Diagnosing Arctic Winter CAM3 Bias with a Stationary Wave Model

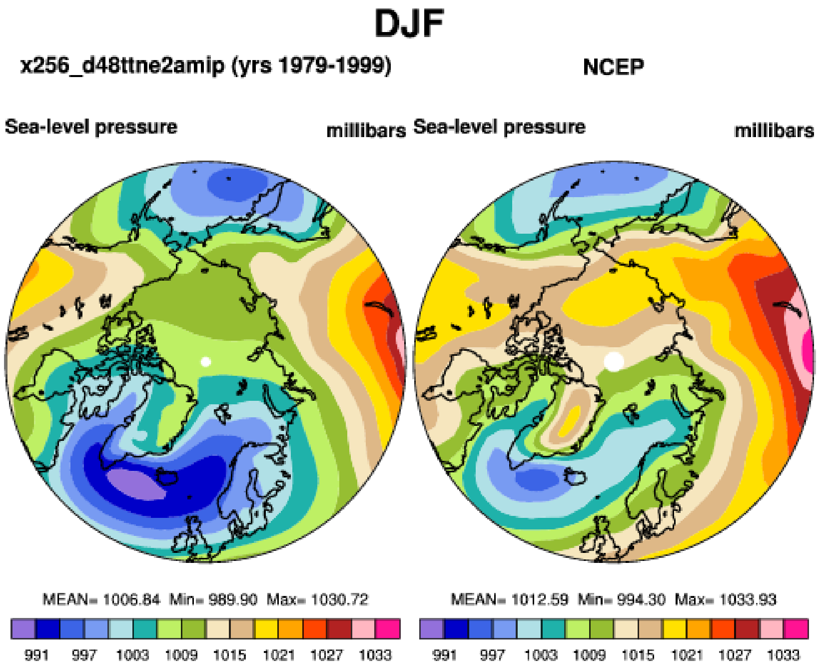
Richard Grotjahn and Muhtarjan Osman

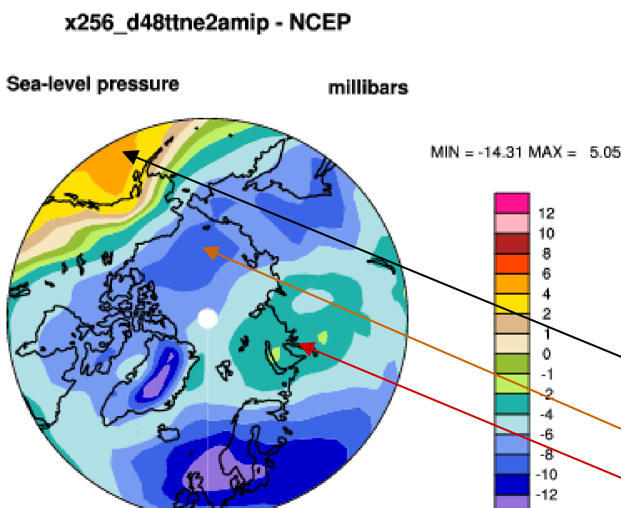
Dept. of Land, Air, & Water Resources
University of California, Davis

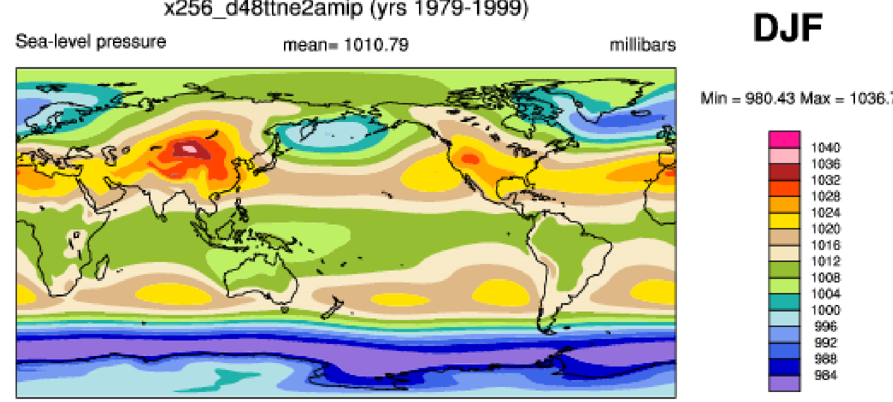
Outline

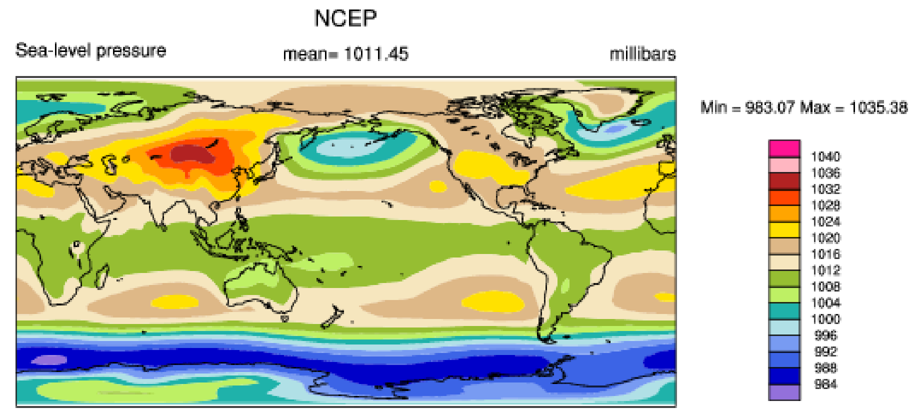
- What is the **bias** in Arctic surface climate?
  - Sea Level Pressure (SLP); part of NH ring pattern
  - Surface winds; on/off shore bias, flow across Alaska
  - Surface temperature; link to on/off shore bias flow
- What can **cause** the bias?
  - How well is it simulated?
  - Sources of simulation error
  - Tools for understanding & improving simulation
- Summary

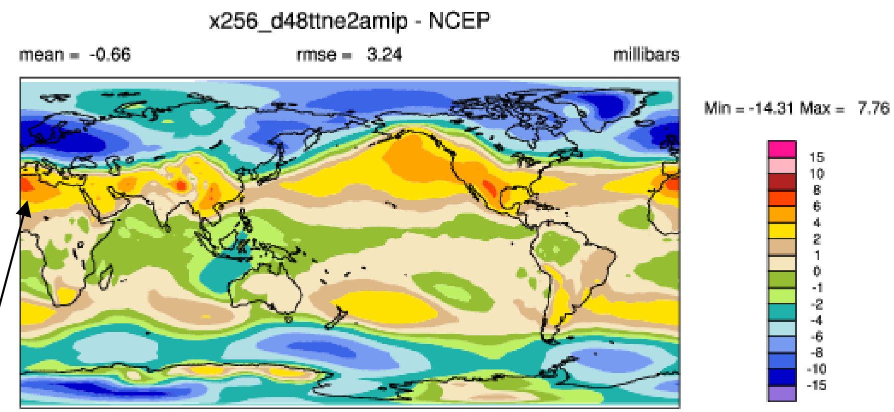
Sea Level Pressure











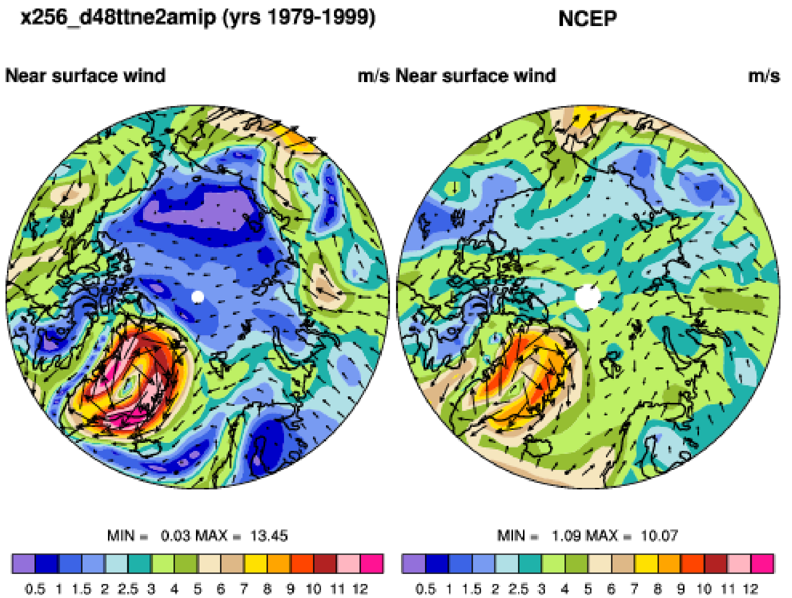
‘Bulls-eye rings’ bias extend outside Arctic

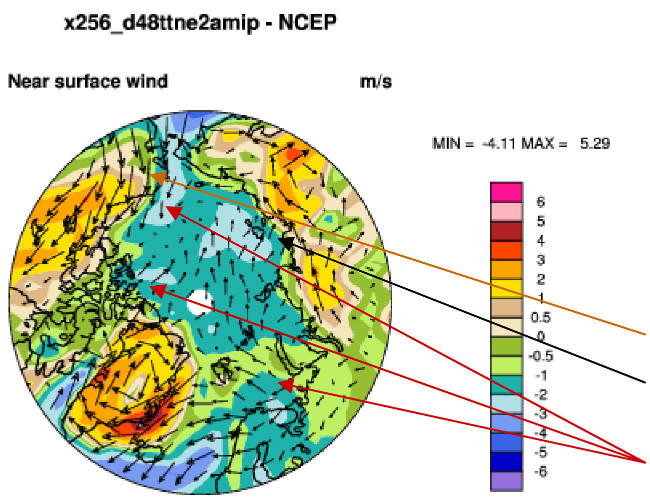
Beaufort high too weak

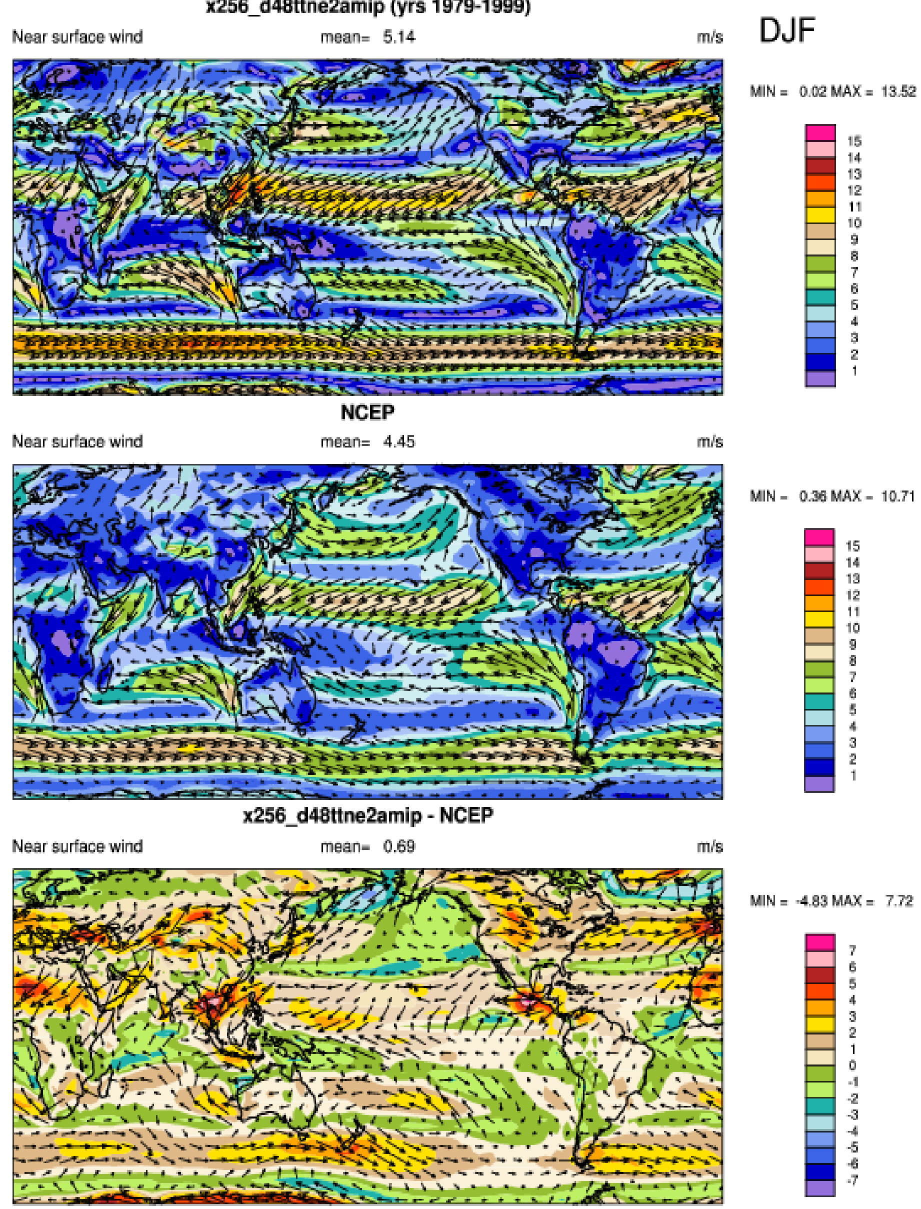
Relative max near Novaya Zemlya

Near-surface Winds:

DJF







Excessive flow over Alaska (mtns too low?)

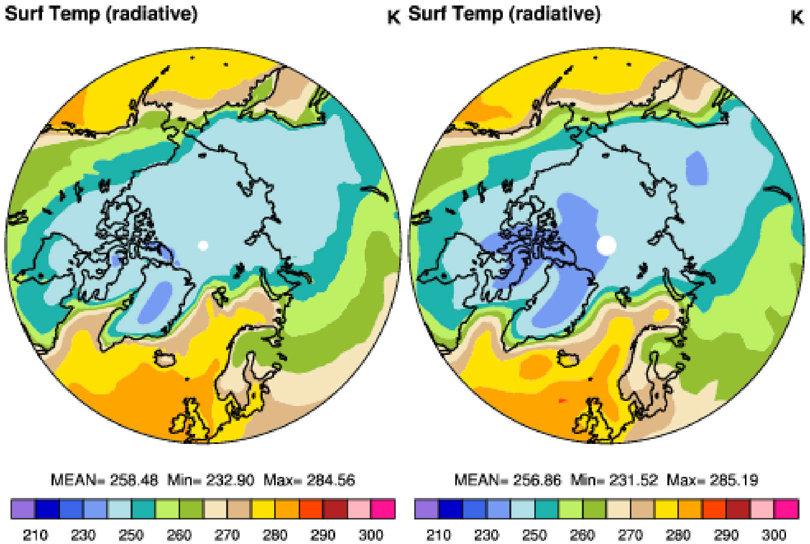
Onshore bias: mid-Siberia

Offshore bias: Alaska; Barents; Canada

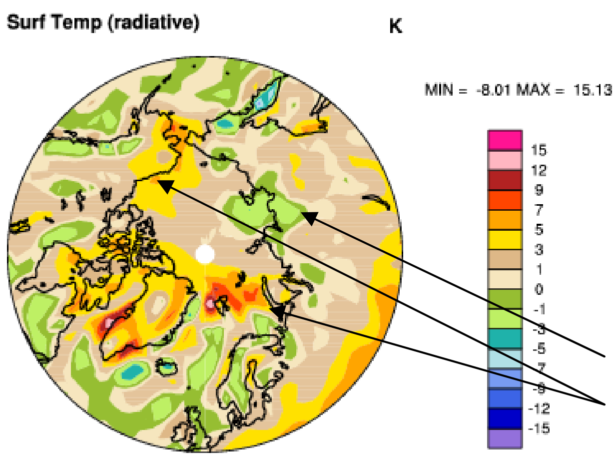
Surface Temperature

DJF

x256_d48ttne2amip (yrs 1979-1999) NCEP

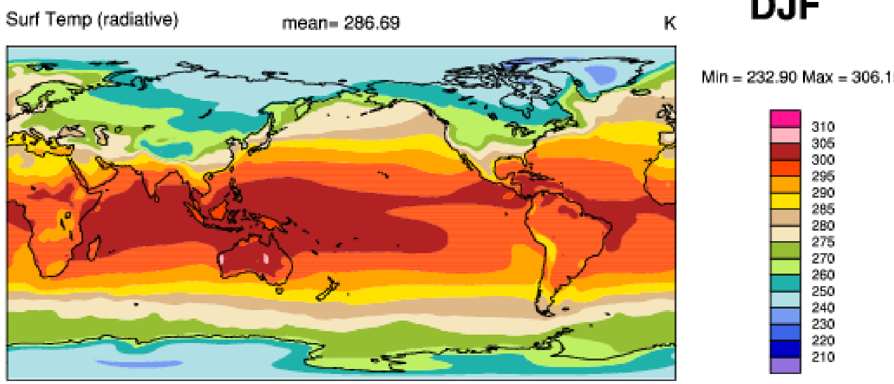


x256_d48ttne2amip - NCEP

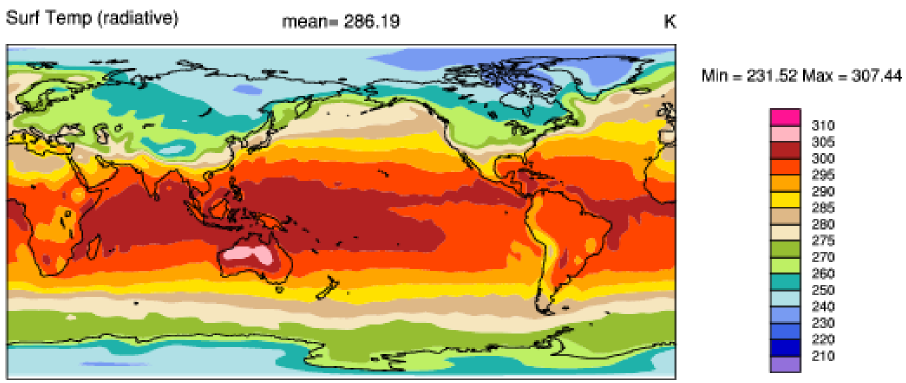


x256_d48ttne2amip (yrs 1979-1999)

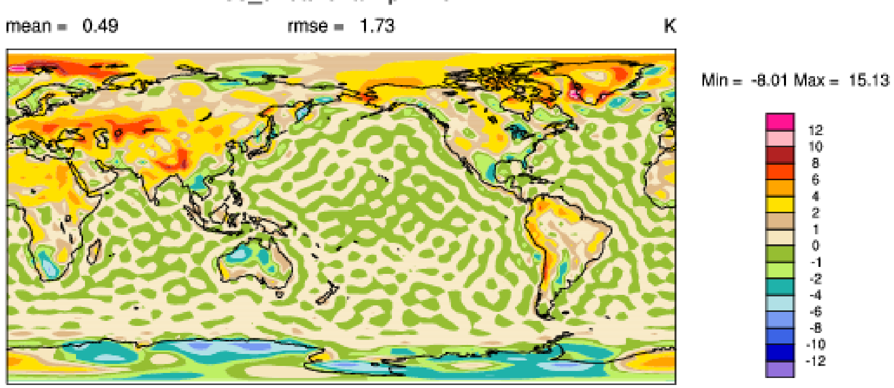
DJF



NCEP



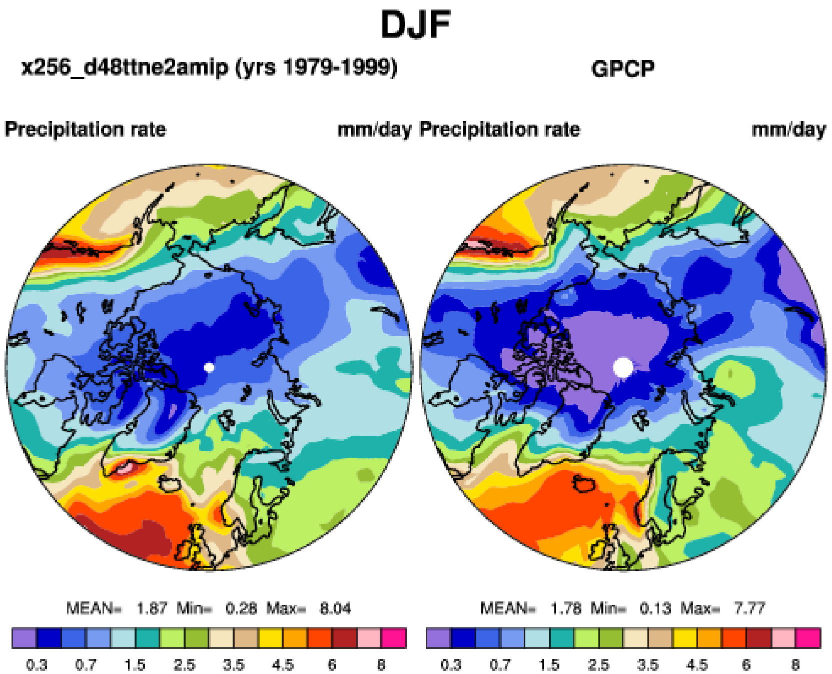
x256_d48ttne2amip - NCEP

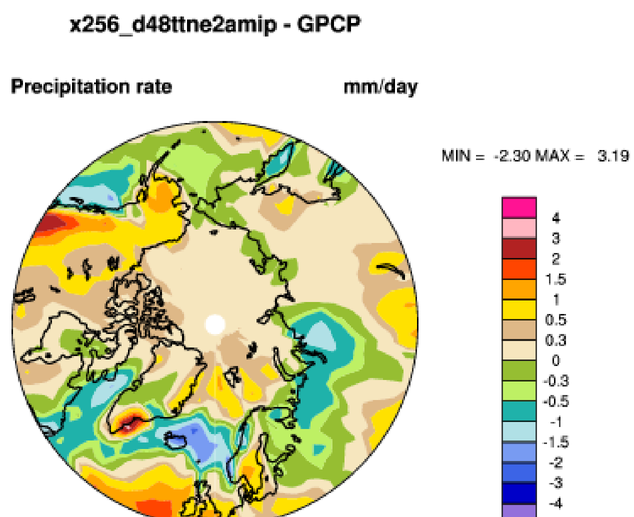


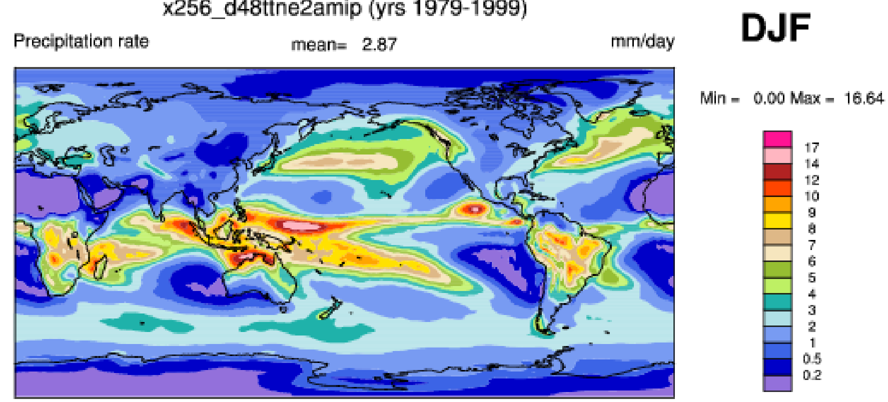
Onshore bias wind -> Cold bias (mid-Siberia)

