Diagnosing weak-constraint model error forcing and variational bias correction interaction in the ECMWF assimilation system

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ECMWF

Background

- ECMWF has re-introduced weak-constraint 4D-Var with model error forcing active above 40hPa.
- During the development it was noted that the first guess departures and bias correction for several instruments were reduced when the weak-constraint formulation was used, particularly for channels peaking in the upper atmosphere.
- We investigate the interaction between model error forcing and variational bias correction (VarBC) and the effect on the mean analysis state.

Background

Strong-constraint 4D-VAR

$$
\begin{aligned}
J(\mathbf{x}_0) =& \frac{1}{2}(x_0 - x_b)^{\mathrm{T}}\mathbf{B}_x^{-1}(x_0 - x_b) \\
&+ \frac{1}{2}\sum_{k=0}^{N}(\mathcal{H}_k(x_k) - y_k)^{\mathrm{T}}\mathbf{R}_k^{-1}(\mathcal{H}_k(x_k) - y_k)
\end{aligned}
\tag{1}
$$

Weak-constraint 4D-VAR with VarBC

$$
\begin{aligned}
J(\mathbf{x}_0, \eta, \beta) =& \frac{1}{2}(x_0 - x_b)^{\mathrm{T}}\mathbf{B}_x^{-1}(x_0 - x_b) + \frac{1}{2}(\beta - \beta_b)^{T}\mathbf{B}_\beta^{-1}(\beta - \beta_b) \\
&+ \frac{1}{2}\sum_{k=0}^{N}(\mathcal{H}_k(x_k) - y_k)^{\mathrm{T}}\mathbf{R}_k^{-1}(\mathcal{H}_k(x_k) - y_k) \\
&+ \frac{1}{2}(\eta - \eta_b)^{\mathrm{T}}\mathbf{Q}^{-1}(\eta - \eta_b)
\end{aligned}
\tag{2}
$$

Both the model error forcing and VarBC have spin up periods of several months but there has been very little research into how they interact and if either dominates over the other. To investigate this we vary three parameters at initialisation;

- initial atmospheric state
- model error forcing
- VarBC
  - NB. In these experiments we consider a VarBC coldstart as all radiances start from mode of first guess, AIREP, GBRAD start from zeros. This is quite an extreme reset, in practice when adding a new instrument just that instrument is spun up.

Initialisation Experiments:

- Weak-constraint 4D-Var - from this experiment we can initialise a spun up:
  - VarBC
  - model error forcing
  - atmospheric state
- Strong-constraint 4D-Var - from this experiment we can initialise a spun up:
  - VarBC
  - atmospheric state

VarBC can be initialised from either experiment or cold started.

Eliminating Less Influential Options

- As expected the initial atmospheric state was found to have very little influence on the analysis state beyond 10-12 days. For this reason here we only show results from an atmospheric state initialised from the spun up weak-constraint experiment.
- Initialising VarBC from either of the pre-spun up initialisation experiments also had little influence on the analysis state. Again we only show results from VarBC warm started from the spun up weak-constraint experiment.

Focussed Experiments

Choosing the initialisations with the largest impact:

	Atmospheric State	Model Error Forcing	VarBC
Control	Weak-constraint	Warm	Warm
Exp 1	Weak-constraint	Warm	Cold
Exp 2	Weak-constraint	Cold	Warm
Exp 3	Weak-constraint	Cold	Cold

