Pacific Decadal Variability in CCSM3

Wilbert Weijer (Los Alamos National Laboratory)
Niklas Schneider (University of Hawaii, Manoa)

Pacific Decadal Variability (PDV)

- North Pacific climate system displays variability on decadal time scales: PDV
  - Stochastic ocean response to atmospheric forcing
  - Preferred time scales due to
    - Unstable modes of coupled ocean/atmosphere interaction
    - Stochastically excited ocean modes
    - Stochastic resonance

Pacific Decadal Variability

Leading hypotheses

- Critical ingredients
  - Variability in North Pacific pressure system…
  - …generates Ekman pumping anomalies…
  - …setting off Rossby waves…
  - …that propagate westward…
  - …impact strength/location of KOE…
  - …and generate SST anomalies that impact atmosphere
- Time scale determined by *basin crossing time*

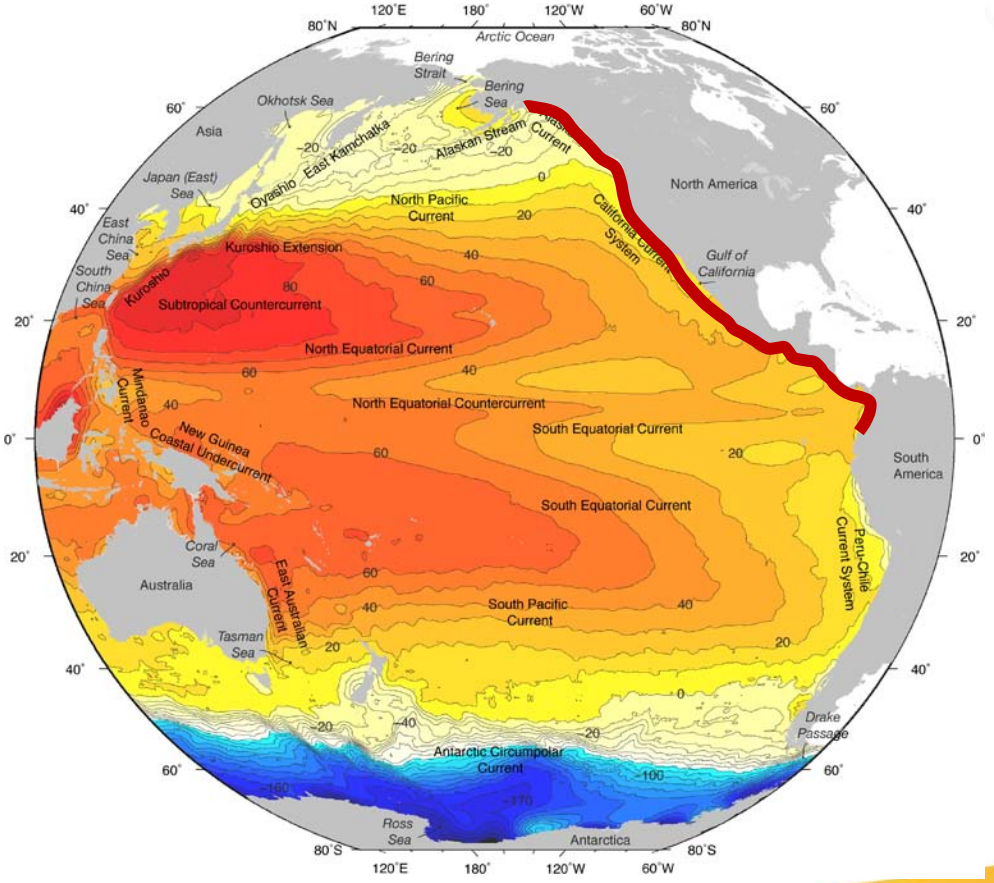
Pacific Decadal Variability in CCSM3

- In CCSM3
  - Significant spectral peaks in North Pacific climate system
  - Spectral peaks on *eastern* boundary
    - 8.5 and 17 yr time scales

Pacific Decadal Variability in CCSM3

Eastern boundary pressure

- P_{500} averaged along eastern basin boundary: P_{east}



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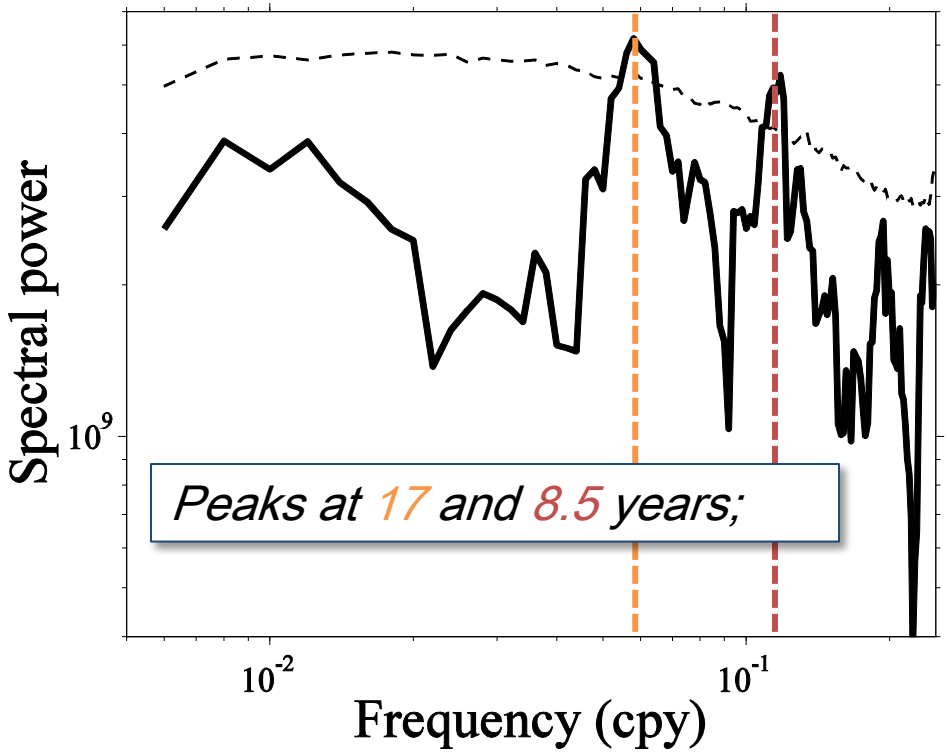
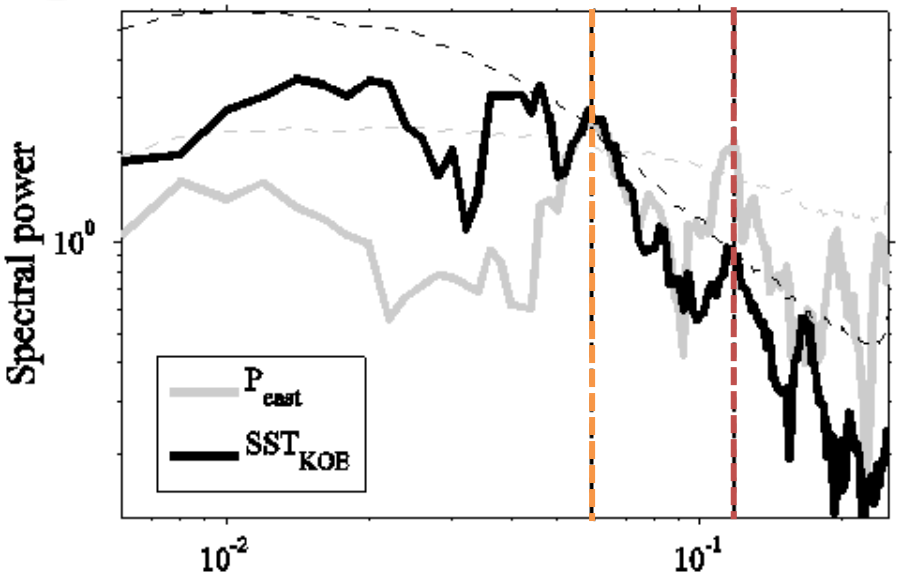
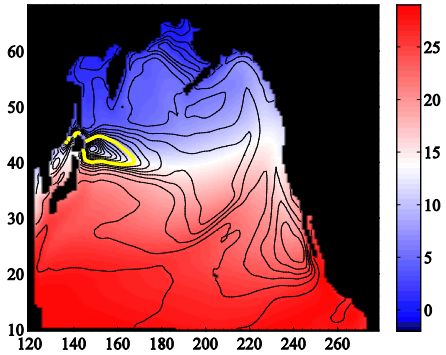


Pacific Decadal Variability in CCSM3

Impact on KOE SSTs

Spectra SST_{KOE} & P_{east}





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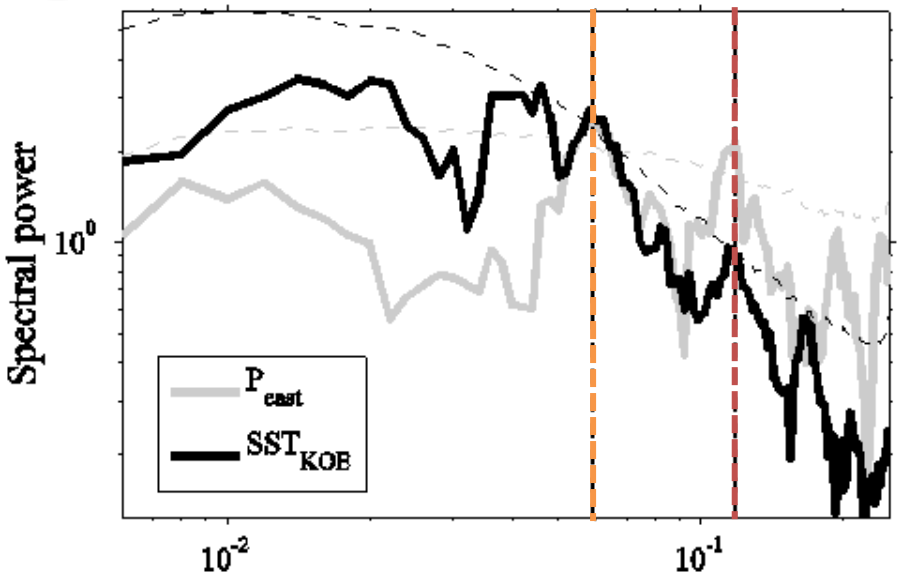
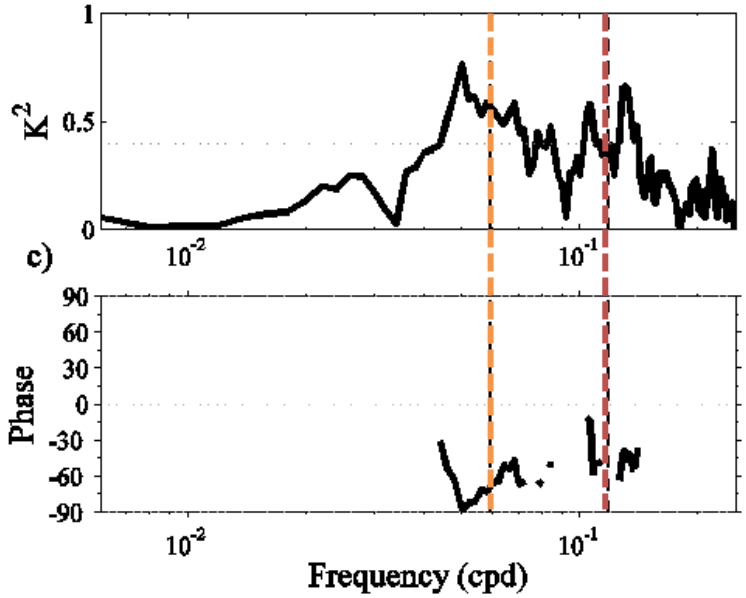
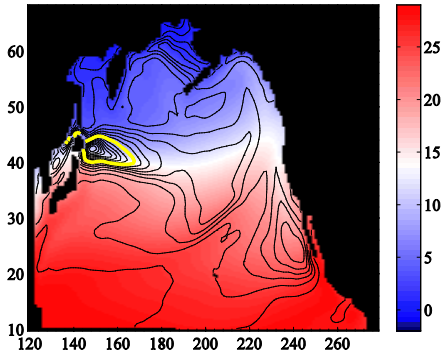


Coherence SST_{KOE} & P_{east}





Questions

- What causes spectral peaks at 8.5 and 17 yr in pressure on eastern basin boundary?
- Does it reflect a resonant mode in North Pacific climate system?
- Are 17 and 8.5 yr periodicities related?

The Model

- We analyze
  - CCSM3
  - 500 year control integration (b30.009)
  - 1990 conditions
  - Annually averaged fields of oceanic and atmospheric variables.
    - 2D fields
    - Baroclinic pressure integrated over upper 500 m (P_{500})
    - Other variables averaged over top 200 m

Hypotheses

- Rossby basin mode
- Passive response to tropical dynamics
- Coupled mid-latitude mode of air/sea interaction
- Stochastic resonance mechanism

Coherence Analysis

- Which variables $F(x, t)$ are involved in oscillations?
- Where is F coherent with P_{east} at 8.5 and 17 yr?
  - Coherence between F and P_{east}
    - Evaluate coherence at 17 yr or 8.5 yr
    - Determine significance @ 90%
    - Display
      - Coherence
      - Phase

Coherence Analysis

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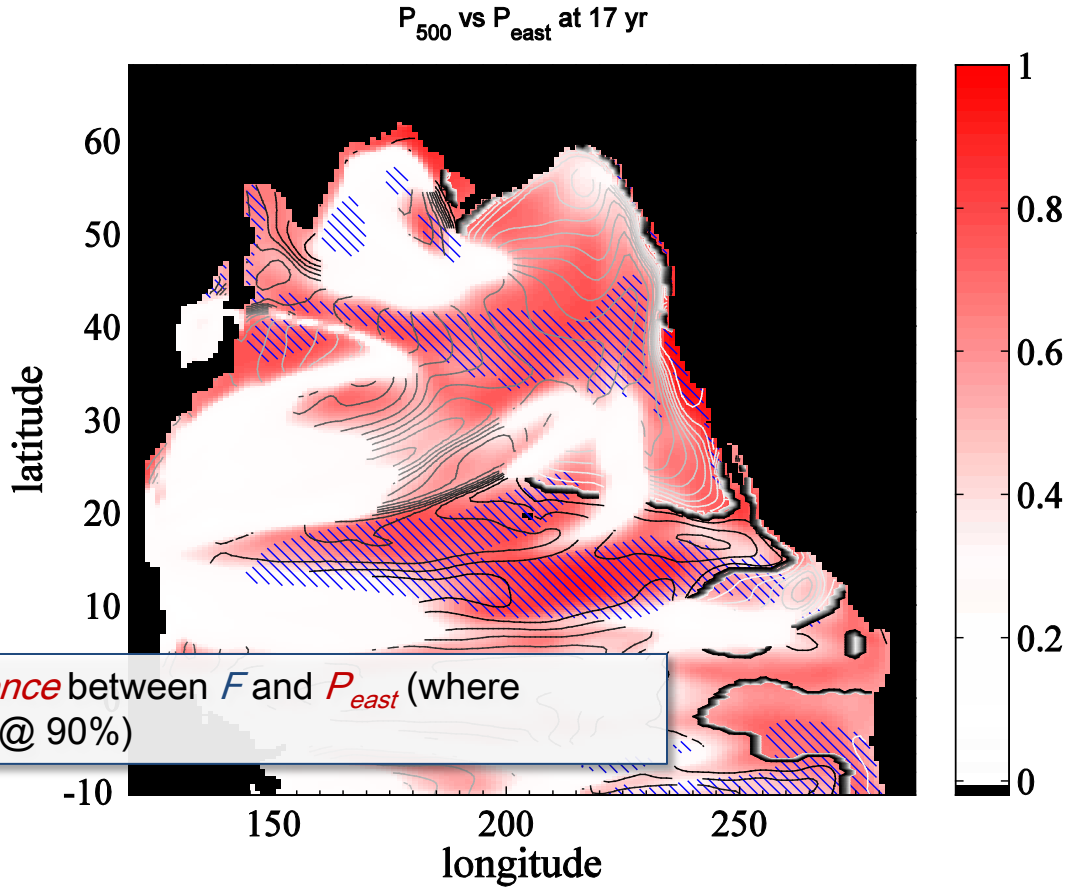
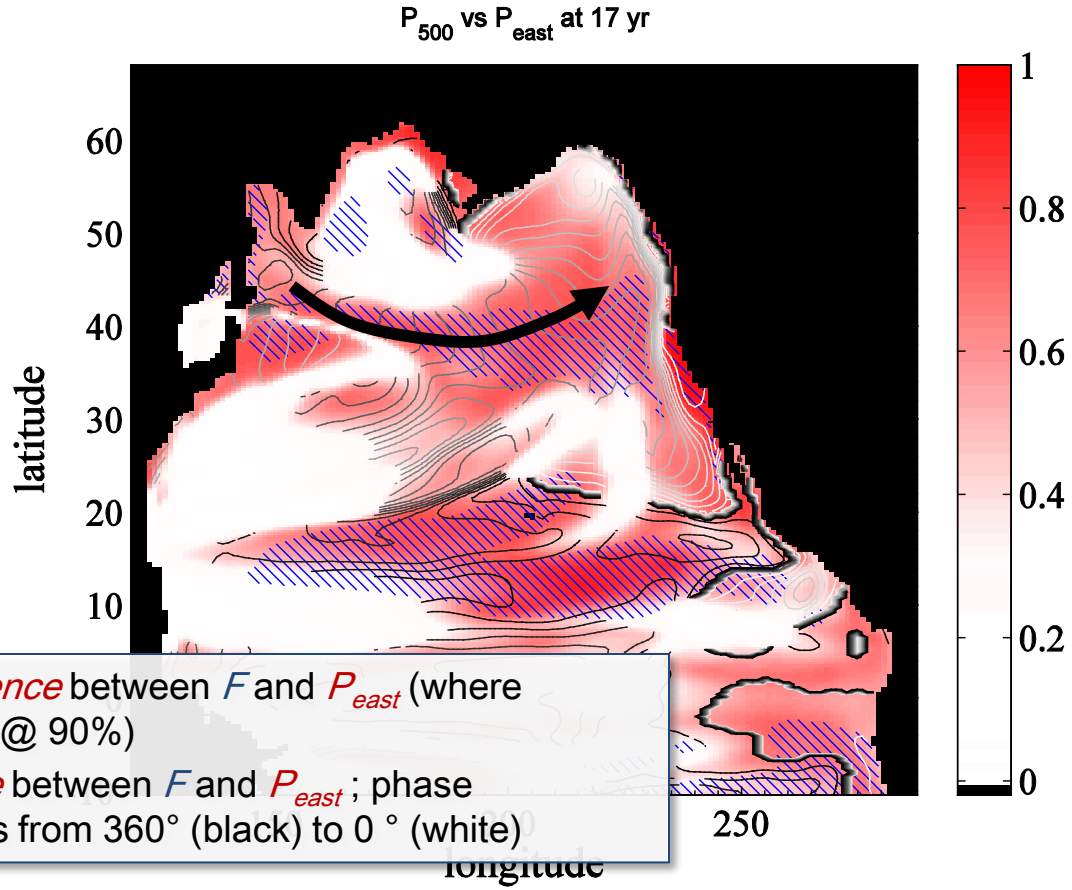
    - Display
      - Coherence
      - Phase
- Where does F contain enhanced energy at 8.5 and 17 yr?
  - Spectral analysis of F
    - Evaluate spectral power at 17 yr or 8.5 yr
    - Determine significance @ 90%
    - Hatch significant regions

