Modeling applications using OOI data

Christopher A. Edwards, UC Santa Cruz

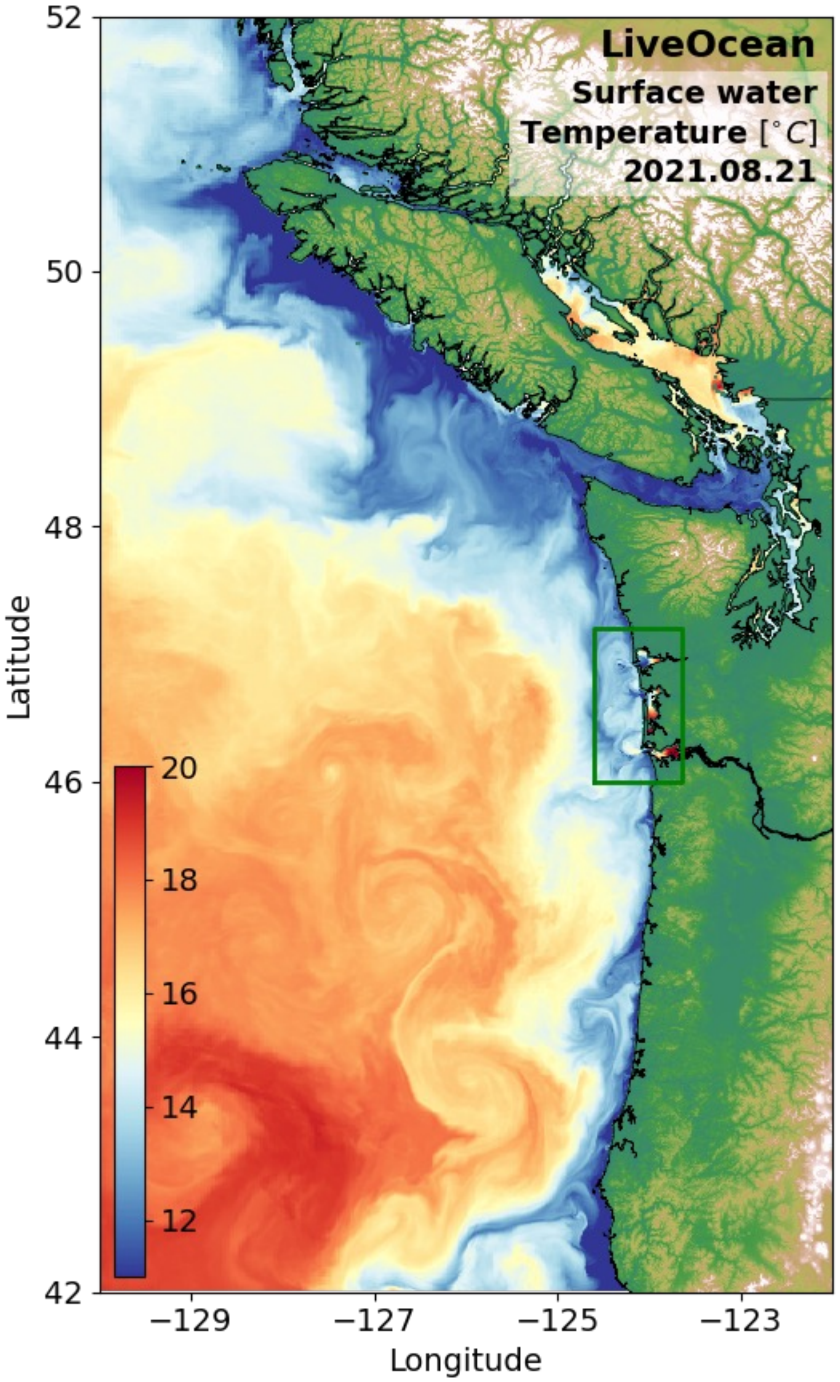
Parker McCready (UW), Samantha Siedlecki (UConn), Alexander Kurapov (NOAA)
John Wilkin (Rutgers), Julia Levin (Rutgers), Hernan Arango (Rutgers),
Andy Moore (UCSC), Paul Mattern (UCSC), Miles Miller (UCSC), Jonathan Izett (UCSC)

Northeast Pacific OOI Community Workshop

Portland, OR, June 7-9 2022

Outline

- LiveOcean/J-SCOPE (Physics/BGC)
- WCOFS (Physics)
- Pioneer data application (Phys)
- Endurance optical data application (BGC -> Phys/BGC)



Example 1:
LiveOcean and the OOI Endurance Array

Marine Water Property Forecasts for the Pacific Northwest and Salish Sea

Parker MacCready

University of Washington, School of Oceanography

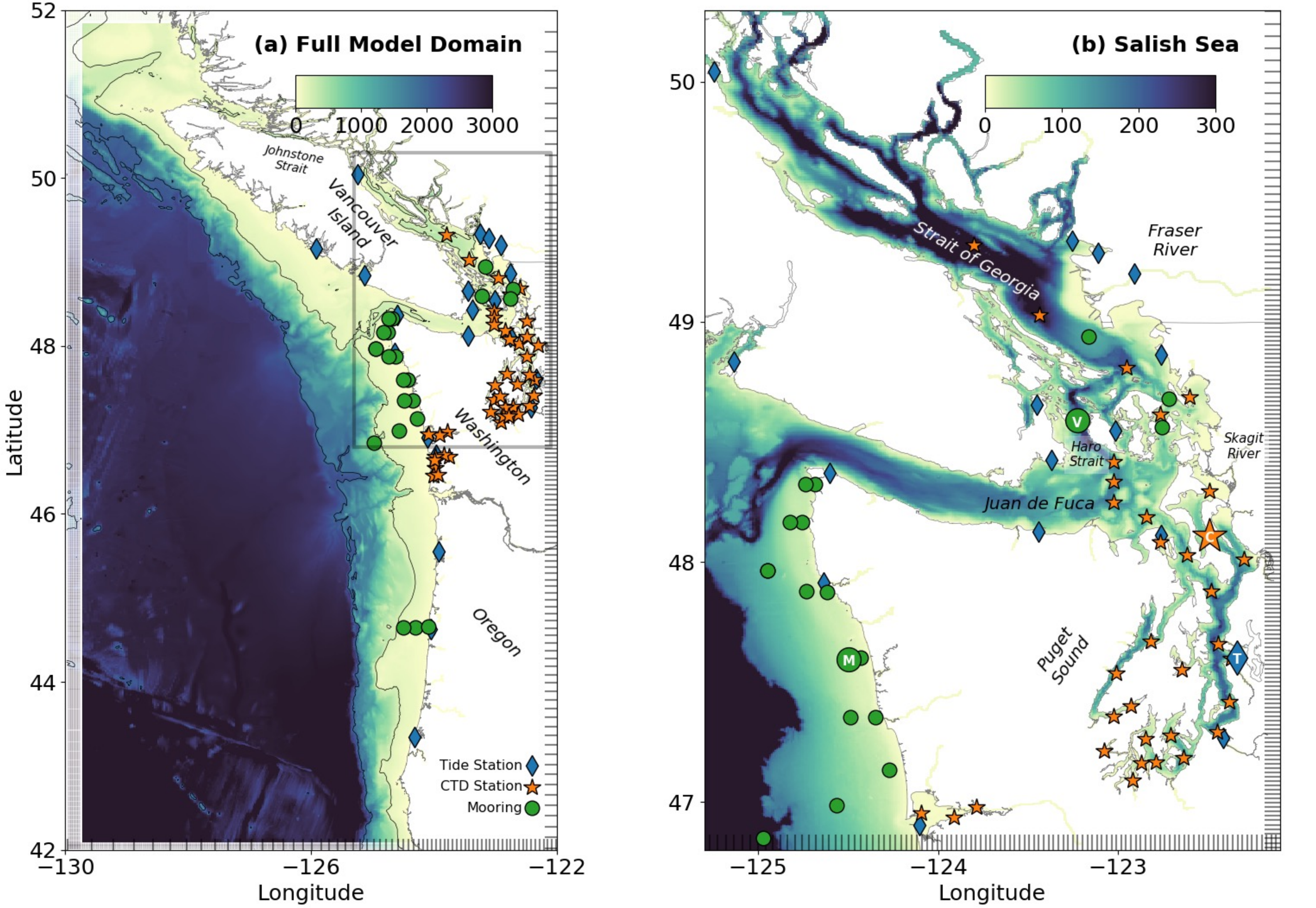
LiveOcean

Daily 3-day forecasts of Pacific Northwest and Salish Sea circulation and water properties

- 500 m grid on coast and in Salish Sea
- 30 vertical layers
- ROMS community model

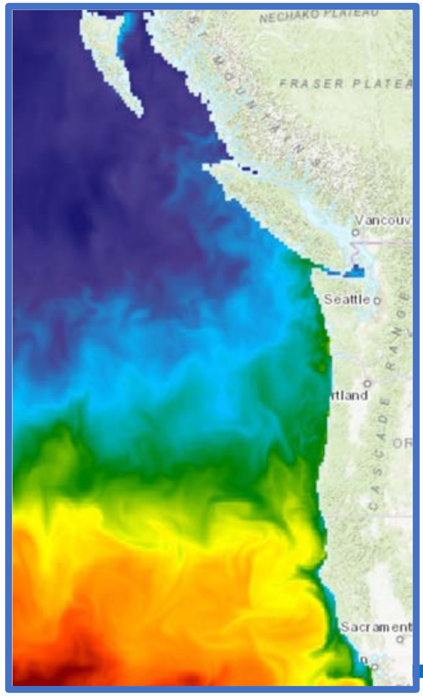
Realistic Forcing:
- Tides
- 45 rivers
- Open ocean conditions
- Wind and solar heating

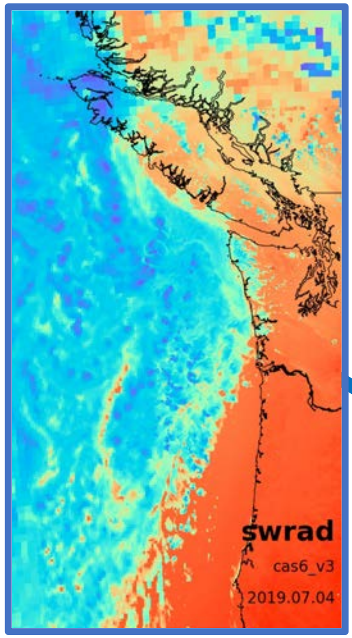
Biogeochemistry:
- Nitrate, Phytoplankton, Zooplankton, Detritus
- Oxygen
- Coastal Acidification



LiveOcean Forcing and System Overview

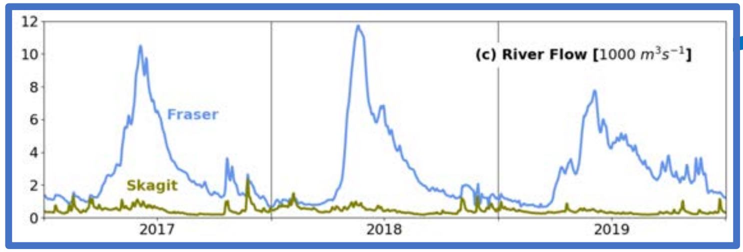
3-Day forecast appears daily on NANOOS NVS