Model Error Forcing Spinup

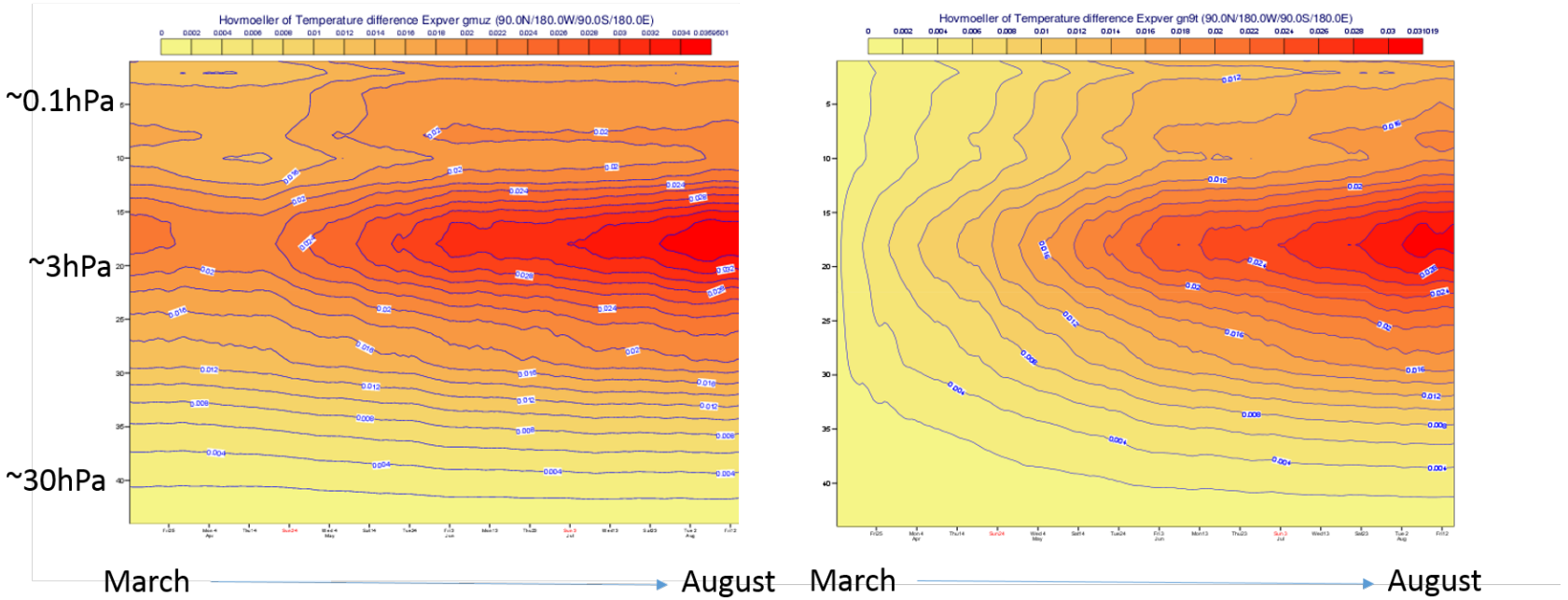
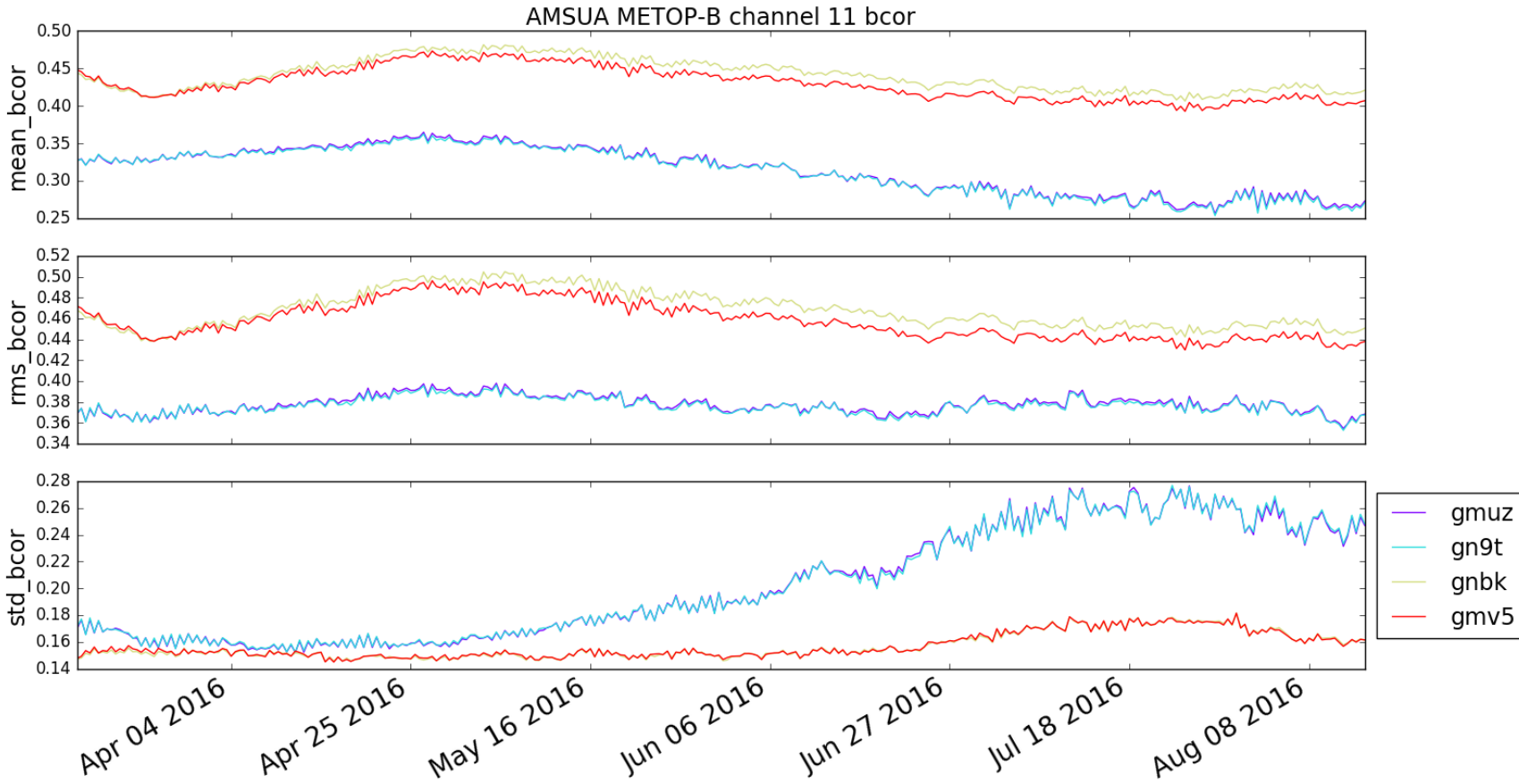


