An Overview of the Modeling Program for Reanalysis Simulations and their Validation, Climate Change, Eutrofication, Hypoxia, Acidification, and Habitat Constraints along the U.S. West Coast

Jim McWilliams, Curtis Deutsch, Lionel Renault, Daniele Bianchi et al.
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A progress report after ~ 5 years by our team, building on a decade of development for realistic, equilibrium regional simulations.

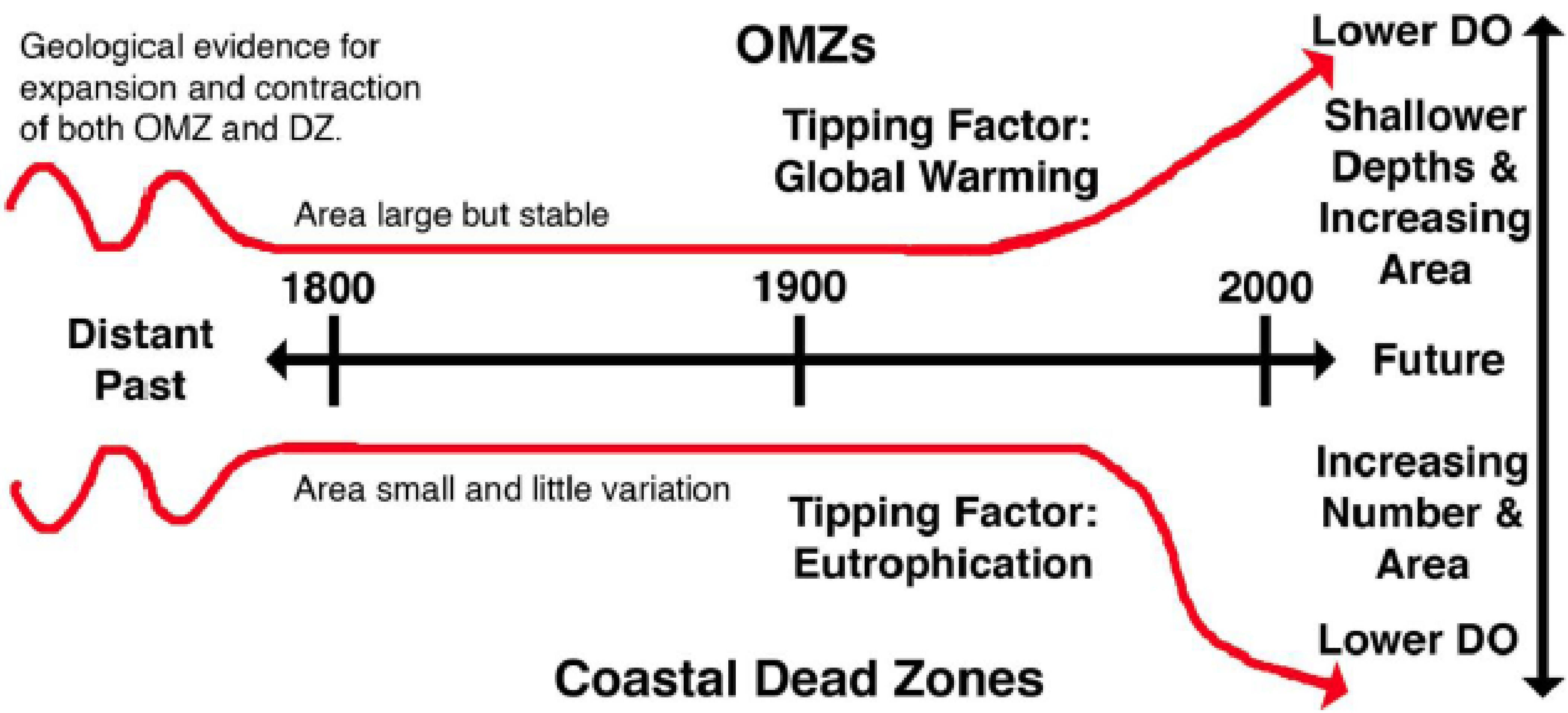
Sponsored by NOAA, NSF, and the CA Ocean Protection Council.

Based on our physical Regional Oceanic Modeling System (ROMS) and Biogeochemical Elemental Cycling (BEC) codes,

with coupling to the Weather Research and Forecast (WRF) and WaveWatch 3 (WW3) models and with initial- and boundary-conditions from various satellite and hydrographic data sets and global reanalysis simulations.

As part of climate change, the oceans are warming and stratifying, dissolved oxygen is decreasing, and corrosiveness for calcium carbonate (shells) is increasing. By extraction (fishing) species diversity is being depleted and habitats disrupted. As by-products of agricultural, industrial, and urban pollution, coastal hypoxia and algal toxicity are also increasing.

Oxygen Minimum Zones (at depth)



Rabalais et al (2010)

Eastern Boundary Upwelling Systems (e.g., California Current)

One of the most biologically productive regions of the world ocean, but seasonal coastal upwelling of low oxygen and low-pH waters (i.e., Ocean Hypoxia and Acidification, OHA) make it particularly vulnerable to even small additional reductions in O_2 and/or pH.

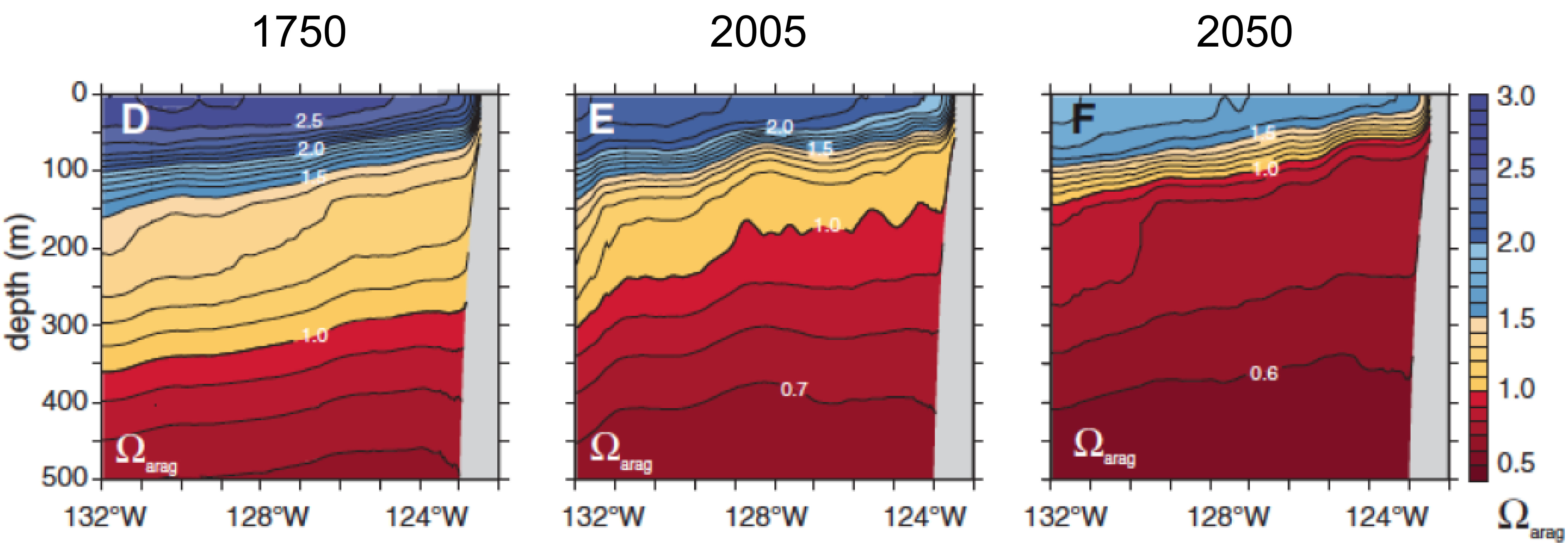
Three prominent coastal phenomena have been implicated:

(1) large-scale (global) acidification and deoxygenation of subsurface waters associated with global warming and increased CO_2;

(2) natural climate variability from years to decades;

(3) local anthropogenic pollution of coastal waters, especially from nutrients in waste-water discharges, agricultural run-off, and atmospheric pollution deposition.

Simulated Acidification in the California Current



Cross-shore sections of Ω, the saturation sate of aragonite.

$\Omega < 1$ (red) implies undersaturation and dissolution of CaCO3 shells.

