GCM projections of mid-latitude storm tracks viewed through the prism of low-order models.

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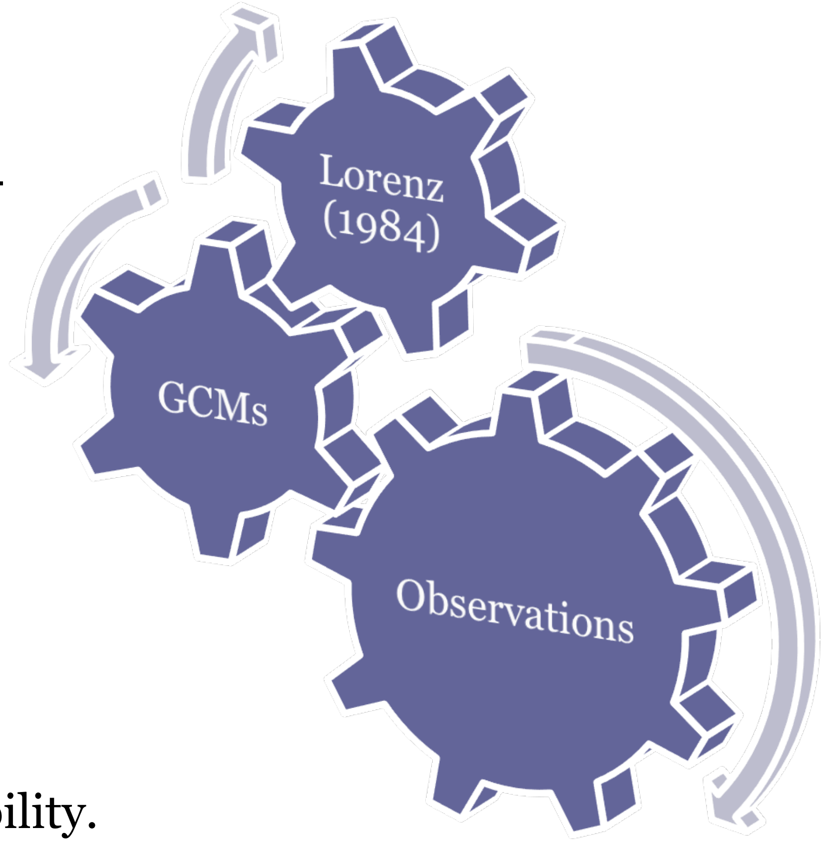
Can we get insights into projected changes & predictability of mid-lat atmospheric circulation through the prism of a low-order model?

Main points

- Observations support the L84 view of surface temperature gradients as important drivers of mid-latitude jet and eddy variability.

- We reduce GCMs to the L84 space and find:
  a) model biases in the temperature gradients
  b) differing model response and sensitivity to decreasing temperature gradients due to AGW.

- Tropical-extratropical teleconnections and their potential changes are manifest in mid-lat predictability.



The Lorenz (1984) model

Jet stream strength → $\dot{X} = -Y^2 - Z^2 - aX + aF$

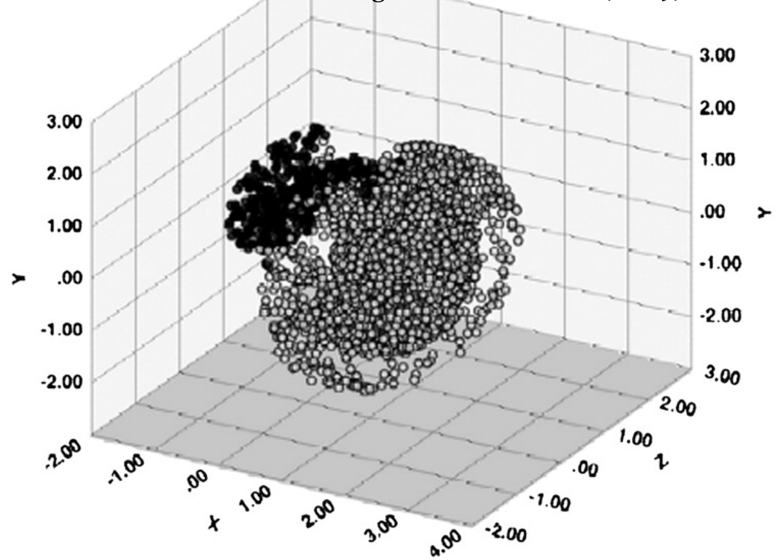
Sine & cosine components of the eddies → $\dot{Y} = XY - bXZ - Y + G$, $\dot{Z} = bXY + XZ - Z$

where

Equator-to-Pole temperature gradient → $F = F_0 + F_1 \cos(\omega_a t)$

Ocean-Land temperature Contrast → $G = G_0 + G_1 \cos(\omega_a t)$

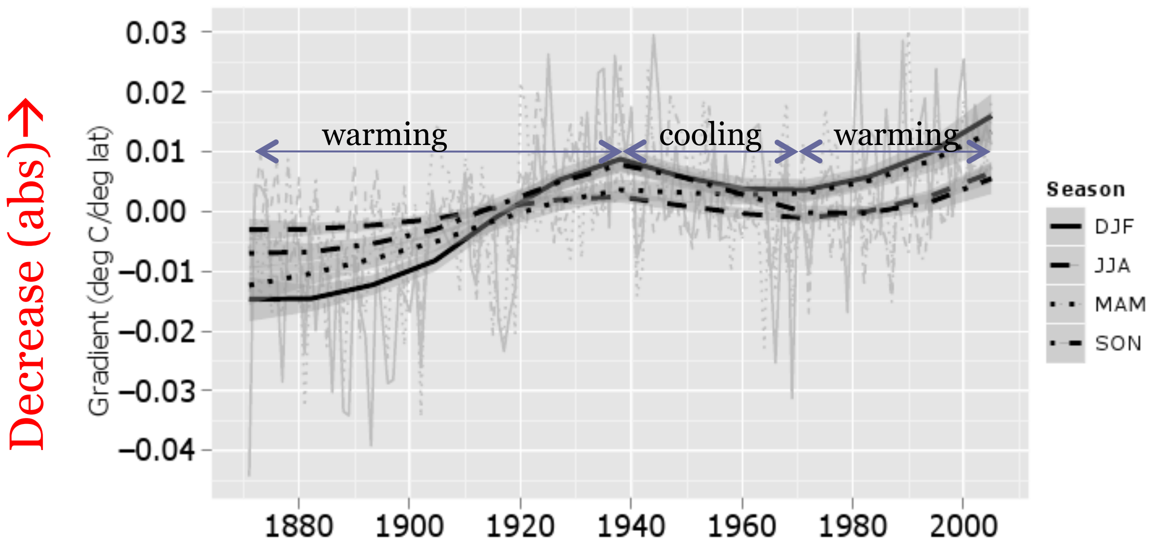
* Figure from Roebber (2009)



Lorenz, E.N. (1984,1990); van Veen (2003); Roebber et al. (1995,1997,2009)

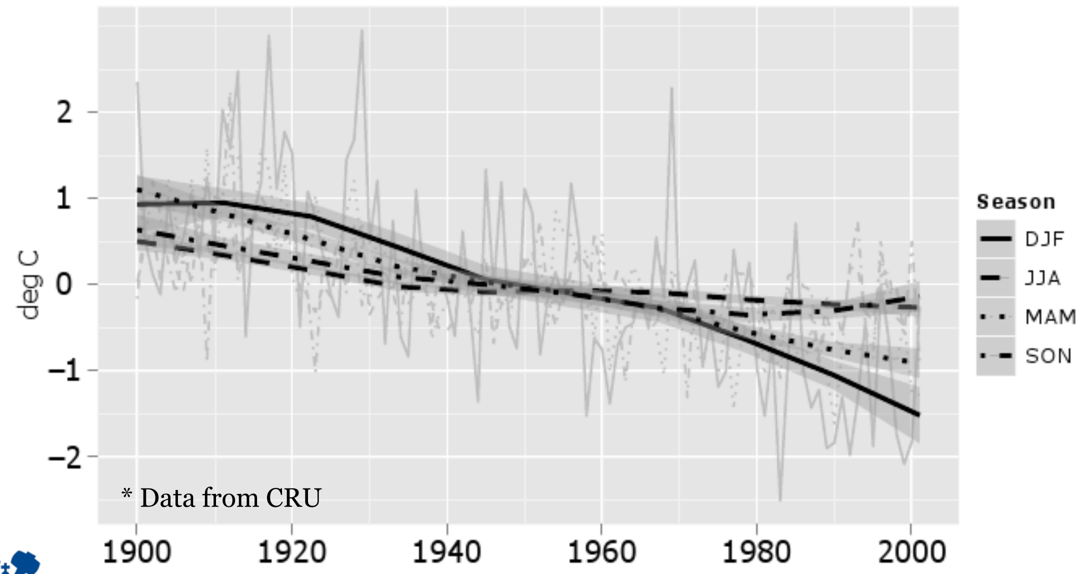
Are the L84 results qualitatively consistent with observations and comprehensive models?

Equator-to-Pole temperature Gradient (EPG) anomalies



EPG:
regression coefficient of zonal mean surface T on latitude

Ocean Land temperature contrast (OLC) anomalies

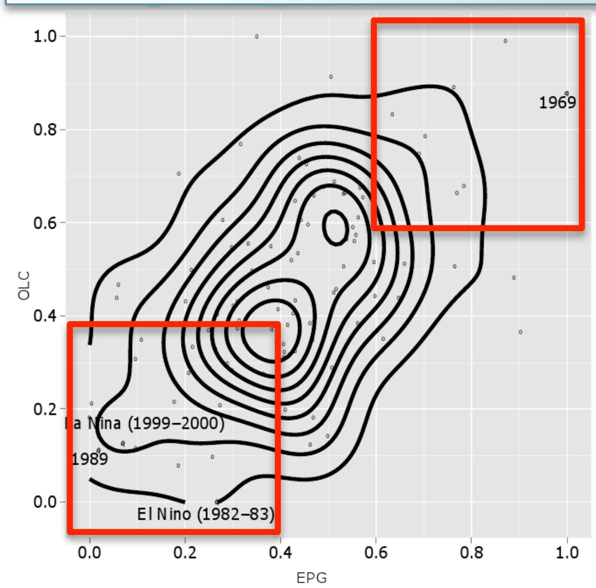


OLC:
area-averaged ocean - land T

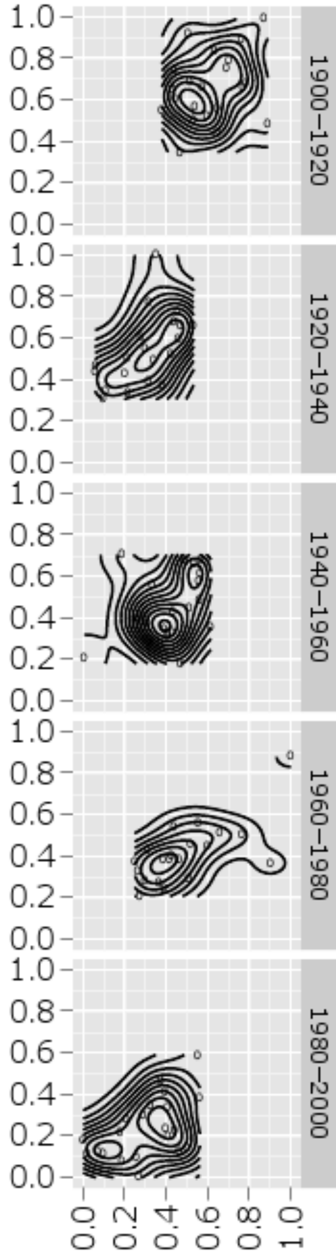
Initial work: Jain et al. (1998)

Karamperidou et al. (2011), in review

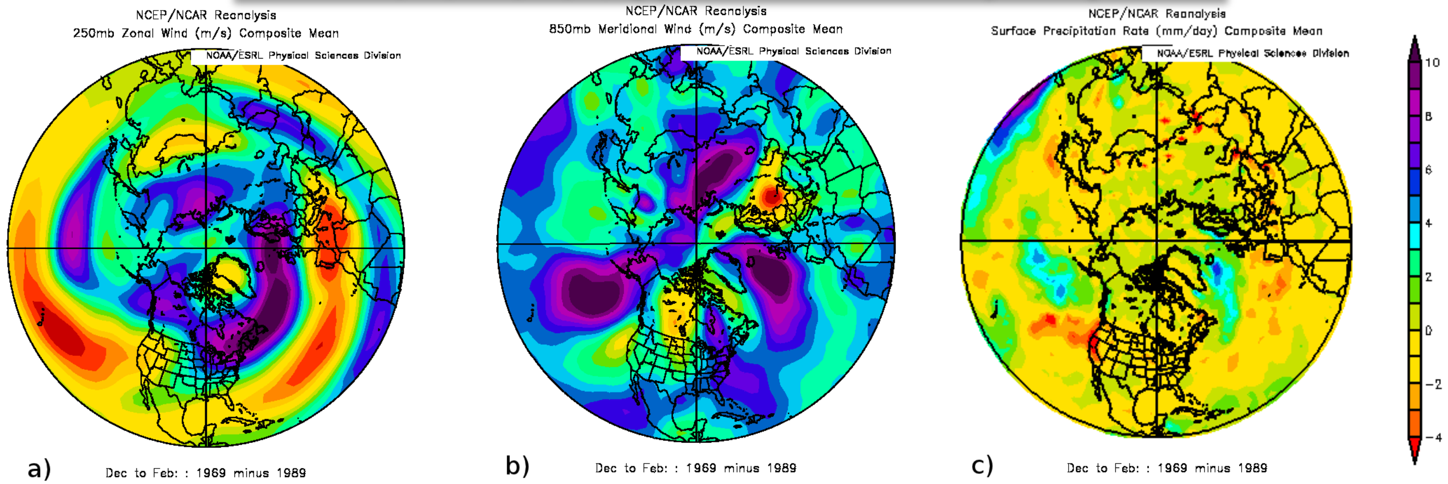
Joint pdf of gradients (DJF):



- The {EPG,OLC} combination matters.
- There is a clear shift of their joint pdf towards minimum values.
- Poleward shift of the jet and prcp regions when going from the upper to lower 25th %ile of the joint pdf.

