The Madden-Julian Oscillation

An overview of the basic processes and possible connections with high-latitude weather and climate

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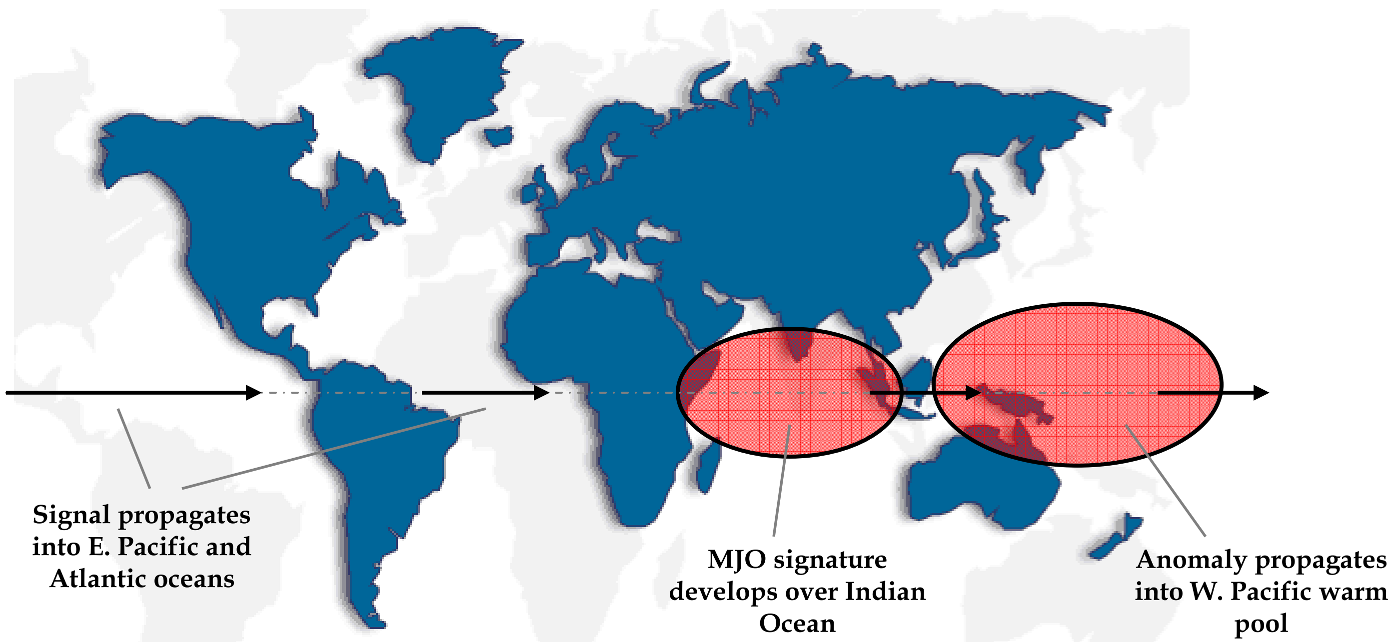
The Madden-Julian Oscillation

• Dominant mode of intraseasonal variability over tropical oceans (mainly Indian and Pacific warm pools, but exists in Atlantic to lesser extent)

• Eastward propagating disturbance detectable mainly in OLR (as a proxy for convection and large-scale vertical motion), precipitation and zonal wind.



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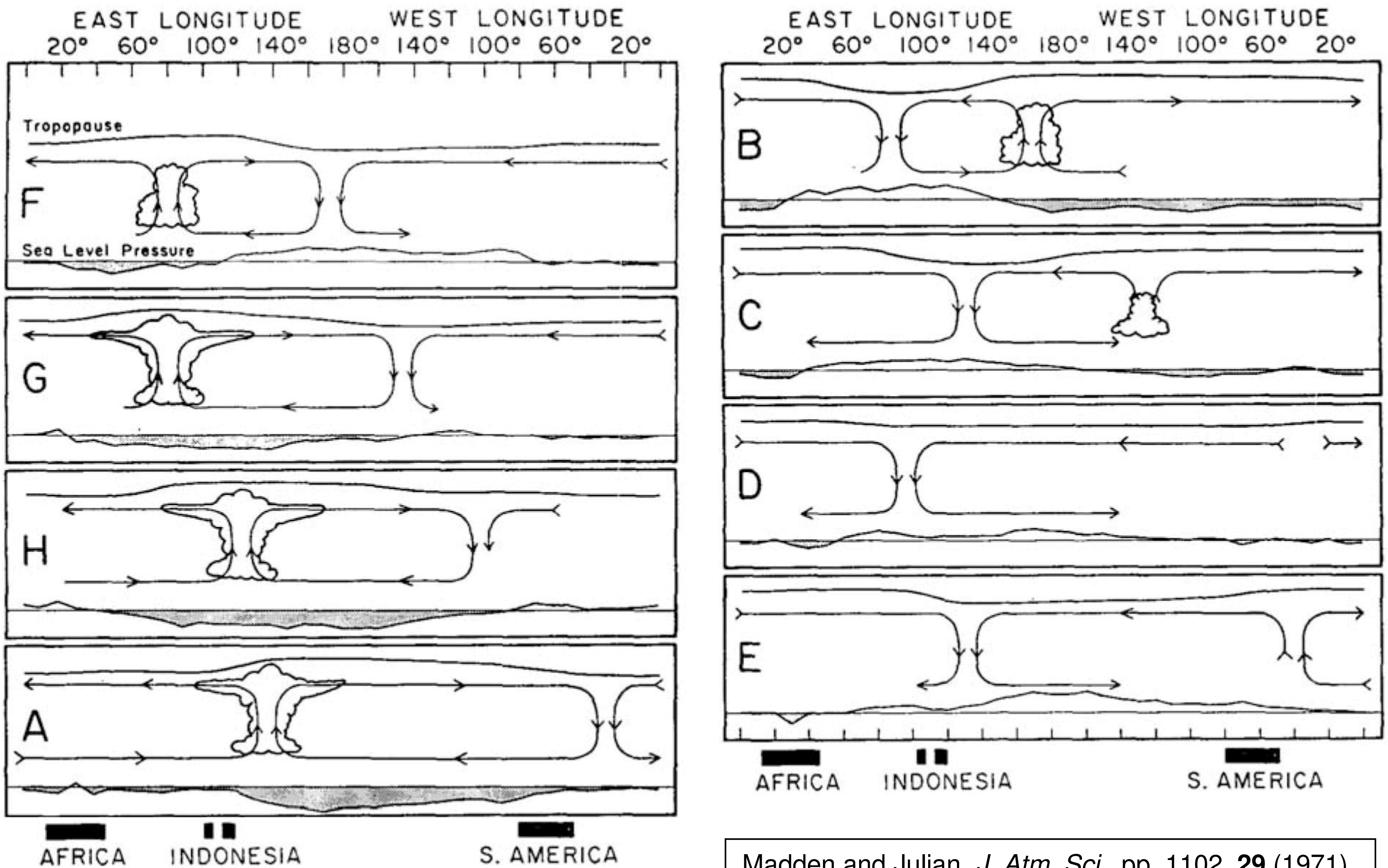
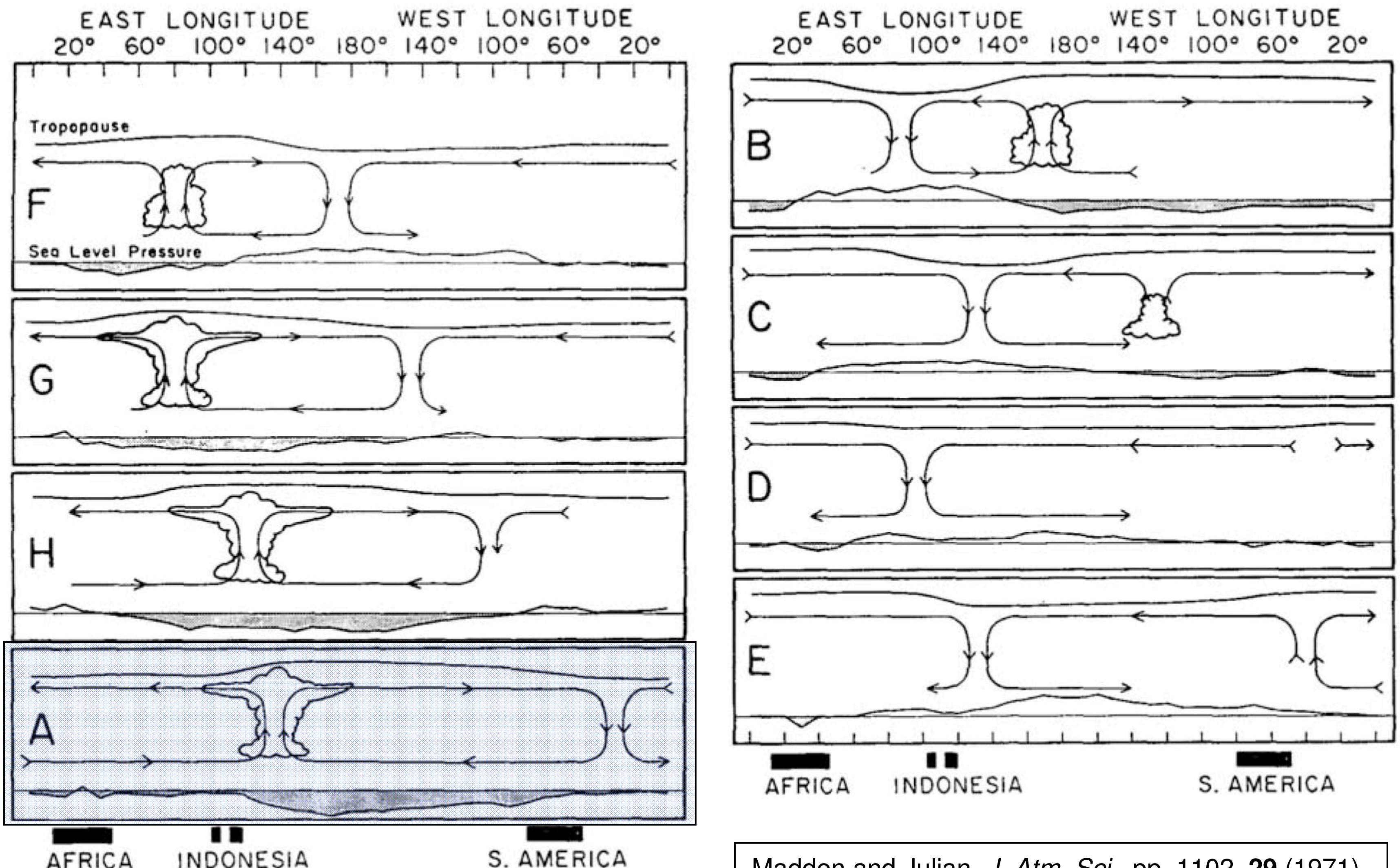