Figure: Left: Warmstart continues to evolve for whole period may still be spinning up or may be seasonal forcing, Right: Coldstart does not spin up to same amplitude as warmstart within 6 months.

VarBC Time Series



Bias Correction Structure

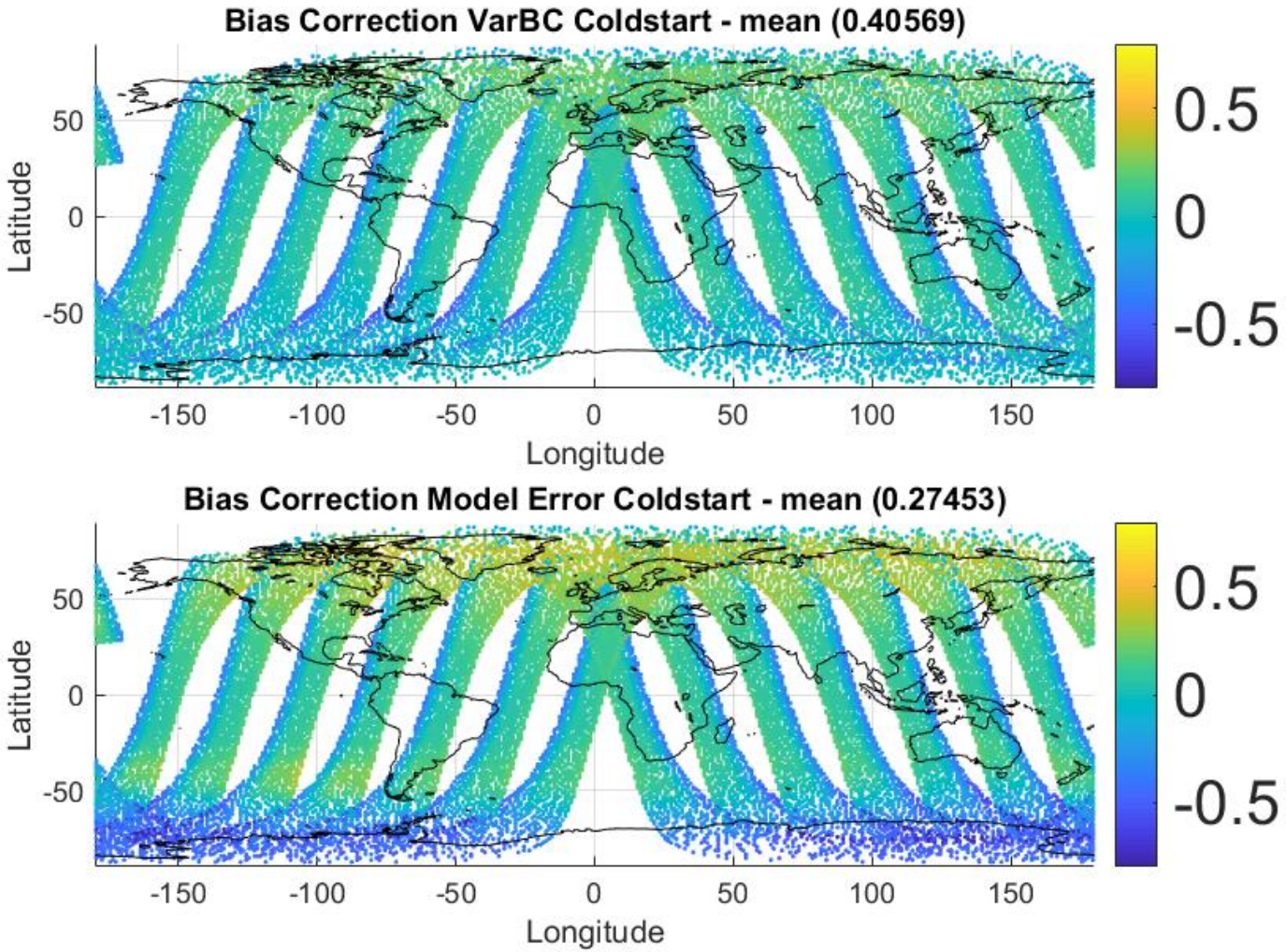


Figure: AMSUA Metop-B Chan 11 14/07/16

Initial Conclusions

- Neither the model error forcing nor VarBC spin-up to the same state after several months of experimentation but instead stabilise at a different state.
- Both the model error forcing and VarBC initialisation were found to influence the mean analysis state in the upper atmosphere 6 months after initialisation.
- Their influence on the mean analysis state is distinct, different in magnitude and in character.
- How significant are these changes in the mean analysis state?