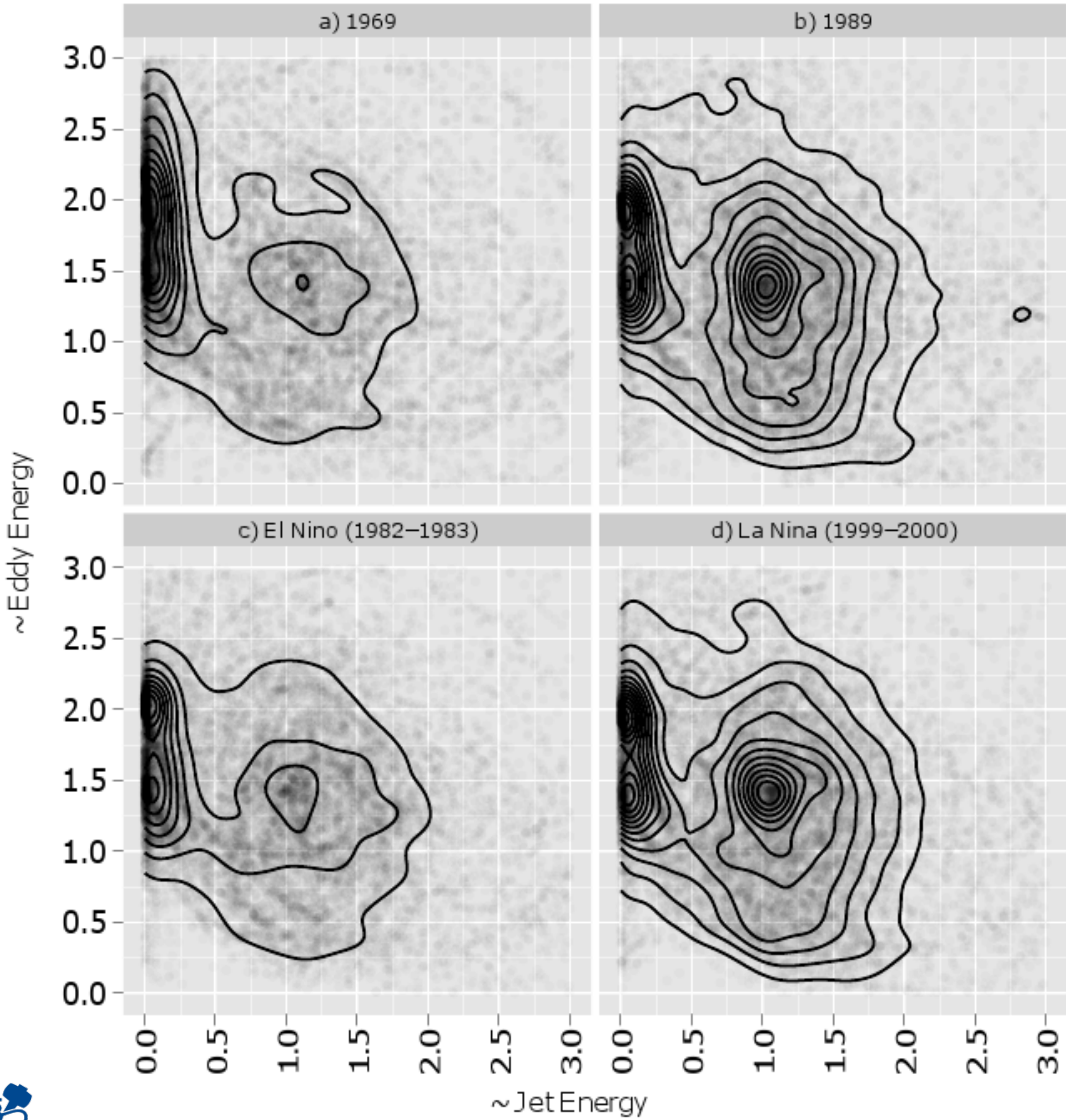


DJF 1969 -1989 (opposite tails of the joint pdf):



u_{250} v_{850} $prcp$

Jet Energy (X^2) vs Eddy Energy (Y^2+Z^2)



Normalize the historical values w.r.t F,G parameters.

Run a 'global warming' paradigm (1989) and ENSO cases.

Results are qualitatively consistent with expectations from observations and GCMs (e.g. Lu et al. 2008).

So far:

▪ Observations support the L84 view of surface temperature gradients as important drivers of mid-latitude jet and eddy variability.

▪We reduce GCMs to the L84 space and find
a) model biases in the temperature gradients
b) differing model response and sensitivity to decreasing temperature gradients due to AGW.

▪ Tropical-extratropical teleconnections and their potential changes are manifest in mid-lat predictability.

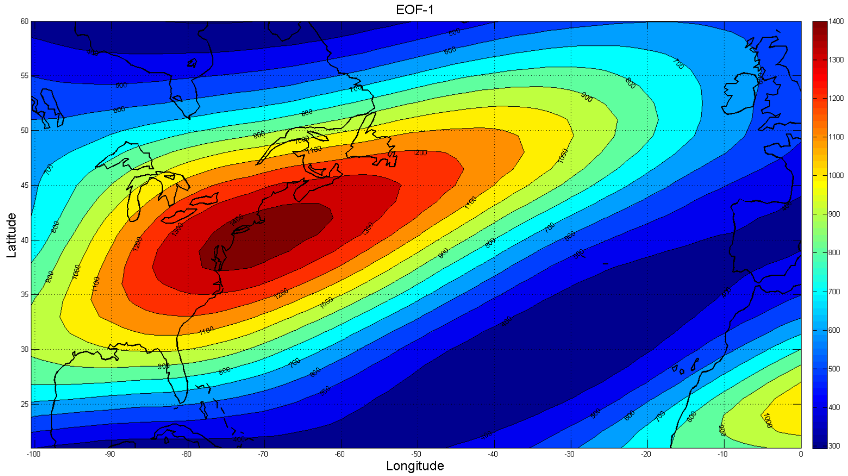
Next:

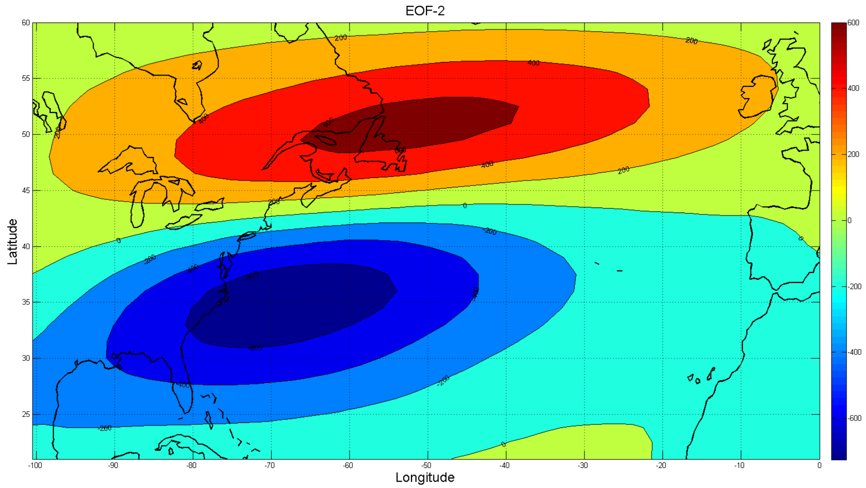
▪ Observations support the L84 view of surface temperature gradients as important drivers of mid-latitude jet and eddy variability.

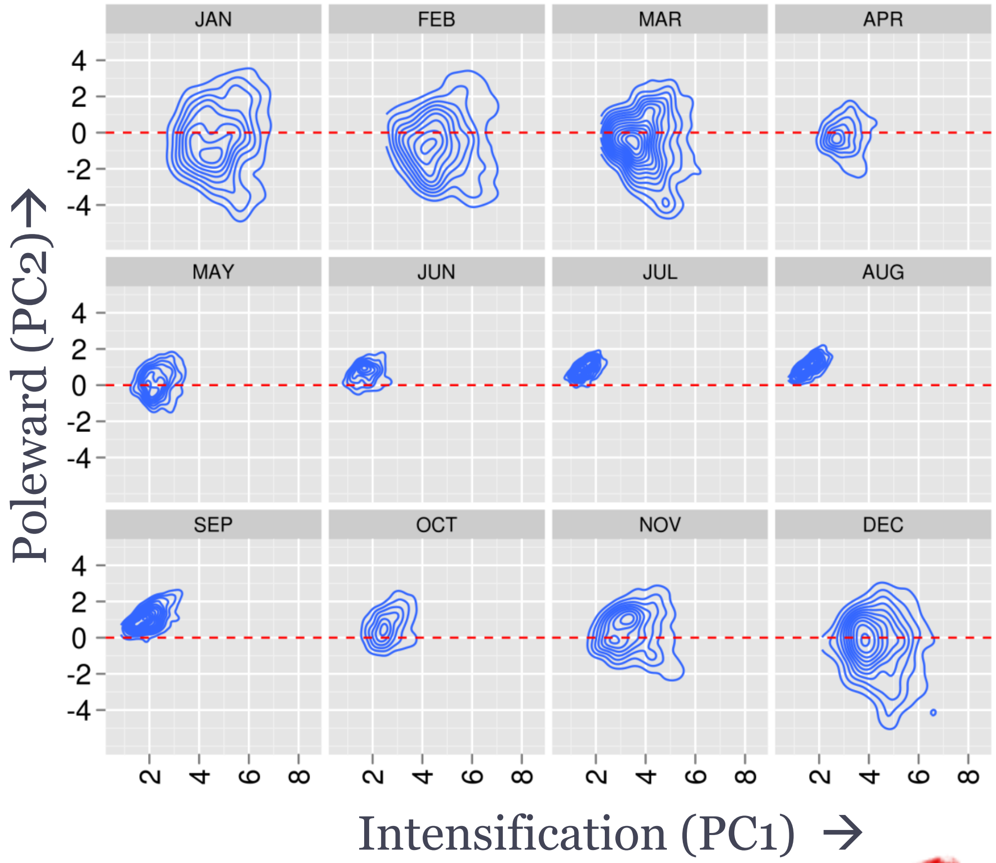
▪ We reduce GCMs to the L84 space and find:
a) model biases in the temperature gradients
b) differing model response and sensitivity to decreasing temperature gradients due to AGW.

▪ Tropical-extratropical teleconnections and their potential changes are manifest in mid-lat predictability.

u_{250}^2 as a proxy for Jet Energy:





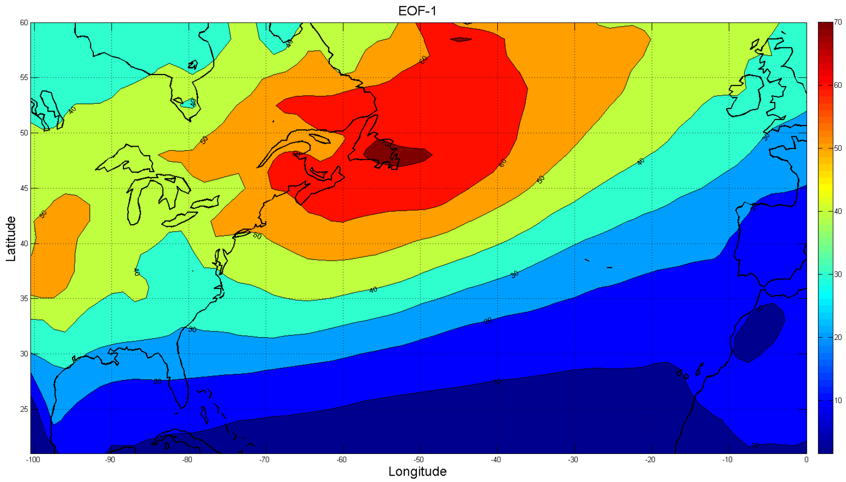


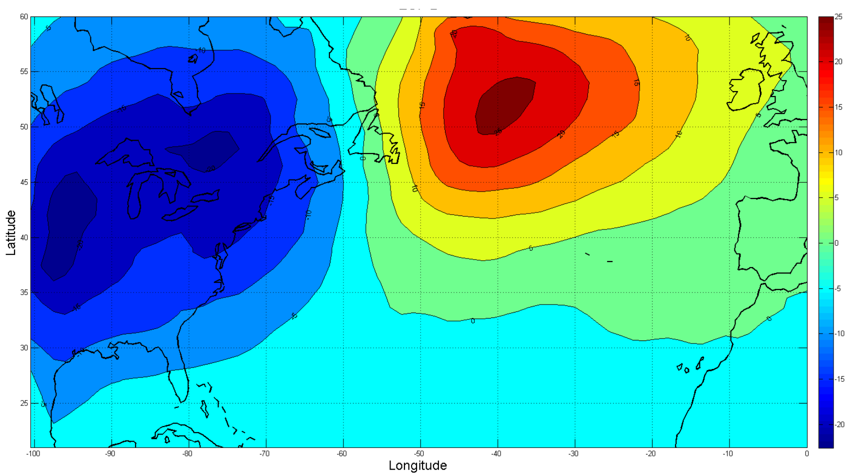
Sanity check

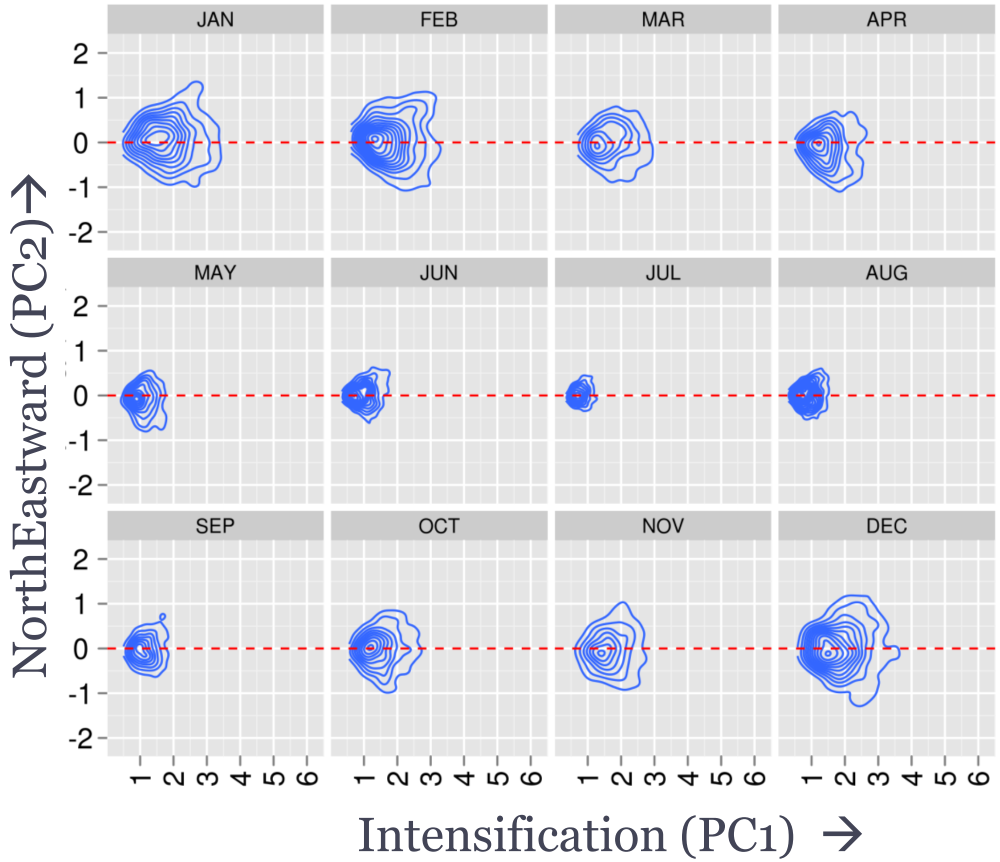
Jet stream: Intensification and equatorward shift during the winter

