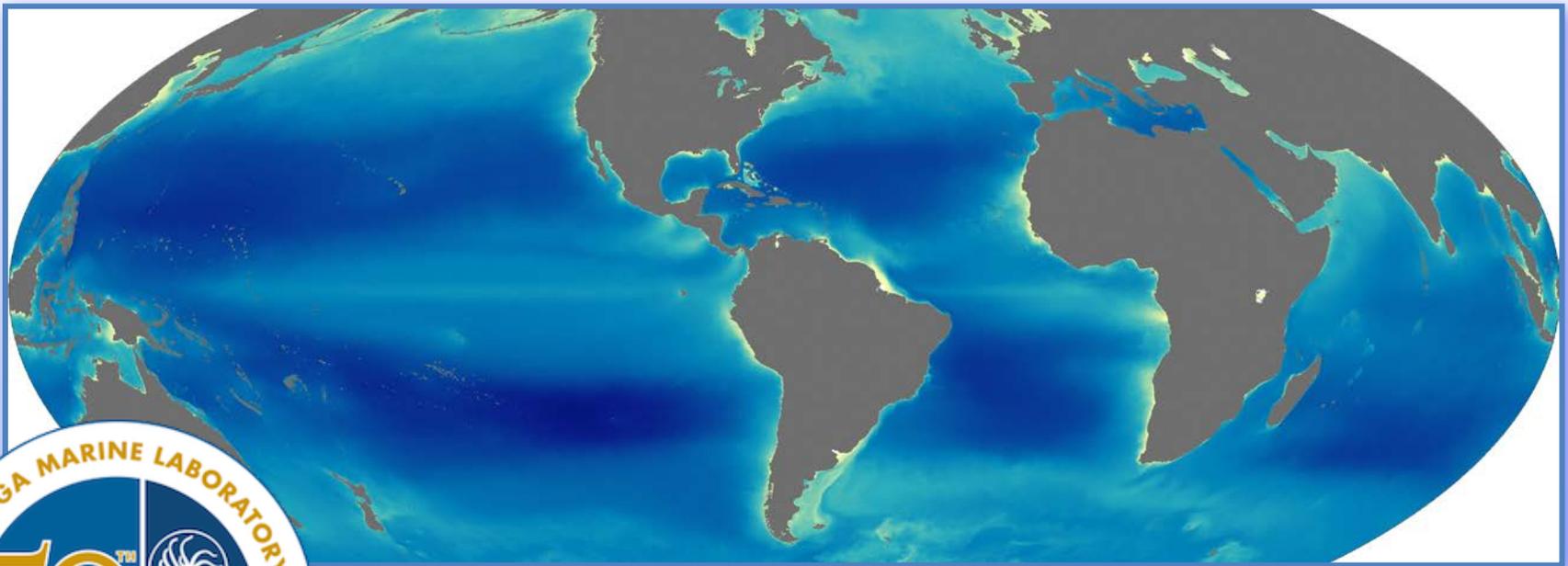


OCEAN CLIMATE SUMMIT
Monitoring the Pulse of the Ocean

Climate-Driven Changes to Ocean Water Properties

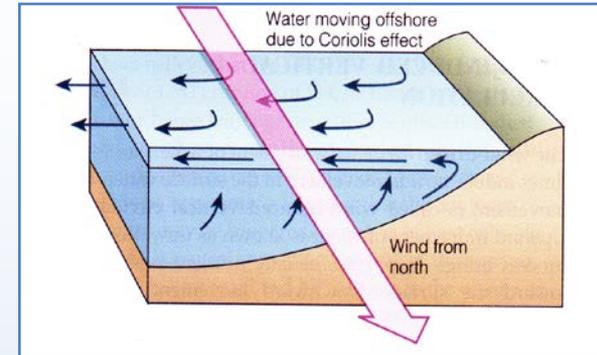


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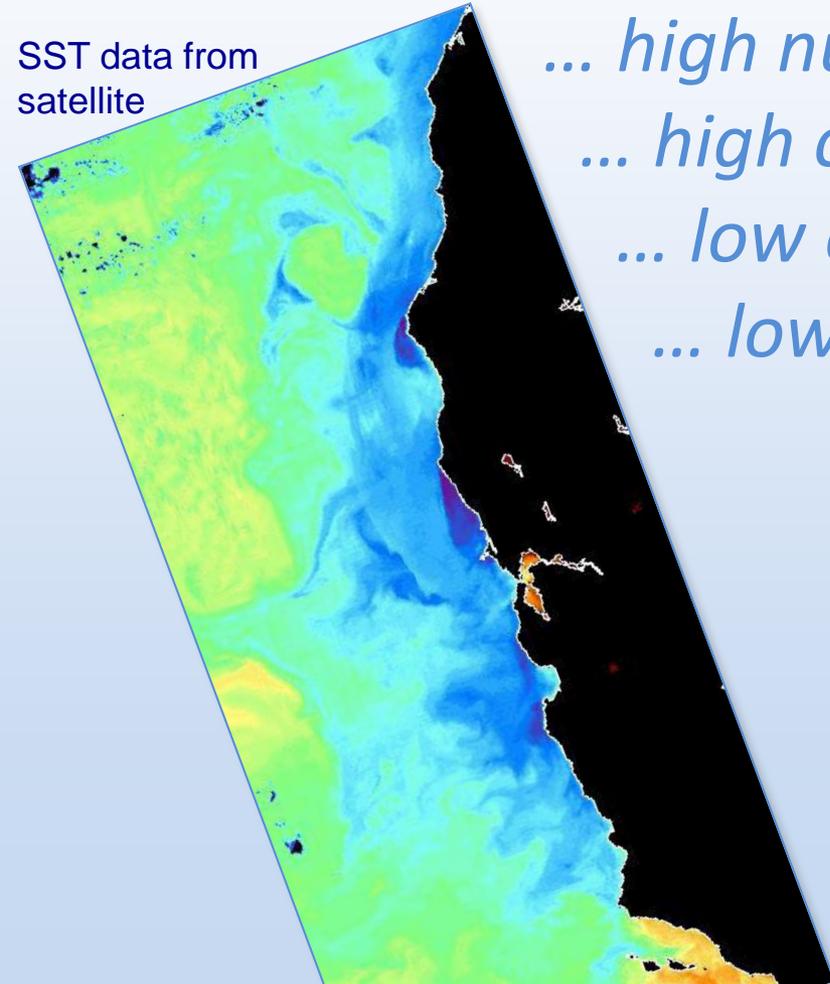
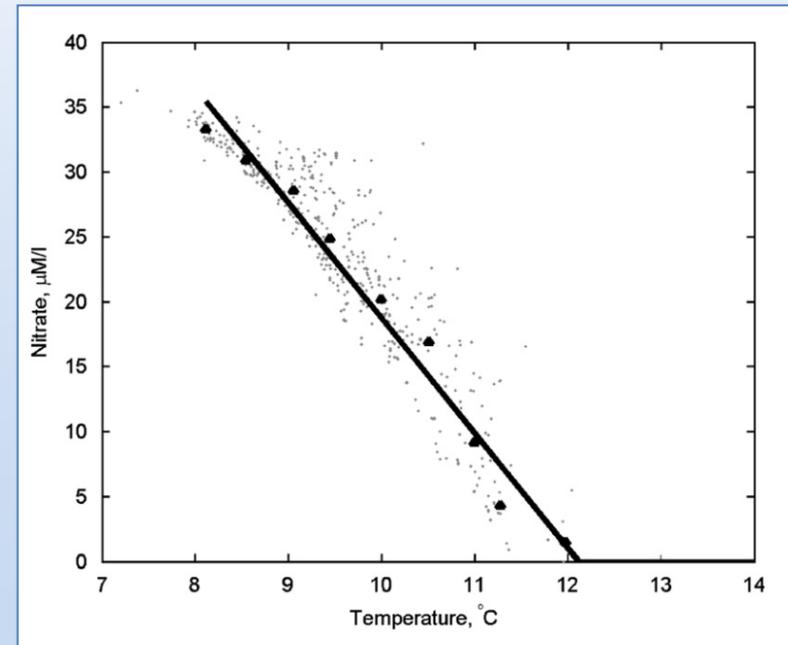
Coastal Upwelling Process