Influence on Analysis State

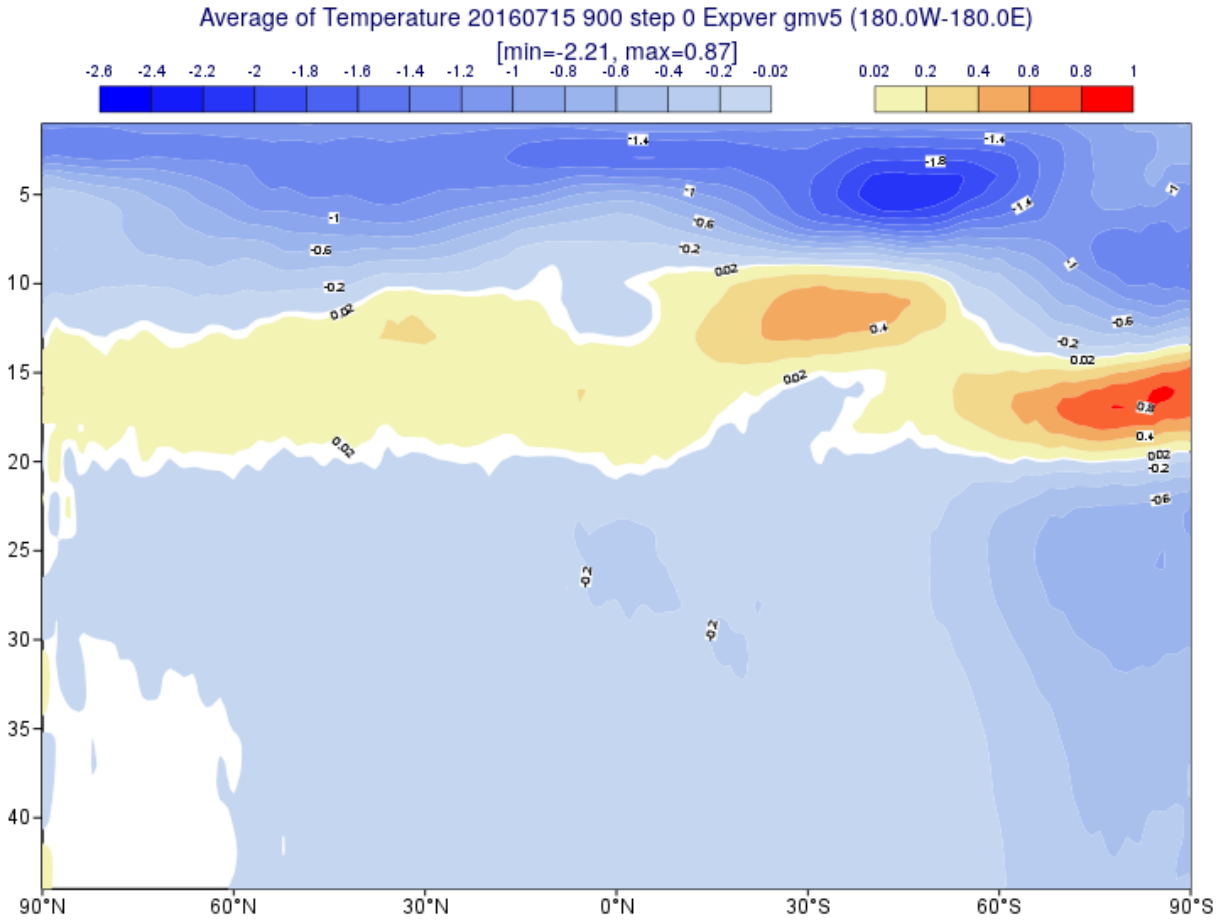


Figure: Difference in the zonal mean temperature analysis (Control - Exp 1), period 15/07/16-15/08/16.

