Can we expect to forecast Weeks 3 and 4?

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Outline of talk

- Study of the mechanics of the atmosphere
- Search for elusive empiric periodicities

Daily vs. extended range forecast skill

Forecast skill

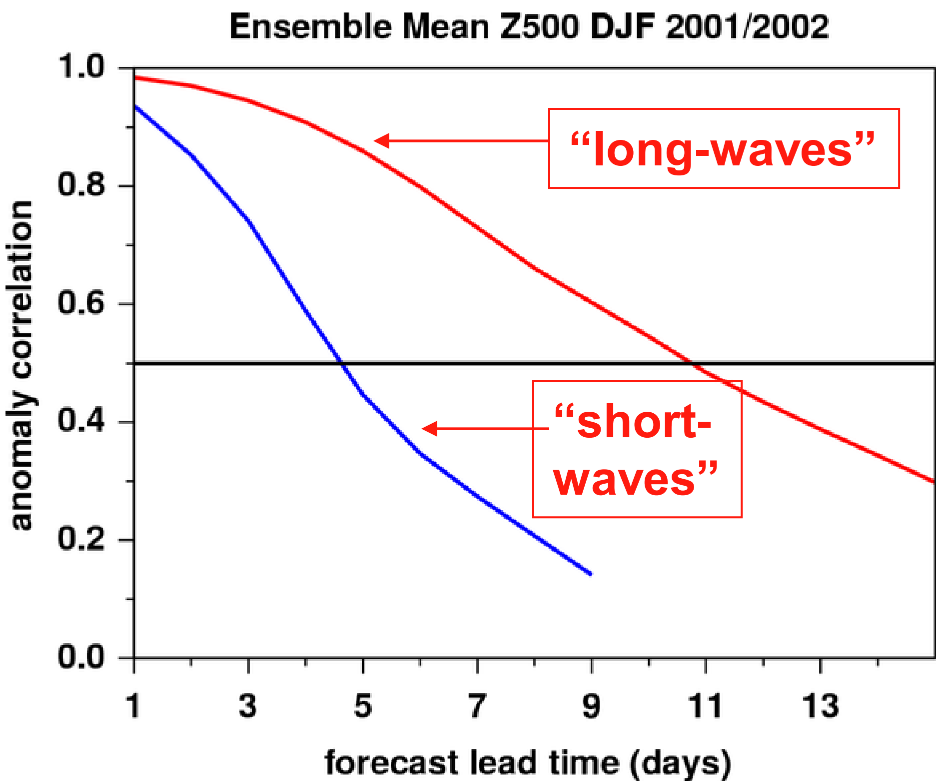


Figure courtesy Jeff Whitaker

- Most skill is lost for “short-waves” for a 5-day forecast.
- “long-waves” skillful well into week 2.
- Obvious point: Weeks 3 and 4 forecasts will mostly be of large-scale dynamics

Teleconnections: high-frequency vs. low-frequency

Differences between synoptic and climate variability appear on timescales as short as a week

The maps show the correlation of the “band-pass filtered” 500 mb anomaly height time series at all points on the hemisphere with the time series at a north Pacific “base point”.

Positive correlations are indicated by red and negative correlations by blue colors.

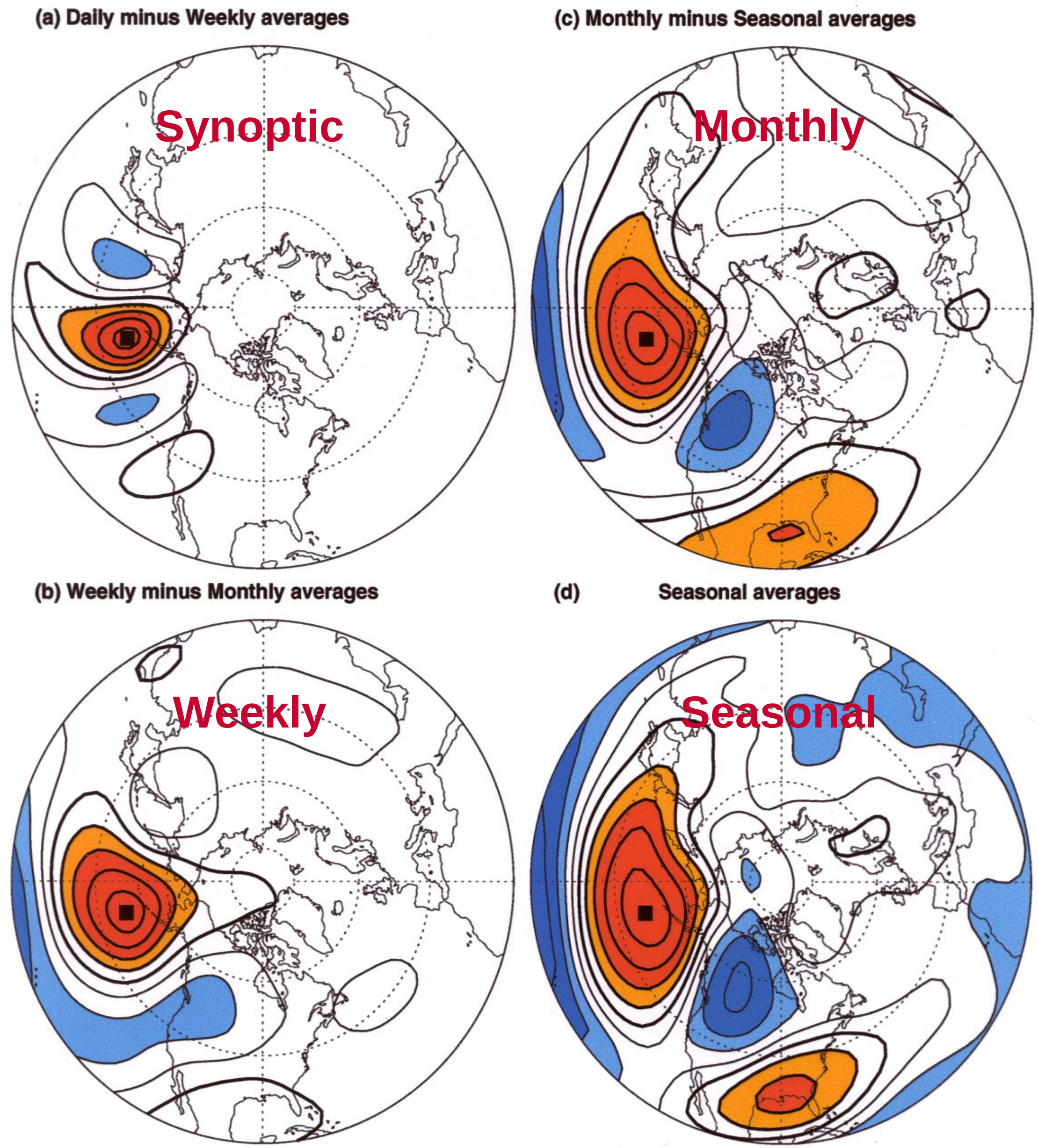


Figure courtesy Gil Compo

Separation of scale: baroclinic and barotropic

Variance-conserving spectra of 500 mb height (left) and omega (right), averaged in high and mid latitudes