This predicts corrosive waters will frequently come to the surface and shoreline by mid-century.

Gruber et al (2012)

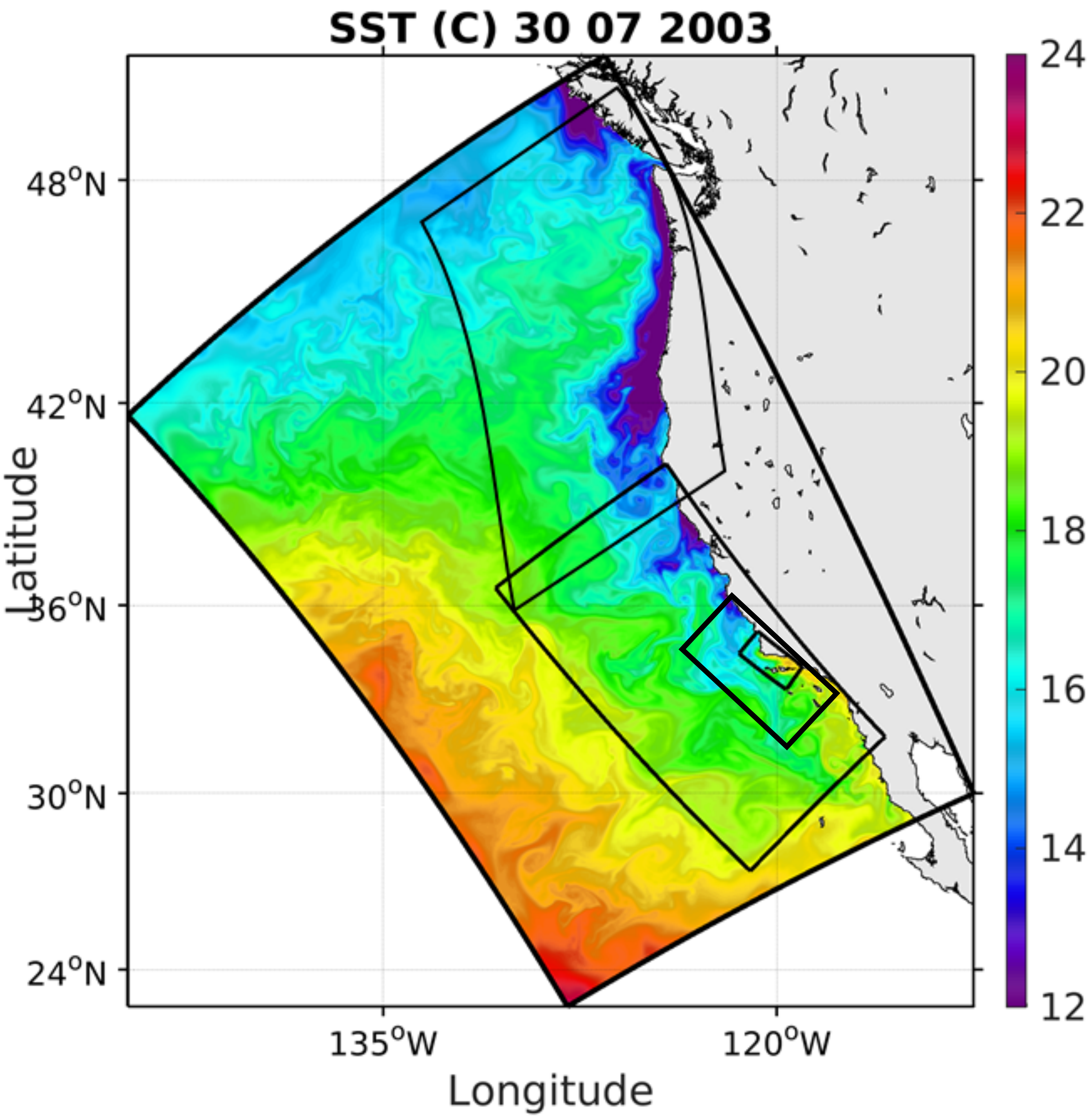
Model Developments

Many elements are needed to make a realistic circulation and biogeochemical-ecological system model. Some were previously pioneered, but for the basic configuration, we have had to make several new developments with significant impact:

- spatial patterns of wind, especially weakening near the coast
- wind-current and wind-SST feedbacks on the eddy scale
- material fluxes by mesoscale eddies and by submesoscale fronts and wakes
- cloud-mediation of photosynthetic light
- regional river and anthropogenic forcing

Further developments are underway for particular processes.

Grid Nesting for Locally High Resolution,
e.g., Santa Barbara Channel & Point Conception



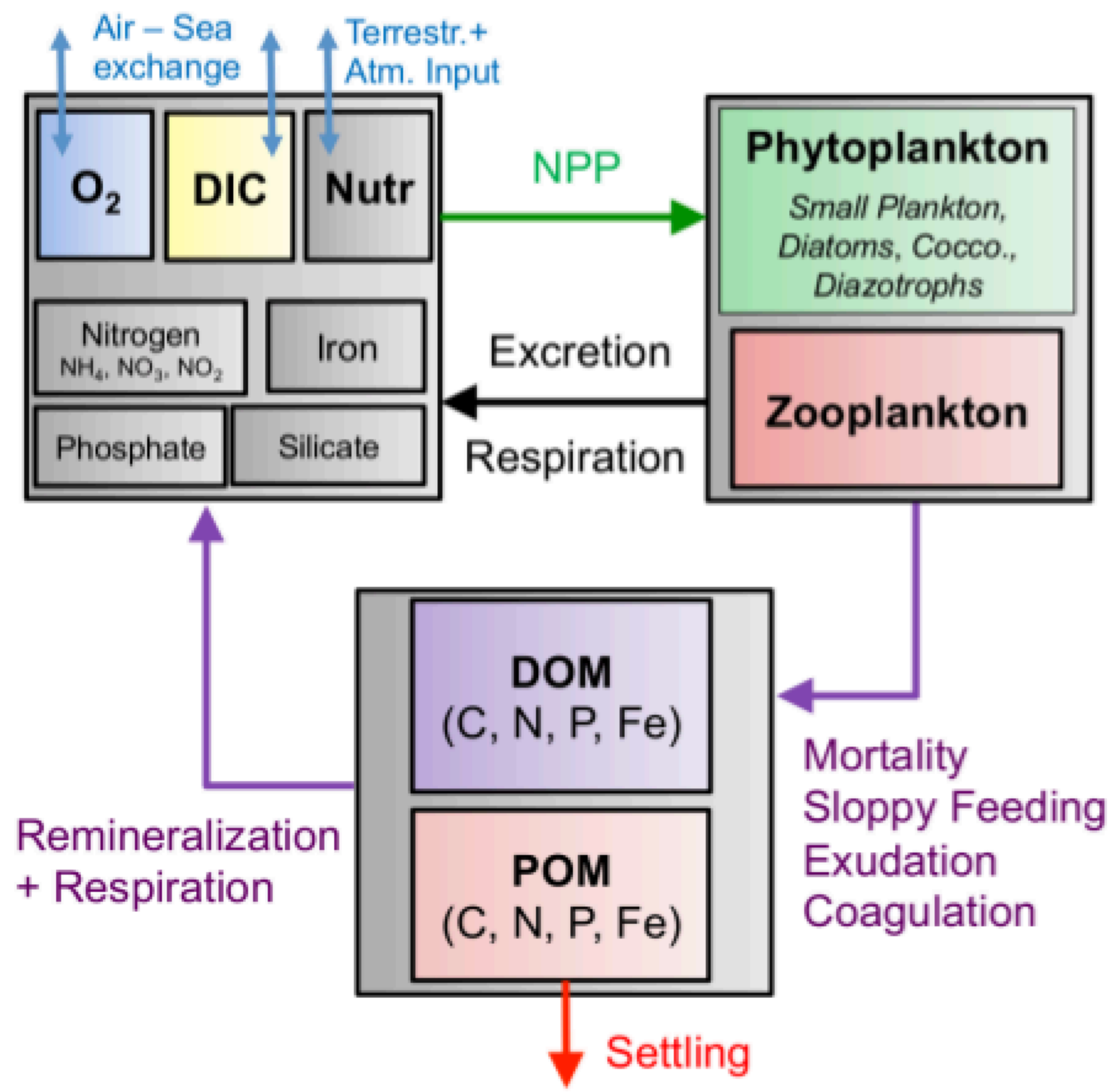
USWC Reanalysis & Validation (1995-2010 —> 2017)

Tests for approximate agreement with nature but fidelity of phenomena and relationships.

