When did the 1976 regime shift occur?

— *Paradigm Lost* —

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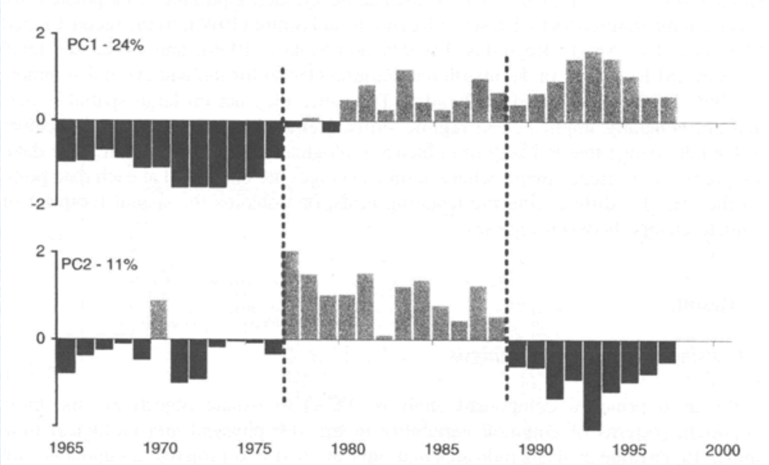
RATIONALE

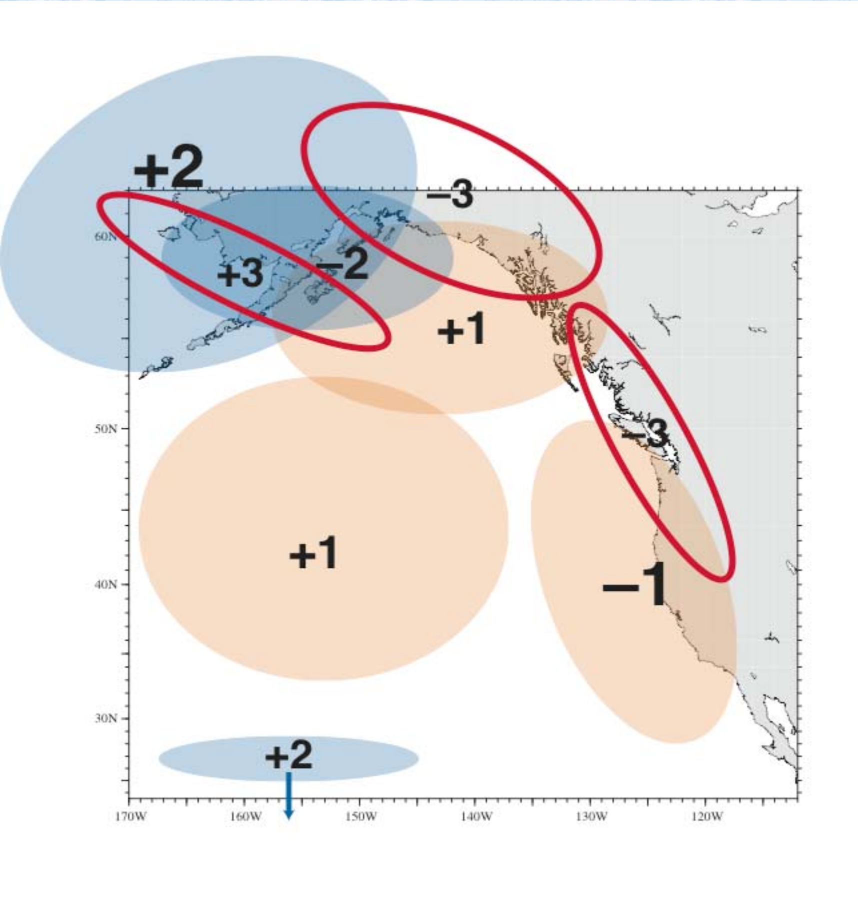
- Better define evolution of North Pacific regime shifts and their mechanisms – *start with "1976"*
- Link climate variability with ecosystem response
- Identify environmental signals for regime shifts in distinct regions, populations
- Build on earlier studies (e.g. Hare & Mantua, 2000), but use other analytical methods

- *Methodology for examining the behavior of climate change and regime shifts in environment and marine populations*

