The effect of NWP model bias on radiance bias correction schemes

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From James Cameron

Operational:

- in Global model, March 2016
- in UKV, July 2017.

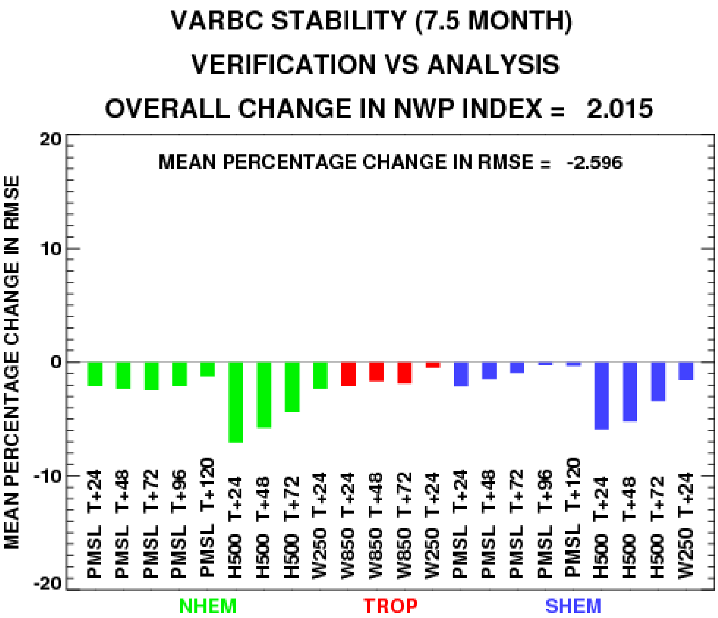
Bias predictors:

- as old scheme (2 thicknesses)

+

- orbital bias predictors for SSMIS

Bias halving time: 2 days



Impact – VERY LARGE!:

- T+24 H500 RMSE vs analysis: **-7.1%** in NH and **-5.9%** in SH
- Improved (O-B) fits, e.g. 2-6% improved fit to ATMS

The bias correction problem in DA

- Standard DA theory assumes observations are unbiased
- … or that they are bias-corrected ahead of the DA

- Bias correction is necessary for assimilation of radiances
- … for biases in the observations and/or their operators

- Two types of observation in DA:
  - "Anchor" observations, assumed unbiased
    - may have been pre-corrected (e.g. sondes)
    - may still contain biases
  - Observations to be bias-corrected within the DA system

HOWEVER …

What is the purpose of observation bias correction in DA?

- ~~To remove biases between observations and NWP fields (backgrounds or analyses)~~

- **To improve NWP analyses and forecasts**

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Types of bias correction scheme used within DA systems

Bias correction schemes can:

- attempt to remove biases:
  - relative to **background**, or
  - relative to **analysis**

- be “**static**” (one-off), or
- iterated to convergence
  (e.g. variational bias correction, **VarBC**)

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Bias correction literature

- “Static” bias correction (against background)
  - Eyre, ECMWF TM 176, 1992
  - Harris and Kelly, QJRMS, 2001
- VarBC (correction against analysis)
  - Derber and Wu, MWR, 1998
  - Dee, ECMWF Workshop, 2004; Dee, QJRMS, 2005
- “Off-line scheme” (like VarBC, but correcting v. background)
  - Auligné et al., QJRMS, 2007
- **General papers on biases in DA and forecast model bias**
  - **Dee and da Silva, QJRMS, 1998; Dee, QJRMS, 2005**

This study

- An attempt to understand scientific differences between Met Office old “static” scheme and new VarBC scheme
- Uses a very simple system (one variable)
- Explores the role of anchor observations
- **Explores the role of model bias**

For details see:

Eyre J.R., 2016. Observation bias correction schemes in data assimilation systems. Q.J.R.Meteorol.Soc., **142**, 2284–2291.

