On Regime Shifts and the Co-variability of the California Current and Gulf of Alaska Ecosystems

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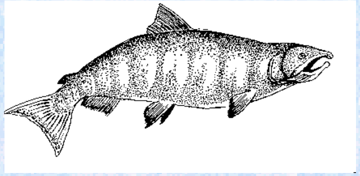

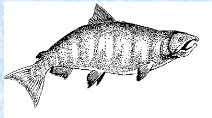

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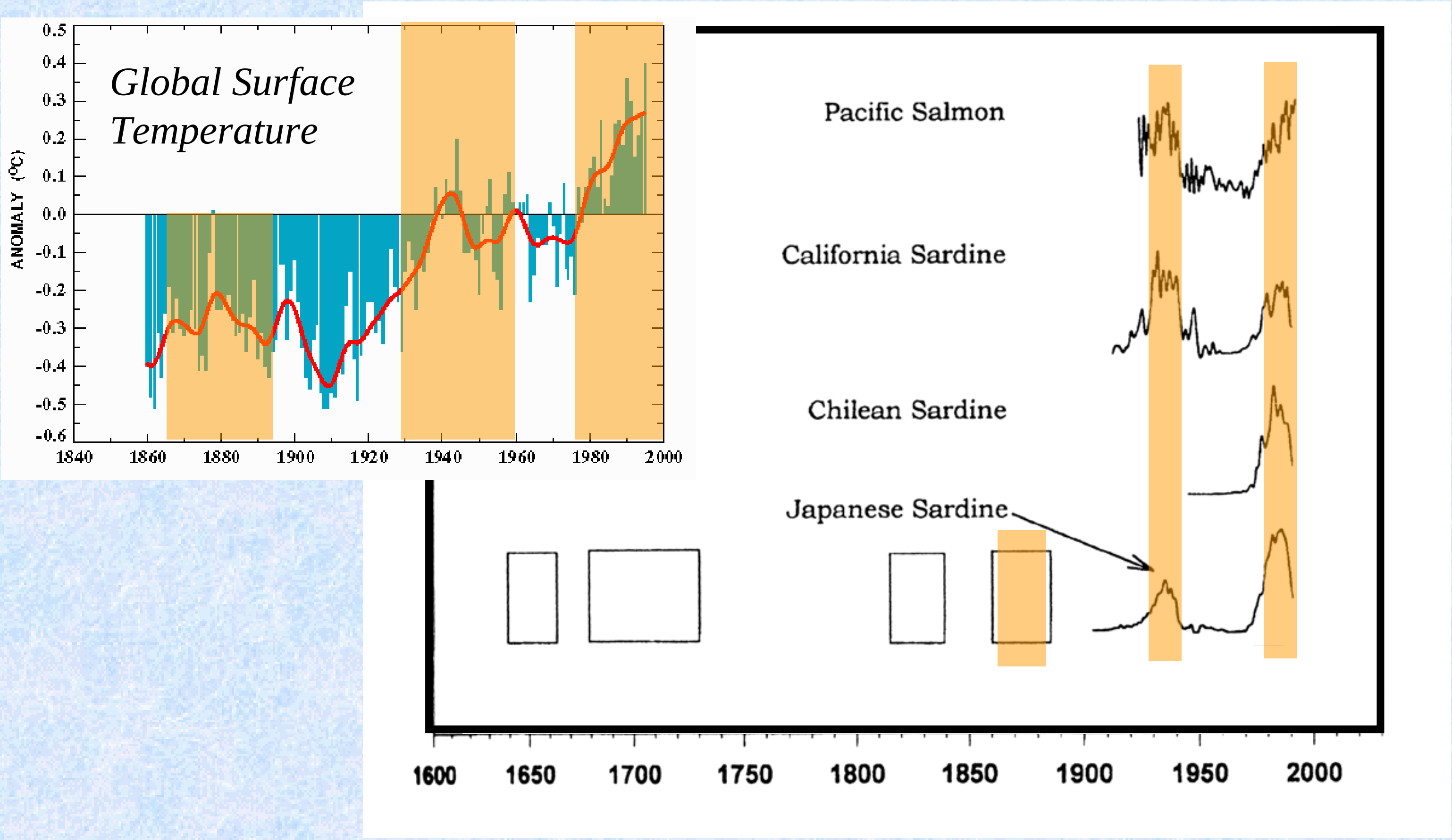
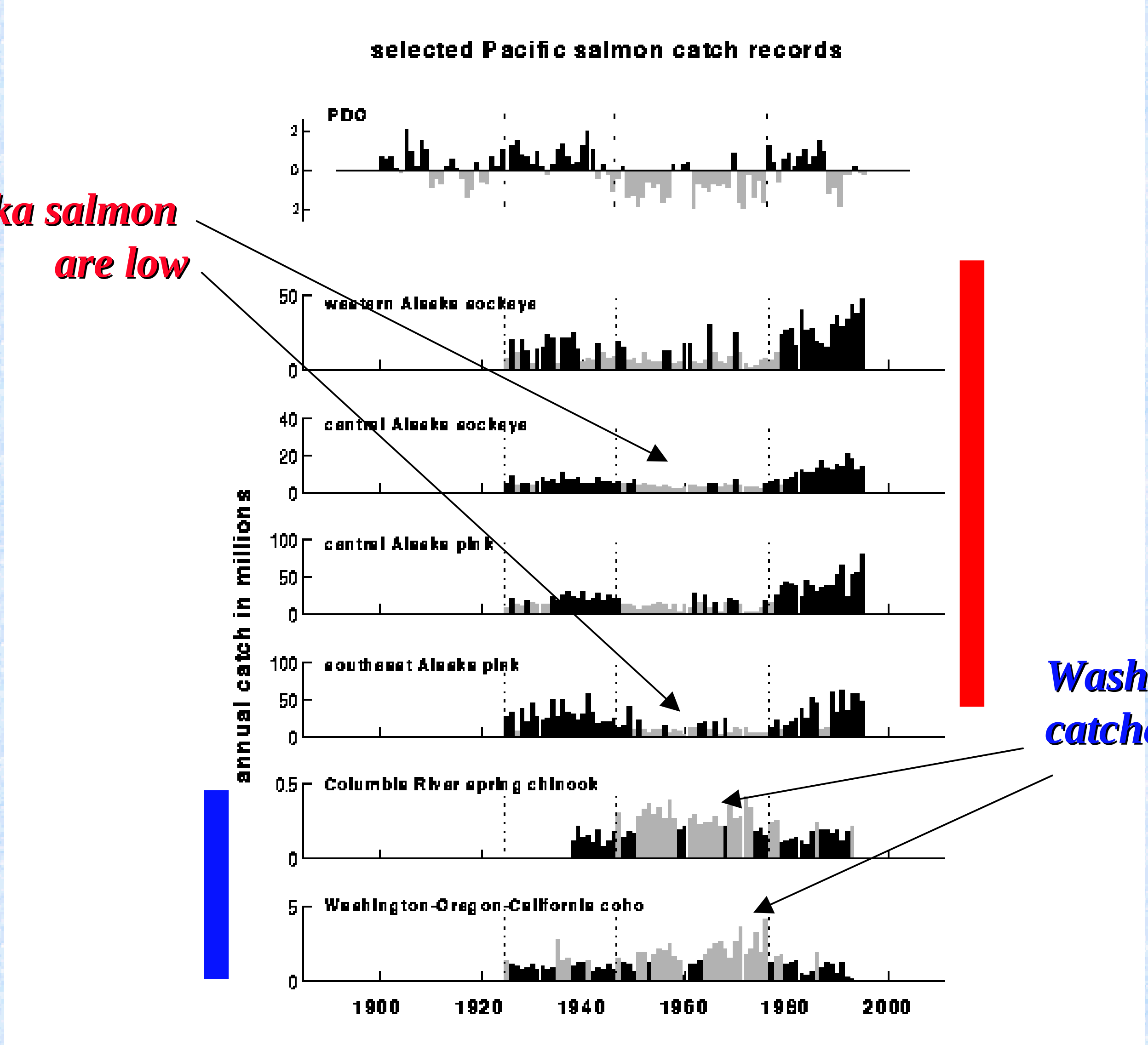
Global Synchrony of Fish Populations



(from Beamish et al. 1999)