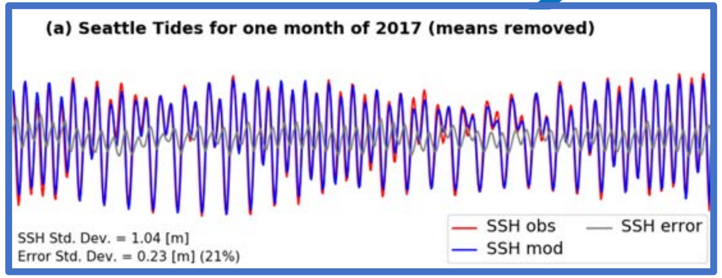


WRF Winds & Heating

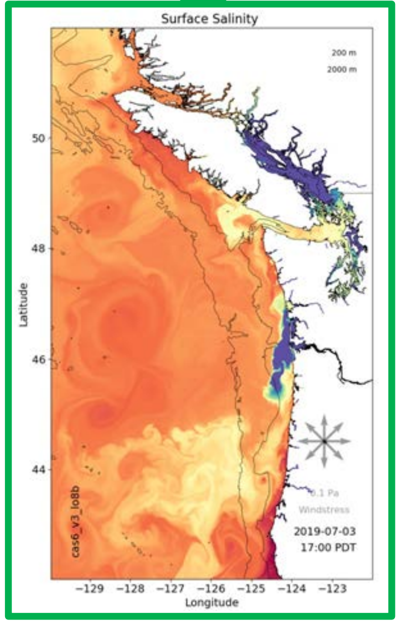
HYCOM Ocean Fields



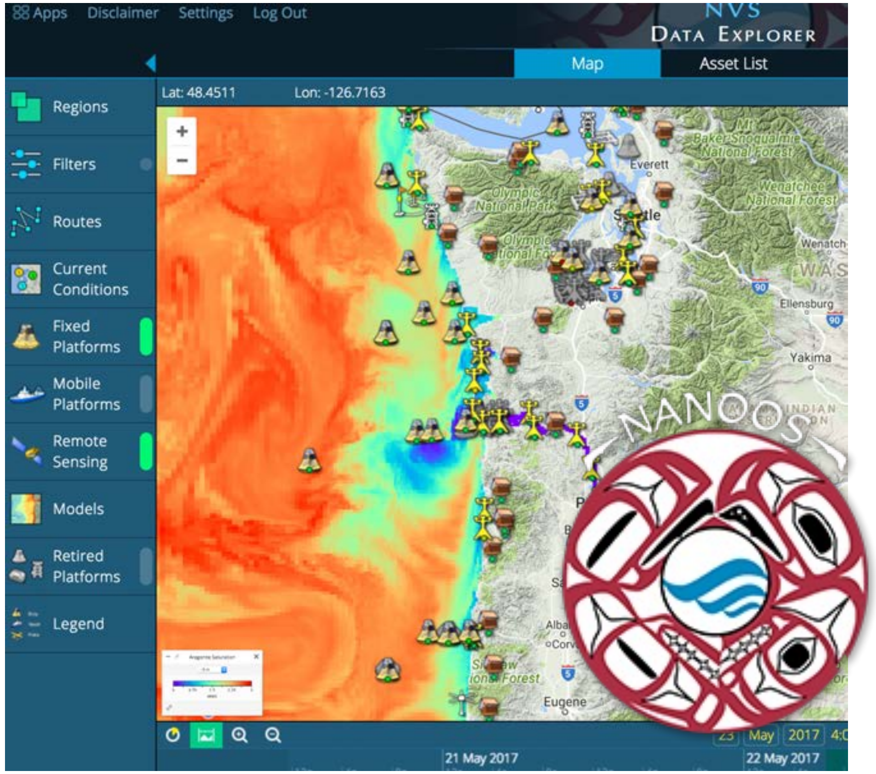
USGS & Canadian Rivers



TPXO Tides

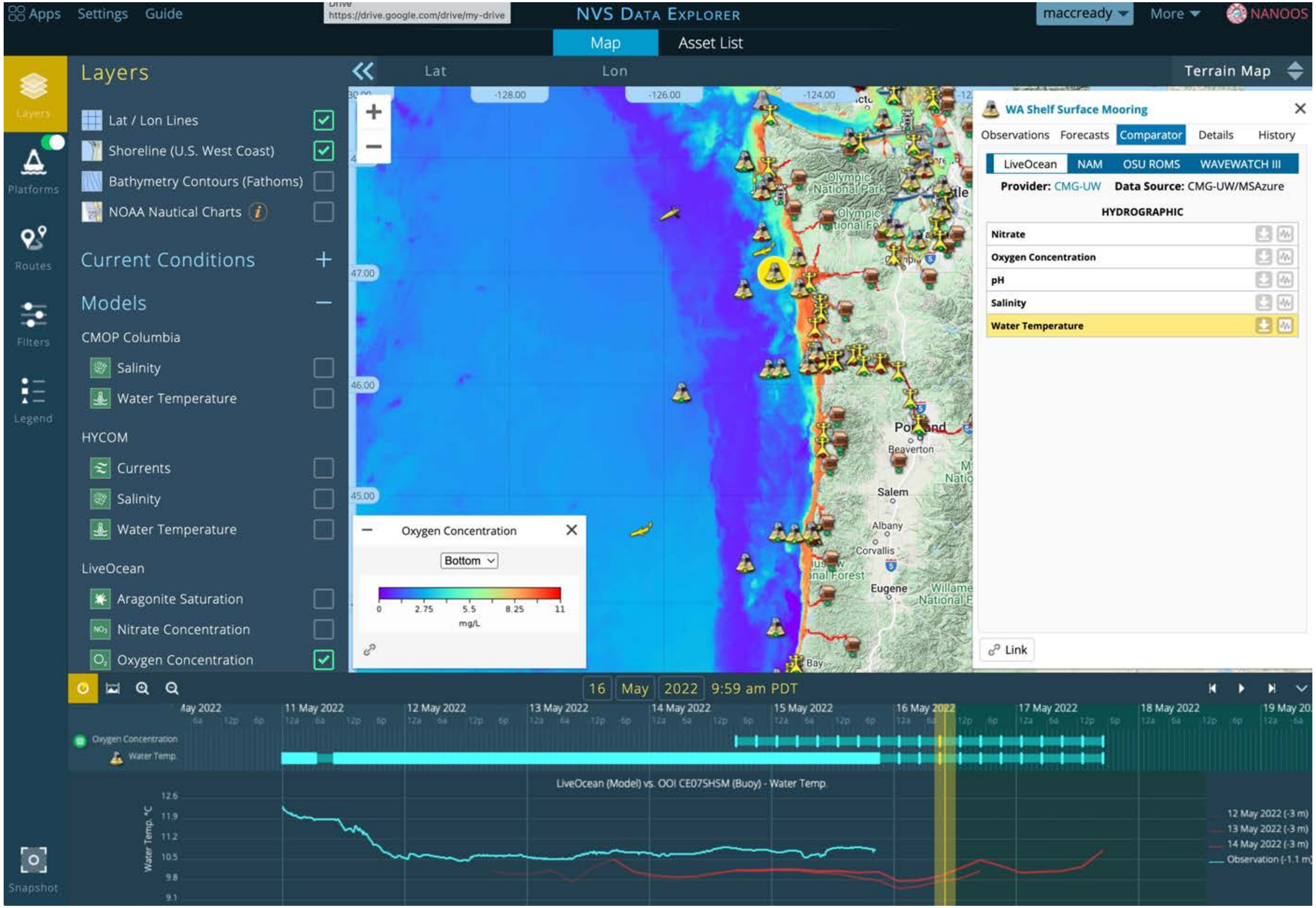


ROMS



The NANOOS NVS Data Explorer: nvs.nanoos.org/Explorer

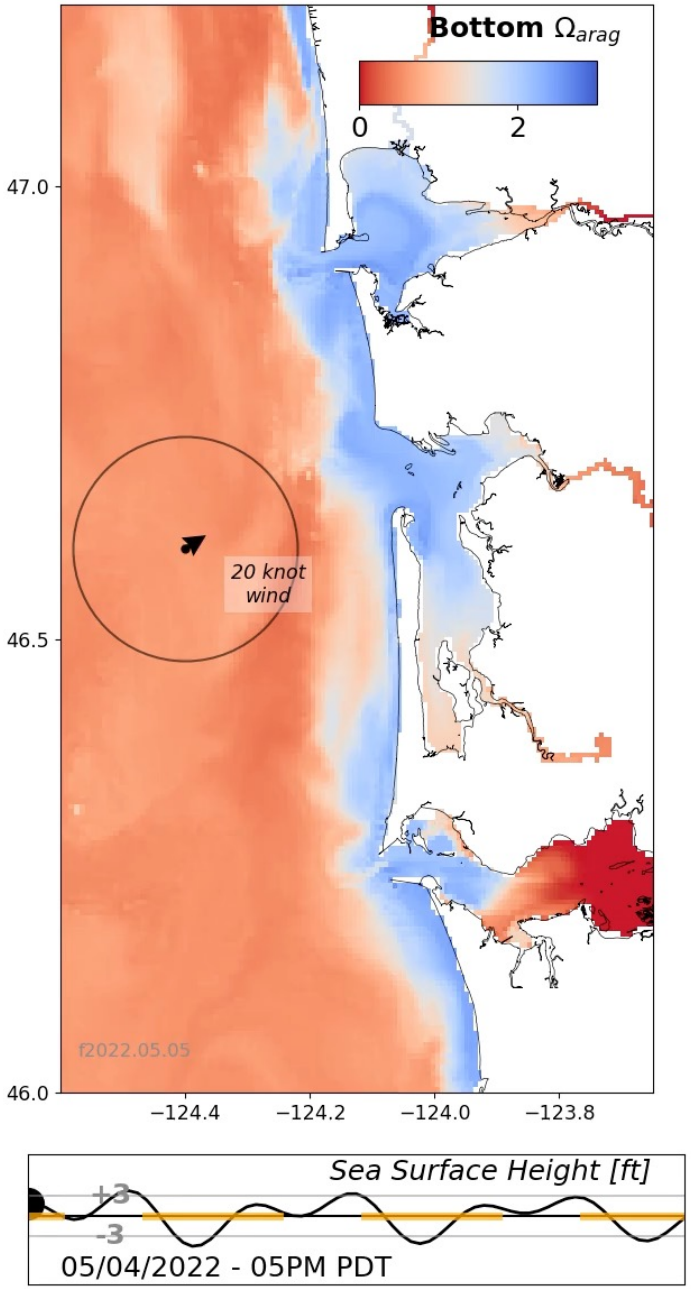
Use the “Comparator” feature to see real-time model comparisons with OOI observations!



APPLICATION 1: Forecast of corrosive water due to Ocean Acidification that harms shellfish aquaculture (WOAC)

One in eight oysters consumed in the US comes from Willapa Bay.

Often larval oysters in Willapa Bay do not survive – due to Ocean Acidification.



Model forecast Aragonite saturation state – corrosive waters from wind-driven upwelling and the Columbia River plume are a key feature.

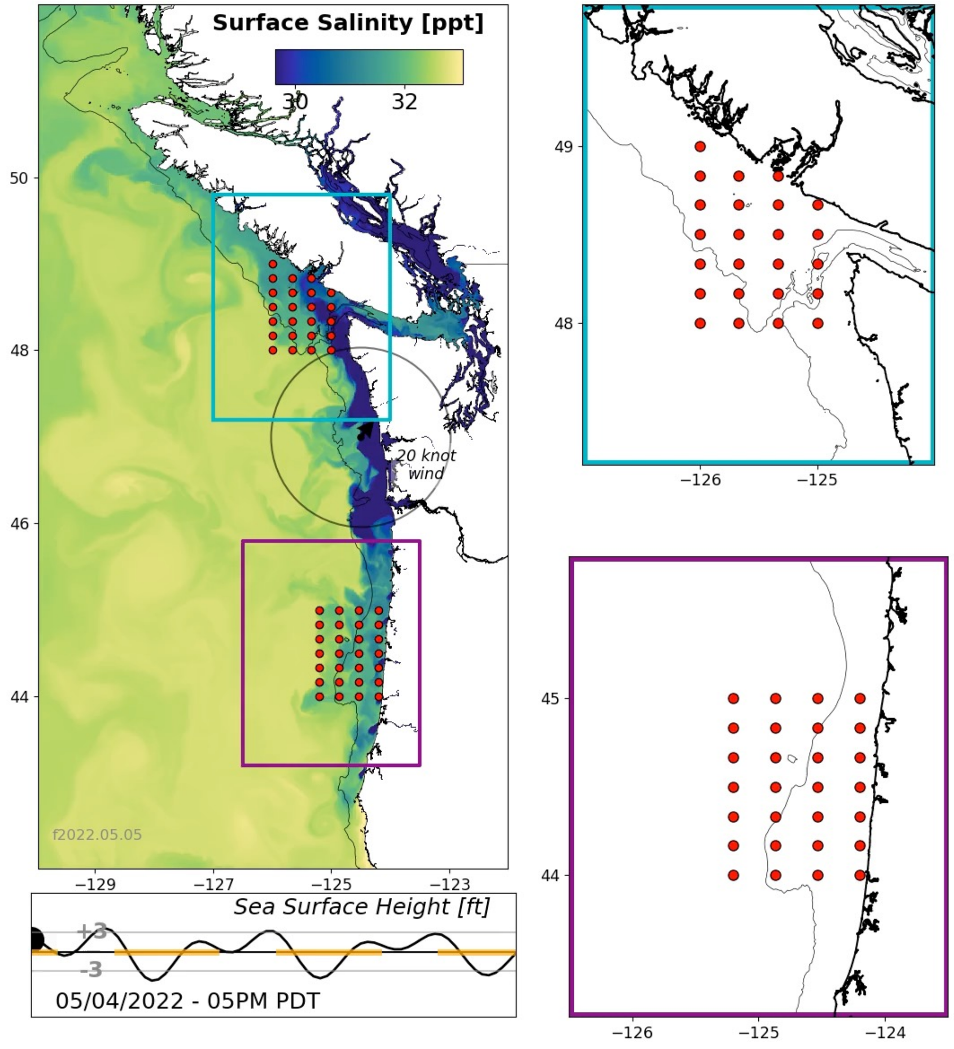
APPLICATION 2: Short-term forecasts of Phytoplankton Blooms and Surface Water Advection from known *Pseudo-nitzschia* HAB Hotspots.

Razor clams

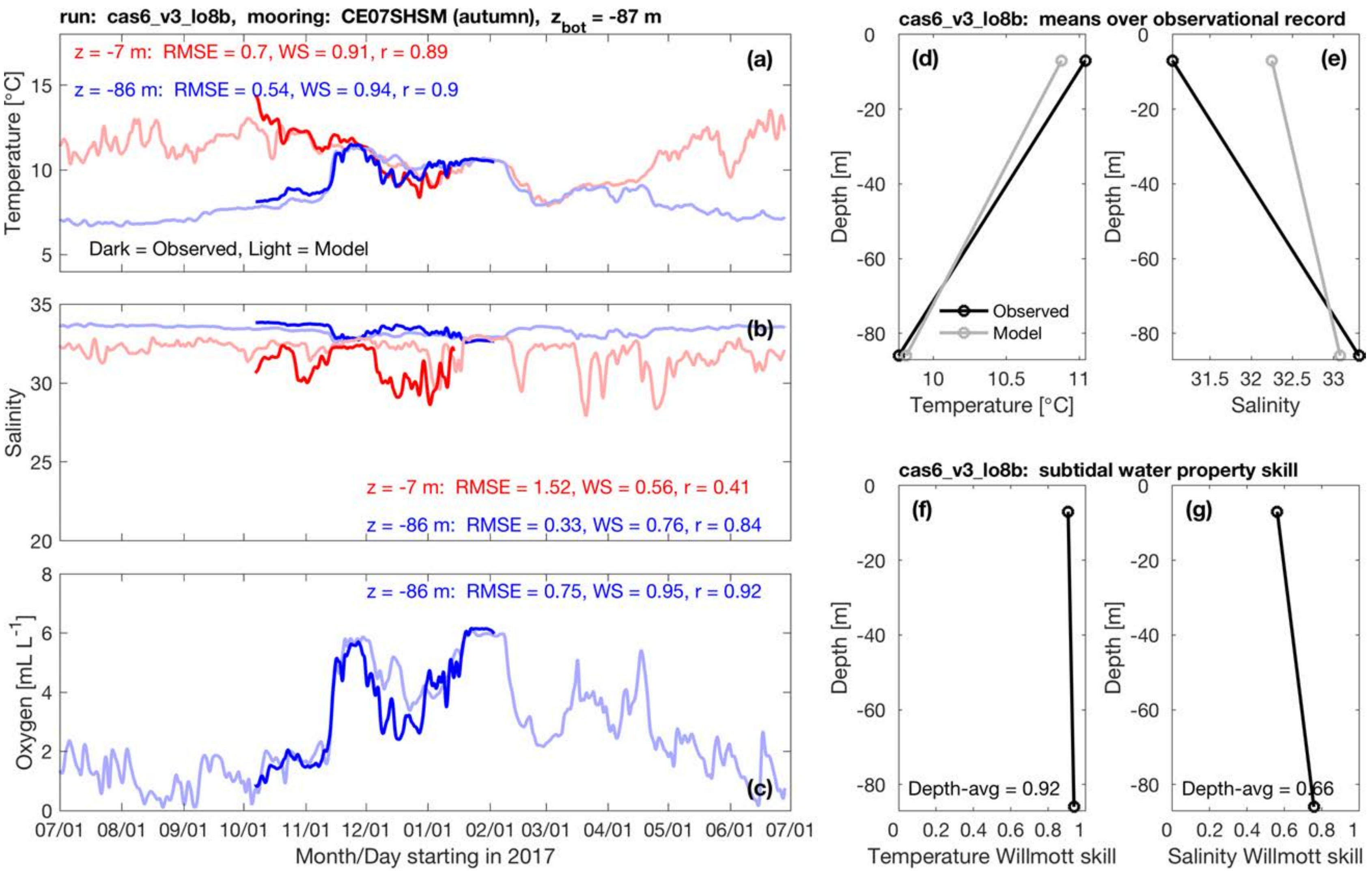
Pacific Northwest Harmful Algal Blooms Bulletin