*Cold waters from ocean depths;
upwelled waters are enriched.*

*... high nutrients
... high carbon dioxide
... low oxygen
... low pH*



Nitrate vs Temperature

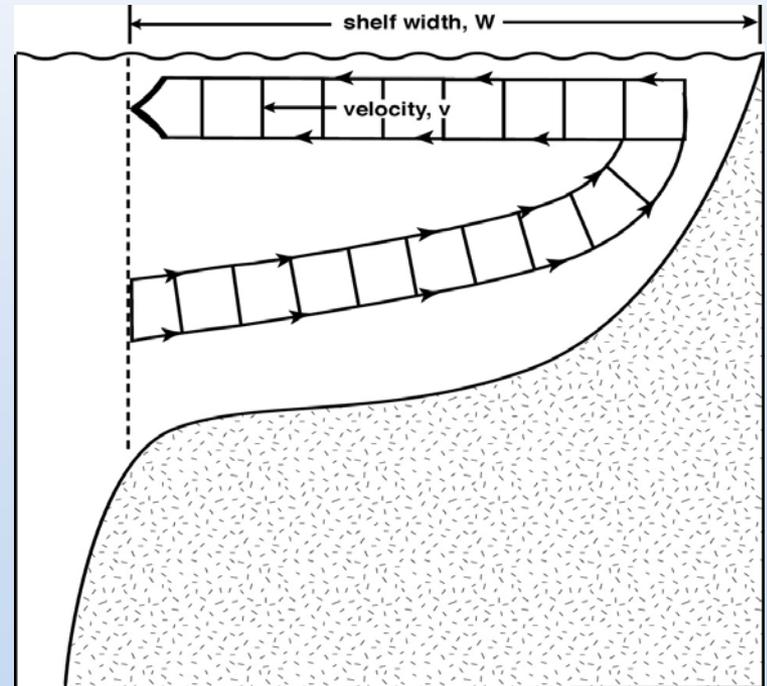


Ecosystem Response

High-nutrient waters upwelled into euphotic zone near the coast – phytoplankton bloom develops as surface water advected offshore in Ekman layer.



Photo of newly upwelled waters,
Cape Town (South Africa)

