Estimating Atmospheric Response Using Fluctuation-Response Based Methods

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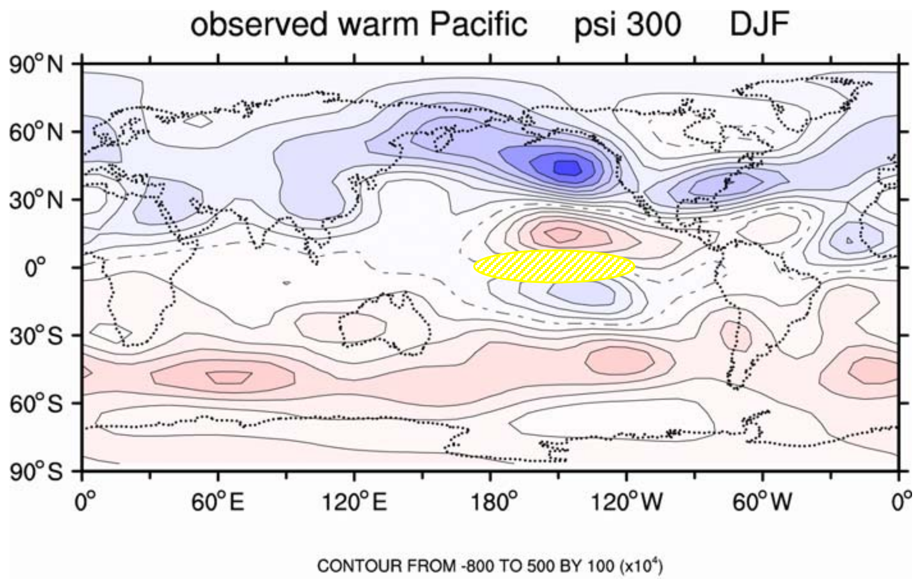
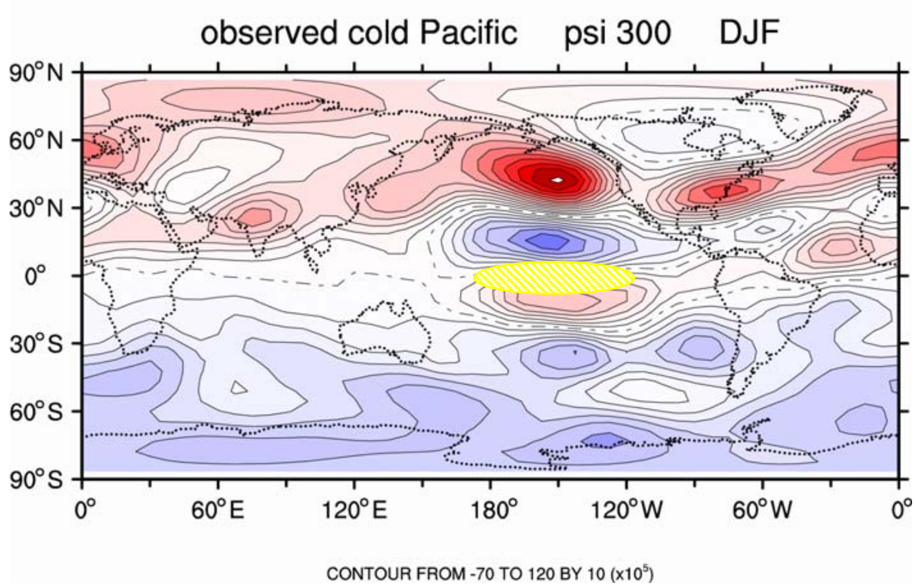
- Linear response operator, L

  $Lr' = s'$

- Why not use an AGCM?
- Is a <u>linear</u> operator of any value?


observed warm Pacific psi 300 DJF
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W
0°
CONTOUR FROM -800 TO 500 BY 100 (x10^4)


observed cold Pacific psi 300 DJF
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W
0°
CONTOUR FROM -70 TO 120 BY 10 (x10^5)

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_\psi \cdot \nabla(\varsigma + f) - \ldots$$

$$() = \frac{1}{T}\int_0^T ()dt + ()'$$

$$\frac{\partial \varsigma'}{\partial t} = -\overline{\vec{v}}_\psi \cdot \nabla(\overline{\varsigma} + f) - \overline{\vec{v}}_\psi \cdot \nabla \varsigma' - \vec{v}'_\psi \cdot \nabla \overline{\varsigma} - \vec{v}'_\psi \cdot \nabla \varsigma' \ldots$$

$$\overline{\vec{v}}_\psi \cdot \nabla(\overline{\varsigma} + f) = -\overline{\vec{v}'_\psi \cdot \nabla \varsigma' + \ldots}$$

$$\frac{\partial \varsigma'}{\partial t} = -\overline{\vec{v}}_\psi \cdot \nabla \varsigma' - \vec{v}'_\psi \cdot \nabla \overline{\varsigma} - (\vec{v}'_\psi \cdot \nabla \varsigma' - \overline{\vec{v}'_\psi \cdot \nabla \varsigma'}) \ldots$$

$$= -\overline{\vec{v}}_\psi \cdot \nabla \varsigma' - \vec{v}'_\psi \cdot \nabla \overline{\varsigma} + damping + noise \ldots$$

$$\frac{\partial \varsigma'}{\partial t} = (A + T)\varsigma' + r'$$

$$T\varsigma'$$

Linear Inverse Model

Assume the observed system is linear, Markovian.

$$\frac{\partial s}{\partial t} + As = \epsilon$$

Then

$$C(t) = Cov(s;t) = \exp(-At)Cov(s;0) = \exp(-At)C(0)$$

$$A = -\ell n[C(t)C(0)^{-1}]$$

Ensemble averaged forced response will be

$$\frac{\partial <s>}{\partial t} + A < s >= r$$

Steady response to steady forcing r_o

$$< s >= A^{-1} r_0$$

Modified Linear Inverse Model (= FDT)

Assume the observed system is linear, Markovian

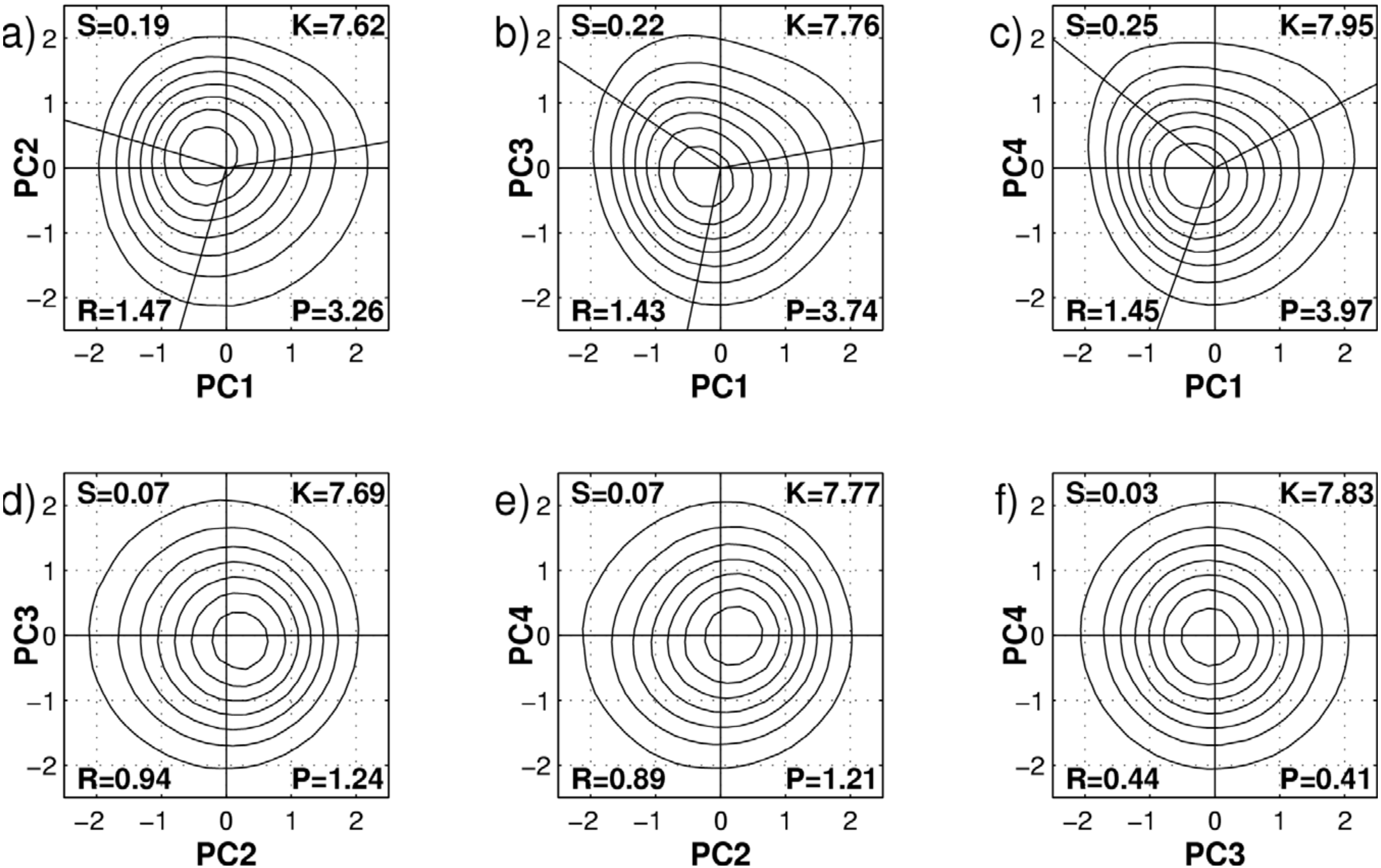
$$\frac{\partial s}{\partial t} + As = \epsilon$$