Pacific Salmon Populations

When Alaska salmon are low



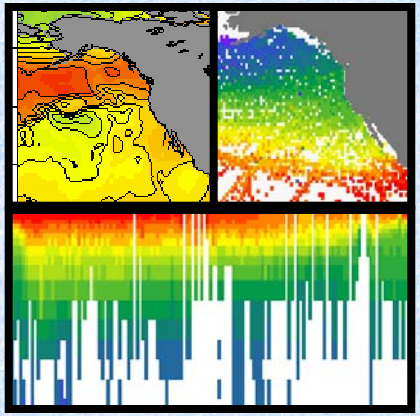
Washington-Oregon catches are high

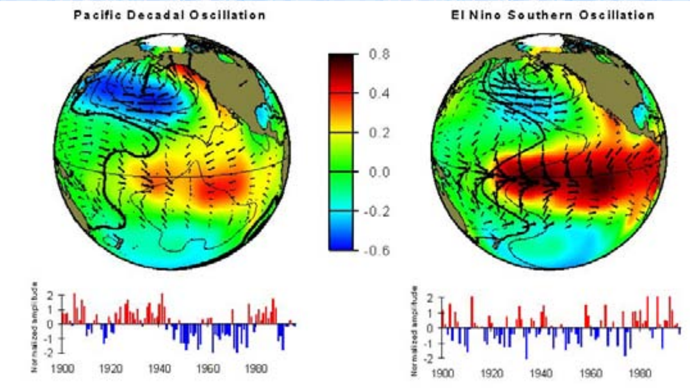
Patterns in Climate Variability

$\vec{x}$ → $f(\ )$ → $\vec{y}$

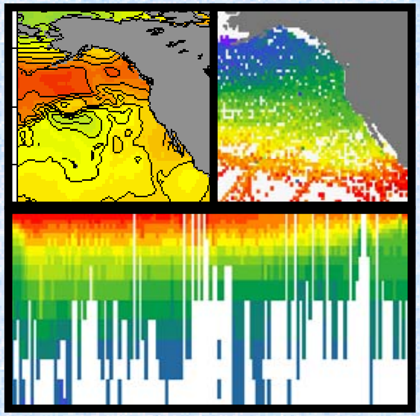
INPUT PROCESS OUTPUT

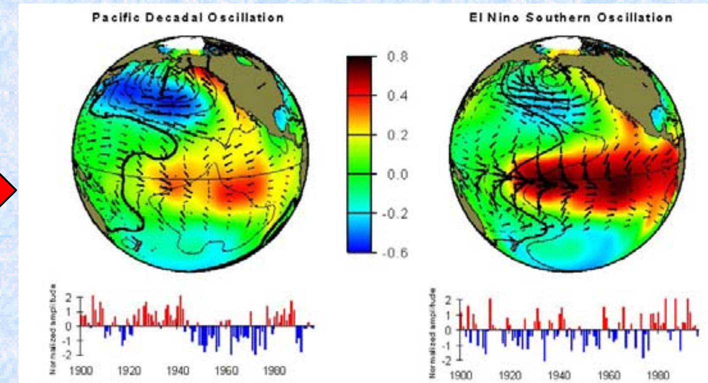
Patterns in Climate Variability



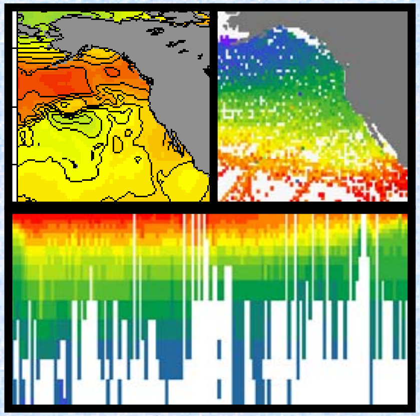


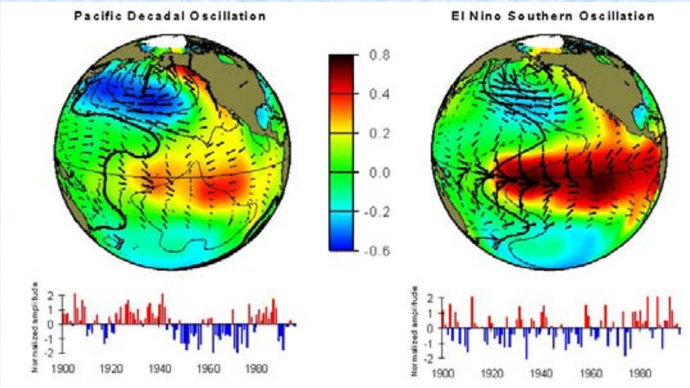
Patterns in Climate Variability

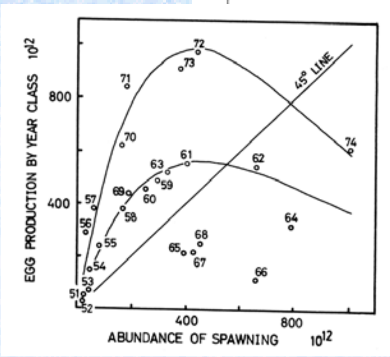


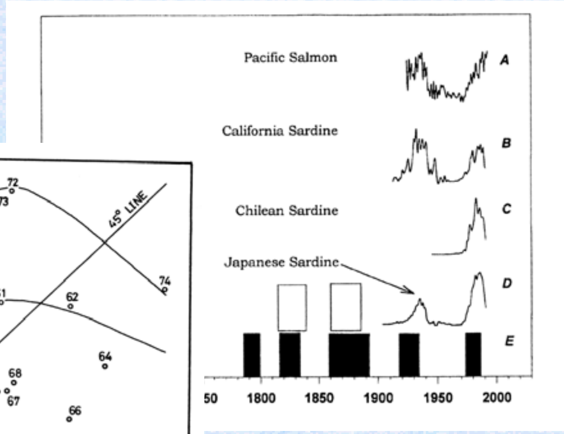


Patterns in Climate Variability

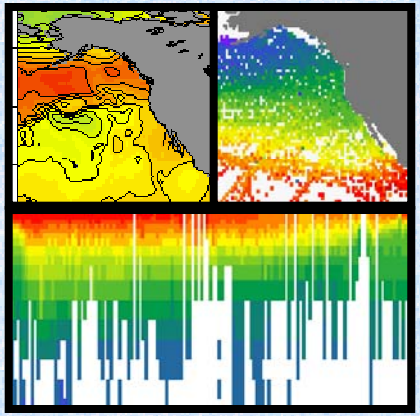


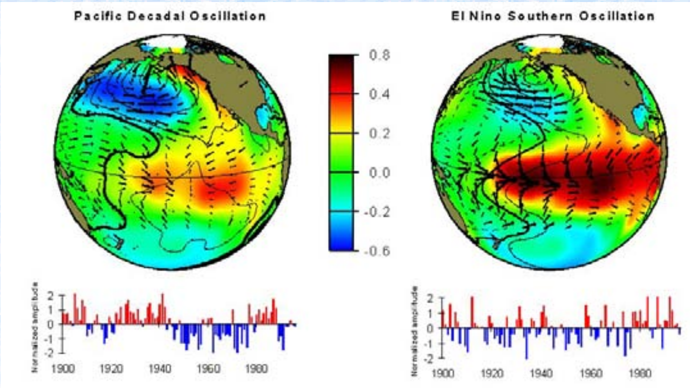


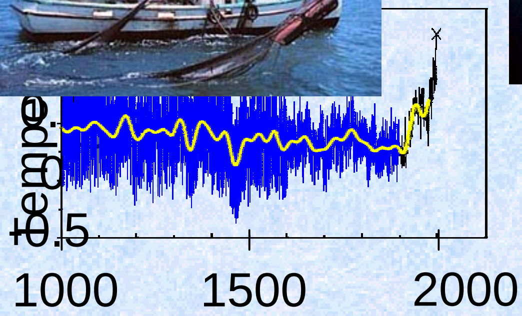


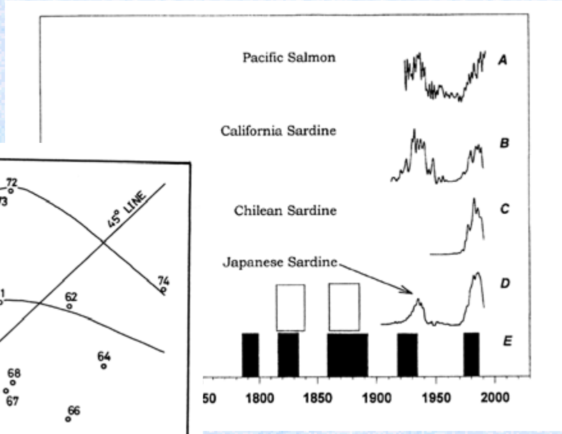


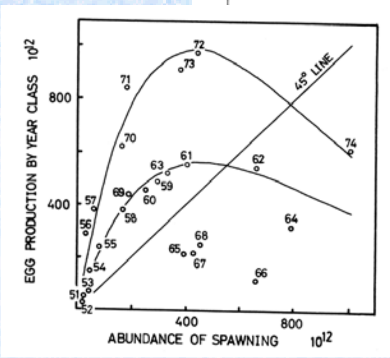
Patterns in Climate Variability











COMPELLING QUESTIONS

Are regime shifts real in the North Pacific?

How do we define and quantify regime shifts?

- What is their timing and morphology?
- What is their (3-D) spatial structure?
- What are their causes and forcing mechanisms?
- What are the biological responses and pathways?
- How are they modulated by local factors?
- Do the GOA and CCS ecosystems always vary out-of-phase?

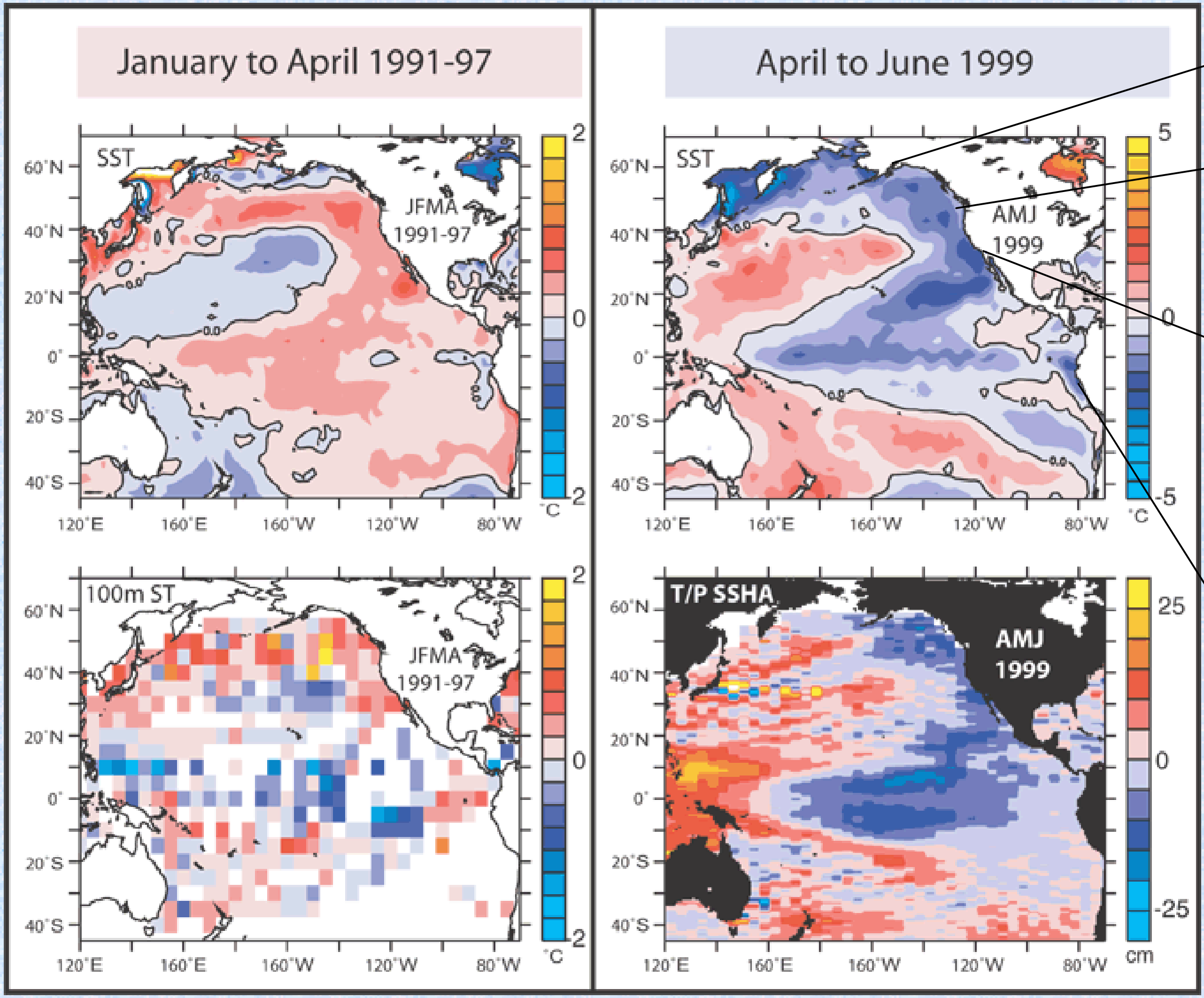
OVERVIEW

Examine analysis methods and indices for regime shifts

- What do they describe?
- What are their limitations and precautions?
- What are their present utility?
- How can they be improved?

APPROACH

- Describe spatial modes of recent "regime shifts" *(ca. 1941,1976, 1989, 1998)*
  - Observations and anecdotal reports
  - Anomaly time series & fields
  - EOF analyses
  - Decomposition of PDO & other indices
  - State-space models of physical & biological series
  - Common trend analyses
- Describe co-variability of the North Pacific & GOA and CCS ecosystems on regime time scales
- Develop indices of GOA-CCS co-variability



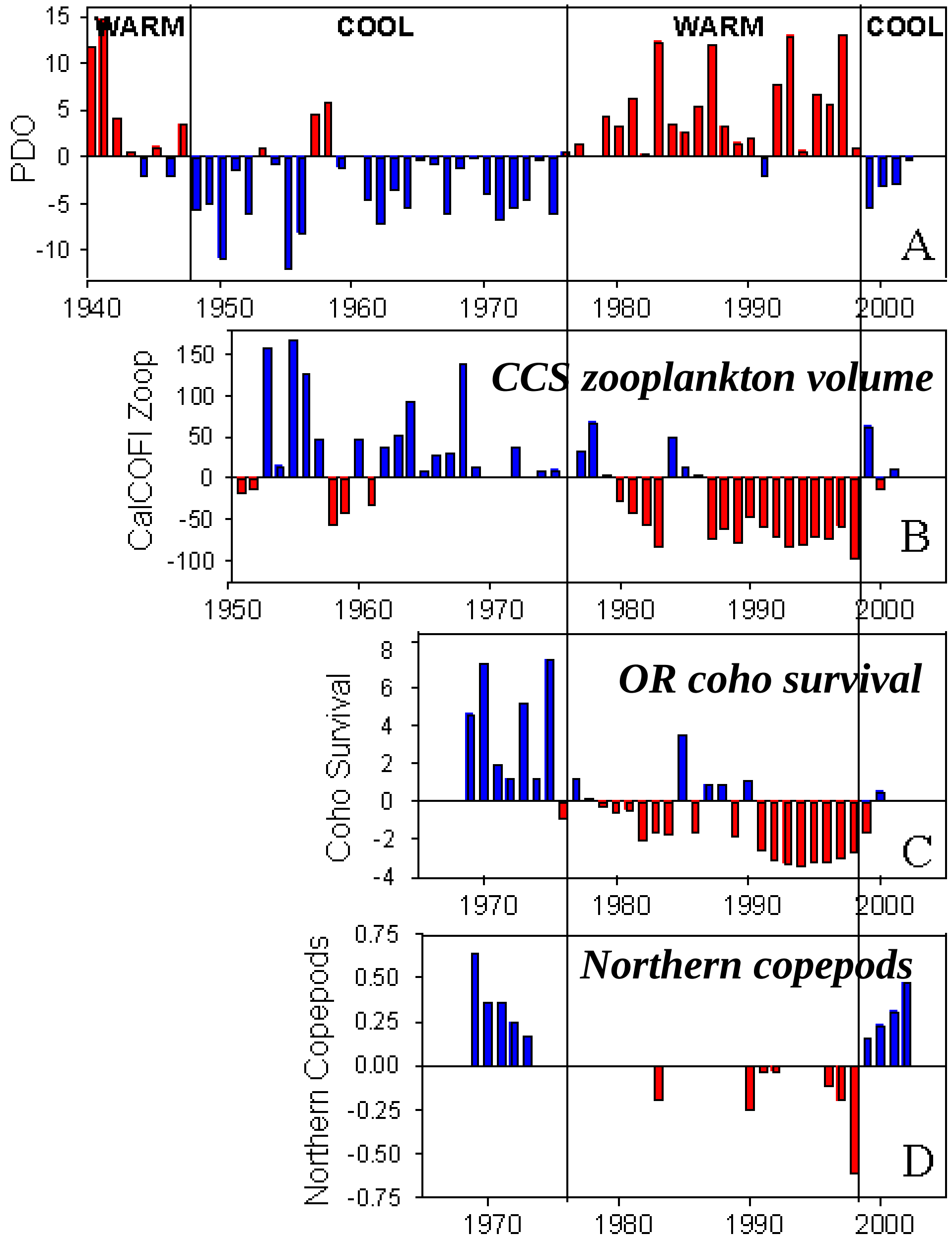
Lower salmon returns
GOA shrimp returning
Bering Sea plankton bloom

Higher salmon returns
Shifts in pelagic community
Shift to subarctic zoopl

Greater rockfish recruitment
Market squid value up
Sardine area reduced
Higher marine bird prod'n
Higher zoopl biomass
Shifts in euphasiids
Higher Macrocystis growth

Anchovy expanding
Sardine declining

Abrupt widespread shifts in physics or biology observed
Are these anomaly patterns repeated over time?

