Diagnosing subseasonal predictability of tropical atmospheric anomalies

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"Multivariate Red Noise" null hypothesis

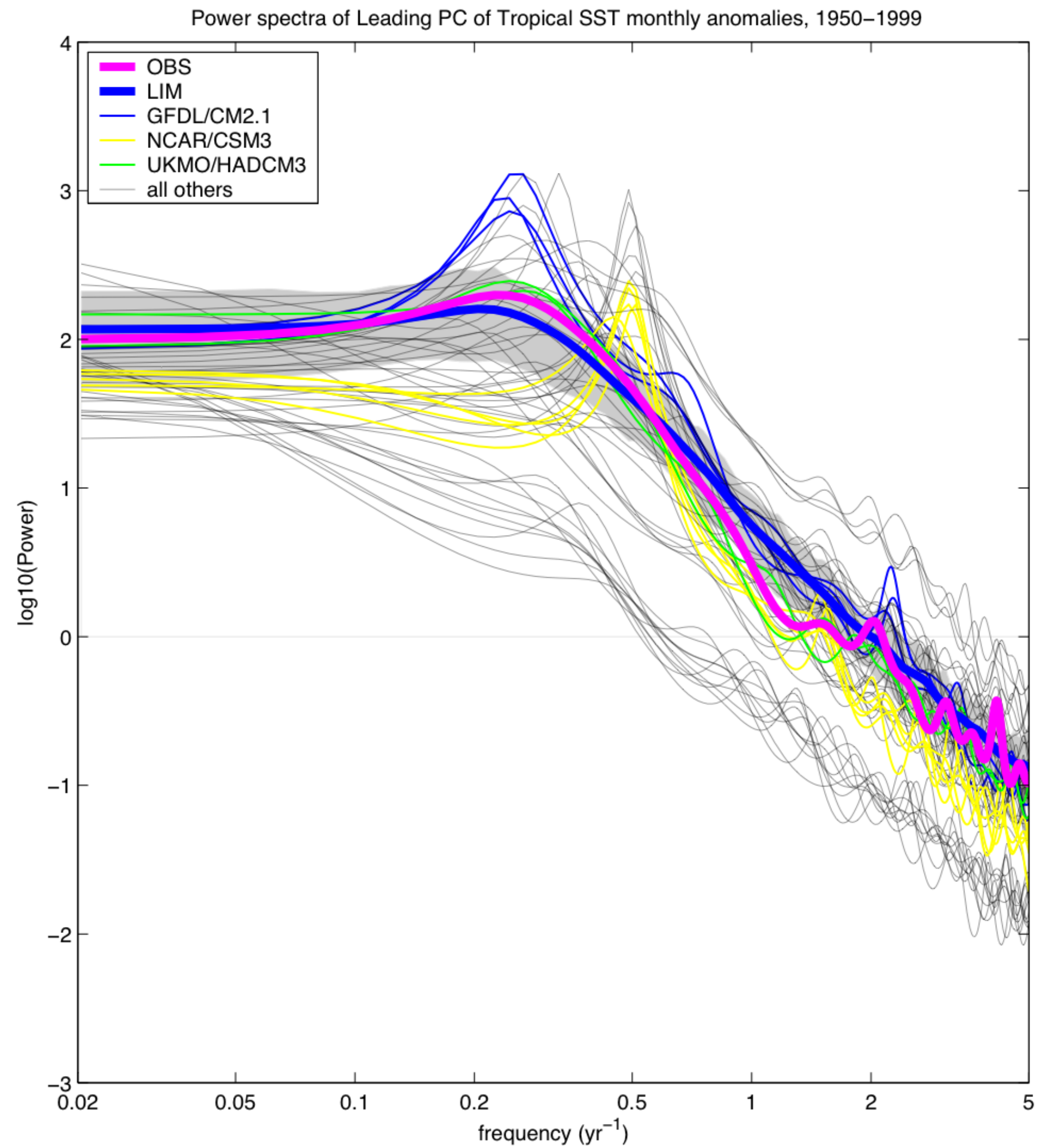
$$d\mathbf{x}/dt = \mathbf{L}\mathbf{x} + \mathbf{F}_s$$

where $\mathbf{x}(t)$ is a series of maps, **L** is stable, and $\mathbf{F}_s$ is white noise (maps)