This study – key result

- Bias correction of observations is not “passive”. …

- … In the presence of model bias,
  bias-correcting a greater proportion of observations pulls the analysis away from the anchor observations and towards the model bias

→ Consequences for how we should do bias correction in future

Very simple assimilation system: the analysis step

- One scalar analysis variable
- Scalar observations in same space as analysis

Analysis, at n^th step:

$$x_{a,n} = w_b x_{b,n} + w_1 y_{1,n} + w_2 y_{2,n}$$

$x_{a,n}$ = analysis, $x_{b,n}$ = background
$y_{1,n}$ = anchor observations, $y_{2,n}$ = observations to be bias-corrected
w_j = analysis weights – general, not necessarily optimal, but …

$$w_b + w_1 + w_2 = 1$$

Very simple assimilation system: the error model

Biases and random errors:

$$x_{j,n} = x_{t,n} + b_j + \varepsilon_{j,n}$$

truth　　bias　　random error

$$y_{j,n} = y_{t,n} + b_j + \varepsilon_{j,n}$$

→

$$b_a = w_b b_b + w_1 b_1 + w_2 b_2$$

Very simple assimilation system: the forecast step and its bias

$$x_{b,n+1} = x_{f,n} = x_{a,n} + \delta x_{m,n}$$

forecast model

$$\delta x_{m,n} = \delta x_{t,n} + \delta b_{m,n} + \varepsilon_{m,n}$$

forecast increment

true increment   bias   random error

Forecast model bias: $$\delta b_{m,n} = \alpha(x_{m,n} - x_{a,n})$$

- a relaxation towards state $x_{m,n}$, which has bias b_m
- where the relaxation rate is α .

→ $$b_{b,n+1} = (1-\alpha)b_{a,n} + \alpha\, b_m$$ bias propagation in time

Theoretical properties (1)

In asymptotic limit, and assuming anchor obs unbiased,

with a **static bias correction scheme** (correcting against background):

$$\frac{b_b}{b_m} = \frac{\gamma}{\gamma + w_1}$$

$$\frac{b_a}{b_m} = \frac{\gamma(1 - w_1)}{\gamma + w_1}$$

b_b	background bias	relative to anchor obs
b_a	analysis bias	relative to anchor obs
b_m	model bias	relative to anchor obs
w_1	weight of anchor observations	
γ	a model relaxation rate, $\gamma = \alpha/(1- \alpha)$	

Theoretical properties (2)

In asymptotic limit, and assuming anchor obs unbiased,

with **VarBC** (correcting against analysis):

$$\frac{b_b}{b_m} = \frac{\gamma(1-w_2)}{\gamma(1-w_2)+w_1}$$

$$\frac{b_a}{b_m} = \frac{\gamma(1-w_1-w_2)}{\gamma(1-w_2)+w_1}$$

w_2 weight of bias-corrected observations

***

So we now have **4 equations** for **bias as a fraction of model bias**:

- for **background bias**, and for **analysis bias**

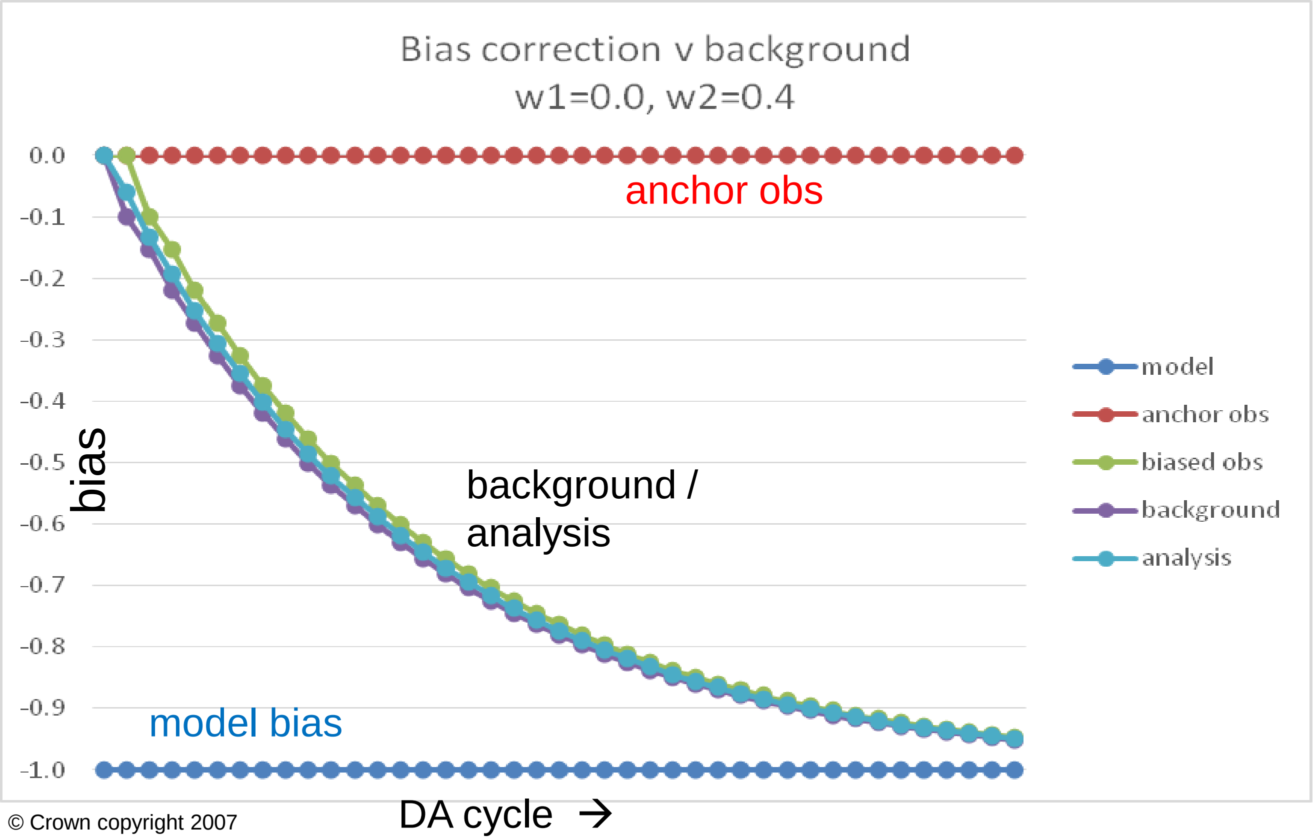
- correcting **against background**, and correcting **against analysis**

