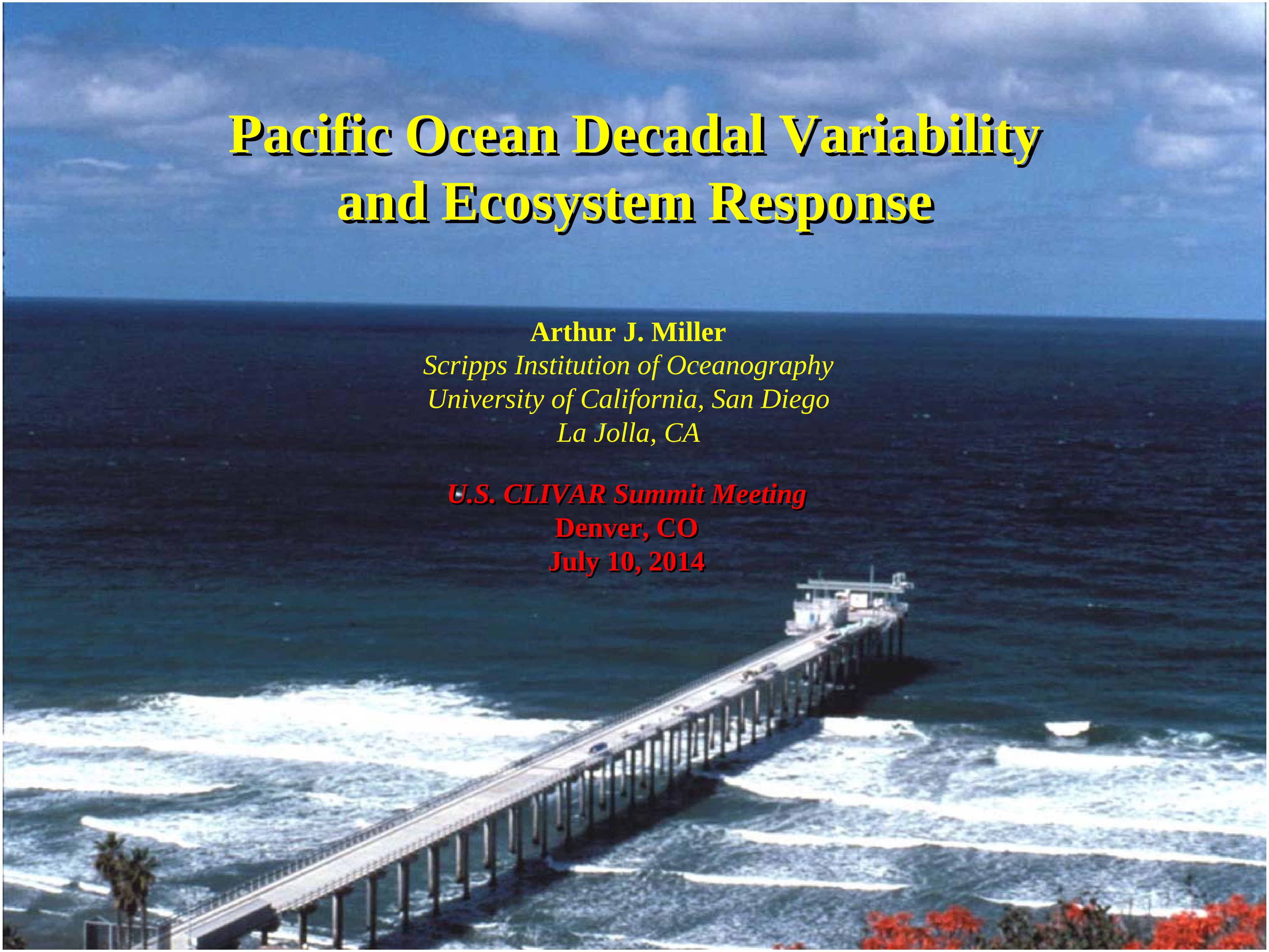

Pacific Ocean Decadal Variability and Ecosystem Response

Arthur J. Miller
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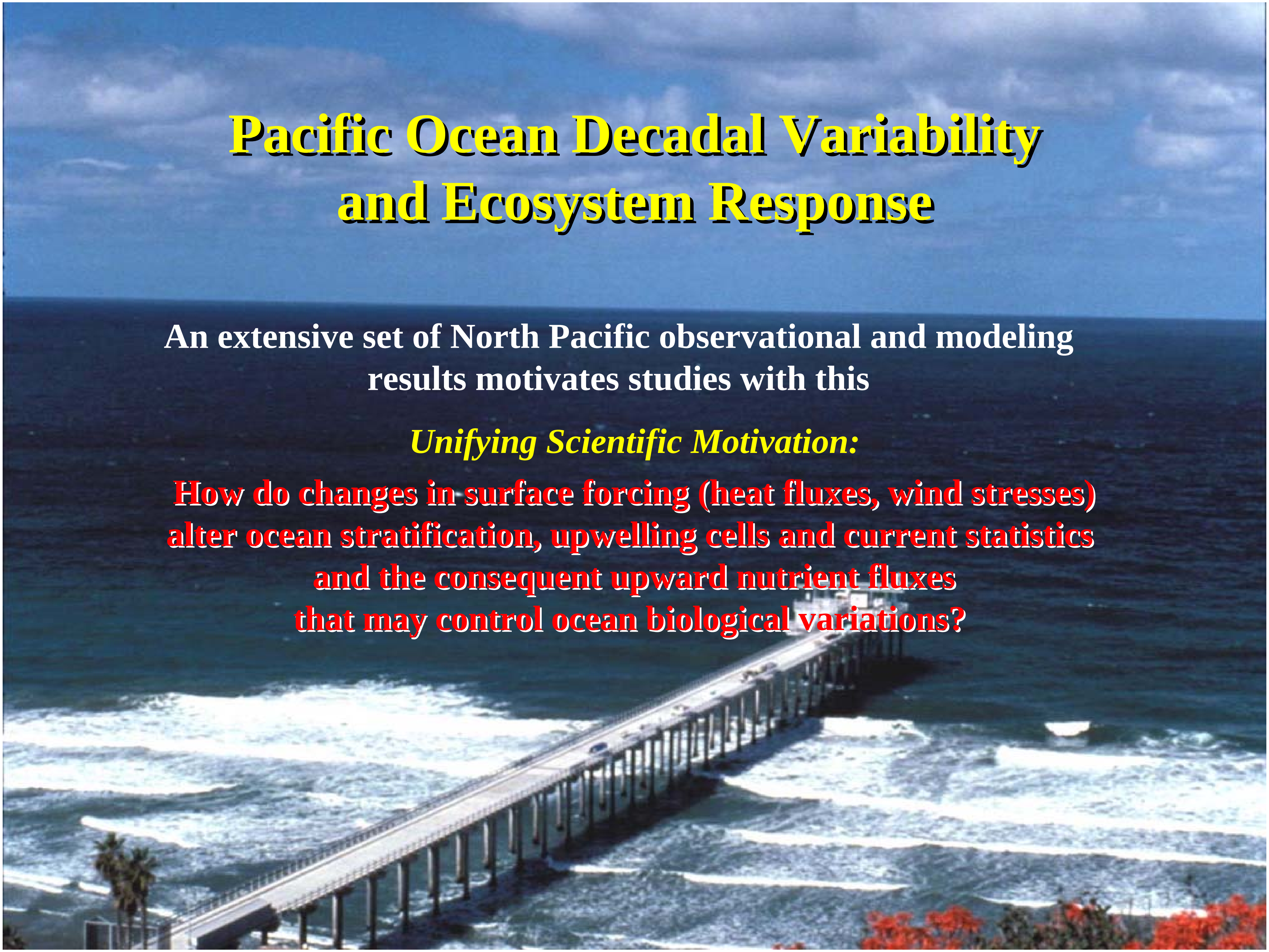
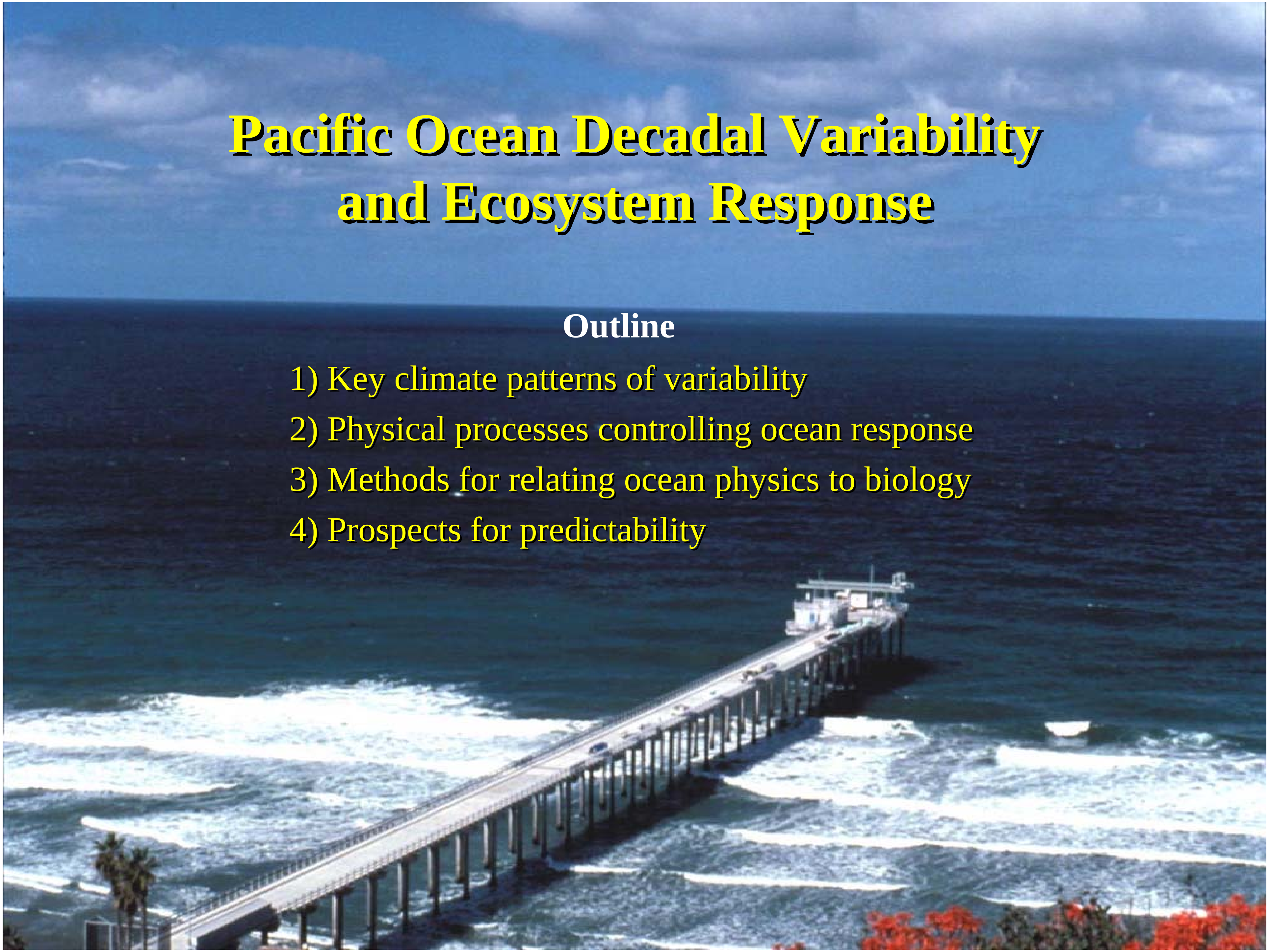
University of California, San Diego
La Jolla, CA