Coherence Analysis



Shading: *coherence* between *F* and P_{east} (where significant @ 90%)

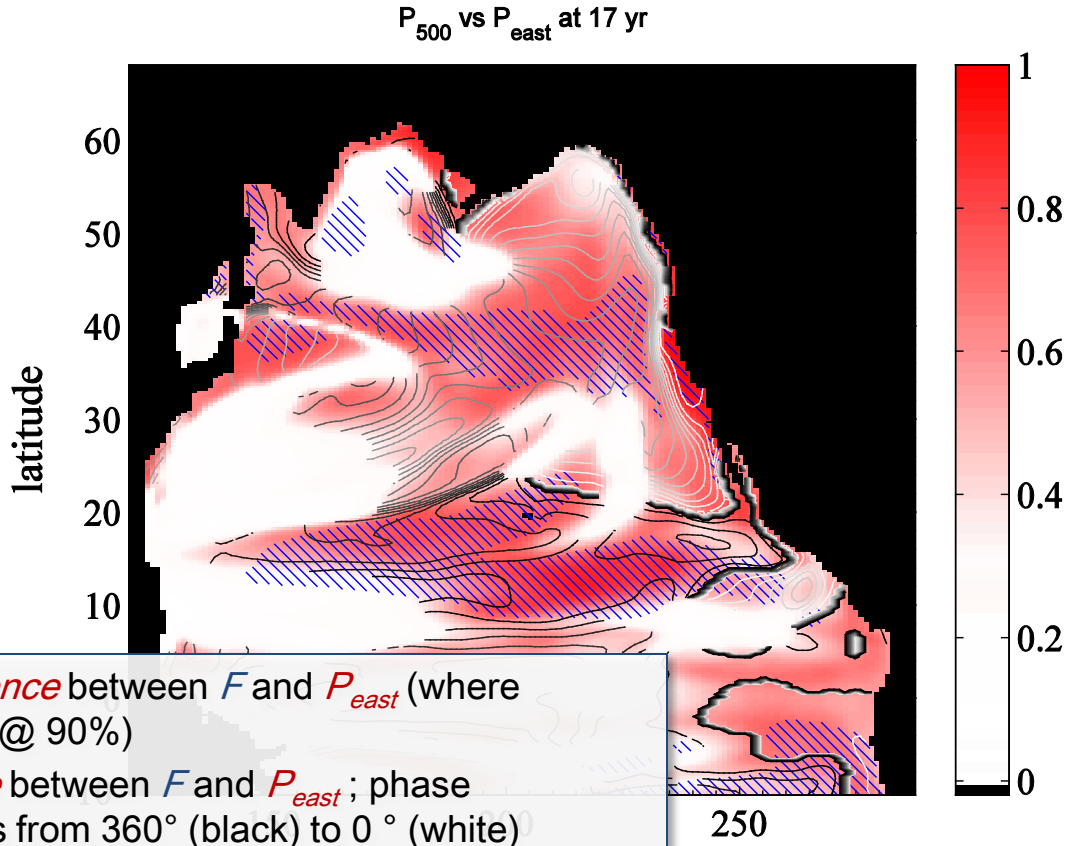
Coherence Analysis



Shading: *coherence* between *F* and P_{east} (where significant @ 90%)

Contours: *phase* between *F* and P_{east} ; phase progresses from 360° (black) to 0 ° (white)

Coherence Analysis



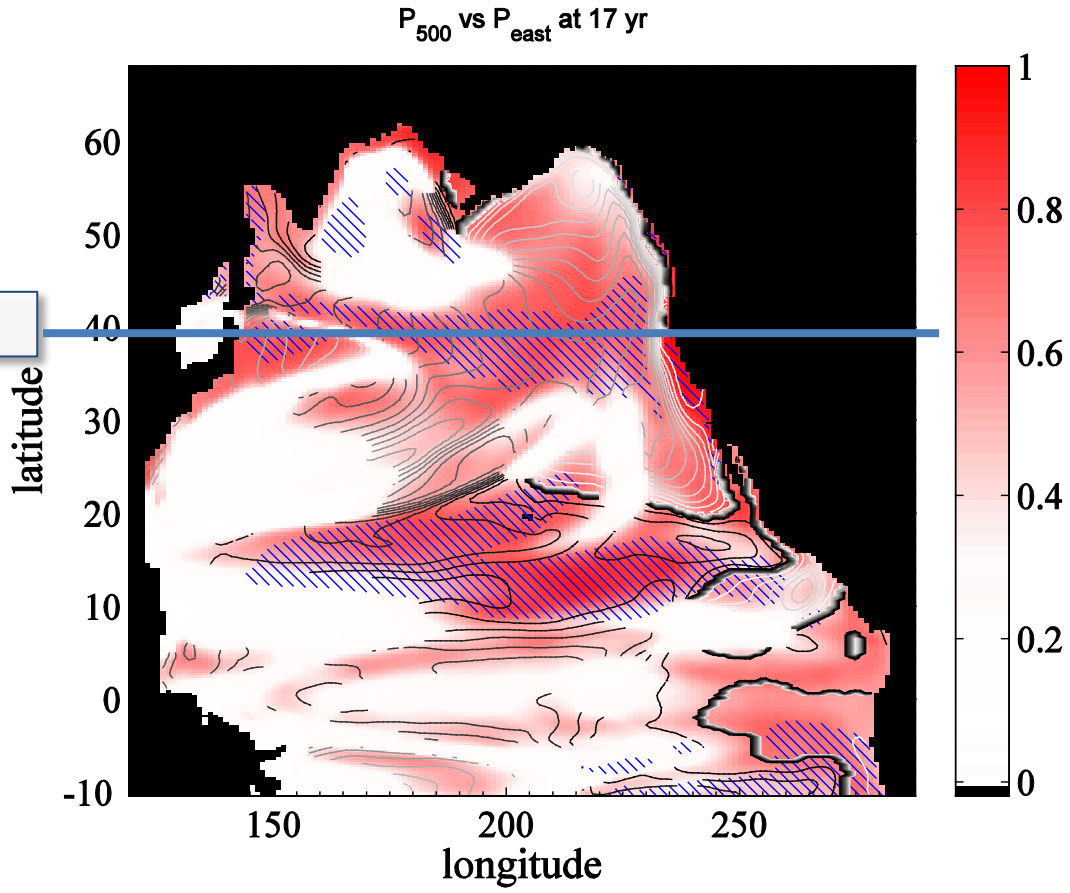
Shading: *coherence* between *F* and P_{east} (where significant @ 90%)

Contours: *phase* between *F* and P_{east} ; phase progresses from 360° (black) to 0 ° (white)

Cross hatching: *spectral power* of *F* enhanced @ 90%

Coherence Analysis

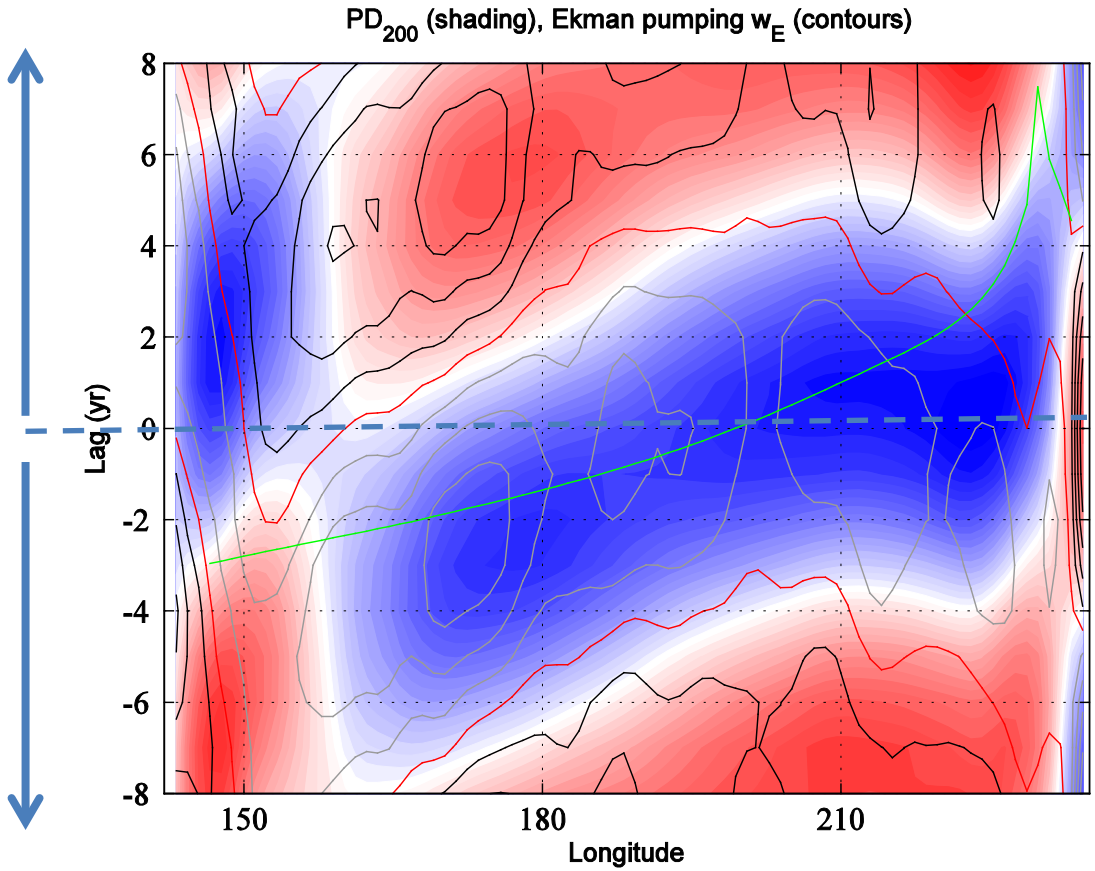
Zonal section 40°N



Lagged Correlation Analysis

- What role do variables $F(x, t)$ play in oscillation?
- Correlation between F and P_{east}
  - Lagged regression between F and P_{east}^{17} & $P_{east}^{8.5}$
    - P_{east}^{17} : 15 – 20 yr band-pass filter (Parks-McClellan)
    - $P_{east}^{8.5}$: 8 – 9 yr band-pass filter (Parks-McClellan)
    - T = +/-8 yr

Lagged Correlation Analysis

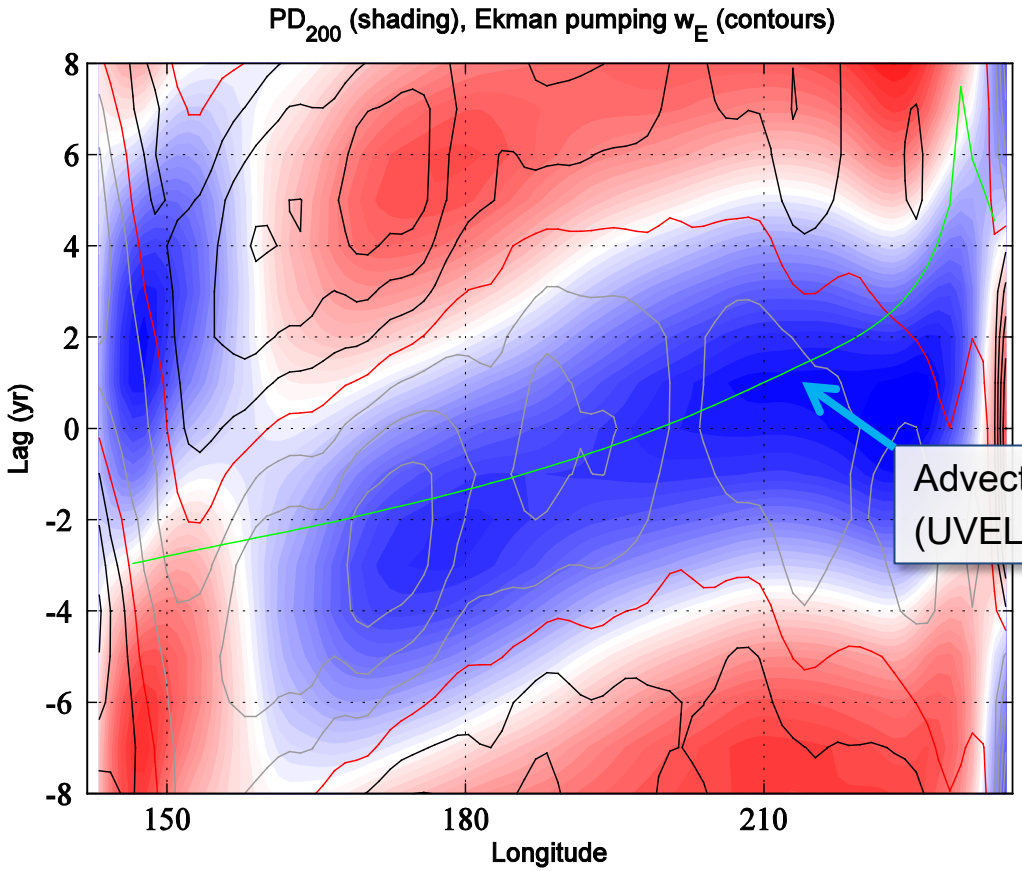


P_{east} leads F

F leads P_{east}

Zonal section 40°N

Lagged Correlation Analysis



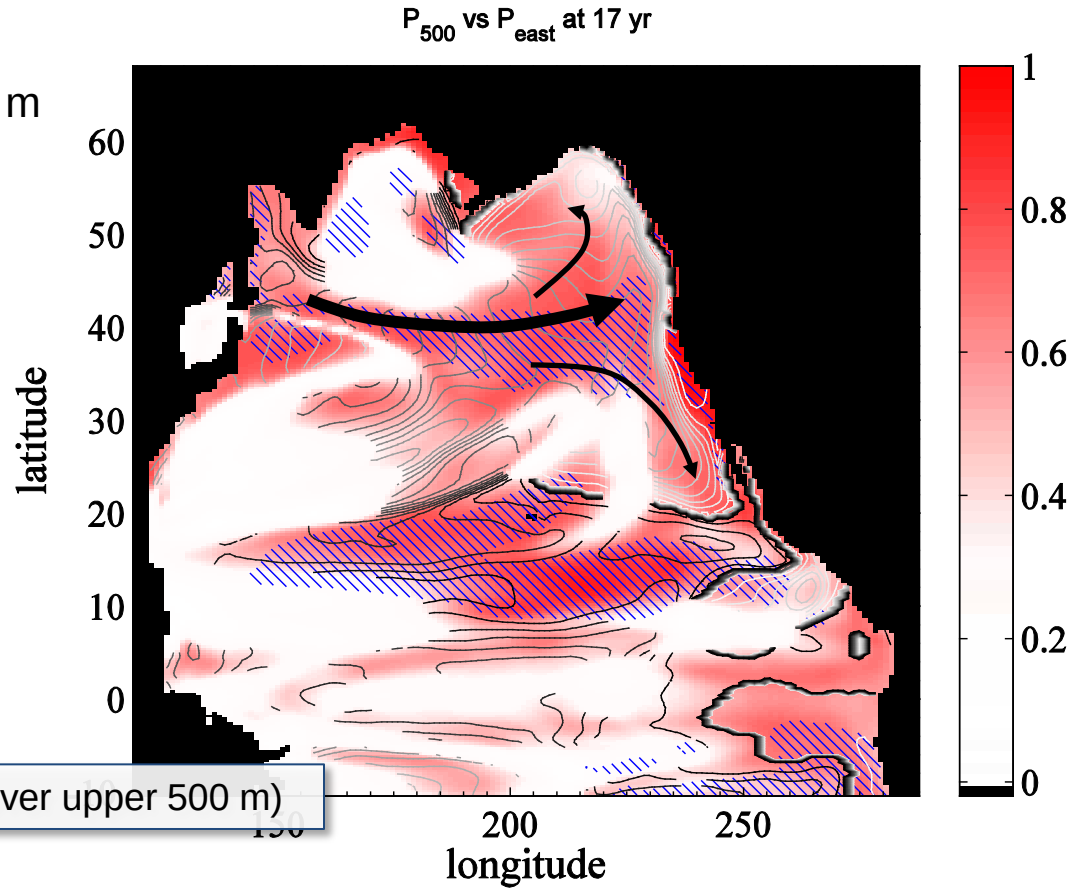
Rossby Basin Mode

- Westward propagating pressure anomalies
- Pressure homogenization along western, equatorial, and eastern boundaries

Rossby Basin Mode?