This study – parameters used

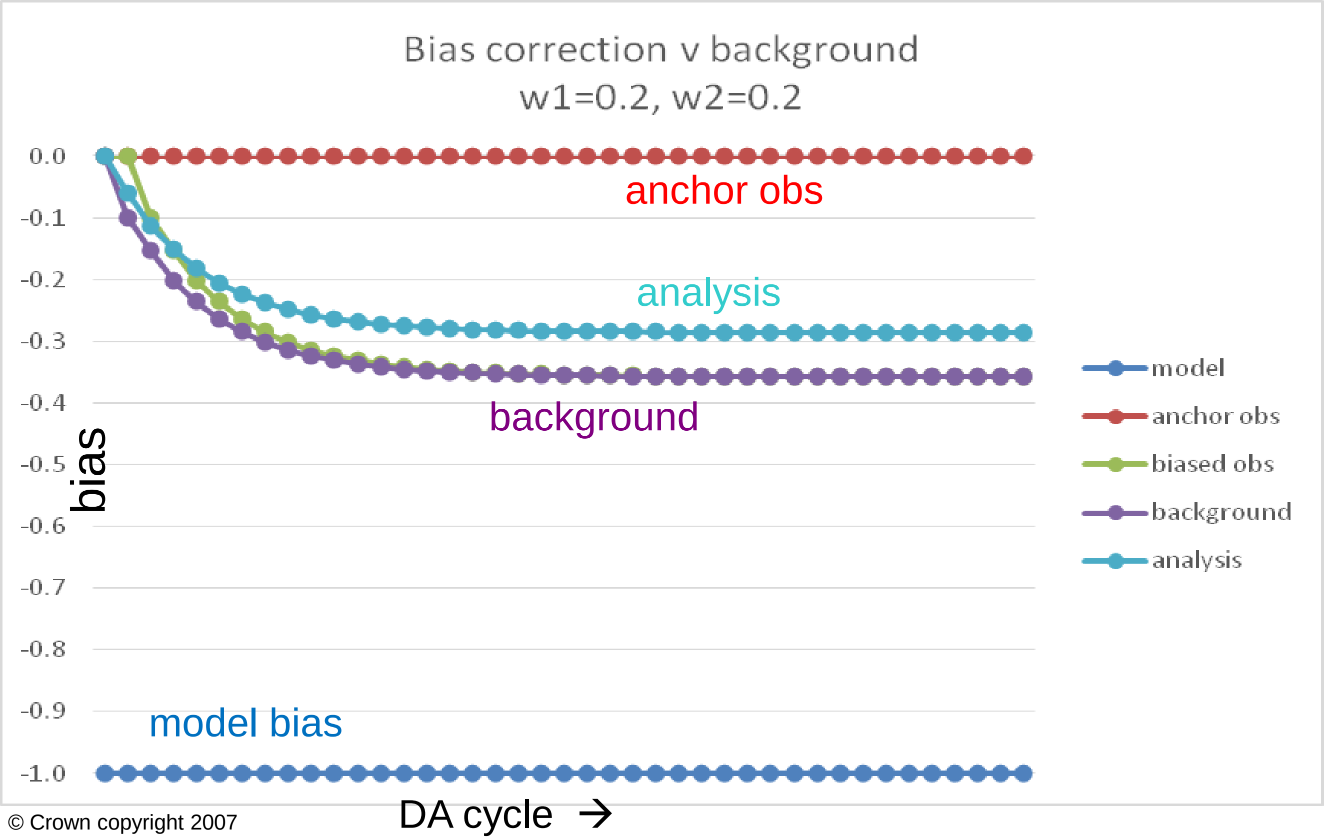
Baseline values – to mimic Met Office global NWP system

