Modeling North Pacific O_2 changes

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- *Motivation: Why O_2? Why North Pacific?*
- *Validation: Model vs. Data*
- *Attribution: Biology vs. Physics*
- *Questions, Conclusions, Caveats*

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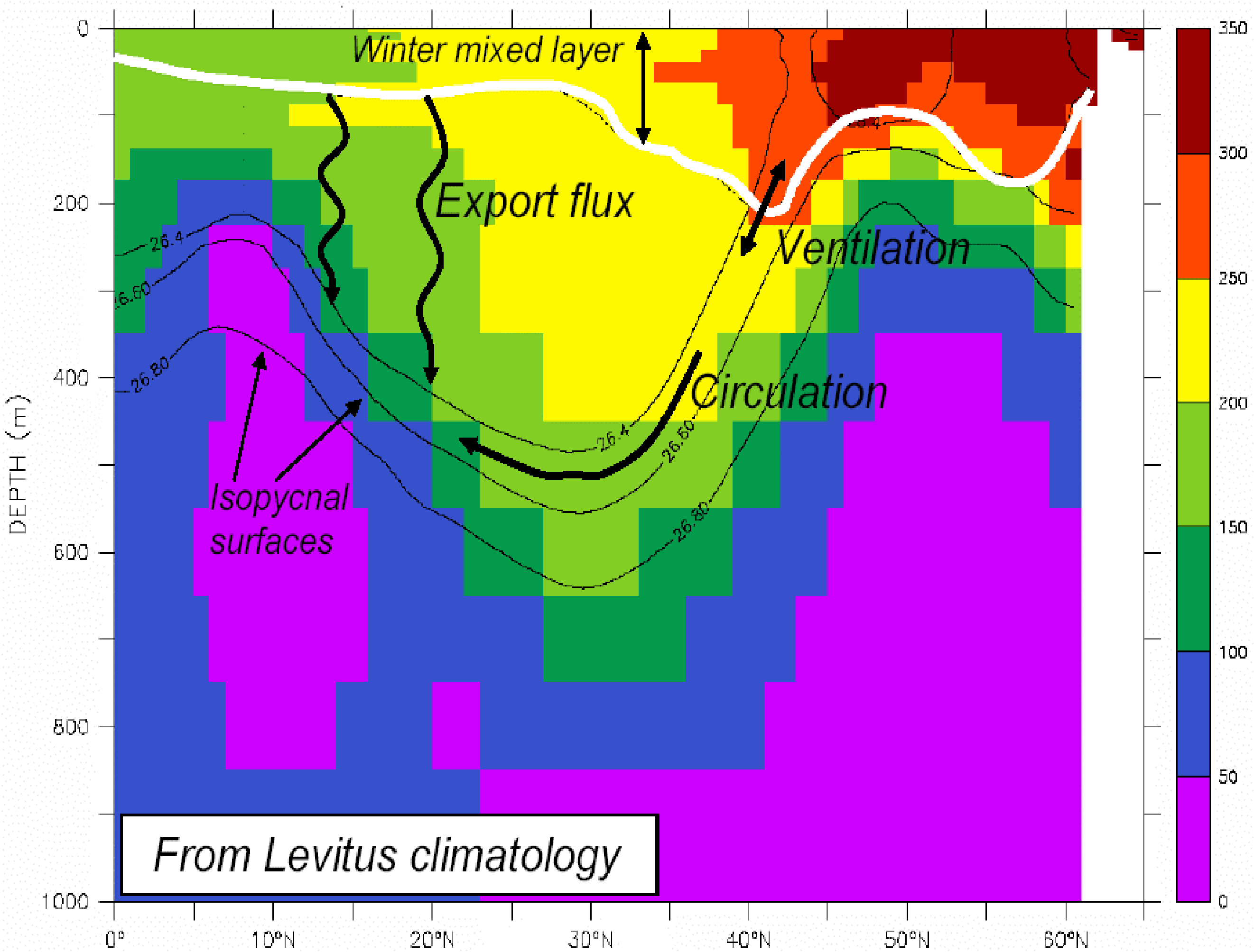
Motivation

Oxygen is a tracer of both physical and biological changes



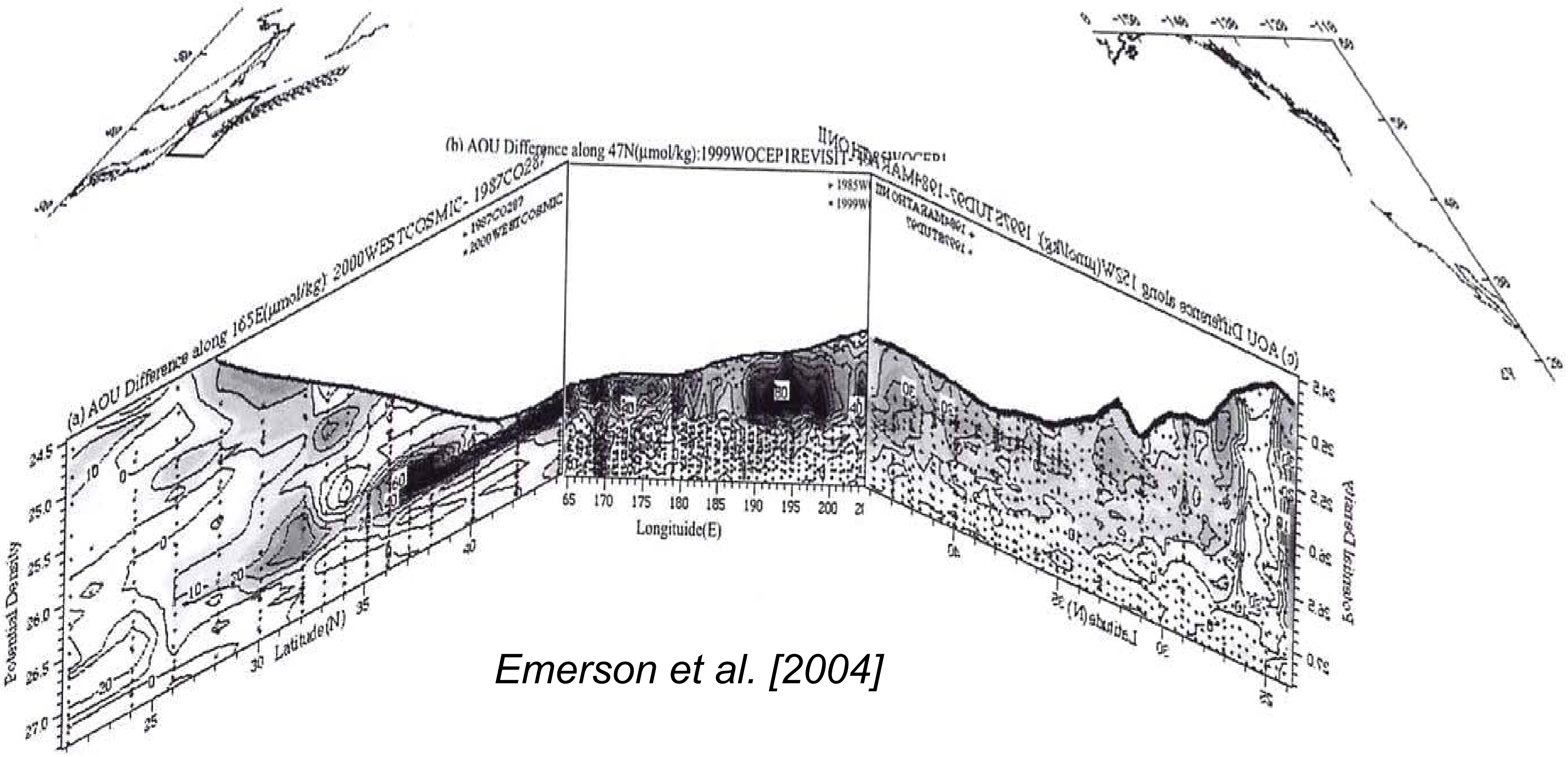
Apparent
Oxygen
Utilization

$AOU = O_2^{sat} - O_2$

$\Delta O_2 = \Delta O_2^{sat} - \Delta AOU$

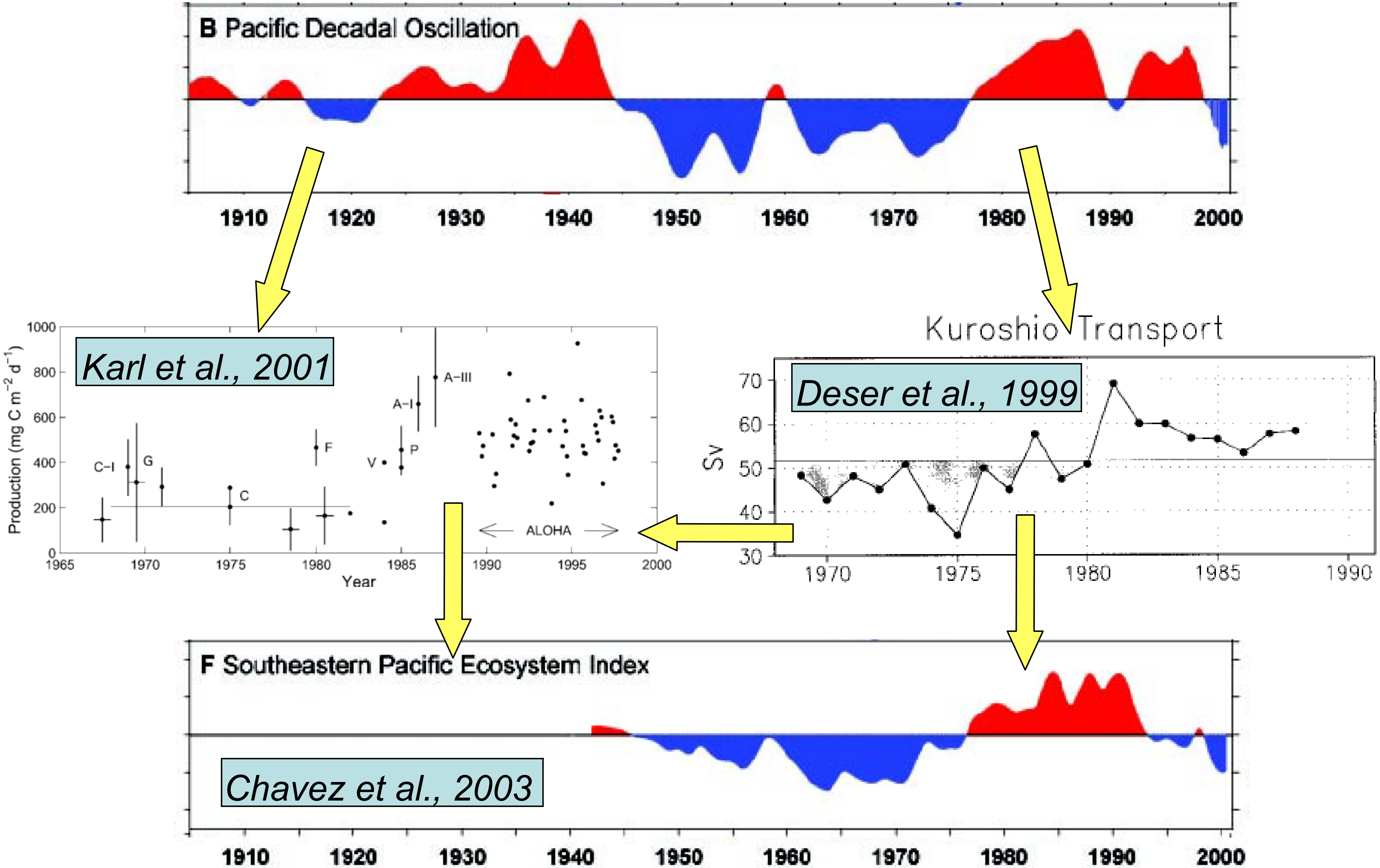
North Pacific O_2 changes

Oxygen has been accurately and widely measured for several decades, allowing changes to be detected.