Then $C(t) = \exp(-At)C(0)$

So, $A^{-1} = \int_o^\infty C(t)C(0)^{-1}dt$

And steady response to steady forcing r_o

$$s = A^{-1}r_o$$



Berner & Branstator (2006)

$$L = \int_0^{\infty} C(t) C^{-1}(0) dt$$

Application

Atmospheric general circulation model (NCAR's CCM0)

Primitive equations, circa 1980 physical parameterizations

Perpetual January, fixed boundary conditions

R15

9 level

} 18352 degrees of freedom

8 million 12hrly simulated states

Reduce Dimensionality

1. Pick fields from

   * ps

   * psi x 9

   * chi x 9

   * T x 9

   * water vapor mixing ratio x 9

2. Truncate each field using EOFs

   * psi 100x9 (>90%)

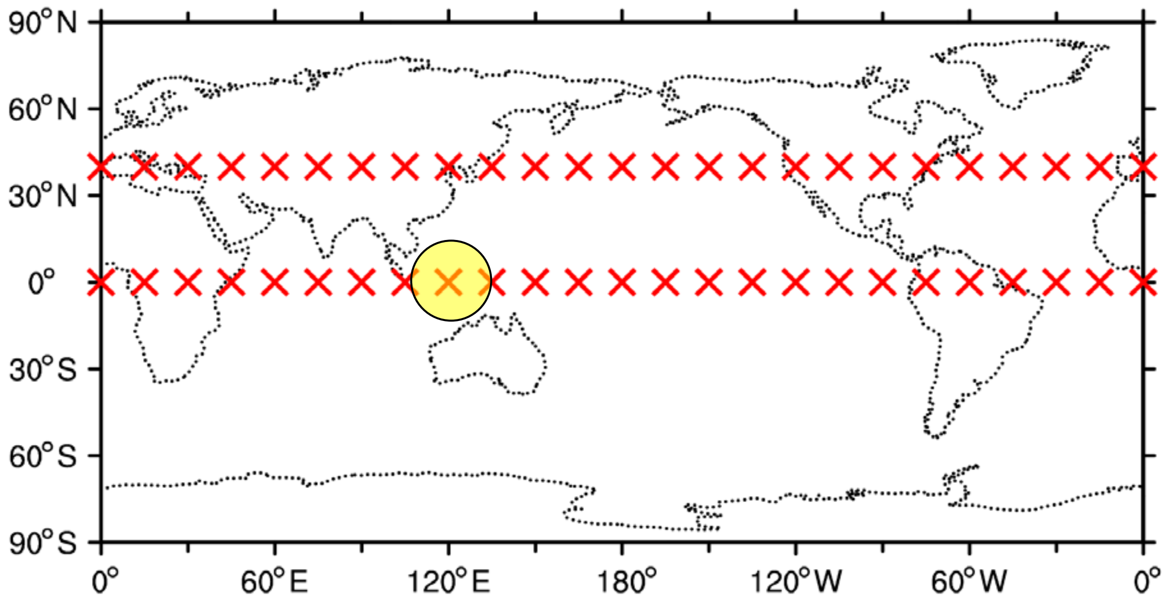
   * T 496x9 (100%)

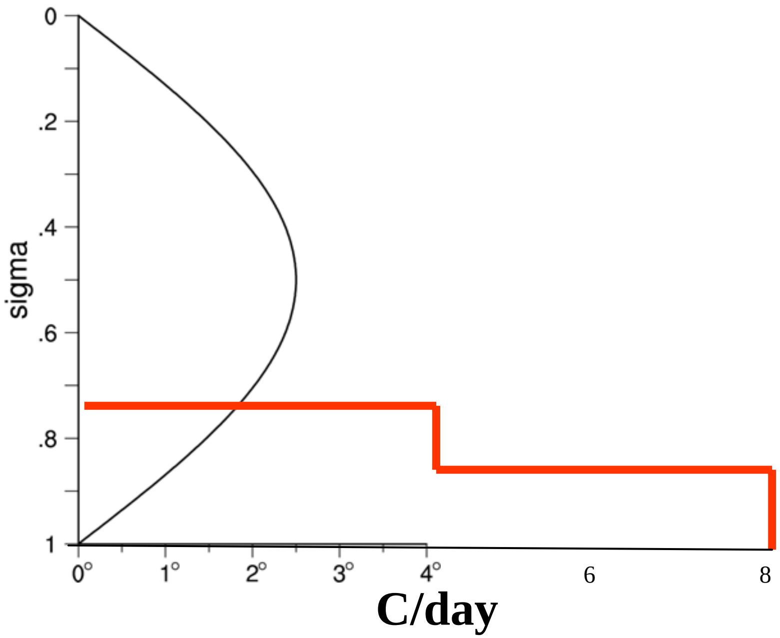
3. Form multivariate (truncated) fields,

   normalize by std dev, giving temperature triple weighting

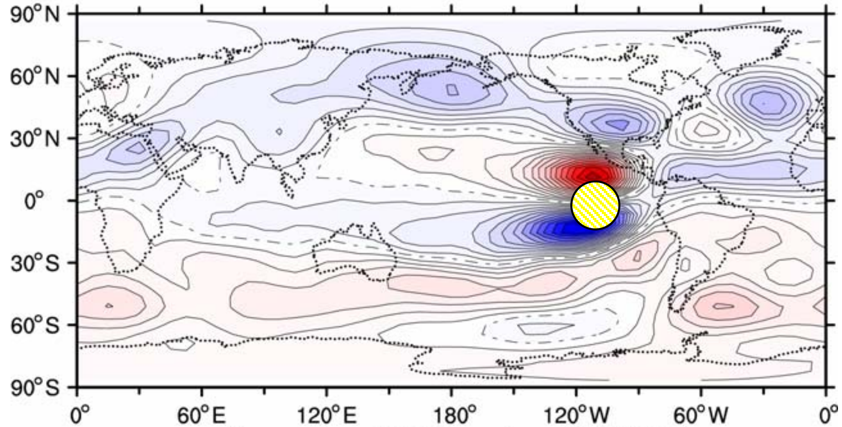
   calculate EOFs

   truncate (1800 EOFs, >95%)