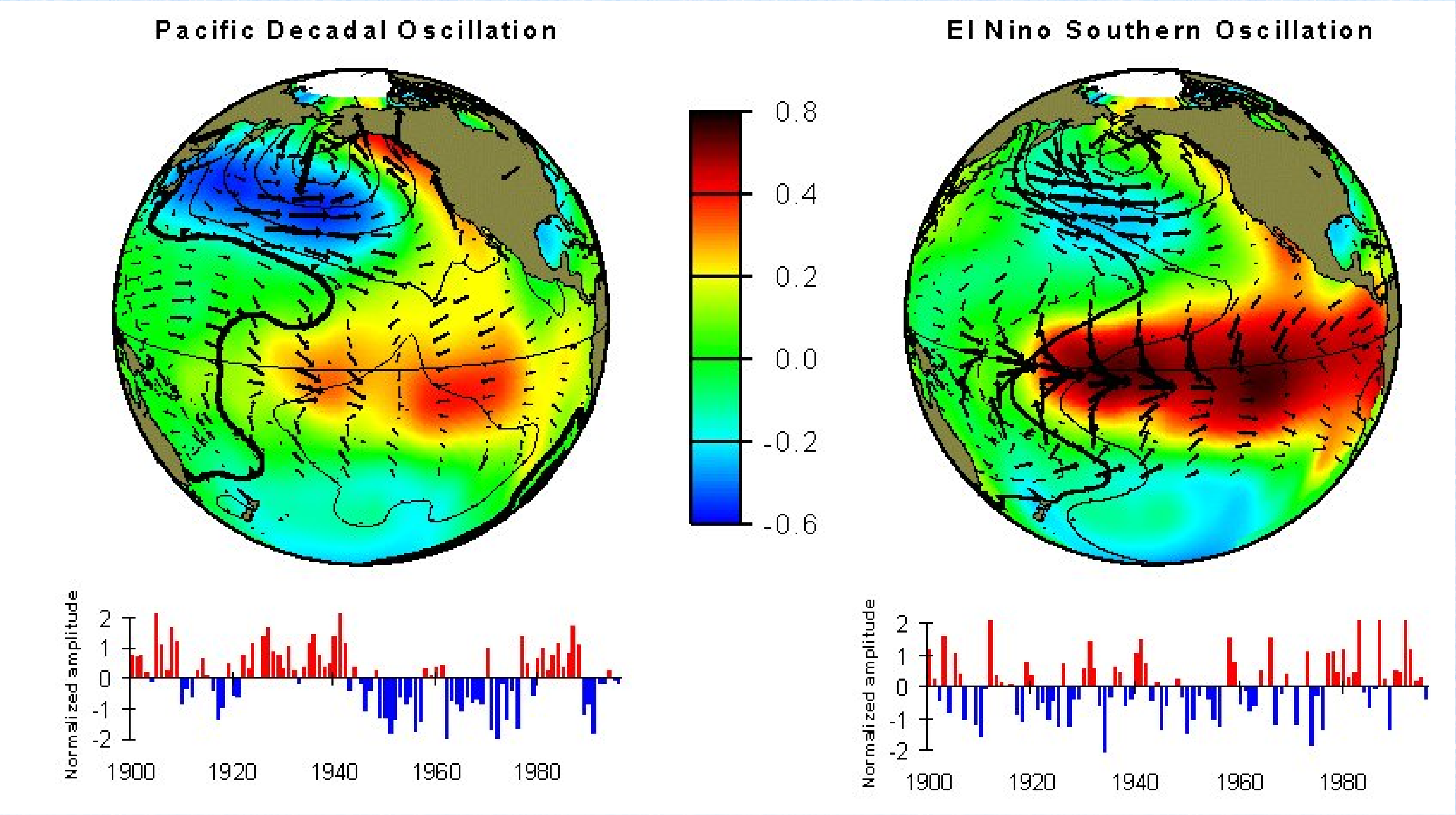


Long time series provide simple indices that correlate repeated episodes of physical & ecosystem variability

But lack mechanistic insight

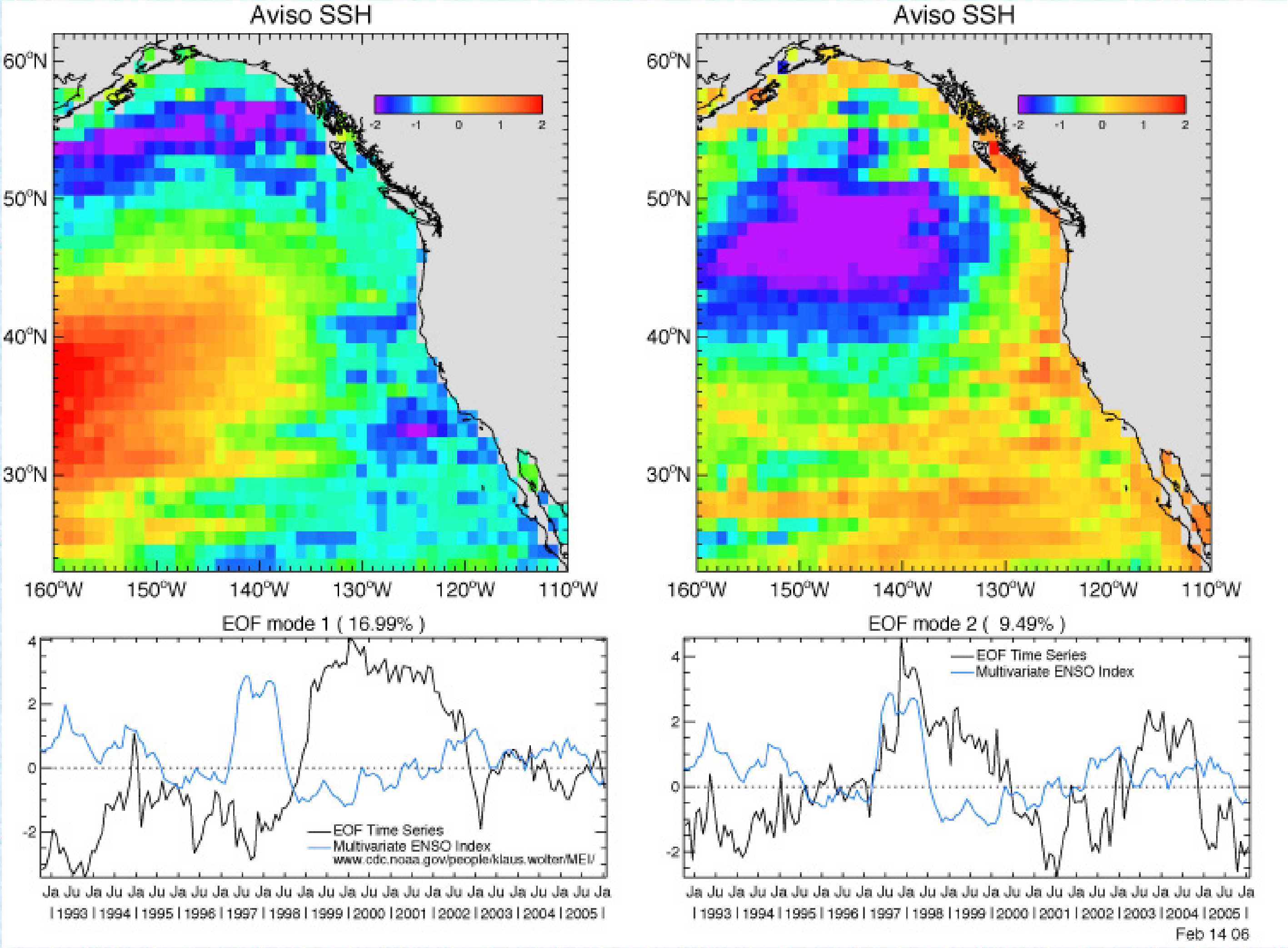
(from Peterson and Schwing, 2003)

SST SPATIAL PATTERNS:
INDICES OF ECOSYSTEM VARIABILITY ?



(from S. Hare & N. Mantua)

SSH Spatial Modes of Regime Shifts – 1993-2005



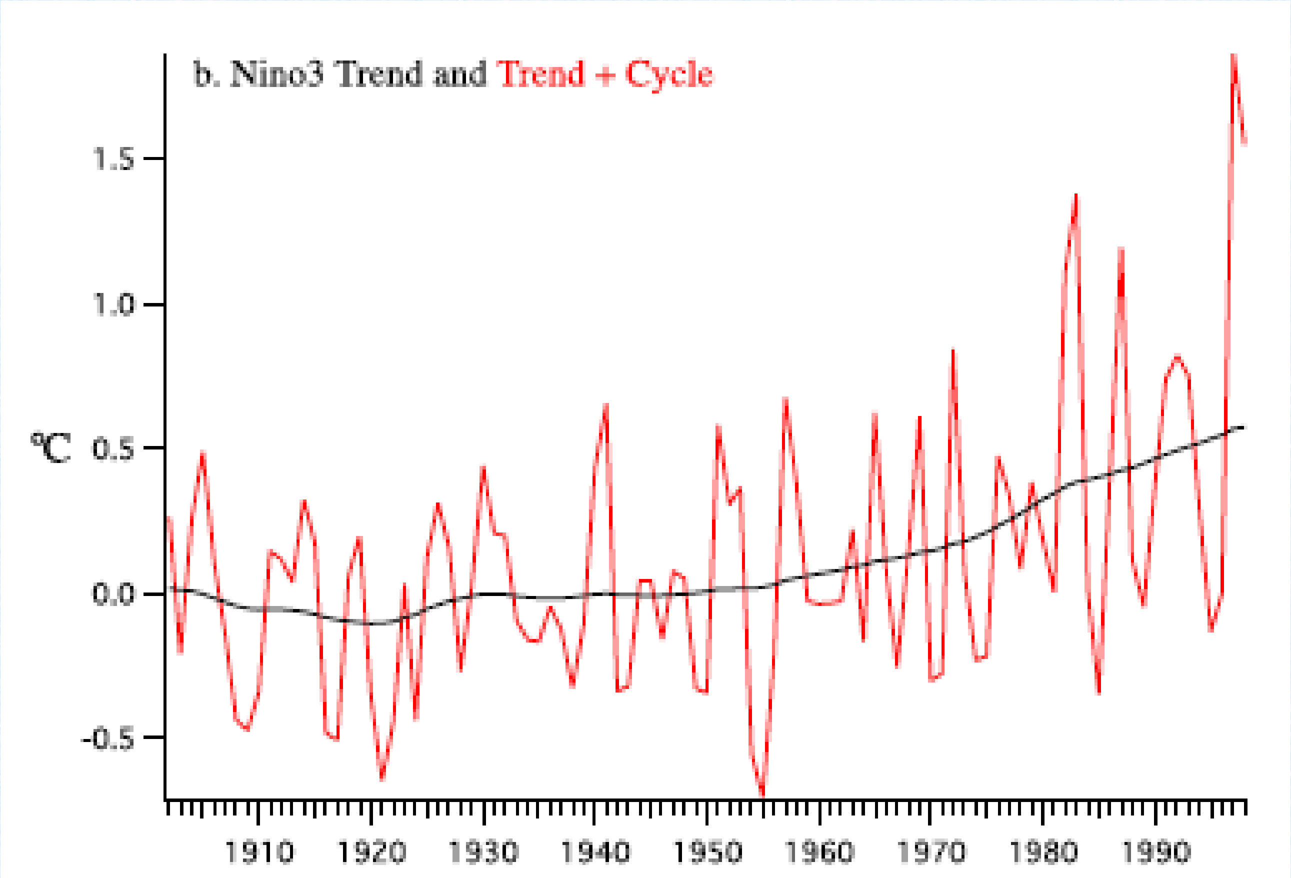
State-space decomposition of time series

Data(t) = Trend(t) + Seasonal(t) + Irregular(t) + Error(t)

Trend - non-linear and non-parametric
Seasonal - non-stationary, changes in phase and amplitude
Irregular - can include AR or stochastic cyclic term
Error - allow for observational error

Model SST data set used to compute PDO
Decompose PDO
Decompose Nino3

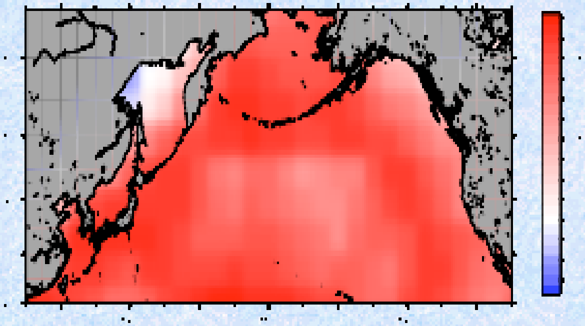
Climate Variability Interactions



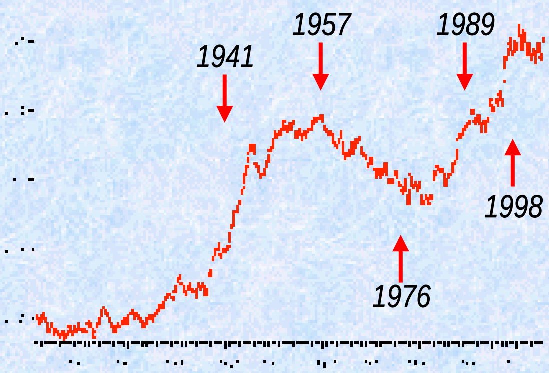
Long-term warming trend enhances El Niño effects

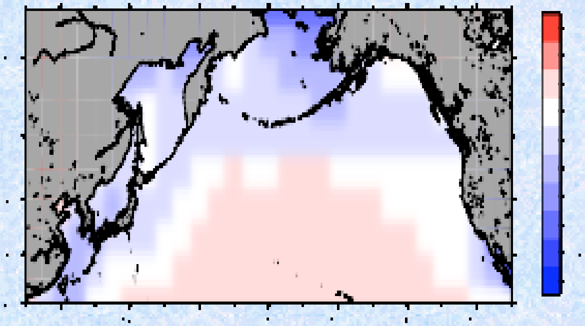
From Mendelssohn et al. (2005)

