Decadal Variability in the North Pacific Ocean in a Physical-Ecosystem Model

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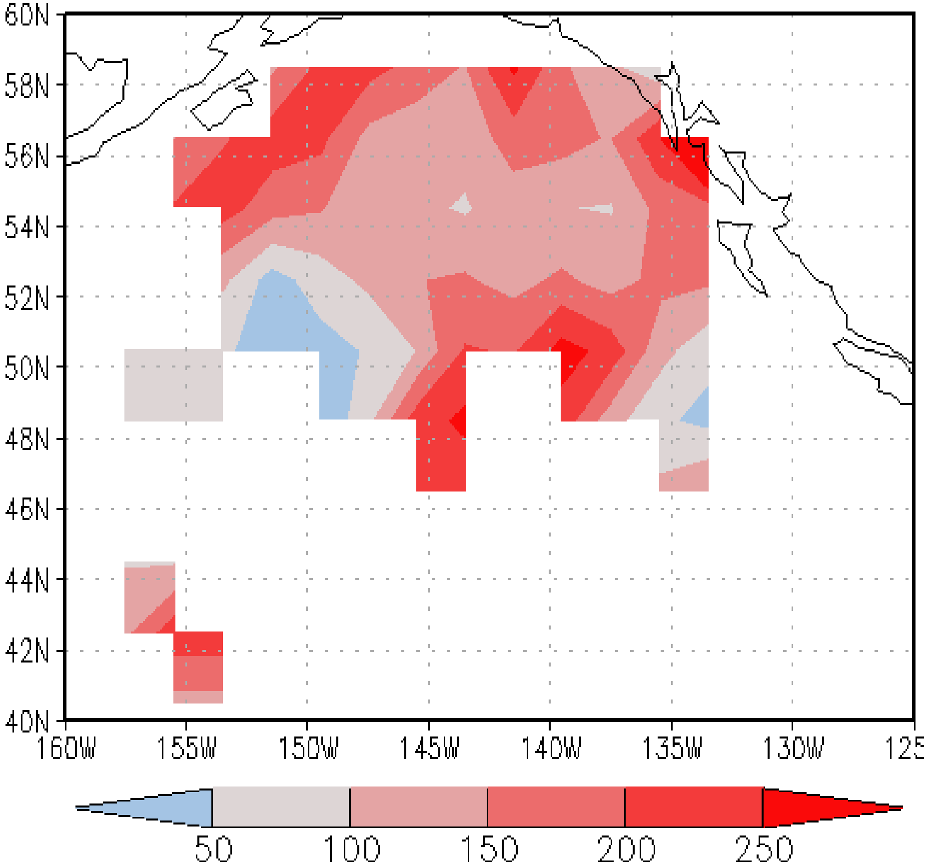
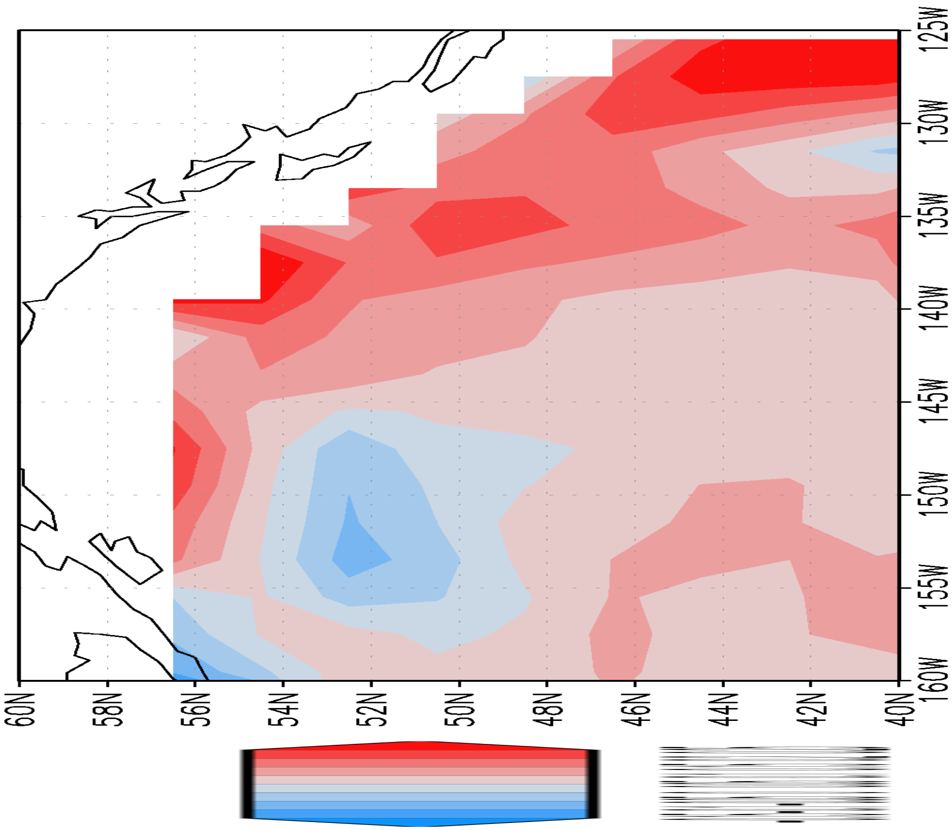
Zooplankton 1980-89 – 1960-62

Observations



Net tow 150 - 0 m; Jun 15-Jul 15 (mg m^{-3}) data from Brodeur

Physical-Ecosystem Model



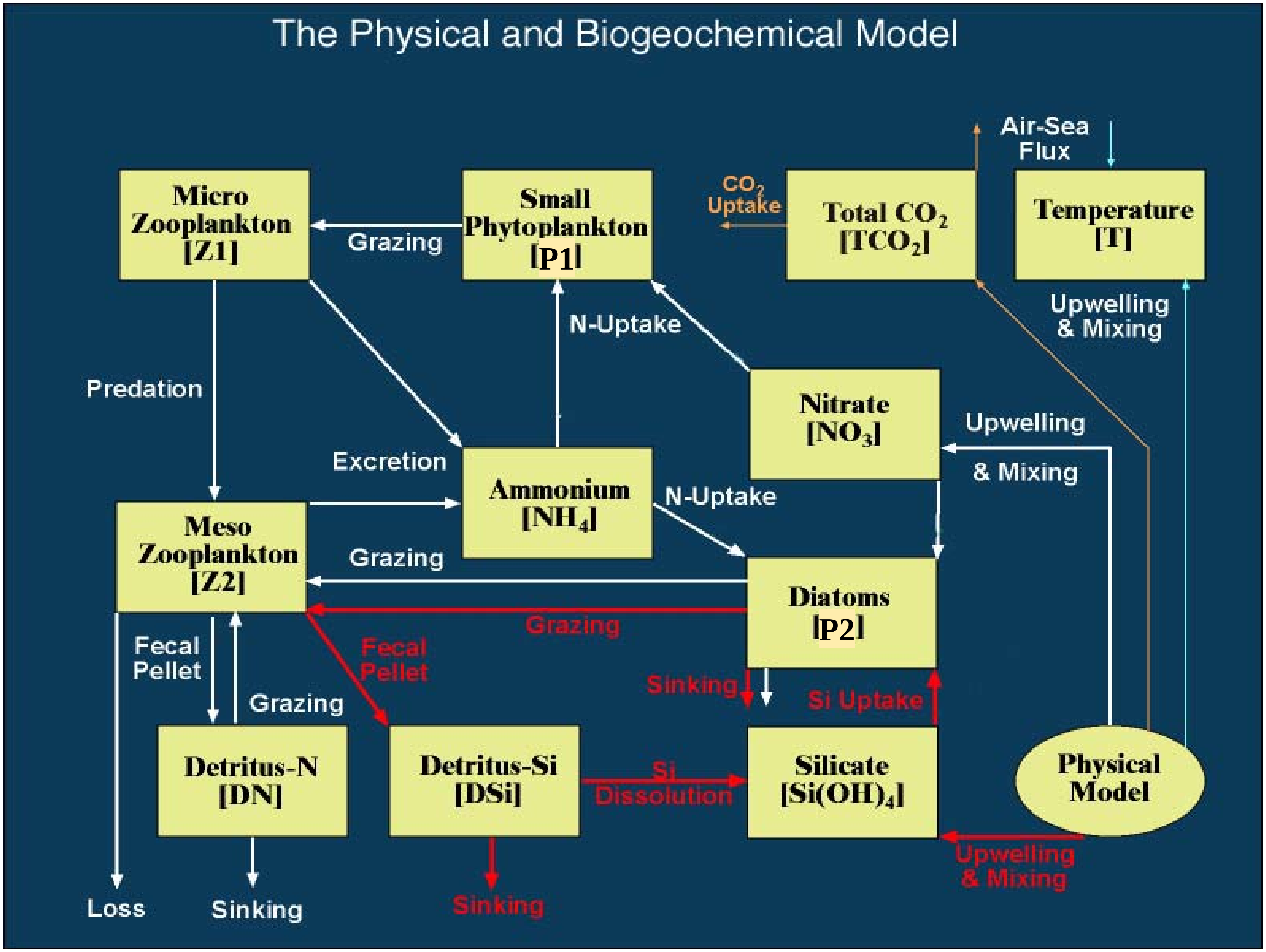
Sum 0-150m Z1 & Z2 Jun-July Ave mmol Nitrogen m^{-3}

Motivation

- Here we explore how the physical changes in the Pacific influence the lower trophic levels of the marine ecosystem using an ocean GCM coupled to an NPZD model.

- Focus on
  - 1977-88 - 1970-76 transition
    - Strong PDO signal (e.g. Bond et al. 2002)
    - Gulf of Alaska (GOA)
    - winter-spring when model ecosystem most productive

Ecosystem (NPZD) Model



Chai et al. 2002; 2003 Nitrogen is the “currency” of the model

“Plankton”

Model Experiment

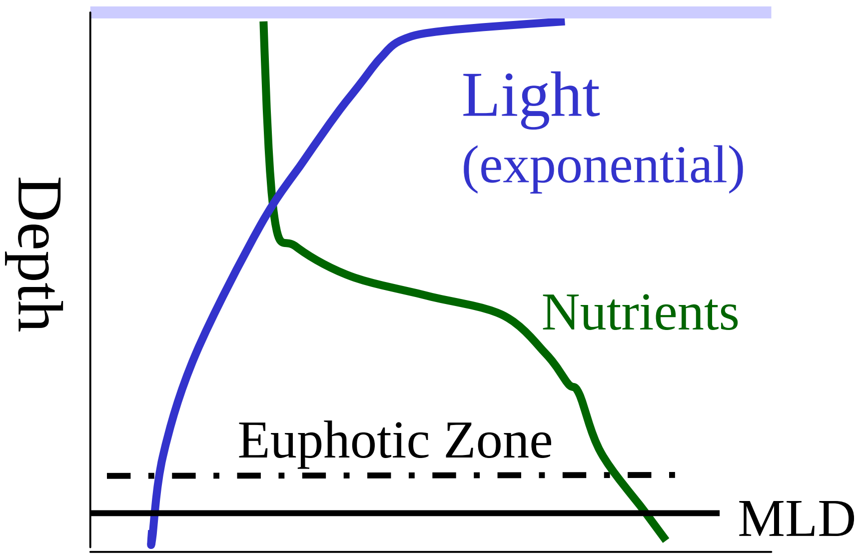
Physical Model

- Late 1990's version of NCAR OGCM

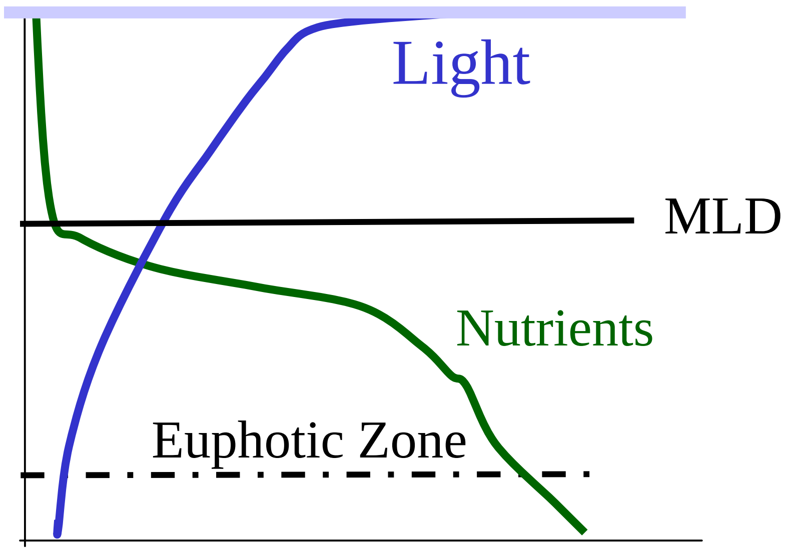
Forcing

- Spin-up 10-year integration with climatological forcing
- Forced with COADS 1955-1993, NCEP 1993-1999
  - Archived monthly values 1960-99
- Surface salinity strongly relaxed to climatological mean
- For more details See Li et al. 2001; Chai et al. 2003

