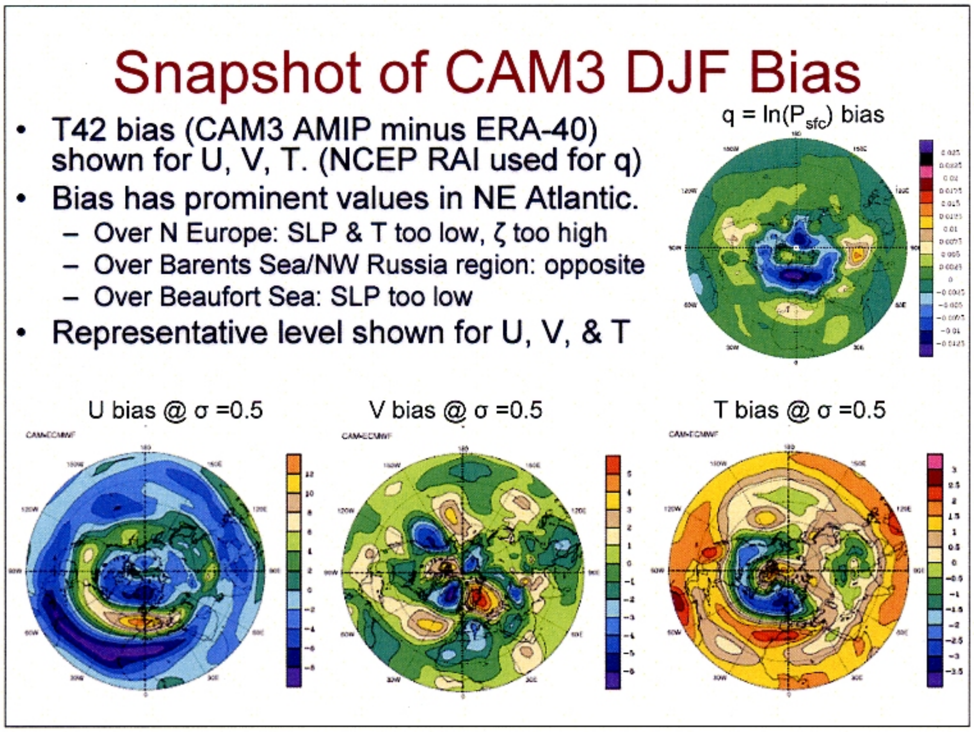
Arctic Surface DJF Biases in CAM3 Viewed As Forcing Fields

Richard Grojahn and Linlin Pan
Dept. of LAWR, Univ. of California, Davis
With assistance from
Joe Tribbia, Grant Branstator and Andy Mai

In this talk we shall only show new calculations since those shown in January 2007 AMWG and June 2007 CCSM workshop.



Bias has multiple poles primarily in the Arctic and in the North Atlantic. The well-known model bias where the downstream end of the N Atlantic storm track enters N Europe instead of heading further north is seen in vorticity bias, SLP dipole straddling Scandinavia, and in the cold temperature bias of the N Atlantic.

FYI: the q bias was calculated using NCEP/NCAR reanalysis I data.

Study Contributions to the Temperature bias equation:

$$\underbrace{\hat{\vec{V}} \bullet \nabla \overline{T}_E + \overline{\vec{V}}_E \bullet \nabla \hat{T} + \hat{\omega}\left(\frac{\partial \overline{T}_E}{\partial p} - \frac{\alpha_E}{C_p}\right) + \overline{\omega}_E\left(\frac{\partial \hat{T}}{\partial p} - \frac{\hat{\alpha}}{C_p}\right)}_{\text{TERM 1}} = \underbrace{-\hat{\vec{V}} \bullet \nabla \hat{T} - \hat{\omega}\left(\frac{\partial \hat{T}}{\partial p} - \frac{\hat{\alpha}}{C_p}\right)}_{\text{TERM 2}}$$

$$\underbrace{-\overline{\vec{V}'_C \bullet \nabla T'_C} + \overline{\vec{V}'_E \bullet \nabla T'_E} - \overline{\omega'_C \frac{\partial T'_C}{\partial p}} + \overline{\omega'_E \frac{\partial T'_E}{\partial p}}}_{\text{TERM 3}} + \hat{Q}\,.$$

