Developing additional products based on the West Coast Operational Forecast System (WCOFS)

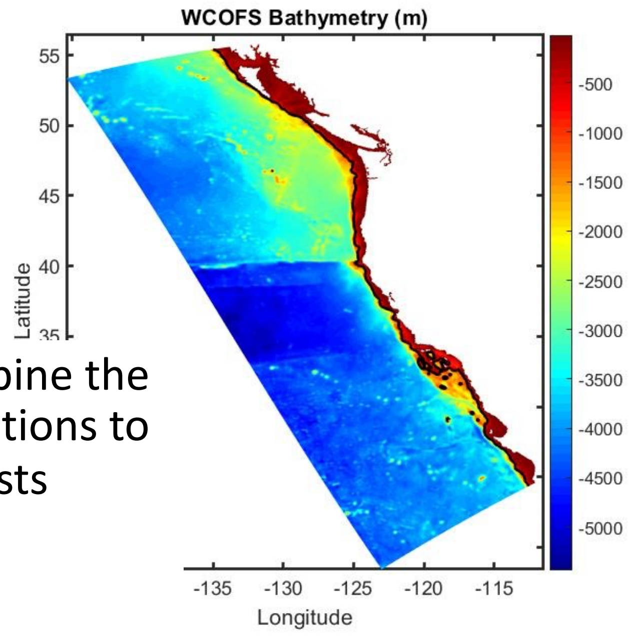
Christopher A. Edwards, UC Santa Cruz

Andrew M. Moore, Patrick T. Drake, Anna Lowe, Clarissa Anderson, Stephanie Brodie, Elliott L. Hazen, Michael G. Jacox, Parker MacCready, and Alexander L. Kurapov

COSS-TT Meeting

McGill University, Montreal, Quebec, May 2-4 2023

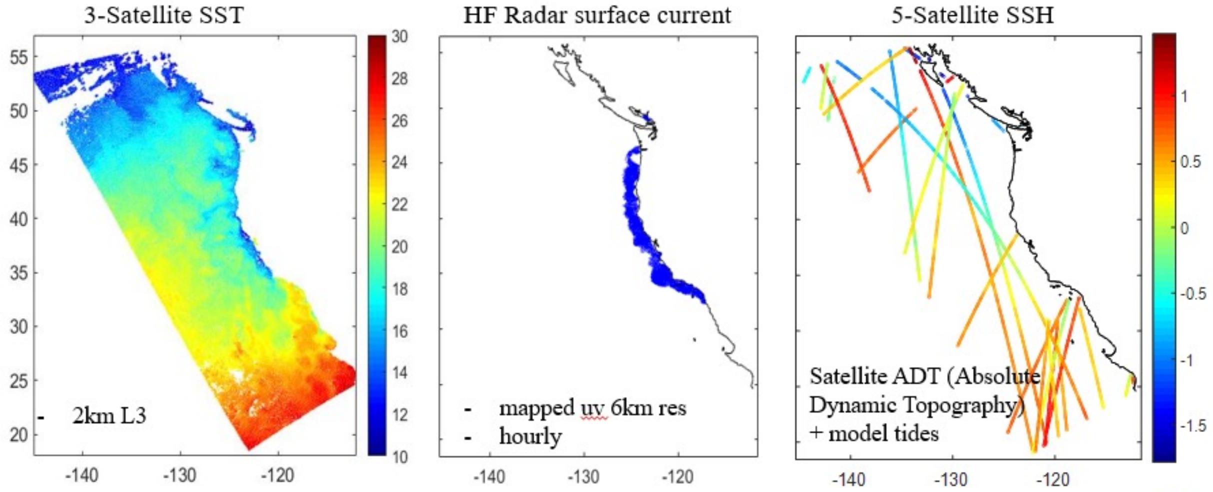
WCOFS – NOAA's West Coast Operational Forecast System (Kurapov)



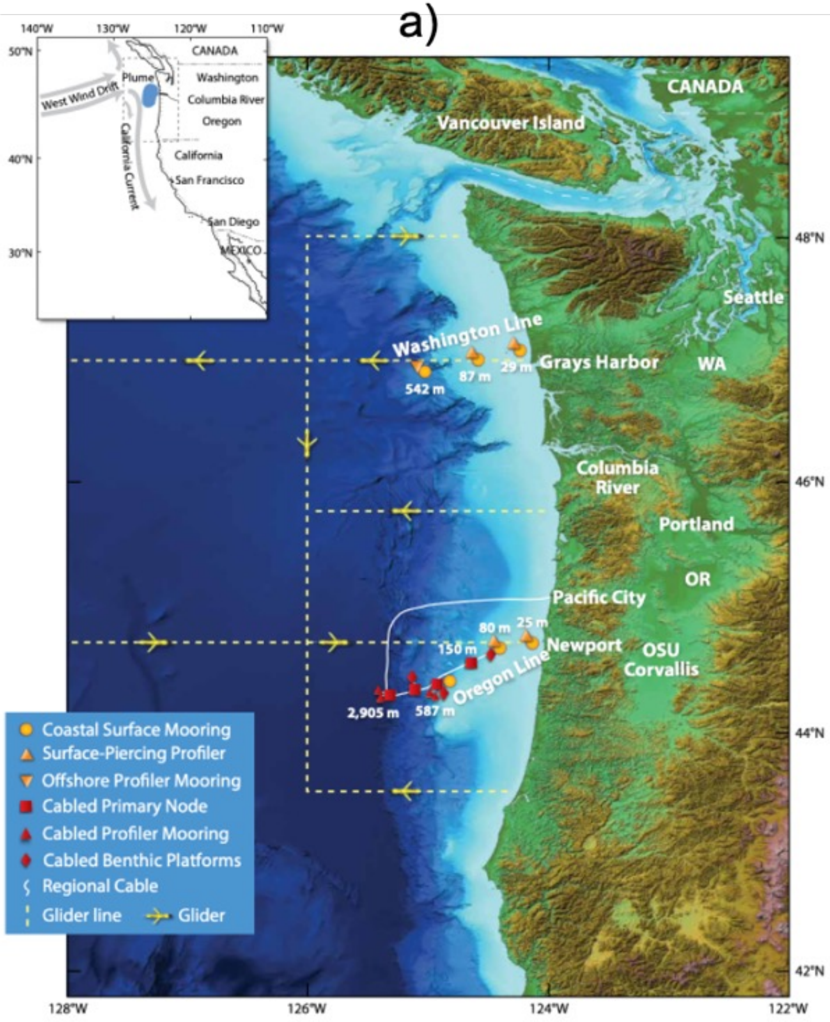
A. Kurapov (NOAA)

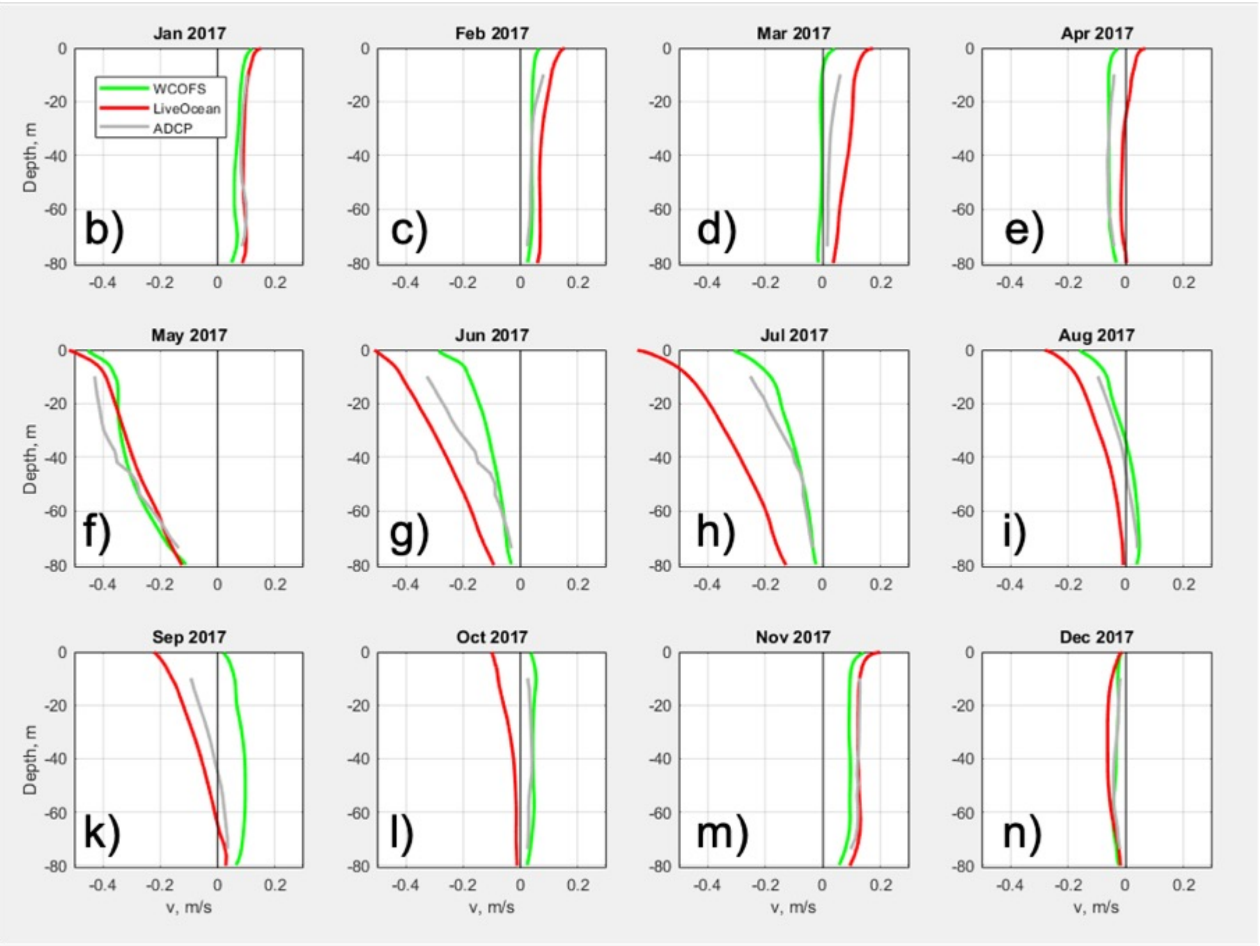
- Model domain: 24N-54N / Offshore extent: 600-1000 km
- Numerics: Regional Ocean Modeling System (ROMS)
- Horizontal resolution: 4-km (data assimilative version)
- 40 terrain-following levels
- Forcing:
  - atmospheric fields from NOAA North American Model (NAM) (*wind forcing, heat flux, evaporation-precipitation*)
  - Non-tidal boundary conditions: NOAA RTOFS (HYCOM-based)
  - Tidal boundary conditions: TPXO [Egbert & Erofeeva, Oregon State U.]
  - Rivers: Columbia R., Fraser R., small rivers in Puget Sound