- Determine **L** and $\mathbf{F}_s$ using "Linear Inverse Model" (LIM)
  - ***x*** is ***SST/OLR/200 and 850 mb wind*** 5-day running mean anomalies in Tropics, 1982-2009 (similar to Newman, Sardeshmukh, and Penland 2009, *J. Climate*)
  - prefiltered in reduced EOF space
  - LIM determined from specified lag τ_o=5 (e.g., the data averaging interval) as in AR1 model, using τ_o and zero-lag covariance of **x**
  - Then test the LIM over much longer time intervals

ENSO in C-LIM and IPCC AR4 “20th-century” CGCMs compared to observations, 1950-1999

C-LIM simulation of observed evolution of variability is as good as in coupled GCMs, so we can use it to quantify predictability.



Newman, Sardeshmukh, and Penland 2009

Using LIM to estimate predictability

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

$\mathbf{L}$ = 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"

Expected forecast error covariance

(assuming no initial error) :

$$\mathbf{E}(\tau) = \langle \varepsilon\varepsilon^T \rangle = \mathbf{C}(0) - \mathbf{G}\,\mathbf{C}(0)\,\mathbf{G}^T$$

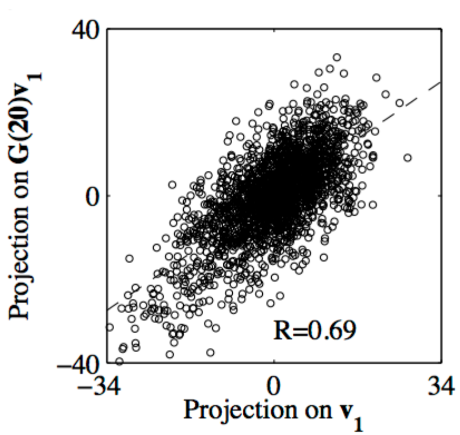
Expected forecast anomaly correlation

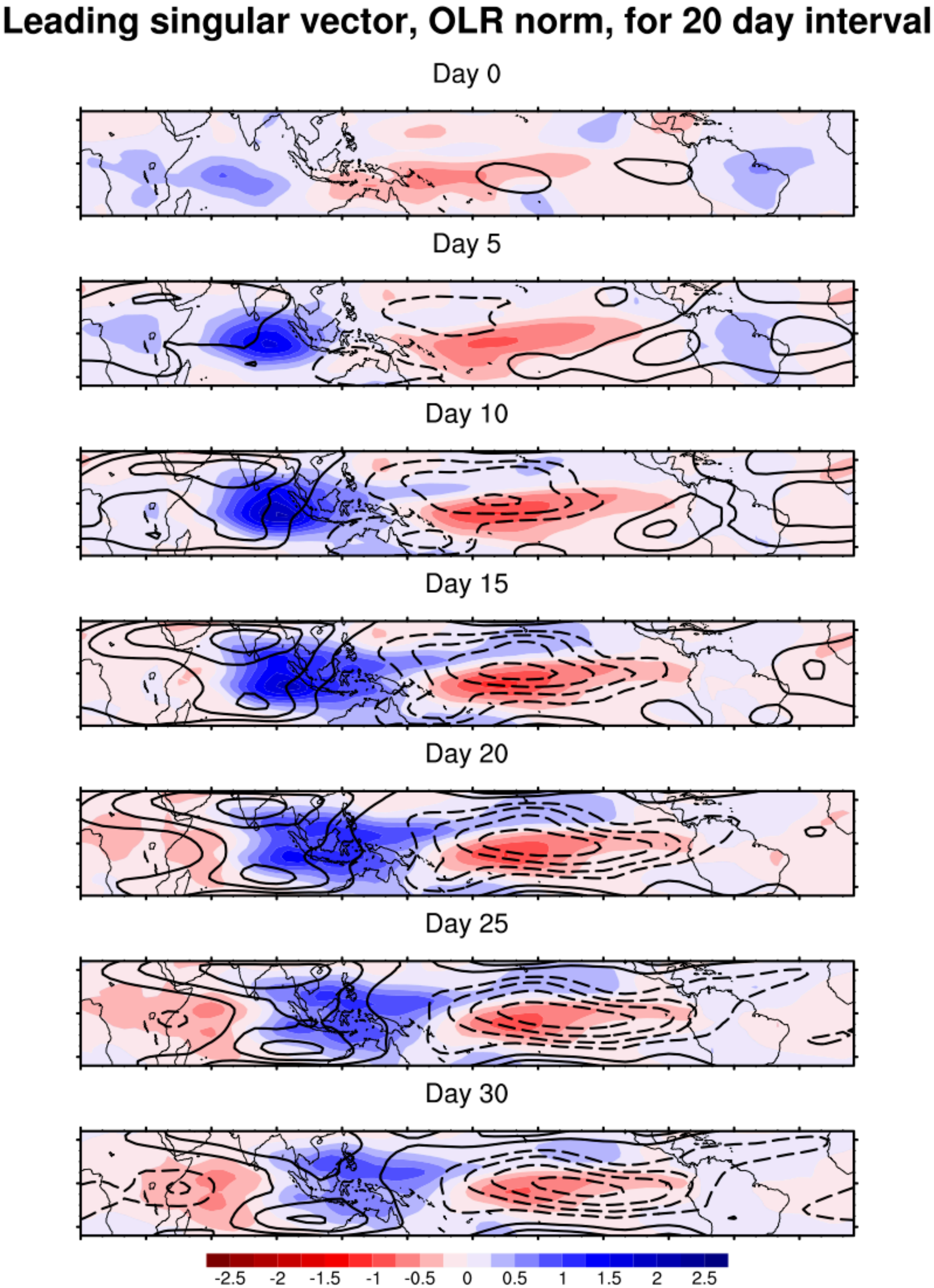
$$\rho_\infty = \frac{s}{\sqrt{1+s^2}}, \text{ where } s^2 = \frac{[\mathbf{G}\,\mathbf{C}(0)\,\mathbf{G}^T]_{ii}}{[\mathbf{E}(\tau)]_{ii}}$$

Larger signal related to leading singular vector of G(τ)