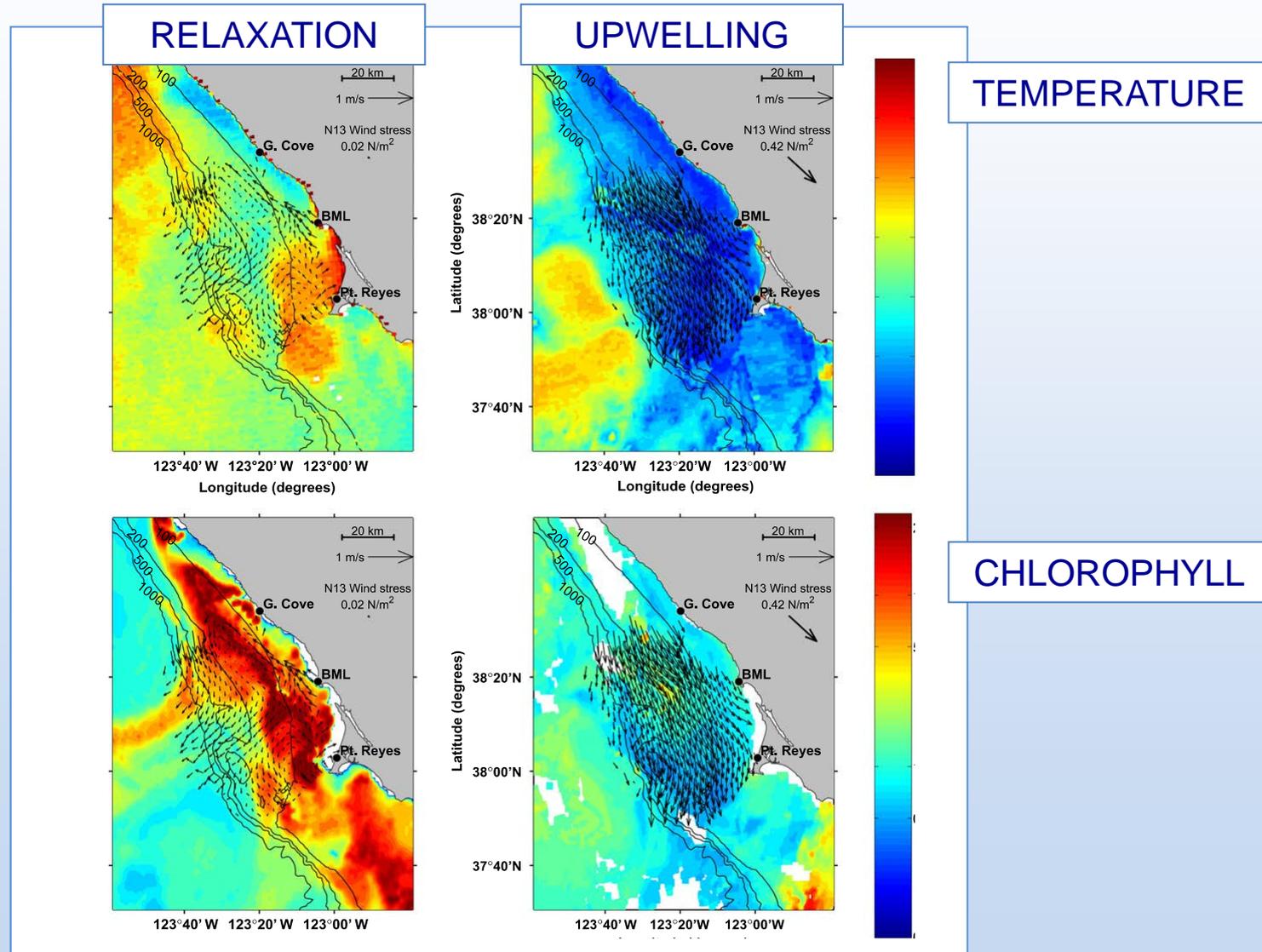


Ecosystem built on plankton.

Supports large numbers of fish, birds, mammals ...