Basic Physics and Photosynthesis:
light vs nutrients



Light Limited

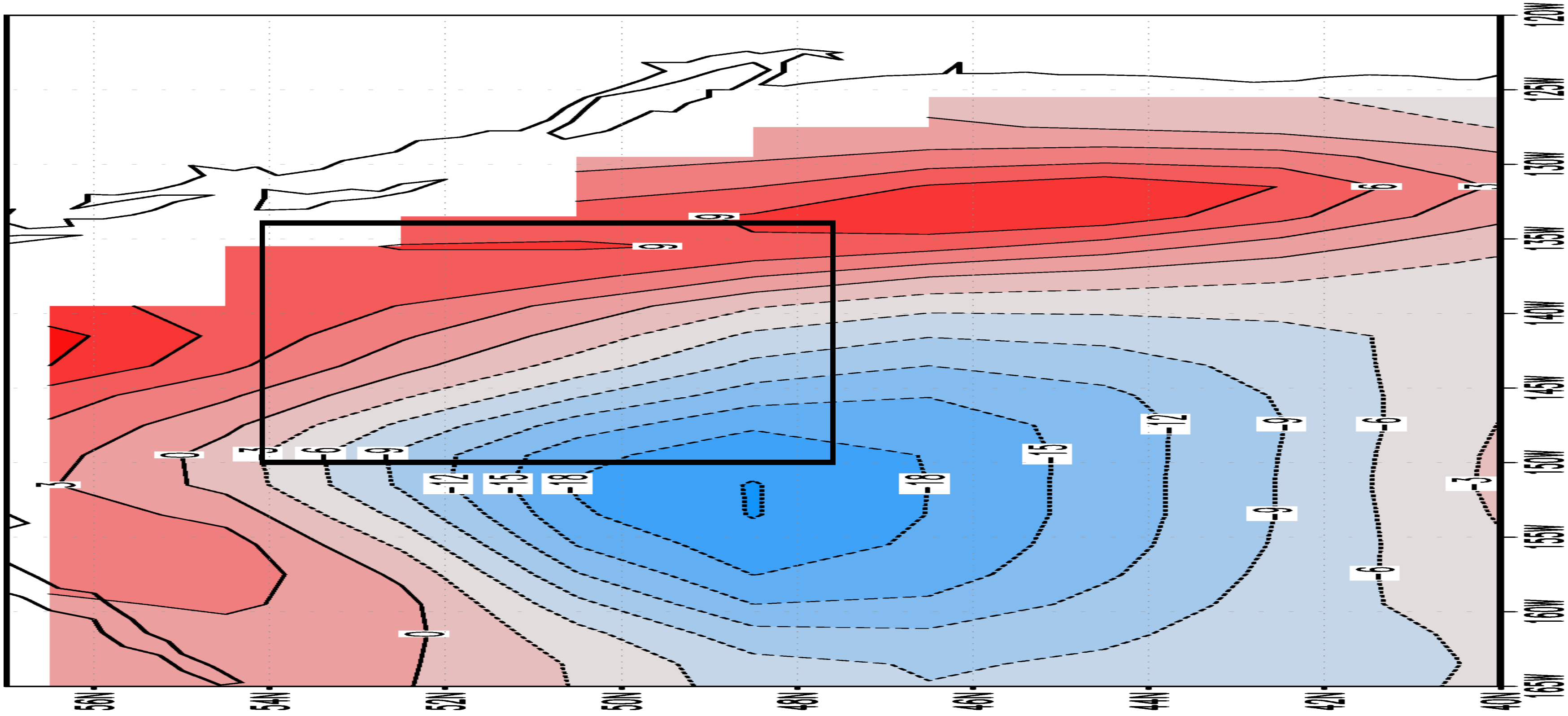


Nutrient Limited

MLD negatively
related to productivity
local correlation < 0

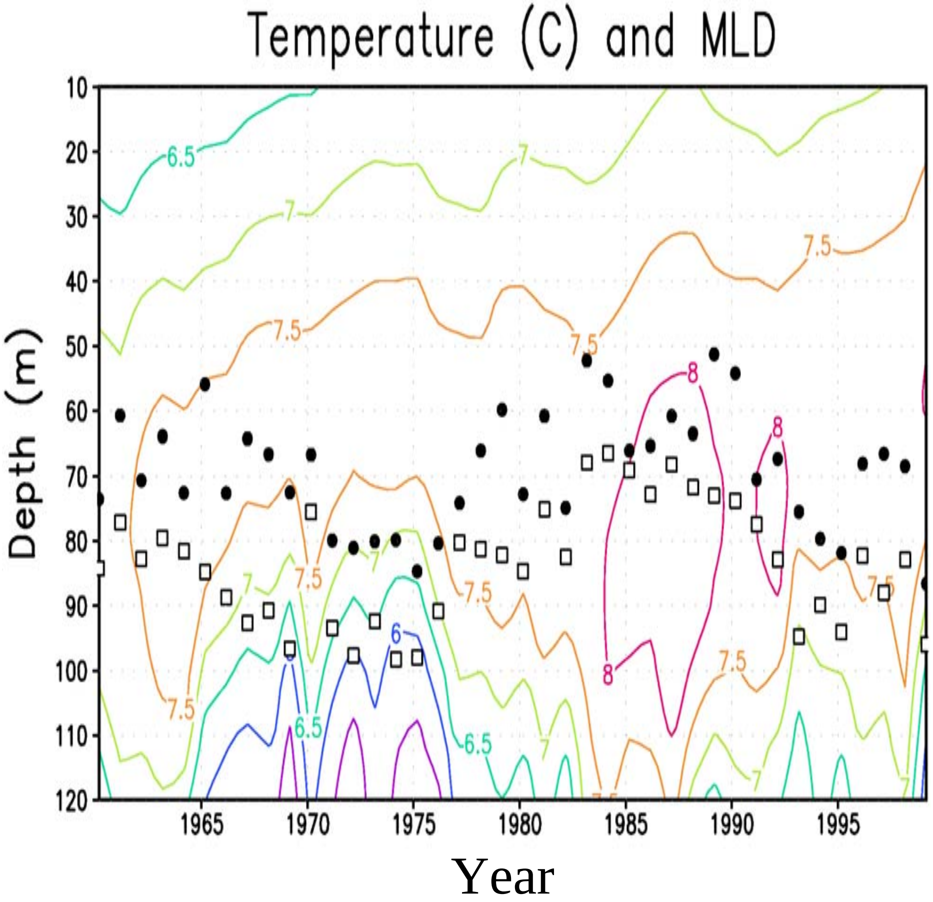
MLD positively
related to productivity
Local correlation > 0

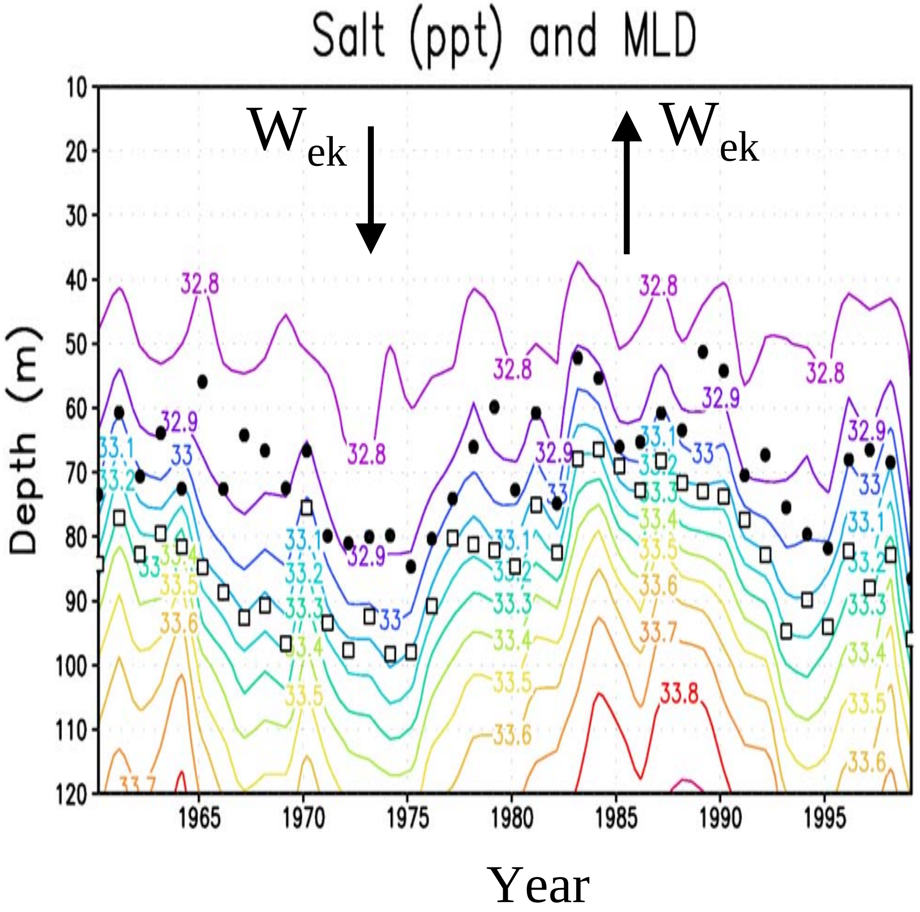
Epoch Difference in MLD (m)
1977-88 - 1970-76 FMA



MLD: $\rho_z = \rho_{sfc} + 0.125$ kg m^{-3}

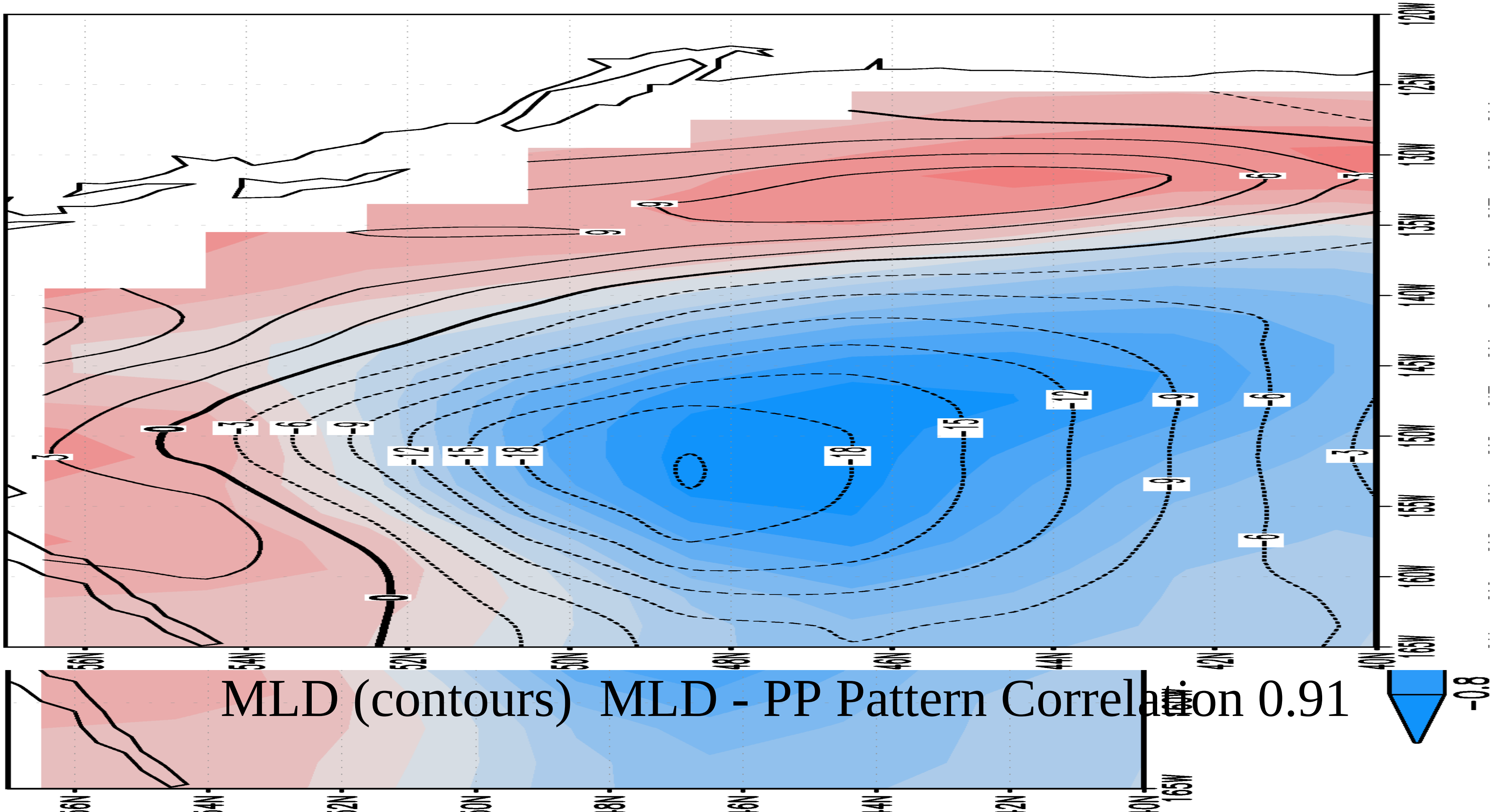
MLD, Temperature, Salt in GOA Region
46ºN-52ºN, 160ºW-140ºW in FMA





● MLD FMA □ MLD FMA

Primary Productivity (mmol of N m^{-3})
1977-1988 - 1970-76 in FMA



MLD (contours) MLD - PP Pattern Correlation 0.91

MLD - Productivity Connection

- Positive correlation between MLD and Primary Productivity suggests nutrient limitation:
  - Deeper MLD => more nutrients => more productive
  - Vice versa
- But Nutrient (nitrate, disolved silicate)
  - Epoch difference doesn’t match MLD or PP
  - Level of Nutrients in both epochs not limiting
    - In central GOA region nutrient levels allow for 85-90% maximum growth
- Previous studies also suggest Northeast Pacific not nutrient limited
  - e.g. Polovina et al. 1995

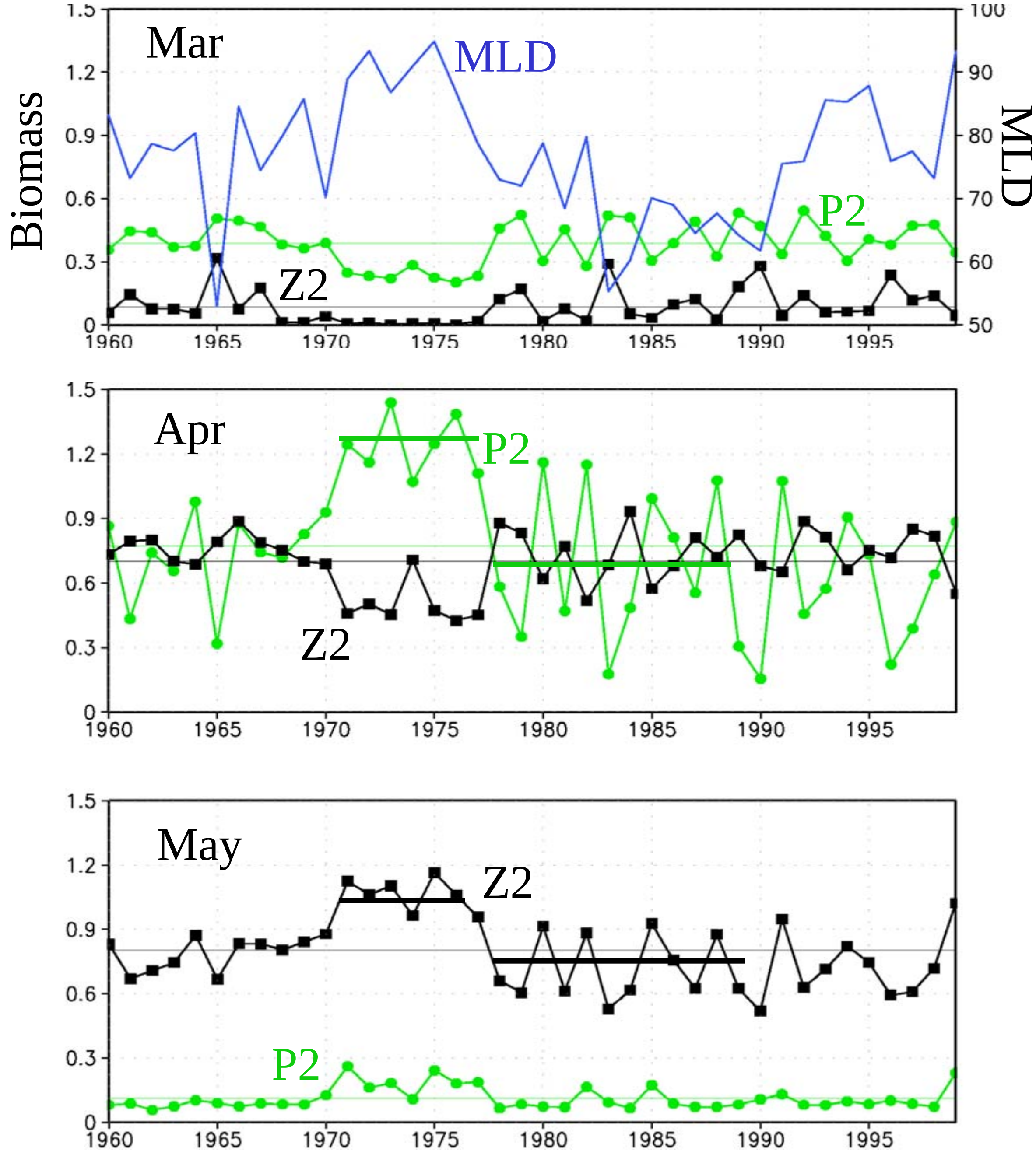
MLD-productivity Connection II

- If not regulated by (maco) nutrients then what?
- Iron limitation (micronutrient)?
  - Important in nature
  - In model implicitly included through initial growth rate constant developed for tropics
    - not effective in NE Pacific