Structure leading to greatest OLR anomaly amplification over 20-day interval

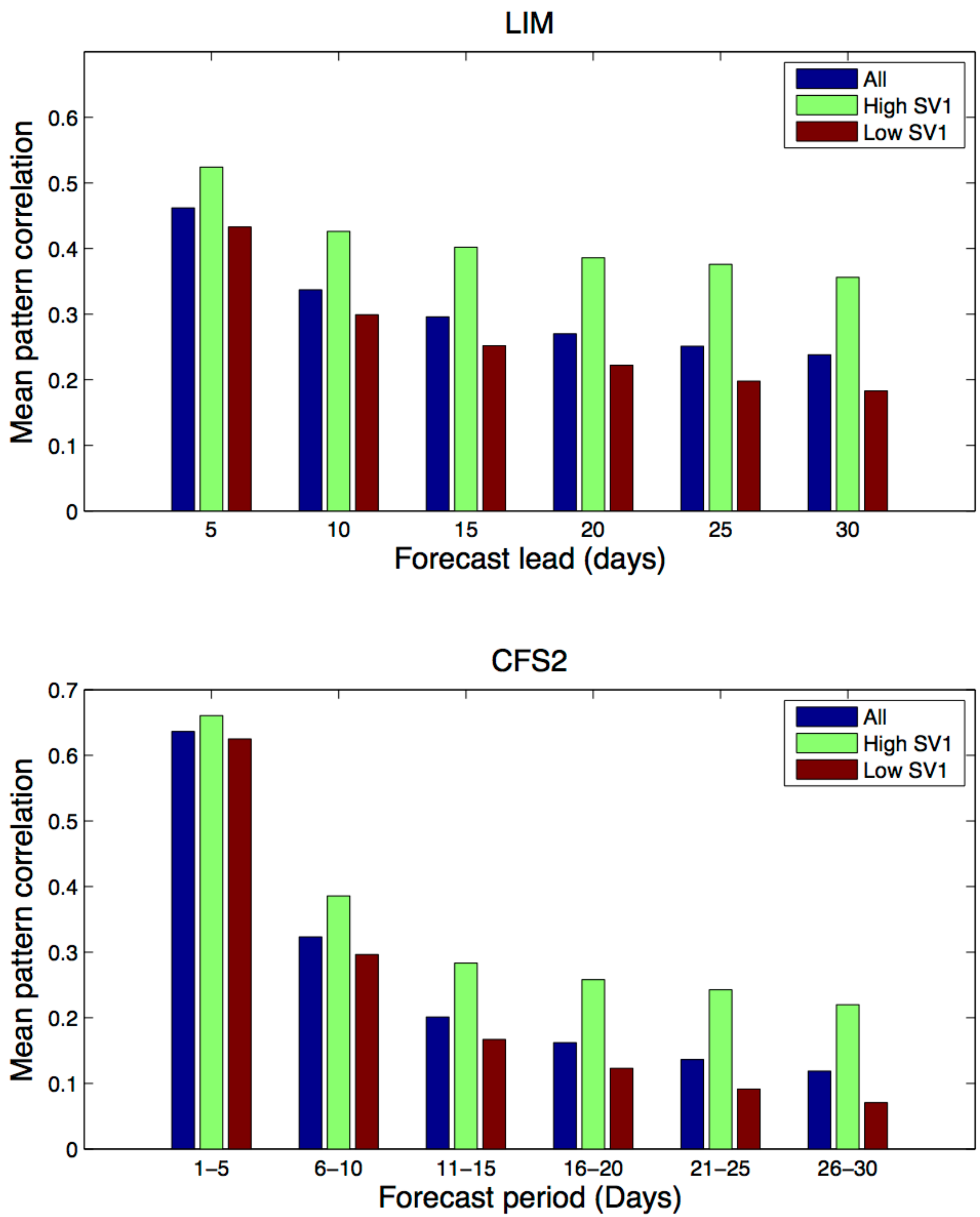
Shading: OLR anomalies
Contours: 200 mb zonal wind anomalies





Using LIM to identify relatively more skillful forecast cases *a priori* from forecast signal-to-noise ratio

Pattern correlation of tropical IndoPacific OLR hindcasts, 1982-2009, stratified by whether initial conditions strongly project on initial growth structure (SV1)



Turn “off” coupling

LIM can be written in its component parts as:

$$\frac{d\mathbf{x}}{dt} = \frac{d}{dt}\begin{bmatrix} \mathbf{T}_O \\ \mathbf{x}_A \end{bmatrix} = \begin{bmatrix} \mathbf{L}_{OO} & \mathbf{L}_{AO} \\ \mathbf{L}_{OA} & \mathbf{L}_{AA} \end{bmatrix}\begin{bmatrix} \mathbf{T}_O \\ \mathbf{x}_A \end{bmatrix} + \begin{bmatrix} \text{SST noise} \\ \text{atmospheric noise} \end{bmatrix}$$

To “uncouple” ocean from atmosphere, define

$$\mathbf{L}_{uncoupled} = \begin{bmatrix} \mathbf{L}_{OO} & \mathbf{0} \\ \mathbf{0} & \mathbf{L}_{AA} \end{bmatrix}$$

<u>This is *not* the same as constructing separate A-LIMs and O-LIMs.</u>

Removing coupling: greatly decreases interannual power
almost no effect on intraseasonal power