A regional ROMS+BEC simulation forced by regional atmospheric down-scaling with WRF. Grid dx = 4 km.

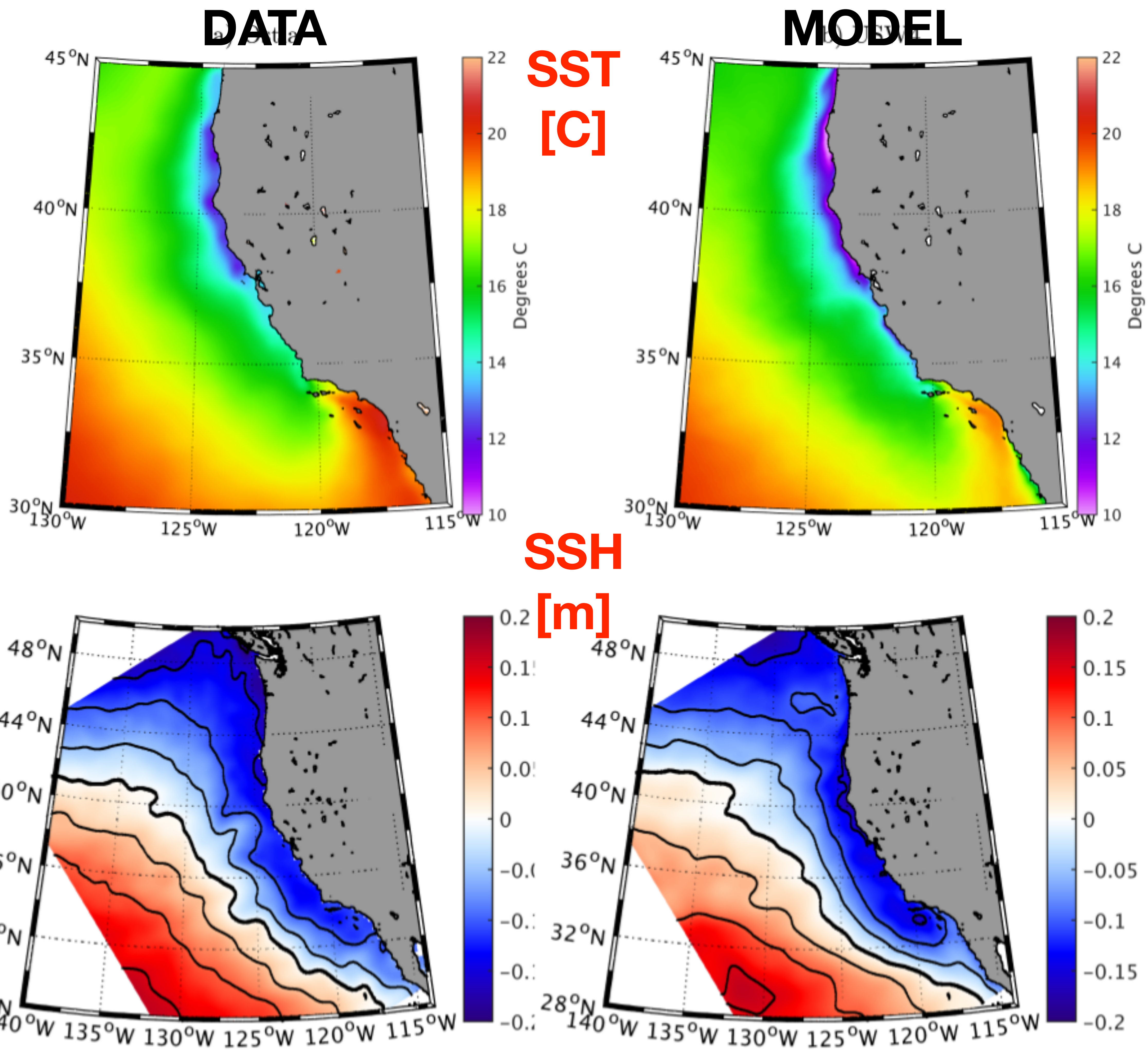
Comparisons against climatological hydrographic and satellite measurements over the whole U.S. West Coast to assess regional skill.

BEC schema



papers

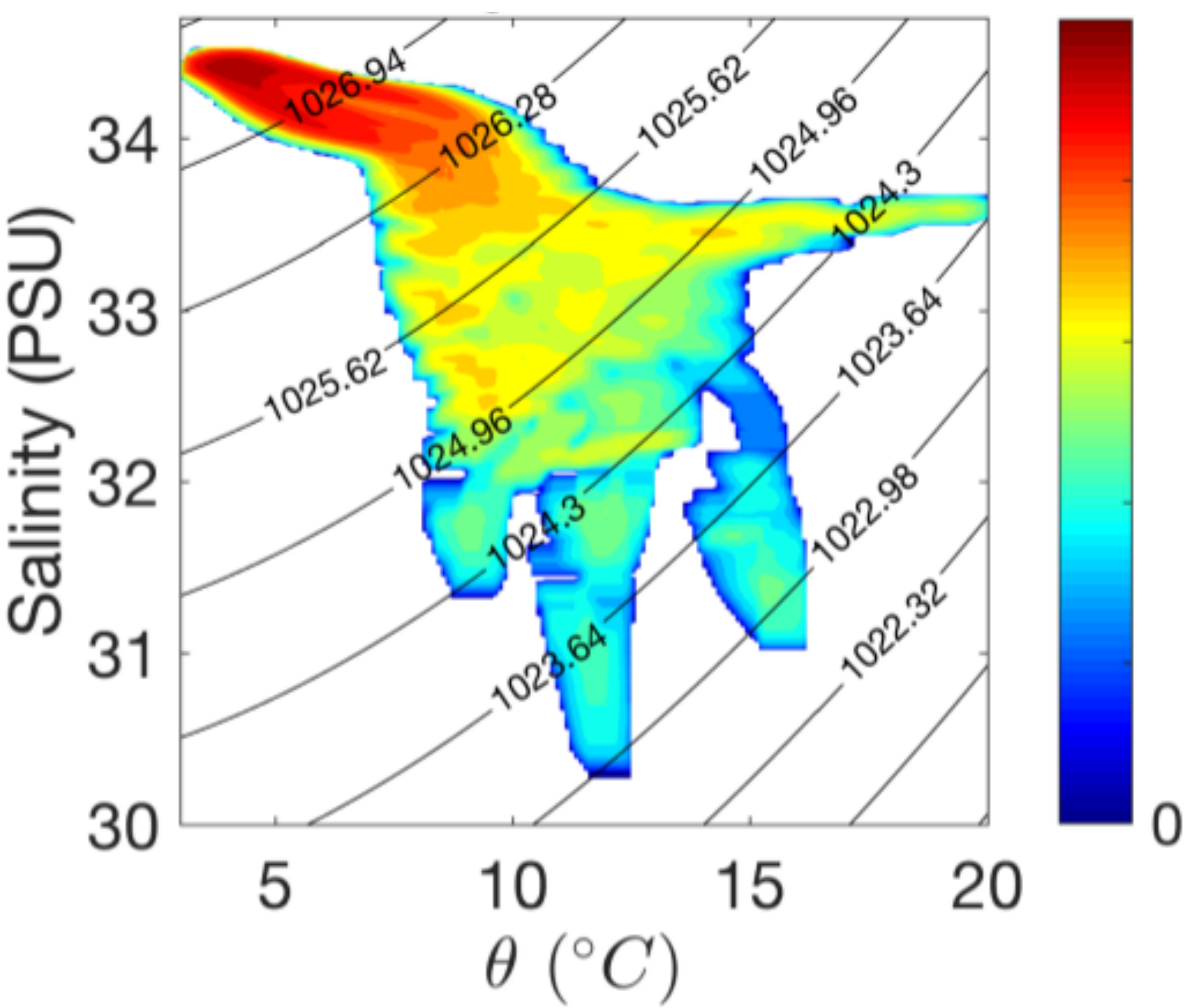
Renault et al., 2019: The physical structure and behavior of the California Current System.
Deutsch et al., 2019: Biogeochemical variability in the California Current System.