- T bias equation is CAM T equation minus ERA-40 T eqn.
  - $\hat{T} = T_C - T_E$. Where T_C is CAM3, T_E is era-40 DJF temperature
  - Term 1 has CAM bias and ERA-40 combinations found in a linear stationary wave (LSW) model such as Branstator (1990)
  - Term 2 (nonlinear bias terms)
  - Term 3 (all transient terms)
  - $\hat{Q} = Q_C - Q_E$ diabatic heating bias. Q_C & Q_E use independent $\overline{Q}$ eqn
- T equation in LSW is Term 1 + forcing term

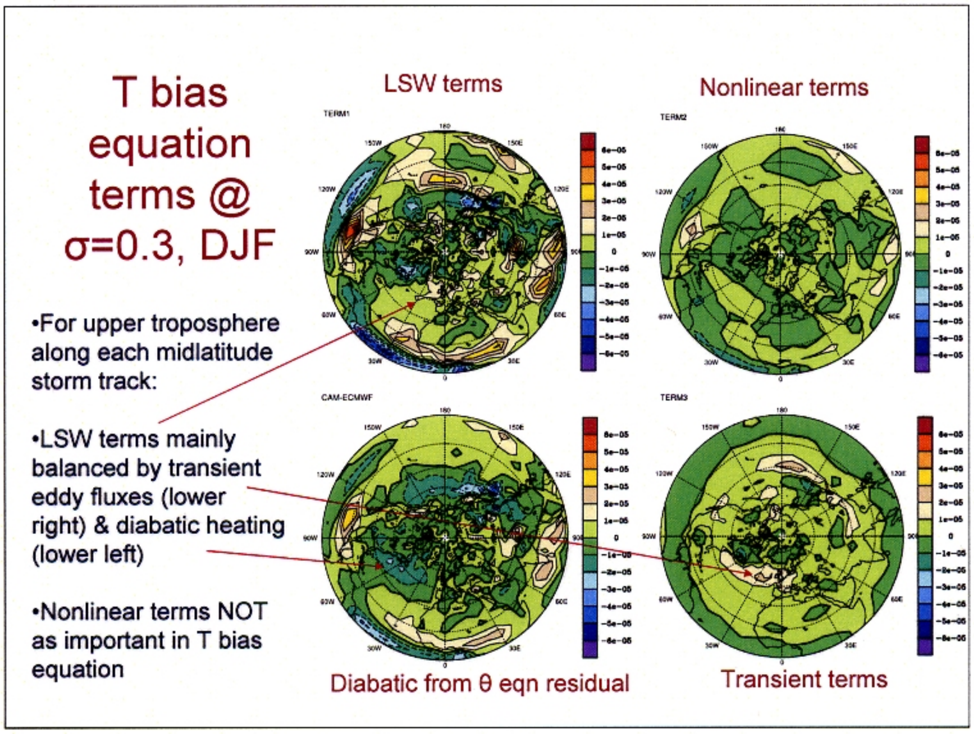
$$\overline{Q} = \overline{\Delta T / \Delta t} + \overline{\vec{V}} \bullet \nabla \overline{T} + (p/p_0)^{\frac{R}{C_p}} \overline{\omega} \partial \overline{\theta} / \partial p + (p/p_o)[\nabla \bullet \overline{\vec{V}\theta'} + \partial(\overline{\omega'\theta'})/\partial p]$$

One can formulate an equation for the bias in temperature (equals T hat) by subtracting the T equation using CAM data from the corresponding T equation using ERA-40 data. This is then time averaged to get the top equation.

The terms are placed into four groups. The group labeled term1 are terms explicitly kept in a linear theoretical model to be discussed later. Term 2 has all nonlinear combinations of the bias terms. Term 3 has all transient heat flux terms from both CAM and ERA-40.

The diabatic heating bias is NOT calculated as a residual of this equation. It is calculated as a residual of a potential temperature equation shown on the bottom line. This follows the Hoskins et al 1989 approach. Q hat is thus somewhat independently estimated.

We next show which groups in the temperature equation are larger.