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*

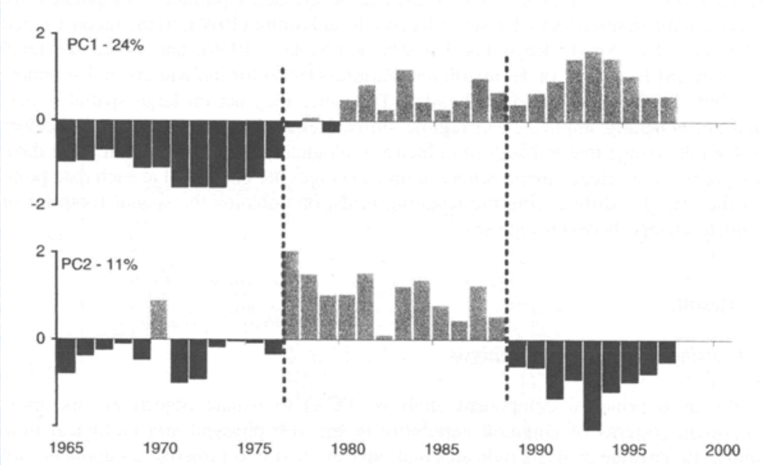


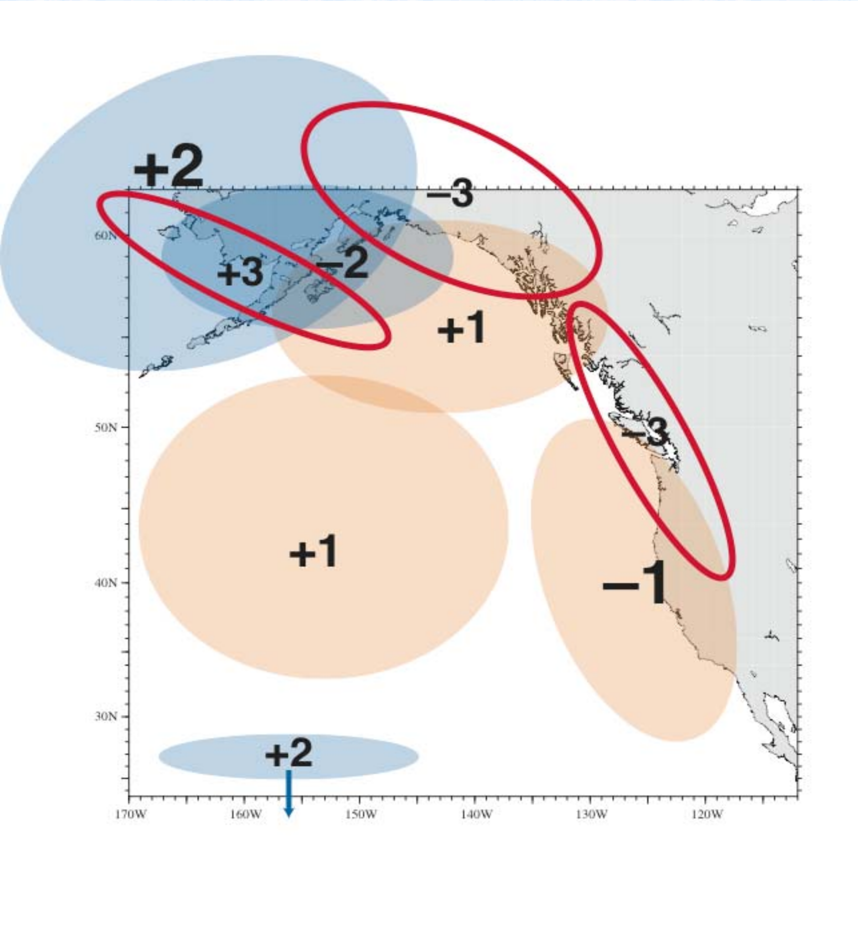


from Hare & Mantua (2000)

Spatial Modes of Regime Shifts

- **Modes may reflect regional, rather than basin-wide shifts**
- **1976 shift may be gradual**
- **Ecosystem response may not be co-located with forcing**