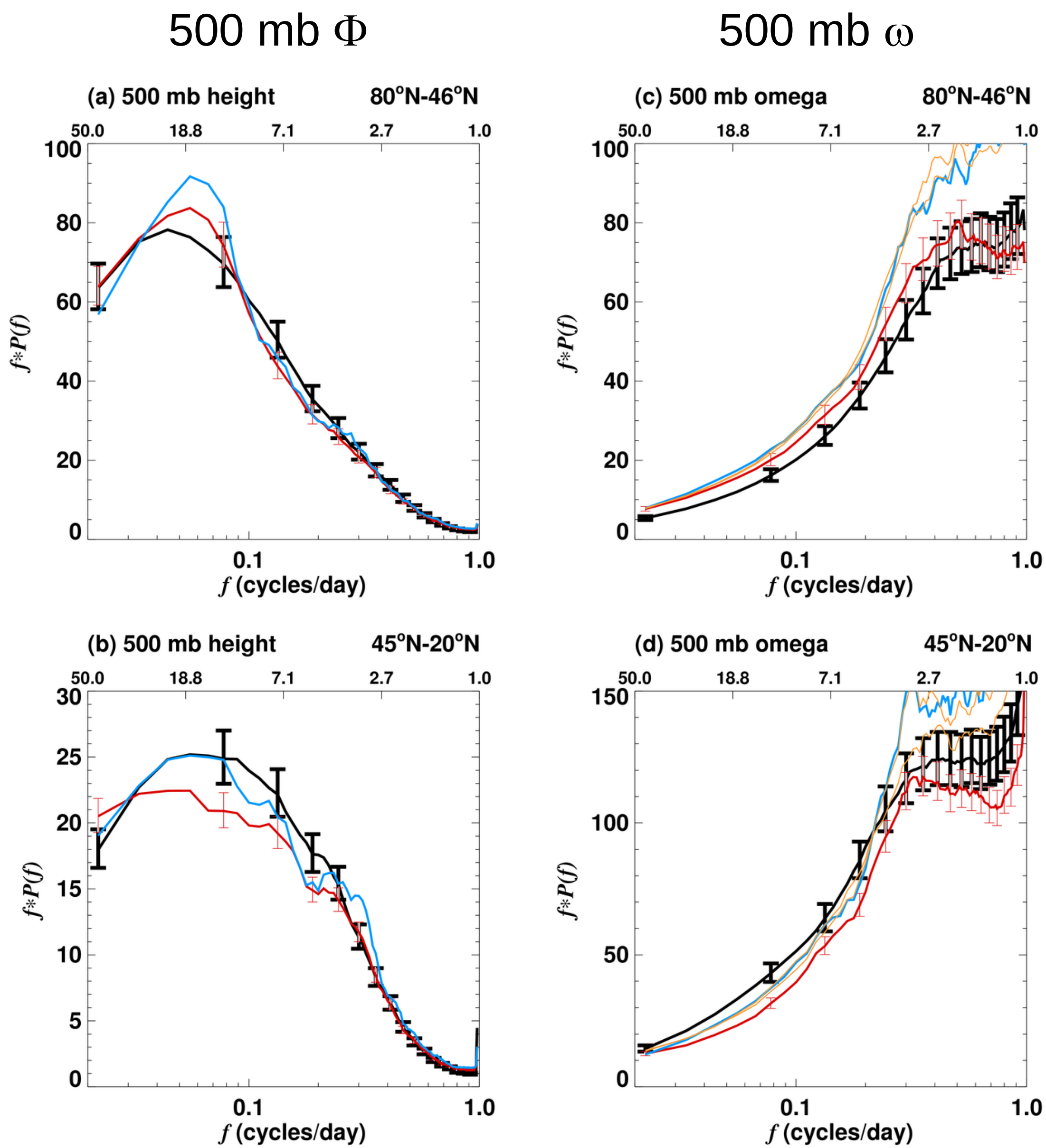


Figure courtesy Gil Compo

Motivation

Consider the dynamical system describing the variable x,

dx/dt = N(x) + F   (N is a nonlinear operator and F is external forcing)

This can always be rewritten as

dx/dt = slow nonlinearity + fast nonlinearity

If:

- we are only interested in the slowly evolving portion of x
- and there is a big difference between “fast” and “slow”

this may be usefully approximated as

dx/dt = Lx + white noise

Barotropic eigenmode

Assume

$$\frac{d\mathbf{x}}{dt} = \mathbf{L_B x} + \mathbf{F}_s$$

where $\mathbf{L_B}$ represents linear barotropic dynamics.

Then weekly variations result from the least damped (closest to neutral) eigenmodes of $\mathbf{L_B}$.

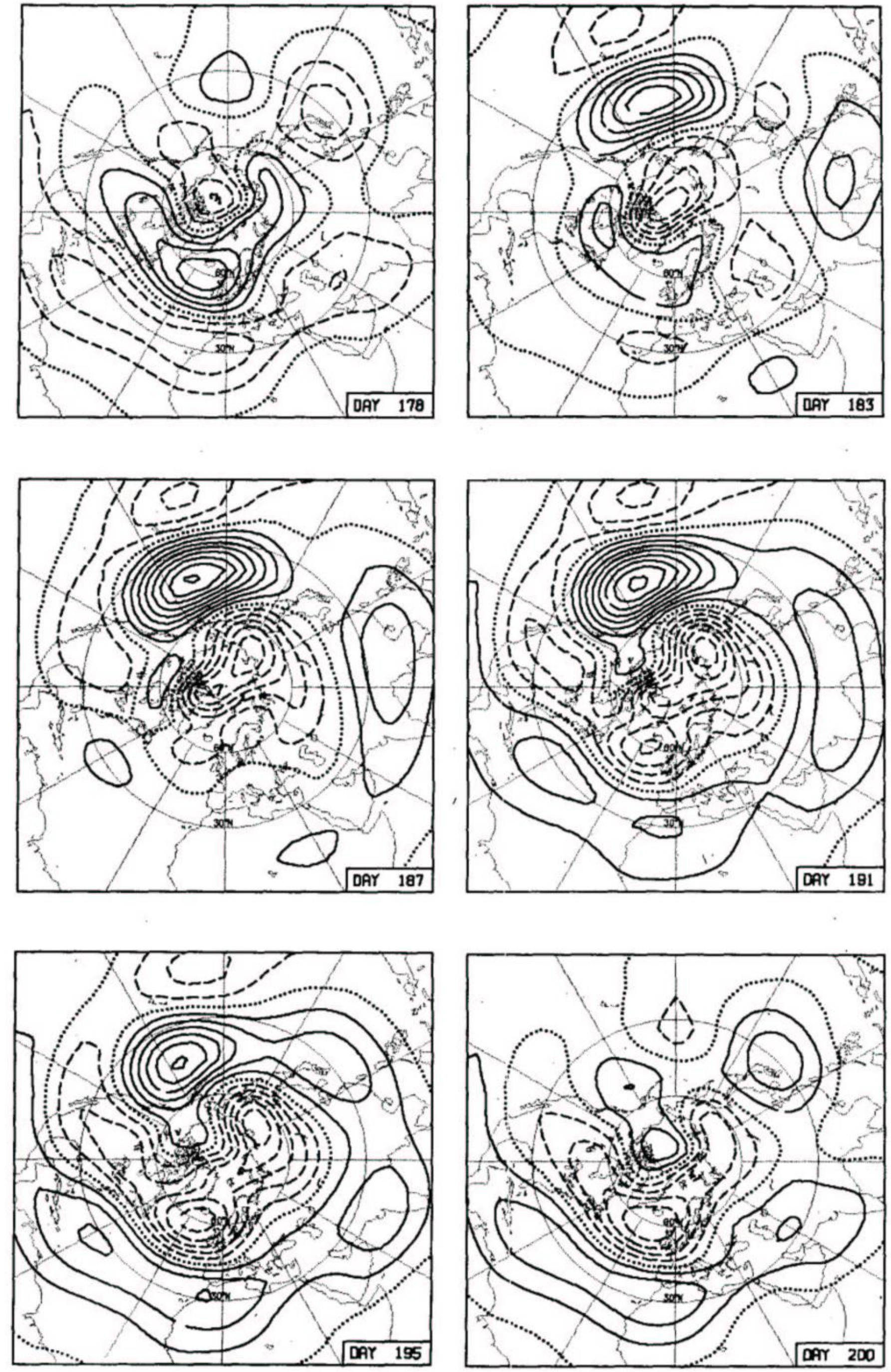


FIG. 11. The streamfunction of the most unstable normal mode at selected days within one-half cycle of its oscillation. The contour interval is arbitrary.

Simmons, Wallace, and Branstator 1983

Problem: Barotropic dynamics alone can't explain time evolution

Solution (?): A different linear operator:

$$d\mathbf{x}/dt = \mathbf{Lx} + \mathbf{F}$$

[but a linear baroclinic **L** is only slightly better]

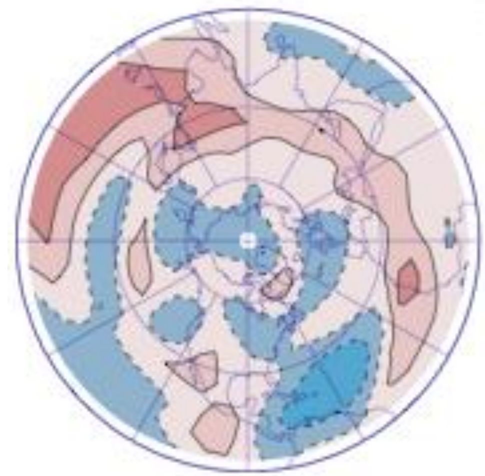
and/or a *second* model for the forcing:

$$d\mathbf{F}/dt = \mathbf{MF} + \xi_s$$

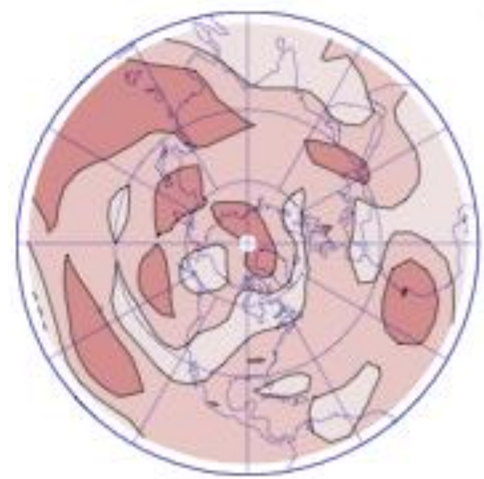
Week 2 skill (250 hPa)