* Data: ERA-Interim

$\tilde{u}_{850}^2 + \tilde{v}_{850}^2$ as a proxy for Eddy Energy:





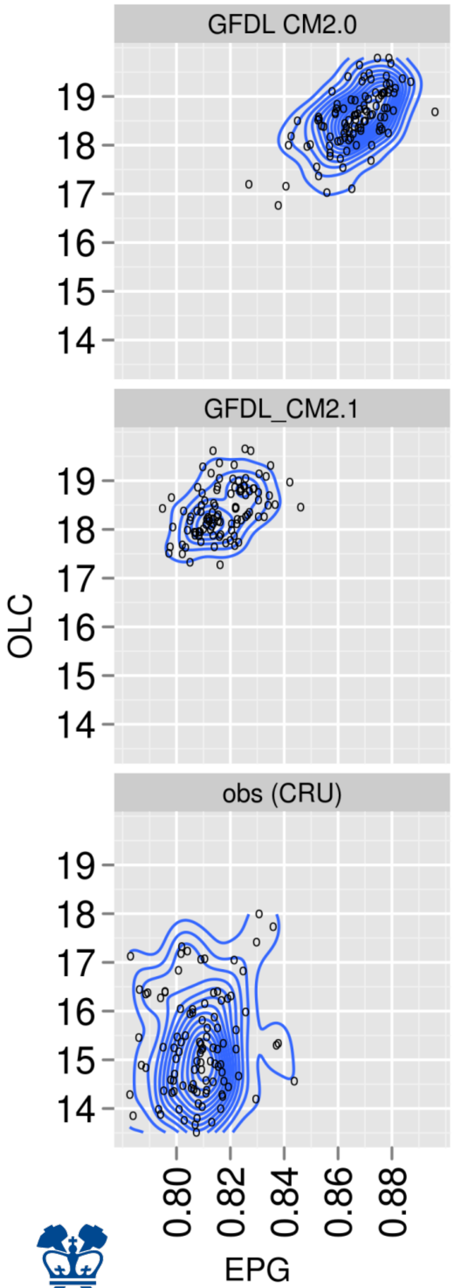


Sanity check

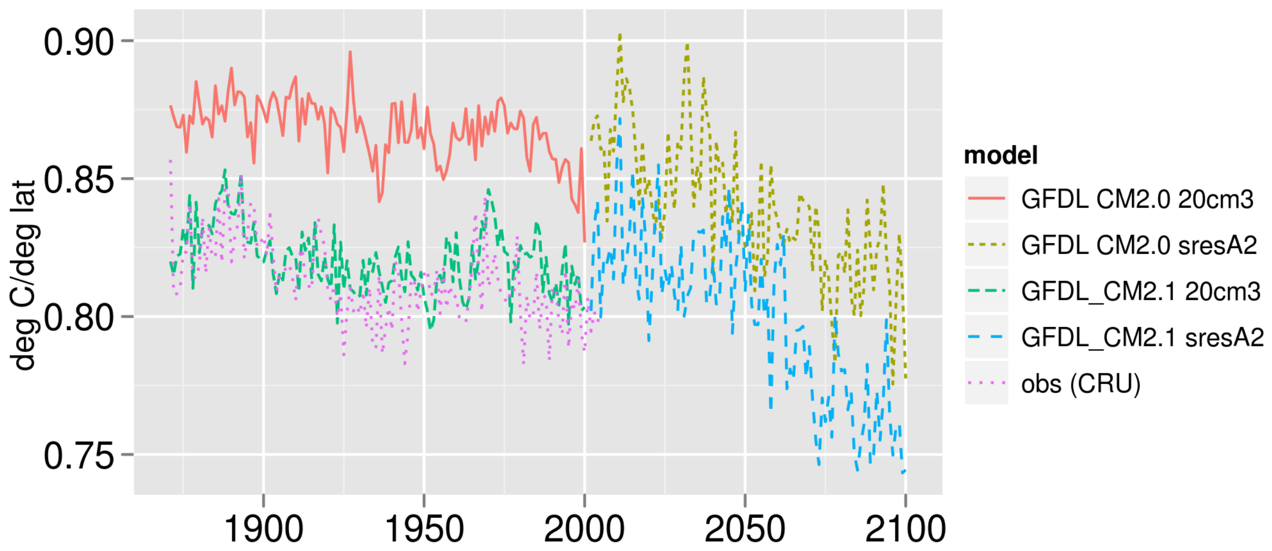
Eddies: Intensification and longitudinal movement during the winter

* Data: ERA-Interim

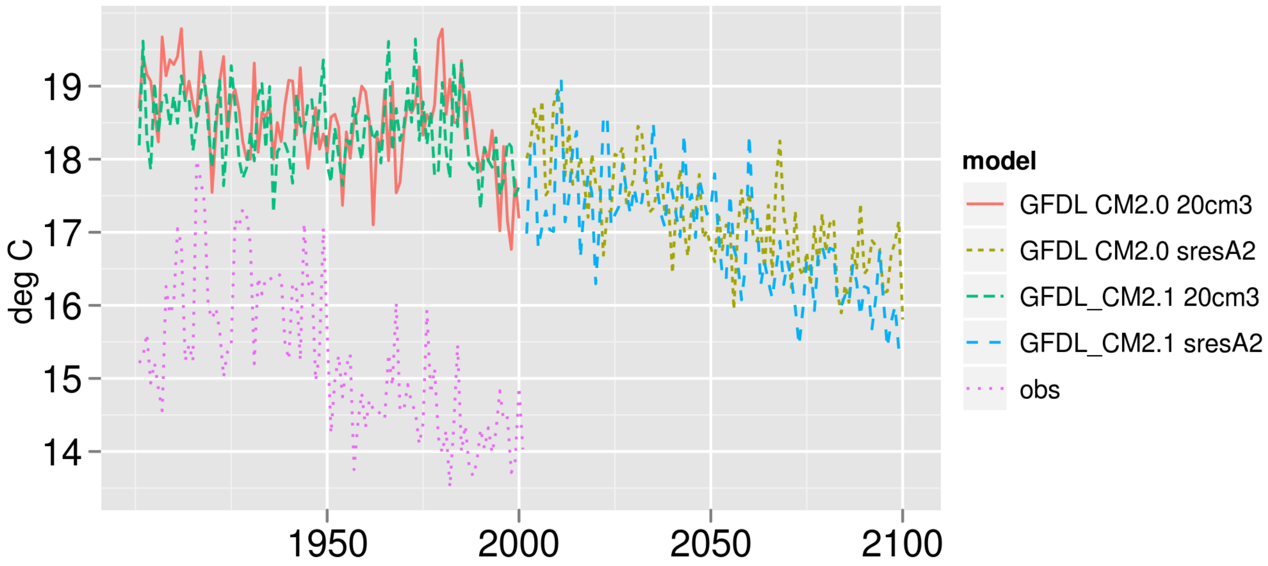
GCM simulations: Relation to Surface Temperature Gradients

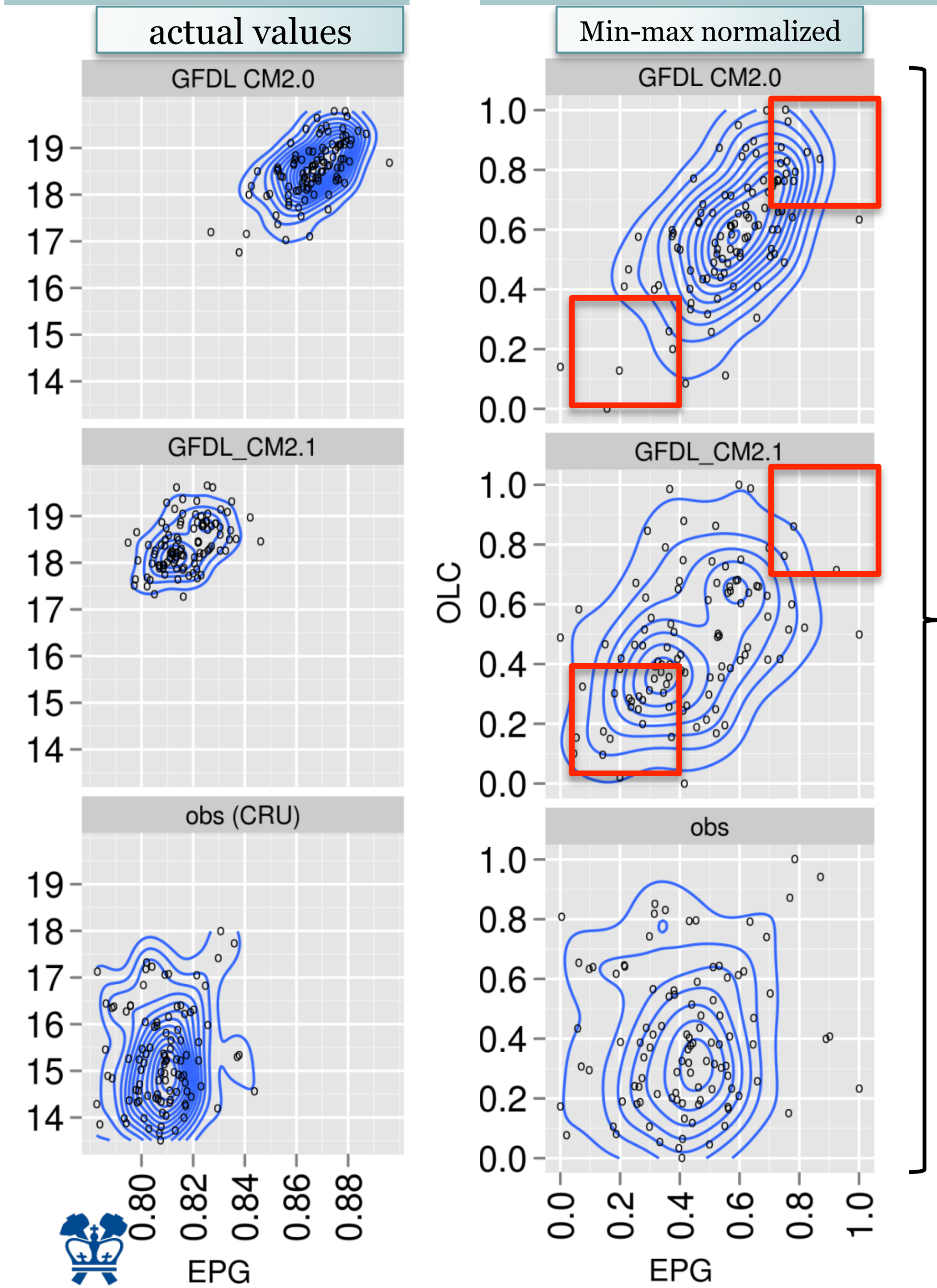


Equator-to-Pole temperature Gradient (EPG)



Ocean Land temperature contrast (OLC)



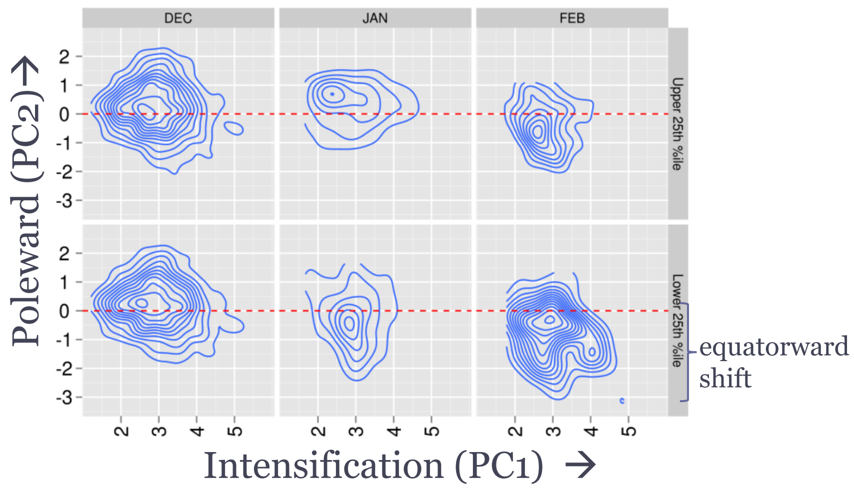


Normalized by the max and min to allow simpler visual comparison, and explore the response of the model to changing temperature gradients.

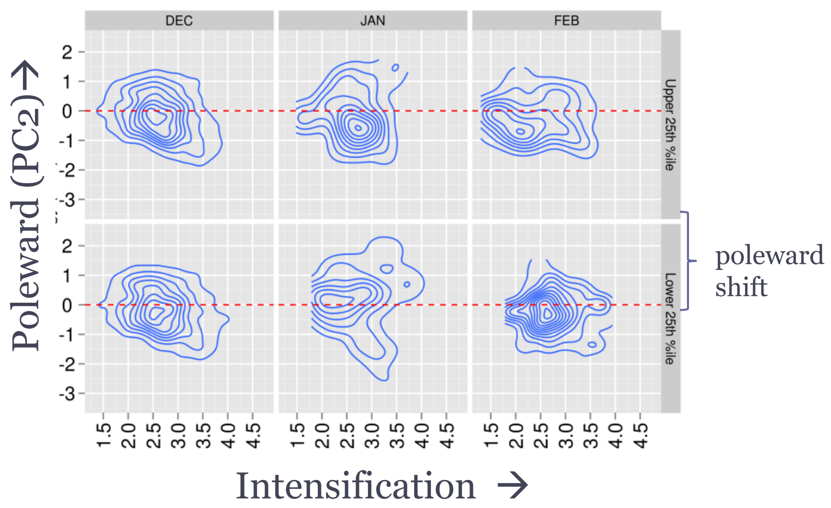
Jet intensification and shifts between the upper and lower 25th percentile of joint {EPG,OLC} pdf

Composite joint pdfs of PCs based on season, and location in the joint distribution of {EPG,OLC}