Influence on Analysis State

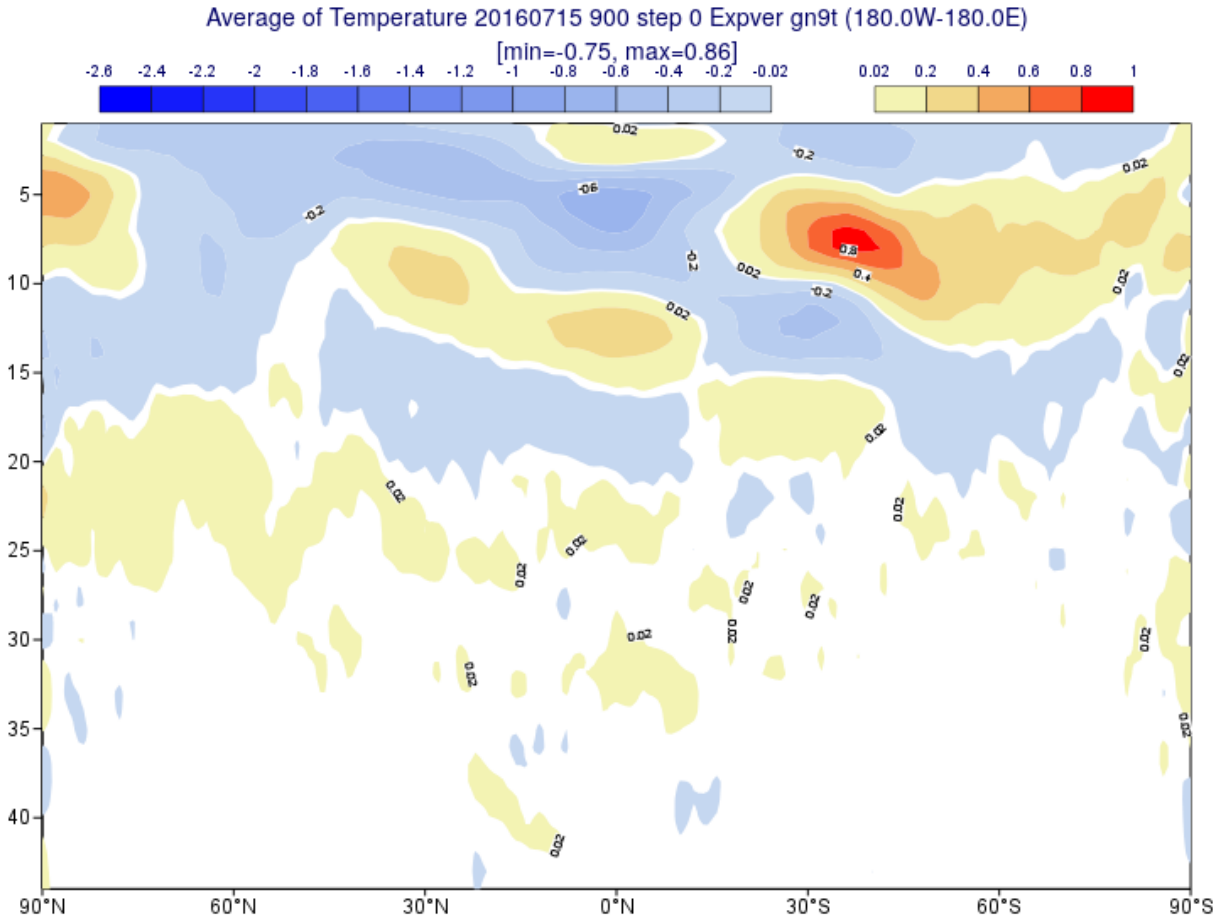


Figure: Difference in the zonal mean temperature analysis (Control - Exp 2), period 15/07/16-15/08/16.