c.i.=0.15; blue < 0

Barotropic model



Persistence

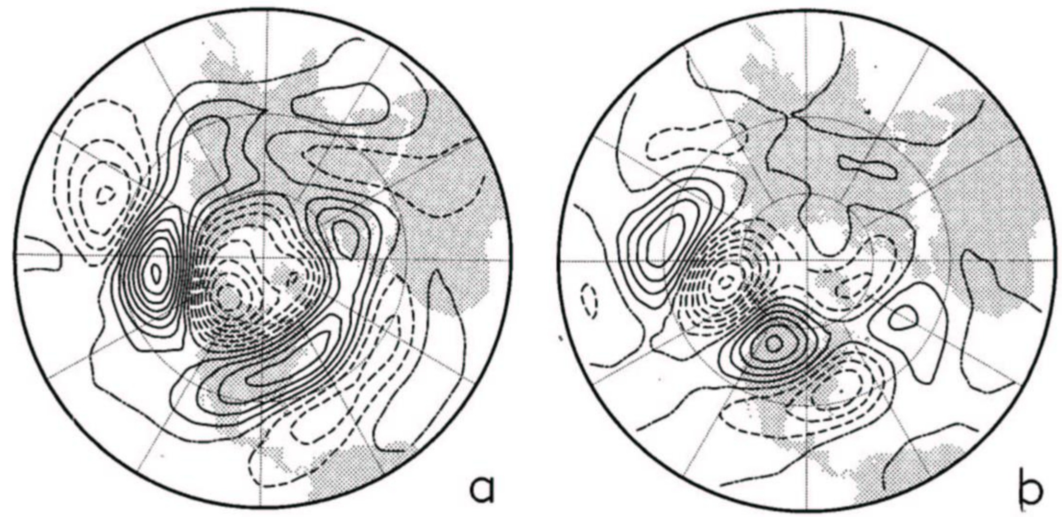


Winkler, Newman, and Sardeshmukh 2001

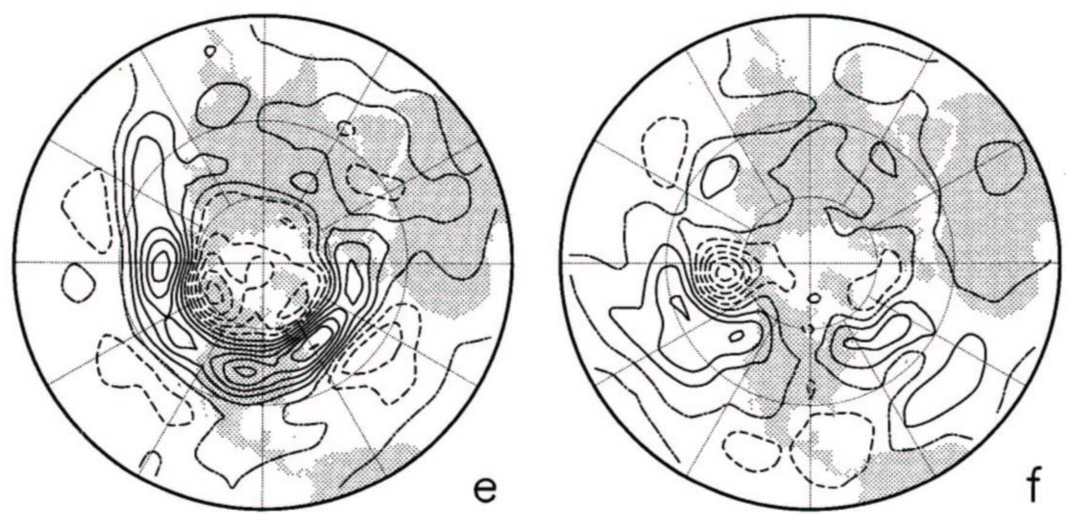
Change **L**: include linear parameterization of transient eddy feedback

Synoptic eddy feedback favors the development of some anomalies (left) but not others (right) in perpetual January GCM run

300 mb streamfunction anomaly



Streamfunction tendency due to synoptic eddies



Branstator 1995

Candidates for “boundary forcing” to extratropical troposphere

- Surface anomalies
  - SST
  - Soil moisture anomalies (warm season)
  - Sea ice/snow cover anomalies (seasonal)
- Tropical heating
  - Driven by SST (e.g., ENSO)
  - Atmospheric phenomena (e.g., MJO)
- Stratospheric anomalies

These act all at the same time and not independently.

Two ways to determine **L**

- “Forward method” -- derive **L** from a physical model (including linear parameterization of nonlinear terms)

  This may be difficult.

- “Inverse method” -- derive **L** from observed statistics of both extratropical anomaly and “forcings”

  This may be easier, but is not pain-free.

Linear inverse model (LIM)

$x(t)$ = 86-component vector whose components are the time-varying coefficients of the leading slp, ψ_T (250 and 750 hPa), H, and ψ_S (30 hPa) PCs of 7-day running means.

L is thus a 86x86 matrix

Trained on 5-day lag

If the climate state **x** evolves as

$$d\mathbf{x}/dt = \mathbf{L}\mathbf{x} + \mathbf{F}_s$$

Then τ_0-lag and zero-lag covariance are related as

$$\mathbf{C}(\tau_0) = \exp(\mathbf{L}\tau_0)\,\mathbf{C}(0)$$

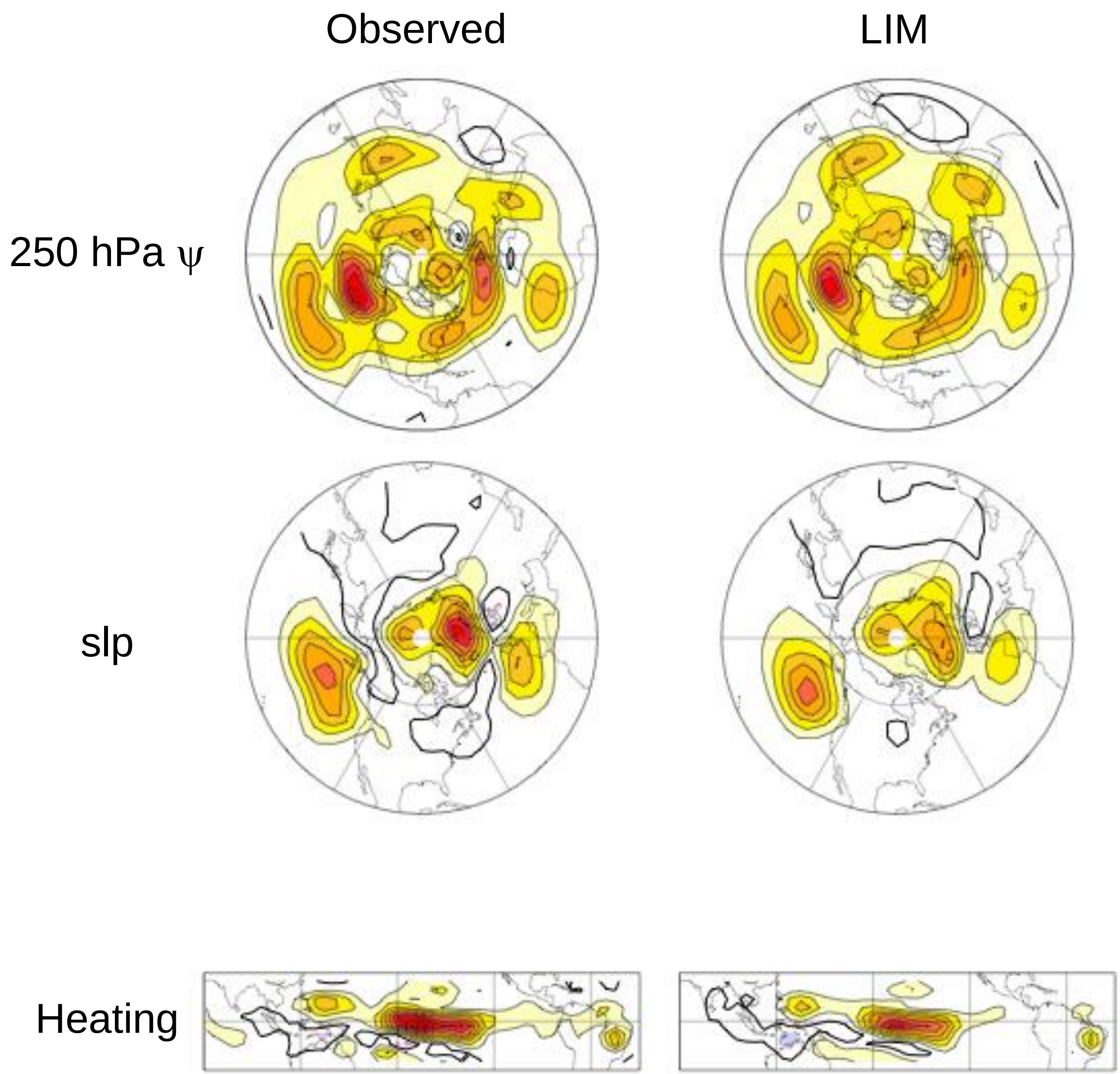
So we can solve for **L**.