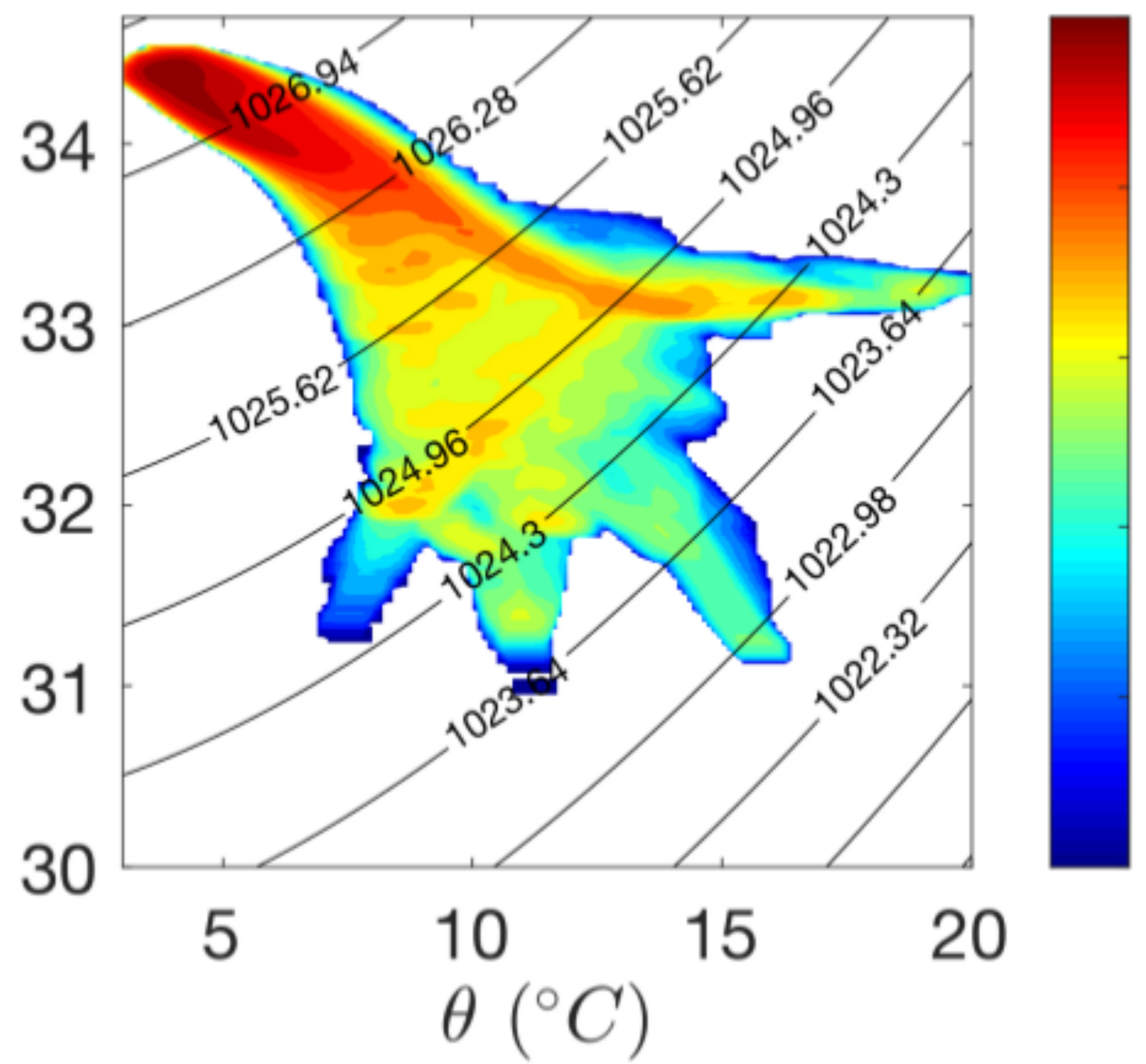

DATA
MODEL
SST
[C]
SSH
[m]
45°N
40°N
35°N
30°N
130°W
125°W
120°W
115°W
Degrees C
22
20
18
16
14
12
10
48°N
44°N
40°N
36°N
32°N
28°N
140°W
135°W
130°W
125°W
120°W
115°W
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2

Joint Probability Distribution of Interior T and S Values (water masses)