- 4D-Var Data Assimilation (DA): combine the model output and available observations to improve initial conditions for forecasts
  - HF radar surface currents
  - Satellite SST (3 platforms)
  - Satellite Sea Level (non-tidal)
  - in-situ: gliders, argo floats etc.
- **Daily operation with 3 day forecasts**



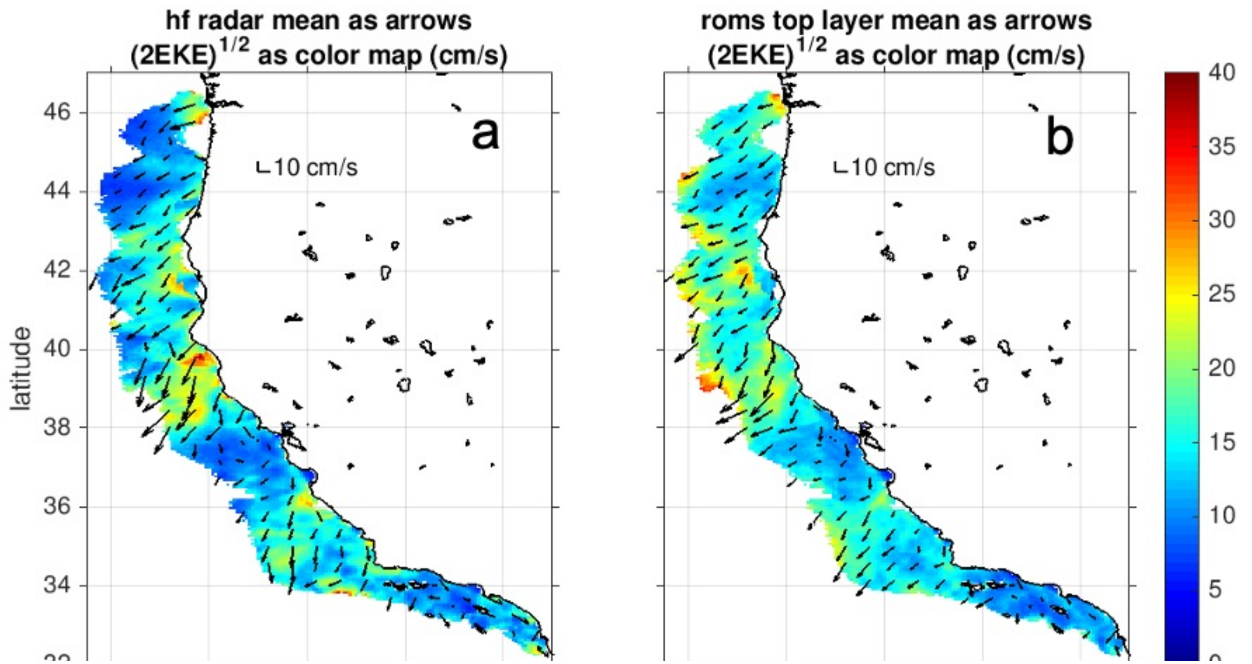
1) Comparison of WCOFS velocities against OOI Endurance moorings

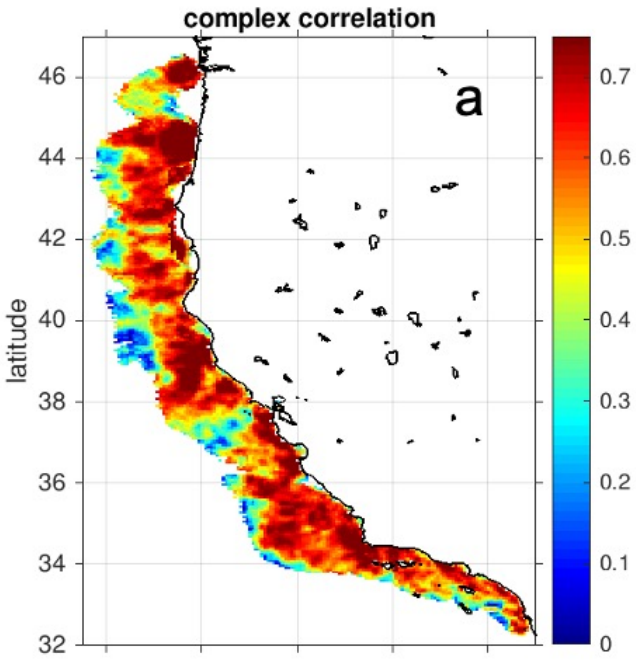




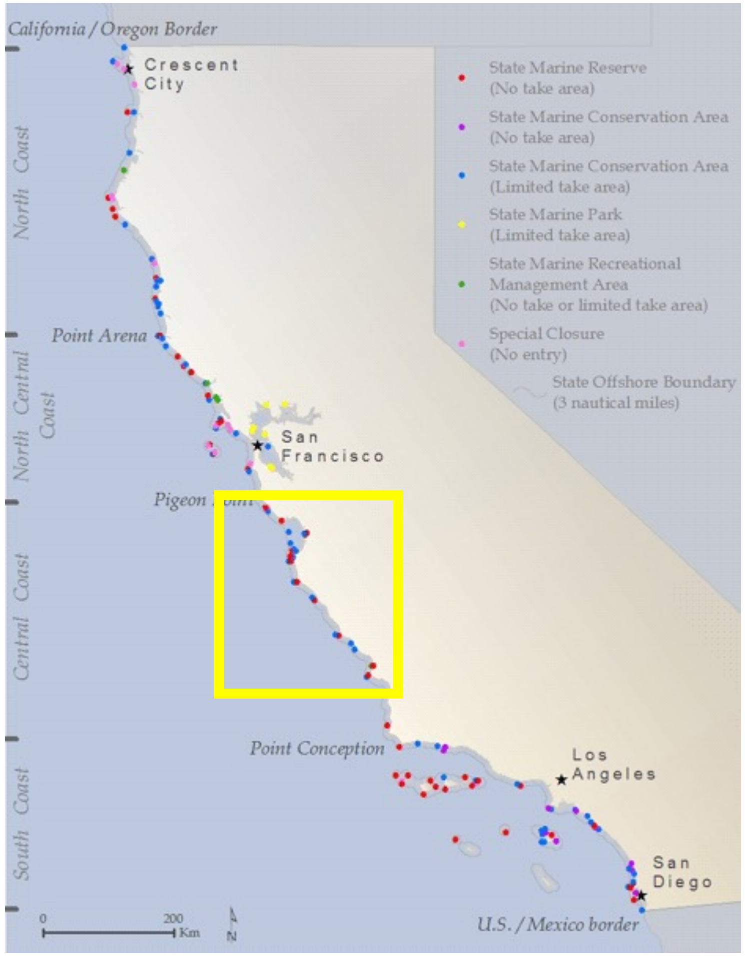
Courtesy Parker MacCready

Correlation between WCOFS surface velocity and HFR velocity vectors (spring/summer example)





