INSTITUTE FOR GEOPHYSICS
JACKSON SCHOOL OF GEOSCIENCES

THE UNIVERSITY OF TEXAS AT AUSTIN

"Structural" EOFs as basis for Metrics for Model Selection and Uncertainty Quantification

Charles Jackson

The University of Texas at Austin

Model Ensemble Control System, The Texas effort "Tex-MECS"

bitbucket.org/mtobis/tex-mecs

- Beta version …. Still a work in progress
- Open source license
- Includes a CAM example
- Particularly gifted in managing dependent experiments.
- Has restart capability. Allows ensemble sampling to continue indefinitely.
- Jackson et al., 2004 (JCL)

$\hat{x}$ is a model estimate of observations x

with representation error ε_x

$$\hat{x} = x + \varepsilon_x$$

$$\bar{x} = \langle x + \varepsilon_x \rangle$$

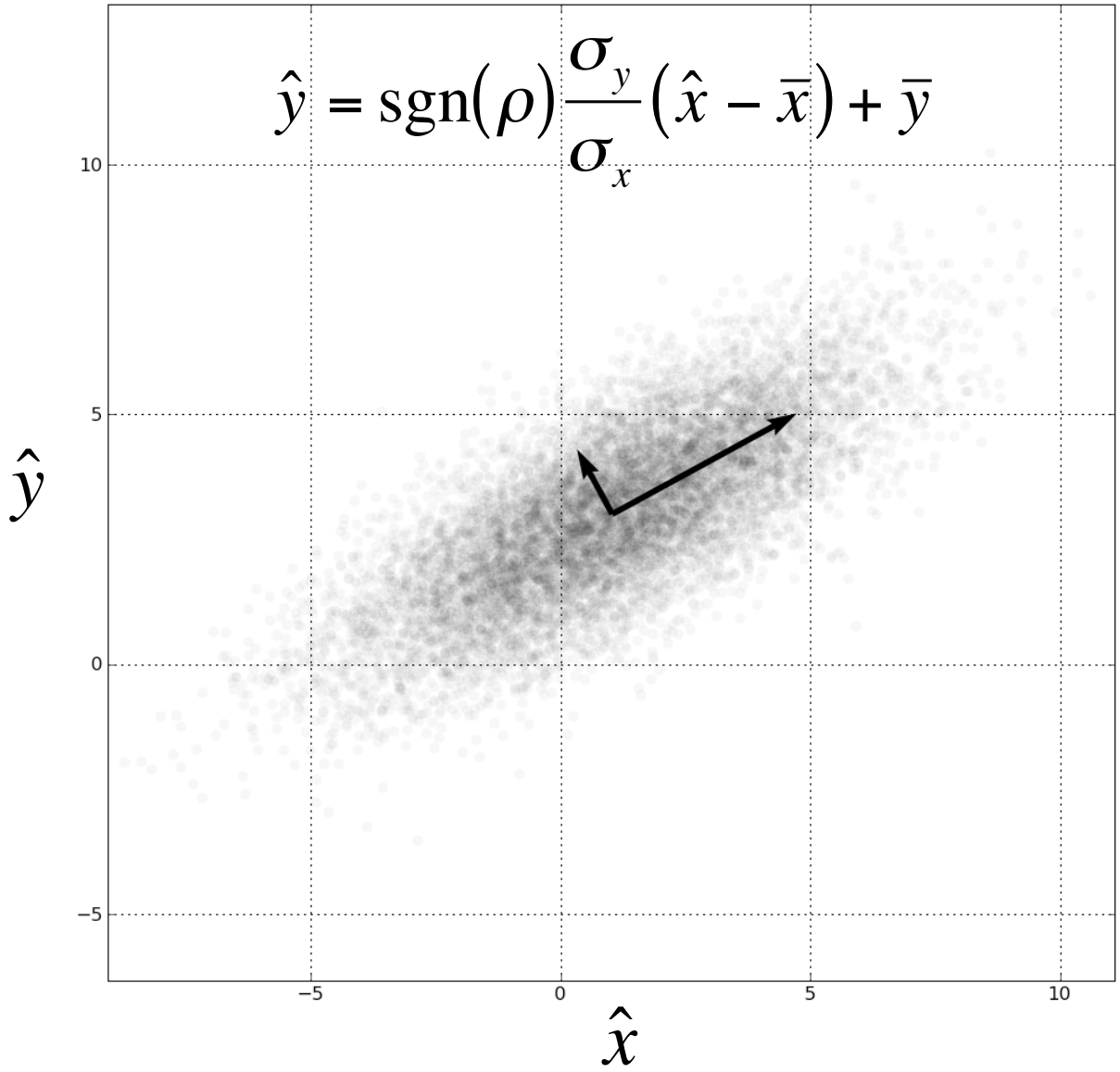
$$\sigma_x^2 = \mathrm{var}(\hat{x})$$

$$pdf(\hat{x}) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left(- \frac{(\hat{x} - \bar{x})^2}{2\sigma_x^2} \right)$$

The joint probability of two correlated quantities is given by:

$$\text{prob}\left(\hat{x} \text{ and } \hat{y}\right) = \text{prob}\left(\hat{x}\right) \cdot \text{prob}\left(\hat{y} \mid \hat{x}\right)$$

$$pdf\left(\hat{x},\hat{y}\right) = \frac{1}{\sigma_x \sigma_y 2\pi\left(1-\rho^2\right)} \exp\left(-\frac{1}{2\left(1-\rho^2\right)} \left[\frac{\left(\hat{x}-\bar{x}\right)^2}{\sigma_x^2} + \frac{\left(\hat{y}-\bar{y}\right)^2}{\sigma_y^2} - 2\rho \frac{\left(\hat{x}-\bar{x}\right)\left(\hat{y}-\bar{y}\right)}{\sigma_x \sigma_y} \right] \right)$$

