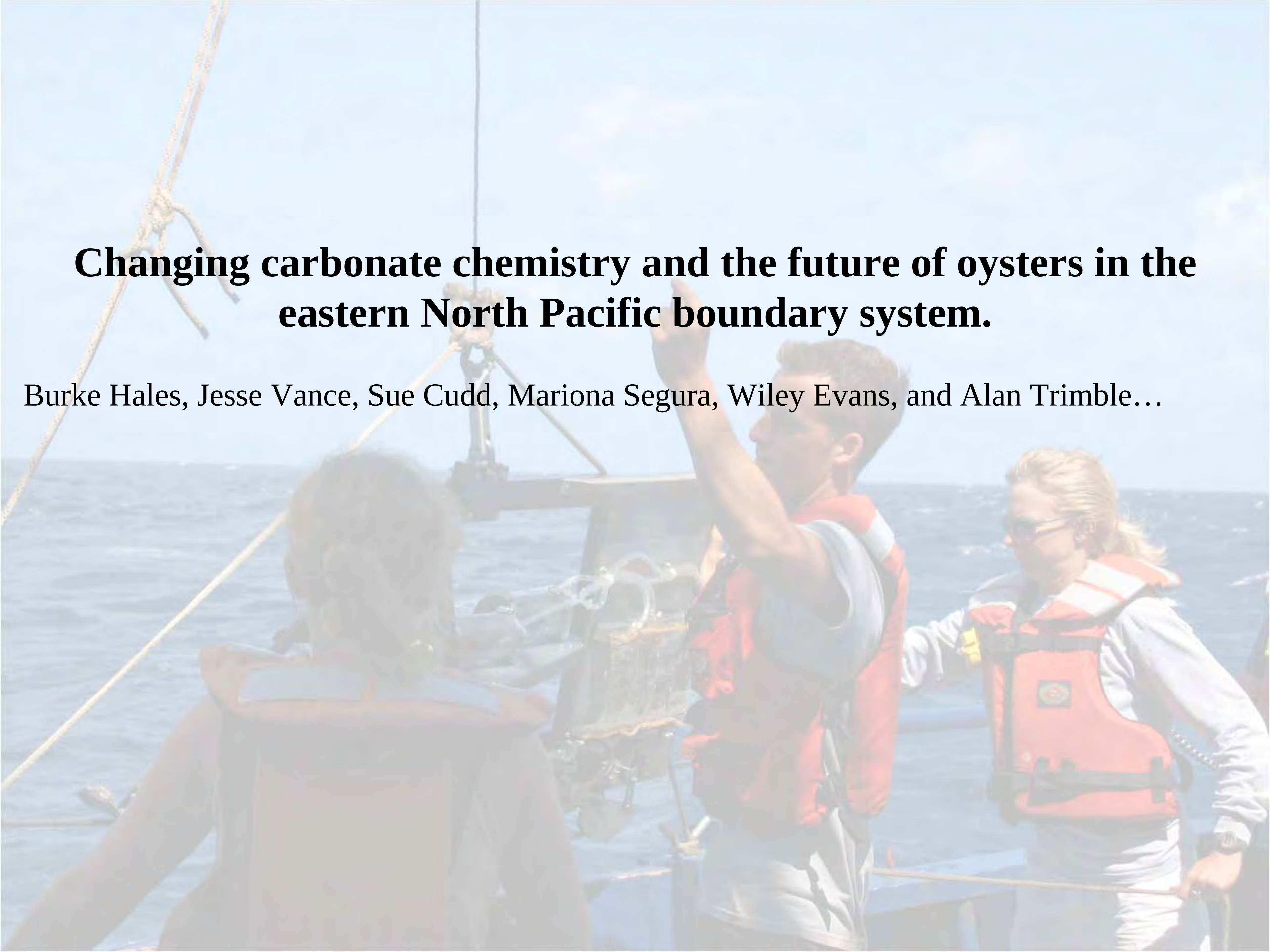


Changing carbonate chemistry and the future of oysters in the eastern North Pacific boundary system.

Burke Hales, Jesse Vance, Sue Cudd, Mariona Segura, Wiley Evans, and Alan Trimble…

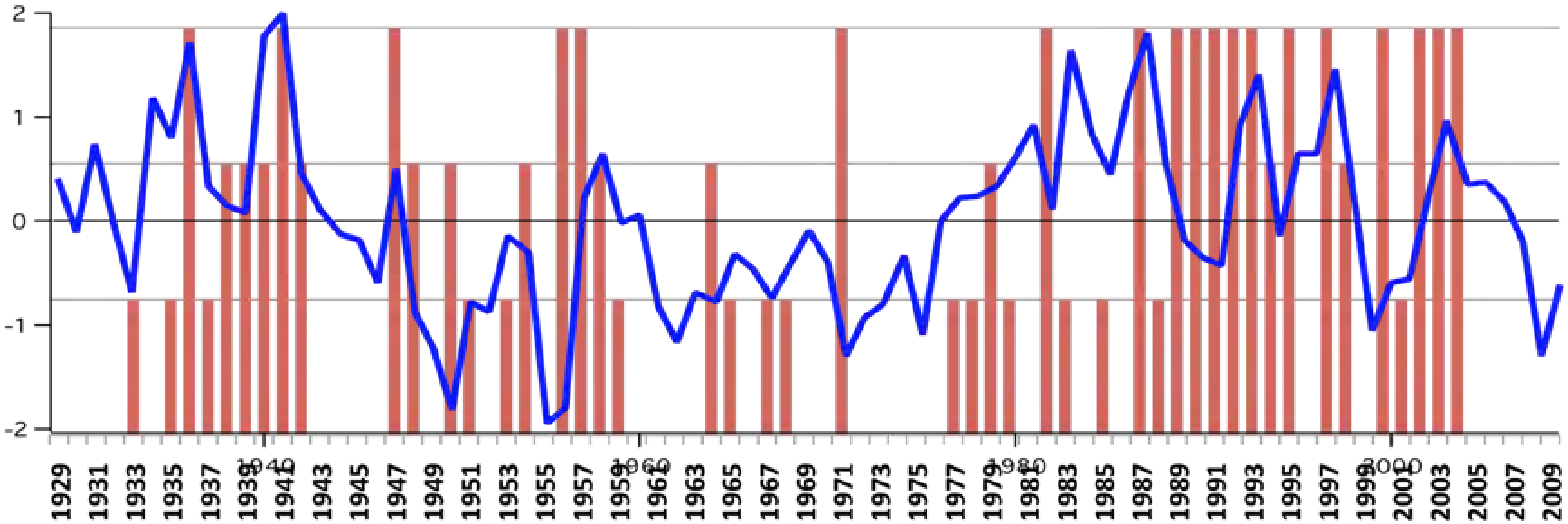
The oyster problem:

•Commercial oyster industry based on the non-native *Crasostrea gigas*, which has unreliable setting success in the wild.

•Industry has relied on hatcheries for spat since bad period in early 70s

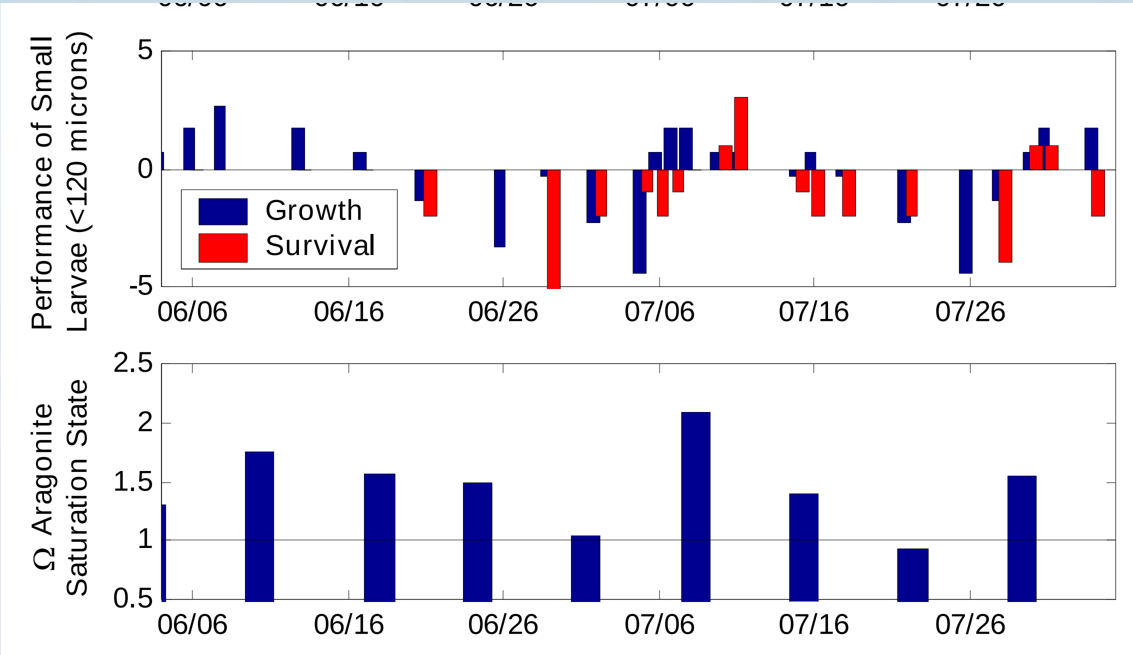
•Hatcheries experienced severe problems in 2006, seemingly as a result of pathogenic *Vibrio tubayashi* related to low-O_2 events

•Problems persisted after *v. t.* cleaned out.



Willapa Bay *C. gigas* settlement success and PDO

In 2009, the hatcheries started doing a more careful job of looking at CO_2 chemistry:



It's pretty clear that larval *C. gigas* don't like low Ω waters.