2) California Marine Protected Areas

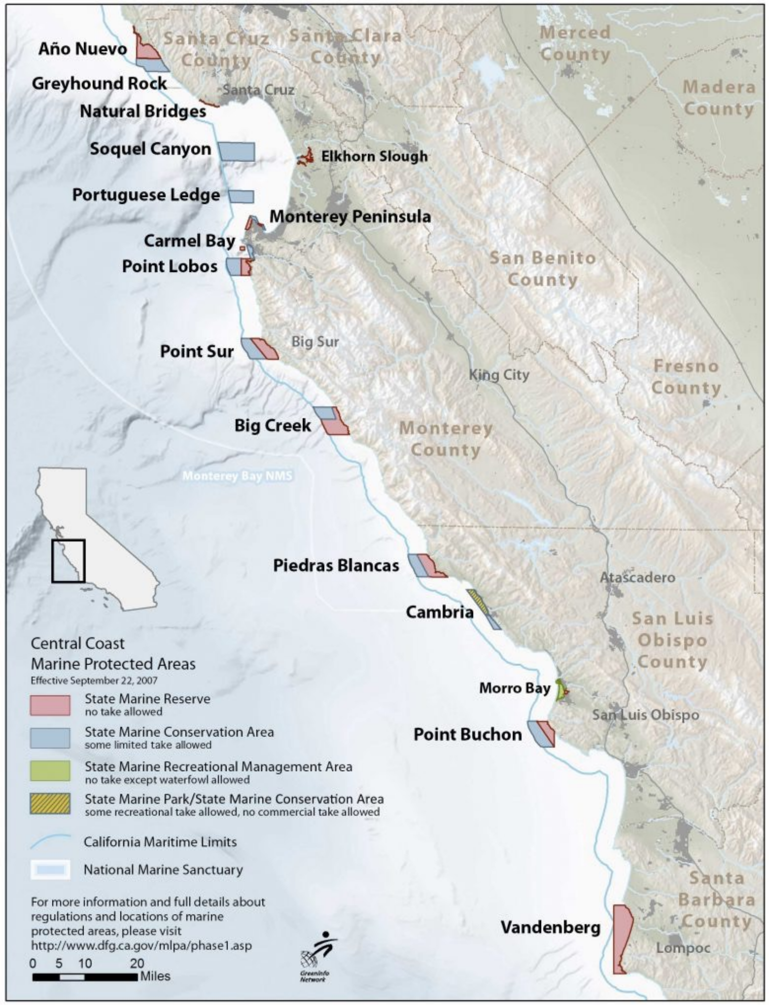


- In 2012, California completed a science-based, stakeholder driven process to designate 124 marine protected areas (MPAs) that cover 16% of state waters.
- Varied amounts of allowed activities and protections (marine reserves, marine conservation areas, and marine parks)
- Help conserve biological diversity, provide a sanctuary for marine life, and enhance recreational and educational opportunities.

Goals of MPA Monitoring

Partnership-based, cost-effective approach to MPA monitoring to build toward a number of goals:

● Inform the evaluation of the MPA network in meeting the goals of the Marine Life Protection Act.
● Mobilize and engage a wide array of community members, experts, and scientists.

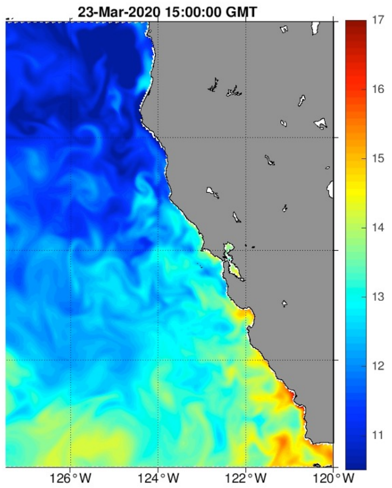


https://www.opc.ca.gov/marine-protected-area-network-overview/

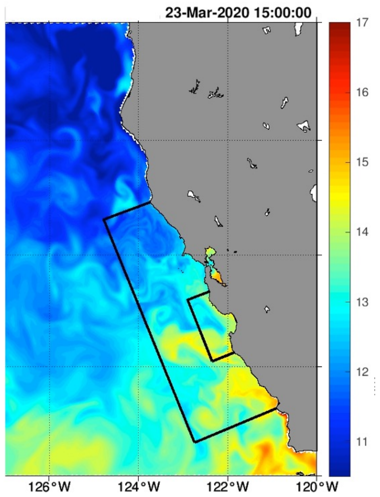
Developing WCOFS nesting capability in support of California MPA monitoring

- 2 high resolution nests focused on central CA coast (800 m) and Monterey Bay (160 m).
- Built on WCOFS, nudged to WCOFS solutions. Operated from March 2020 (pre-operational WCOFS) through September 2021.
- Larvae released from MPA regions and tracked for 3 months. Neutral, near surface, sub-surface mixed layer, diel vertical migration.
- **Capability will provide information about marine connectivity of planktonic organisms between MPAs and between MPAs and the broader coastal regions.**

UCSC rerun of WCOFS

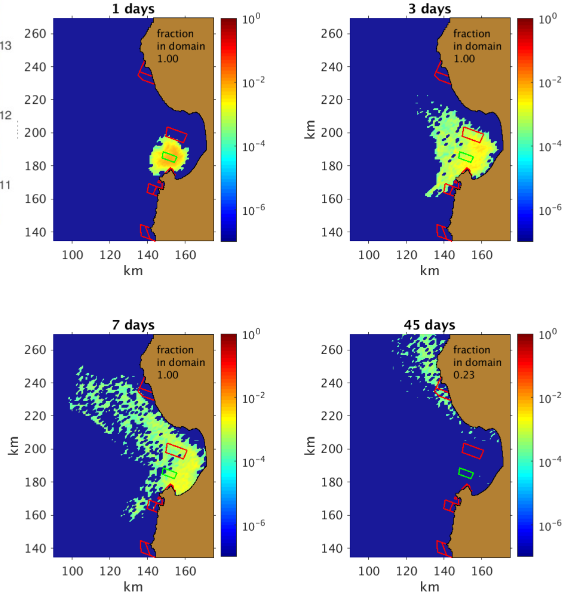


UCSC nests



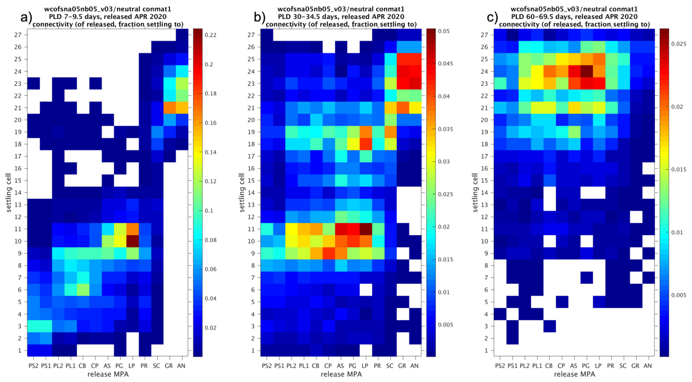
Local MPAs and PDFs of larval dispersal

Portuguese Ledge release (green box), 2D pdf
no larval behavior; middle nest
released throughout MAY 2020