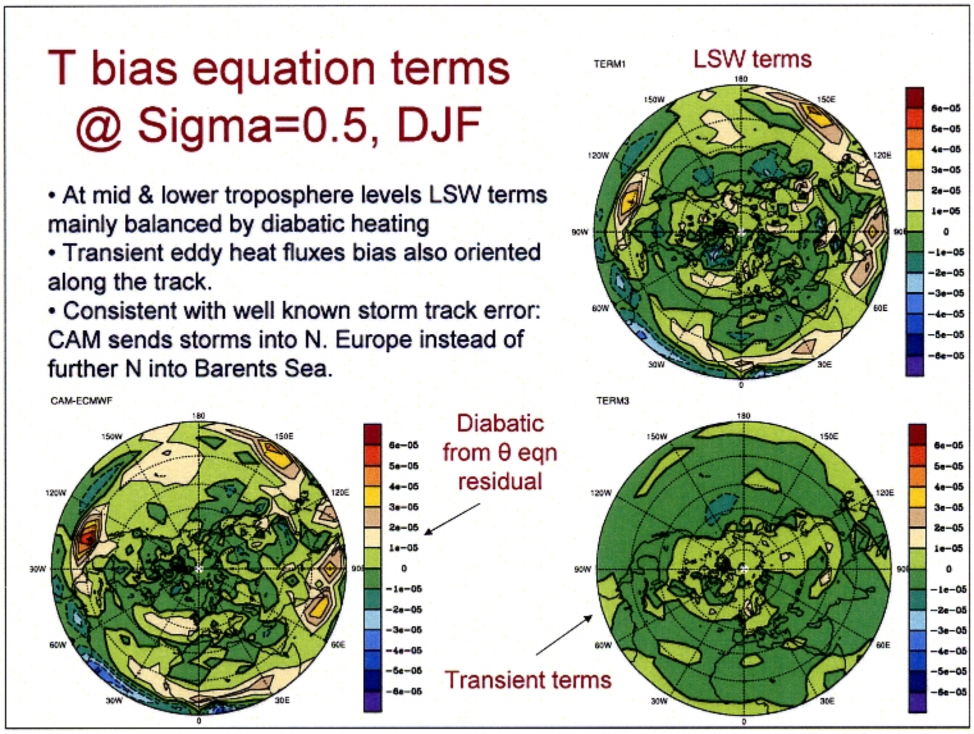


The terms in the LSW are actually the larger terms.

The nonlinear terms not kept in Grant's model are small N of 20N and cannot balance the LSW terms.

The transient terms are small in the lower troposphere but more important in the upper troposphere as shown here. The transient terms are larger in parts of the midlatitude storm tracks (Atlantic and to a lesser extent the Pacific).

The diabatic heating bias balances the LSW terms in the tropics. For areas N of 20N diabatic bias is important in the N Atlantic at this upper troposphere level. Diabatic bias is more important at mid tropospheric and lower tropospheric levels not shown on this slide.



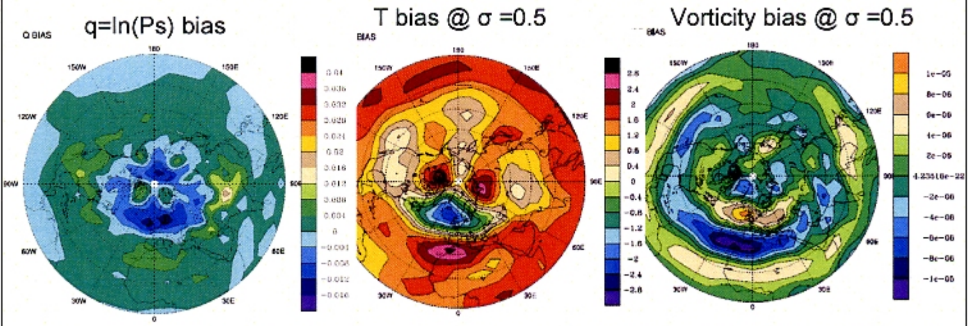
Similar to last slide but for a mid tropospheric level.

The scale changes between figures, but the diabatic term is a larger than the the transient heat flux terms in the N Atlantic storm track region.

The transient terms are similar to bias in the heat flux components (not shown) that are consistent with the storm track error.