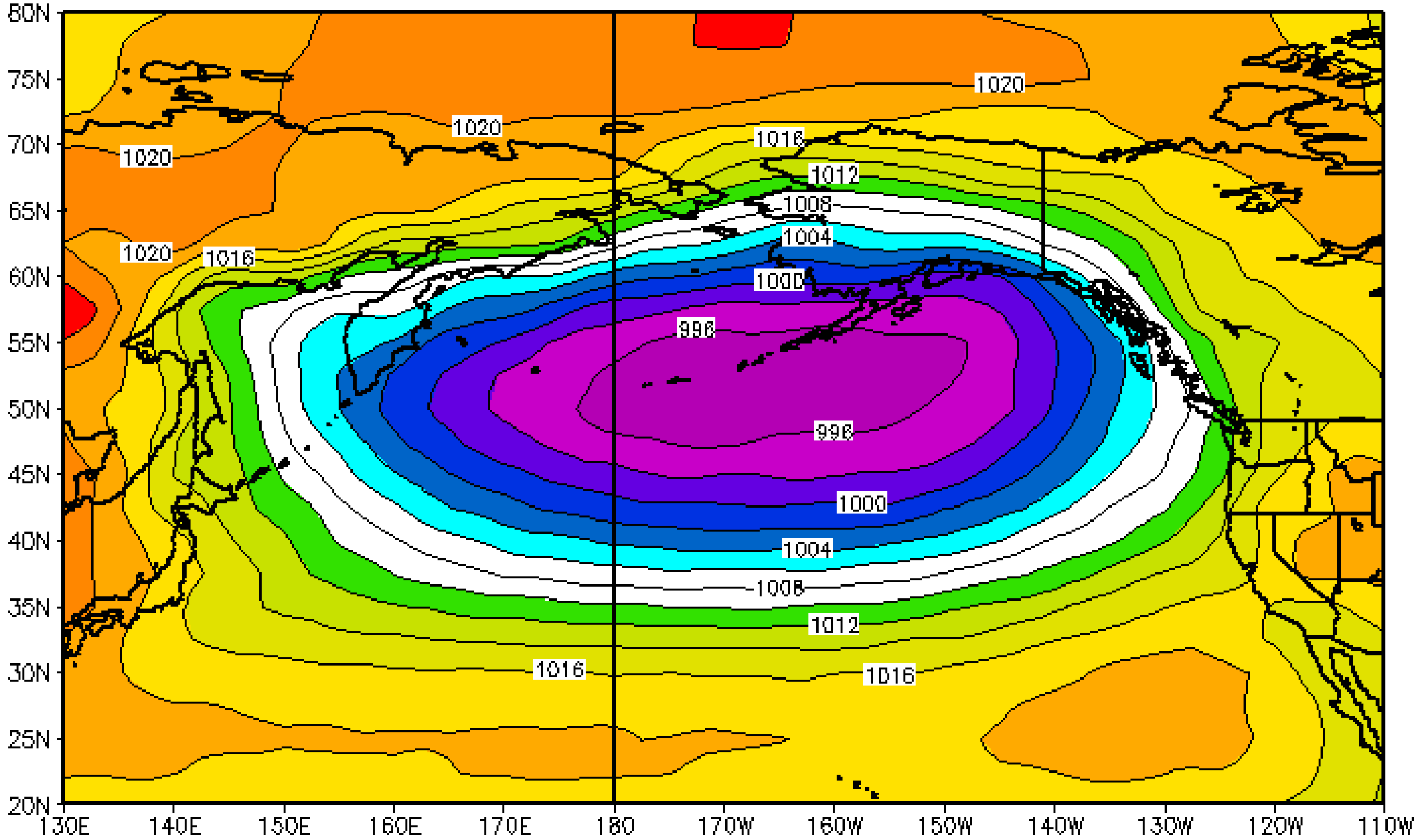
U.S. CLIVAR Summit Meeting
Denver, CO
July 10, 2014


Pacific Ocean Decadal Variability
and Ecosystem Response
An extensive set of North Pacific observational and modeling
results motivates studies with this
Unifying Scientific Motivation:
How do changes in surface forcing (heat fluxes, wind stresses)
alter ocean stratification, upwelling cells and current statistics
and the consequent upward nutrient fluxes
that may control ocean biological variations?


Pacific Ocean Decadal Variability
and Ecosystem Response
Outline
1) Key climate patterns of variability
2) Physical processes controlling ocean response
3) Methods for relating ocean physics to biology
4) Prospects for predictability

Variability around the averages:
What controls the atmospheric forcing?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales



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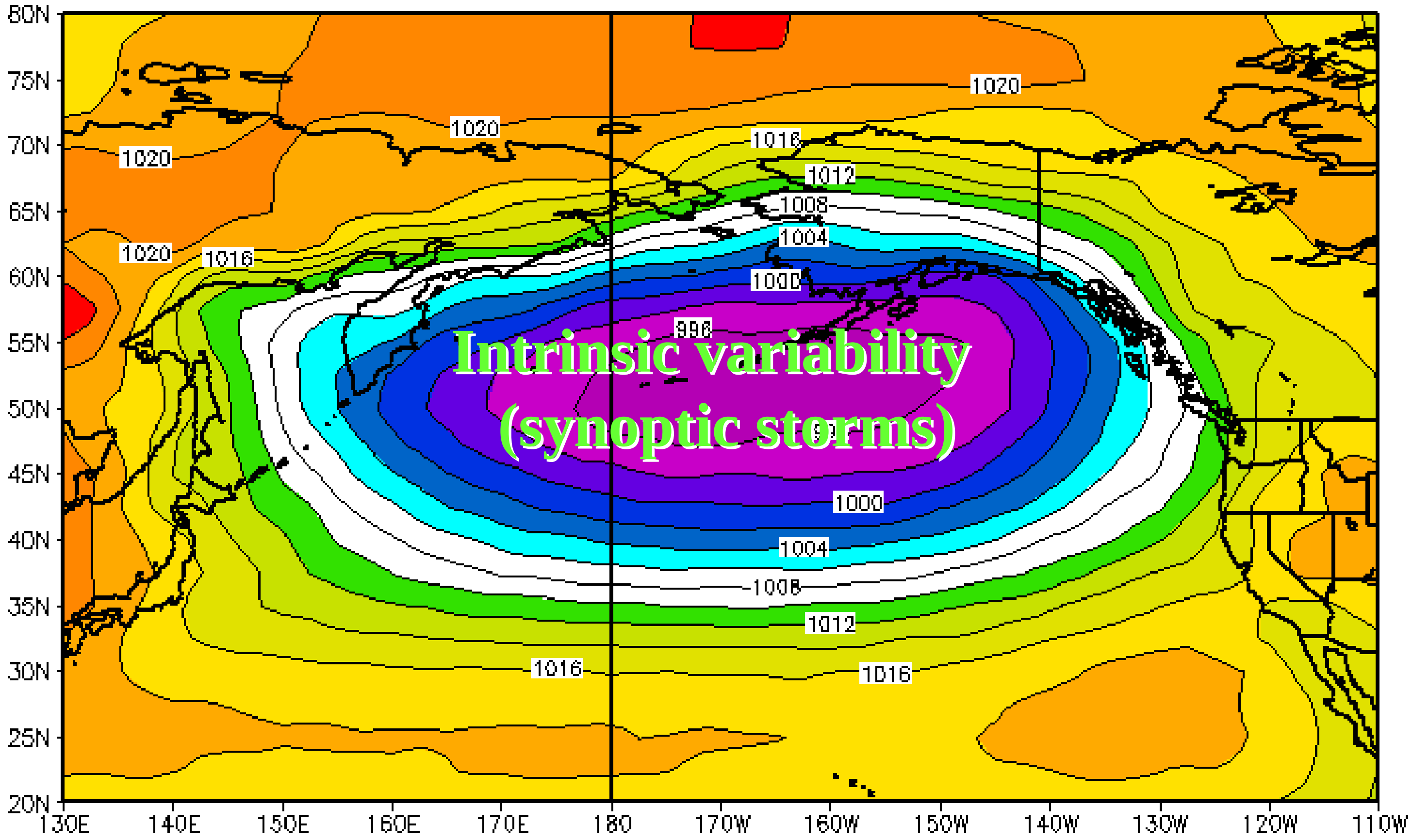