Spatial Modes of Regime Shifts
State-Space Common Trends

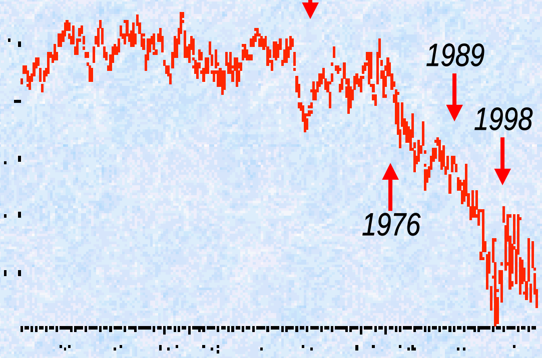


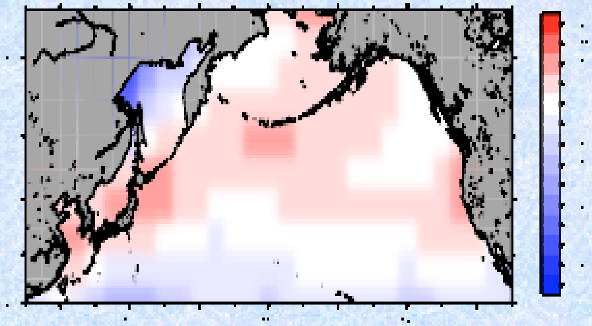
mode 1



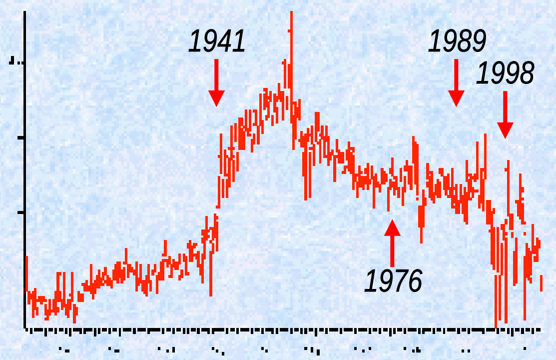


mode 2

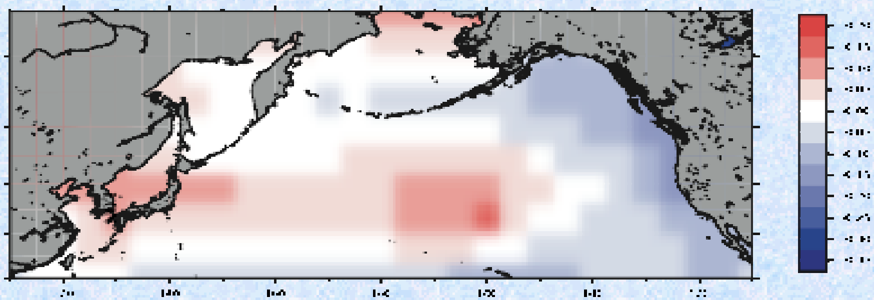


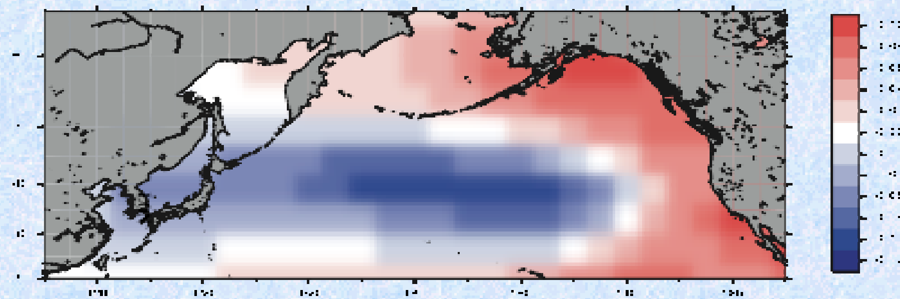


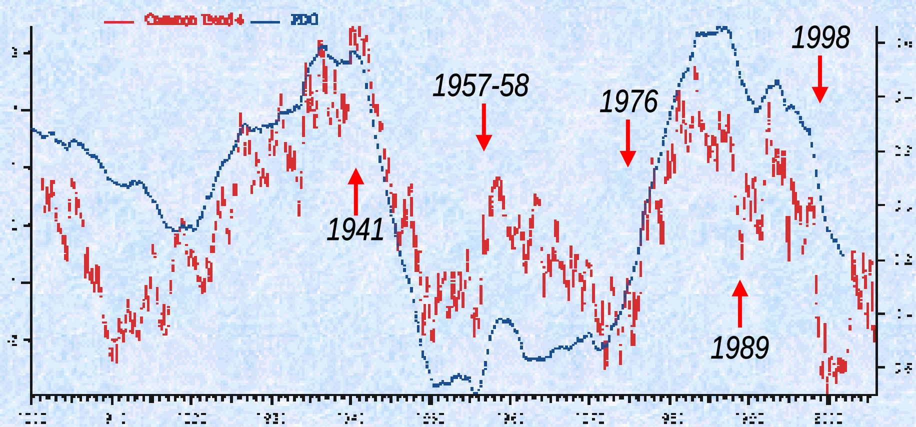
mode 3

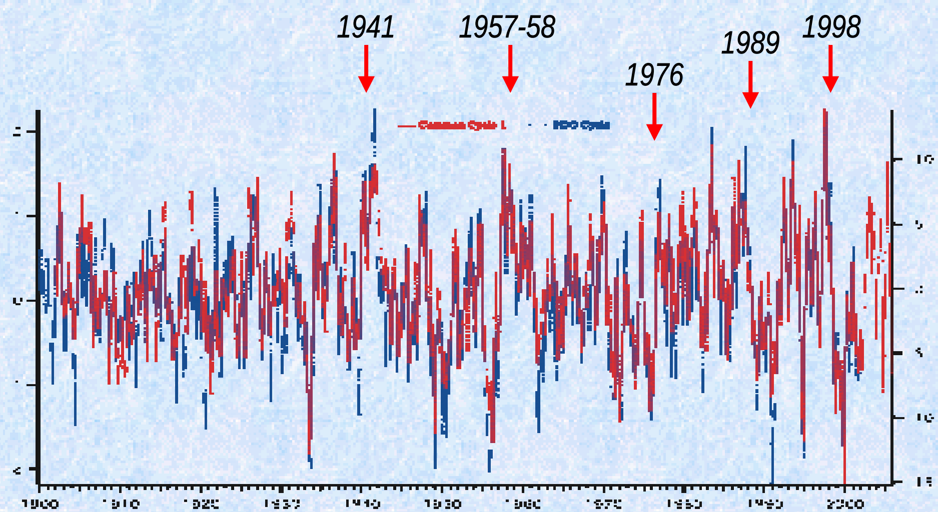


Spatial Modes of Regime Shifts - PDO









CONCLUSIONS

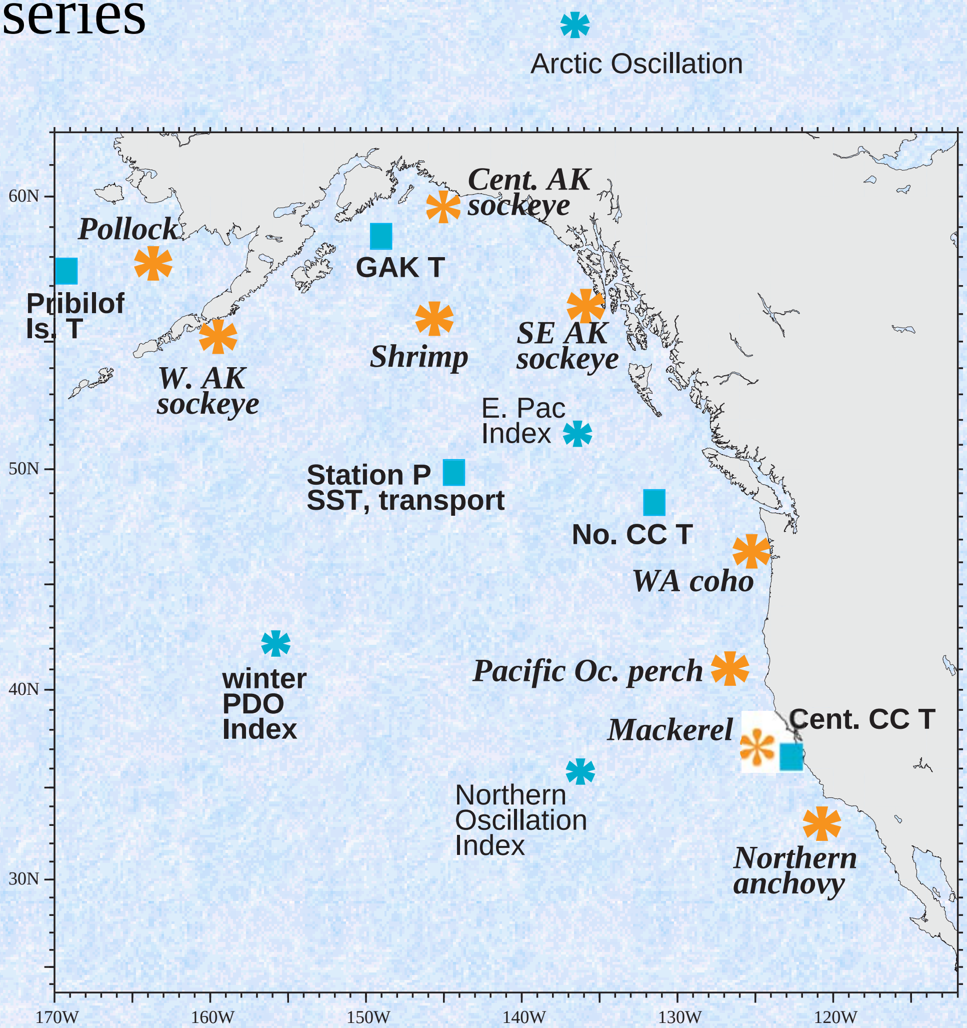
- **Indices may be too simple to characterize climate variability impacts on marine ecosystems**
- **Multiple analysis methods give a more complete picture of climate variability**
- **Current methods and assumptions may not be appropriate for discerning complex climate patterns (as marine populations see them)**

UNANSWERED QUESTIONS

- Are regime shifts real and quantifiable?
- Are they a biological or physical phenomenon?
- How do we capture their ecological impacts with indices?
- How do local conditions modulate large-scale climate forcing?
- What is the sensitivity of marine ecosystems to future climate change scenarios?

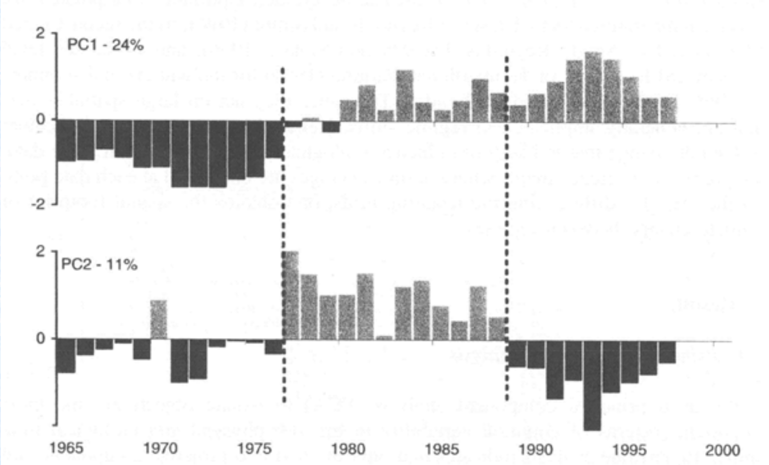
Time Series

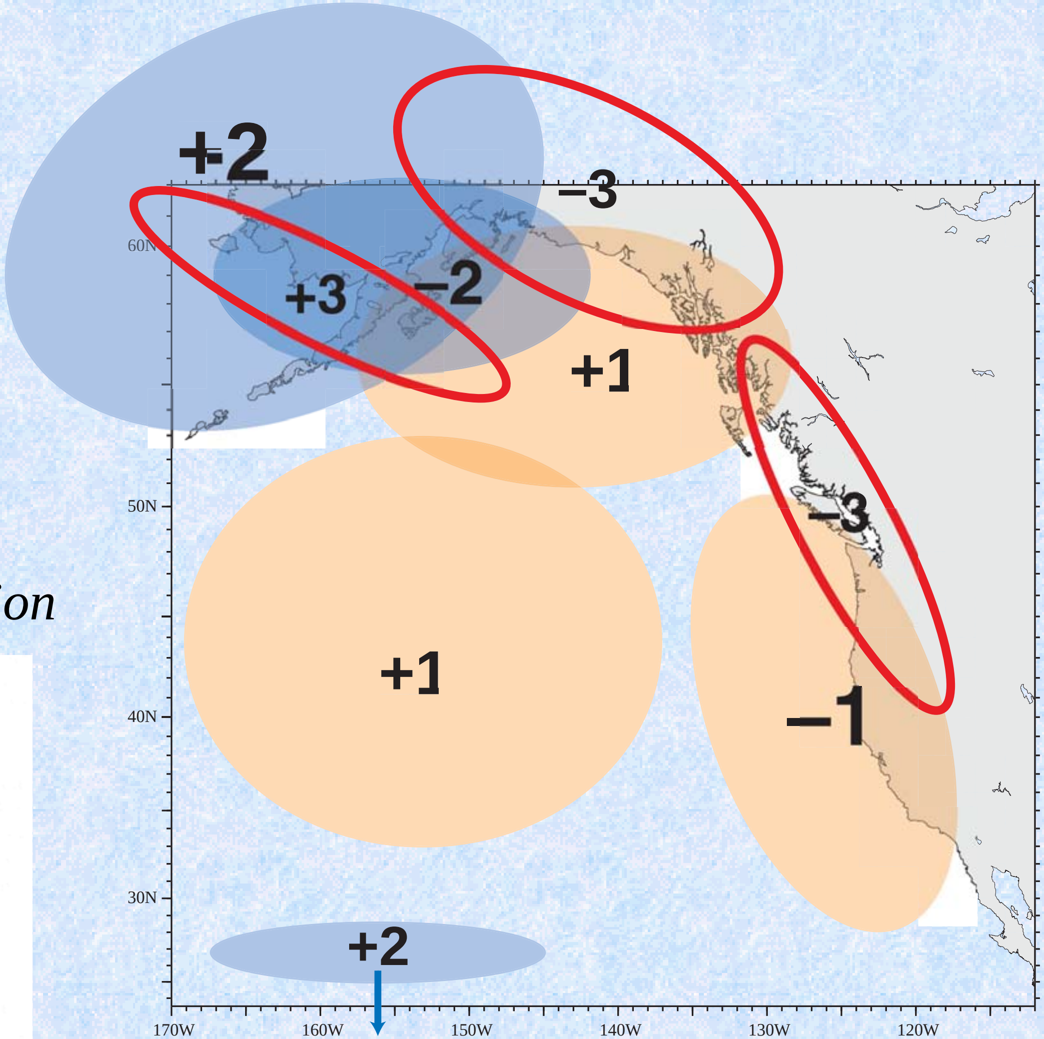
- State-space analysis of individual series
- Most series from Hare & Mantua
- Trends displayed for:
  - 4 large-scale indices
  - 8 ocean series
  - 9 fishery series
- Based on:
  - climate signal strength
  - representative of other series
  - commercial importance