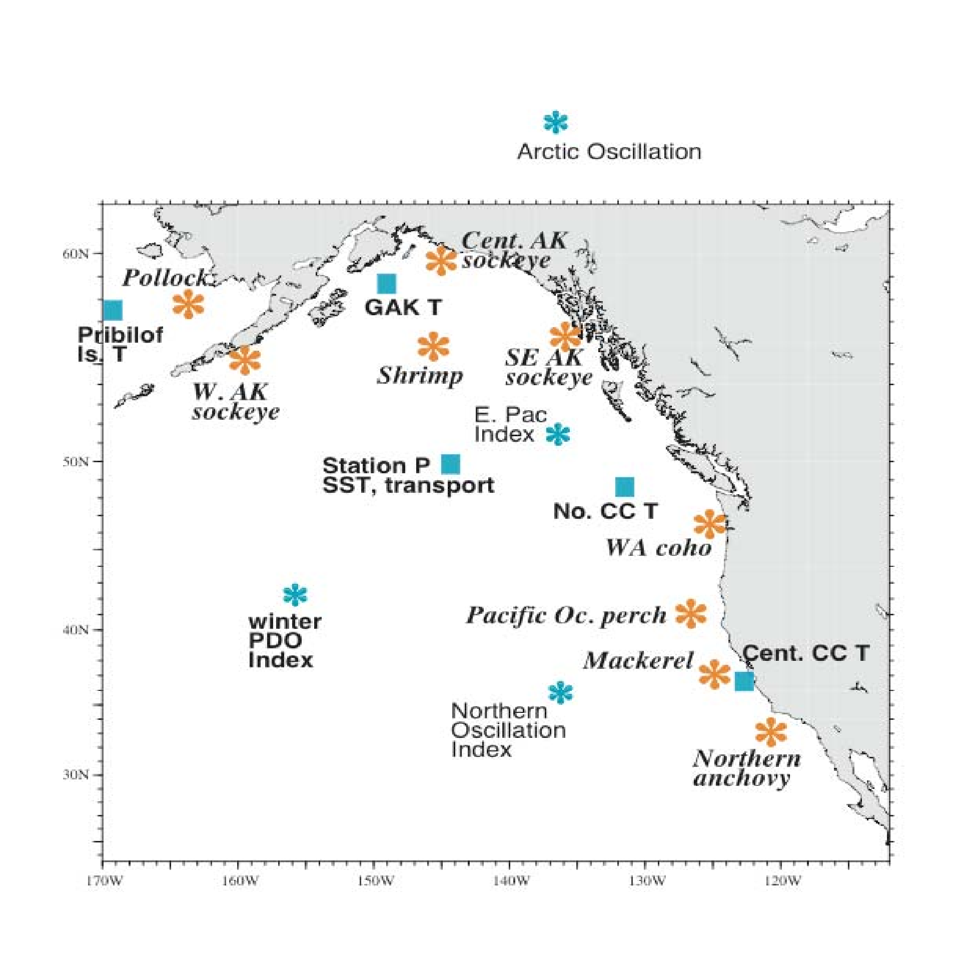




from Hare & Mantua (2000)

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



(1) 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 stationary, stochastic cyclic term
Error - allow for observational error

Statistical criteria for determining "best" model

(2) Stationary, stochastic cycle

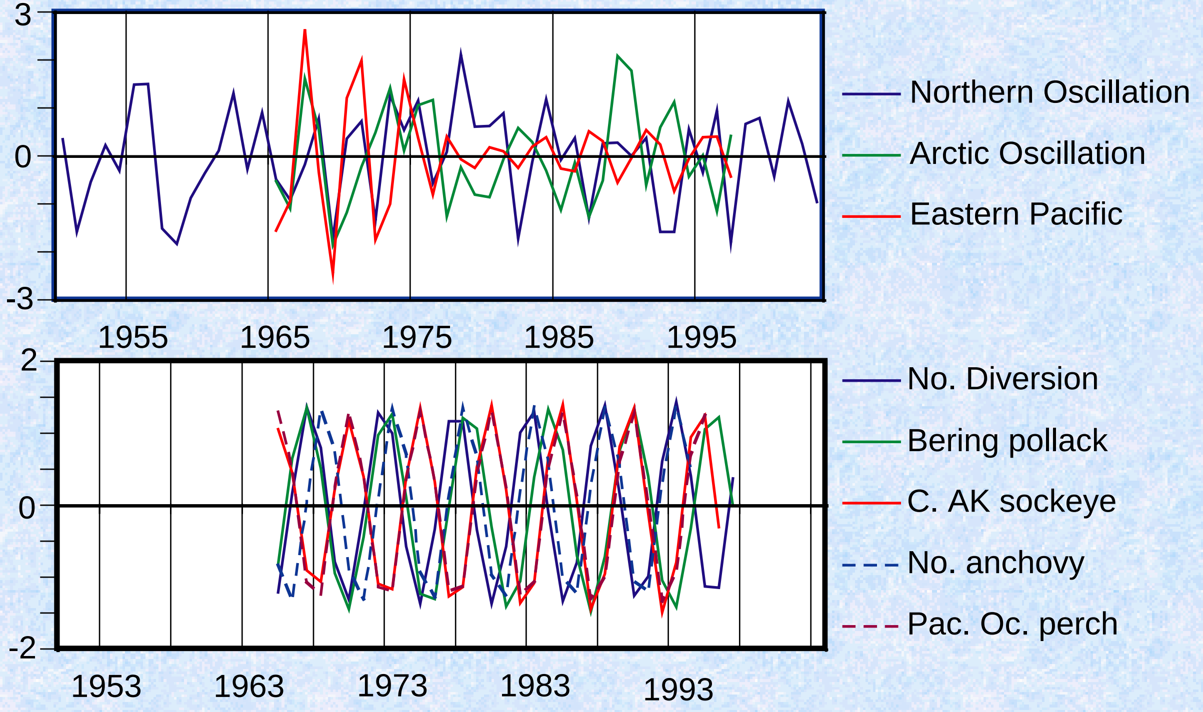
$$\begin{bmatrix} \psi_t \\ \psi_t^* \end{bmatrix} = \rho \begin{bmatrix} \cos\lambda_c & \sin\lambda_c \\ -\sin\lambda_c & \cos\lambda_c \end{bmatrix} \begin{bmatrix} \psi_{t-1} \\ \psi_{t-1}^* \end{bmatrix} + \begin{bmatrix} \kappa_t \\ \kappa_t^* \end{bmatrix}, \qquad t = 1, \ldots, T, \qquad (1)$$