- Total observation weight, $\mathrm{Tr}(\mathbf{W})/p \approx 1-\{\mathrm{E}(J_{of})/\mathrm{E}(J_{oi})\}^{0.5}$
  where $\mathbf{W}$ is matrix of obs weights, dimension p,
  $\mathrm{Tr}(\ldots)$ = trace, $\mathrm{E}(\ldots)$ = expected value,
  J_{if} = VAR initial observation cost,
  J_{of} = VAR final observation cost.
  For Met Office global 4D-Var, $J_{if}/J_{of} \approx 0.6\text{-}0.7$,
  and so $\mathrm{Tr}(\mathbf{W})/p \approx 0.2$
- FSOI results → $w_1 \approx w_2$ → $w_1 = w_2 = 0.2$
- Model relaxation time ≈3 days → $\gamma = 0.1$ (per DA cycle)

Asymptotic behaviour:
no weight to anchor observations



Asymptotic behaviour:
baseline weights



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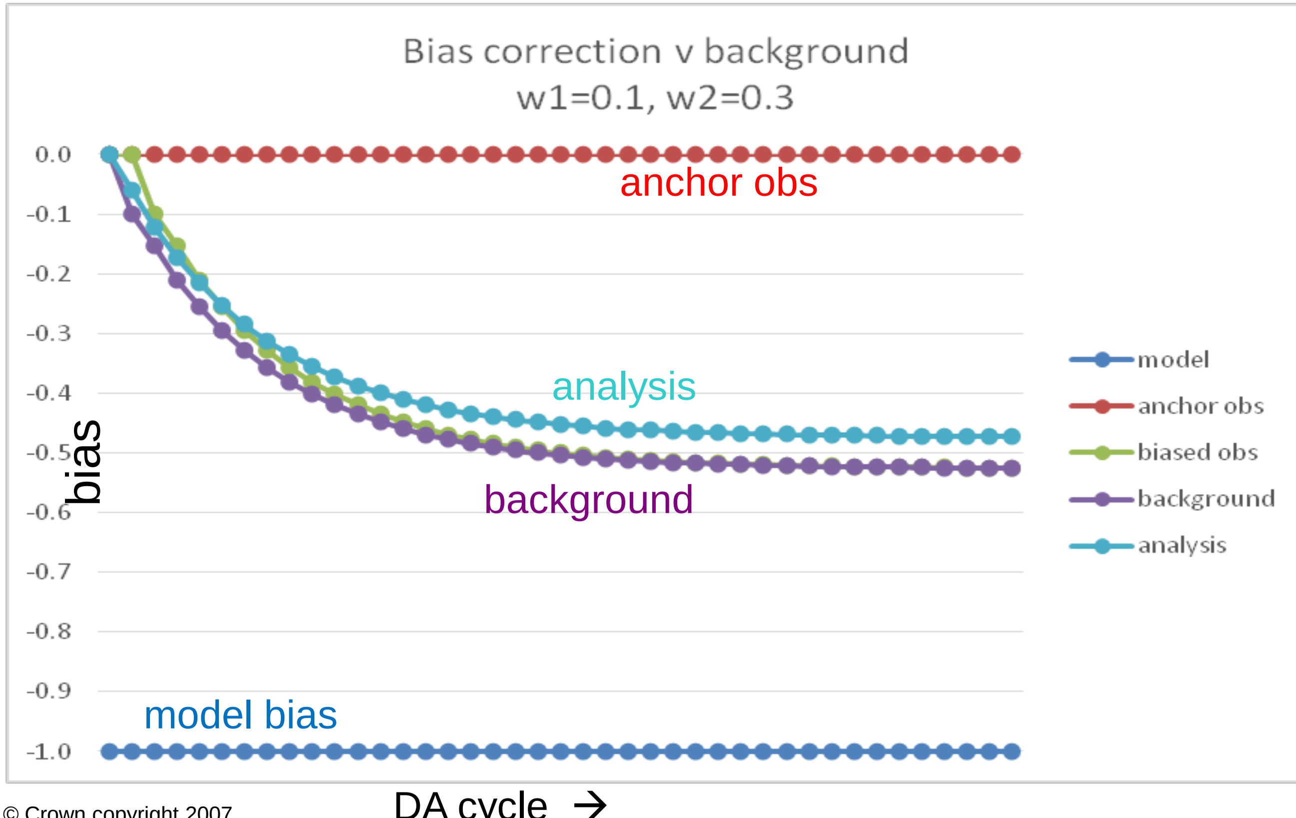
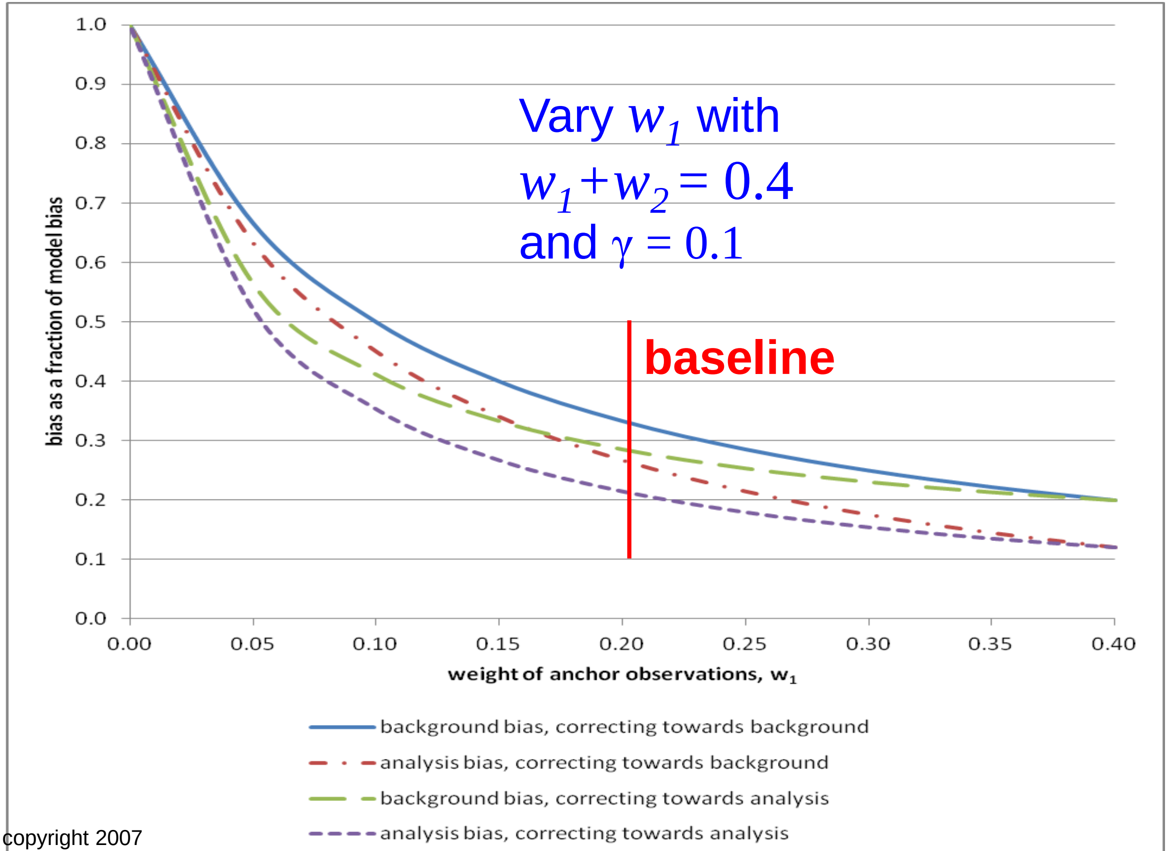
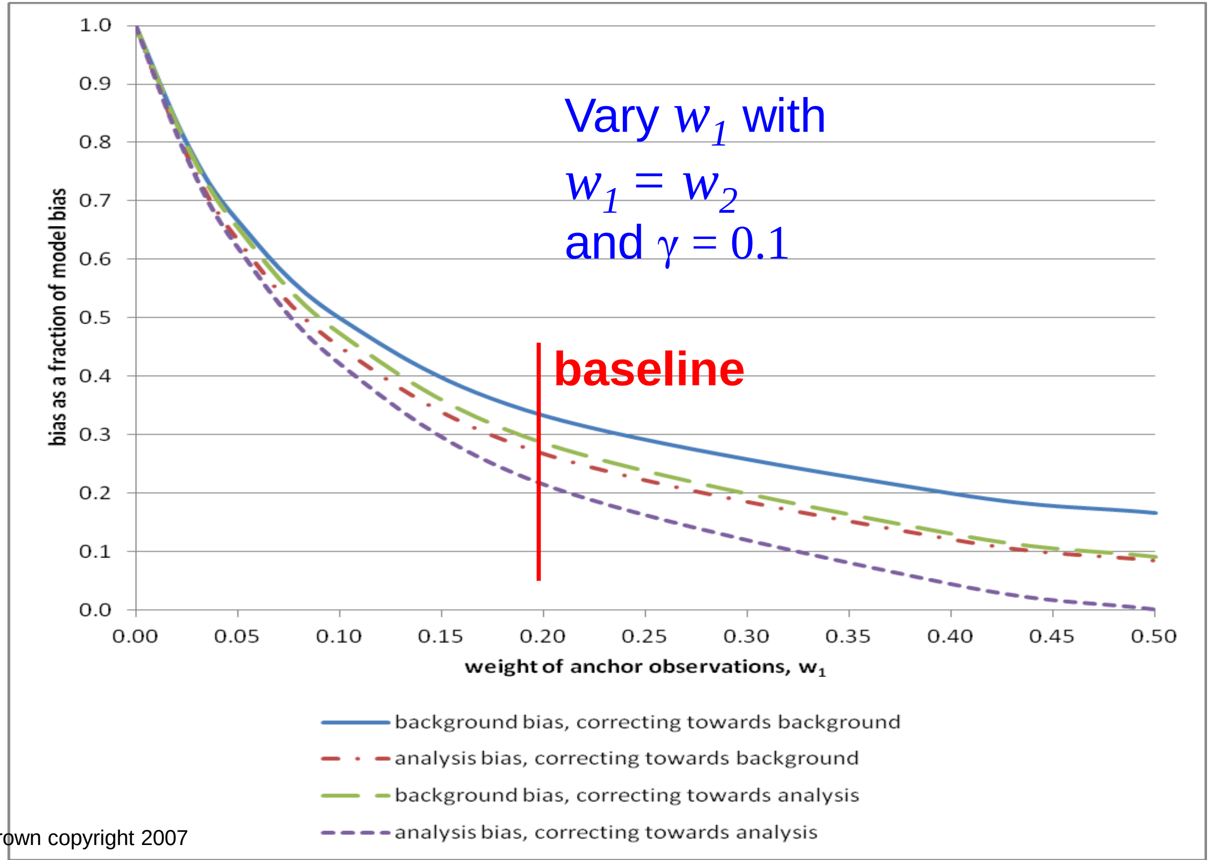
Asymptotic behaviour:
reduced weight to anchor observations