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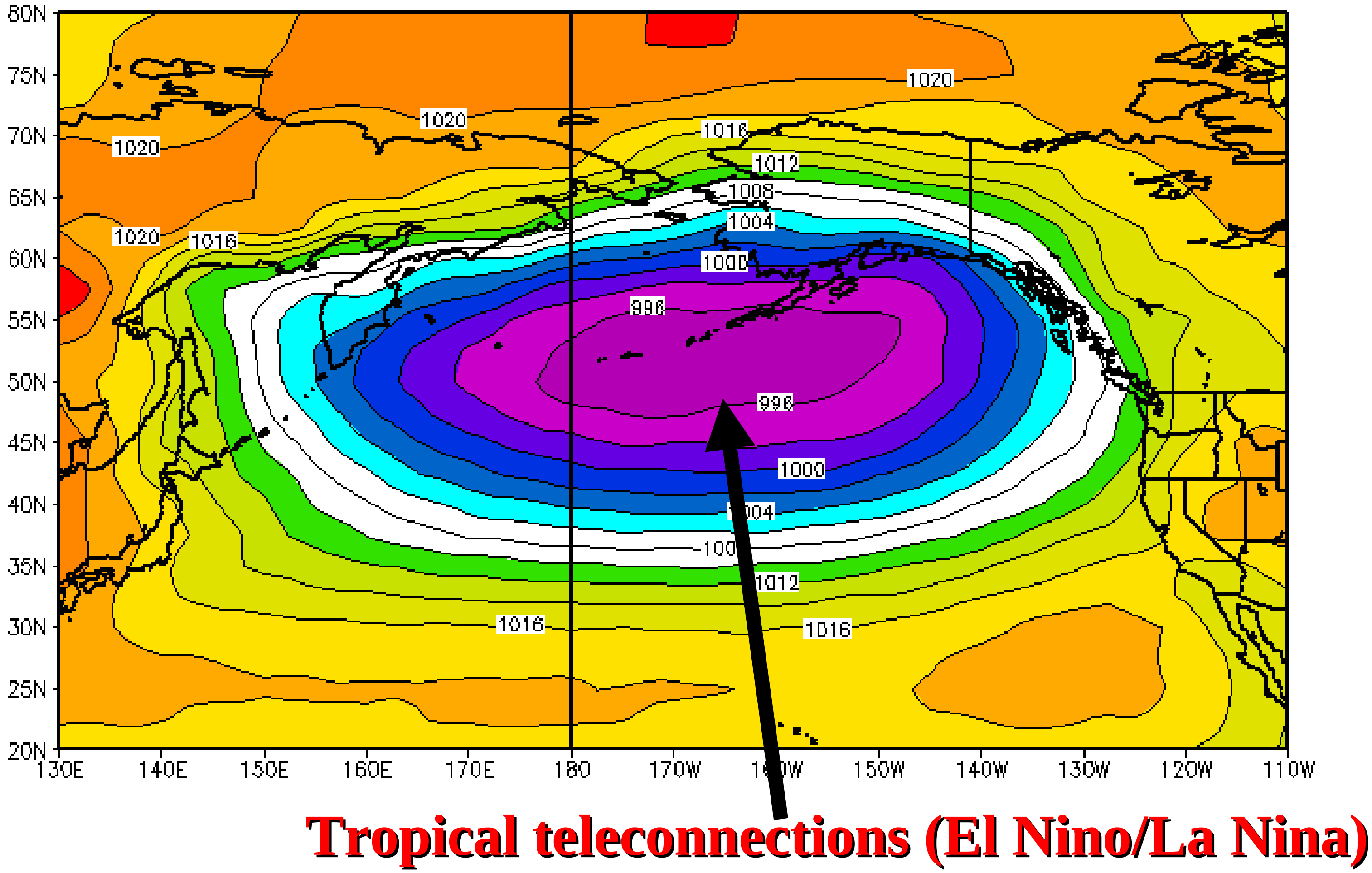

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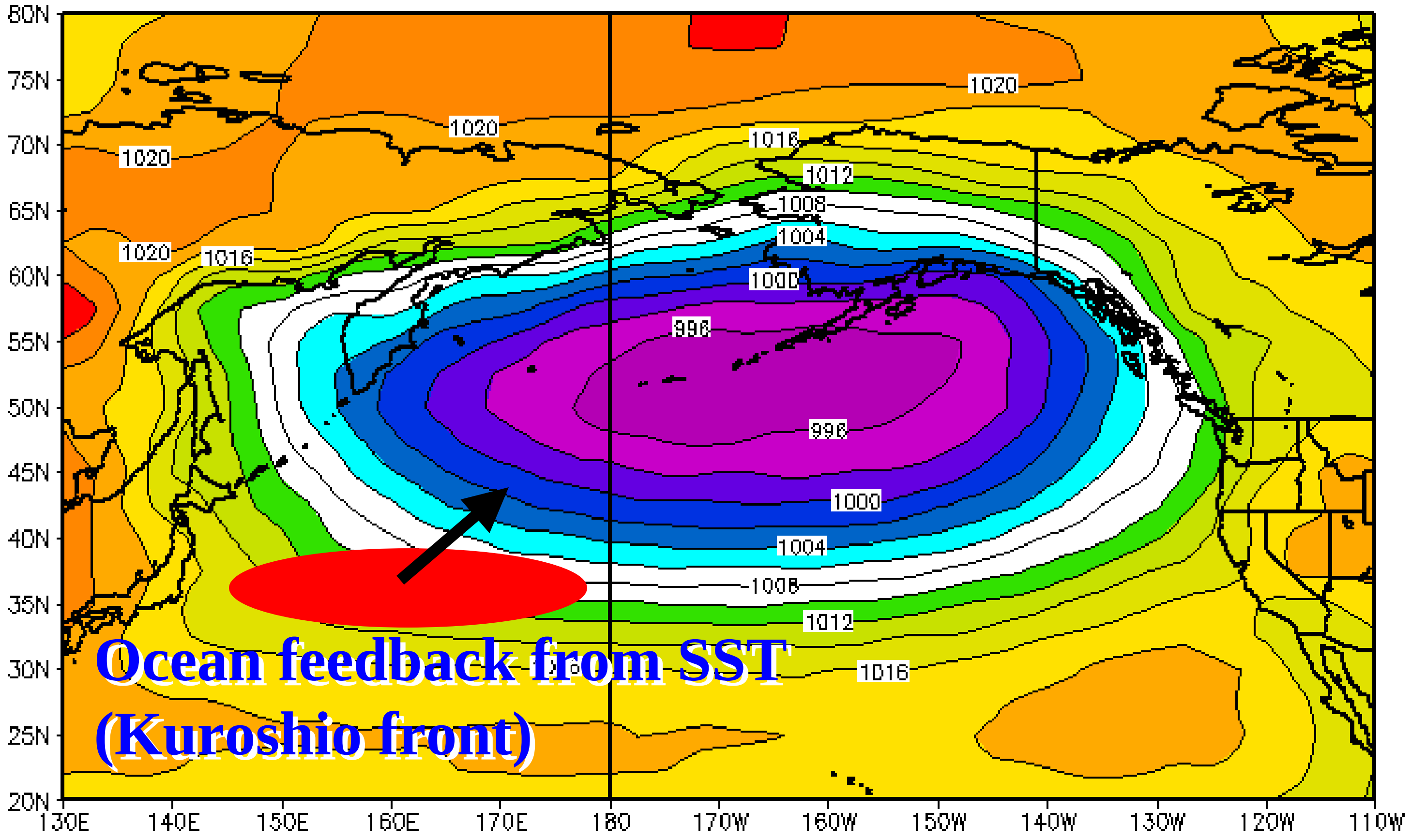

Variability around the averages:
What controls the oceanic response?

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Large-scale climate pattern variations organize the oceanic physical processes that affect ocean biology

-***Defining a Climate Index*** and relating to biological variables is frequently done, but…
-***Physical processes*** in the ocean can ***vary*** in space and can therefore affect the biology in different ways
-***Understanding*** these processes is therefore critical to unraveling mechanisms of biological variations
-Plus, lagged effects of climate mode forcing of the ocean may have ***predictable components***

Dynamics and Thermodynamics of Upper Ocean Variability

Dynamics of Currents: (**Adiabatic** Forcing)

- Wind Stress (**Ekman transport**: Coastal upwelling)
- Wind Stress Curl (**Ekman pumping**: Open-Ocean upwelling)

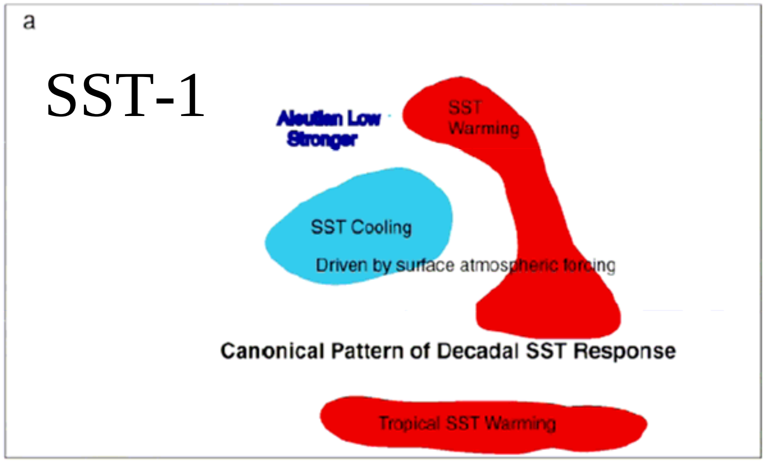
Thermodynamics of Ocean Temperature: (**Diabatic** Forcing)

- Surface Heat Flux (***Latent***, Sensible, solar, radiative)
- Advection (due to currents: ***Ekman***, pressure-gradient, upwelled)
- Vertical turbulent mixing

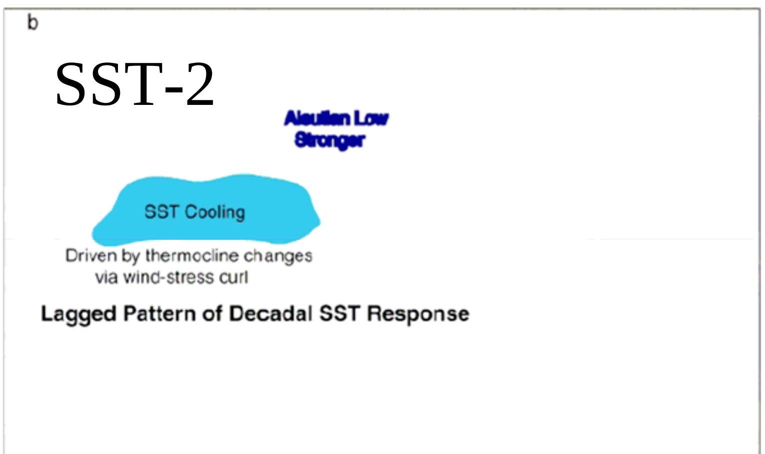
When the winds change, all these effects act together,
but in different relative strength in different places….

Variability around the Averages: What controls the oceanic response?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales



Aleutian Low anomalies force surface heat fluxes, Ekman current advection, and turbulent mixing (diabatic effects) to drive ***East-West pattern of SST***



Miller et al. (2004)

Aleutian Low wind stress curl anomalies (adiabatic) force thermocline waves that propagate westward (lagged by several years) to force ***SST cooling in the West***

Variability around the Averages:
What controls the oceanic response?