- Trophic Interactions?
  - Grazing pressure impacts primary productivity
  - Hypothesis for less plankton in later epoch:

    Shallower in late winter MLD => More Light => More phytoplankton => more zooplankton => more grazing => suppresses phytoplankton and zooplankton during spring peak

MLD (March) Plankton and Zooplankton Biomass in central/west GOA region

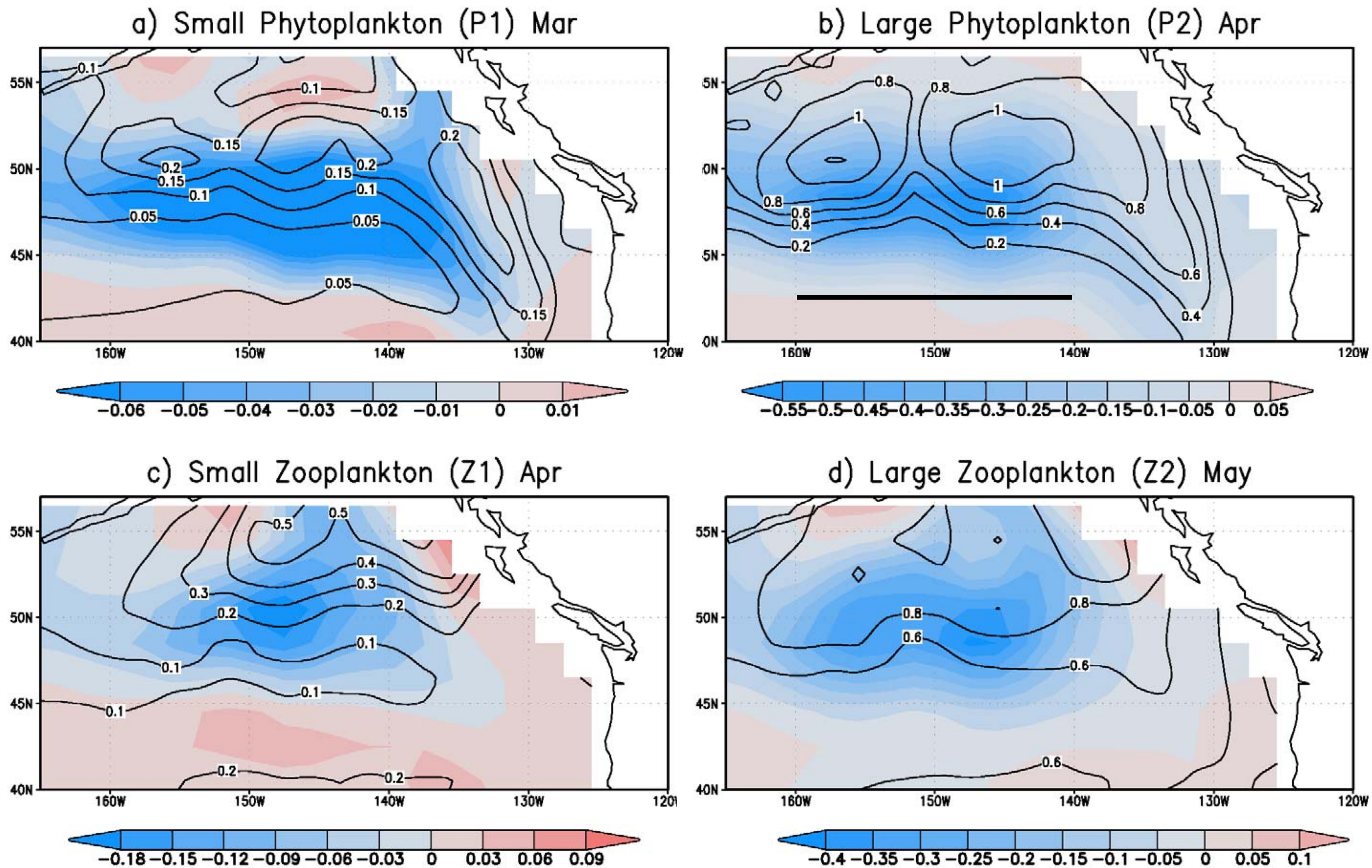


Correlations:

P2(Mar) - Z2(Apr) = 0.89
Z2(Mar) - P2(Apr) = -0.84

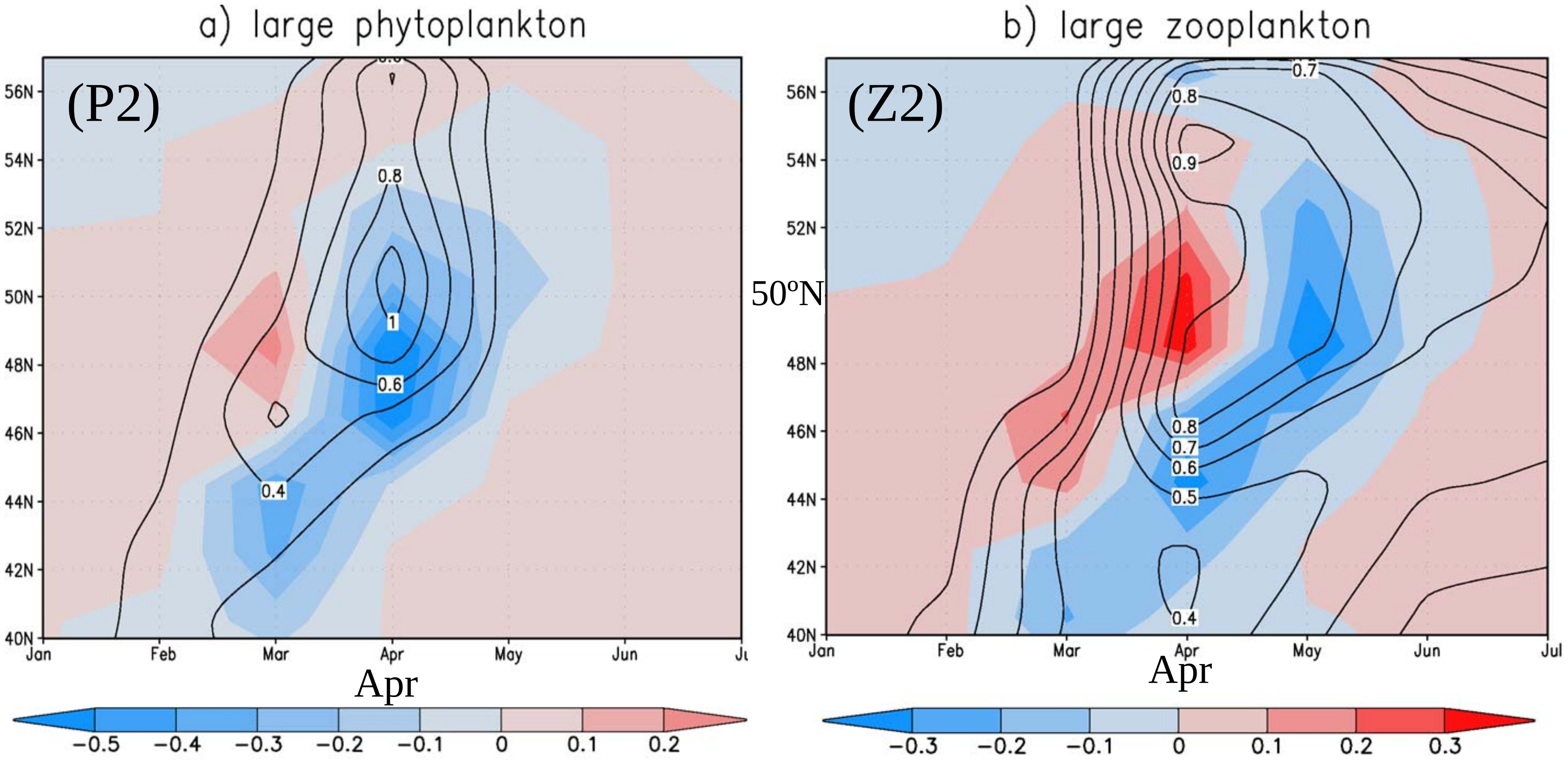
P2(Apr) - Z2(May) = 0.95
Z2(Apr) - Z2(May) = -0.85

Plankton at Peak 1977-88 - 1970-76 (shaded)
1977-1988 mean (contour)



Plankton Biomass Averaged 160ºW-140ºW

1977-88 - 1970-76 (shaded) 1977-88 (contours)



Hypothesis for the Simulated Ecosystem Changes in the central GOA region

In 1977-88 relative to 1970-76:

- Deeper Aleutian Low
- Spin up Gyre / Enhanced Ekman pumping
- Halocline and thus winter MLD shoals
- More light available for photosynthesis, phytoplankton biomass increases earlier in the year

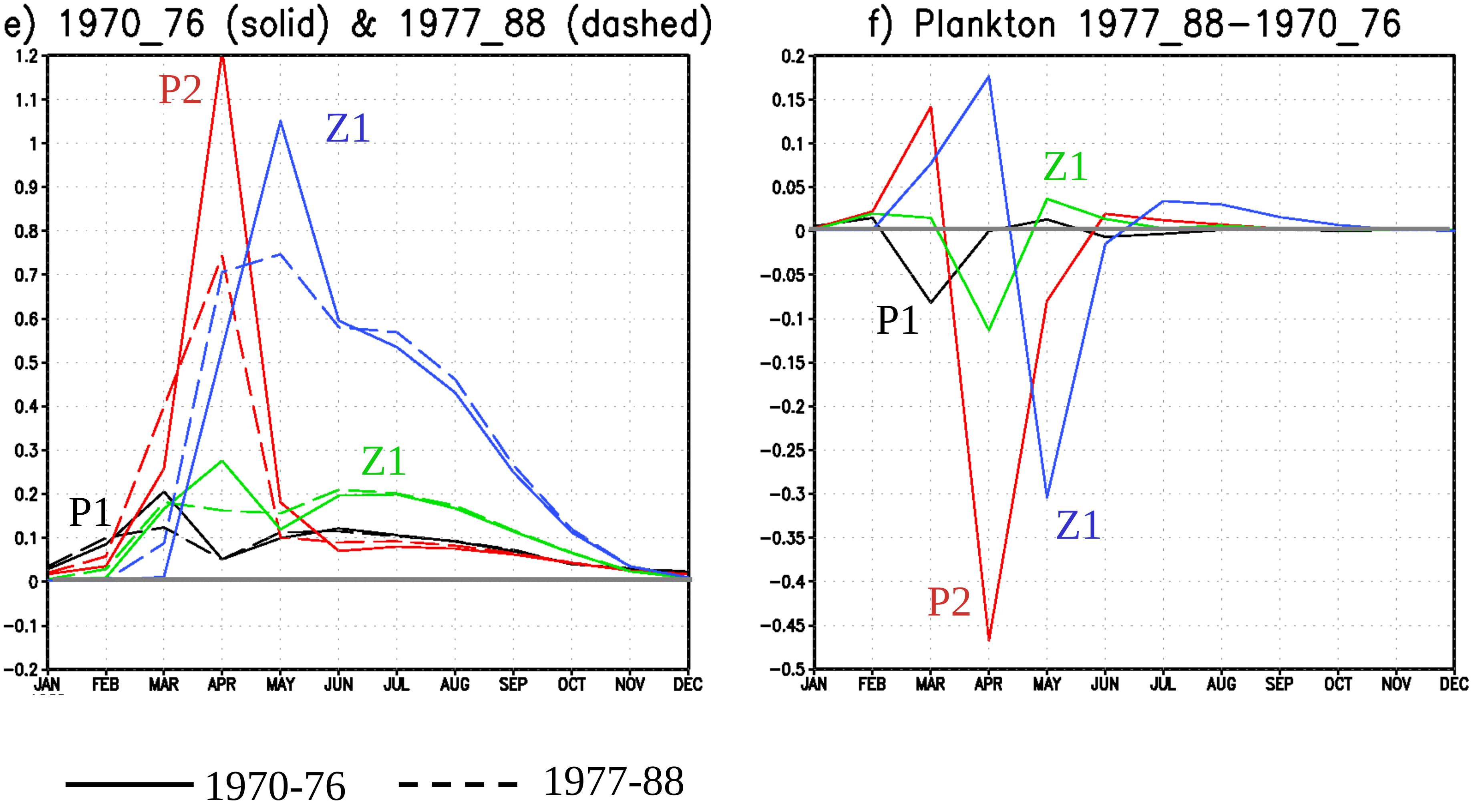
  (Or further north relative to normal)
- Zooplankton biomass grows by grazing on phytoplankton
- Maximum phytoplankton biomass suppressed in April => Maximum zooplankton biomass suppressed in May
  - Reduction of 40%
- Reduced grazing in May allows modest phyto & zooplankton increase in summer