Comparing L and $L_{uncoupled}$

Two distinct classes of eigenmodes of L

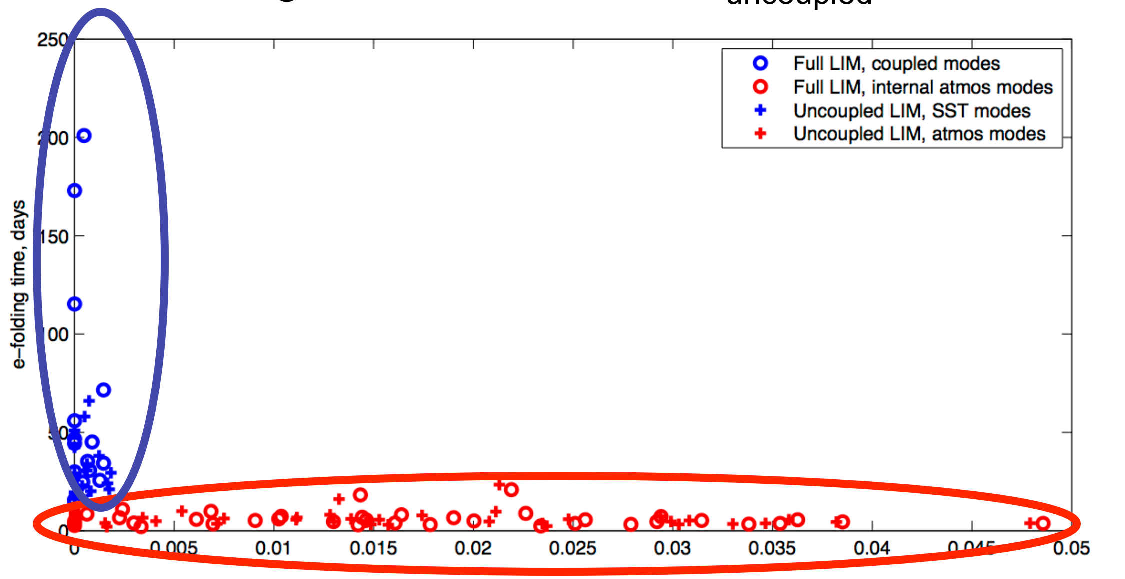
"coupled"

Longer eft, low frequency modes strongly modified by coupling

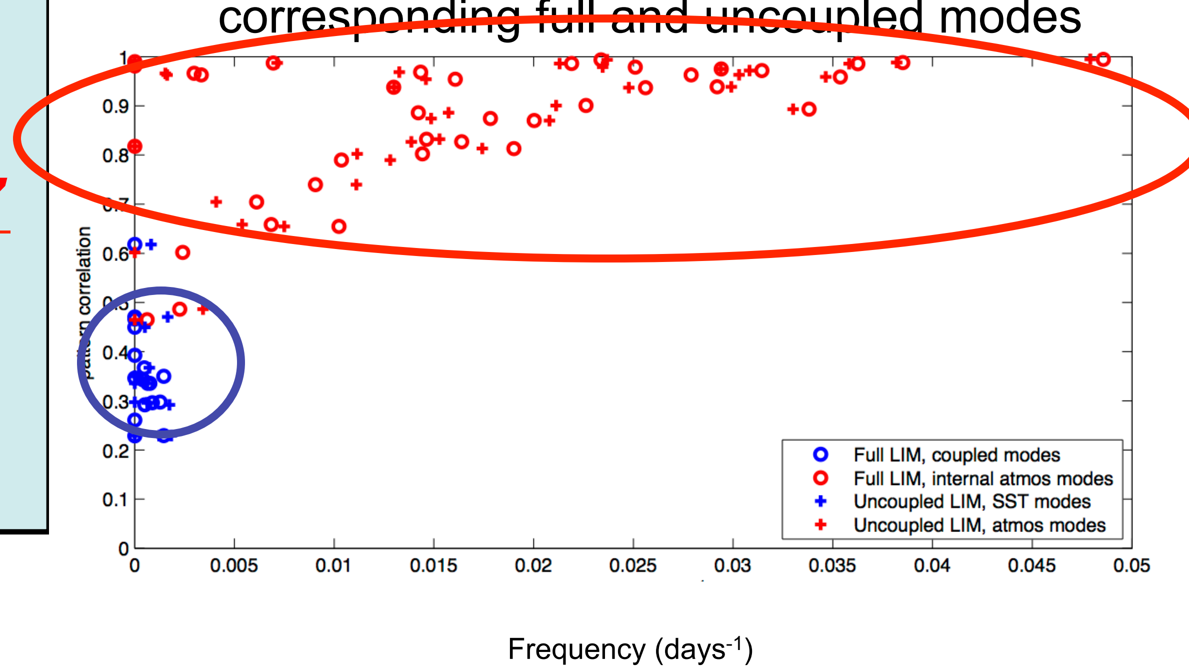
"internal atmospheric"