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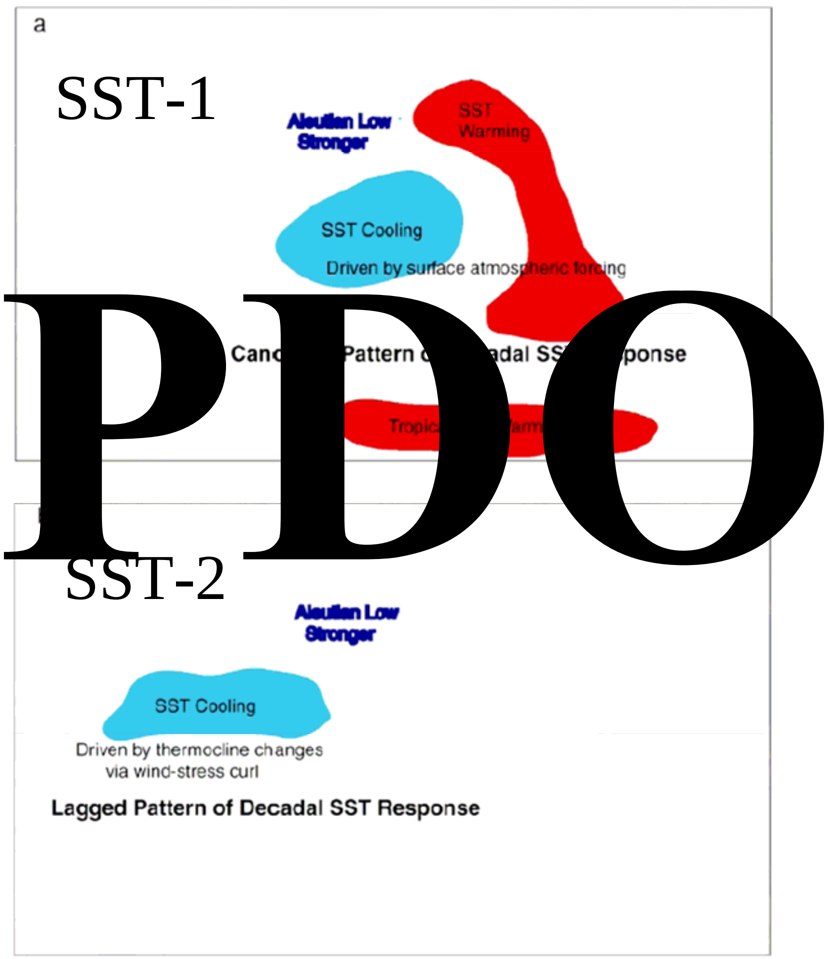

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Variability around the Averages: What controls the oceanic response?

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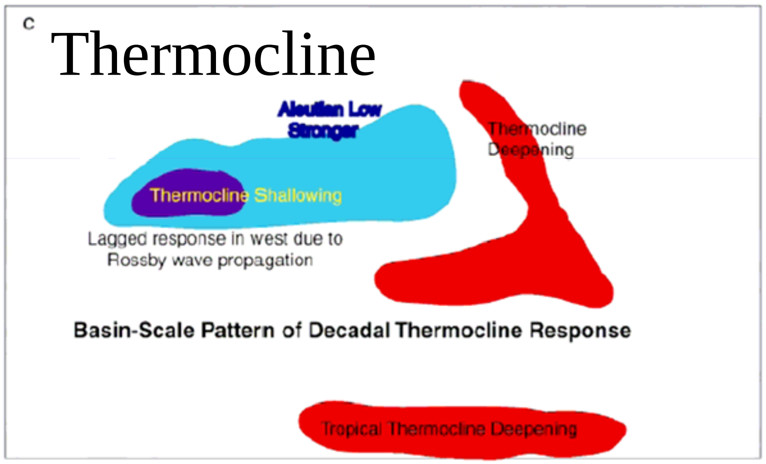
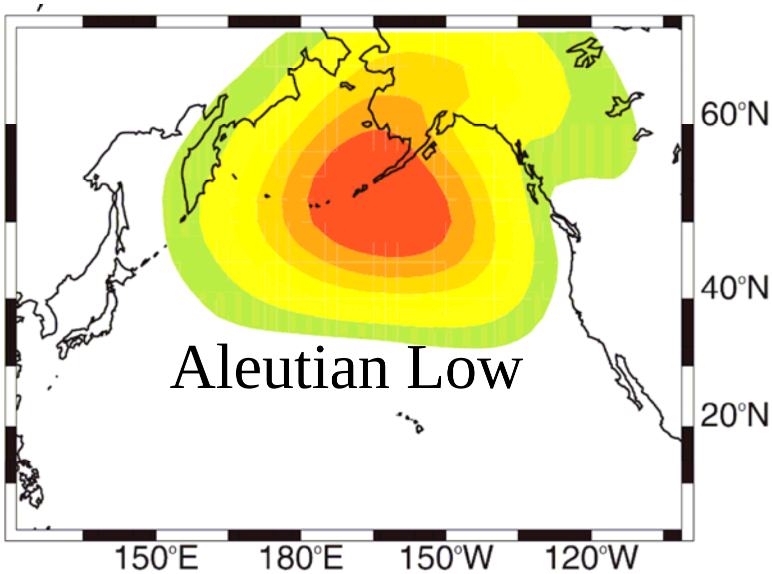
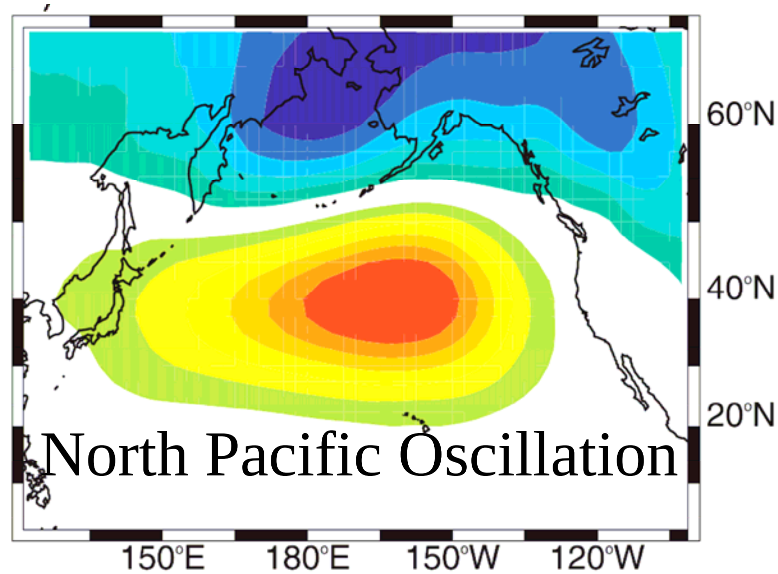


Miller et al. (2004)

Additionally,
Aleutian Low wind stress curl anomalies force (**adiabatically**) thermocline deflections (Ekman pumping) that change the **gyre-scale circulation** and affect the California Current and subsurface temperature (**thermocline**) structure, sea level, and currents

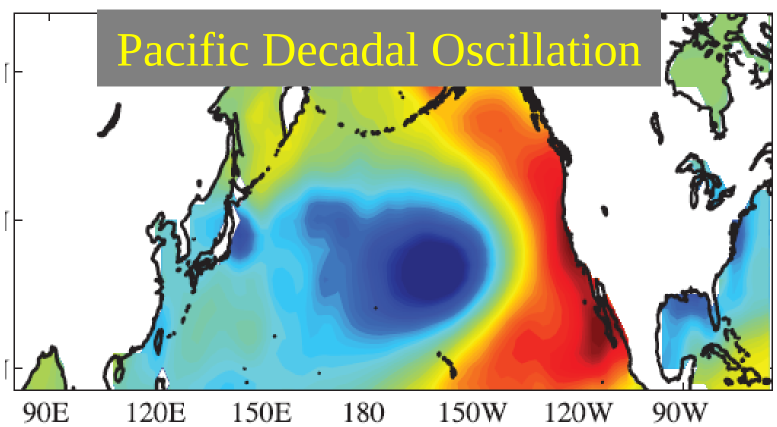
Parallel Physical Processes and Orthogonal Patterns: NPGO Driven by 2nd Atmospheric Pressure Mode (NPO)

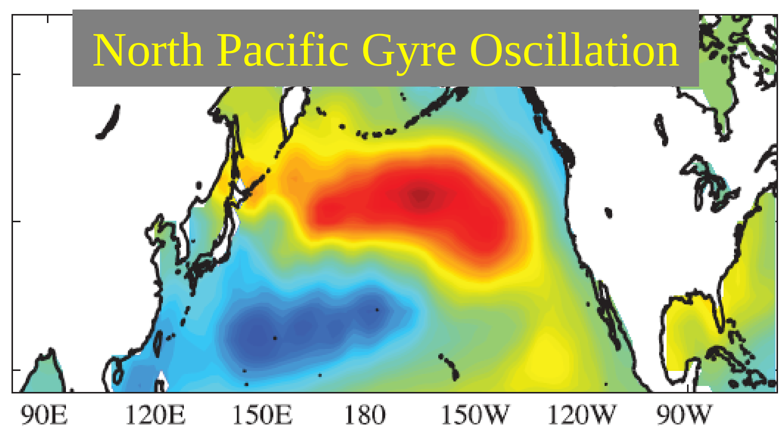




Drives the ***PDO*** pattern of SST

Drives the ***NPGO*** pattern of SST





(Ceballos et al., 2009; Furtado et al., 2011)