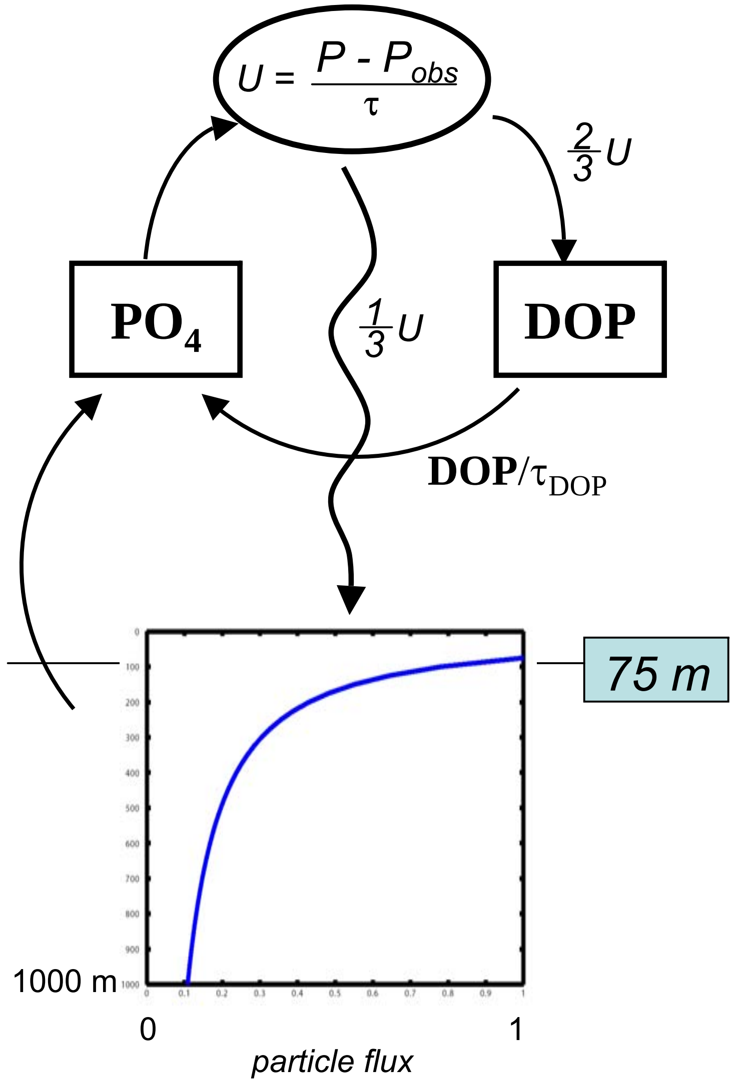
Emerson et al. [2004]

Physical-Biological connections?

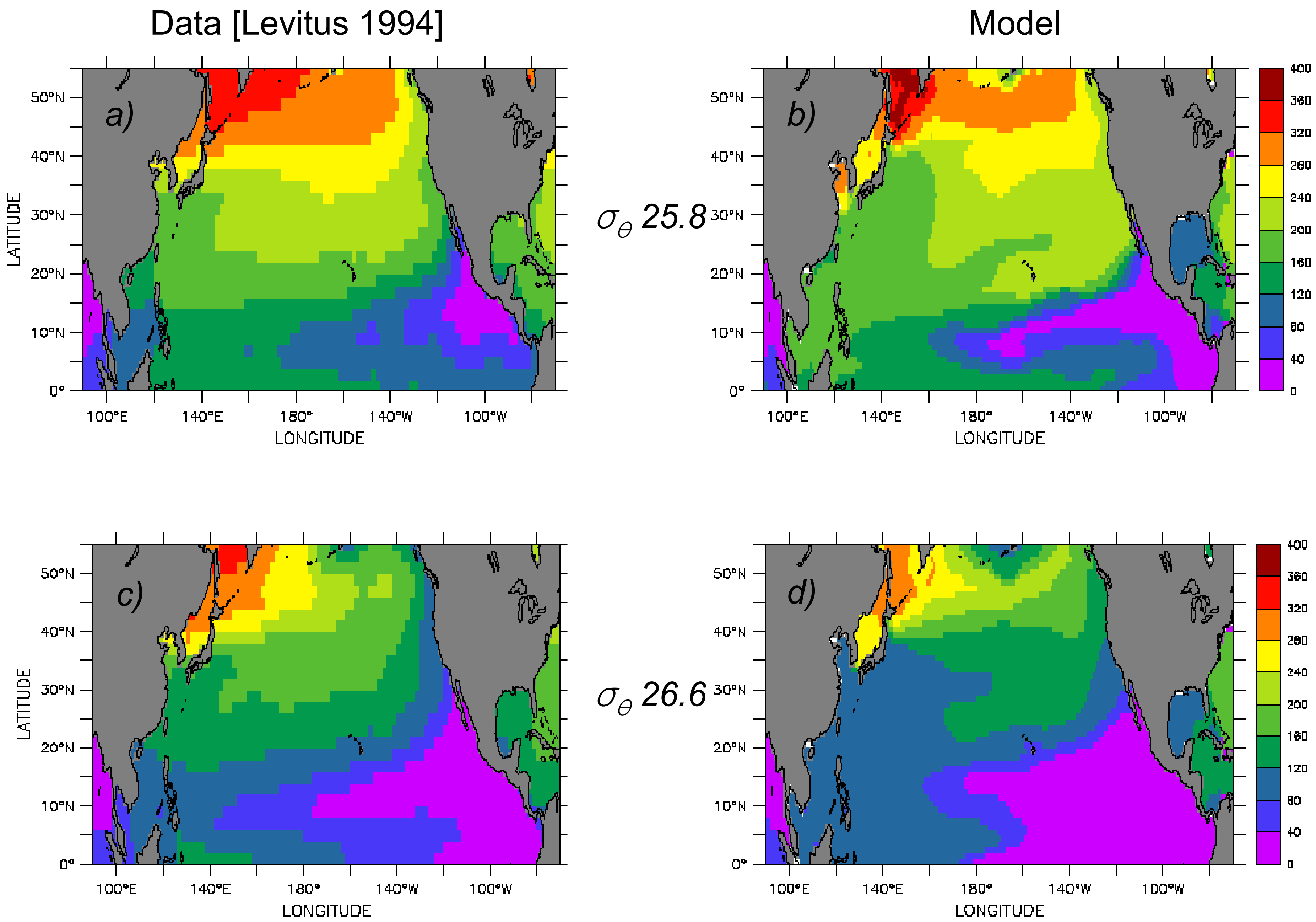


Biogeochemical GCM

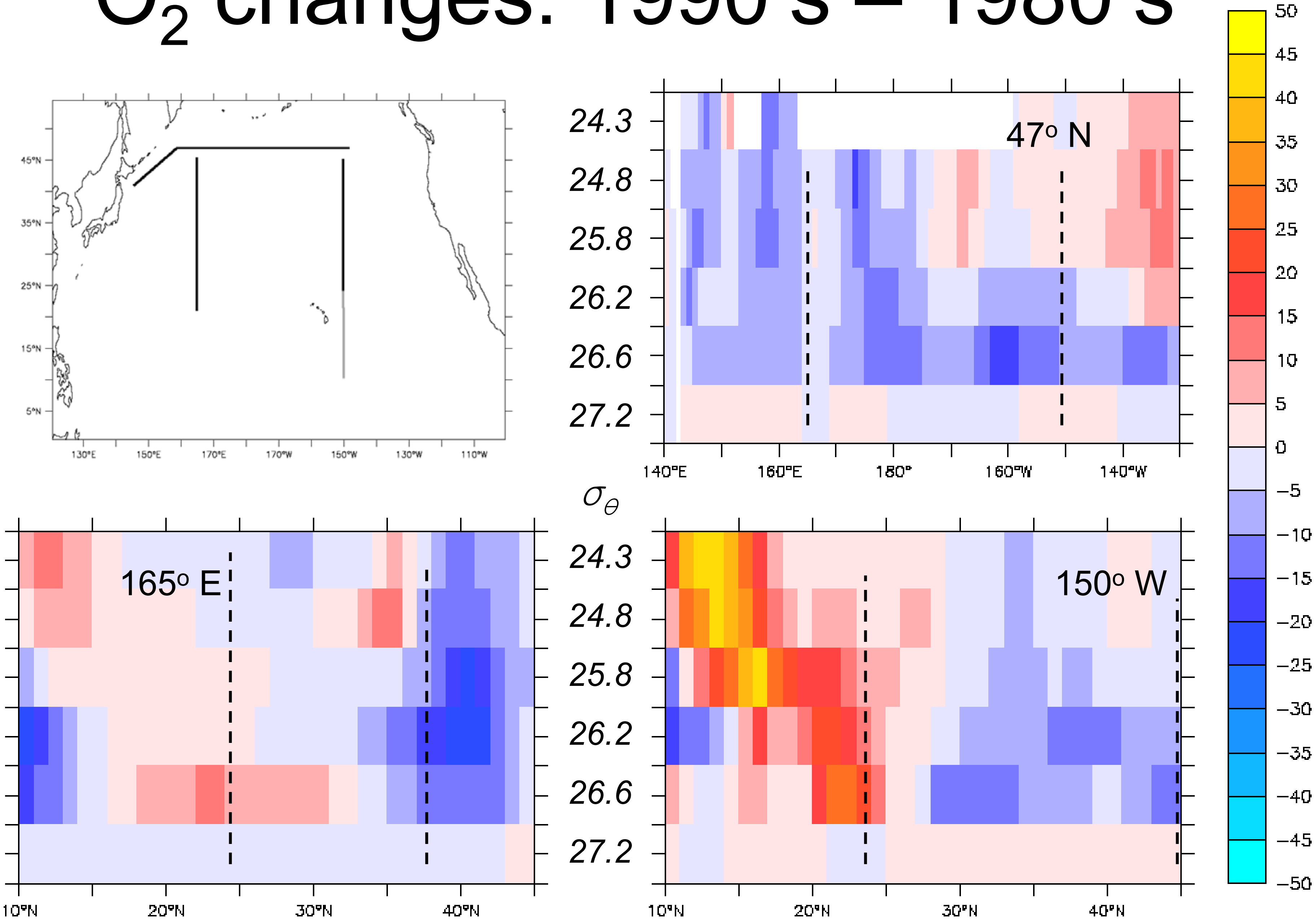
- Isopycnal GCM (HIM)
  - North Pacific domain (20°S – 60°N)
  - 1° resolution, 14 layers + mixed layer
  - Offline tracer advection/diffusion
- Historical atmospheric forcing
  - NCEP, 1948-2000
  - Winds, Temp only (no salinity change)
- OCMIP protocol
  - surface PO_4 restoring
  - "Martin curve" remineralization
  - DOP with a 1-year half-life
  - constant O_2:P stoichiometry (170:1).
- O_2 set to saturation in mixed layer