90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W
0°

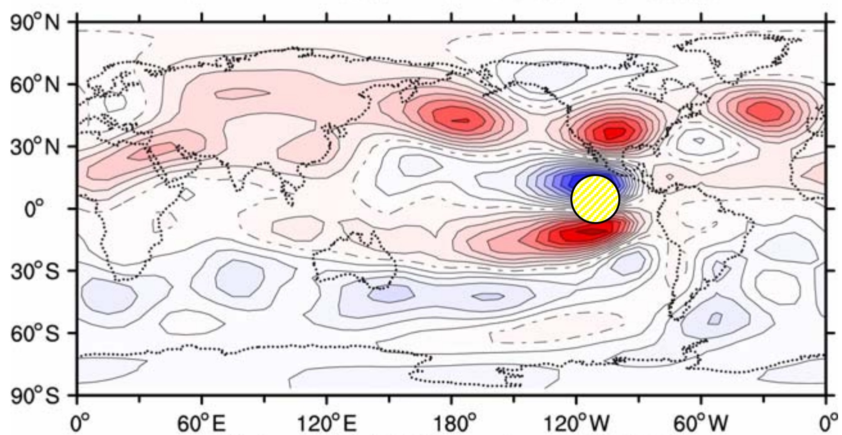

sigma
0
.2
.4
.6
.8
1
0°
1°
2°
3°
4°
6
8
C/day

300mb PSI
Anomaly +2.5deg 105W
/MAI/DYNAMIC/FF20xx - /MAI/PJ300PAVG.100000

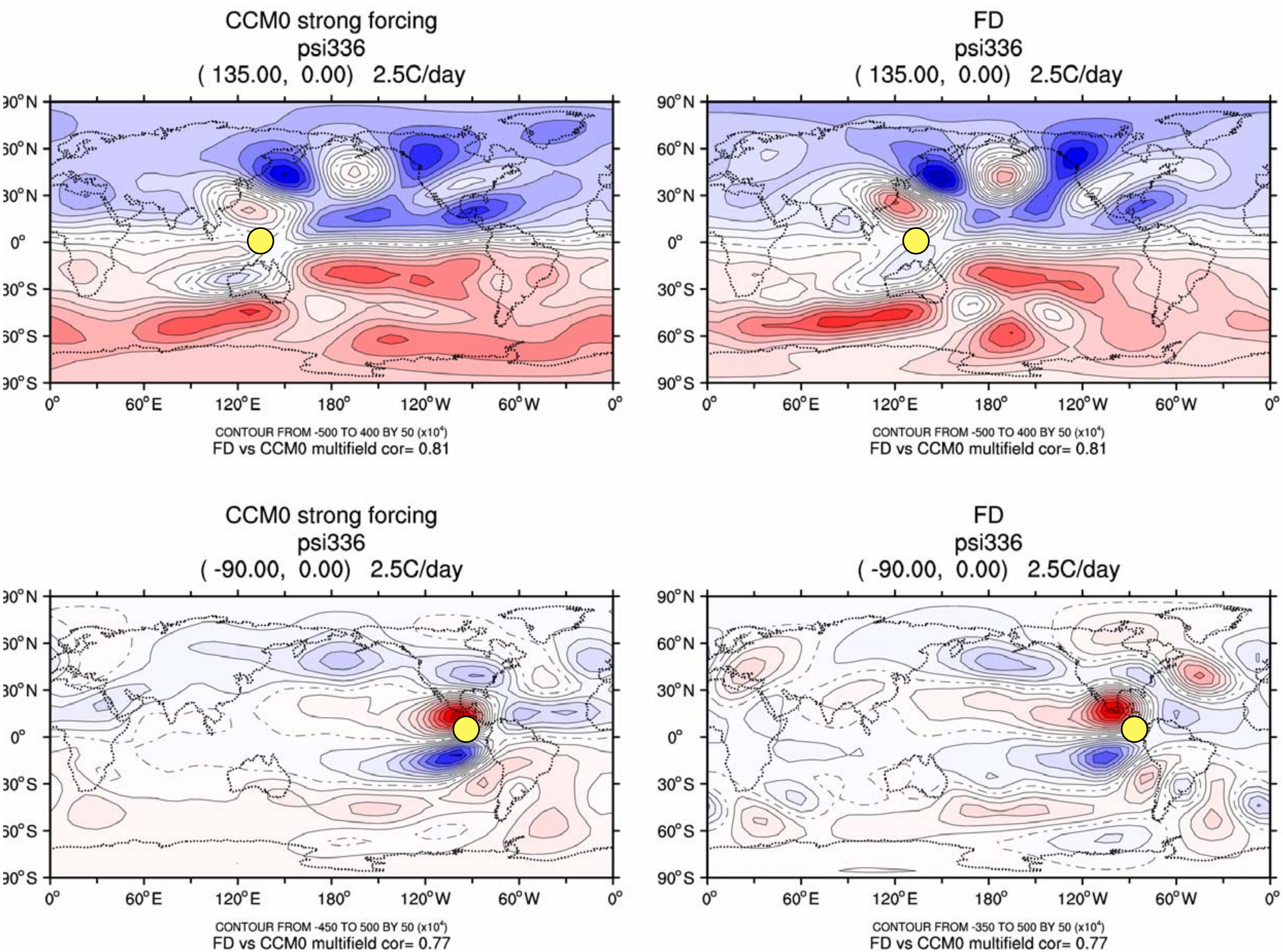


~/datasets/stats/PSI300anom2.unx (11/29/2003)
CONTOUR FROM -520 TO 560 BY 40 ($x10^4$)

300mb PSI
Anomaly -2.5deg 105W
/MAI/DYNAMIC/J85xxx - /MAI/PJ300PAVG.100000

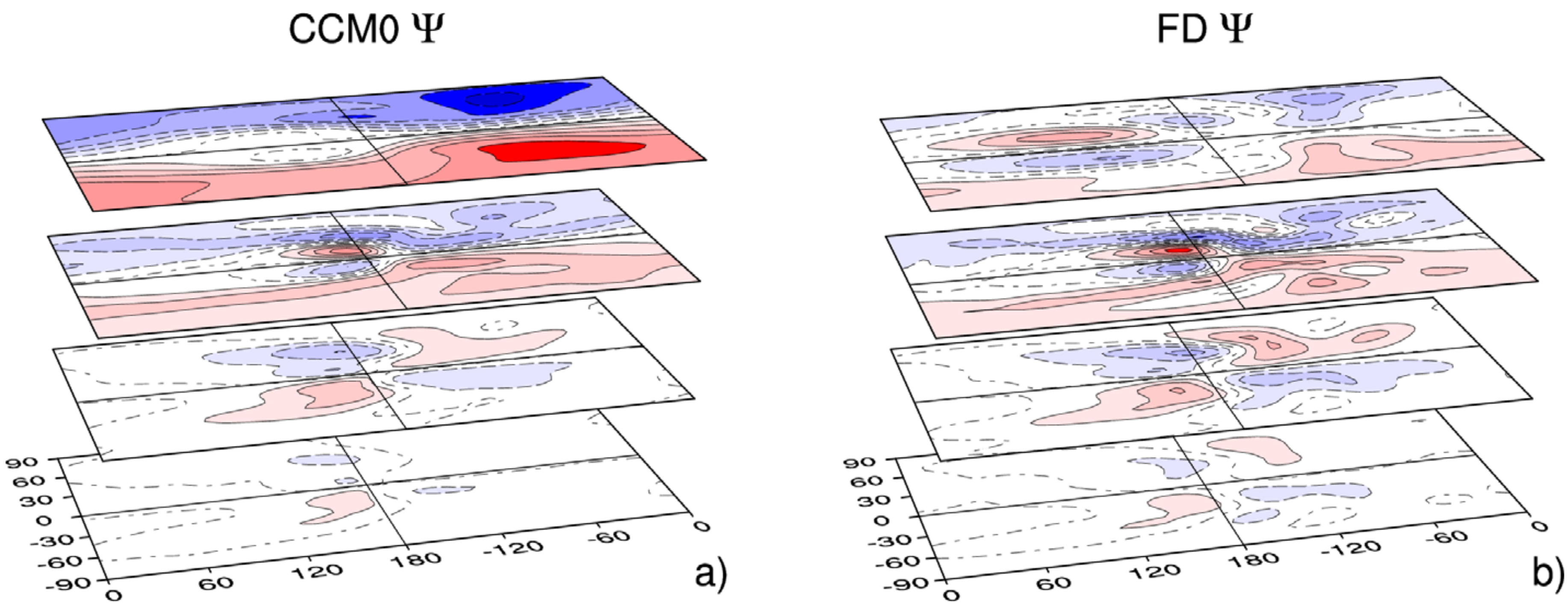


~/datasets/stats/PSI300anom2.unx (11/29/2003)
CONTOUR FROM -440 TO 360 BY 40 ($x10^4$)