where λ_c is the frequency, in radians, in the range $0 < \lambda_c \leq \pi$, κ_t and κ_t^* are two mutually uncorrelated white noise disturbances with zero means and common variance σ_κ^2, and ρ is a damping factor. A stochastic cycle becomes a first order autoregression if λ_c is 0 or π. Moreover, it can be shown that as $\rho \to 1$, then $\sigma_\kappa^2 \to 0$ and the stochastic cycle reduces to the stationary deterministic cycle:

$$\psi_t = \psi_0 \cos\lambda_c t + \psi_0^* \sin\lambda_c t, \qquad t = 1, \ldots, T. \qquad (2)$$

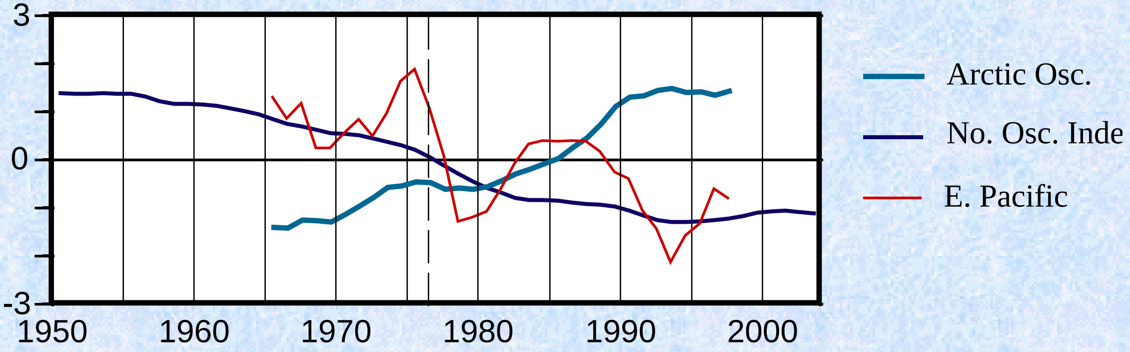
Cyclic Behavior

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



North Pacific Atmospheric Indices

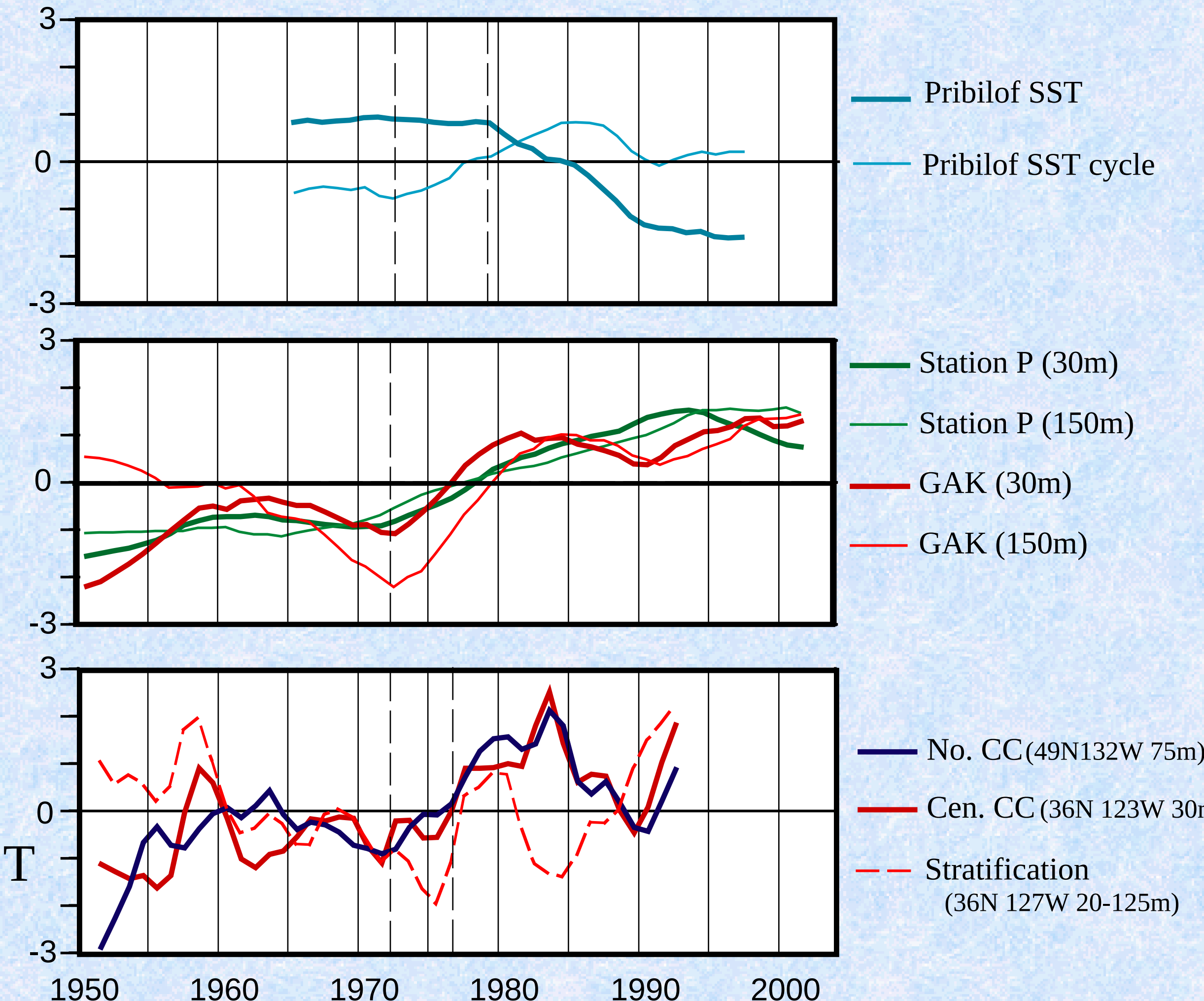
- Long-term trend from 1950
- Small "shift" in 1976
- Decadal fluctuations



Ocean Temperature Trends

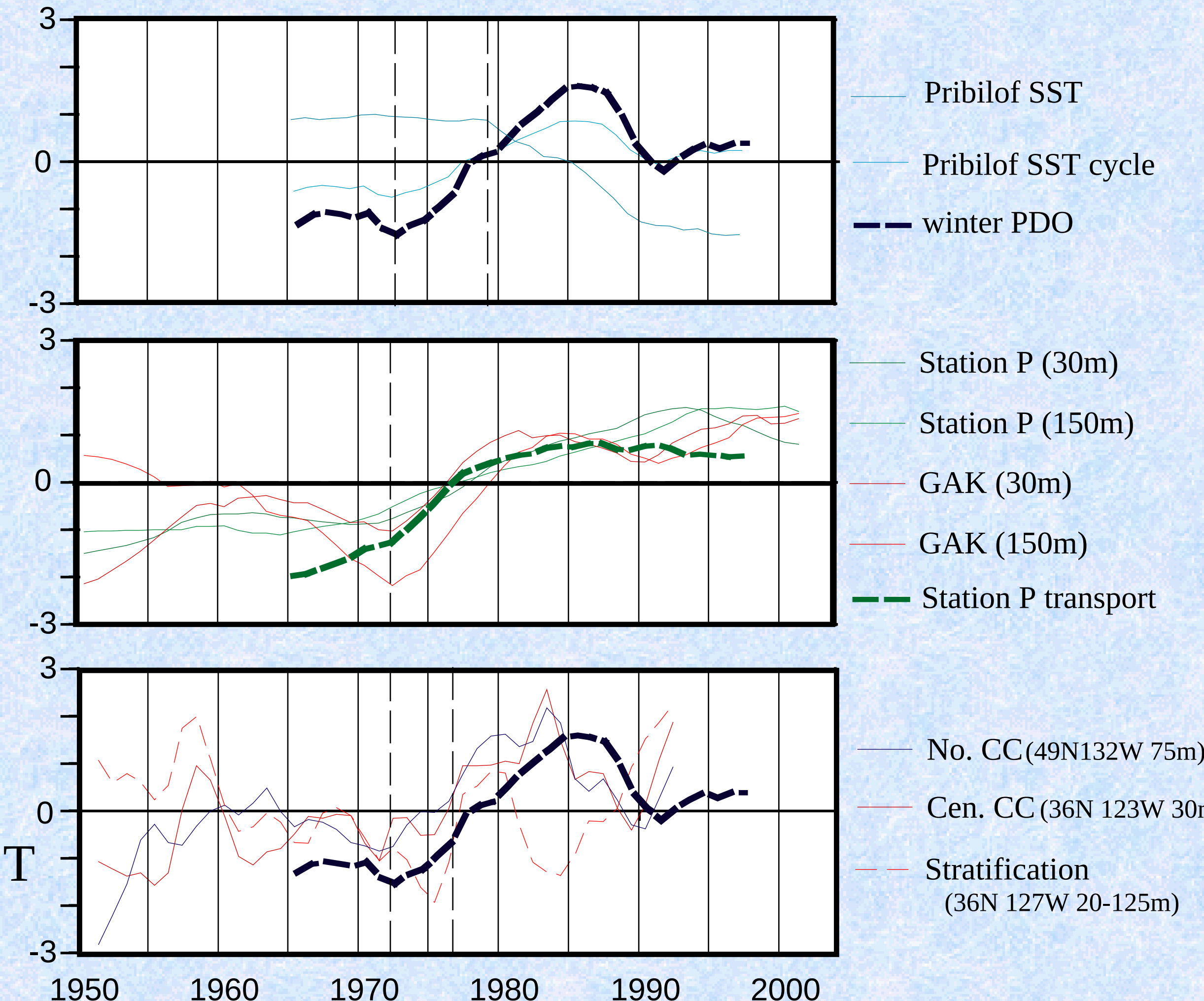
- **Bering Sea**
  - cooling begins in 1979
  - cyclic warming in 1972
- **Gulf of Alaska**
  - warming begins in 1972
  - no clear change in 1976
- **California Current**
  - warming begins in 1972
  - accelerates in 1976