Annual Mean Oxygen

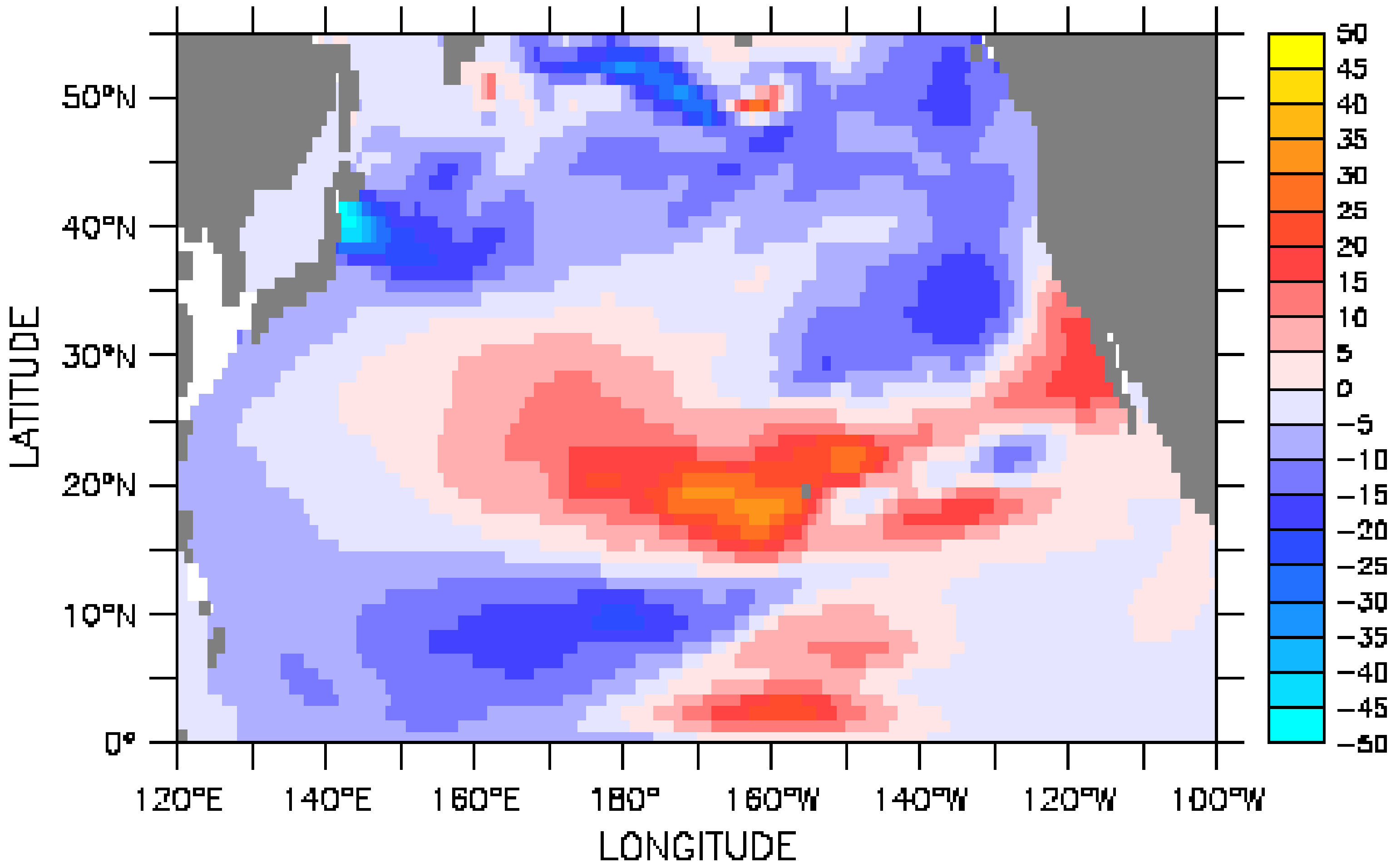


O_2 changes: 1990's – 1980's



O_2 changes: σ_Θ 26.6

1990's – 1980's



Finding Fingerprints

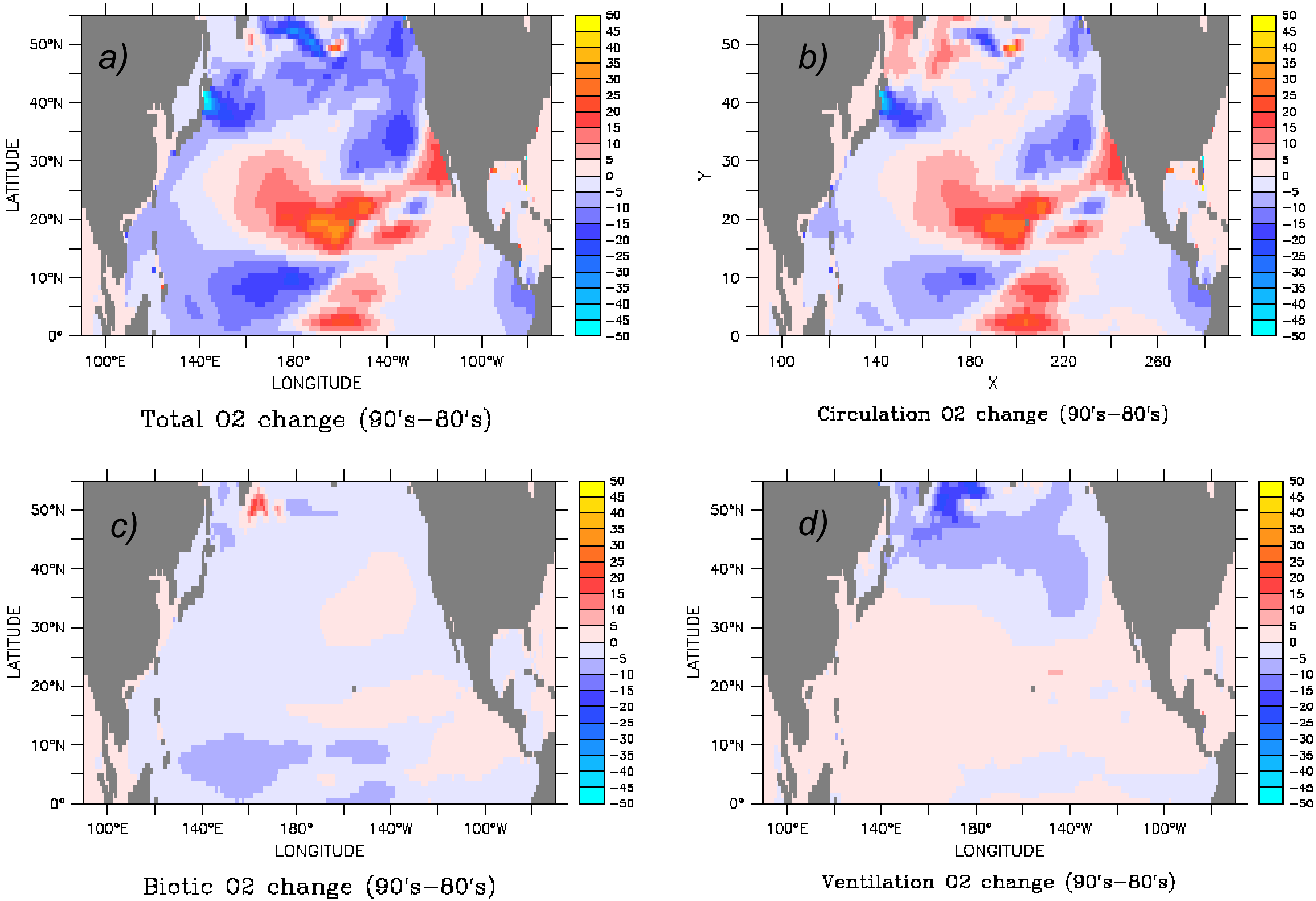
$$AOU = AOU_o - \blacksquare\ OUR * \frac{d\vec{s}}{v}$$

$$\Delta AOU = \underbrace{\Delta AOU_o}_{} - \underbrace{\Delta OUR*circ}_{} - \underbrace{OUR*\Delta circ}_{}$$

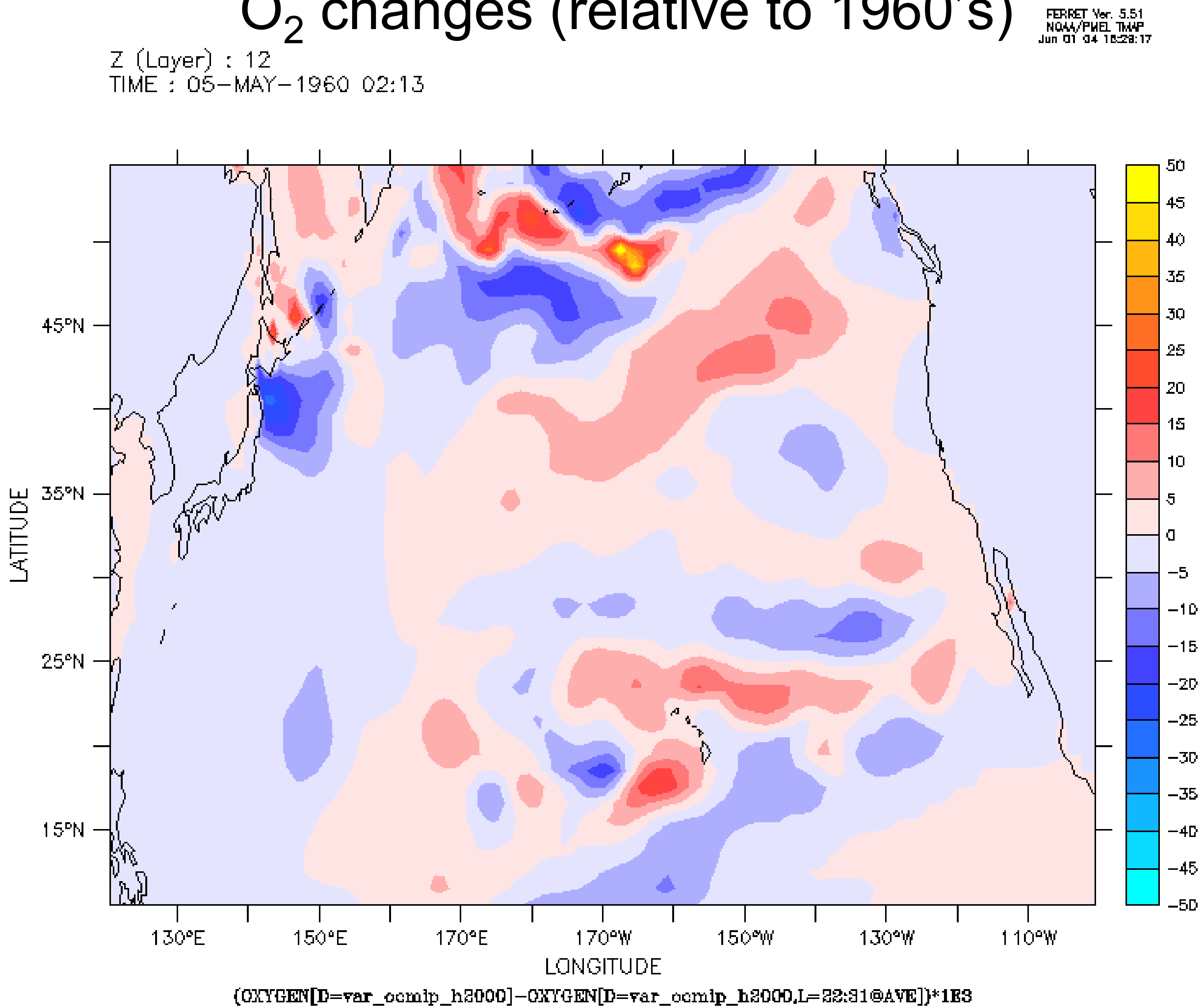
$$= \Delta AOU_{vent} + \Delta AOU_{bio} + \Delta AOU_{circ}$$

Experiment	AOU changes present
1) Total variability	$\Delta AOU_1 = \Delta AOU_{vent} + \Delta AOU_{bio} + \Delta AOU_{circ}$
2) Constant OUR	$\Delta AOU_2 = \Delta AOU_{vent} + \cancel{\Delta AOU_{bio}} + \Delta AOU_{circ}$
3) Constant OUR + constant AOU_o	$\Delta AOU_3 = \cancel{\Delta AOU_{vent}} + \cancel{\Delta AOU_{bio}} + \Delta AOU_{circ}$