Test of linearity: for much longer lags τ, is

$$\mathbf{C}(\tau) = \exp(\mathbf{L}\tau)\,\mathbf{C}(0) \quad ?$$

Dynamics are effectively linear

Observed **21-day lag covariance** (left) reproduced by the LIM (right)



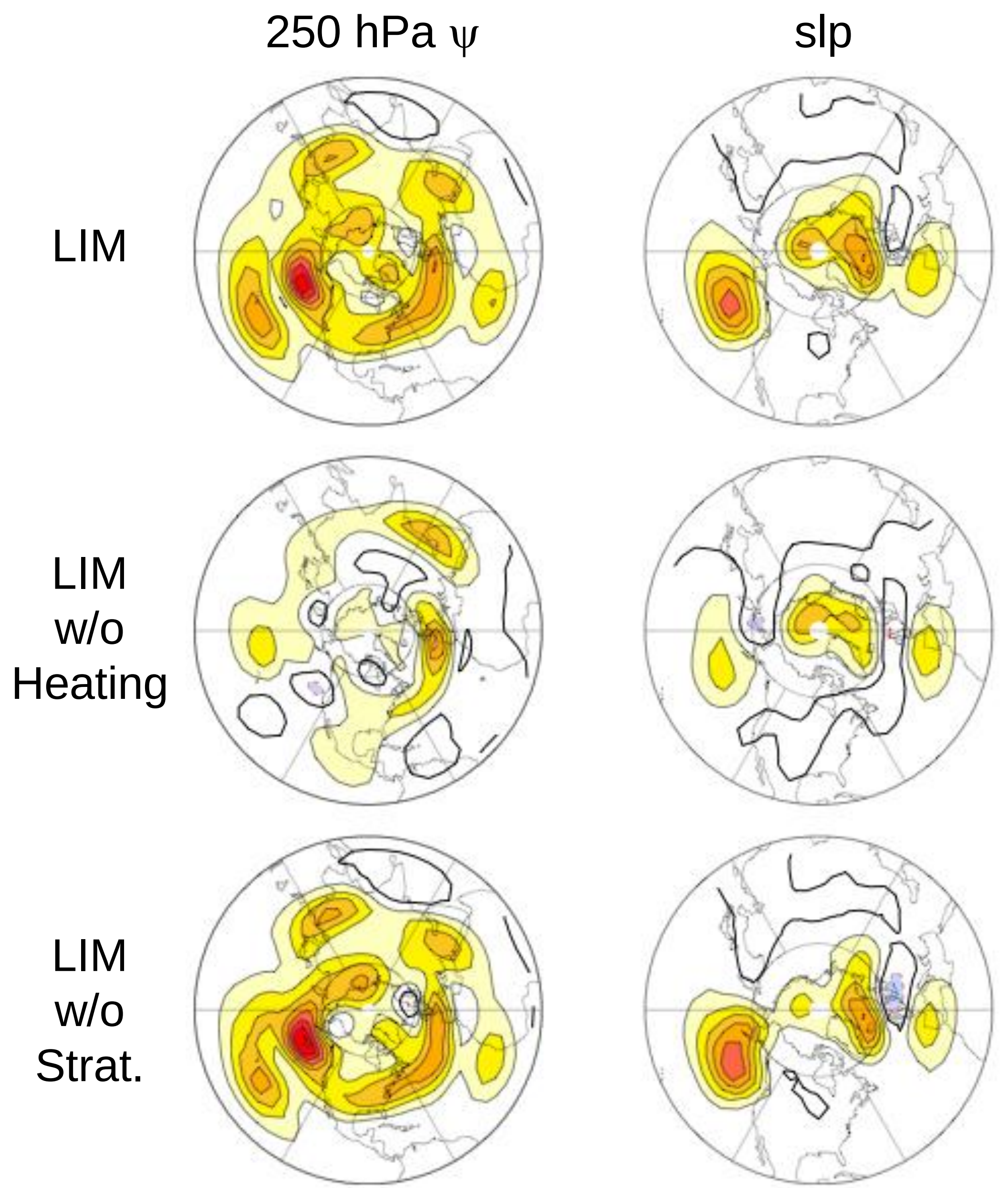
Newman and Sardeshmukh 2007

Heating is responsible for most of the persistent variability captured by this LIM

Top:
LIM **21-day lag covariance**

Middle:
LIM **21-day lag covariance**,
effects of H removed from **L**

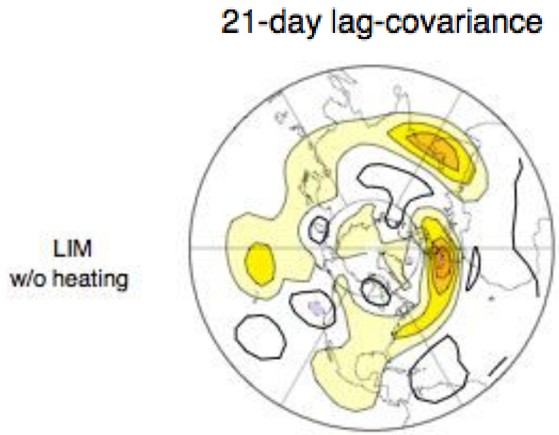
Bottom:
LIM **21-day lag covariance**,
effects of ψ_s removed from **L**

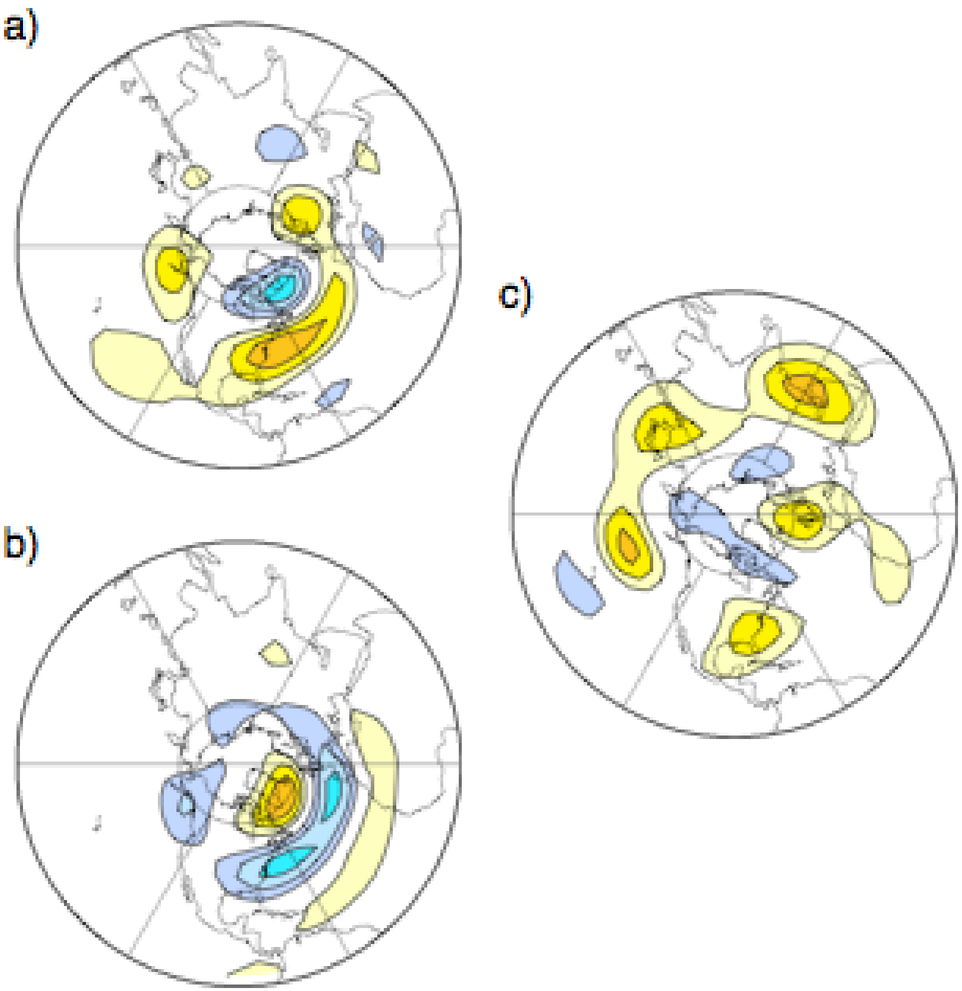


Newman and Sardeshmukh 2007

Remaining persistence due to “internal” extratropical dynamics

Leading eigenmodes of “troposphere-only” portion of **L** correspond to remaining persistence