Linear Model to Study CAM3 Bias

- **We treat CAM3 bias as if it is a forced linear stationary solution.**
- Use Linear Stationary Wave (LSW) model of Branstator (1990)
- Use model to input bias field and find forcing. (Can input subset of bias)
- Can input forcing and find solution: as check or to test subsets of the forcing.
- **Model severely limited to low resolution**: R17 with 8 levels (R11 unaliased)
- R11 bias shown; differs from T42; warm bias over N Canada and NW Russia much larger. BUT R11 has similar dipole in N Atlantic due to storm track error.
- **LSW tests find: Arctic bias linked to forcing in the local region of the Arctic AND to the N Atlantic storm track forcing. NOT linked to tropics.**



Since the linear bias terms are larger than the nonlinear terms, we can use a linear stationary wave model to study the bias. The transient eddy forcing and the diabatic forcing can be lumped into a 'forcing' term in that linear model.

We use LSW model of Branstator (1990) to calculate what forcing is sufficient to generate parts of the bias field. Due to the large matrix size, this model is severely limited in the horizontal truncation.

Reducing the truncation alters some properties of the bias. Most notably for this study, the warm bias over N Canada and NW Russia is more prominent at R11. There is still a temperature dipole in the N Atlantic, though its position is shifted somewhat.

Bias in the Arctic region is not affected by including forcing in tropical latitudes in Grant's LSW model. That result was deduced from various runs. For example using only that portion of the forcing N of 30N (derived from global bias) recovers the Arctic bias input. This was further narrowed down to forcing in the Arctic and the the N Atlantic. (Not the tropics, and not much from the Pacific storm track)

Conclusions

- **A temperature bias equation has been examined.**
- T bias eqn terms comprise 4 groups:
  - linear combinations of the T bias,
  - diabatic heating bias,
  - transient heat fluxes bias,
  - nonlinear (bias x bias) terms.
- **The diabatic heating and and transient eddy groups are prominent at latitudes higher than 30N (mainly in the midlatitude storm tracks) Nonlinear bias terms are small**
- The diabatic heating and transient heat fluxes are consistent with the well know storm track error in the N Atlantic.
- **The linear terms are included in a linear stationary wave (LSW) model, so such a model can be used to study the bias as if the bias were a stationary wave pattern. (The LSW model also includes divergence, vorticity, and log of surface pressure equations.)**
- LSW model severely limited by low resolution but previously we showed:
  - Bias in Arctic can be reproduced from forcing in Arctic and the N Atlantic.
  - Vorticity & T forcing have larger contribution than divergence and ln(Ps) forcing.
- **Future work may include testing the forcing in CAM from this T eqn analysis and from a corresponding vorticity eqn analysis.**

A temperature bias equation was formed and examined. The T bias eqn terms comprise 4 groups:

1. linear combinations of the T bias and the analysis,
2. diabatic heating bias,
3. transient heat fluxes bias,
4. nonlinear (in the bias) terms

The diabatic heating and and transient eddy groups are prominent at latitudes higher than 30N (mainly in the midlatitude storm tracks) Nonlinear bias terms are small

The diabatic heating and transient heat fluxes are consistent with the well know storm track error in the N Atlantic.

The linear terms are included in a linear stationary wave (LSW) model, so such a model can be used to study the bias as if the bias were a stationary wave pattern. (The LSW model also includes divergence, vorticity, and log of surface pressure equations.)

LSW model is severely limited by low horizontal resolution but previously we showed:

> The bias in the Arctic can be reproduced from using only the forcing in Arctic plus the forcing in the N Atlantic.
>
> Vorticity & T forcing were found to have larger contribution to reproducing the input bias than did the divergence and ln(Ps) forcing.