CCM0 strong forcing
psi336
(135.00, 0.00) 2.5C/day
CONTOUR FROM -500 TO 400 BY 50 (x10^4)
FD vs CCM0 multifield cor= 0.81
FD
psi336
(135.00, 0.00) 2.5C/day
CONTOUR FROM -500 TO 400 BY 50 (x10^4)
FD vs CCM0 multifield cor= 0.81
CCM0 strong forcing
psi336
(-90.00, 0.00) 2.5C/day
CONTOUR FROM -450 TO 500 BY 50 (x10^4)
FD vs CCM0 multifield cor= 0.77
FD
psi336
(-90.00, 0.00) 2.5C/day
CONTOUR FROM -350 TO 500 BY 50 (x10^4)
FD vs CCM0 multifield cor= 0.77
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W

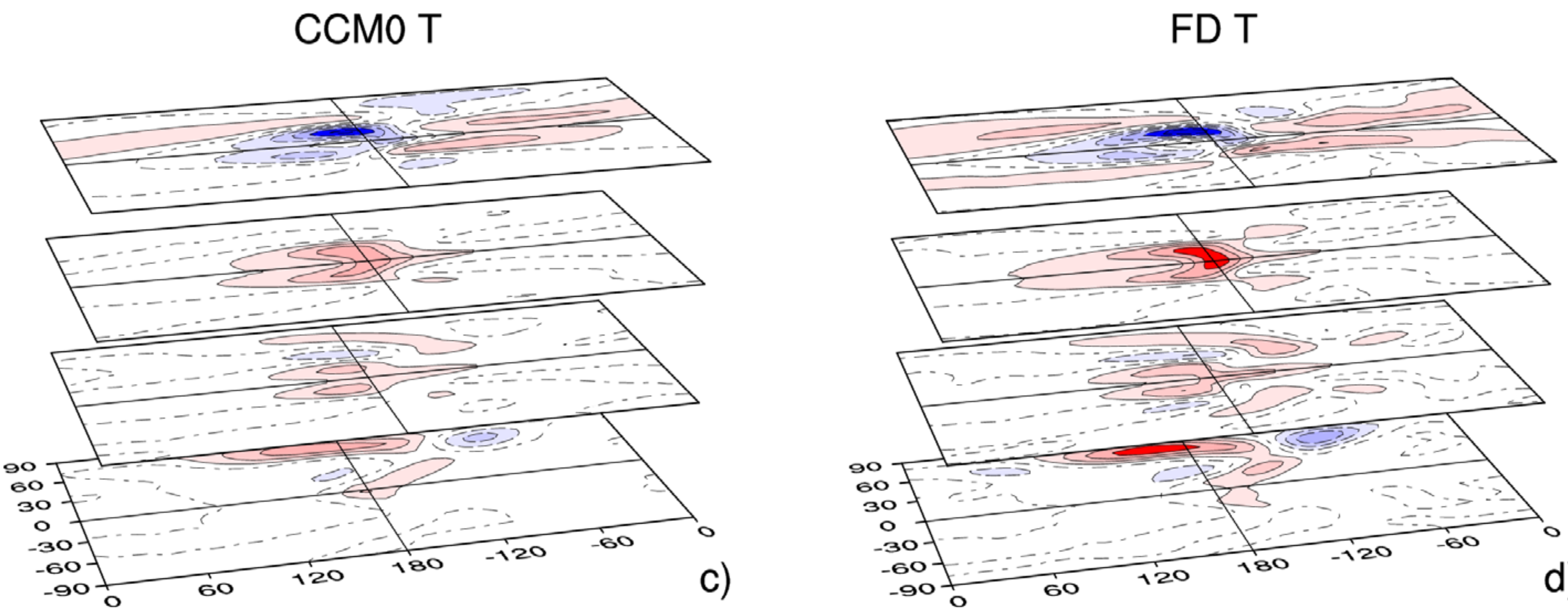
24 case average response to sinusoidal equatorial heating

(streamfunction)



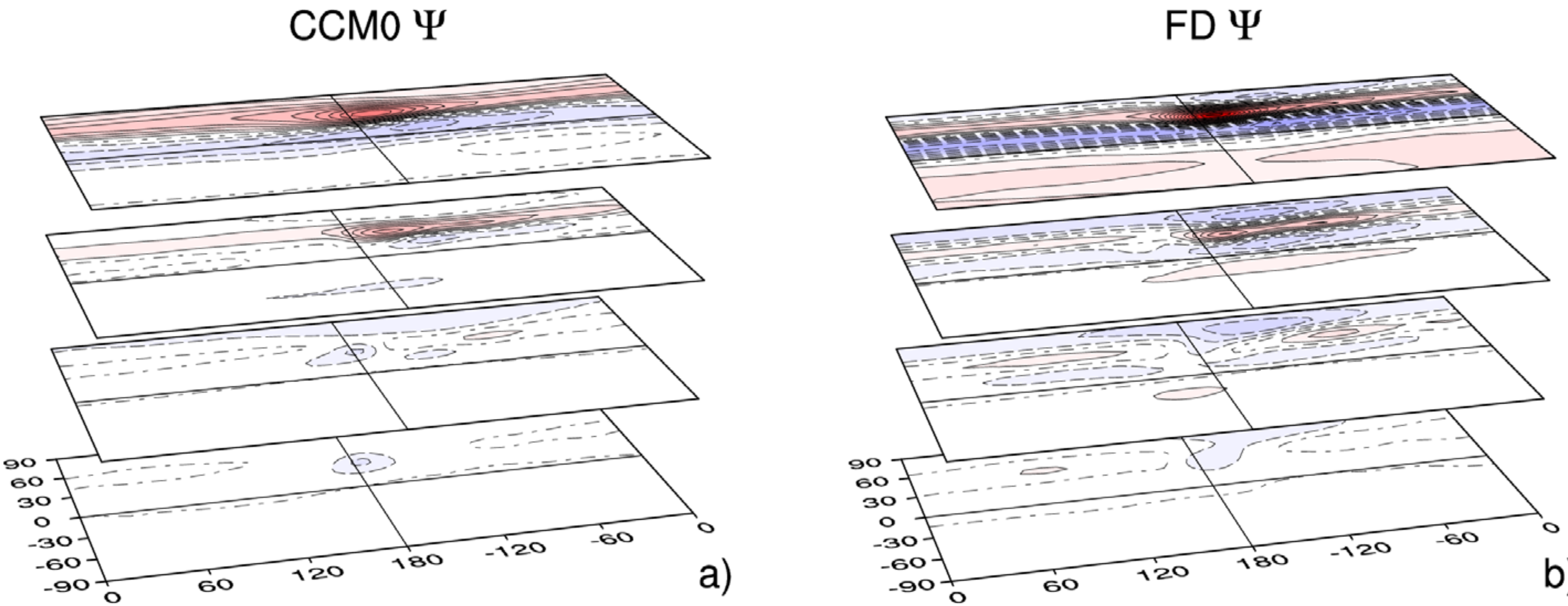
24 case average response to sinusoidal equatorial heating

(temperature)