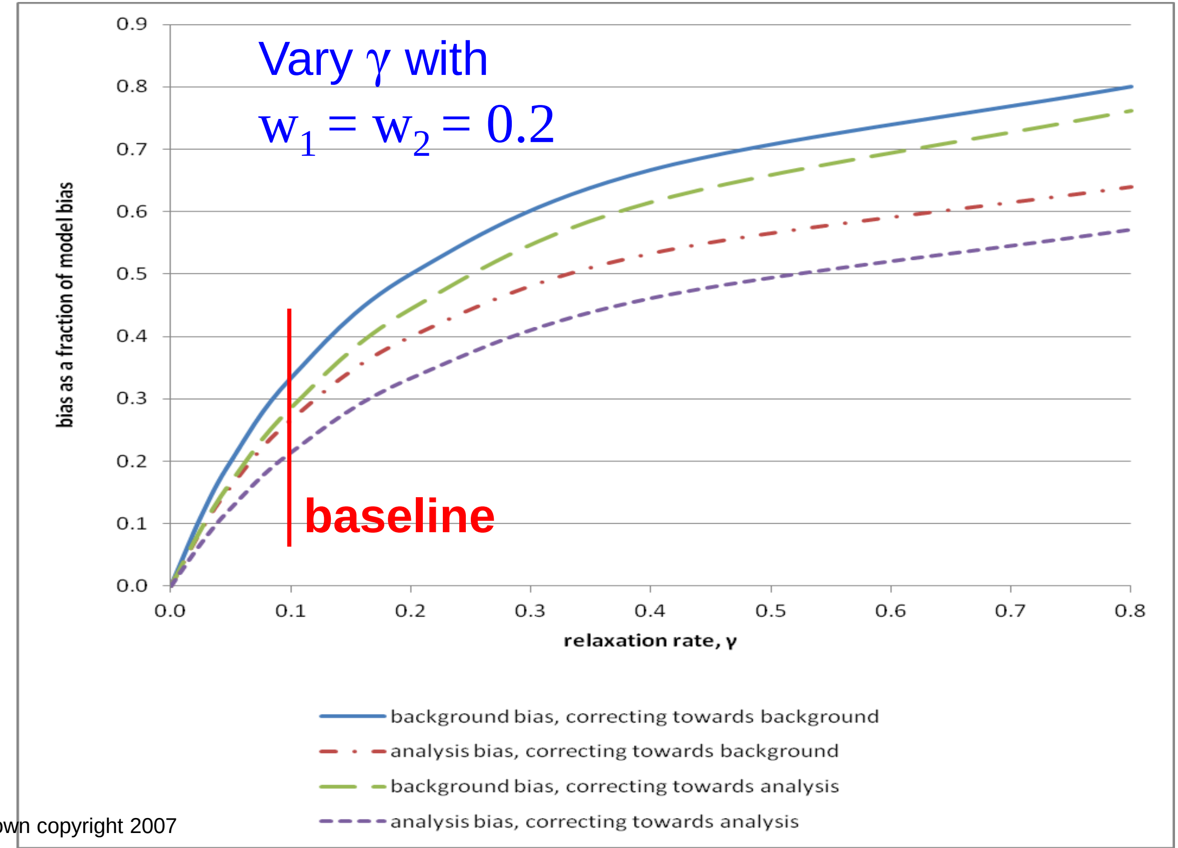
At convergence:
varying relative weight of anchor obs