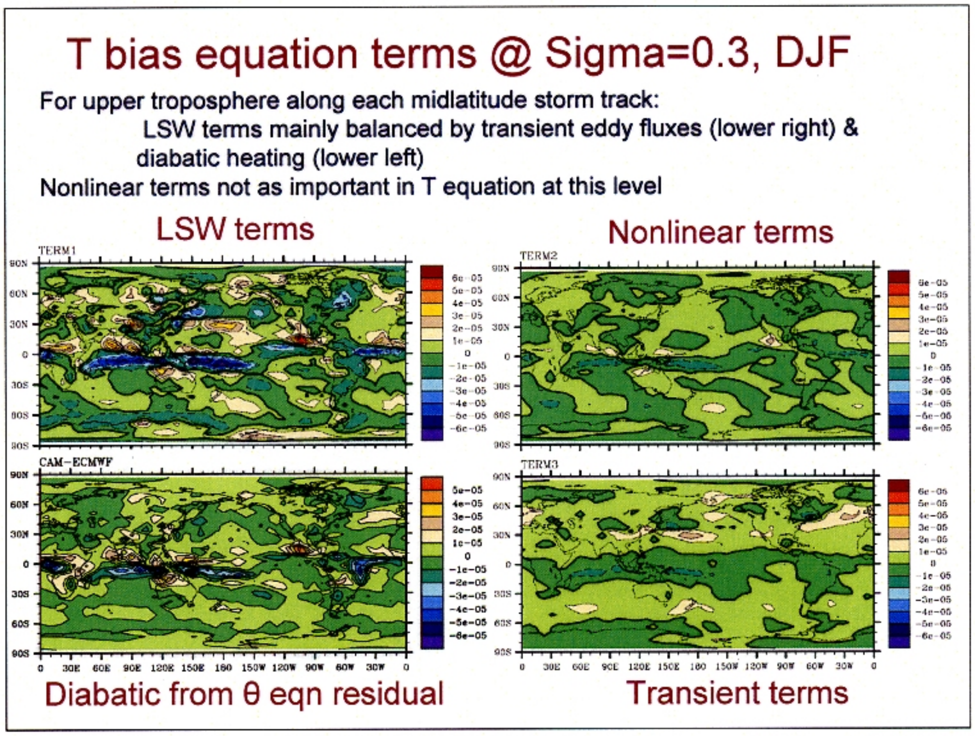
Future work may include testing the forcing in CAM from this T eqn analysis and from a corresponding vorticity eqn analysis.

The End

- Thanks for your attention!
- (Thanks Joe for giving this presentation!)

Storage below

- Slides below may be useful if there are questions.

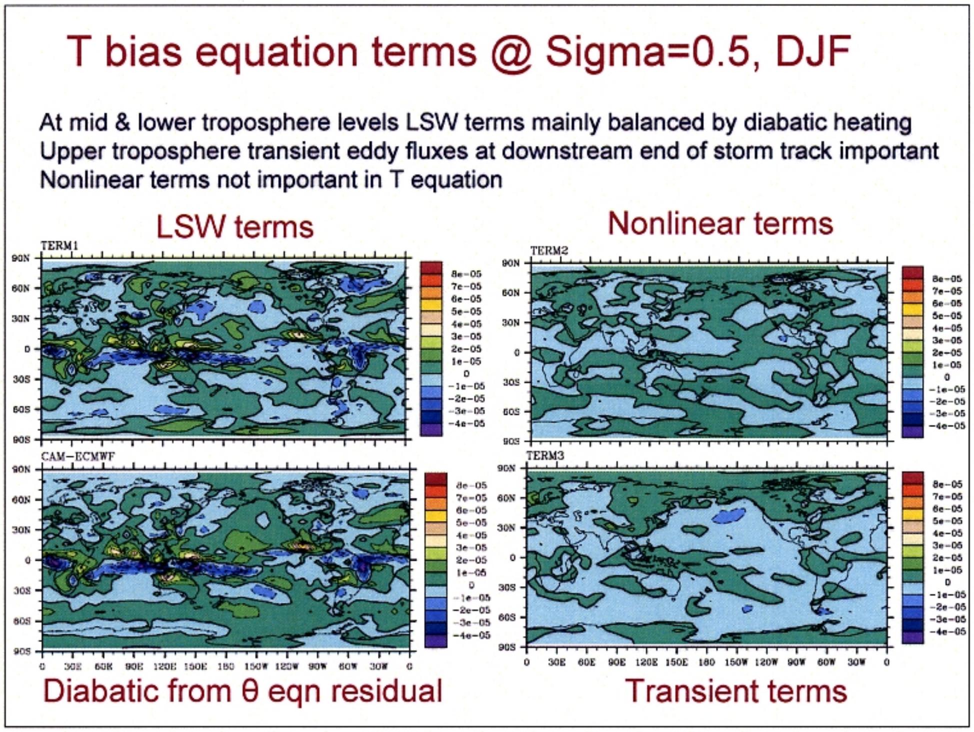


This is different map projection of slide 4. Tropical values are more easily seen if that is of interest.