Spatial Modes of Regime Shifts

- **PCA 1 –**
  - *Steady increase 1970-93*
  - *CCS–GOA/NP oscillation*
- **PCA 2 –**
  - *Abrupt changes in 1976, 1989*
  - *Bering Sea oscillation*
  - *Equatorial Pacific linked*
- **PCA 3 (physical) –**
  - *Bering Sea–West Coast oscillation*

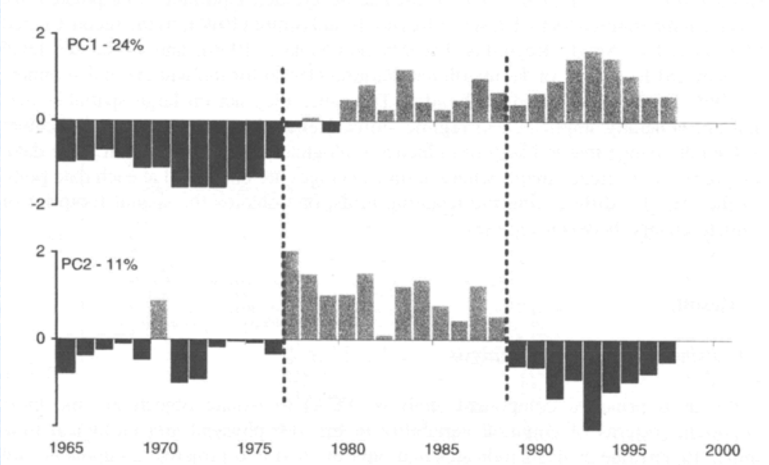


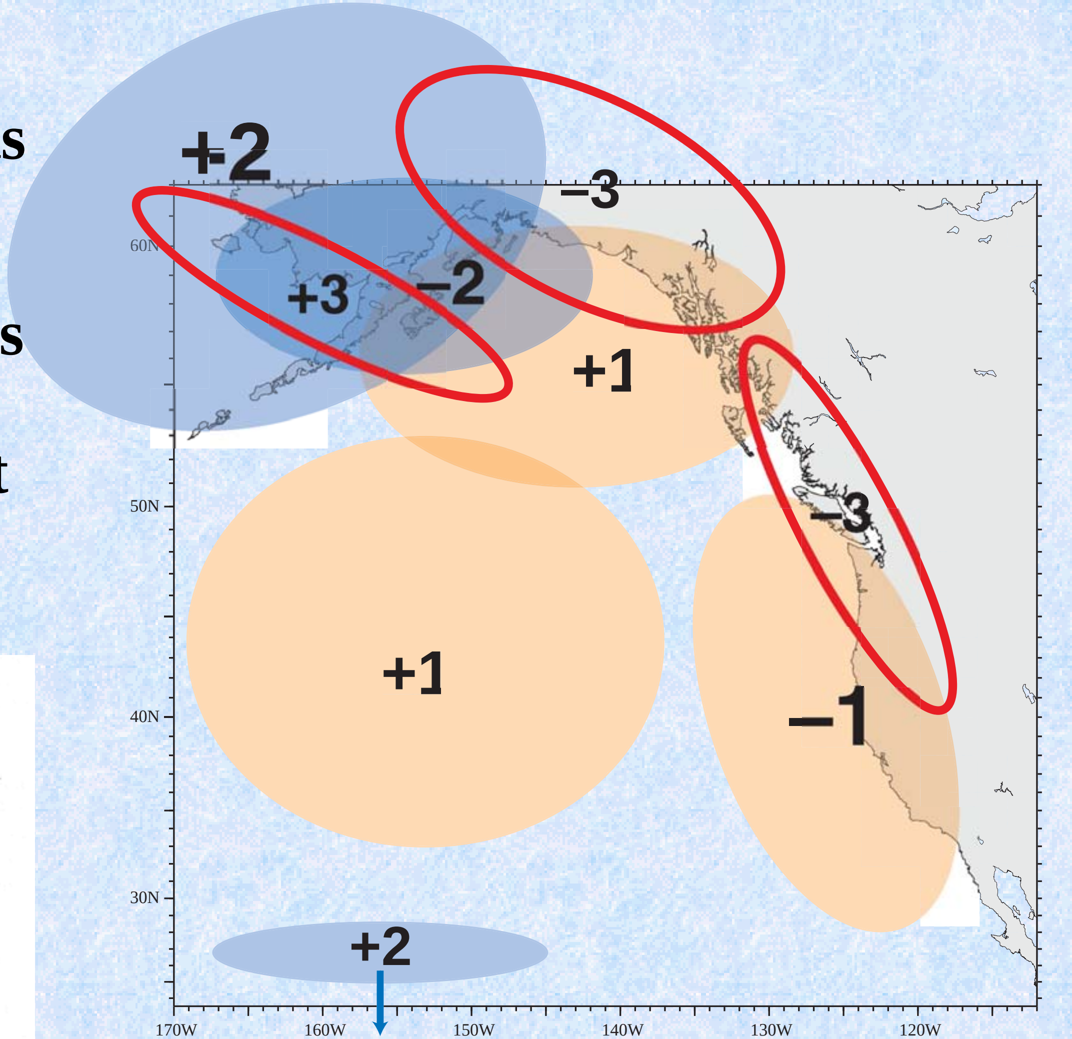


from Hare & Mantua (2000)

Spatial Modes of Regime Shifts

- **Modes may reflect regional, rather than basin-wide shifts**
- **Shifts may be gradual and asynchronous between series**
- **Ecosystem response may not be co-located with forcing**

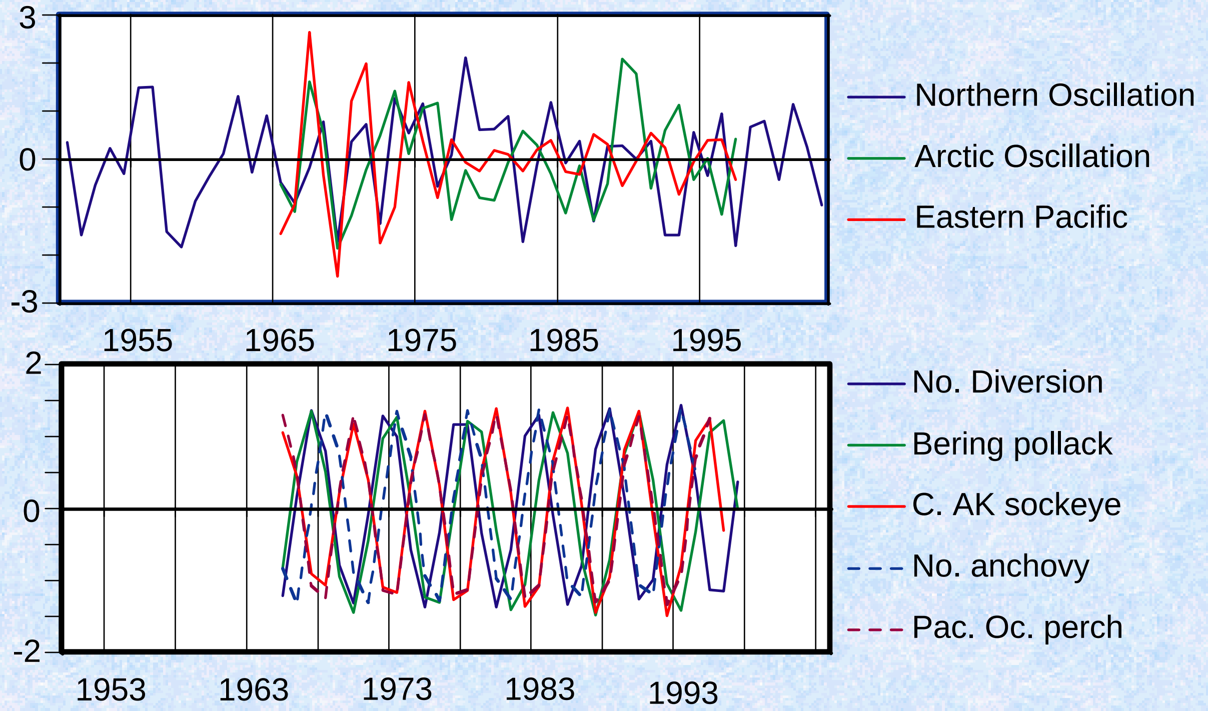




from Hare & Mantua (2000)

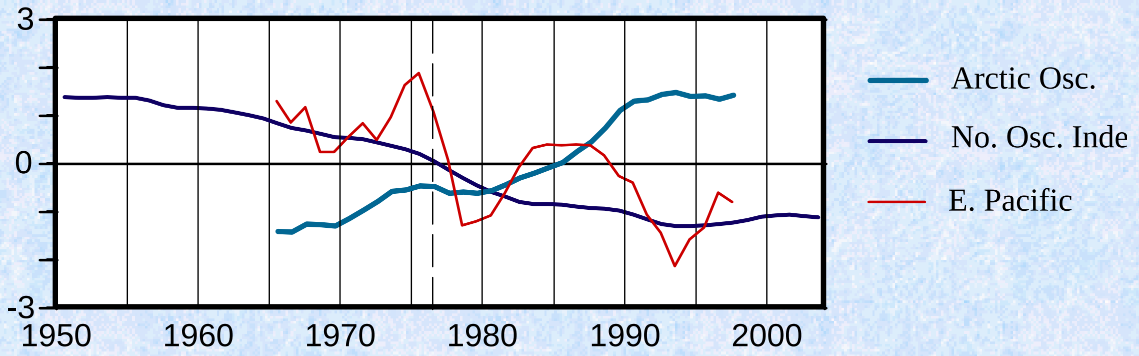
Cyclic Behavior

- Many series exhibit non-stationary cyclic components
  - *interact with trends to affect strength of shifts*
- Many fishery series exhibit highly regular cycles
  - *model artifacts ?*



North Pacific Atmospheric Indices

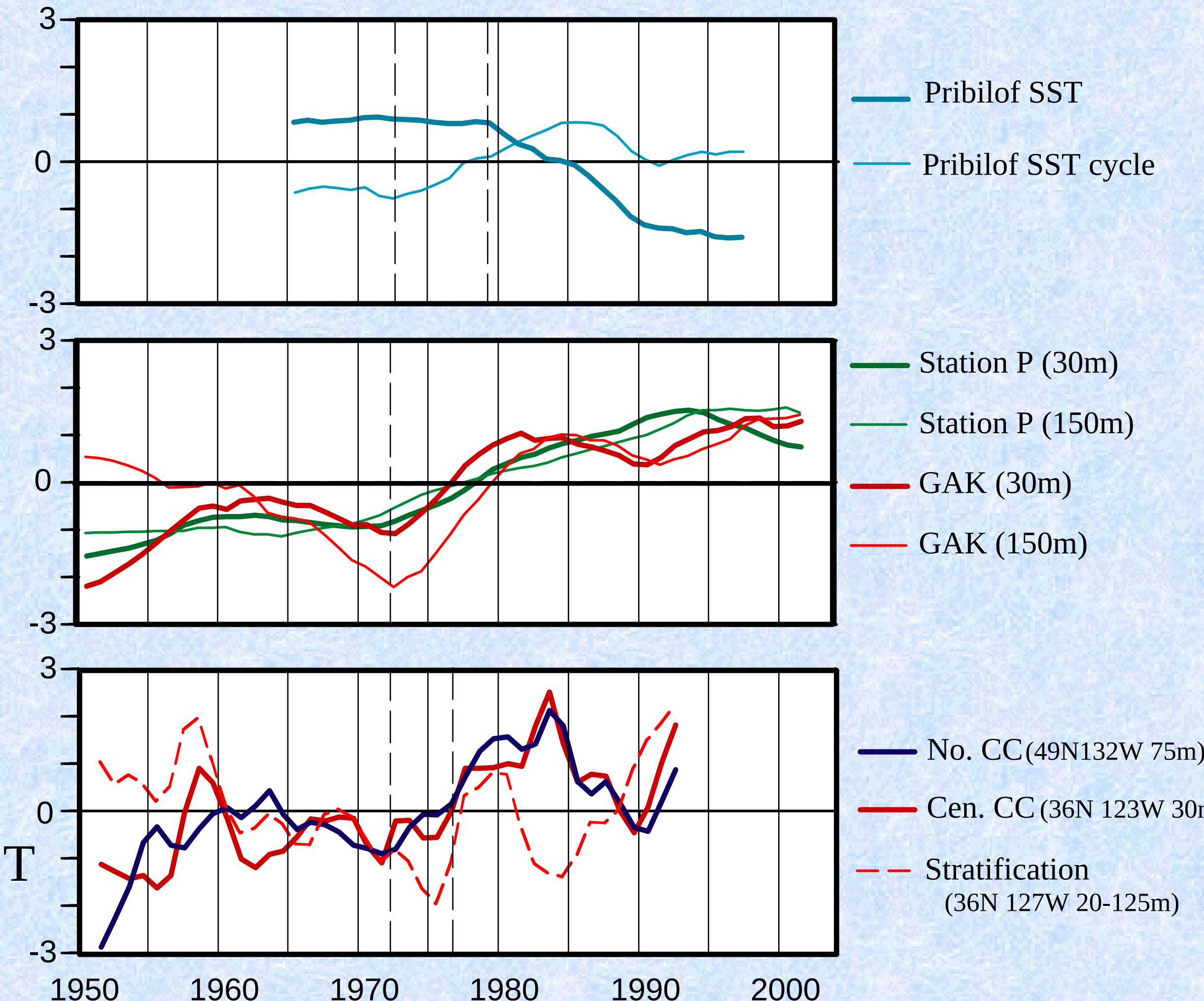
- Long-term trend from 1950
- Small “shift” in 1976
- Decadal fluctuations