At convergence:
varying total weight of observations



At convergence:
varying model relaxation rate



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Some findings (1)

- In asymptotic limit, **biases in background and analysis are weighted averages of model bias and bias in anchor observations**, when correcting against background or against analysis.

- When **more** observations are bias-corrected, less weight is given to anchor observations and **more** weight to model bias.
- This effect is less pronounced when correcting v. analysis (VarBC) than when correcting v. background … but difference is small.

- In VarBC, effect of model bias is realised quickly; …
- …in static scheme not fully realised, or only through repeated application of scheme.

Some findings (2)

- Baseline values used in this scheme are intended to be representative of Met Office global NWP system

  → **background/analysis bias is ~0.3 of model bias** ! …

- … but much variation expected within model domain – according to observation density, fraction of anchor observations, height, model variable

Implications and questions

- Effect of adding more and more radiances
- Role of radio occultation
- Bias correction of radiosondes?
- Choice of bias predictors?
  - Avoid predictors for which variables have large model biases, particularly if they change rapidly, e.g. LST or cloud
- Choice of radiances used to compute bias correction coeffs.?
  - Take care with radiances affected by land surface or cloud

- Need for improved bias correction strategies?

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Conclusions

- In the absence of model bias, bias correction of observations is relatively straightforward.
- **Radiance bias correction is not "passive" – it reinforces model bias.**
- VarBC is less affected by model bias that an equivalent scheme attempting to remove bias relative to the background,
- … but difference is small compared with model bias itself.
- With baseline values used here background / analysis biases are ~0.3 of model bias – larger than expected.
- **As relative weight of anchor observations decreases,**

  effect of model bias on background/analysis bias increases

  → important implications for observation bias correction strategies.

