Regional Impacts of Large-Scale Climate Variations on the Pacific Ocean Ecosystem

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Outline

1. Basic physics that organizes the patterns of Pacific ocean decadal variability
2. Relations to our current research on regional ecosystem response
   a. California Current
   b. Gulf of Alaska
   c. Kuroshio-Oyashio Extension
3. Comments on possible biologically induced feedbacks

Recent Collaborators

Physics: Schneider, Di Lorenzo, Pierce, Kim, Bograd, Alexander, Capotondi, Deser, Lynn, McWilliams, Mestas-Nunez

Biology: Moisan, McGowan, Neilson, Chai, Chiba, Gabric

Funding: NSF, NASA, NOAA, DOE, ONR
North Pacific Ocean Decadal Variations

Decadal Sea Level Pressure Change

Zonal Wind Stress Change

Ekman transport
Vertical mixing
Surface heat flux

SST anomaly (central/eastern N Pac)
Subducted temperature anomaly

Ekman pumping

Thermocline depth (Sverdrup response)

Western boundary transport

SST anomaly (western N Pac)

Feedback to atmosphere?

Rossby waves

Canonical SST Pattern

(Miller and Schneider, 2000, Prog. Oceanogr.)
Canonical Pattern of Decadal SST Response (Aleutian Low Strengthening)

From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)
Lagged Pattern of Decadal SST Response
(Aleutian Low Strengthening)

Schematic

From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)
Basin-Scale Pattern of Decadal Thermocline Response (Aleutian Low Strengthening)

Lagged response in west due to Rossby wave propagation

Tropical Thermocline Deepening

From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)
Sources of North Pacific Decadal Variability

1. Tropical Teleconnections (requires tropical decadal mechanism)
   a. Atmospheric (ENSO-like)
      - canonical SST pattern
      - basin-scale thermocline response
   b. Oceanic (ENSO-like)
      - eastern boundary thermocline response

2. Subduction Modes

3. Midlatitude Gyre Modes

4. Stochastic Forcing
   - oceanic spectral peaks possible
   - predictable components possible

5. Deterministic Forcing
   - solar cycles, greenhouse gases
What Forces the Pattern and Timescales of the Pacific Decadal Oscillation?

PDO: a response of North Pacific SST to
- El Nino
- Aleutian Low
- Transport of the Kuroshio/Oyashio Extension

Schneider and Cornuelle, *J. Climate*, submitted
Hindcast of annual averaged values of SST: the PDO

Schneider and Cornuelle, *J. Climate*, submitted

\[ T_n = \alpha T_{n-1} + \gamma_i F_{i,n} \]

Autoregressive model forced by

- El Nino
- Aleutian Low
- KOE adjustment to Ekman pumping

\[ T_n = \alpha T_{n-1} + \gamma_i F_{i,n} \]
Summary of Some Regional Ecosystem Impacts
Organized by Pacific Decadal Variability

Adapted from Yasuda et al., 1999, Fish. Oceanogr.
What Drives the Warming of the California Current?

Di Lorenzo, Miller, Schneider and McWilliams

Journal of Physical Oceanography, in press.
CalCOFI Observations along the Southern California Coast

Over 50 yrs...

1 deg C warming of SST...

...70% decline in macro zooplankton

Roemmich and McGowan
Science, 1995
Local Atmospheric and Remote Oceanic Forcings That Can Affect the Regional Oceanic Heat Budget

- Mean Advection
- Anomalous Advection
- Local Surface Heat Fluxes
- Alongshore Wind Stress
- Southern California
- Upwelling

Di Lorenzo et al., JPO, in press
Upwelling Winds have increased in the CCS

**NCEP Winds**

EOF 1

**Wind Stress Curl**

EOF 1

**PC 1**

Di Lorenzo et al., JPO, in press
Timeseries of surface net heat fluxes averaged over Southern California

Ocean is Cooling

Ocean is Heating

Di Lorenzo et al., JPO, in press
An eddy-permitting ocean model hindcast captures the observed SST and thermocline variations.

Thermocline depth over the last 50 yrs shows an overall deepening of 20 m.

Warming is due to large-scale decadal surface heat fluxes combined with southward advection of concomitantly warmed water. Increase in upwelling favorable winds partially cools water column.

Di Lorenzo, Miller, Schneider and McWilliams, JPO, in press.
Decline in Chl-a linked to thermocline deepening in the model simulation. This is consistent with the observed zooplankton decline.

Chlorophyll response to these physical changes in NPZD-type 7-component model hindcast

How does primary production respond to these modeled changes?

Increased winds only

Warming and winds together

Miller, Gabric, Moisan, Chai, Neilson, Pierce and Di Lorenzo, *sub judice*, 2004
Observed changes in the seasonal cycle of Zooplankton in the CCS

McGowan, Bograd, Lynn and Miller, DSR, 2003
What changes in Mixed-Layer Depth have occurred in CalCOFI data after the 1976-77 climate regime shift?

And how are these related to nutricline, thermocline, chlorophyll, and zooplankton changes?

Hey-Jin Kim, Art Miller, Doug Neilson, and John McGowan

Scripps Institution of Oceanography
La Jolla, CA
Probability Density Functions of MLD: Pre/Post 1976-77

(Hey-Jin Kim, Miller, McGowan and Neilson, in prep)
Thermocline vs. Nutricline: are they correlated?