Madden and Julian, *J. Atm. Sci.*, pp. 1102, **29** (1971)

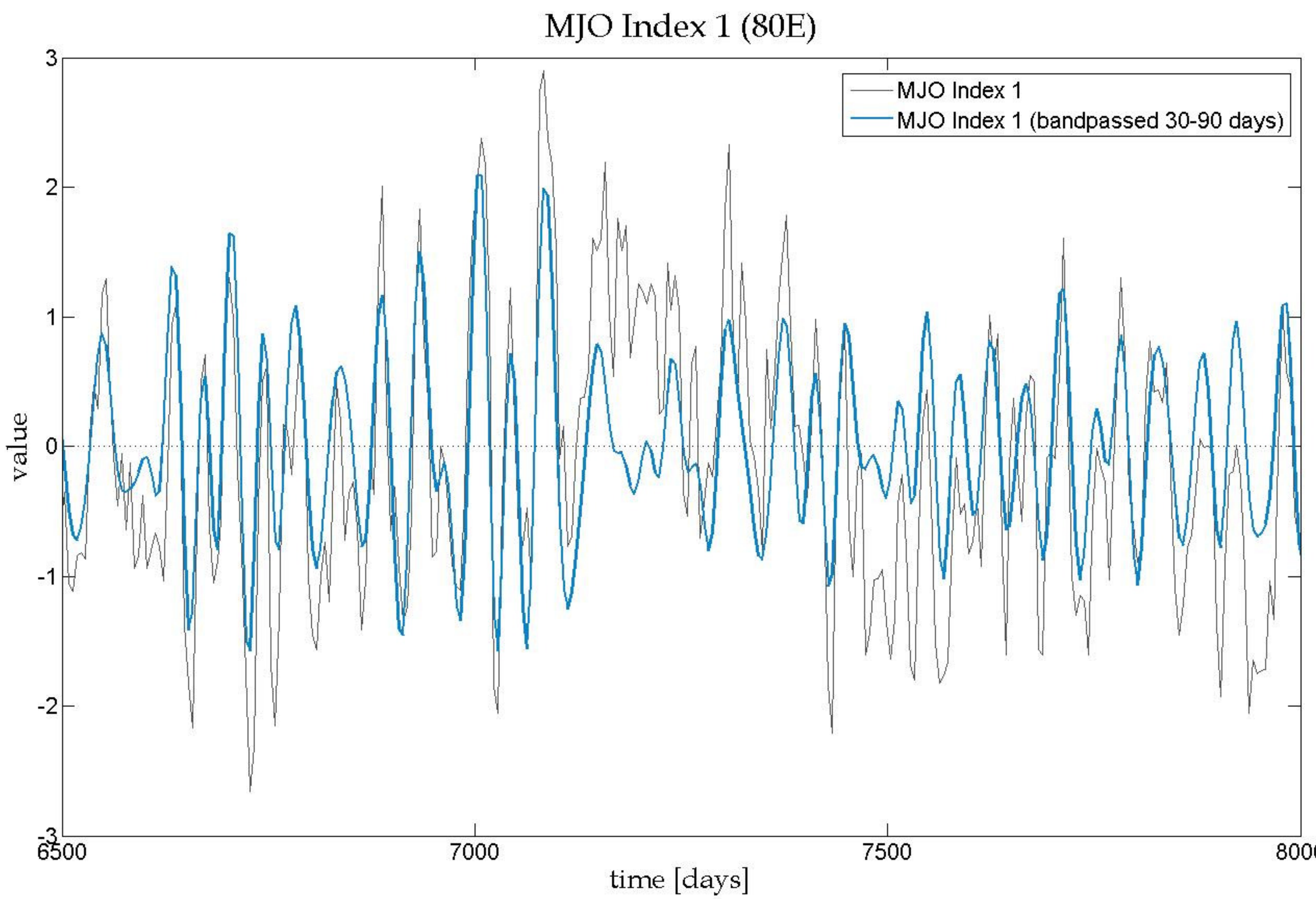
The Madden-Julian Oscillation



Madden and Julian, *J. Atm. Sci.*, pp. 1102, **29** (1971)

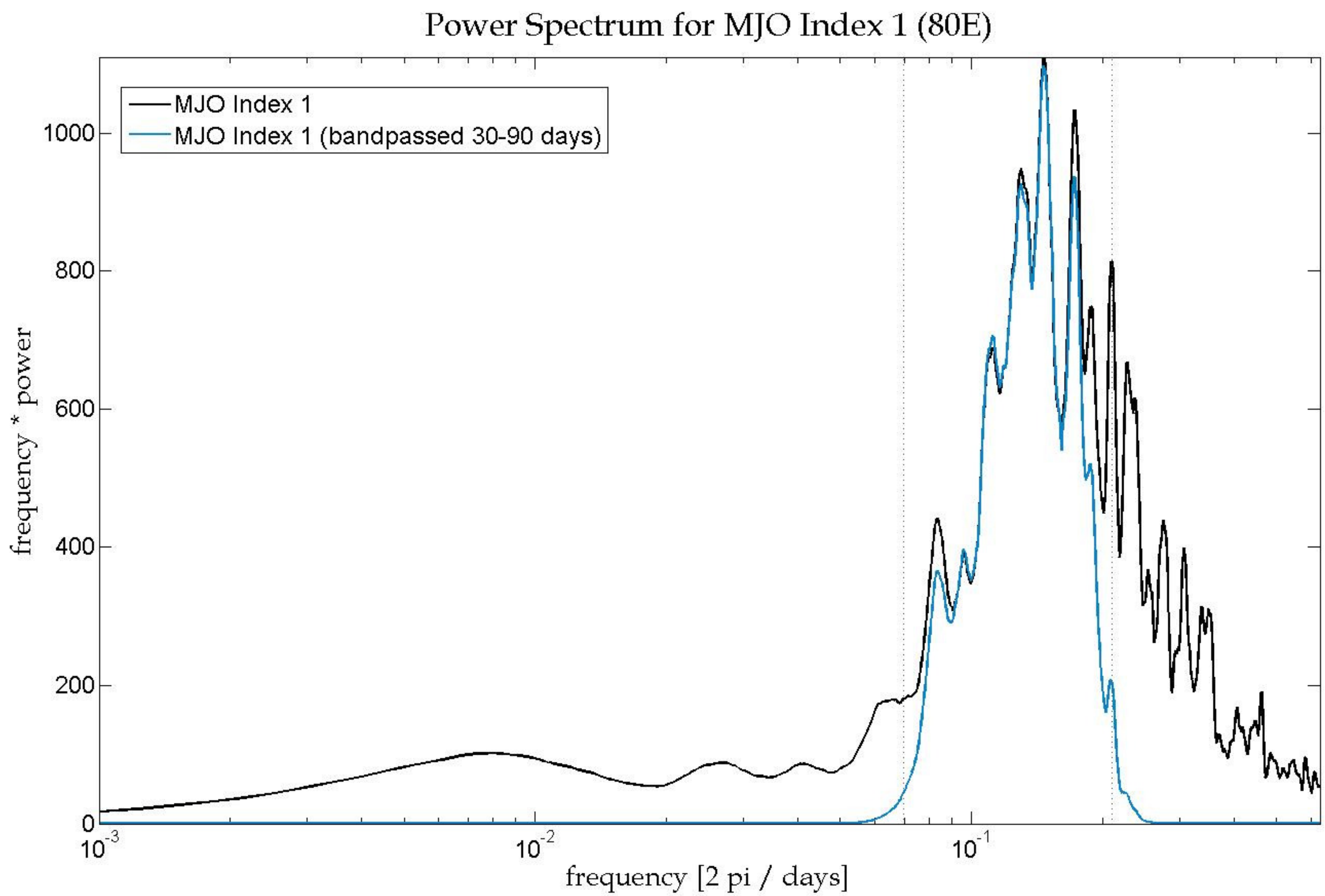
MJO indices

- Example of time-series of an MJO index:



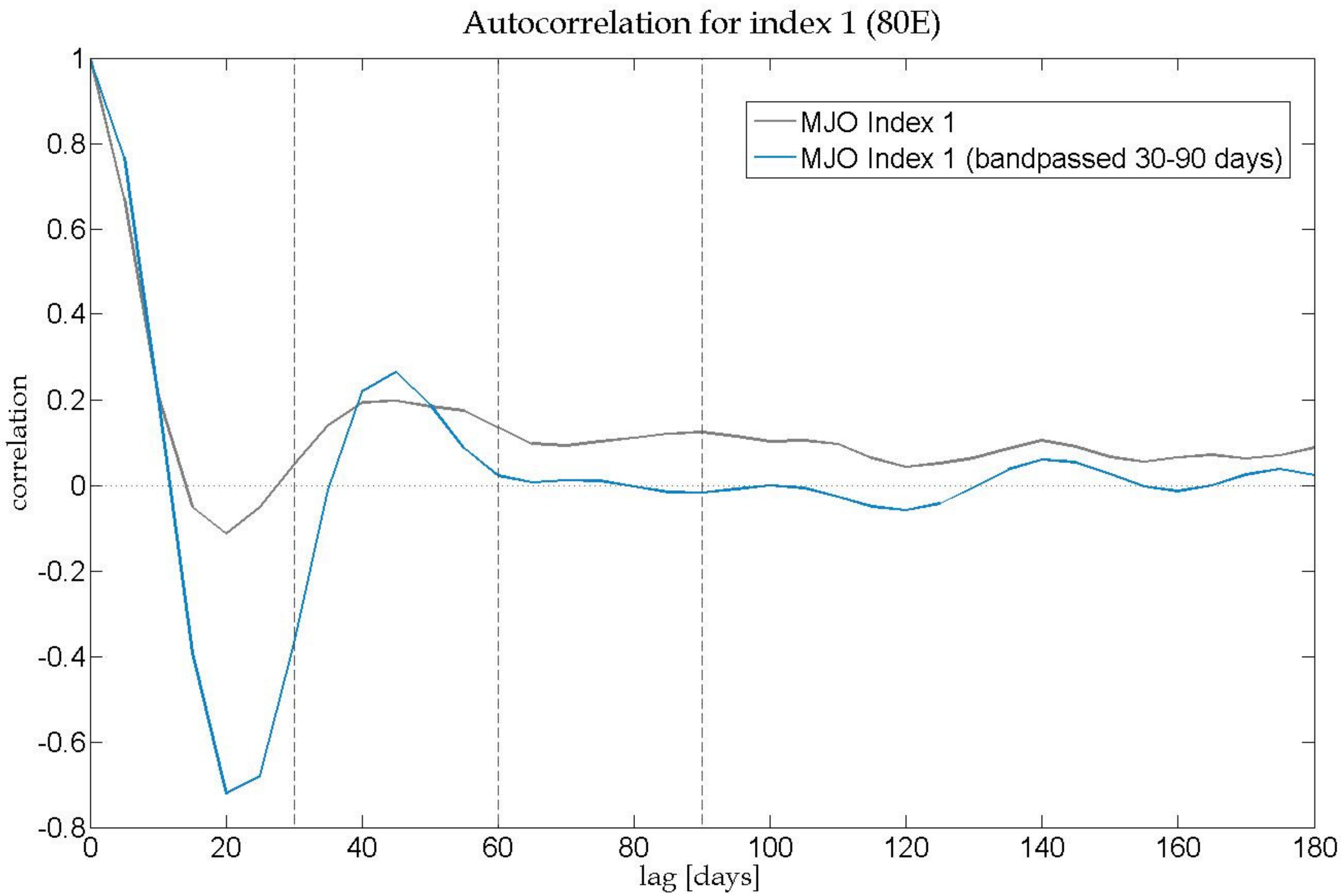
MJO indices

- Power spectrum of an MJO index:



MJO indices

- Autocorrelation of an MJO index:



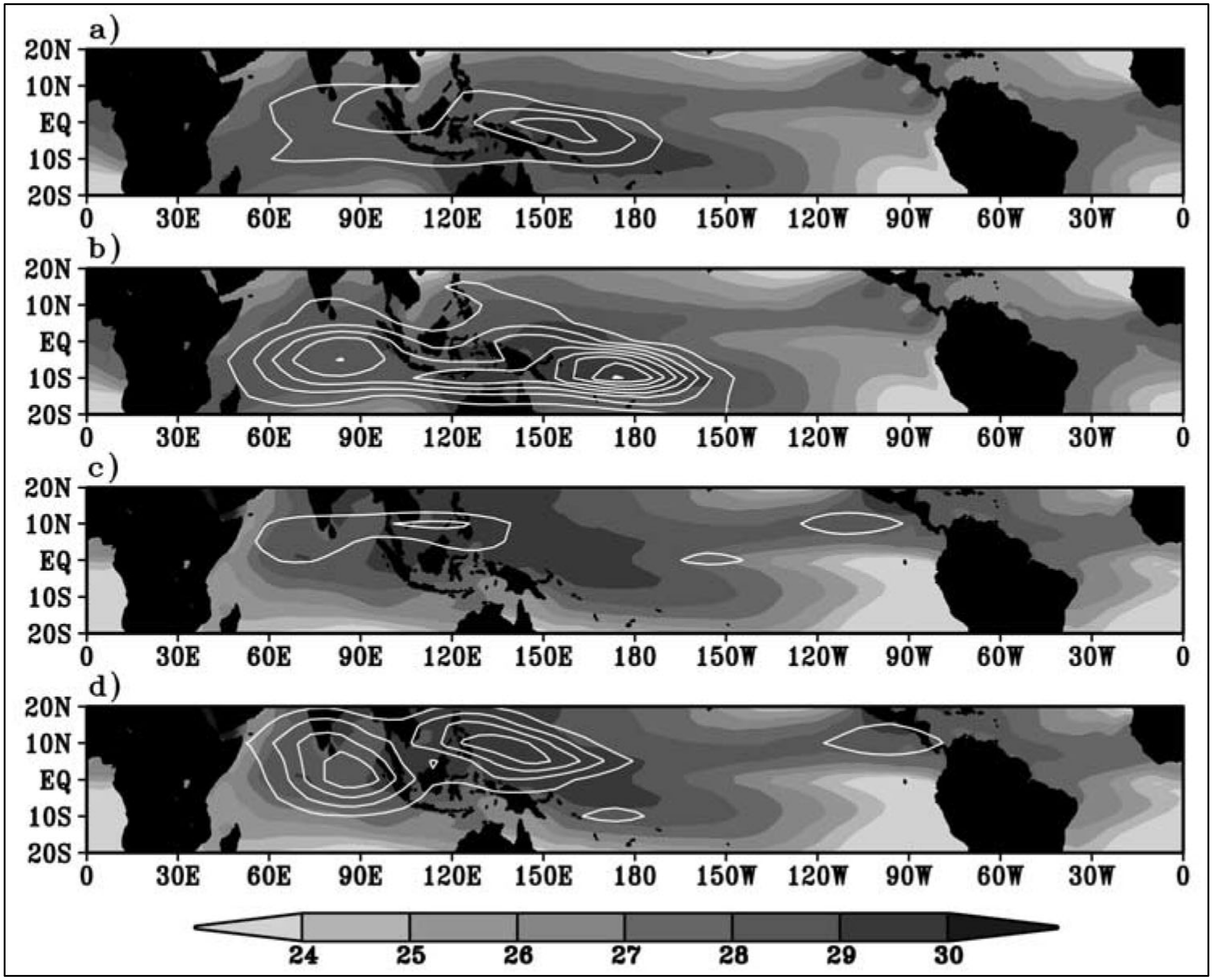
Observational understanding

- Our understanding of the MJO is limited mainly to observations
- Dominant ``period'' spreads over ~30-90 days
- Stronger over oceans than land (*i.e.*, E. Indian and W. Pacific vs. Indonesia)
- More satisfactorily described as a semi-regular *pulse*-like event than as an *oscillation*
- No satisfactory theory (*yet…*)
    - Theory generally involves both Rossby and Kelvin waves since disturbances associated with MJO have both E and W propagation directions
    - Speed of disturbance is never recovered from mathematical models
- Difficult to simulate in Global Circulation Models (GCMs)
- Skillful empirical prediction has been demonstrated on timescales of 15-20 days