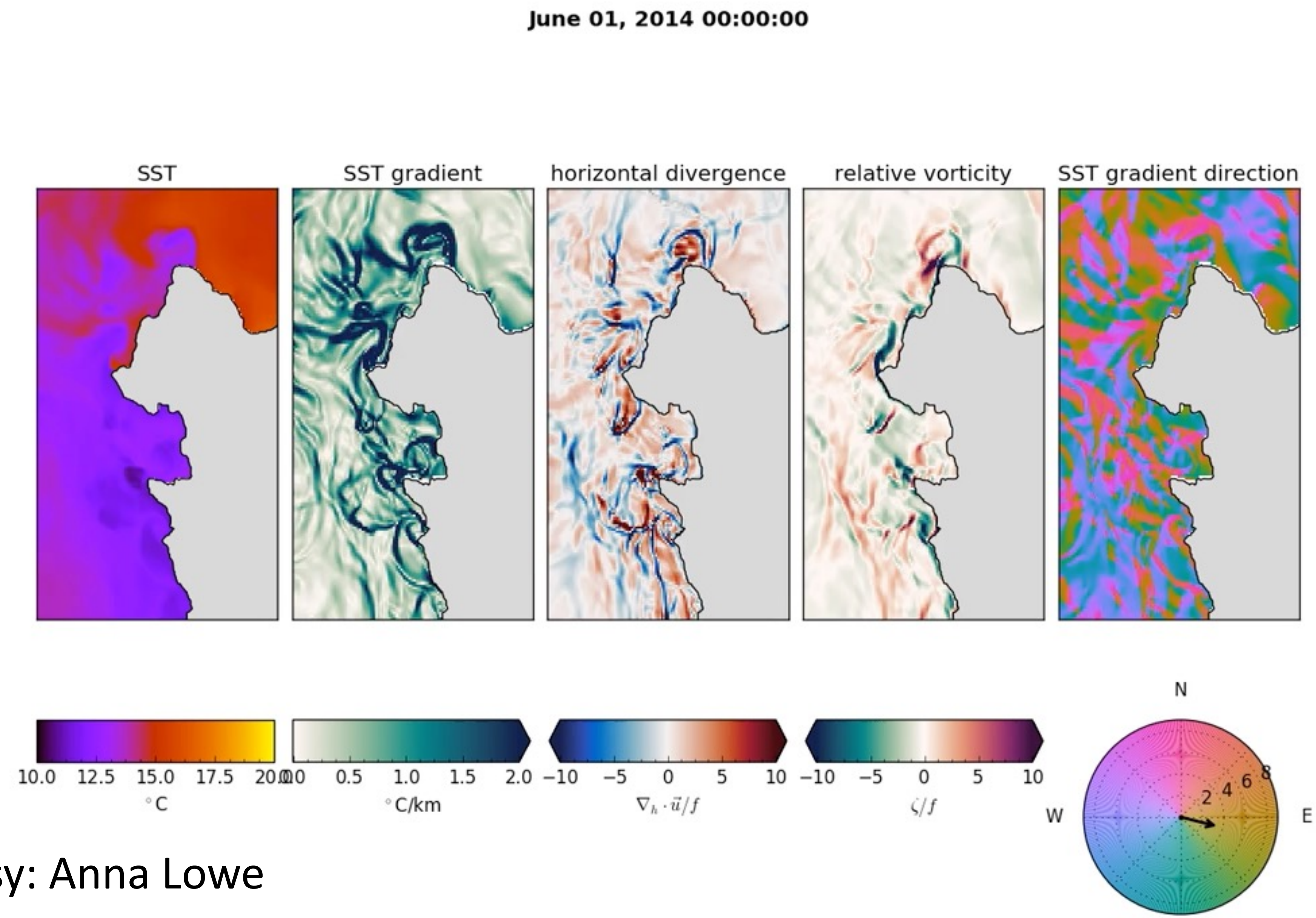


run wcofsna05_v03_b05_seeding/neutral, created 09/10/2021

Connectivity matrices for different PLDs

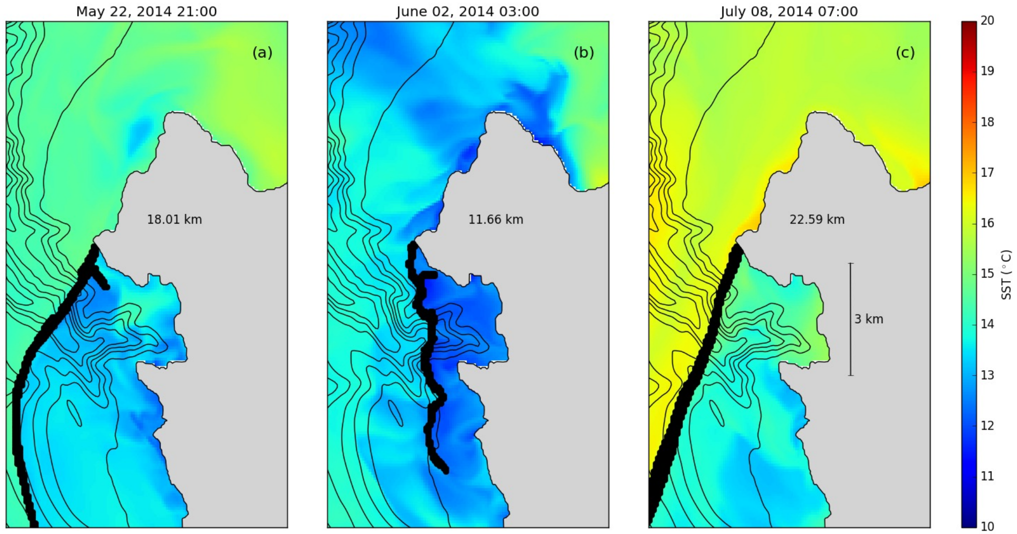


Expect complex submesoscale dynamics

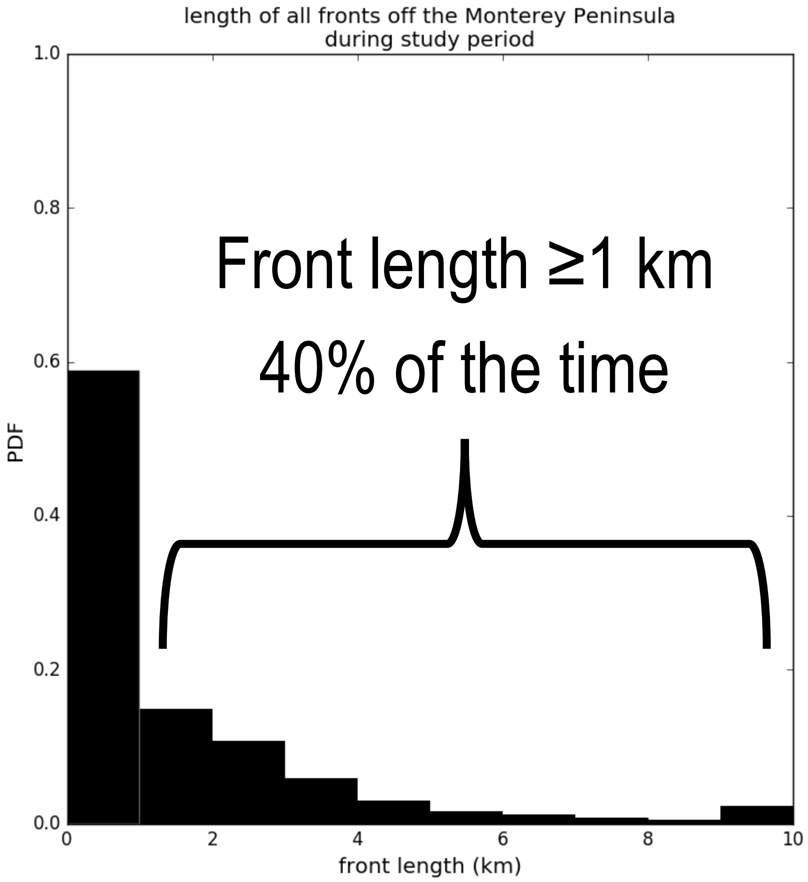


Courtesy: Anna Lowe

Recurrent front anchored off the Monterey Peninsula

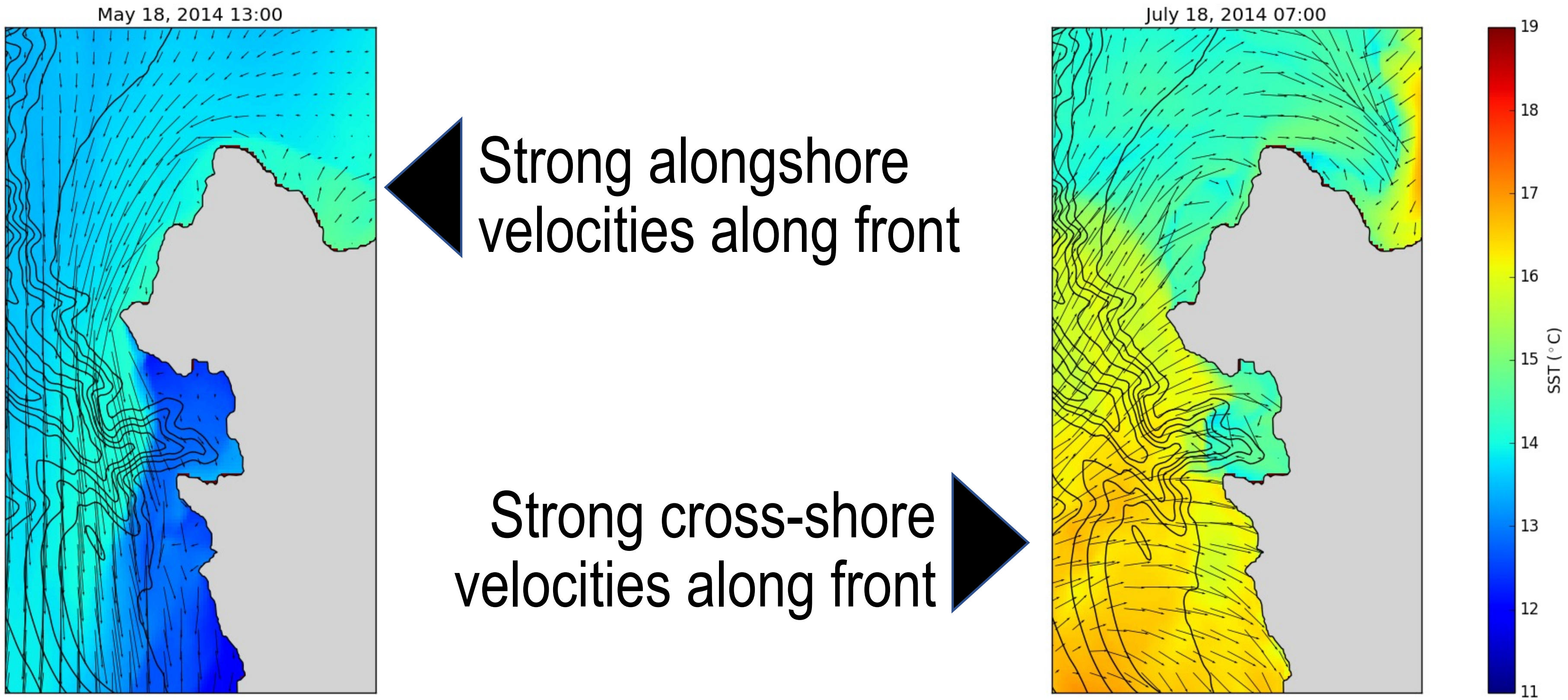


3 examples of long fronts



Courtesy: Anna Lowe

Two flavors of fronts in this region

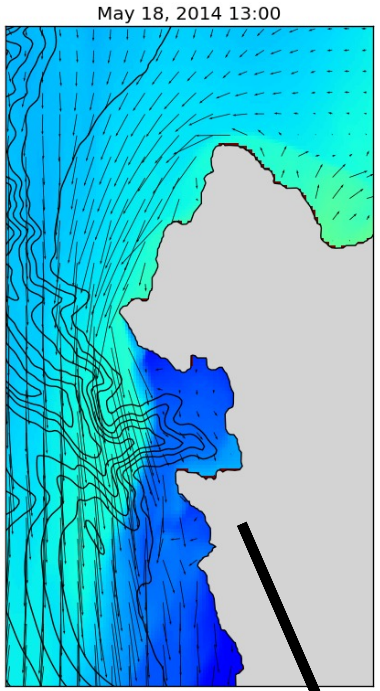


Strong alongshore velocities along front

Strong cross-shore velocities along front

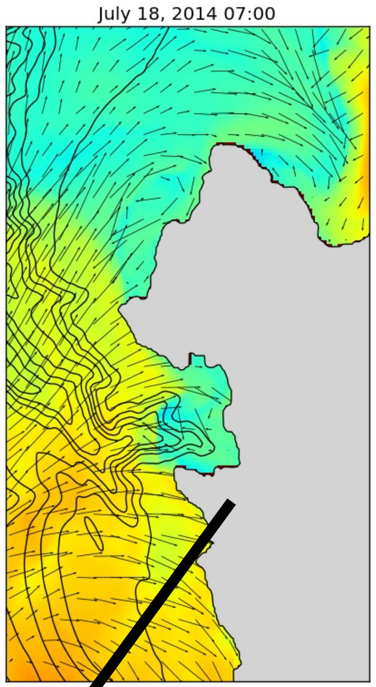