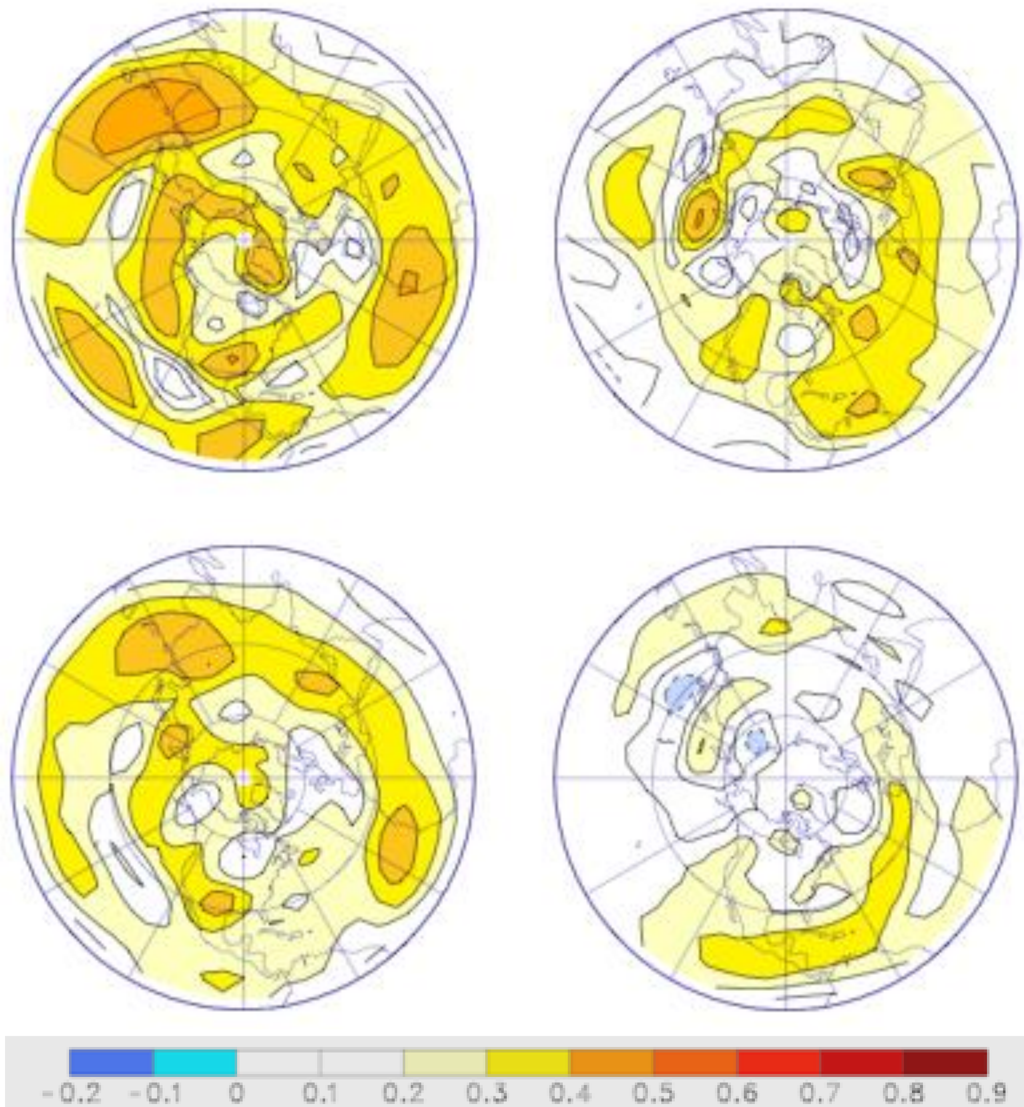
Newman and Sardeshmukh 2007

Week 3 250 hPa ψ skill, LIM and Reforecast (1979-2000)

WINTER SUMMER

LIM
(cross-validated)

Reforecast



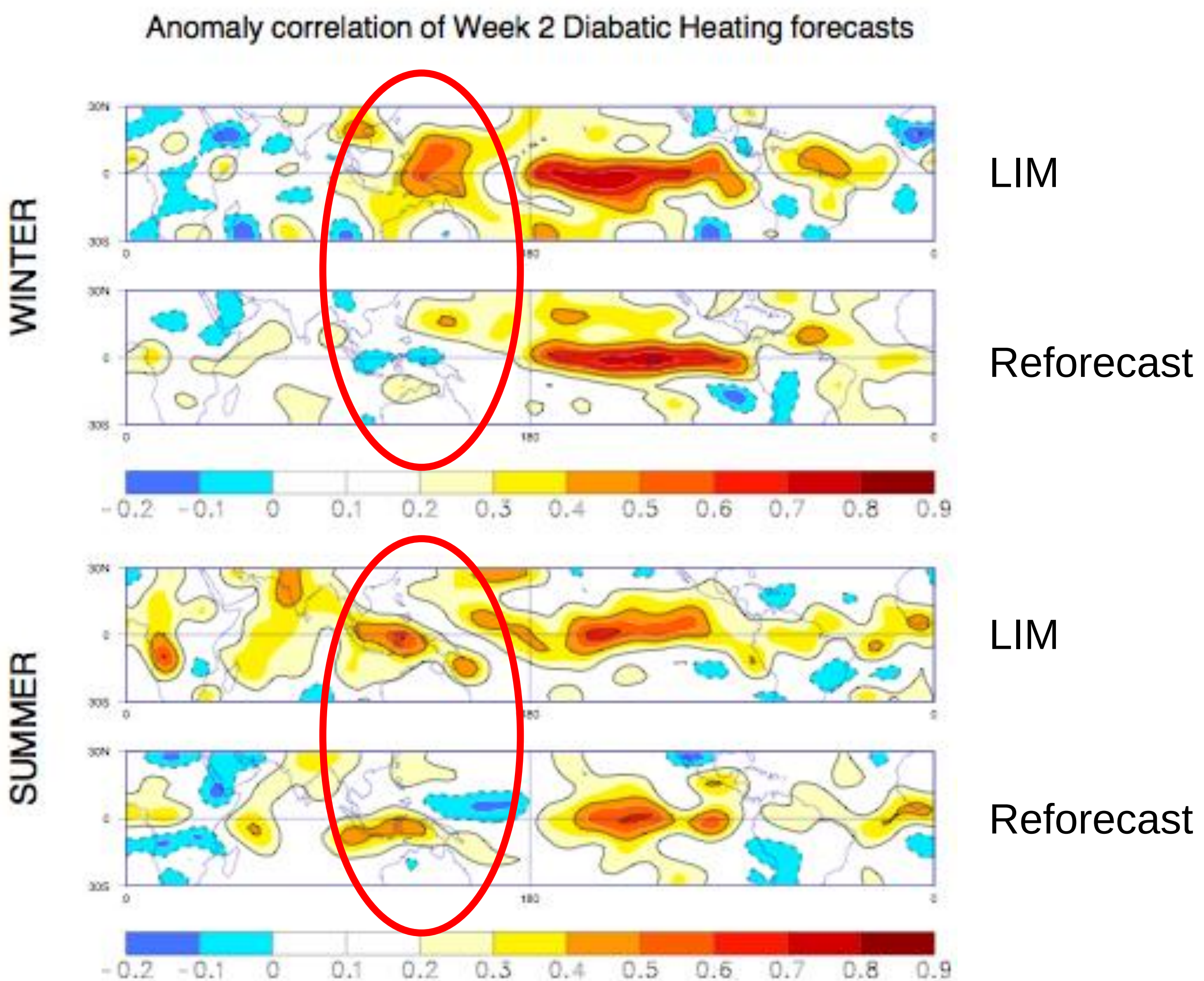
Newman,
Sardeshmukh,
Winkler, and Whitaker
2003

Even if the climate system is exactly effectively linear, why does the LIM outperform the GCM at Week 3?

[Or, are there sources of skill that may be exploited in future GCMs?]