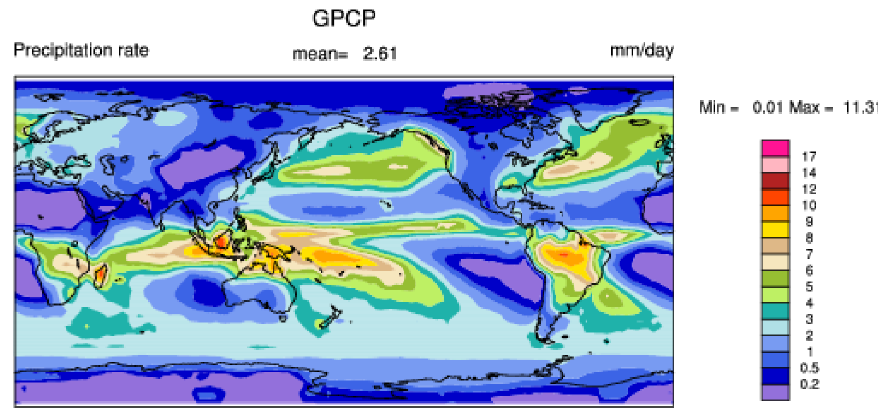
Offshore bias wind -> warm bias (AK; Barents)

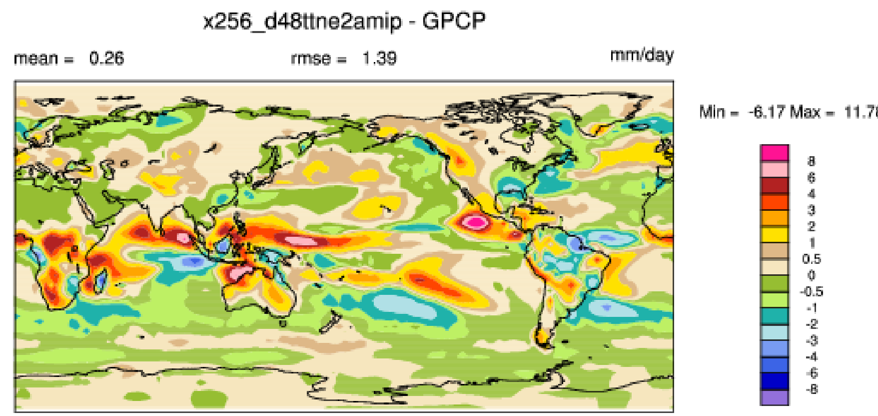
Precipitation Rate











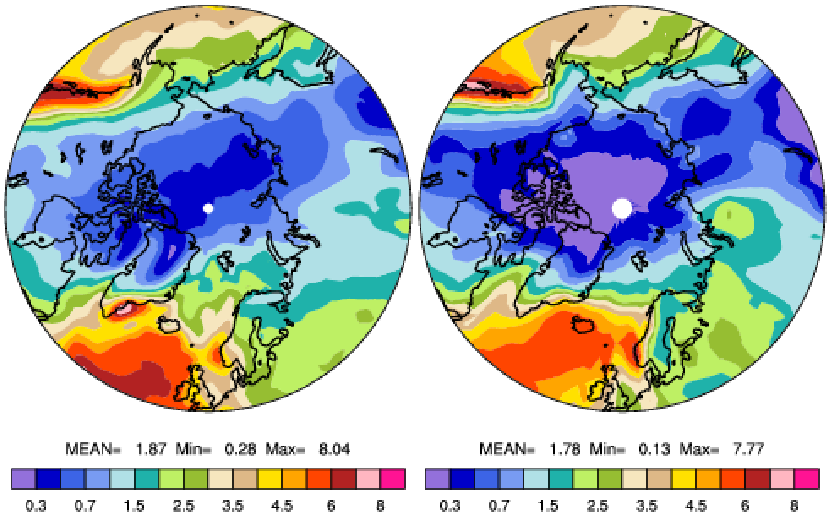
GPCP observed analysis

Precipitation Rate

DJF

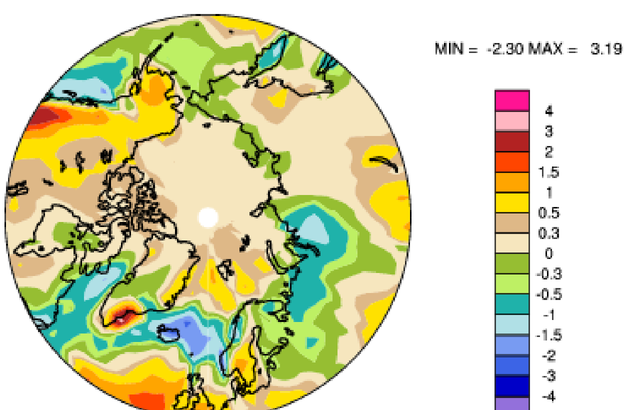
x256_d48ttne2amip (yrs 1979-1999)   GPCP

Precipitation rate   mm/day   Precipitation rate   mm/day



x256_d48ttne2amip - GPCP

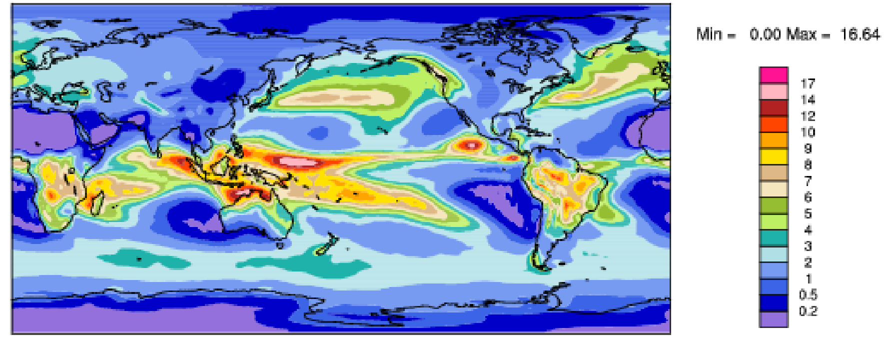
Precipitation rate   mm/day



x256_d48ttne2amip (yrs 1979-1999)

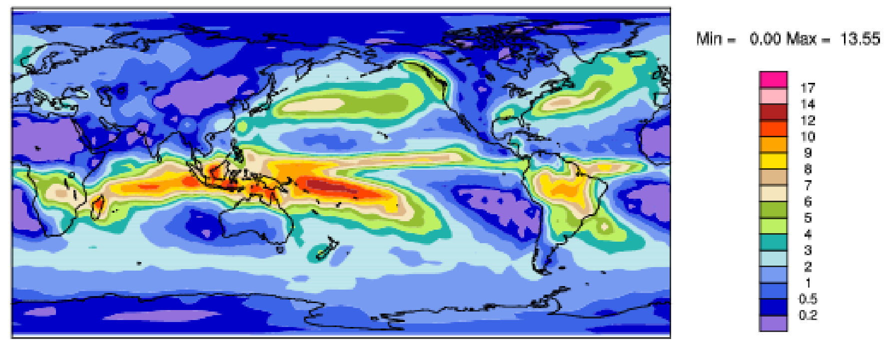
DJF

Precipitation rate   mean= 2.87   mm/day



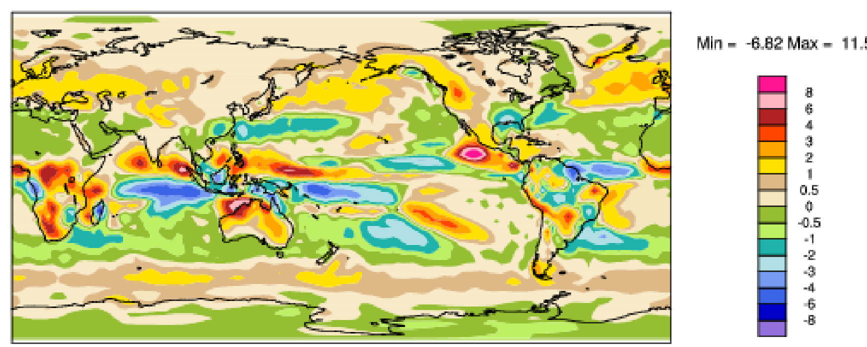
XIE-ARKIN

Precipitation rate   mean= 2.64   mm/day



x256_d48ttne2amip - XIE-ARKIN

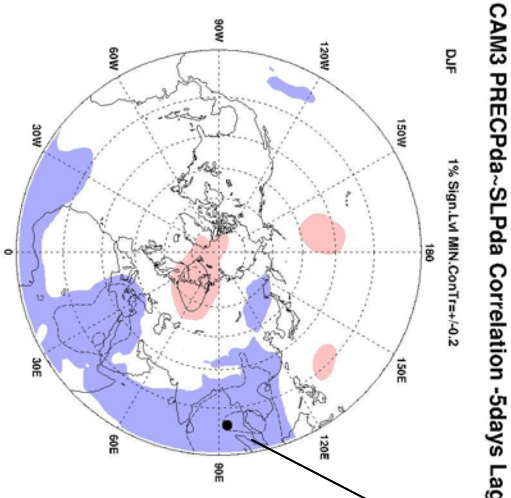
mean = 0.23   rmse = 1.40   mm/day

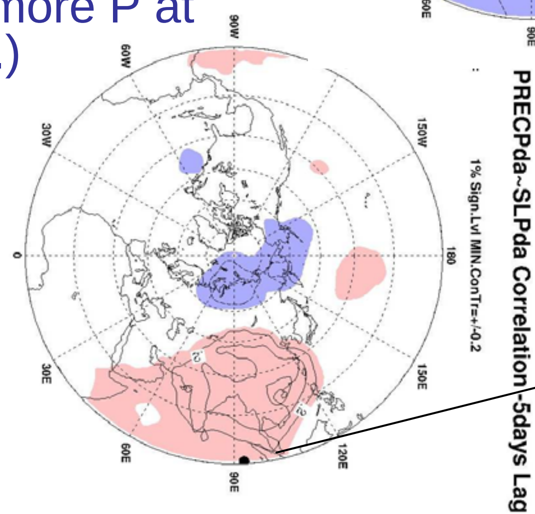


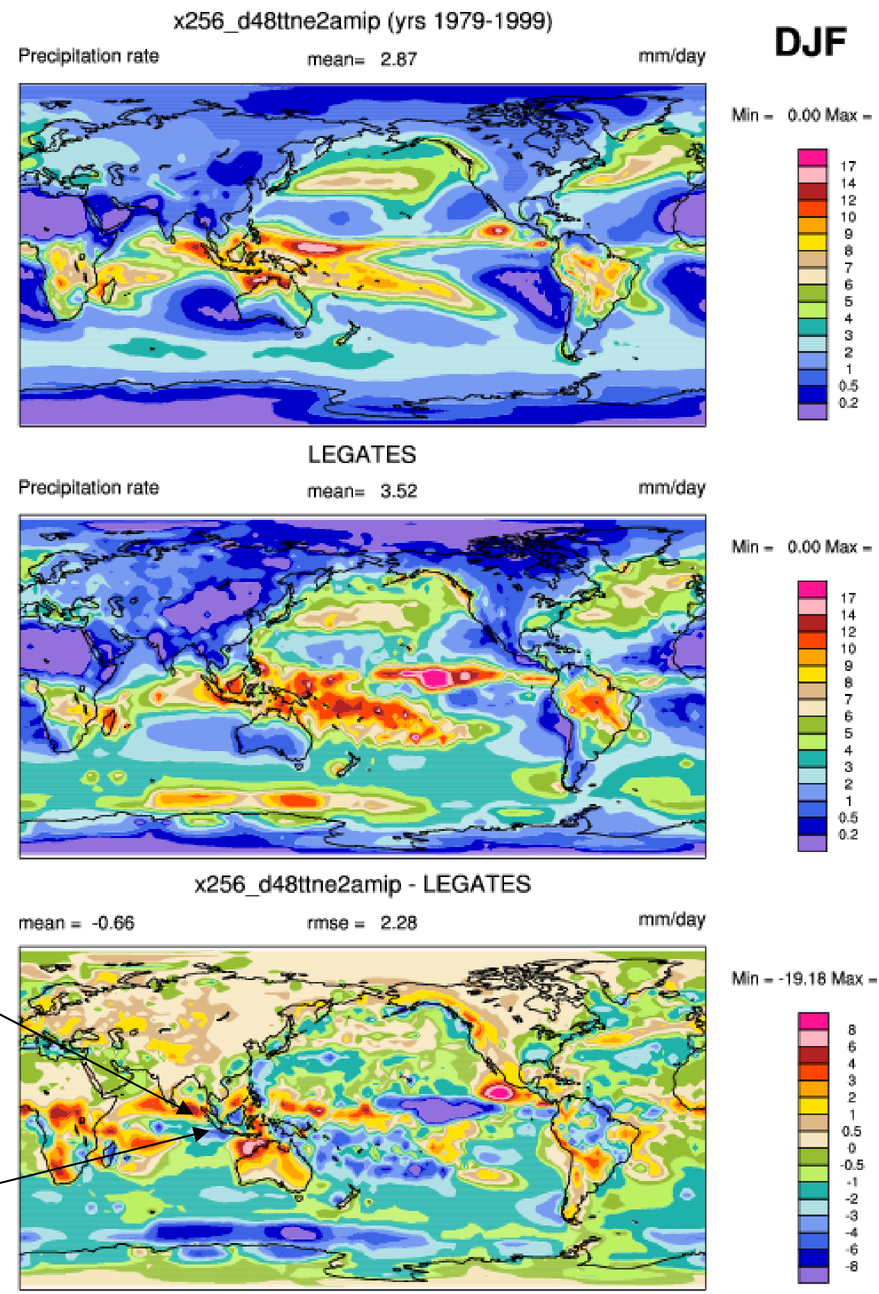
Xie-Arkin observed analysis above

Model error versus observed link to Indian Ocean P.

- Model bias consistent with observed & simulated links between Indian ocean rainfall (P) and Arctic sea level pressure (SLP)
- (SLP correlation with more P at point.)



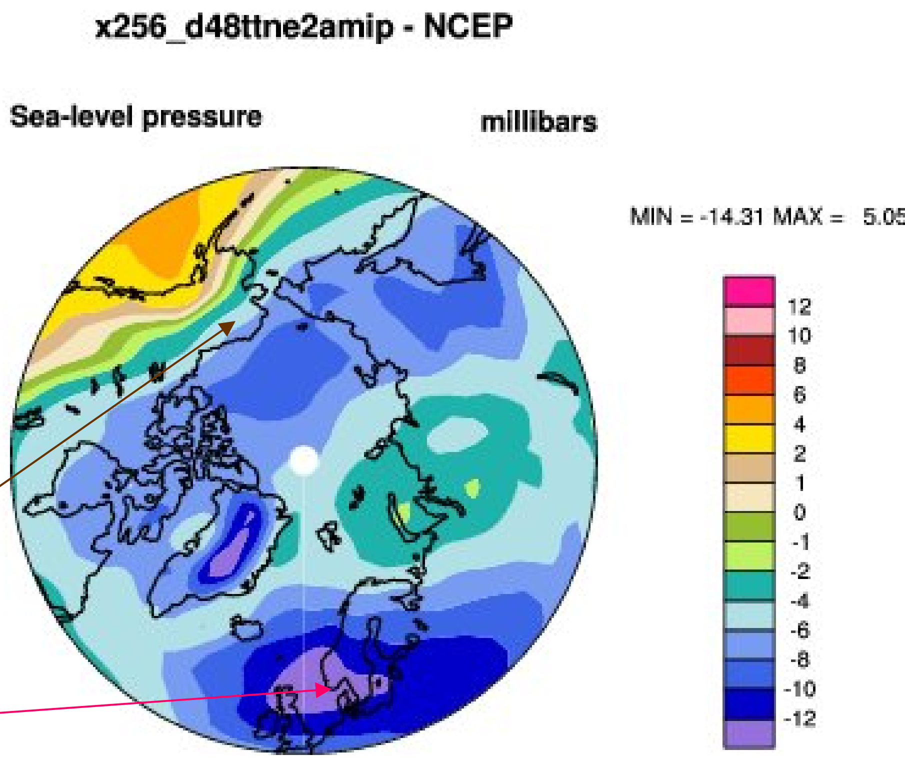




20-40% bias

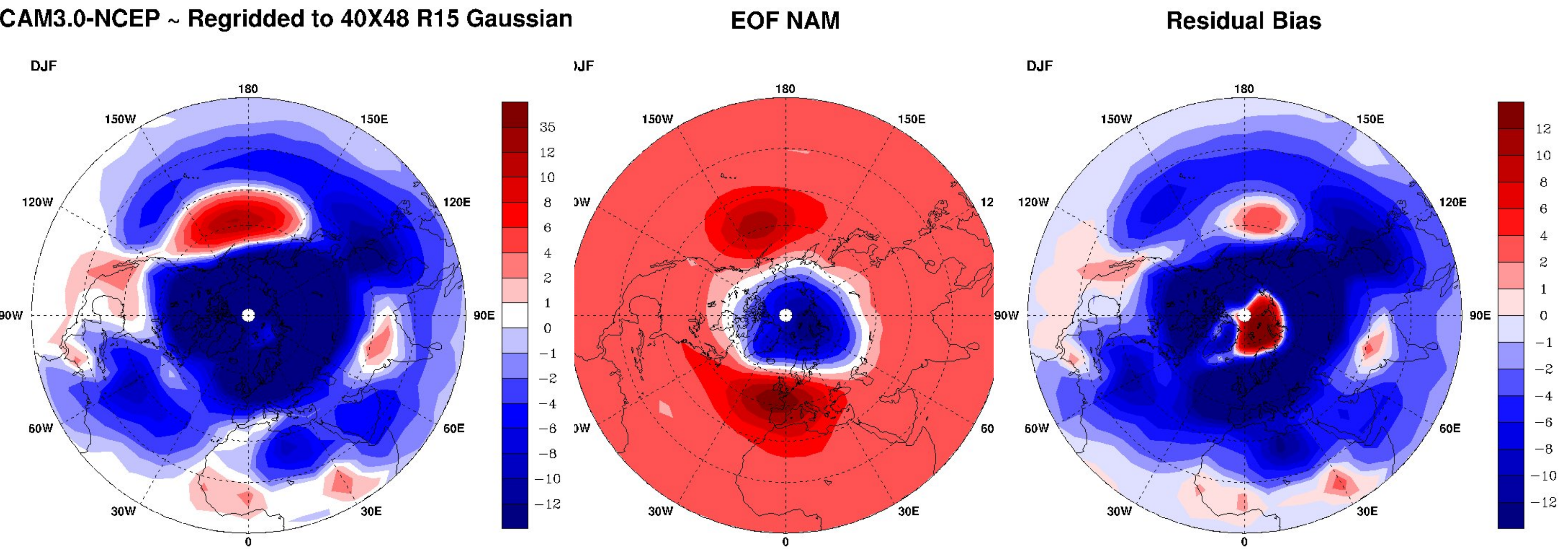
Q: Why do models have a similar bias in Arctic surface climate?

- Need to study how variables are linked in model and real atmosphere.
  - Statistical analysis (correlations, composites)
  - Is it reproduced in simpler models?
- There are plenty of candidates:
  - Local radiative, thermal, and mass coupling
  - Poorly simulated remote processes?
    - Pacific storm track has too much interaction with Arctic?
      - Siberian and Alaskan mtns too low (See sfc wind bias plots)
      - Surface drag too low over mtns
    - Subtropical or tropical bias forcing?
    - Storm tracks too strong and in wrong (downstream) place?

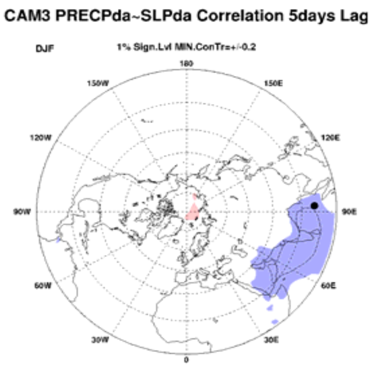


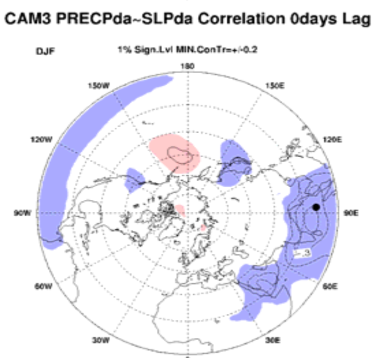
Is the SLP bias mainly the AO?