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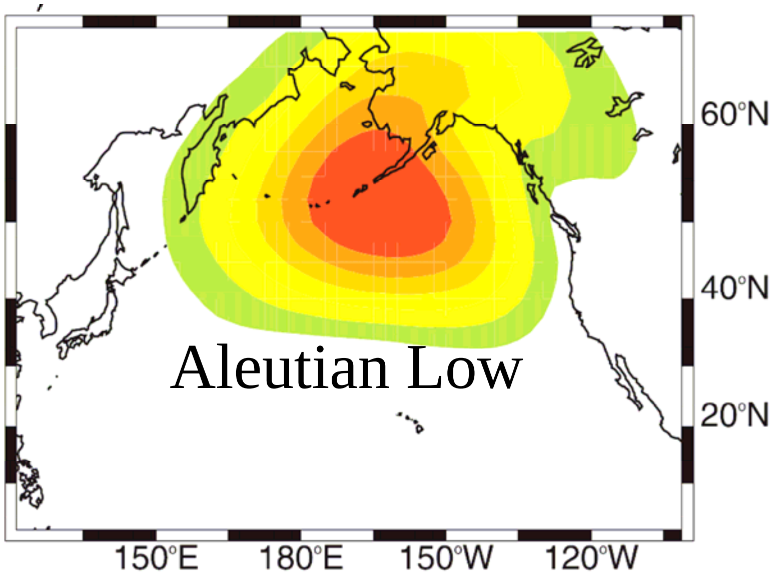
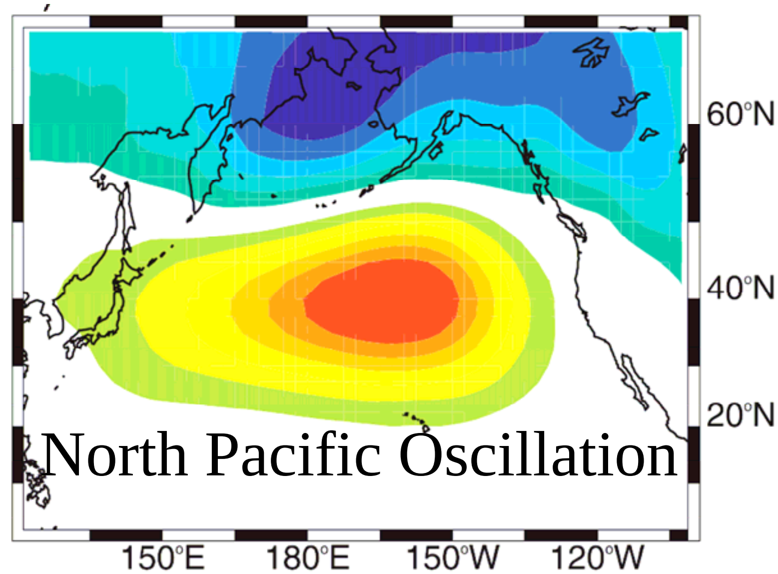
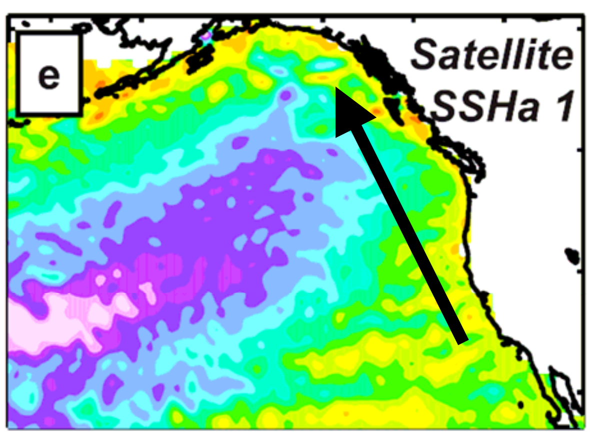
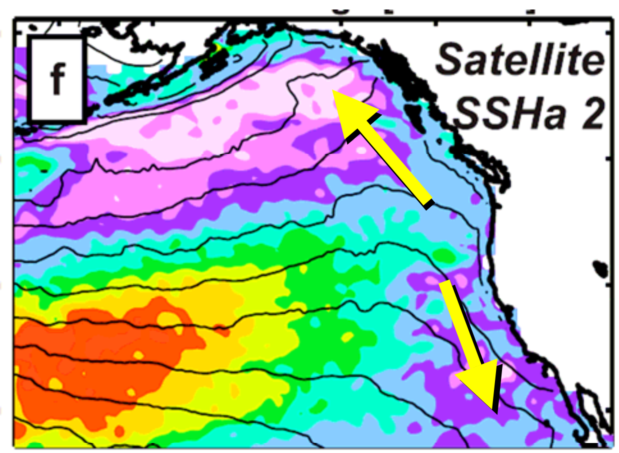




Drives the ***PDO*** pattern of SST, SLH

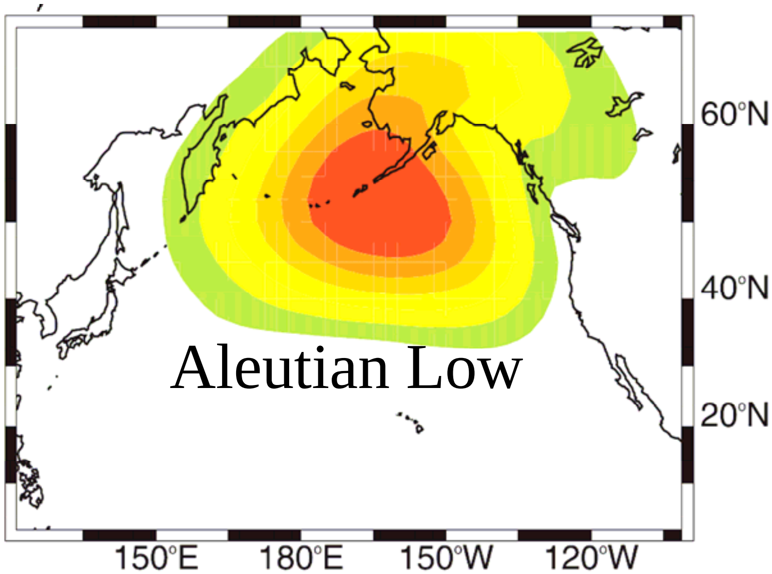
Drives the ***NPGO*** pattern of SST, SLH

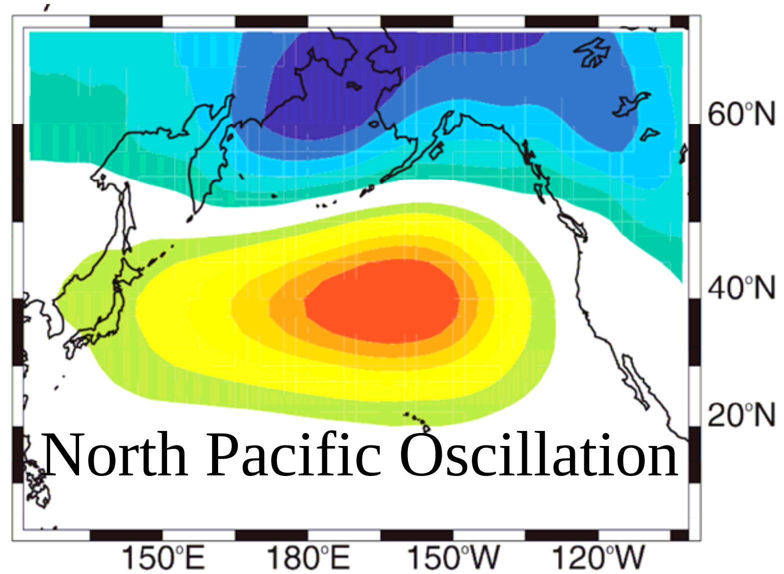




(Ceballos et al., 2009; Di Lorenzo et al., 2008)

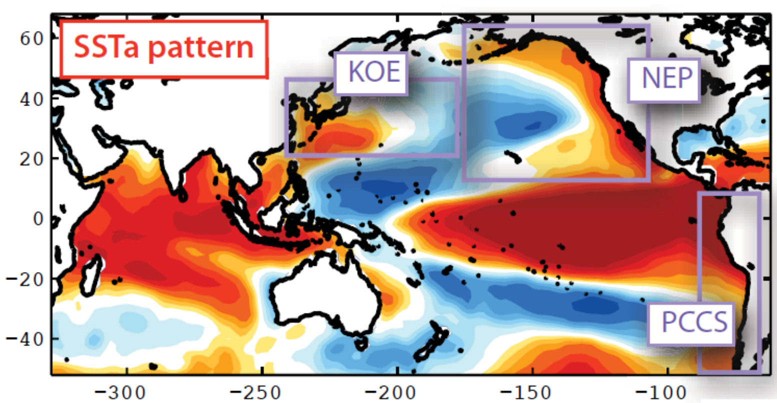
Parallel Physical Processes and Orthogonal Patterns: NPGO Driven by 2nd Atmospheric Pressure Mode (NPO)

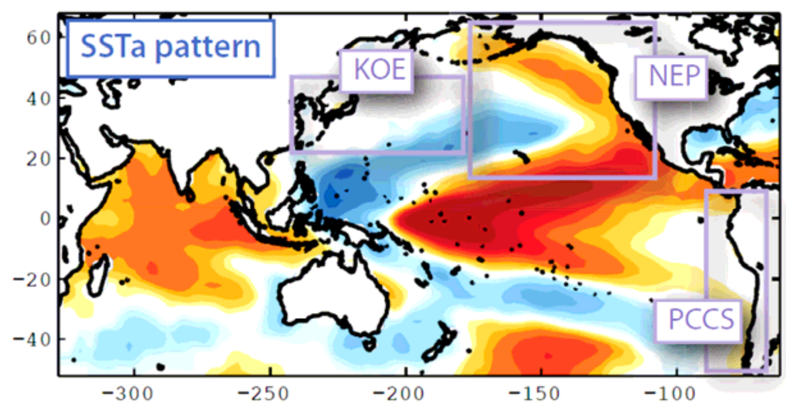




AL/***PDO*** => Eastern Pacific ENSO

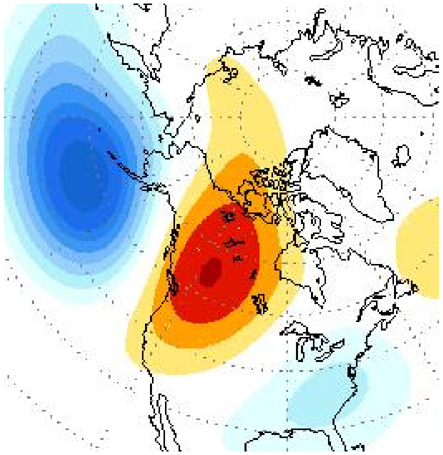
NPO/***NPGO*** => Central Pacific ENSO



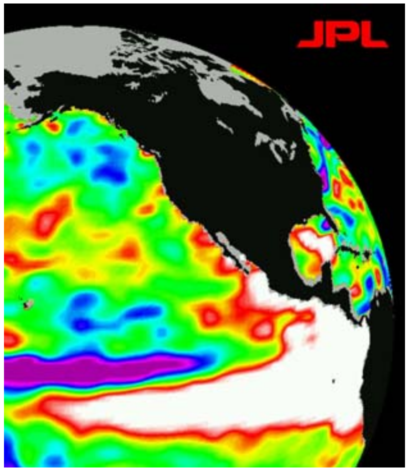


(Ceballos et al., 2009; Di Lorenzo et al., 2010)