17 yr

- Dominant *eastward* propagation in upper 500 m

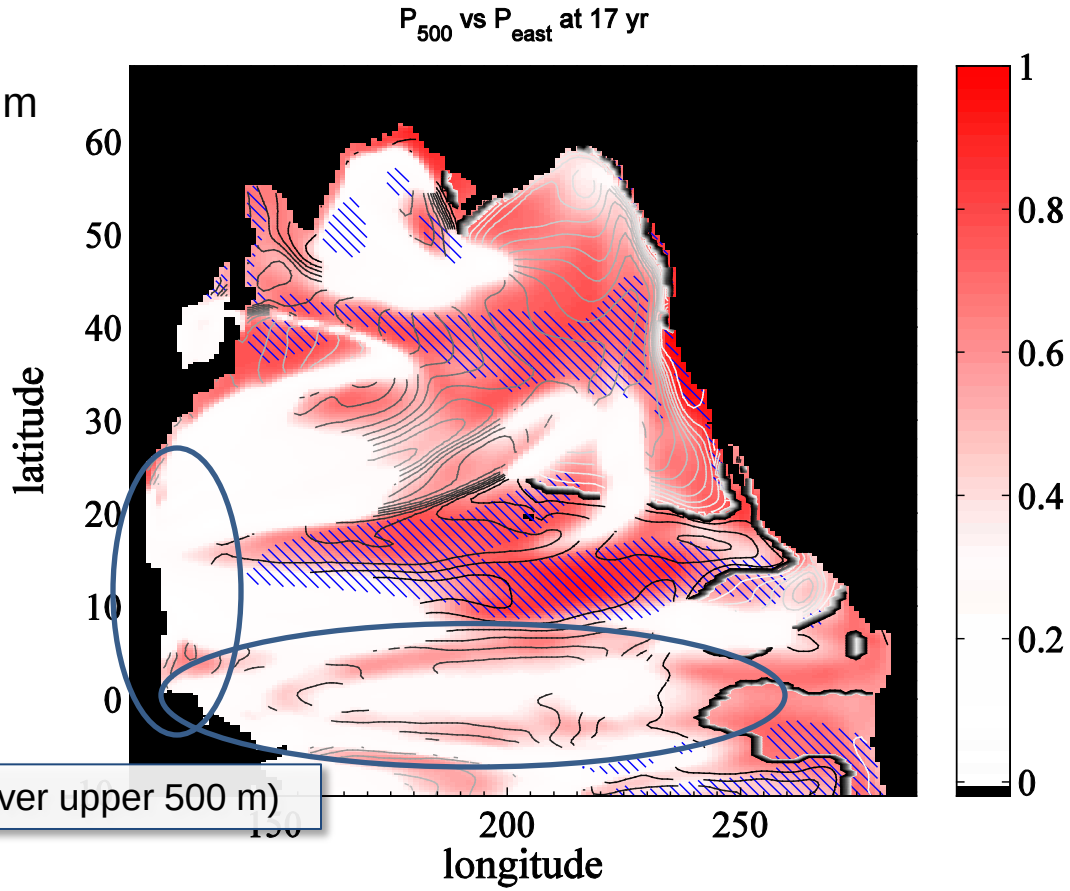


P_{500} (pressure integrated over upper 500 m)

Rossby Basin Mode?

17 yr

- Dominant *eastward* propagation in upper 500 m
- No coherent signal along western/equatorial boundary

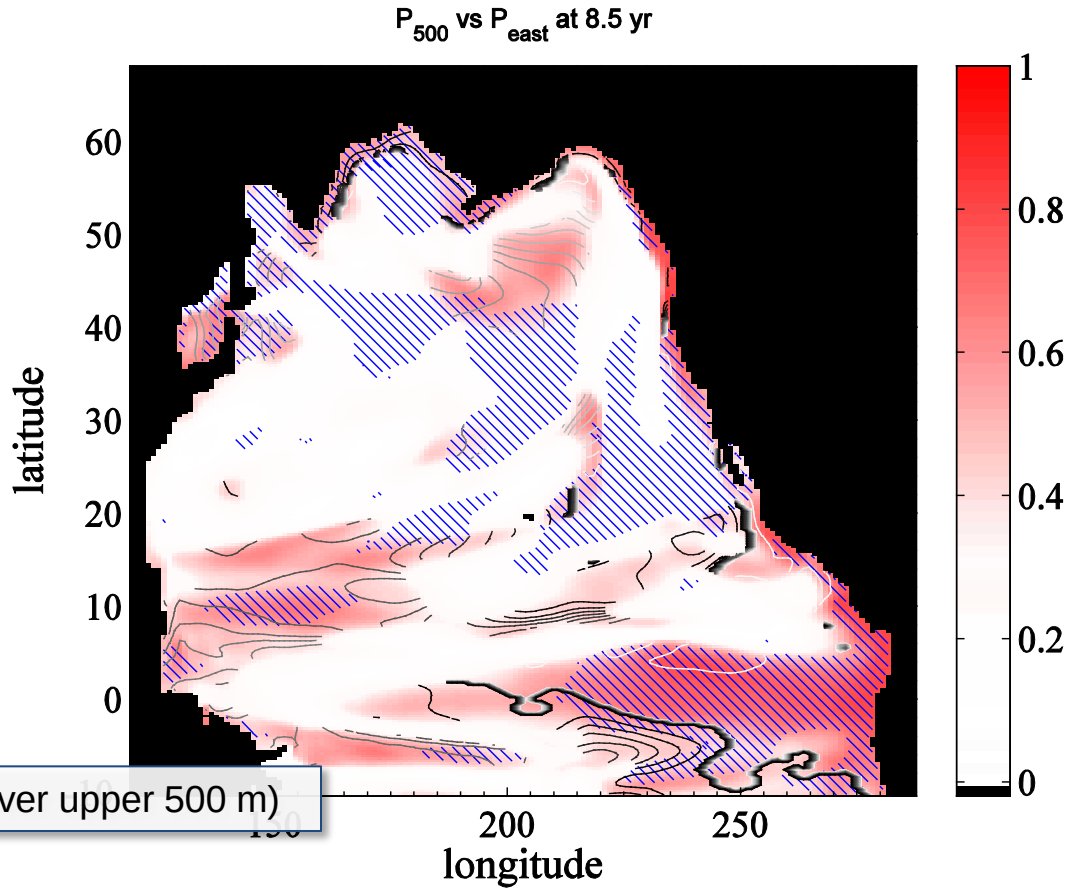


P_{500} (pressure integrated over upper 500 m)

Rossby Basin Mode?

8.5 yr

- Weaker, less wide-spread coherences

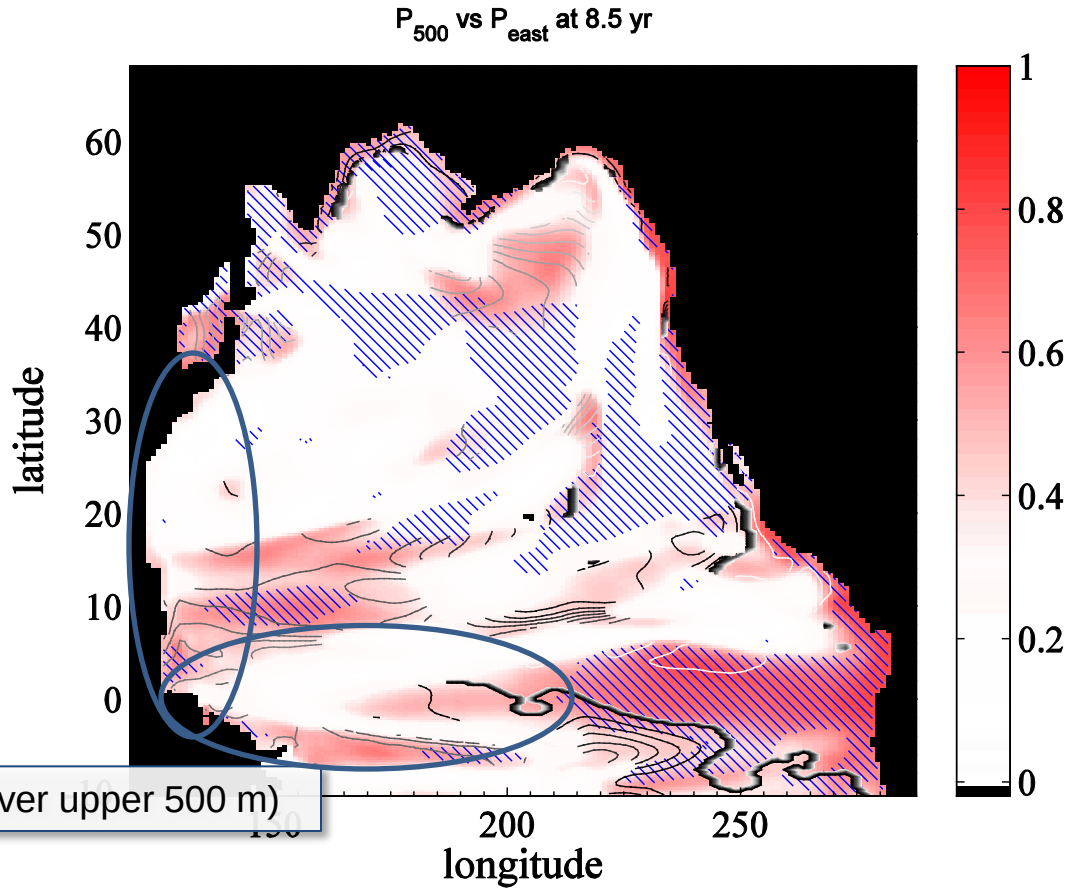


P_{500} (pressure integrated over upper 500 m)

Rossby Basin Mode?

8.5 yr

- Weaker, less wide-spread coherences
- No clear western/equatorial connection



P_{500} (pressure integrated over upper 500 m)

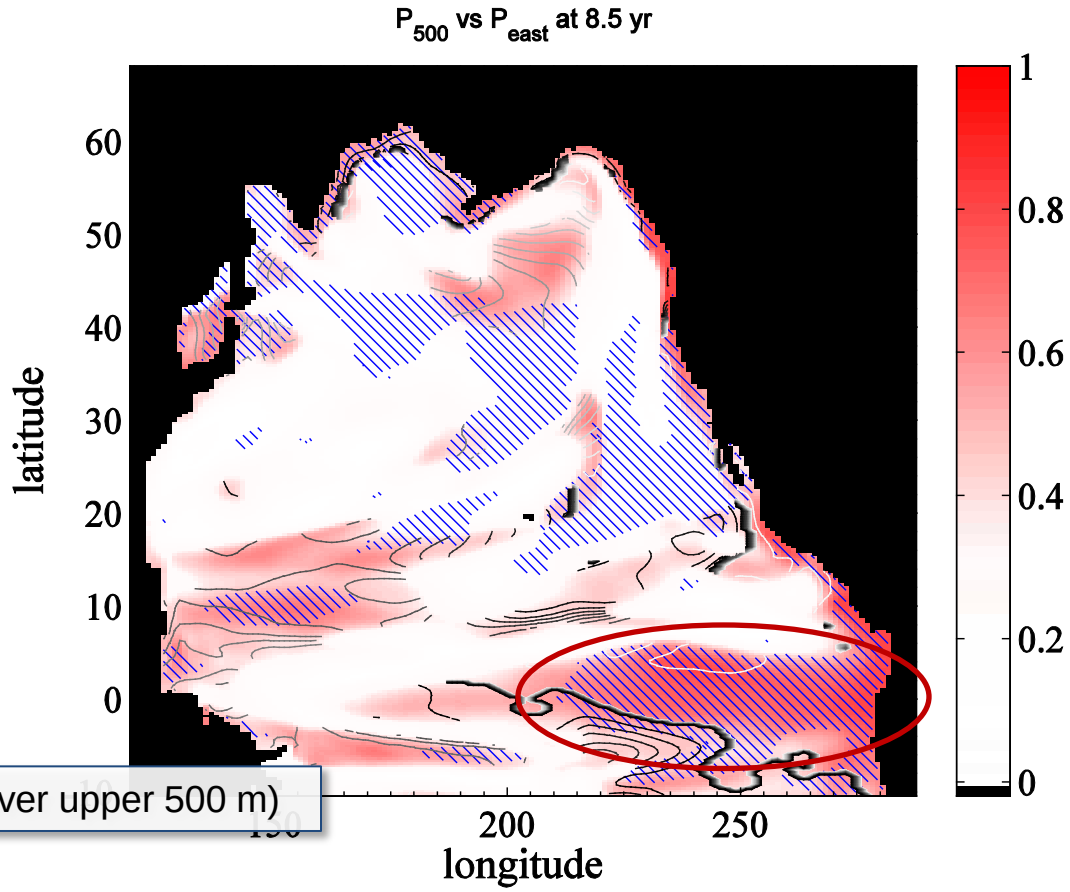
Equatorial Origin

- Through the ocean
  - coastally trapped gravity waves
- Through the atmosphere
  - Significant spectral energy carried by atmospheric variables

Equatorial Origin?

8.5 yr

- Significant signal in eastern equatorial Pacific

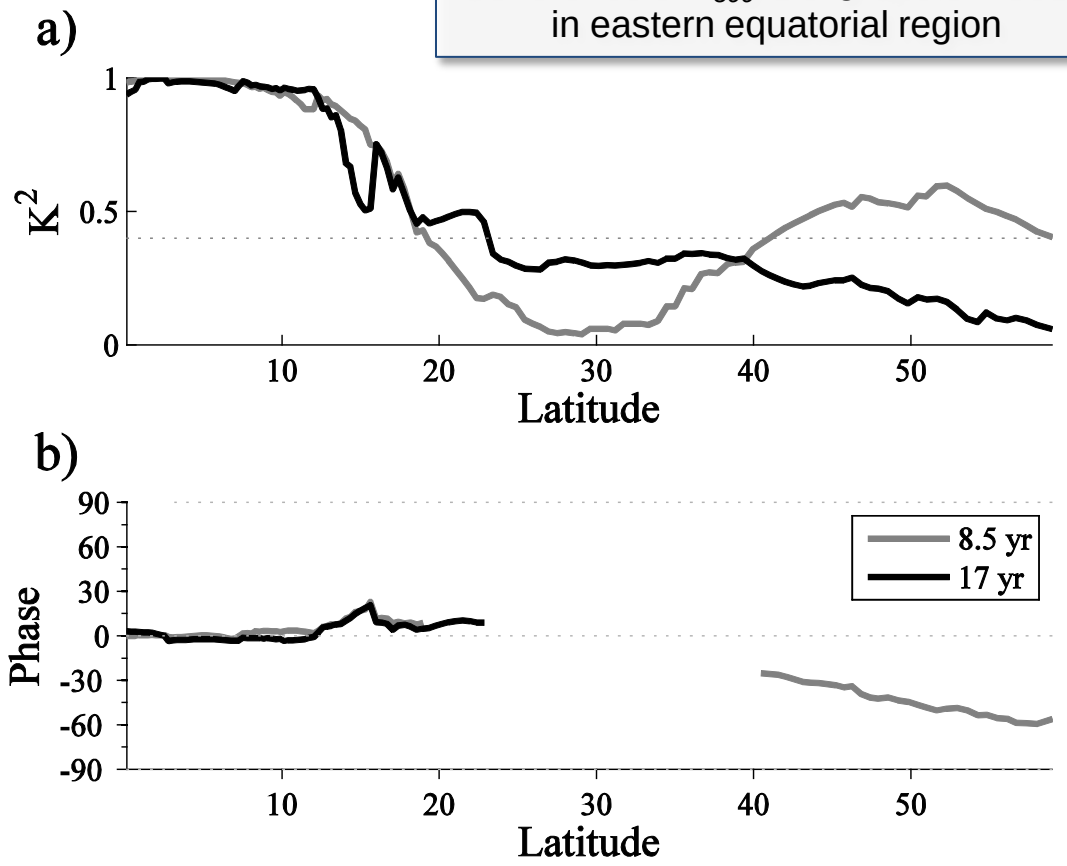


P_{500} (pressure integrated over upper 500 m)

Equatorial Origin?