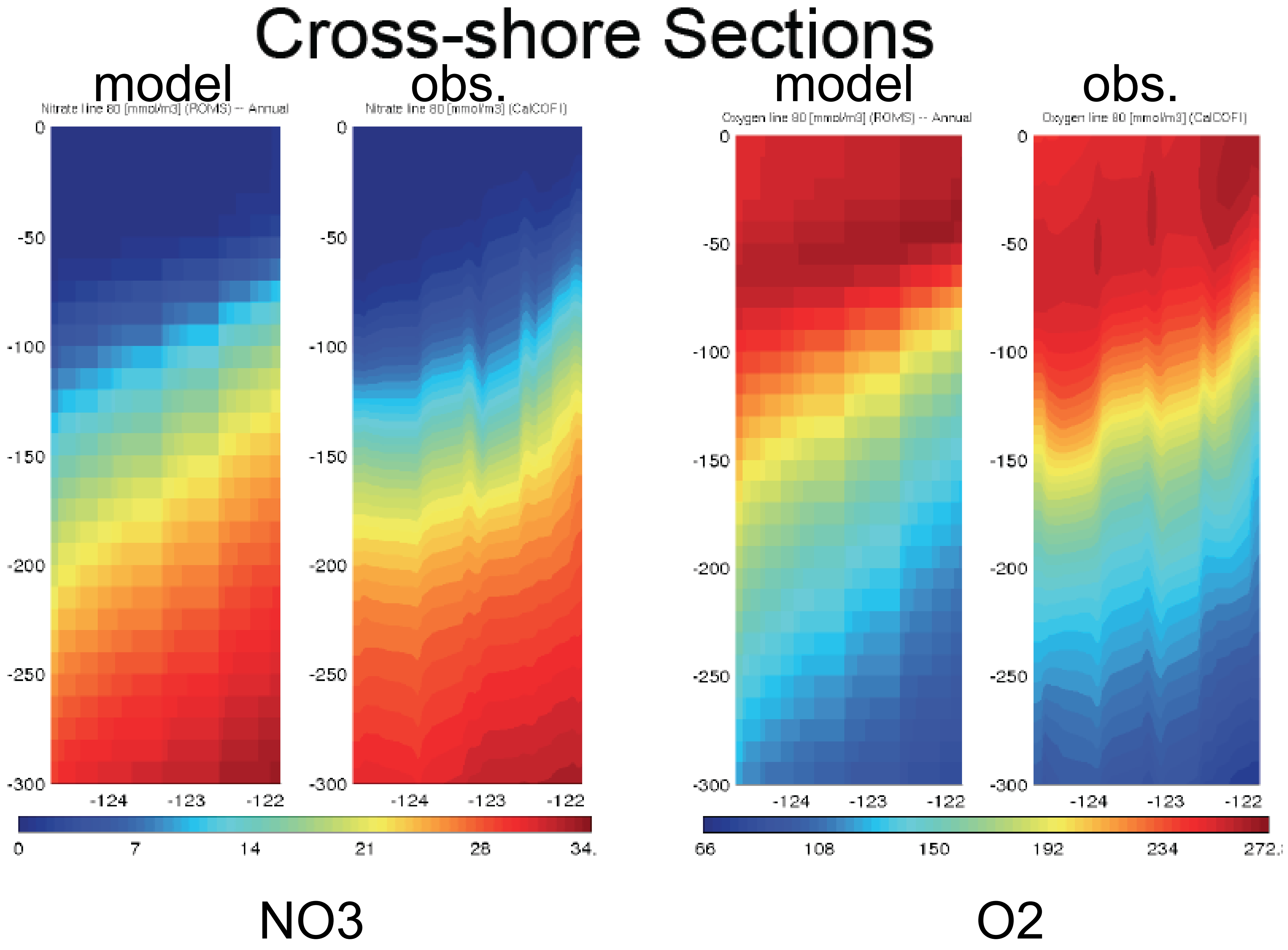
DATA

MODEL





model validation: mean NO3 and O2 on CalCOFI line 80

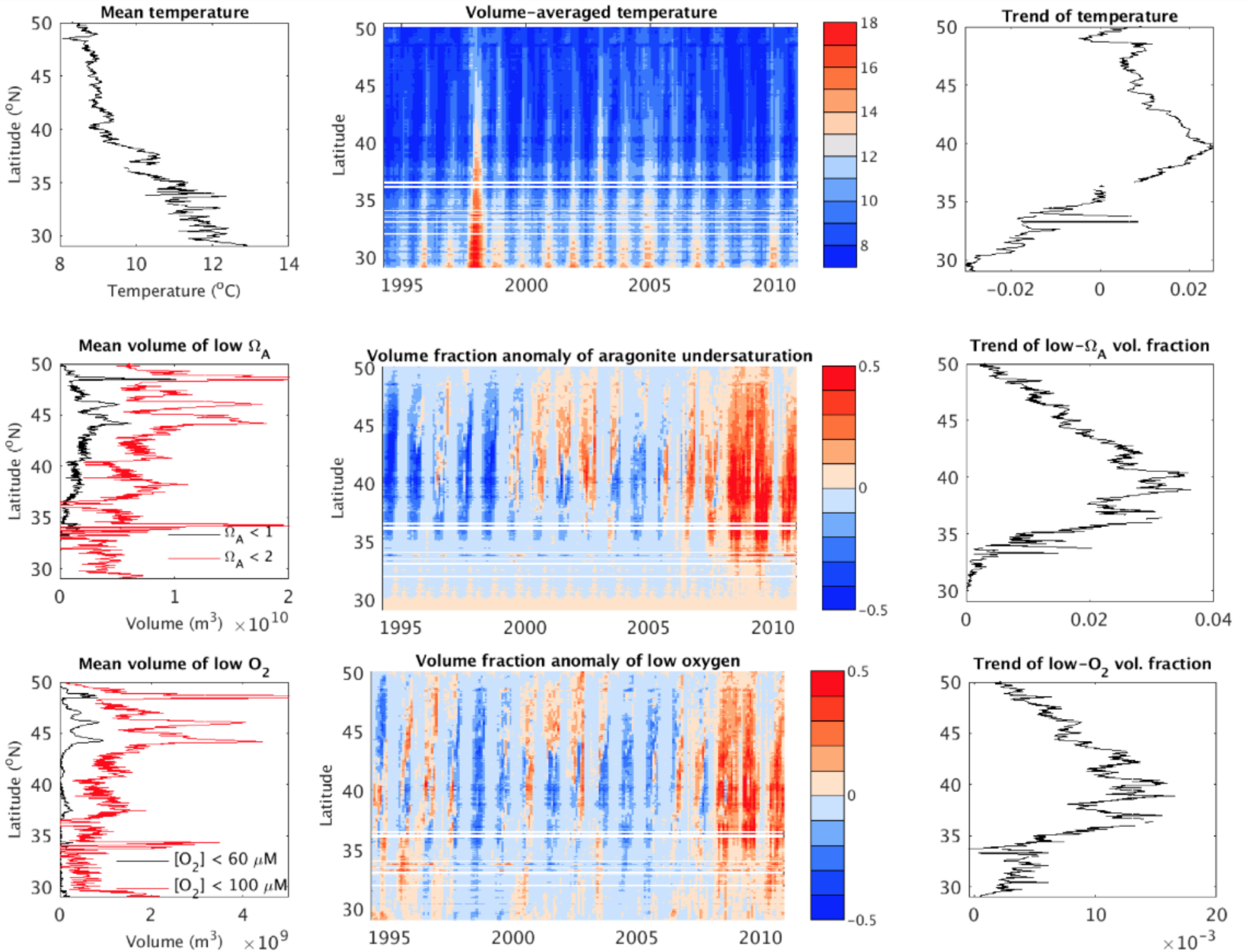


Deutsch et al (2017)