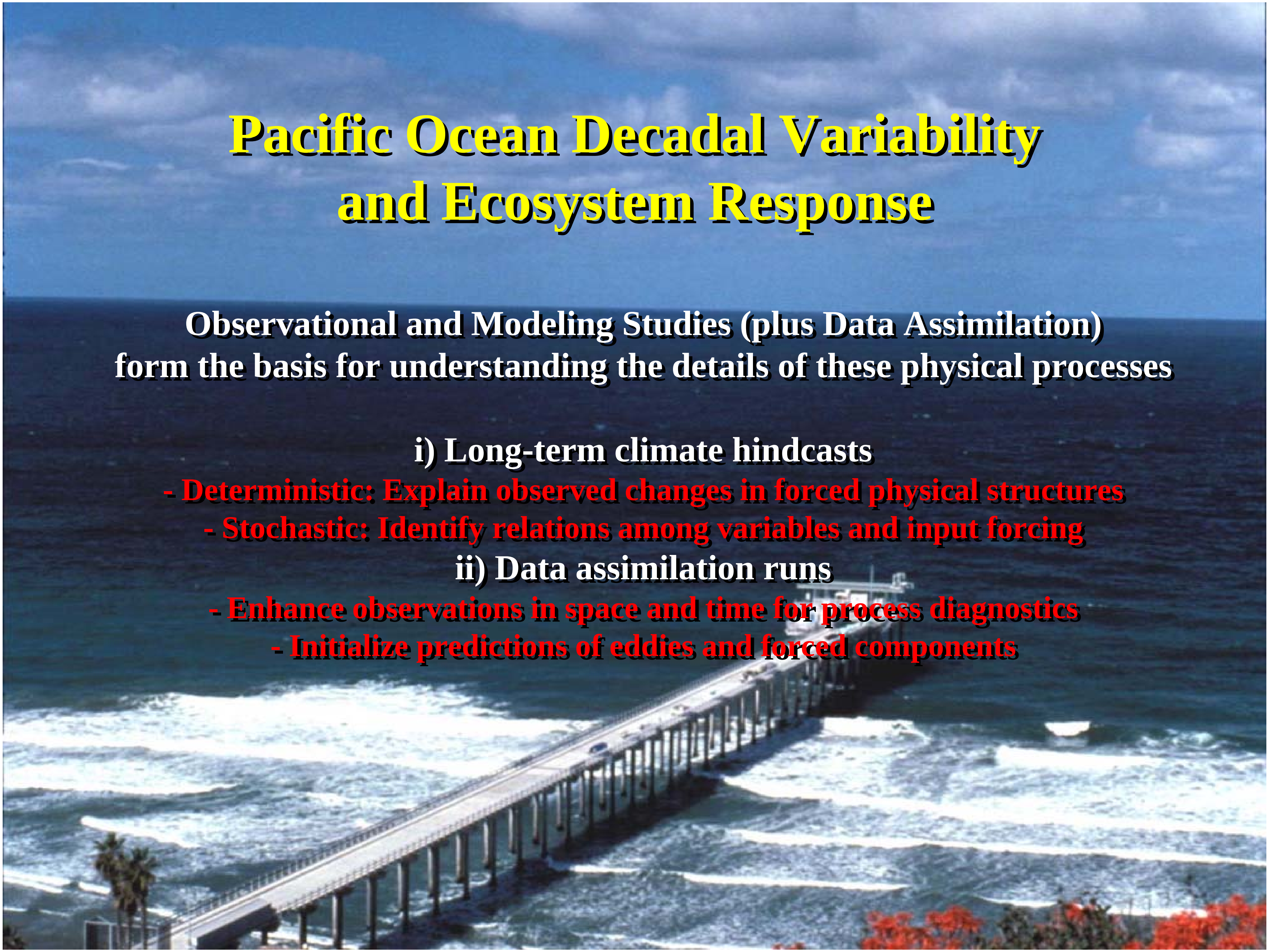
An Aside: Comments on ENSO



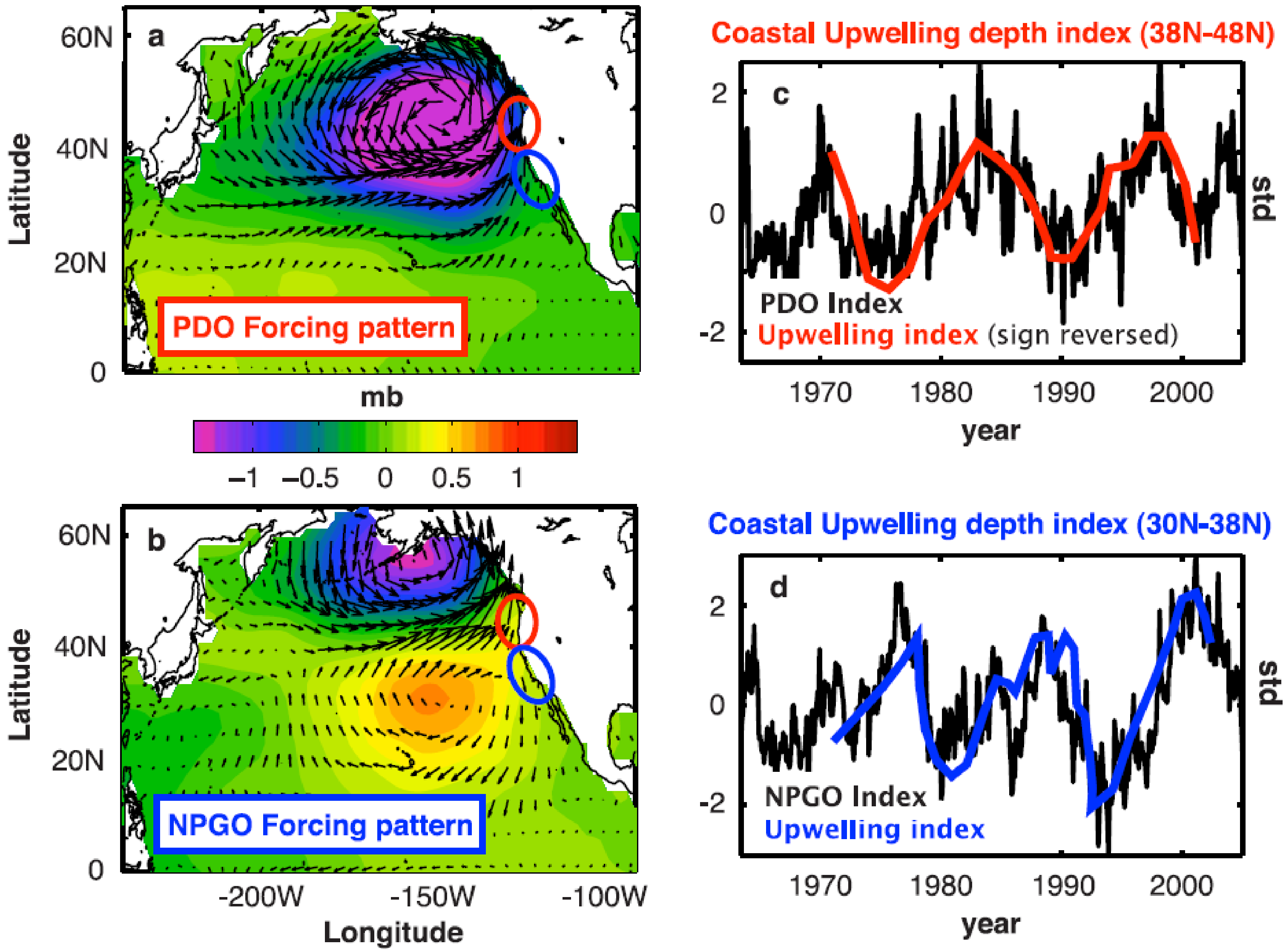
- ENSO dominates the interannual
  response of the CCS
  - Atmospheric teleconnections
    (stationary Rossby waves, PNA-like)
    Dominate the eastern boundary
  - Oceanic teleconnections
    (trapped Kelvin-like waves)
    Blocked by Gulf of California
    Fast linear Kelvin waves (cf. models)



- Clear predictable components on seasonal timescales
  need to be quantified (e.g., JISAO forecasts)


Pacific Ocean Decadal Variability
and Ecosystem Response
Observational and Modeling Studies (plus Data Assimilation)
form the basis for understanding the details of these physical processes
i) Long-term climate hindcasts
- Deterministic: Explain observed changes in forced physical structures
- Stochastic: Identify relations among variables and input forcing
ii) Data assimilation runs
- Enhance observations in space and time for process diagnostics
- Initialize predictions of eddies and forced components

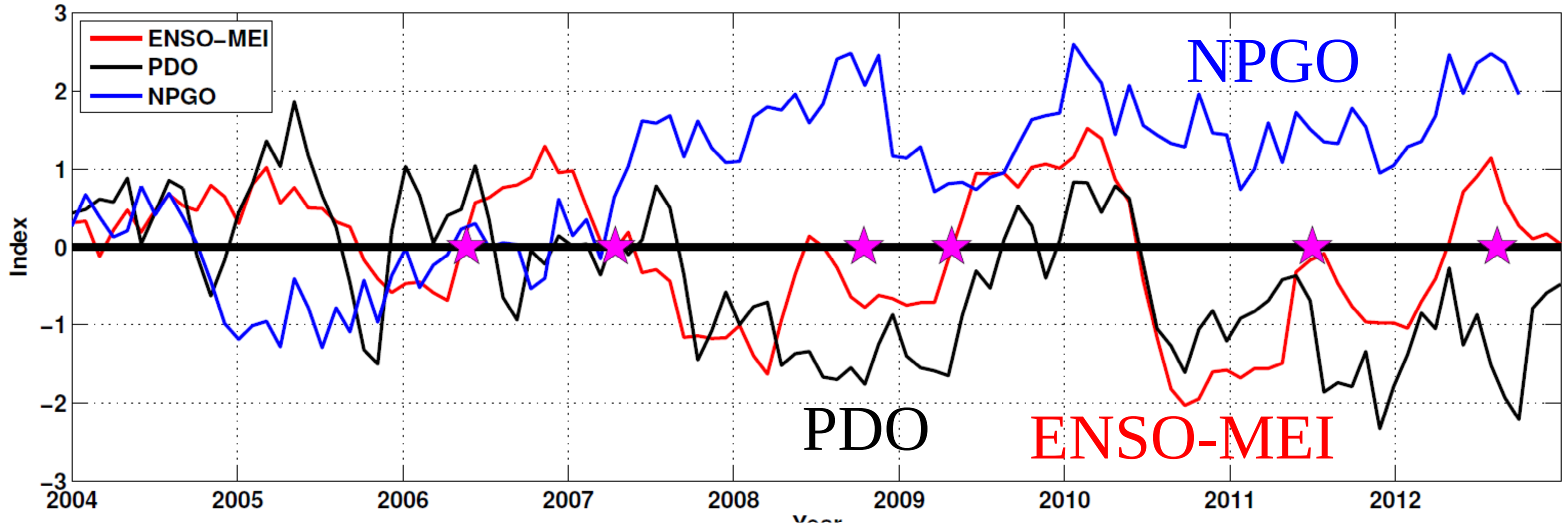
Coastal upwelling regions controlled by PDO and NPGO: Northern vs. Southern California Current

