The Madden-Julian Oscillation and Local and Remote Forcing of the Ocean

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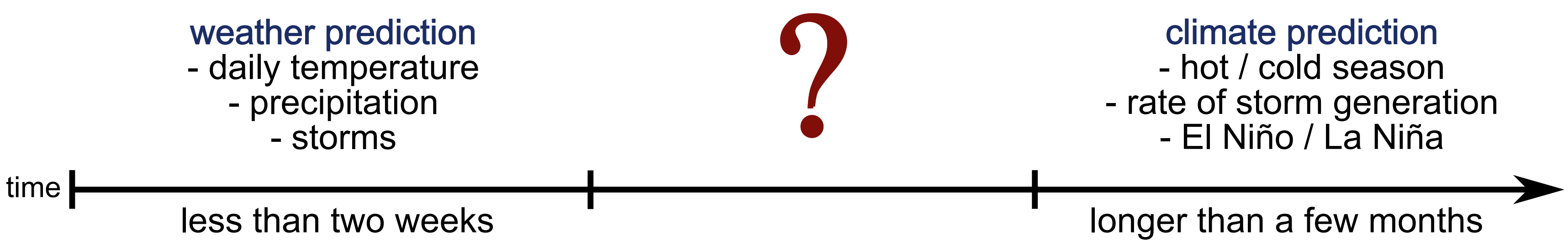
Background and Motivation

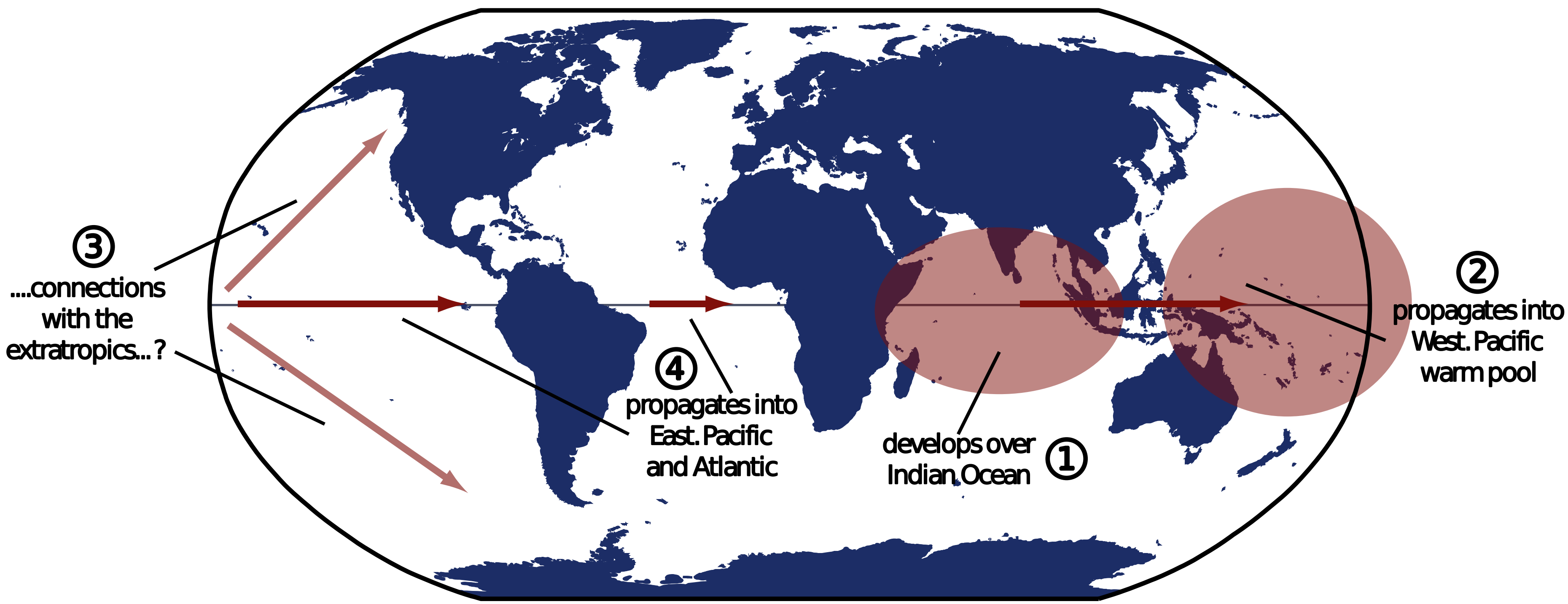
- There is growing interest in extending the range of weather forecasts and developing a seamless scheme that bridges both weather and climate.



- Main prospect on intraseasonal timescales is the **Madden–Julian Oscillation**
- This work:
  - Identifies global patterns of connections between the MJO and sea level variability using a novel metric.
  - Identifies regions where the MJO excites a significant response in sea level anomaly (**SLA**).
  - Models three region independently in order to explain dynamics and specific connections between the ocean and the MJO.

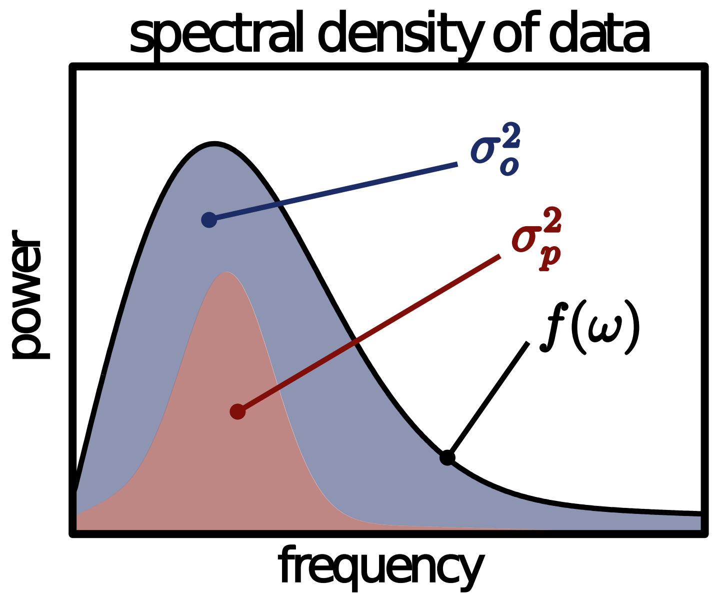
The Madden-Julian Oscillation

- The MJO is the dominant mode of variability in the tropical atmosphere on **intraseasonal timescales** (~30–90 days)
- Consists of eastward propagating disturbance detectable in OLR/precip. and zonal wind
- Shows promise for enhancing predictability over **weeks to months**