- Tropical heating forecast skill in LIM
- No climate drift in LIM

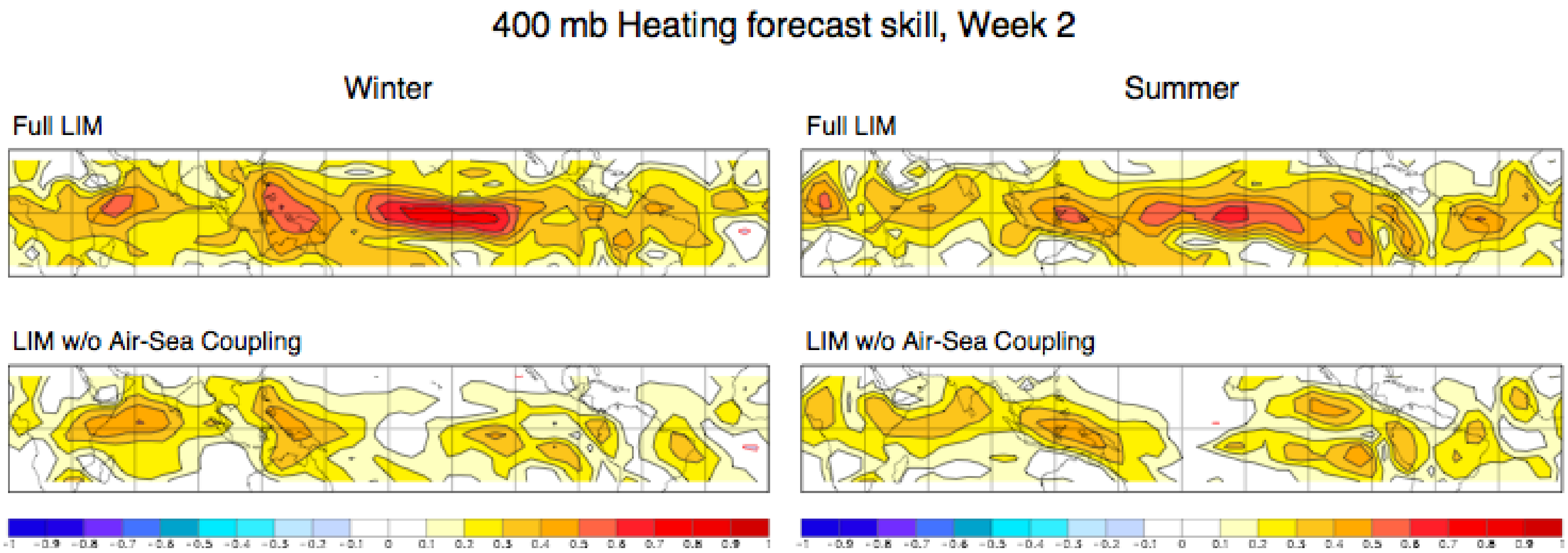
Week 2 TROPICAL skill, LIM and Reforecast



Newman, Sardeshmukh, Winkler, and Whitaker 2003

Week 2 skill from tropical "C-LIM"

Different state vector: 3 levels each of tropical heating, streamfunction, velocity potential, plus SST (38 PCs)



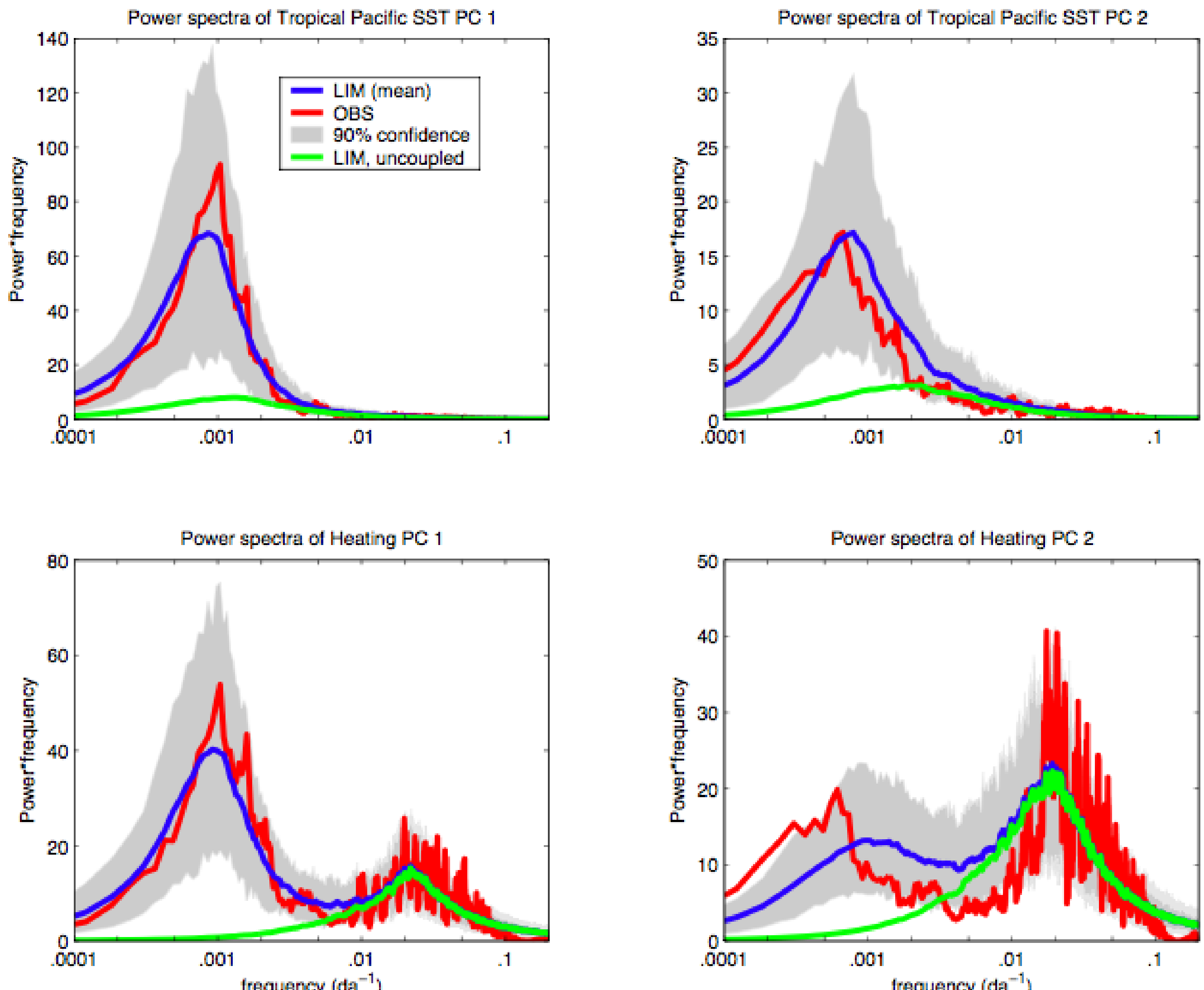
Diabatic heating forecast skill severely degraded without air-sea coupling, but this is mostly due to lack of ENSO SST forcing.

Power spectra of leading SST, heating PCs

Test of linearity: LIM trained on 1-week lag reproduces 40-50 day and 4-7 yr spectral peaks.

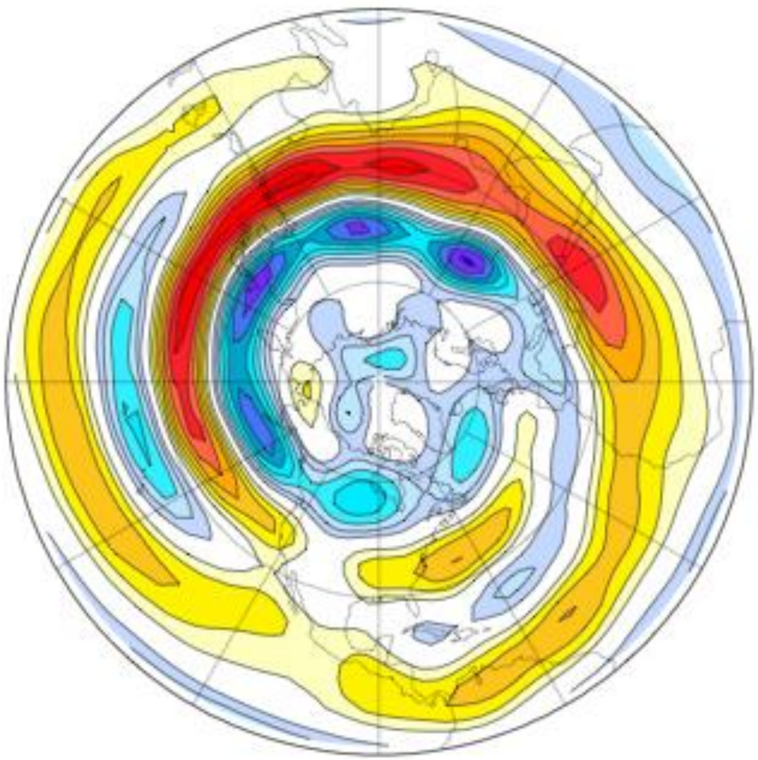
Without coupling: SST variability is weakened and peak period is shorter.

Heating variability on subseasonal timescale is minimally altered.