Changes in CO_3^{2-} impact the solubility of carbonate minerals:

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_{3(p)}$$

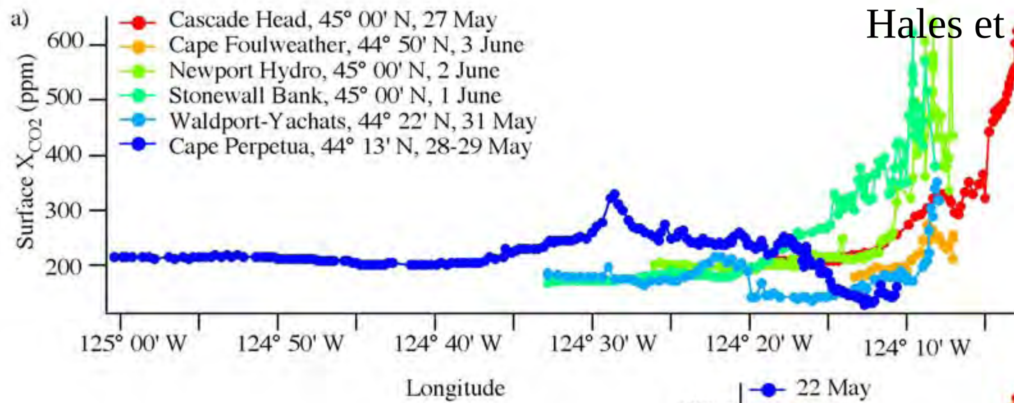
The saturation state Ω is given by

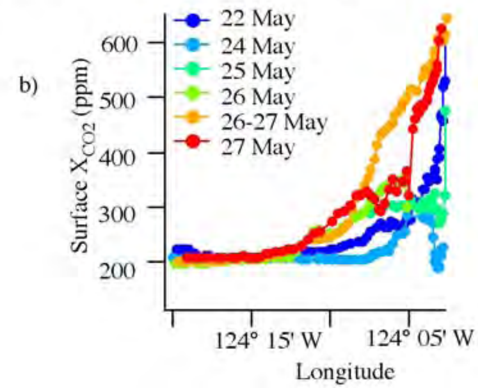
$$\Omega_p \equiv \frac{\left[Ca^{2+}\right]\left[CO_3^{2-}\right]}{K_p^s}$$

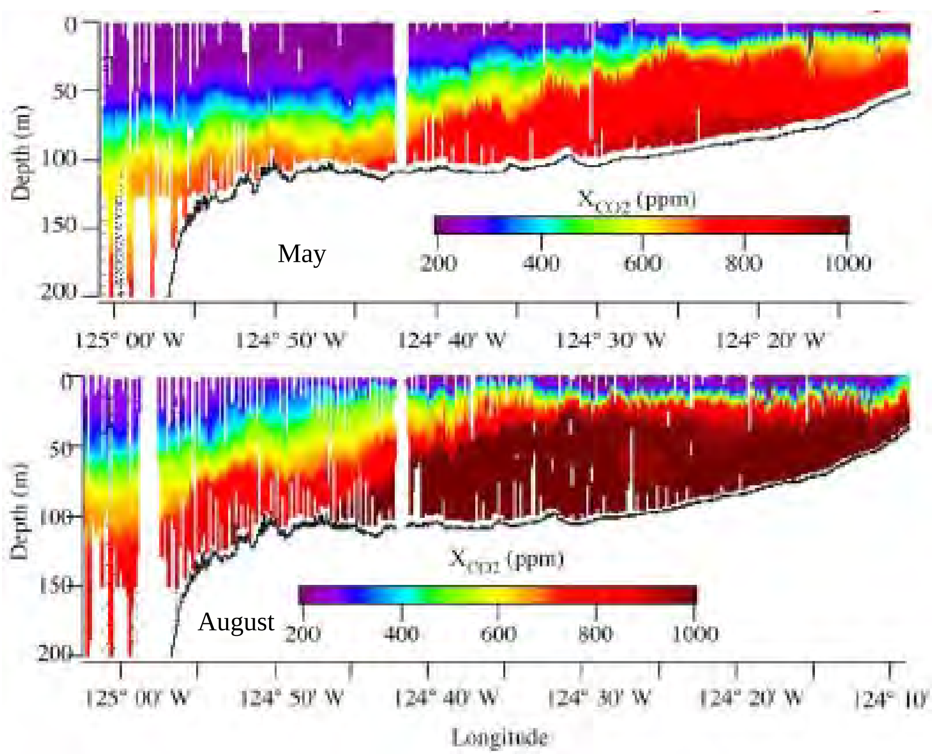
precipitation occurs when Ω>1; dissolution when Ω<1.