Influence on Analysis State

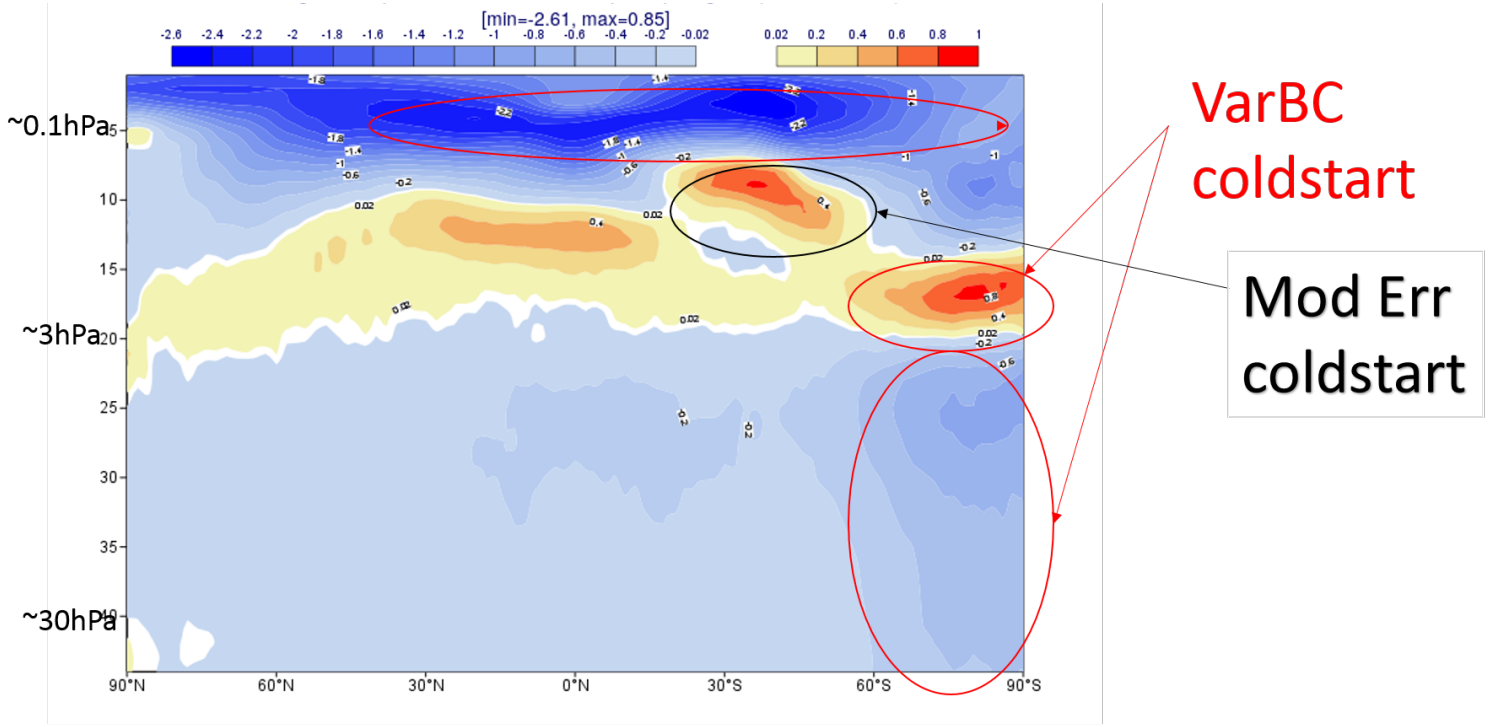
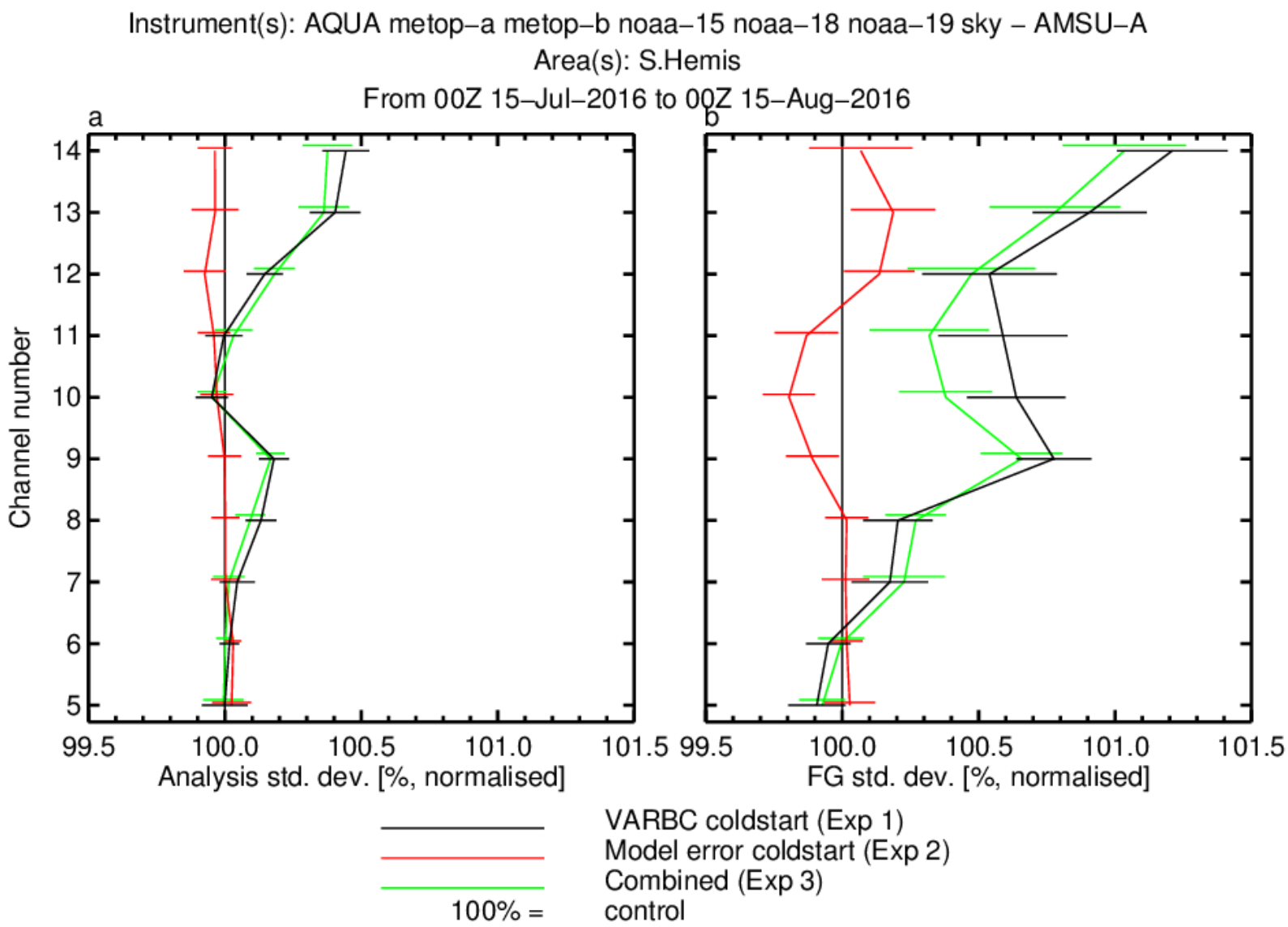