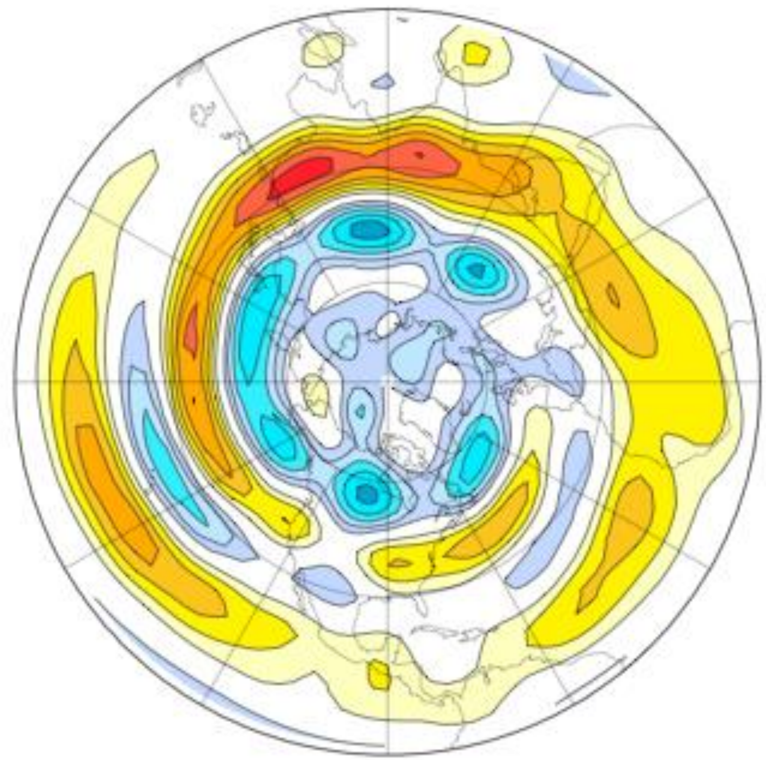


Week 2 June climate drift

Mean June 200 mb vorticity, 1981-2004



Reanalysis 2

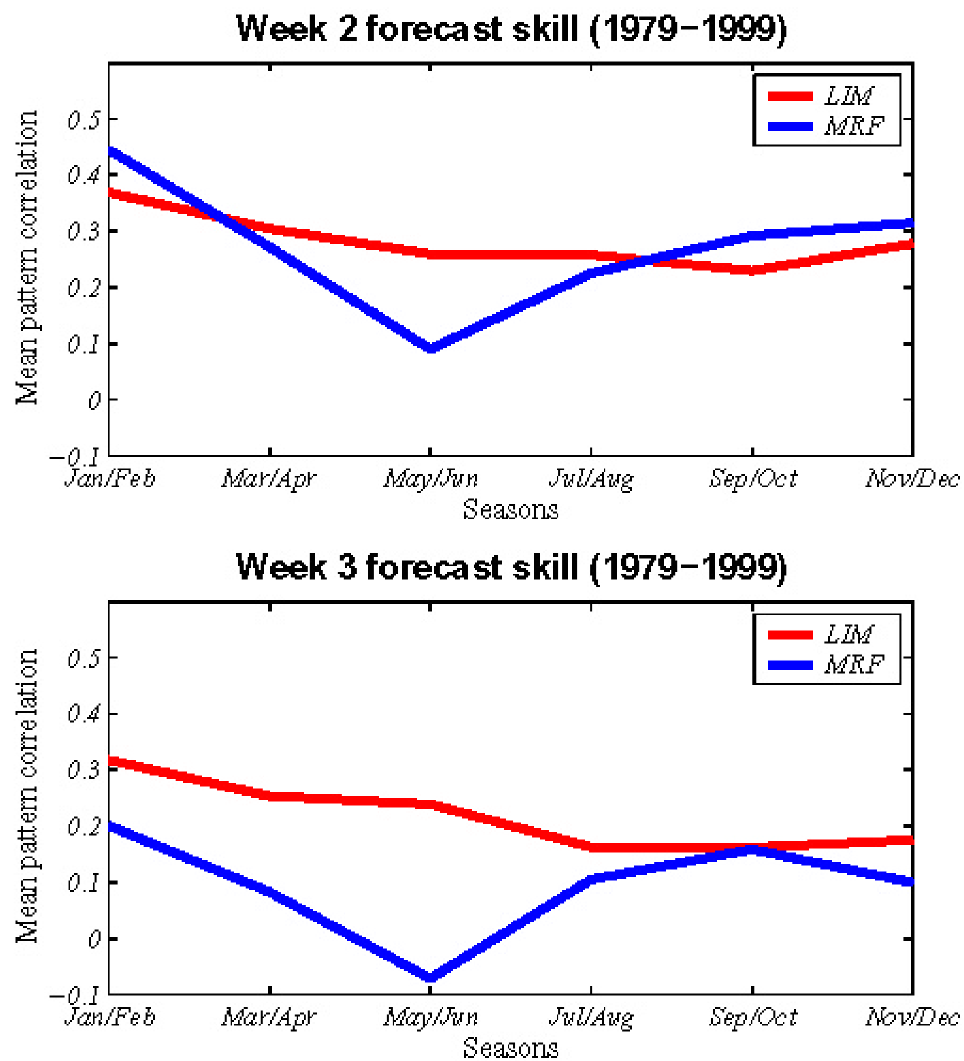


CFS Week 2

Seasonal cycle of LIM, Reforecast skill

Skill of LIMs (red line) constructed
for two-month
“seasons” compared to reforecast skill (blue line).

Skill measure is pattern correlation of 250 hPa streamfunction in Northern Hemisphere between 120E-60W.



J/F M/A M/J J/A S/O N/D

Predicting skill within the LIM

$$\mathbf{d\,x / dt} \;=\; \mathbf{L\,x} \;+\; \mathbf{F_s}$$

$\mathbf{L}$ = constant, $\mathbf{F_s}$ = additive (state-independent) noise.

$$\mathbf{x}(t+\tau) \;=\; \exp(\mathbf{L}\tau)\,\mathbf{x}(t) + \varepsilon \;=\; \mathbf{G}(\tau)\,\mathbf{x}(t) + \varepsilon$$

"signal"

"noise"

<u>**Expected forecast error covariance**</u>

(assuming no initial error) :

$$\mathbf{E}(\tau) \;=\; <\varepsilon\,\varepsilon^{\mathrm{T}}> \;=\; \mathbf{C}(0) - \mathbf{G}\,\mathbf{C}(0)\,\mathbf{G}^{\mathrm{T}}$$

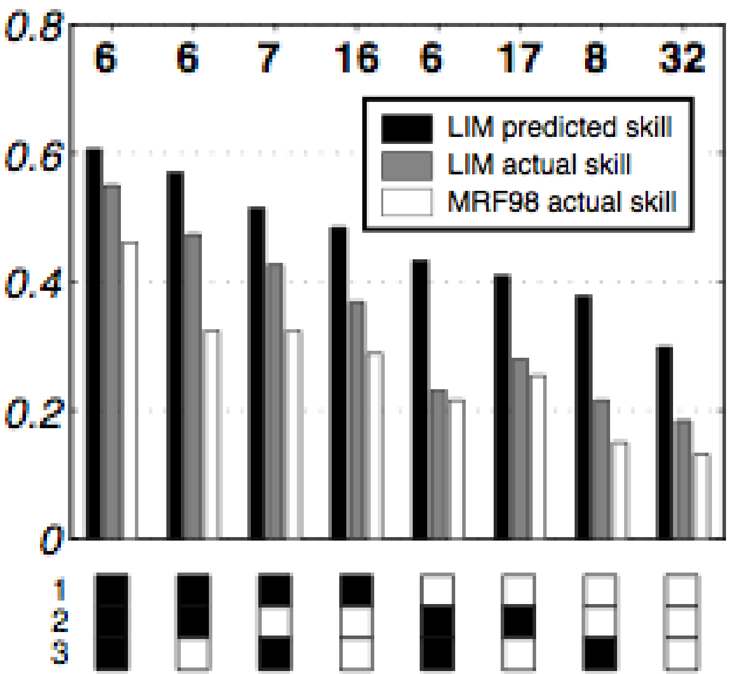
<u>**Expected forecast anomaly correlation**</u>

$$\rho_\infty \;=\; \frac{s}{\sqrt{1+s^2}}\;,\ \text{where}\ \ s^2 \;=\; \frac{[\mathbf{G}\,\mathbf{C}(0)\,\mathbf{G}^{\mathrm{T}}]_{ii}}{[\mathbf{E}(\tau)]_{ii}}$$

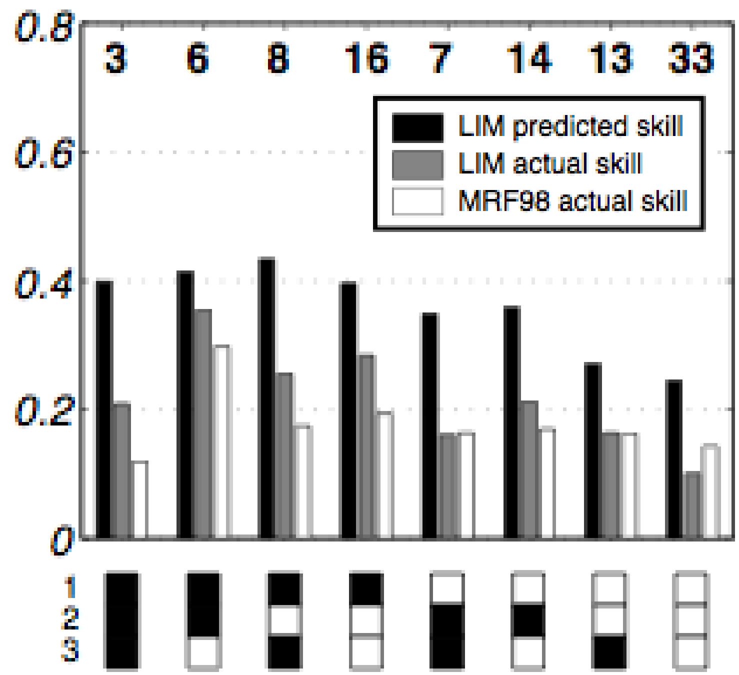
Predicting Week 3 skill

Comparing predicted LIM forecast skill with actual LIM and reforecast skill (pattern correlation of NH 250 hPa ψ)