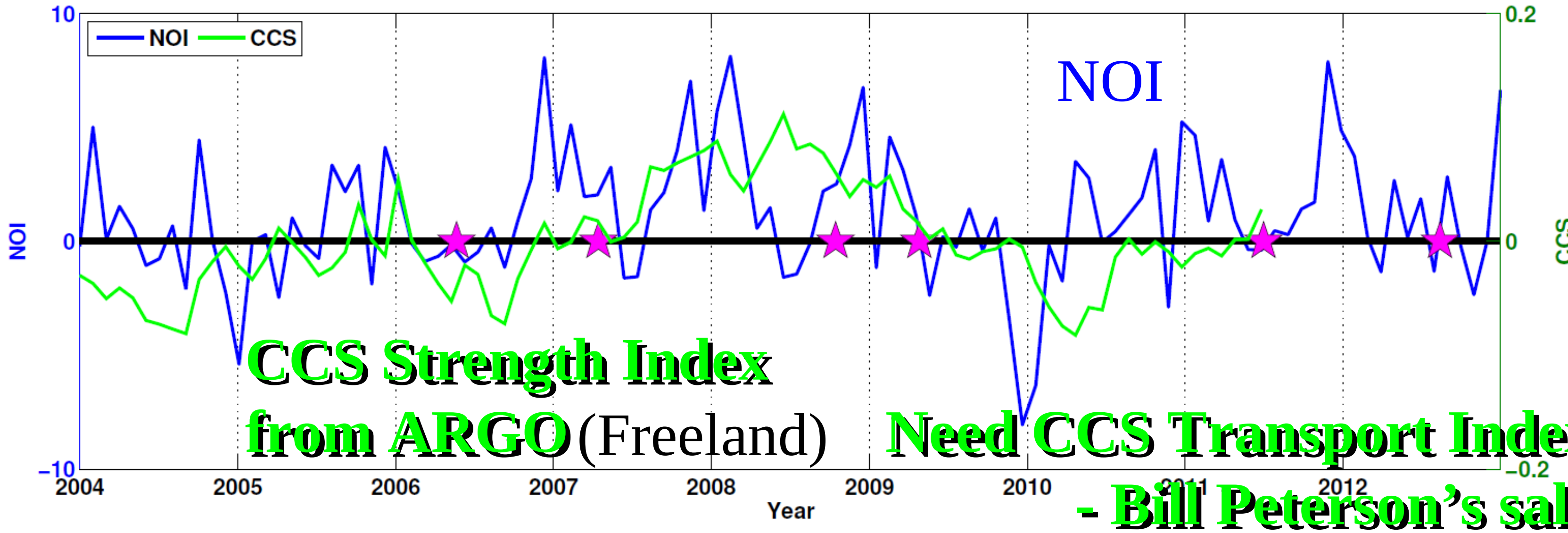


Di Lorenzo et al., GRL, 2008

An Aside: CCS physical climate variations since 2004
PDO and NPGO not enough to explain CCS Transport

Climate indices in the CCS (2004-2012)and CCE-LTER Process Cruises (Starred)





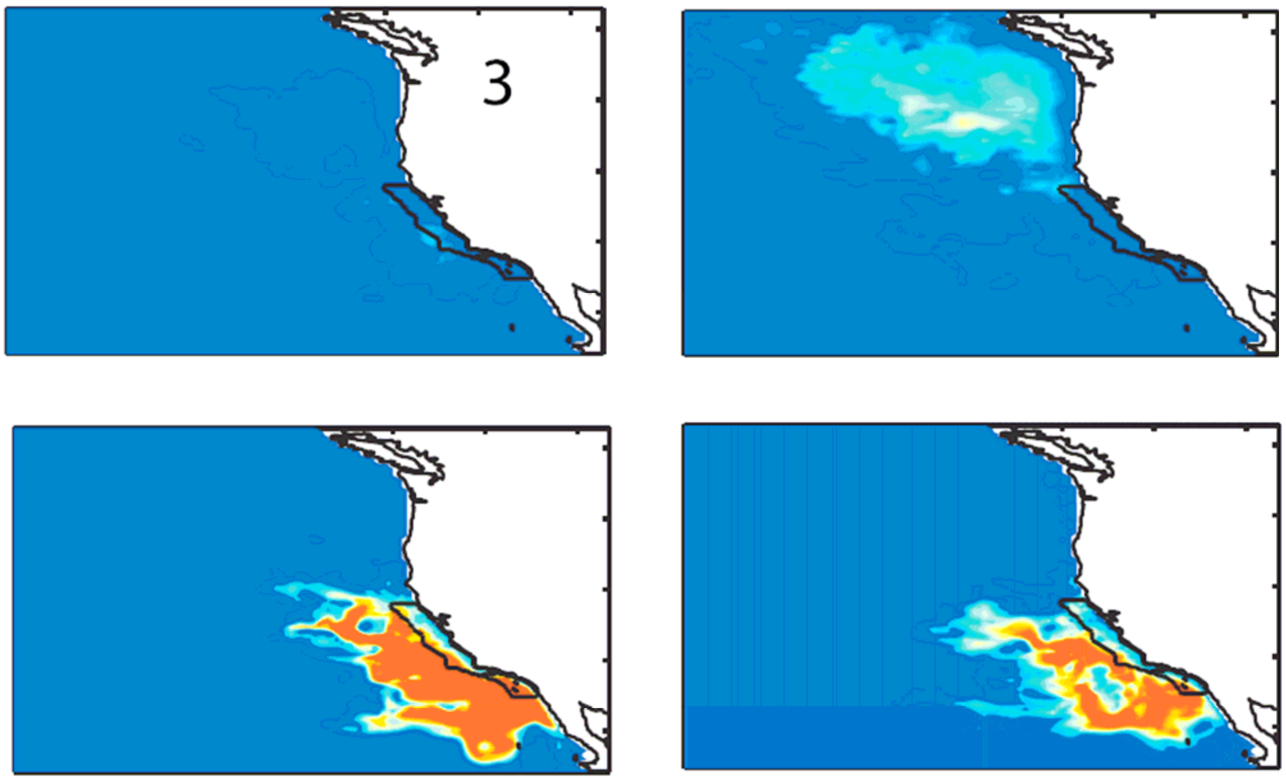
Need CCS Transport Index!

- Bill Peterson's salmon

(Miller, Song and Subramanian, 2014, DSR)

Biological impacts of PDO phase changes?
Weaker upwelling winds cause shallower coastal upwelling cell

Cool PDO Phase **Warm PDO Phase**



Surface layer transport into coastal upwelling zone

Mid-depth (150m) transport into coastal upwelling zone

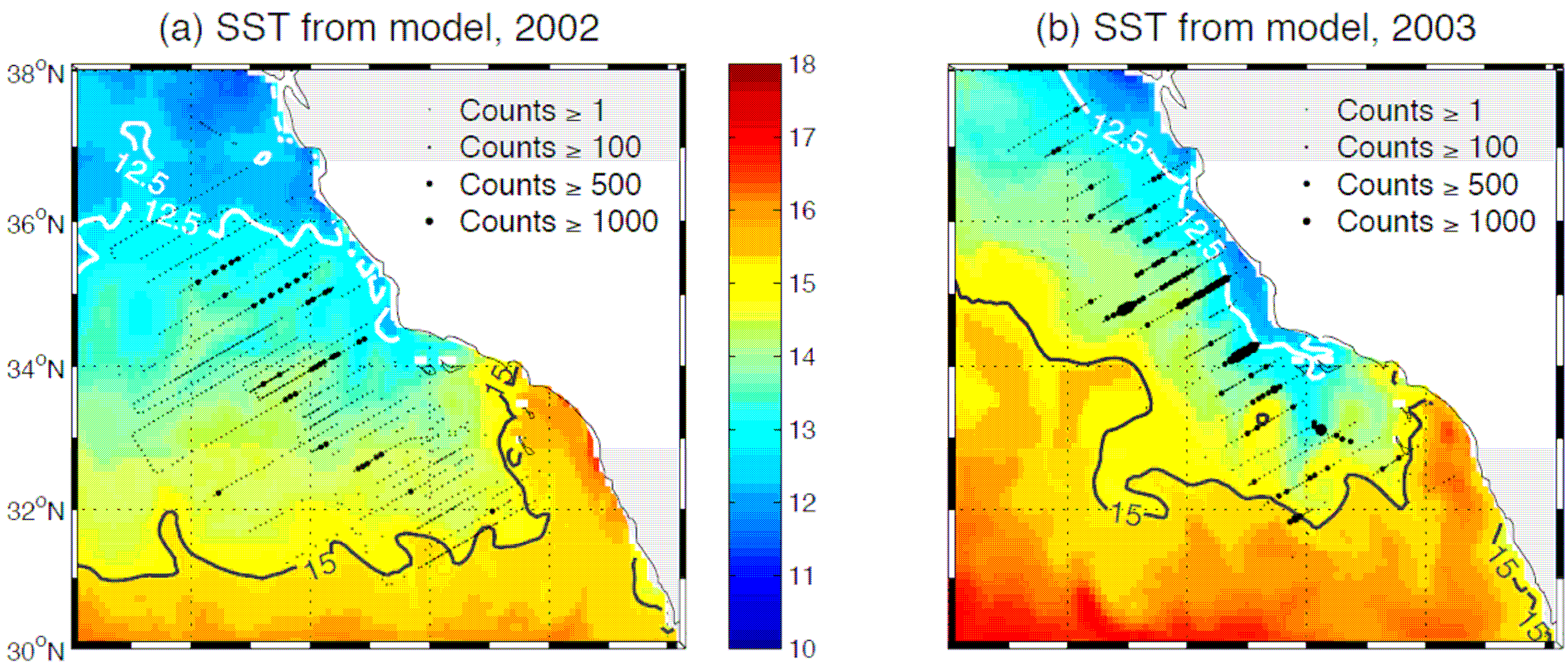
More nutrient flux to surface **Less nutrient flux to surface**

Model Adjoint *backward* runs of passive tracer in upwelling zone

(Chhak and Di Lorenzo, 2007)

Using Physical Ocean Models with Data Assimilation to Explain Changes in Sardine Spawning Habitat Quality

- **2002: stronger offshore transport of surface waters than 2003**
- **2003 source waters in nearshore spawning** area upwell from more productive **deep water in the central California Current**



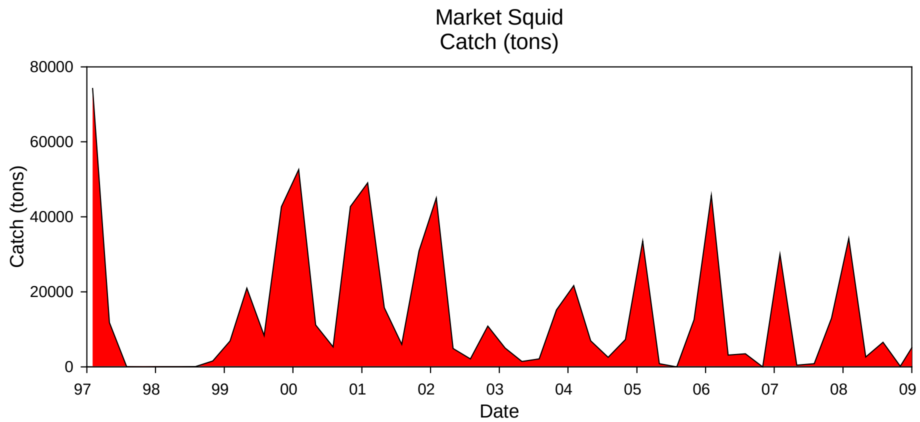
Offshore spawning, fewer eggs: **La Nina** Nearshore spawning, many eggs: **El Nino**

Data includes: T-S (CalCOFI, Argo, CUFES), SLH (AVISO), SST (AVHRR) Song et al., 2012

Thermocline Influences on Squid Spawning Habitat

Spawning Squid need sandy bottom, depths of 20-70m and temperatures between 10-14°C.