Statistical Connection With the MJO

- The areas under the curves below represent the variance of the observed signal (blue) and that of the MJO index (red)



$$\bar{\kappa}^2 = \frac{\int \rho^2(\omega) f(\omega) d\omega}{\int f(\omega) d\omega} = \frac{\sigma_p^2}{\sigma_o^2}$$

Ratio represents the proportion of variance explained by the MJO

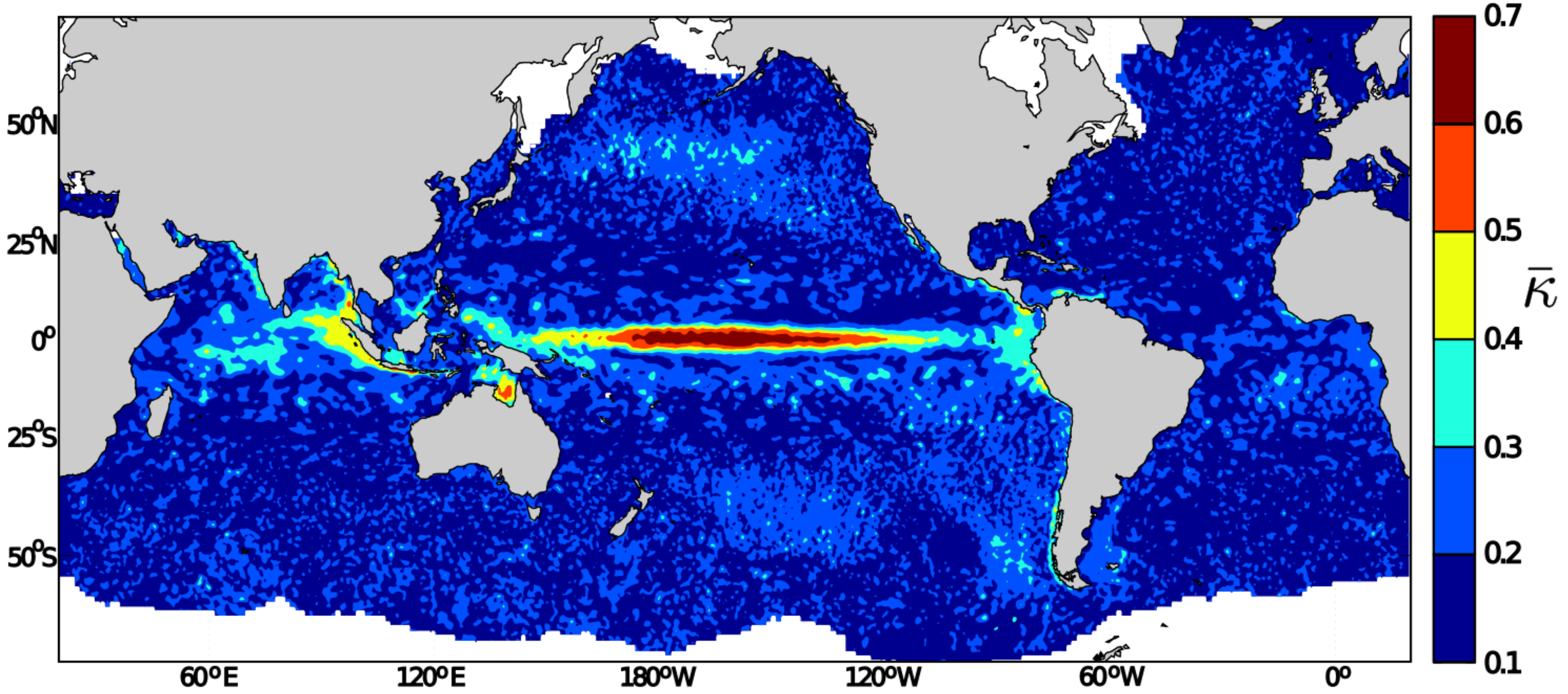
- This allows us to avoid choosing an arbitrary MJO frequency band

The MJO and Global Sea Level

- $\bar{\kappa}$ is calculated globally for SLA
- Average 5% significance level (~ 0.3) represented by think black contour
- Interested in regions where both $\bar{\kappa}$ and σ_p are large