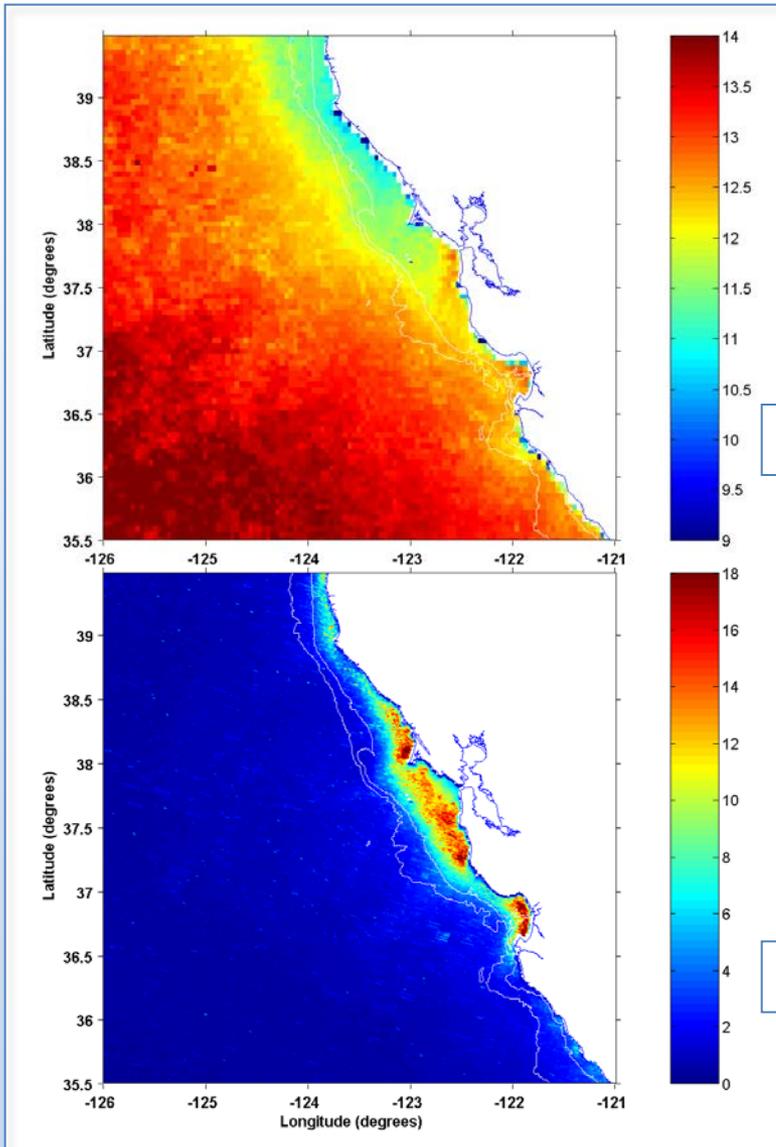
Upwelling & Phytoplankton Vary

“Synoptic Variability” ... upwelling and relaxation events



Ocean Climate

*What do we expect?
What is the typical pattern?*



TEMPERATURE

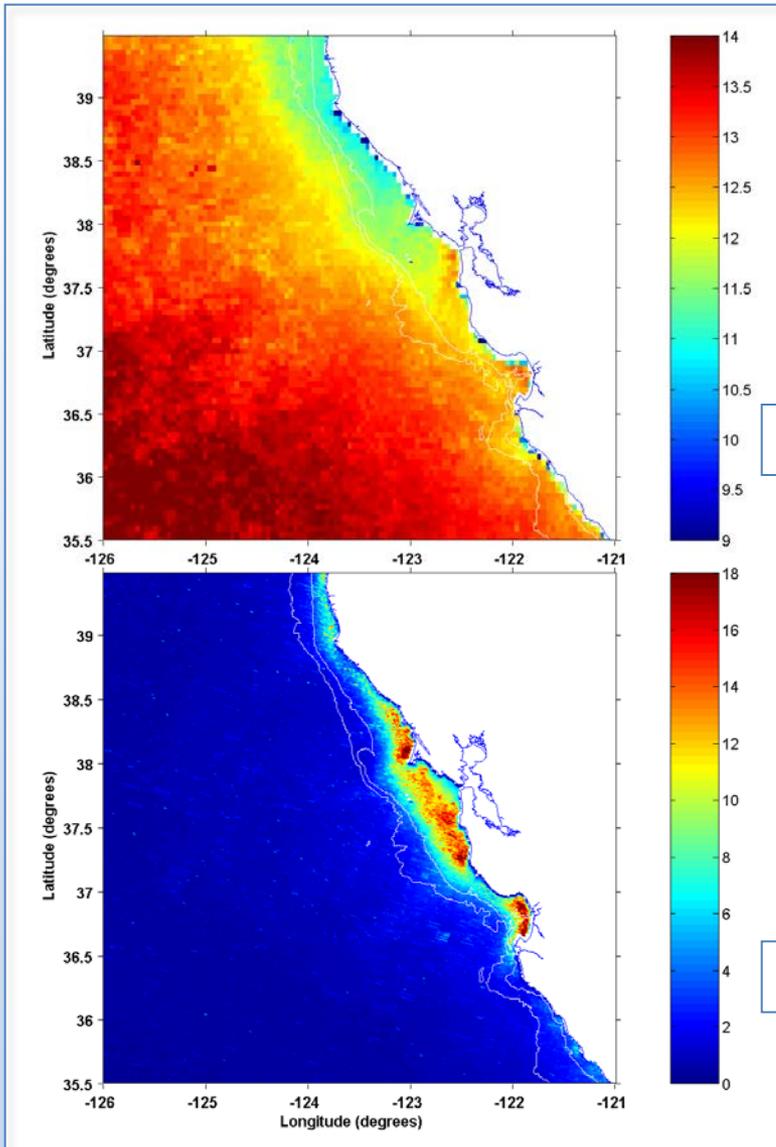
CHLOROPHYLL

5-year average data of surface data from satellite

Ocean Climate

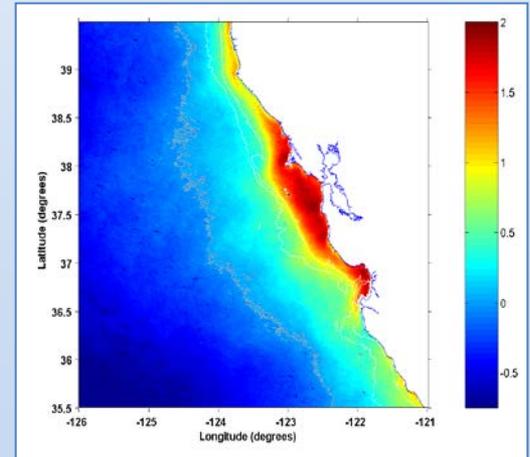
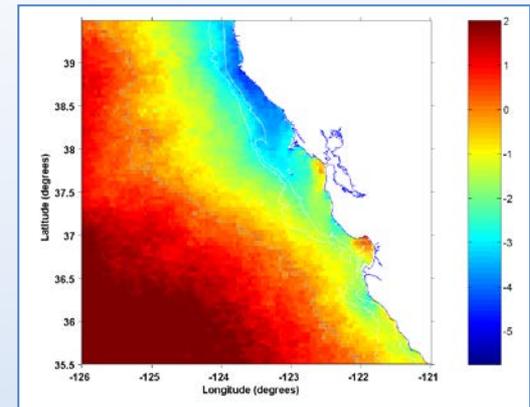
What do we expect?

What is the typical pattern?



TEMPERATURE

CHLOROPHYLL



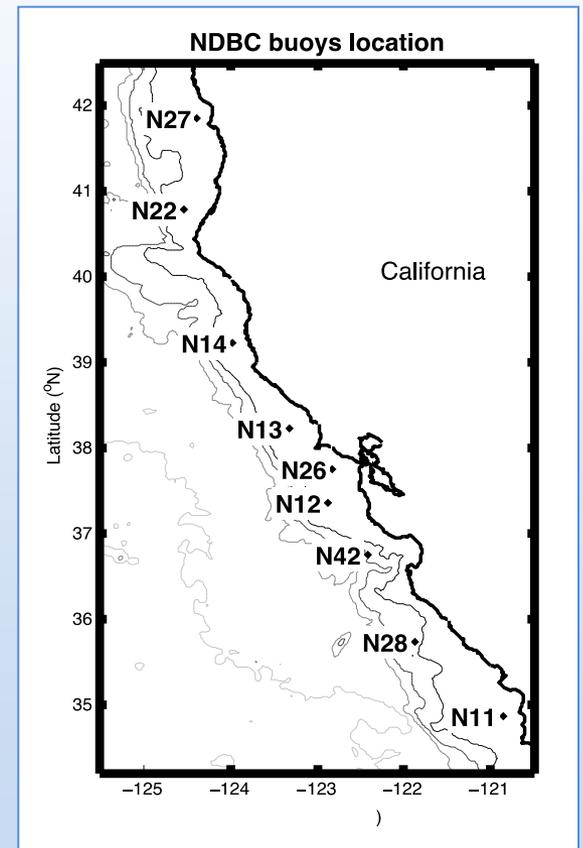
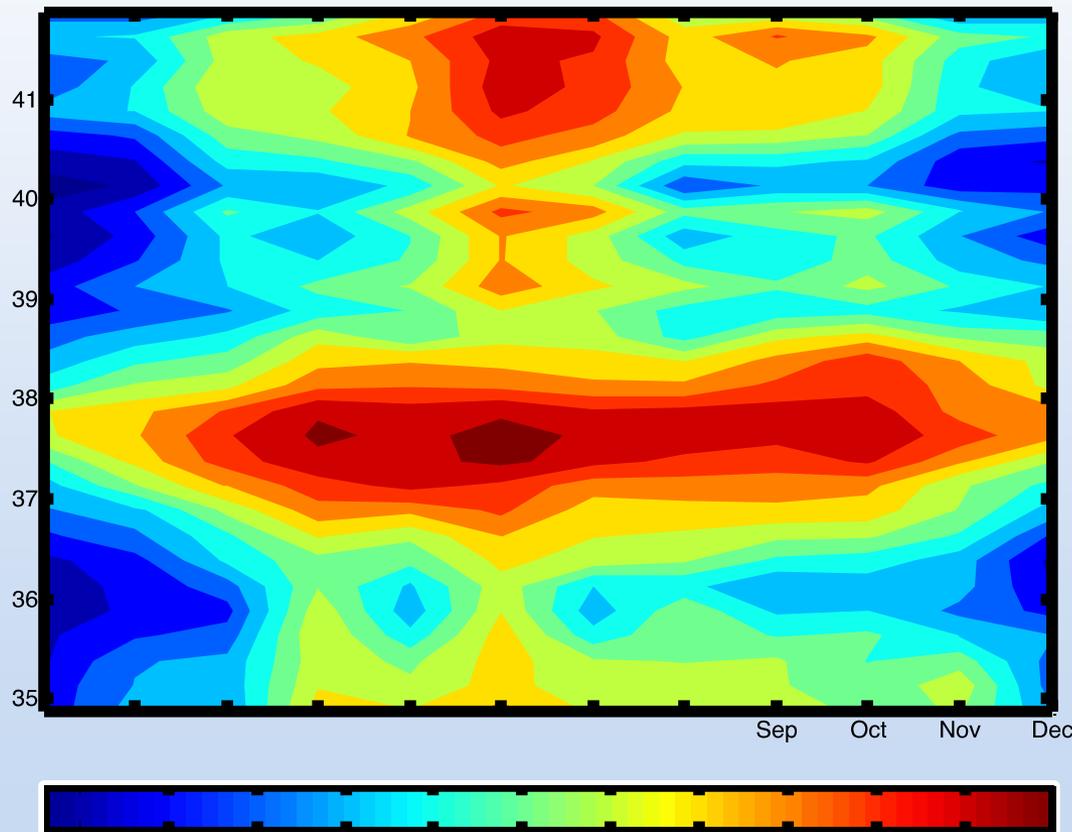
EOF
34%
49%

5-year average data of surface data from satellite

Ocean Climate

What to expect ... seasonal climatology vs latitude

Surface chlorophyll concentration (pelagic habitat)