Concluding Thoughts/Questions

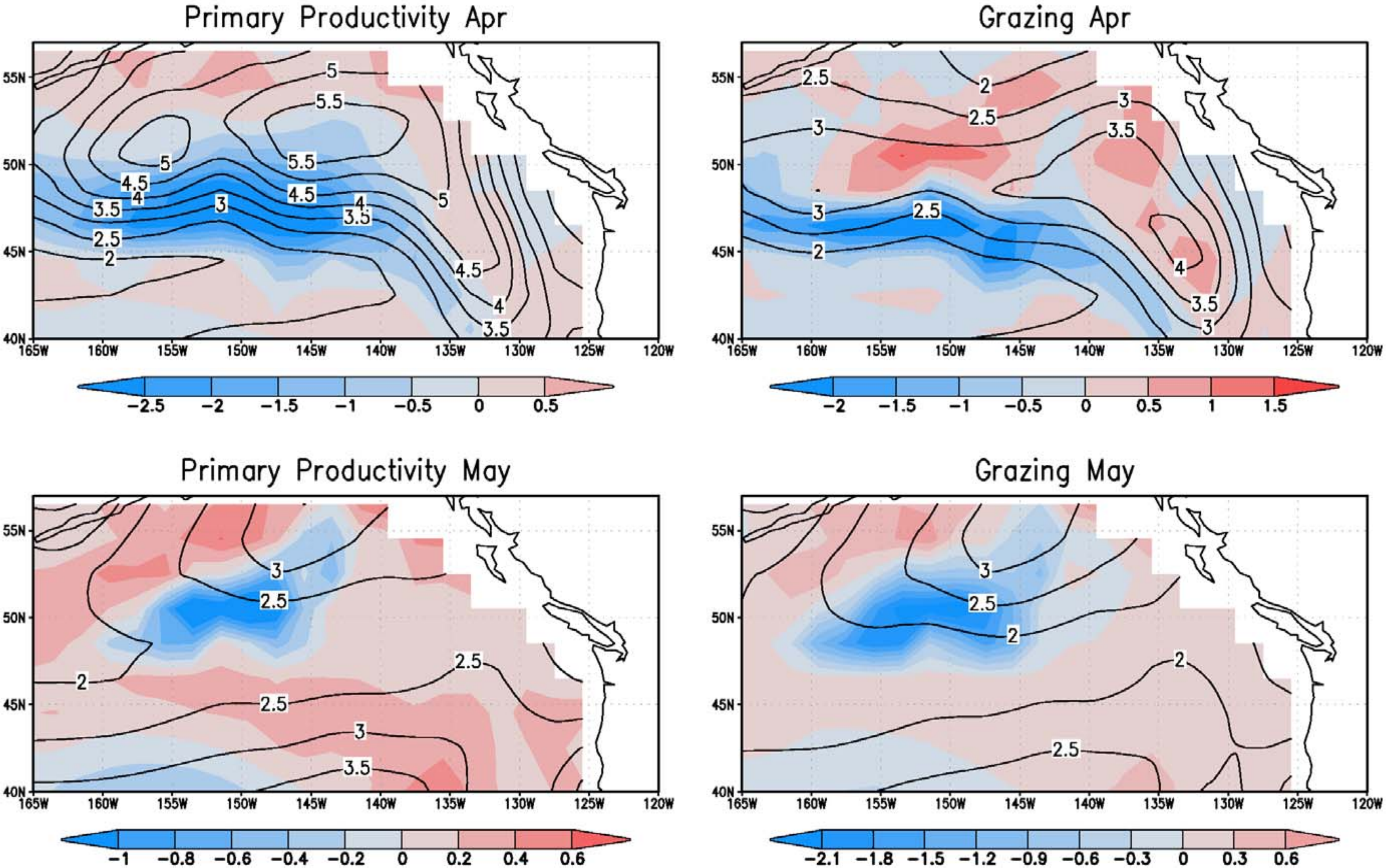
- Decadal changes can be manifest as altering the seasonal cycle.
- “Regime-like” behavior most pronounced in 1970-76 period, 1980-89 close to the mean and exhibits much more interannual variability
  - Latter could impact data assessment of regime changes
- Role of iron limitation?
  - Model’s mean spring maximum too large by ~2
- Role of eddy mixing & coastal processes?
- Role of nutrient recycling?
- Two-way interactions with higher trophic levels?

Plankton Biomass (mmol N m^{-3})

Central/West GOA region: 46ºN-52ºN, 160ºW-140ºW

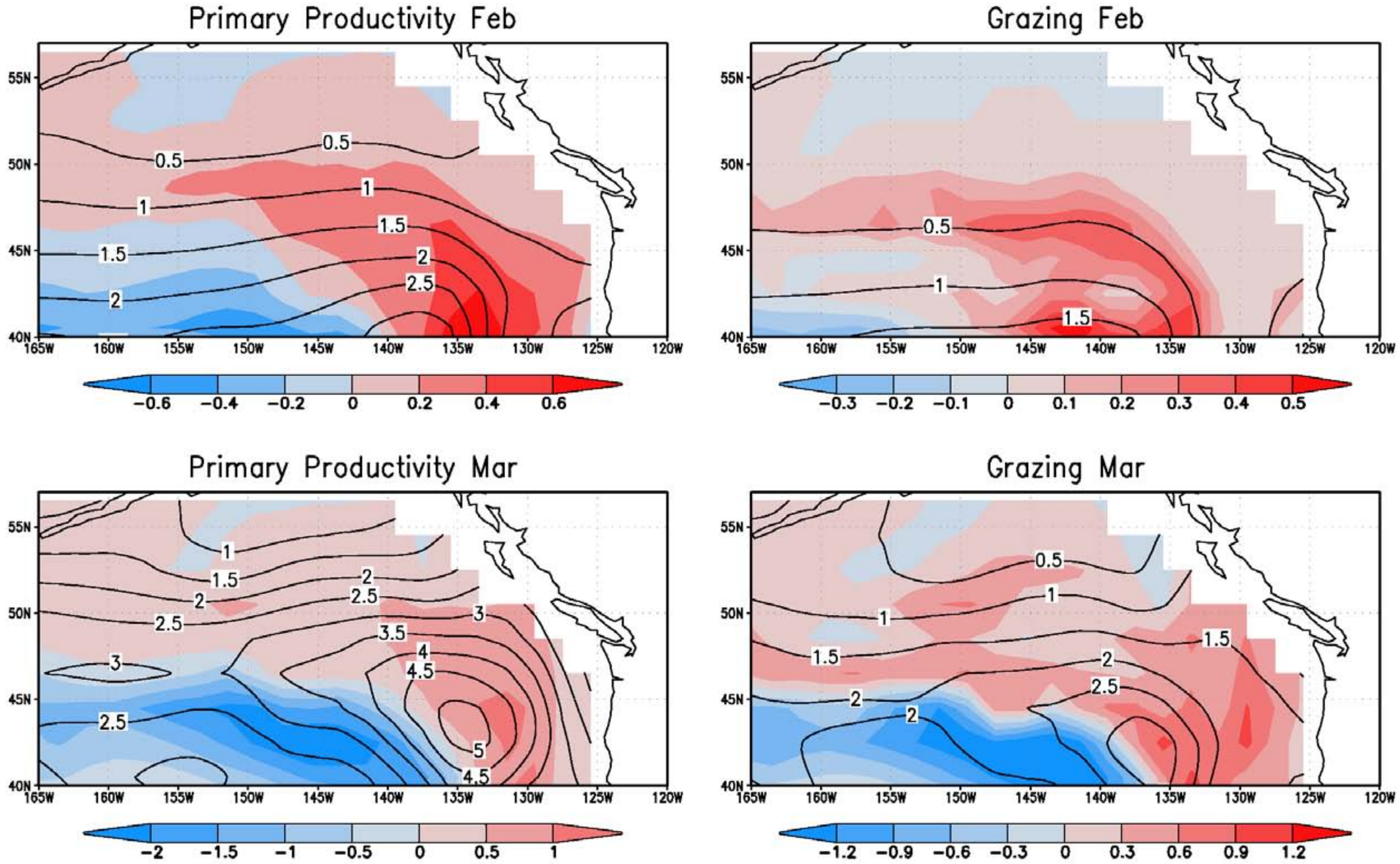


Productivity and Grazing Apr-May



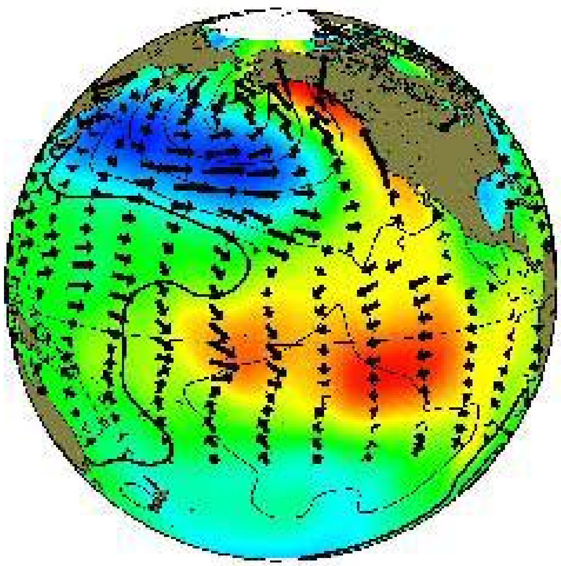
Primary Productivity and Grazing Feb-Mar

Productivity and Grazing 1977_88−1970_76 (shading) and 1977_88(contour)

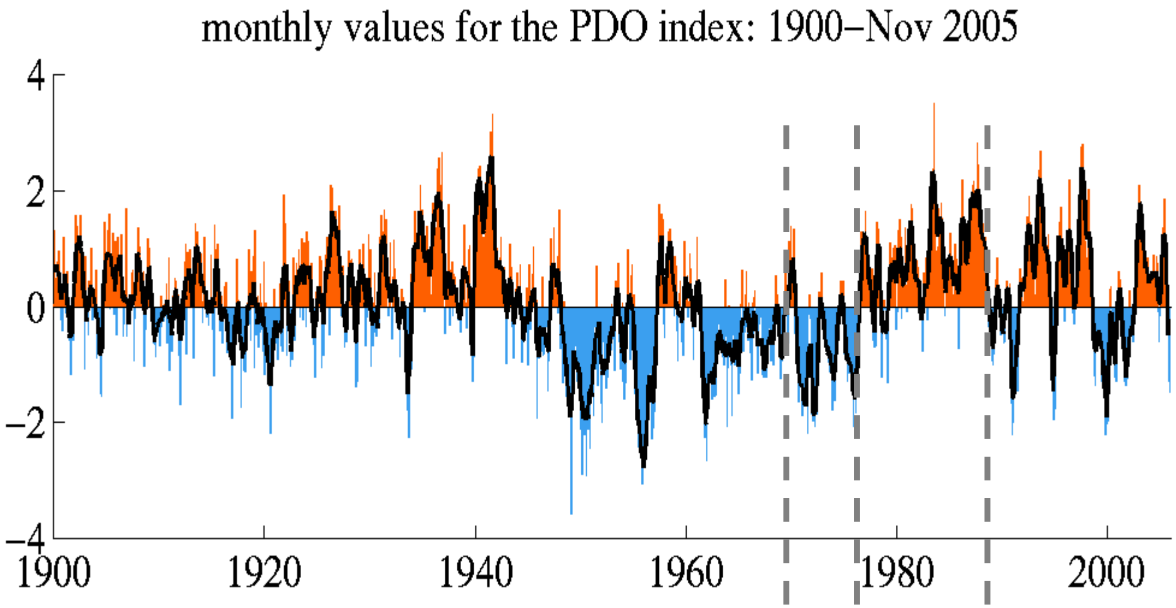


Units: mmol Nitrogen m^{-3} day^{-1}

PDO - a Measure of Decadal Variability



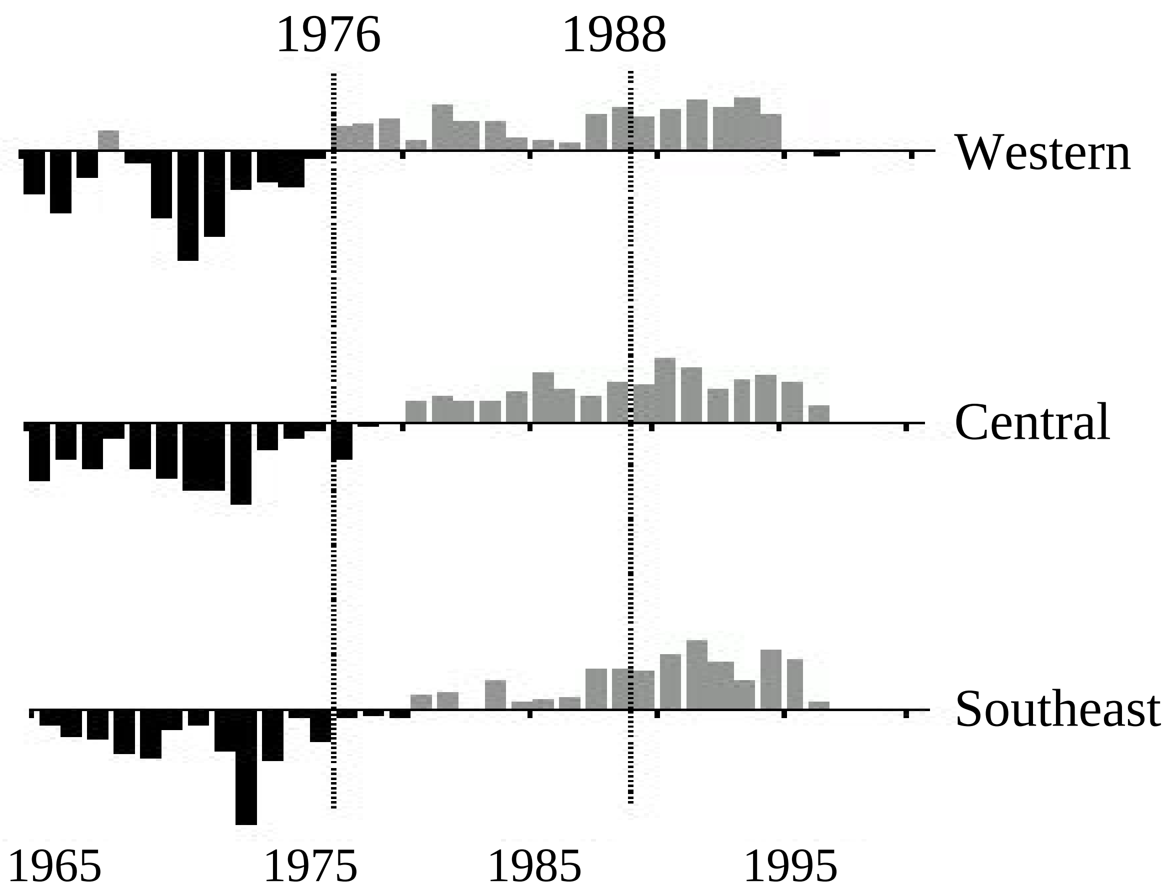
SST, SLP,Winds



70 76/77 1988

Mantua et al. 1997

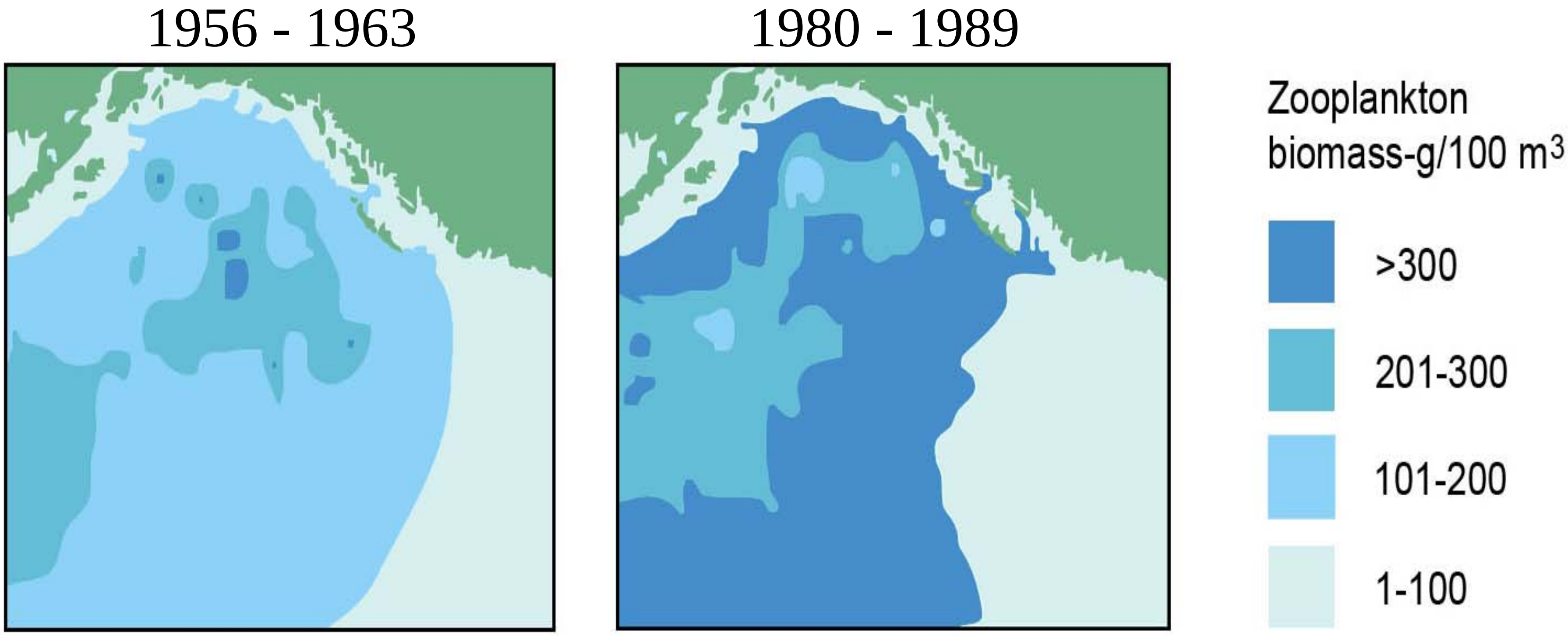
Alaska Sockeye Salmon Catch



Hare and Mantua, 2000

Zooplankton Biomass From Net Trawls

June 15th-July 15th



from Brodeur et al. (1996)