There are physical processes going on

which we do not fully (or at all) understand

Observational understanding



Contours:

Winter 850-hPa zonal wind

Winter precipitation

Summer 850-hPa zonal wind

Summer precipitation

Shading: mean SST

Zhang, *Rev. Geophys.*, 2004RG000158 (2005)

Observational understanding

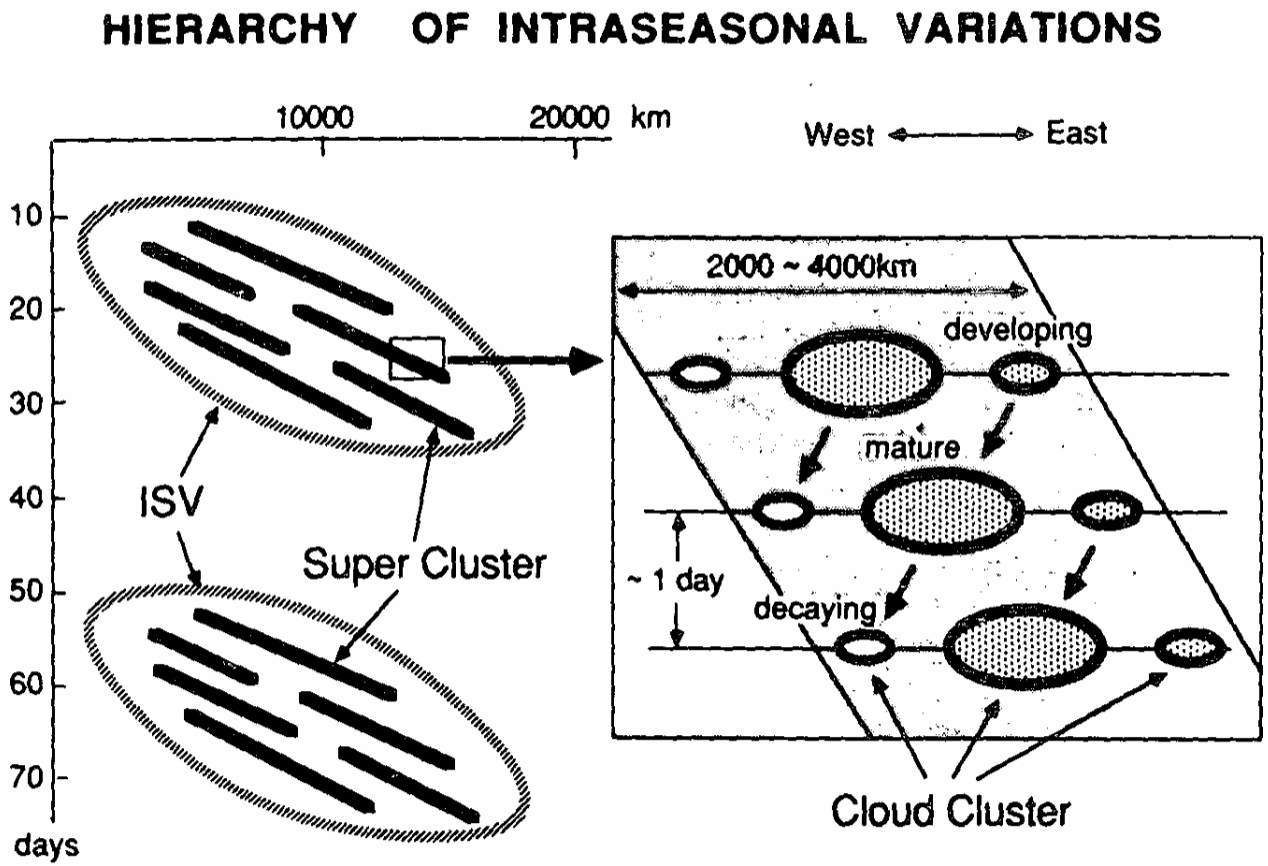
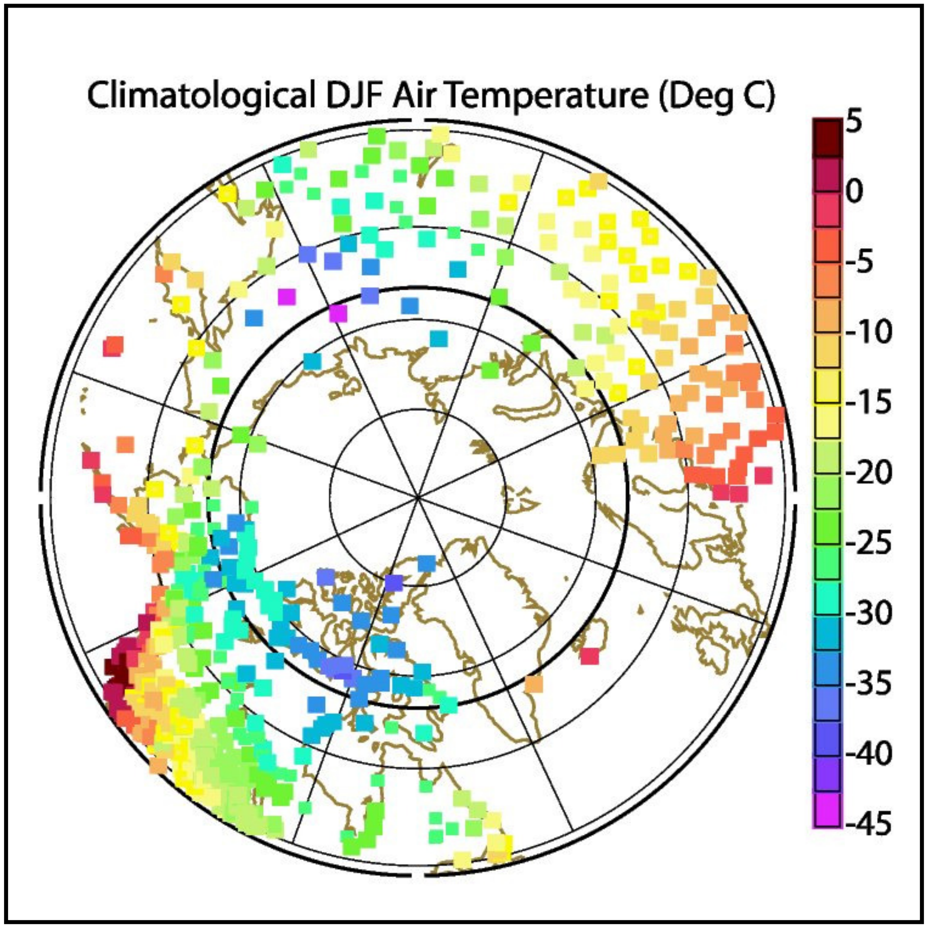


FIG. 7. Schematic describing the details of the large-scale eastward-propagating cloud complexes [slanting ellipses marked ISV (intraseasonal variability) on the left-hand side]. Slanting heavy lines represent super cloud clusters (SCC) within the larger complexes or ISV. The right-hand side illustrates the fine structure of the SCC with smaller westward-moving cloud clusters that develop, grow to maturity, and decay in a few days (from Nakazawa 1988).

Madden and Julian, *Monthly Weather Review*, pp. 814, **122** (1994)