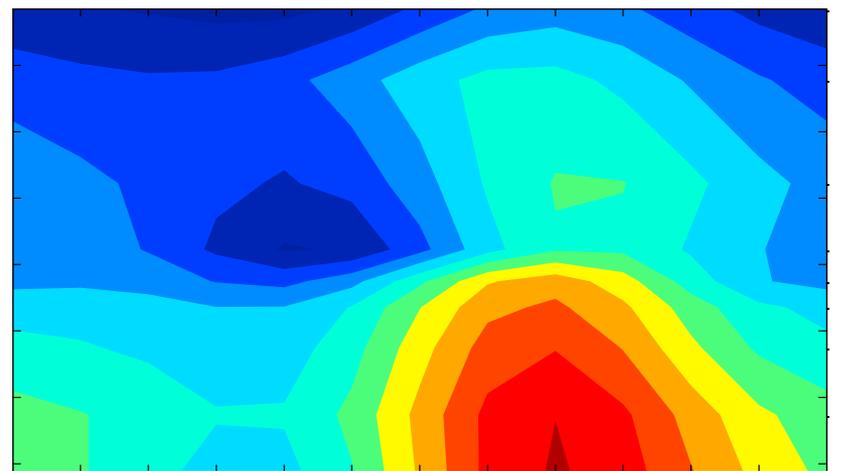
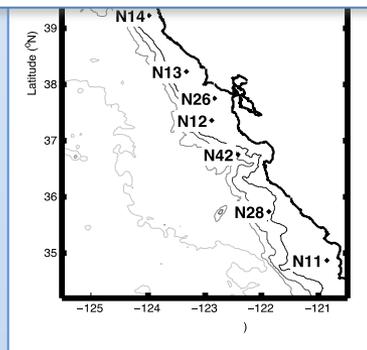
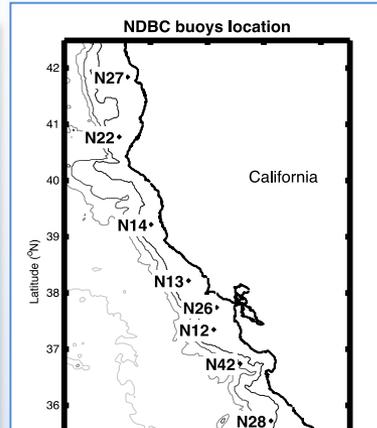
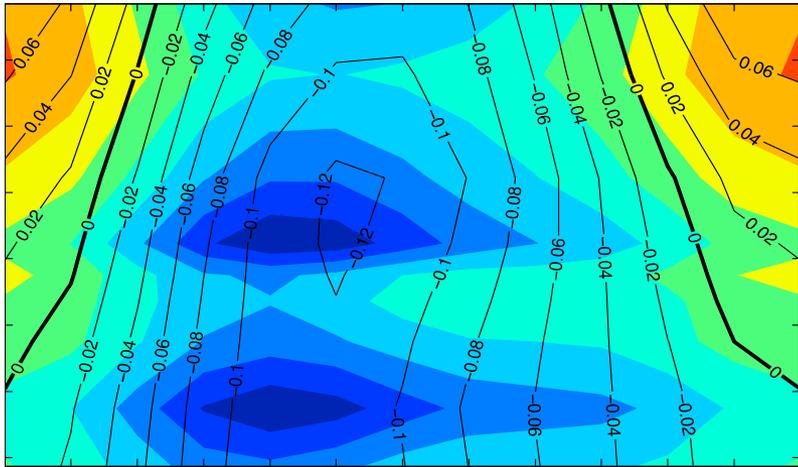


Garcia-Reyes & Largier 2012

Monthly average data on surface chlorophyll from satellite

Ocean Climate

Seasonal climatology of wind and temperature.



Monthly average data
on winds and SST from
moored buoys

But, the times are a-changin ...

CLIMATE CHANGE

- Greenhouse gas emissions*
- Surface warming, stratification, deoxygenation ...*
- CO₂ invasion, ocean acidification ...*
- Intensification of upwelling*
- Land runoff (via San Francisco Bay)*
... and parallel locally driven changes in runoff, plastics, etc.

Many Changes in the Ocean

Sanctuary “Climate Change Impacts” ... Largier et al (2010)

Physical Effects of Climate Change

Changes in sea level, temperature, precipitation, runoff, winds, waves, ocean pH, ...

Responses in Biological Processes

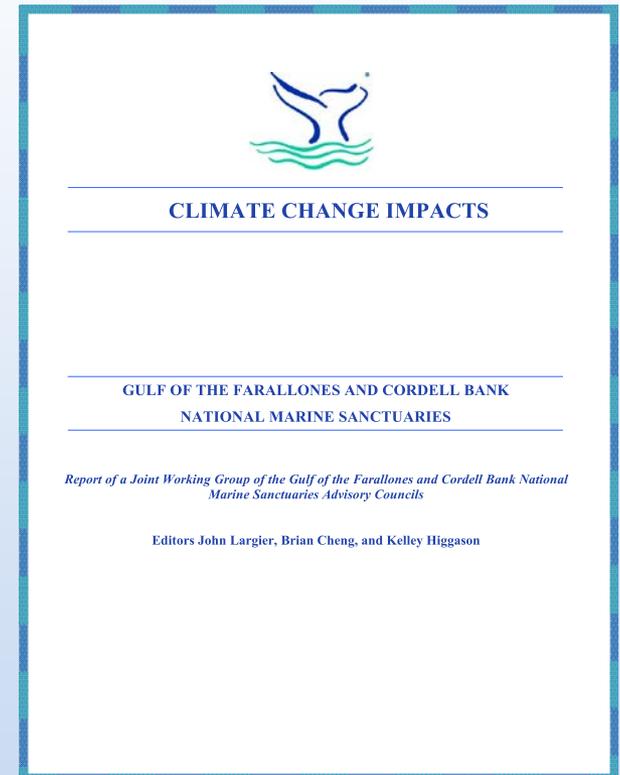
Changes in physiology, distributions, timing, connectivity, ...