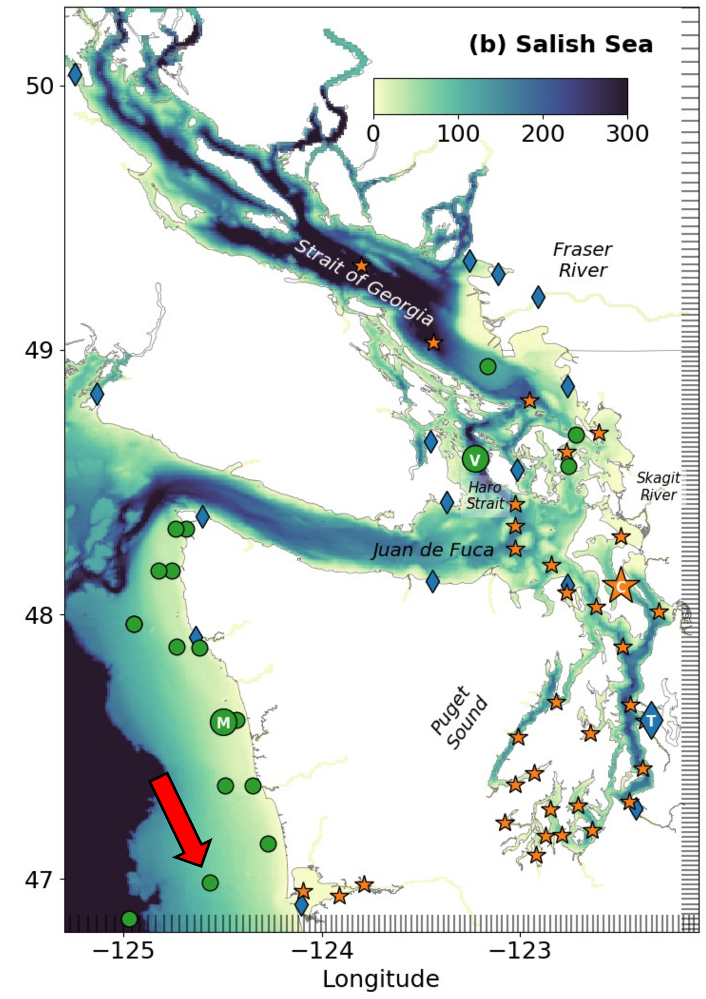
Sep 27, 2021 HAB risk =

HAB risk key:
- = low
- = medium
- = high

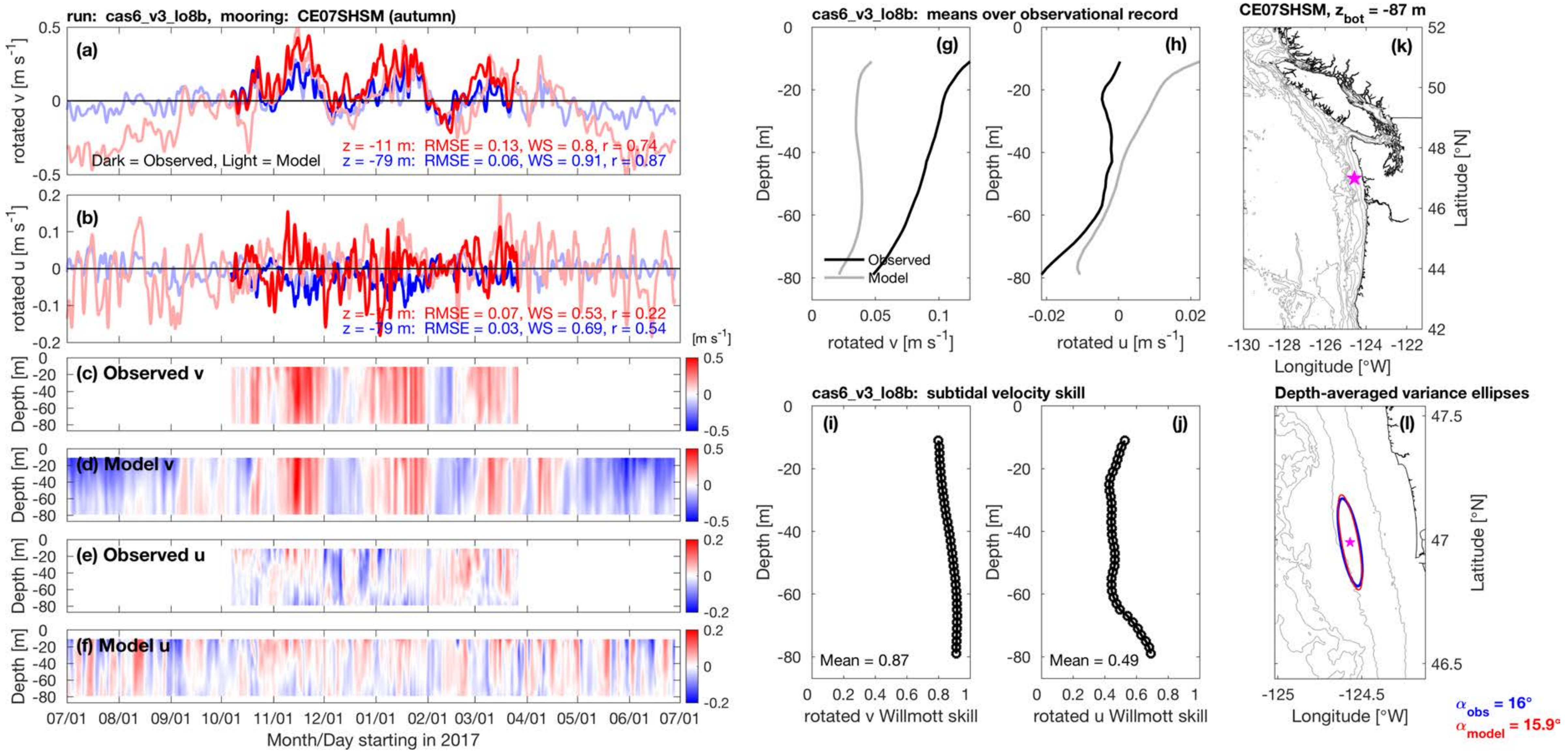


Validation Example: OOI Mooring, WA Shelf



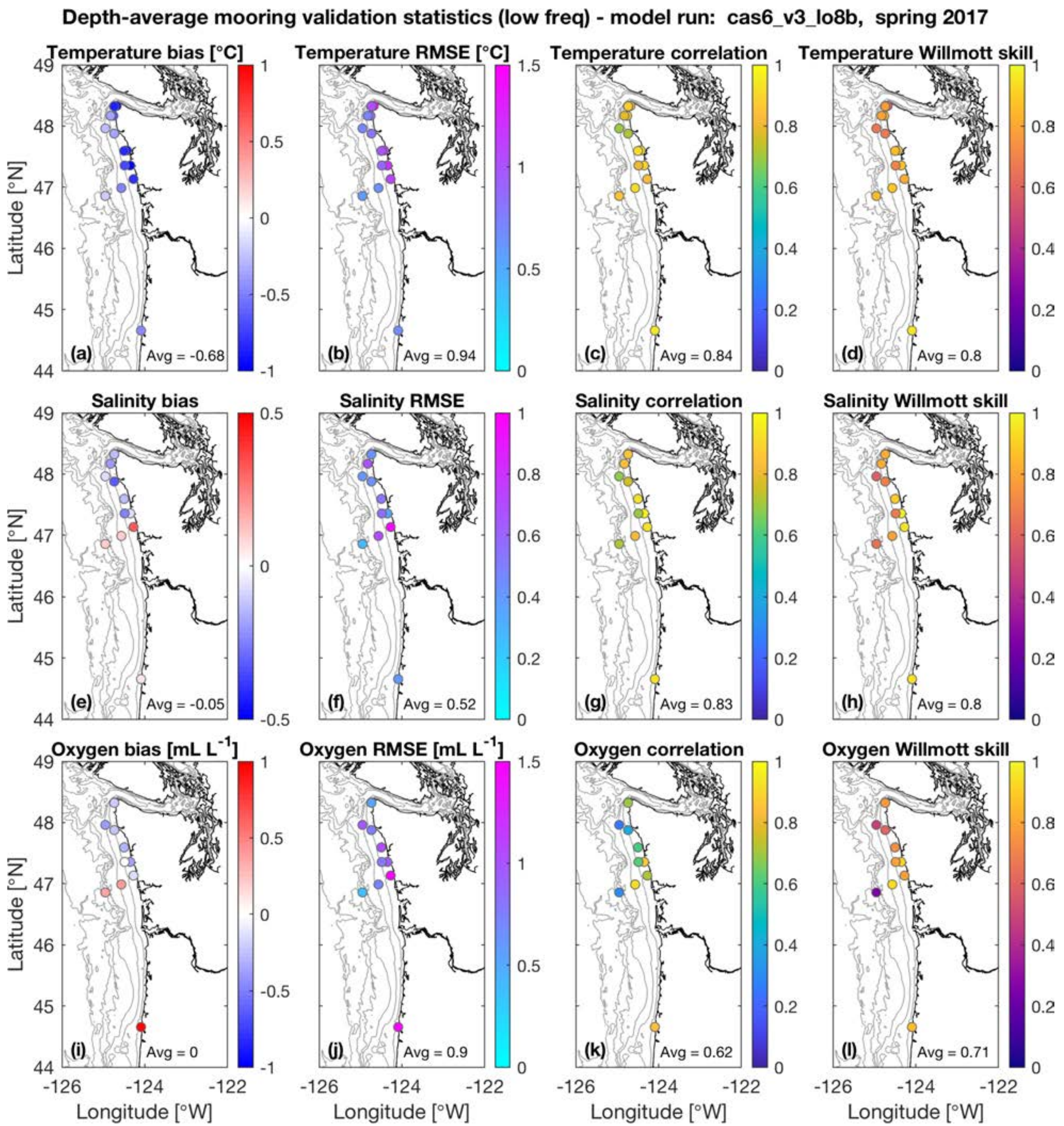


Validation includes ADCP Velocity



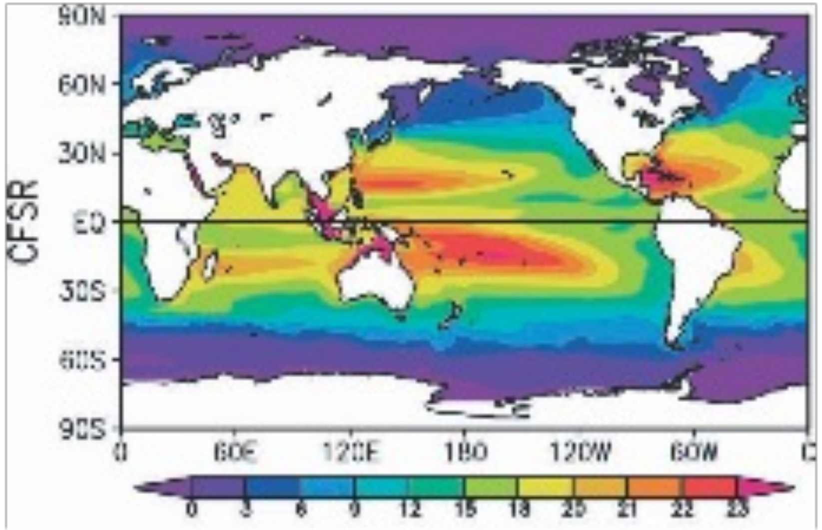
Validation from all shelf moorings in seasonal statistics

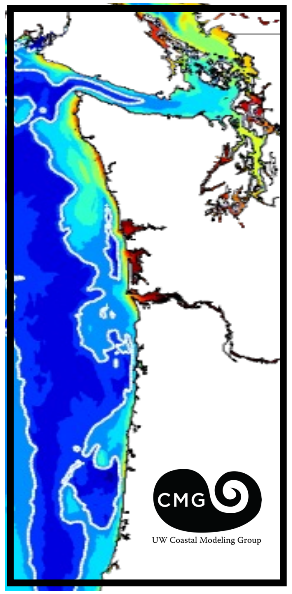
Includes OOI, OCNMS, and NANOOS moorings

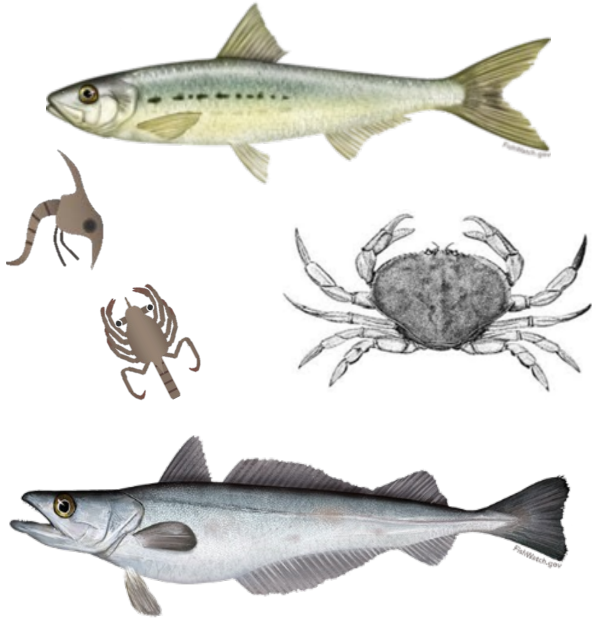


Application 3: J-SCOPE Seasonal Forecast System

JISAO Seasonal Coastal Ocean Prediction of the Ecosystem







<u>Climate Forecast System (CFS)</u>

~200 km atmospheric resolution

~50 km ocean resolution

<u>Regional Ocean Model (UW Cascadia)</u>

~1.5 km resolution

Physics and biogeochemistry (temperature, salinity, chlorophyll, nitrate, oxygen, pH, aragonite saturation state)

http://faculty.washington.edu/pmacc/cmg/cmg.html; Siedlecki et al. 2016

<u>Habitat Models and Indices</u>

Sardine (Kaplan et al., 2016)