8.5 yr & 17 yr

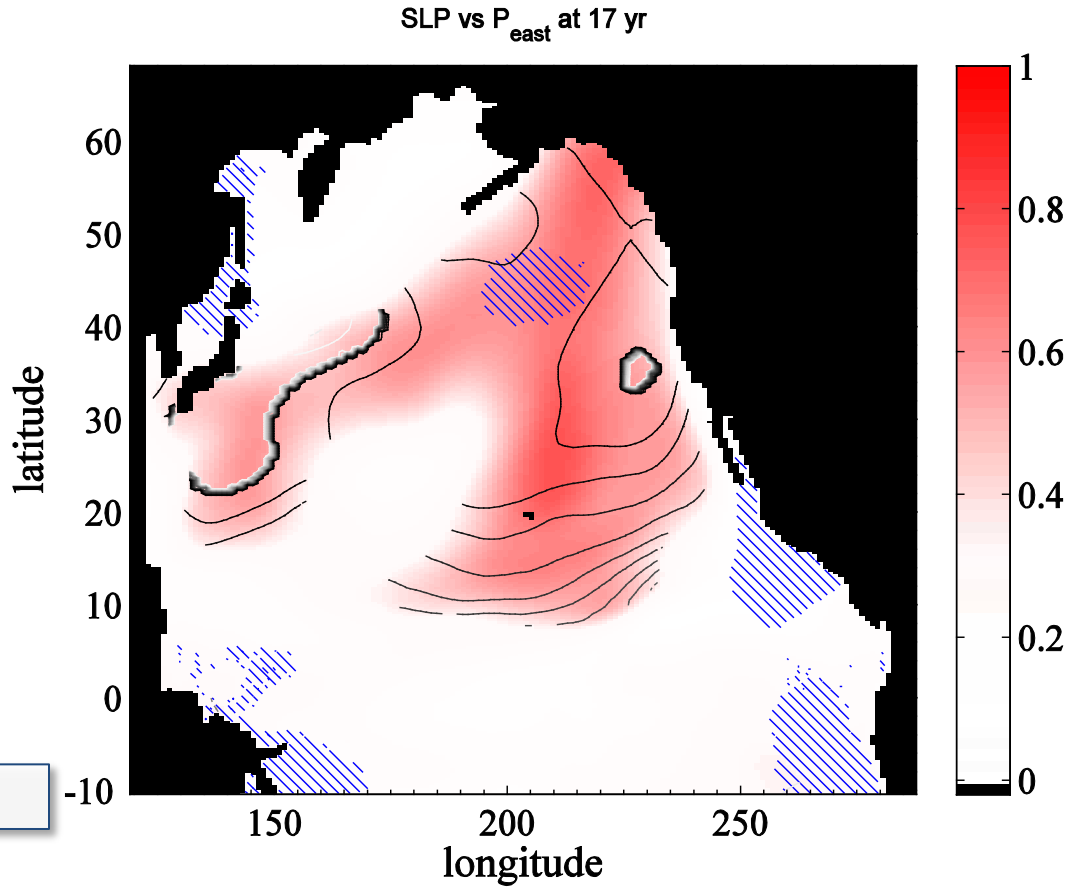
Coherence of P_{500} along eastern boundary with P_{500} in eastern equatorial region



Equatorial Origin?

17 yr

- No signal in equatorial Pacific

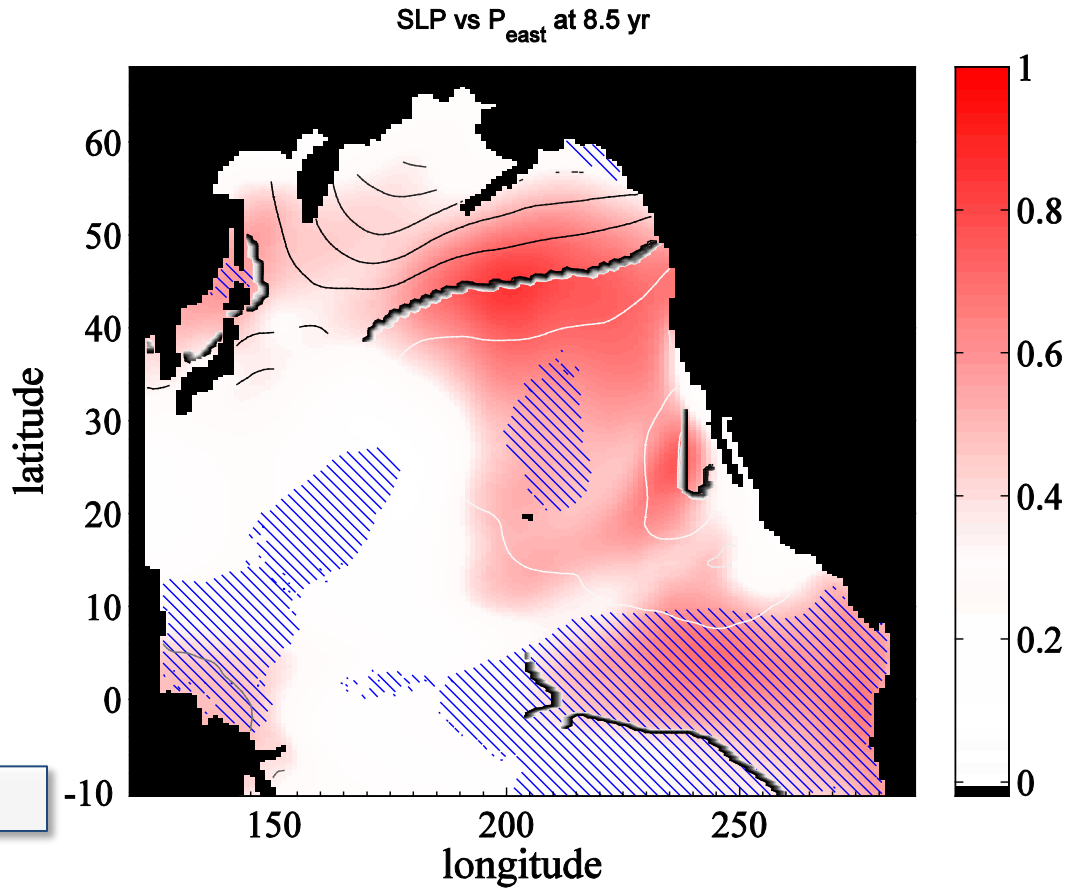


Sea Level Pressure (SLP)

Equatorial Origin?

8.5 yr

- Significant signal in eastern equatorial Pacific
- But mechanism?



Sea Level Pressure (SLP)

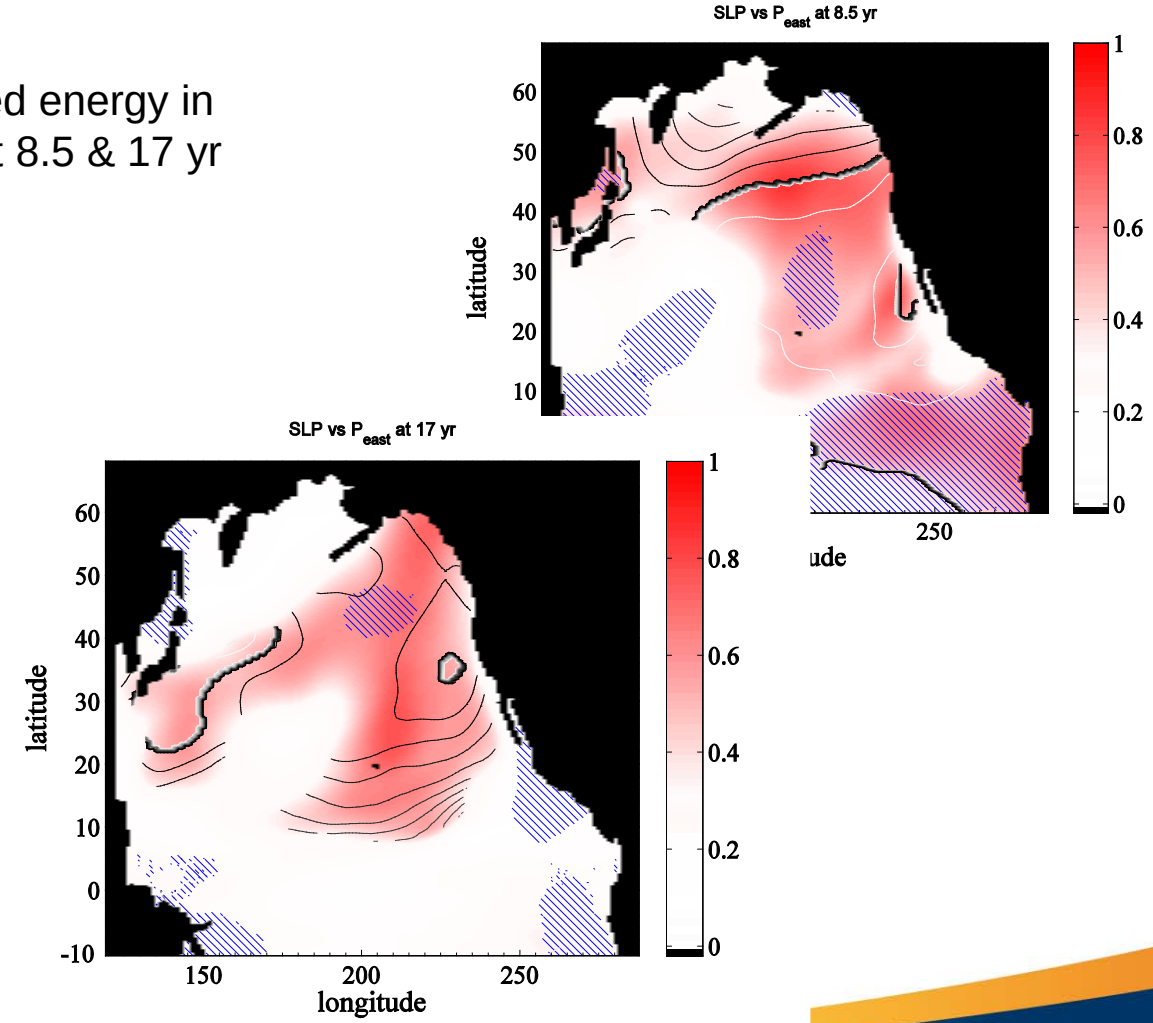
Mid-latitude Coupled Mode

- Enhanced power carried both by ocean and atmosphere variables

Mid-latitude Coupled Mode?

8.5 & 17 yr

- No significantly enhanced energy in atmospheric variables at 8.5 & 17 yr



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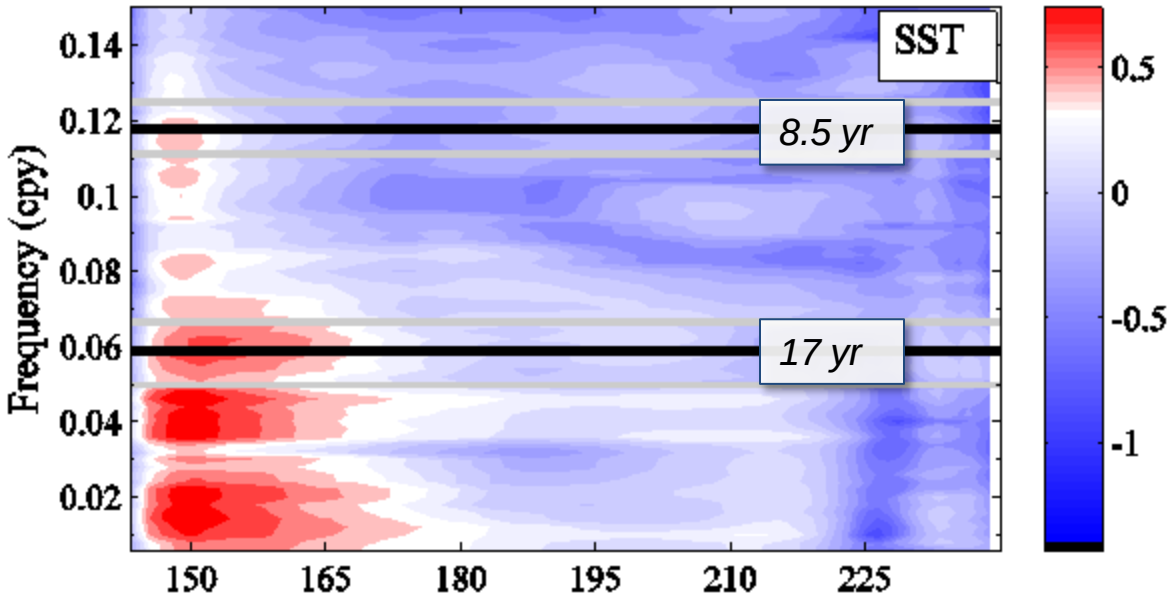
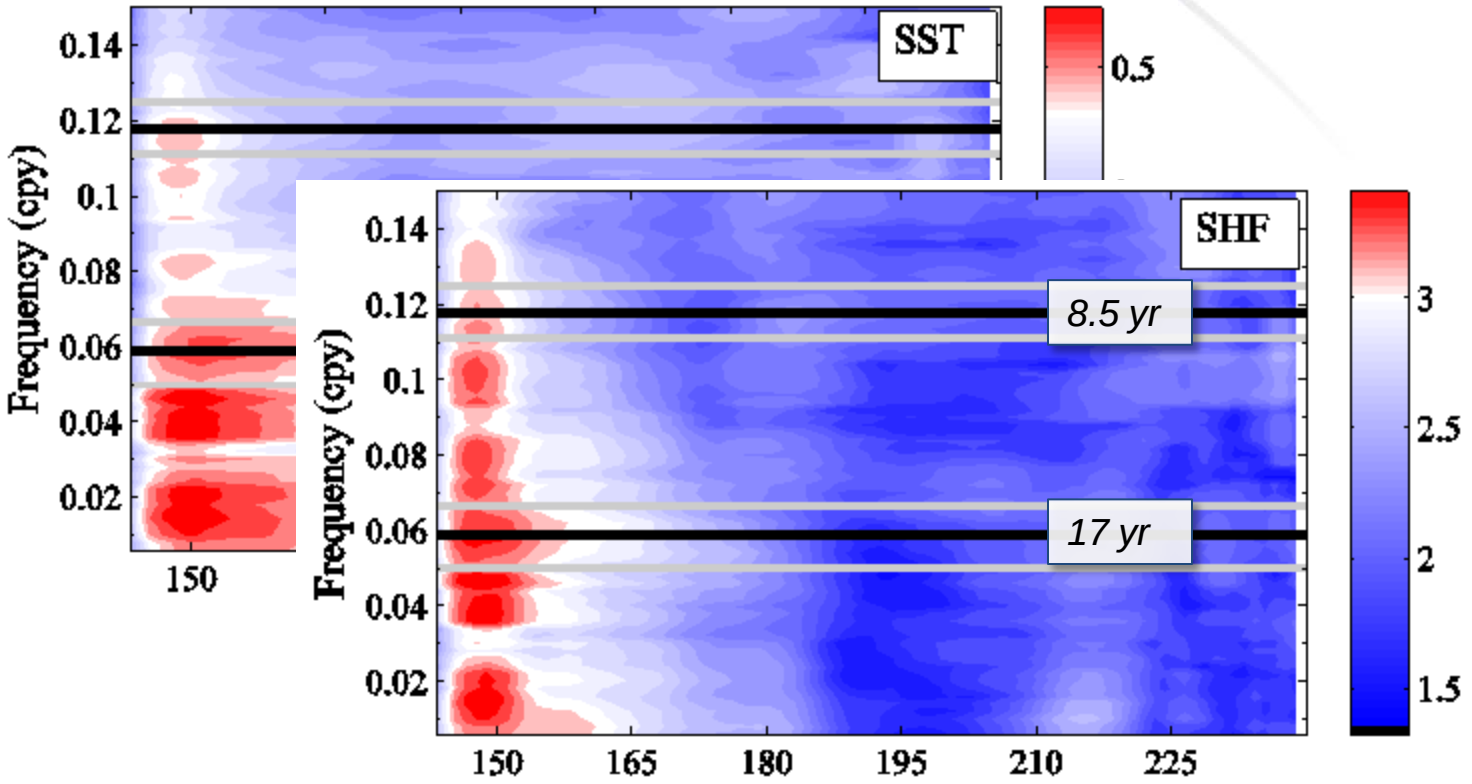


Average over 35°-45°N

Mid-latitude Coupled Mode?