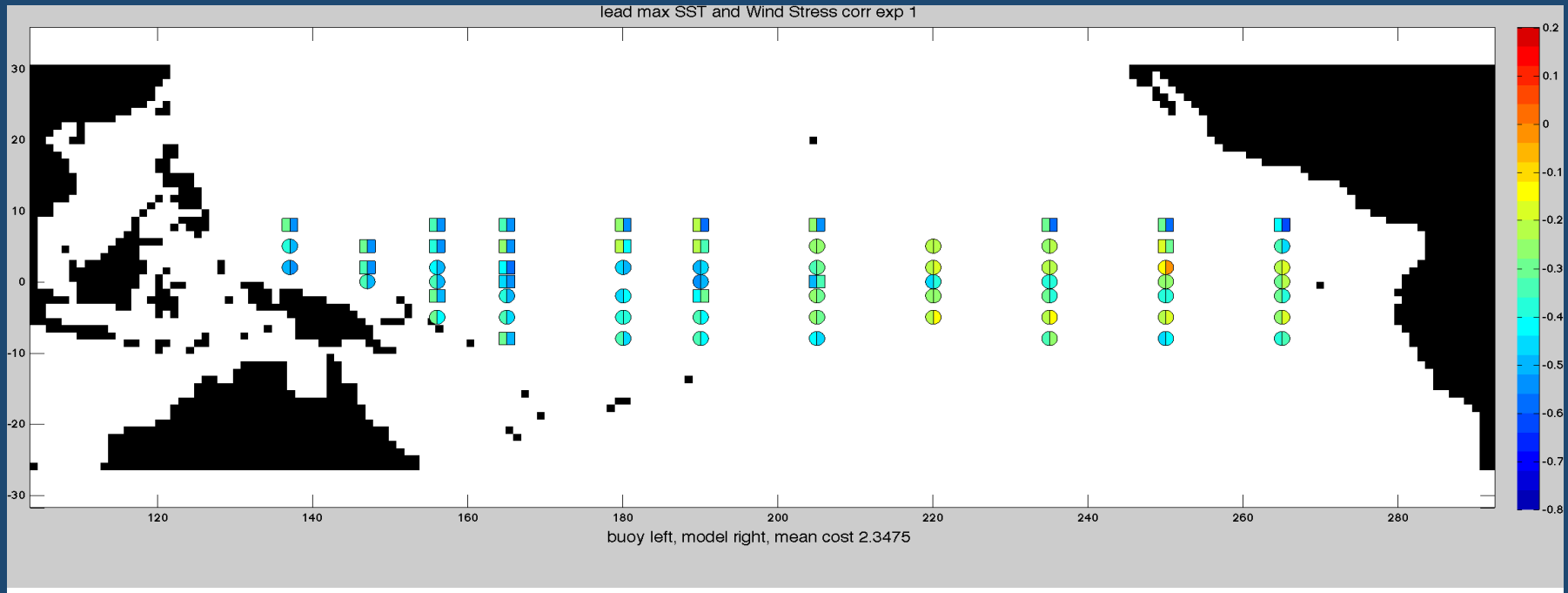

$\hat{y} = \mathrm{sgn}(\rho)\frac{\sigma_y}{\sigma_x}(\hat{x} - \bar{x}) + \bar{y}$
10
5
0
−5
−5
0
5
10
$\hat{y}$
$\hat{x}$