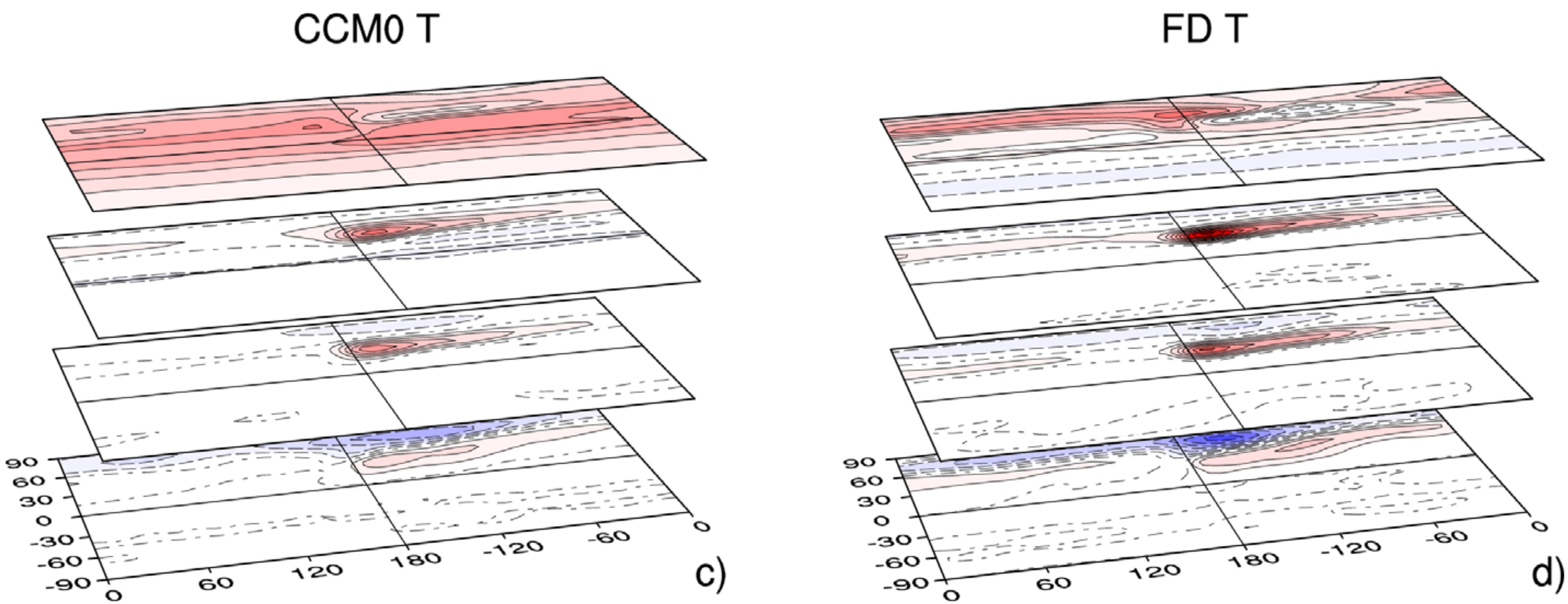
24 case average response to sinusoidal 40N heating

(streamfunction)



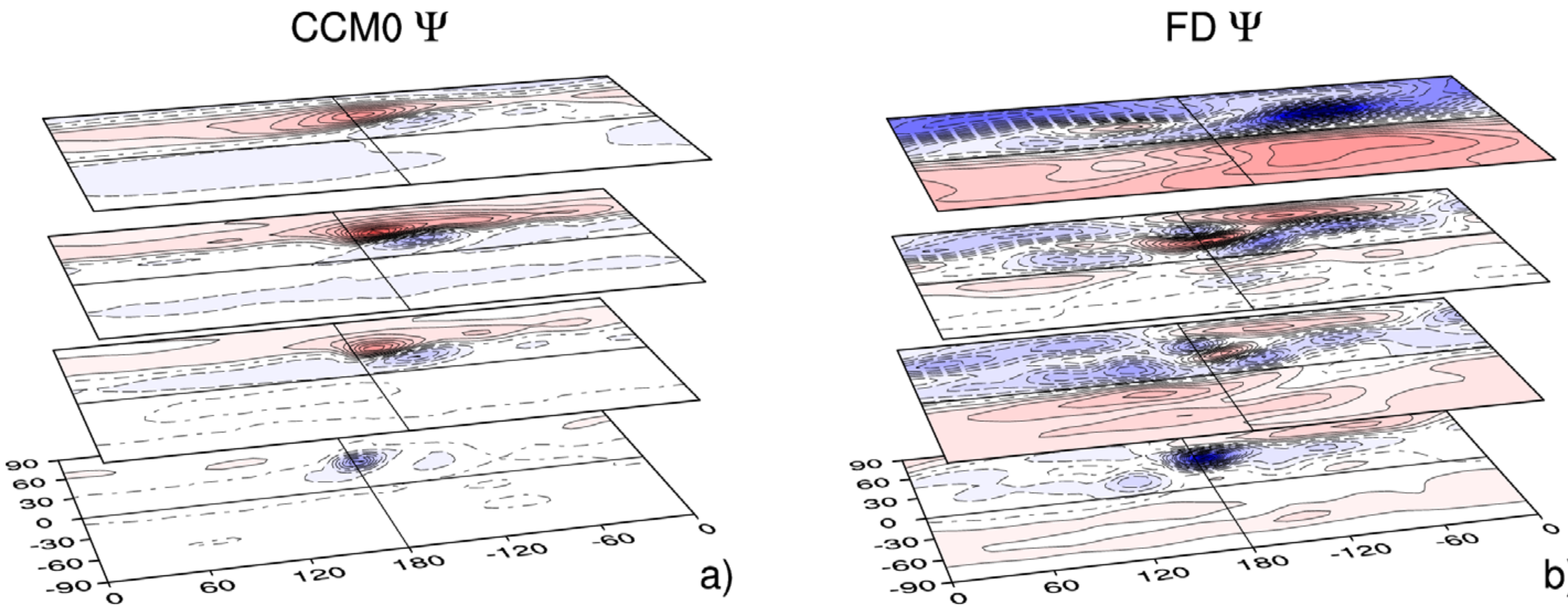
24 case average response to sinusoidal 40N heating

(temperature)