Figure: Difference in the zonal mean temperature analysis (Control - Exp 3), period 15/07/16-15/08/16.

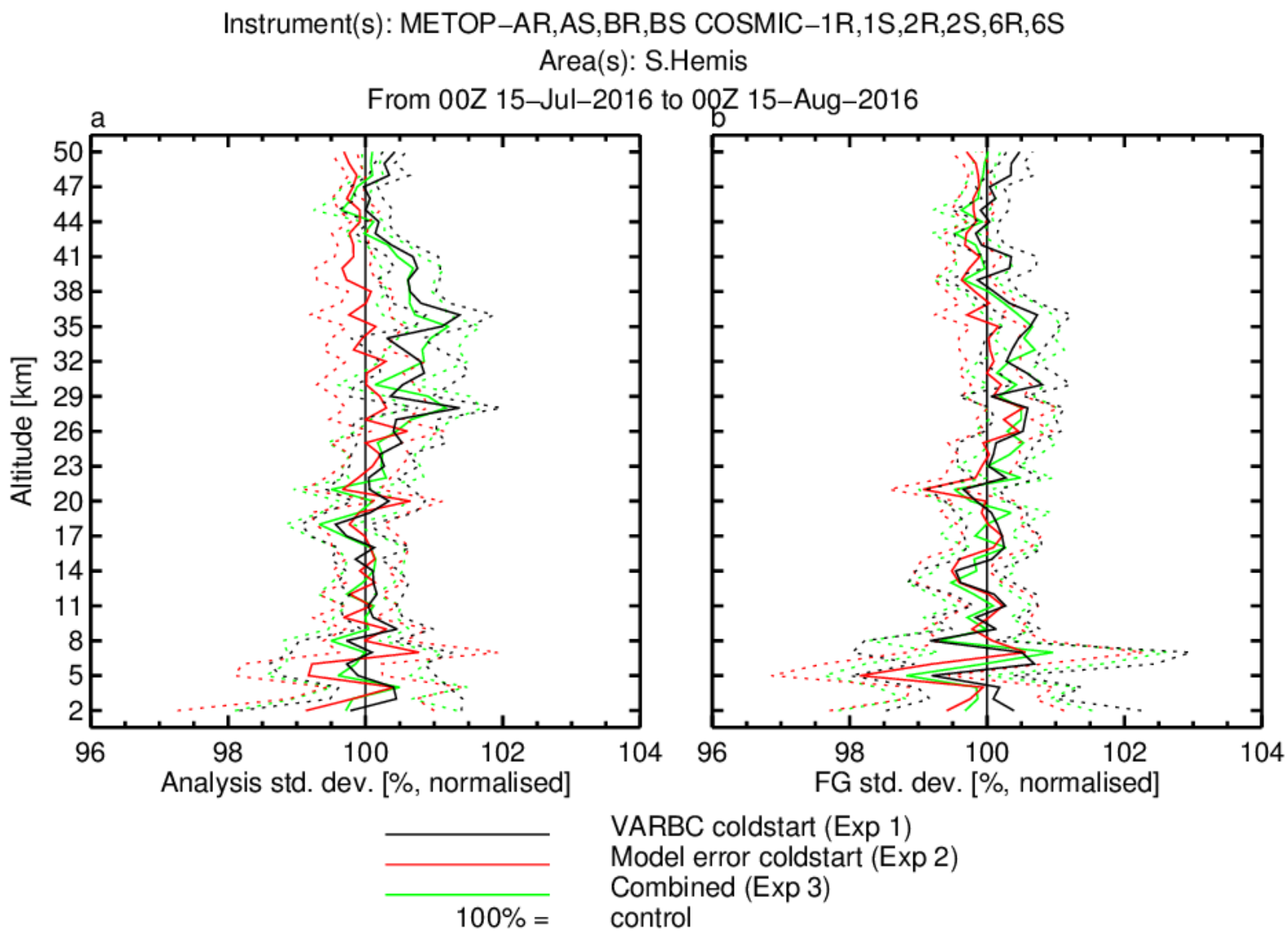
Uncertainty

- Both model error forcing coldstart and VarBC coldstart influence the analysis state but how confident are we on the true atmospheric state?
- We have temperature observations from radiosondes (up to 5 hPa) and bending angles from Global Positioning System Radio Occultation (GPSRO) measurements which have relatively poor sensitivity above about 5hPa.
- There are not many datasets which give temperature information with good global coverage in the upper stratosphere/lower mesosphere.
- The changes to the analysis state above 10hPa are within the uncertainties of the model but the changes lower down can be compared to observations for verification.

Obstat


Instrument(s): AQUA metop–a metop–b noaa–15 noaa–18 noaa–19 sky – AMSU–A
Area(s): S.Hemis
From 00Z 15–Jul–2016 to 00Z 15–Aug–2016
a
b
Channel number
14
13
12
11
10
9
8
7
6
5
99.5
100.0
100.5
101.0
101.5
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
