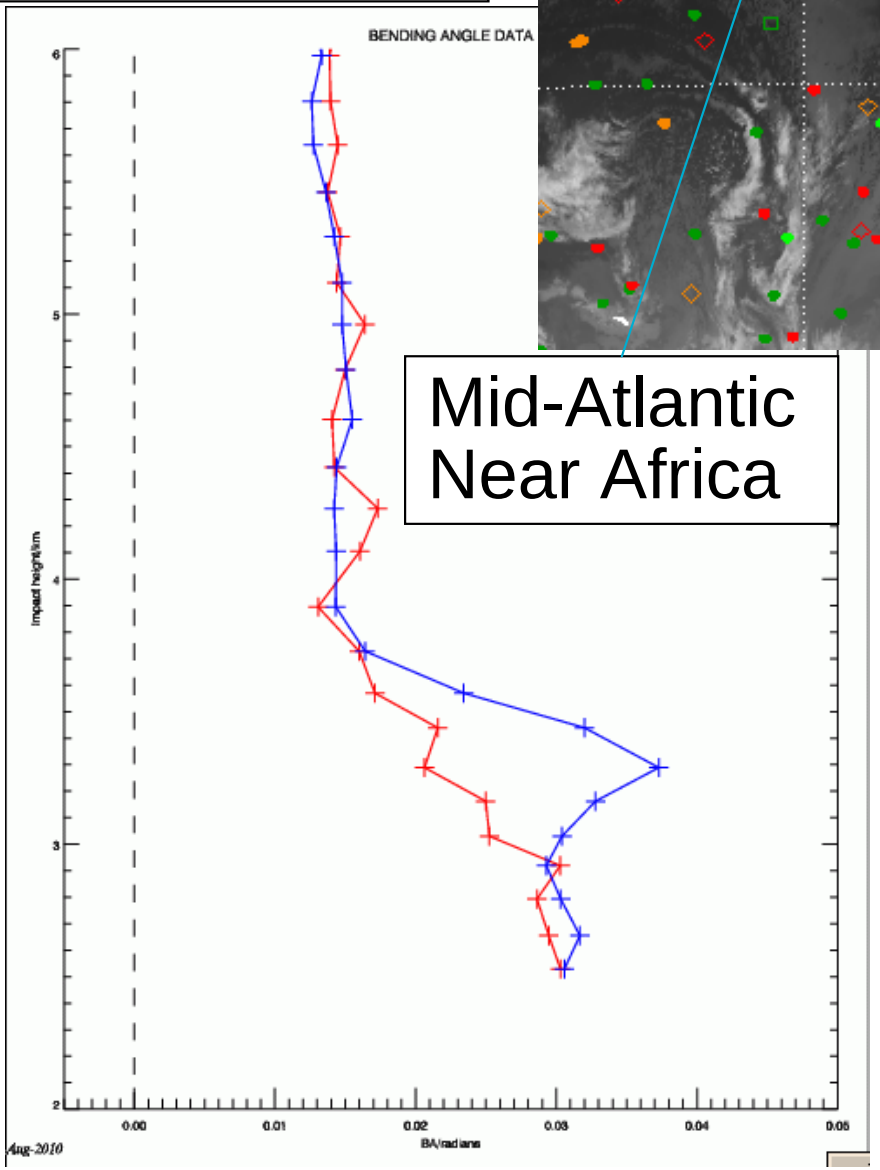
- Could argue the forward model is not simulating the obs accurately – since actual behaviour of instrument is complex in such conditions!