Brodeur and Ware (1992) north of 46ºN as limited data further south

Physical Model

- NCAR Ocean Model (NCOM)
  - OGCM based on MOM with KPP
    - (Large et al. 1997, Gent et al. 1998)

- Modified for the Pacific Basin
  - (Li et al., 2001, JPO)
  - 45ºS - 65ºN

- 2º lat x 2º lon outside of tropics
  - Not coastal or eddy resolving

Large Phytoplankton Tendency

d(P2)/dt = 2*(Production - Grazing by Z2 - Sinking)

- factor of 2 for N & Si uptake

Production = μ_{max}* nutrient regulation * light regulation

μ_{max} = maximum growth rate

Nutrient regulation - $Si(OH_4) / (K + Si(OH_4)$

K = 3.0 mmol m^{-3} (half Saturation)

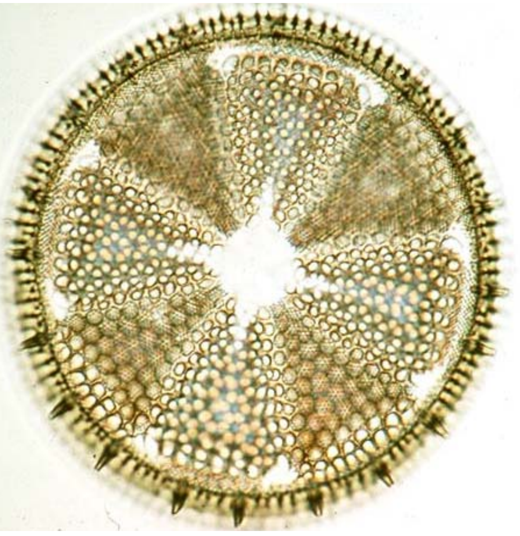
Light regulation - 1.0 - $\exp(-\alpha * I / \mu_{max})$

α - initial growth rate constant

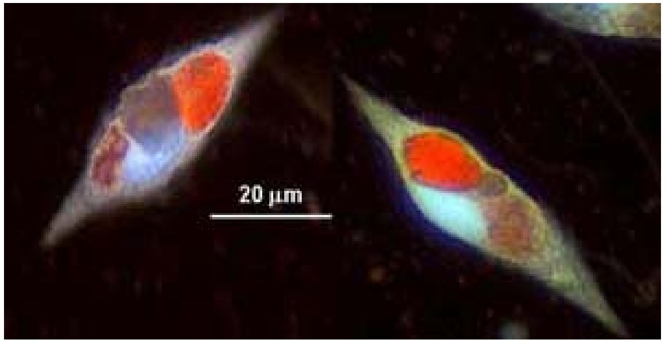
(“iron regulation” - implicitly in α but set with equatorial values

Plankton Classes

Micro Phytoplankton (P1)
Coccolithophore



Large Phytoplankton (P2)
Diatoms



Microzooplankton (Z1)
Dinoflagellates

Mesozooplankton (Z2)
Copepods

Model Experiment (Chai et al., 2003)

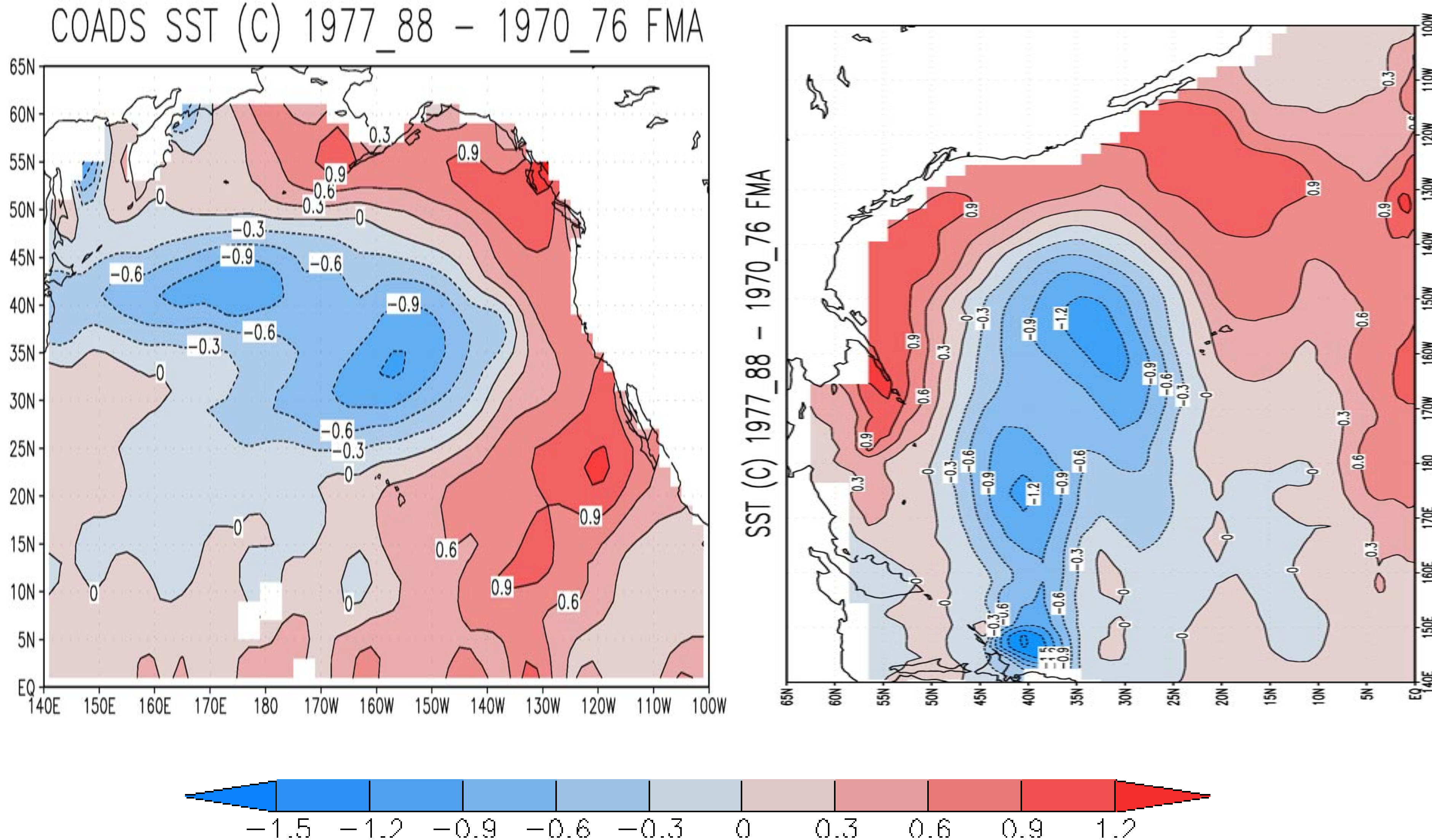
Initial Conditions

- T, S, Nutrients initialized with LTM from NODC
- Biological components assigned constant surface values decrease exponentially with depth

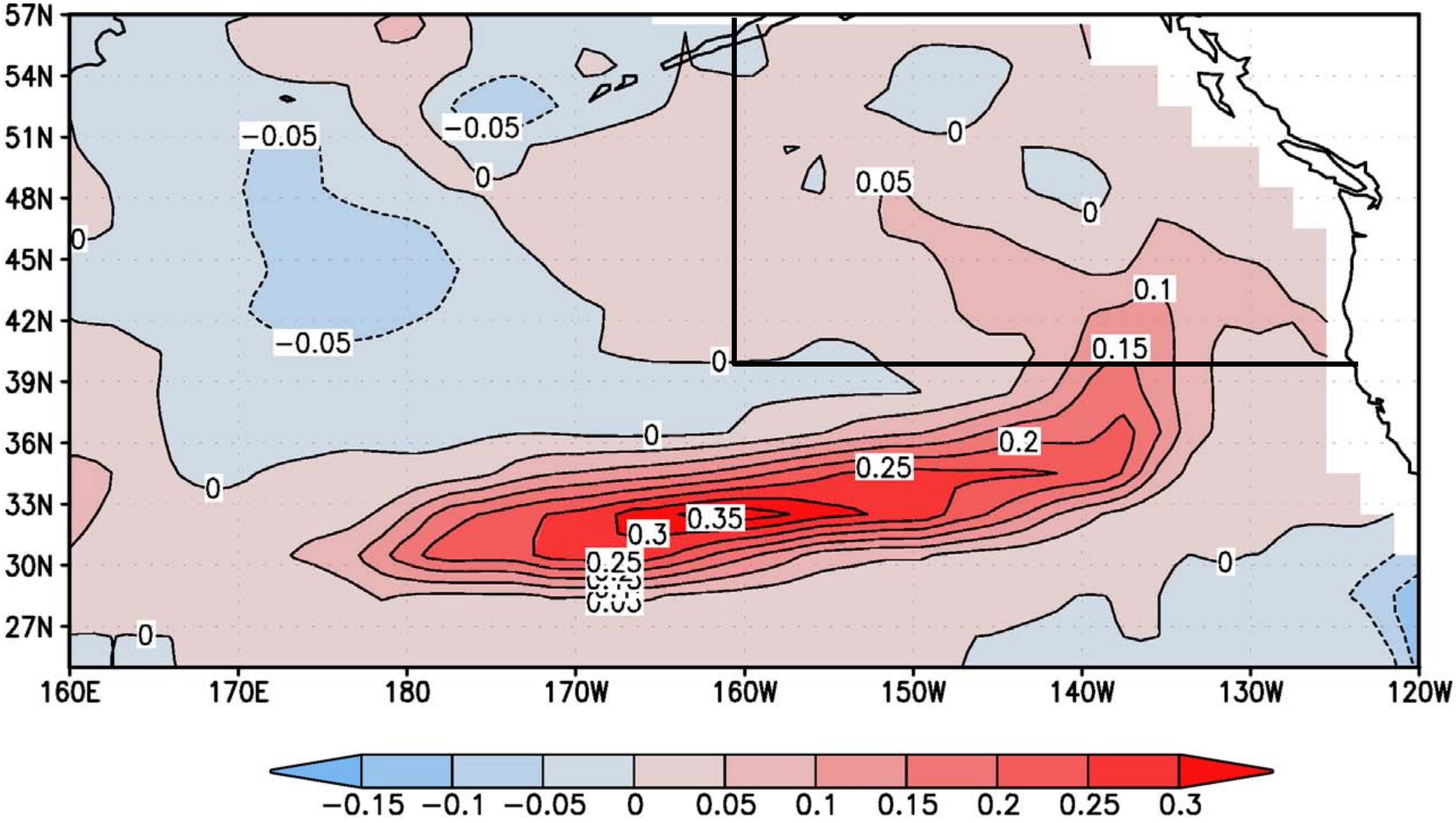
Forcing

- 10-year integration with climatological forcing
- Forced with COADS 1955-1993, NCEP 1993-1999
  - Archived monthly values 19060-99
  - winds, air temp & moisture, radiative fluxes
  - radiative fluxes: formulas from Miyakoda ad Rosati (1988)
- Surface salinity strongly relaxed to climatological mean
  - Forced with P-E but damped using 30-day time scale