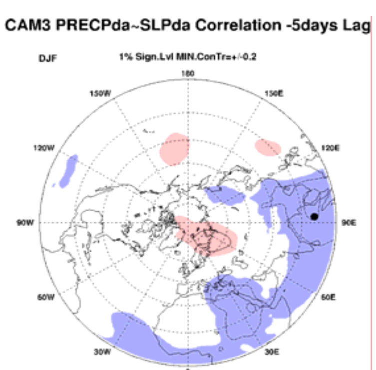
- No.
- Projection of the leading model SLP EOF:
  - Has a large residual
  - Residual amplifies ring pattern, similar to CCM3.6
- Perhaps bias might not be an internal mode



Model Bias vs P in NE Indian Ocean

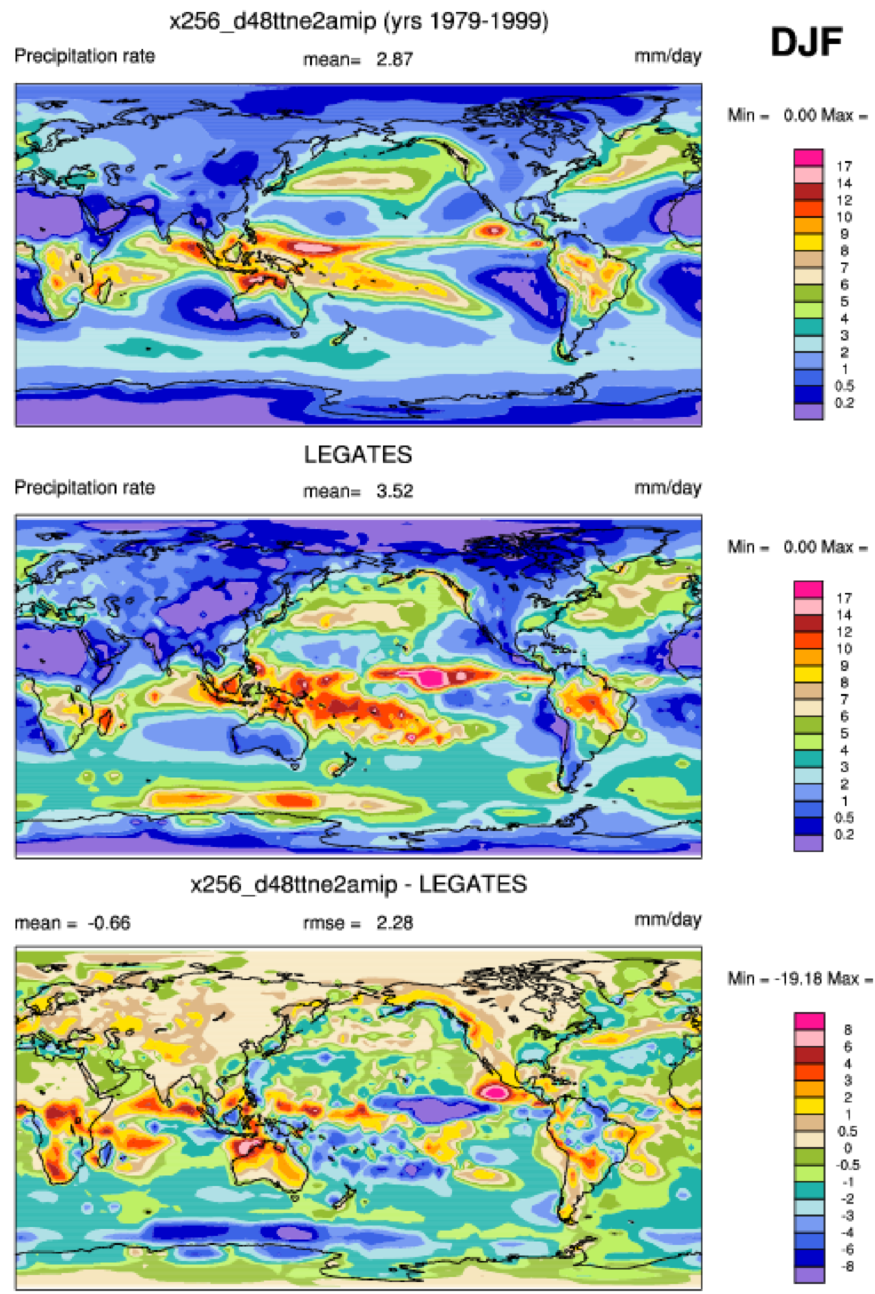






Time →

- Model bias consistent with observed & simulated links between Indian ocean rainfall and Arctic sea level pressure
- BUT Arctic SLP LEADS Indian Ocean Precip.
- Indian ocean tropical rainfall shifted northward in model



Linear Stationary Wave Model

- Basic state: N/N ReAnalysis DJF mean
- Model can be run two ways:
  - Perturbation field: solution or input bias
  - Forcing field: bias-inspired or solution

$$\frac{\partial \zeta'}{\partial t} = \frac{1}{a\cos^2\varphi}\frac{\partial}{\partial\lambda}M_v - \frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi}M_u - \alpha_\zeta\zeta' + K_\zeta\nabla^2\zeta' + K_v\frac{\partial^2\zeta'}{\partial\sigma^2} + R_\zeta \quad \text{(A5)}$$

$$\frac{\partial D'}{\partial t} = \frac{1}{a\cos^2\varphi}\frac{\partial}{\partial\lambda}M_u + \frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi}M_v - \nabla^2(u'\bar{u} + v'\bar{v} + \Phi') - \alpha_D D' + K_D\nabla^2 D' + K_v\frac{\partial^2 D'}{\partial\sigma^2} + R_D \quad \text{(A6)}$$

$$\frac{\partial T'}{\partial t} = \frac{-1}{a\cos\varphi}\frac{\partial}{\partial\lambda}(\bar{u}T' + u'\bar{T}) - \frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi}(\bar{v}T' + v'\bar{T}) + D'\bar{T} + \bar{D}T' - \bar{\dot{\sigma}}\frac{\partial T'}{\partial\sigma} - \dot{\sigma}'\frac{\partial\bar{T}}{\partial\sigma} + \kappa\bar{T}\left(\frac{\omega}{p}\right)' + \kappa T'\overline{\left(\frac{\omega}{p}\right)} - \alpha_T T' + K_T\nabla^2 T' + K_v\frac{\partial^2}{\partial\sigma^2}(T'\sigma^{-\kappa}) + R_T \quad \text{(A7)}$$

$$\frac{\partial q'}{\partial t} = -\hat{D}' - \hat{\mathbf{v}}'\cdot\nabla\bar{q} - \hat{\bar{\mathbf{v}}}\cdot\nabla q' + R_q, \quad \text{(A8)}$$

where

$$M_u = \left[\zeta'\bar{v} + (\bar{\zeta} + f)v' - \frac{R_d\bar{T}}{a\cos\varphi}\frac{\partial q'}{\partial\lambda} - \frac{R_d T'}{a\cos\varphi}\frac{\partial\bar{q}}{\partial\lambda} - \bar{\dot{\sigma}}\frac{\partial u'}{\partial\sigma} - \dot{\sigma}'\frac{\partial\bar{u}}{\partial\sigma}\right]\cos\varphi$$

$$M_v = \left[-\zeta'\bar{u} - (\bar{\zeta} + f)u' - \frac{R_d\bar{T}}{a}\cos\varphi\frac{\partial q'}{\partial\varphi} - \frac{R_d T'}{a}\cos\varphi\frac{\partial\bar{q}}{\partial\varphi} - \bar{\dot{\sigma}}\frac{\partial v'}{\partial\sigma} - \dot{\sigma}'\frac{\partial\bar{v}}{\partial\sigma}\right]\cos\varphi$$

$$\bar{\dot{\sigma}} = \sigma\hat{\bar{D}} - \bar{\hat{D}}^{\sigma} + (\sigma\hat{\bar{\mathbf{v}}} - \bar{\hat{\mathbf{v}}}^{\sigma})\cdot\nabla\bar{q}$$

$$\dot{\sigma}' = \sigma\hat{D}' - \hat{D}^{\sigma\prime} + (\sigma\hat{\bar{\mathbf{v}}} - \bar{\hat{\mathbf{v}}}^{\sigma})\cdot\nabla q' + (\sigma\hat{\mathbf{v}}' - \hat{\mathbf{v}}^{\sigma\prime})\cdot\nabla\bar{q}$$

$$\overline{\left(\frac{\omega}{p}\right)} = -\frac{1}{\sigma}\bar{\hat{D}}^{\sigma} + \left(\bar{\mathbf{v}} - \frac{1}{\sigma}\bar{\hat{\mathbf{v}}}^{\sigma}\right)\cdot\nabla\bar{q}$$

$$\left(\frac{\omega}{p}\right)' = -\frac{1}{\sigma}\hat{D}^{\sigma\prime} + \left(\bar{\mathbf{v}} - \frac{1}{\sigma}\hat{\bar{\mathbf{v}}}^{\sigma}\right)\cdot\nabla q' + \left(\mathbf{v}' - \frac{1}{\sigma}\hat{\mathbf{v}}^{\sigma\prime}\right)\cdot\nabla\bar{q}$$

$$\Phi' = -\int_1^{\sigma}\frac{R_d T'}{\sigma}d\sigma$$

$$\hat{X} = \int_1^0 X d\sigma$$

$$\hat{X}^{\sigma} = \int_1^{\sigma} X d\sigma$$

$$q = \ln p_s$$

$$\sigma = p p_s^{-1}$$

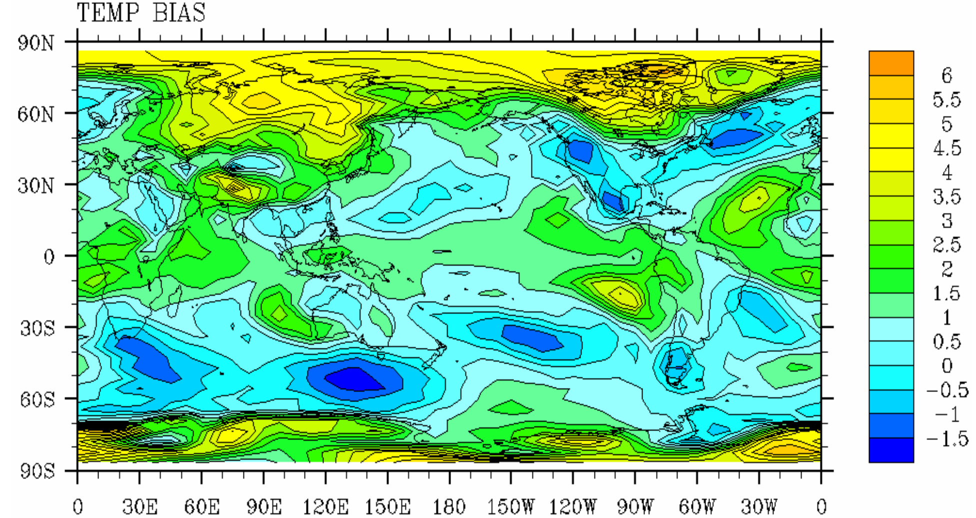
$$\kappa = R_d C_p^{-1}.$$

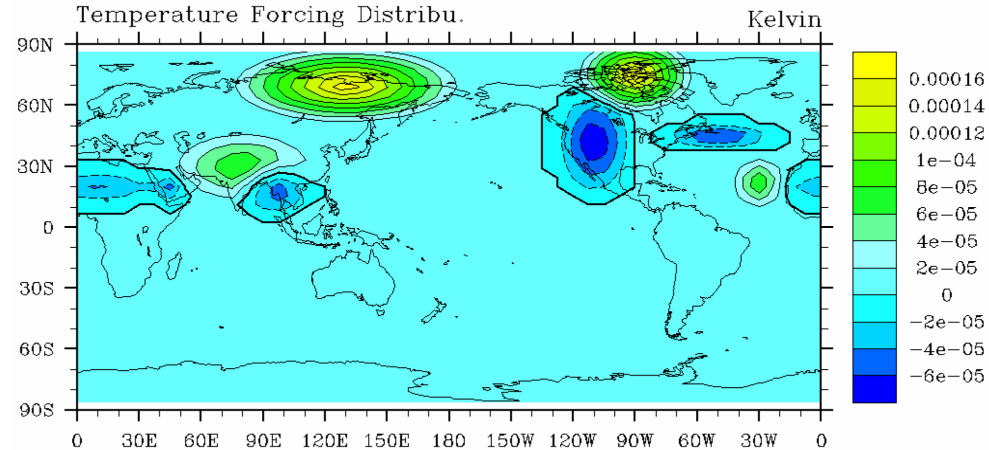
Express as
L x = F

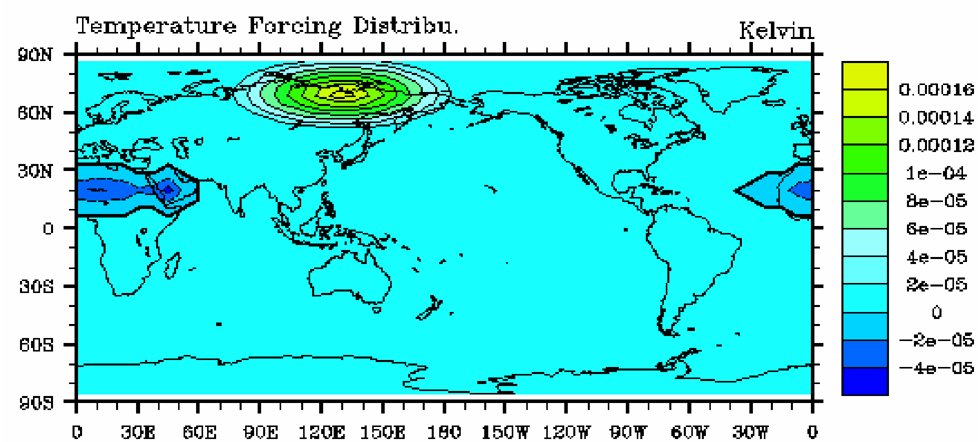
Reproduced from Branstator (1990)

Some LSWM results

- Use temperature bias to inspire thermal forcing
  - Forcing by main elements of T bias
  - Forcing by subset of T bias
    - Sahara & Arabian deserts
    - N Siberia)
- Solutions capture parts of the Arctic SLP bias

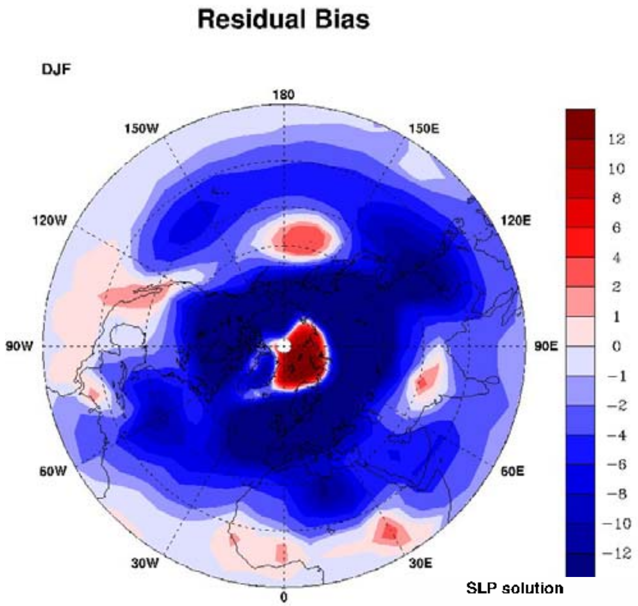


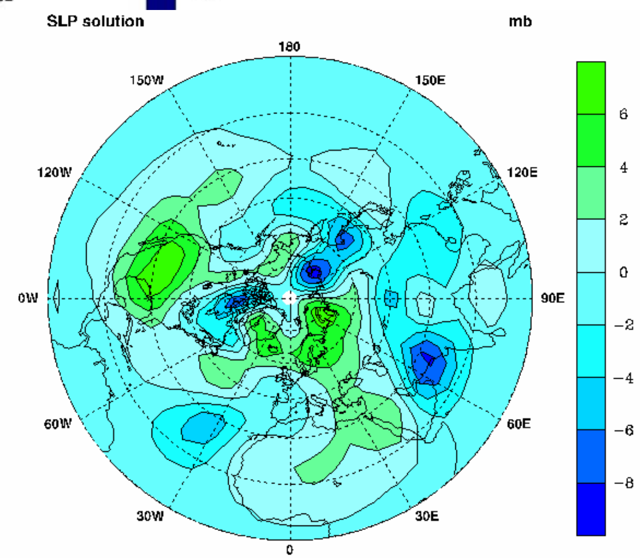


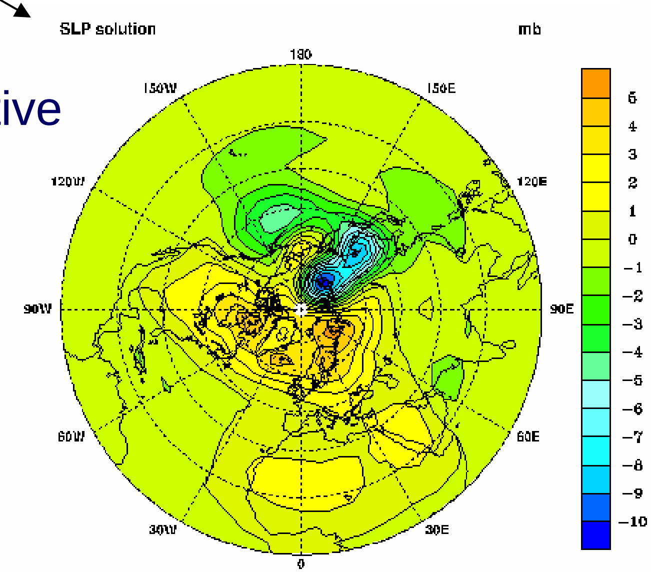


LSWM results

- Use temperature bias to inspire thermal forcing
  - Forcing by main elements of T bias
  - Forcing by subset of T bias
    - Sahara & Arabian deserts
    - N Siberia)
- Solutions capture parts of the Arctic SLP bias
- Subset captures
  - Novaya Zemlya positive bias
  - Beaufort high negative bias

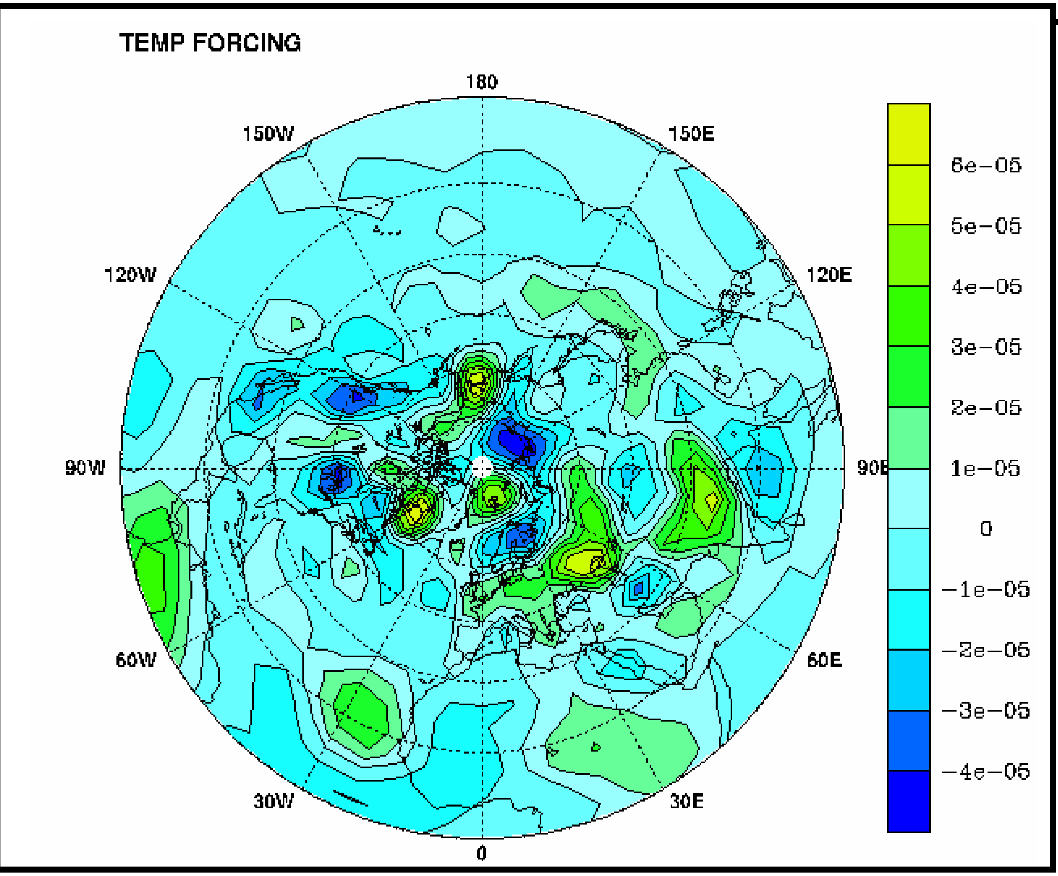




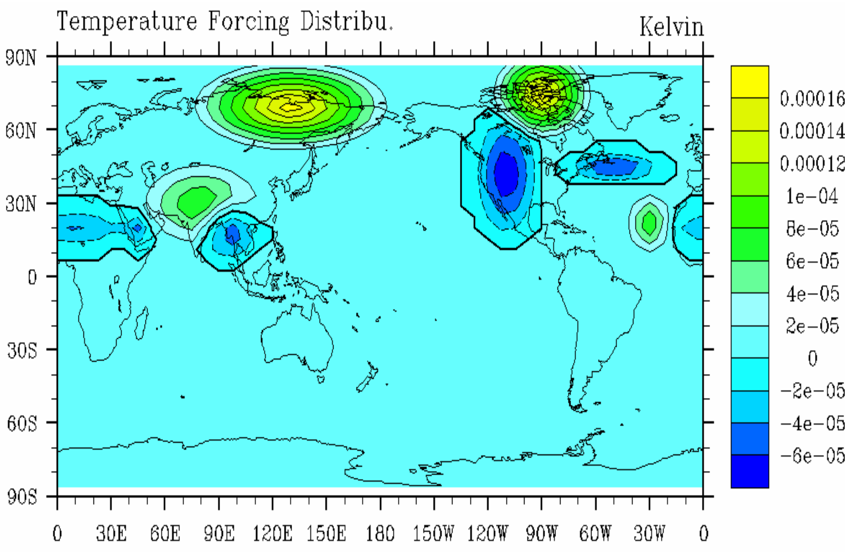


“Backward” Run: Find F from bias X only using T&Q bias bias in X

At Sigma = 0.991

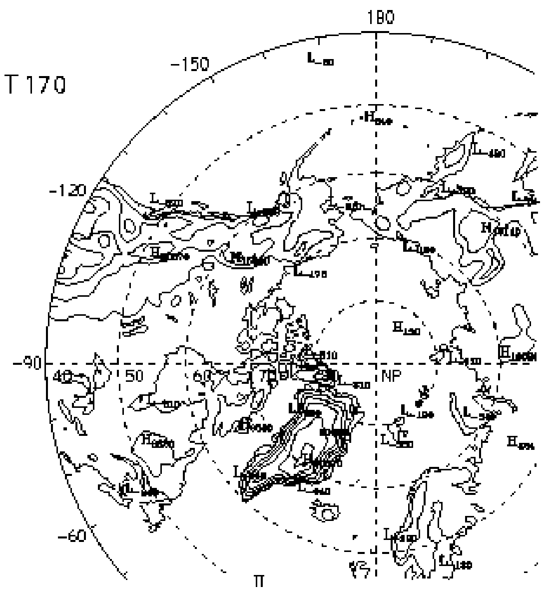


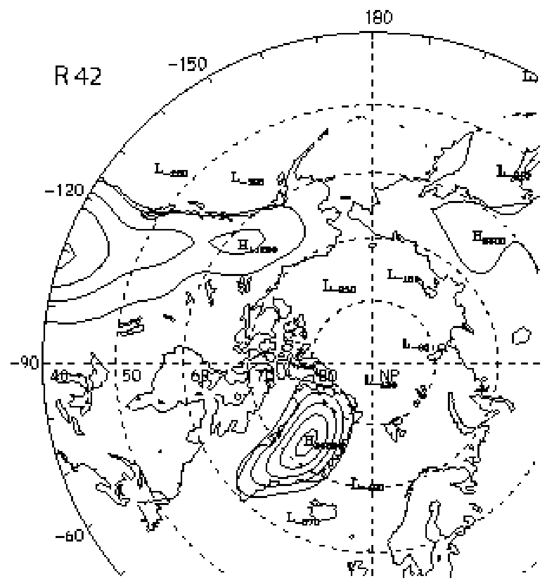
Compare to simple guess of thermal forcing based on T bias