Example –ve biased COSMIC BA profiles



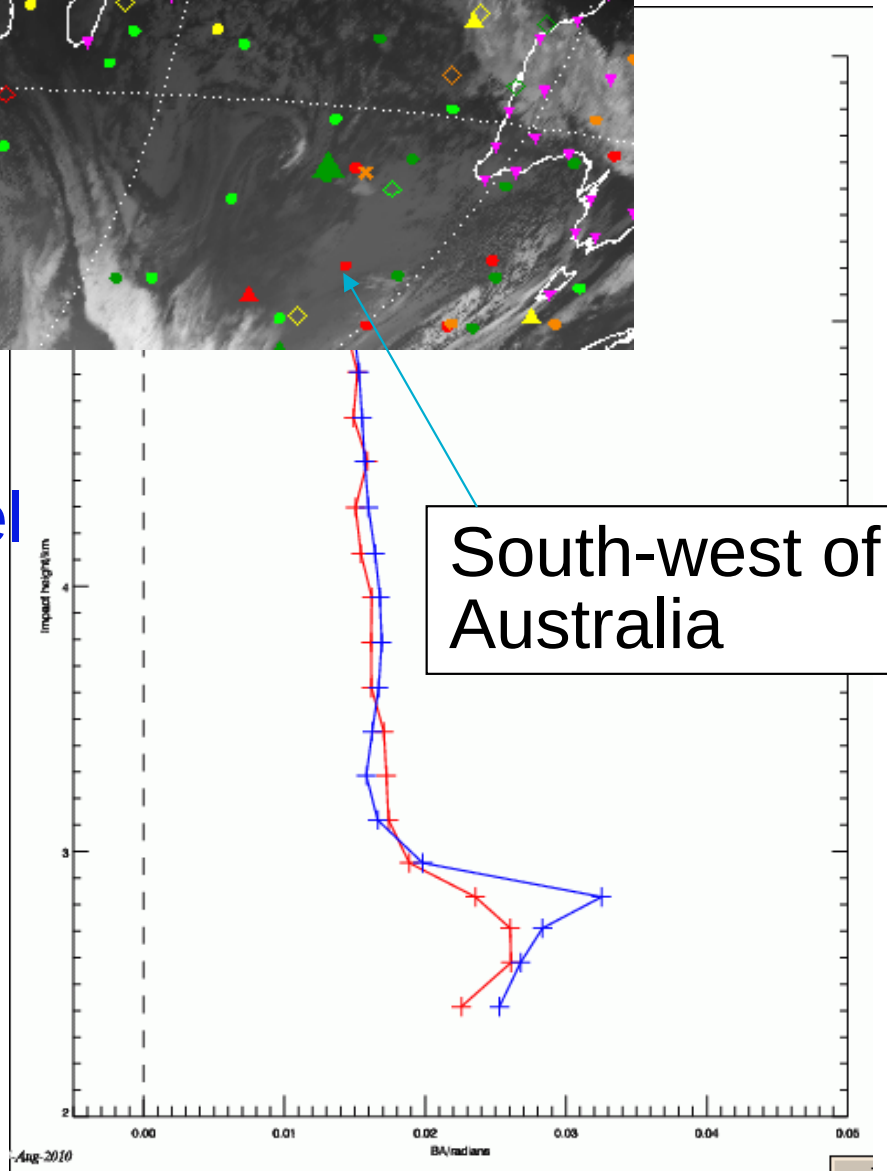
IR imagery shows Sc



Mid-Atlantic Near Africa

model

obs



South-west of Australia

4. Using BA to 60 km

- New 70-level model can have large temperature biases around stratopause:
  - Unified Model alone does not develop biases – problem lies with DA.
  - Related to correlations in background error covariance matrix between troposphere and stratosphere.
  - Biases develop around Winter-polar vortex.

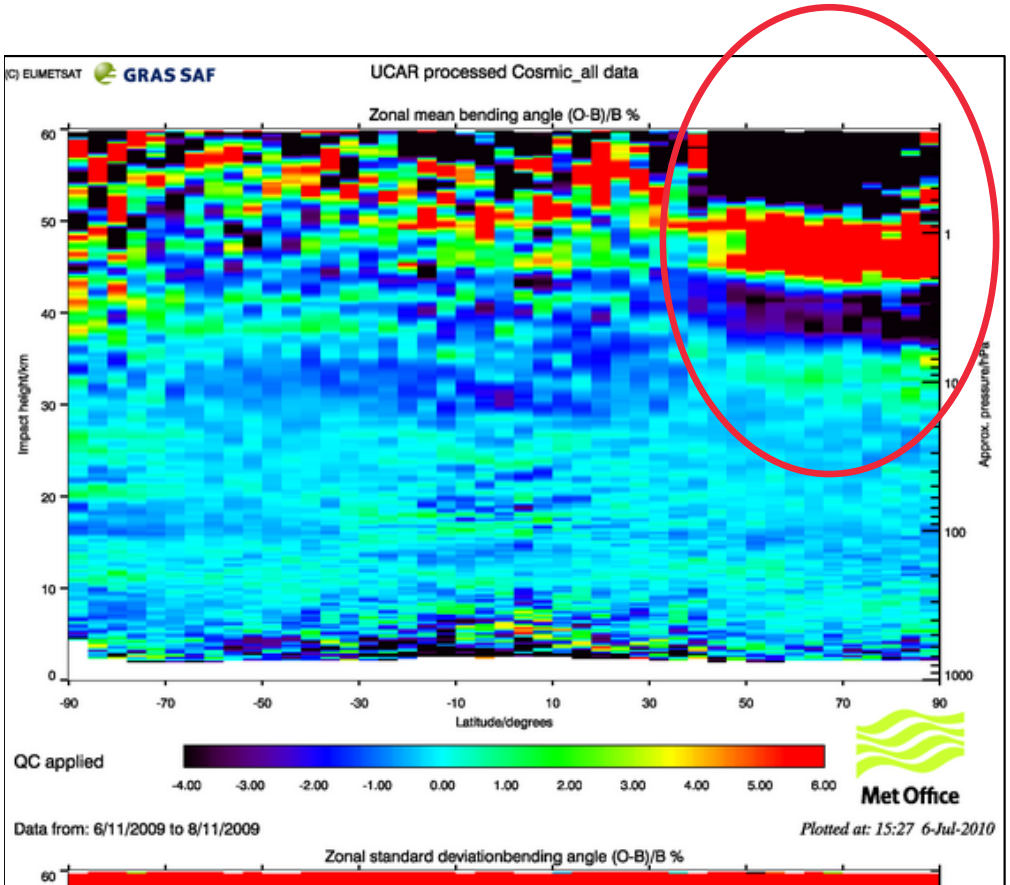
- Artificially reducing analysis increments above ~50 km improves the bias.