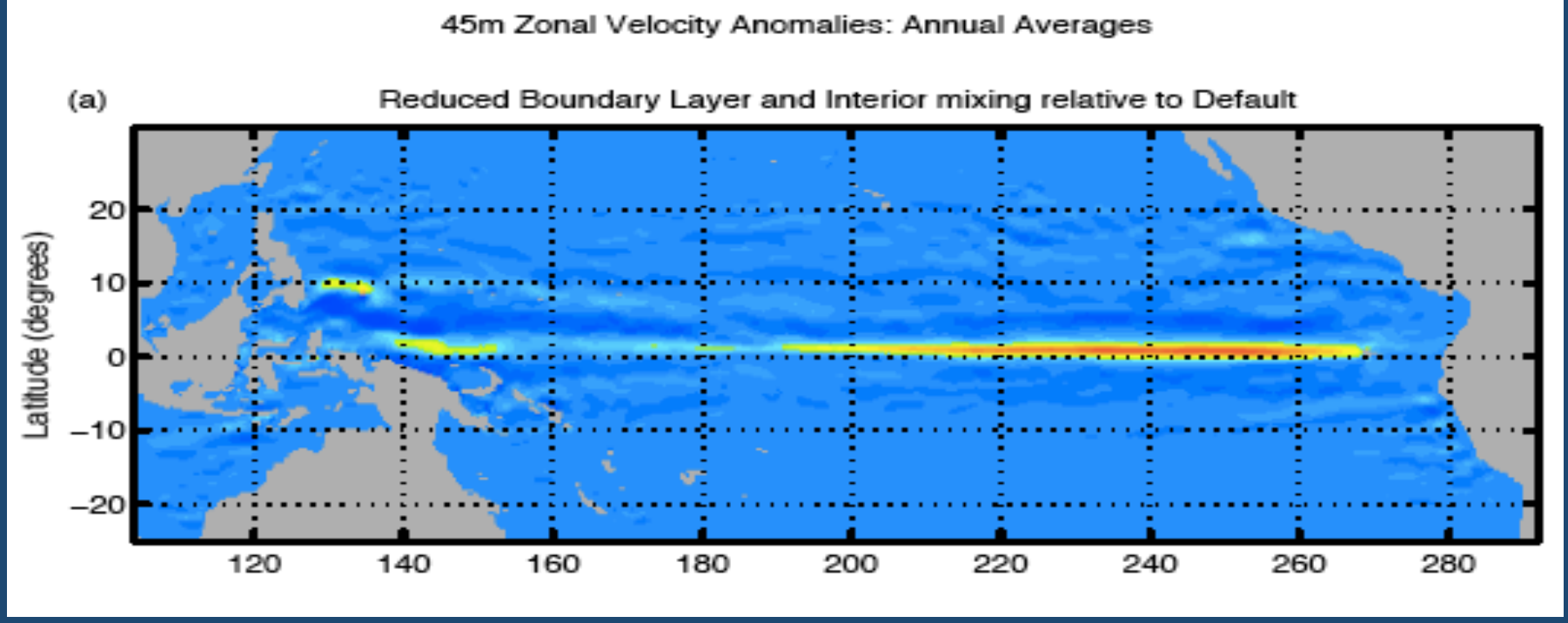
In matrix notation

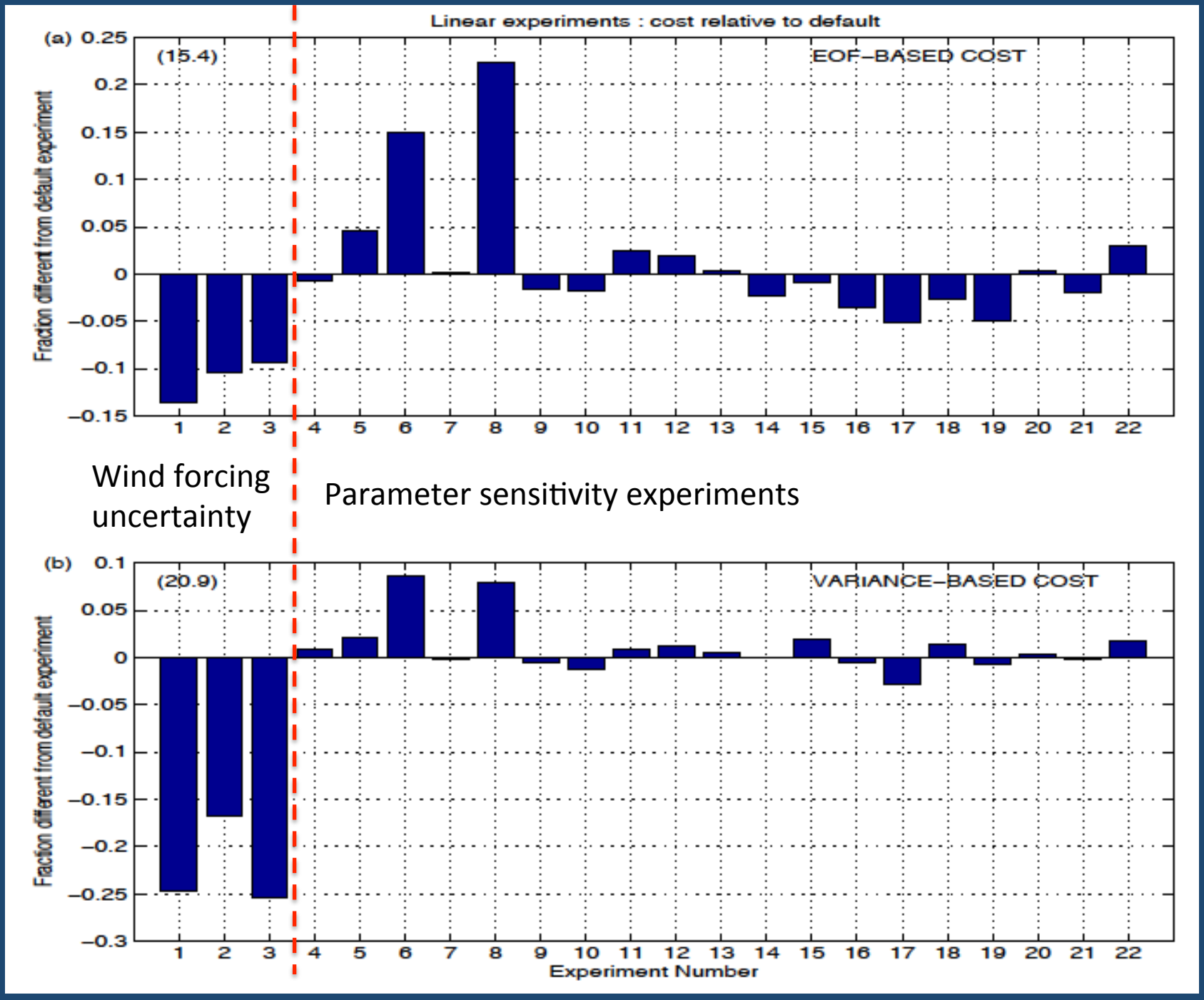
$$\mathbf{X} = \begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix}$$

$$\mathbf{C} = \begin{bmatrix} \sigma_x^2 & \rho\sigma_x\sigma_y \\ \rho\sigma_x\sigma_y & \sigma_y^2 \end{bmatrix} = \begin{bmatrix} \mathbf{eof}_1 & \mathbf{eof}_2 \end{bmatrix} \cdot \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix}$$