Ocean Temperature Trends

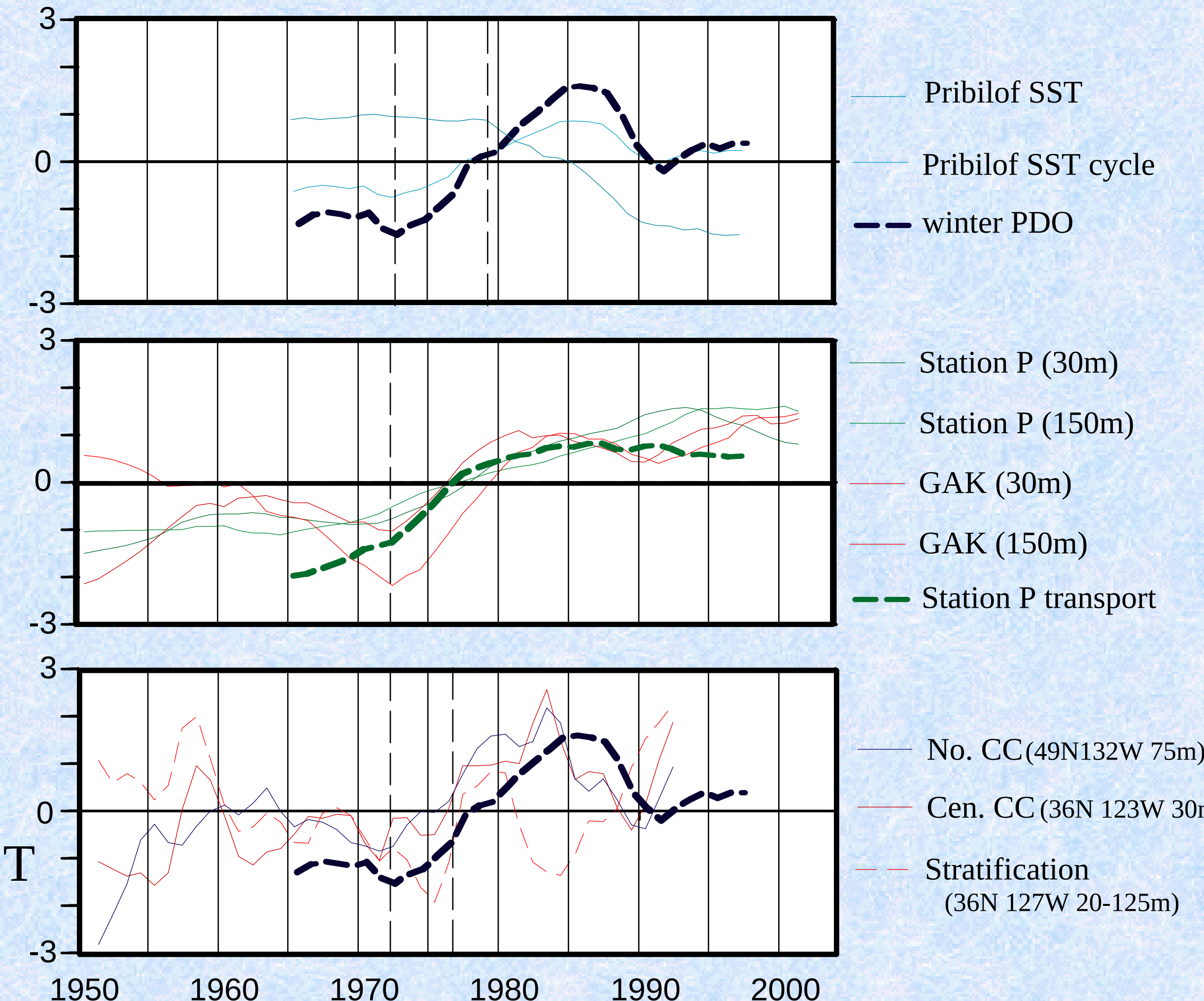
- **Bering Sea**
  - cooling begins in 1979
  - cyclic warming in 1972
- **Gulf of Alaska**
  - warming begins in 1972
  - no clear change in 1976
- **California Current**
  - warming begins in 1972
  - accelerates in 1976

    greater signal in south, SST



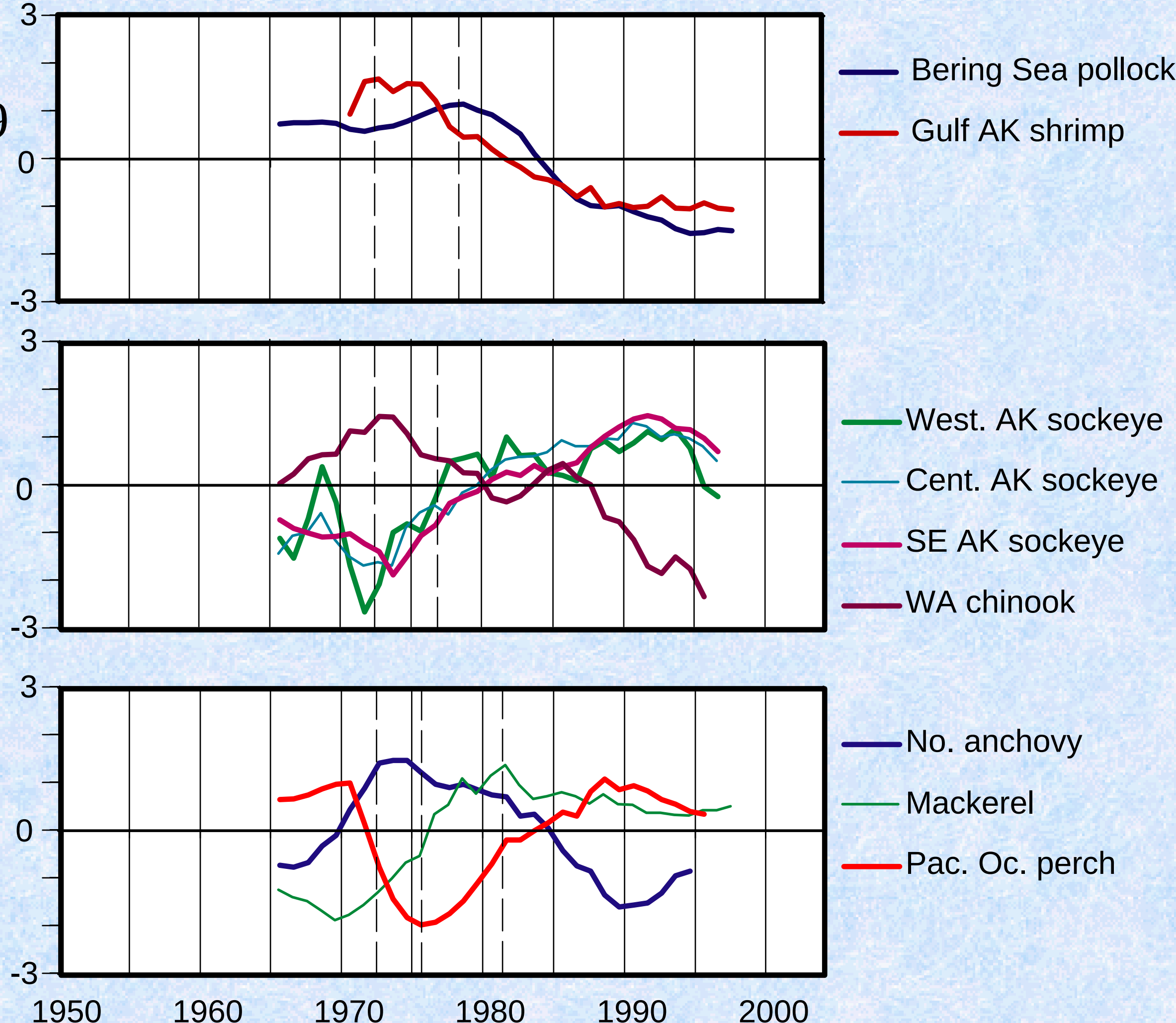
Ocean Temperature Trends

- **Bering Sea**
  - cooling begins in 1979
  - cyclic warming in 1972
  - includes PDO signal
- **Gulf of Alaska**
  - warming begins in 1972
  - no clear change in 1976
  - reflects transport increase
- **California Current**
  - warming begins in 1972
  - accelerates in 1976
    greater signal in south, SST
  - stratification may differ



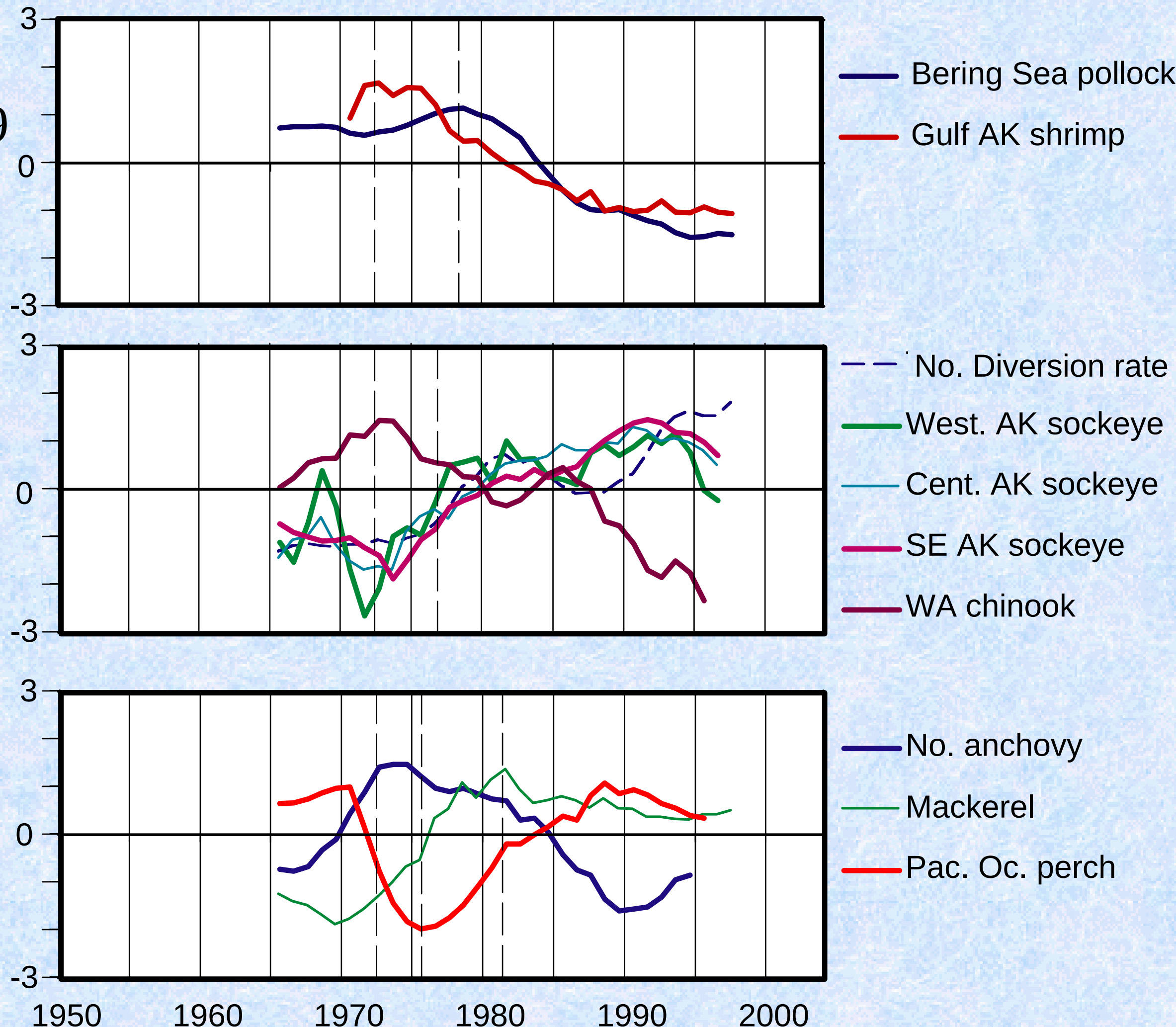
North Pacific Fisheries Trends

- **Bering Sea/ Gulf of AK**
  - pollock recruits drop in 1979
  - shrimp decline 1972-75
- **No. Pacific salmon**
  - catch changes in 1972
  - AK increases in 1976
- **California Current**
  - shift begins in 1972-75
  - mackerel transition species