- Can increasing the vertical range of GPSRO BA to 60 km help?

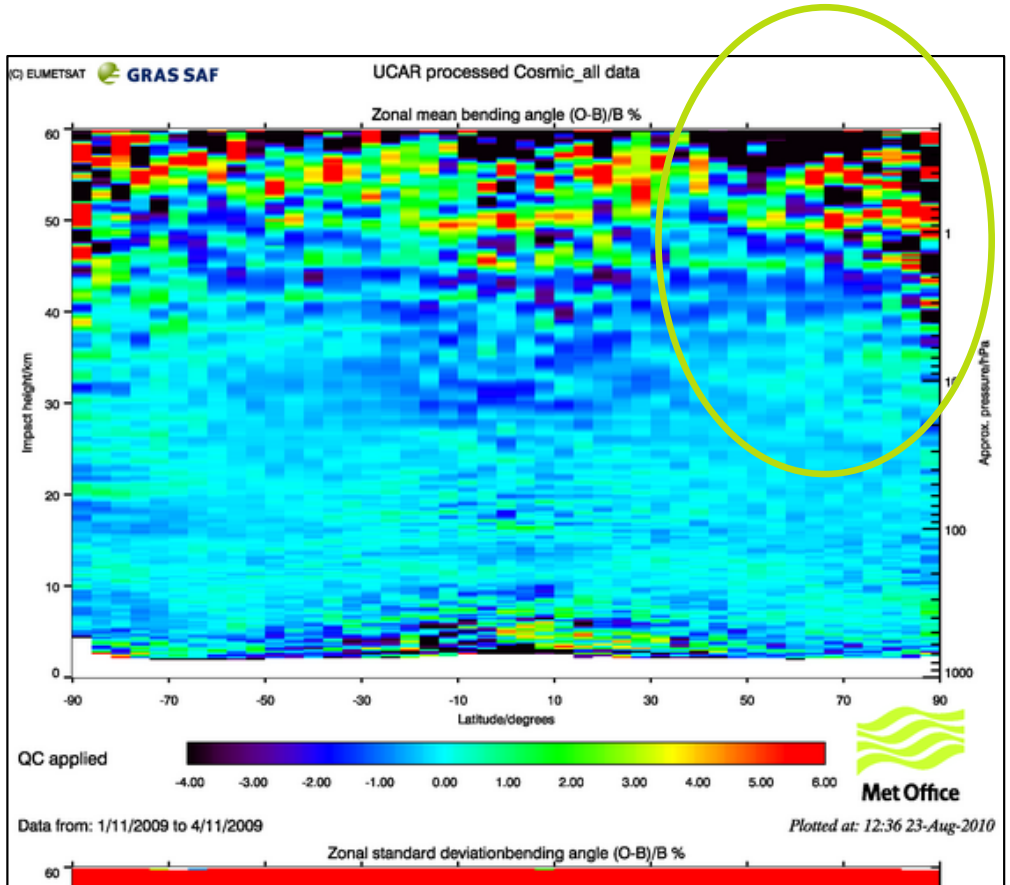
Affect of higher GPSRO on biases in Nov 2009