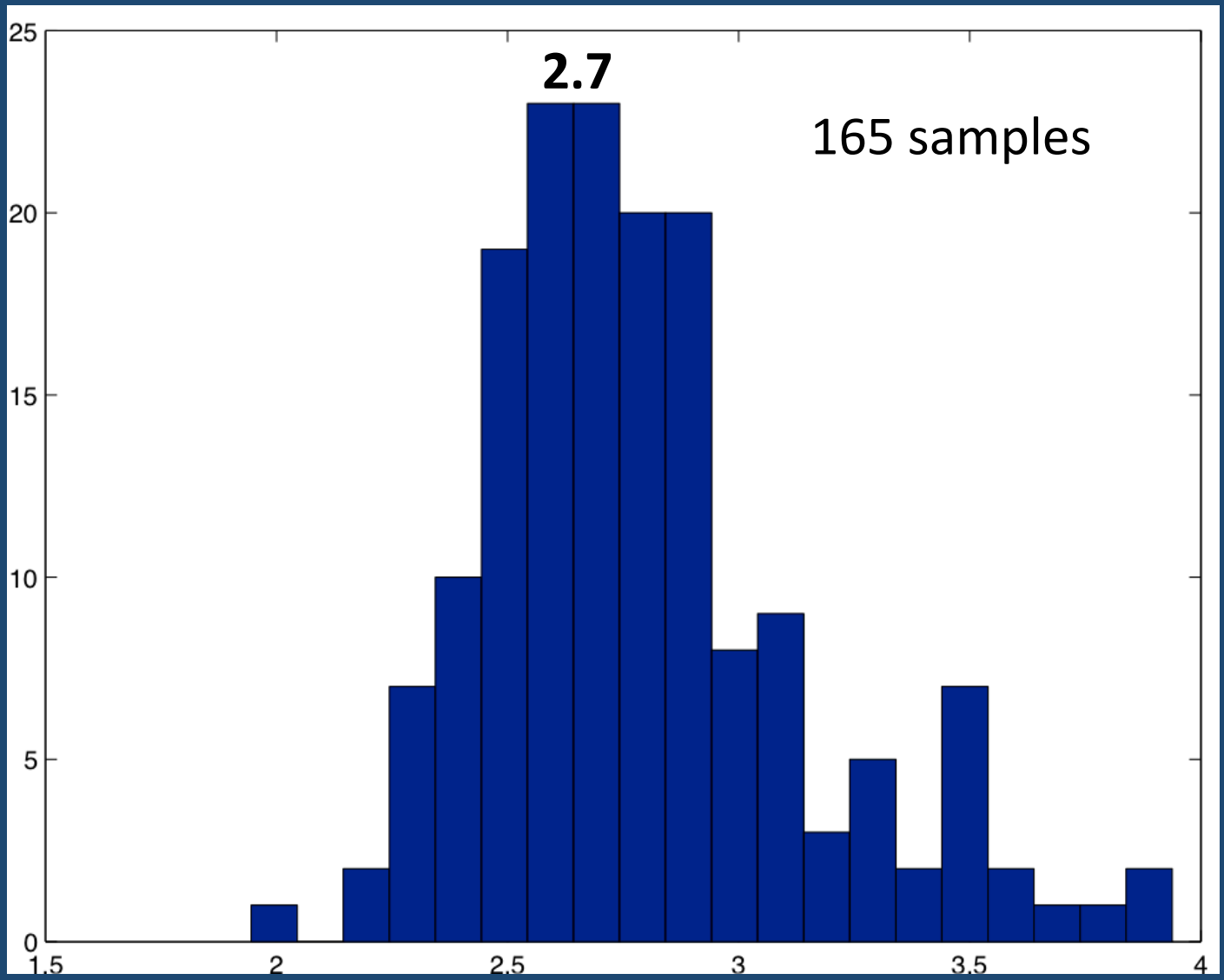
$$pdf(\mathbf{X}) = \frac{1}{2\pi|\mathbf{C}|^{\frac{1}{2}}} \exp\left(-\frac{1}{2}\left(\mathbf{X} - \overline{\mathbf{X}}\right)^T \mathbf{C}^{-1}\left(\mathbf{X} - \overline{\mathbf{X}}\right) \right)$$