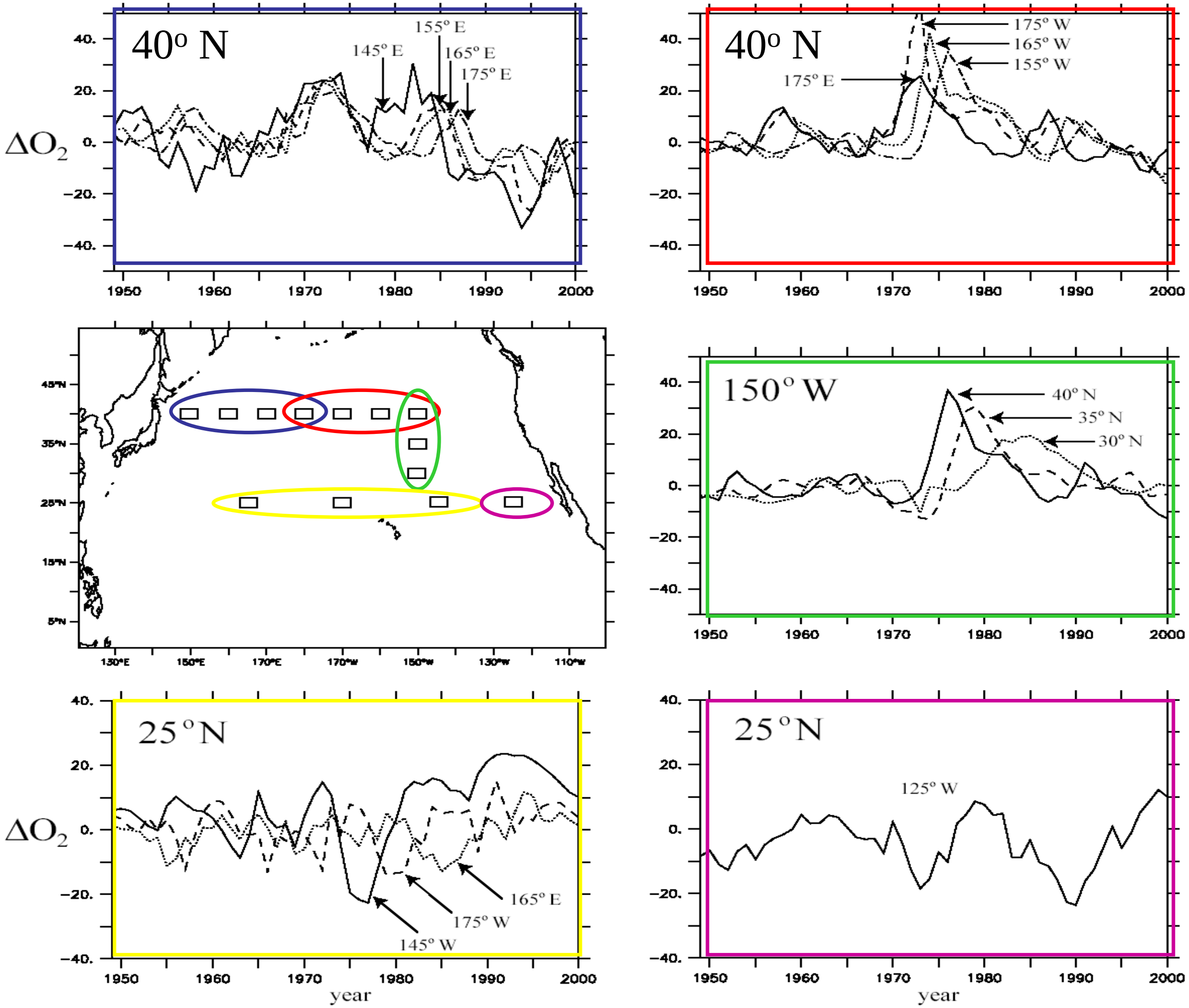
Causes of oxygen change (1990's-1980's) σ_θ 26.6



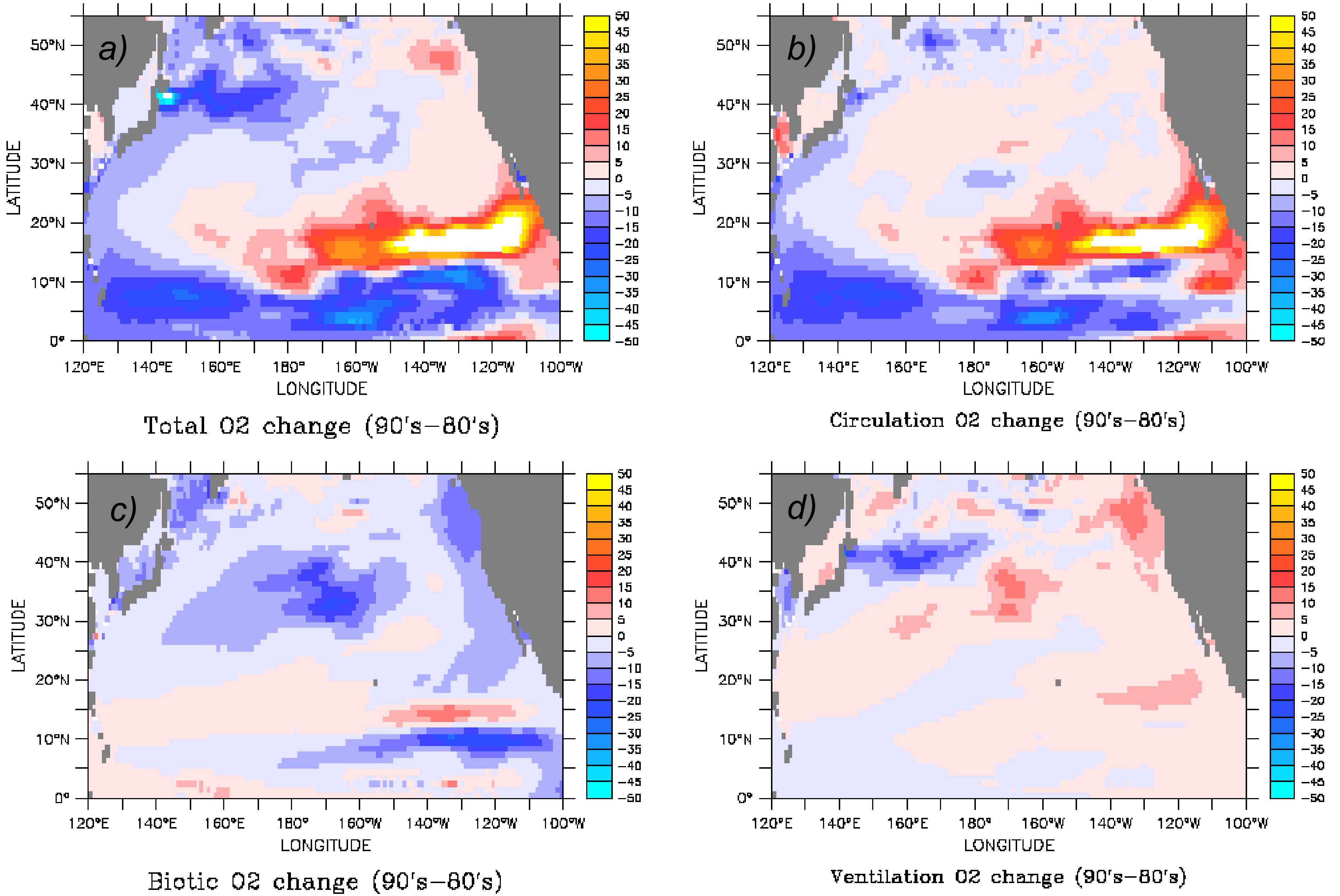
O_2 changes (relative to 1960's)



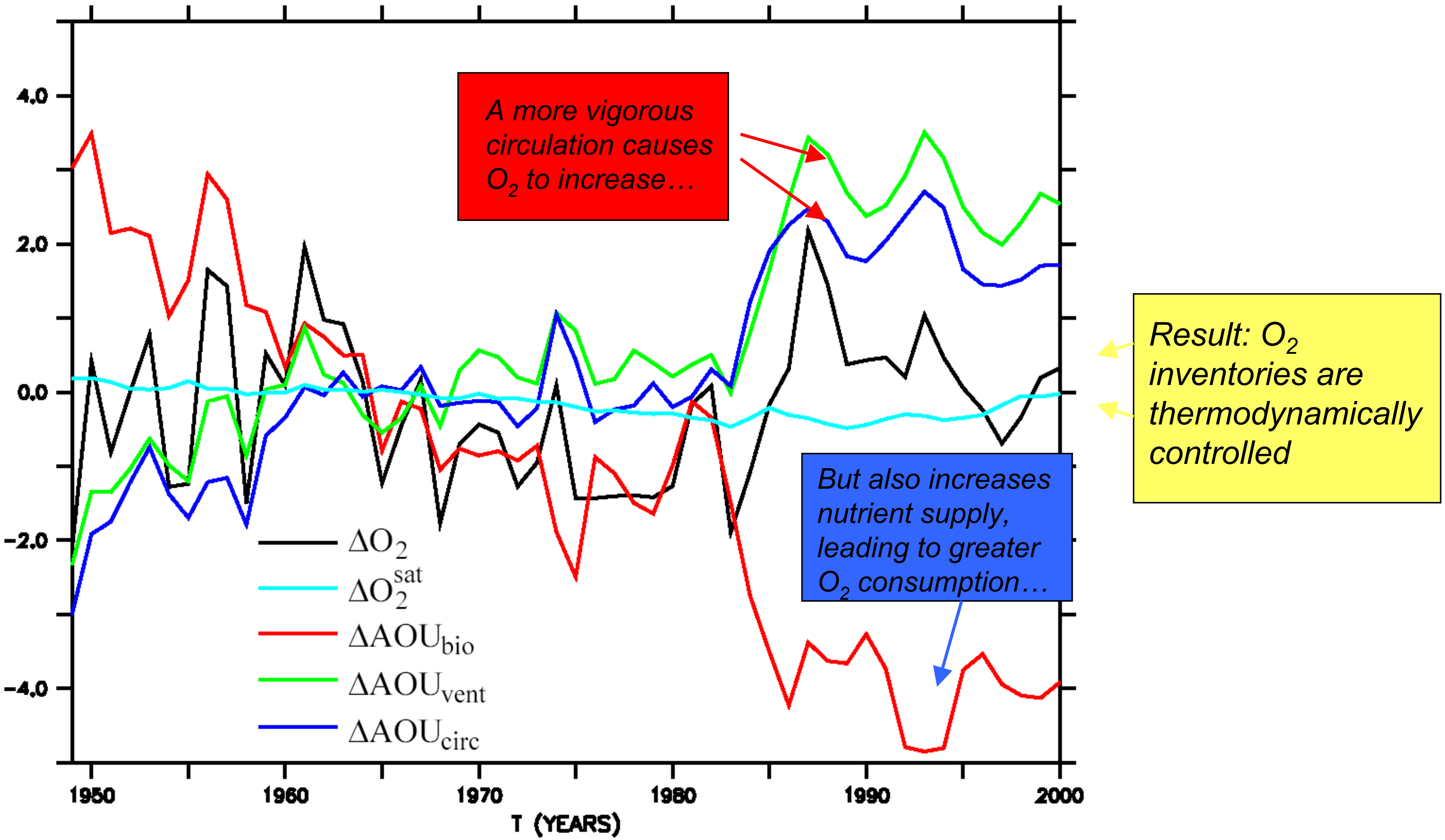
ETNP and Kuroshio Extension: Engines of O_2 variability



Causes of oxygen change (1990's-1980's) σ_θ 25.8



Integrated O_2 changes



Conclusions

- A hind cast model of the North Pacific with simple biogeochemistry captures many of the observed AOU/O_2 changes in the thermocline over the past few decades.

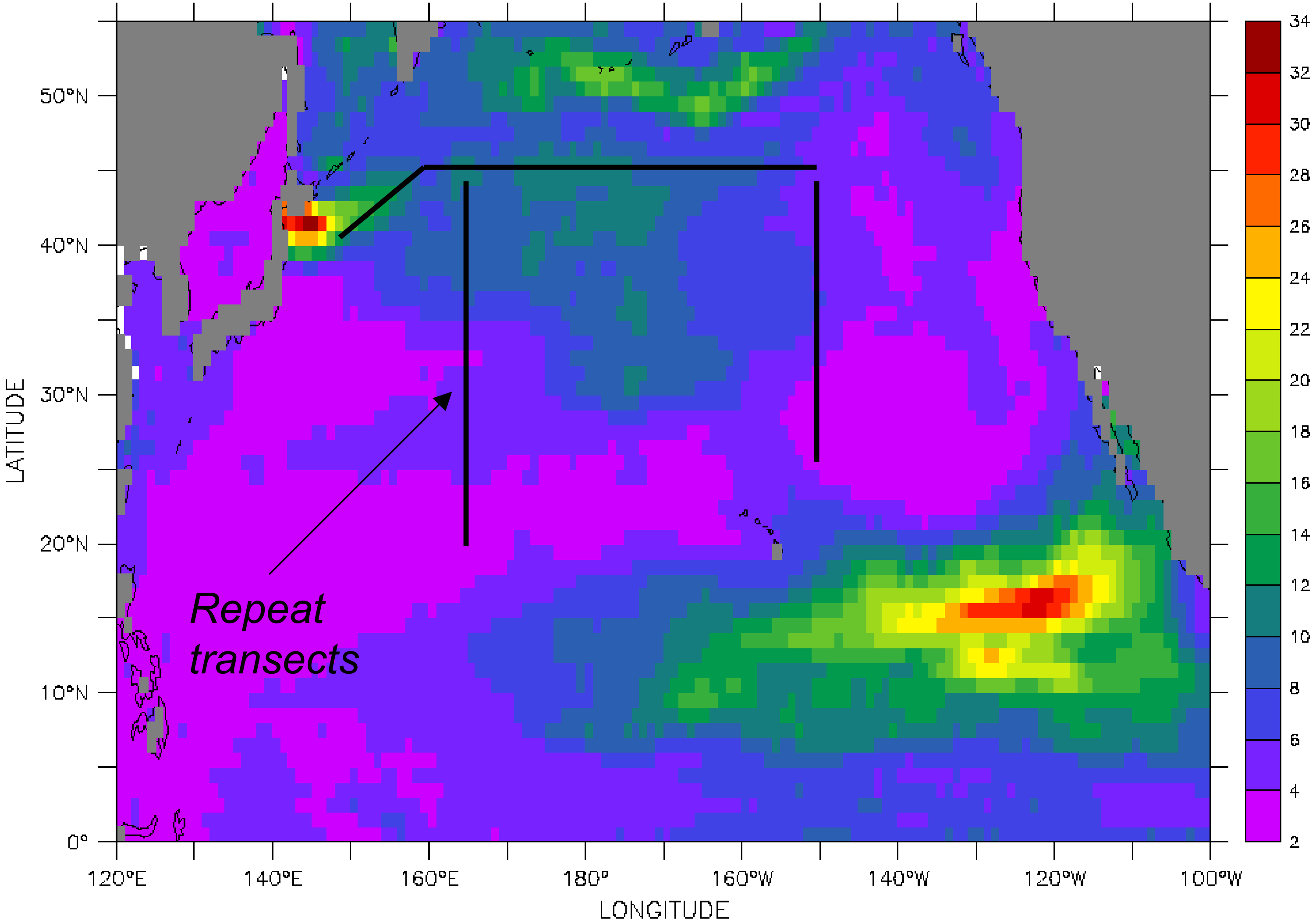
- Circulation and ventilation changes are the dominant drivers of these changes in the lower ventilated thermocline. O_2 may be a useful physical tracer in these regions.