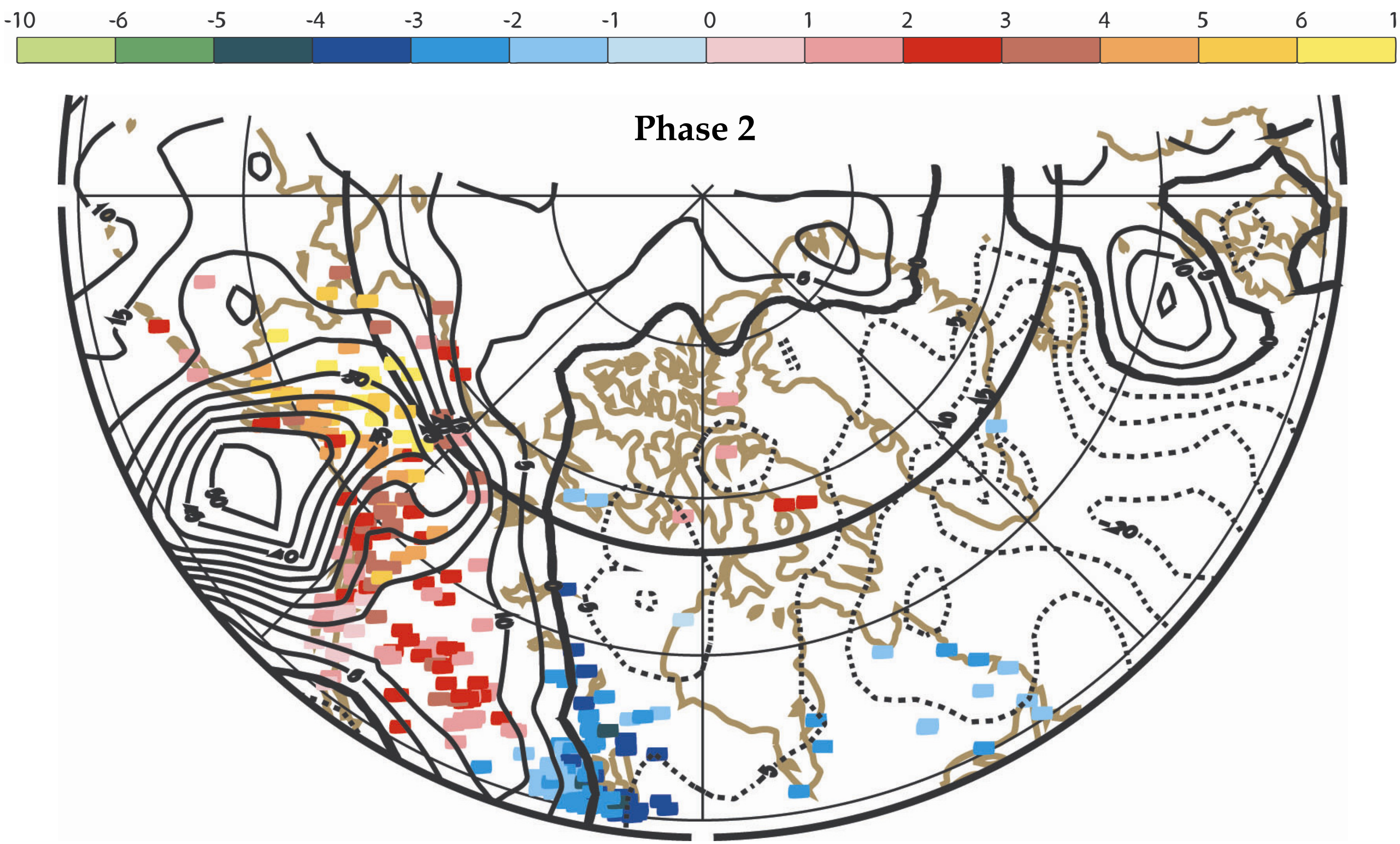
Connections with northern high-latitude SAT

- Statistical relation between MJO and northern high-latitude SAT
- SAT: Daily mean SAT from USSR, and minimum from rest of North. Monthly climatology used to generate anomalies
- Anomalies are composited with respect to the MJO and statistical significance is tested using a two-tailed Normal-*z* test (90% sig.)
- SAT data is compared with MJO composites of atmospheric data (from NCEP/NCAR reanalysis) in order to compare spatial patterns
- There seems to be a close relationship between SH700 and SAT anomalies



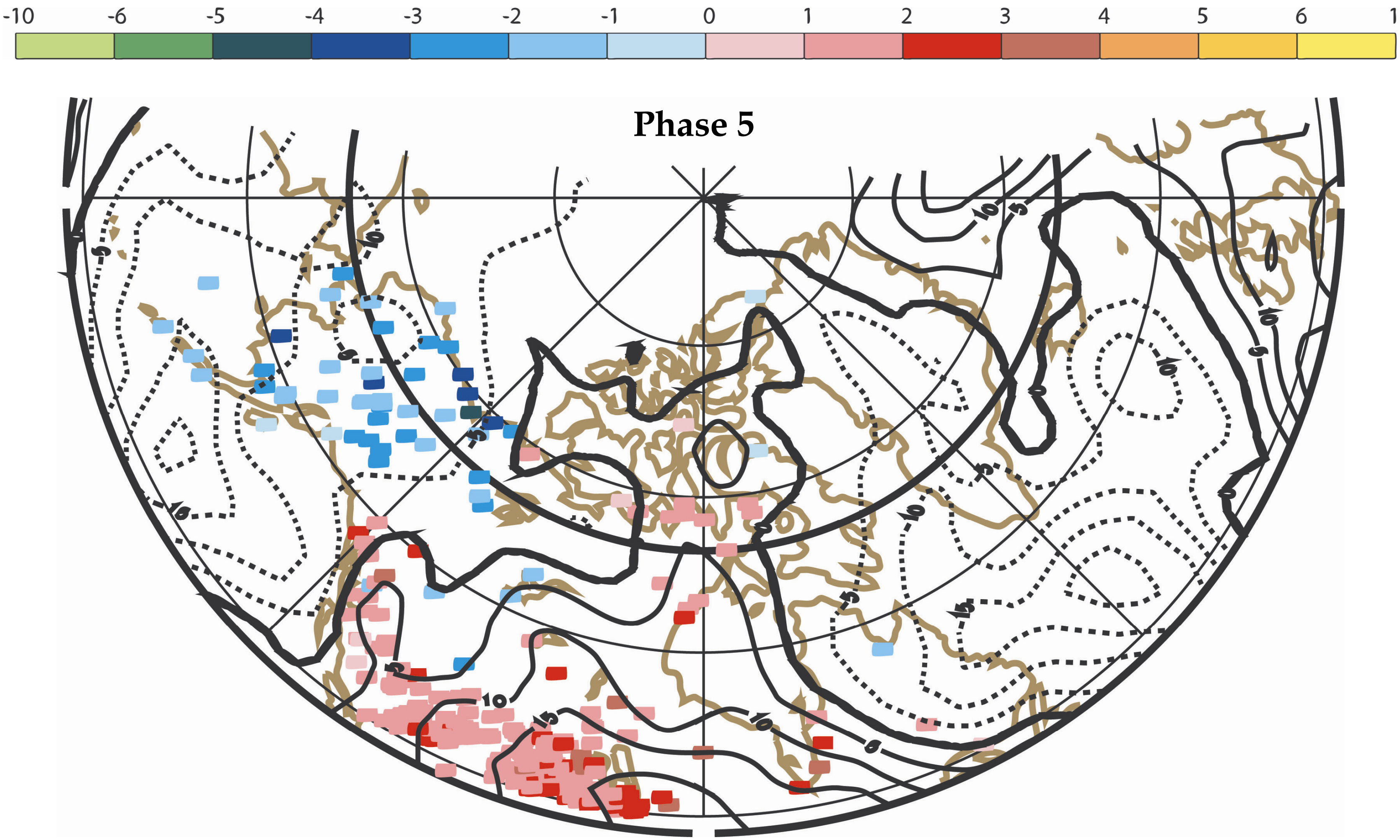
Vecchi and Bond, *The MJO and northern high-lat. wintertime SAT*, GRL, 2004

Connections with northern high-latitude SAT



(contours: composite SH700 anomalies, shaded points: composite SAT anomalies)

Connections with northern high-latitude SAT



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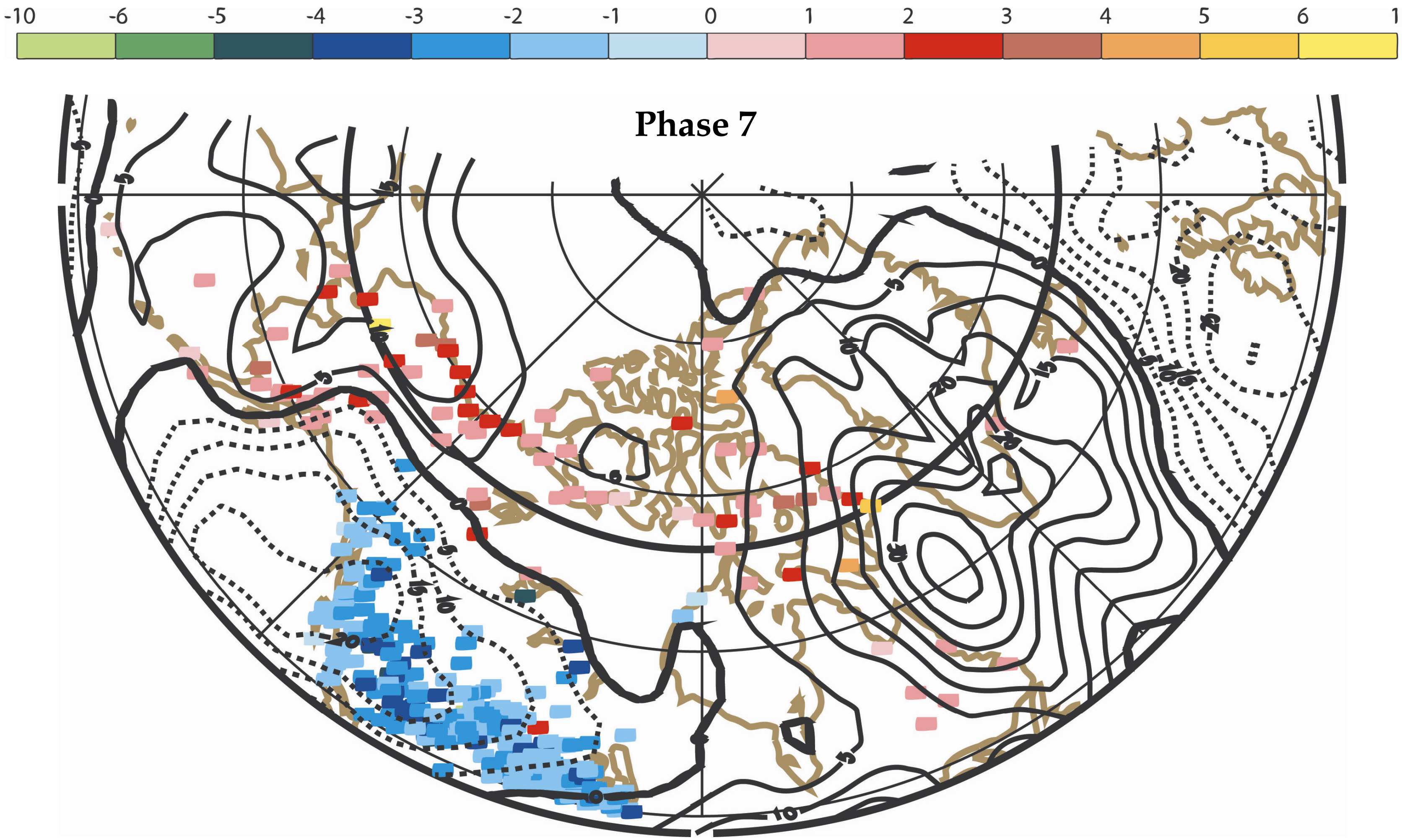