Responses in Marine Organisms

Changes for specific marine populations
– multiple influences on each

Responses in Ecological Communities

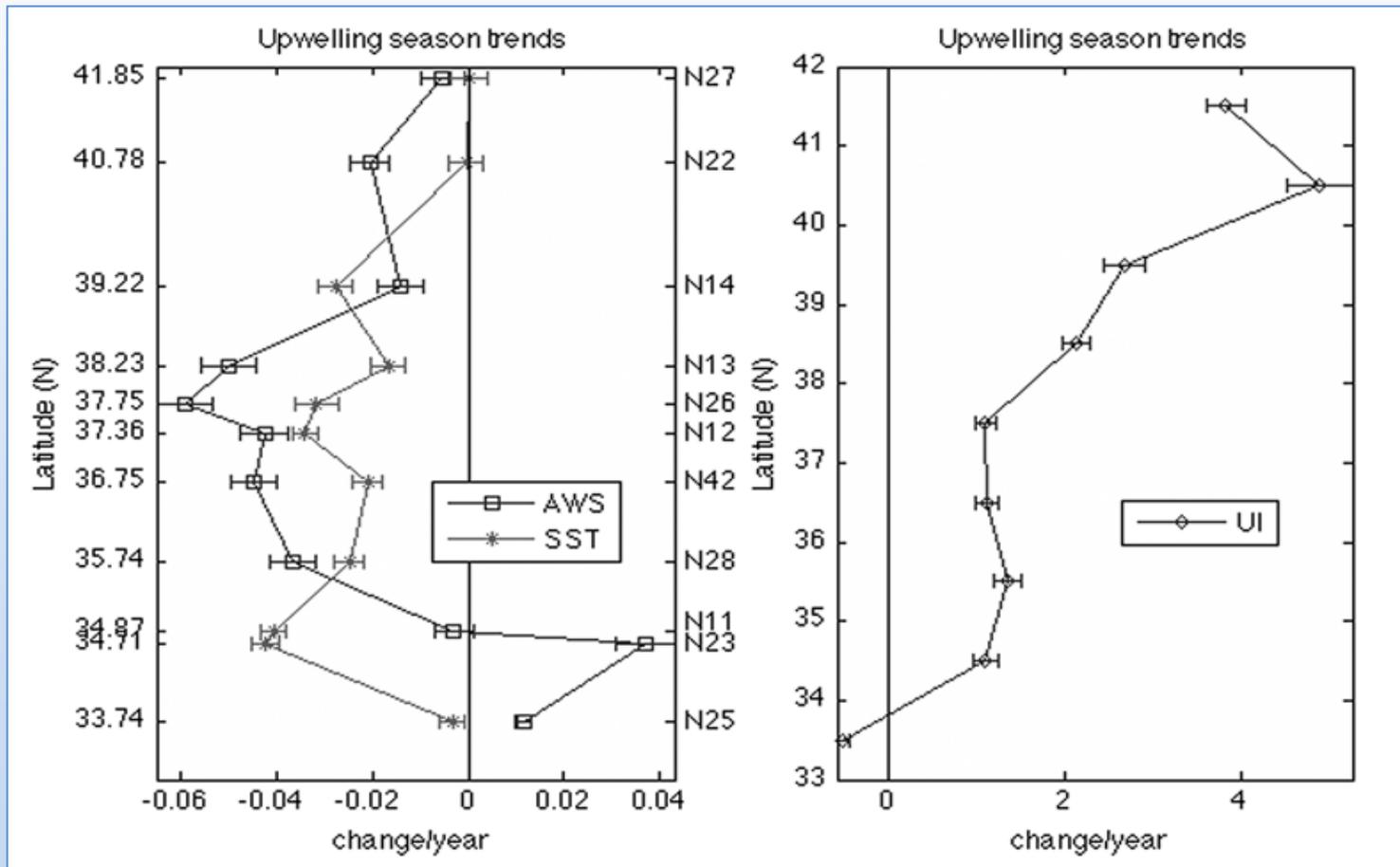
Changes for specific habitat
– multiple influences & multiple interacting species



Focus #1. Upwelling Intensification

3-decade trend of increased upwelling

... stronger winds & more upwelling days & colder water

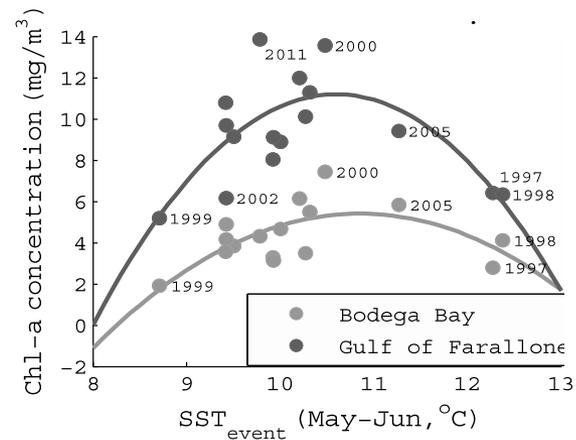


Wind data
SST data
from moored
NOAA buoys

Plankton Productivity vs Upwelling

Upwelling trade-off ... nutrients vs export

Too much of a good thing?