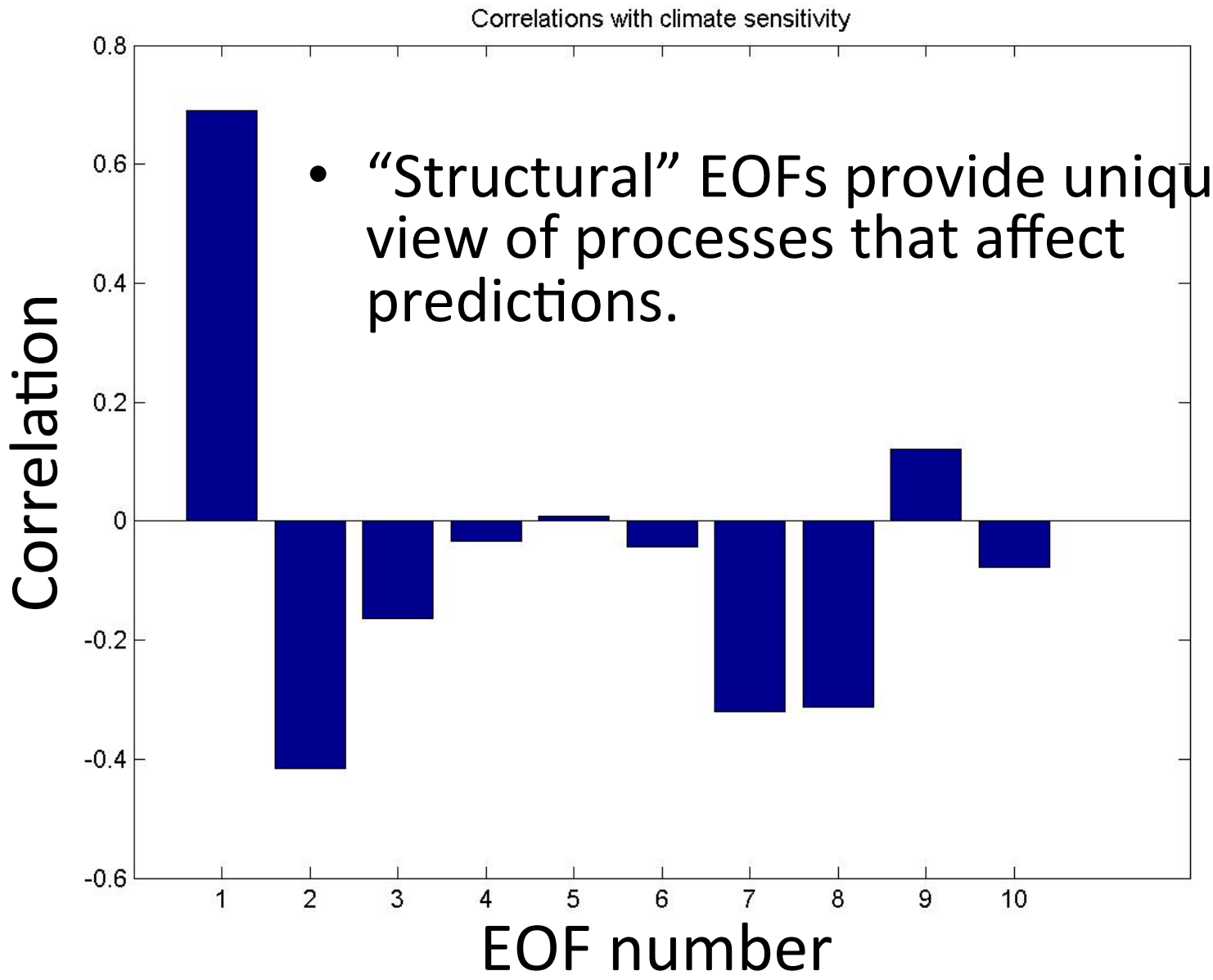

lead max SST and Wind Stress corr exp 1
30
20
10
0
-10
-20
-30
120
140
160
180
200
220
240
260
280
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
buoy left, model right, mean cost 2.3475


45m Zonal Velocity Anomalies: Annual Averages
(a)
Reduced Boundary Layer and Interior mixing relative to Default
Latitude (degrees)
20
10
0
−10
−20
120
140
160
180
200
220
240
260
280


Linear experiments : cost relative to default
(a)
(15.4)
EOF–BASED COST
Fraction different from default experiment
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Wind forcing uncertainty
Parameter sensitivity experiments
(b)
(20.9)
VARIANCE–BASED COST
Fraction different from default experiment
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−0.3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Experiment Number

CAM 3.1 Equilibrium Climate Sensitivity





- "Structural" EOFs provide unique view of processes that affect predictions.