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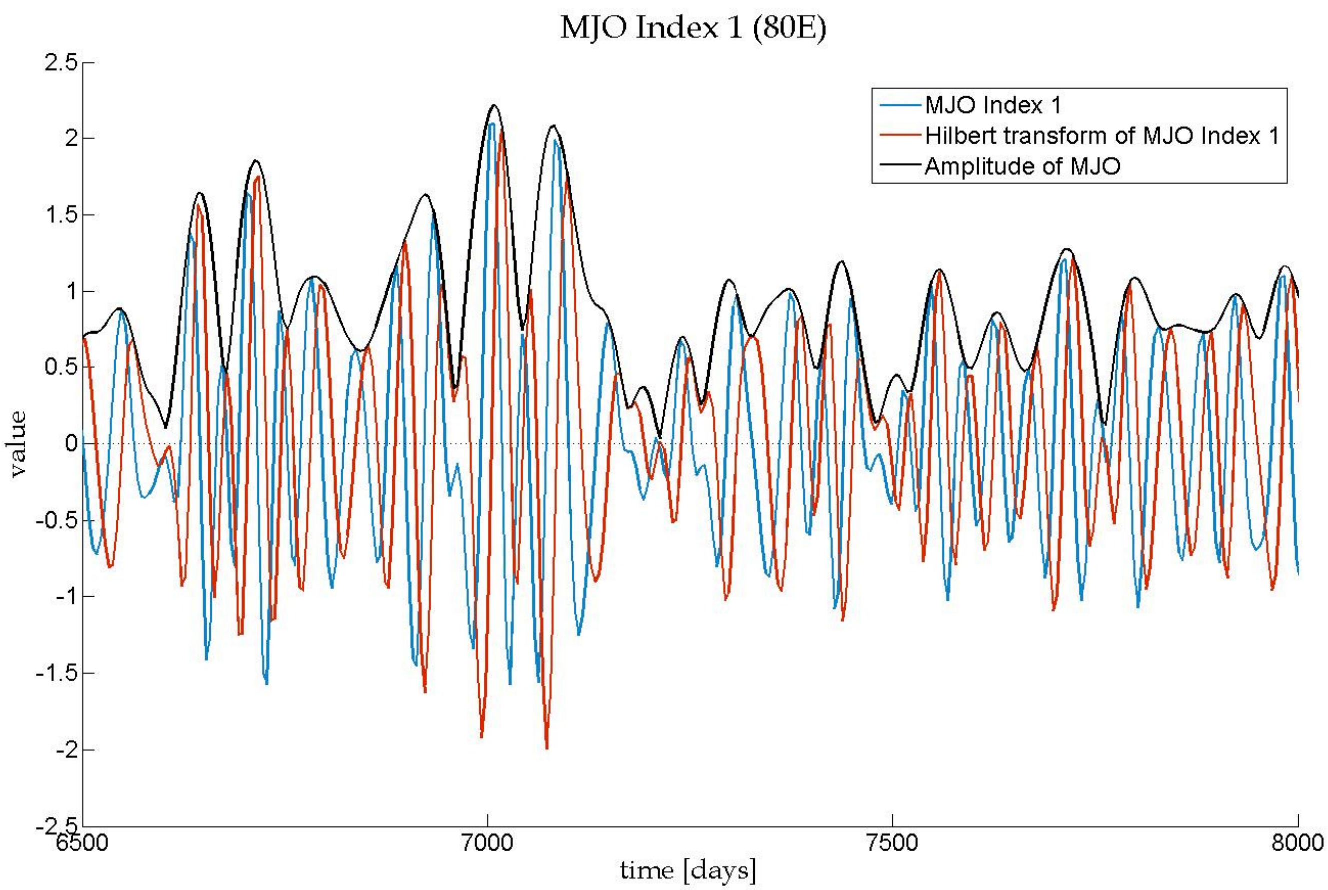
Our characterization of the MJO

- We characterize the MJO by analyzing it's position in ``MJO phase space''
- Yields a radius and angle which we can use as indicators of MJO *phase* and *strength*



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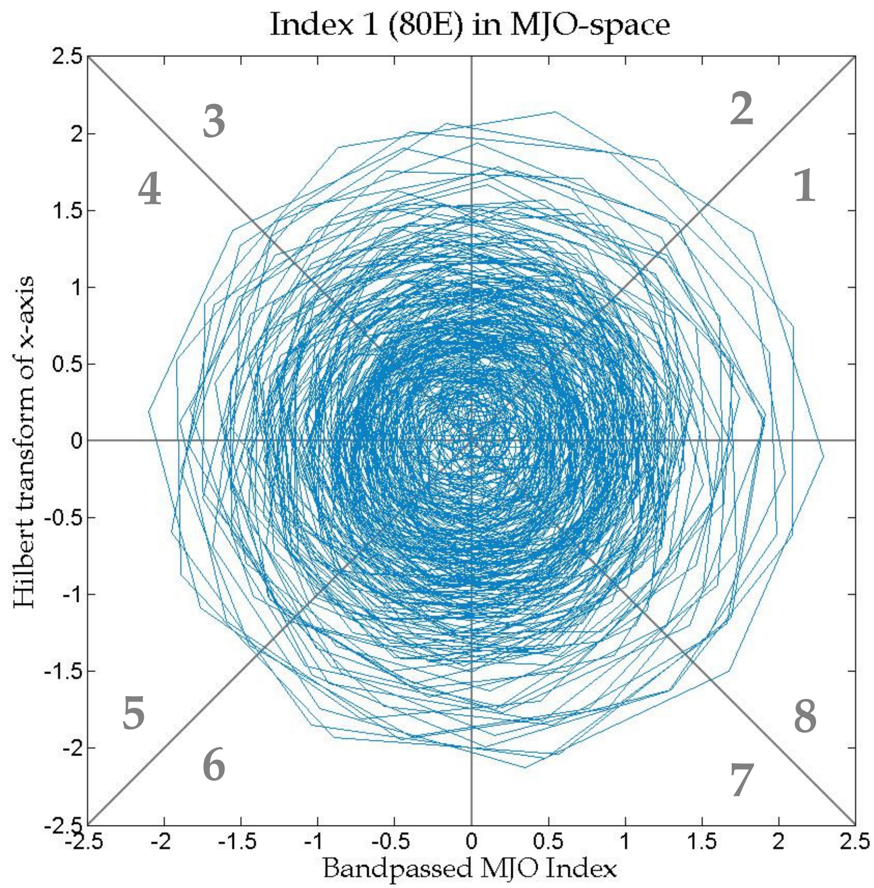