8.5 & 17 yr



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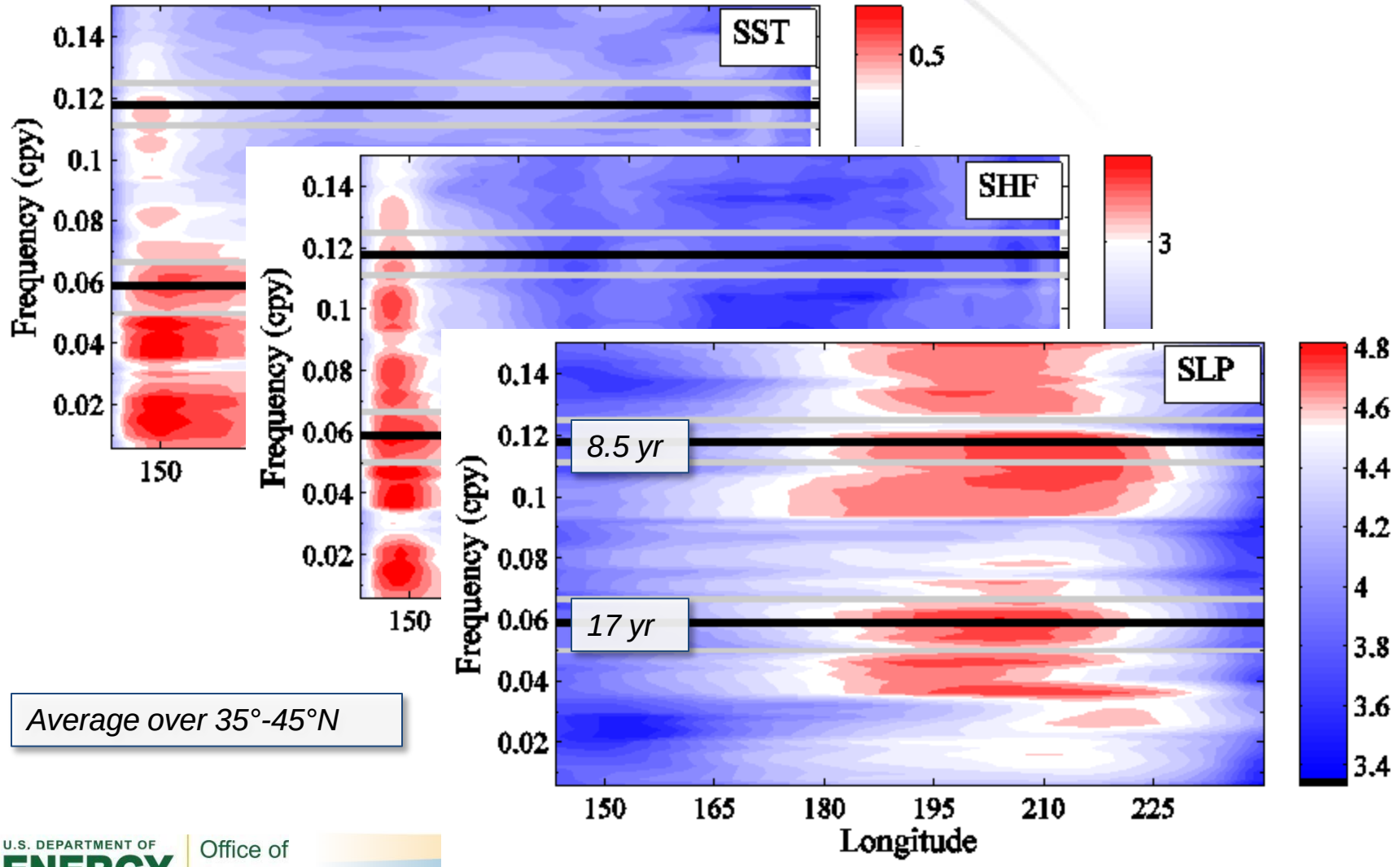


Average over 35°-45°N

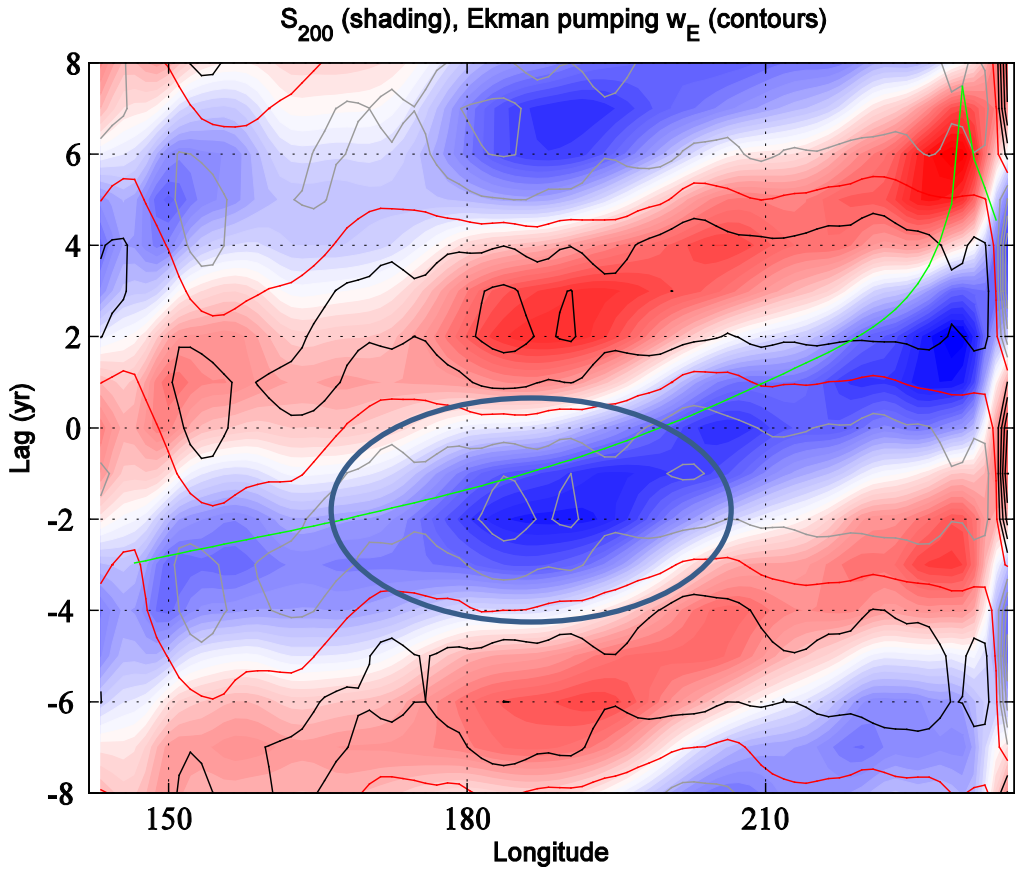
Advective Resonance

- Advection carries water parcels through alternating (bipolar) forcing regime
- Enhanced power in atmosphere not critical

Advective Resonance

8.5 yr

- S_{200} anomaly generated east of dateline by Ekman pumping…



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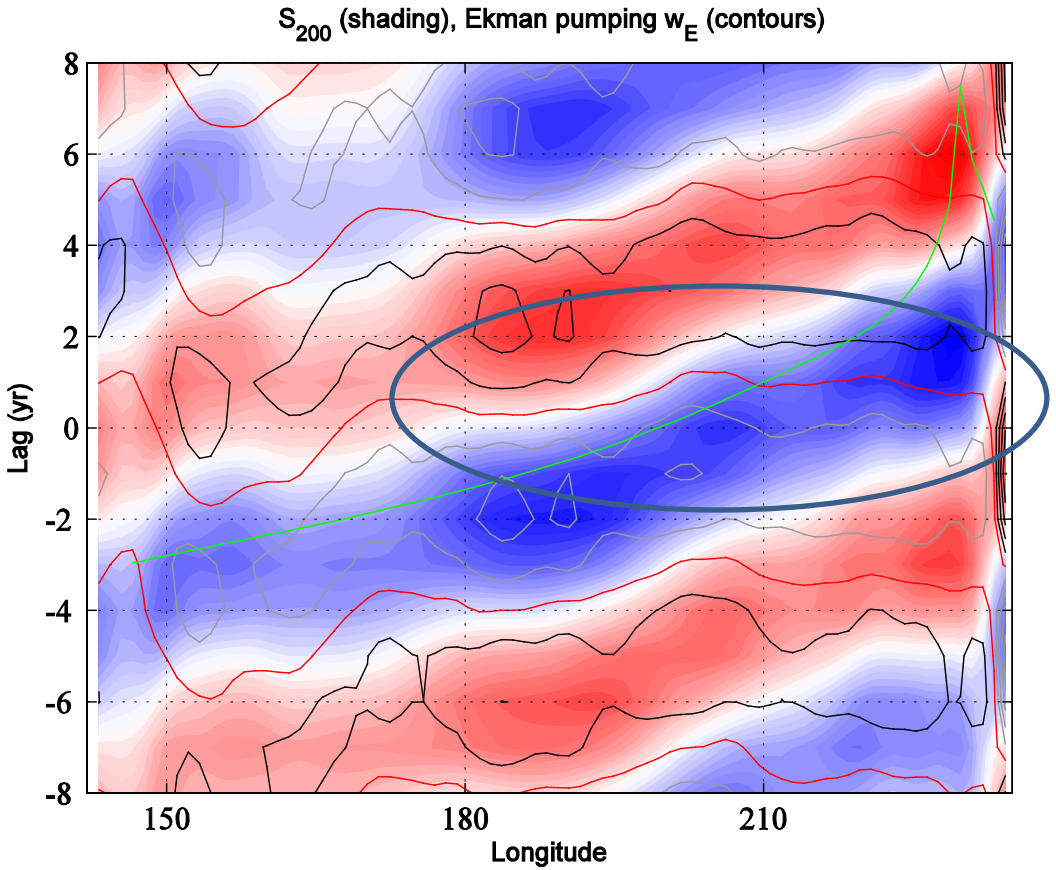
- …is advected *eastward* by mean flow…



Advective Resonance

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- S_{200} anomaly generated east of dateline by Ekman pumping…
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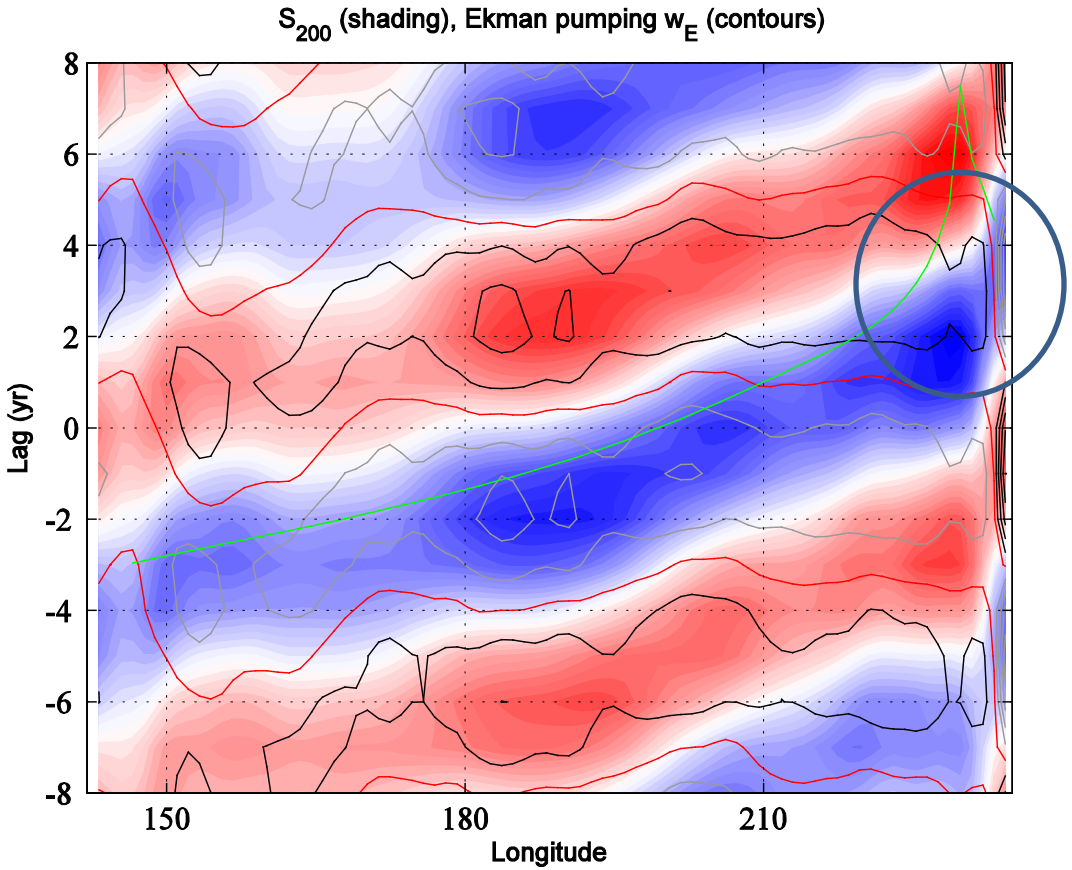
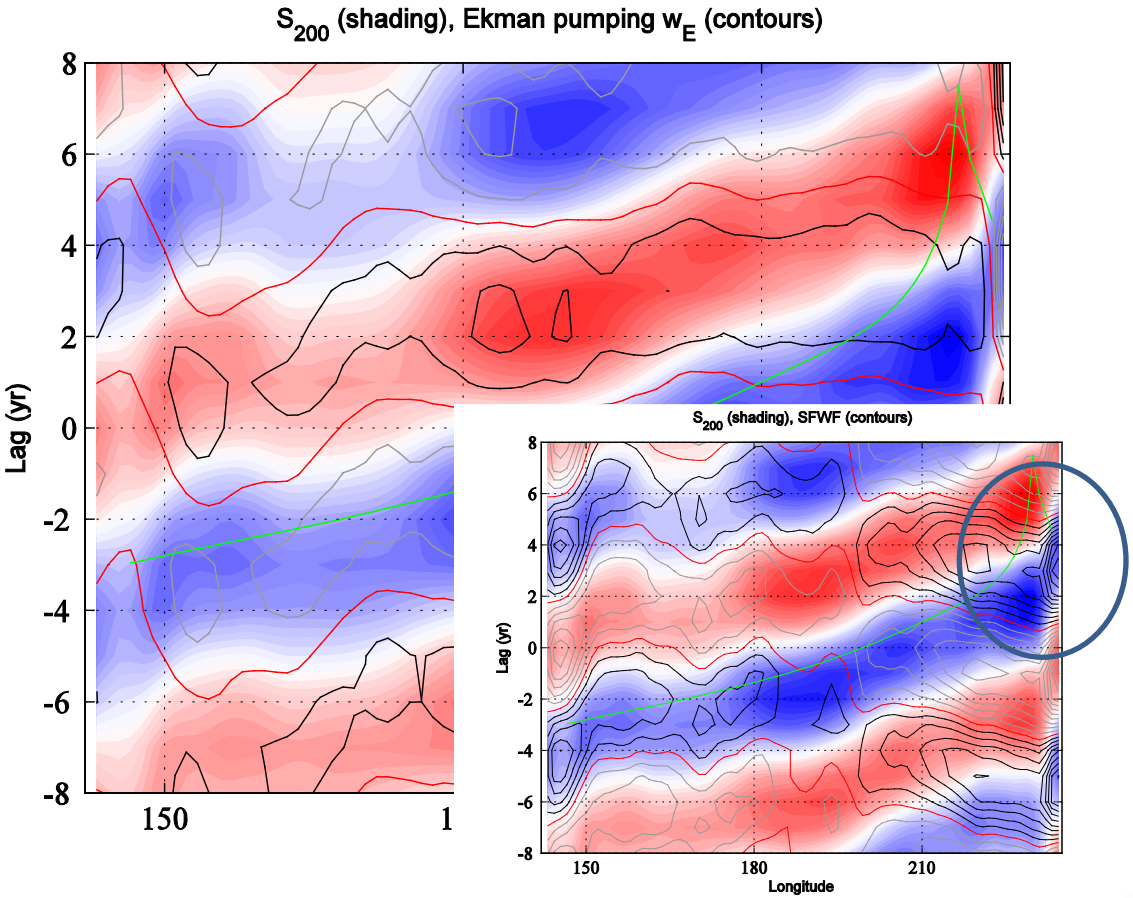


Advective Resonance

8.5 yr

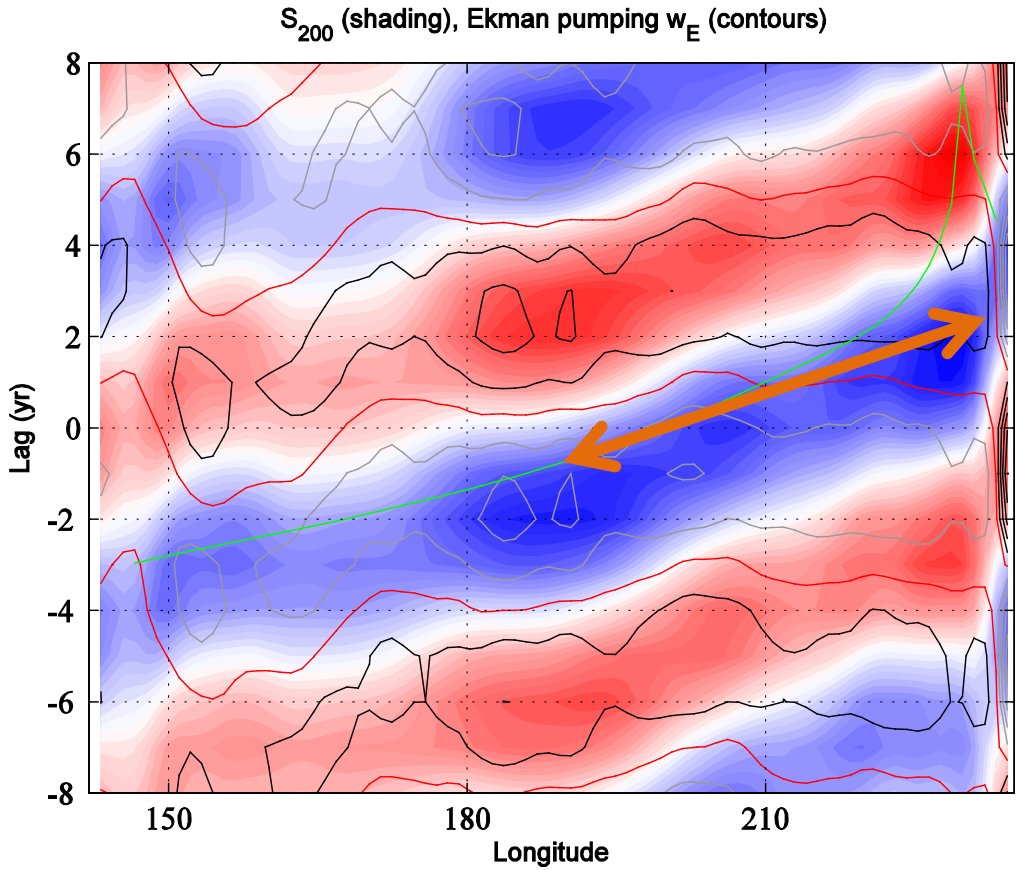
- S_{200} anomaly generated east of dateline by Ekman pumping…
- …is advected *eastward* by mean flow…
- …is amplified by coastal upwelling…
- …and run-off