What is not as important

- Cloud fraction
- Zonal mean temperature
- Surface wind stress
- Zonal winds

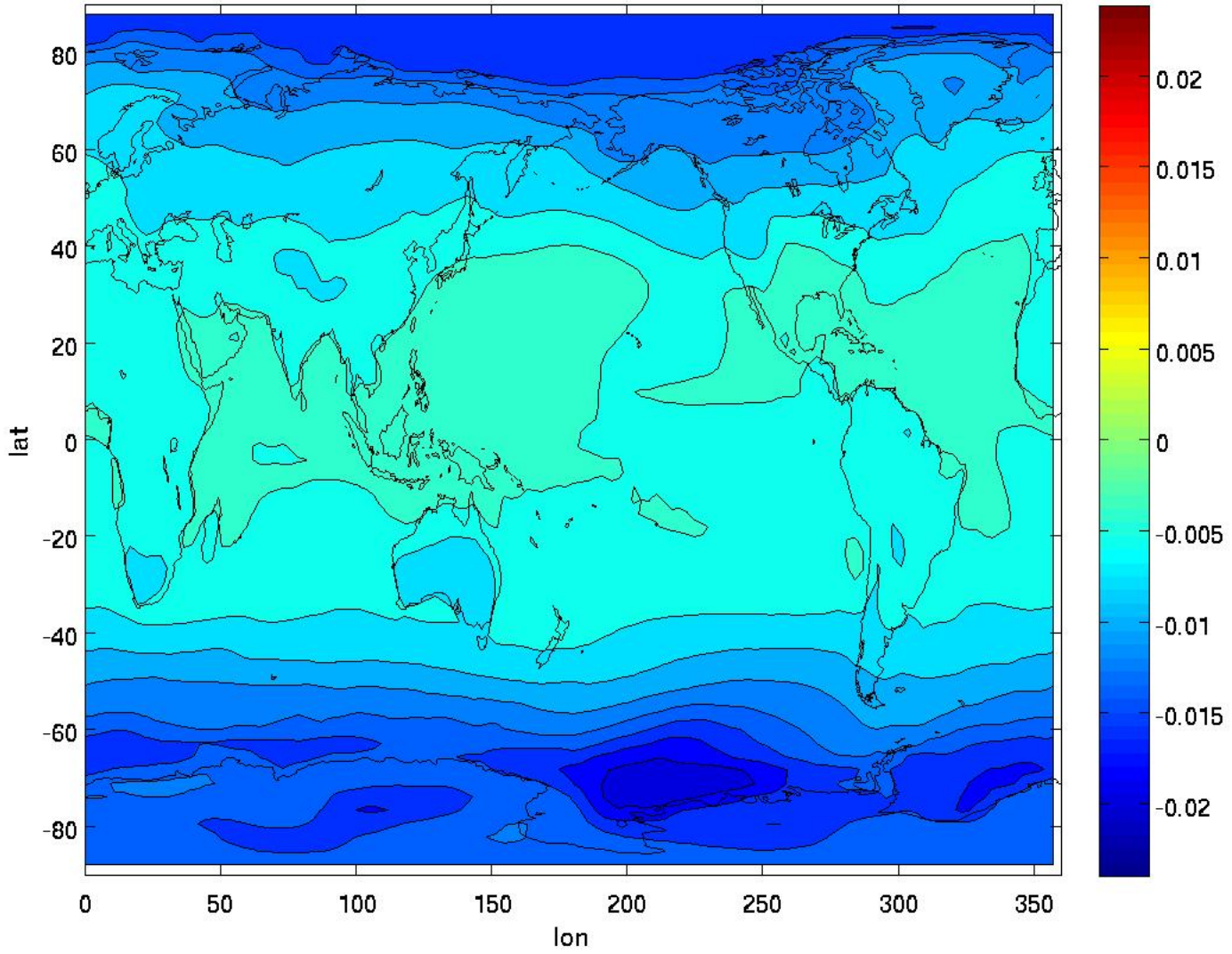
What is important

- Longwave fluxes at TOA
- Longwave cloud forcing
- Shortwave flux at TOA
- Shortwave cloud forcing
- Precipitation
- Zonal relative humidity
- 2 meter air temperature