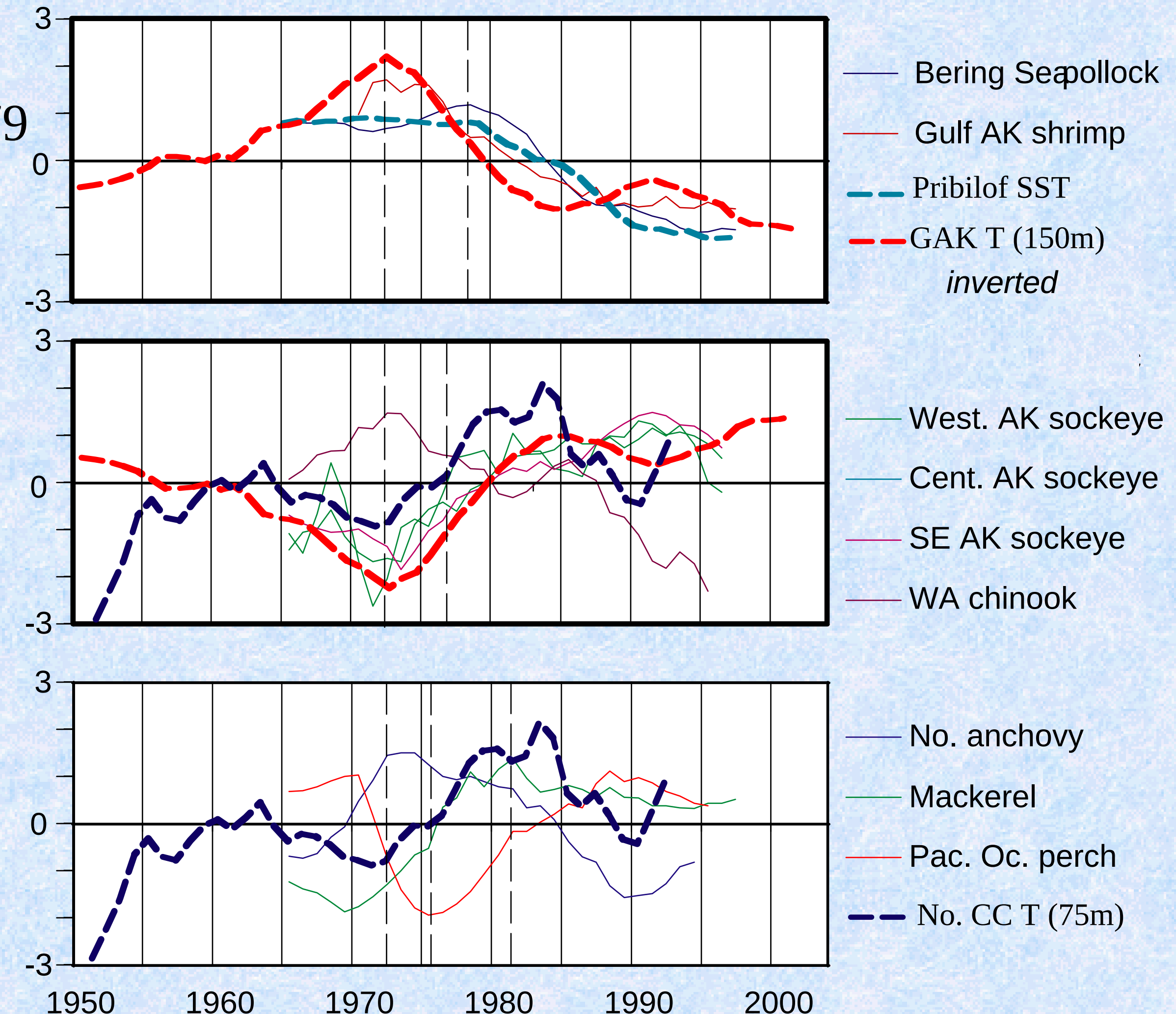
North Pacific Fisheries Trends

- **Bering Sea/ Gulf of AK**
  - pollock recruits drop in 1979
  - shrimp decline 1972-75
- **No. Pacific salmon**
  - catch changes in 1972
  - AK increases in 1976
  - NDR matches catch pre-86
- **California Current**
  - shift begins in 1972-75
  - mackerel transition species



North Pacific Fisheries Trends

- **Bering Sea/ Gulf of AK**
  - pollock recruits drop in 1979
  - shrimp decline 1972-75
  - local temperature forcing
- **No. Pacific salmon**
  - catch changes in 1972
  - AK increases in 1976
  - responds to sub-sfc temp
- **California Current**
  - shift begins in 1972-75
  - mackerel transition species
  - responds to local temp
  - temp proxy for forcing



SUMMARY OF RESULTS

- Ocean signals change in ca. 1970, accelerate in ca. 1976
- Large-scale atmospheric forcing primarily a 1976 shift

- Fisheries-
  - North Pacific Salmon- 1970 shift with 1976 acceleration
    linked to ocean temperature
  - California Current- 1970 shift, with biological lags (?)
    responding to thermocline temperature, esp. in No. CC
  - Bering Sea- 1976 shift
    due to local ocean forcing, linked to large-scale

- PC analysis may be dominated by a few series,
  must link processes to individual population series

Conceptual Bifurcation of the North Pacific Current

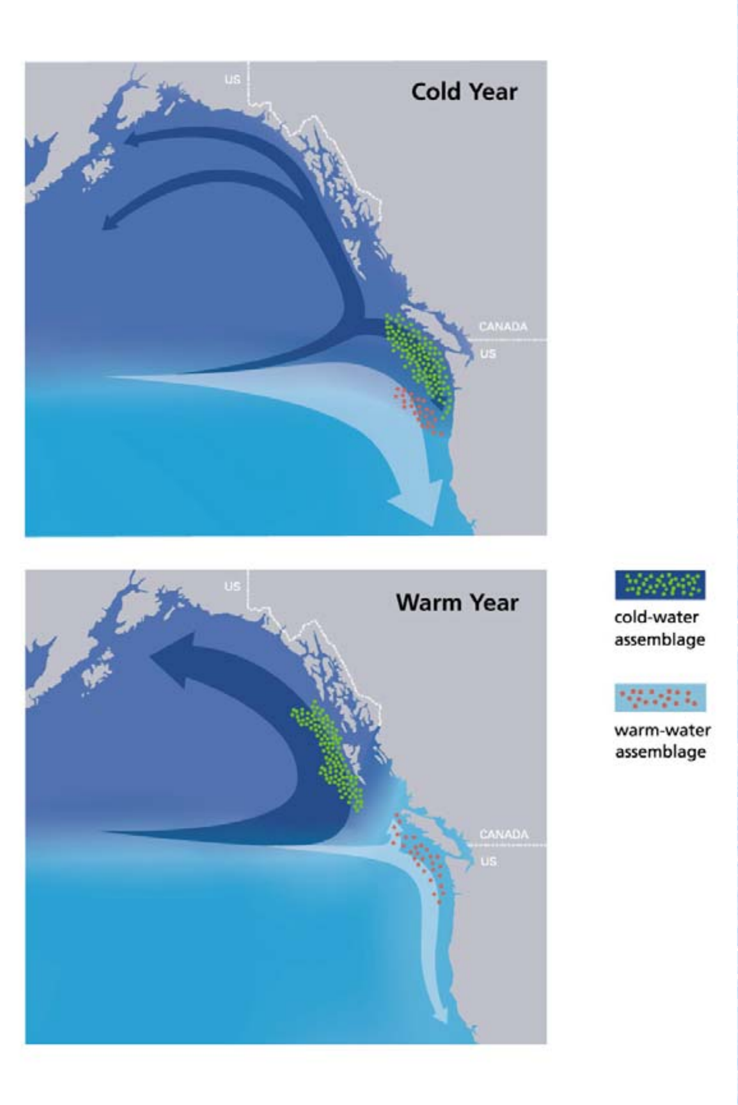
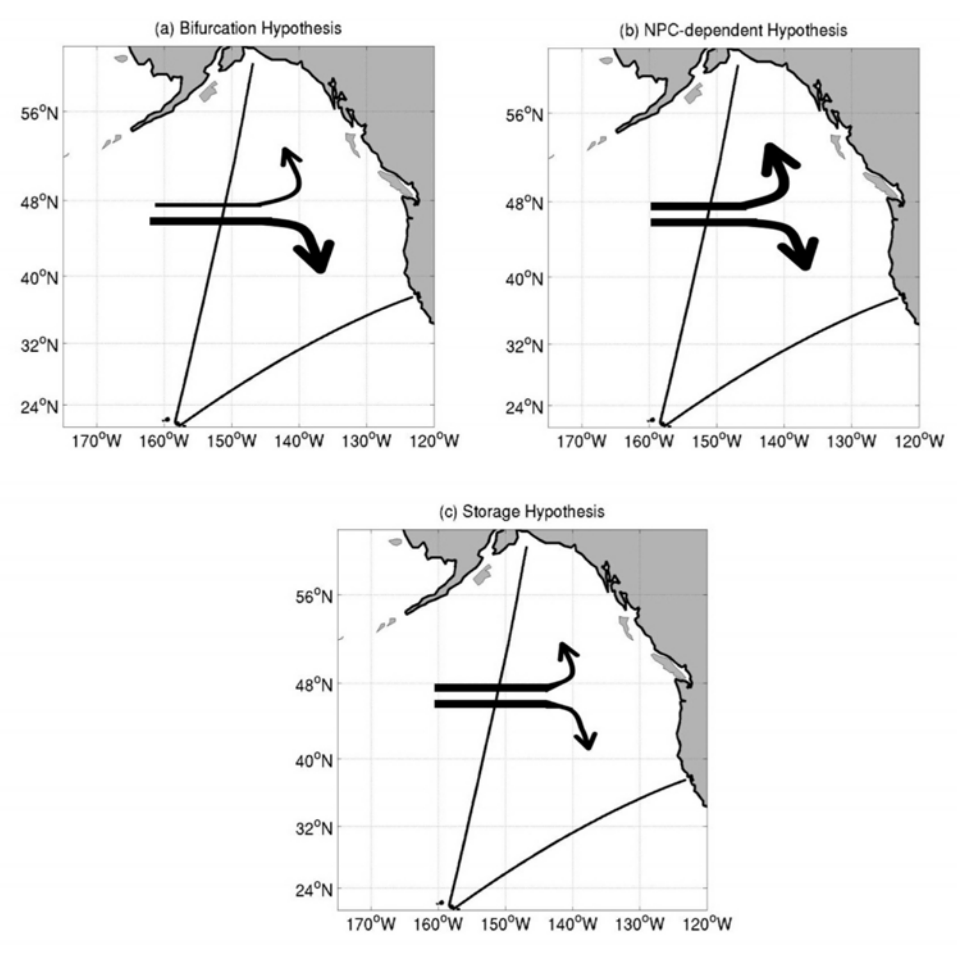
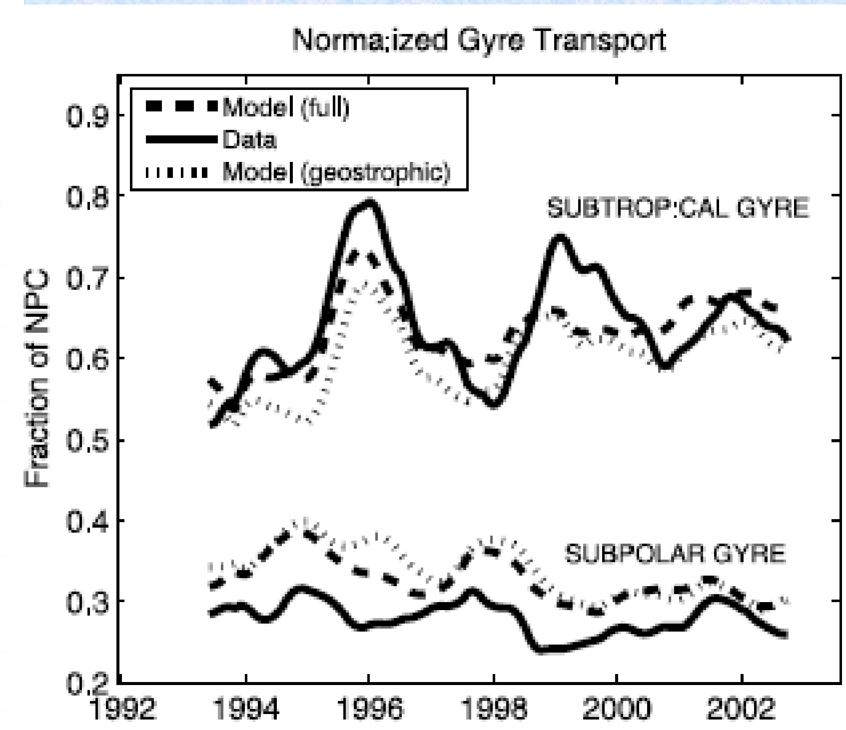