GPSRO can ‘see’ the vertical structure of the stratospheric/mesospheric bias

Zonal mean[(O-B)/B]: BA **used to 40 km**

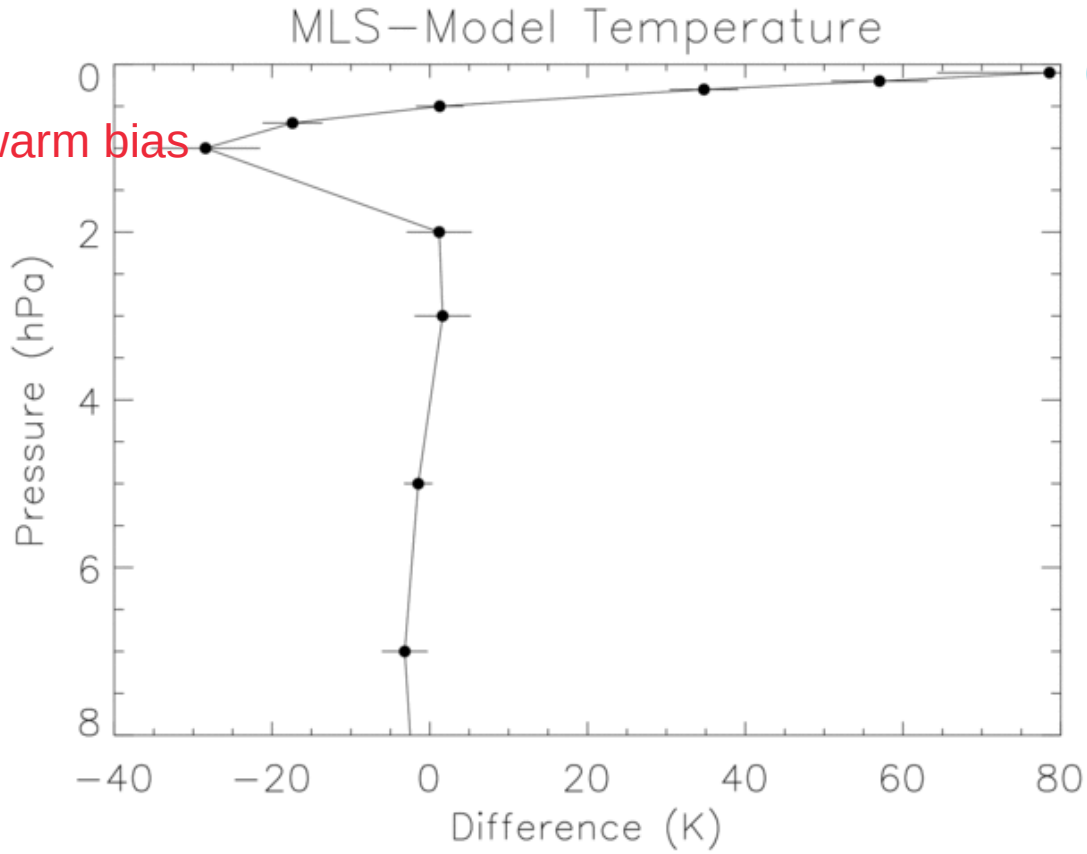


Zonal mean[(O-B)/B]: BA **used to 60 km**



Biases seen with Microwave Limb Sounder retrievals