Advective Resonance

8.5 yr

- Time scale determined by
  - *advection speed*



Advective Resonance

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- Time scale determined by
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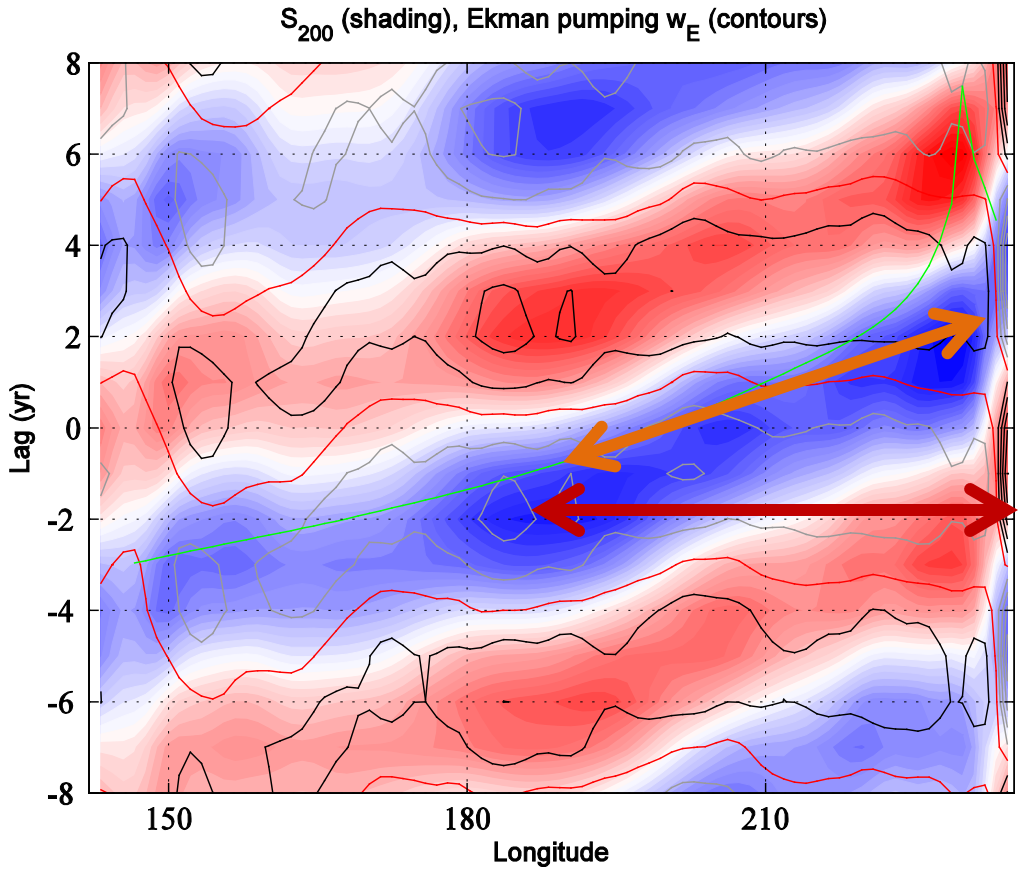
  - *length scale* of forcing



Advective Resonance

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- Time scale determined by
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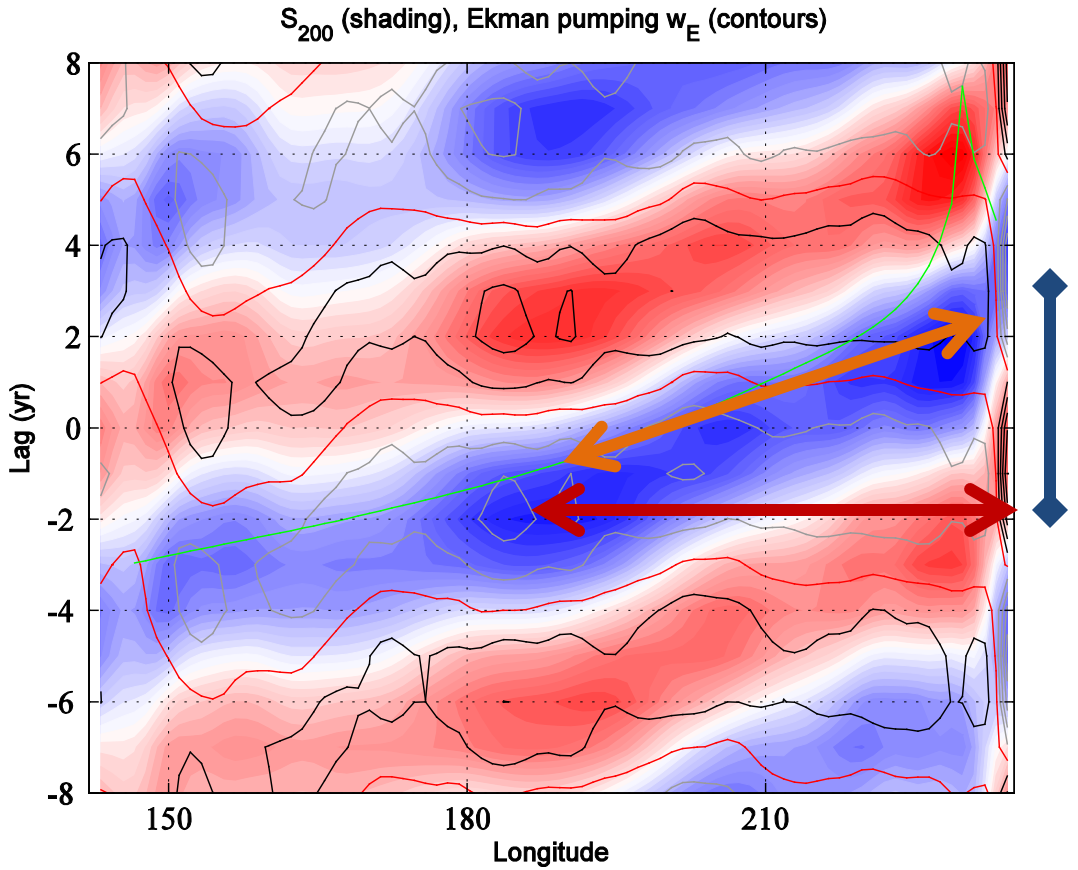
  - *length scale* of forcing
- ~ **5 yr**



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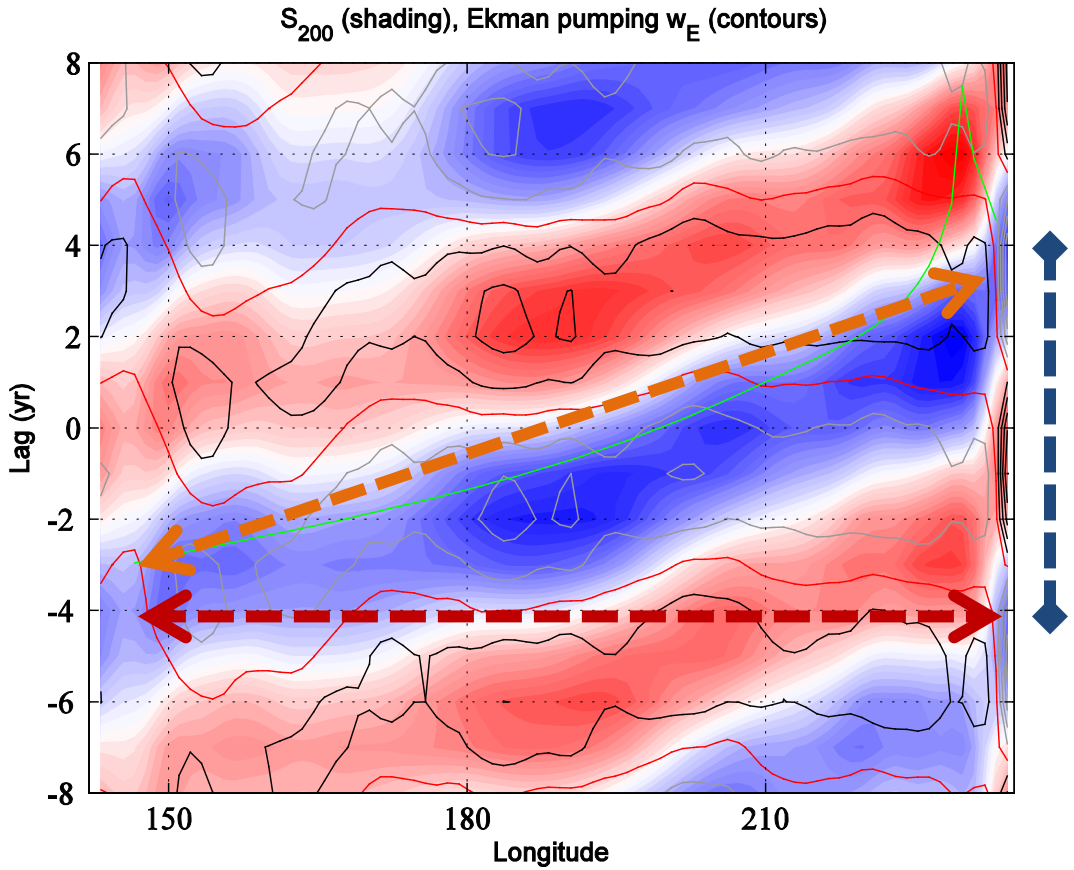
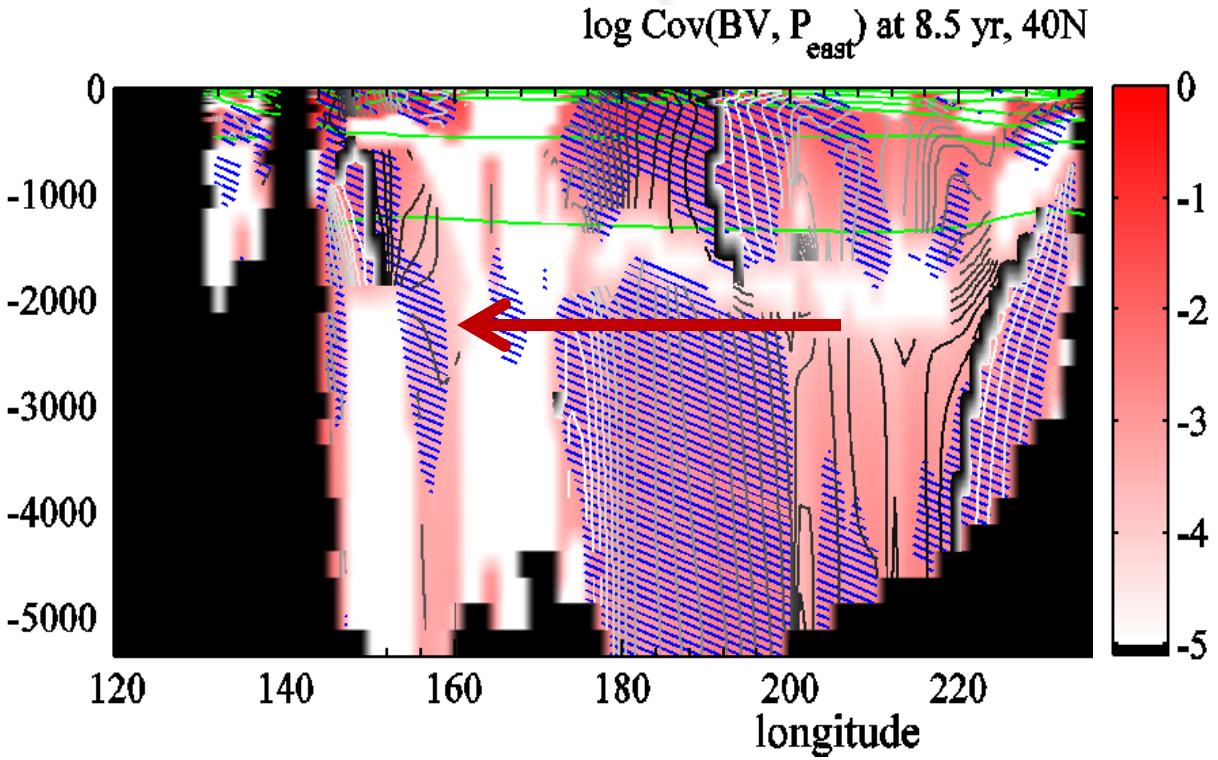


Advective Resonance

8.5 yr

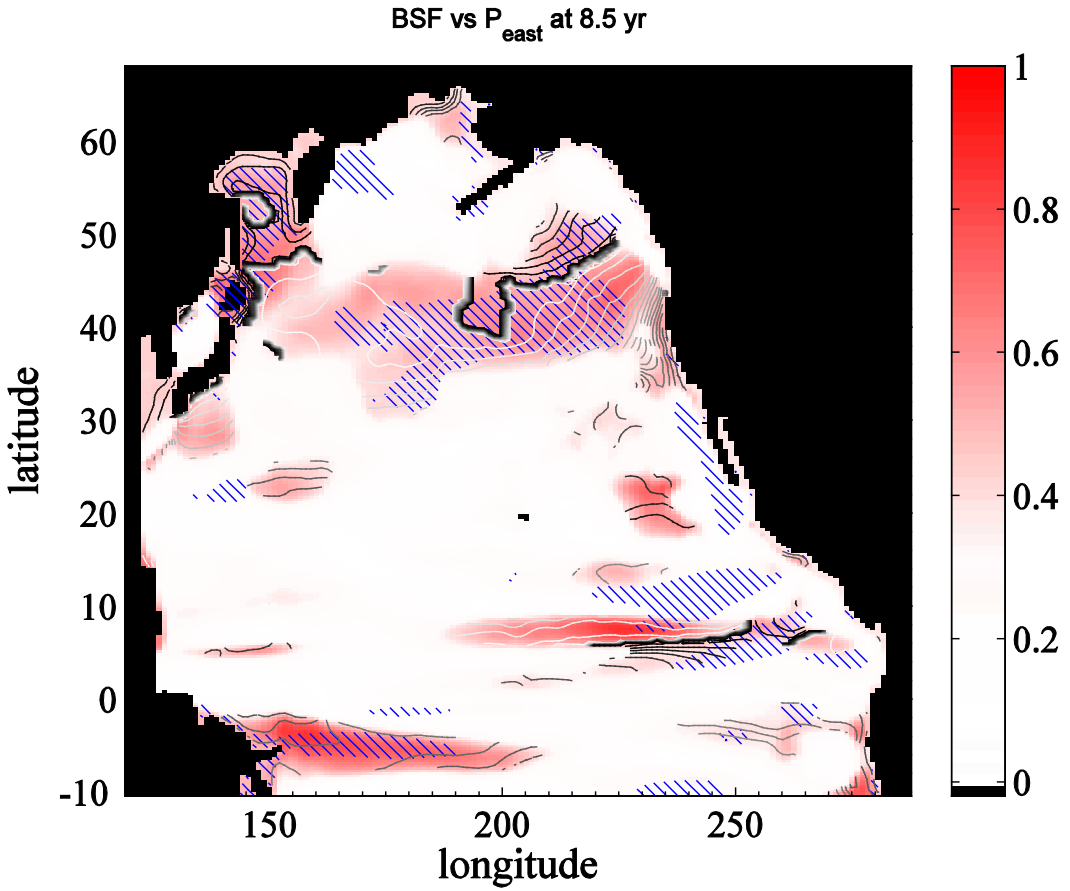
- Baroclinic meridional velocity displays westward propagation with 1st baroclinic modal structure
- But connection with KOE region breaks up west of dateline



Advective Resonance

8.5 yr

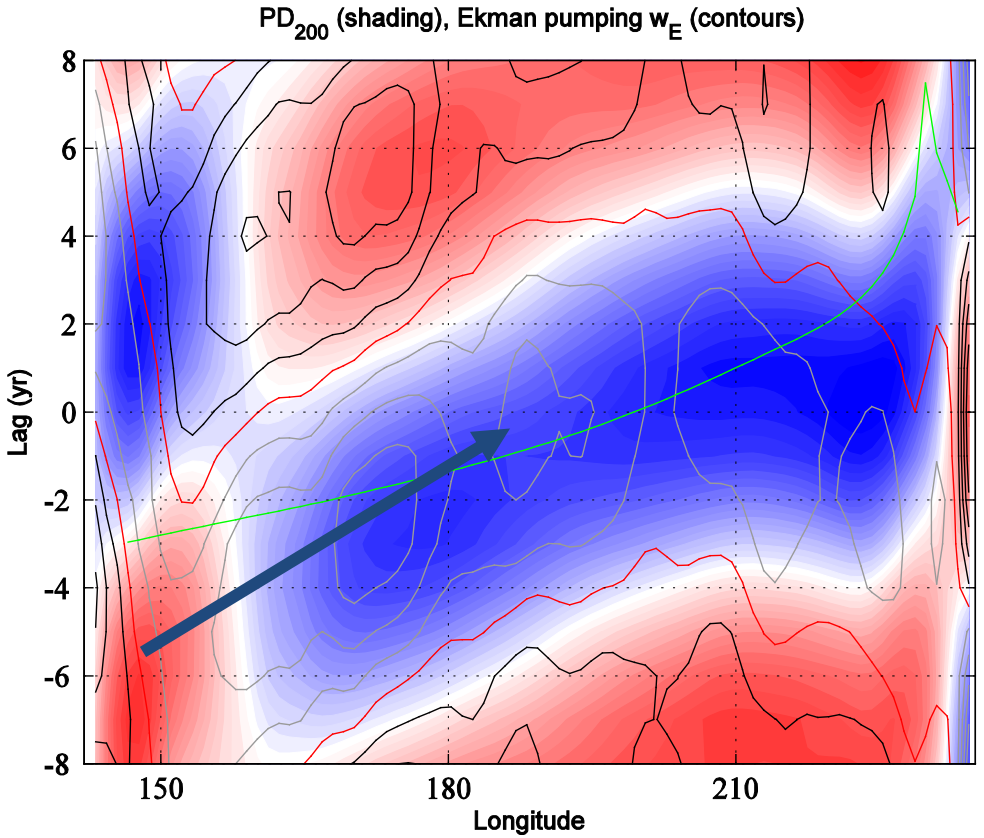
- Barotropic Stream Function shows connection with KOE region



Advective Resonance

17 yr

- Bit less clear
  - k = ½
  - Eastward propagation of coupled air/sea anomalies
  - Probably basin-wide signal