SST(°C) 1977-88 – 1970-76 FMA

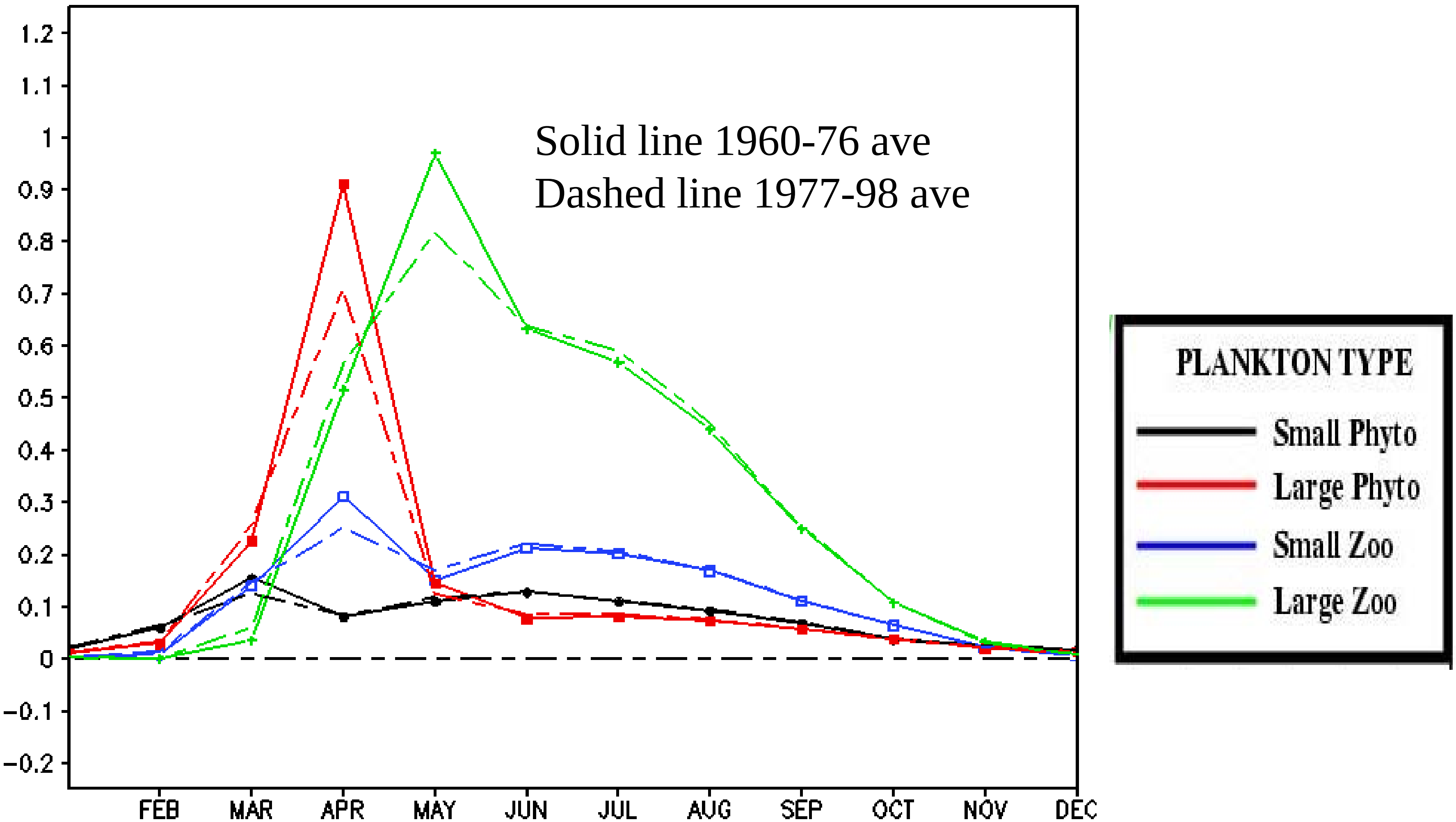


Surface Zooplankton 1977-88 -1970-76 Jun-Jul

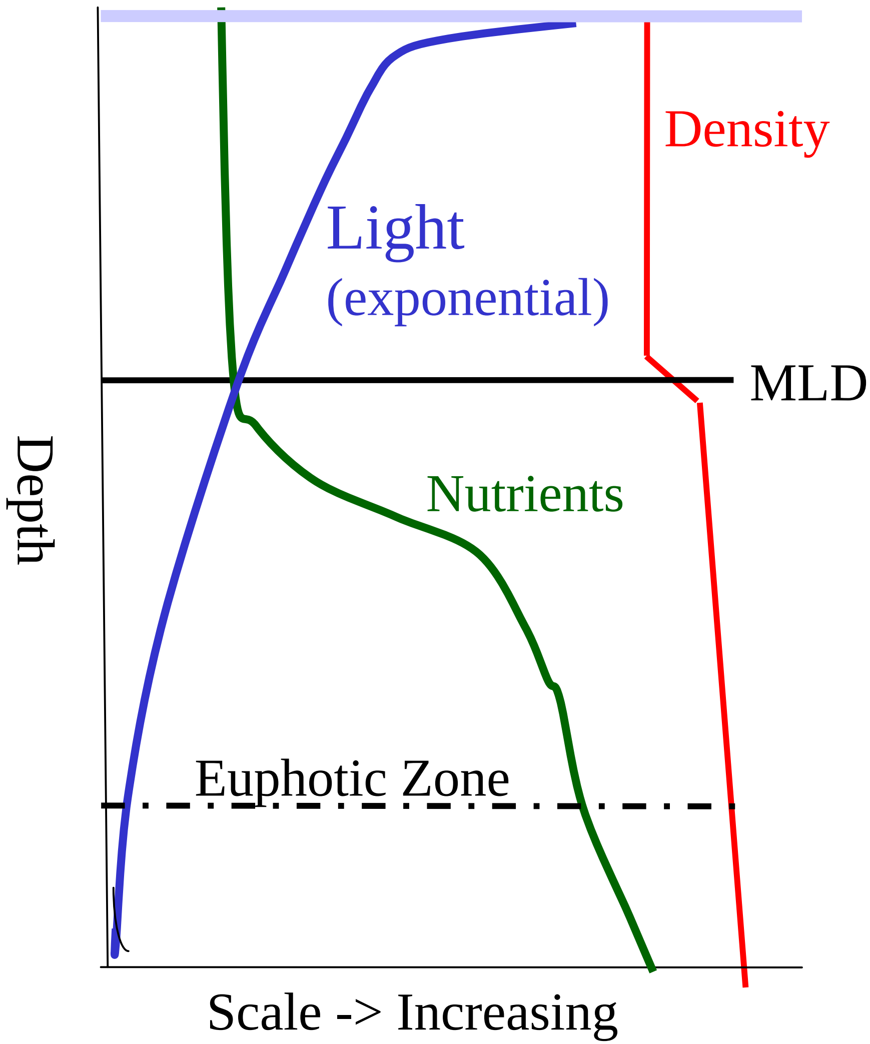


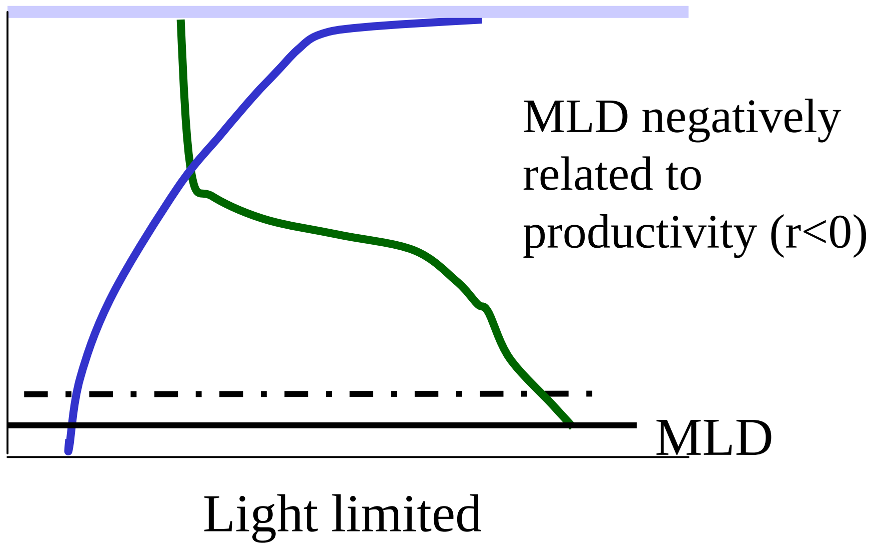
Shift in the subtropical and chlorophyll fronts enhanced post 1976
Obs: Polovina et al. 2001, model Haigh et al. 2001; Chai et al. 2003

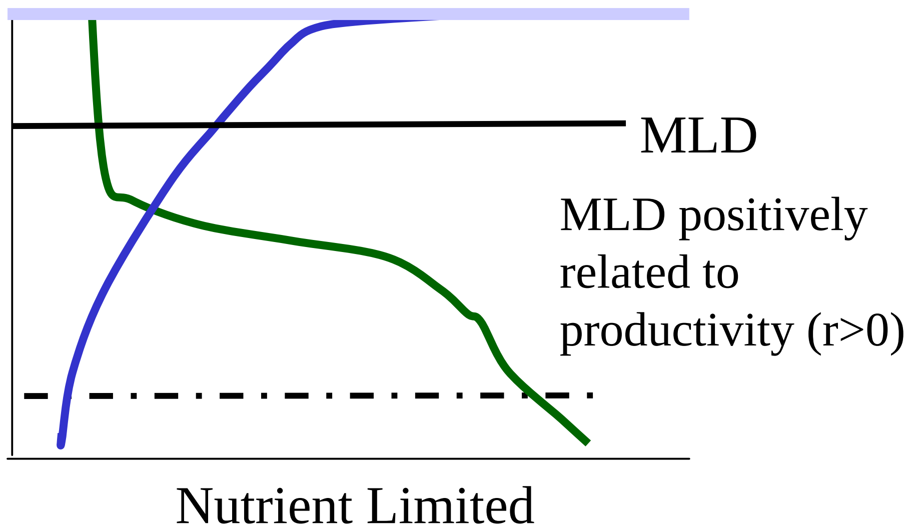
Epoch Mean and Difference
4 Plankton classes in NE Pacific



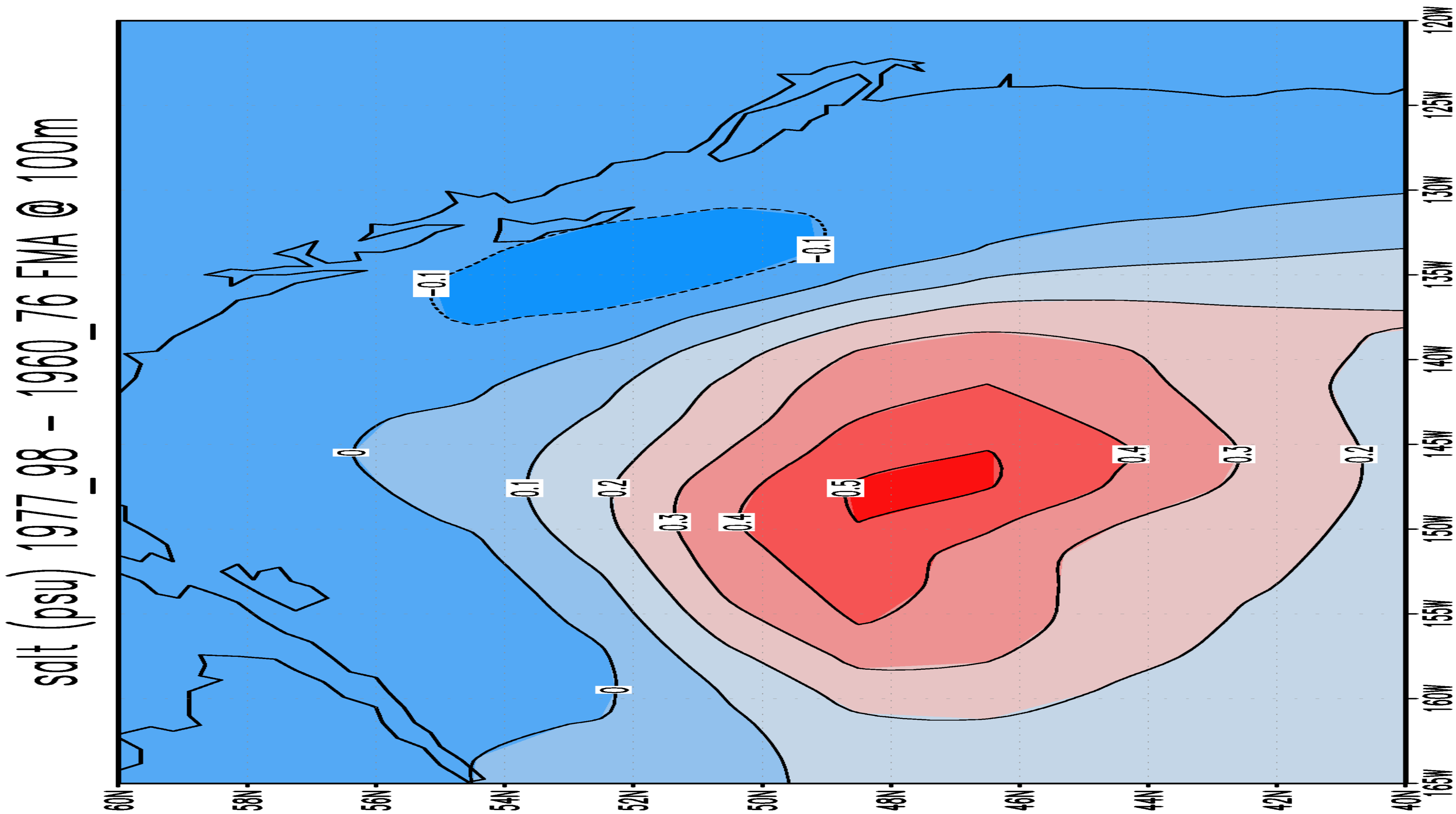
Basic Physics and Photosynthesis: light vs nutrients