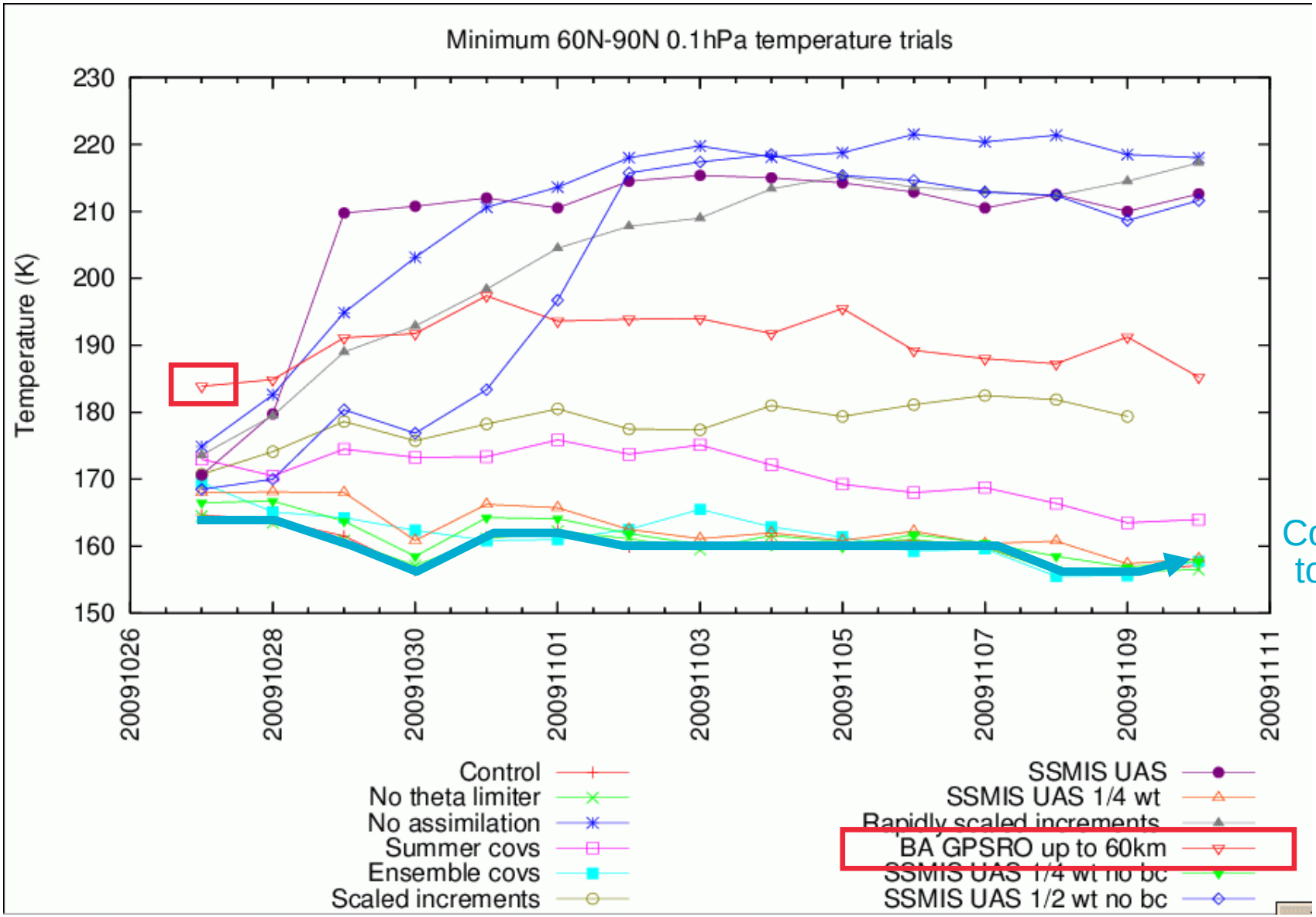
1 hPa: model warm bias



0.1 hPa: model cold bias

Plot courtesy of Brett Candy

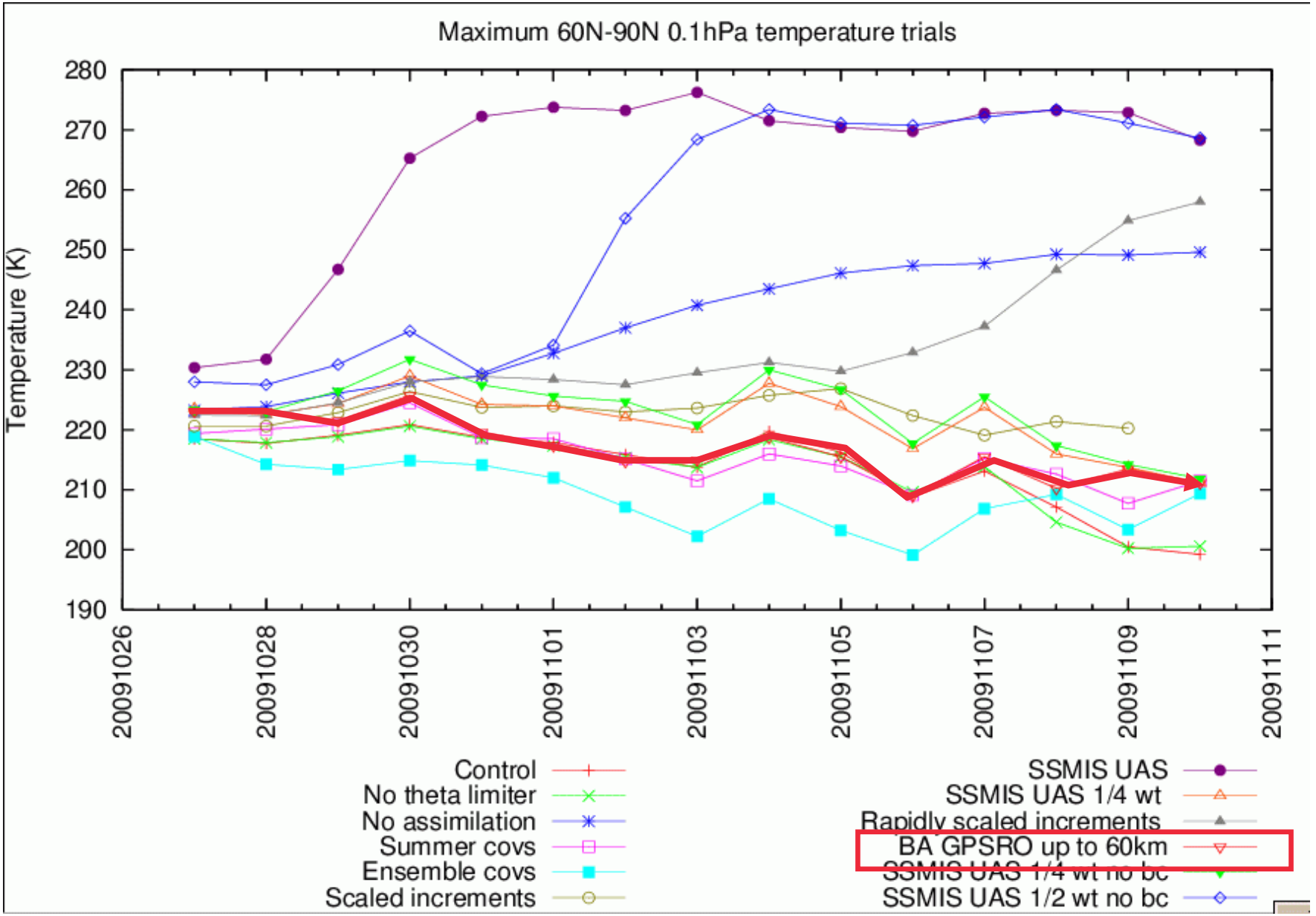
Min. temp. at 0.1 hPa, with potential solutions to **cold bias**