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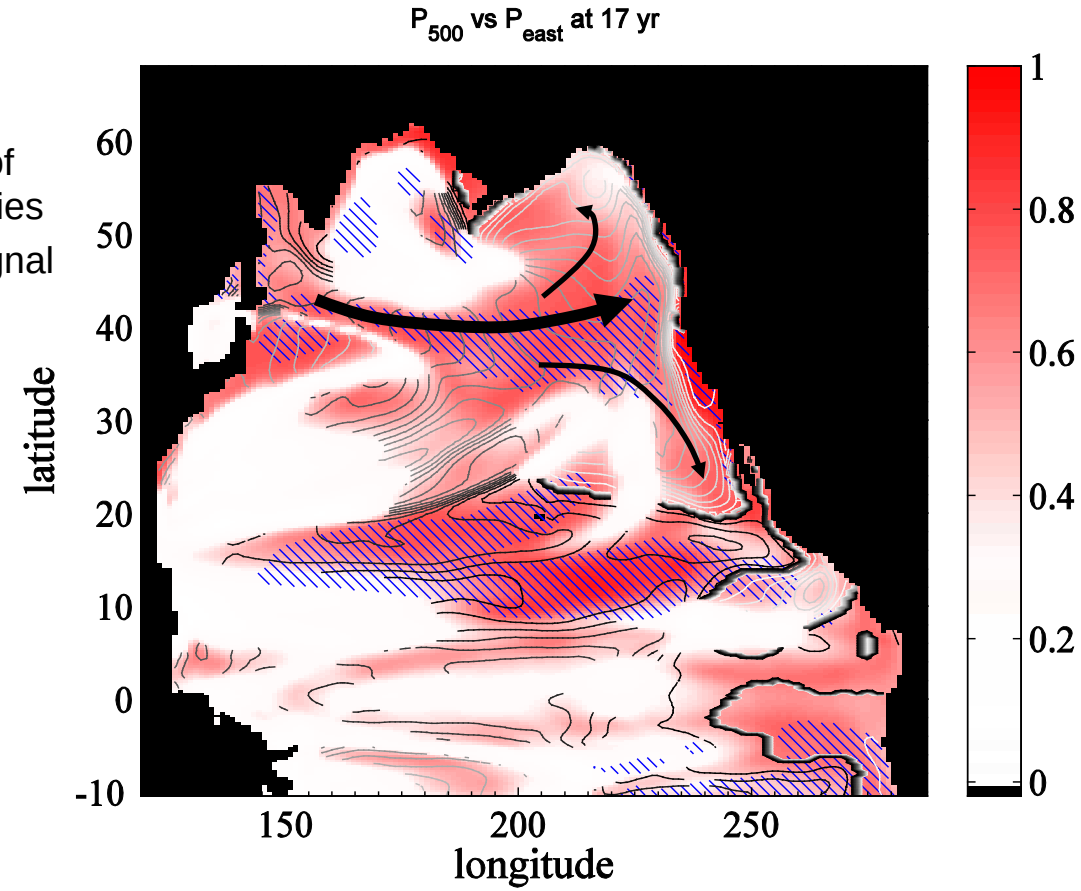
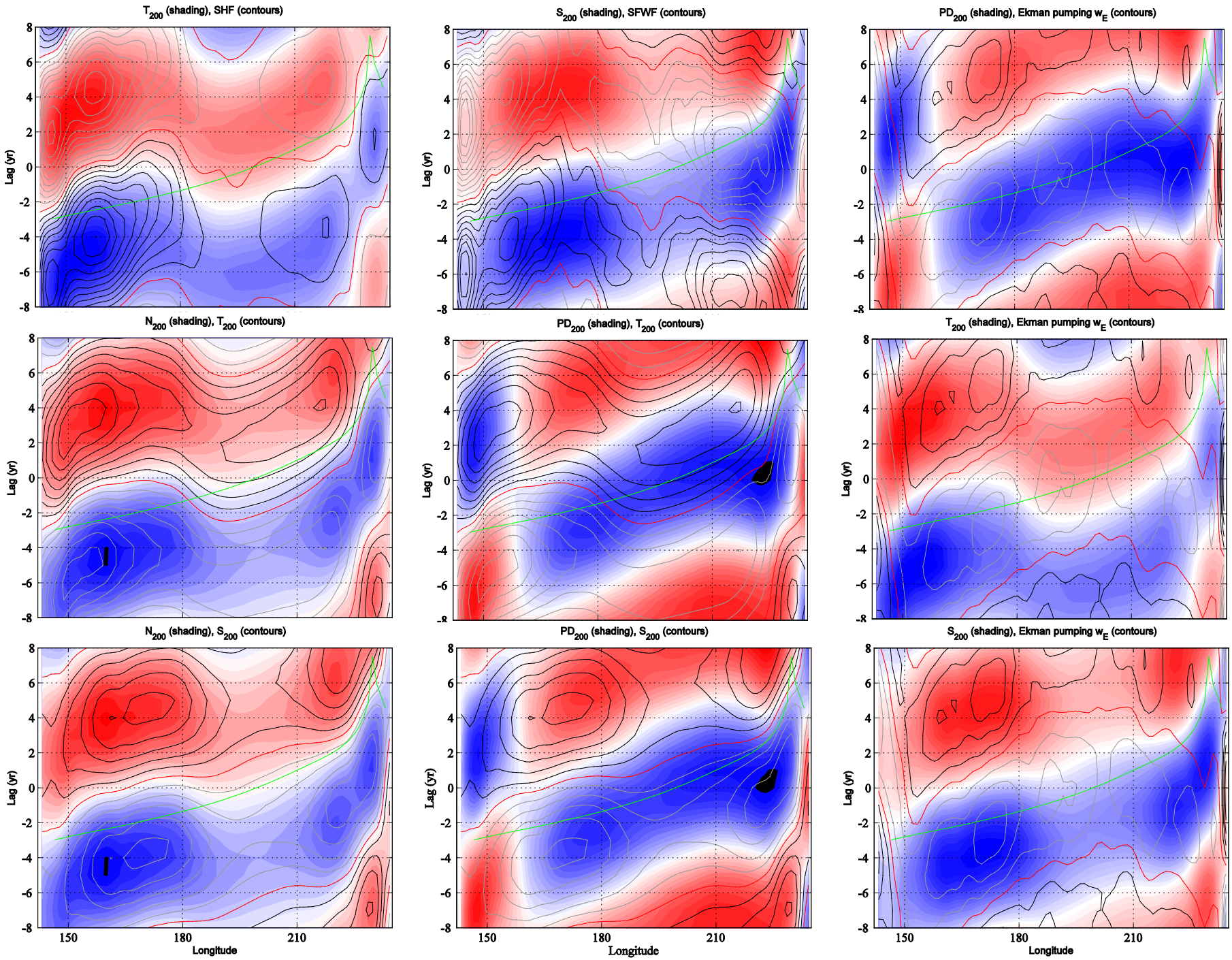


Conclusions

- Distinctive modes of decadal climate variability in North Pacific climate system in CCSM3
  - 8.5 and 17 yr
  - Energy on *eastern* boundary
  - Project onto SST in KOE region
- Possible advective resonance mechanism
  - Forcing dipole is interior/boundary Ekman pumping
- But
  - Relation 8.5 and 17 yr?


T_{200} (shading), SHF (contours)
S_{200} (shading), SFWF (contours)
PD_{200} (shading), Ekman pumping w_E (contours)
N_{200} (shading), T_{200} (contours)
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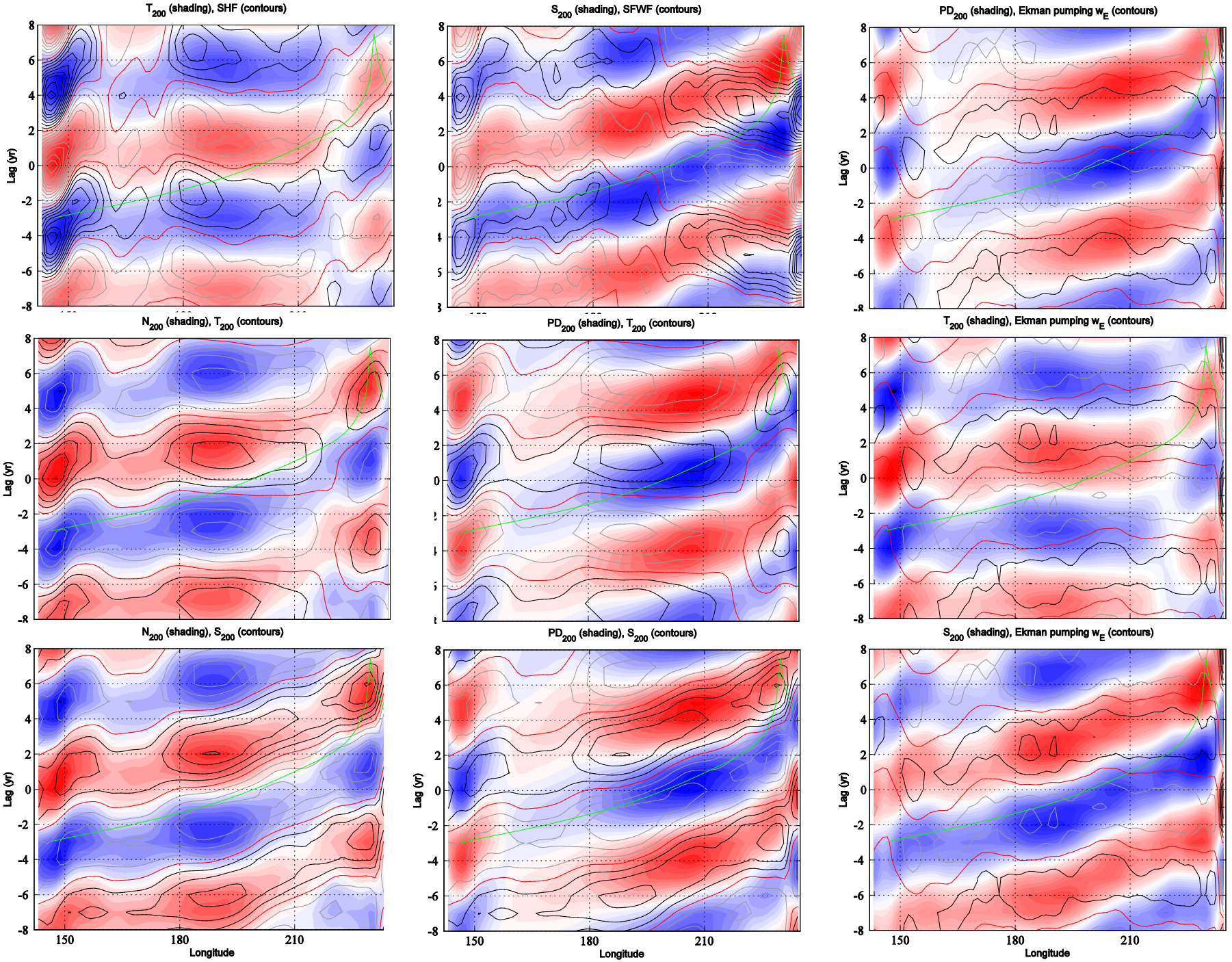
Lag (yr)
Longitude
8
6
4
2
0
-2
-4
-6
-8
150
180
210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Dominant Modes of Variability
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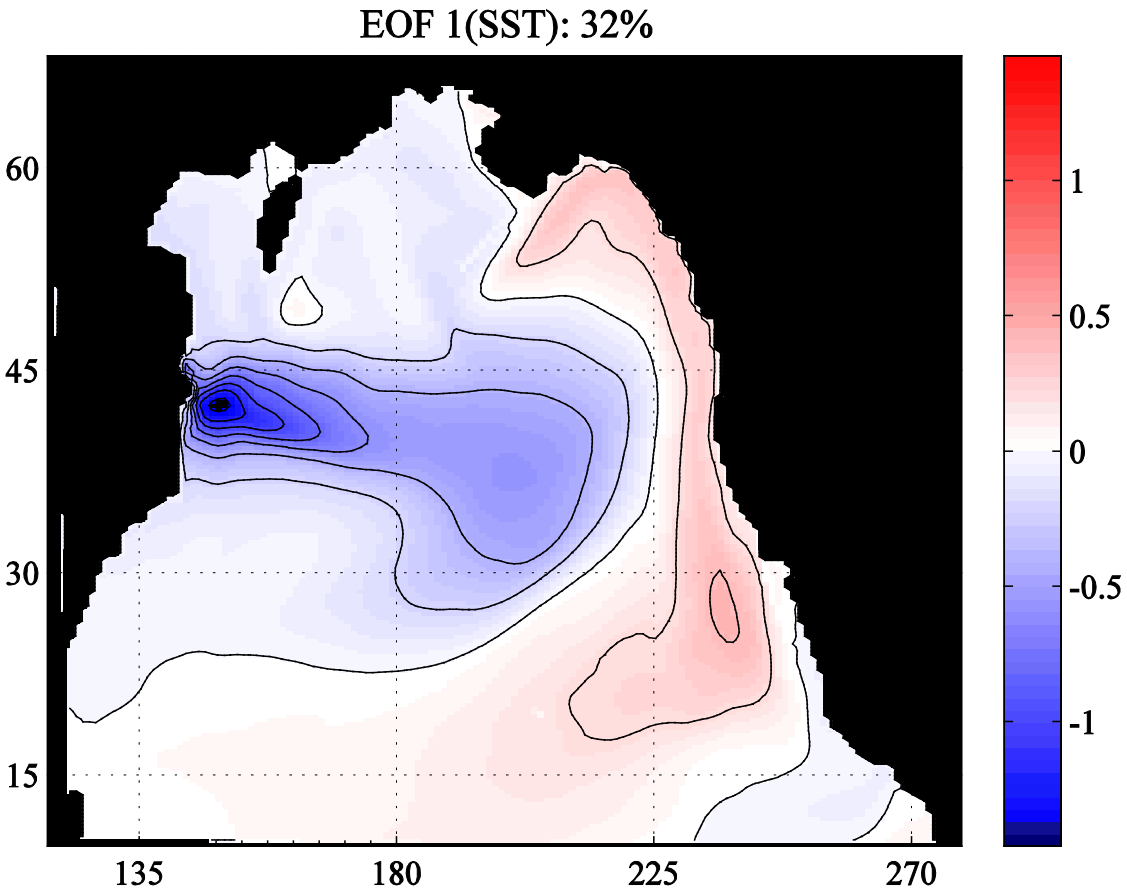
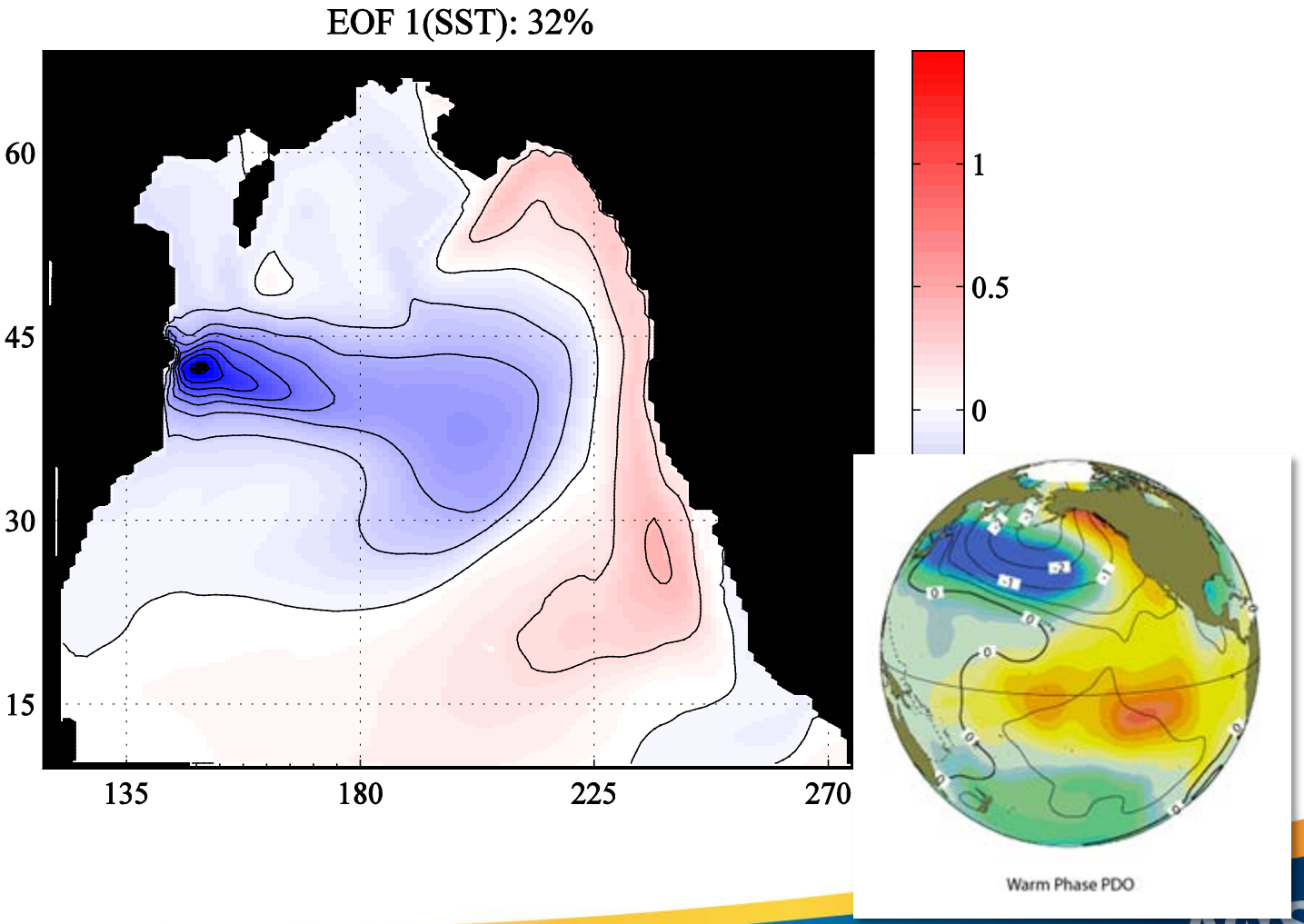
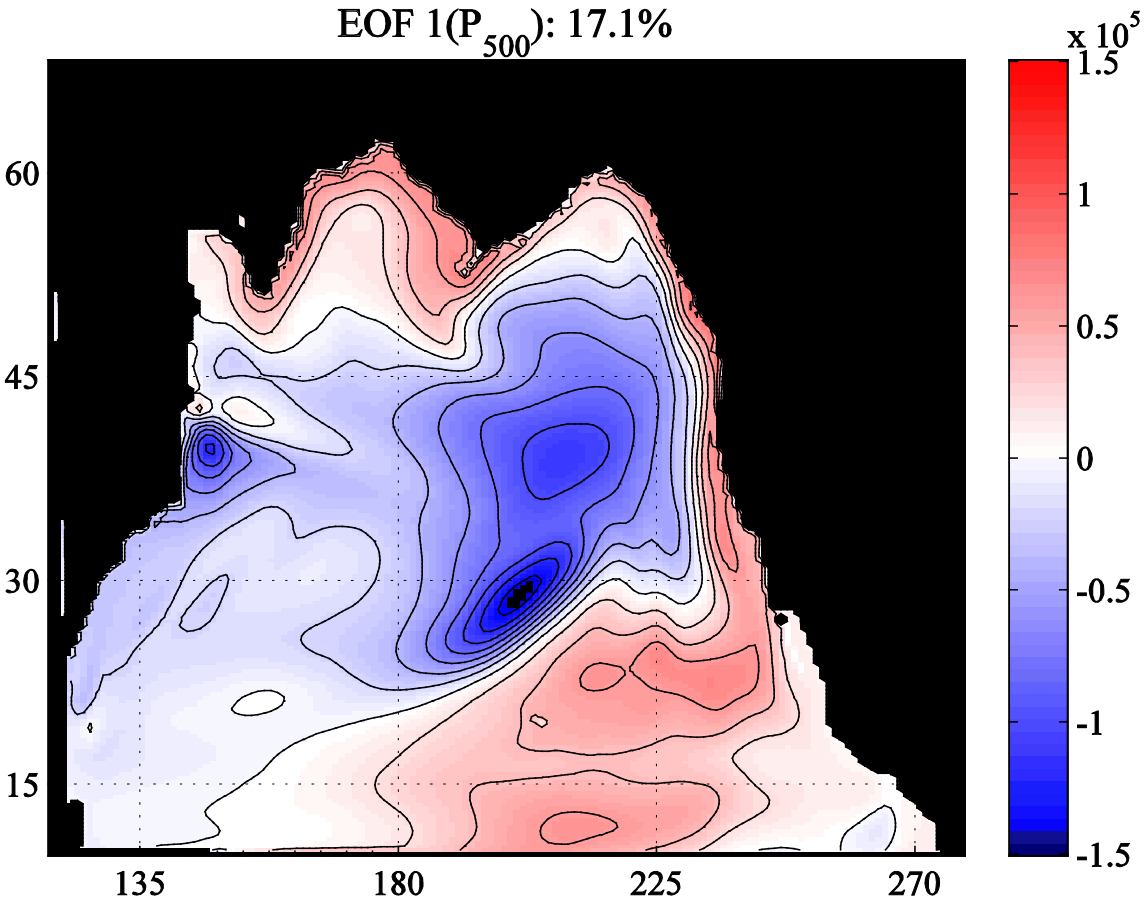