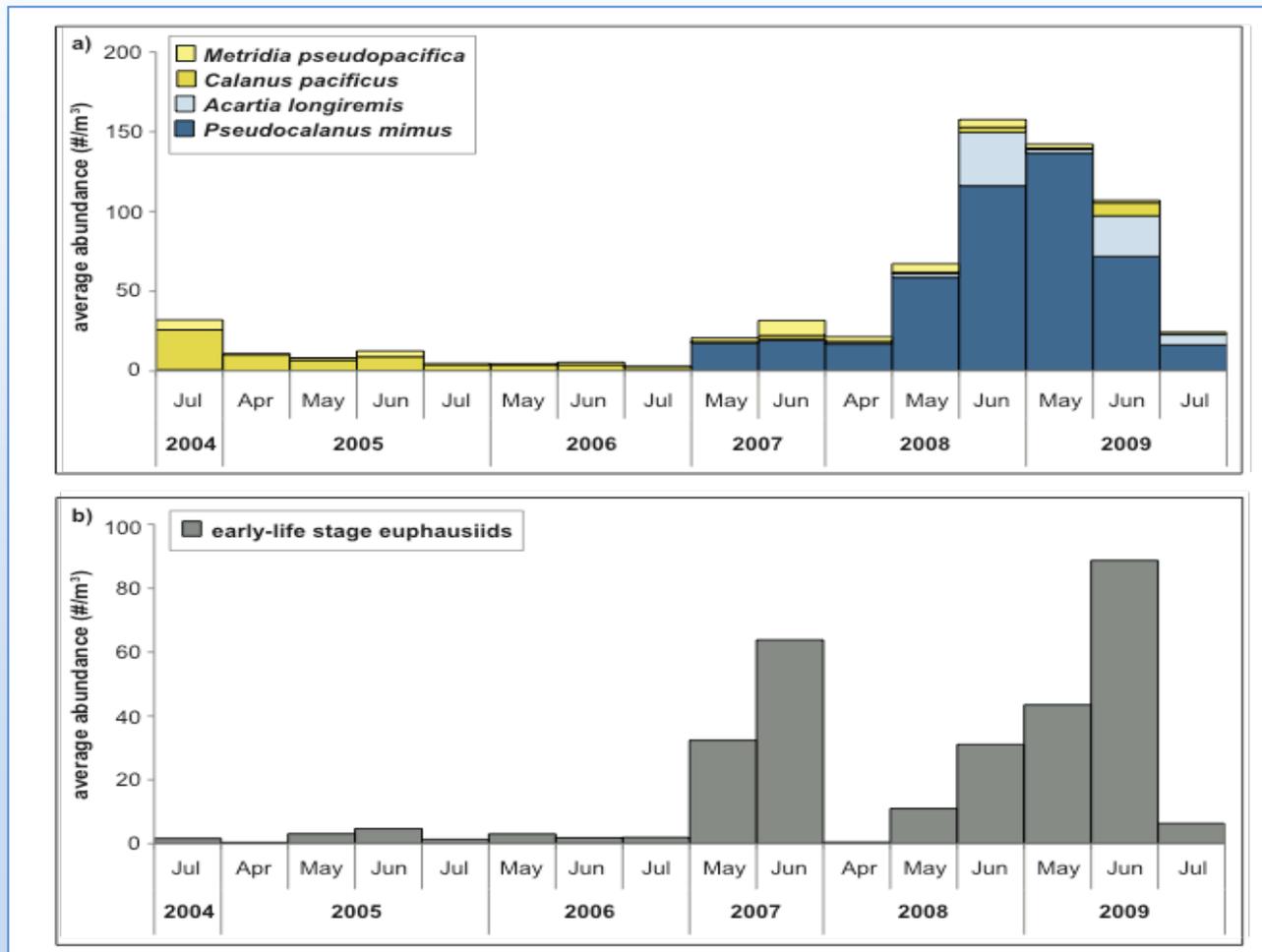
CHLOROPHYLL

KRILL

STRENGTH OF UPWELLING

Plankton Productivity vs Transport

Fat copepods imported by alongshore transport when winds are strong



Focus #2. Deoxygenation

Hypoxic waters upwell to coast during wind events, but this is new ... shoaling of OMZ & intensified upwelling.

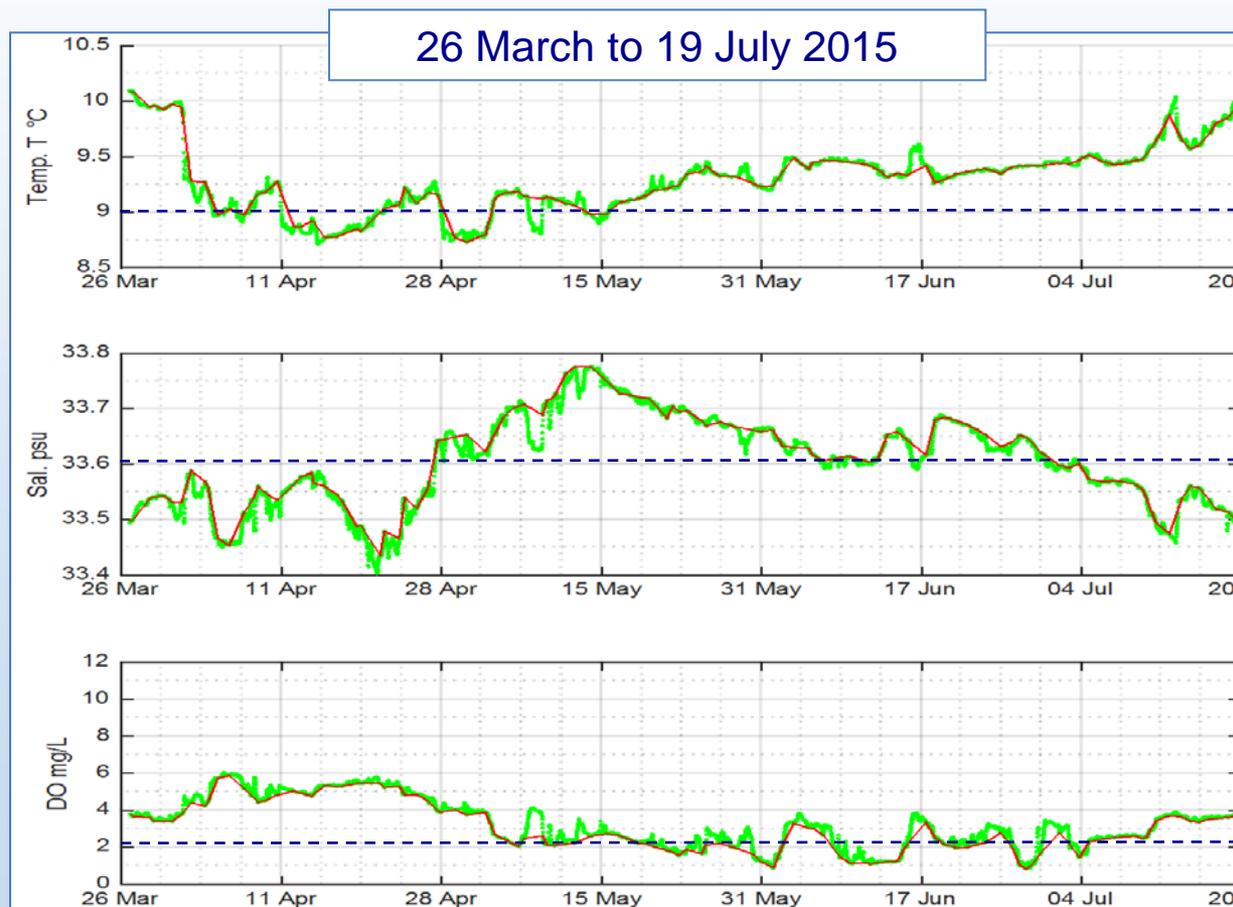
Bottom water
in Gulf of
Farallones
(2015)

$T = 9^{\circ}$

$S = 33.6$

Local uptake?

$DO = 2 \text{ mg/L}$



Focus #3. Ocean Acidification

Upwelling of enriched waters – now more enriched!