Short eft, high frequency modes only slightly modified by coupling

Eigenvalues of **L** and $\mathbf{L}_{uncoupled}$



Maximum pattern correlation between corresponding full and uncoupled modes



Project tropical state vector **x** into "coupled" and "internal" subspaces of full operator **L**

Define

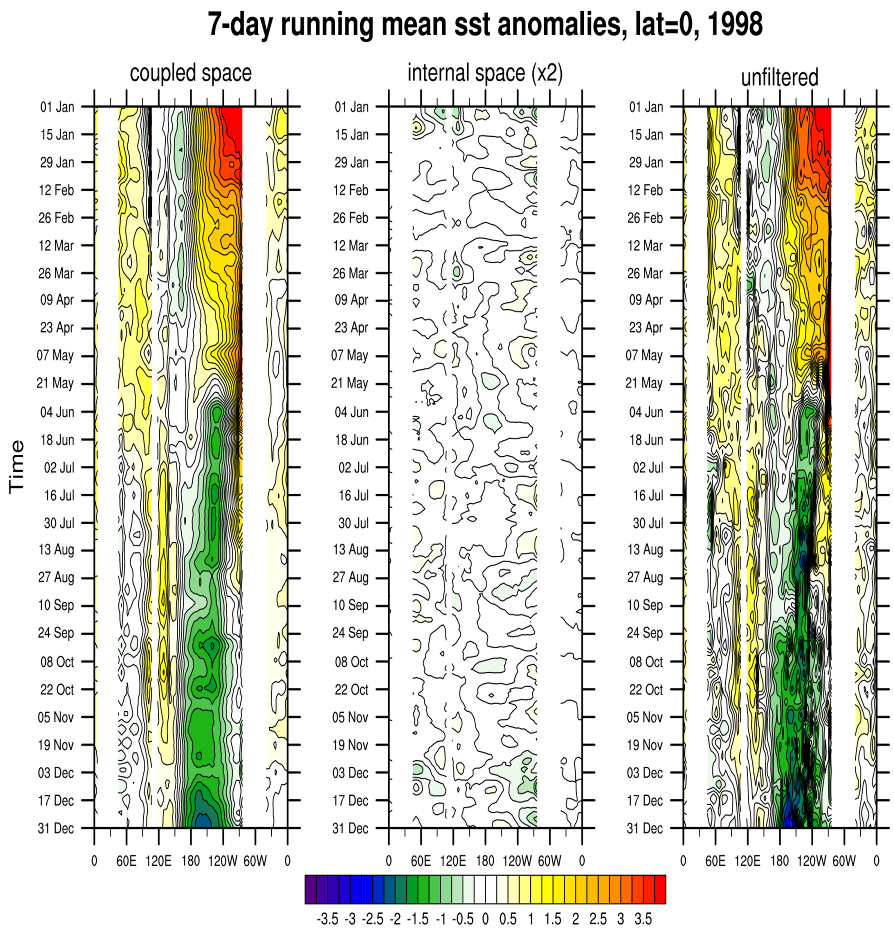
$$\mathbf{x} = \mathbf{x}^{\text{coup}} + \mathbf{x}^{\text{int}}$$