The Eastern Pacific Margin CO_2 Story

Hales et al., 2005

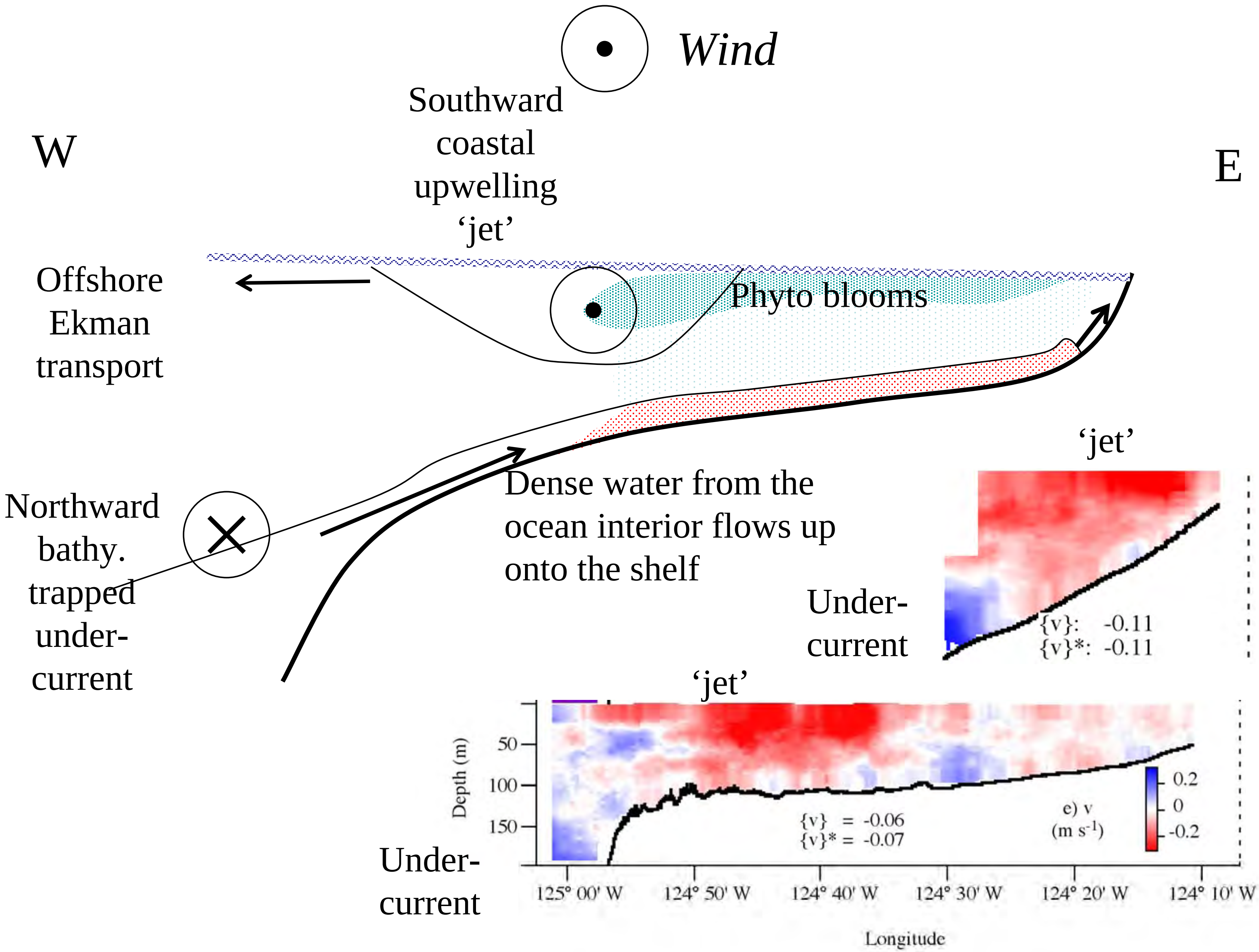


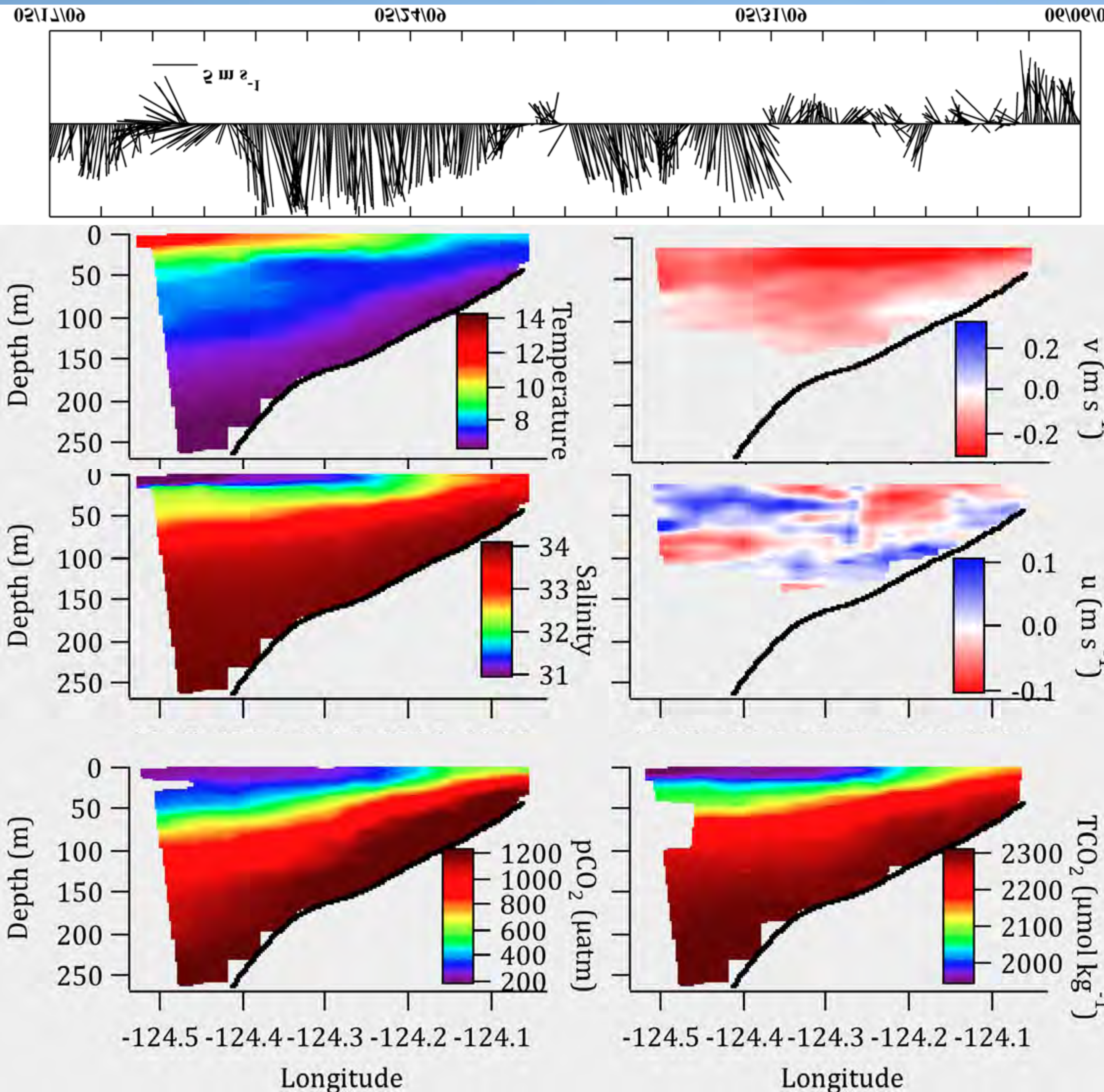




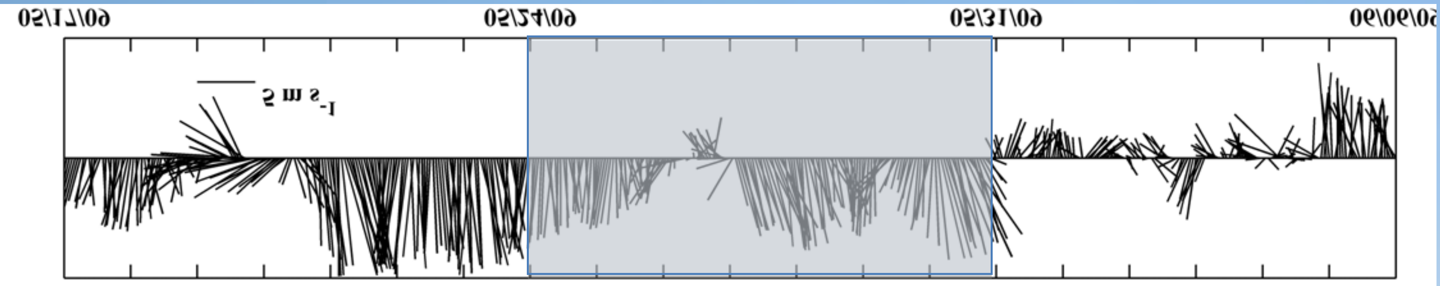
These systems show high variability over multiple t,**x** scales, and extreme CO_2 chemistry (Y2200)

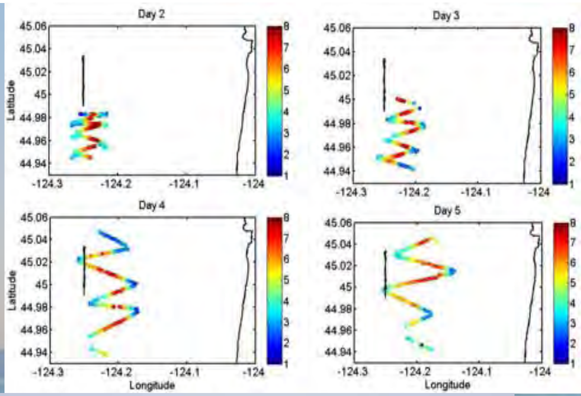
The E. N. Pacific coastal ocean is dominated by upwelling forcing



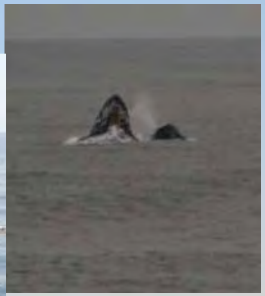


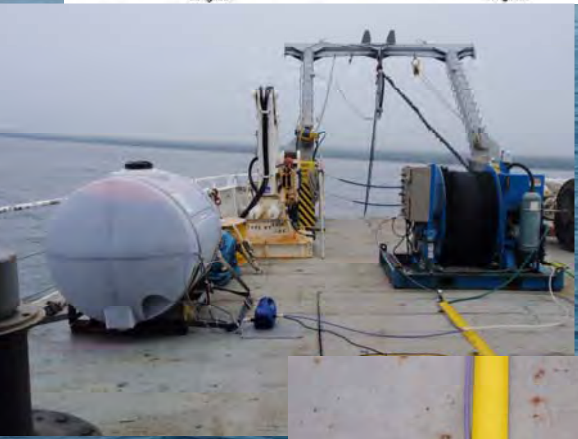
Upwelled source waters are drawn from the the undercurrent, and hydrographic distributions show cross-shelf continuity in the Bottom Boundary Layer (BBL)

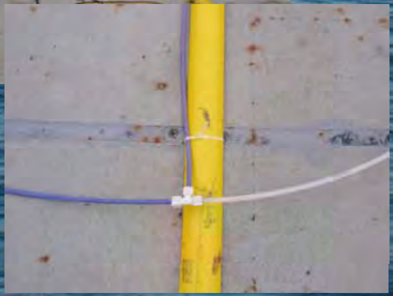




BBL tracer injection shows that near-bottom waters move onshore in direct connection to upwelling forcing.







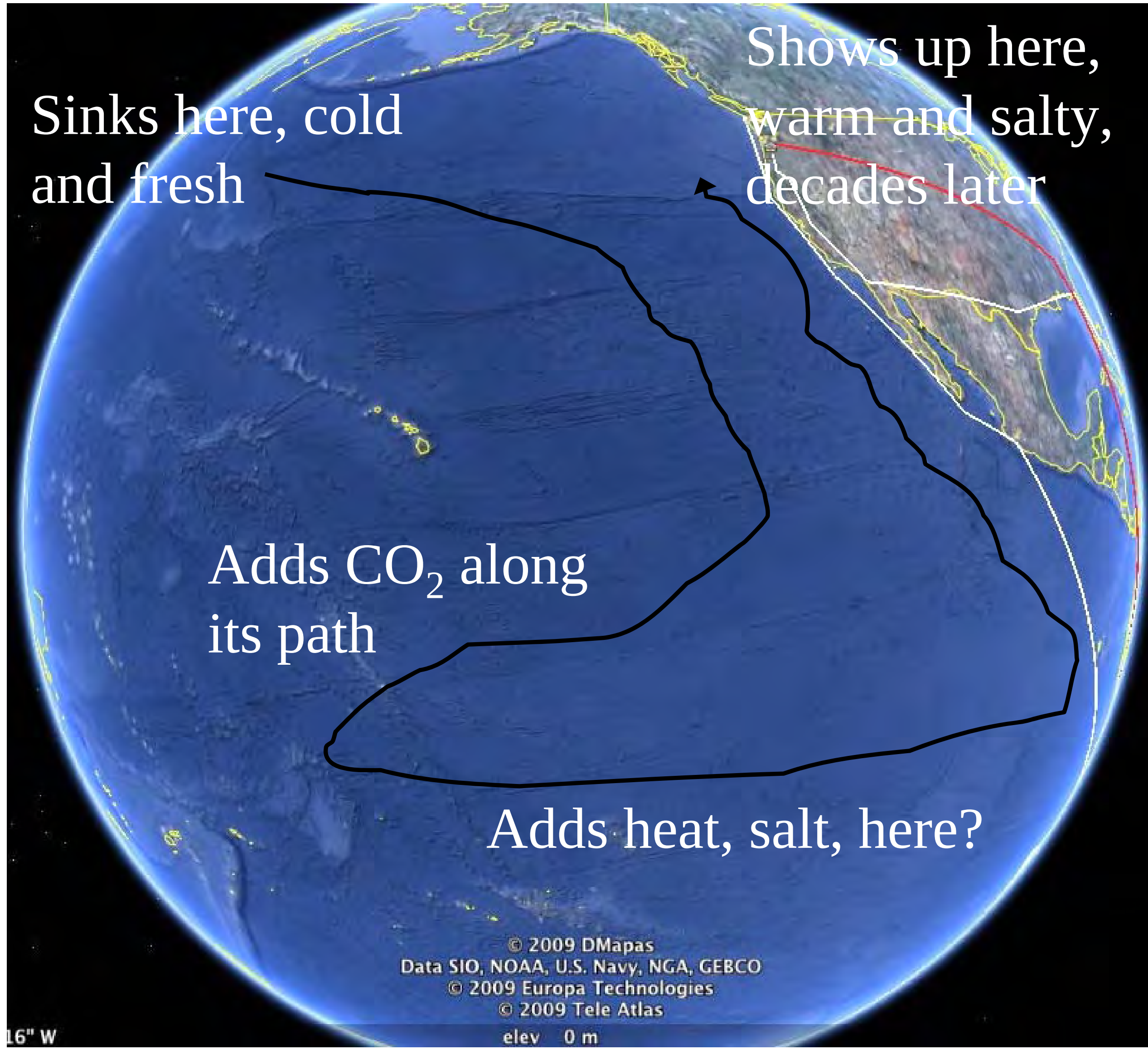
The undercurrent source water takes a long time to get here.

Water takes a circuitous path to upwelling centers.

Takes decades (TTs say ~3; O_2 says ~5?) to get here.