Figure by A. Femia

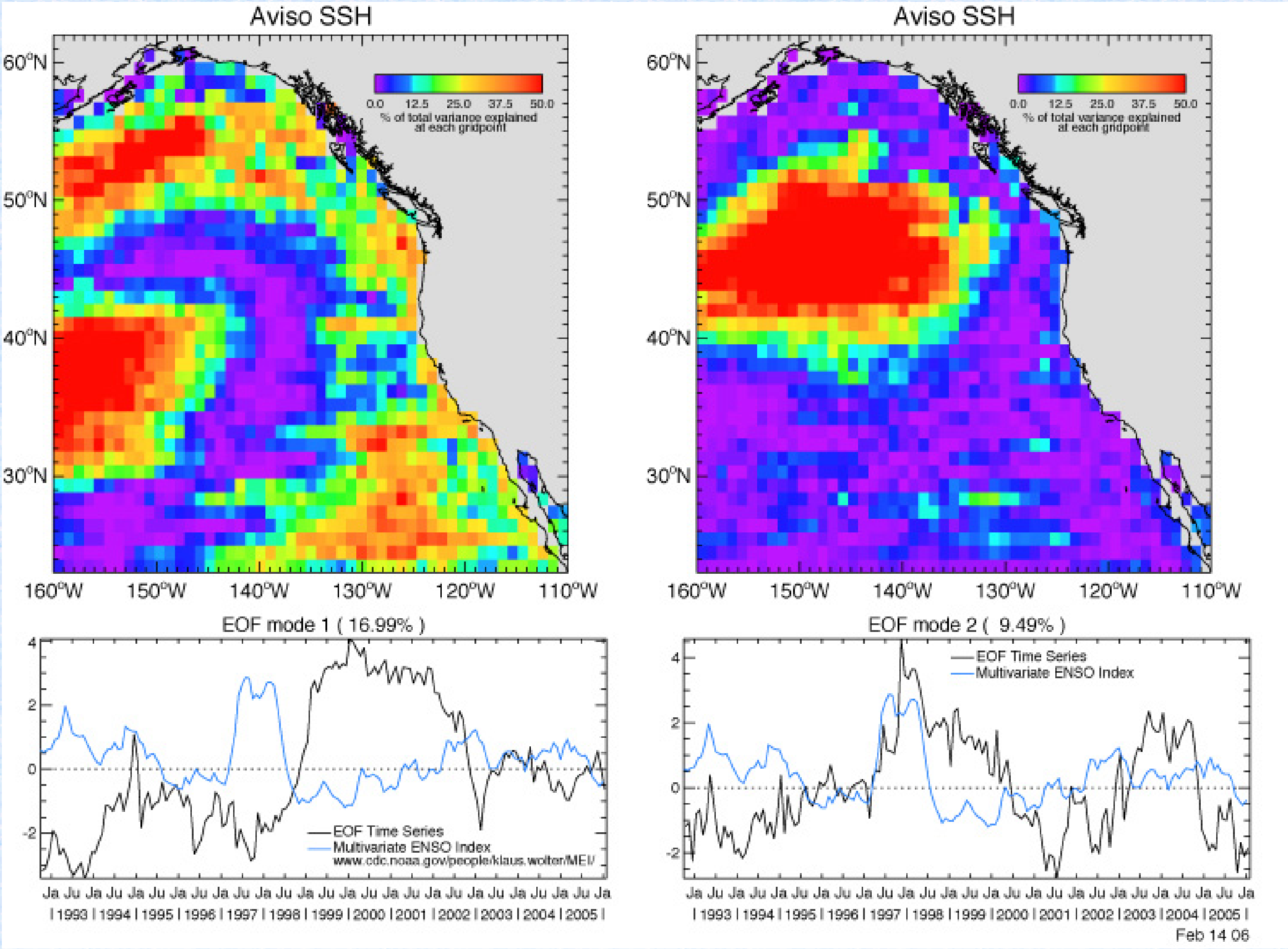
Bifurcation Modes of the NPC



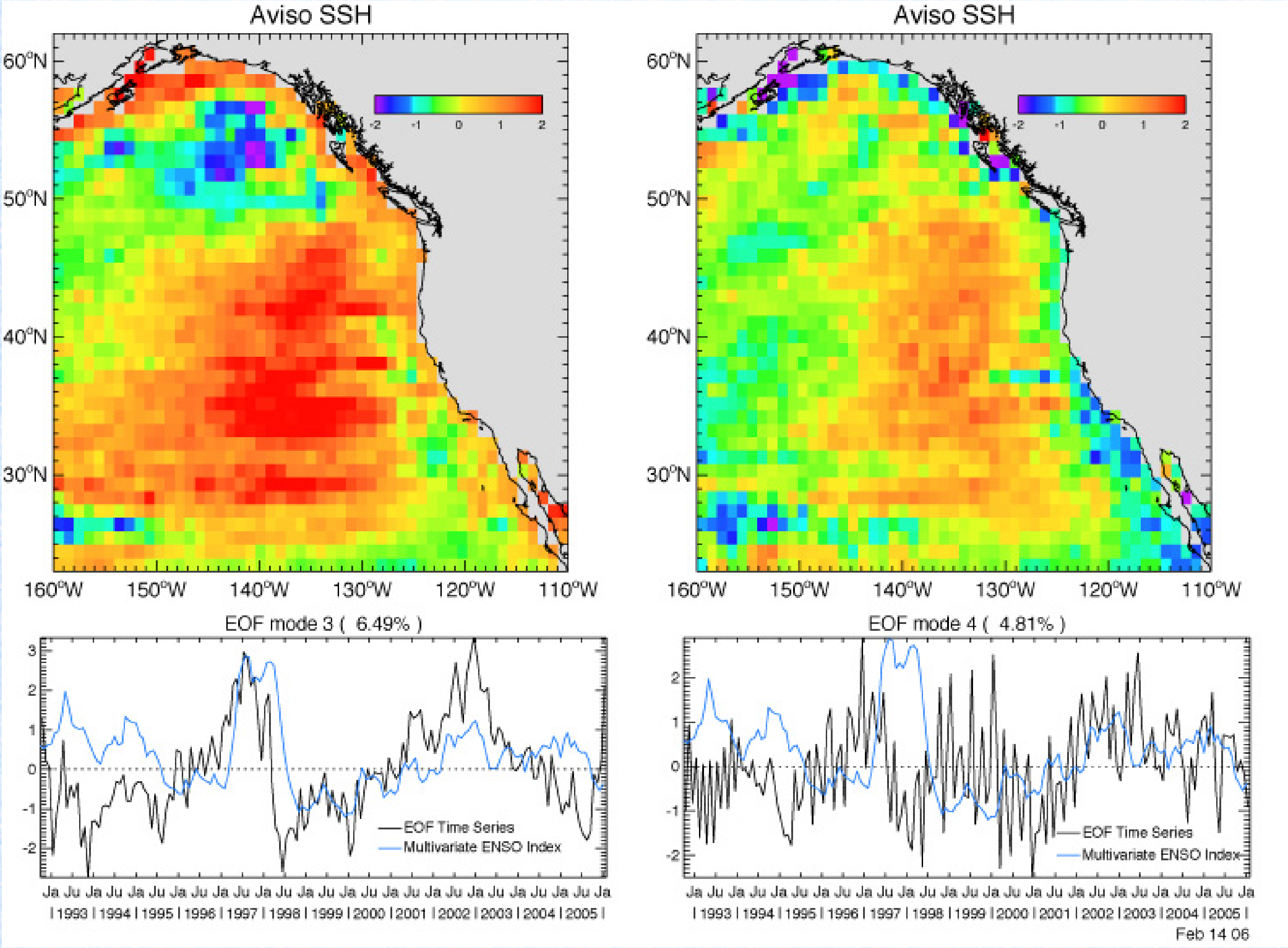


(from Douglass et al. 2006)

Spatial Modes of Regime Shifts - EOF



Spatial Modes of Regime Shifts - EOF



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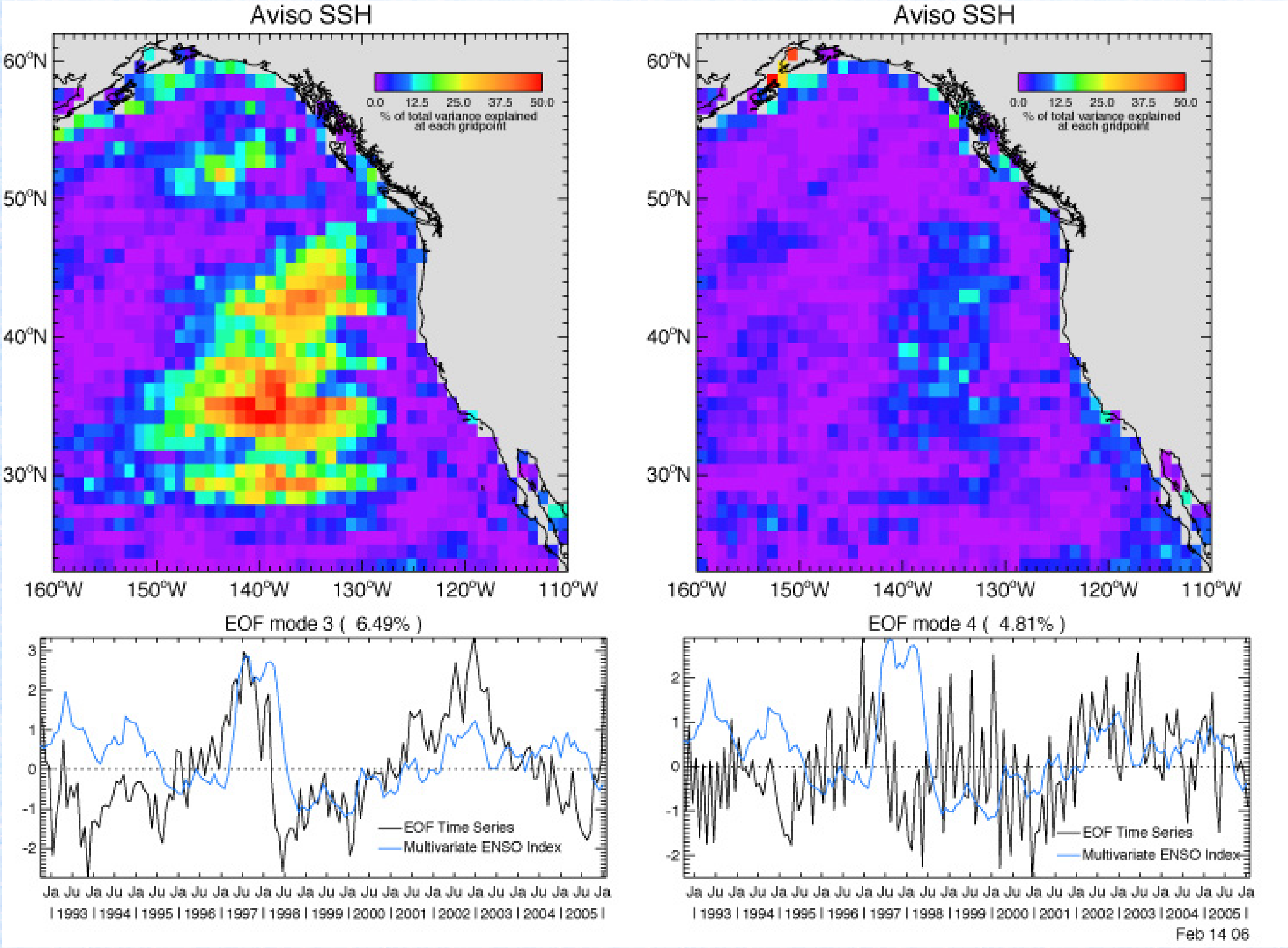

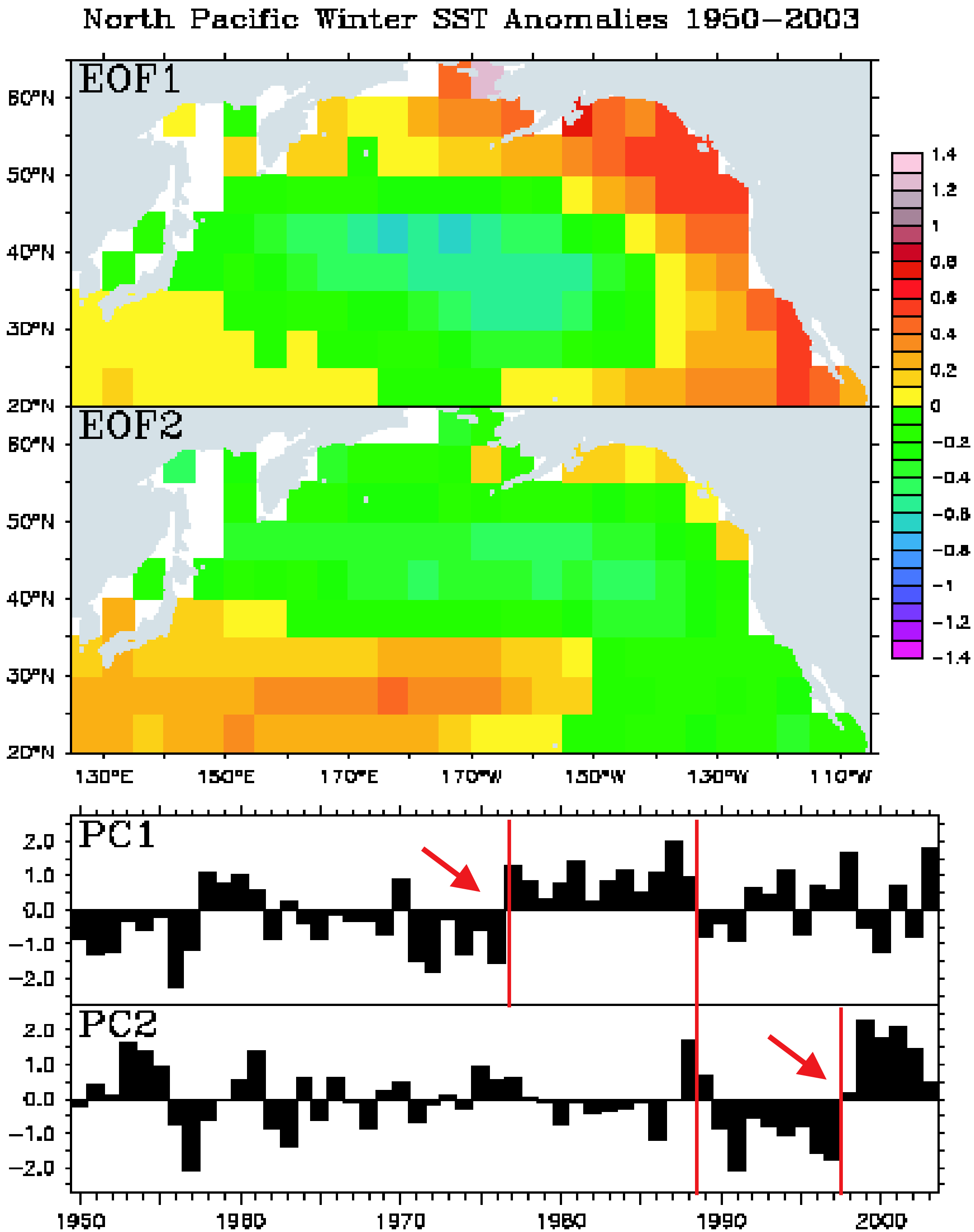

Multiple modes of SST decadal variability

Possibly more than two regime states

(from Bond et al., 2003)

Development of a Bifurcation Index

CONCLUSIONS

- “1976” regime shift began in 1970, evolved over 10-year period
- Regional, rather than basin, regime shifts
  Local factors modulate large-scale climate variability
- Some populations respond to internal ocean variability, others large-scale climate variability
- Regime shifts may be driven by random (white-noise) processes, or a combination of trend & cyclic/AR behavior
- Prospect of *predicting shifts* may not be good
- But improved recognitions of ecological response & mechanisms affecting each population will improve ability to *forecast response*