The nonlinear terms not kept in Grant's model are small N of 20N and cannot balance the LSW terms.

The transient terms are small in the lower troposphere but more important in the upper troposphere as shown here. The transient terms are larger in parts of the midlatitude storm tracks (Atlantic and to a lesser extent the Pacific).

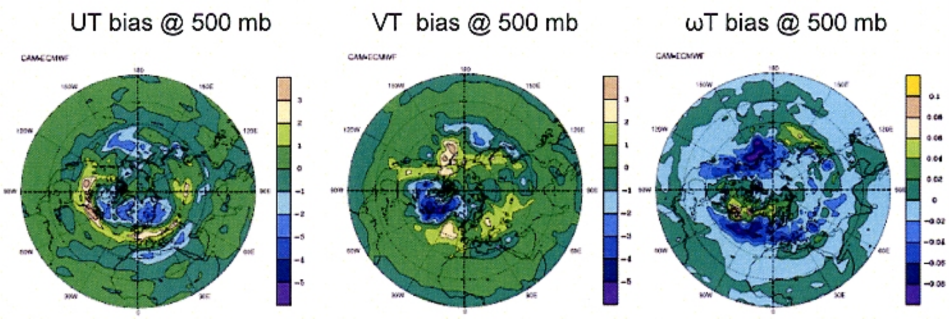
The diabatic heating bias balances the LSW terms in the tropics. For areas N of 20N diabatic bias is important in the N Atlantic at this upper troposphere level. Diabatic bias is more important at mid tropospheric and lower tropospheric levels not shown on this slide.



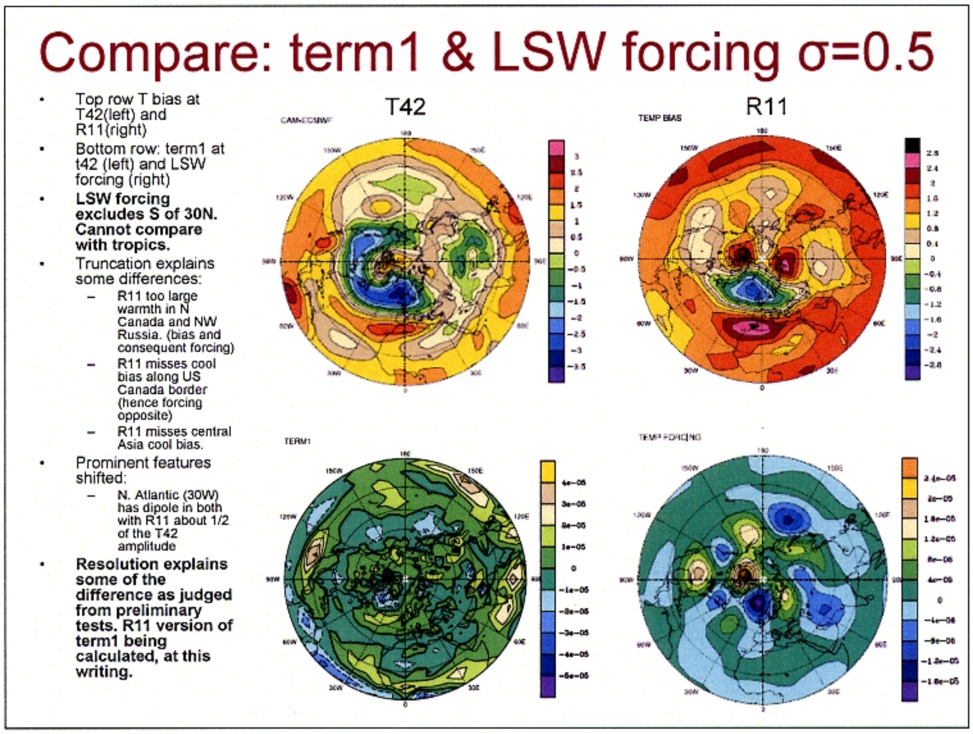
Similar to slide 5 but for a different map projection.

Bias in the heat flux components

- The 3 components of the heat fluxes.
- These include transient and stationary contributions.



These show the storm track shift on downstream end



This partly illustrates how the resolution change gives a different bias and a different forcing. Left column is from T bias equation at T42 resolution. Right column is from LSW model at R17 (but with R11 truncation shown since that part is alias-free.)