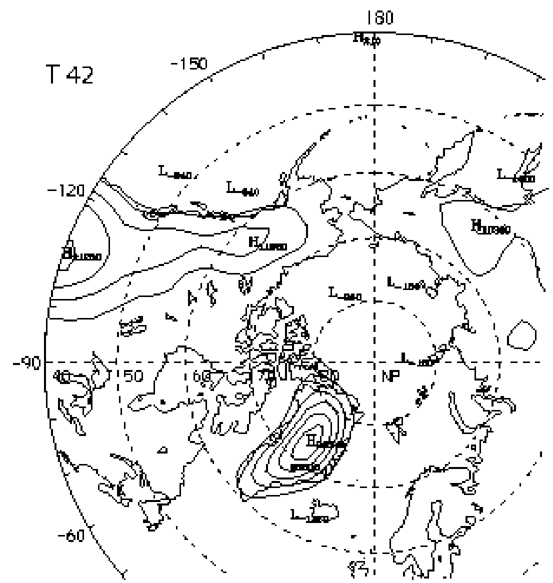


Future work

- Focus on poorly simulated remote processes
  - Forcing by bias field
  - Storm tracks have too much interaction with Arctic (topography) See bias field for near surface wind. NOT YET STUDIED
    - Test other topography formulations
    - Test other surface drag formulations
  - Storm tracks too strong and (downstream end) in wrong place







Future Work

- Focus on poorly simulated remote processes
  - Forcing by bias field
  - Storm tracks have too much interaction with Arctic
  - Storms too strong and tracks (downstream end) are in wrong places (NOT YET STUDIED)
    - Test eddy flux contributions to T forcing in LSWM
    - Examine time series of eddy statistics
    - Examine spin up of bias

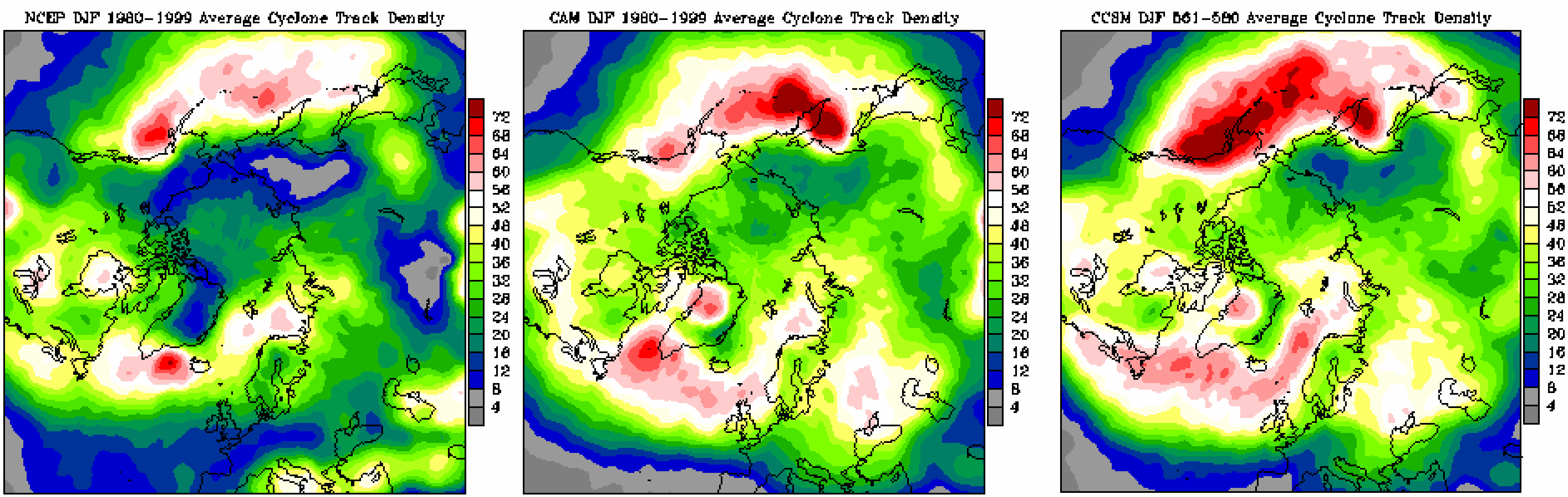


Figure courtesy of Richard Cullather

Summary

- Arctic surface climate bias studied. Consistencies exist between near surface winds, sea level pressure (SLP) pattern, and temperature (T).
  - anomalous SLP high near NW Russian coast, southerlies & warm T in Barents.
- SLP pattern is 3 concentric rings centered on Novaya Zemlya, similar to prior versions examined (at least as far back as CCM3.6)
- Despite superficial similarity to the Arctic Oscillation (AO), the SLP has little projection onto the AO.
- Statistical studies have so far been ambiguous in showing tropical or subtropical forcing that leads SLP in Arctic region
  - Monthly mean data show strong links between Arctic SLP and SLP or other variables in lower latitudes
  - Lag correlations & composites (to identify a chain of events) have much less evidence for such links, even with low pass filtered data
- A stationary wave model can examine links between remote forcing and a time mean field that looks like the bias
  - Low level T bias field can suggest multiple monopoles in T tendency forcing that lead to a solution field similar to the SLP bias over the Arctic
  - A subset of T tendency monopoles (mainly N. Siberia >0 tendency, and Sahara-Arabia deserts <0 T tendency) are main forcing for Beaufort high <0 bias and Novaya-Zemlya >0 bias
- A stationary wave model can find what forcing balances the bias fields
  - Vorticity and Divergence bias give unrealistic results
  - T and ln surface pressure (=q or Q) bias give T forcing with similarities to forcing anticipated from T bias.

Oral Presentation Slide

- (next slide)

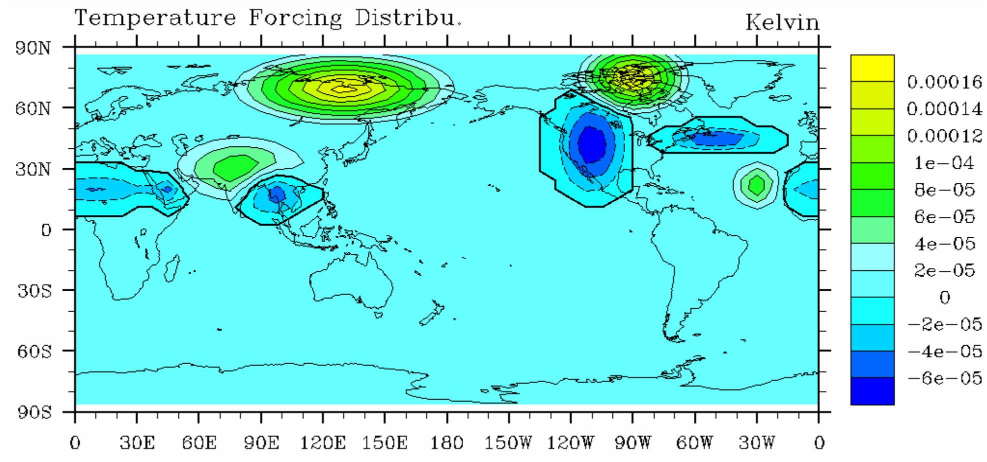
Diagnosing Arctic Winter CAM3 Bias with a Stationary Wave Model

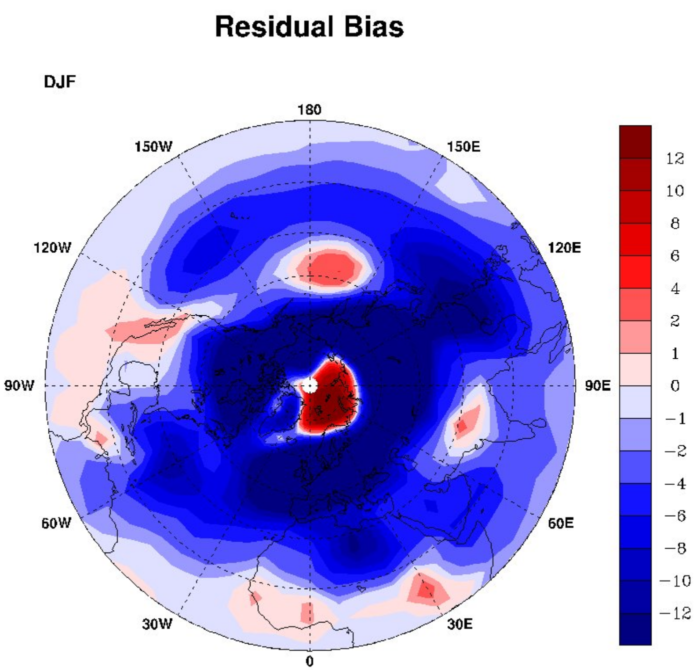
Richard Grotjahn and Muhtarjan Osman (UC Davis)

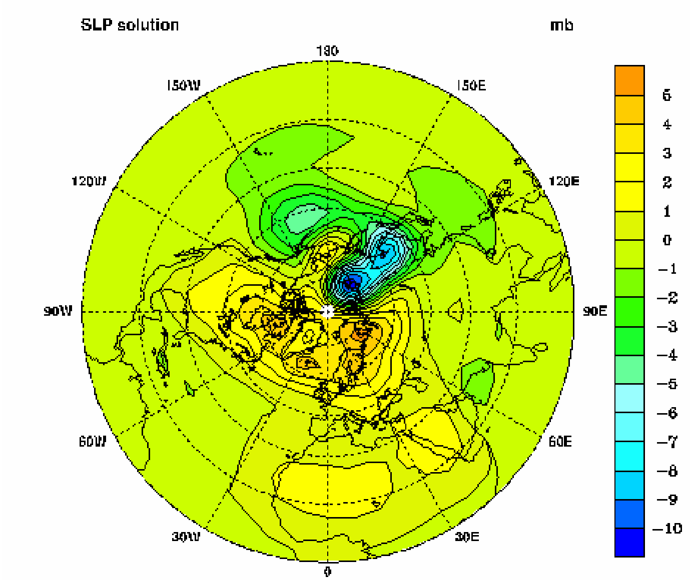
Superficial similarity to AO, but SLP has little projection onto AO.

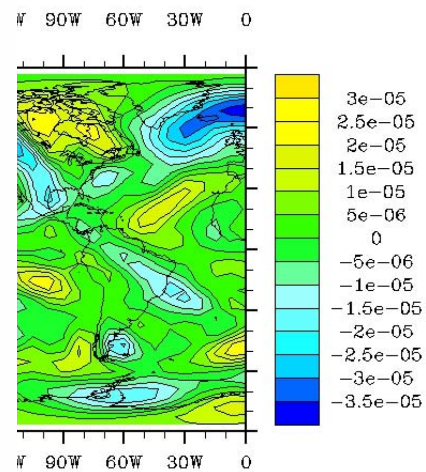
Stationary wave model finds forcing to make the T & ln(P_{sfc}) bias fields

Stationary wave model tests links between remote forcing and time mean bias (9-poles; RS+NES only)



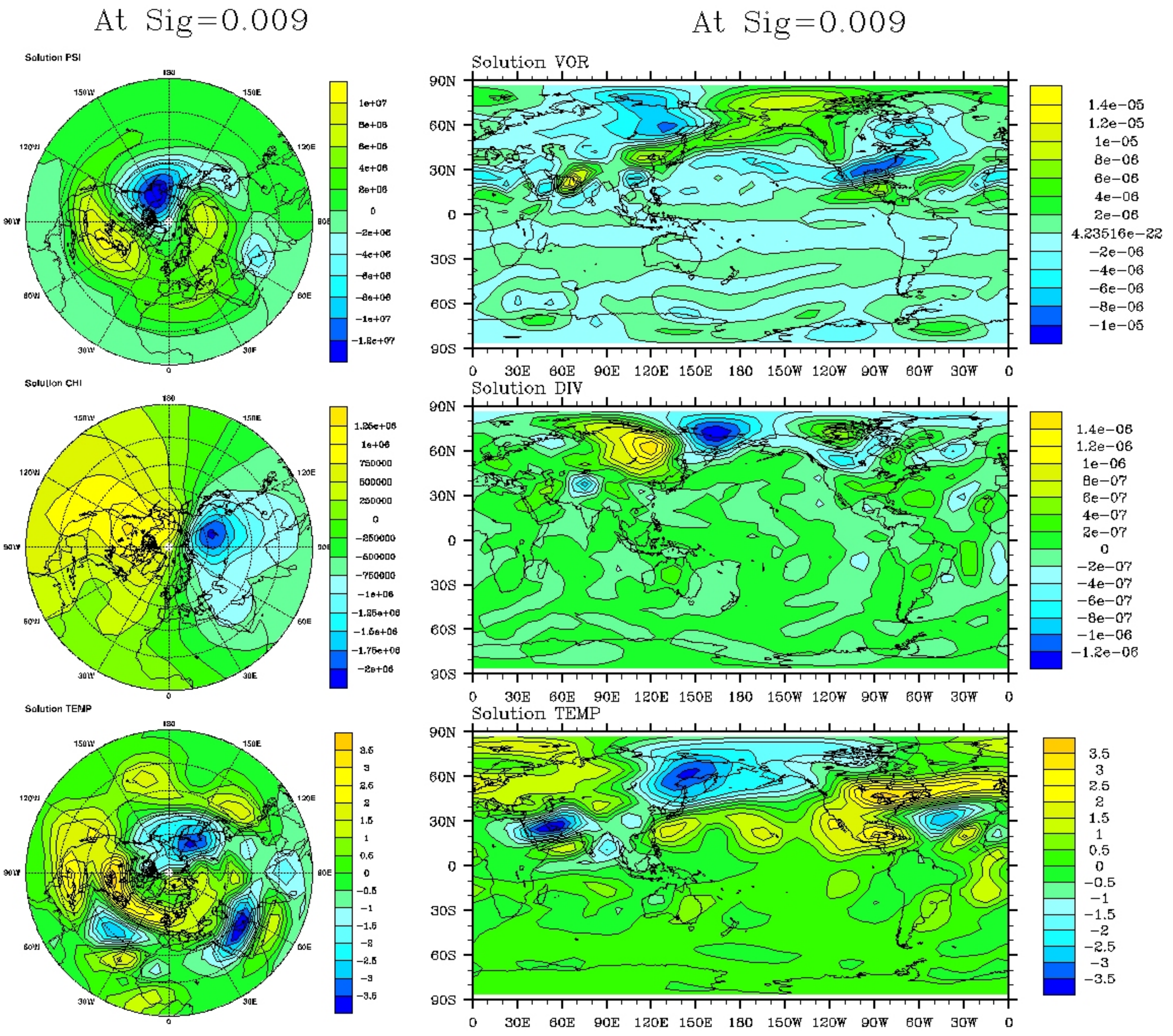




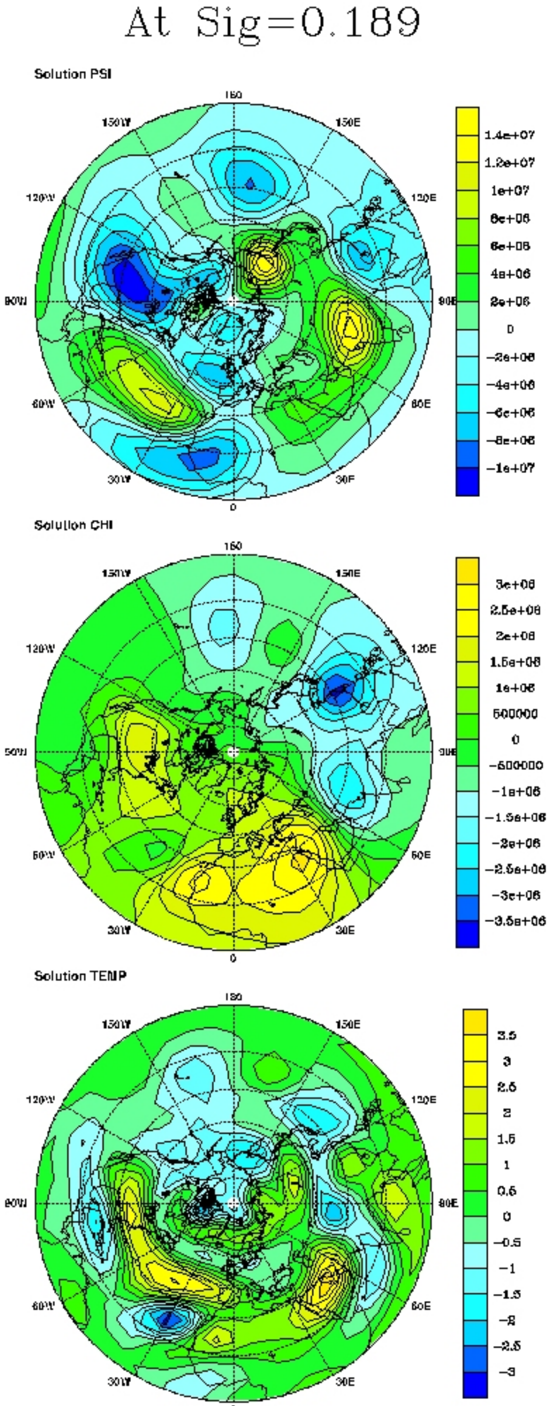


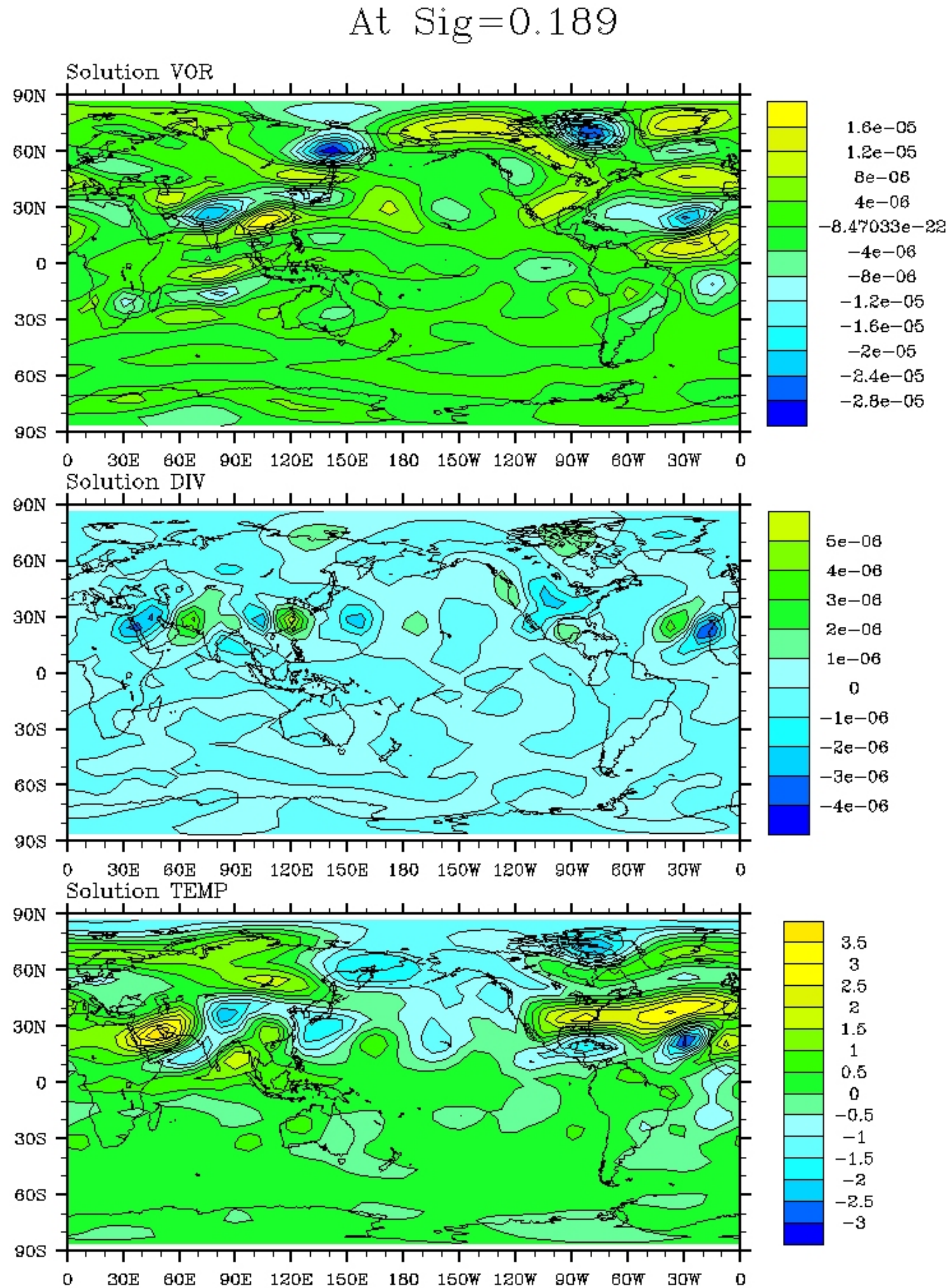
Complete Plot sequences from Selected Runs