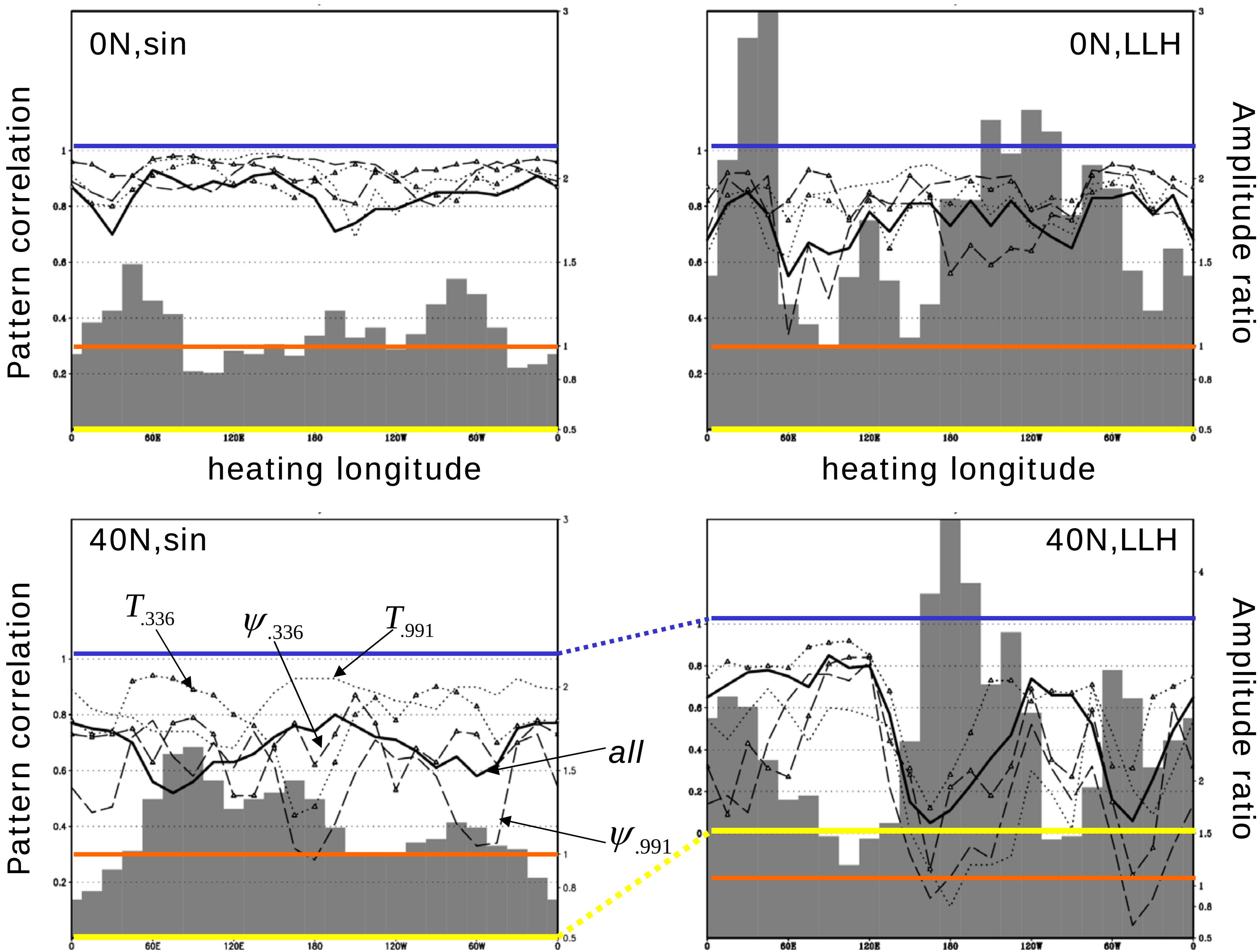


24 case average response to sinusoid low level 40N heating

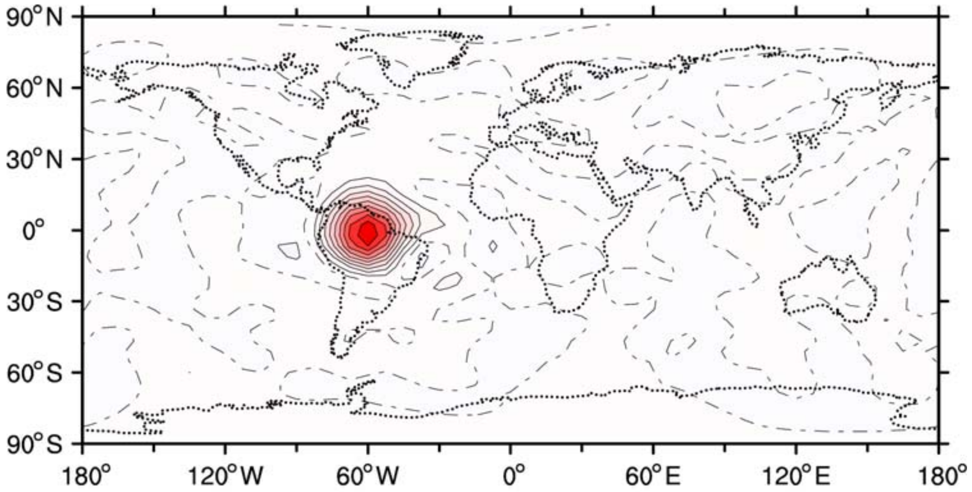
(streamfunction)



FD skill for individual cases

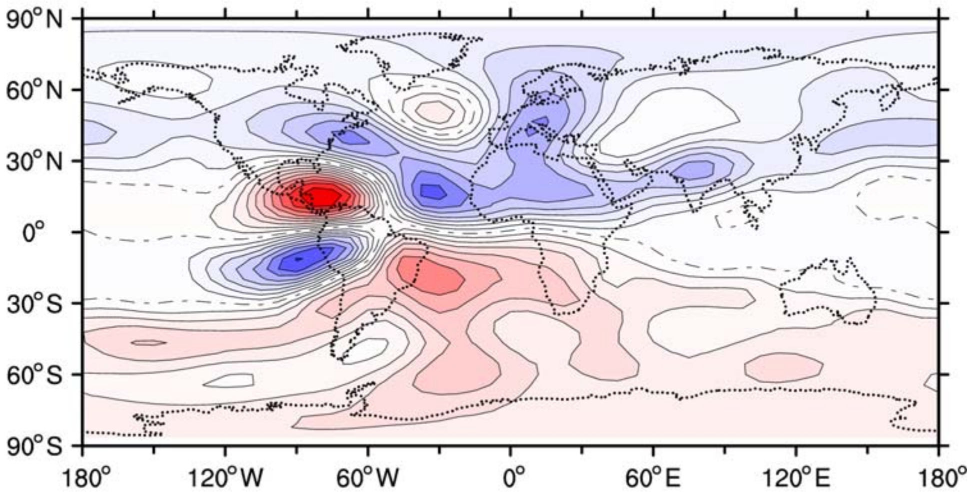


500mb heating inserted into CCM0



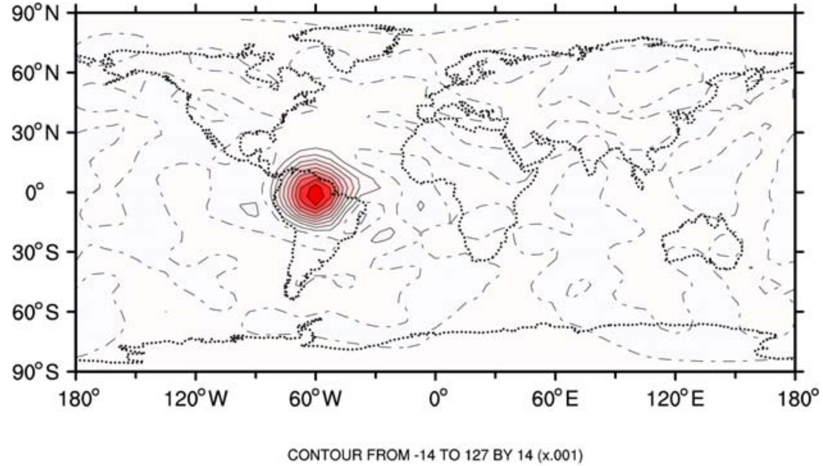
CONTOUR FROM -14 TO 127 BY 14 (x.001)

336mb streamfunction CCM0 response



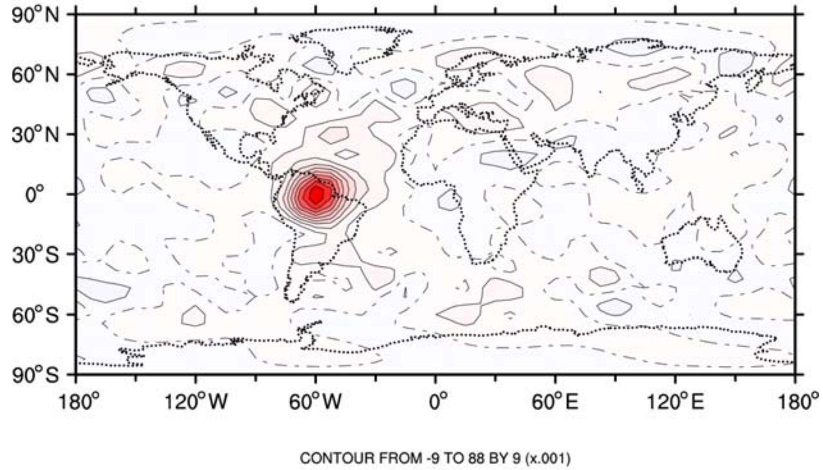
CONTOUR FROM -178 TO 201 BY 22 ($x10^4$)