Hake (Malick et al. 2020)

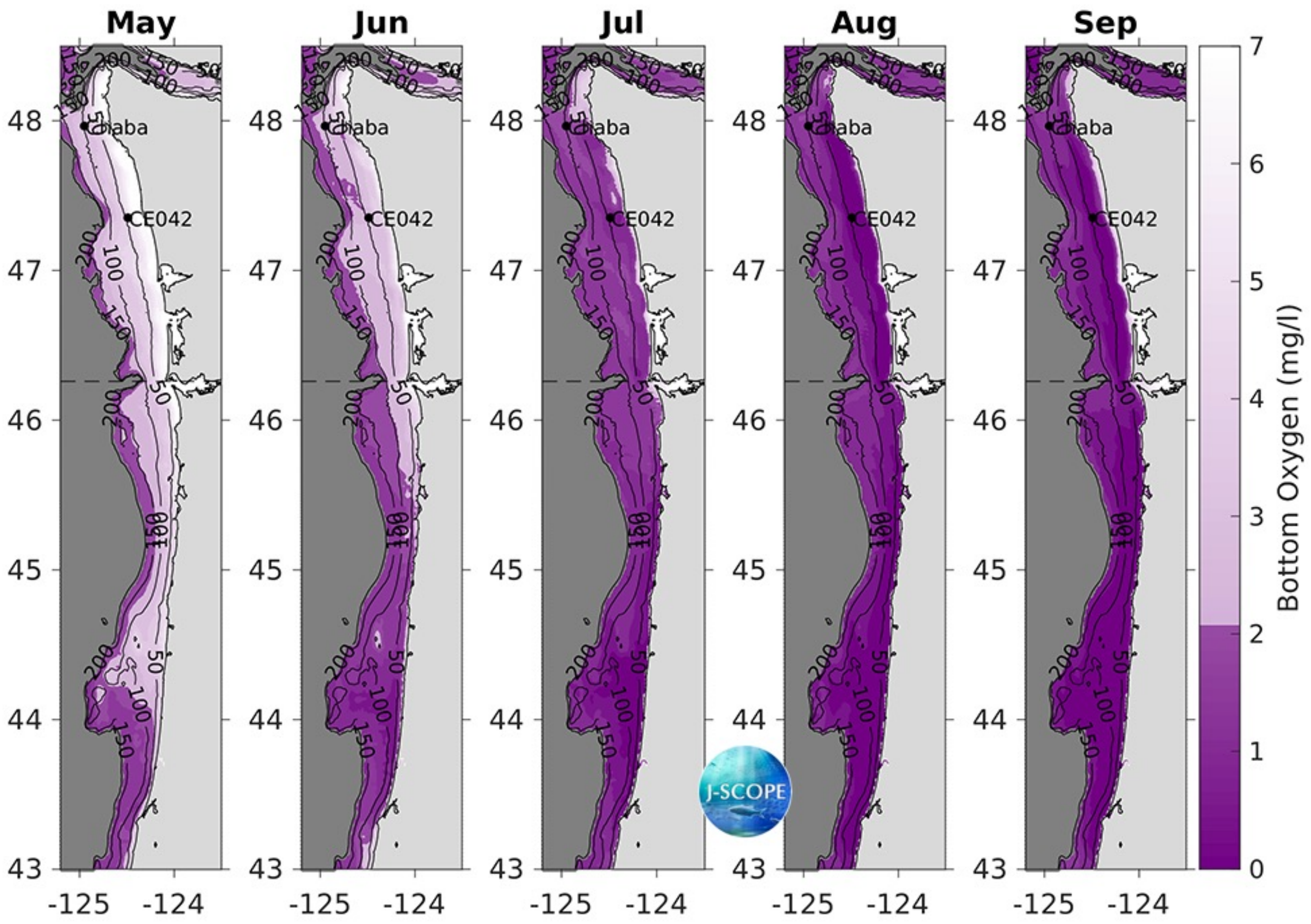
Juvenile crab (Norton et al. 2020)

Adult crab (Norton et al. in prep)

Courtesy Sam Siedlecki

J-SCOPE

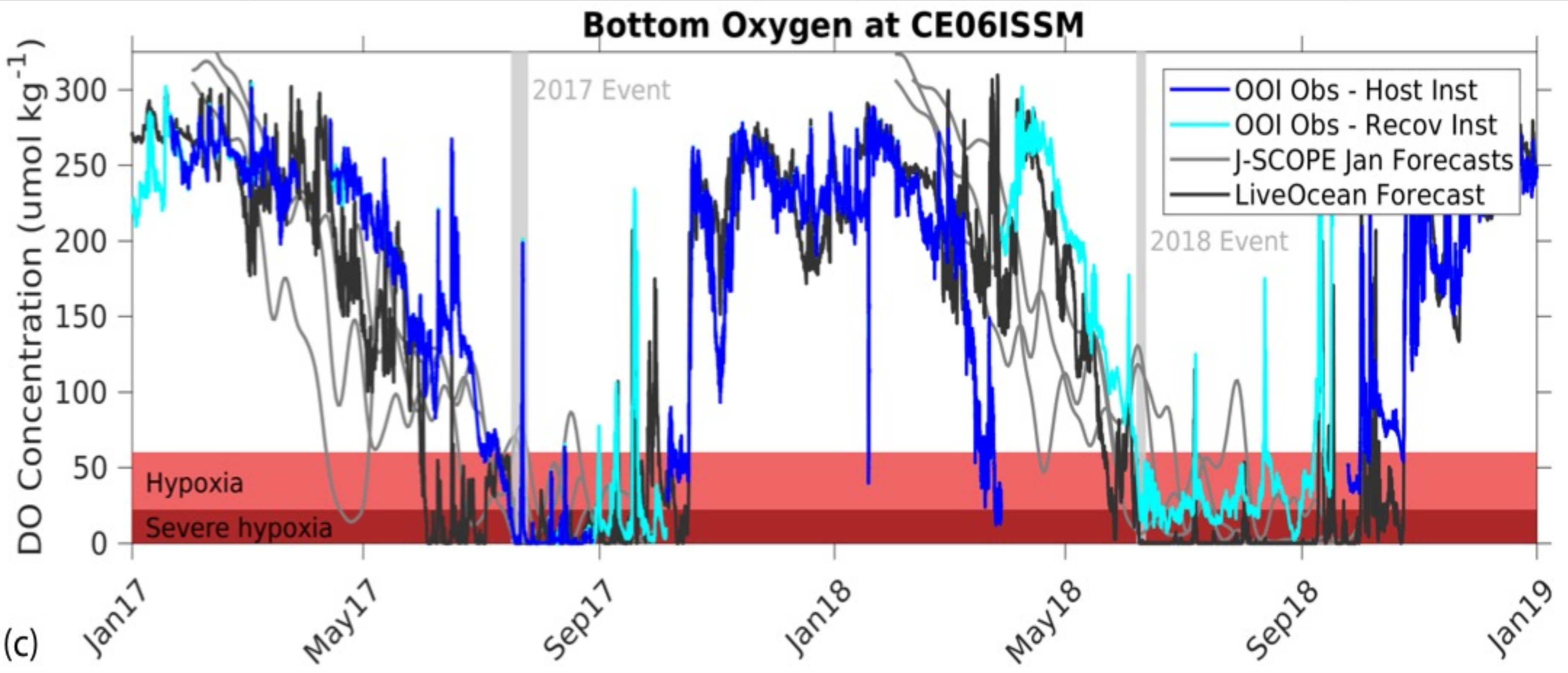
Dungeness crab state and tribal co-designed products targeting summer hypoxia



Courtesy Sam Siedlecki

Management Decision Point - Crabs and O2

The Quinault Indian Nation did take management action based on observations and J-SCOPE forecasts to close the 2018 fishery early due to recurring hypoxic conditions in the summer.



Courtesy Sam Siedlecki

The OOI Moorings are an essential part of the LiveOcean validation

- Time series exist for the much of the model hindcast period
- The OOI moorings are unique in combining ADCP and water properties
- Biogeochemical fields: nitrate, oxygen, and pH are also extremely important for stakeholders
- The real-time capability of the OOI data will soon be used to improve confidence in the modeled shelf hypoxia and coastal acidification fields (important for Dungeness crab fishery and oyster growers)

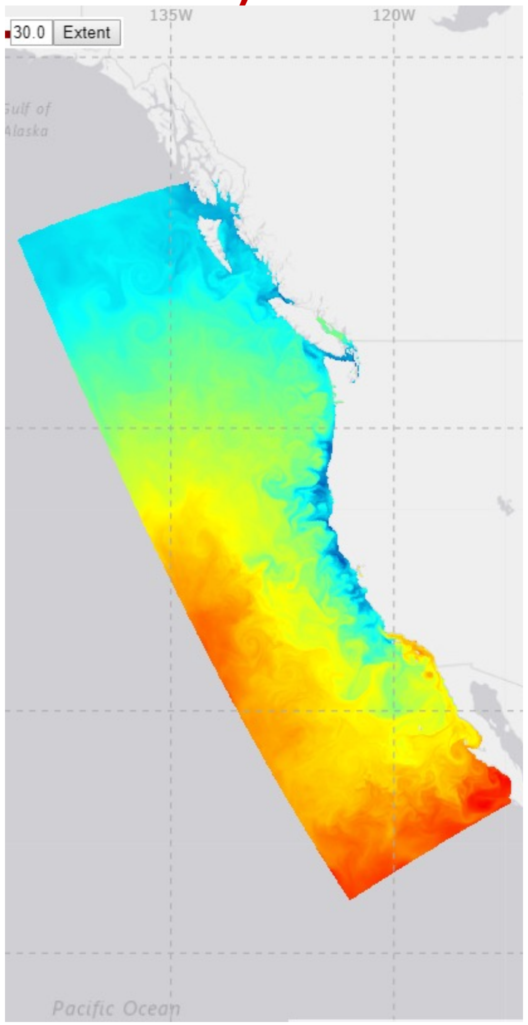
Example 2: OOI data is also being used to evaluate the West Coast Ocean Forecast System (WCOFS)

- Model domain: 24N-54N / Offshore extent: 600-1000 km
- Numerics: Regional Ocean Modeling System (ROMS)
- Horizontal resolution: 4-km (data assimilation 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

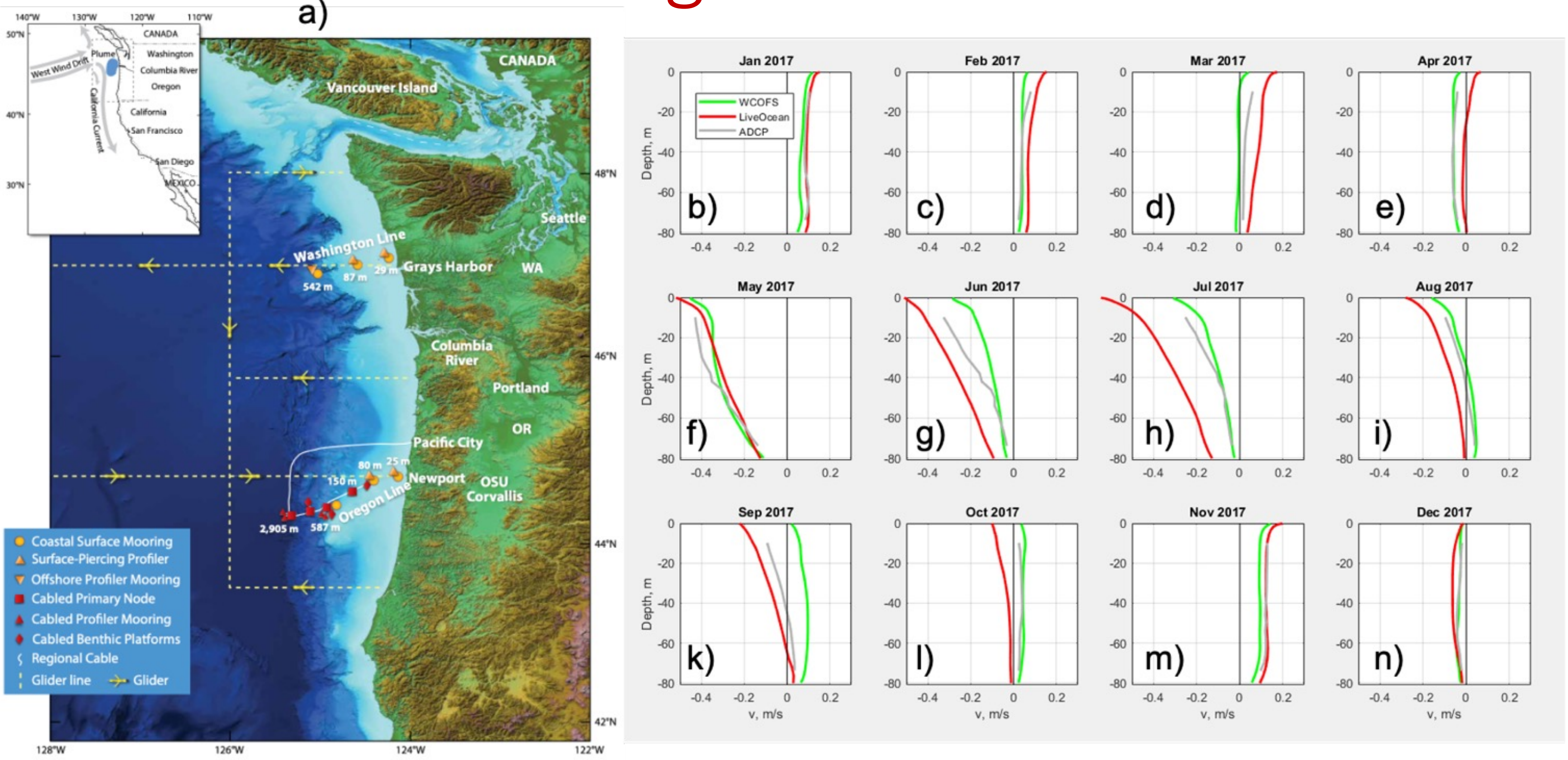
- 4D-Var Data Assimilation (DA): combine the model output and available observations to improve initial conditions for forecasts
  - HF radar surface currents
  - Satellite SST (3 platforms)
  - Satellite Sea Level (non-tidal)
  - in-situ: gliders, argo floats etc.