- Winter 1998, only ~4% of potential habitat was cool enough.
- Winter 2000, nearly all of 20-70m depths and sandy substrates were between 10-14°C.



Zeidberg et al., 2011

Prospects for Decadal Atmospheric Prediction

- Deterministic forcing (global warming, aerosols) starts to rise above the noise in roughly "10 years" – provides an estimate of the shift in ***mean*** and ***variance*** of atmospheric fields
- Effects of initial conditions (e.g., persistence of initial state, presence of dynamical modes of variability: ENSO, PDO, NPGO) dies out over "years"

  - Premise for predictability is vital

  - Atmospheric imprint is difficult to prove (e.g. AMOC appears to oscillate only in ocean)

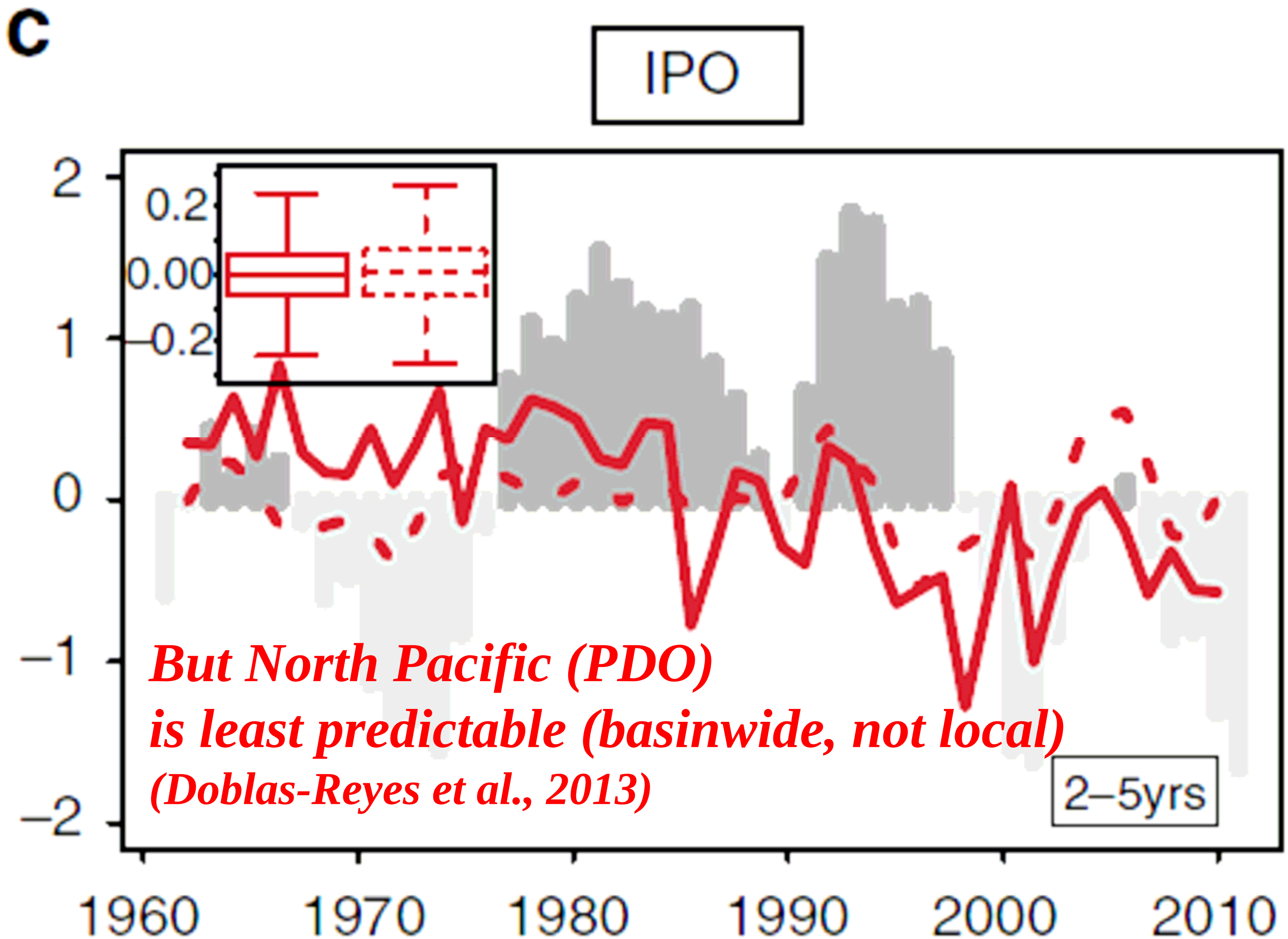
  - Active subject of research to ID these effects

  - Focus often on Surface Air Temperature (~SST!)

  - Beware "running means" and persistence

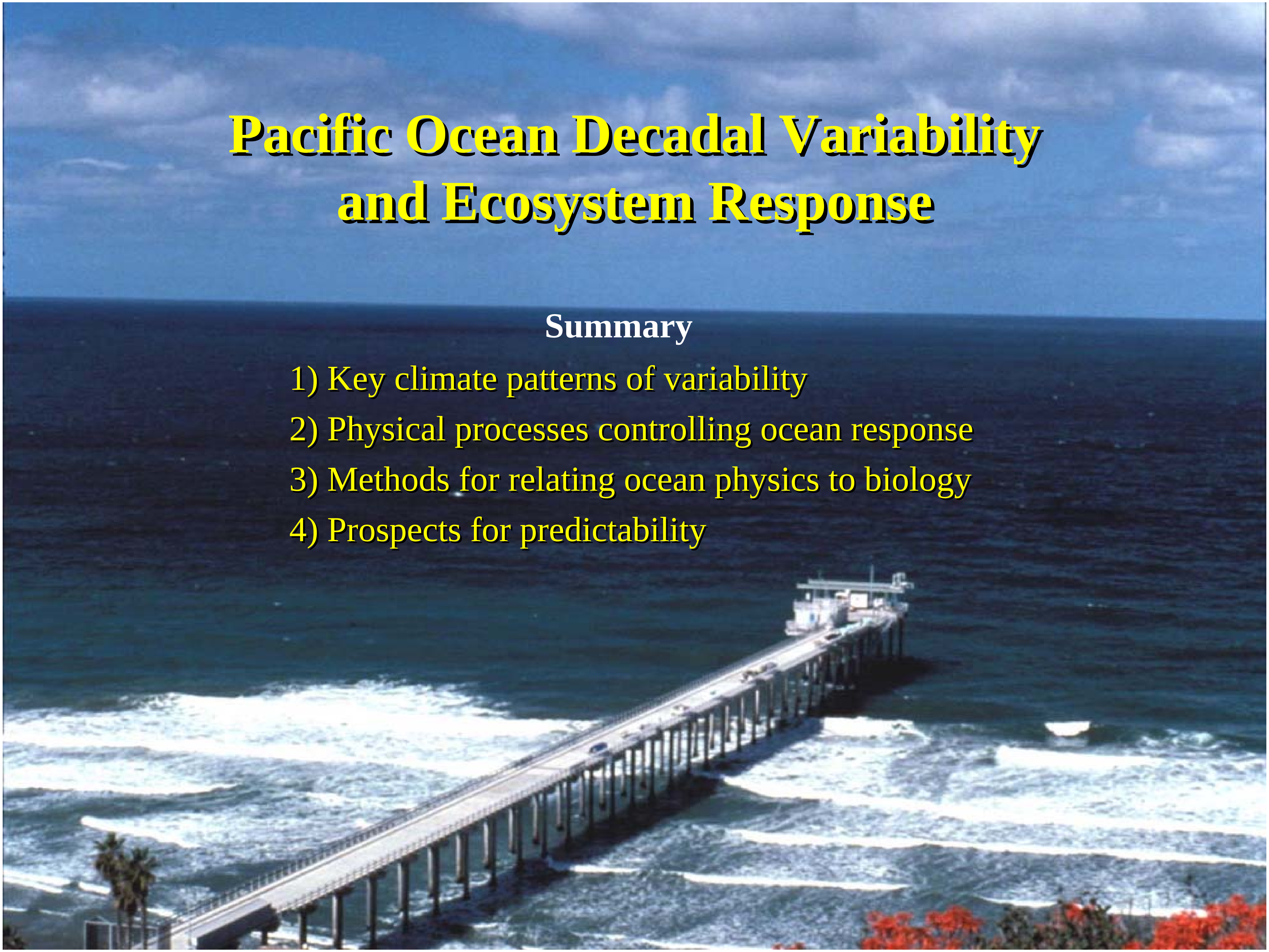
  - Uncertainty must be specified

Prospects for Decadal Atmospheric Prediction



Prospects for Ocean Prediction

- Deterministic forcing (global warming – over decades) vs. natural variations (ENSO, PDO, NPGO – years)
- Even if atmospheric variability is random, the ocean organizes patterns of response that can exhibit predictable components over interannual timescales:
  - Thermocline (Rossby) waves
  - Advection of anomalies by mean currents
- Biological "memory" through life histories: e.g., following Year Classes (No Physics!)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Thanks!