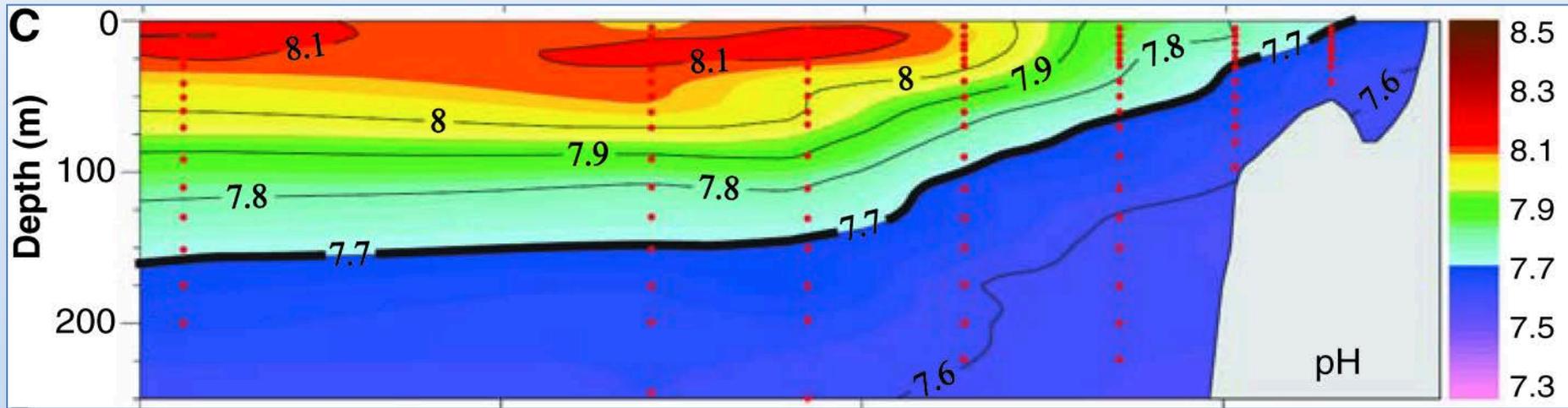
... stronger upwelling, digging deeper

... increased CO₂ when last at surface (decades ago)

... changes in respiration/decomposition along aphotic pathway

... local effects

Plot of pH levels – $\Omega \sim 1$ at pH ~ 7.7



Feely et al 2008

Focus #3. Ocean Acidification

Not just pH ... changing carbonate chemistry.

Affects shell-forming organisms

(e.g., pteropods & oysters)



Aragonite saturation used to quantify carbonate availability

$\Omega > 1$ shells can form

$\Omega < 1$ difficult to form shells

There are several OA measures: pH, Ω , $p\text{CO}_2$, alkalinity ...

***Spatial pattern** – ocean vs coast; upwelling centers*

***Temporal pattern** – upwelling season & events*

Temperature plots give an idea of patterns of exposure

Climate Trends and Climate Fluctuations

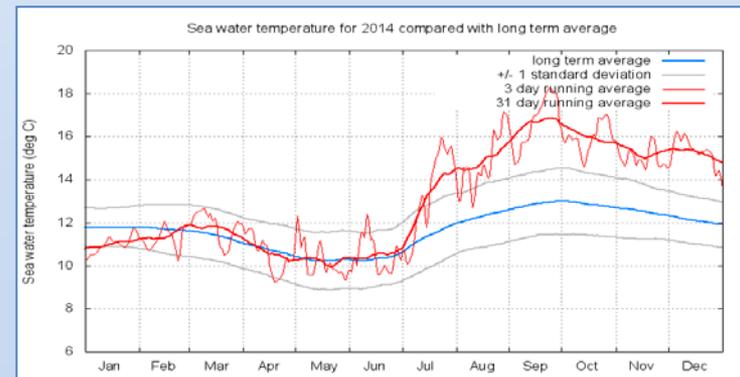
Long-term **climate trends**: ocean acidification, deoxygenation, upwelling intensification, offshore/bay warming – plus ...

Climate fluctuations

- *El Nino Southern Oscillation (ENSO)*
- *Pacific Decadal Oscillation (PDO)*
- *North Pacific Gyre Oscillation (NPGO)*

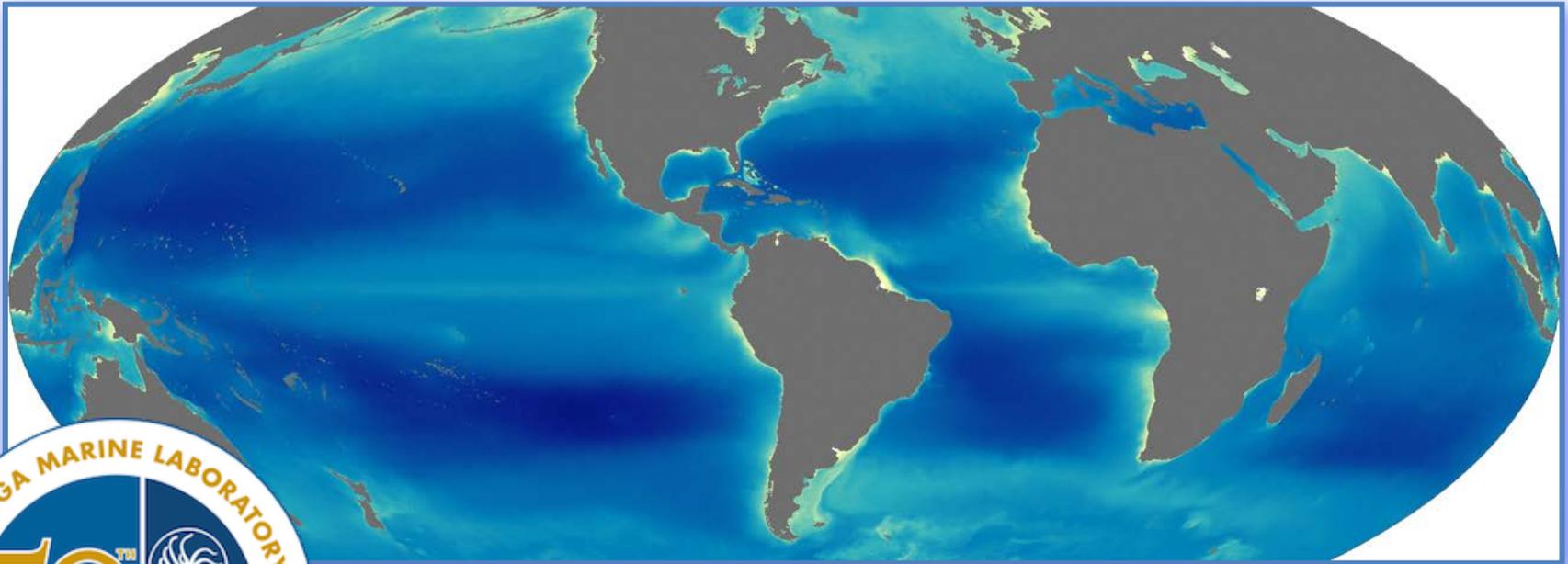
And climate anomaly “events”

- *Delayed upwelling in 2005*
- *NE Pacific “warm blob” 2014-15*



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