- Simulated O_2 changes include both sustained decadal trends as well as large-scale transient anomalies that propagate across the basin.

- Physically forced overall O_2 increases are compensated by enhanced biological O_2 consumption, which contributes substantially to upper thermocline O_2 variability.

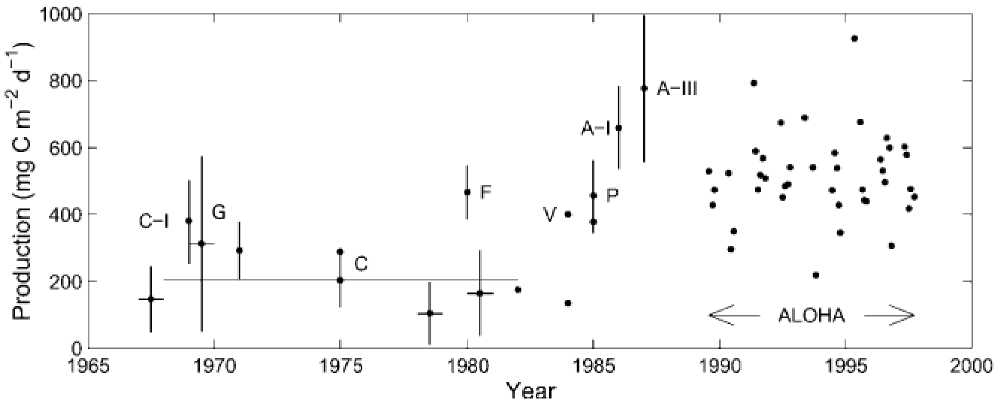
Extra material

Thermocline Oxygen Variability

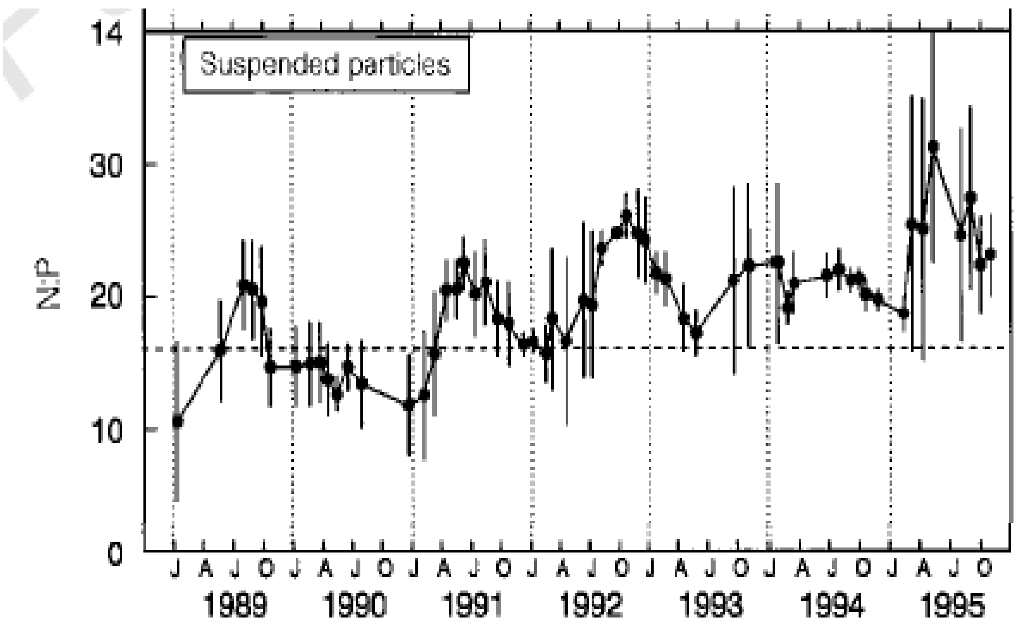


Standard Deviation of Annual Mean O2 [uM]

Biological changes



Chlorophyll concentration and ^{14}C Primary Production have increased in surface waters of the Subtropical Pacific between the1970s and 1990s (Karl et al, 2000).

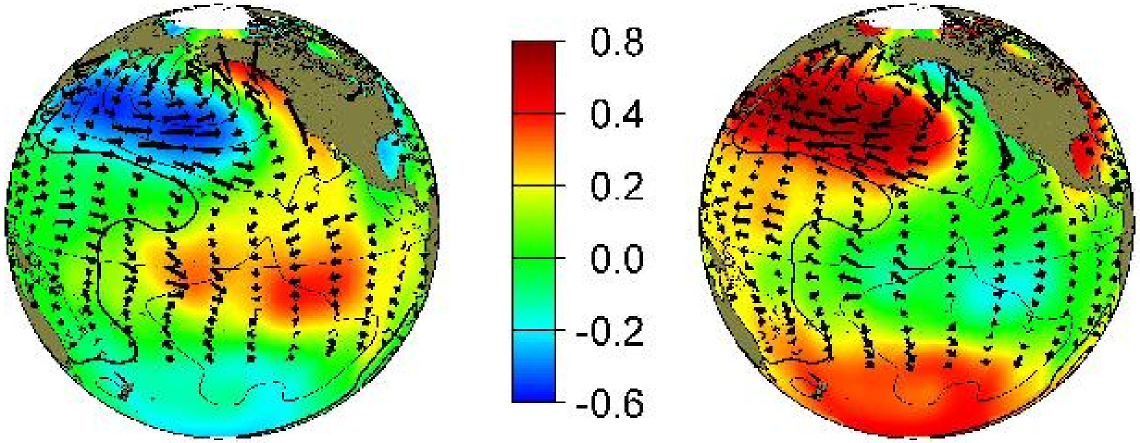


Changes in N:P stoichiometry also point to an increase in N_2 fixation in recent decades, with significant implications for the biological pump in the subtropical Pacific (Karl et al., 1997, 2002)

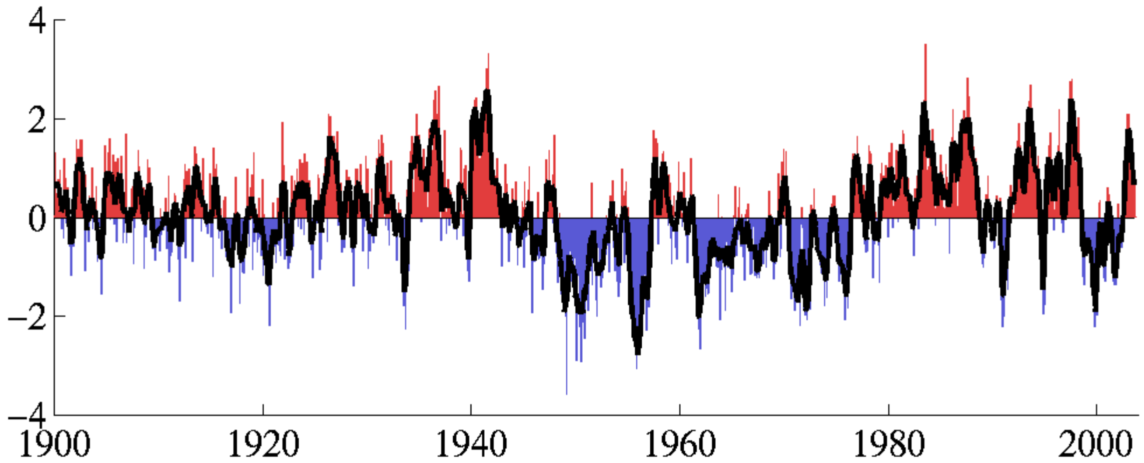
Physical variability: surface

THE PACIFIC DECADAL OSCILLATION

The PDO is a spatial pattern of SST variability.



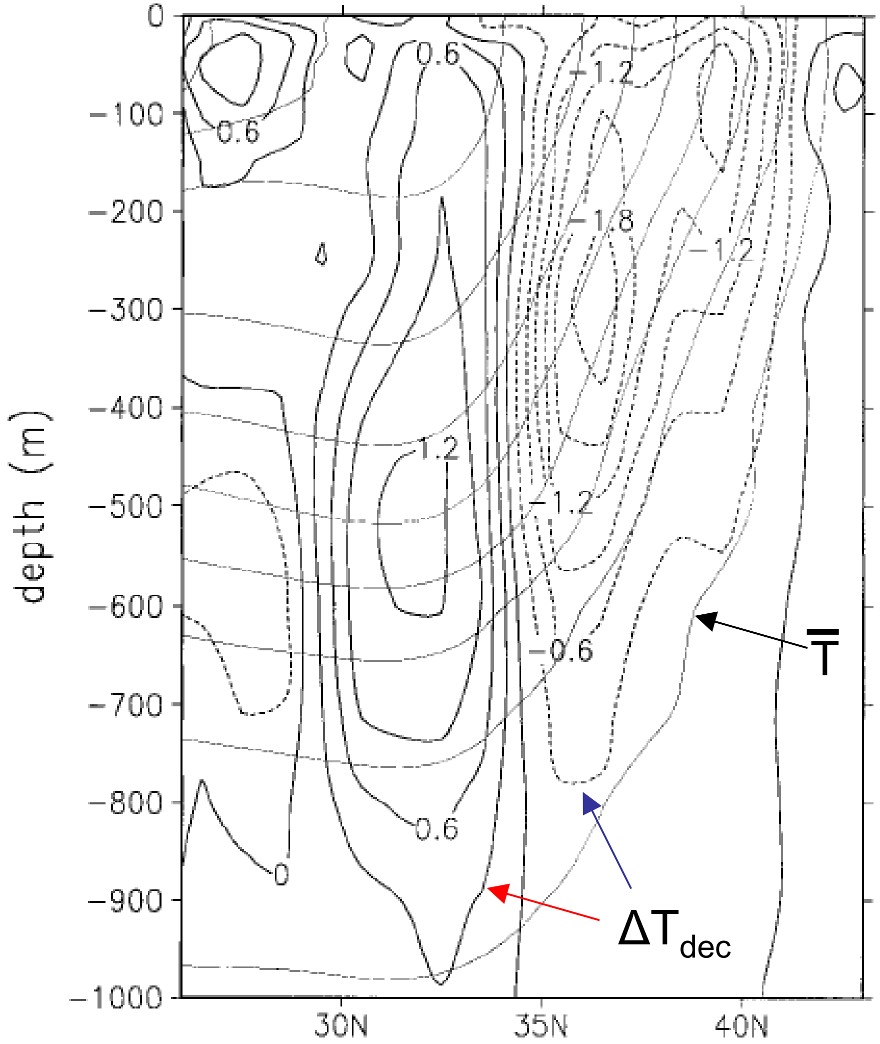
The pattern oscillates with a period of a few decades.



From http://tao.atmos.washington.edu/pdo

Physical variability: thermocline

Surface variability propagates into the thermocline, altering large-scale features of the circulation, like an intensified Kuroshio current in the 1980's.