VARBC coldstart (Exp 1)
Model error coldstart (Exp 2)
Combined (Exp 3)
100% =
control

Obstat

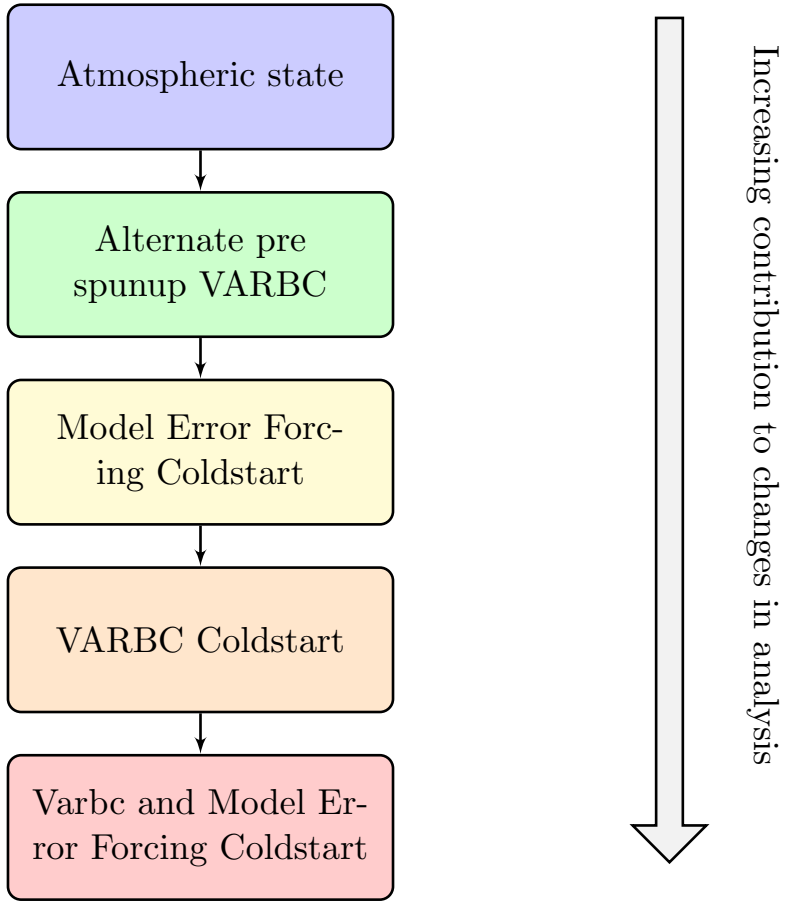

Instrument(s): METOP–AR,AS,BR,BS COSMIC–1R,1S,2R,2S,6R,6S
Area(s): S.Hemis
From 00Z 15–Jul–2016 to 00Z 15–Aug–2016
a
b
Altitude [km]
50
47
44
41
38
35
32
29
26
23
20
17
14
11
8
5
2
96
98
100
102
104
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
VARBC coldstart (Exp 1)
Model error coldstart (Exp 2)
Combined (Exp 3)
100% =
control

Conclusions

VARBC and model error forcing interaction:

- The experiments with cold-starting the model error forcing or VarBC show that both take a number of months to spin up, and they do not necessarily converge to the same state as a warm-started experiment.
- The model error term continues to spin up after 6 months of experimentation without reaching the same amplitude as a warm-started experiment.
- Effects of a cold start can also be seen in the zonal mean temperature analysis after 6 months of experimentation.

Most Influential Factor: Tentative Conclusions



Any Questions?