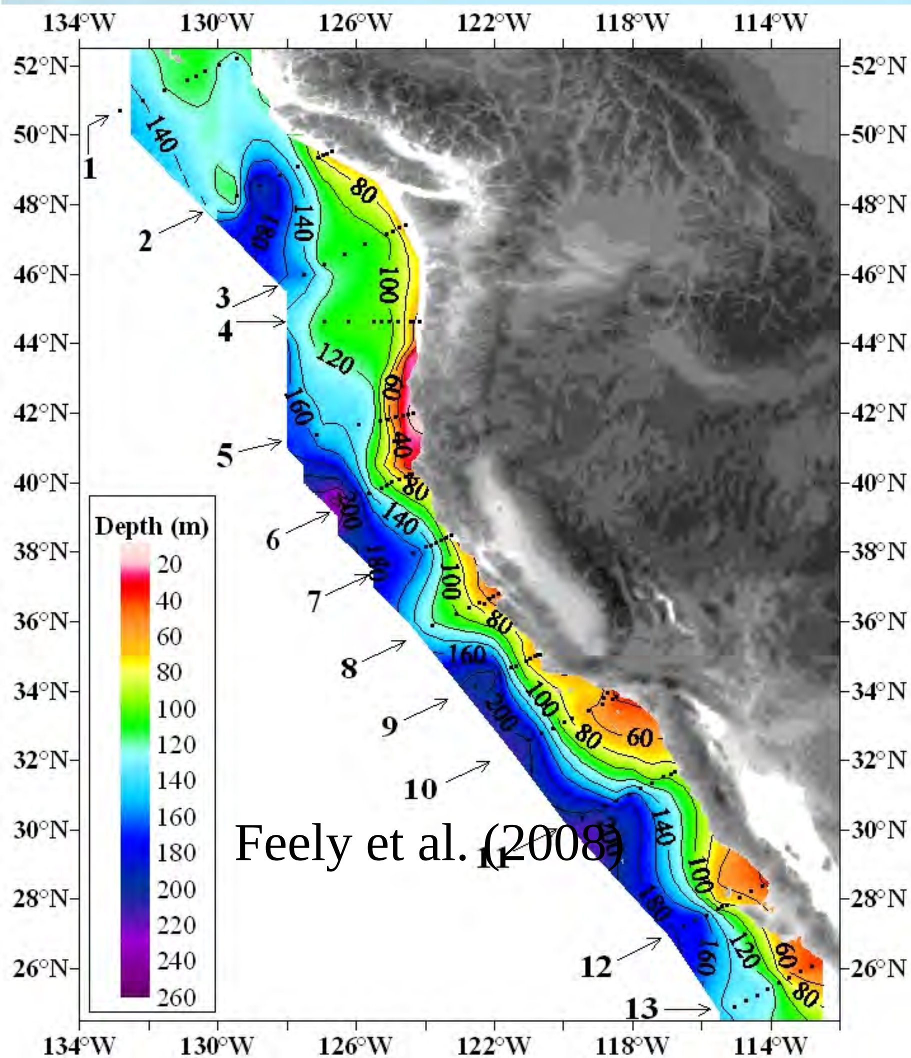
Water gets as deep as ~500m along its route.

During its entire transit, metabolic processes add CO_2.



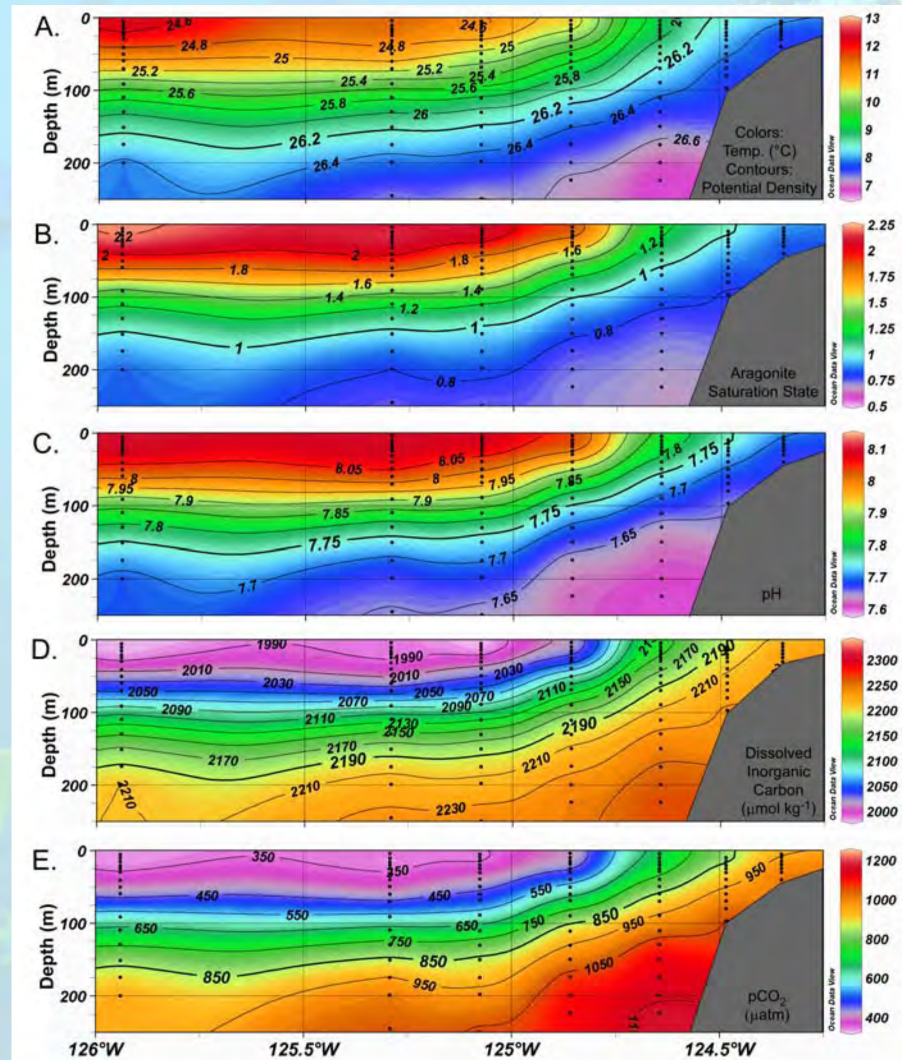
Upwelled waters naturally have a lot of CO_2, and E. N. Pacific margin waters have probably always looked like this to some extent*

Aragonite saturation depths along central NA Pacific coast:

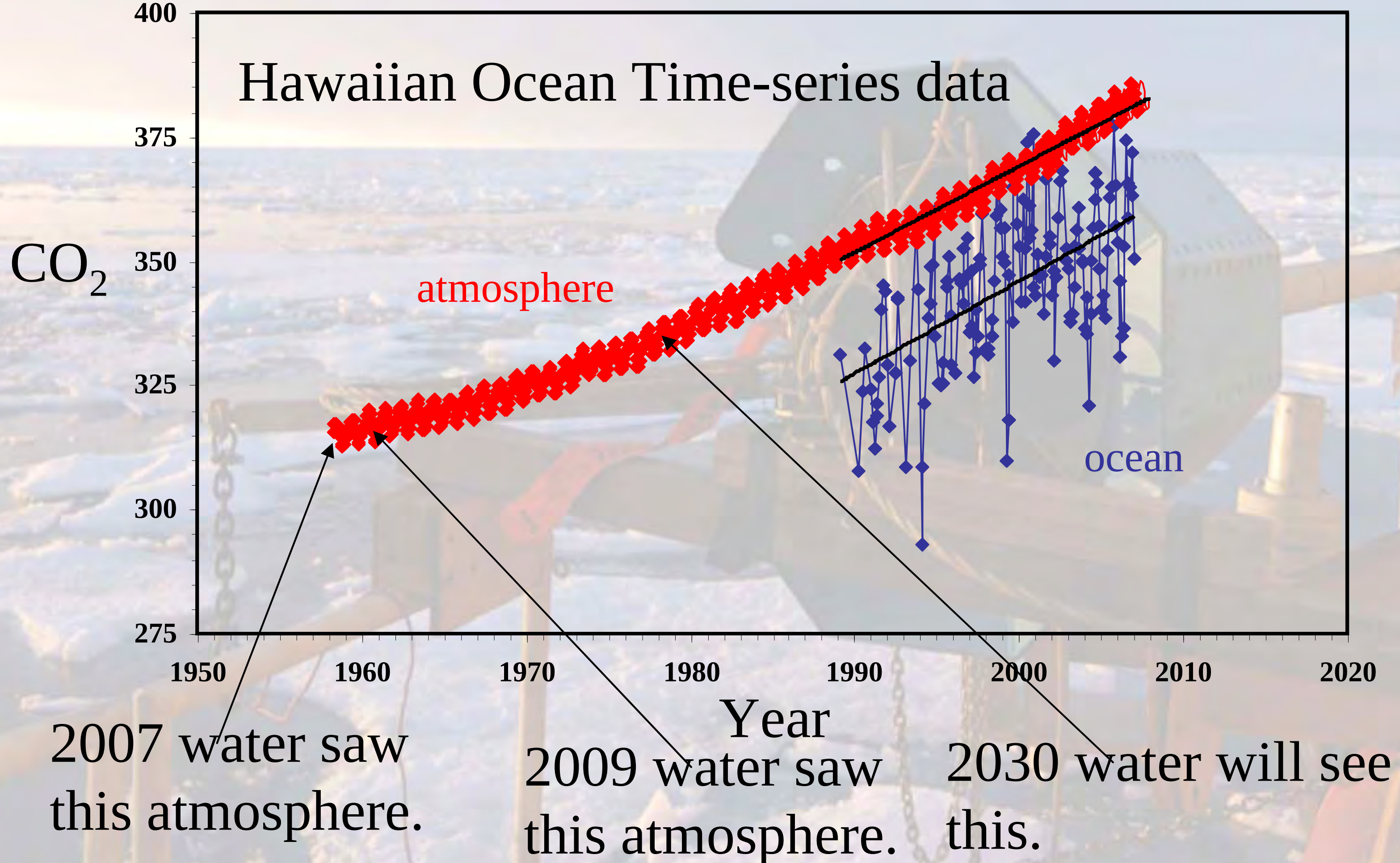


Feely et al. (2008)