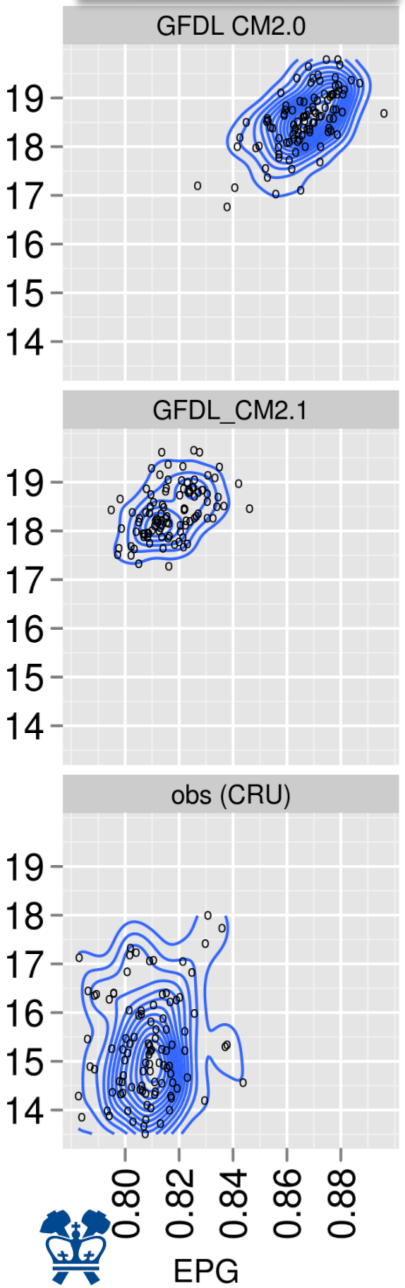
CM2.0 20cm3



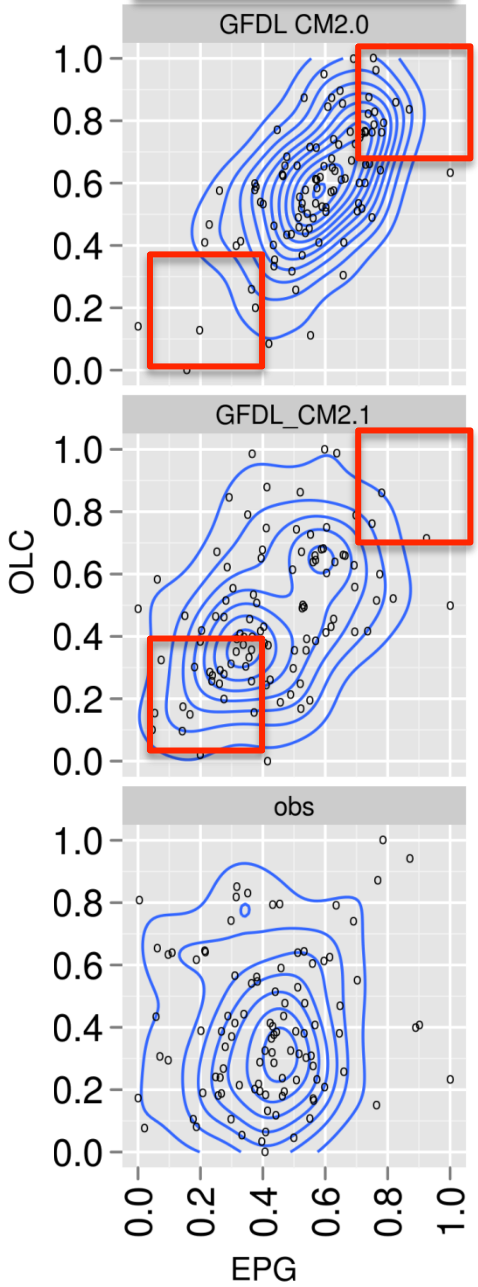
CM2.1 20cm3



actual values

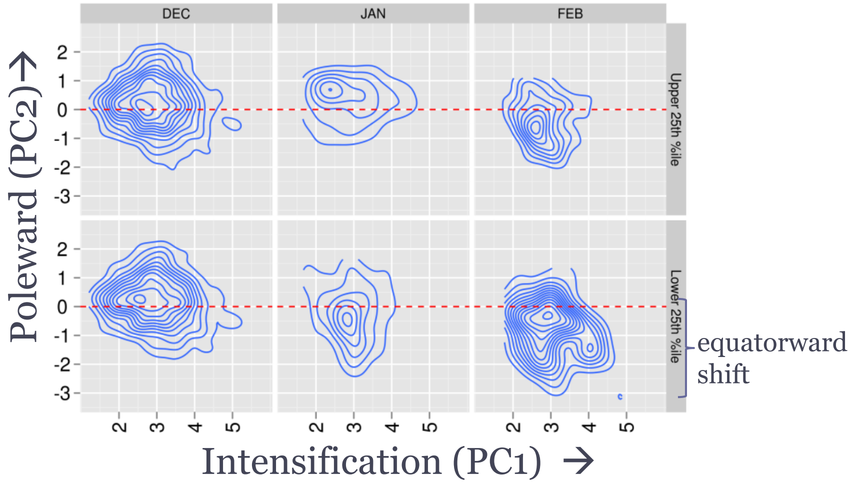


Min-max normalized

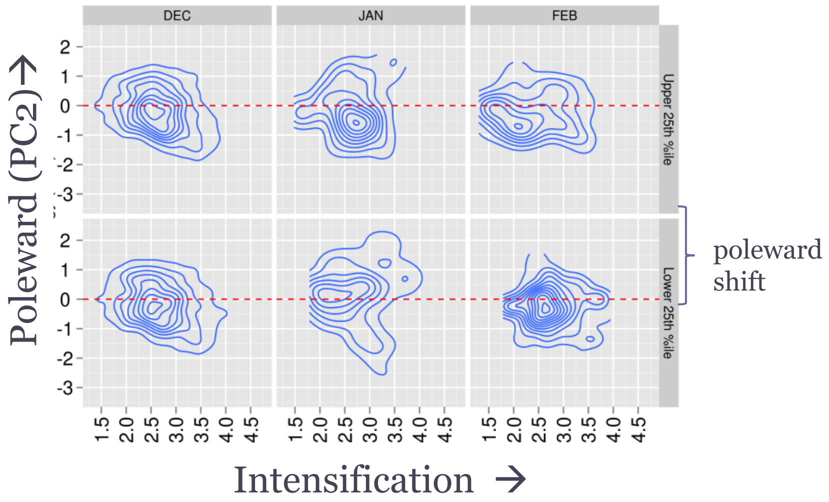


Jet intensification and shifts between the upper and lower 25th percentile of joint {EPG,OLC} pdf

CM2.0 20cm3



CM2.1 20cm3

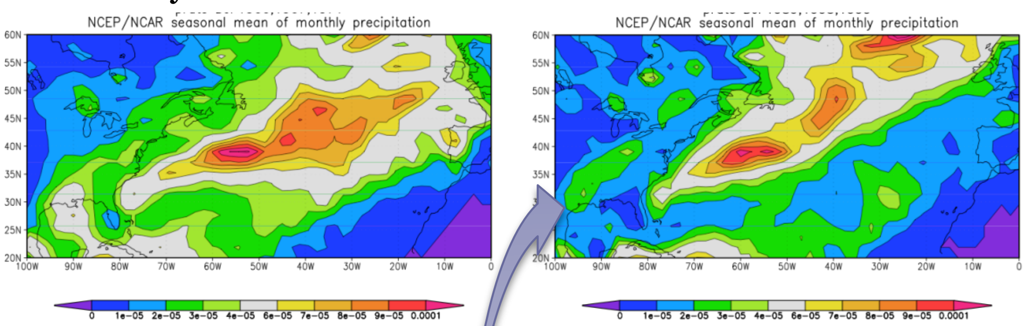


Mean precipitation

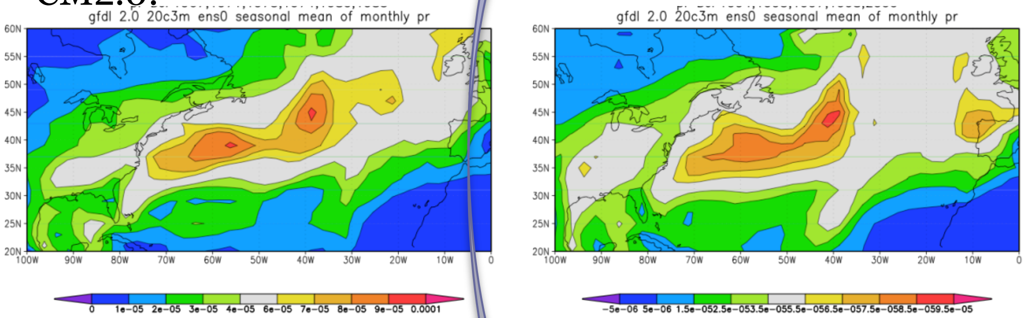
Jet intensification and shifts between the upper and lower 25th percentile of joint {EPG,OLC} pdf

Upper 25th %ile | Lower 25th %ile

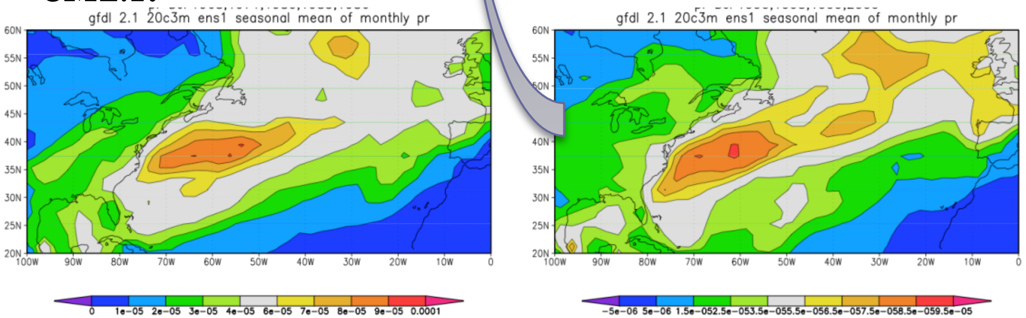
Reanalysis:



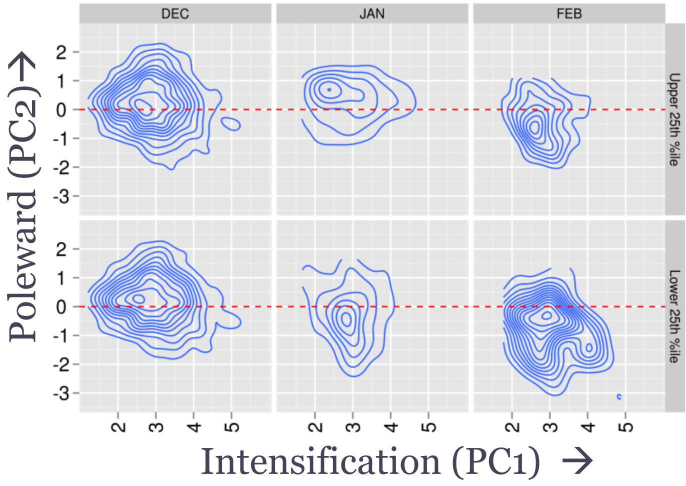
CM2.0:



CM2.1:

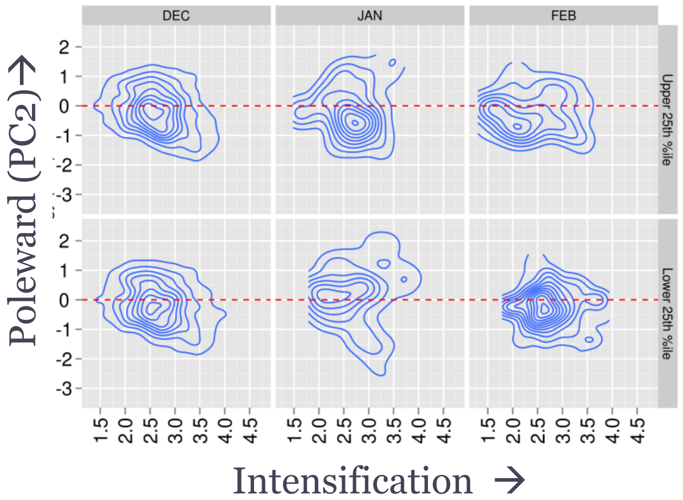


CM2.0 20cm3



equatorward shift

CM2.1 20cm3

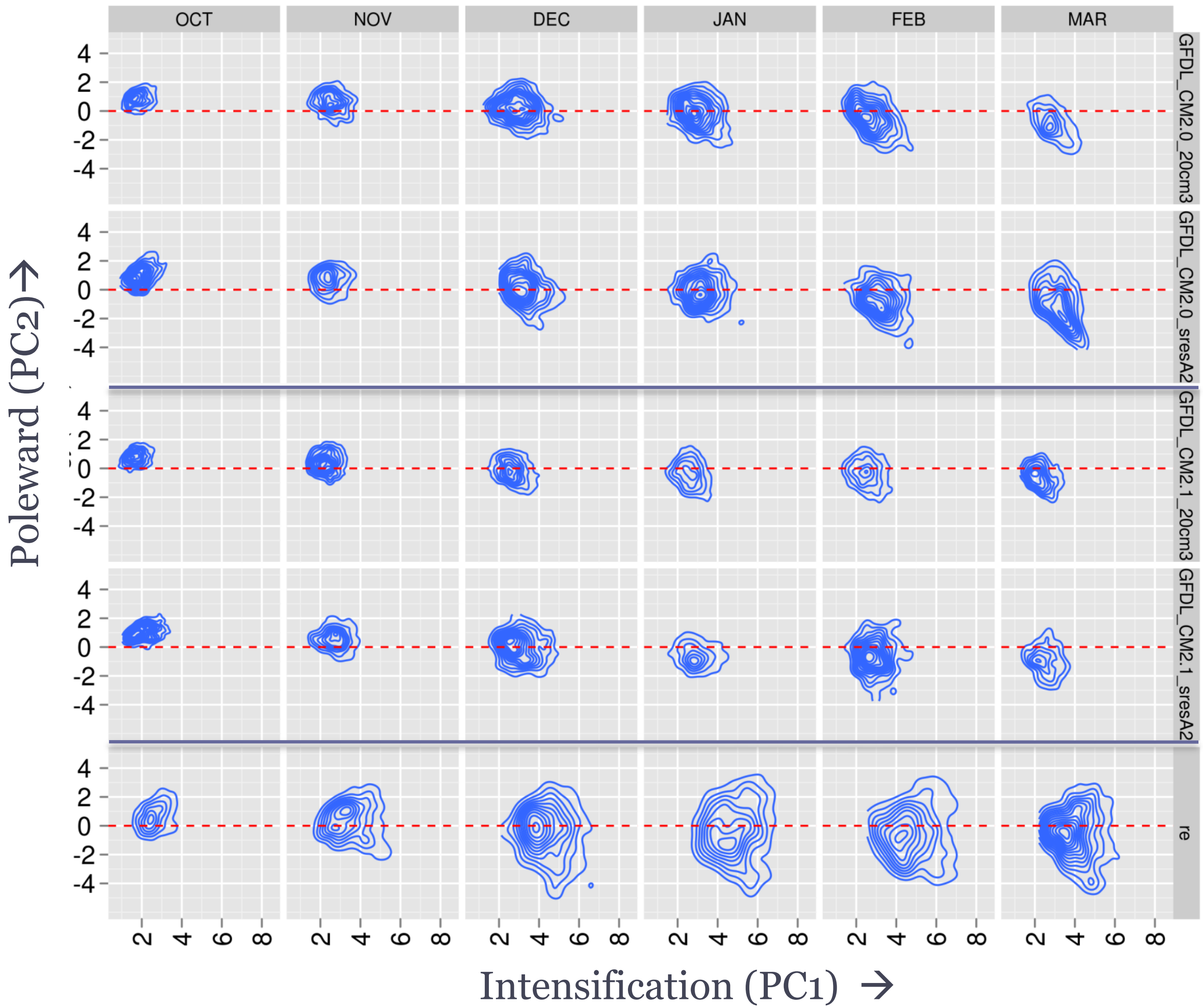


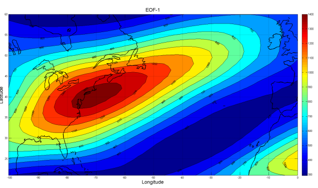
poleward shift

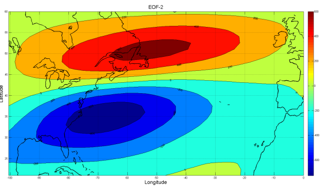
Not much change in intensity and position of the N.Atlantic jet in the A2 simulation.