500mb heating applied to CCM0



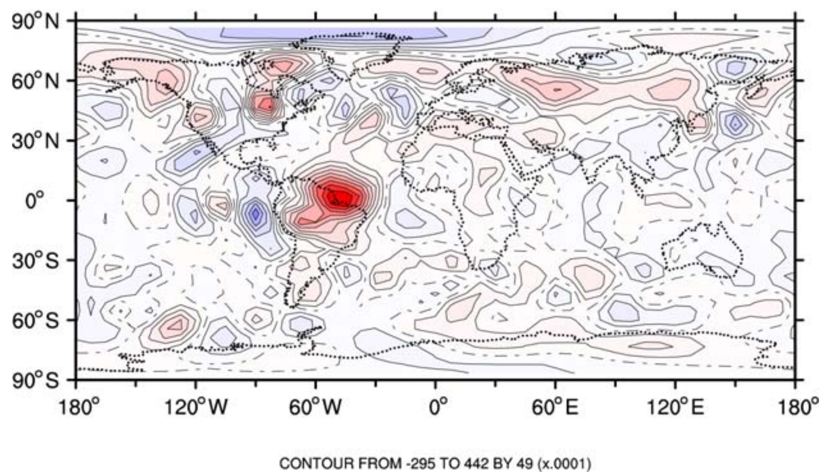
.014

500mb heating derived from inverse of FDO

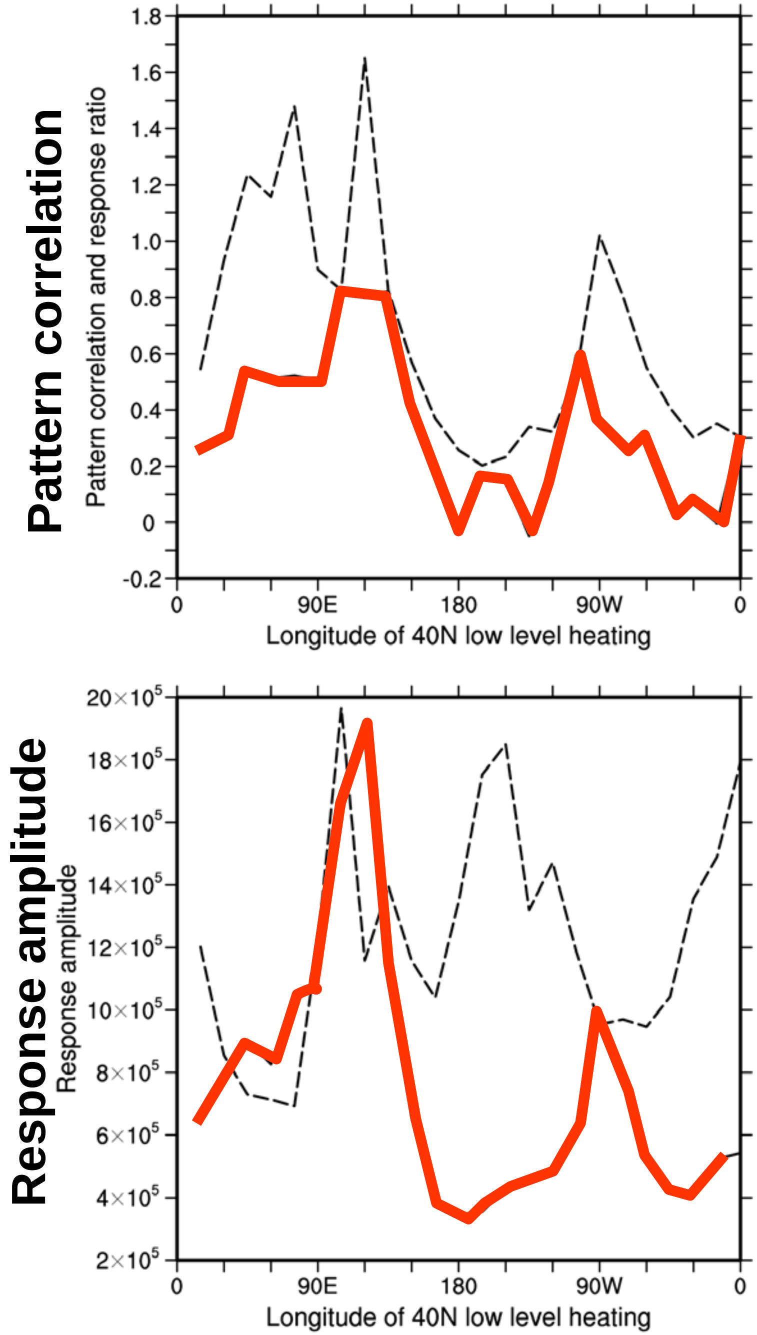


.009

811mb heating derived from inverse of FDO

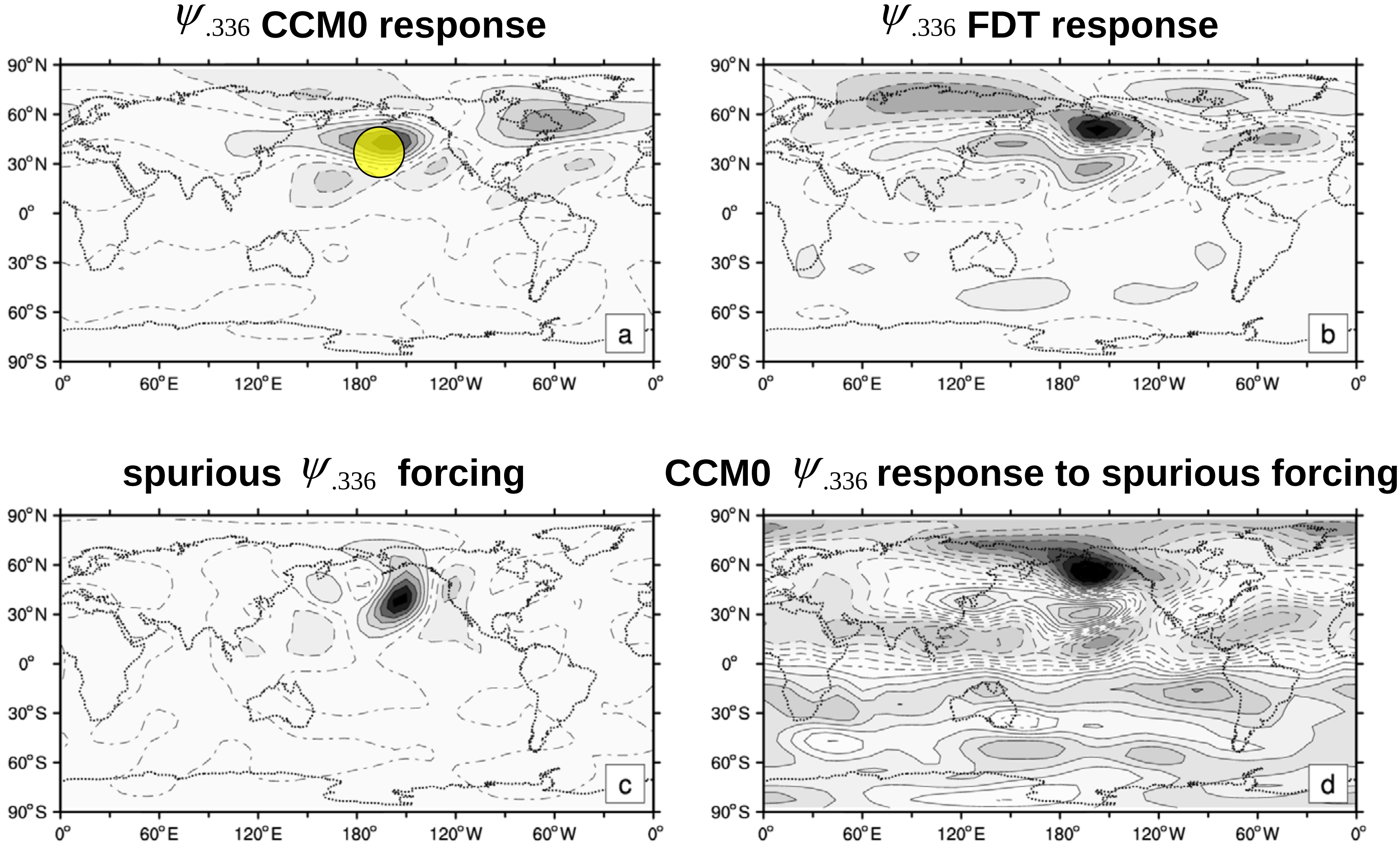


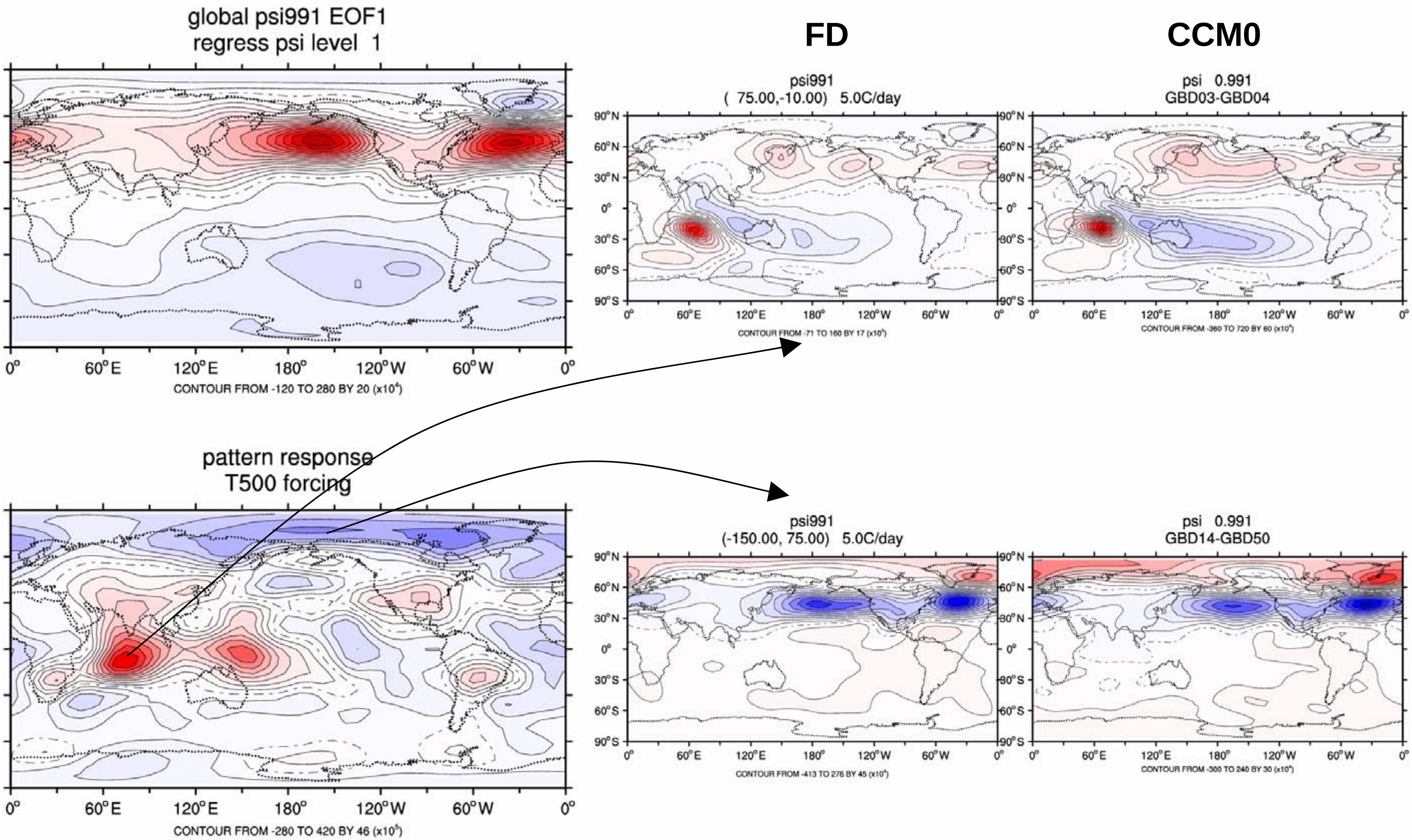
.005



Pattern correlation
Pattern correlation and response ratio
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
0
90E
180
90W
0
Longitude of 40N low level heating
Response amplitude
Response amplitude
20×10^5
18×10^5
16×10^5
14×10^5
12×10^5
10×10^5
8×10^5
6×10^5
4×10^5
2×10^5
0
90E
180
90W
0
Longitude of 40N low level heating

(40N,165W) low level heating

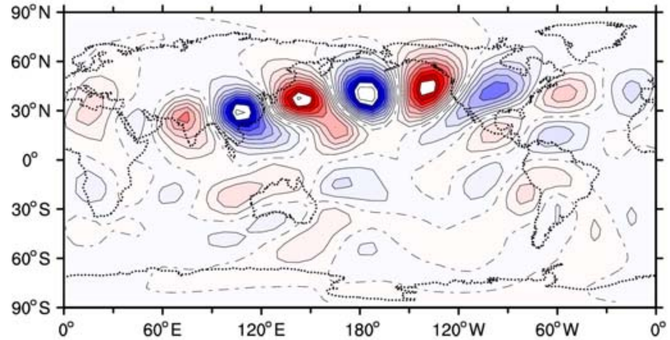




FD
CCM0
global psi991 EOF1
regress psi level 1
CONTOUR FROM -120 TO 280 BY 20 (x10^4)
psi991
(75.00,-10.00) 5.0C/day
CONTOUR FROM -71 TO 160 BY 17 (x10^5)
psi 0.991
GBD03-GBD04
CONTOUR FROM -360 TO 720 BY 60 (x10^4)
pattern response