Courtesy: Anna Lowe

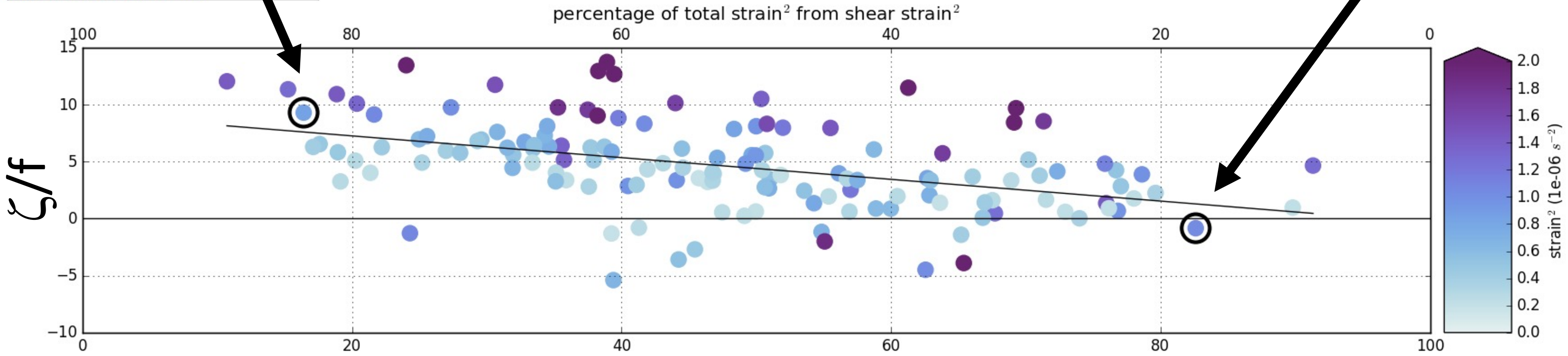
Characterize fronts by their shear or normal strain
This fraction influences alongshore propagule transport



$$Strain = \sqrt{\underbrace{(v_x + u_y)^2}_{\textit{shear strain}} + \underbrace{(u_x - v_y)^2}_{\textit{normal strain}}}$$

shear strain *normal strain*

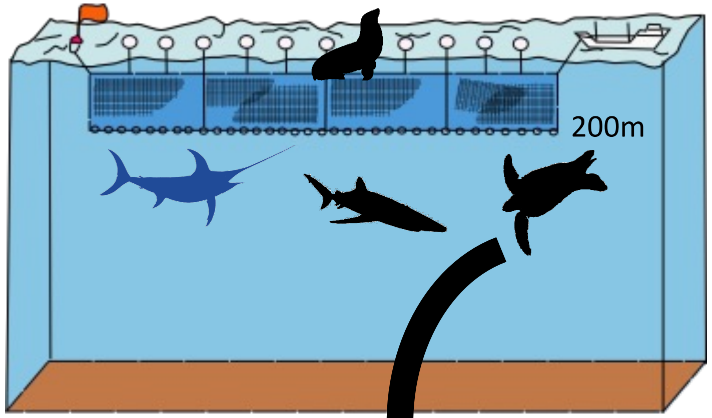




Lowe et al. (in revision)

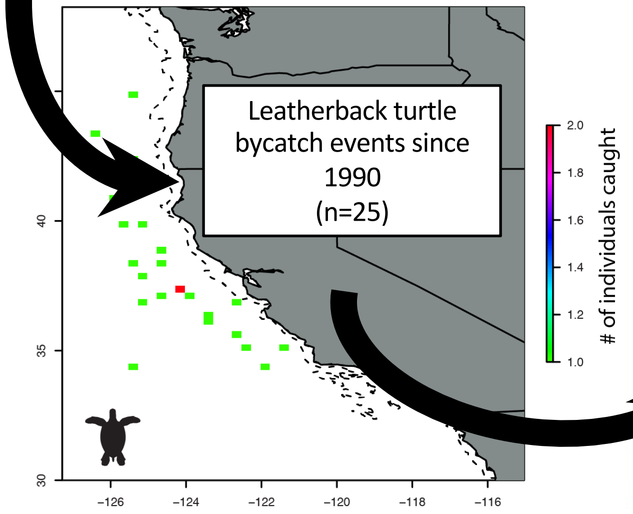
Percentage of total strain^2 from normal strain^2

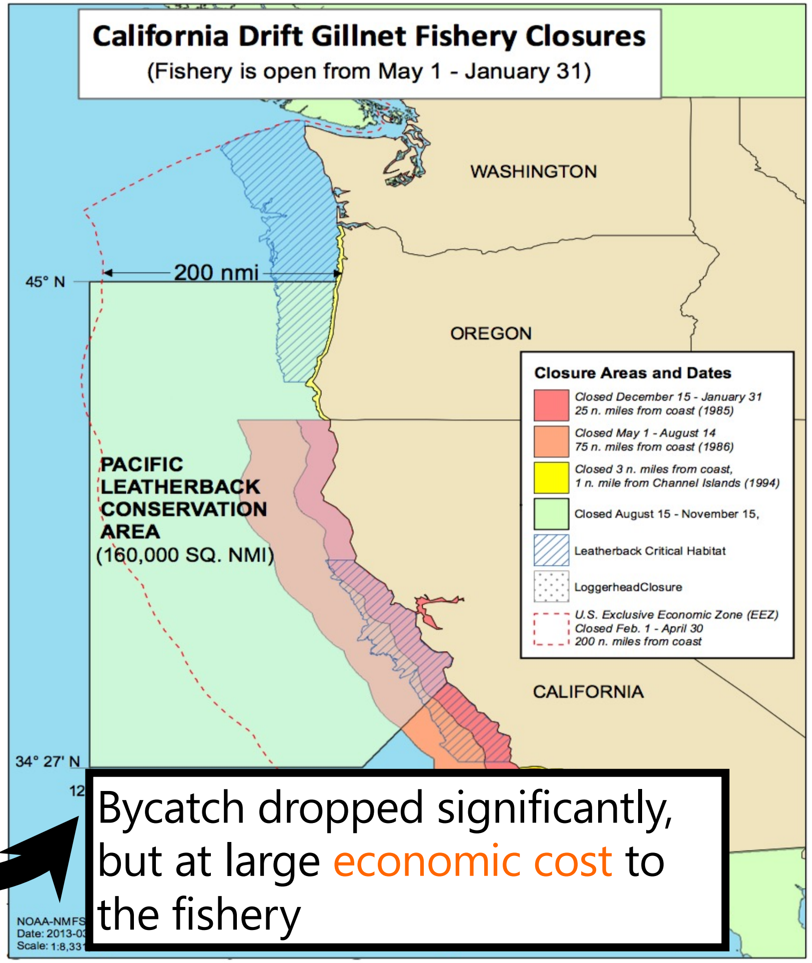
3) Fisheries use of ocean state estimates
Static fishery closures are costly



Bycatch to be managed:

- Swordfish
- Sea turtles
- CA Sea lions
- Blue sharks

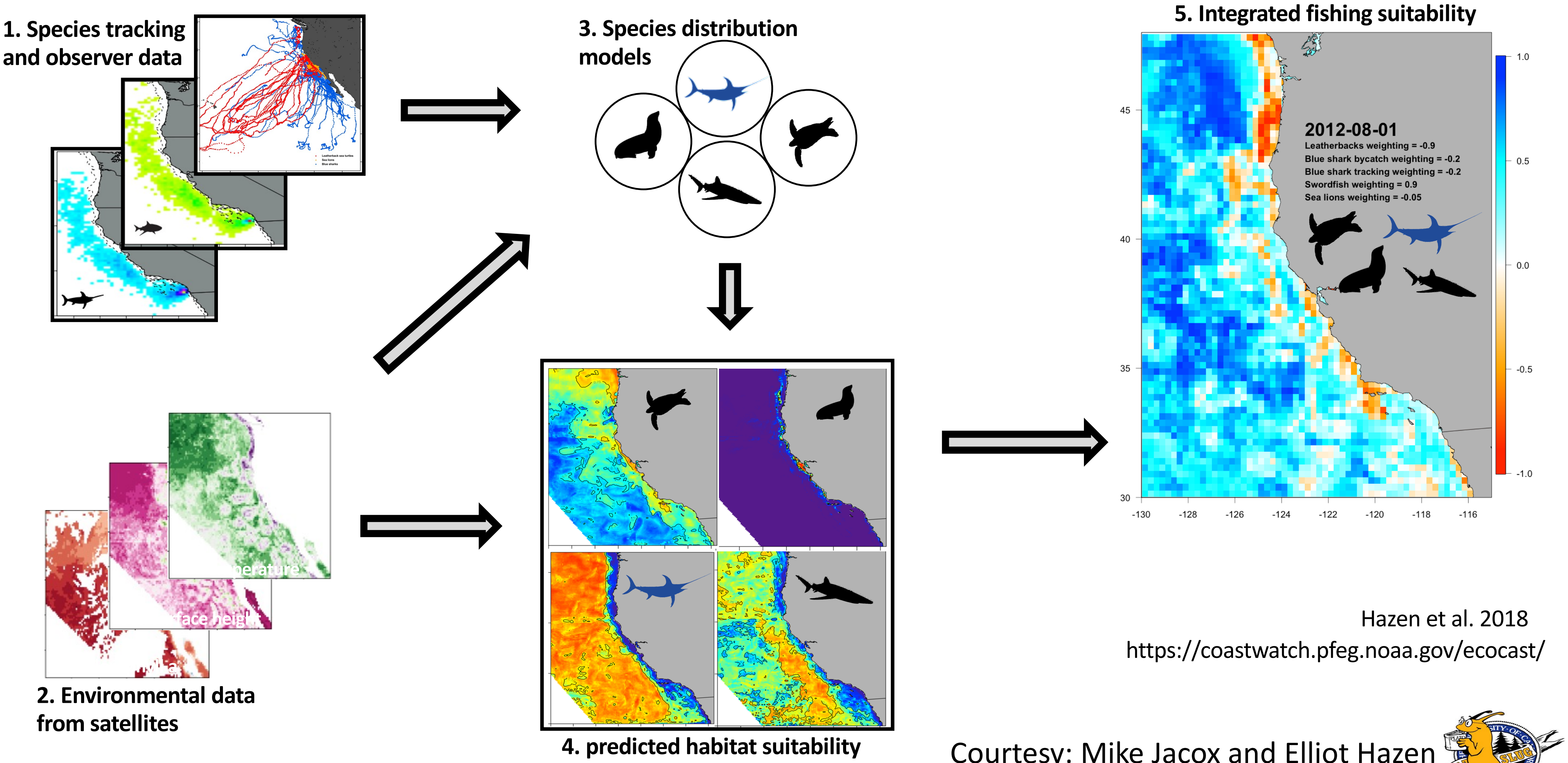




Bycatch dropped significantly, but at large economic cost to the fishery

Courtesy: Mike Jacox and Elliot Hazen

Another approach: dynamic habitat mapping

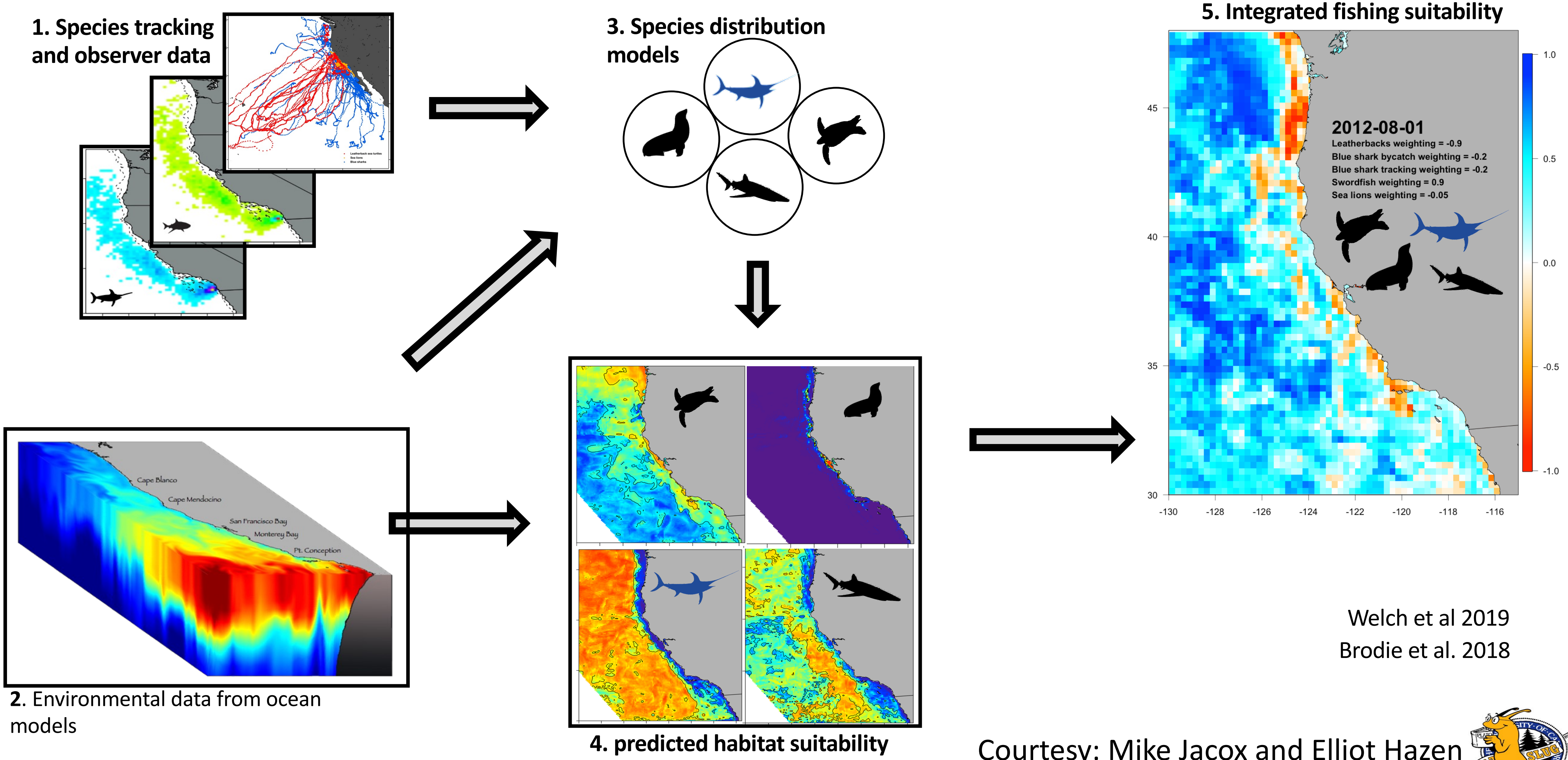


Hazen et al. 2018

https://coastwatch.pfeg.noaa.gov/ecocast/

Courtesy: Mike Jacox and Elliot Hazen

Fisheries application



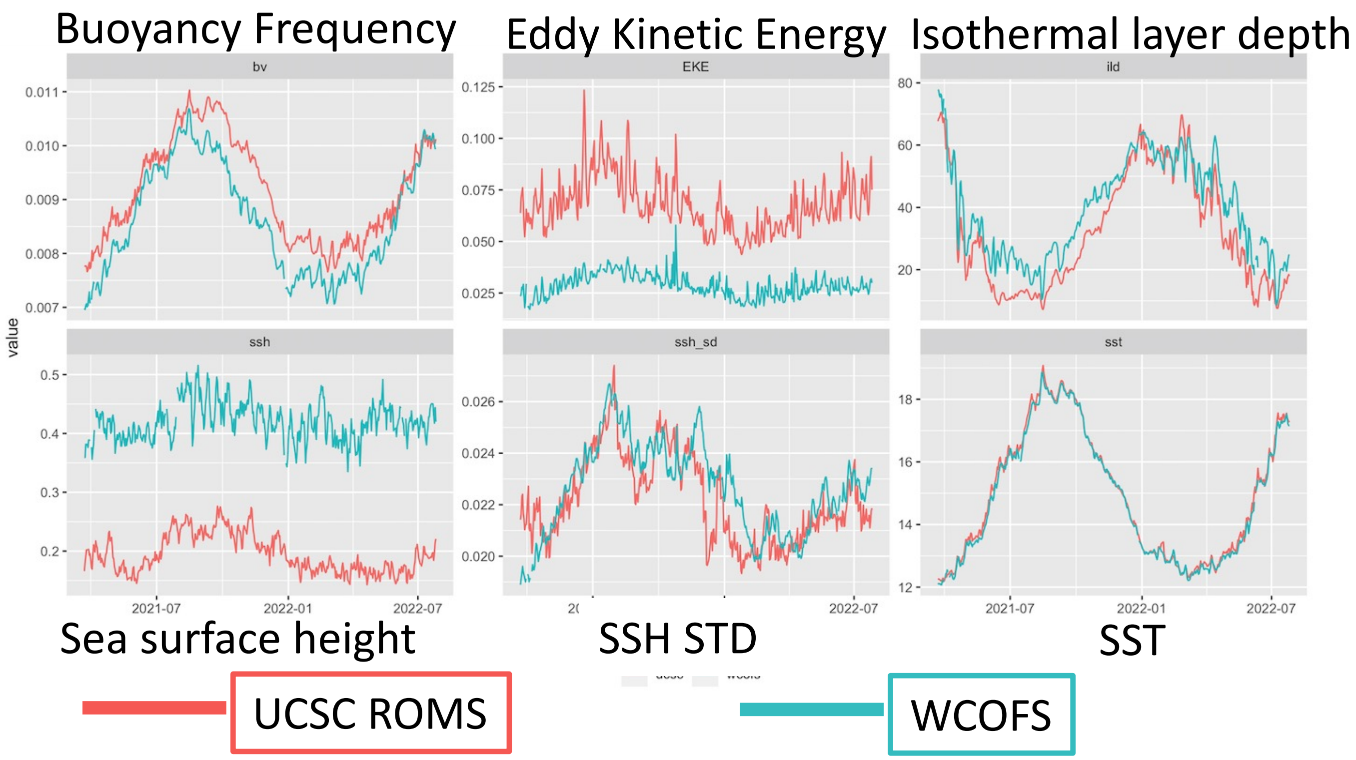
Welch et al 2019
Brodie et al. 2018

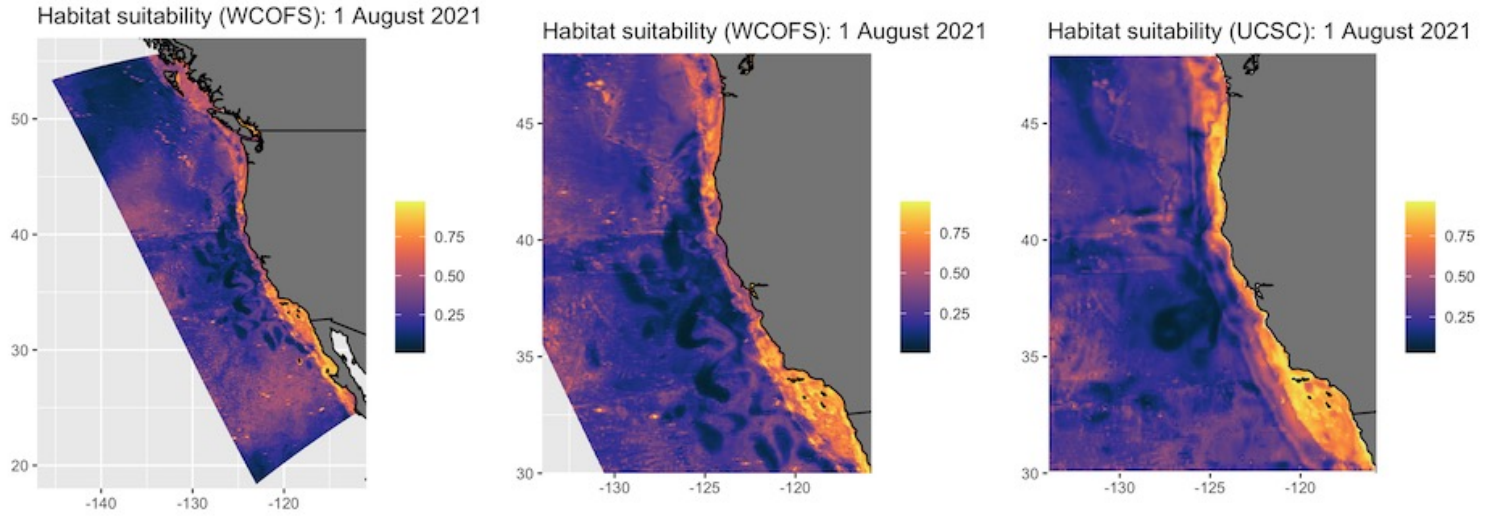
Courtesy: Mike Jacox and Elliot Hazen

An example: blue whale habitat prediction using WCOFS

Comparison of key parameters between UCSC state estimation product upon which statistical species distribution model (SDM) was based and WCOFS shows good agreement for most fields

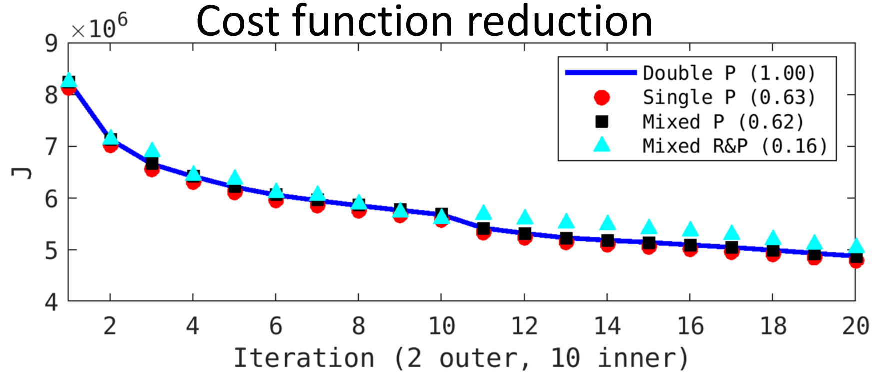
1. Buoyancy Frequency
2. EKE (bias)
3. Isothermal layer depth
4. SSH (bias)
5. SSH standard deviation
6. SST





Courtesy: Steph Brodie

4) Improving 4D-Var data assimilation computational efficiency



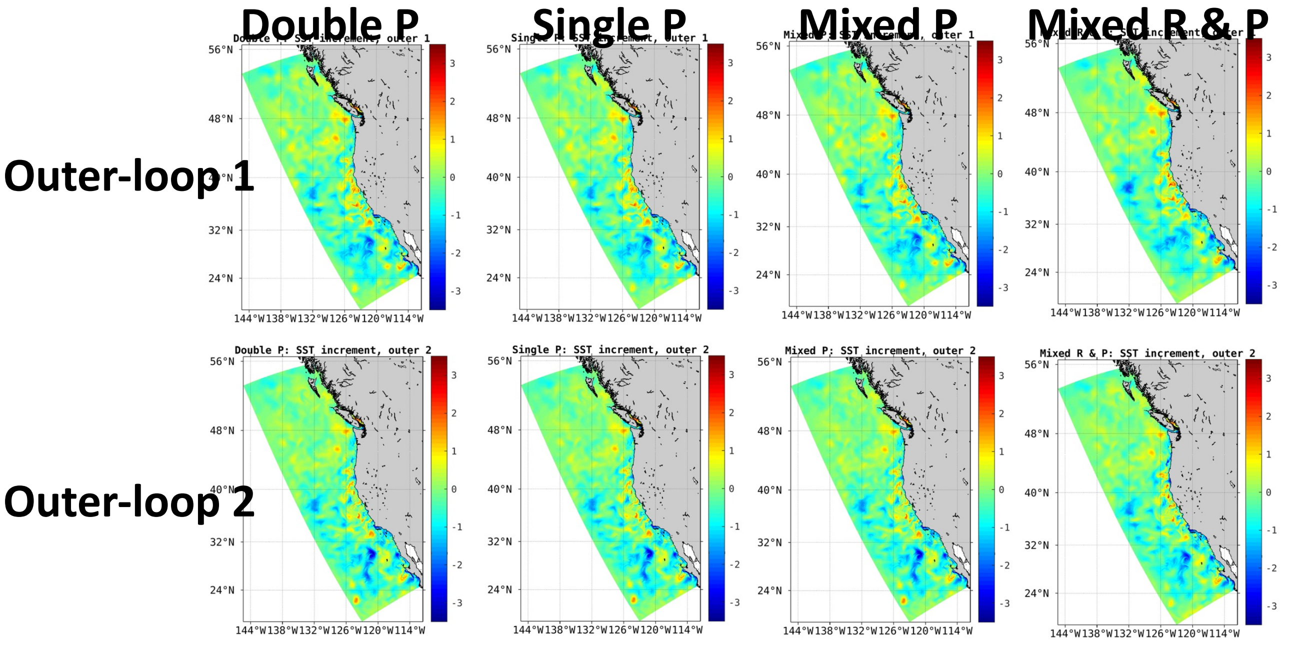