9-Pole Solutions



9-Pole Solutions





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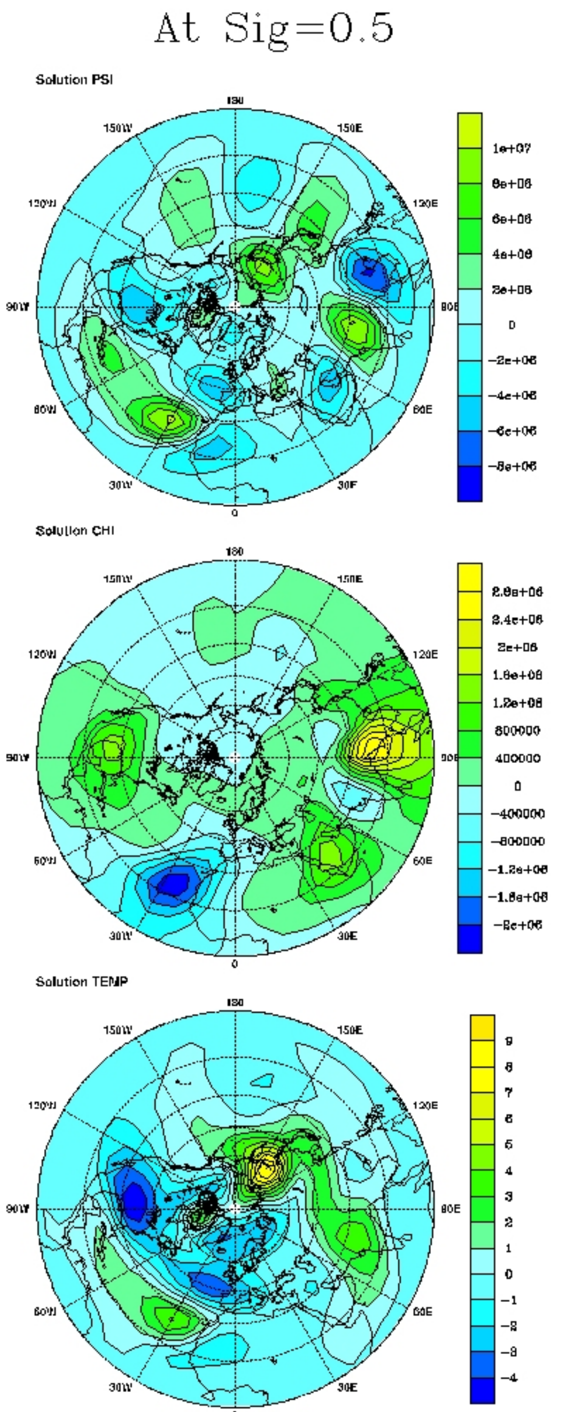
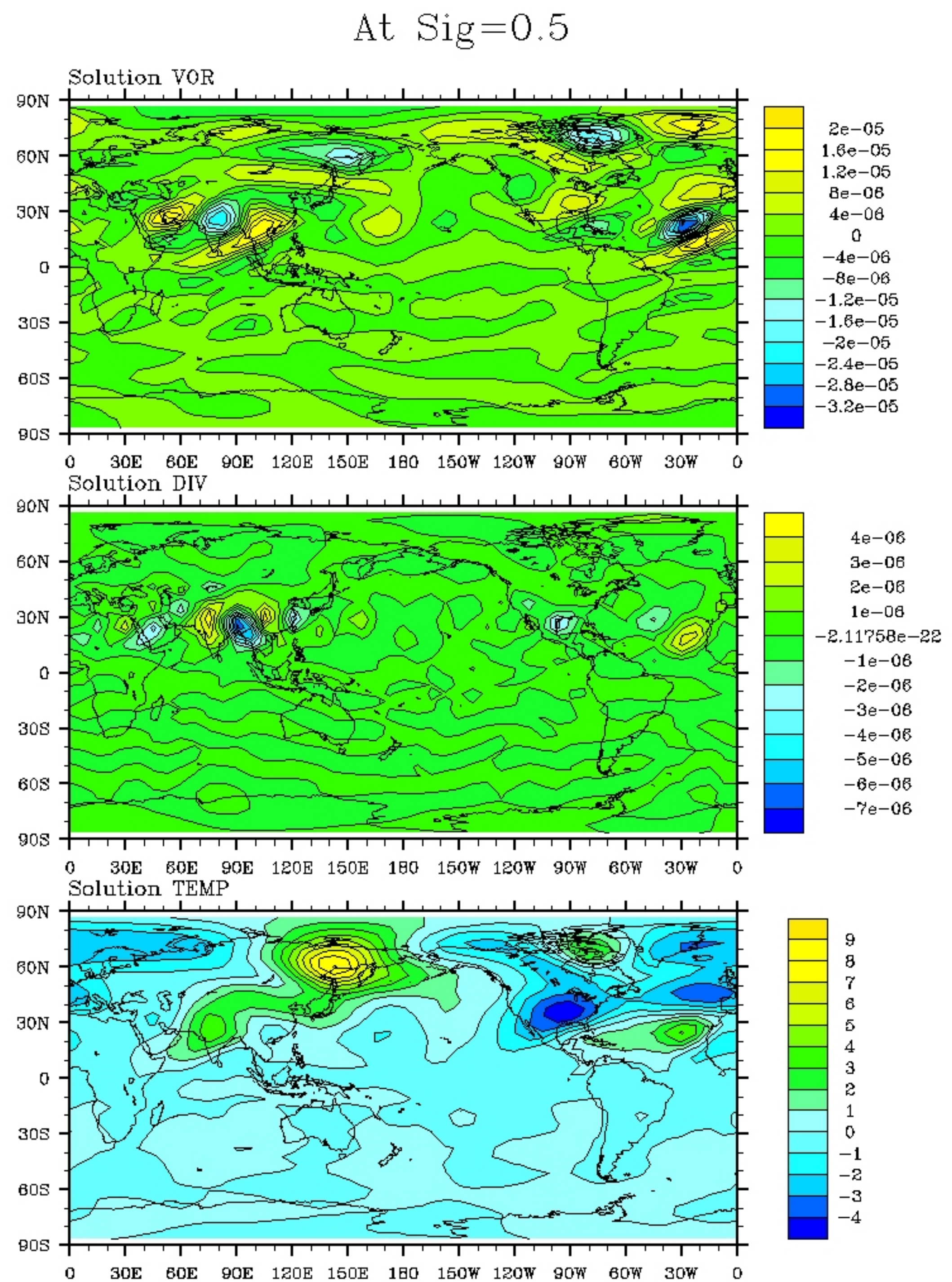
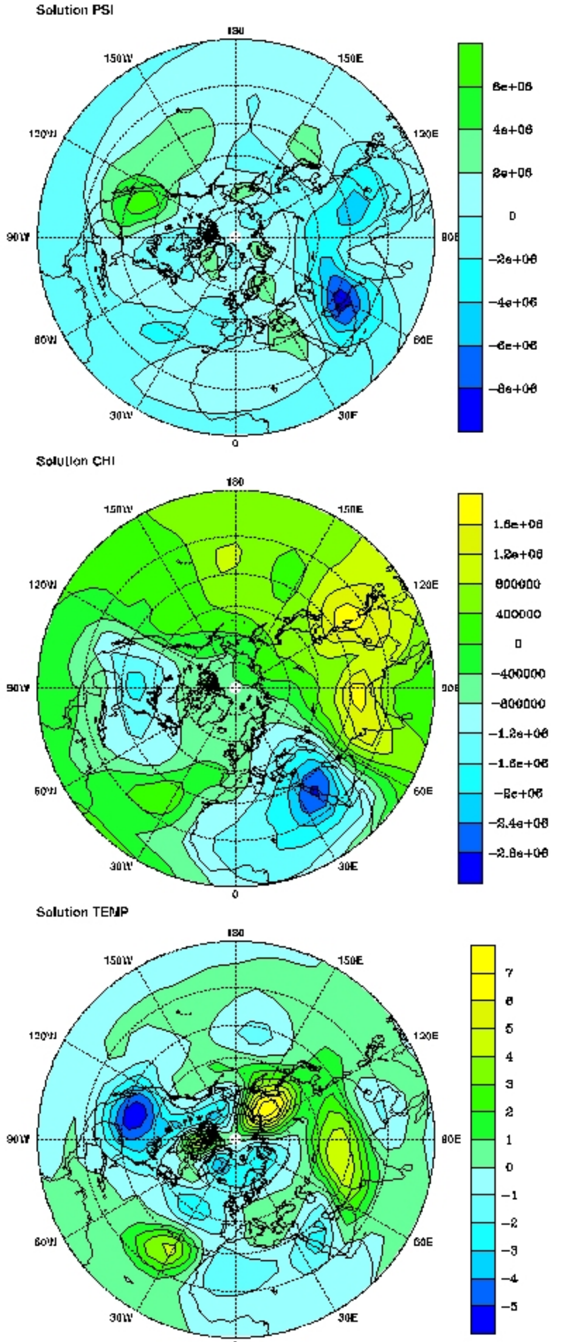