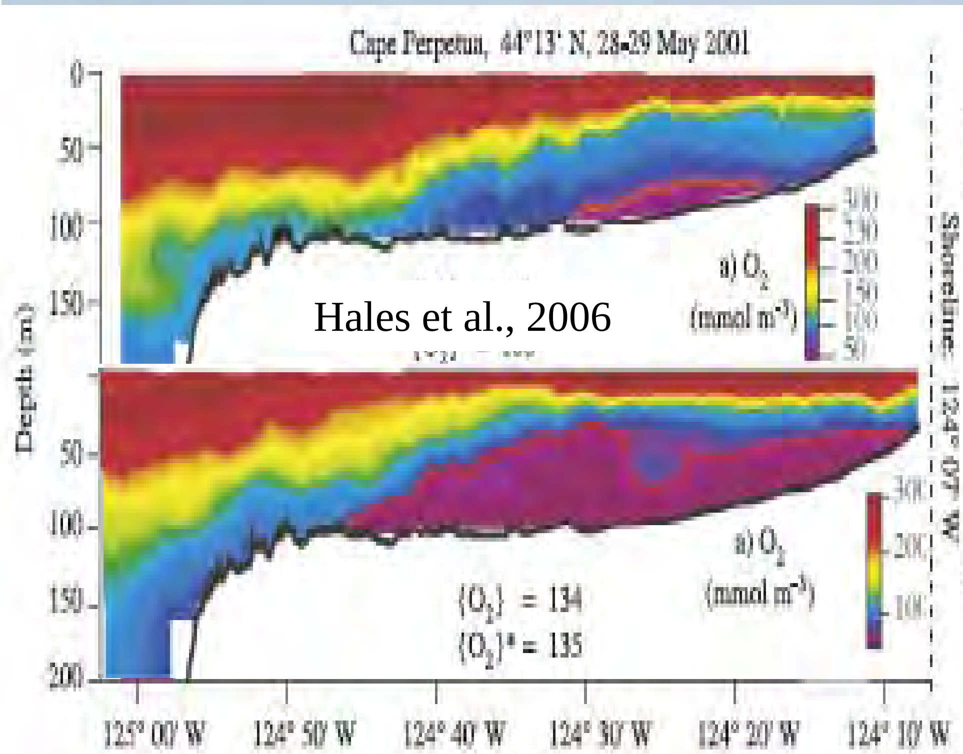
Cross-shelf distributions at Point St. George (Line 5):



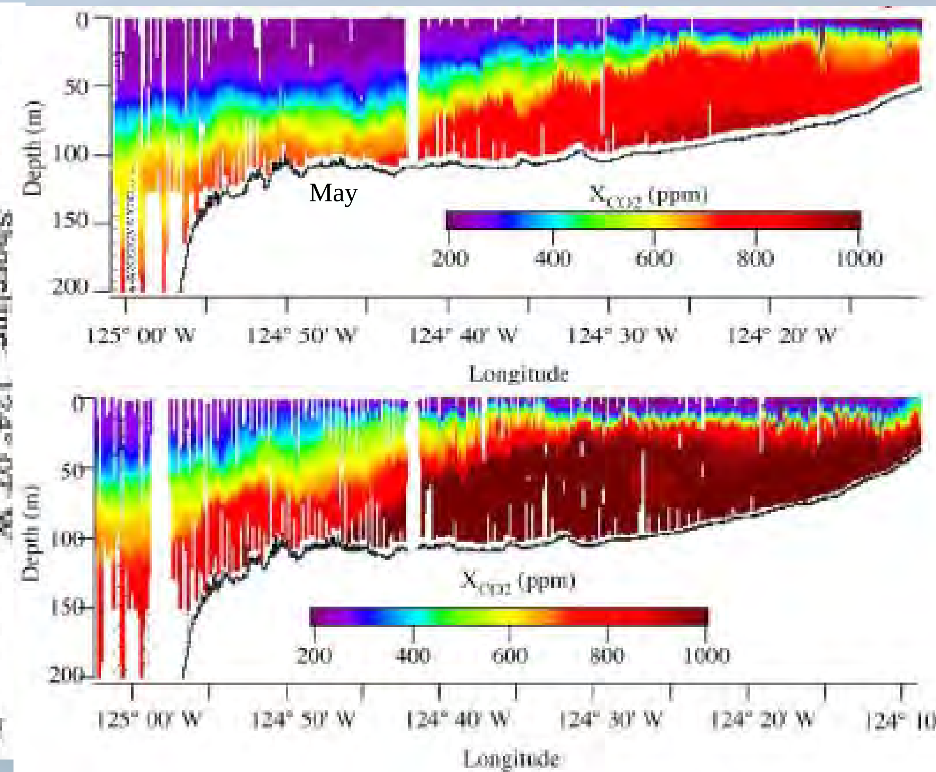
*And now for the bad news. Feely et al (2008) determined that the naturally added CO_2 was enough to get upwelled waters close to aragonite saturation. Added anthropogenic CO_2 was enough to cause corrosivity. Extrapolating:



Is there more to it than just rising CO_2?



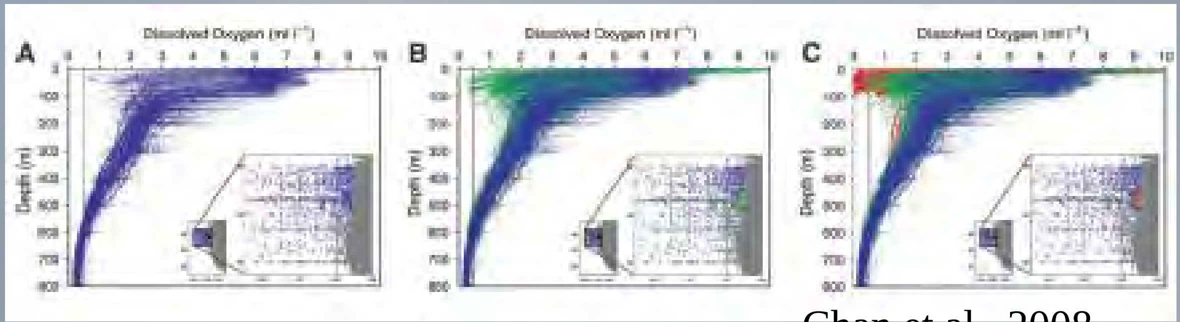
Hales et al., 2006



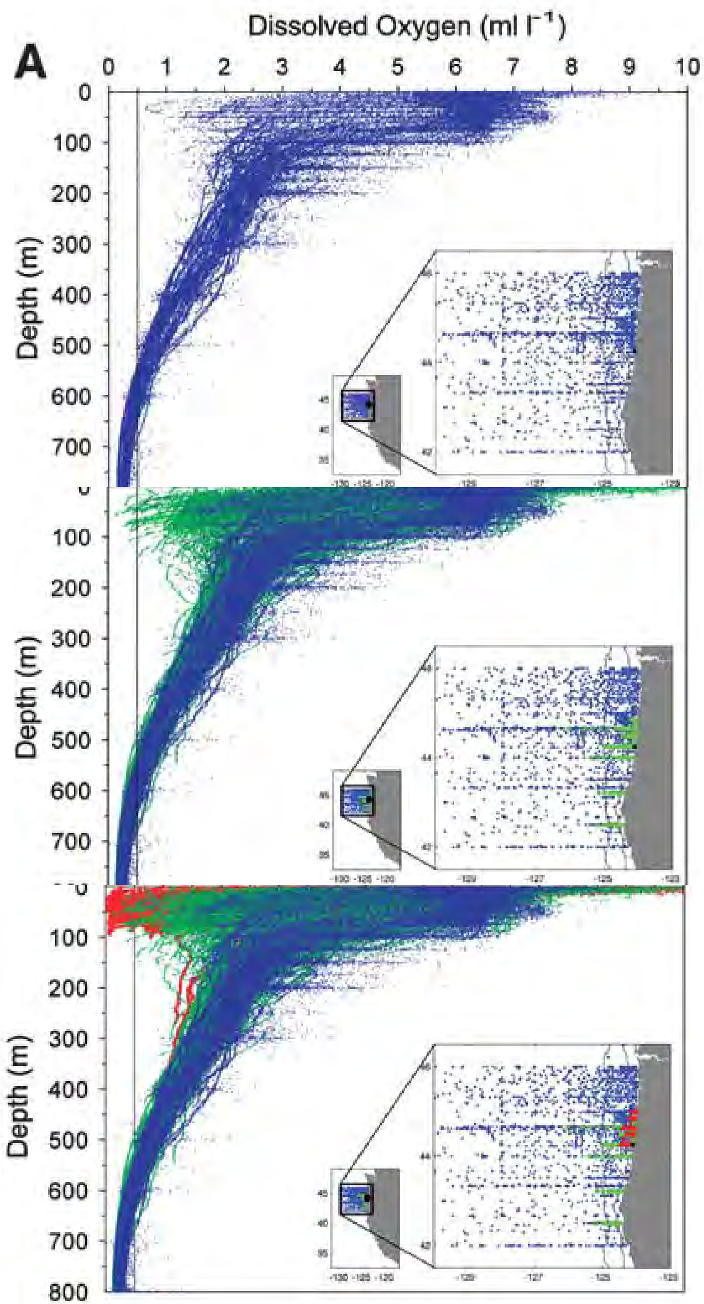
Yep. Degradation of organic matter over the upwelling season depletes oxygen, but also drives pCO_2 up, causing more corrosive conditions.

Hypoxia and corrosivity are closely linked

If this is a trend…



Chan et al., 2008



Pre-1999

Pre-1999 + 1999-2005

Pre-1999 + 1999-2005 + 2006

Is there a trend? What is the nature of it?