strong physical connection

strong practical value for prediction



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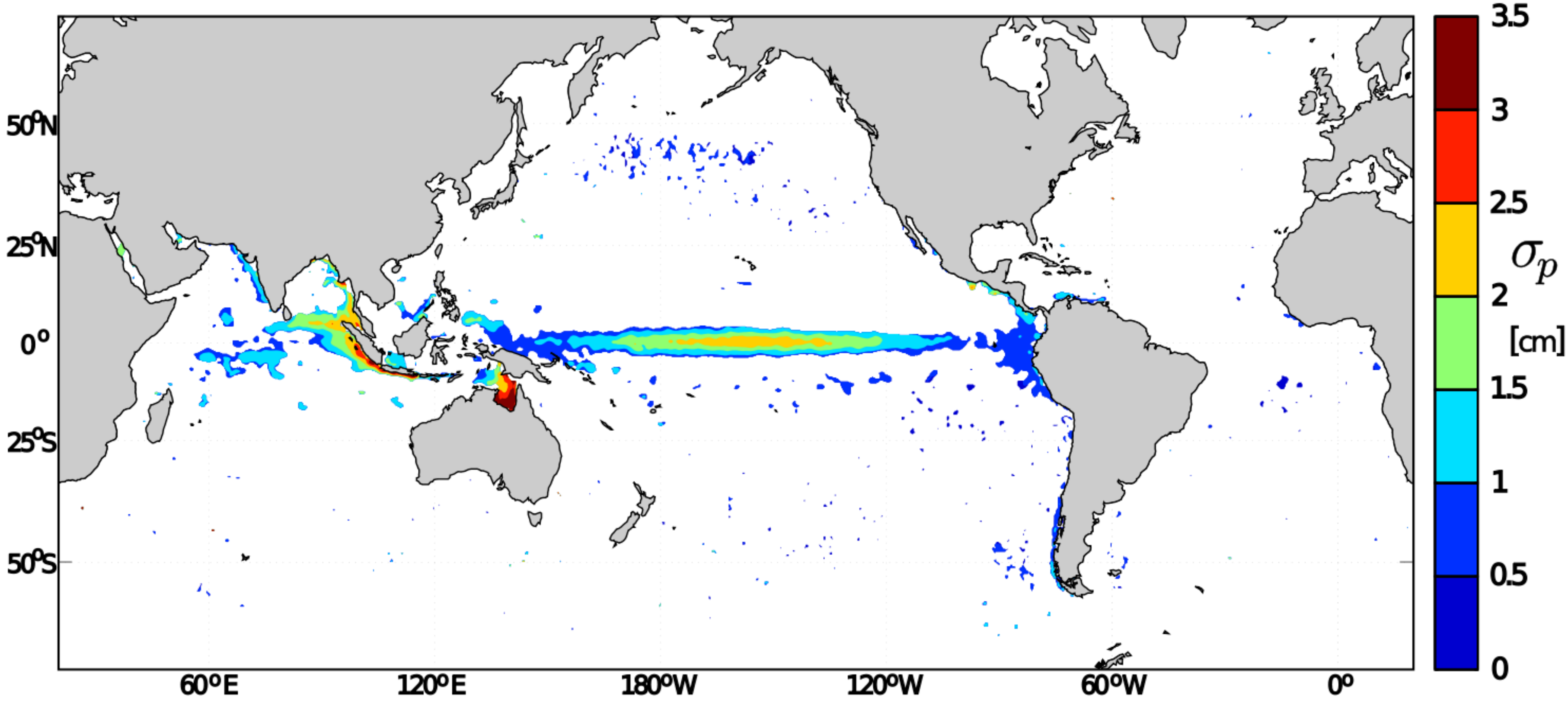