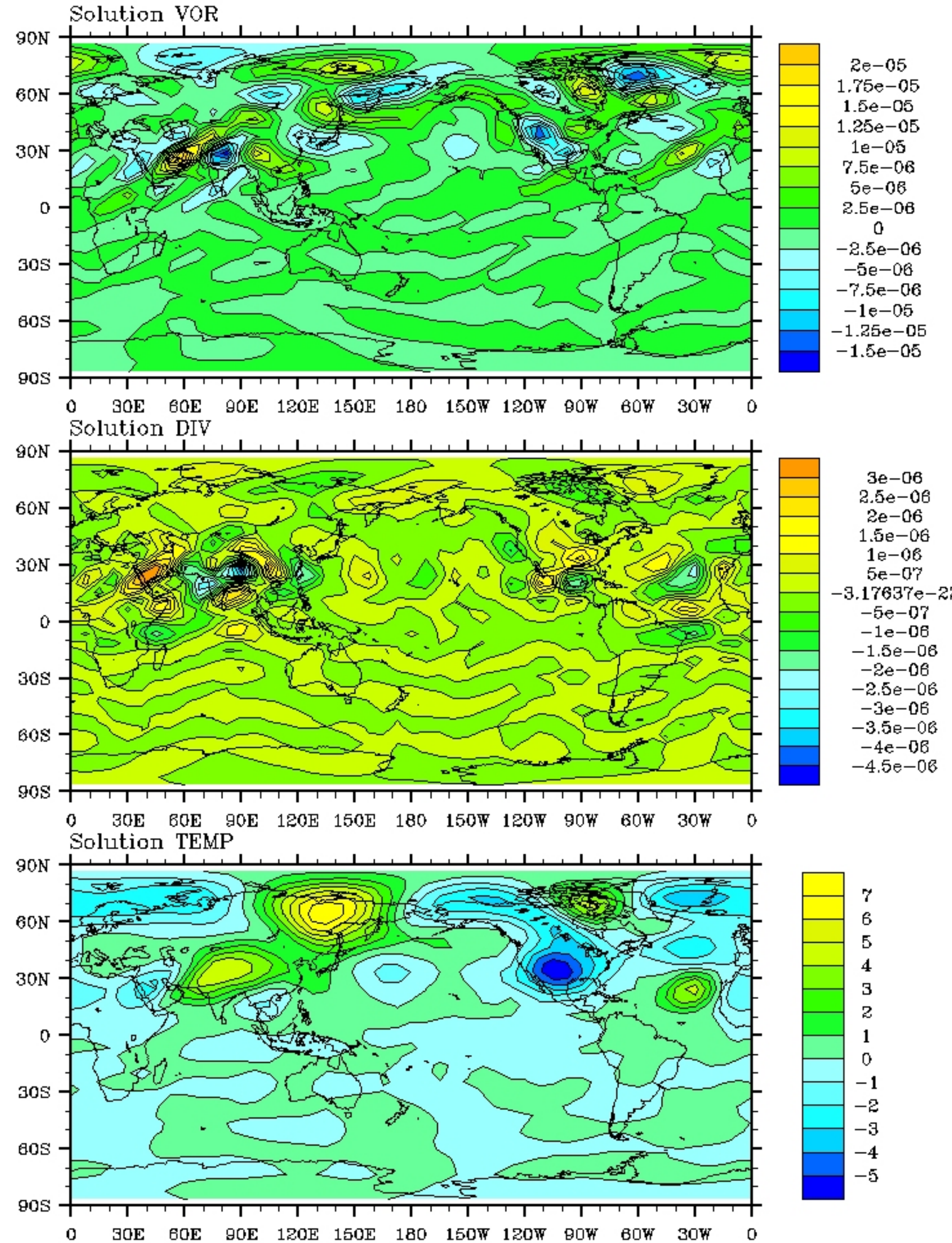


9-Pole Solutions

At Sig=0.811



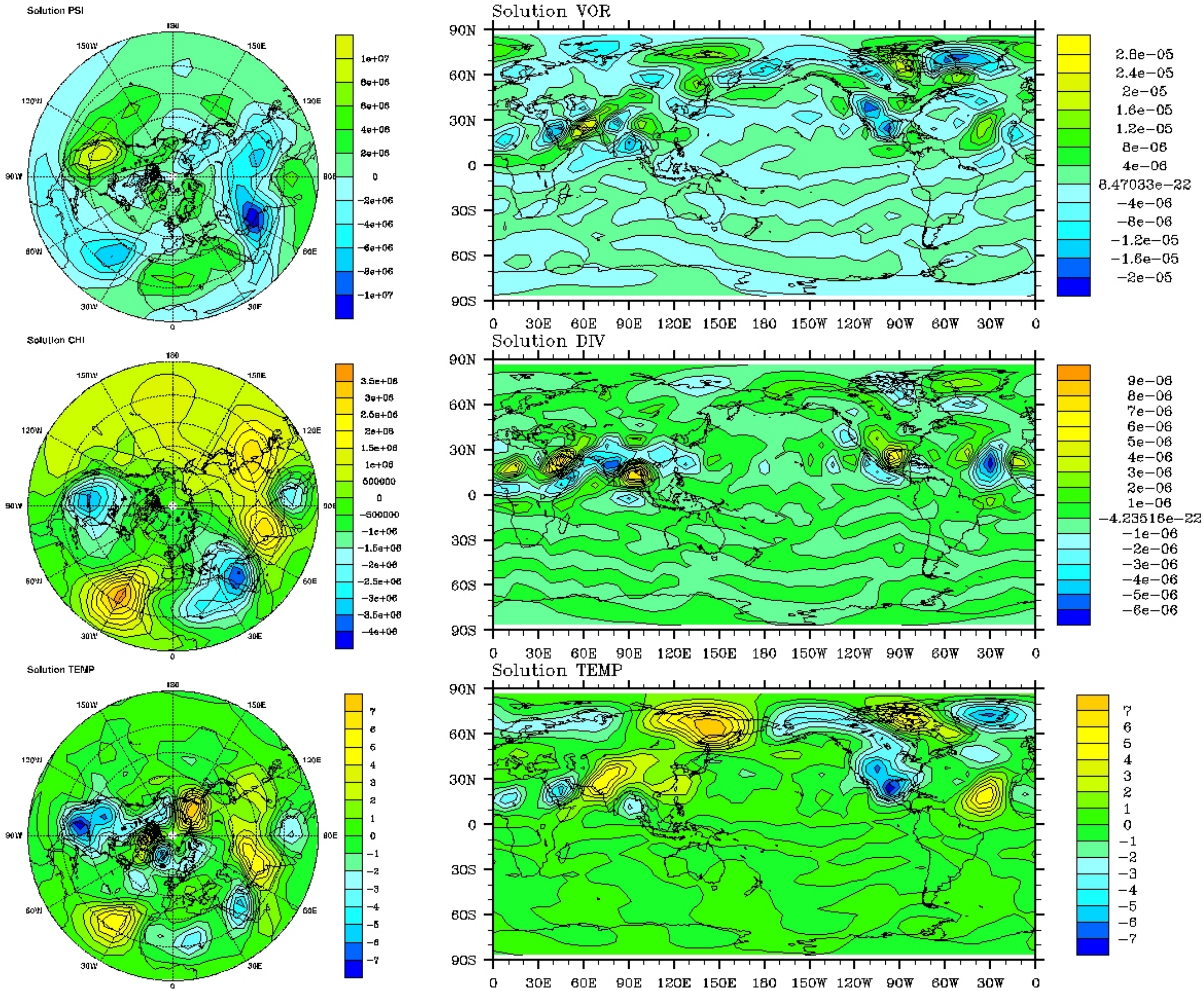
At Sig=0.811



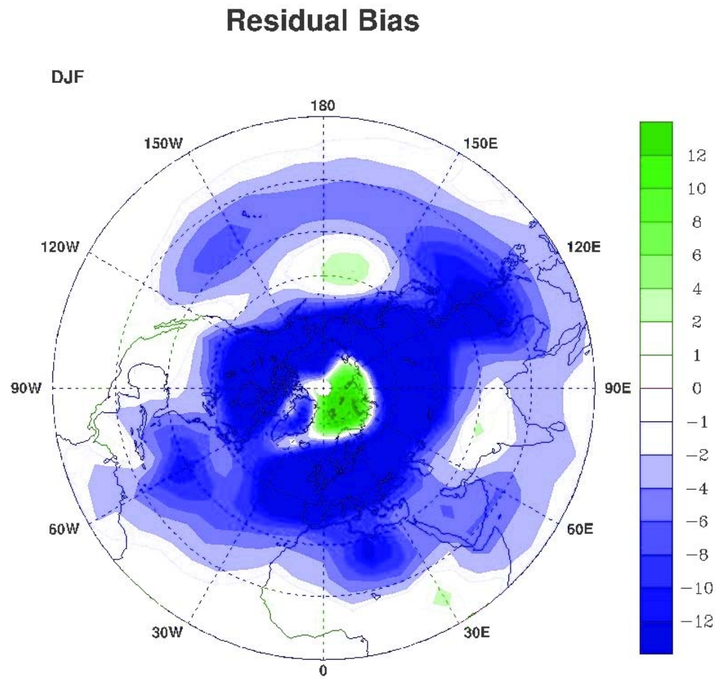
9-Pole Solutions

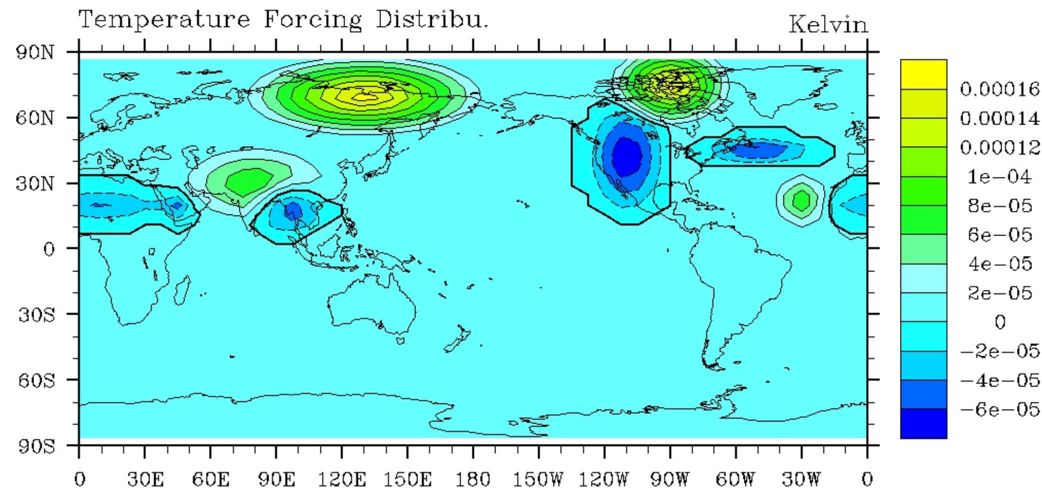
At Sig=0.991

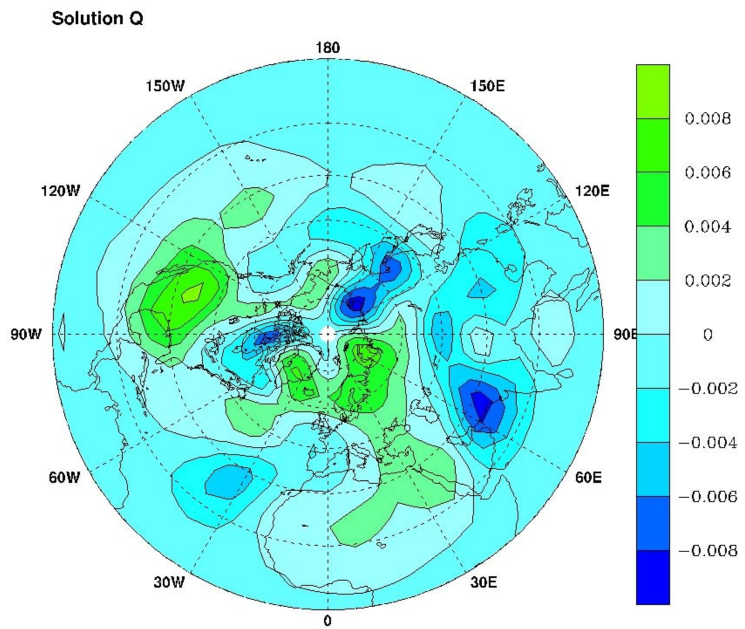
At Sig=0.991

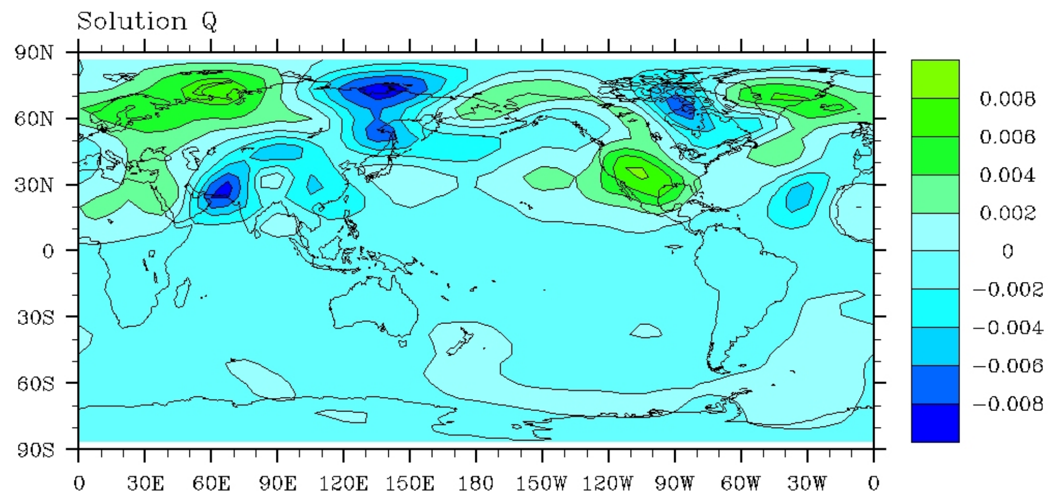


9-Pole Solutions

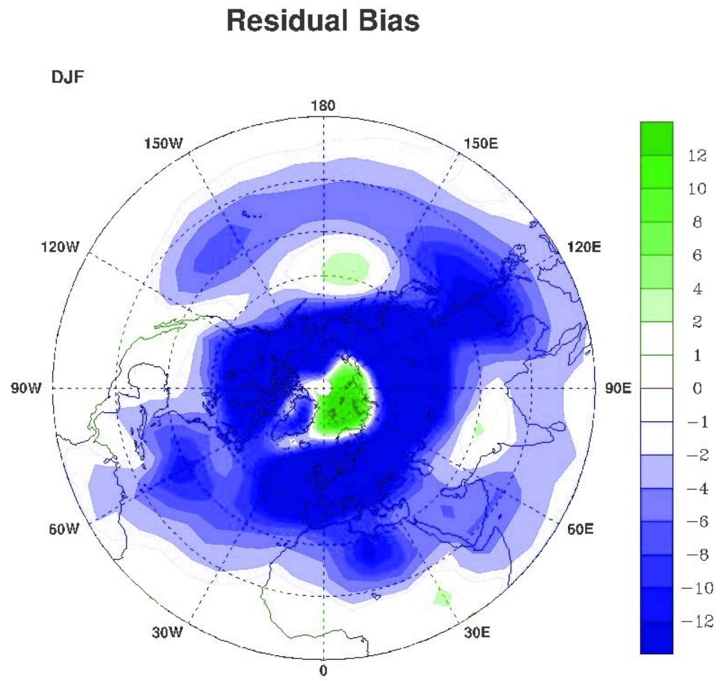


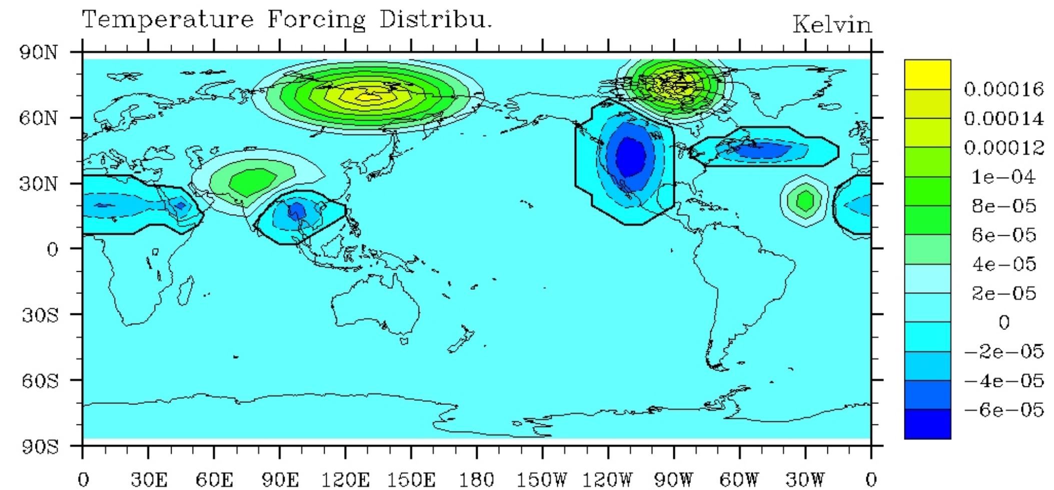


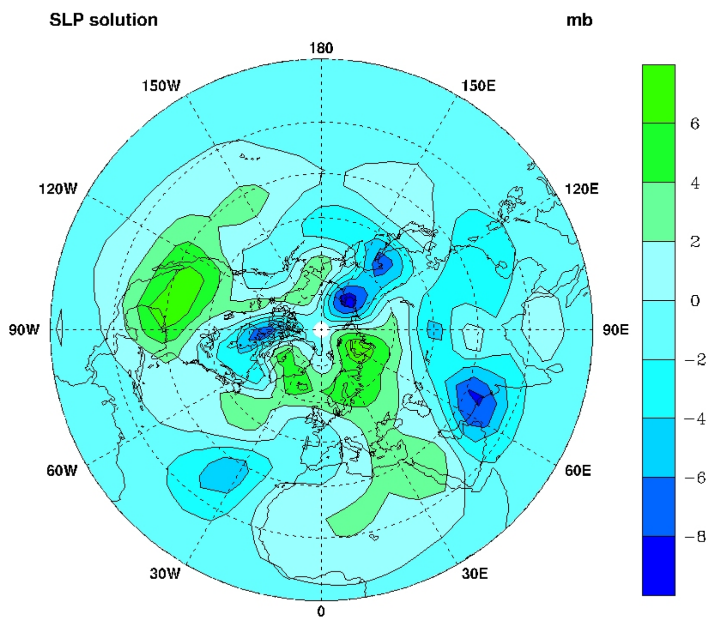


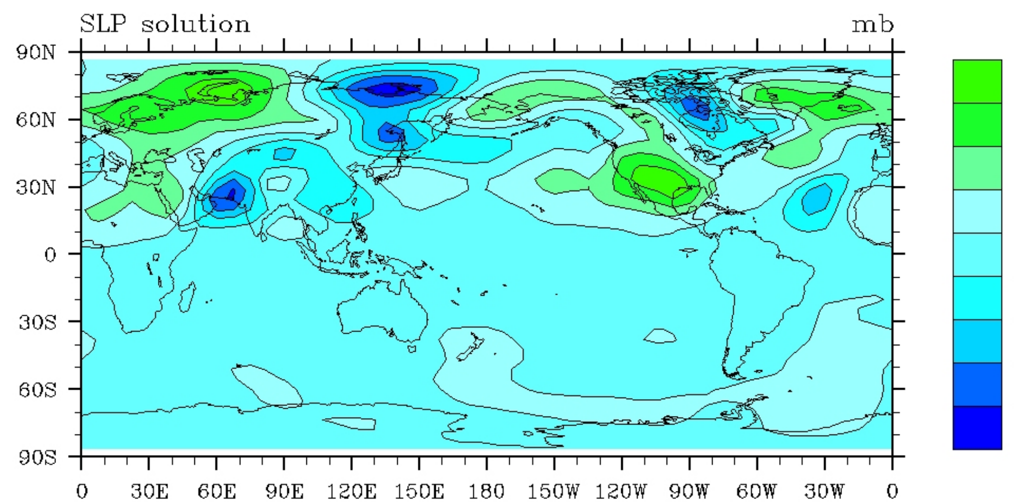


9-Pole Solutions

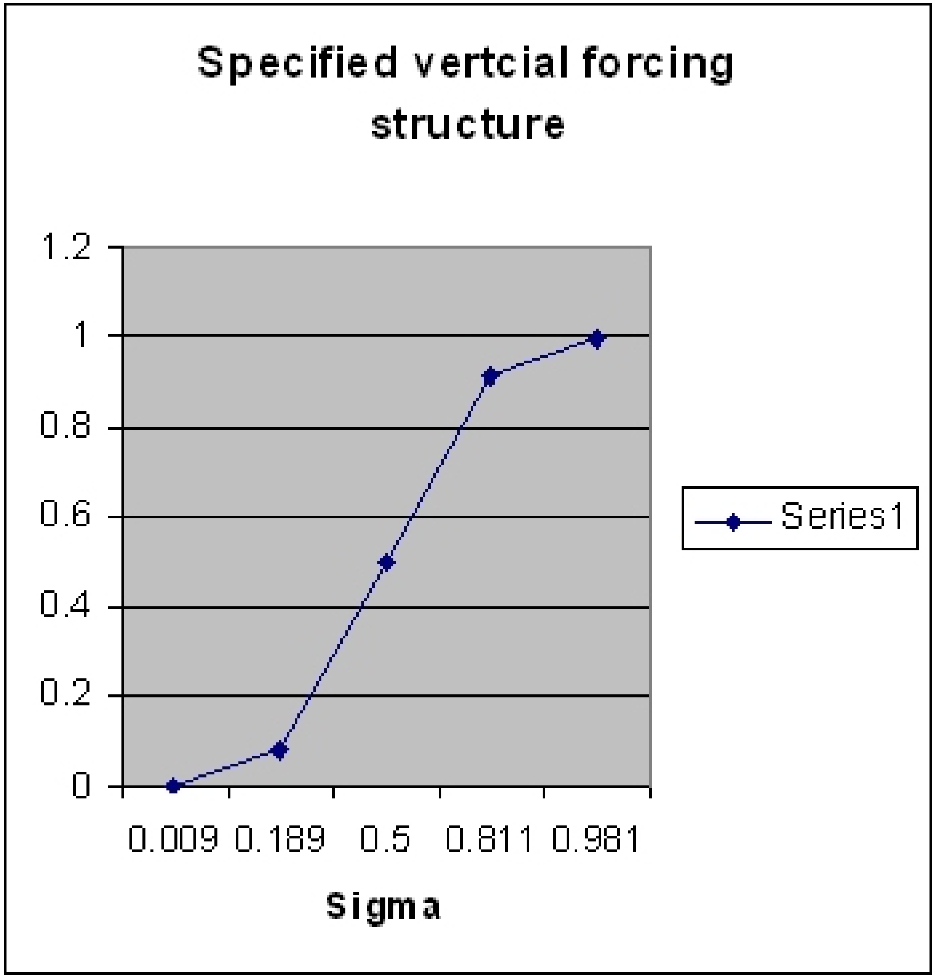






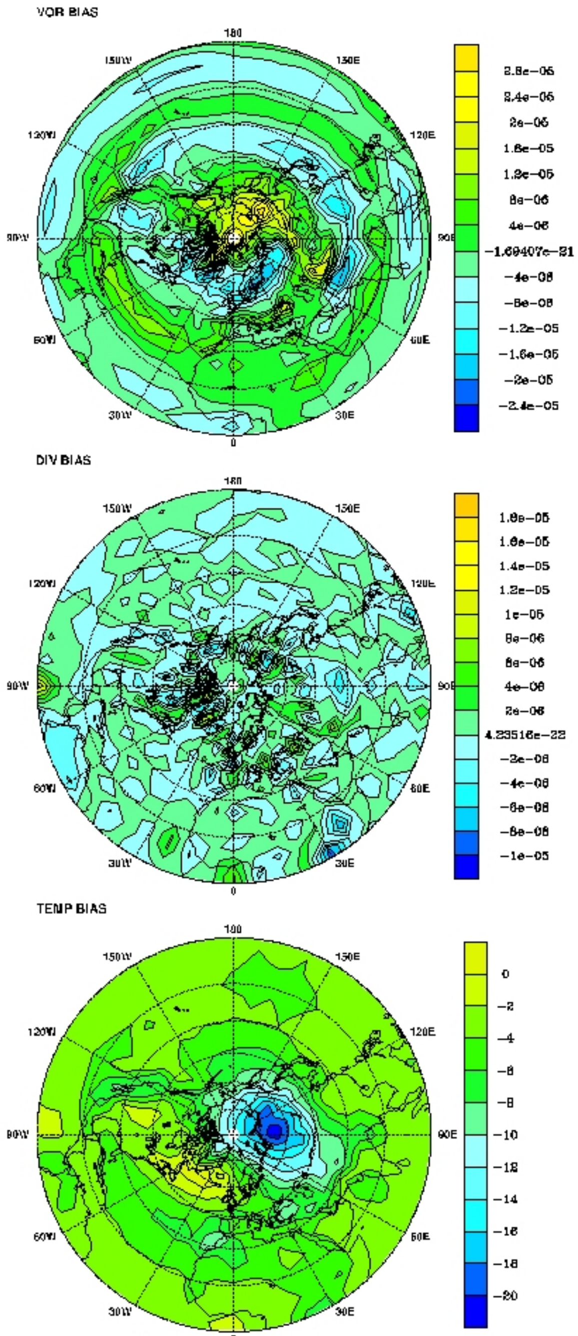


Specified T forcing variation in vertical

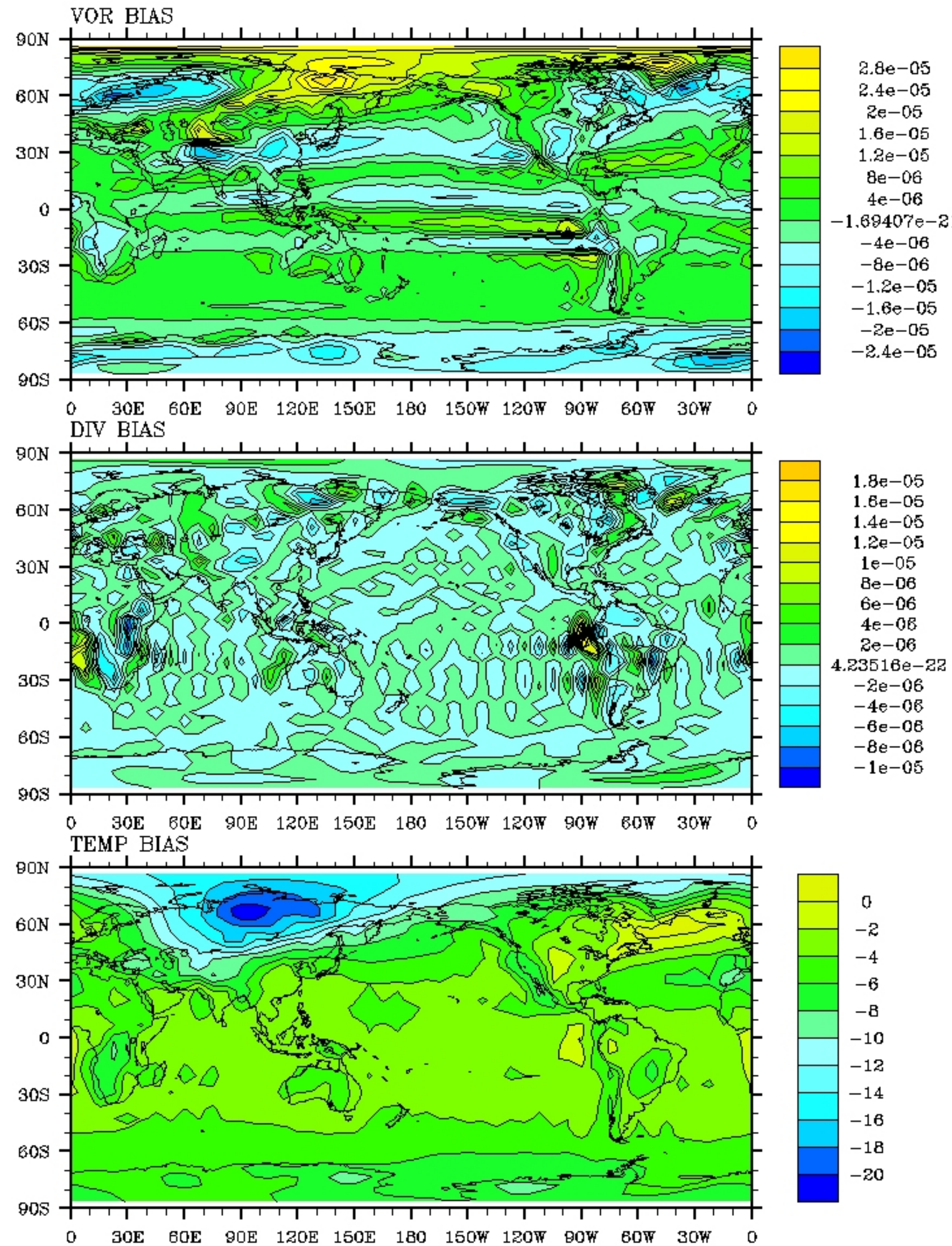


Model Bias

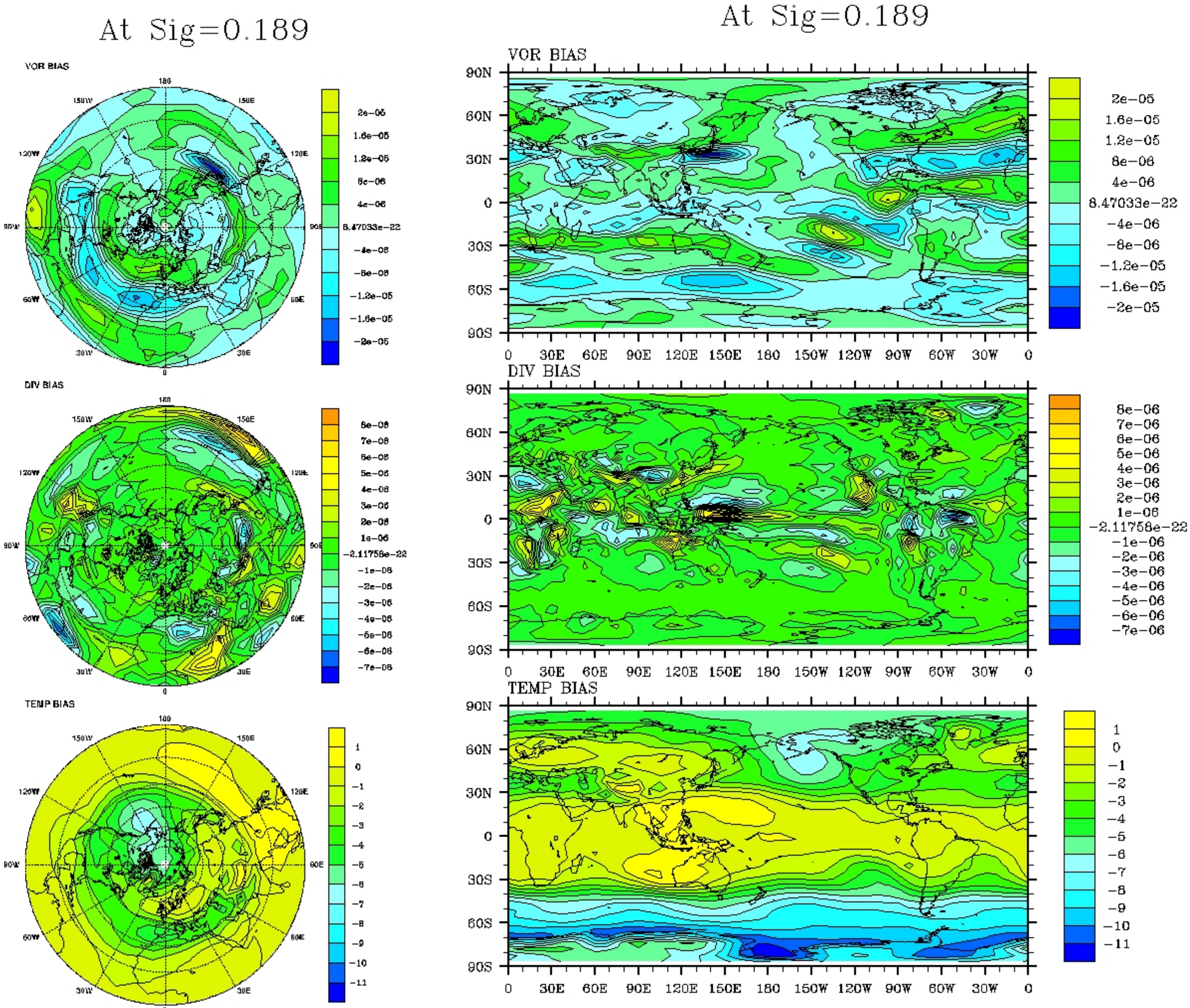
At Sig=0.009



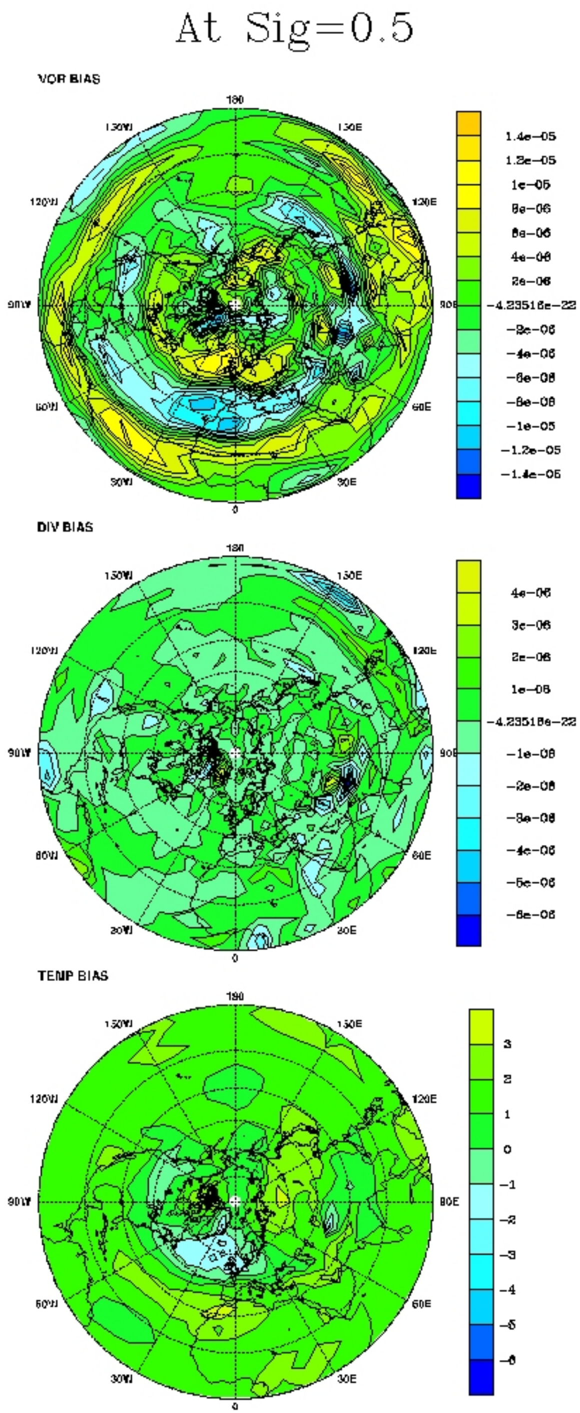
At Sig=0.009

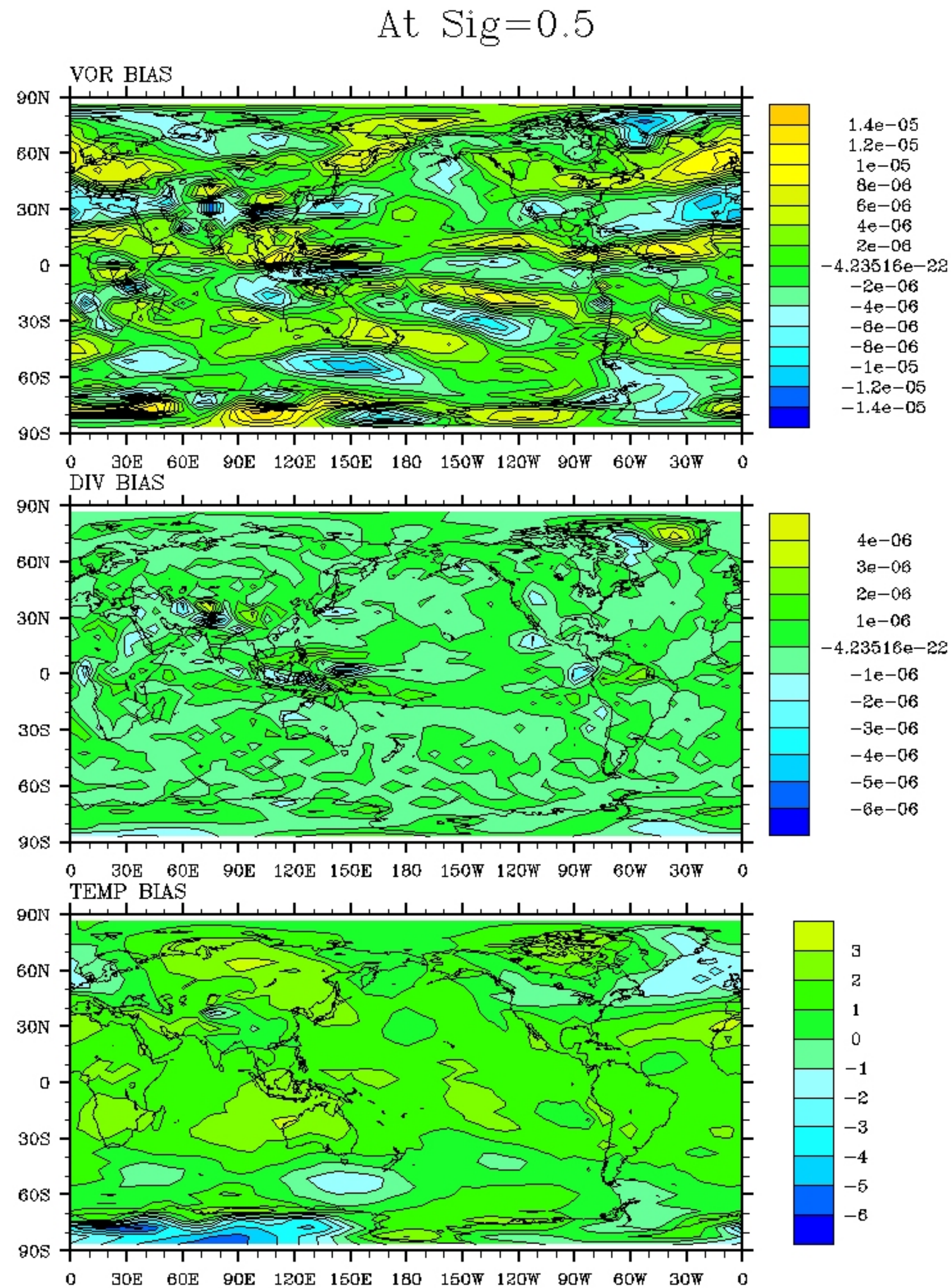


Model Bias

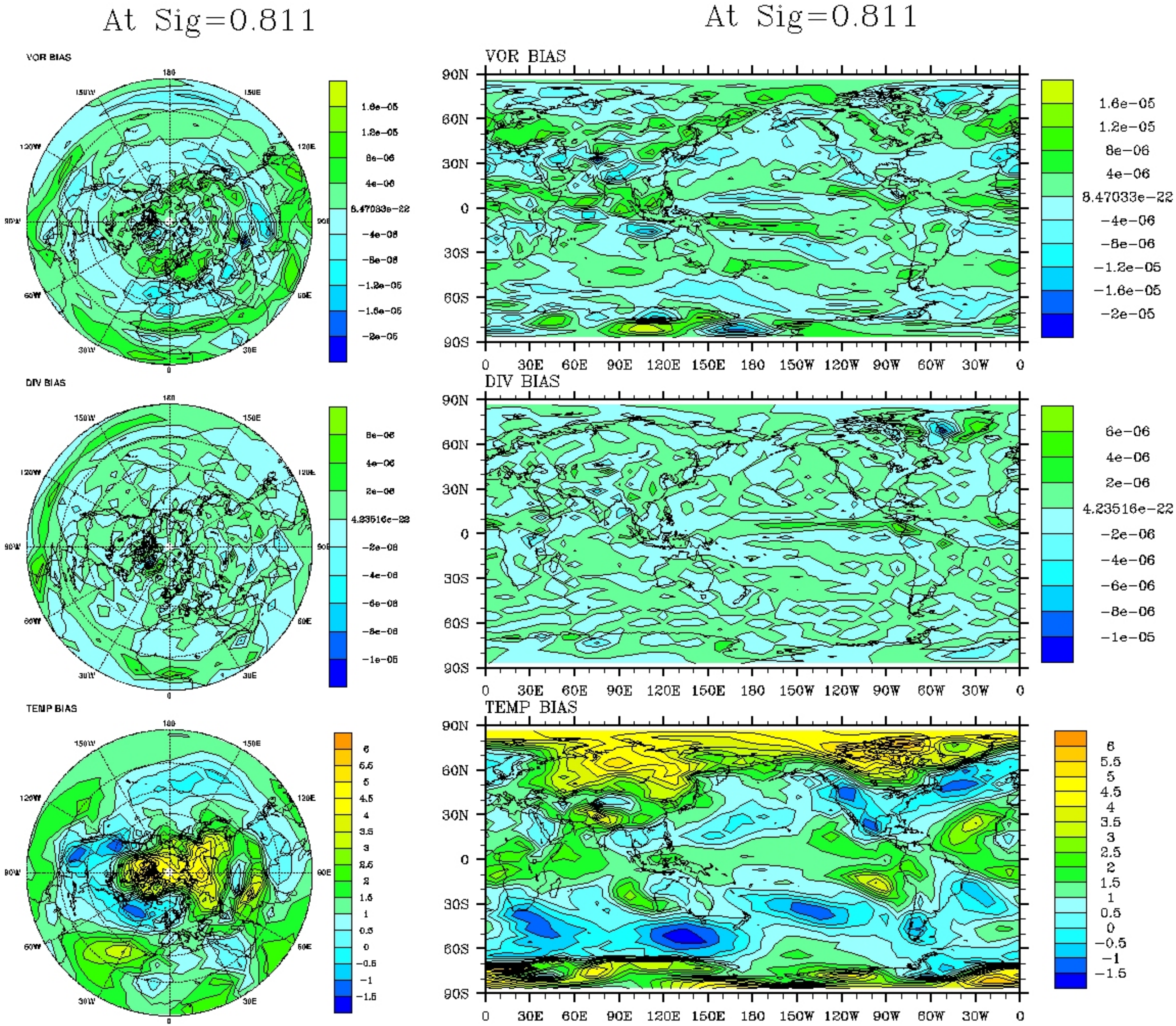

At Sig=0.189
At Sig=0.189
VOR BIAS