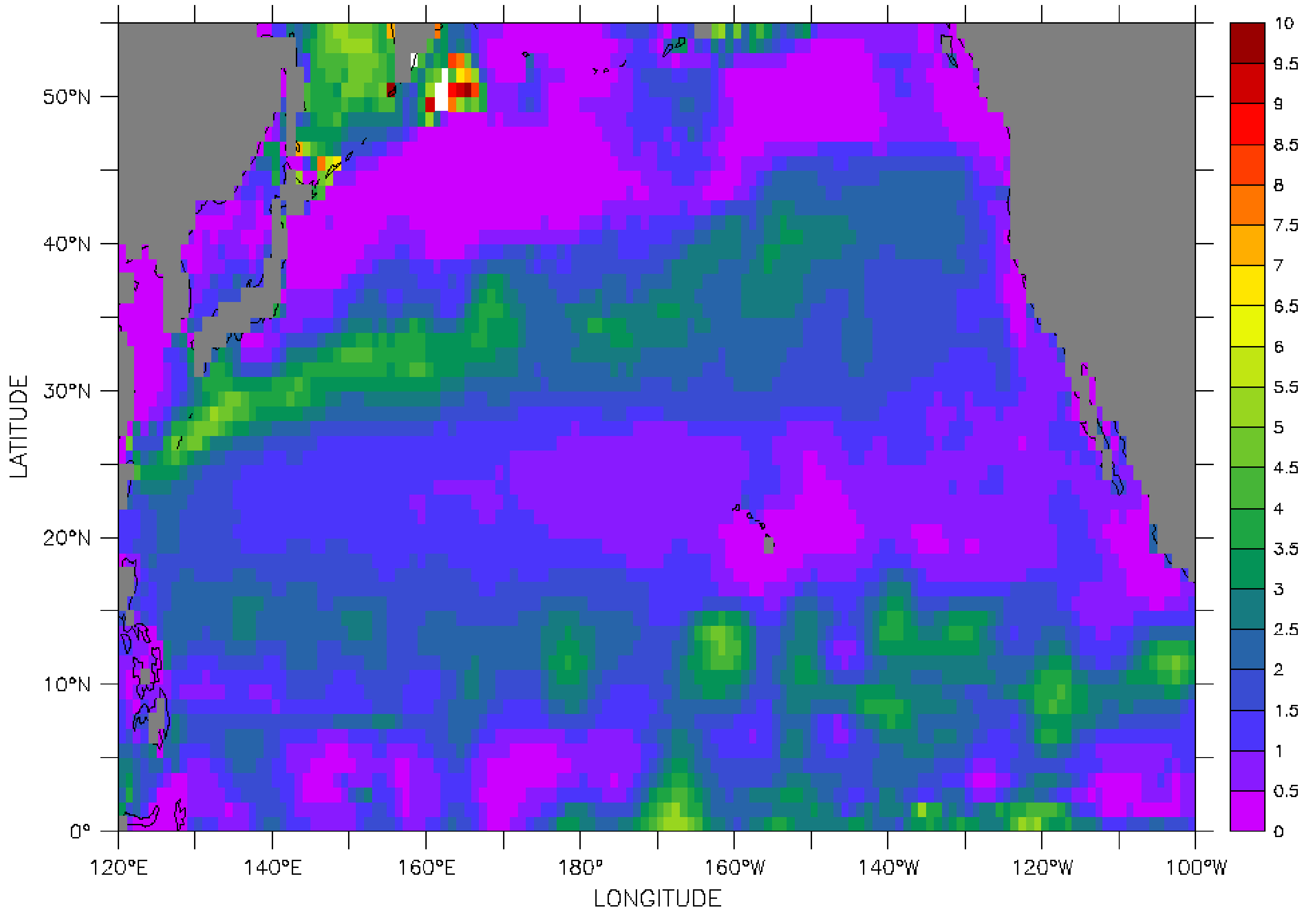
from Deser et al., 1999

Physical Model

- Isopycnal coordinate (Hallberg Isopycnal Model)
- North Pacific domain (20^oS – 60^oN, with sponges)
- 1 degree horizontal resolution
- 14 isopycnal layers + Kraus Turner mixed layer
- → Historical atmospheric forcing (NCEP, 1948-2000)

  Temperature and wind only; salinity restoring
- Offline tracer advection/diffusion routine

Export Production

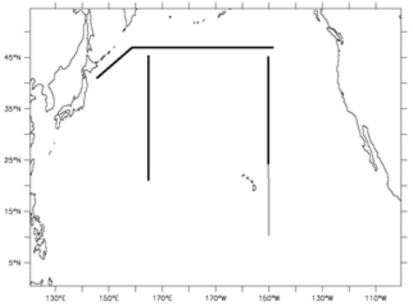


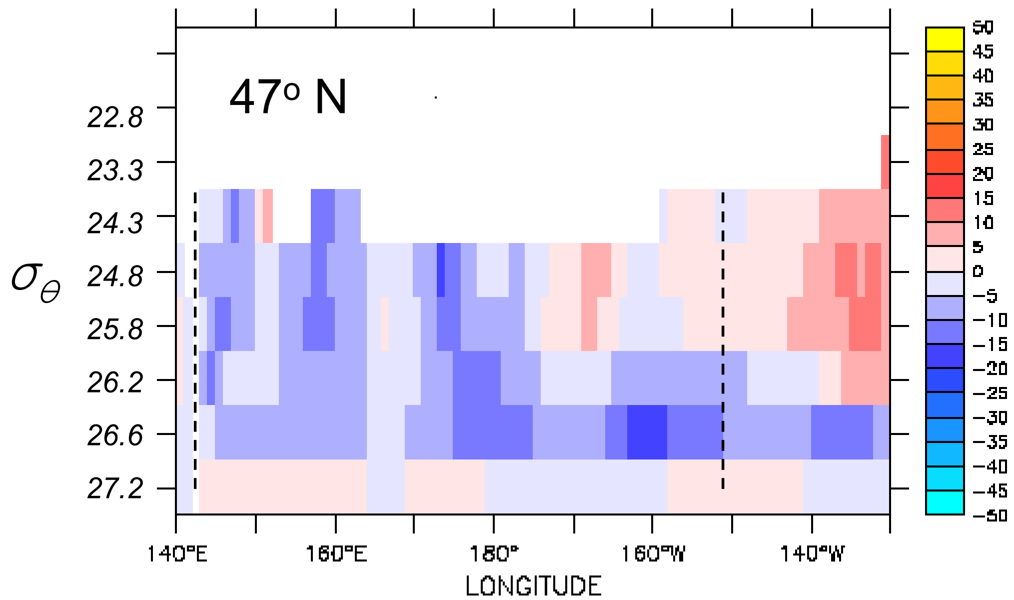
$\frac{mmol\ C}{m^2\ yr}$

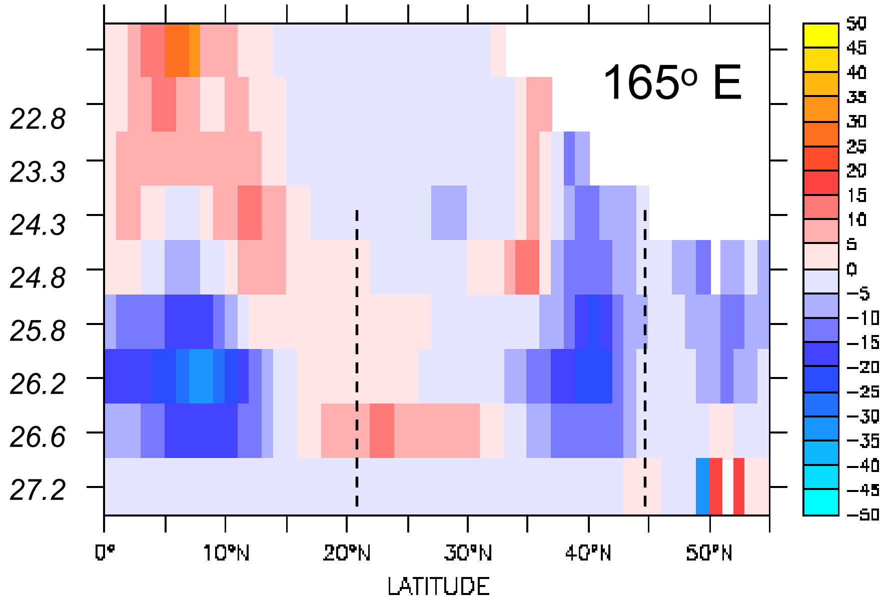
Questions and Caveats

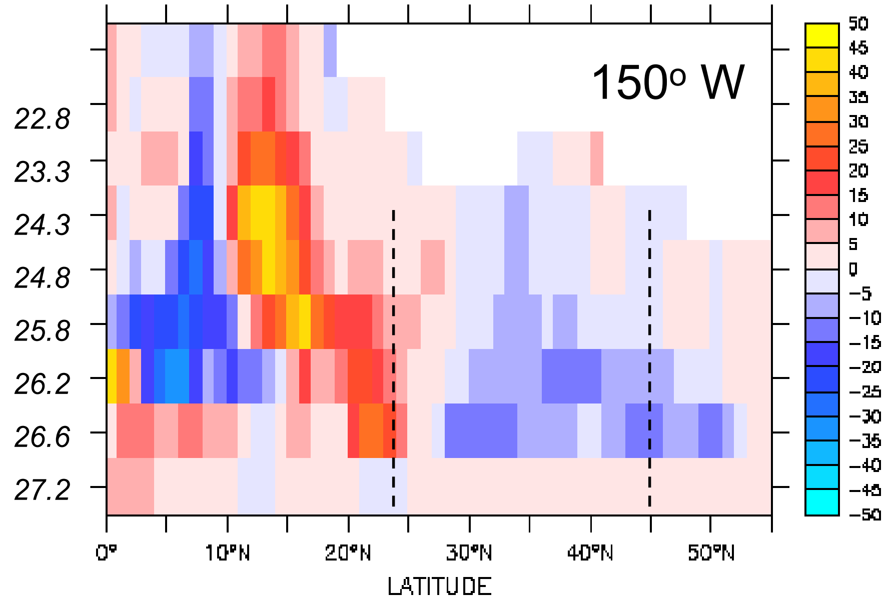
- Role for salinity forcing?
- Consequences of ETNP engine: N*
- Connecting surface/thermocline fingerprints