  greater signal in south, SST



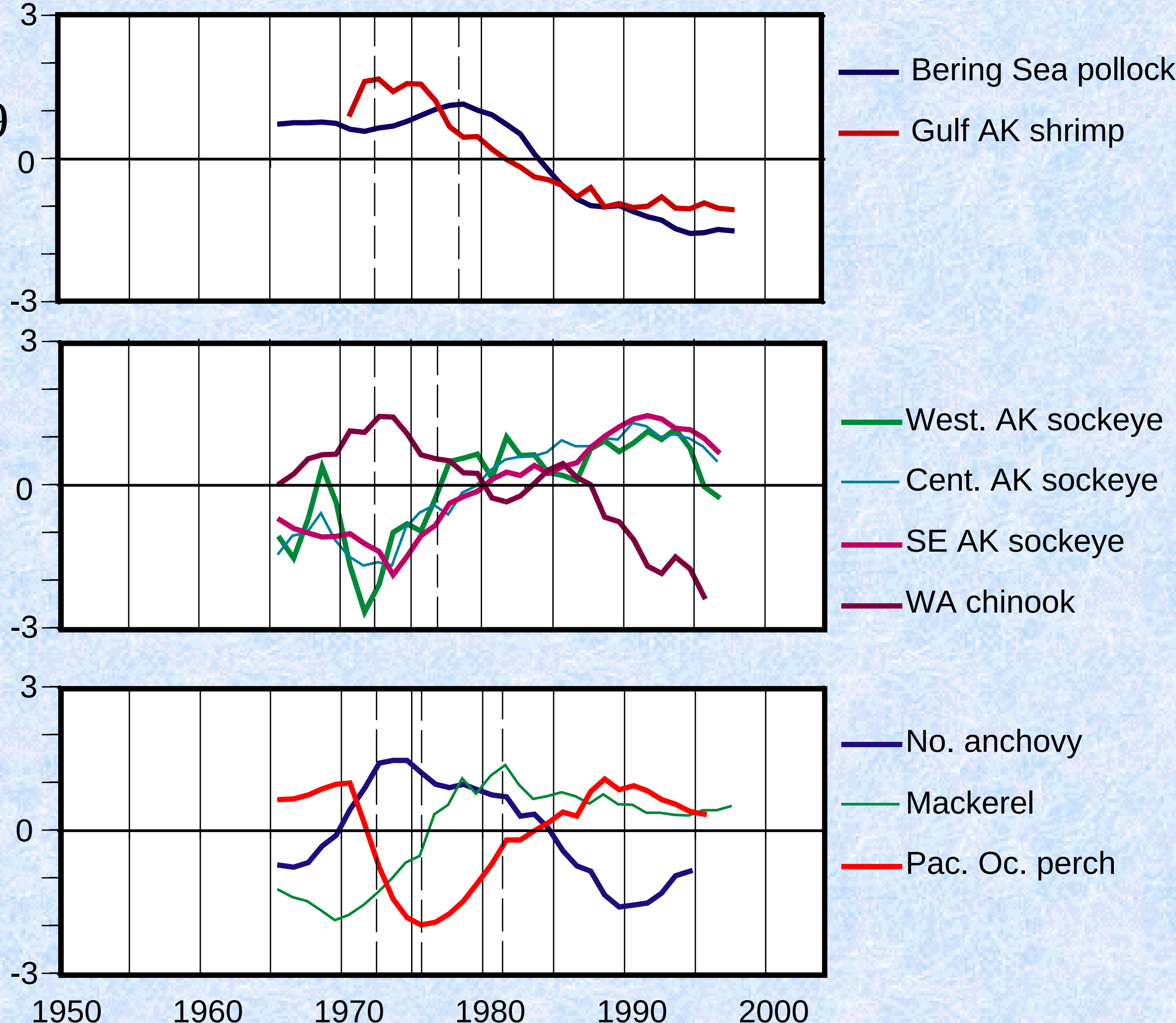
Ocean Temperature Trends

- **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



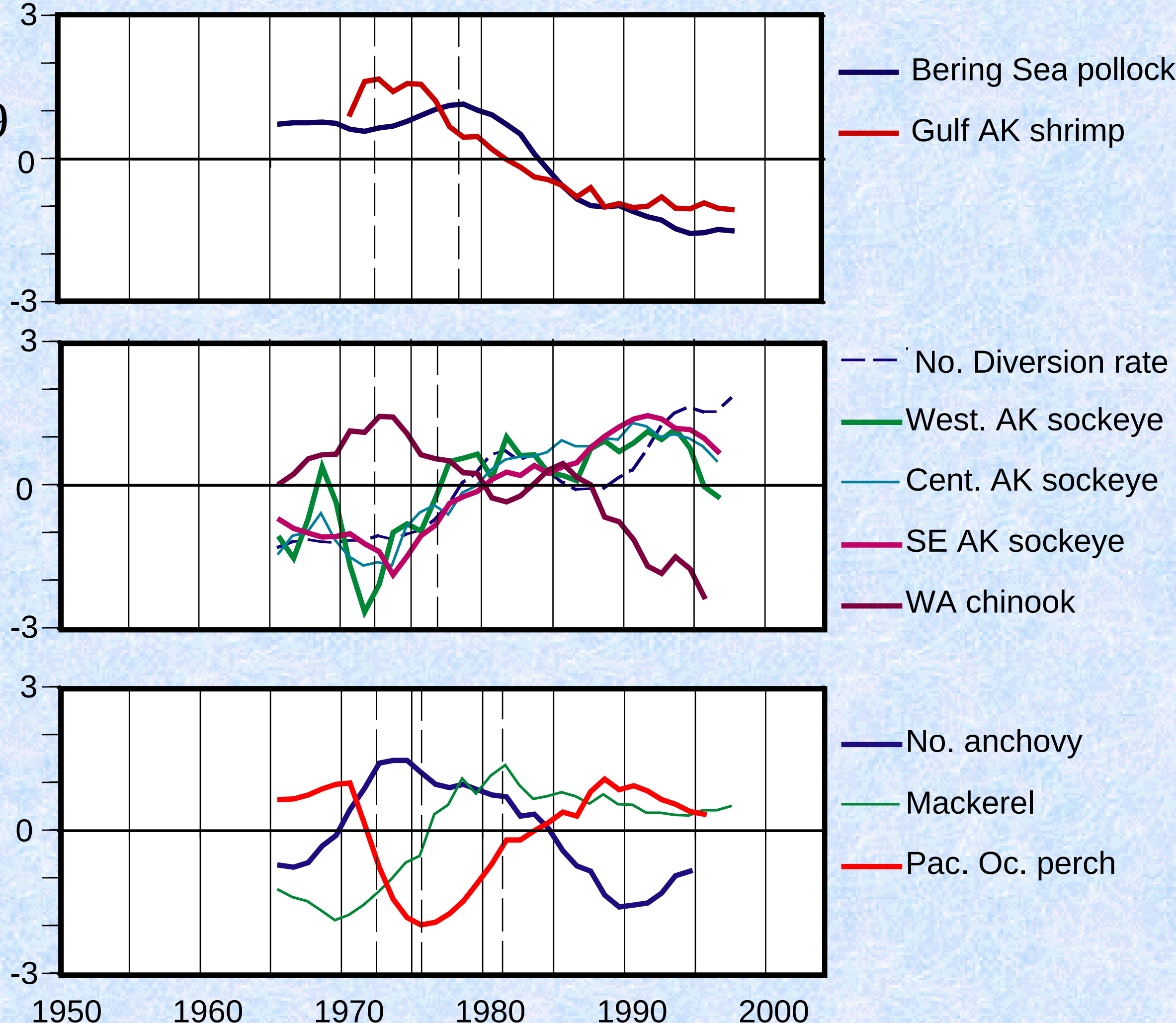
North Pacific Fisheries Trends

- **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



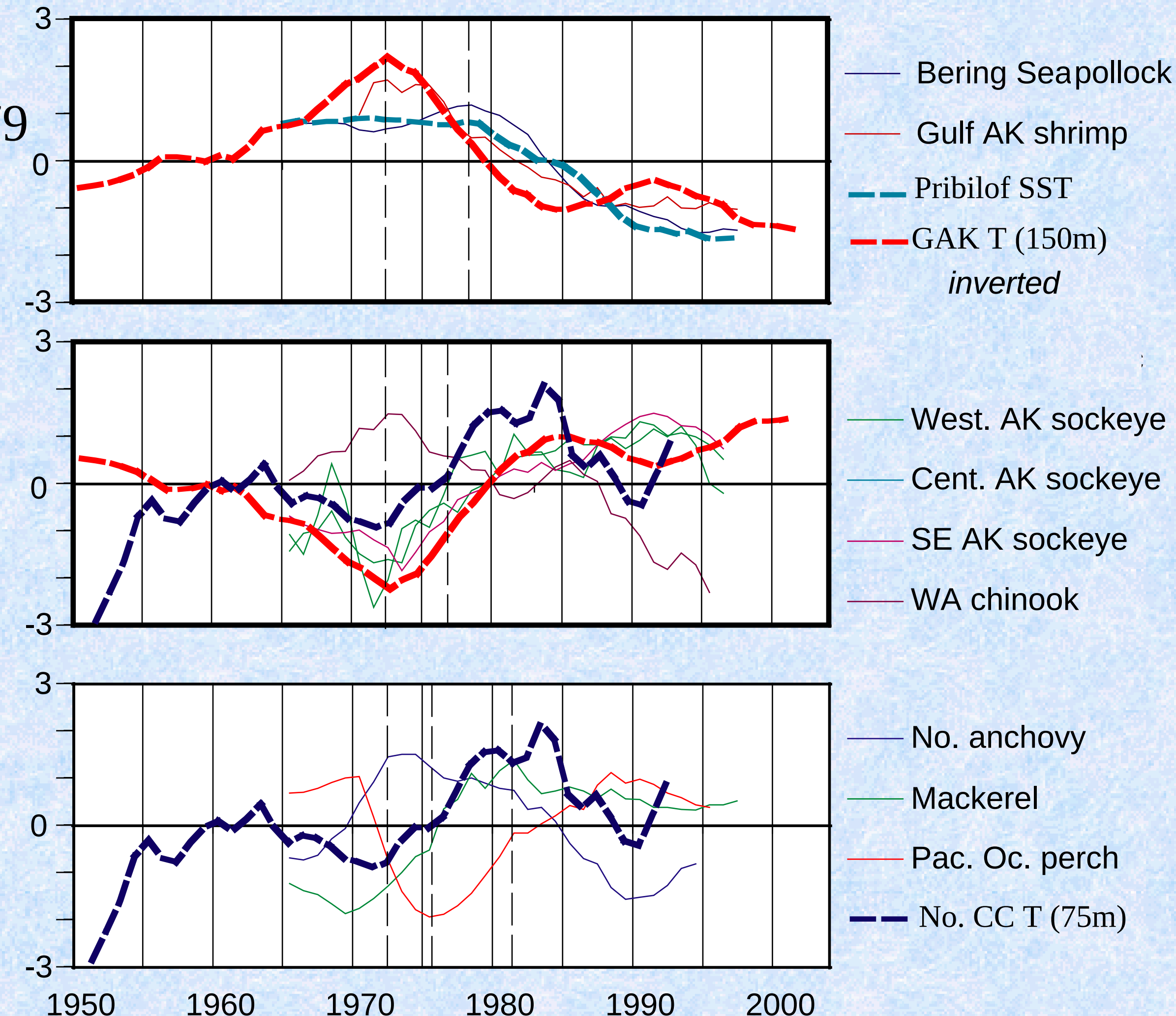
North Pacific Fisheries Trends

- **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. 1972, accelerate in ca. 1976
- Large-scale atmospheric forcing primarily a 1976 shift

- Fisheries-
  - North Pacific Salmon- 1972 shift with 1976 acceleration
    linked to ocean temperature
  - California Current- 1972 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

CONCLUSIONS

- “1976” regime shift began ca. 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 stationary or white-noise processes, or a combination of trend & cyclic/AR behavior
- Prospect of *predicting shifts* may not be good
- But improved monitoring to recognize ecological responses & mechanisms affecting each population will improve ability to *forecast ecosystem response*