WINTER



SUMMER

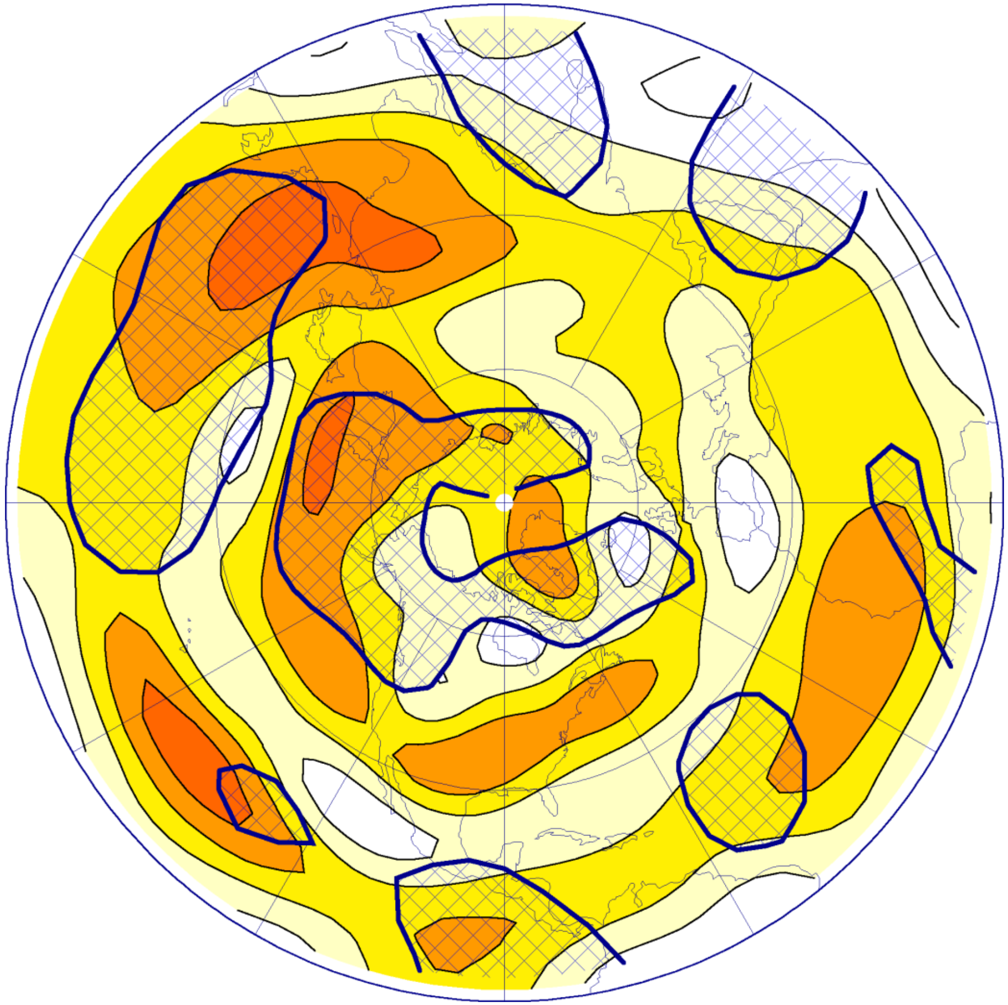


Poorer LIM summer skill: reality or due to missing land obs?

LIM is skillful even where the PDF is non-Gaussian

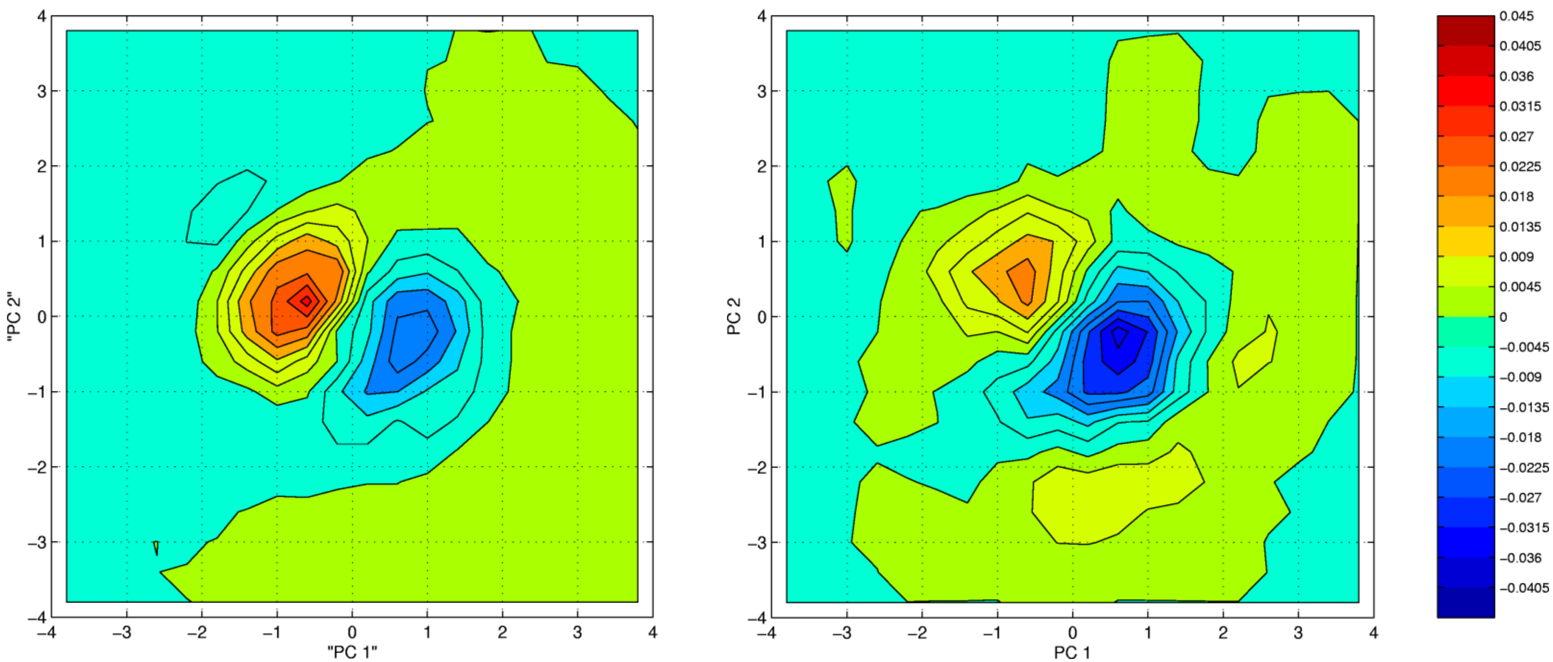
Color Shading:
Wintertime Week 3 LIM forecast skill, 250 hPa ψ

Hatching:
where the streamfunction PDF is non-Gaussian (by the K-S criterion, 95% significant)



Sura, Newman, Sardeshmukh, and Penland 2004

Observed departures from Gaussianity can be mimicked by linear multiplicative noise (can be part of* L*)



Departure from Gaussianity of joint pdf derived from least damped barotropic mode (period=33 days, eft=14 days) with some *stochastic damping* and steady forcing

Departure from Gaussianity of Joint p.d.f of first two EOFs of 750 mb streamfunction, DJF 1950-2002

Sura, Newman, Sardeshmukh, and Penland 2004

Can we expect to forecast Weeks 3 and 4?

Yes, but:

- Empirical models (LIM + others in Tropics) appear to still have better forecast skill than GCM

  But there are may be areas of nonoverlapping skill (particularly for skewed distributions), and/or we may use more skillful tropical LIM forecasts to nudge GCM.

- Extratropical forecast skill is modest on average

  But there are cases when the skill is relatively high. These cases can to some extent be identified a priori and provide forecasts of opportunity.

- As GCM skill surpasses LIM, predictability estimates from LIM may remain useful

  But in the mean time, <u>Week 3 and Week 4 forecasts may be made now.</u>

Week 3 skill not **all** ENSO

Predictability Variations: Winter vs. Summer

Solid: LIM (Actual) Circles: LIM (predicted) Dotted: Reforecast

ENSO: Red arrows warm events; Blue arrows cold events