Model oxygen change: 1990's – 1980's

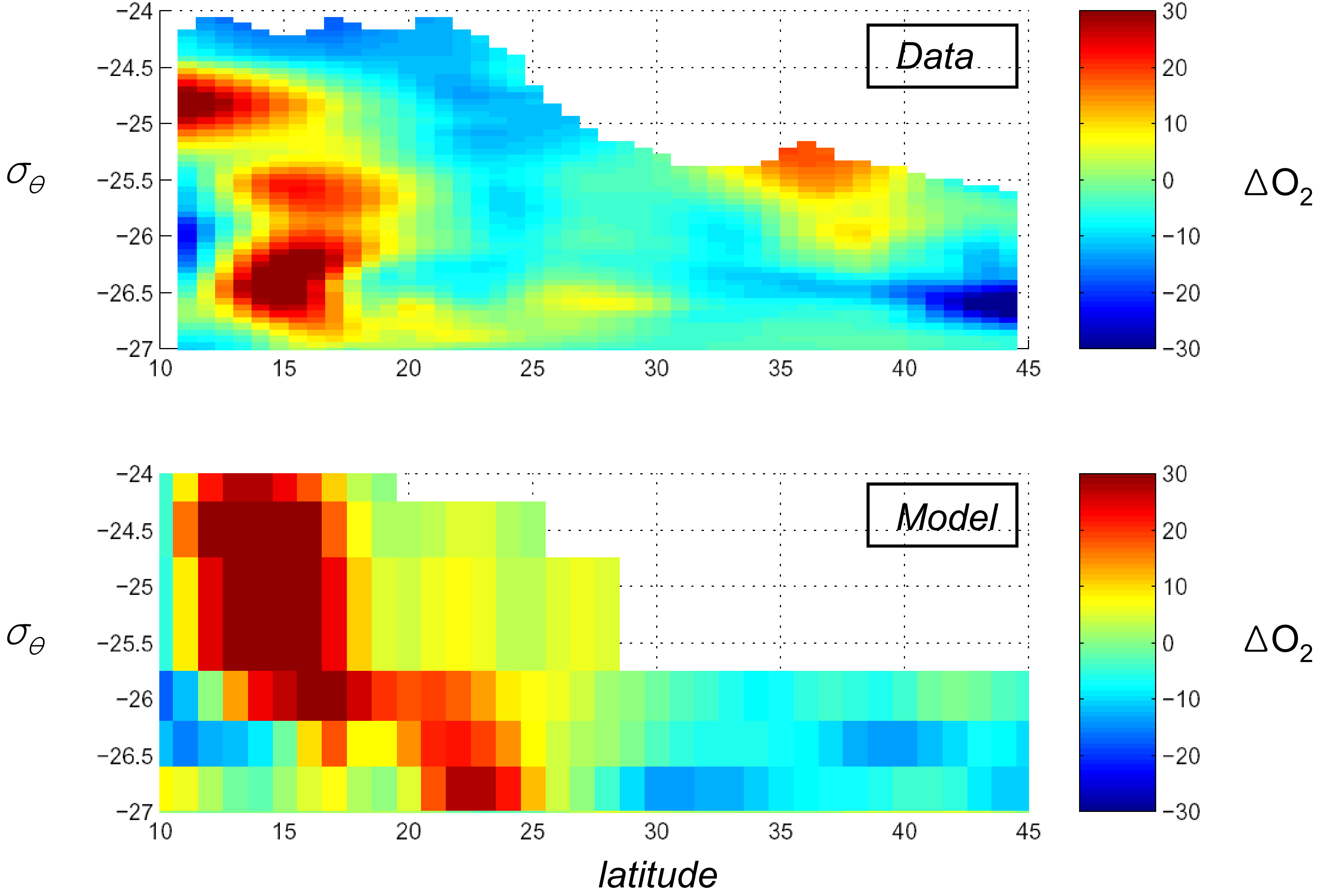






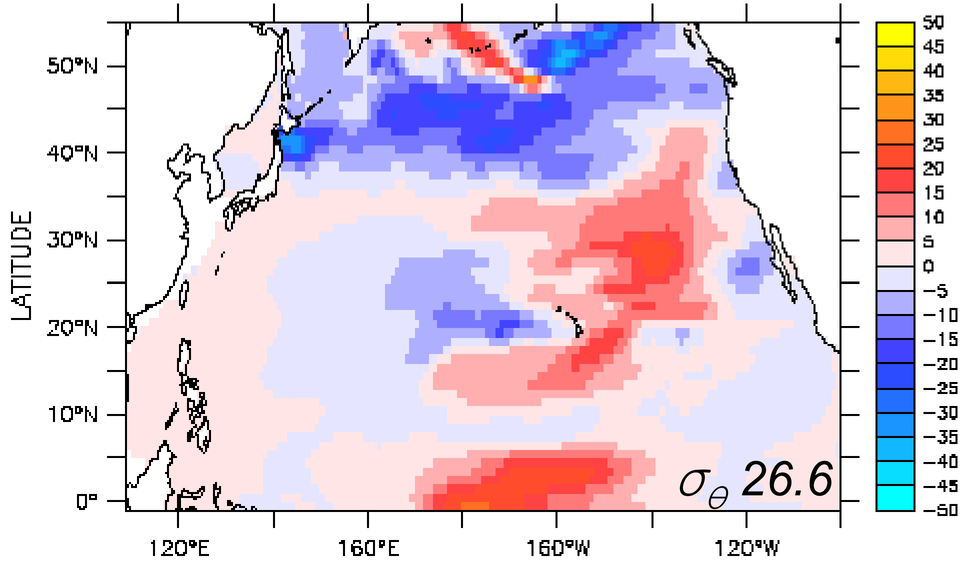


O_2 Changes: 150° W

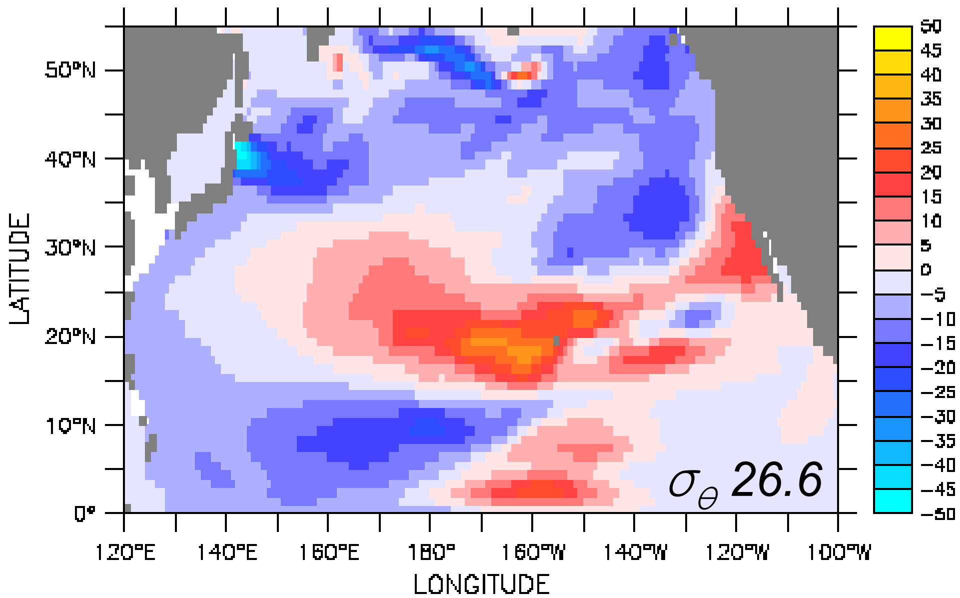


Trends vs. Transients

1980's – 1970's

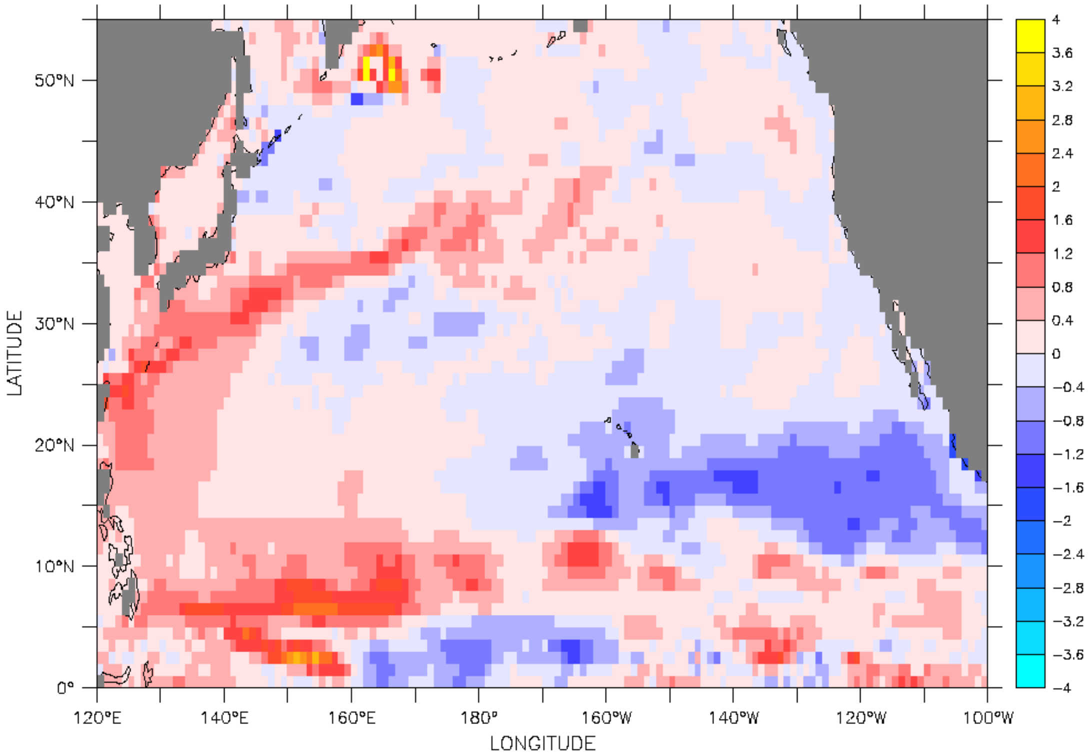


1990's – 1980's



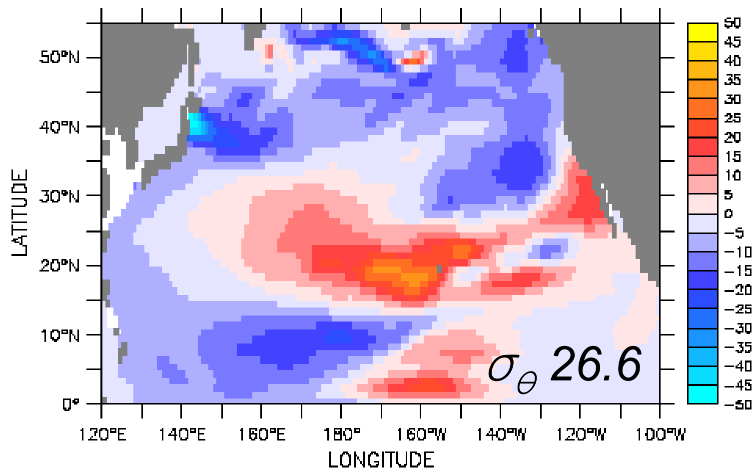
Attribution

Export flux change: 1990's – 1980's



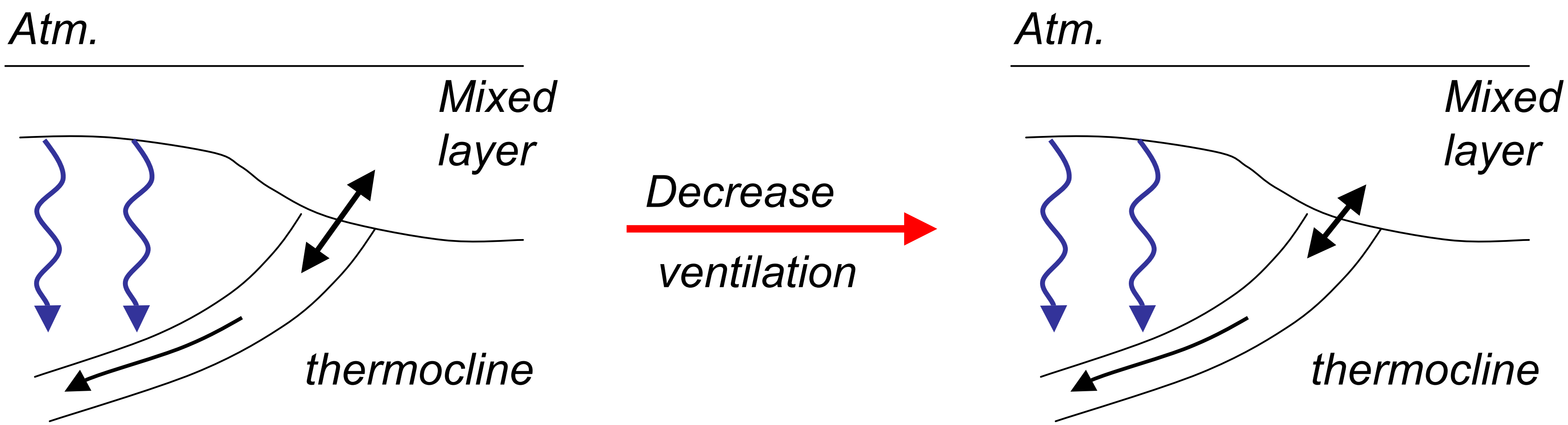
Decadal mean changes in surface export production are significant (~ 25%)…

Oxygen change: 1990's – 1980's

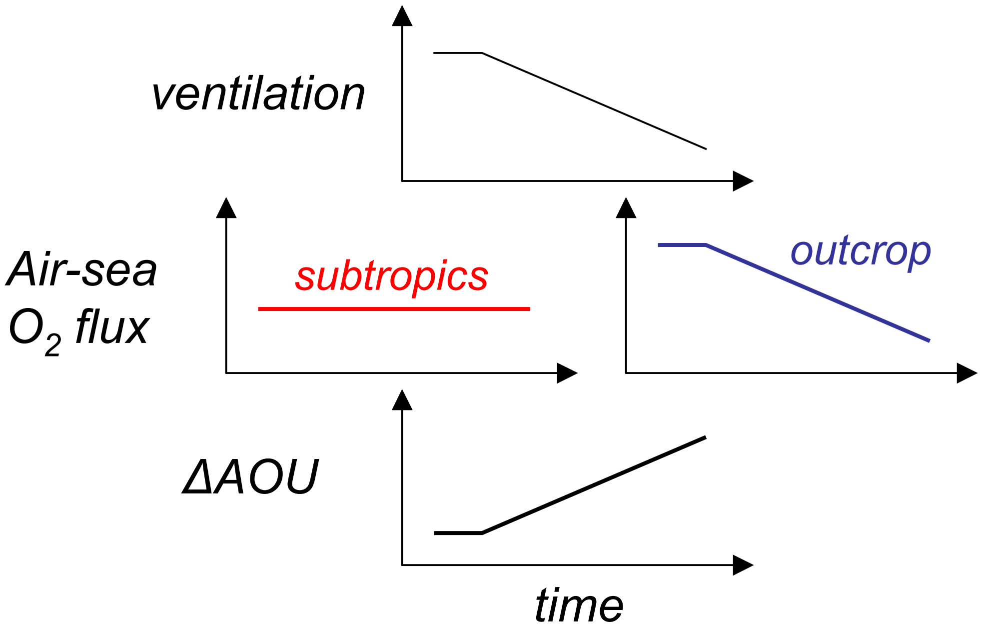


…but they bear little resemblance to subsurface oxygen changes in the lower ventilated thermocline.