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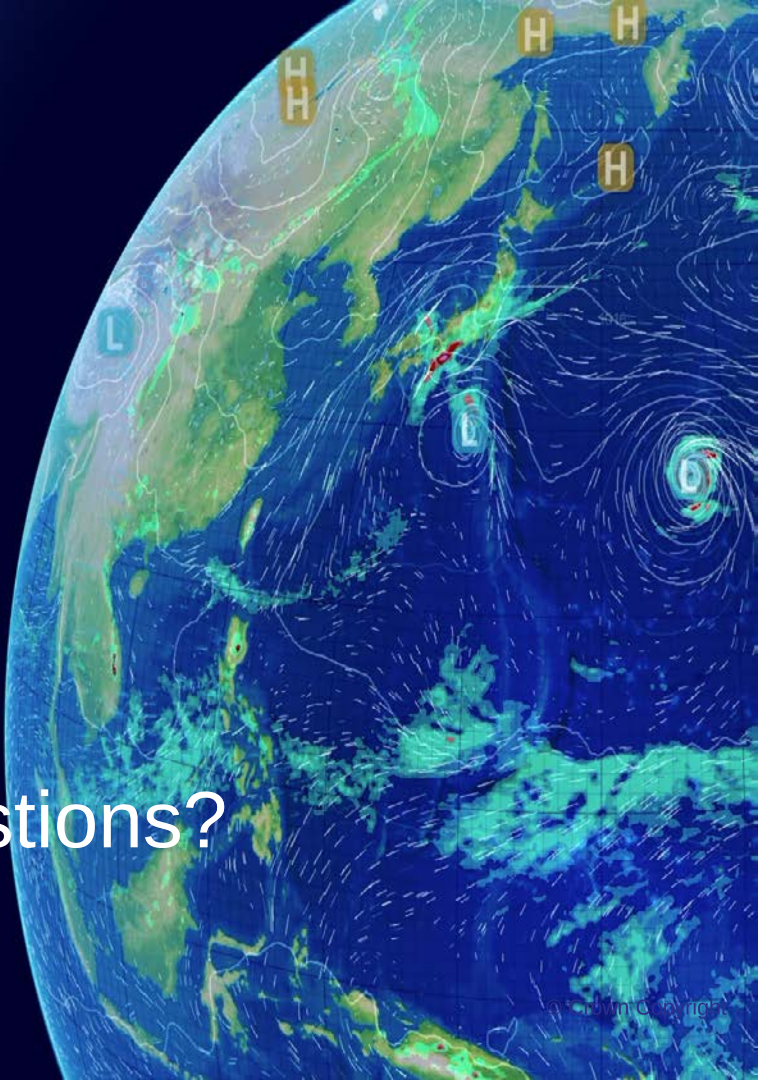

Thank you! Questions?

A very simple assimilation system (4)

Combining these equations →

$$b_b = b_a + \alpha(b_m - b_a) = (1-\alpha)b_a + \alpha b_m$$

→

$$b_b = \frac{\gamma b_m + w_1 b_1 + w_2 b_2}{\gamma + w_1 + w_2}$$

$$b_a = \frac{\gamma(1 - w_1 - w_2)b_m + (1+\gamma)(w_1 b_1 + w_2 b_2)}{\gamma + w_1 + w_2}$$

weighted averages

where $\gamma = \alpha/(1-\alpha)$

Special case – no model bias

No model bias: $\alpha = \gamma = 0$:

→ $$b_a = b_b = \frac{w_1 b_1 + w_2 b_2}{w_1 + w_2}$$

If also, $w_2 = 0$

→ $$b_a = b_b = b_1$$

Bias correction strategy:

- introduce observations y_2 into DA system passively: $w_2 = 0$
- monitor bias in y_2 against background: $c_2 = b_2 - b_b$
- bias-correct y_2 : $y_2{}^* = y_2 - c_2$

These bias-corrected observations will now have bias:

$$b_2{}^* = b_2 - c_2 = b_b = b_a = b_1$$

PERFECT!!!

Effects of model bias (1)

With a **static bias correction scheme**, after 1st application:

using (O-B) statistics →
$$c_2 = b_2 - b_b = b_2 - \frac{\gamma b_m + w_1 b_1 + w_2 b_2}{\gamma + w_1 + w_2}$$

In principle, you can stop here.

*** But we tend to repeat the process in an ad hoc manner ***

If you repeat the process to convergence:

→
$$b_b = \frac{\gamma b_m + w_1 b_1 + w_2 b_b}{\gamma + w_1 + w_2}$$

If $b_1 = 0$, →
$$\frac{b_b}{b_m} = \frac{\gamma}{\gamma + w_1}$$
$$\frac{b_a}{b_m} = \frac{\gamma(1 - w_1)}{\gamma + w_1}$$