$x(t) \equiv \text{MJO index}$

$y(t) \equiv \text{Hilbert}(x(t))$

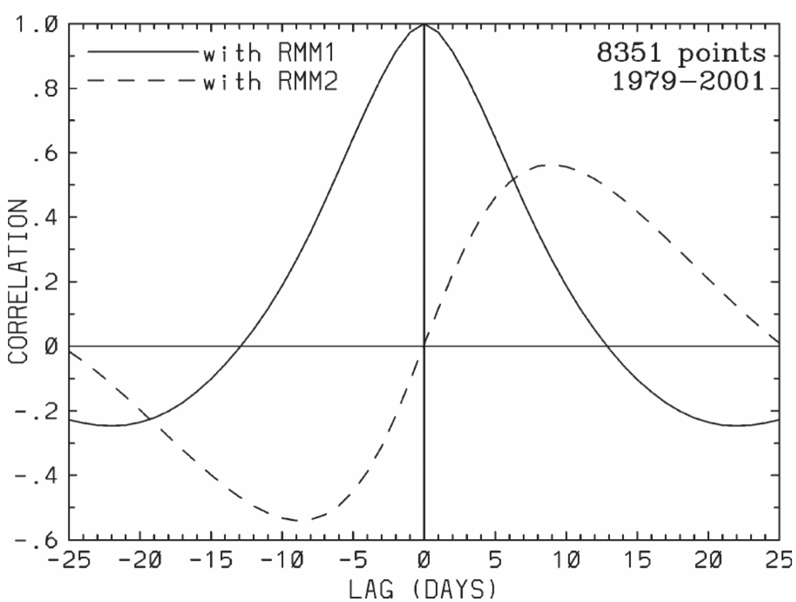
$R = \sqrt{x^2 + y^2}$

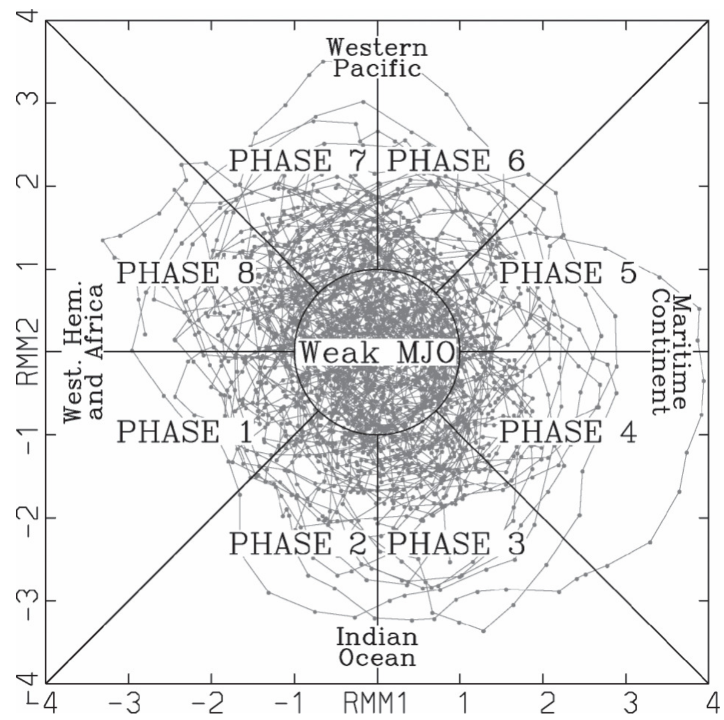
$\theta = \arctan\left(\frac{y}{x}\right)$

Aside: another way to characterize the MJO

• In the past, characterizations of the MJO have produced a similar ``phase space'' using a slightly different method

• In one study*, atmospheric data (OLR, 250 hPa and 850 hPa zonal wind) are filtered to remove seasonal and interannual signals, then the first two PCs are taken to represent the phase space coordinates



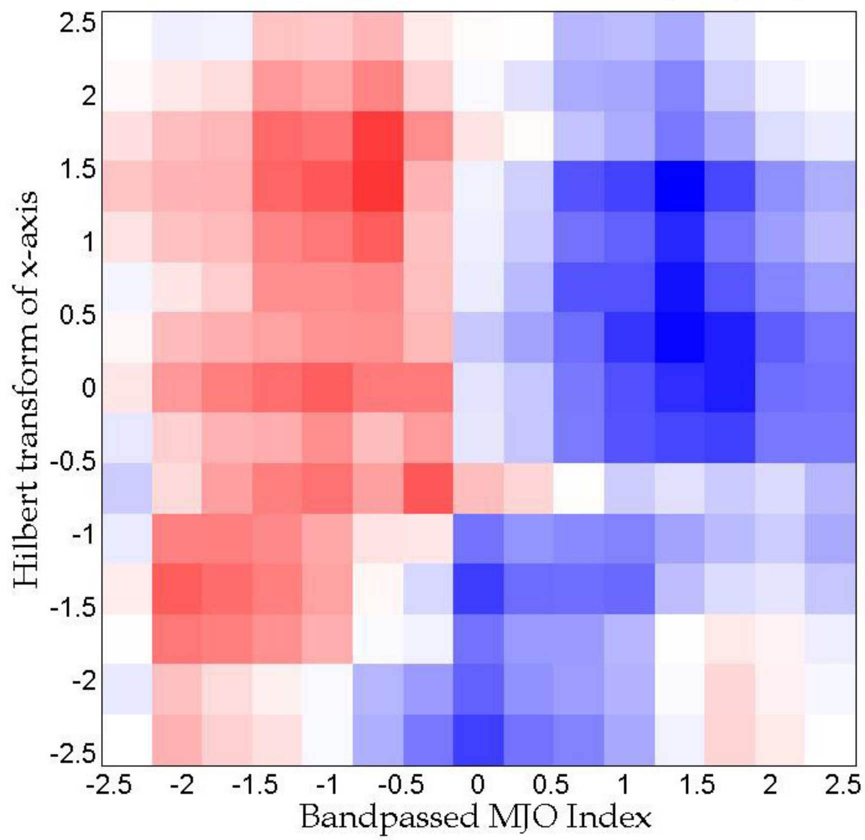


* Wheeler and Hendon, *Monthly Weather Review*, pp. 1917 (2004)

MJO weather composites

- Given a weather time series, *w(t)*, we can now generate composites of weather anomalies, *w′(t)*, based on position in MJO phase space
- Allows for nonlinear processes
- Can set conditions on composited data (i.e., winter only, high ENSO)
- Typical variability for Goose Bay pressure +/- 0.3-0.4 kPa and for Goose Bay temperature +/- 0.5 °C
- This is in agreement with Vecchi and Bond!

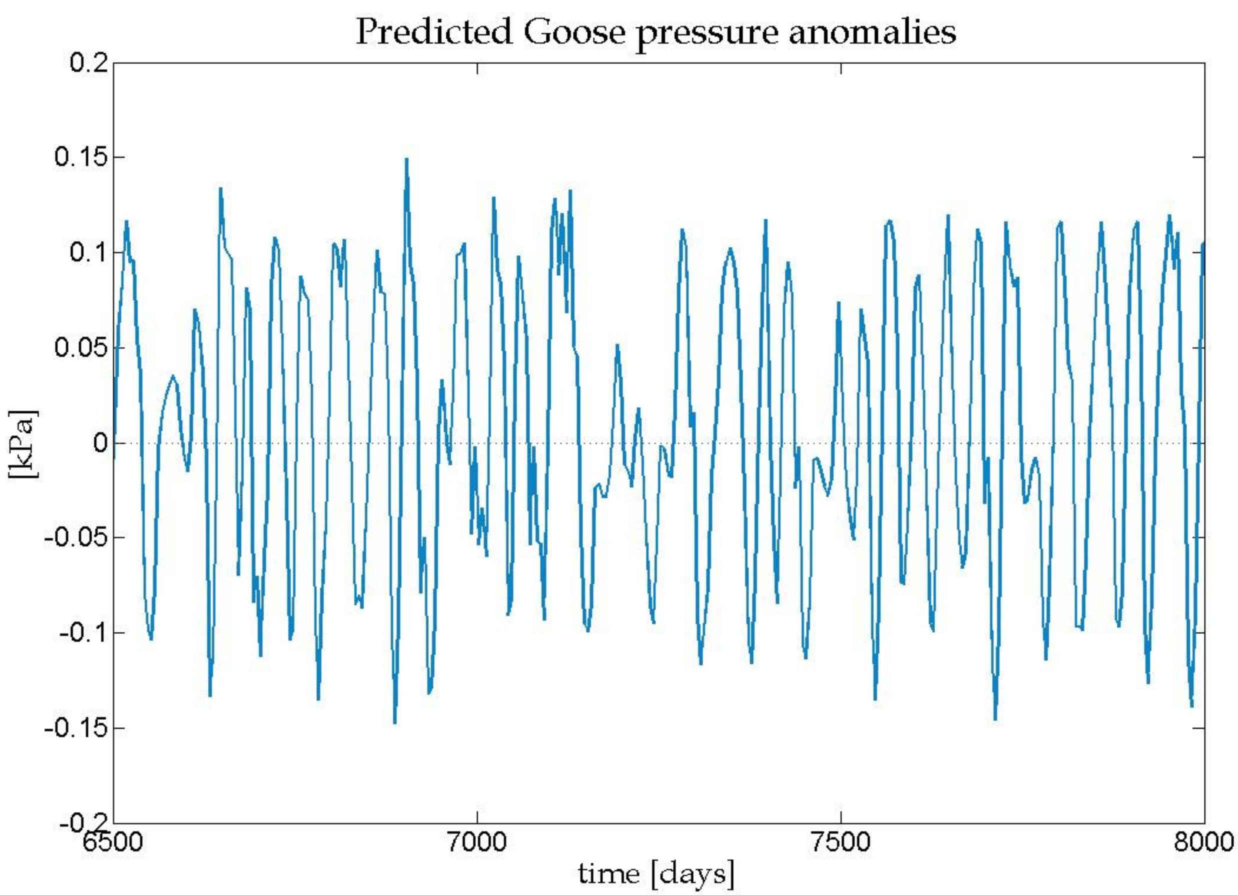
Goose Pressure composite in Index 1 (80E) MJO-space



(blue = -0.17 kPa, red = 0.14 kPa)

Predicted MJO weather anomalies

- Given the composite weather in MJO phase space we can treat it as a *canonical map* which can be used to transform between a time series of the MJO index, $x(t)$, and a time series of predicted weather anomalies, $w_p'(t)$.