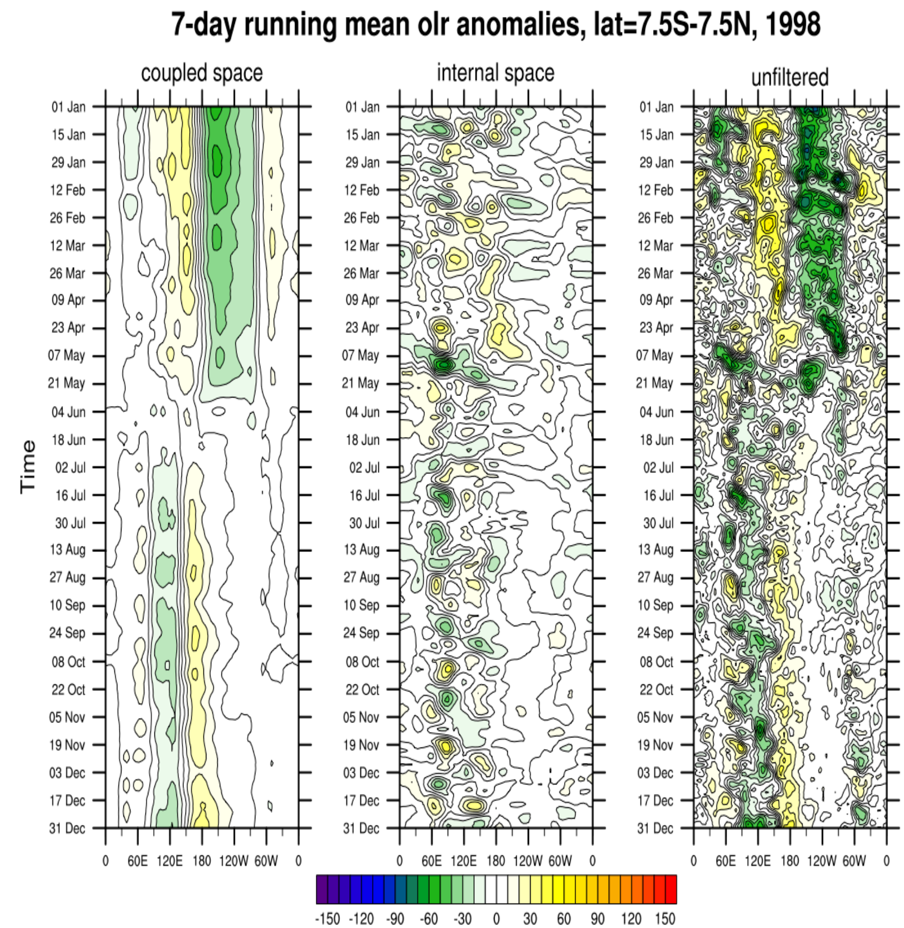
where

$$\mathbf{x}^{\text{coup}} = \sum_j \mathbf{u}_j^{\text{coup}} \alpha_j^{\text{coup}}(t) \qquad \mathbf{x}^{\text{int}} = \sum_j \mathbf{u}_j^{\text{int}} \alpha_j^{\text{int}}(t)$$

Note: $\mathbf{x}^{\text{coup}}$ and $\mathbf{x}^{\text{int}}$ need not be orthogonal