The first model shows some equatorward shifts that were to be expected from its response to EPG decreases.

Less variability in the models compared to reanalysis.



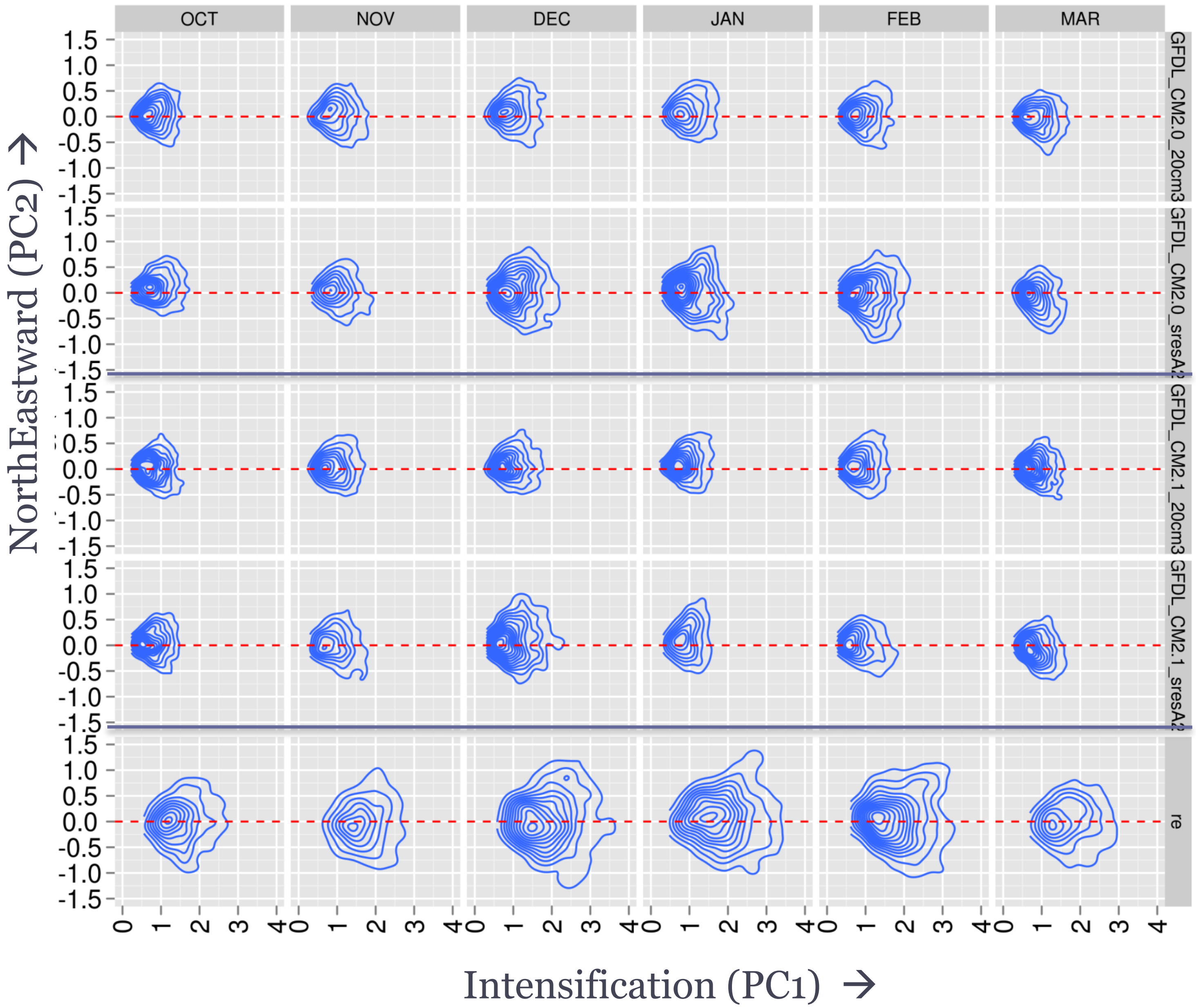


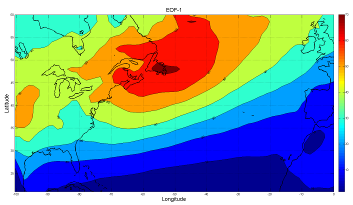


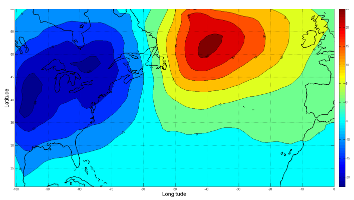
No significant changes between the 20th century and A2 simulations.

Enhanced storm variability in the A2 simulations.

Still, less variability than reanalysis







a) Temperature gradients are decreasing in the 21st century simulations.

b) One model that
   1) has the opposite than expected response to the decreasing temperature gradients
   2) has consequent discrepancies in the precipitation response to decreasing gradients
   3) shows no/equatorward shifts in the jet in the N. Atlantic region in 21st century.

c) A second model that
   1) responds to decreasing temperature gradients as expected
   2) shows consistent precipitation changes in response to decreasing gradients
   3) shows little poleward shift in the N. Atlantic jet in the 21st century.

d) Neither model shows significant changes in the eddy components.

e) Both models have less storm variability than reanalysis.

Remaining Point:

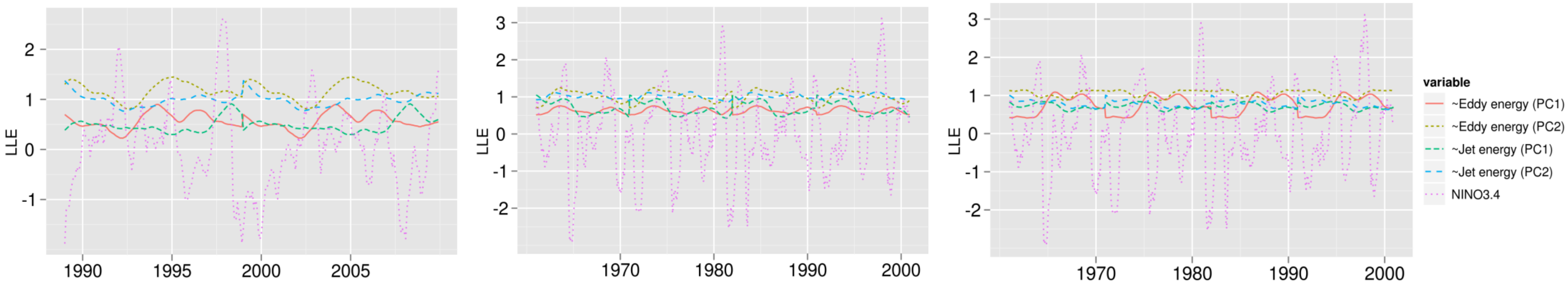
- Observations support the L84 view of surface temperature gradients as important drivers of mid-latitude jet and eddy variability.

- We reduce GCMs to the L84 space and find
- a) model biases in the temperature gradients
- b) different model responses and sensitivity to decreasing temperature gradients.

- Tropical-extratropical teleconnections and their potential changes are manifest in mid-lat predictability.

Local Lyapunov Exponents:

ERA-Interim GFDL CM2.0 GFDL CM2.1



Local Lyapunov Exponents (LLE):

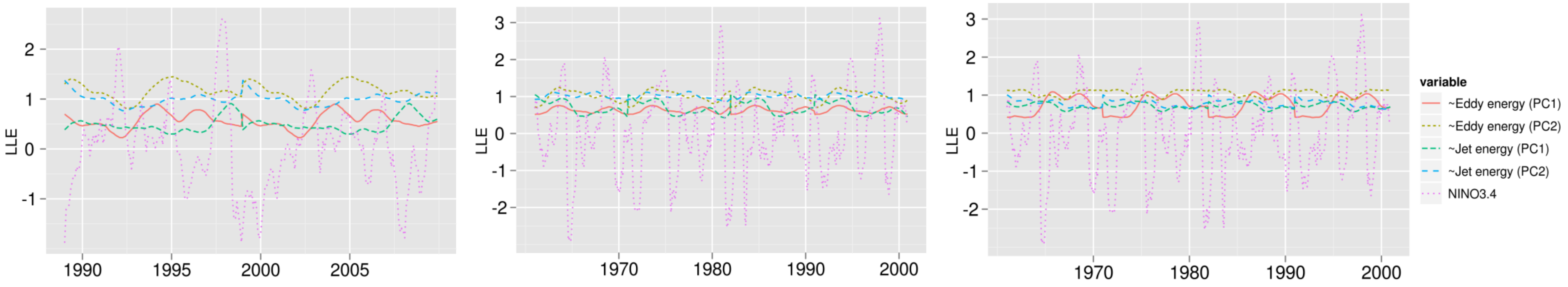
divergence of trajectories in the time-delayed phase-space reconstruction of each PC.

- **Low** LLE implies **enhanced** predictability in a 16-month window.
- **High** LLE implies **reduced** predictability in a 16-month window.

Bryant et al. (1990), Abarbanel et al. (1993)

Local Lyapunov Exponents:

ERA-Interim GFDL CM2.0 GFDL CM2.1

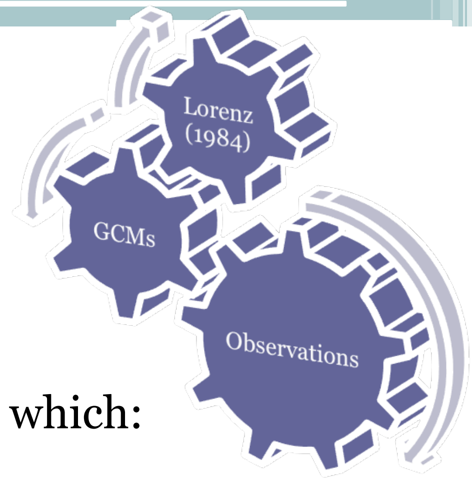


Correlation of NINO3.4 & LLEs (measure of teleconnection):

	Jet Intensity (PC1)	**Jet Position (PC2)**	**Eddy Intensity (PC1)**	**Eddy Position (PC2)**	**model**
NINO3.4	-0.16	-0.44	-0.07	-0.25	ERA-Interim
NINO3.4	-0.038	0.14	0.008	0.05	CM2.0-20cm3
NINO3.4	-0.06	-0.29	-0.28	-0.08	CM2.0-sresA2
NINO3.4	-0.06	-0.22	0.05	-0.14	CM2.1-20cm3
NINO3.4	0.01	-0.01	-0.1	0.18	CM2.1-sresA2

This measure seems consistent with the 20th and 21st run composites of the jet and storms w.r.t. ENSO.
A change in the teleconnection is noted in the 21st century simulations.

Conclusions:



- When brought to a ‘real-parameter’ space, the L84 model gives results consistent with expectations.

- The surface temperature gradients that drive the L84 model are:
(a) reflecting GW signals
(b) useful diagnostic indicators of circulation patterns.

- We reduced the GCM simulations to an L84-inspired variable space, which:
(a) contains the basic info about persistence and predictability, and
(b) provides a simplified, yet comprehensive, description of circulation features.

- Model biases in the temperature gradients affect the temporal representation of circulation and precipitation in the models.

- Differing responses of circulation to decreasing temperature gradients are reflected in the GW projections.

→ Large-scale prcp correction on the basis of temperature gradients could be possible.

- Predictability propagation as a measure of tropical-extratropical teleconnection? Do teleconnections change with global warming? (e.g. Wu et al.)

- Variability in mid-lat precipitation associated with ENSO may swamp the GW signal?

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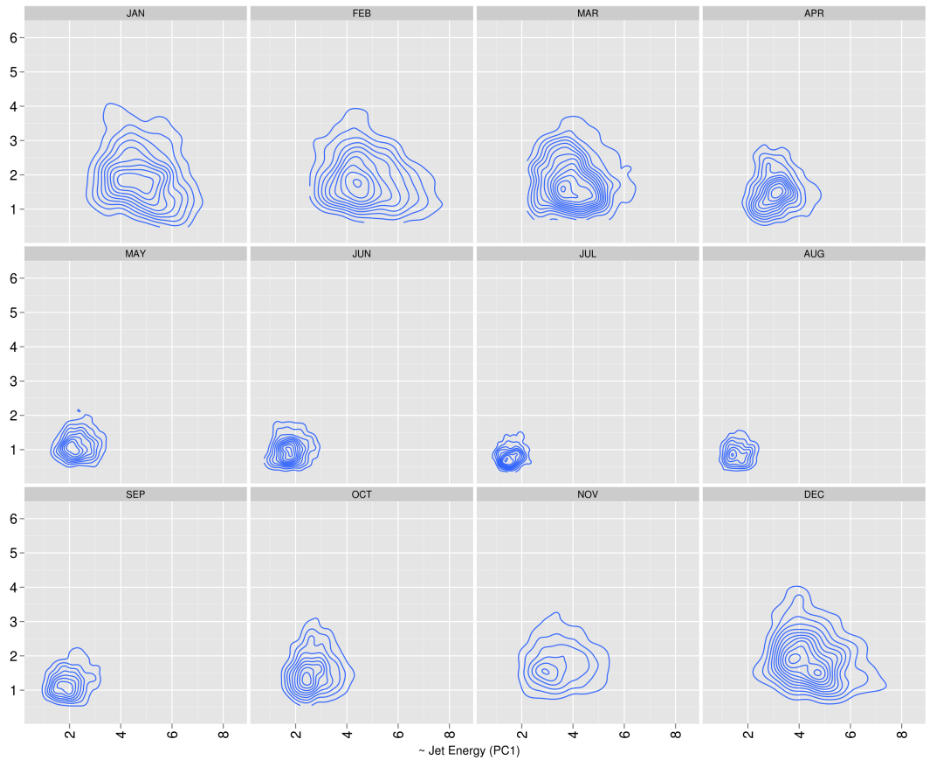
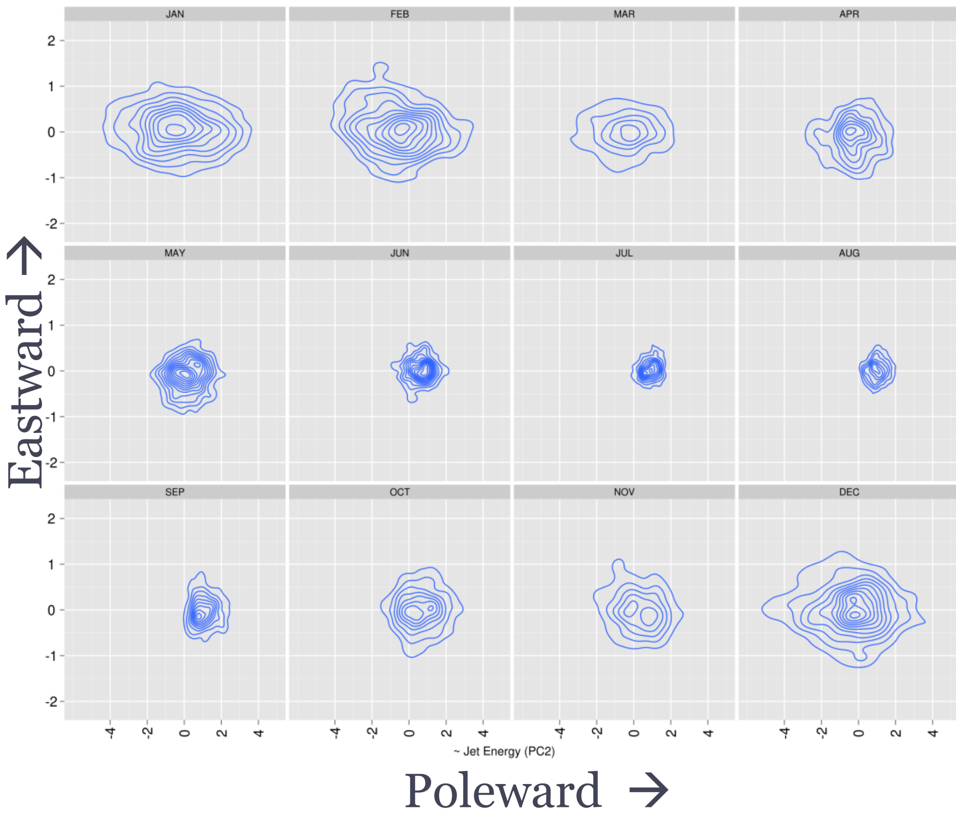
Reserve Slides