Nutricline is much deeper than thermocline, which is deeper than MLD, suggesting decoupling of nutrient fluxes

(Hey-Jin Kim, Miller, Neilson, McGowan, in prep)

Linear regression:
\[ \alpha = 1.3 \pm 0.01 \]
(95 % confidence level, \( r^2 = 0.98 \))
Effects of anthropogenic forcing on biological activity

Biological Model Phytoplankton [ mmol C/m³ ]

Ratio, Year 2100 / Year 2000

Pierce, Climate Change, 2004
California Current Circulation in a Global Warming Scenario

**Baseline:** NCEP 50-yr climatology of wind stress and curl

**Perturbation:** ACPI PCM 2040-2050 climate minus 1986-1996 climate downscaled with RSM
California Current Circulation in a Global Warming Scenario

**Baseline**: NCEP 50-yr climatology of surface heat flux

**Perturbation**: ACPI PCM 2040-2050 climate minus 1986-1996 climate downsampled with RSM
Regional SST Changes in a Global Warming Scenario

**Baseline:** 1 deg C warming over last 50 years of CalCOFI data

**Perturbation:** Forced by 2040-50 winds and surface heat fluxes, but not BC changes:
SST warmed 0.4 - 0.7 deg C

(Auad, Miller, Pierce, Di Lorenzo, in prep)
Mesoscale Eddy Variance Changes in a Global Warming Scenario

**Baseline**: Offshore variance max increased after 1976-77 shift (Di Lorenzo et al., 2004)

**Perturbation**: Forced by 2040-50 winds and surface heat fluxes, but not BC changes: variance generally reduced (only 6 yr long run)

(Auad, Miller, Pierce, Di Lorenzo, in prep)
The Climate-Ocean Regime Shift Hypothesis of the Steller Sea Lion Decline

Relating temporal variability in the physical system to ecosystem changes
SSL population declines since 1976-77 Climate Shift:
Western Gulf of Alaska population dropped
Eastern Gulf of Alaska population was stable
Did Climate Do it? (Trites, 2004)
Observed Changes in Ekman pumping

Pre-shift mean conditions
1960-75
Dec-May

Change after shift
(1977-97)
-(1960-75)

Capotondi, Alexander,
Deser and Miller
(JPO, sub judice)
Coarse Resolution Model Pycnocline ($26.4\sigma_\theta$) depth changes
Period2 (1977-97) – Period1 (1964-75)

**Strengthened**
Alaskan Stream!

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**Model vs. Obs PAPA**

**Model vs. Obs GAK**

Corr. = 0.69

Corr. = 0.77
Eddy-Permitting Model
Mean Surface Currents

Before 76-77 Shift

After 76-77 Shift

Difference

Large in western gulf
Little change in east

Miller et al., Atmosphere-Ocean, sub judice
Eddy-Permitting Model

Eddy Surface Currents

Before 76-77 Shift

- More eddies north of Kodiak
- Fewer eddies southwards

Kodiak Is.

Miller et al., Atmosphere-Ocean, sub judice

After 76-77 Shift

Surface Velocity Variance Change After Climate Shift

Difference

- More eddies north of Kodiak
- Fewer eddies southwards
Circulation Changes in the Gulf of Alaska associated with the Decline of the Steller Sea Lion Population


• Consistent with sea lion populations being reduced 80% in the western Gulf, but remaining stable in the eastern Gulf.

Why Did They Decline?

Good

- Increase
- Positive
- Energy Richer
- Fattier fishes (forage fish)

Bad

- Decline
- Negative
- Energy Poorer
- Leaner fishes (gadids & flatfish)

Trites, Miller, Maschner and 22 co-authors, *Fisheries Oceanogr.*, sub judice
Ecosystem response processes in KOE on long timescales
Strengthened Aleutian Low

Miller, Chai, Chiba, Moisan and Neilson, J. Oceanogr., 2004
Regional scale influence of Rossby waves on Kuroshio-Oyashio Extension

(Tagushi, Xie, Mitsudera and Kubokawa, *J Climate*, submitted)

Post 76-77, nonlinear strengthening of eastward flows in KOE

Sea level  Zonal currents
Regional upwelling (downwelling) around KOE.....

...linked to regional enhanced (reduced) primary and secondary production in model.

Schematic of the Gu-Philander class of decadal mode

Subduction Mode

A

Equatorial Upwelling

Subsurface flow

Atmospheric Response

Midlatitude Gyre Mode

B

Gyre Circulation Change
Schematic of the Gu-Philander class of decadal mode with DMS aerosols and phytoplankton heat absorption effects

Schematic of the Latif-Barnett class of decadal mode with DMS aerosols and phytoplankton heat absorption effects

Stratus deck influenced by aerosols.

Phytoplankton can produce aerosols.

Coastal upwelling not resolved in climate models, so how would it affect the ocean-atmosphere-ecosystem response?

Linked to whole Walker Cell Circulation.

What controls the stratus deck off South America?

Cool SST influenced by heat fluxes from coastal upwelling.
Directions….

Atmosphere
- Details of atmosphere response over KOE region
- Sensitivity to ocean biology: DMS aerosols
- Regional downscaling over mountains and coasts

Ocean
- Physical mechanisms of adjustment to forcing
- Lags and predictable components
- Changes in eddy statistics
- Sensitivity to ocean biology: phytoplankton absorption

Biology
- Organization of response by ocean patterns
- Lags and predictable components
- Distinguishing forced from intrinsic variations

…and Global Change effects on all these….
Thanks!

\textit{PICES CLIVAR Intersection Workshop}

\textit{Honolulu, Hawaii}