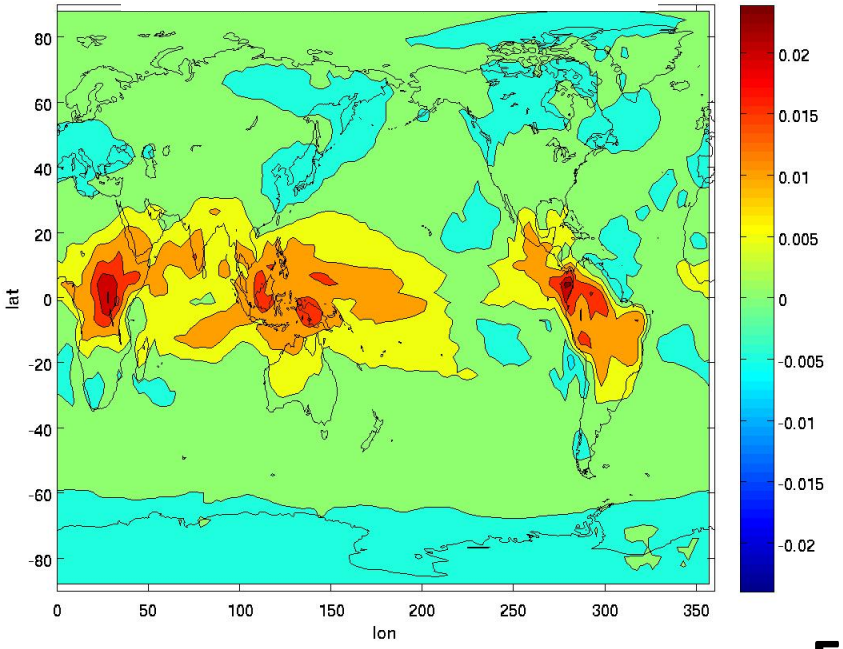
TOA = top of atmosphere

EOF 1

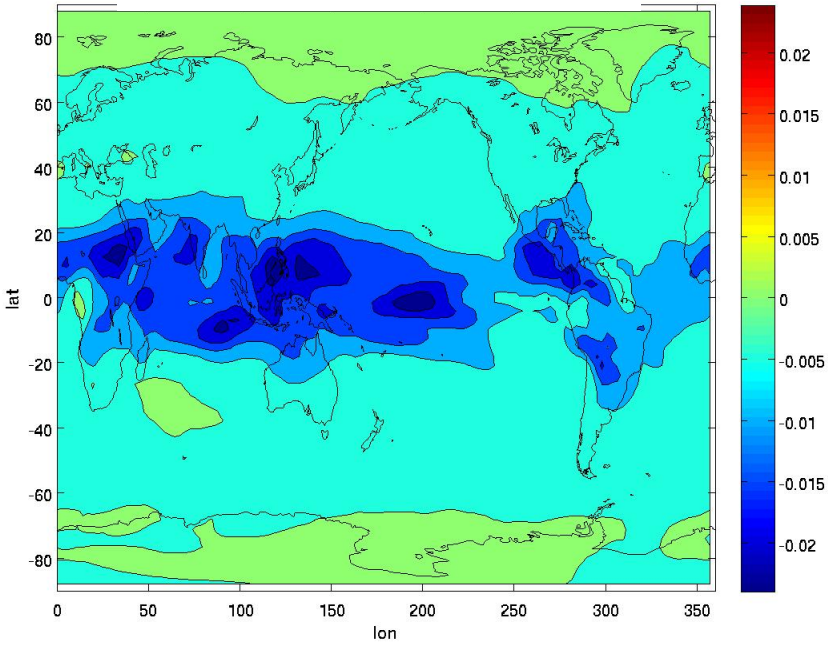
2 meter air temperature



Shortwave Cloud Forcing

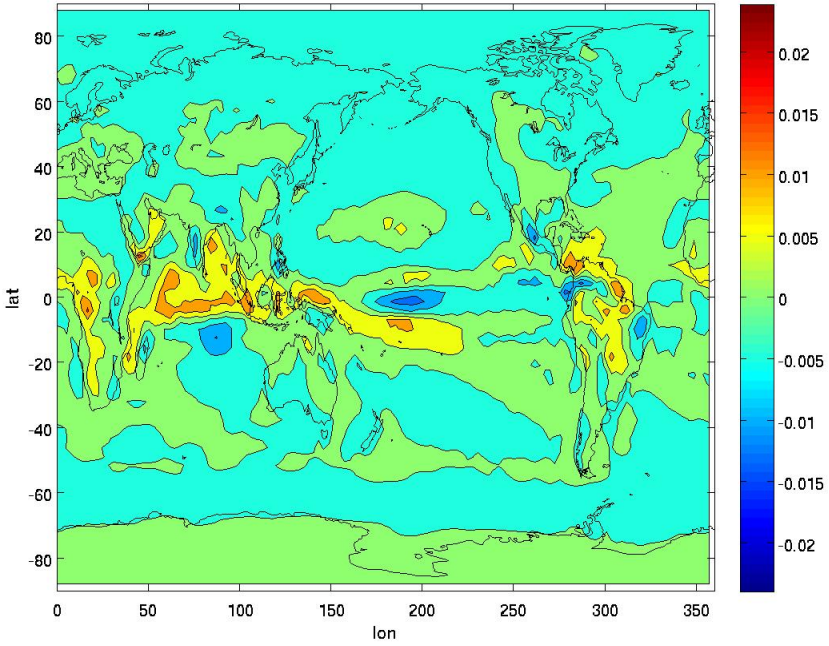


Longwave Cloud Forcing

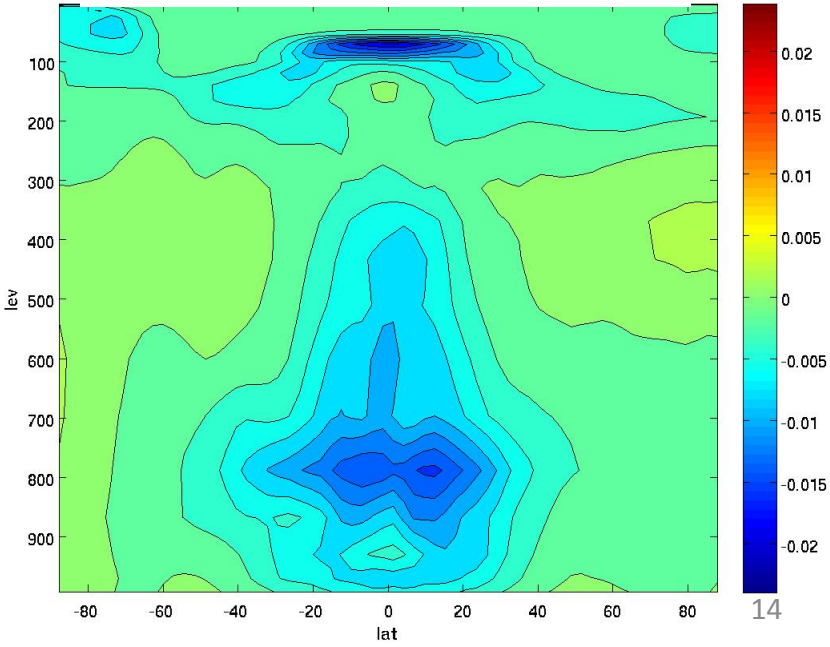


EOF 2

Precipitation

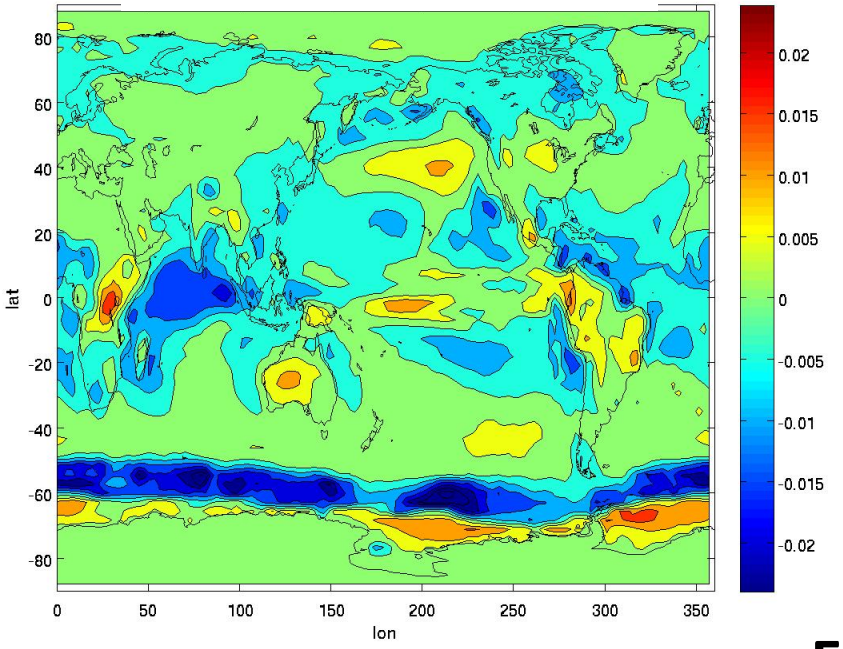


Zonal Relative Humidity

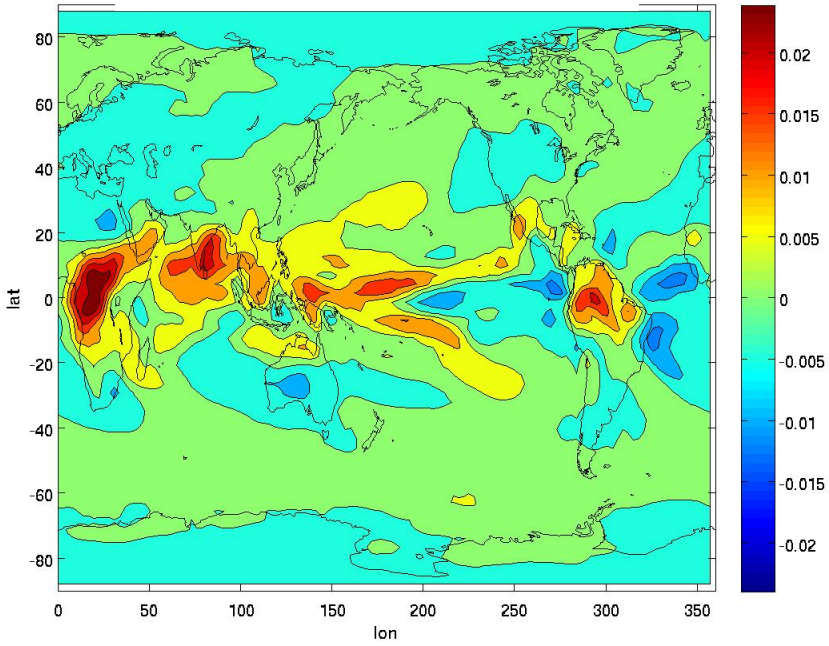


EOF 7

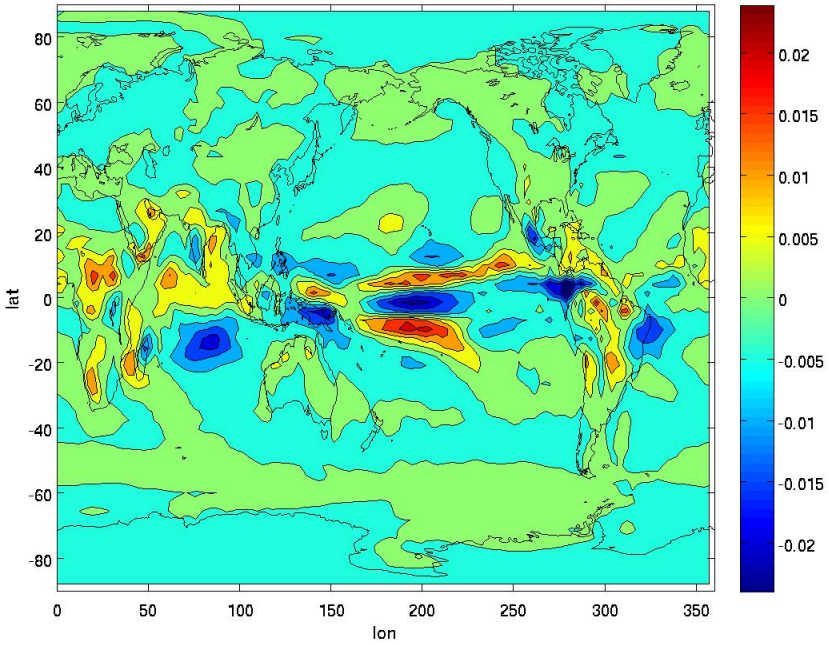