Eddies vs. jet

Intensity:

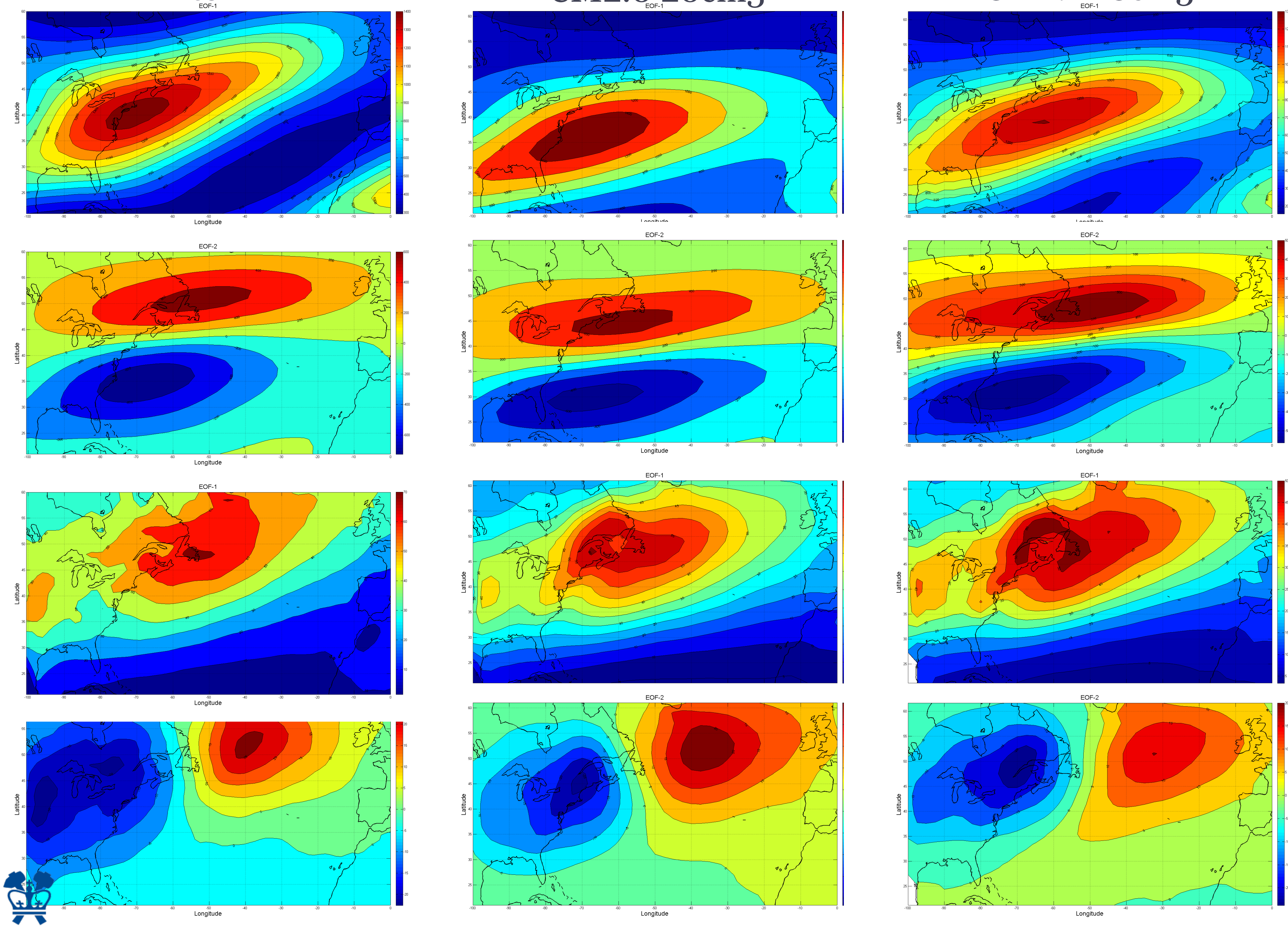


Shifts:



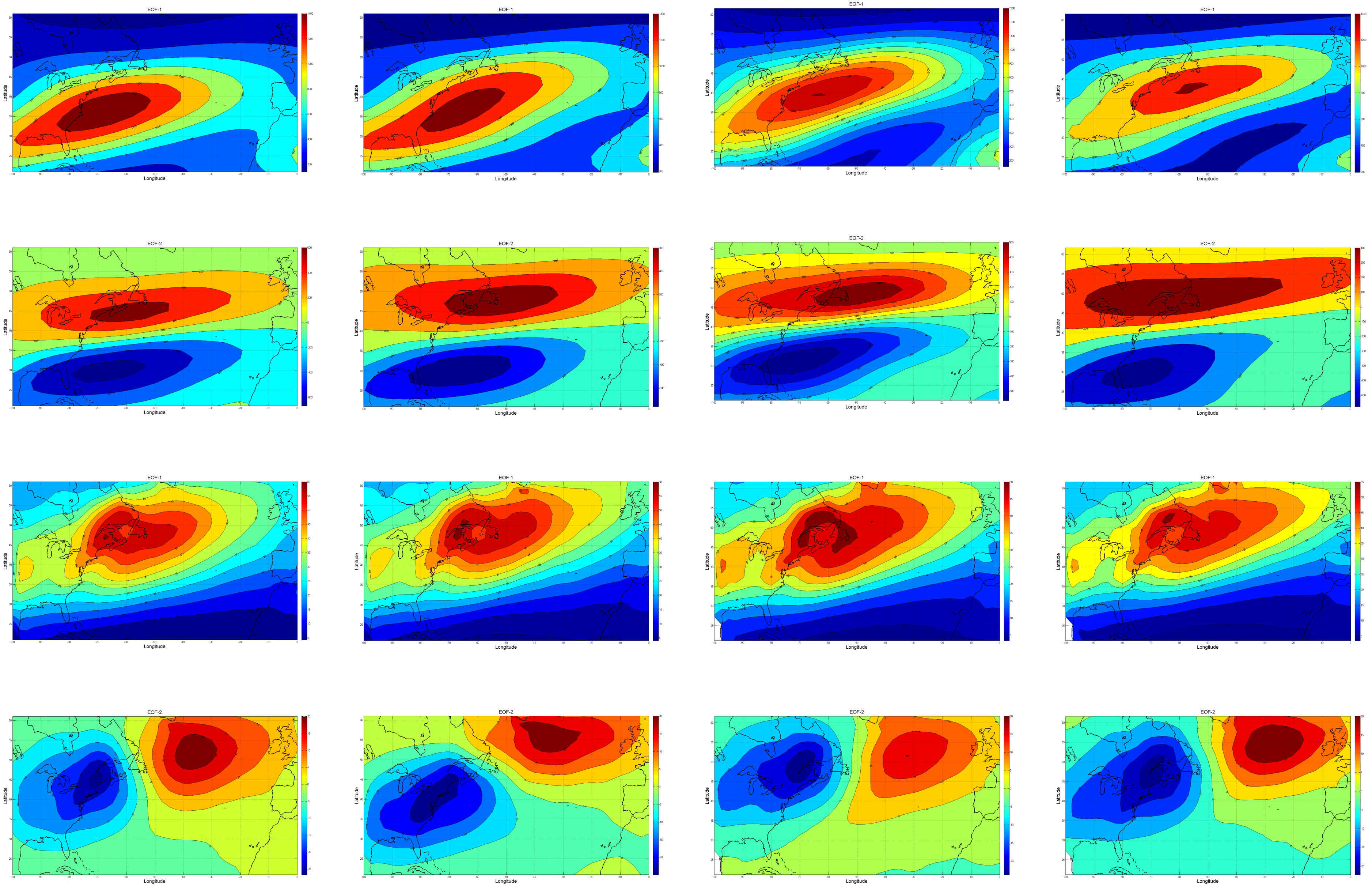
Sanity check

ERA Interim | CM2.0 20cm3 | CM2.1 20cm3

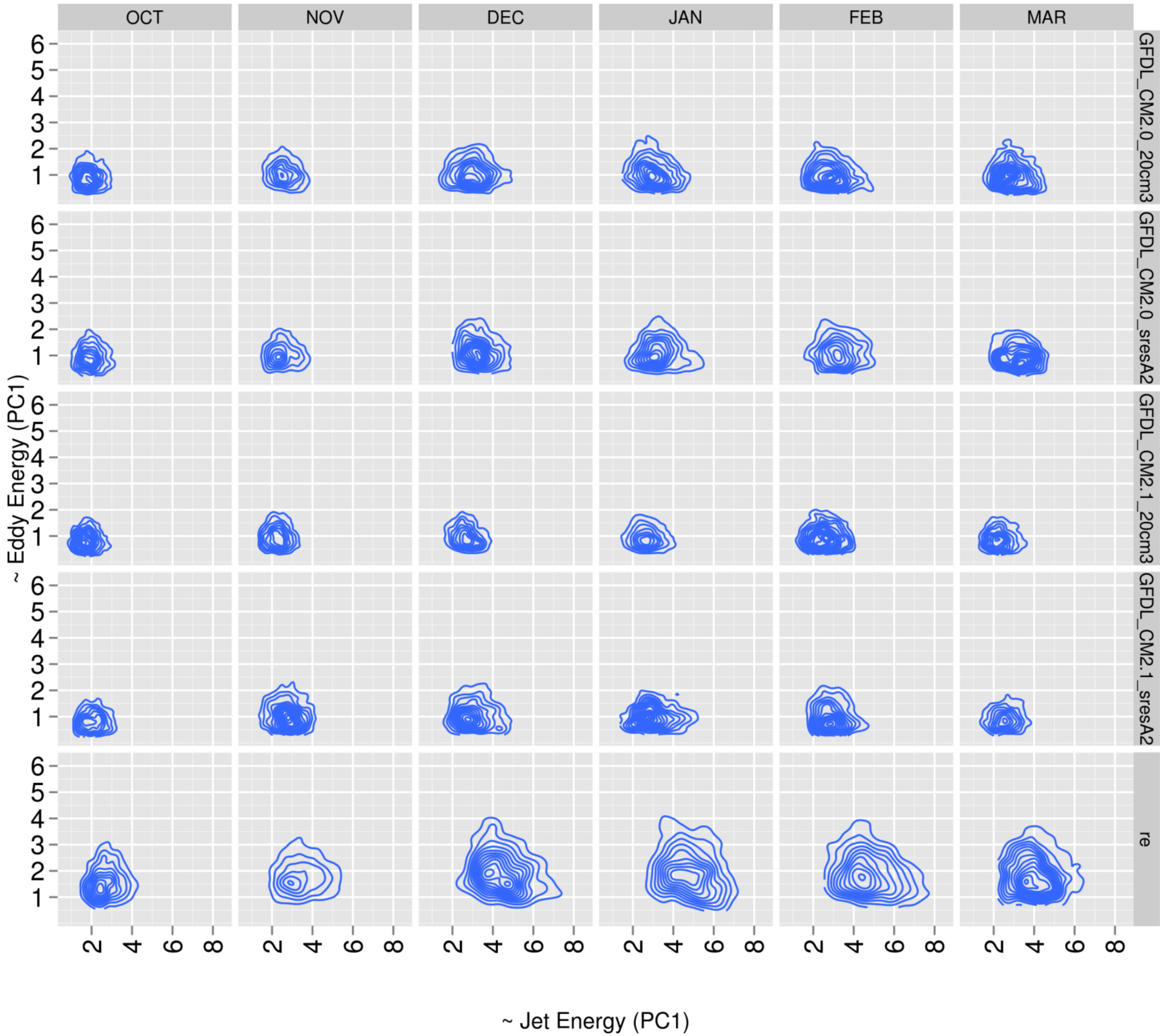


GCM simulations: EOF analysis

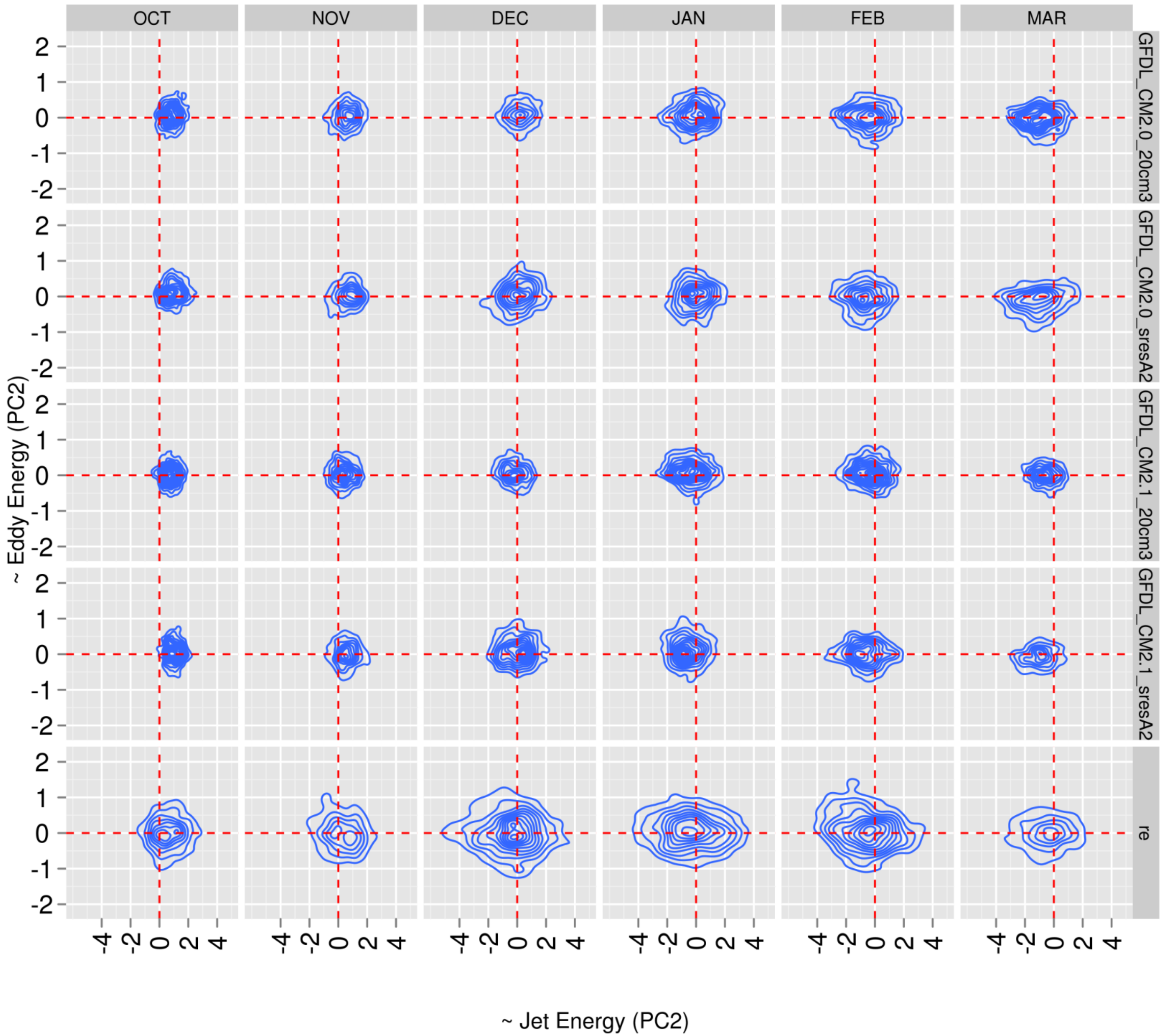
CM2.0 20cm3 | CM2.0 sresA2 | CM2.1 20cm3 | CM2.1 sresA2