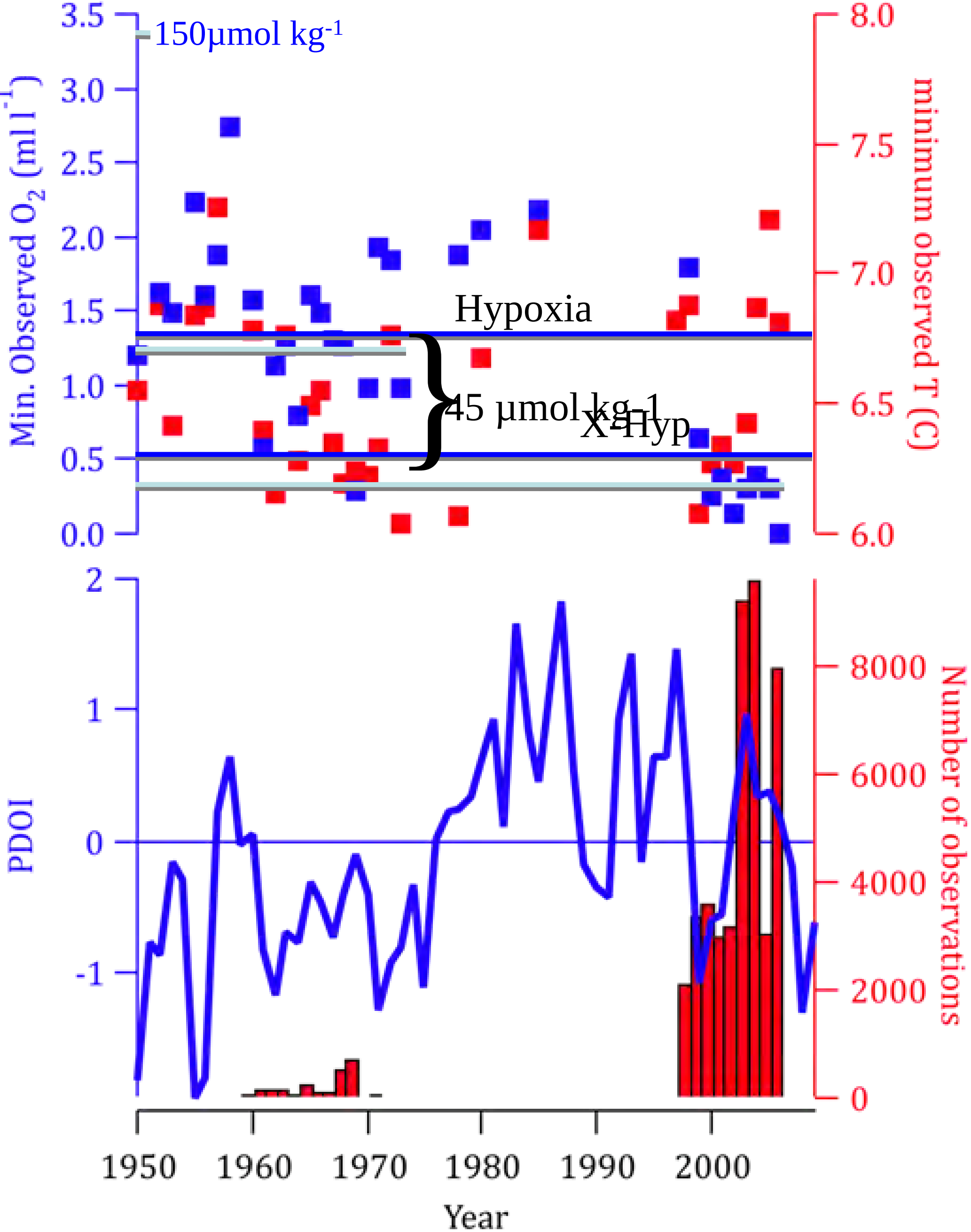
We know that observation of low-O_2 conditions is favored by sampling near the bottom, over the shelf later in the upwelling season.

There IS a sampling artifact in this dataset that HAS increased emphasis on the most-likely-to-deoxygenate regions.

What happens if we filter for subsurface (deeper than 30 m) data associated with the broad Heceta Bank region (43.5-45.5N, inshore of 125.2W, shallower than 200 m), late in the upwelling season (July-September)? Can the artifact be minimized?

F. Chan et al., Science 319, 920 (2008)

Published by AAAS



But what can we say about trends?

1. Most recent observations are indeed lowest on record;

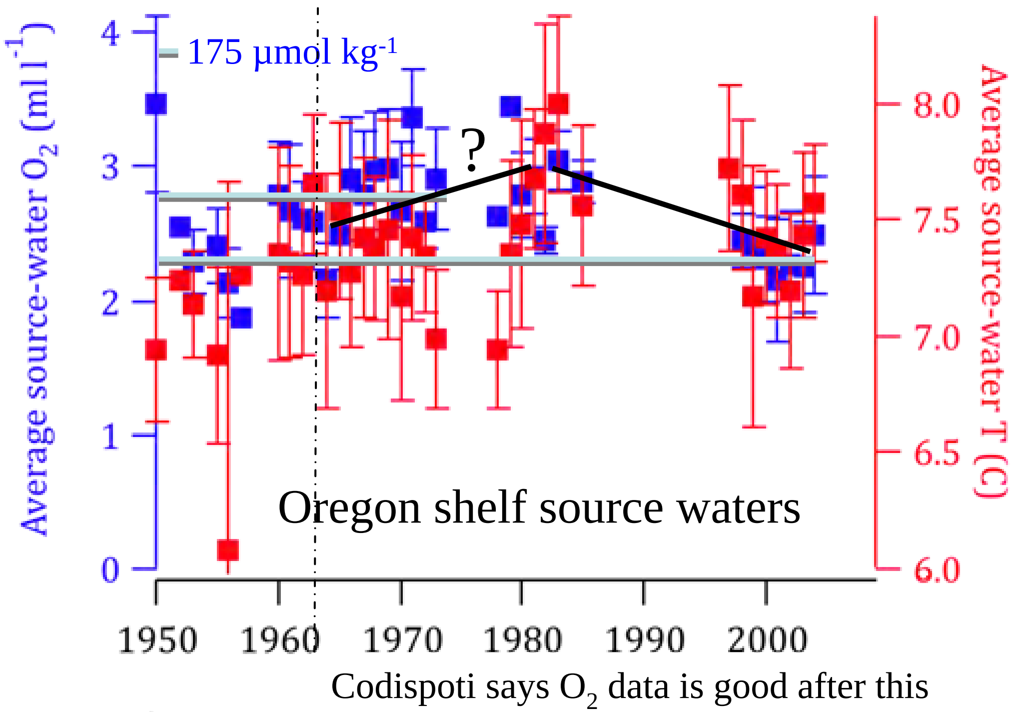
2. There were other observations of low-O_2 conditions during 60s-mid 70s;

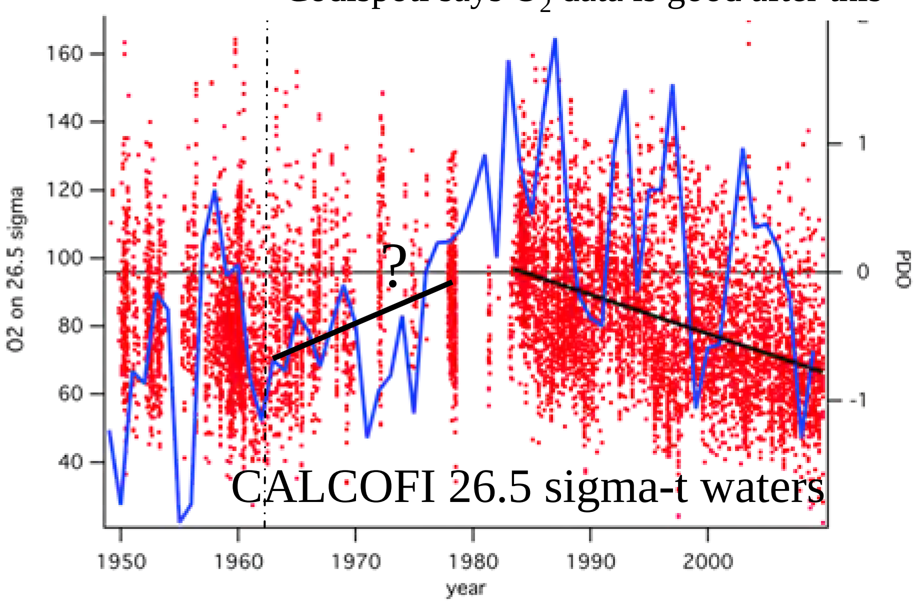
3. Earlier observations coincided with period of cold-phase PDO and low observed minimum temperatures (source-water effect?)

4. Recent low-O_2 observations have some similarity in PDO, but do not coincide with such low observed minimum temperatures (not source-water effect?)

5. Sampling artifact still must be acknowledged.

6. Best we can say is that there may be a recently intensified PDO relationship.





Could it be source-water?

Very, very, very, very rough guess says source waters have de-oxygenated by ~17 µmol kg^{-1} over ~35 yr since last cold-phase PDO; similar to CALCOFI data.

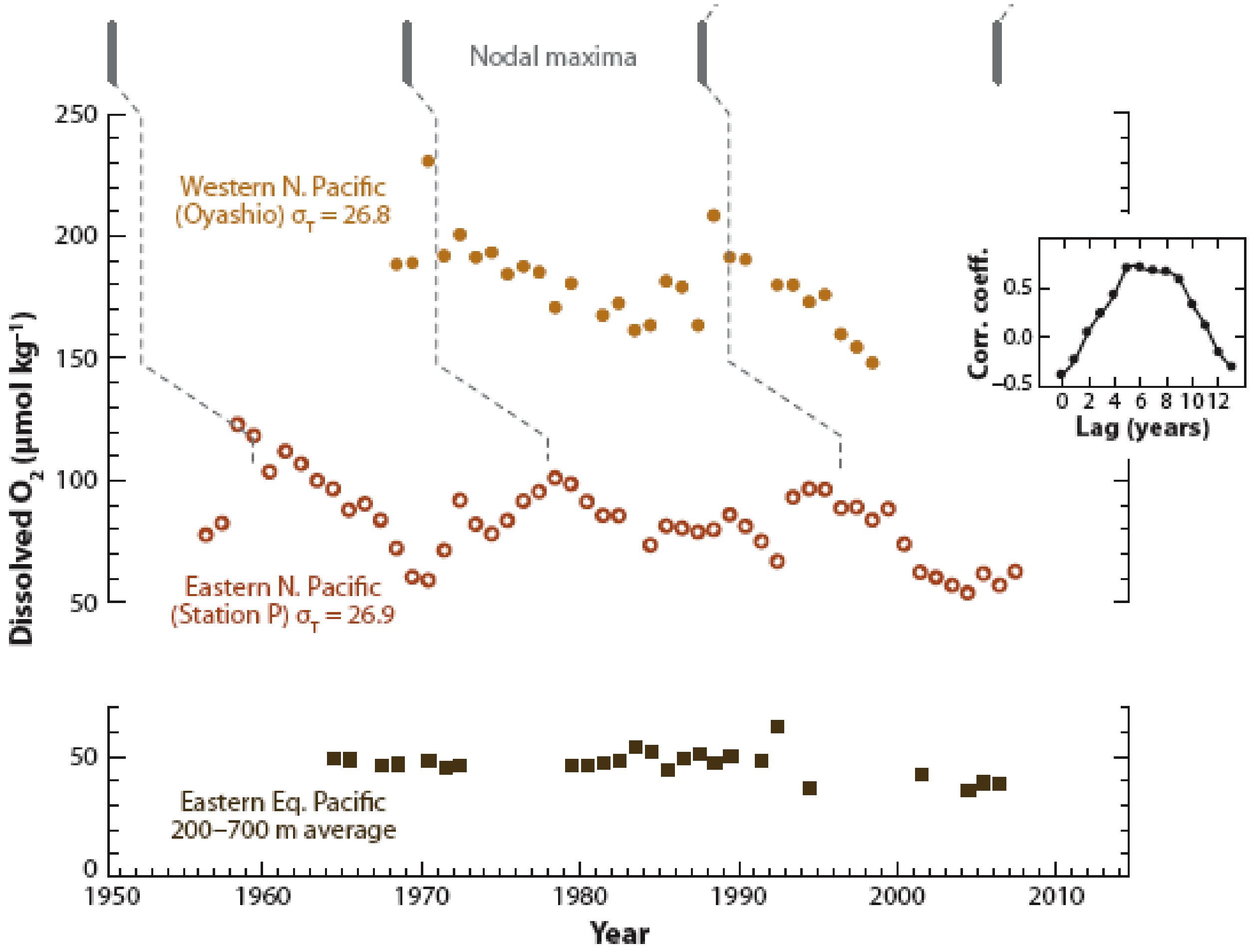
This change is on the low side of that predicted from temporal trends on ocean-interior iso-surfaces, and only about 35% of the observed shift in minimum shelf O_2 over the same time period.