Control is too cold

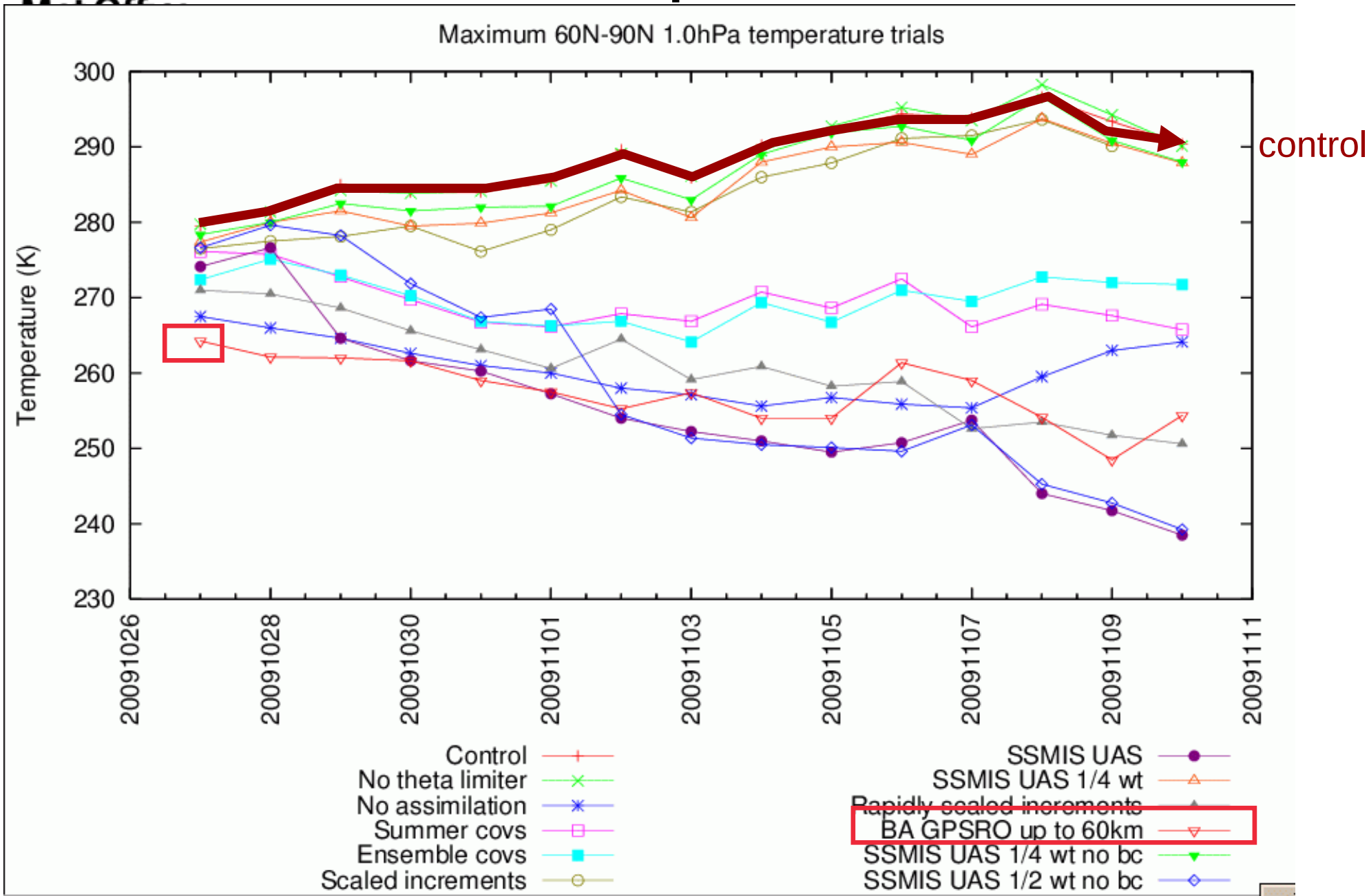
Plot courtesy of Mike Thurlow

Max. temp. at 0.1 hPa

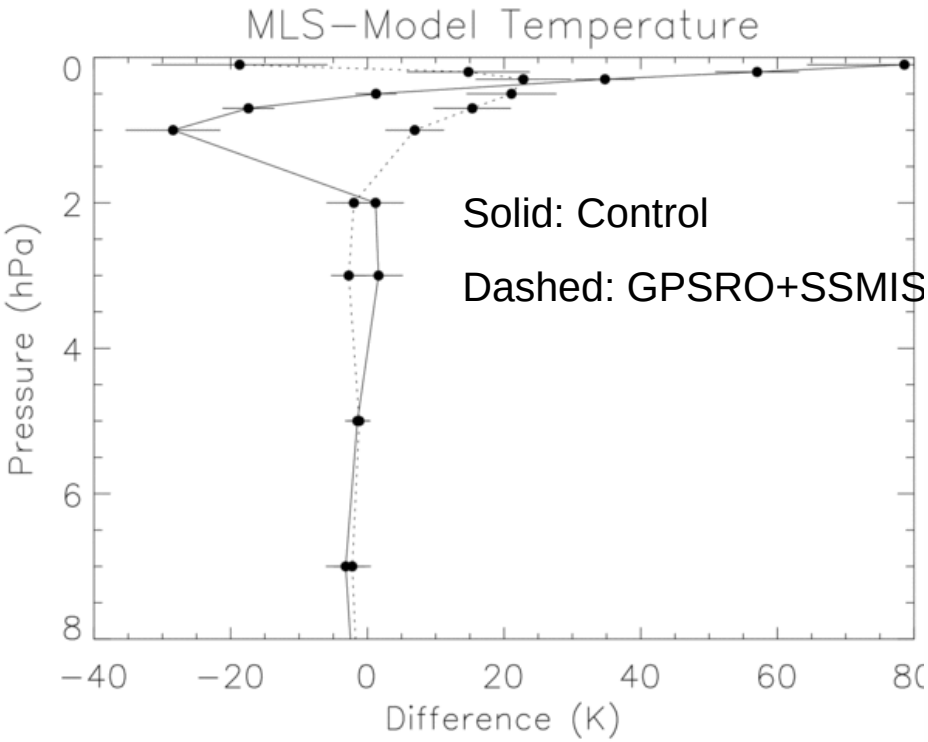


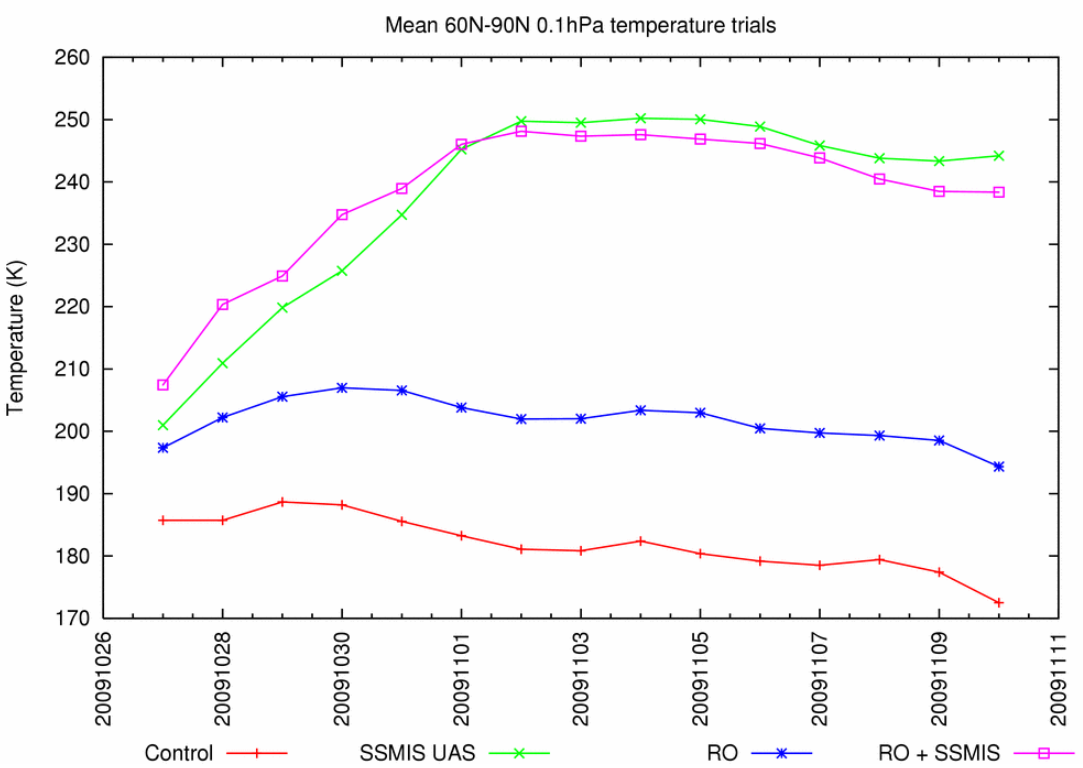
Plot courtesy of Mike Thurlow

Max. temp. at 1 hPa, with **warm bias** potential solutions