along-coast profiles

Time Series of T, O_2, Ω_A

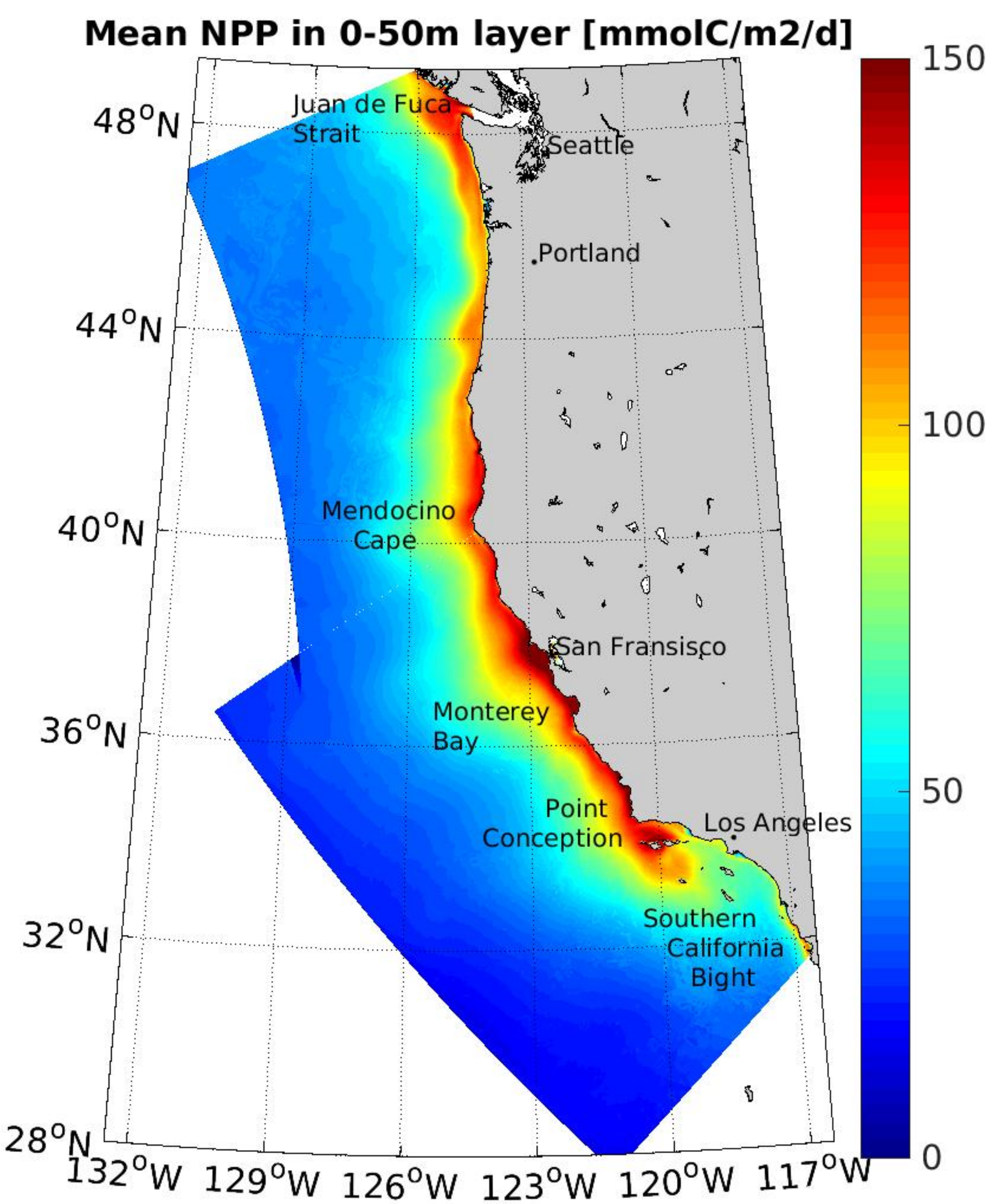
trends

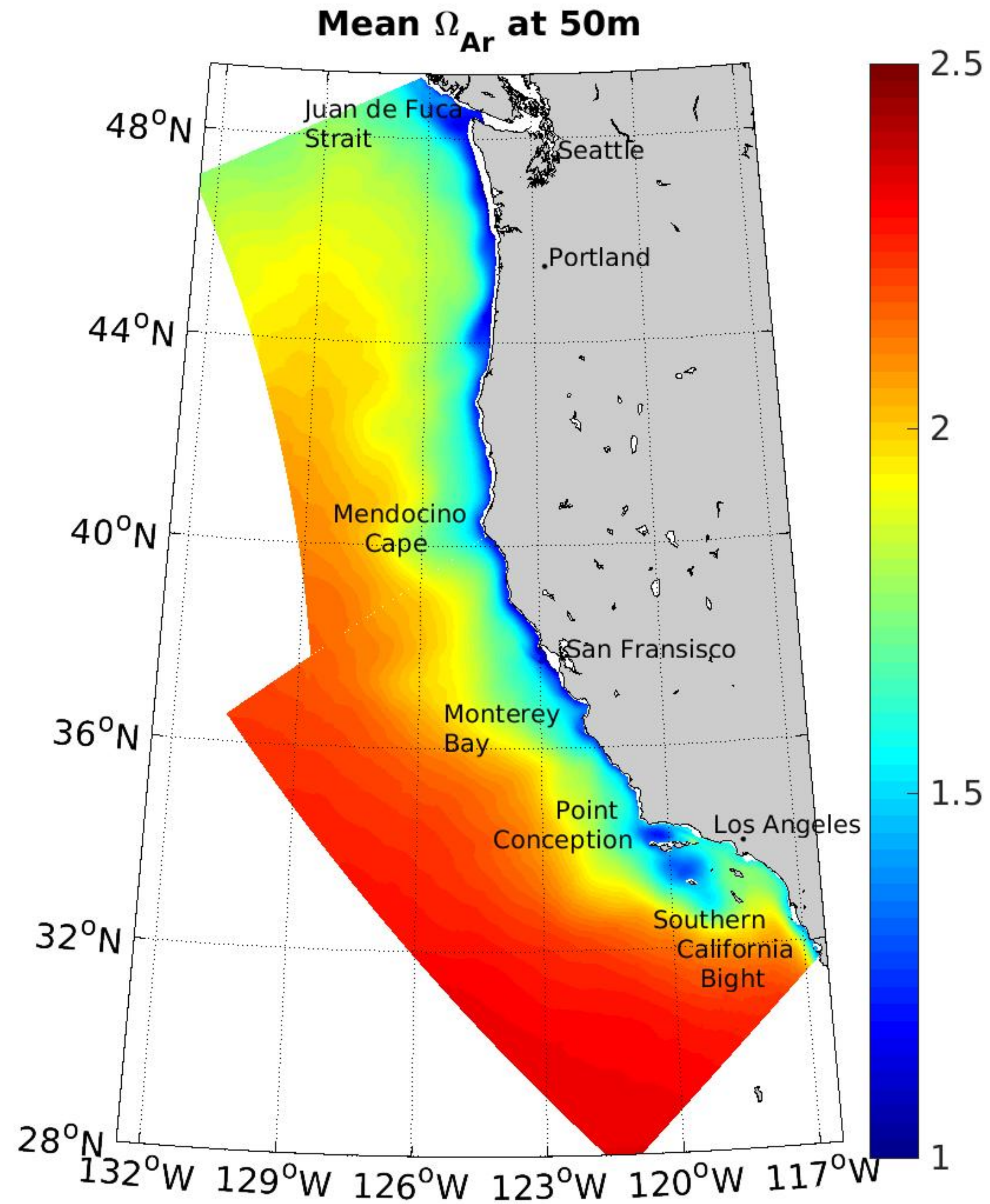


general approach: nested subdomains with higher resolution
—> importance of mesoscale and submesoscale eddy fluxes