Shortwave Cloud Forcing



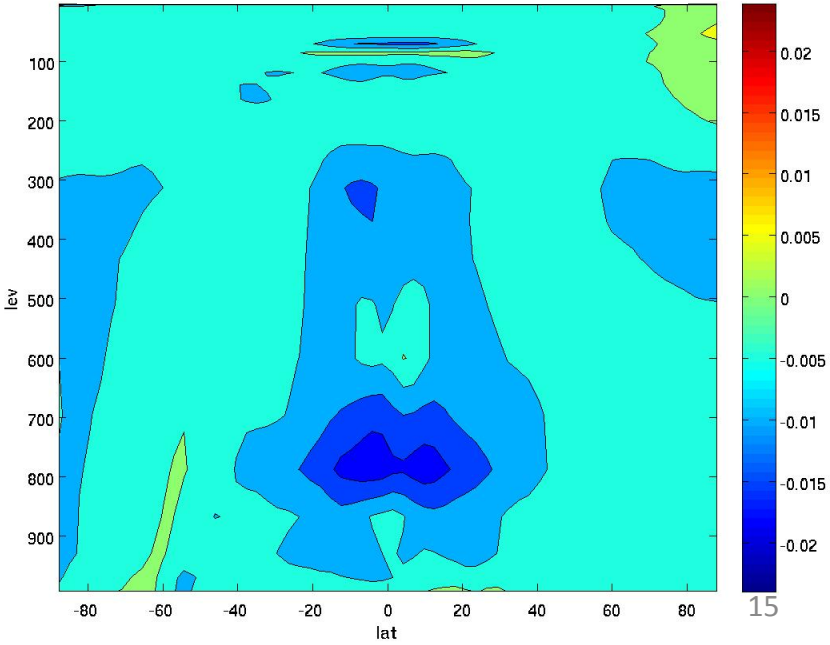
Longwave Cloud Forcing



Precipitation



Zonal Relative Humidity



Summary

- Beta version of Tex-MECS is available for anyone to manage large ensembles over HPC resources.
- Perturbed Physics Ensembles can be used to generate “structural” EOFs, which in turn can suggest how observational constraints can be combined into a scalar metric.
- Not all uncertain model structures affect predictions.