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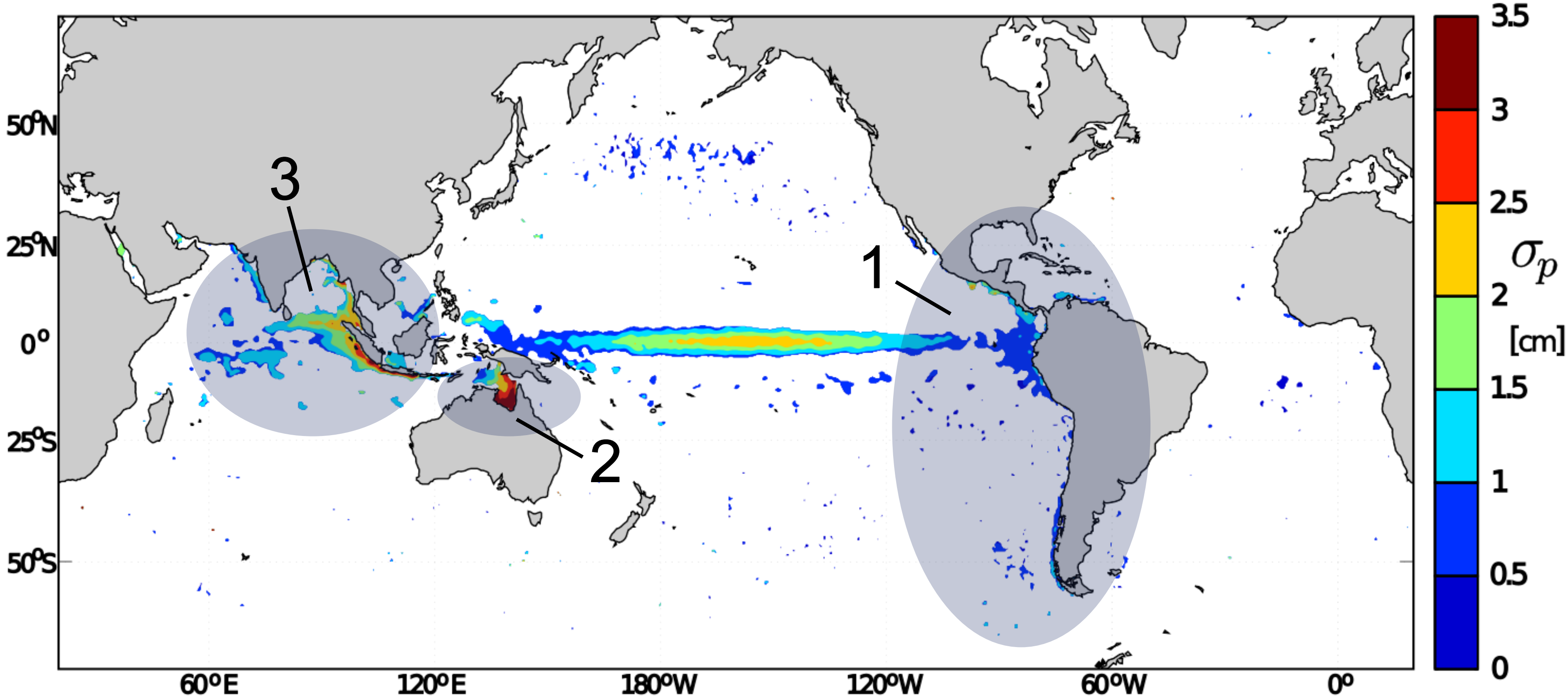
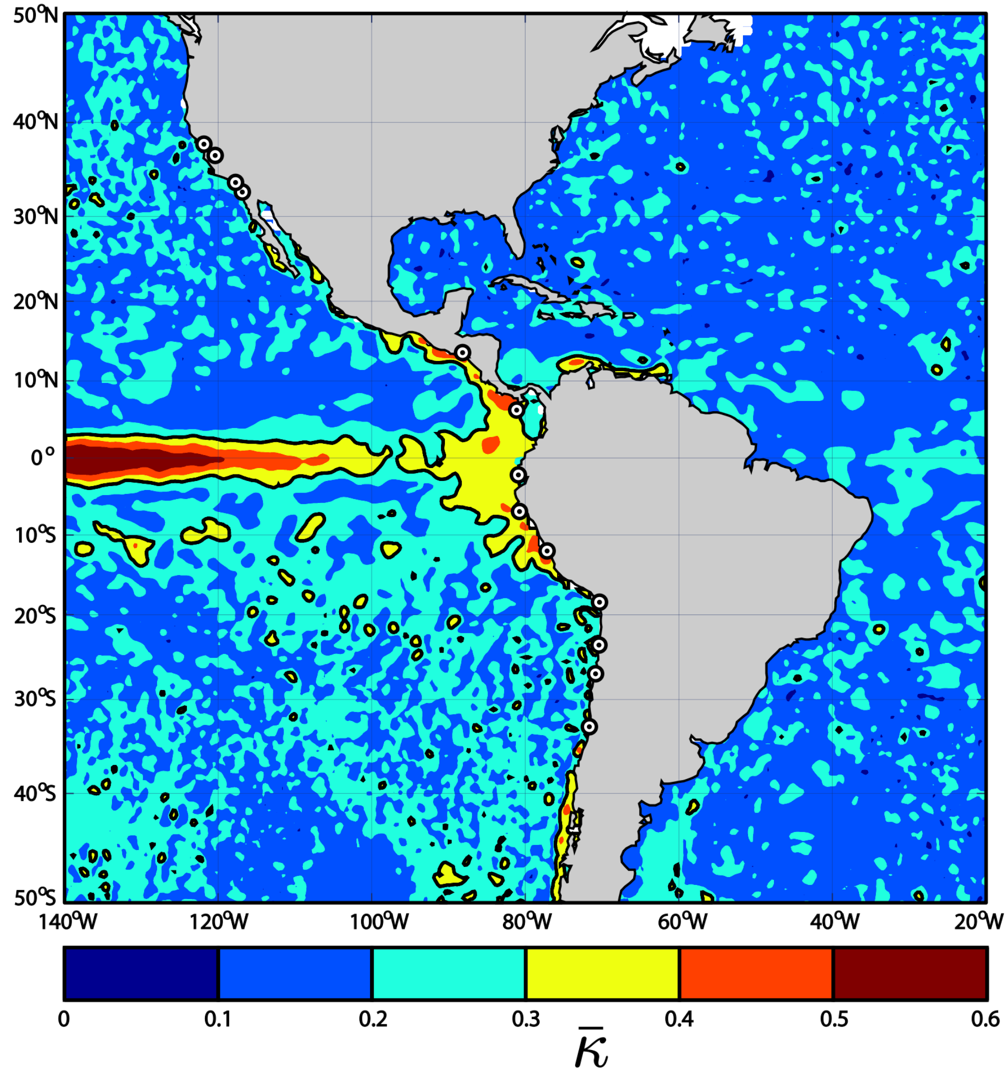
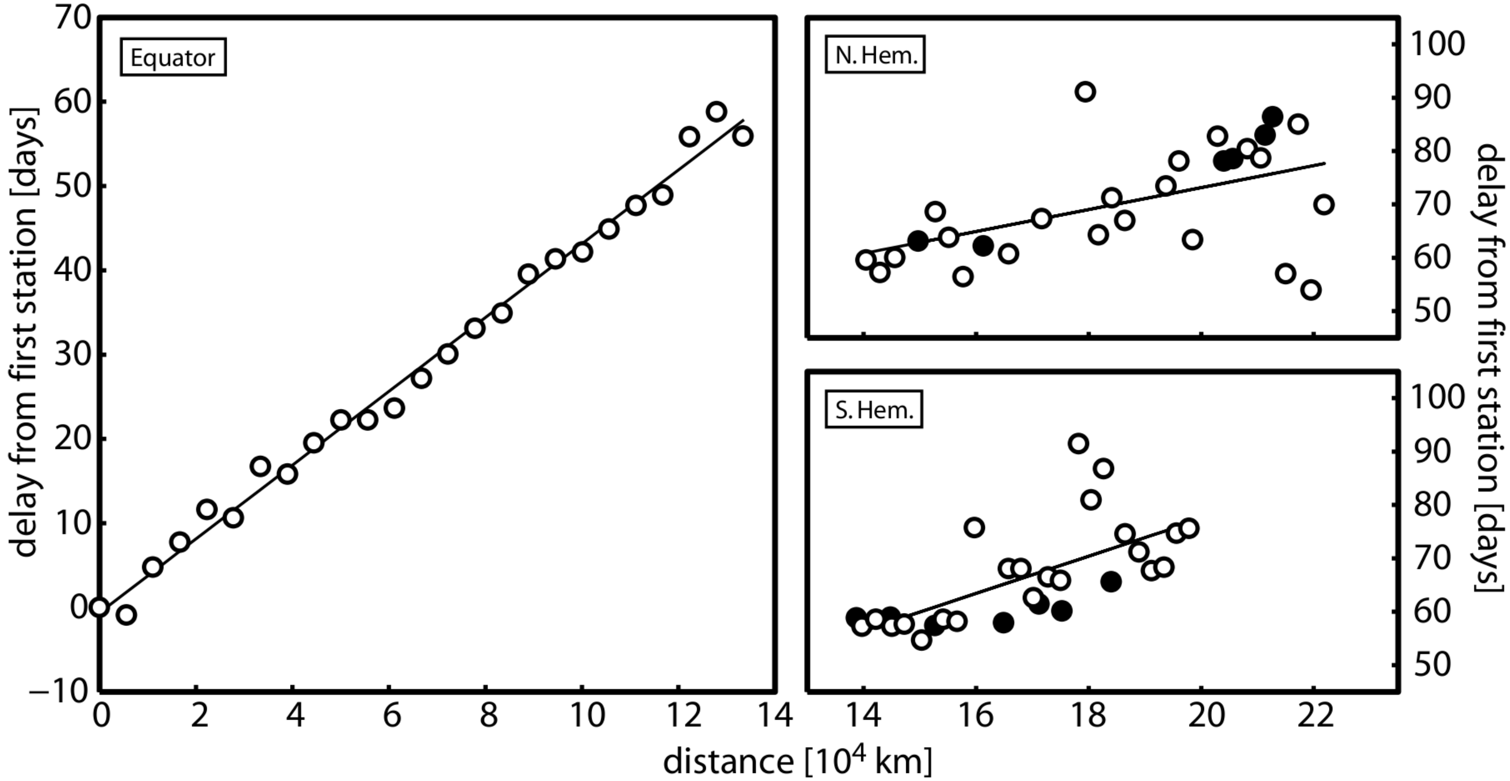