for grid dx = 1 km in northern and southern nested grids

Flux Balances & “Hot Spots” for N, O, and C

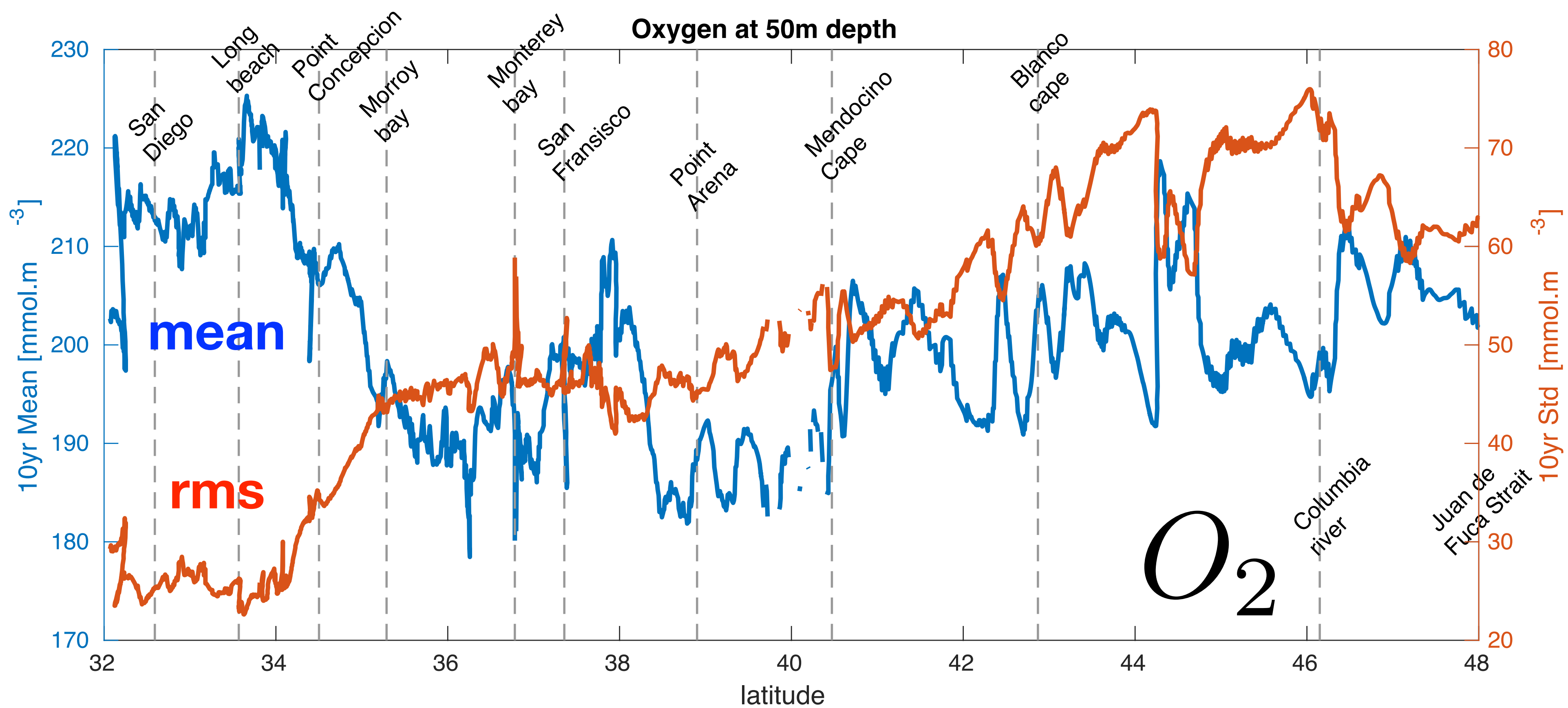




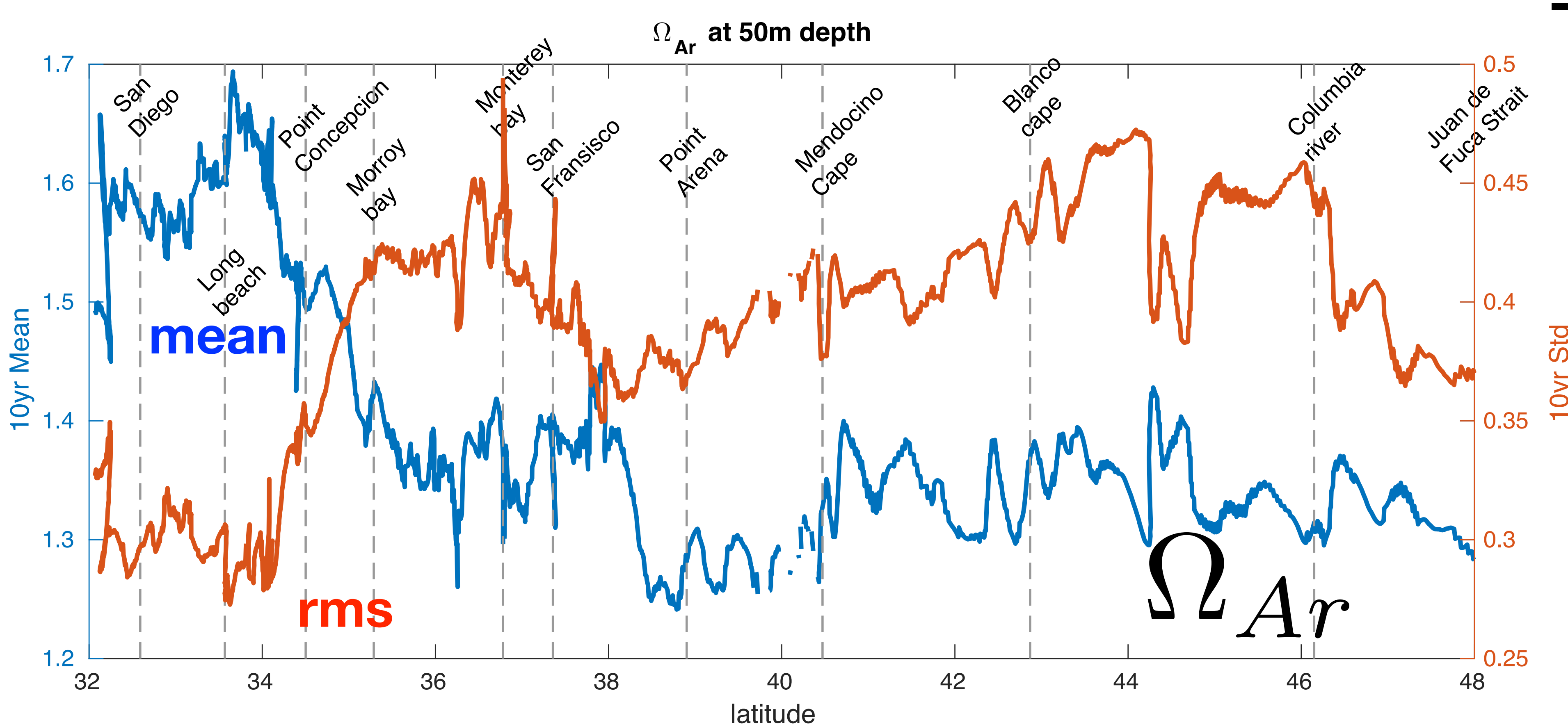
paper Kessouri et al., 2019: Submesoscale currents modulate the seasonal cycle of nutrients and productivity in the California Current System.

Natural Variability and Hot Spots/Events

at 50 m depth along the coast near the 100 m isobath



Mexico –> –> Canada



Future Climate Scenarios for the CCS: Attributing Mechanisms and Impacts

A mechanistic approach by adding separate perturbations to the reanalysis solutions representing ~ 100 year changes seen in 5 earth-system models (GFDL, MPI, IPSL, Hadley Center, NCAR)

1. winds

2. stratification (surface fluxes and lateral b.c. for T, S)

3. BGC tracers ("   "   "   for N, O, C)

4. photosynthetic light changes (clouds)

5. all together

==> Regional downscaling at grid dx =12 km leads to large-scale CCS changes not dramatically different from global models in upwelling, heating, productivity, hypoxia, and acidification. The global progression is regionally inescapable.

All four influences matter for the BGC, but the wind changes are most uncertain and have the least impact.

paper Howard, et al., 2019: Basin-scale water biogeochemistry and stratification changes are decisive factors in the response of the California Current System to climate change.

Regional Anthropogenic Pollution Impacts

Protocol: add local anthropogenic pollution forcing to a nested grid in the Southern California Bight with a grid size dx = 300 m.

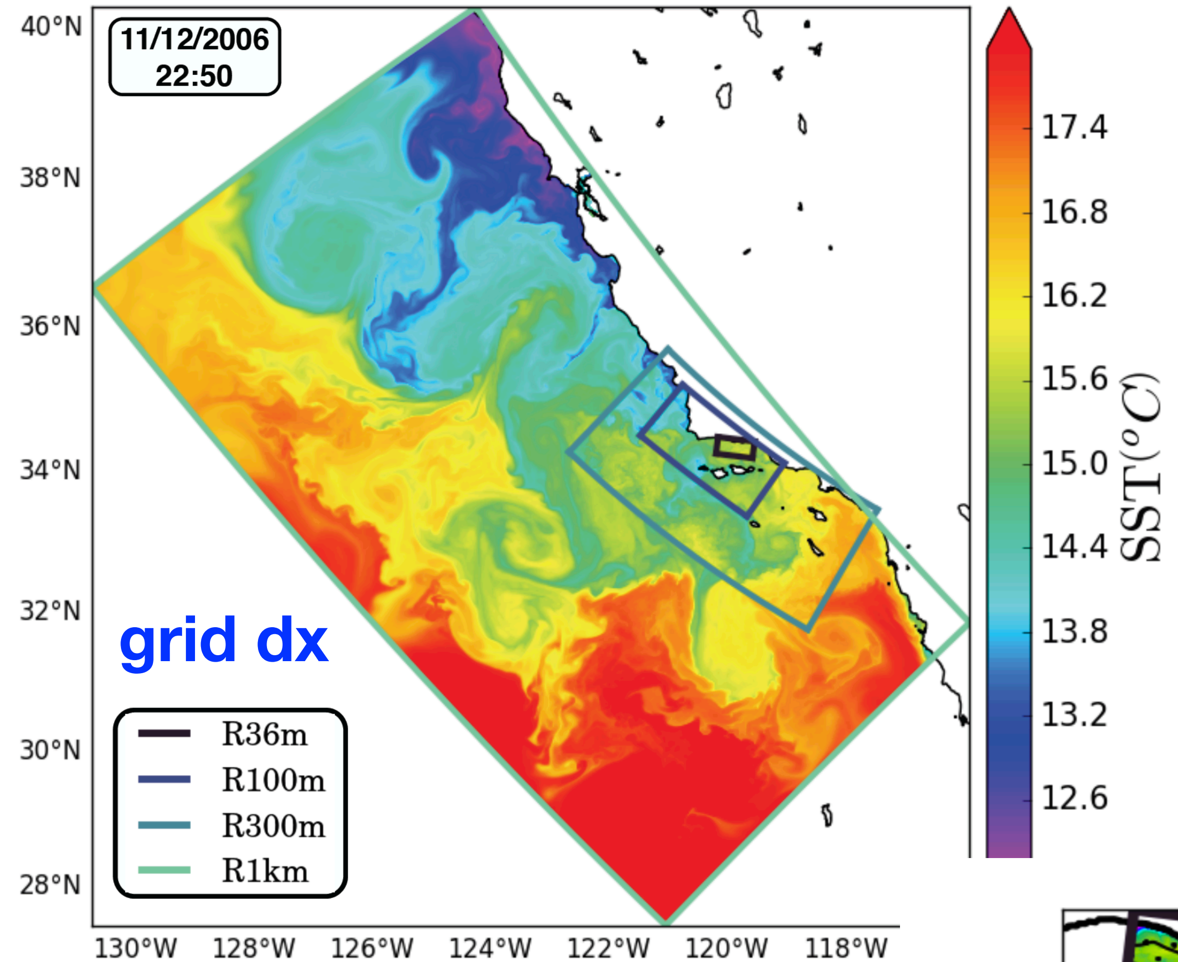
Compare simulations with only “natural” BGC forcings (i.e., regional scale) and with added anthropogenic effects.

General conclusion is that the impact is large, mainly by POTW NH_4 effluent.

