Pacific Decadal Variability in CCSM3

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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: $P_{east}$
Pacific Decadal Variability in CCSM3

Eastern boundary pressure

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

Peaks at 17 and 8.5 years;
Pacific Decadal Variability in CCSM3 Impact on KOE SSTs

Spectra $SST^{KOE}$ & $P_{east}$

![Graph showing spectral power for SST_KOE and P_east](image)

![Map showing temperature distribution](image)
Pacific Decadal Variability in CCSM3 Impact on KOE SSTs

Spectra $SST_{KOE}$ & $P_{east}$

Coherence $SST_{KOE}$ & $P_{east}$

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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

- 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 $P_{east}$
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    - Determine significance @ 90%
  - 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%
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

PD_{200} (shading), Ekman pumping w_E (contours)

Advective characteristic (UVEL 200 m)
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

\[ P_{500} \text{ vs } P_{\text{east}} \text{ at 17 yr} \]
Rossby Basin Mode?

17 yr

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

8.5 yr

- Weaker, less widespread coherences

\[ P_{500} \text{ (pressure integrated over upper 500 m)} \]
Rossby Basin Mode?

8.5 yr

- Weaker, less widespread 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

Sea Level Pressure (SLP)
Mid-latitude Coupled Mode?
8.5 & 17 yr

Average over 35°-45°N
Mid-latitude Coupled Mode?
8.5 & 17 yr

Average over 35°-45°N
Mid-latitude Coupled Mode?

8.5 & 17 yr

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…
Advective Resonance

8.5 yr

- $S_{200}$ anomaly generated east of dateline by Ekman pumping...
- ...is advected *eastward* by mean flow...
Adveective 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…
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

8.5 yr

- Time scale determined by
  - *advection speed*
  - *length scale* of forcing
Advective Resonance
8.5 yr

- Time scale determined by
  - advection speed
  - length scale of forcing
- \(~ 5 \text{ yr}~\)
Advective Resonance

8.5 yr

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

- ~ 5 yr
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
  - $k = \frac{1}{2}$
  - Eastward propagation of coupled air/sea anomalies
  - Probably basin-wide signal
Advective Resonance
17 yr

- Bit less clear
  - $k = \frac{1}{2}$
  - Eastward propagation of coupled air/sea anomalies
  - Probably basin-wide signal
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?
Dominant Modes of Variability

SST

EOF 1(SST): 32%
Dominant Modes of Variability

SST

EOF 1(SST): 32%
Dominant Modes of Variability

$P_{500}$

EOF 1($P_{500}$): 17.1%
Dominant Modes of Variability
Spectral signatures

**SST**

**$P_{500}$**
Dominant Modes of Variability
Spectral signatures

**SST**

Peak at 25 years

**P\textsubscript{500}**

But nothing here!
Dominant Modes of Variability
Spectral signatures

**SST**

**$P_{500}$**

Peaks at 17 years
Dominant Modes of Variability
Spectral signatures

SST

$P_{500}$

Peaks at 8.5 years
Dominant Modes of Variability
Spectral signatures

SST

$P_{500}$

But nothing here!

Peaks at 10 and 12.5 years