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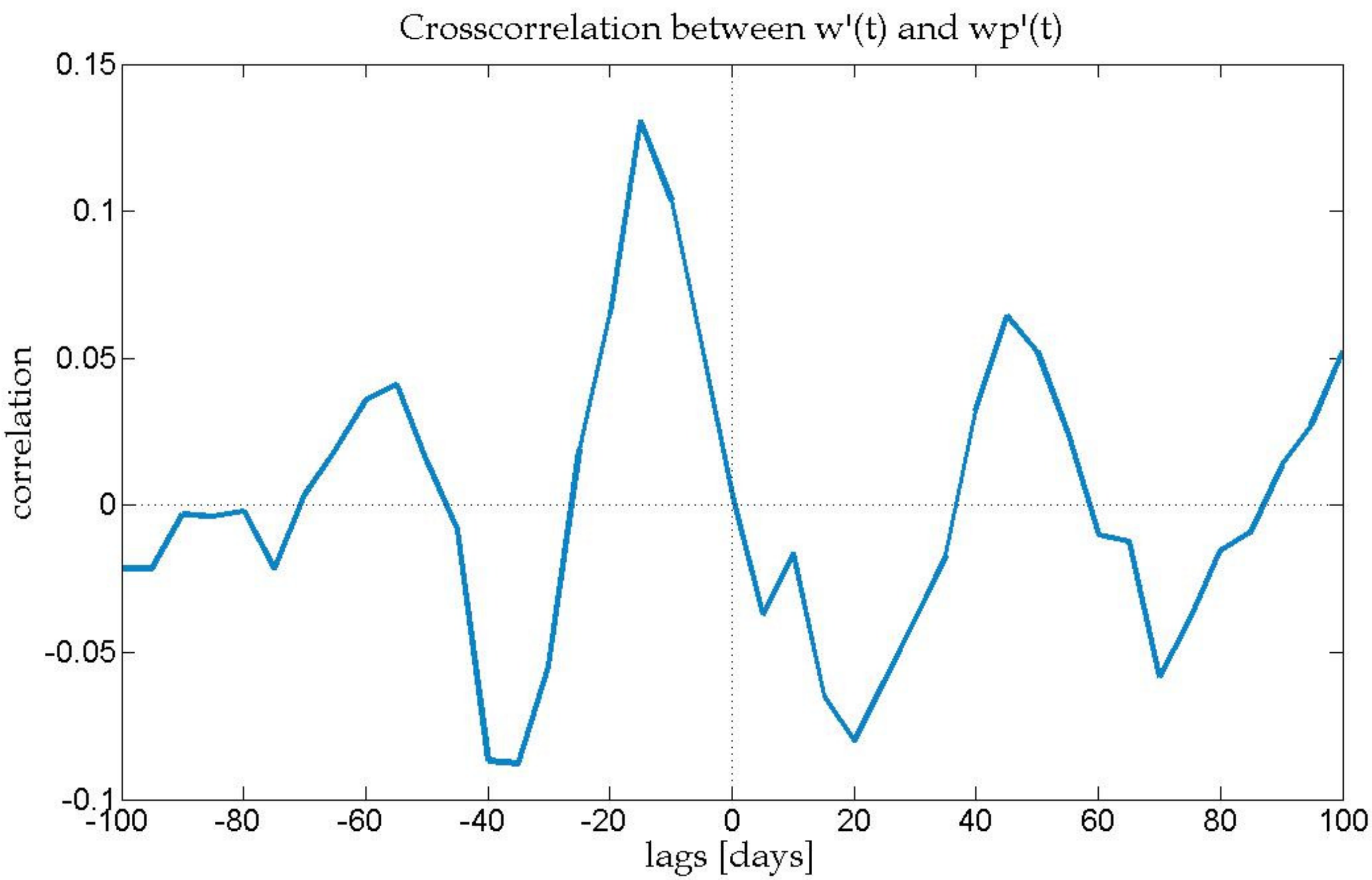

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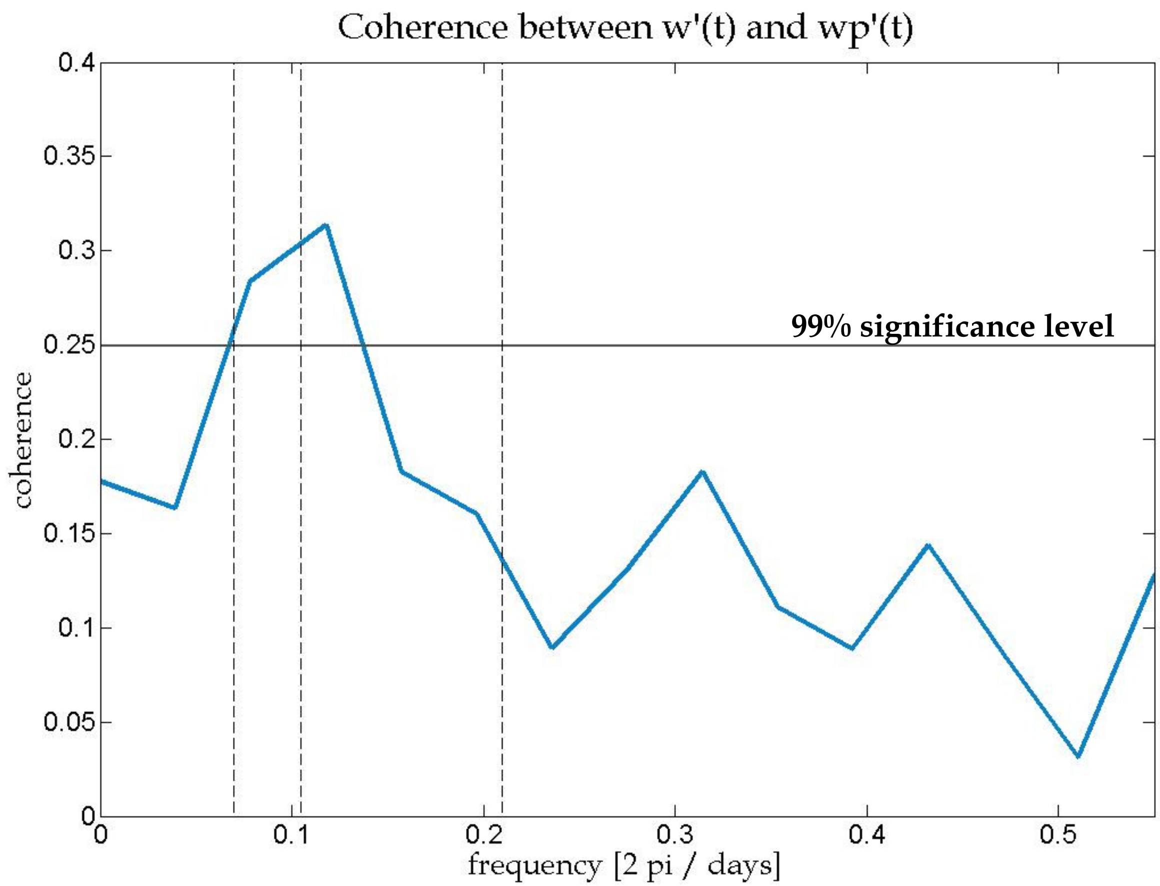

Possible future work

- Create maps of various atmospheric quantities in MJO phase space by compositing based on MJO
- These can then be conditionally averaged based on conditions such as
  - Season (*i.e.*, winter anomalies only)
  - ENSO state (*i.e.*, high ENSO only)
- Use these maps to generate canonical MJO anomalies for these quantities
- Use these anomalies to drive an ocean model and observe the response
- If the ocean response were a linear process then the ocean response would be the same as the intraseasonally filtered response to total forcing
- This can be done with available data and an ocean model with high spatial resolution in the tropics

Conclusions

- MJO dominant mode of intraseasonal variability in the tropics
- Governing mechanisms of MJO not very well understood
- Possibilities of enhanced weather prediction beyond synoptic time-scales using empirical methods
- Primarily confined to tropics but clear connections with extra tropics
    - Northern high-latitude SAT (Vecchi and Bond, 2004)
    - Goose Bay SAP
- Need to enhance our understanding of the MJO through theoretical and numerical modeling