Source waters have also gotten ~colder.

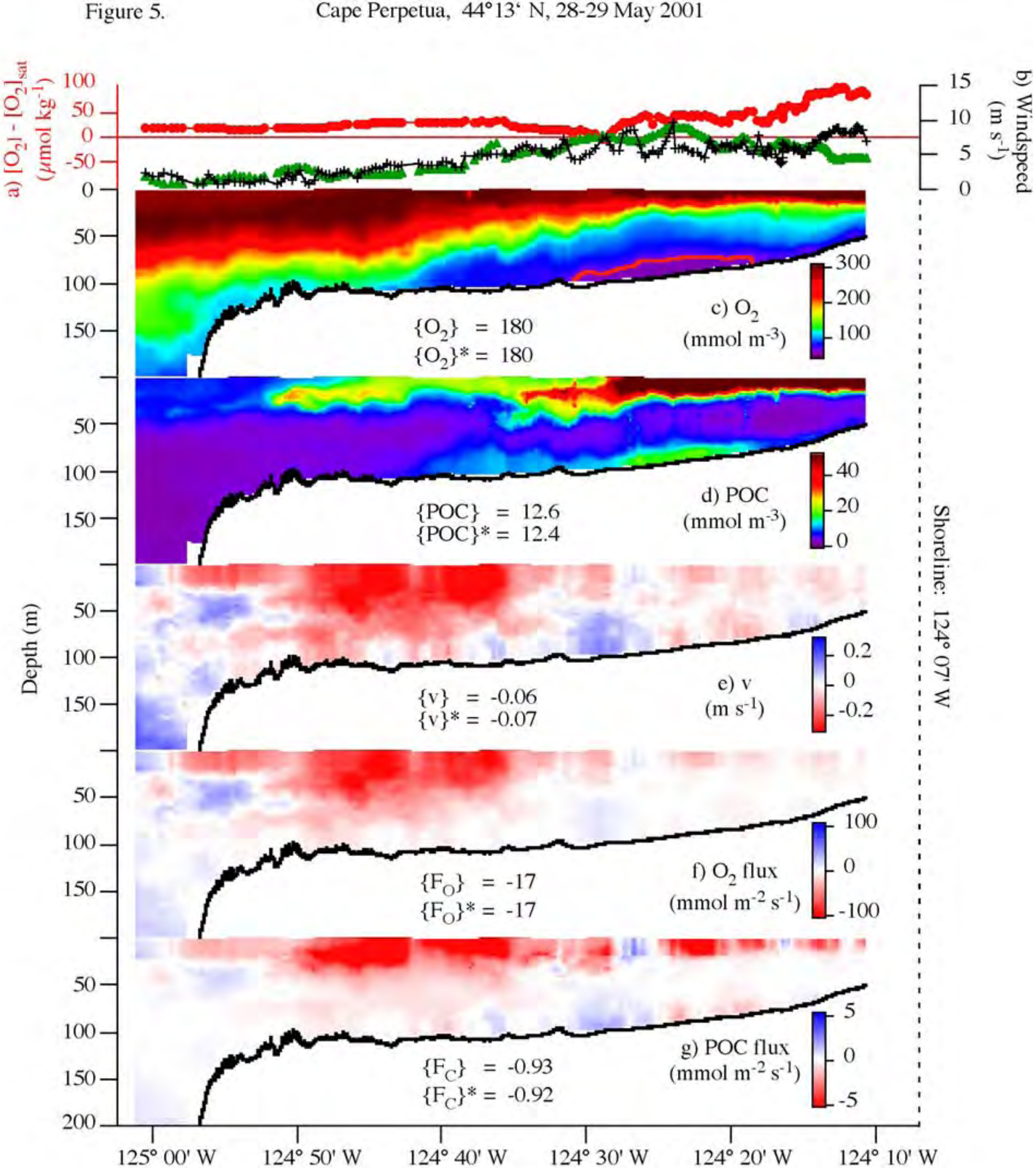
Transit-time lag makes this comparison difficult. Can we use recent estimates of ~50-yr trends in ocean interior water to compare today's ~50-year-old water to ~50 years ago's ~50-yr old water?

Source-water can't be the whole story.

North Pacific interior waters show oscillating O_2 content on multiple-decade scales. Source-water story may be one of low-frequency variability.



As presented by Keeling et al. (2010)



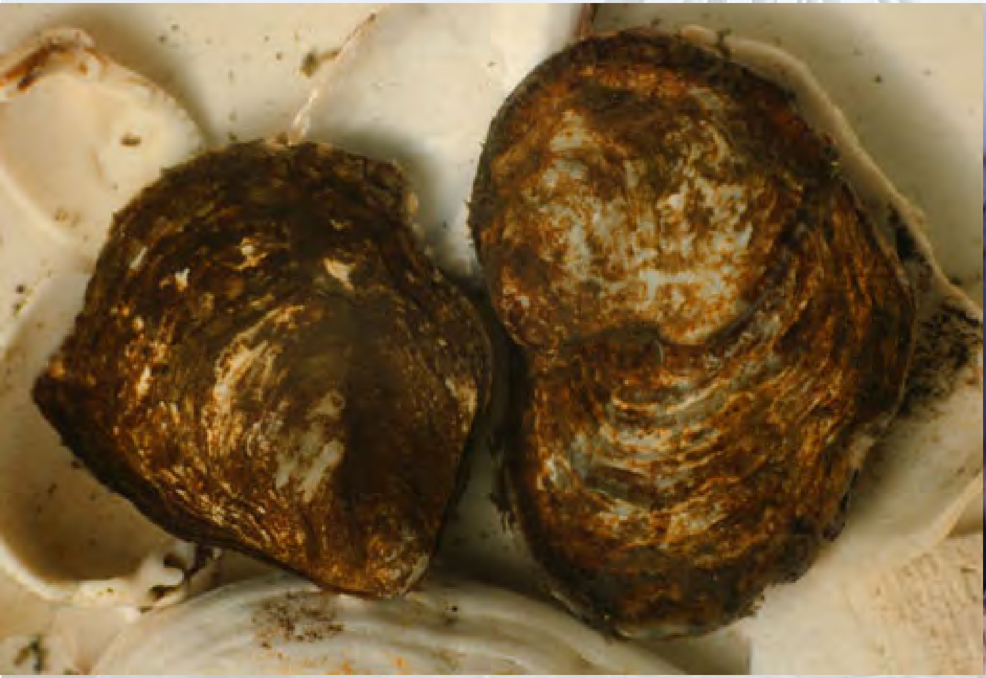
Hales et al., GBC 2006

Hales et al. 2006 found that mass-balance of O_2 and POC *required* the majority of production on the shelf be exported before being respired locally, and suggested that modulation of the upwelling forcing was key.

Extreme hypoxic years (2002, 2006) experienced more persistent upwelling with longer times between relaxation.

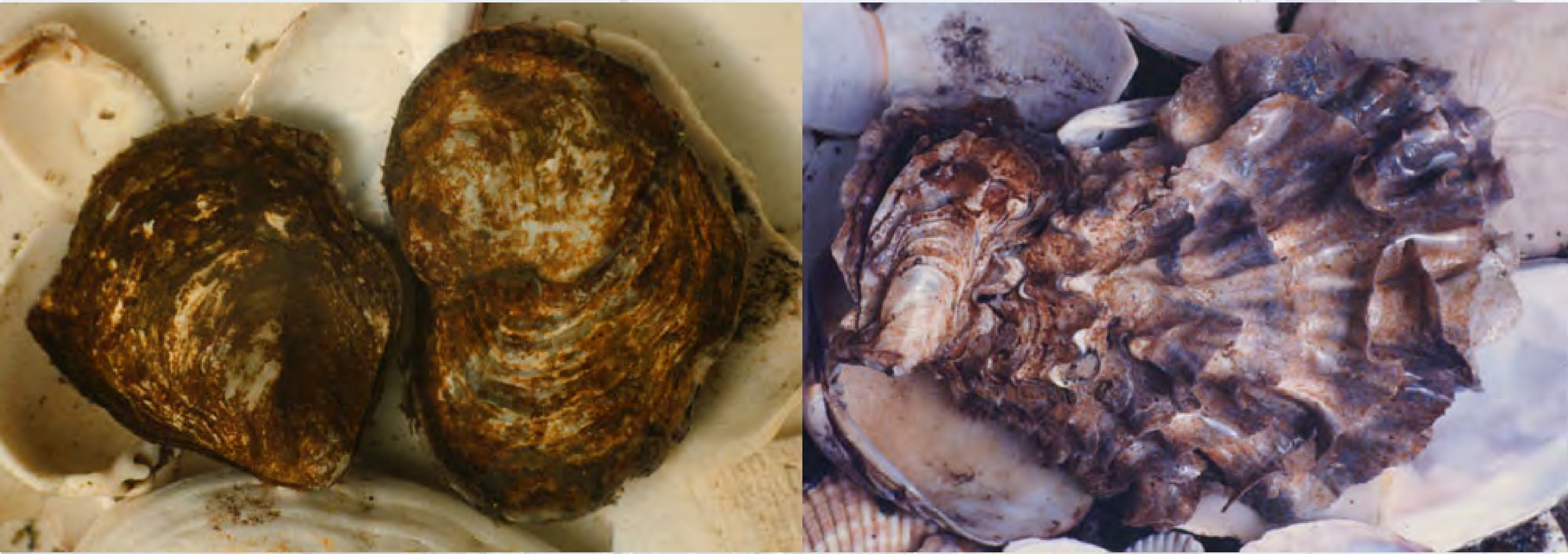
If source-water minima match up with persistent wind-forcing and shelf retention conditions, extreme O_2, and by proxy CO_2, conditions have probably been part of the long term record.