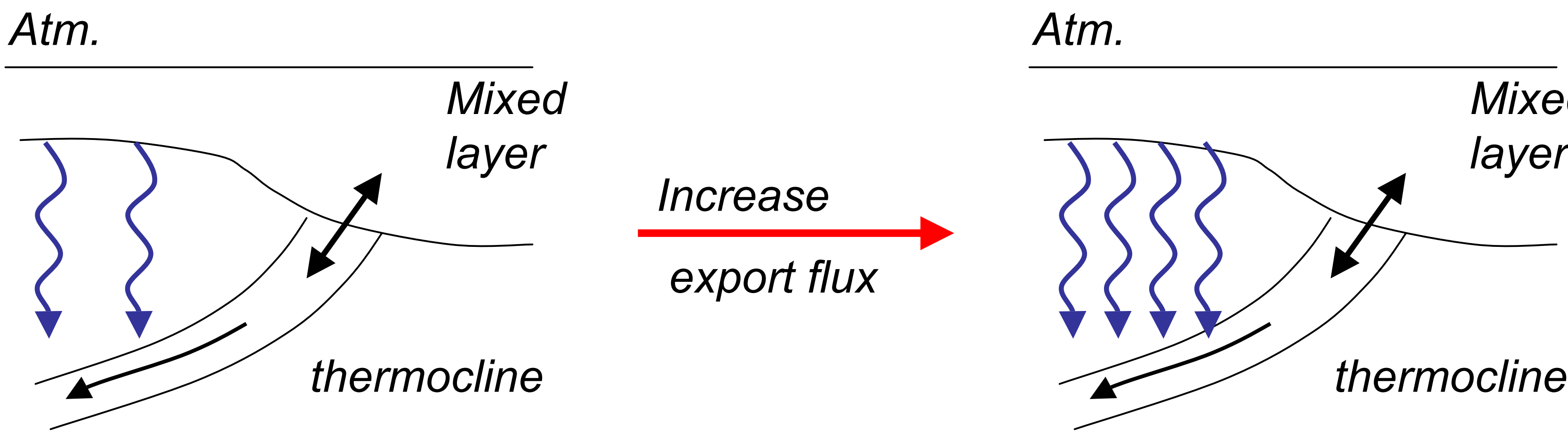
Surface fingerprints: ventilation



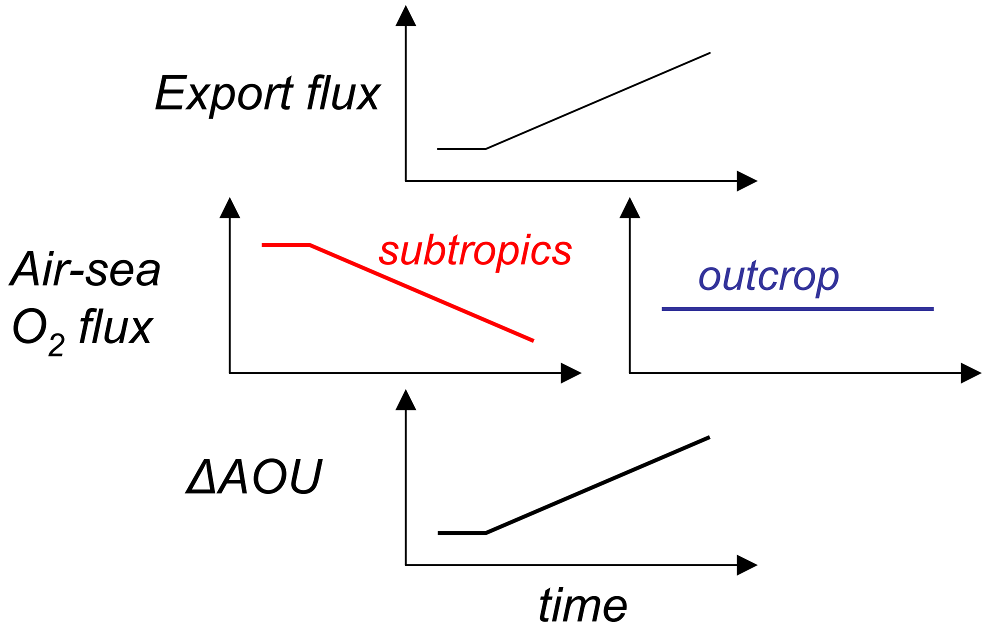
An increase in AOU due to decreased ventilation will cause changes in air-sea fluxes of both O_2 and CO_2 coincident with the ventilation change…



Surface fingerprints: export

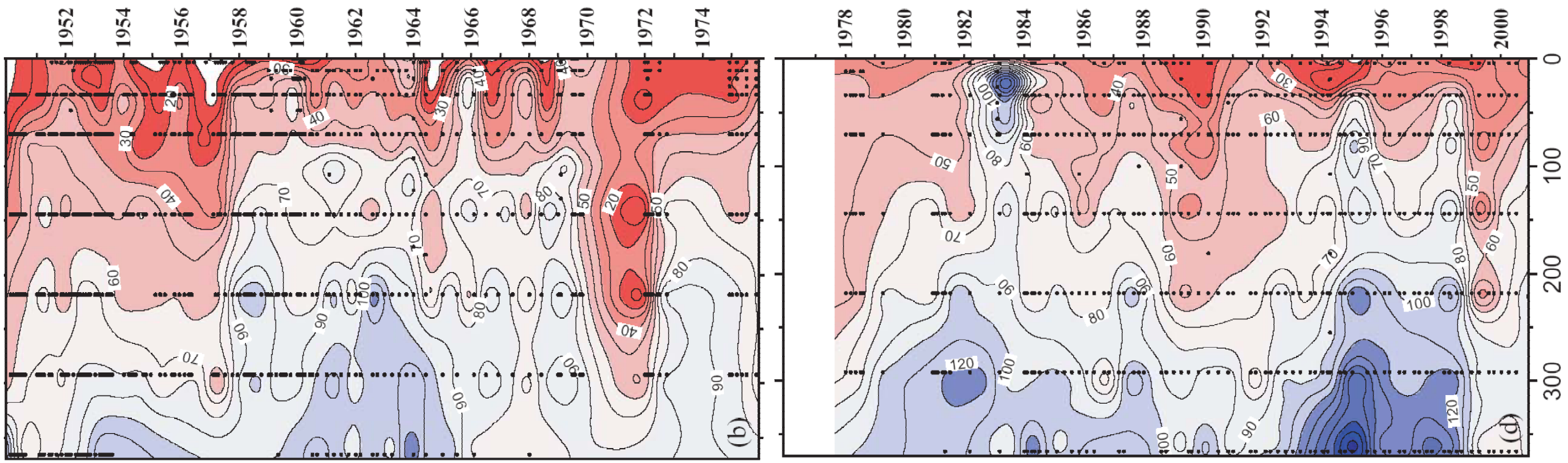


Similar AOU anomalies may be caused by increased export flux, with very different signatures of O_2/CO_2 gas exchange.



A role for the CCS?

The California Current System exhibits significant physical variability.

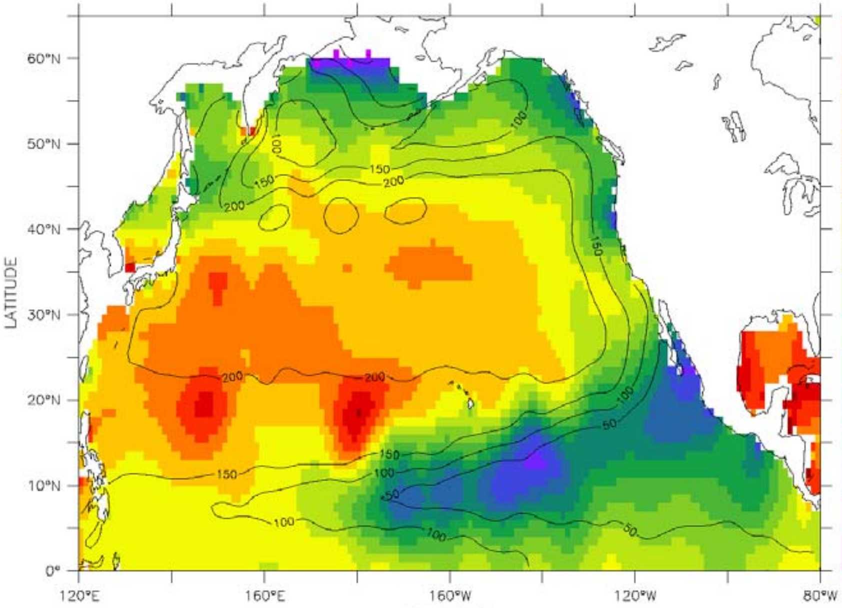


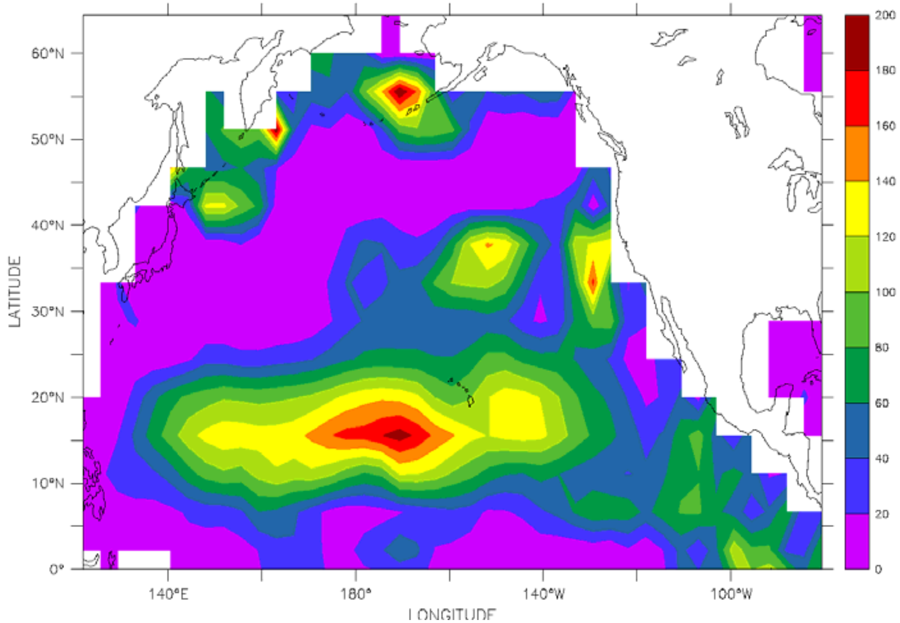
From Bograd et al. 2003

Is this variability important to the biogeochemistry of the broader basin?

Biogeochemical Consequences

Nitrate deficits produced in the oxygen minimum zone stimulate N_2 fixation in the subtropical gyre





$N^* = NO_3 - 16^* PO_4$ —— *model* ——→ *N_2 fixation*

Does variable entrainment from the OMZ into the gyre contribute to the changes in subtropical N_2 fixation inferred at station ALOHA?

Questions

- What are the gas exchange fingerprints associated with subsurface O_2 variability?
- How can trends in air-sea CO_2 flux be used to better constrain the relative roles of biology and physics.
- Are there other biogeochemical consequences of climate forced O_2 variability?