- Experiments with single and mixed precision show nearly identical performance as previously standard double precision and ~38% reduction in computational effort.

- Shown are SST increments on day 3 at the end of each outer-loop for 4 experiments.

- **Experiments with mixed precision and twice the grid spacing (8 km) for inner loops yield no significant degradation in the 4D-Var estimate and 84% reduction in computational effort.**

- These experiments were performed on WCOFS assimilation cycles.

SST Increments

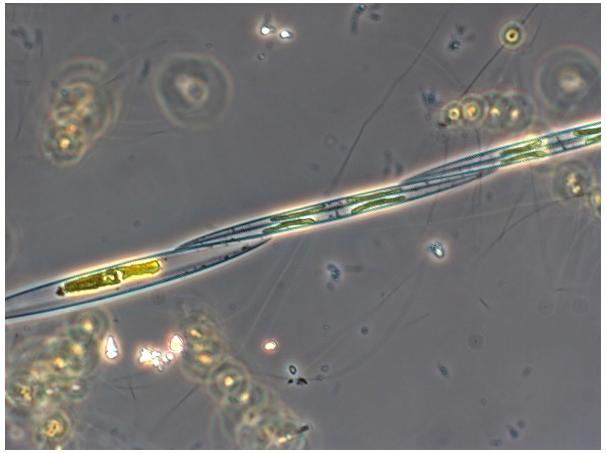


Courtesy: Andy Moore

5) California-Harmful Algae Risk Mapping (C-HARM)

- Domoic acid (DA, from Pseudo-nitzschia blooms) is the leading Harmful Algal Bloom issue on the U.S. West Coast
- Stressed diatoms, *Pseudo-nitzschia,* produce a toxin, domoic acid, that in sufficient concentrations lead to strandings of marine mammals and birds.
- The toxin is passed through shellfish to humans.
- C-HARM is a statistical model to predict presence or absence of pseudo-nitzschia and domoic acid from satellite-derived remote sensing reflectance (Rrs) and model temperature and salinity (issue).