DIV BIAS
TEMP BIAS
2e-05
1.6e-05
1.2e-05
8e-06
4e-06
8.47033e-22
-4e-06
-8e-06
-1.2e-05
-1.6e-05
-2e-05
8e-06
7e-06
6e-06
5e-06
4e-06
3e-06
2e-06
1e-06
-2.11758e-22
-1e-06
-2e-06
-3e-06
-4e-06
-5e-06
-6e-06
-7e-06
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0

Model Bias


At Sig=0.5
VOR BIAS
DIV BIAS
TEMP BIAS

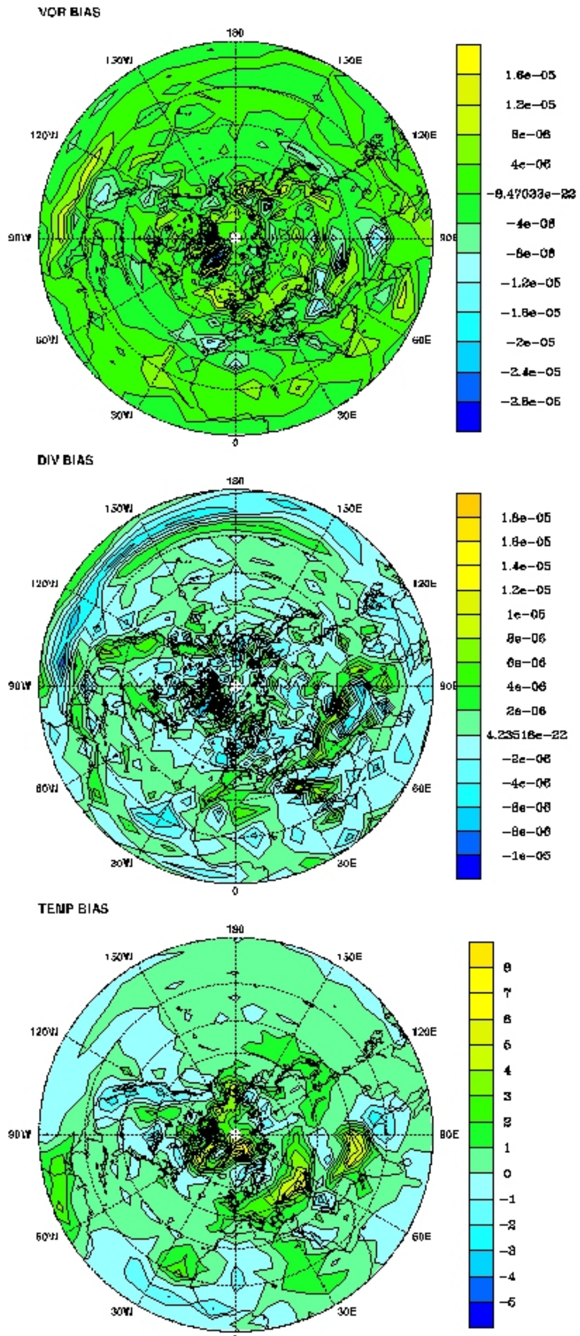

At Sig=0.5
VOR BIAS
1.4e-05
1.2e-05
1e-05
8e-06
6e-06
4e-06
2e-06
-4.23516e-22
-2e-06
-4e-06
-6e-06
-8e-06
-1e-05
-1.2e-05
-1.4e-05
DIV BIAS
4e-06
3e-06
2e-06
1e-06
-4.23516e-22
-1e-06
-2e-06
-3e-06
-4e-06
-5e-06
-6e-06
TEMP BIAS
3
2
1
0
-1
-2
-3
-4
-5
-6
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W

Model Bias

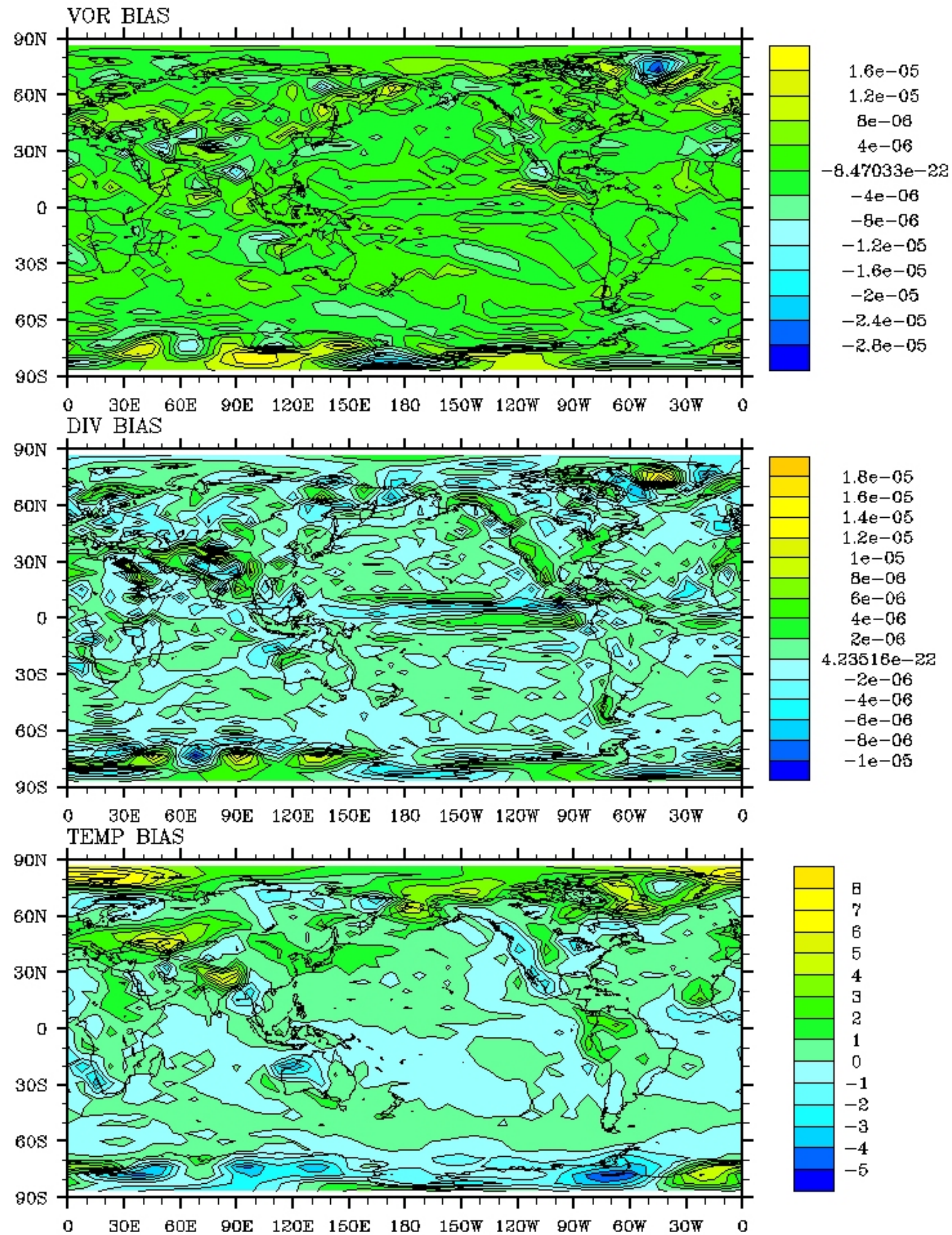

At Sig=0.811
At Sig=0.811
VOR BIAS
1.6e-05
1.2e-05
8e-06
4e-06
8.47033e-22
-4e-06
-8e-06
-1.2e-05
-1.6e-05
-2e-05
DIV BIAS
6e-06
4e-06
2e-06
4.23516e-22
-2e-06
-4e-06
-6e-06
-8e-06
-1e-05
TEMP BIAS
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W