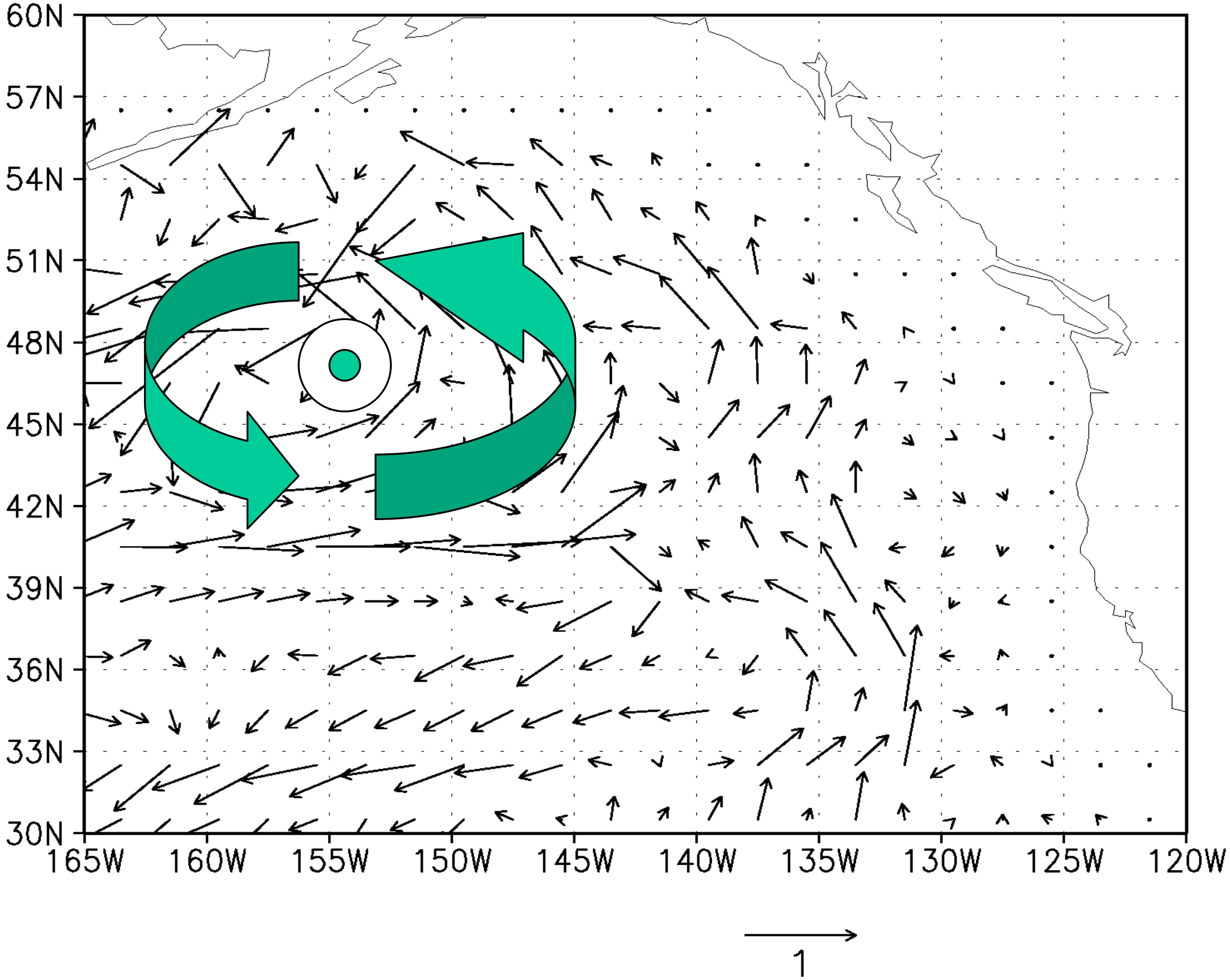




Epoch Salinity Difference

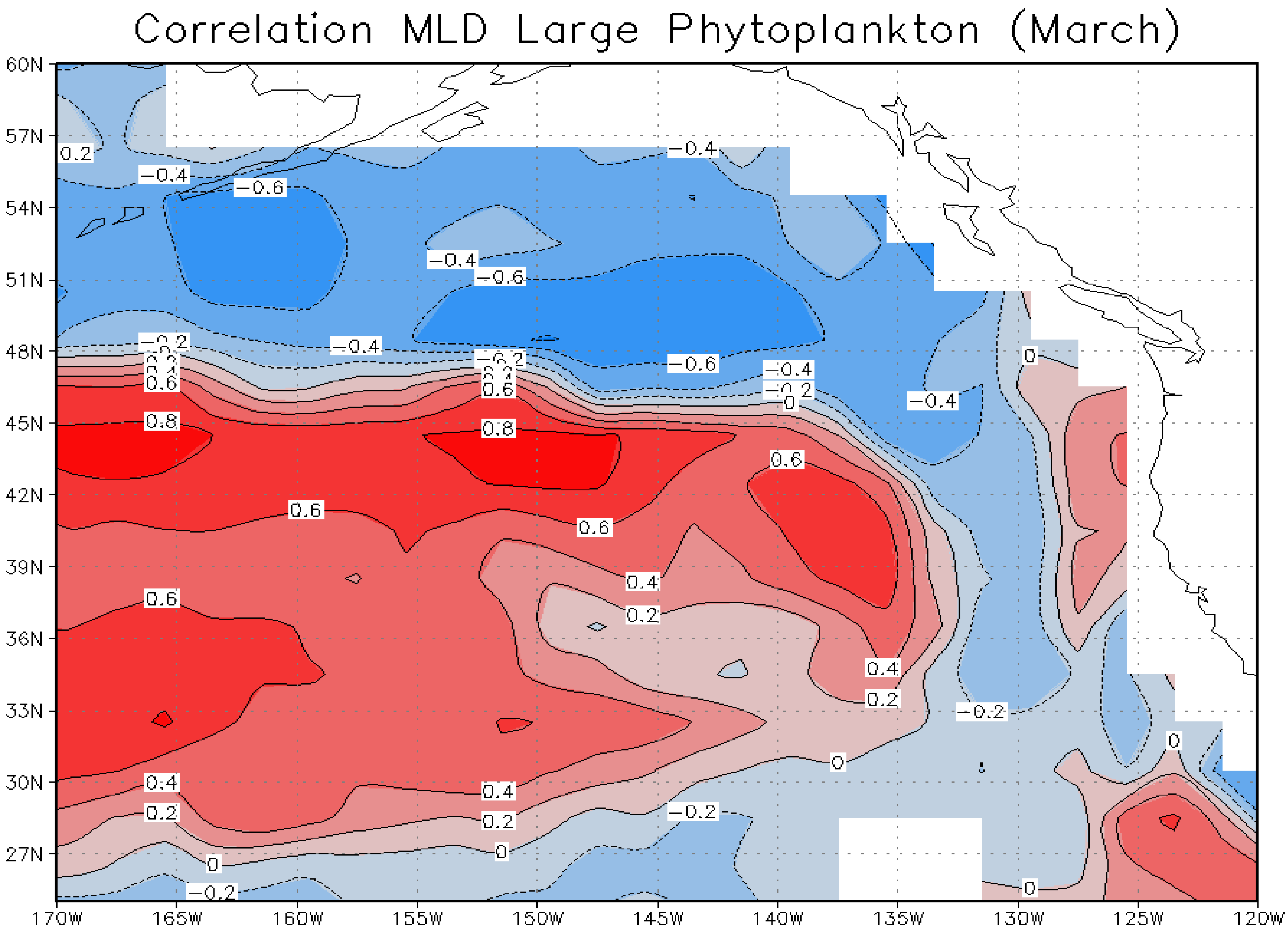


Currents (cm s^{-1}) 1977-1988 - 1970-76
Annual Average, 0 -200m



Spin-up of the Alaskan Gyre

MLD Influence on Biology



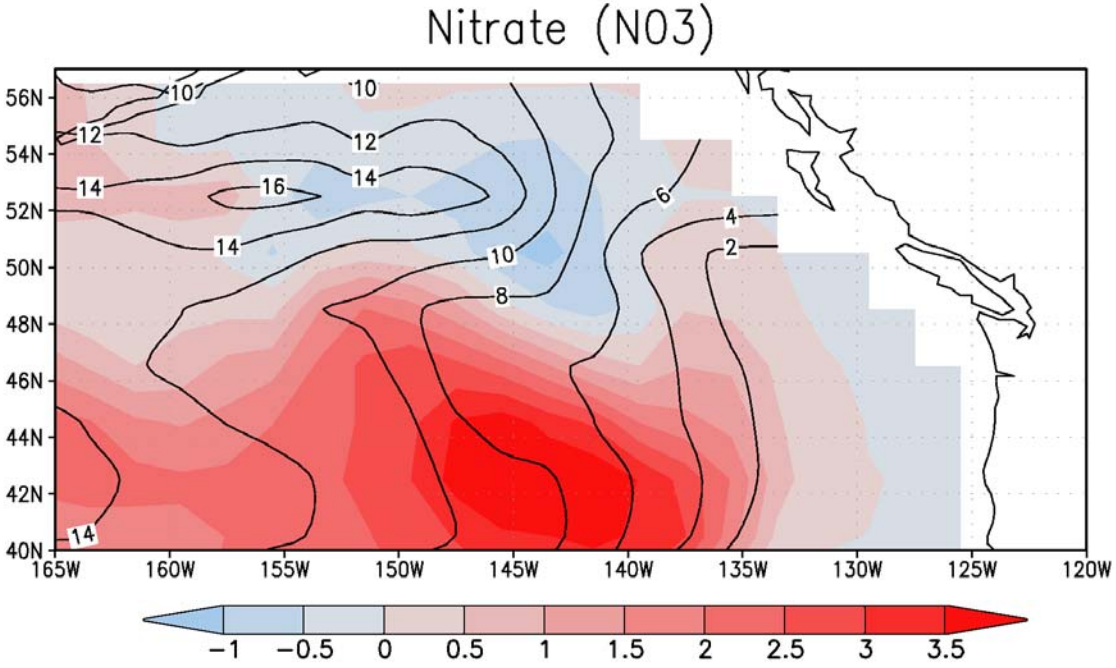
Nutrients

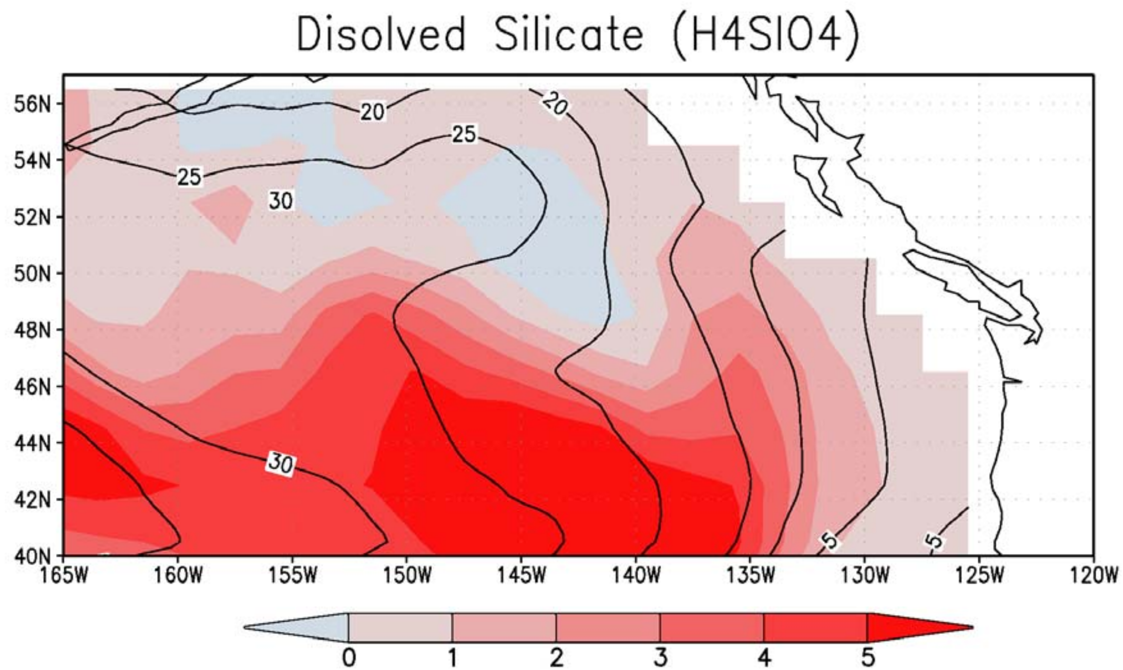
1977-88 - 1970-76
(Shaded)

1970-88 average
(Contours)