Using the LIM to “filter” the data



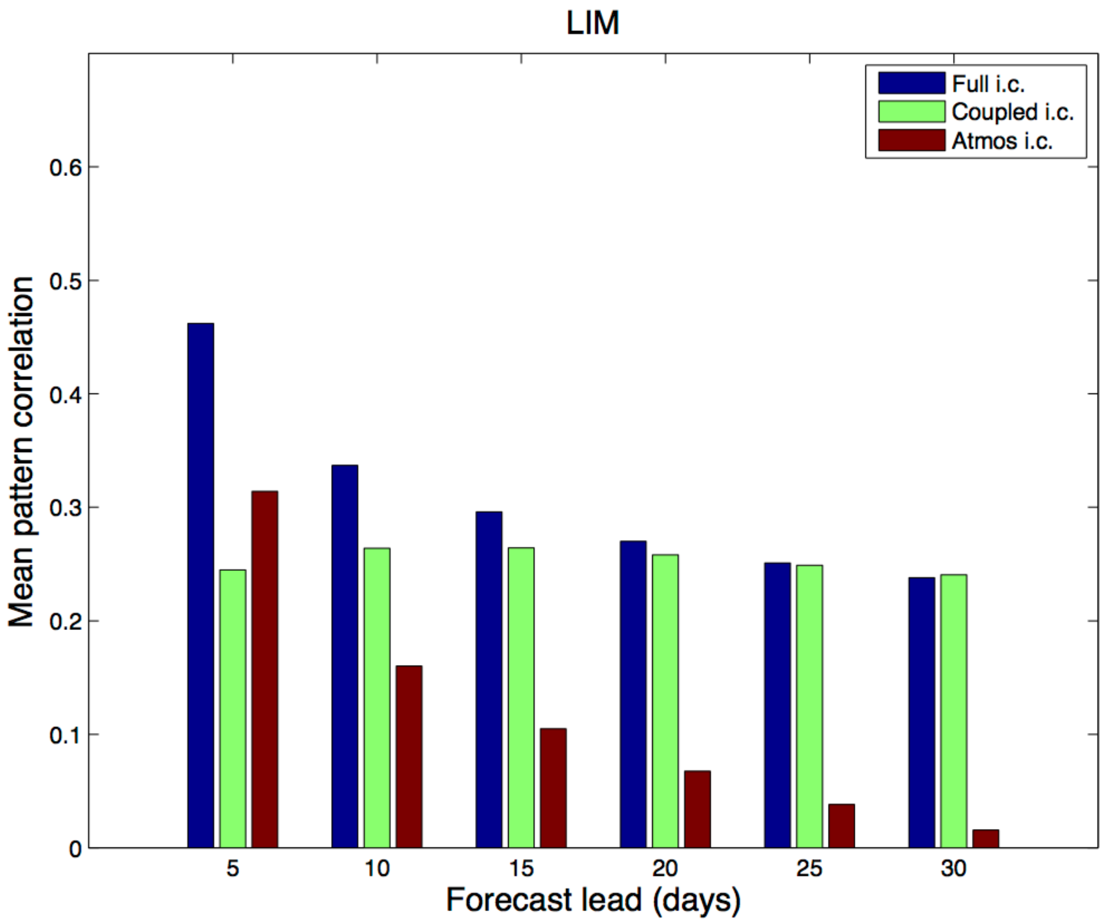


1. **no temporal filter is applied**
2. **interannual variability defined dynamically**

Most LIM skill due to coupled space initial conditions for leads > 15 days

Pattern correlation of tropical IndoPacific OLR LIM hindcasts, 1982-2009, where forecast initial conditions are either:

Full
Coupled space only
Internal space only



Conclusions

- LIMs useful for diagnosis of predictability, ***because*** its forecast skill is competitive with coupled GCMs and it reproduces observed spatio-temporal statistics
- In Tropics, two nonorthogonal linear dynamical systems:
  - Slow (~interannual) coupled space (more predictable)
  - Fast (~intraseasonal) internal atmosphere space (less predictable)
  - Projecting data onto coupled space acts as an effective "filter"; MJO indices may convolve dynamics
- Subseasonal forecasts skill may itself be *predicted* based on signal-to-noise
  - In LIM, there is no "spread/skill" relationship, but note this need not be a constraint for all linearly predictable systems
  - Plan to institute "forecasts of forecast skill" in LIM forecast web page http://www.esrl.noaa.gov/psd/forecasts/clim/

Near realtime tropical forecasts (“C-LIM”)