Diatom *Pseudo-nitzschia*



HAB Variable (Threshold)	Best-fit Logistic GLM - **RS** $P_{bloom} = e^{(logit)}/[e^{(logit)} + 1]$
Pseudo-nitzschia (10^4 cells mL^{-1})	**(i)** $logit = 8.54 - 10.84*[R_{rs}(510/555)] - 0.216*[Month] + 4.67*[R_{rs}(490/555)]$
	(ii) $logit = 5.32 - 2.87*[R_{rs}(490/555)] - 0.165*[Month]$
pDA (500 ng L^{-1})	$logit = -134.3 + 0.253[Chl] + 4.0*[Sal] - 502*[R_{rs}(555)]$
cDA (10 pg $cell^{-1}$)	$logit = -90.0 - 0.35*[Temp] - 666*[R_{rs}(555)] + 2.87*[Sal]$

For Real-time Operations:

obtained from satellite

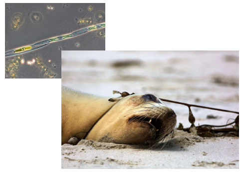
obtained from model

obtained from model

Courtesy: Clarissa Anderson

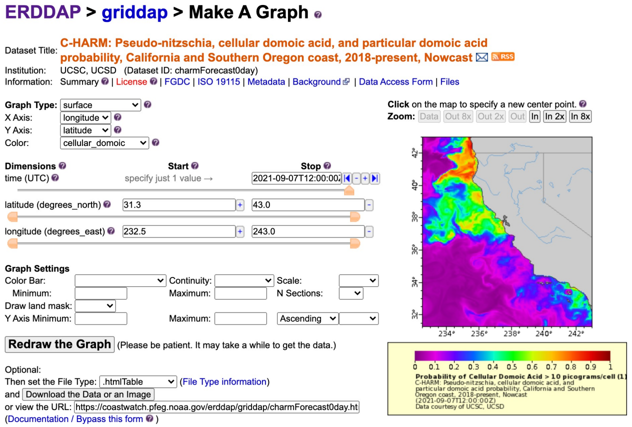
from Anderson et al. (2011)

CALIFORNIA HARMFUL ALGAE RISK MAPPING (C-HARM) SYSTEM



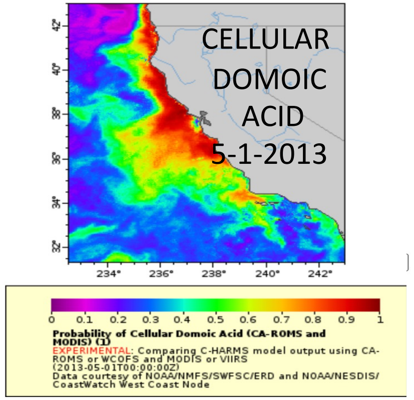
Domoic acid (DA, from *Pseudo-nitzschia* blooms) is the leading Harmful Algal Bloom issue on the U.S. West Coast.
Shellfish growers, fisheries, public health managers, and marine mammal rescue groups want an early warning system.

Operational NOAA Product, CoastWatch

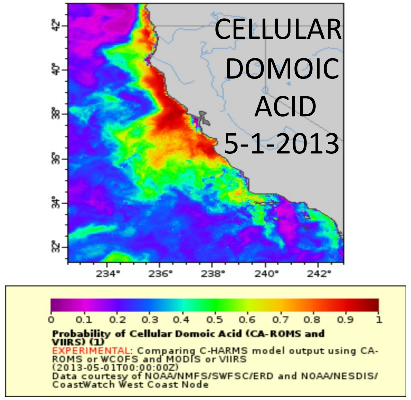


COMT Analysis running C-HARM with WCOFS and VIIRS

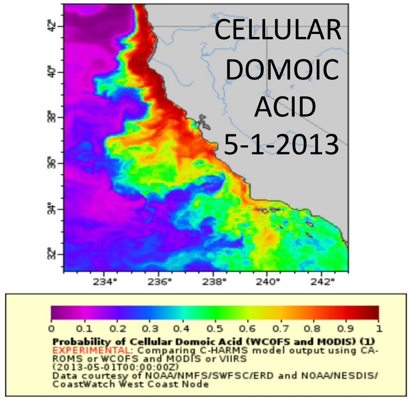
CA ROMS + MODISA



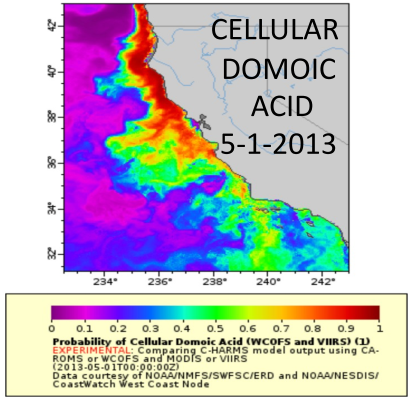
CA ROMS + VIIRS



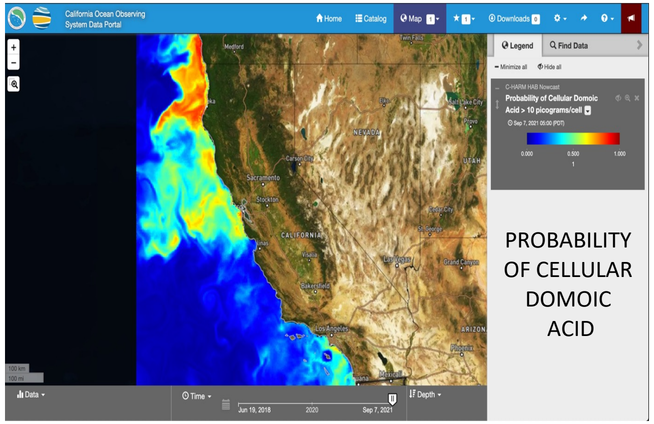
WCOFS + MODISA



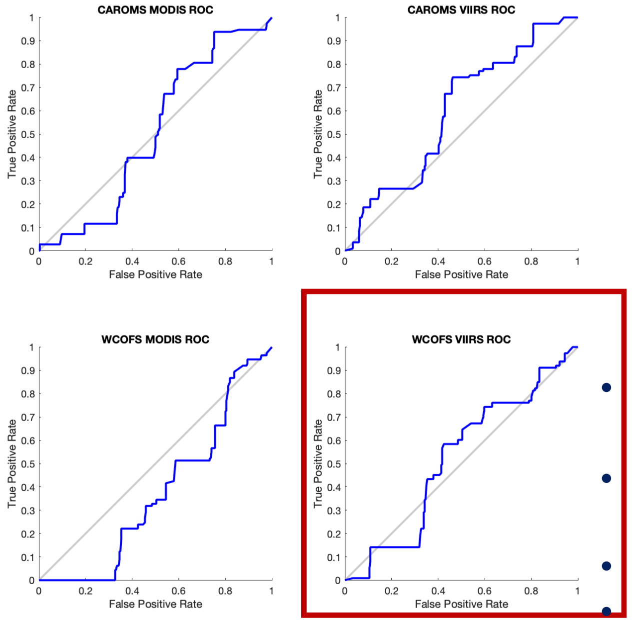
WCOFS + VIIRS



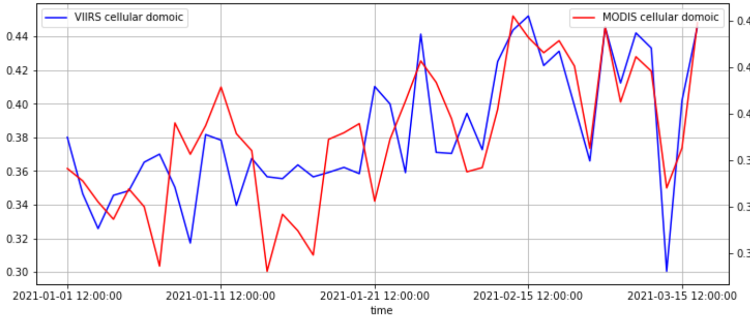
Shared broadly on CalOOS Portal



CA ROMS + VIIRS = Best Model Performance



Cellular Domoic Acid 2021 MODIS vs. VIIRS



- C-HARM was developed with NASA & NOAA support to spatially predict DA risk in the CCE
- C-HARM transitioned to demonstration at NOAA NCCOS, followed by operations at NOAA Coast Watch in 2018

- Transitioning CA ROMS to the NOAA West Coast Operational Forecast System (WCOFS)
- Conducting sensitivity analyses comparing CA ROMS vs. WCOFS and MODIS-AQUA vs VIIRS for 2013-2015 ONLY
- **Made operational transition to WCOFS/VIIRS in June 2022**
- C-HARM now part of NASA PACE EARLY ADOPTER PROGRAM

Courtesy: Clarissa Anderson

Summary

- WCOFS is increasingly mature. Model shows good agreement to in situ observations, though further improvements are desired.
- Several products are in development based on this reliable output.
  - Nested models with propagule transport in support of Marine Protected Area assessment with complex submesoscale dynamics
  - C-HARM HAB prediction model
  - Fisheries dynamic habitat mapping
- Improvements to ROMS 4D-Var infrastructure is ongoing (e.g., 84% decrease in computational cost using multiple resolutions and precision.)