Region 1

- Important for following reasons:
  - Connection to MJO
  - Geography: long unbroken coastline may channel information from the tropics to the extratropics
- Data used in regional analysis:
  - Altimeter: 25 points along the equator (155E–85W) and 44 along the coastline (45S–44N)
  - Tide gauge: 13 stations along coastline (see dots in figure)



Region 1

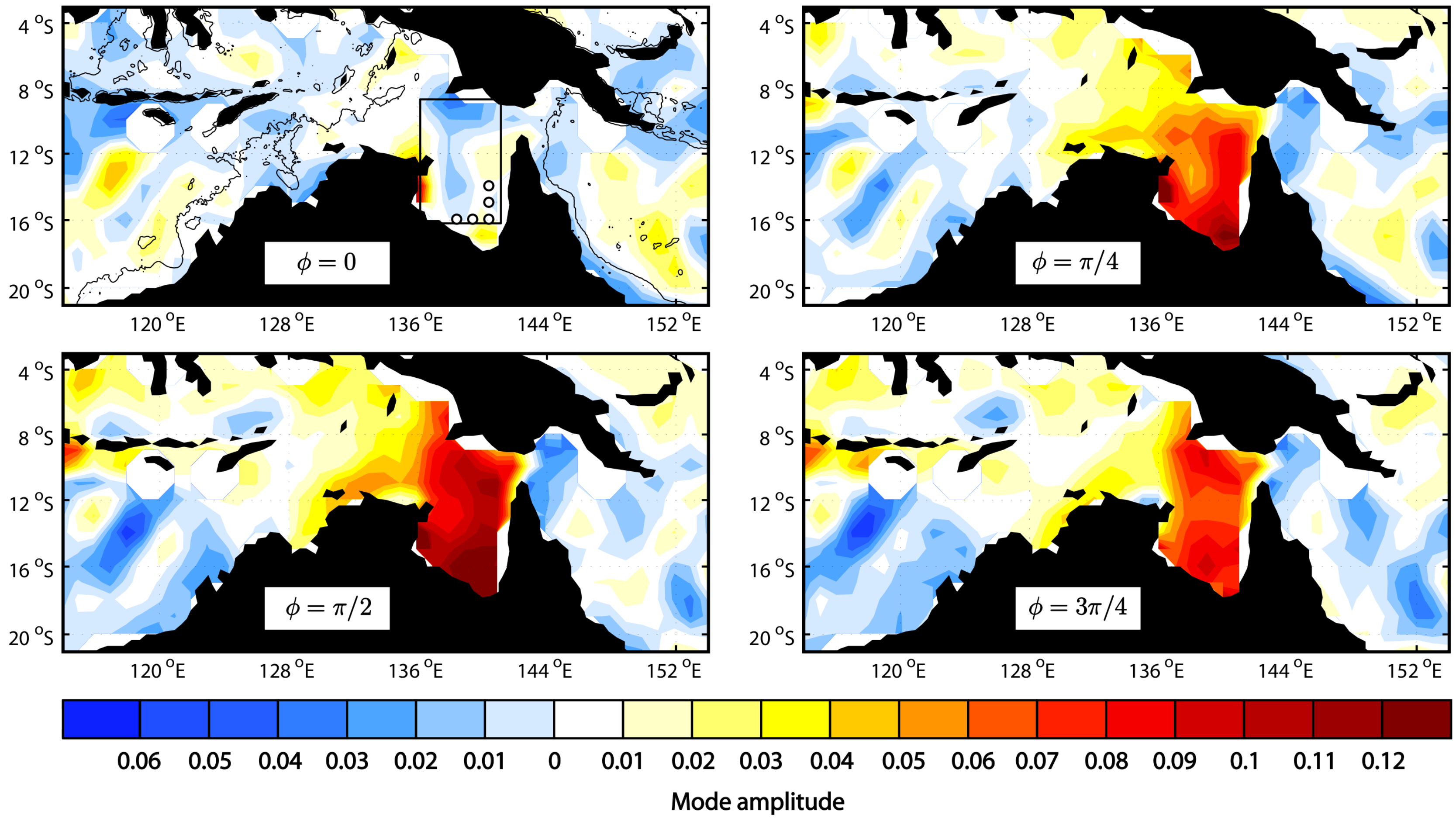


- First FDEOF mode – period of 75 days – 67% variance explained
- Wave speeds [m/s]:

Equator: 2.6 +/– 0.1   N. Hem.: 5.6 +/–2.6   S. Hem.: 3.3 +/– 0.6

Region 2

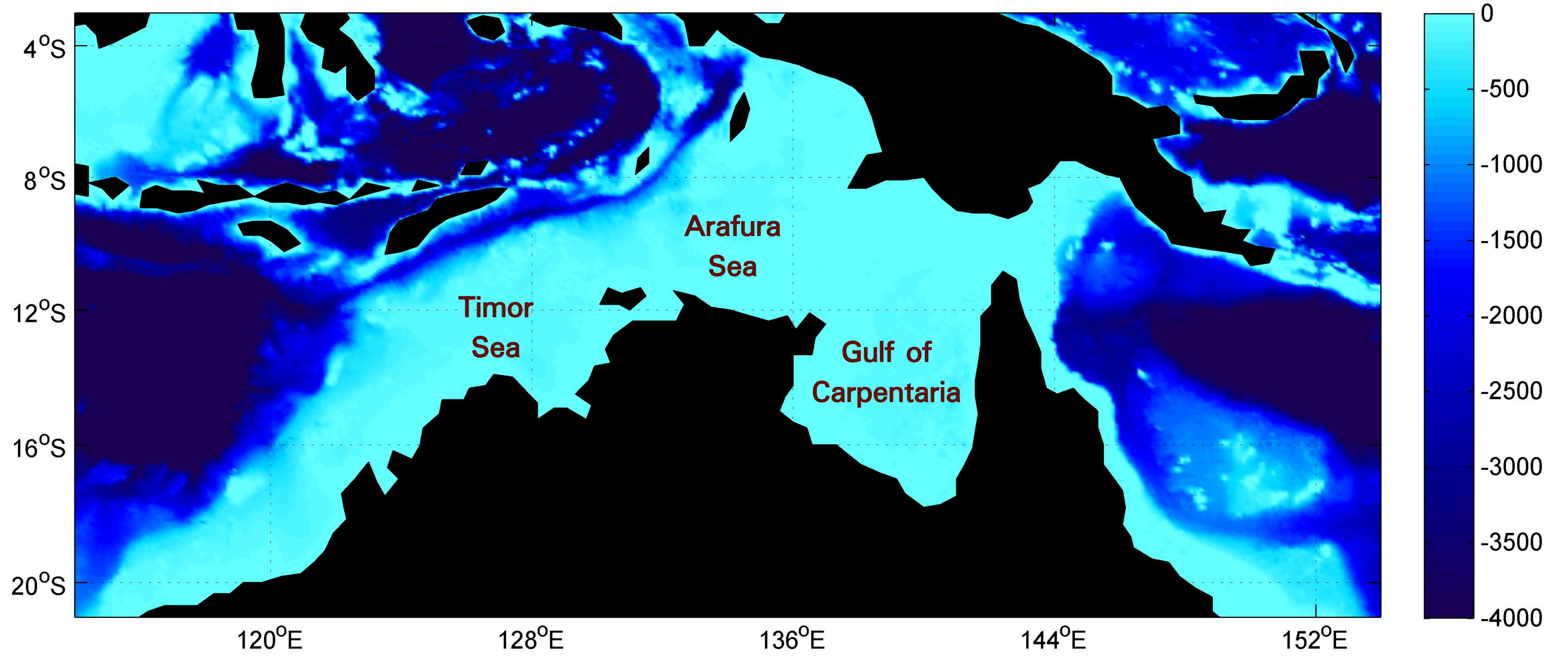
- First FDEOF mode – period of 75 days – ~35% variance explained
- Standing mode in Gulf of Carpentaria and travelling waves in deep water



Region 2

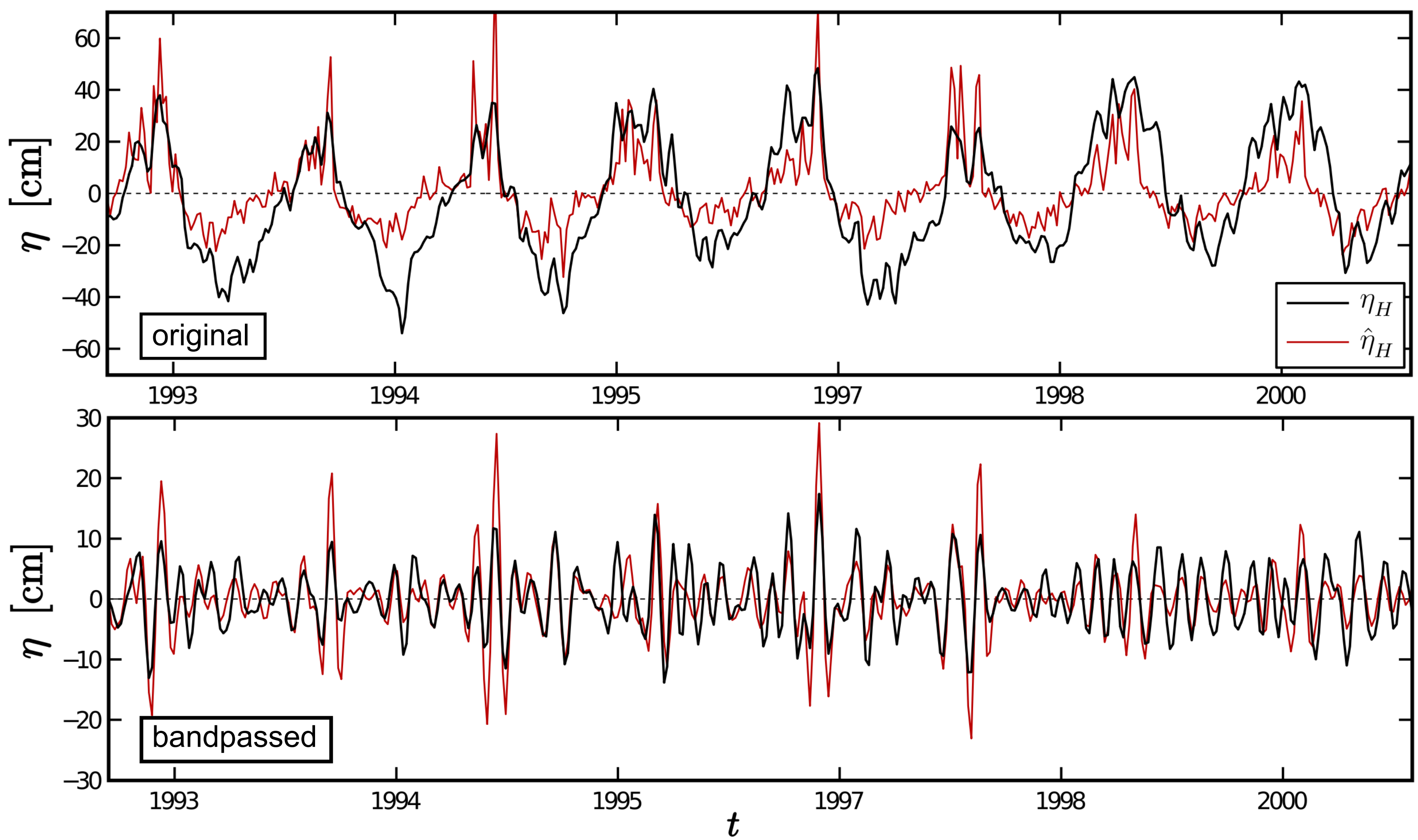
- Standing mode is in shallow water, wind–MJO connection strong in region
- Model: wind–forced shallow water equations, no bottom friction, linear, steady state leads to approximation of sea level set up due to wind:

$$\Delta\eta' = \frac{L\tau}{\rho g H} \qquad \textit{where:} \qquad \begin{aligned} \tau &= \rho_{\mathrm{a}} c_d(a) a u_{\mathrm{w}} \\ a^2 &= |\boldsymbol{u}_{\mathrm{w}}|^2 + 4\sigma^2 \end{aligned}$$

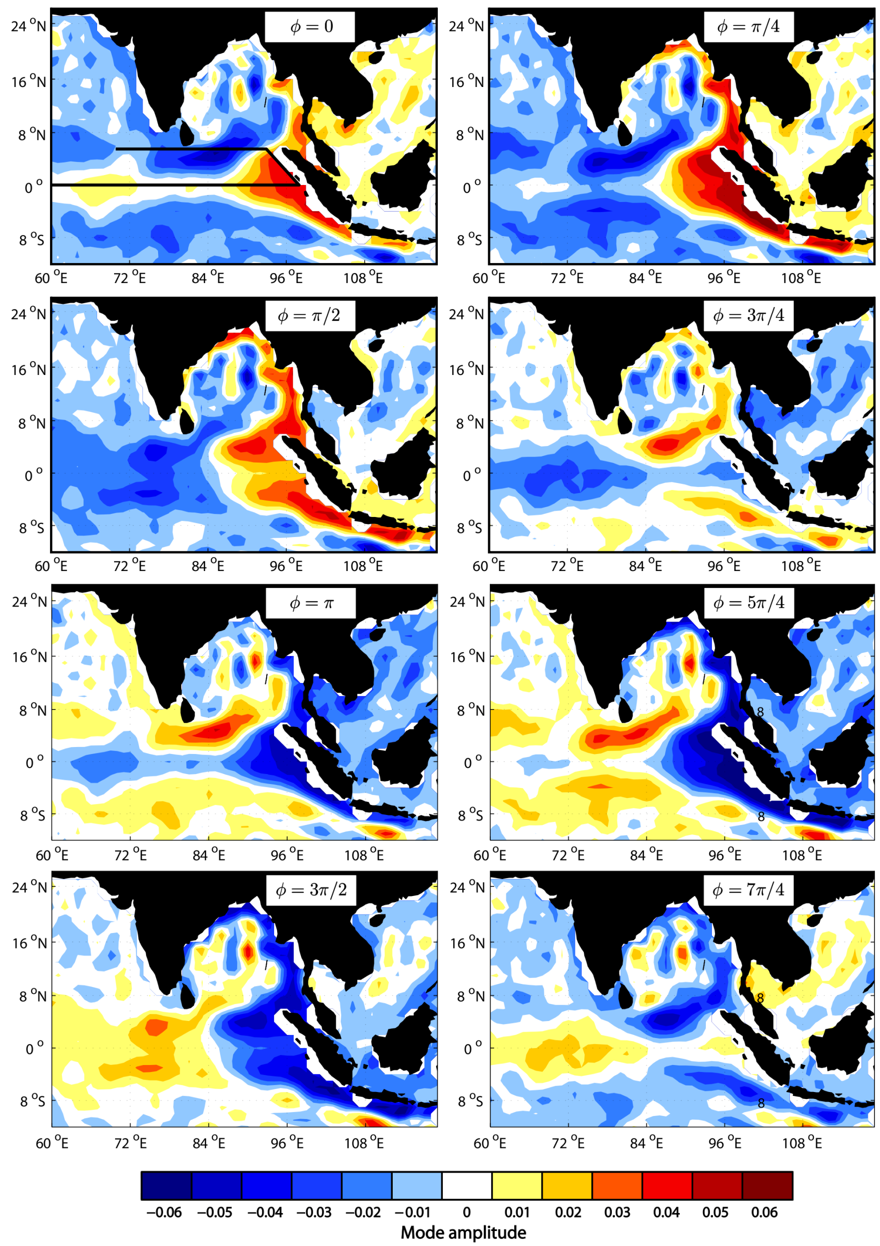


Region 2

- Bandpasss sea level and prediction have cross-correlation of **0.70**
- Note that at 75 days, coherence between MJO index and northwesterly wind is **0.68** … **set up is mostly due to MJO-driven surface winds**