[See Faycal Kessouri’s talk]

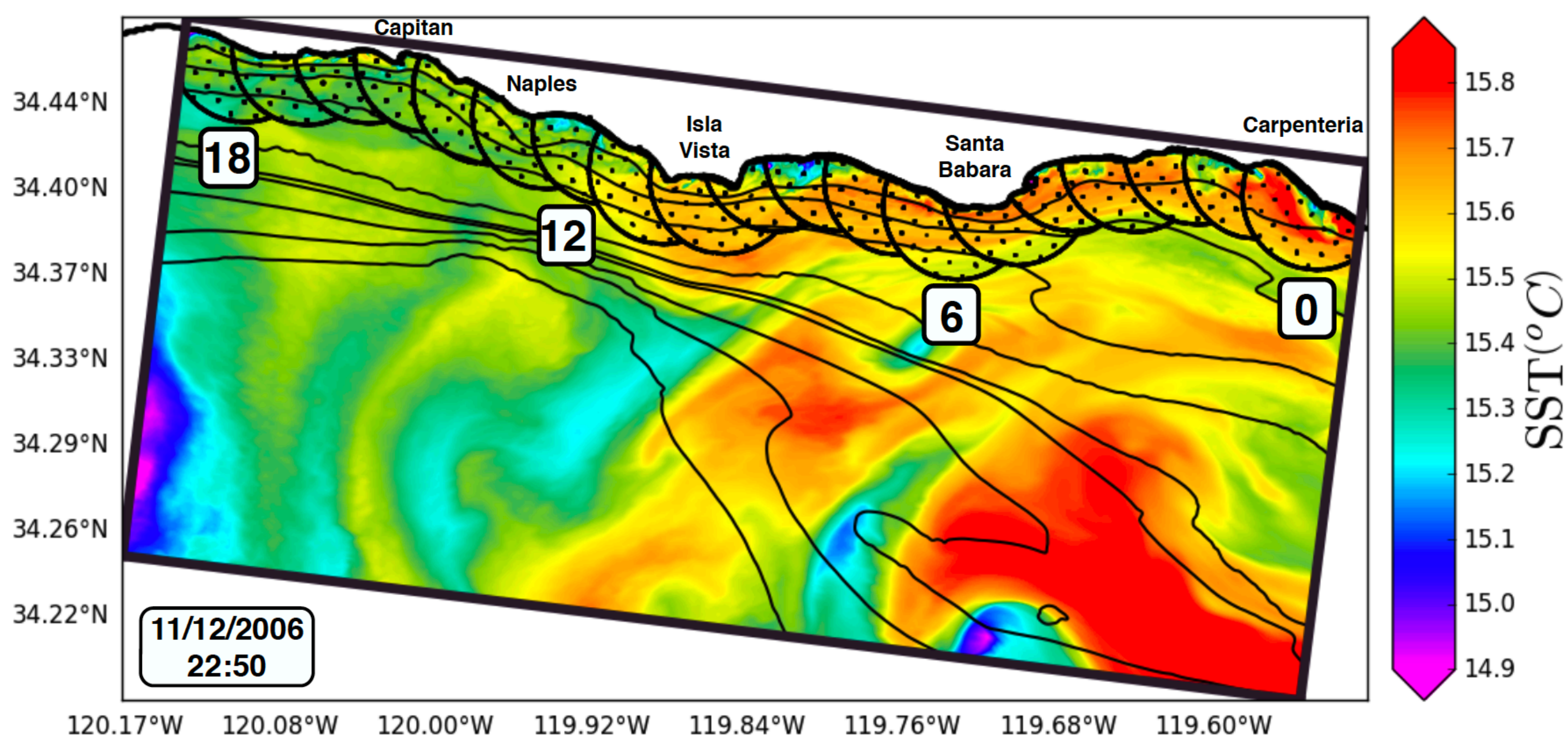
A new project is to do the same for the Central Coast (San Francisco Bay and Salinas valley agriculture areas), sponsored by San Francisco Estuary Institute.

Nearshore Environments and Surface Wave Impacts



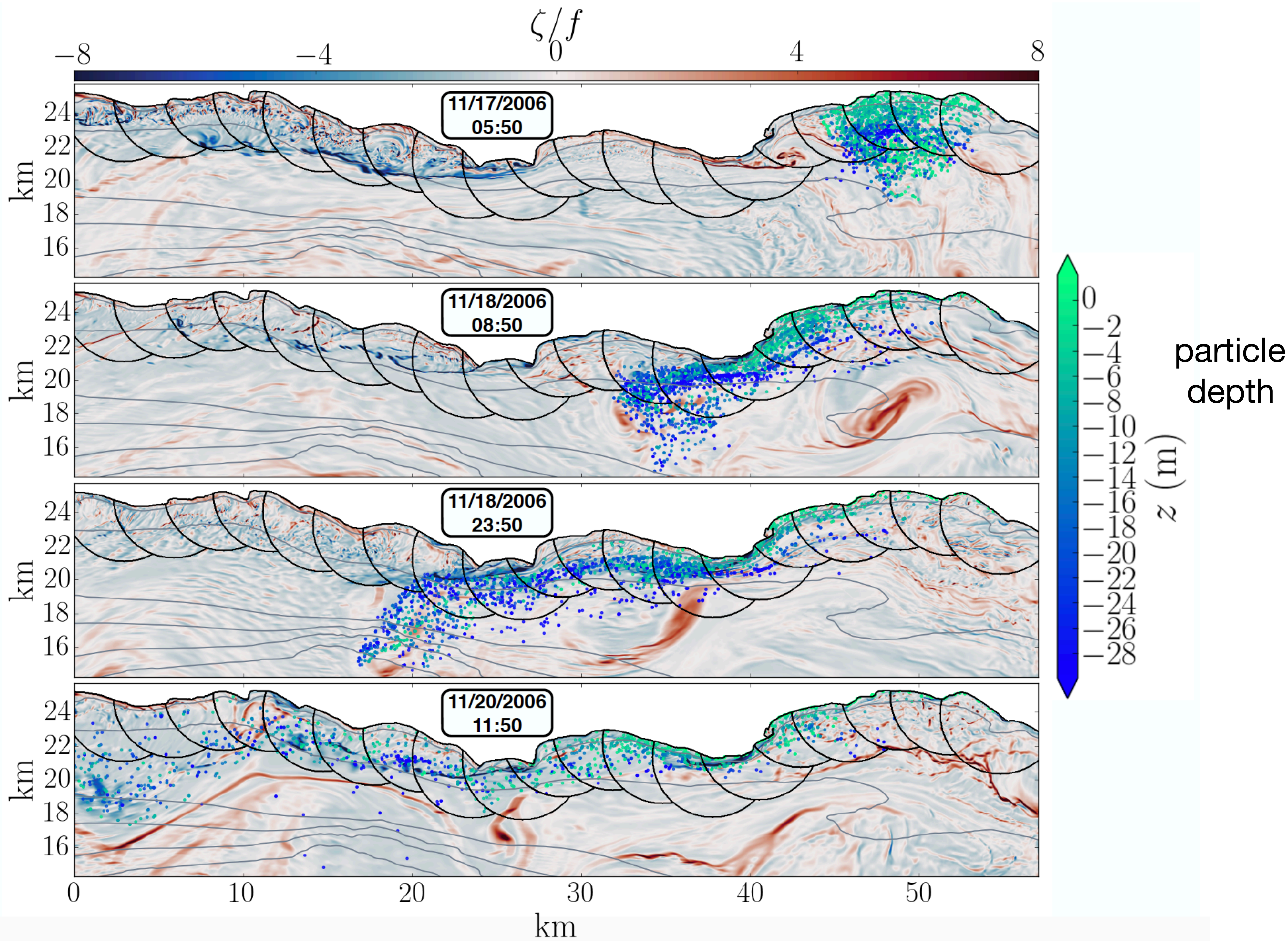
5-level grid nesting down to a nearshore subdomain within the Santa Barbara Channel [finest grid dx = 36 m]

Protocol: recurrently release particles in nearshore zones and track them with the simulated currents



paper Dauhajre and McWilliams, 2019: Nearshore Lagrangian connectivity.

A 3-day event off Santa Barbara when a headland wake current became a front and rapidly transmitted surface particles alongshore and downward.
[grid dx = 35 m]



Other Current Modeling Projects

informed by U.S. West Coast ROMS+BEC simulations

Habitat Constraints from T, O_2, & Ω (Curtis Deutsch et al.)

POTW Effluent Plume Turbulence (Jeroen Molemaker et al.)

Shoreline Ecosystems (Rich Ambrose et al.)

Harmful Algal Blooms (Daniele Bianchi et al.)

Size-Based Marine Foodwebs (Daniele Bianchi et al.)

Kelp Aquaculture (Kristen Davis et al.) for potential bioenergy and for acidification, hypoxia, and eutrophication remediations

Summary

A skillful USWC simulation model has been constructed and is being deployed on a variety of regional and local problems.

We are in an era in which global-regional-local pollution and habitat changes are significantly modifying ecosystem functioning.

This scientific approach is the new normal: model-based assessments and scenarios to guide environmental management.

How and when will the relevant communities buy in?

The activity is expensive in people and computing resources --- but cheap compared to measurement and remediation.

Long-term continuity of financial support, staffing, and model evolution are necessary.