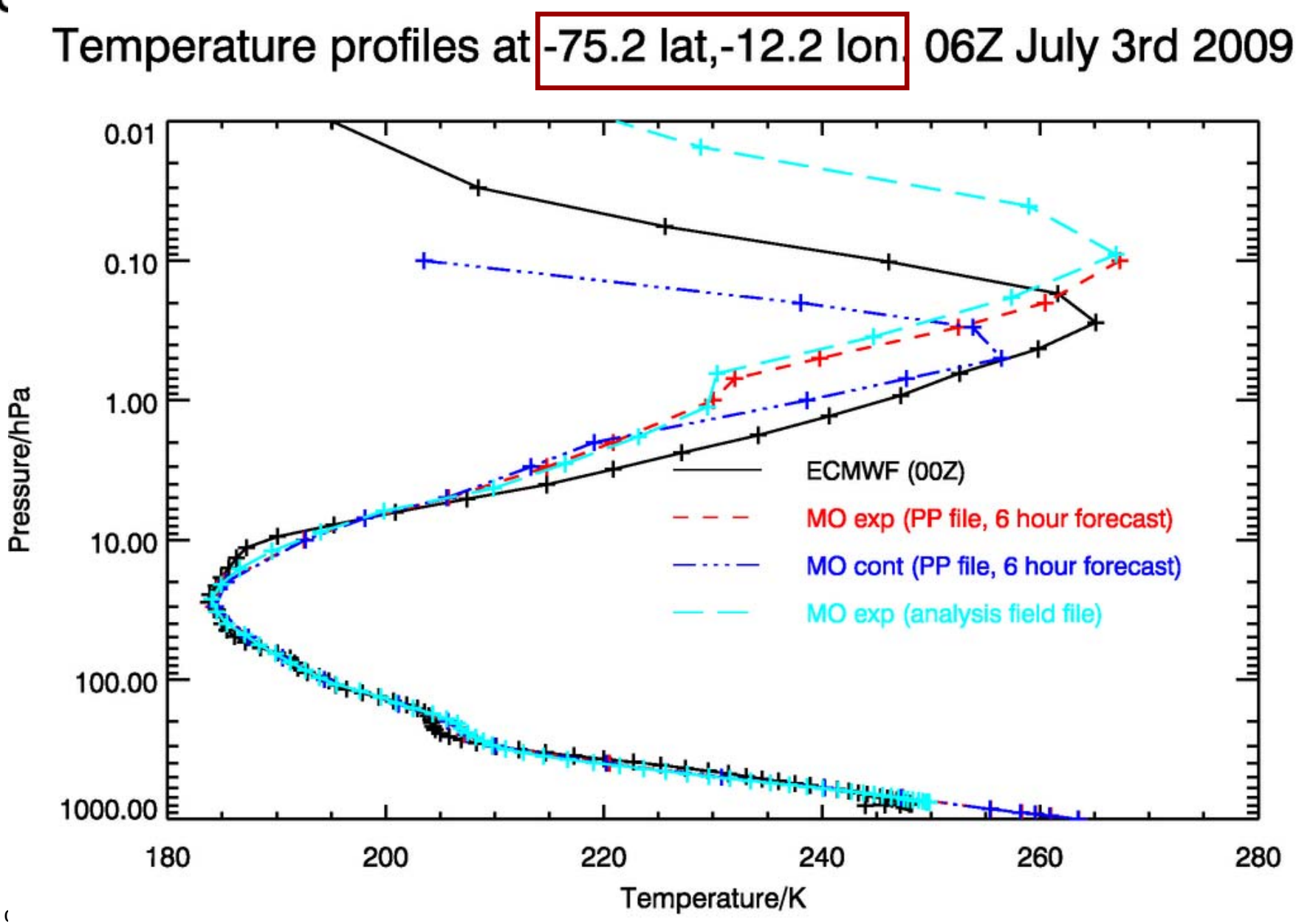
GPSRO+SSMIS UAS (21,22)





Plots courtesy of Brett Candy and Mike Thurlow

GPSRO+SSMIS effect in Antarctica (Jul 2009) – raises stratopause



Questions and answers

Potential future activities

- Examine quality of Terra SAR-X (GFZ) data for operational usage.
- Investigate GPSRO impact with new adjoint sensitivity tools.
- Investigate -ve bias in UT/S of UMKO model – what is GPSRO fighting against (probably aircraft temperatures).
- Analyse GRAS wave-optics-derived output, when available.
- More flexible obs errors – rather than latitudinal bands,