- **Daily operation with 3 day forecasts**



Courtesy Alex Kurapov (NOAA)

Comparison of WCOFS velocities against OOI Endurance moorings



Courtesy Parker MacCready

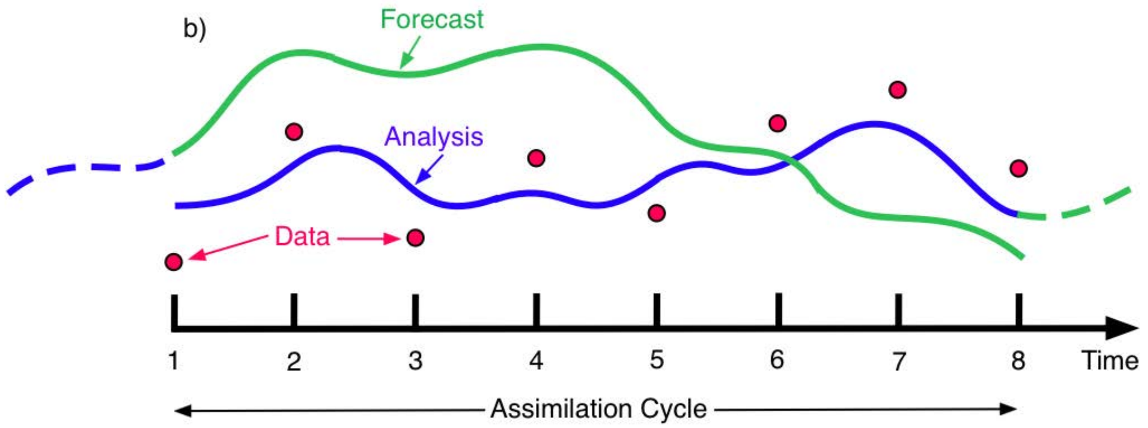
Example 3: Nested data assimilative modeling of submesoscale variability at the Pioneer Coastal Array

John Wilkin, Andrew Moore*, Julia Levin and Hernan Arango

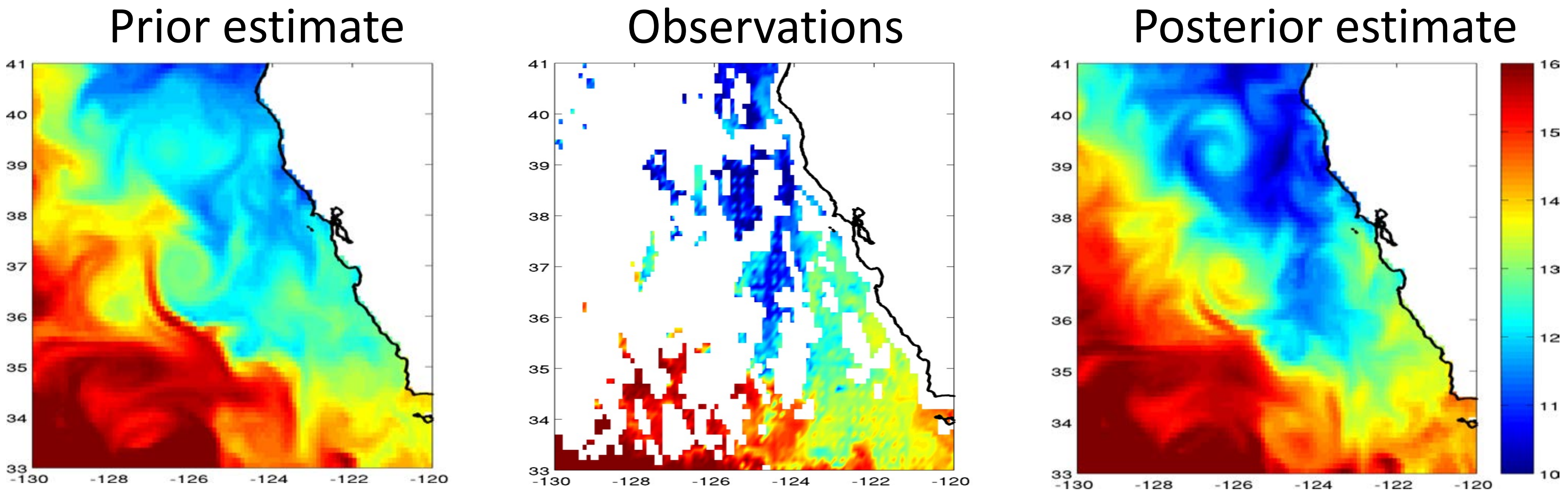
Department of Marine and Coastal Sciences, Rutgers, The State University of New Jersey

**Department of Ocean Sciences, University of California, Santa Cruz*

Data Assimilative Modeling



An example (SST):

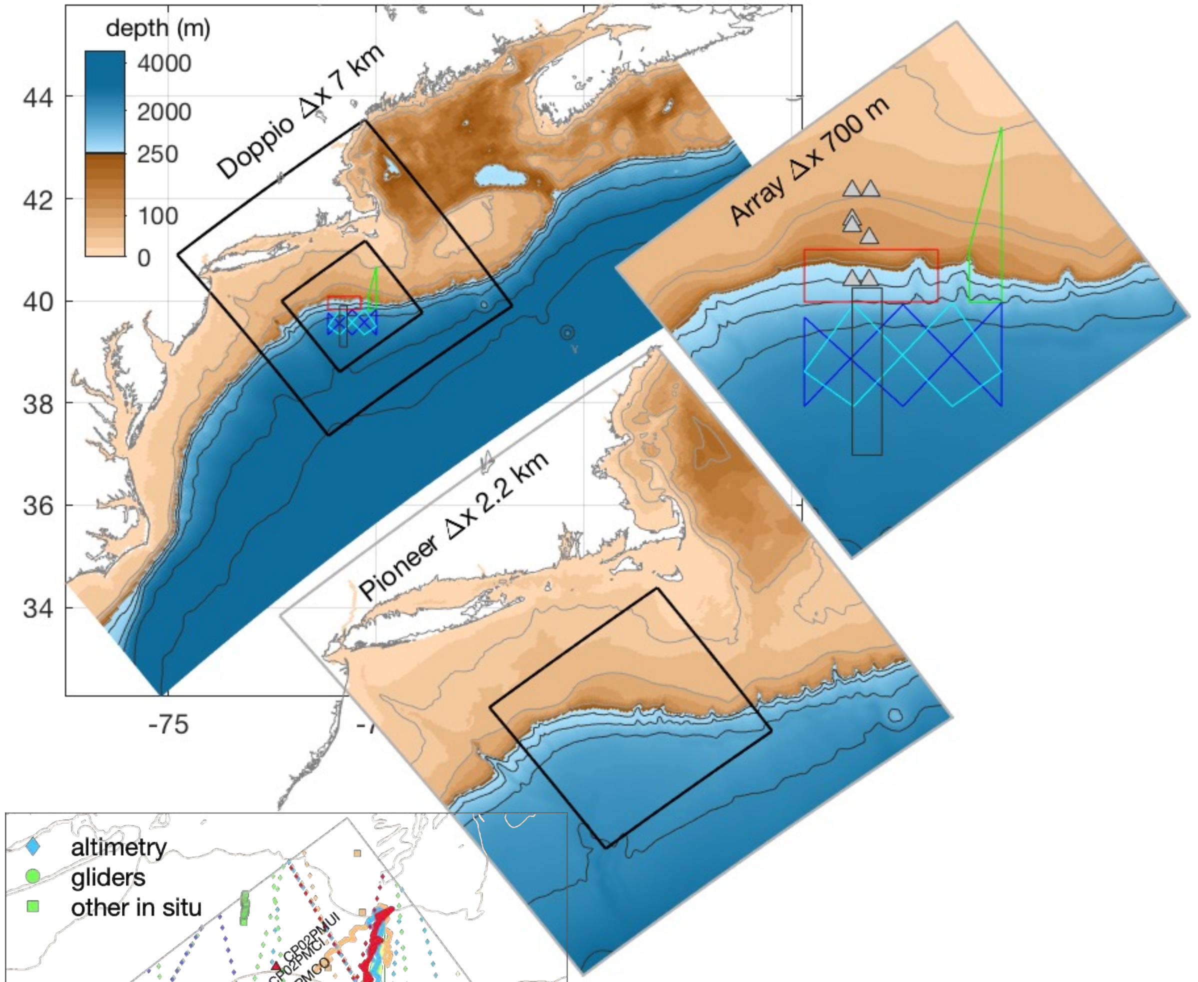


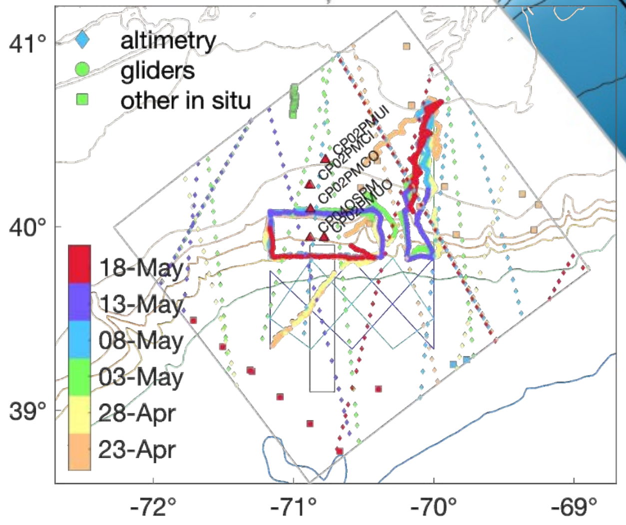
- Though SST is shown, all variables are adjusted in ways consistent with background and observation error covariances

Model/Data details

- A hierarchy of three 1-way nested ROMS grids is used (7 km, 2.3 km and 700 m resolution) with 4D-Var data assimilation at each successive level of grid refinement.
- Boundary conditions from each parent grid analysis is imposed on the subsequent nest.
- Data: Satellite SSH; SST; OOI glider T,S; mooring T,S,**u**; all IOOS T,S; HF-radar **u**
- 4D-Var analysis cycle: 3 days in *Doppio* and *Pioneer*, 1 day in *Array.*
- Background error covariance scales: 40 km, 14 km and 5 km

Doppio –> Pioneer –> Array 1-way nested grids





Courtesy John Wilkin

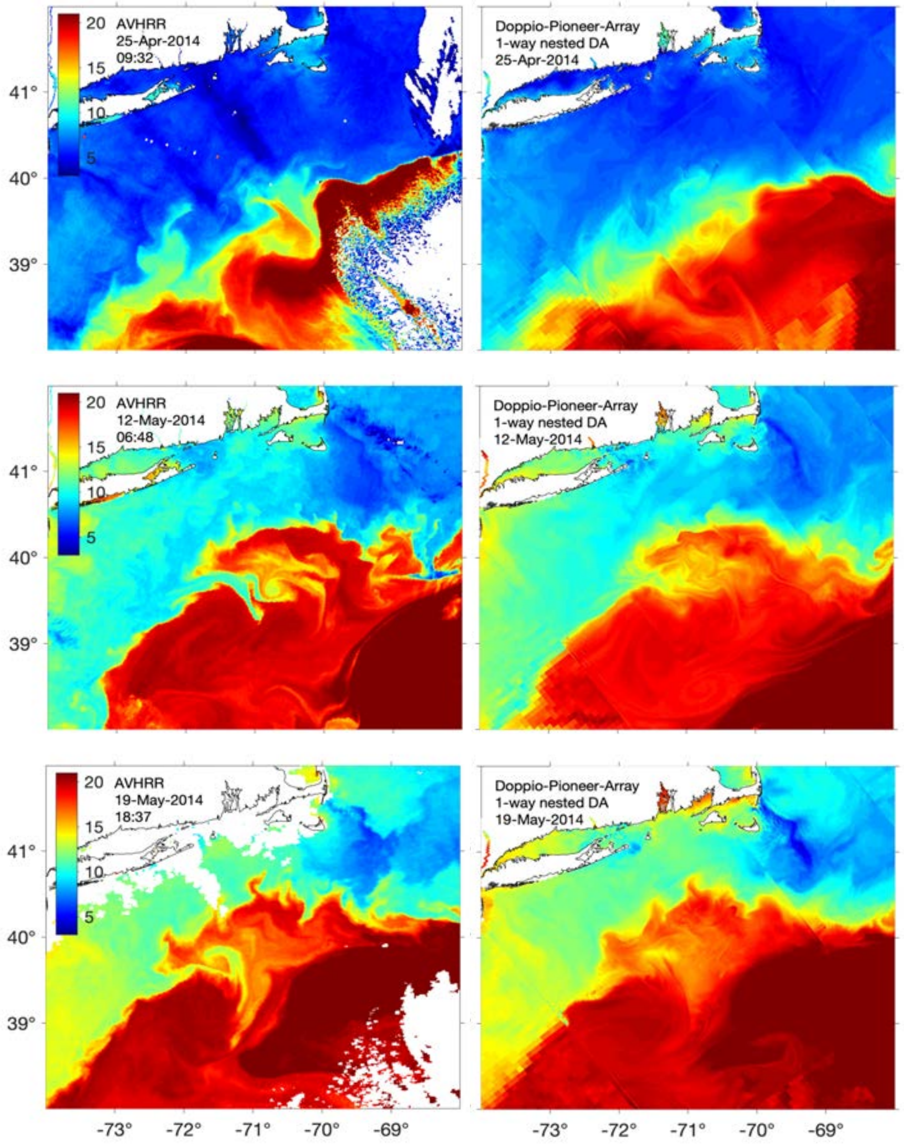
Pinocchio Nose Intrusions

Gulf Stream warm-core rings that impinge on the Mid-Atlantic Bight (MAB) shelf-break generate along-isobath intrusions that grow like Pinocchio's nose. The Pinocchio Nose Intrusions (PNI) contribute significantly to exchange of shelf and Slope Sea water masses (Zhang and Gawarkiewicz, 2015; Cherian and Brink, 2018).