Model Bias

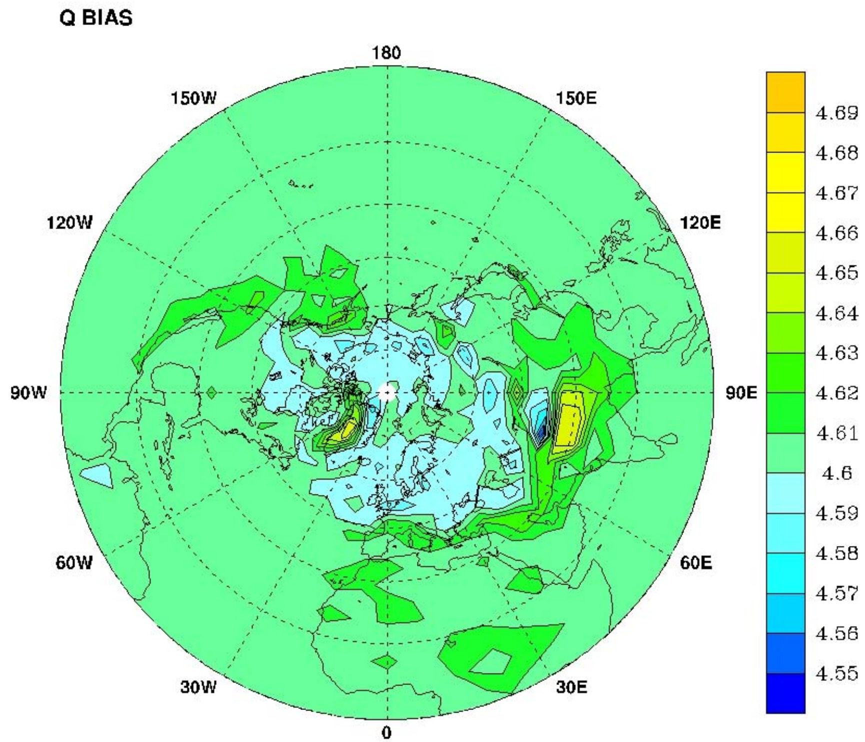
At Sig=0.991



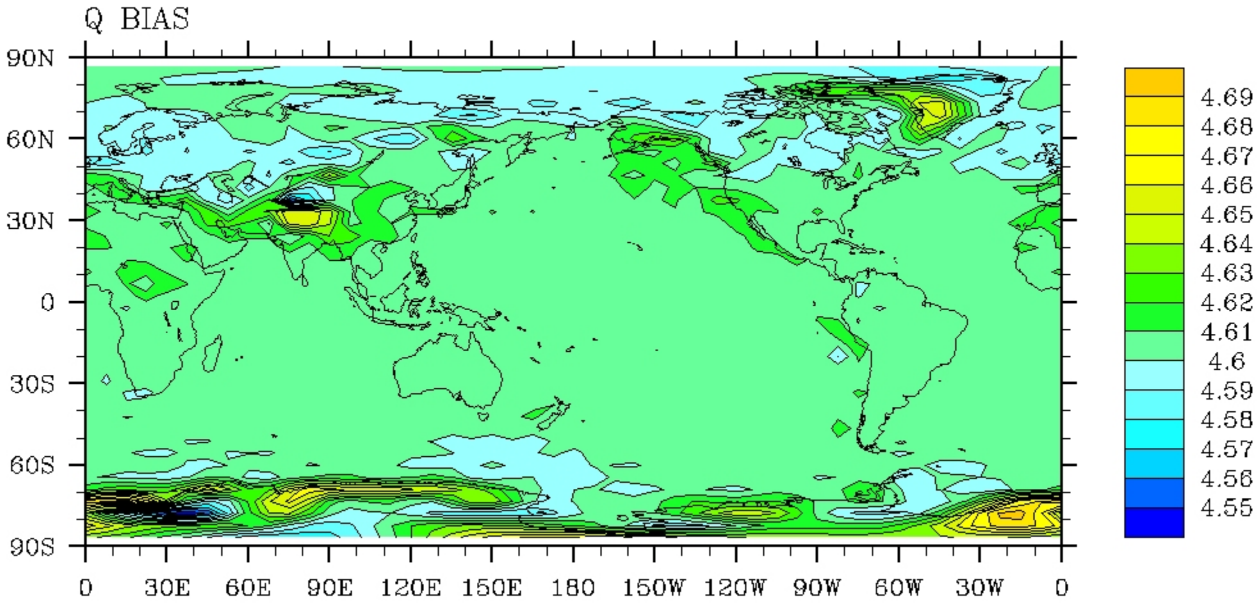
At Sig=0.991



Model Bias

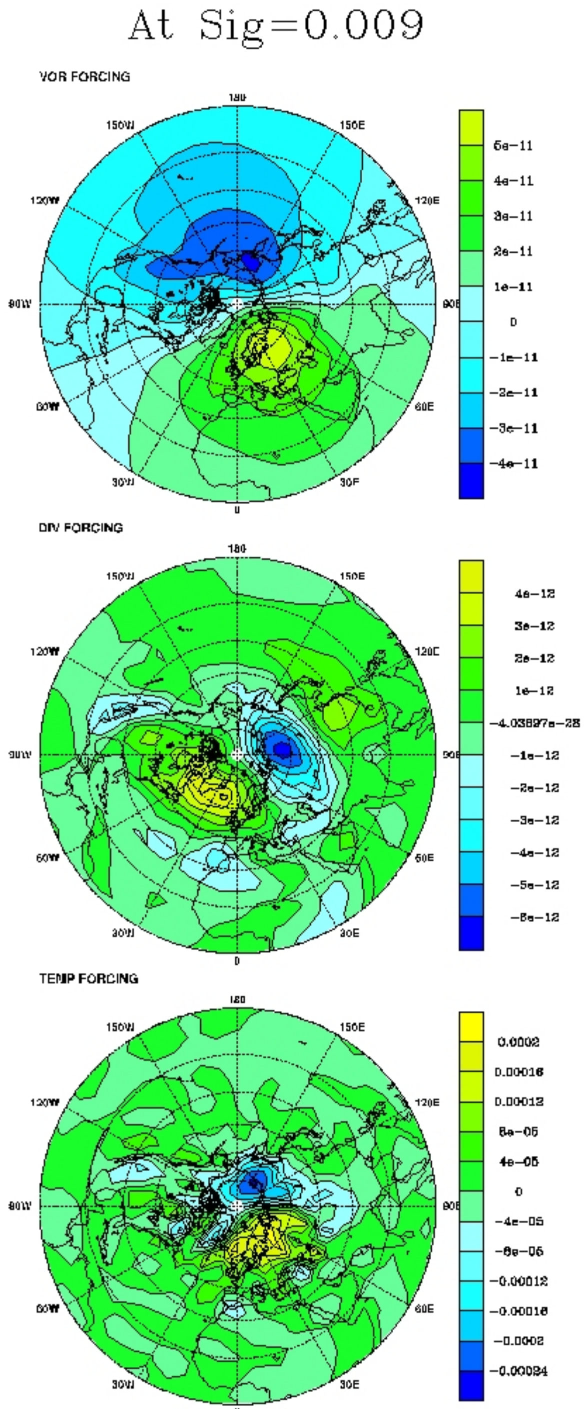


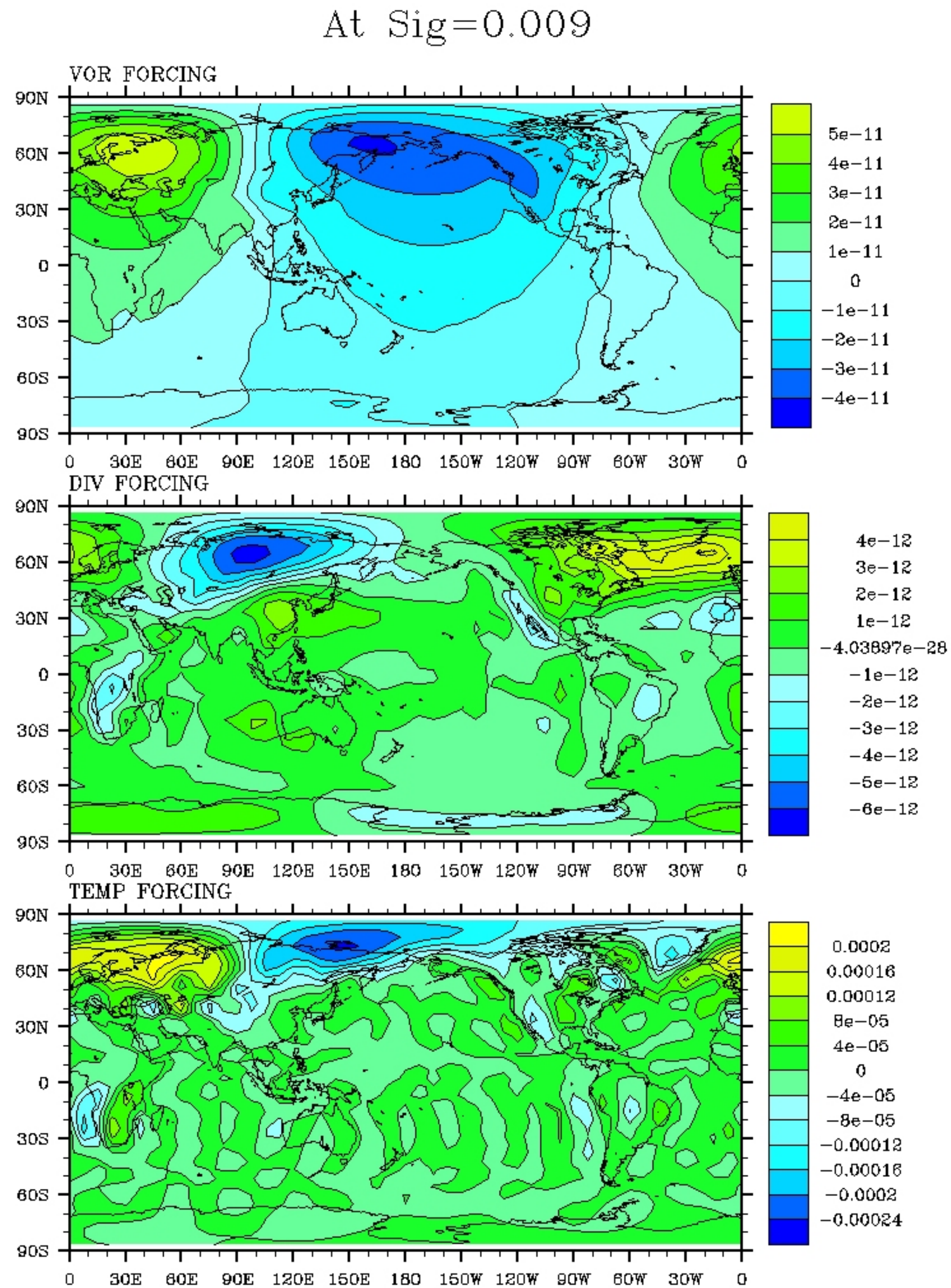
Q BIAS
180
150W
150E
120W
120E
90W
90E
60W
60E
30W
30E
0
4.69
4.68
4.67
4.66
4.65
4.64
4.63
4.62
4.61
4.6
4.59
4.58
4.57
4.56
4.55



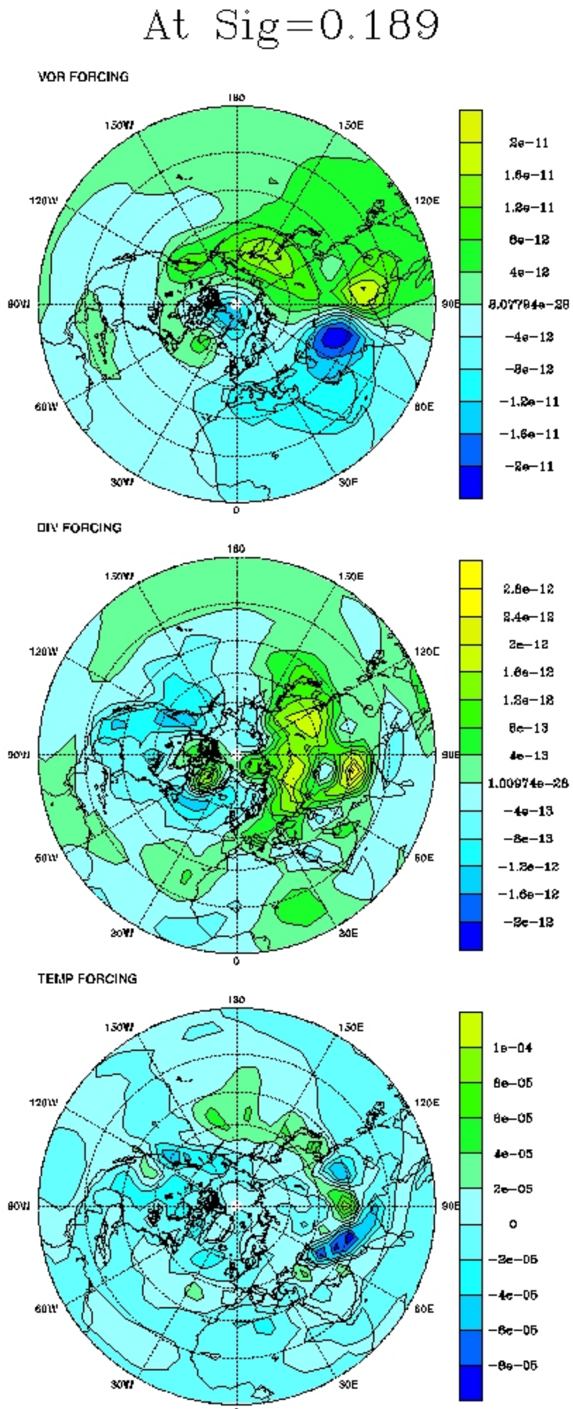
Q BIAS
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
4.69
4.68
4.67
4.66
4.65
4.64
4.63
4.62
4.61
4.6
4.59
4.58
4.57
4.56
4.55

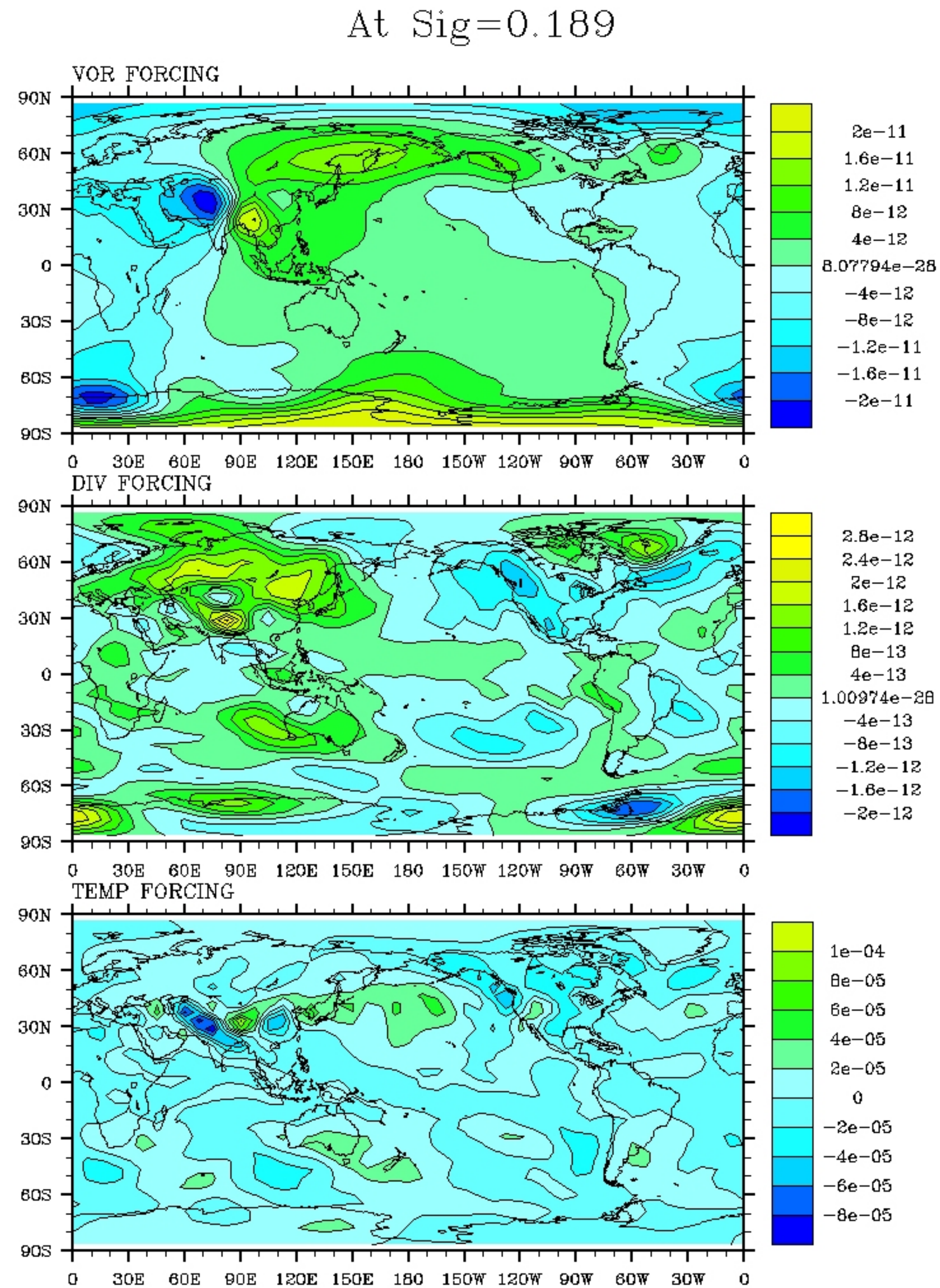
Forcing from the Model Bias



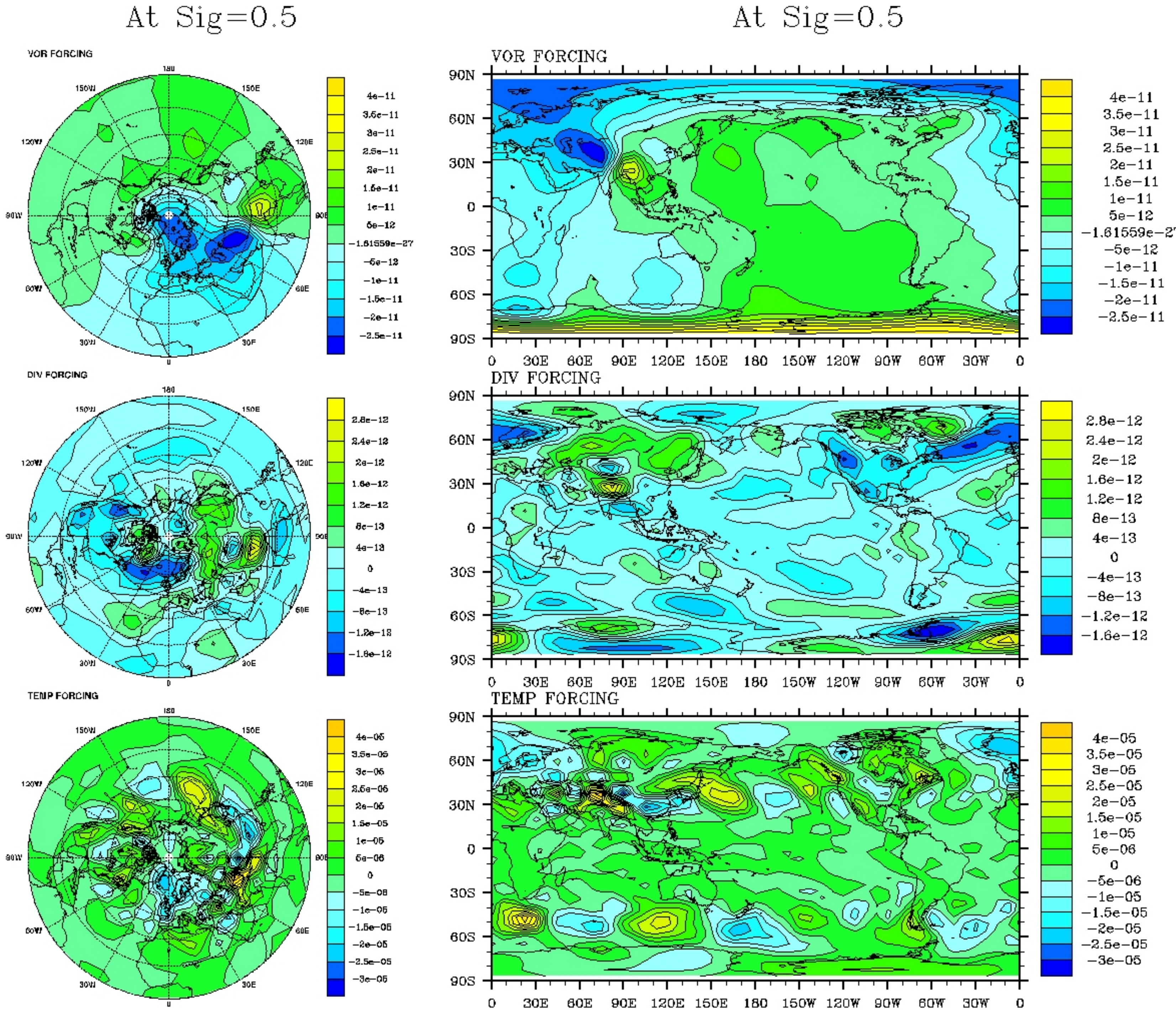


Forcing from the Model Bias

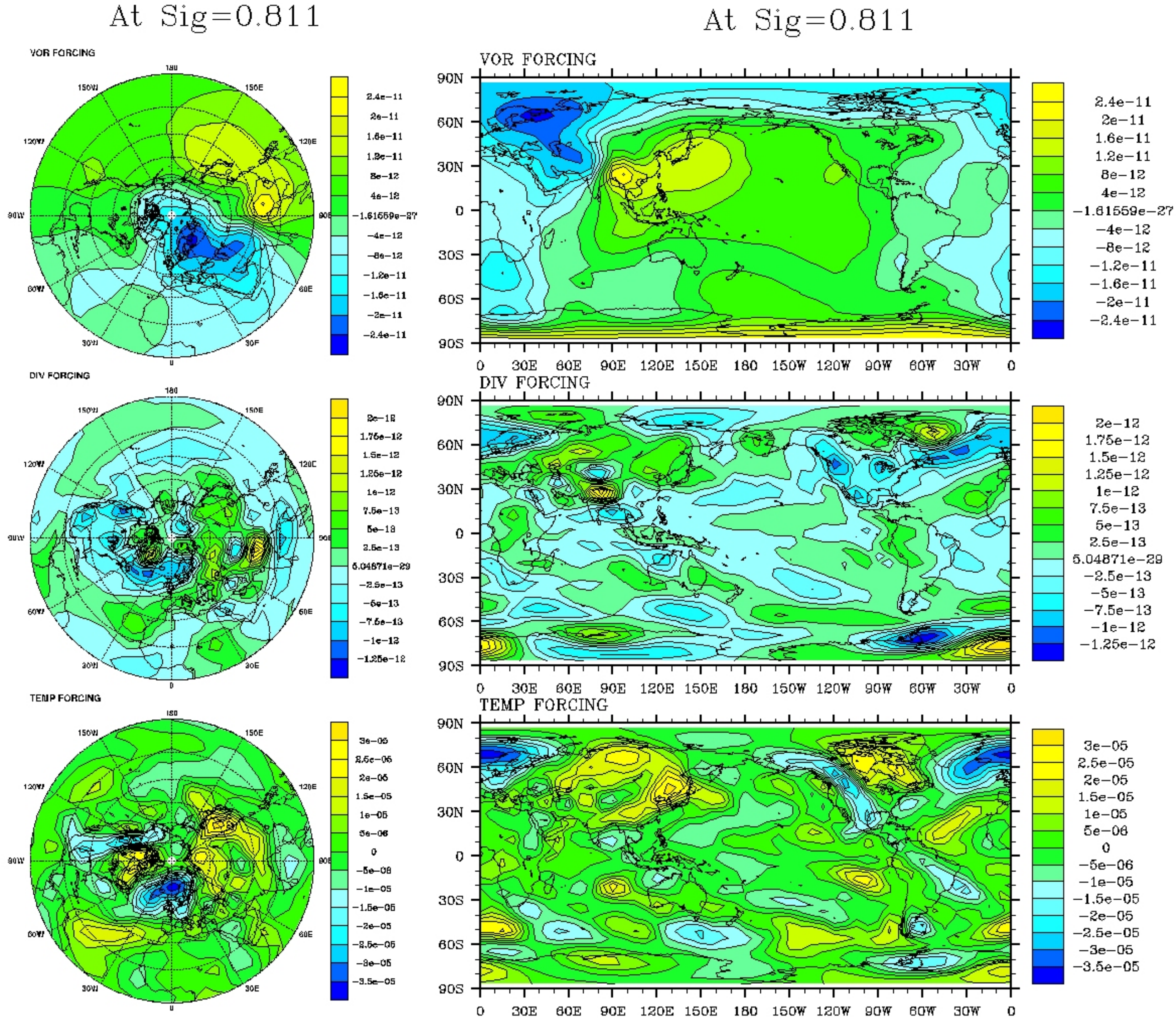




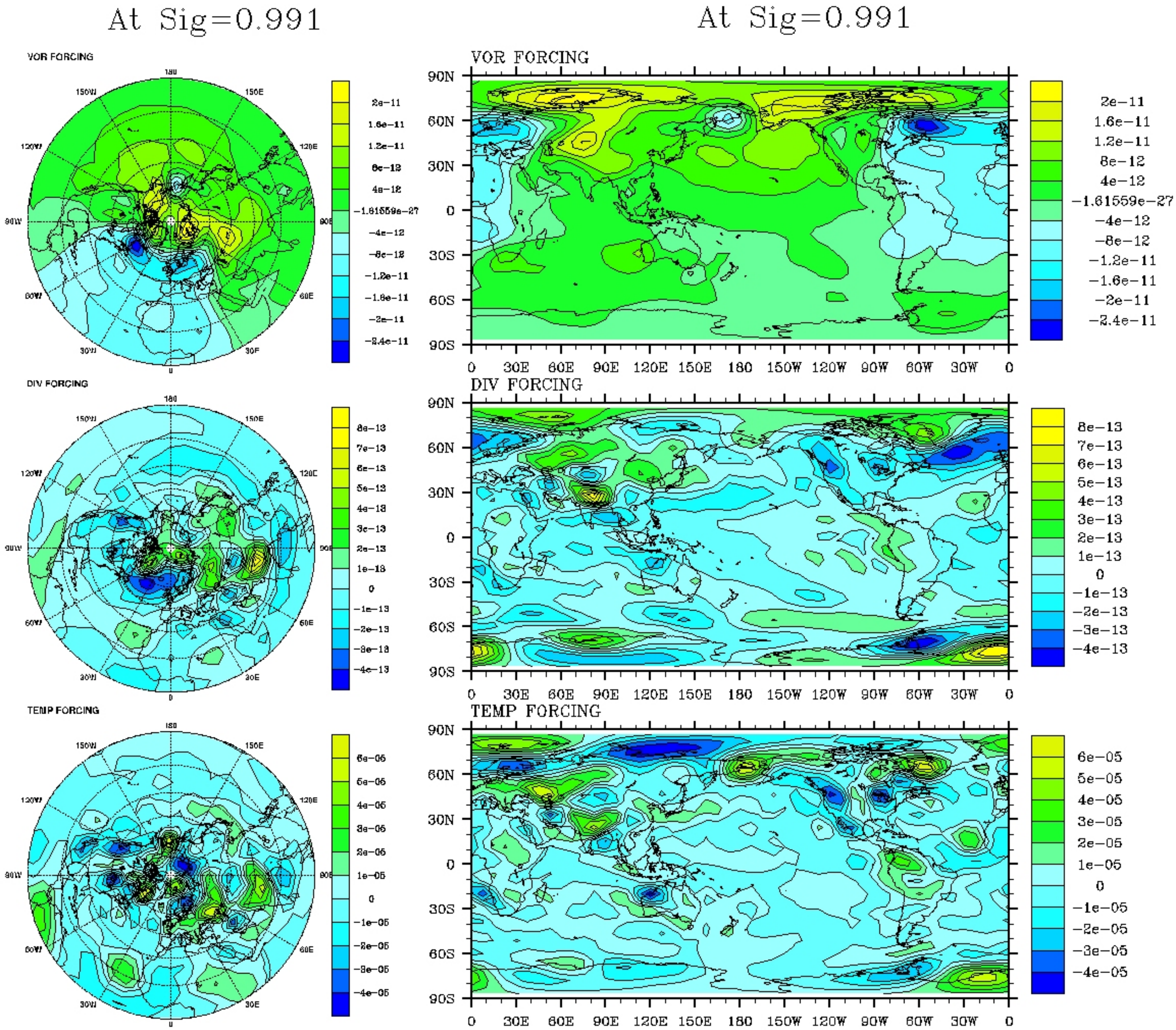
Forcing from the Model Bias



Forcing from the Model Bias



Forcing from the Model Bias



Forcing from the Model Bias