Region 3

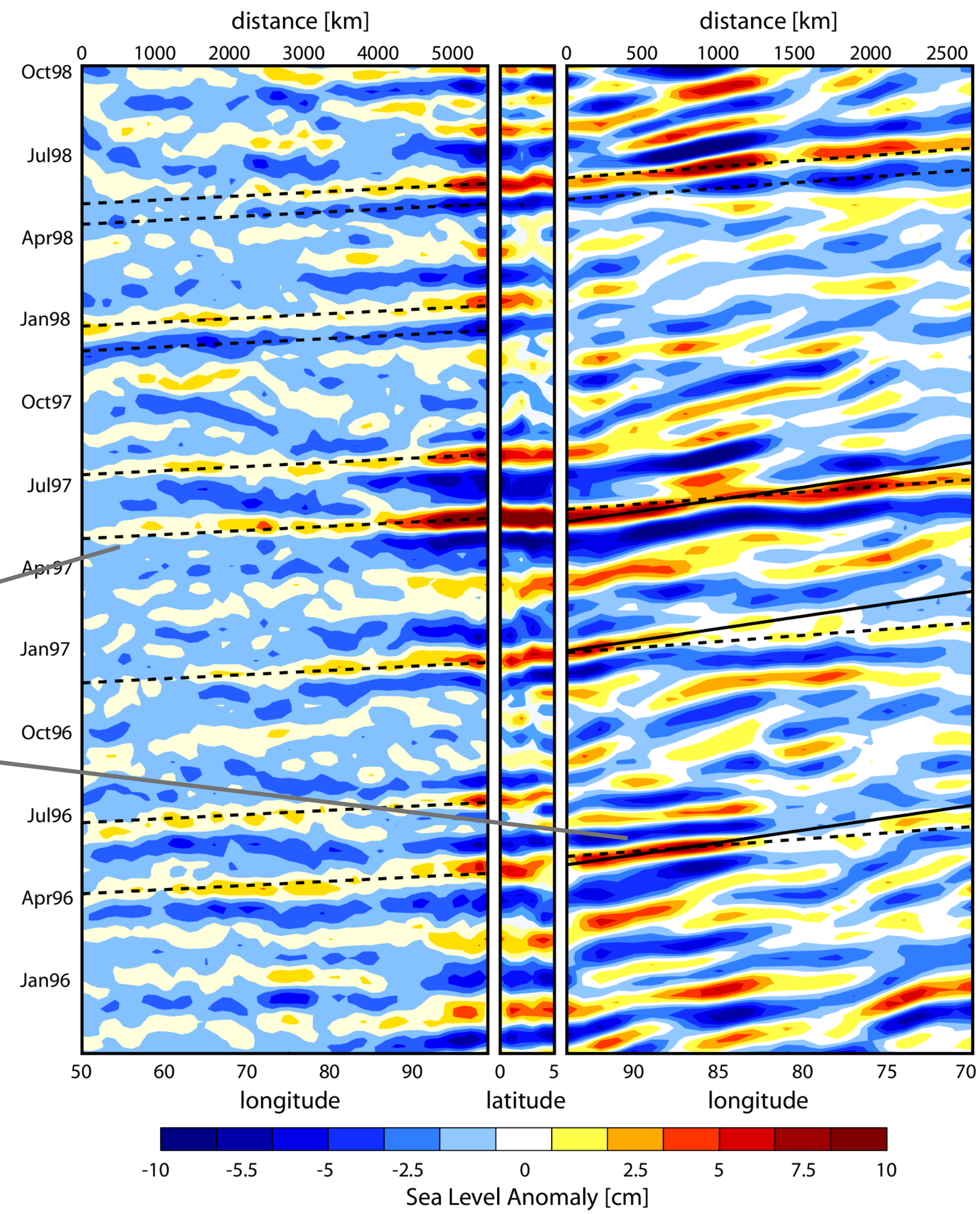


- First FDEOF mode
- 75 day period
- explains ~25% of variance

- Complex dynamics:
  - Equatorial wave
  - Westward Rossby waves (~5.5N)
  - Coastal Kelvin waves

Region 3

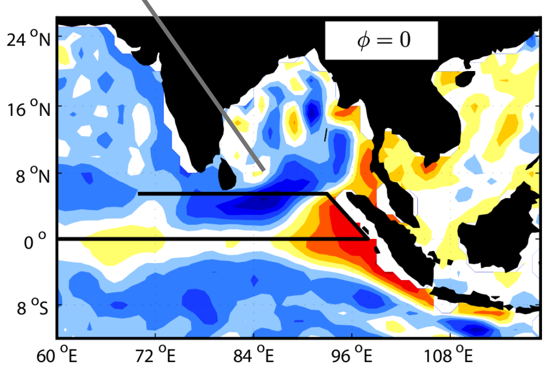
- Modified Hoffmueler diagram
- Follows path shown below
- Shows wave energy is transferred along equator, then to the coast of Sumatra, and then reflected as Rossby waves at ~5.5N



Eq. trapped Kelvin wave
2.8 m/s

path used
in diagram

Rossby waves
0.93 and 0.47 m/s



Conclusions

- The **MJO has expressions in global sea level** and we focus on three specific regions
- Regional analysis show a variety of mechanisms;
  - **The Pacific Americas**: equatorially trapped wave exciting poleward propagating coastall trapped waves
  - **The Gulf of Carpentaria**: sea level set up in shallow water regions due to MJO–related surface winds
  - **The NE Indian Ocean**: complex dynamics including equatorially trapped Kelvin waves, westward Rossby waves and coastally trapped waves...
- Future work: (i) similar study with SST, and (ii) numerical modeling

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