Dominant Modes of Variability
SST



Dominant Modes of Variability

P_{500}

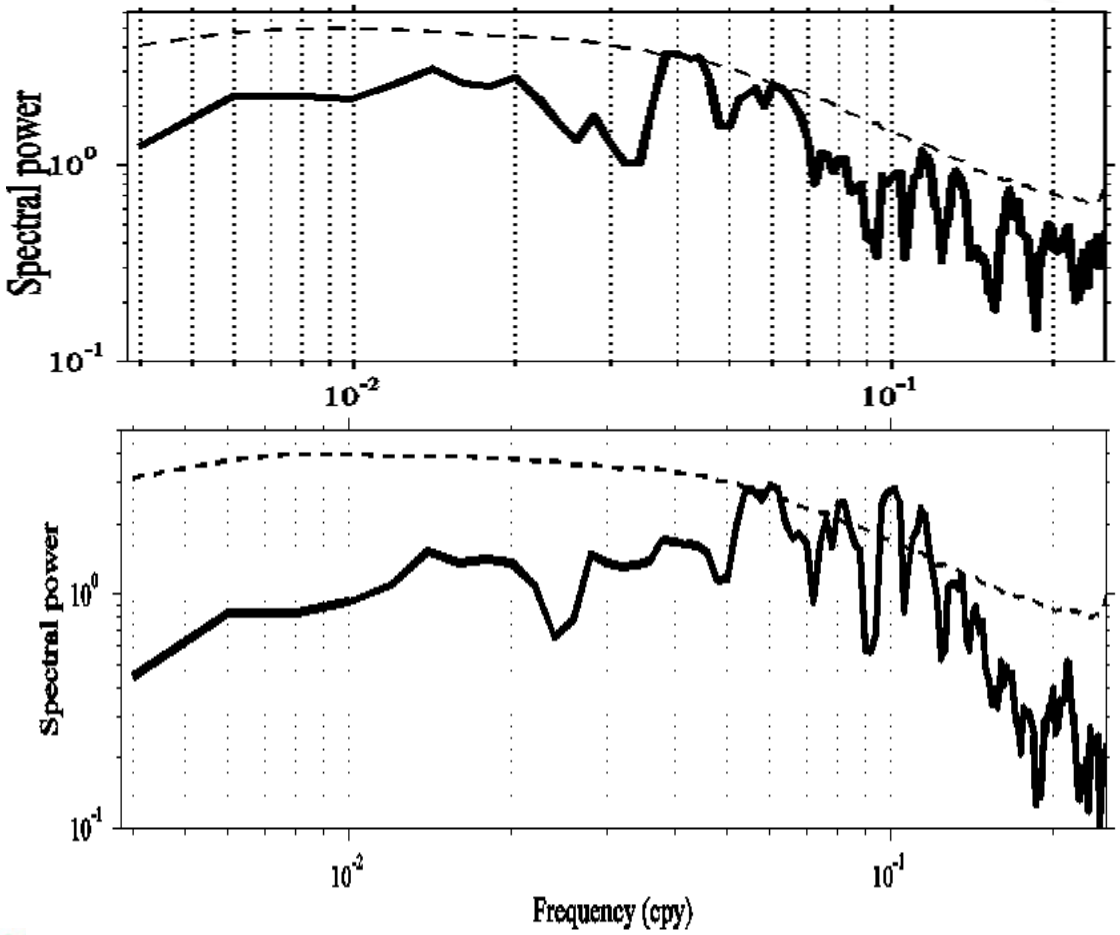


Dominant Modes of Variability

Spectral signatures

SST

P_{500}

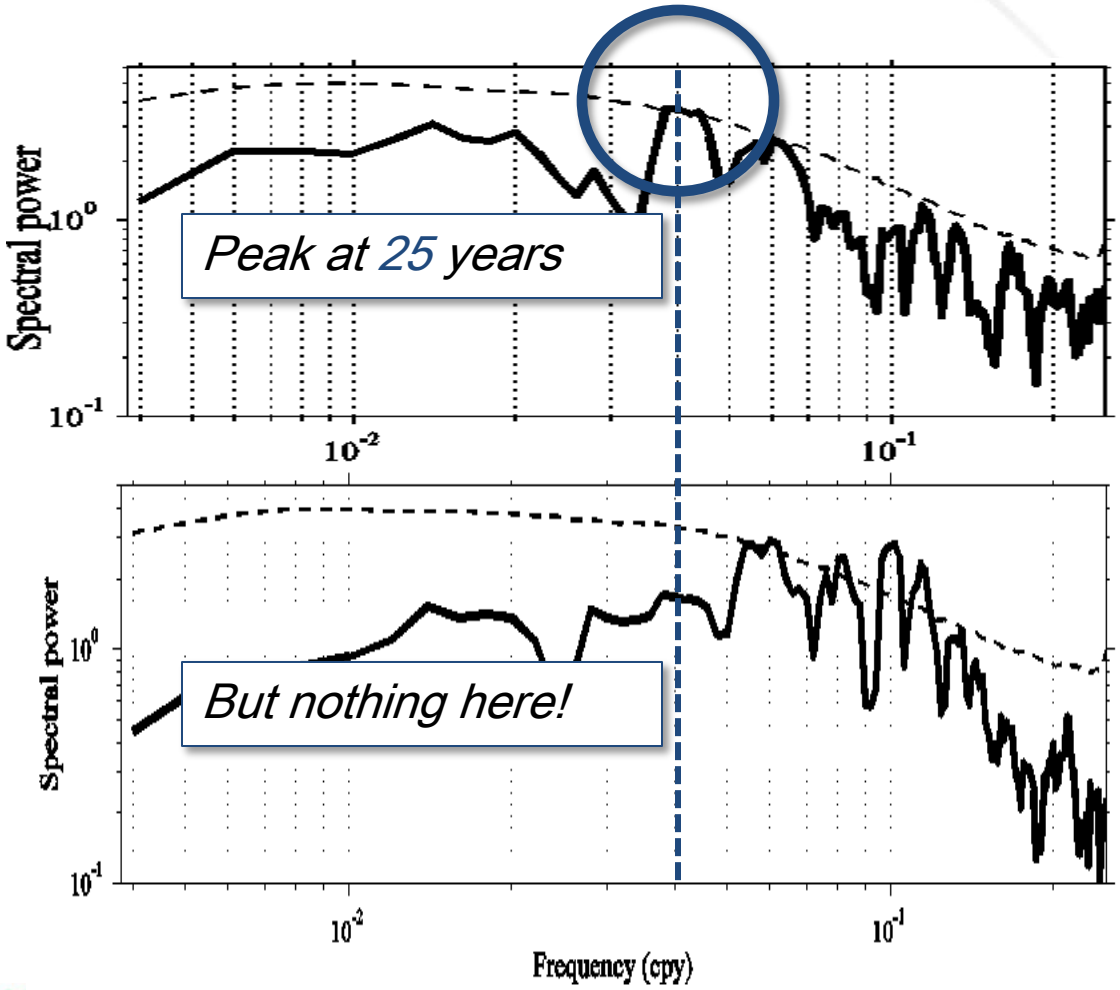


Dominant Modes of Variability

Spectral signatures

SST

P_{500}

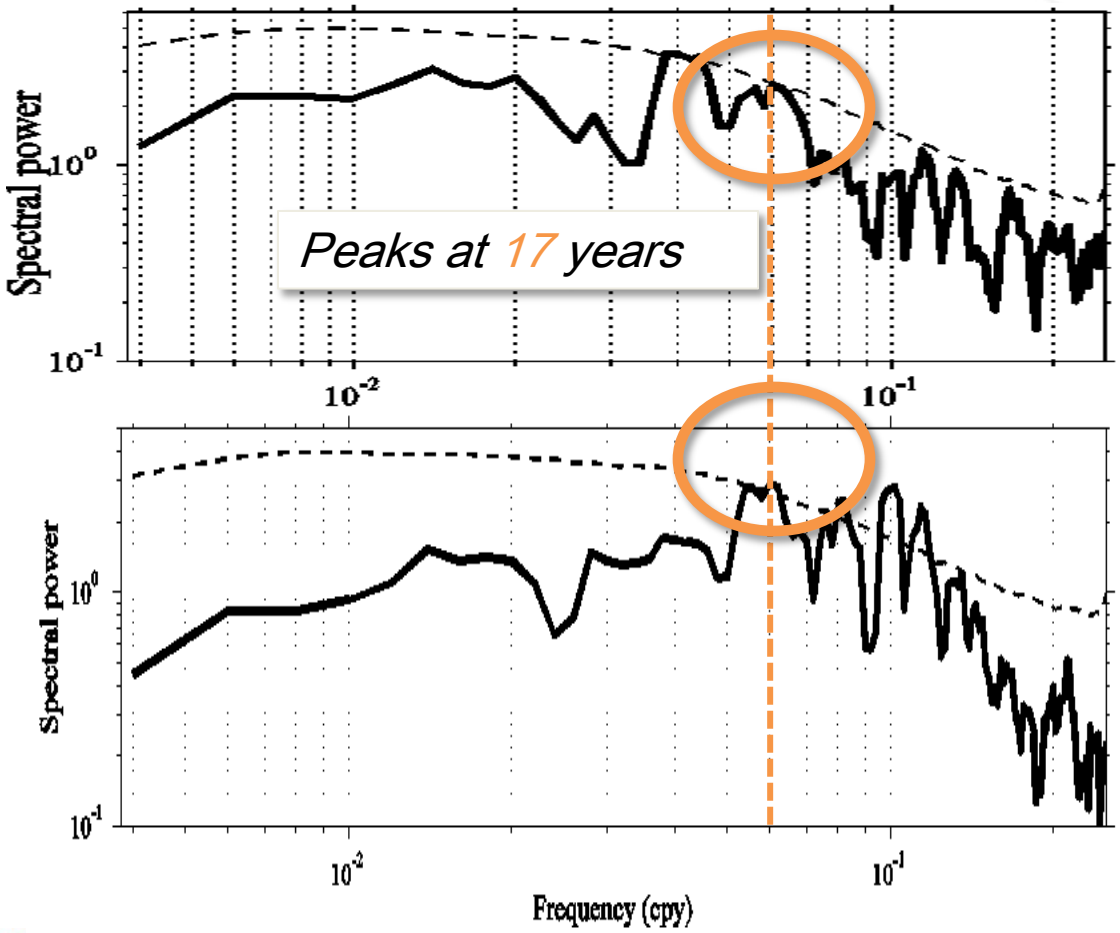


Dominant Modes of Variability

Spectral signatures

SST

P_{500}

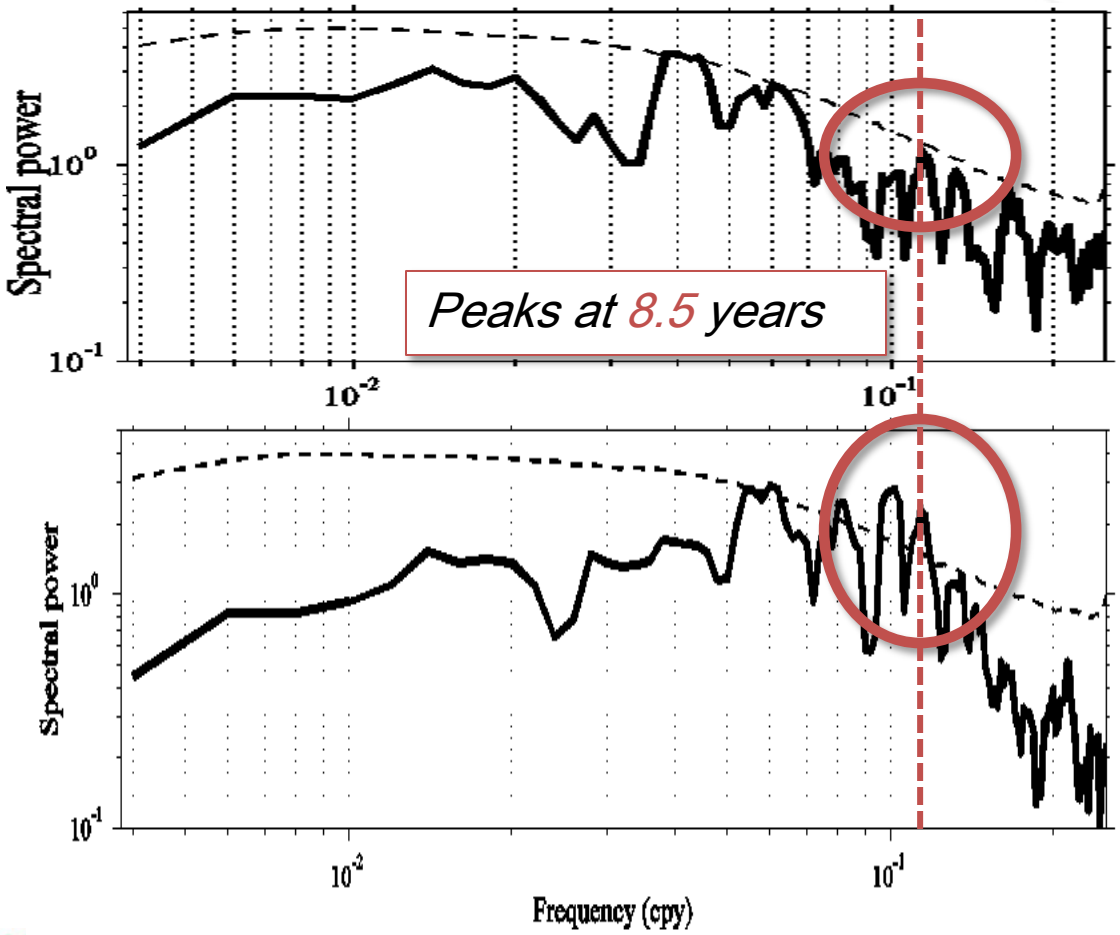


Dominant Modes of Variability

Spectral signatures

SST

P_{500}



Dominant Modes of Variability

Spectral signatures

SST

P_{500}