PNI evolves rapidly in early May ζ_z/f ~o(1)

AVHRR data

1-way nested model

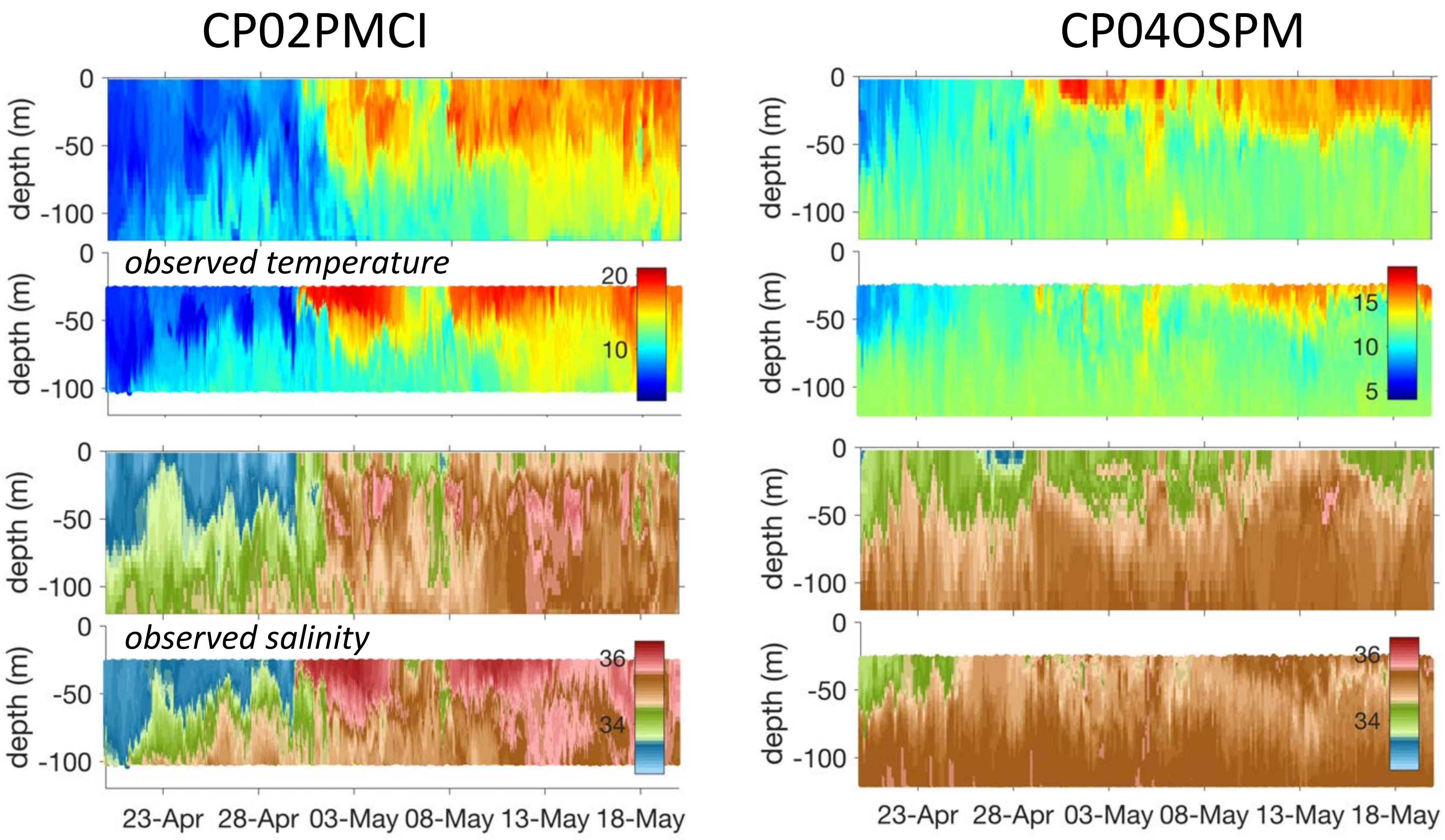


Cherian, D.A. and Brink, K.H., (2018), Shelf Flows Forced by Deep-Ocean Anticyclonic Eddies at the Shelf Break. Journal of Physical Oceanography, 48(5), pp.1117-1138.

Zhang, W. G., and G. G. Gawarkiewicz (2015), Dynamics of the direct intrusion of Gulf Stream ring water onto the Mid-Atlantic Bight shelf, Geophysical Research Letters, 42, doi:10.1002/2015GL065530.

Moored profiling CTD comparisons

- Temperature shows value of SST in combination with in situ CTD
- Salinity information may not be communicated well to mixed layer.
- 1-way nesting with data assimilation at each level of grid refinement achieves event-wise correspondence of modeled and observed ocean submesoscale features in the vicinity of the OOI *Pioneer Coastal Array.*
- The strongly filamentous and turbulent flow likely has implications for biogeochemical process interactions.
- Open question: On what time scale can event agreement be forecast?



Example 4: Building a tool to investigate phytoplankton community structure using OOI Endurance Array absorption and scattering data (work in progress)

Miles Miller (UCSC)

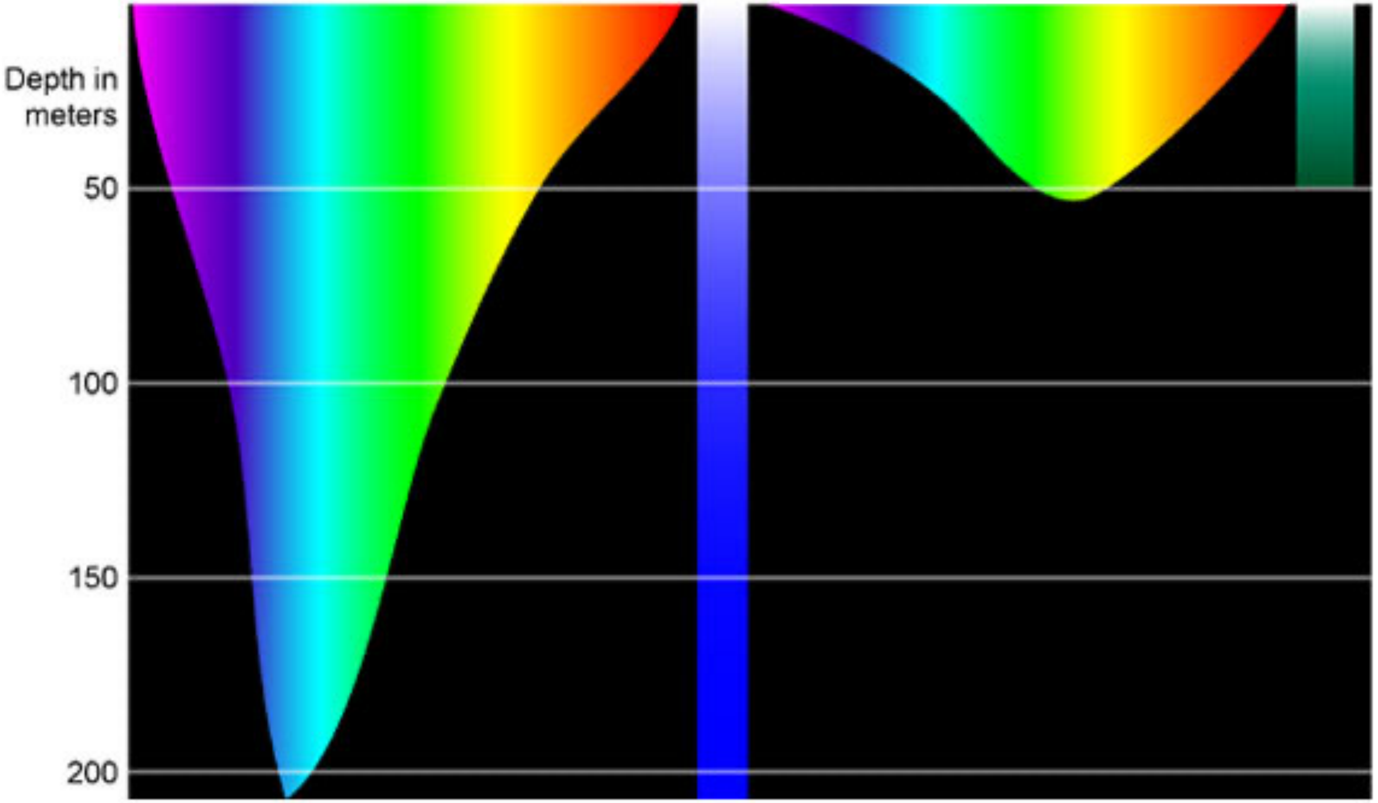
Christopher Edwards (UCSC), John Wilkin (Rutgers), Jonathan Izett (UCSC)

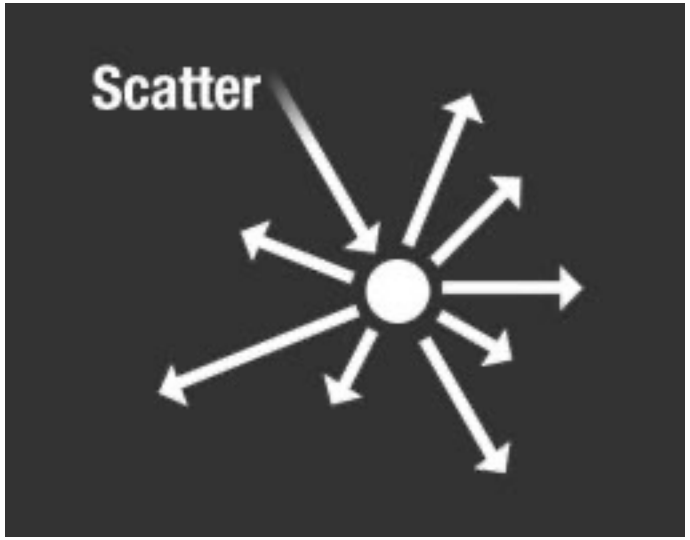
Many Thanks to Chris Wingard (OSU)

Simple Ocean Optics, absorption and scattering

Light penetration in open ocean waters

Light penetration in coastal waters





Differences result from constituents in the water column

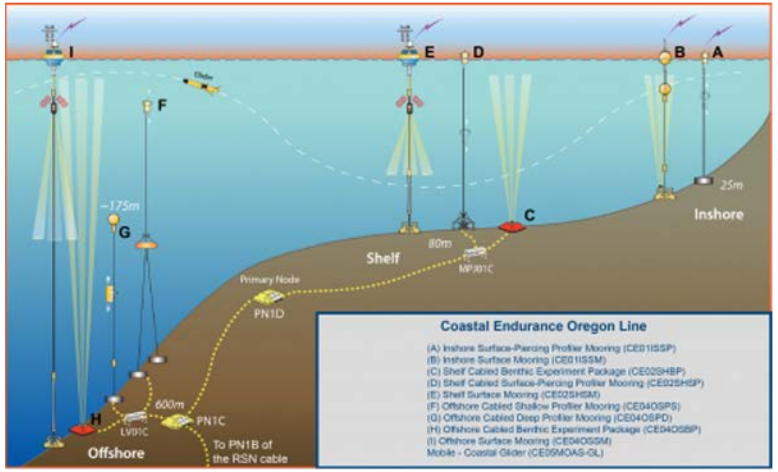
- Detritus
- CDOM
- Phytoplankton
- Zooplankton

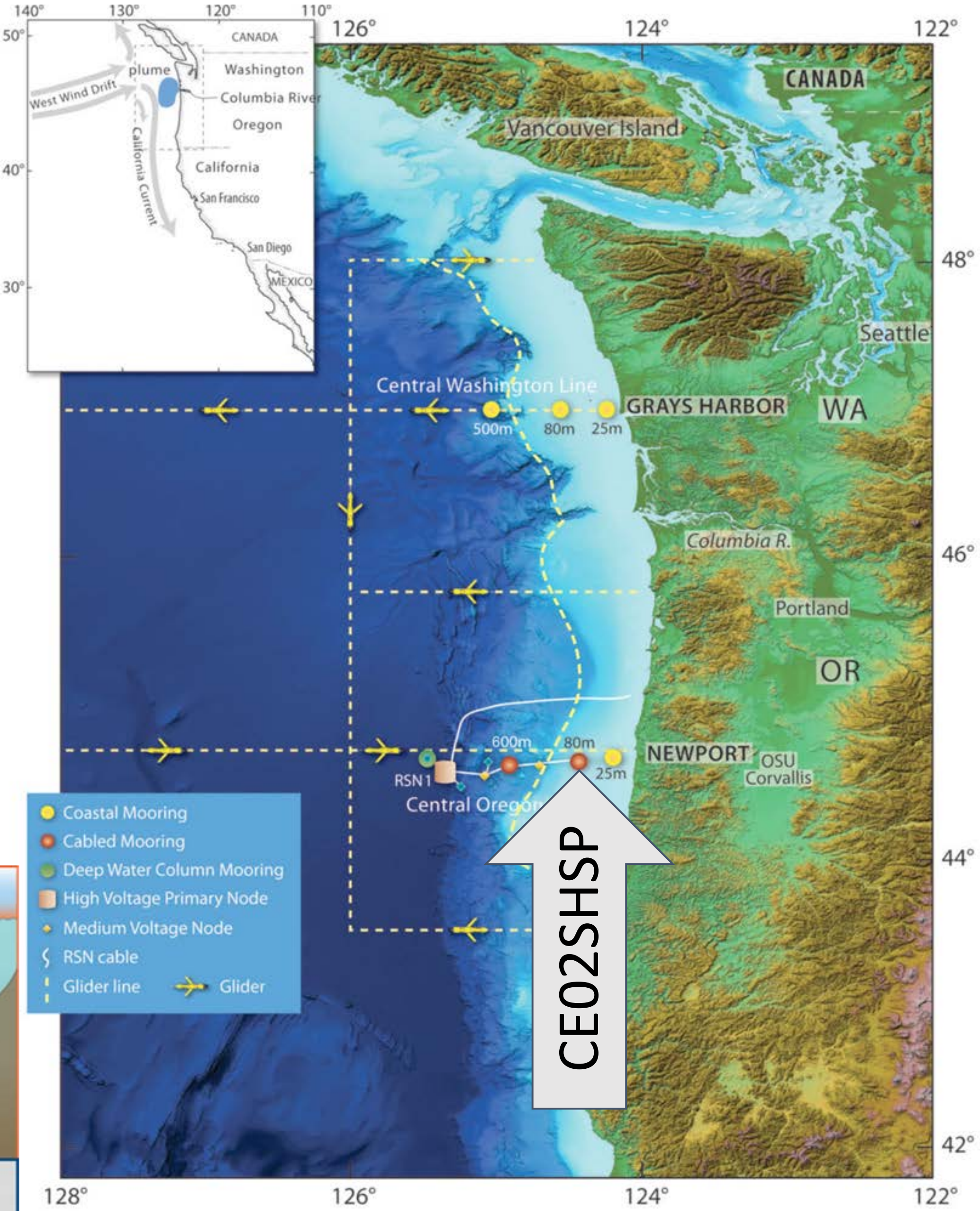
OOI Data Product

Site: Oregon Shelf Surface Piercing Profiler Mooring (CE02SHSP)
→ Location: 44.6372°N, 124.299°W
→ Depth: 81 meters