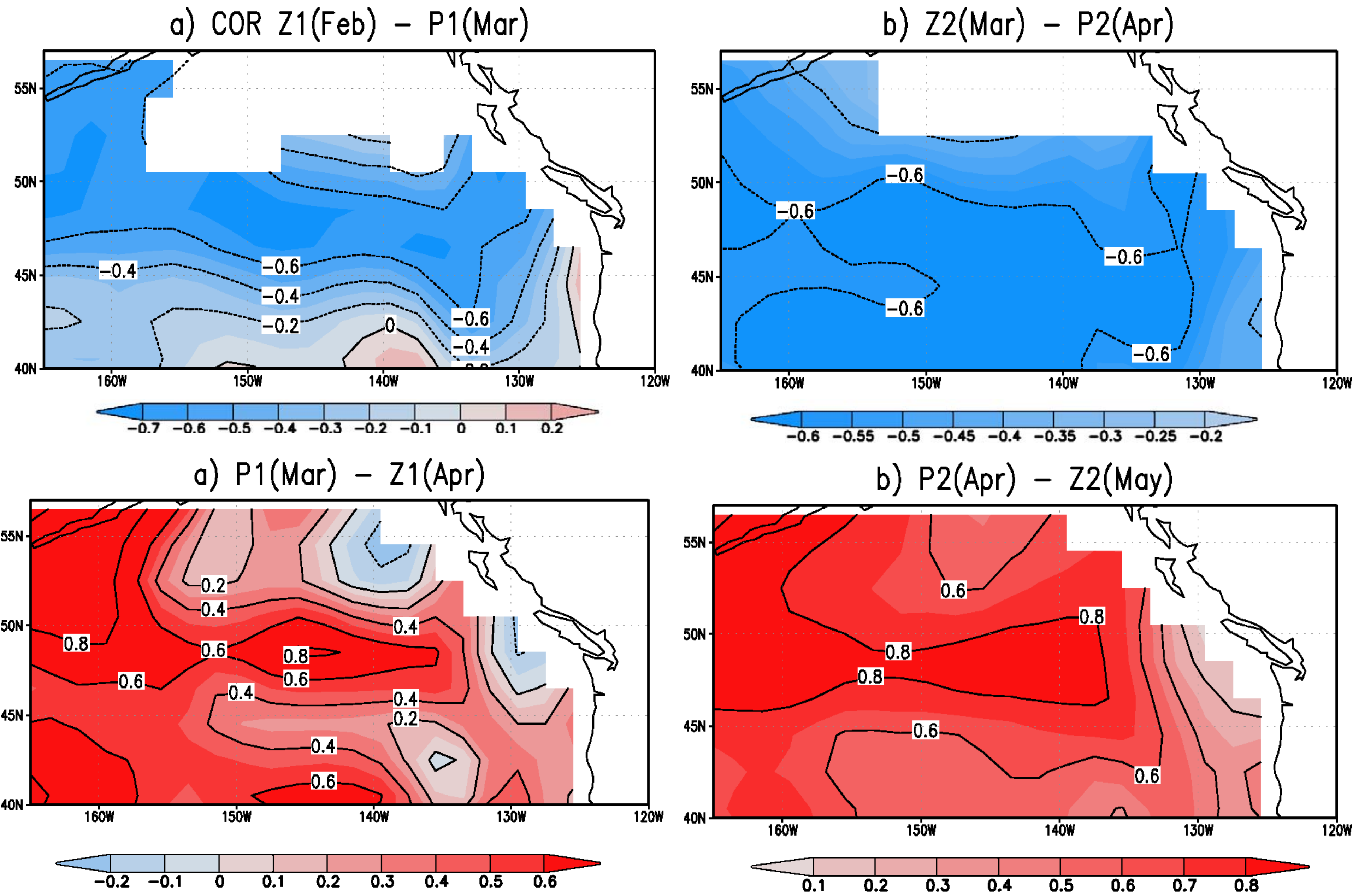
Pattern different than
PP/MLD epoch dif

Nutrients not limiting:
GOA region 85-90%
Maximum growth

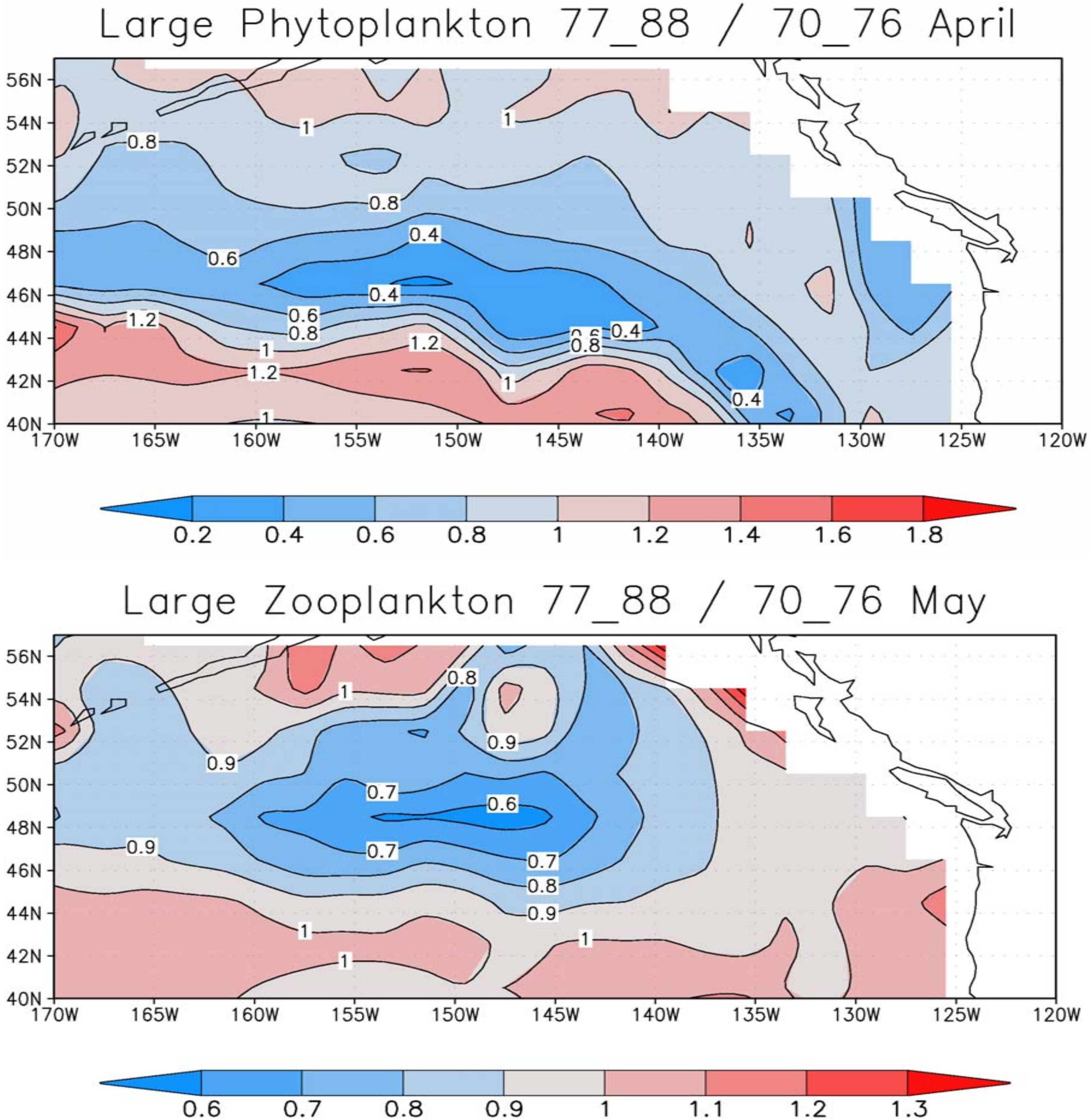




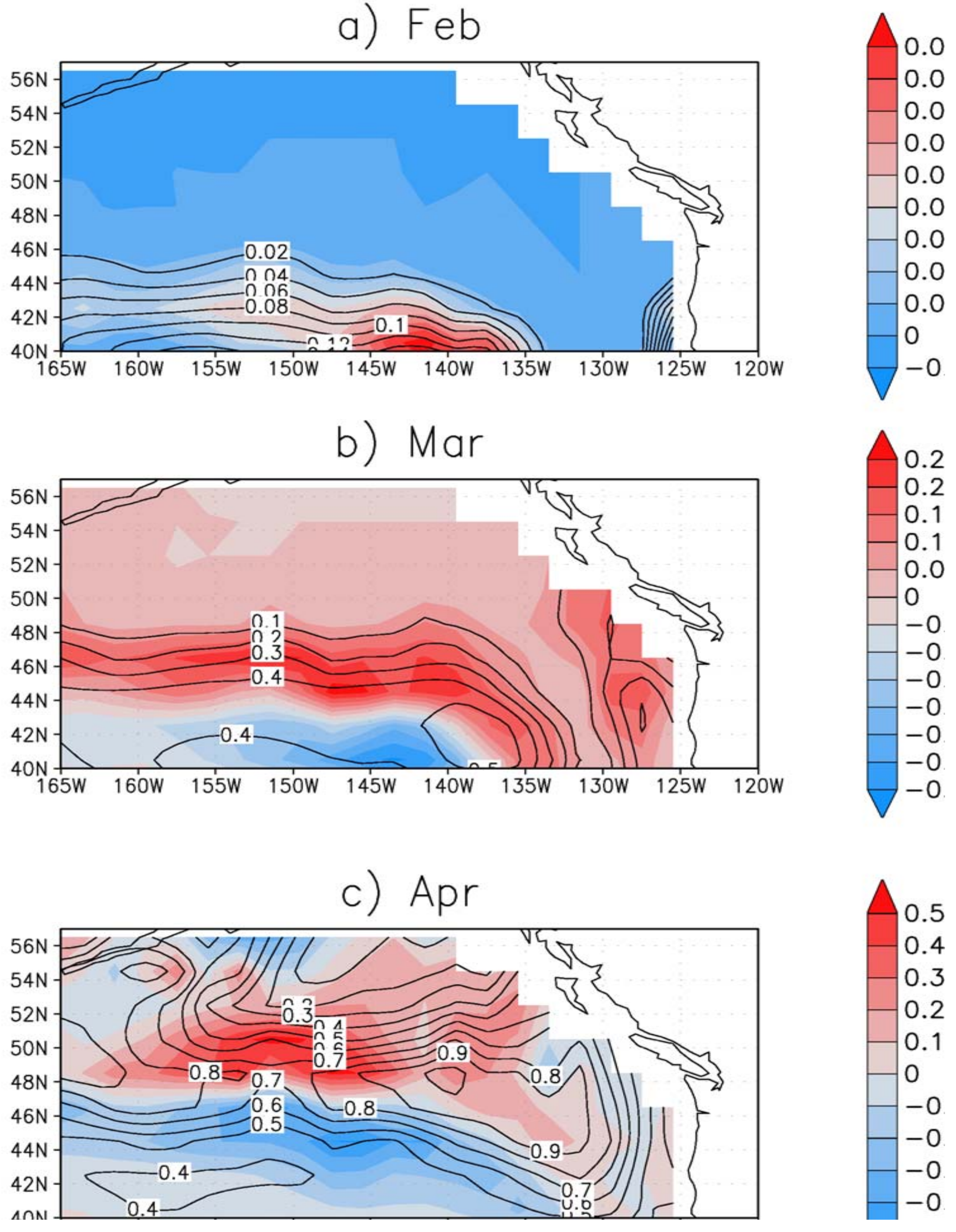
1 month Lead/Lag P-Z Correlations



Ratio of Plankton in two epochs

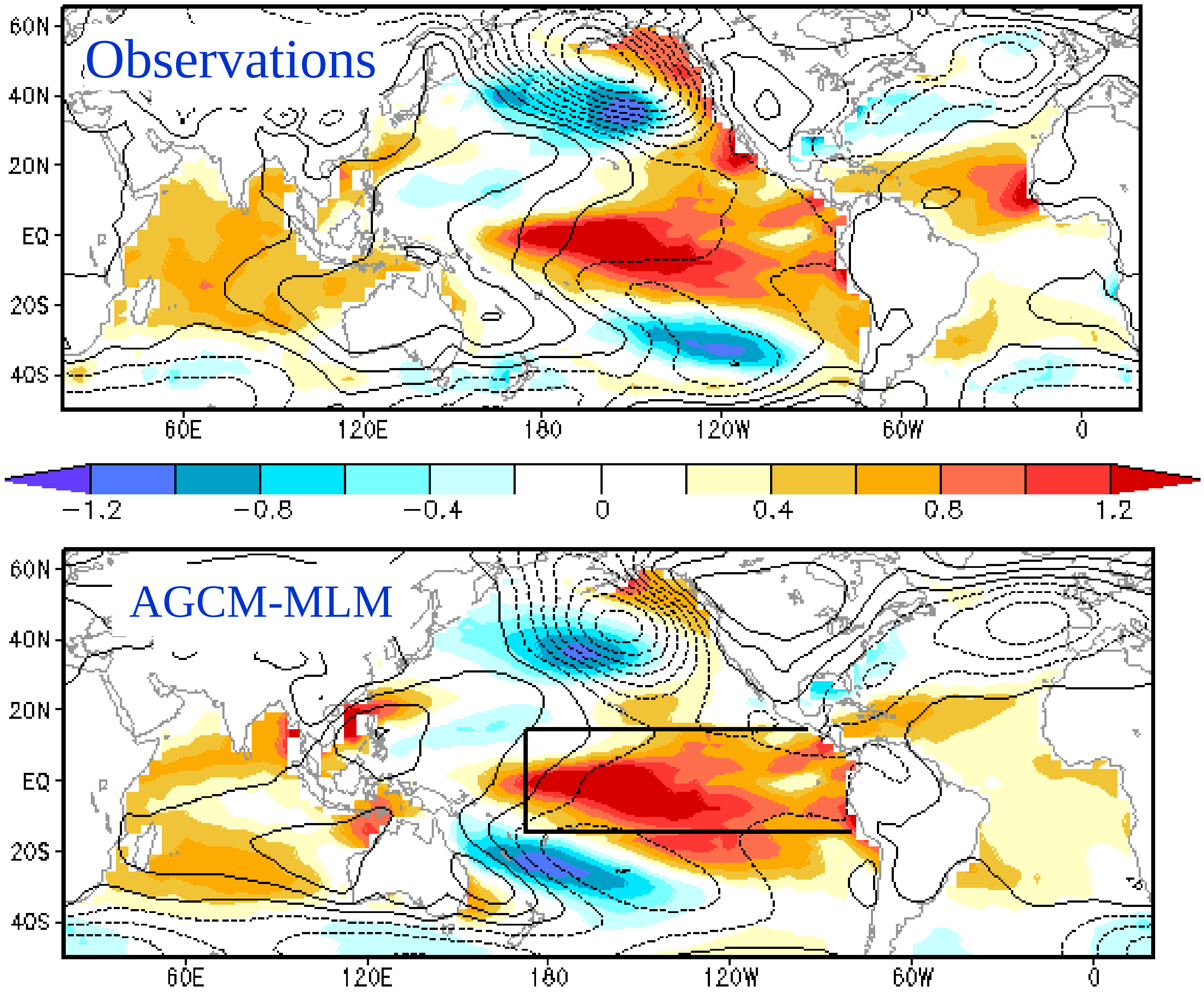


Large Zooplankton: 1977-88 - 1970-76 (shaded); 1977-88 (contours)



El Niño – La Niña Composite:

DJF SLP Contour (1 mb); FMA SST (shaded ºC)



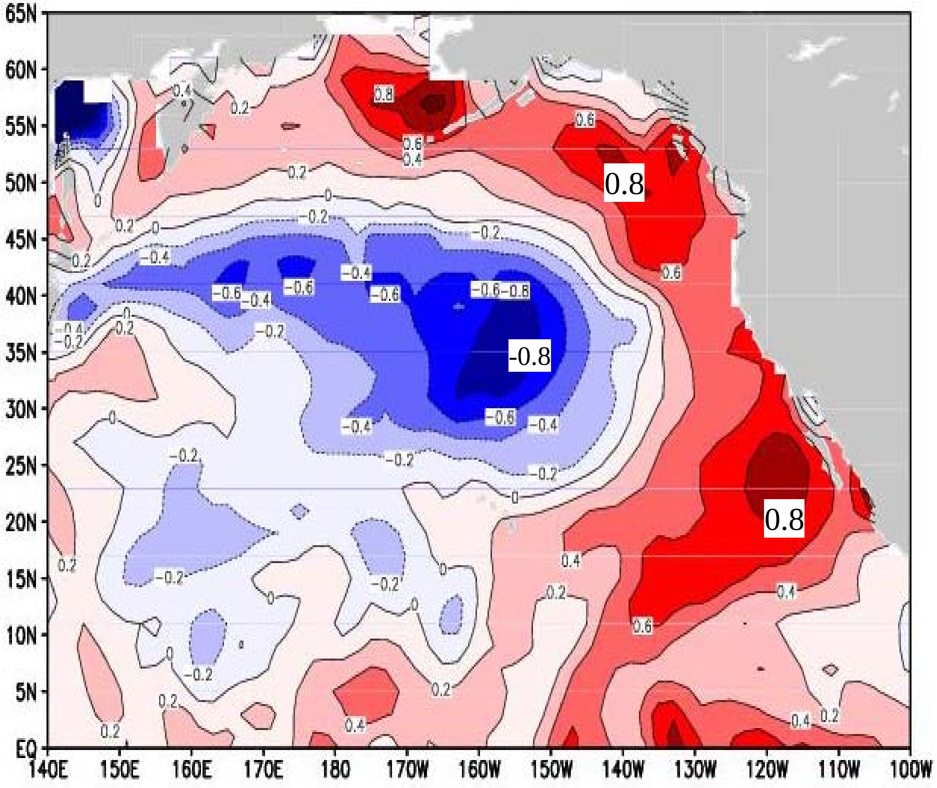
Climate shifts and sea lions populations?

- Number of Steller sea lions dropped from 200,000-20,000 from 1970-1990
- Corresponded to a change in North Pacific Climate in the mid 1970s'
- Change in climate => sea lions through the food web
- Physics, Changes in:
  - MLD,
  - near-shore currents,
  - ocean eddies

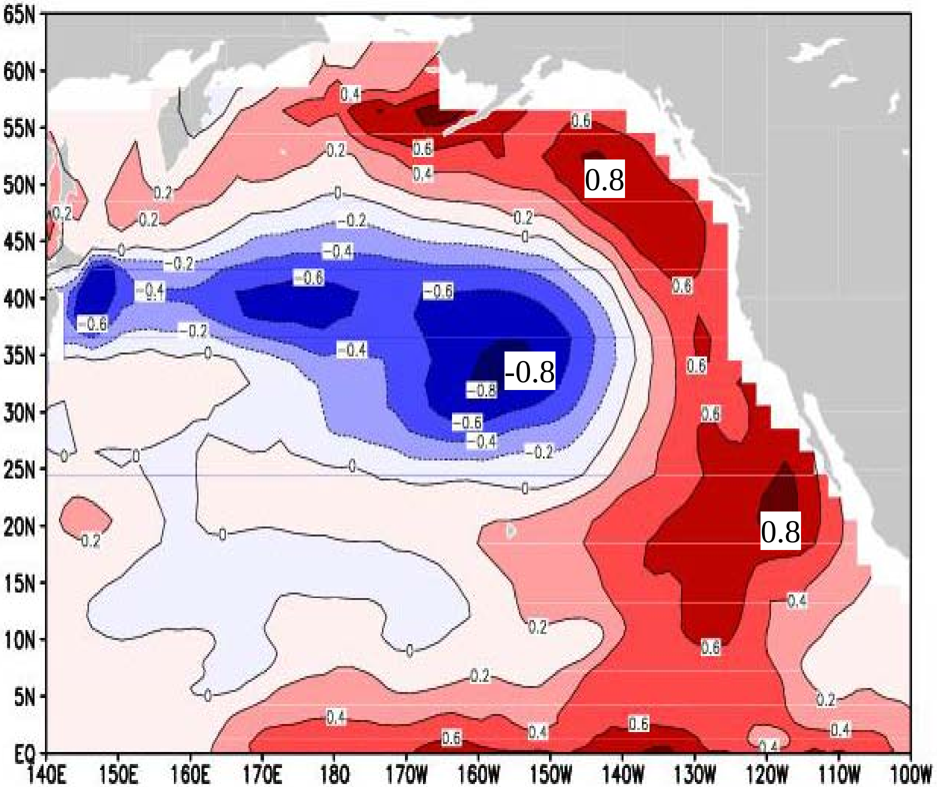
Epoch SST difference

SST (°C) 1977_98 - 1960_76 FMA

Observations (COADS)



Model: NCAR OGCM



Ocean General Circulation Model (OGCM)
Observed Atmospheric Boundary values 1960-1999