Back to Pacific oysters:



Ostrea lurida, 'olympia'oyster, native to eastern Pacific. Commercially overfished in mid-late 1800s

Crasostrea gigas, 'Pacific' 'giant' or 'Japanese' oyster, native to western Pacific. Introduced to E. Pacific ~1900, basis of commercial oyster industry in PNW.



•*C. gigas*, which evolved in the western Pacific where upwelling is limited and biogeochemical variability is less, is a broadcast spawner that reproduces in the peak of the upwelling season.

•*O. lurida* is a brooding species that tends to spawn early and late relative to upwelling (S. Cudd and A. Barton, pers. comm.)

Has the E. N. Pacific ever been a good place to be *C. gigas*? Is there a CO_2 scenario explaining its historical absence?

Conclusions

• Recent *C. gigas* larval survival failures in PNW hatcheries appear to be linked to high CO_2 events.

•Historical record shows many instances of wild *C. gigas* settlement failures over the past century.

•Climatological, physical, and biogeochemical arguments suggest the eastern North Pacific should be subject to periods of intensely high CO_2, *even if hypoxic conditions are not experiencing long-term increasing trends*.

• Historical absence of *C. gigas* and spawning behavior of native *O. lurida* suggest evolutionary response to local ocean conditions.

•Source-water age and rising atmospheric CO_2 imply at least decades of increasing CO_2 levels in upwelled source waters.

So coastal bays 'feel' the ocean

Variation in upwelling forcing drives both positive and negative responses by oyster larvae

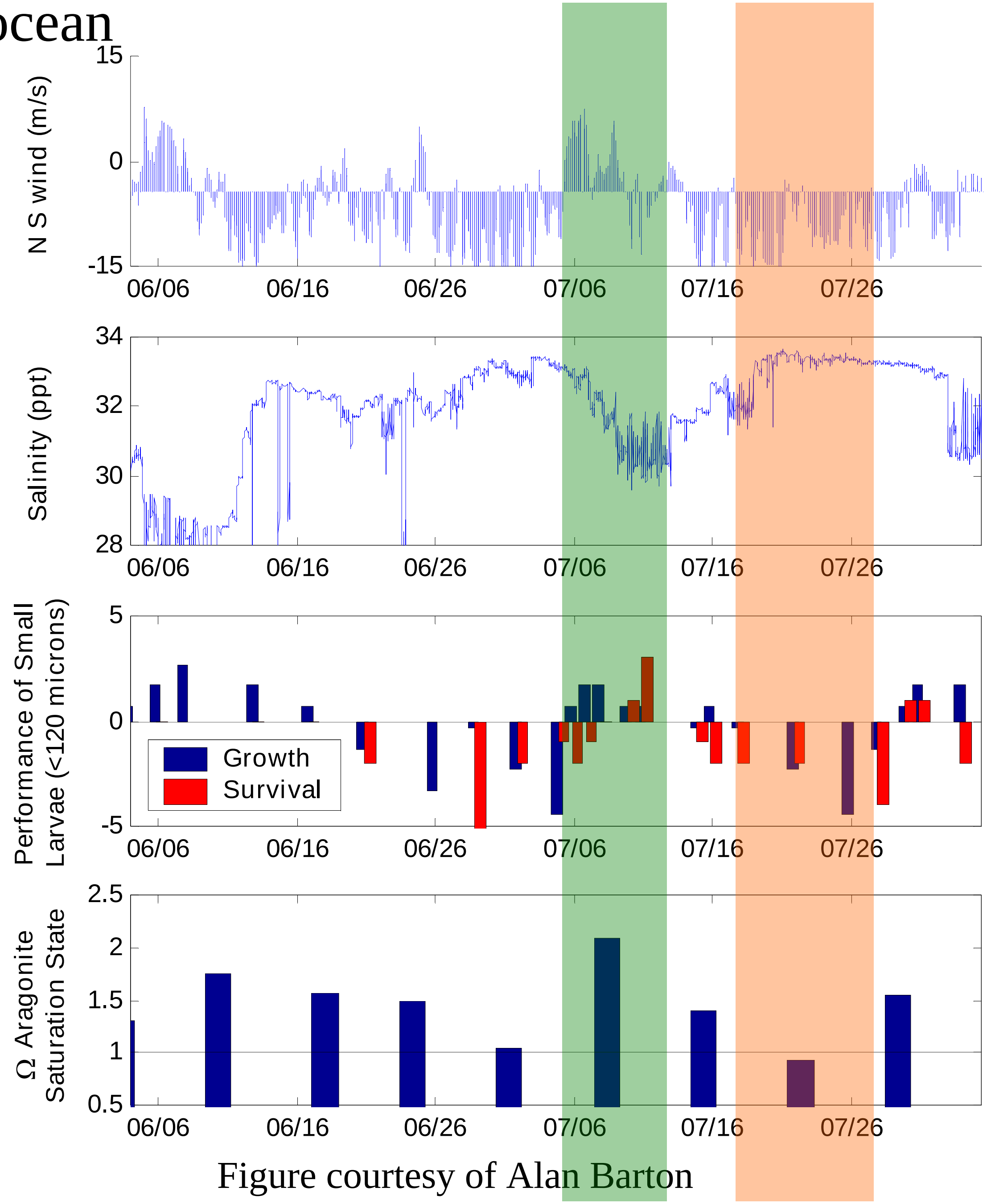
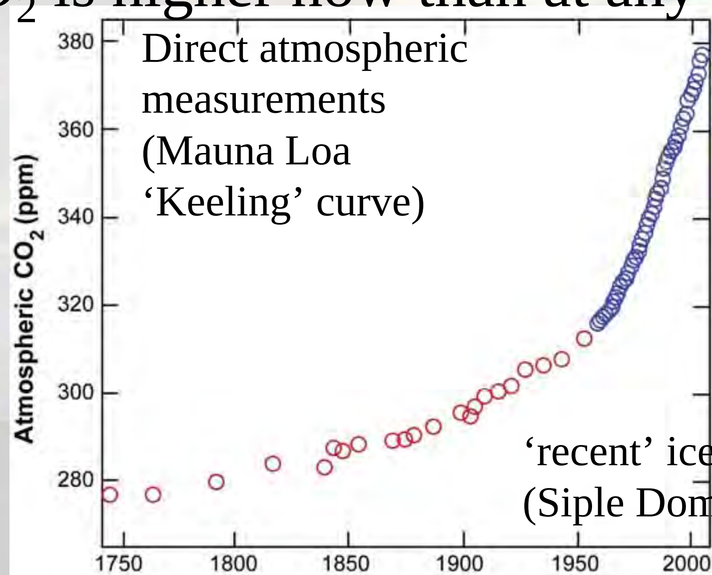


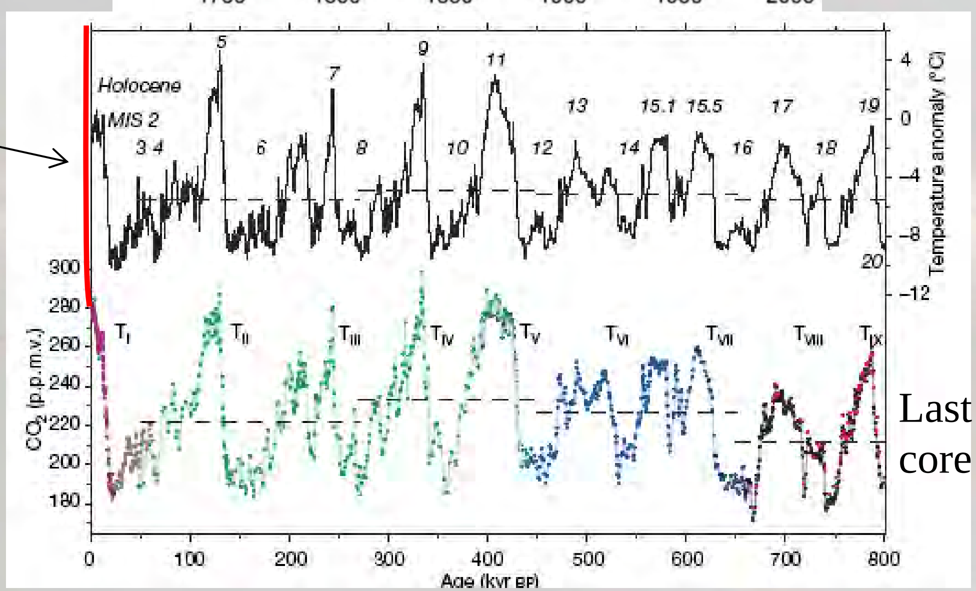
Figure courtesy of Alan Barton

Background: The modern carbon cycle

Atmospheric CO_2 is higher now than at any point in the last million years:



Last 250 years



Last ~ Myr ice core data

Conclusions

- The carbon cycles of the eastern North Pacific present challenges to organisms that depend on $CaCO_3$ shells. Upwelling coastal waters are particularly sensitive because of natural processes, and rising atmospheric CO_2 levels may be pushing us past important biological thresholds.

- Rising atmospheric CO_2 may be intensifying natural long-term corrosivity variations.

- The natural variability in ocean-water corrosivity may be giving us opportunities to study future environments and adaptive strategies.

- The historical distributions and reproductive strategies of Pacific oysters may give insight into evolutionary responses to EOC forcing.