Instrument and Data Products Used:
→ Fluorometer (FLORT)
– Fluorometric Chlorophyll-a
– Fluorometric CDOM
→ Spectrophotometer (OPTAA)
– Optical Attenuation
– Beam Attenuation
→ Spectral Irradiance (SPKIR)
– Spectral Downwelling Irradiance

Deployment:
→ Deployment Number: 19
→ Start Date: 2021-04-06
→ End Dat: 2021-04-29
→ Profile Count: 54

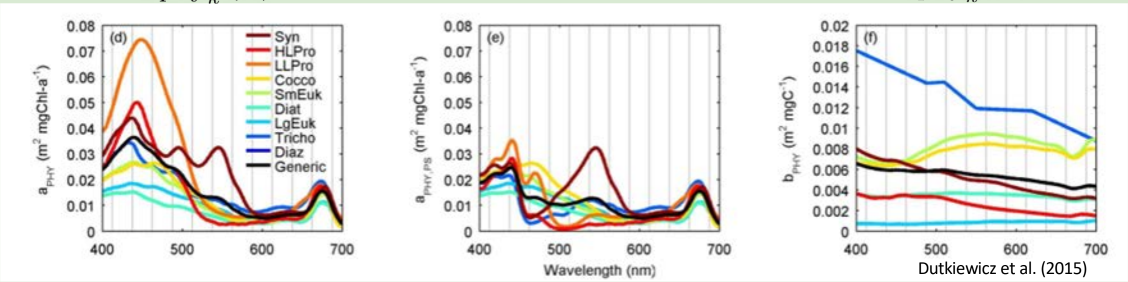




Constrained and Weighted Least Squares Absorption-Scattering Phytoplankton Community

Phytoplankton Species Specific Effective Absorption and Scattering

$a_{\mathrm{phy}_k}(\lambda)$ $\qquad$ $b_{\mathrm{phy}_k}(\lambda)$



$$\alpha_{\mathrm{phy}_k}(\lambda) = \mathrm{Chla}_{\mathrm{ooi}} a_{\mathrm{phy}_k}(\lambda)$$

$$\beta_{\mathrm{phy}_k}(\lambda) = \mathrm{Chla}_{\mathrm{ooi}} b_{\mathrm{phy}_k}(\lambda)$$

Effective OOI Absorption and Scattering

$a_{\mathrm{ooi}}(\lambda) =$ OOI OPTAA optical_absorption at z_0

$c_{\mathrm{ooi}}(\lambda) =$ OOI OPTAA beam_attenuation at z_0

$\mathrm{Chla}_{\mathrm{ooi}} =$ OOI FLORT fluorometric_chlorophyll_a at z_0

$$\beta_{\mathrm{ooi}}(\lambda) = c_{\mathrm{ooi}}(\lambda) - a_{\mathrm{ooi}}(\lambda)$$

$$\alpha_{\mathrm{ooi}}(\lambda) = a_{\mathrm{ooi}}(\lambda) - a_{\mathrm{cdom}}(\lambda)$$

Least Squares Formulation

→ Coupled Absorption and Scattering:

$$\sum_{k=1}^{\infty} p_{\mathrm{phy}_k} \beta_{\mathrm{phy}_k}(\lambda) = \beta_{\mathrm{ooi}}(\lambda) \quad \text{and} \quad \sum_{k=1}^{\infty} p_{\mathrm{phy}_k} \alpha_{\mathrm{phy}_k}(\lambda) = \alpha_{\mathrm{ooi}}(\lambda)$$

→ Solve for x:

$$\arg\min_{\mathbf{x}} ||\mathbf{A}\mathbf{x} - \mathbf{y}|| \ \text{ subject to } \mathbf{x}_k \geq 0 \text{ and } \sum_{k=0}^{M} \mathbf{x}_k = 1$$

System of Equations [Coupled Absorption/Scattering]

$$\mathbf{A} = \begin{bmatrix} w_a \alpha_{\mathrm{phy}_0}(\lambda_0) & w_a \alpha_{\mathrm{phy}_1}(\lambda_0) & \dots & w_a \alpha_{\mathrm{phy}_M}(\lambda_0) \\ w_b \beta_{\mathrm{phy}_0}(\lambda_0) & w_b \beta_{\mathrm{phy}_1}(\lambda_0) & \dots & w_b \beta_{\mathrm{phy}_M}(\lambda_0) \\ w_a \alpha_{\mathrm{phy}_0}(\lambda_1) & w_a \alpha_{\mathrm{phy}_1}(\lambda_1) & \dots & w_a \alpha_{\mathrm{phy}_M}(\lambda_1) \\ w_b \beta_{\mathrm{phy}_0}(\lambda_1) & w_b \beta_{\mathrm{phy}_1}(\lambda_1) & \dots & w_b \beta_{\mathrm{phy}_M}(\lambda_1) \\ \vdots & \vdots & \dots & \vdots \\ w_a \alpha_{\mathrm{phy}_0}(\lambda_N) & w_a \alpha_{\mathrm{phy}_1}(\lambda_N) & \dots & w_a \alpha_{\mathrm{phy}_M}(\lambda_N) \\ w_b \beta_{\mathrm{phy}_0}(\lambda_N) & w_b \beta_{\mathrm{phy}_1}(\lambda_N) & \dots & w_b \beta_{\mathrm{phy}_M}(\lambda_N) \end{bmatrix}$$

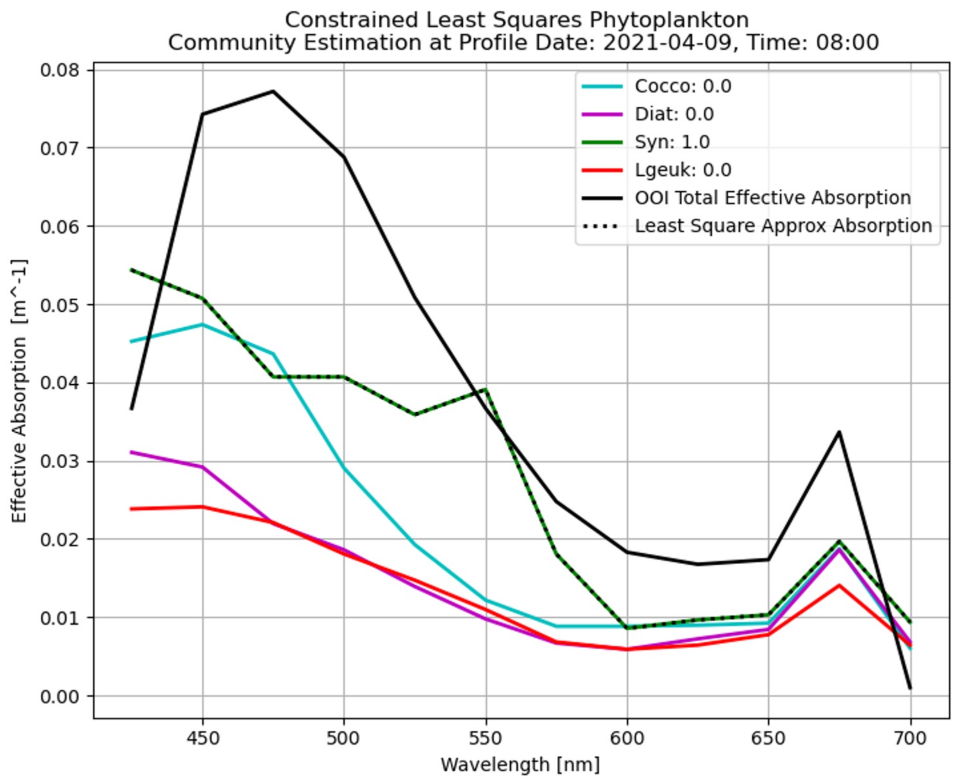
$$\mathbf{x} = \begin{bmatrix} p_{\mathrm{phy}_0} \\ p_{\mathrm{phy}_1} \\ \vdots \\ p_{\mathrm{phy}_M} \end{bmatrix} \qquad \mathbf{y} = \begin{bmatrix} w_a \alpha_{\mathrm{ooi}}(\lambda_0) \\ w_b \beta_{\mathrm{ooi}}(\lambda_0) \\ w_a \alpha_{\mathrm{ooi}}(\lambda_1) \\ w_b \beta_{\mathrm{ooi}}(\lambda_1) \\ \vdots \\ w_a \alpha_{\mathrm{ooi}}(\lambda_N) \\ w_b \beta_{\mathrm{ooi}}(\lambda_N) \end{bmatrix}$$

$$w_b = \frac{1}{\bar{\alpha}_{\mathrm{ooi}}} \qquad w_a = \frac{1}{\bar{\beta}_{\mathrm{ooi}}}$$

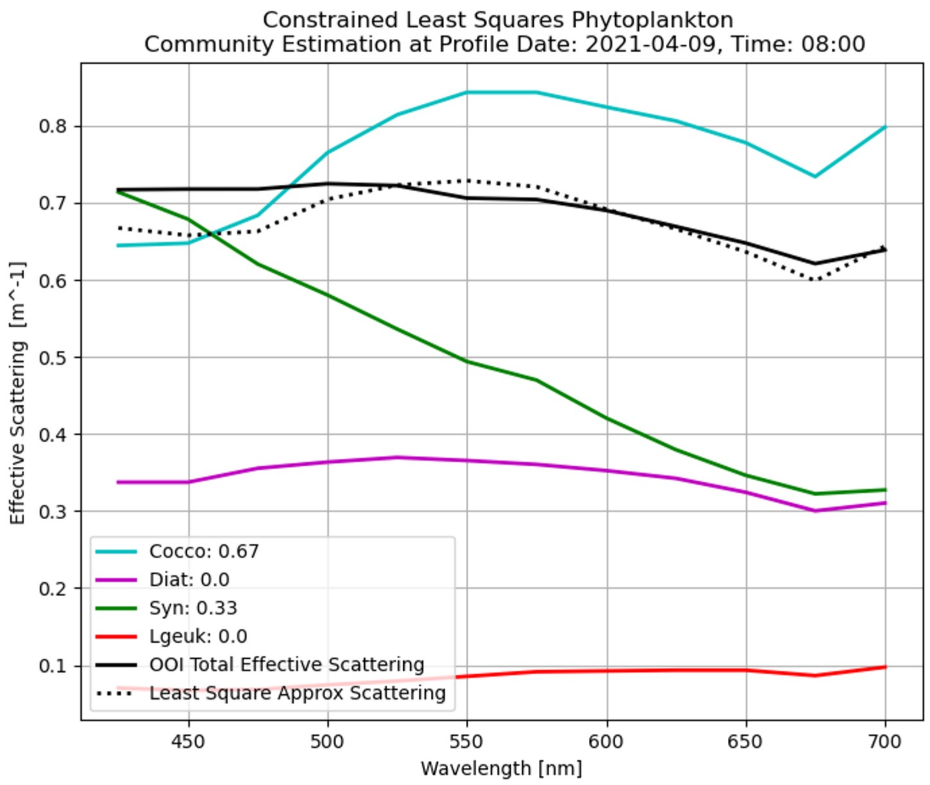
Estimate phytoplankton community that best match absorption OR scattering spectra (at one depth at one time)

Coccolithophores only
Diatoms only
Synechococcus only
Large Eukaryotes only
Phytoplankton Community
OOI Observed