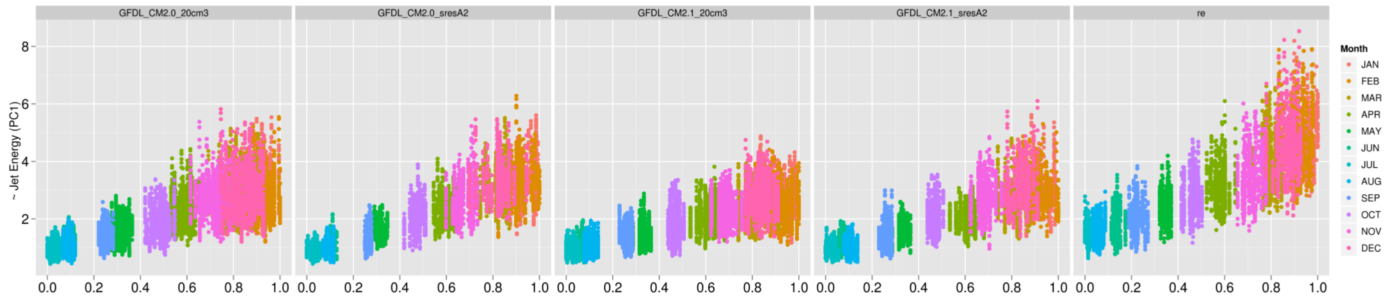
GCM simulations: Eddy vs. jet energy

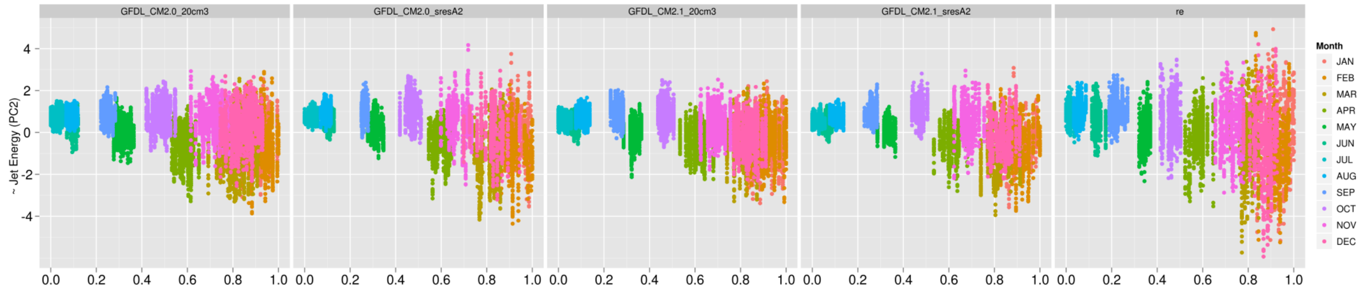


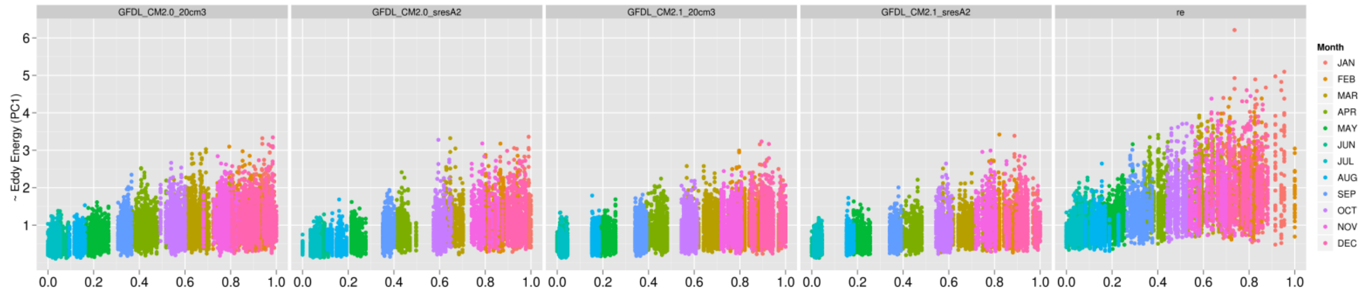
GCM simulations: Eddy vs. jet shifts

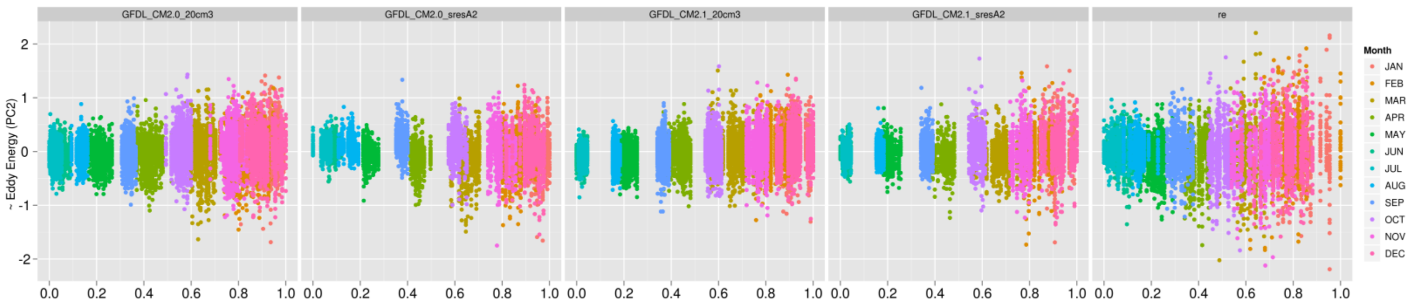


GCM simulations: Relation to Surface Temperature Gradients



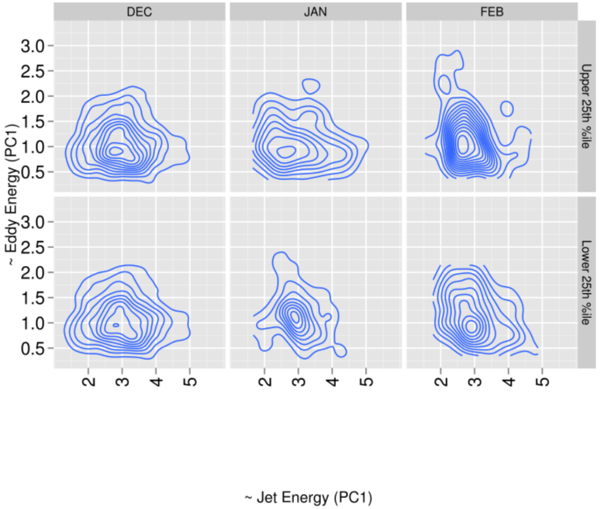


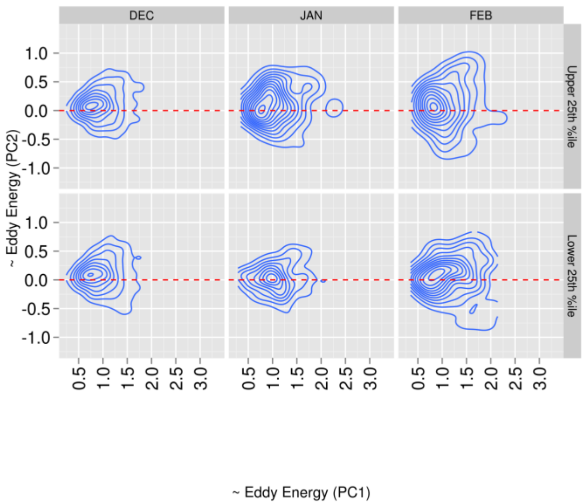


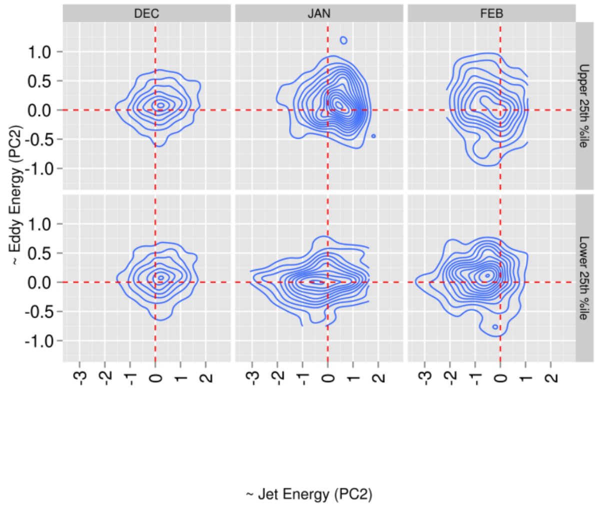


GCM simulations: Changes between upper and lower 25th percentile

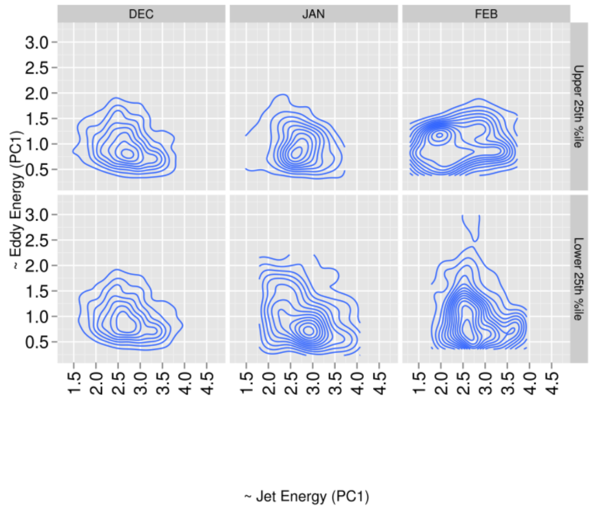
CM2.0 20cm3

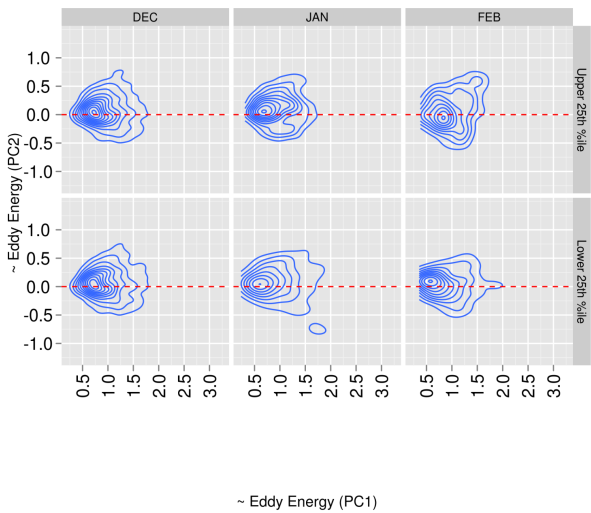


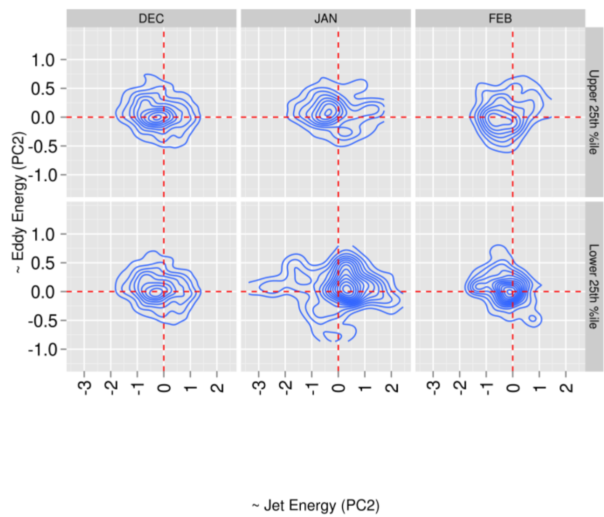


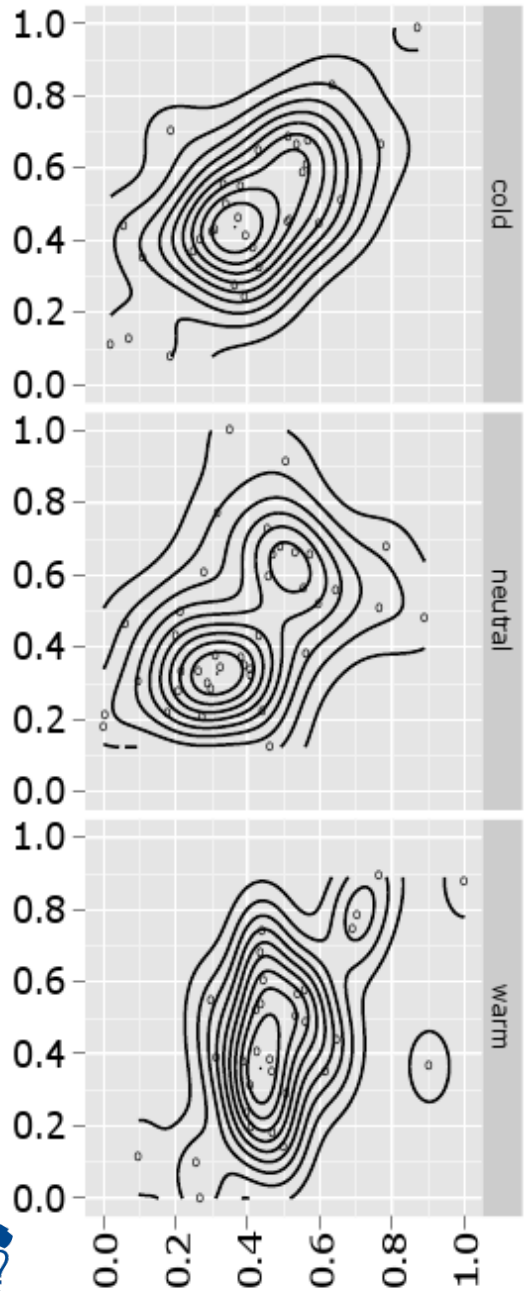


CM2.1 20cm3

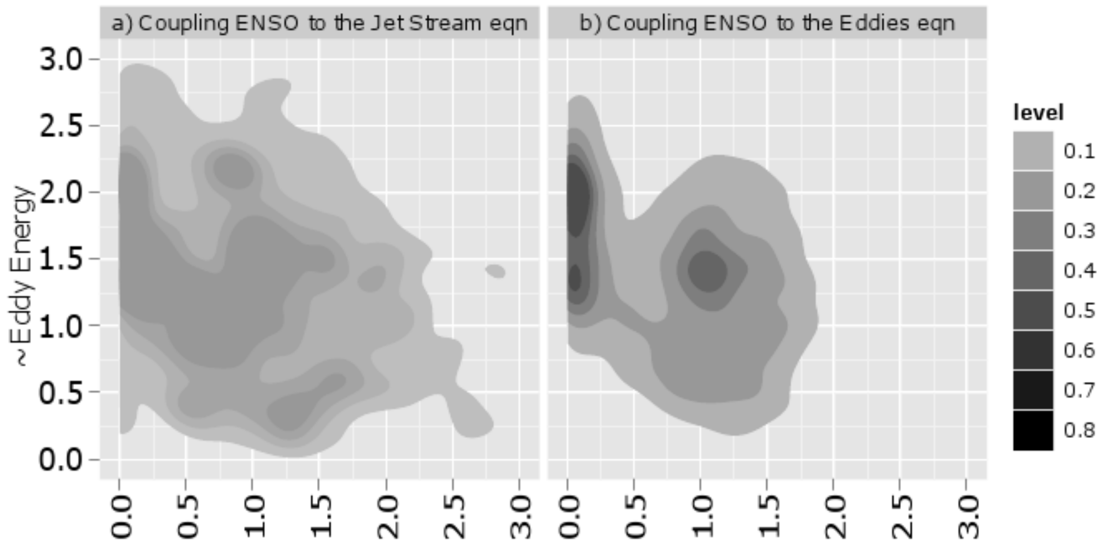




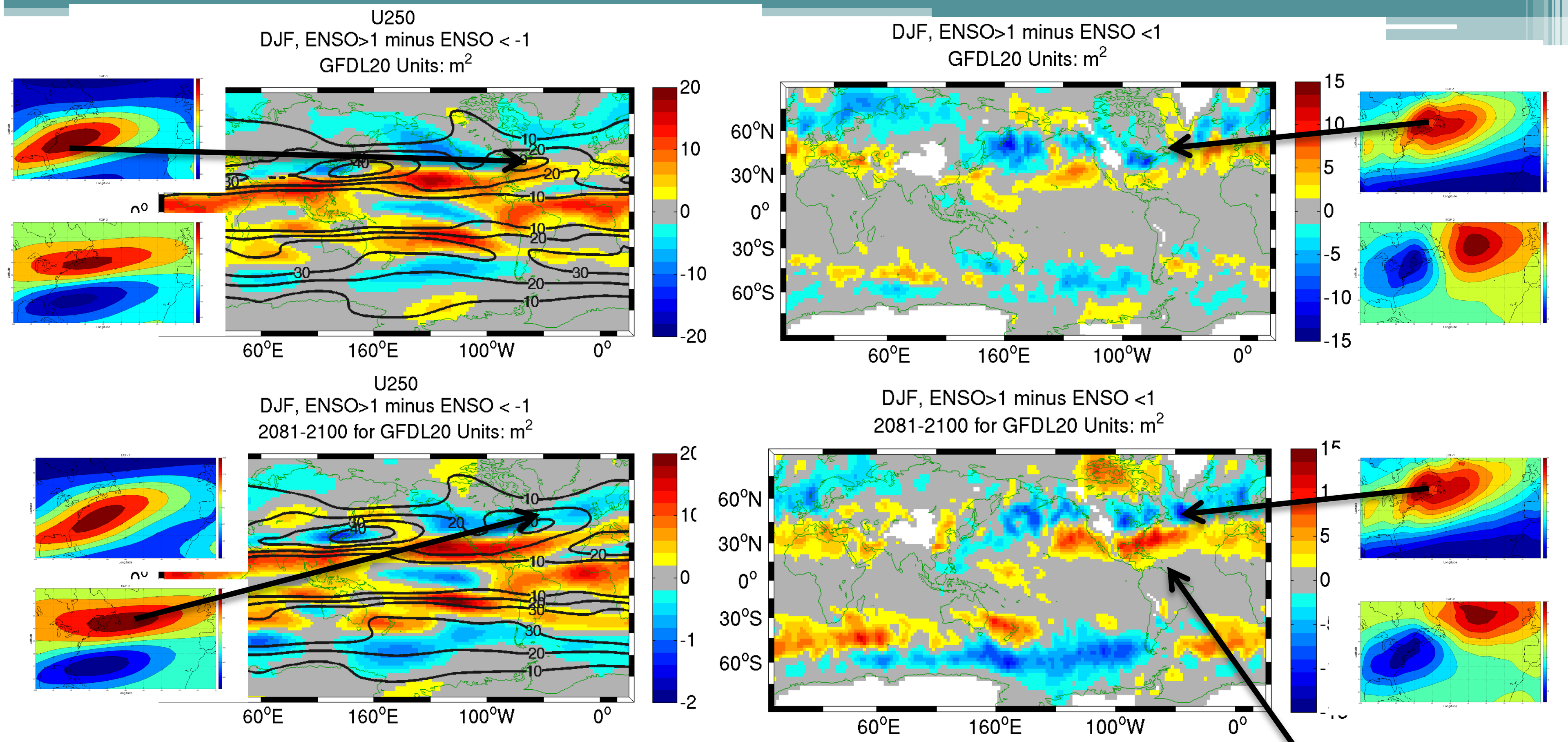


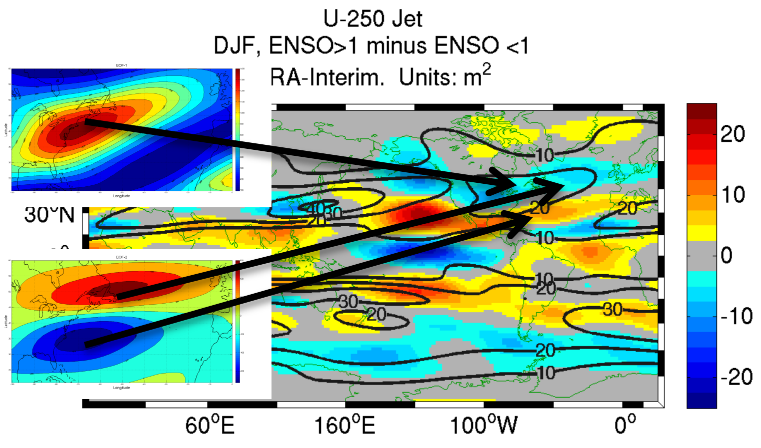


- ➢ Run a coupled L84-ENSO model
- a) delayed ENSO effect on jet stream equation
- b) direct ENSO effect on eddy equation

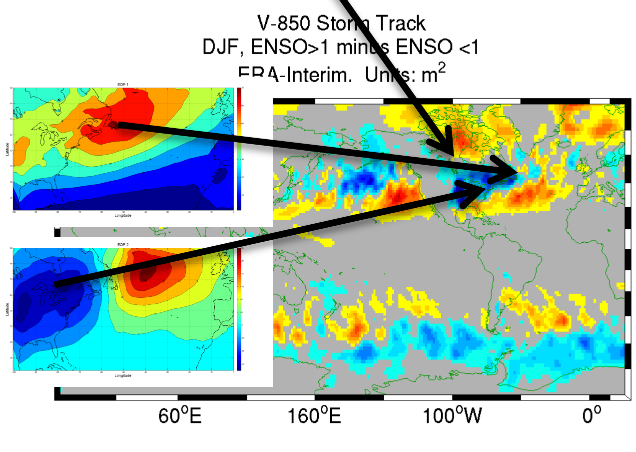


ENSO composites—CM2.0

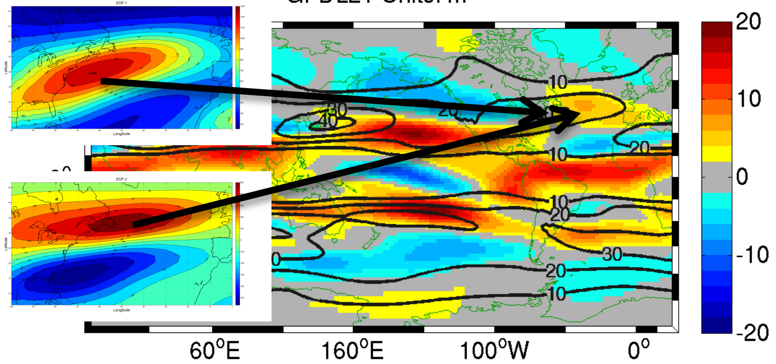




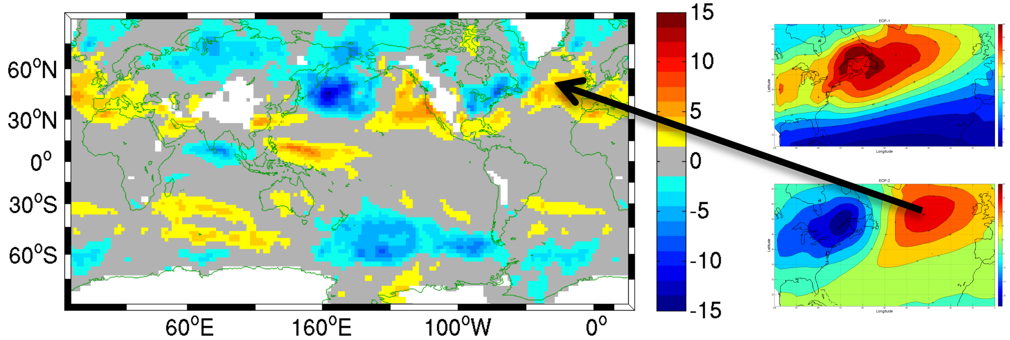
:compare to:



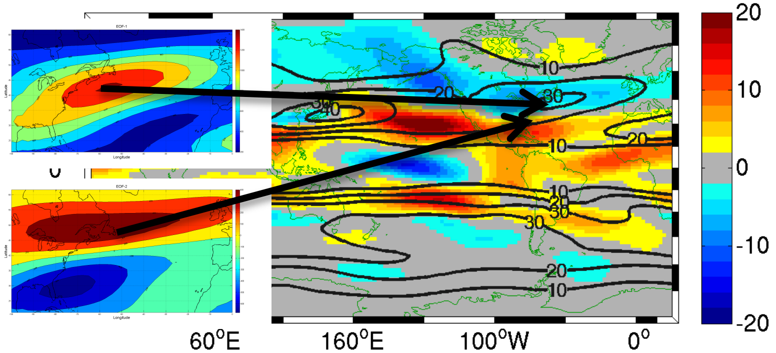
U250
DJF, ENSO>1 minus ENSO < -1
GFDL21 Units: m^2



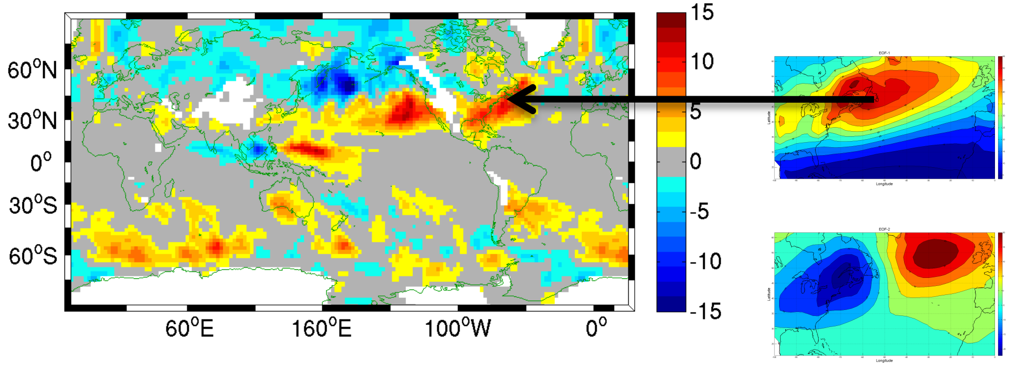
DJF, ENSO>1 minus ENSO <1
GFDL21 Units: m^2



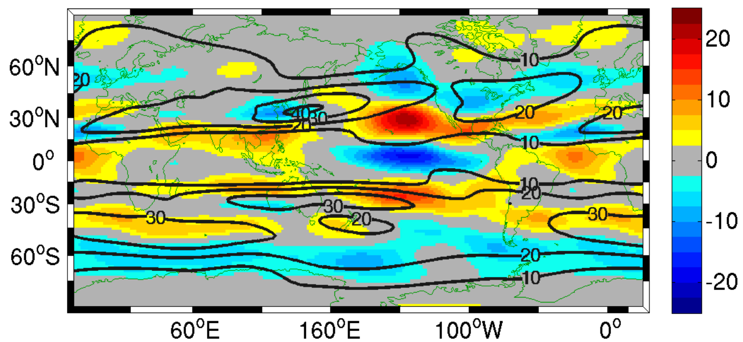
U250
DJF, ENSO>1 minus ENSO < -1
2081-2100 for GFDL21 Units: m^2



DJF, ENSO>1 minus ENSO <1
2081-2100 for GFDL21 Units: m^2



U-250 Jet
DJF, ENSO>1 minus ENSO <1
ERA-Interim. Units: m^2



:compare to:

V-850 Storm Track
DJF, ENSO>1 minus ENSO <1
ERA-Interim. Units: m^2