T500 forcing
CONTOUR FROM -280 TO 420 BY 46 (x10^5)
psi991
(-150.00, 75.00) 5.0C/day
CONTOUR FROM -413 TO 276 BY 45 (x10^4)
psi 0.991
GBD14-GBD50
CONTOUR FROM -300 TO 240 BY 30 (x10^4)
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°
60°E
120°E
180°
120°W
60°W
0°

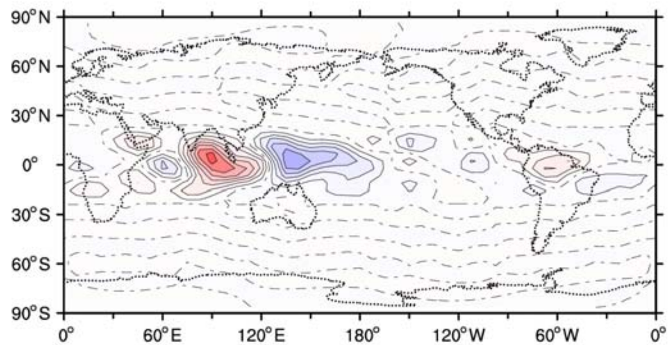
v336 EOF1 for FDO randomly

forced by midtropospheric heating



CONTOUR FROM -150 TO 150 BY 15 (x10^5)

Forcing associated with vEOF1



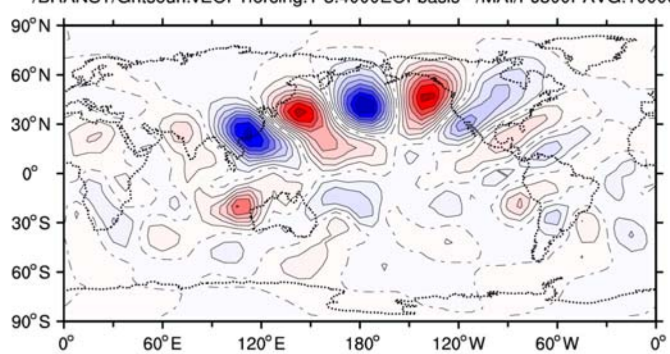
CONTOUR FROM -100 TO 140 BY 20 (x.001)

300mb V

Gr75 anomaly (10000 days) (Gr69 MFAC=0.1)

/BRANST/Gritsoun.vEOF1forcing.1-3.4000EOFbasis - /MAI/PJ300PAVG.100000

CCM0 v300 response



~/datasets/stats/PSI300anom.unx (12/4/2003 2.)

CONTOUR FROM -120 TO 120 BY 15 (x10^5)

Potential improvements & elaborations:

1. Data requirements / choice of basis and truncation

2. Nongaussianity

3. Estimating statistics beyond the mean

4. Time dependent response