Absorption Only

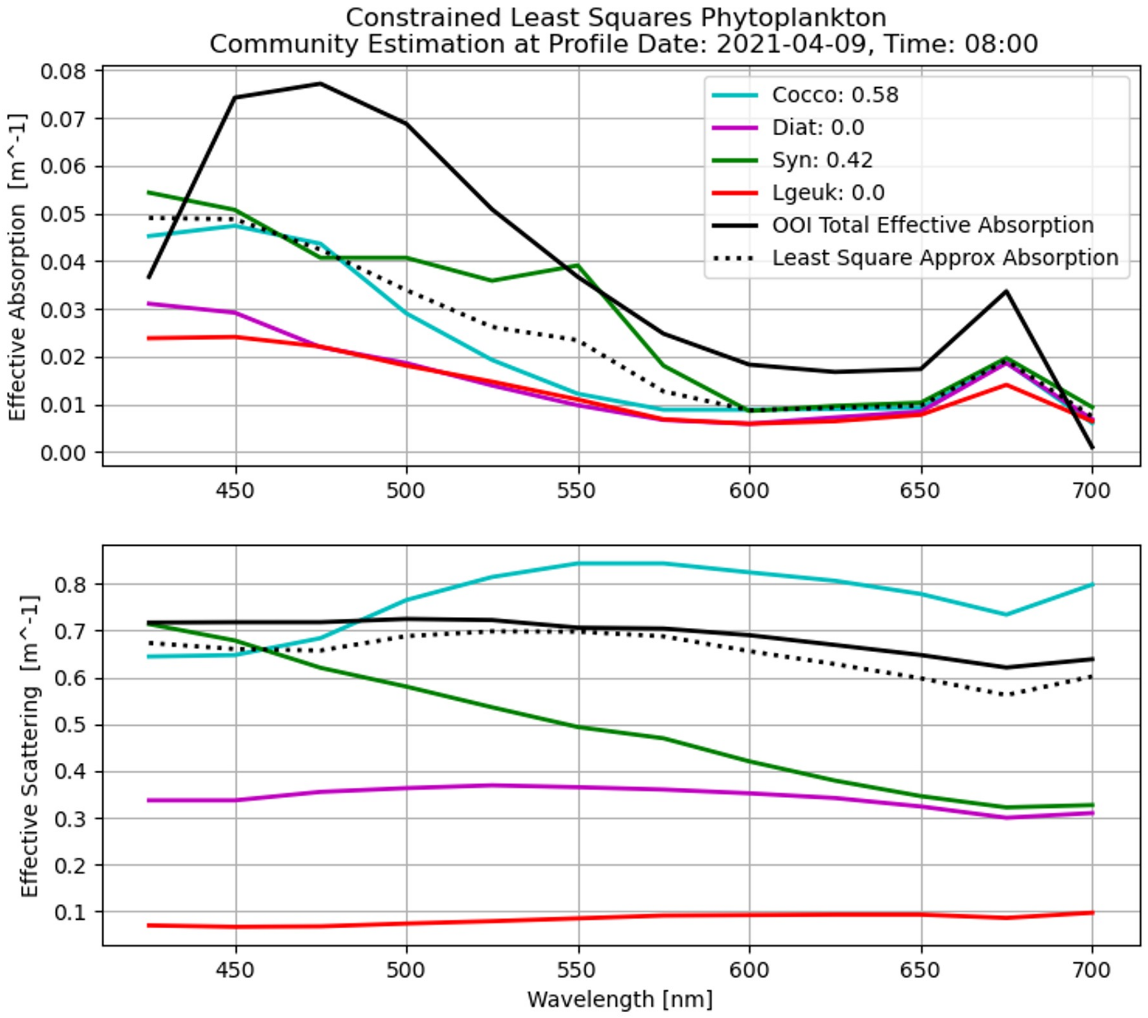


Scattering Only



Phytoplankton community that best match BOTH absorption AND scattering spectra (at one depth at one time)

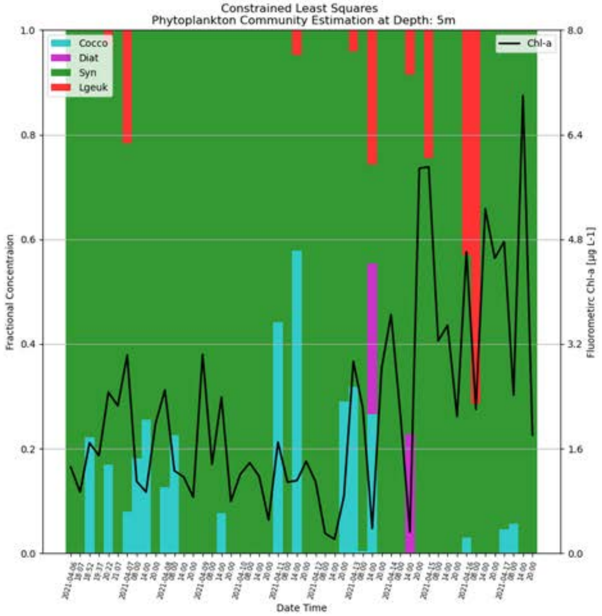
Coccolithophores only
Diatoms only
Synechococcus only
Large Eukaryotes only
Phytoplankton Community
OOI Observed



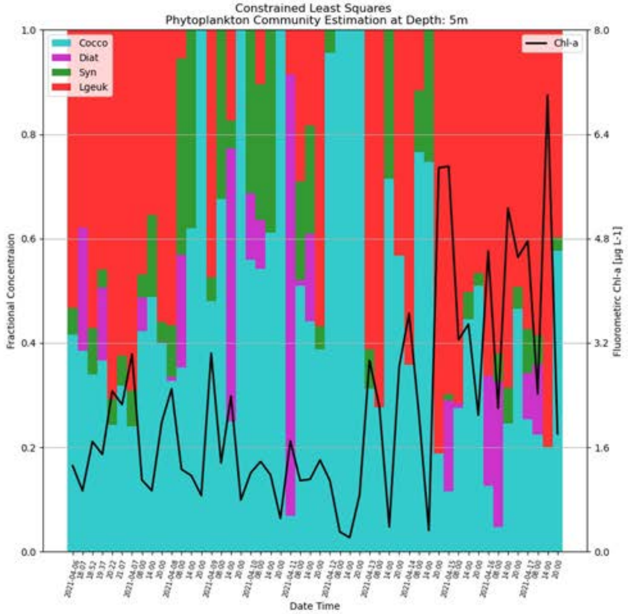
Time-series of phytoplankton community

Coccolithophores
Diatoms
Synechococcus
Large Eukaryotes

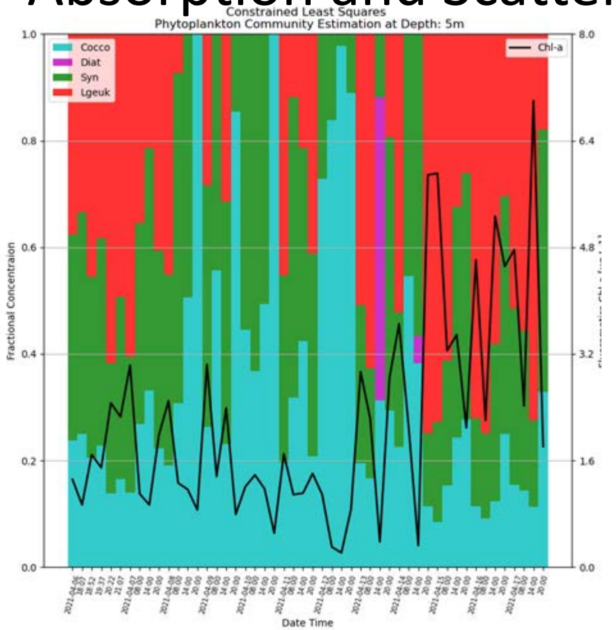
Absorption Only



Scattering Only



Absorption and Scattering



OOI observed Chlorophyll

- Work is in progress. Two left figures should have closer resemblance

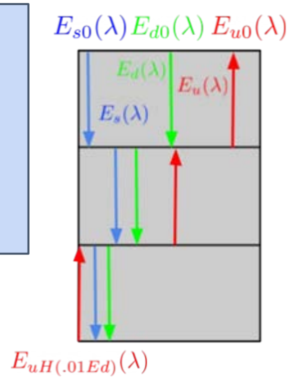
- Large discrepancies in implied communities between absorption and scattering data communities suggests errors in
  - chosen phytoplankton types or spectra
  - missing constituents
  - data issues/uncertainty

Where this work can go: Wavelength dependent Radiative transfer

$$\frac{dE_d(\lambda)}{dz} = -\frac{a(\lambda)+b(\lambda)}{\bar{\nu}_d}E_d(\lambda)$$

$$\frac{dE_s(\lambda)}{dz} = -\frac{a(\lambda)+r_s b_b(\lambda)}{\bar{\nu}_s}E_s(\lambda) + \frac{r_u b_b(\lambda)}{\bar{\nu}_u}E_u(\lambda) + \frac{b_f(\lambda)}{\bar{\nu}_d}E_d(\lambda)$$

$$-\frac{dE_u(\lambda)}{dz} = -\frac{a(\lambda)+r_u b_b(\lambda)}{\bar{\nu}_u}E_u(\lambda) + \frac{r_s b_b(\lambda)}{\bar{\nu}_s}E_s(\lambda) + \frac{b_b(\lambda)}{\bar{\nu}_d}E_d(\lambda)$$



$$a(\lambda) = a_w(\lambda) + a_{phy}(\lambda)$$

$$b(\lambda) = b_w(\lambda) + b_{phy}(\lambda)$$

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bphy}(\lambda) \qquad b_{bphy}(\lambda) = f(ESD)$$

→ We solve a radiative transfer problem for light in the upper ocean (following Dutkiewicz et al., 2015).

– Calculate three irradiances (downward direct [Ed], downward diffuse [Es], upward backscattered [Eu])

– Function of z.

– Dependent on absorption coefficients a and backscattering coefficients b based on sea water and phytoplankton concentration .

→ Specified Upper boundary conditions for Ed and Es.

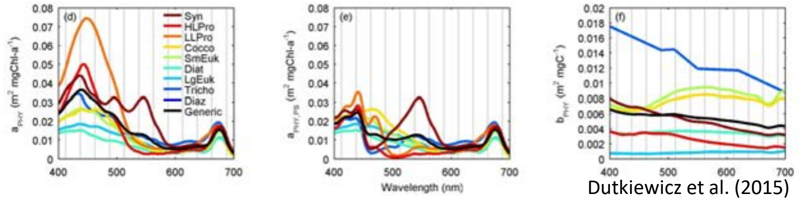
→ Shooting method solves for Eu at surface.

– Integrating upwards works best.

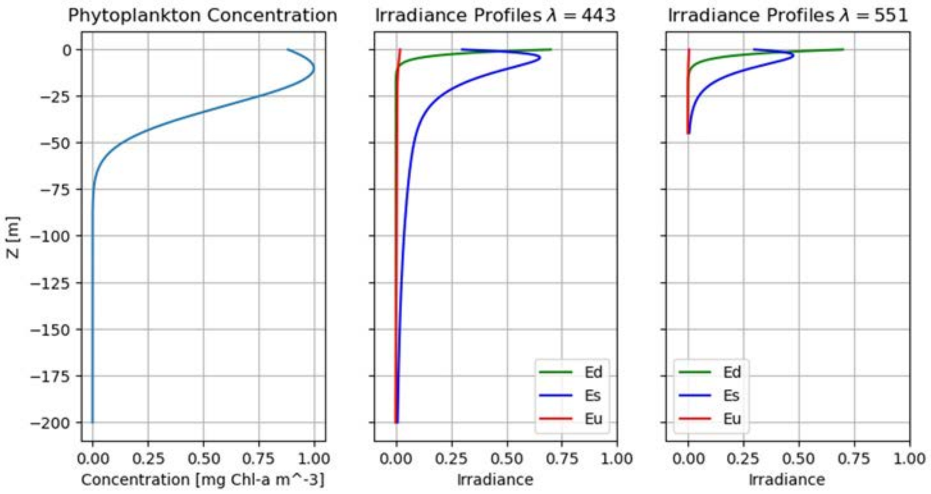
– Logarithmic vertical grid.

– Integrates to the 1% light level

Absorption and Scattering Coefficients Based on Phytoplankton Type and Wavelength



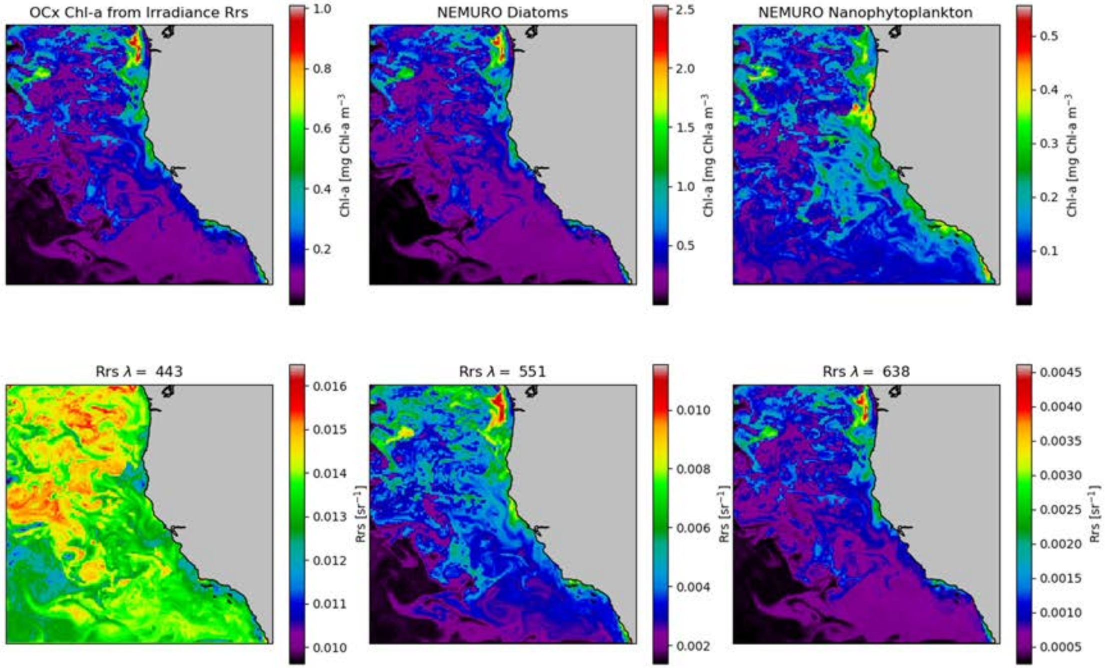
Dutkiewicz et al. (2015)

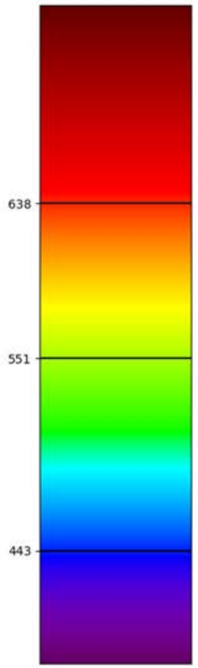


Idea: Apply the Dutkiewicz radiative transfer model to yield wavelength-dependent light fields.

→ A more extensive comparison of model output to satellite information.

→ Potential for data assimilation of these partially untapped satellite data sets.





Ocean Biogeochemical Model

↓

Phytoplankton Concentrations

↓

Radiative Transfer Model

↕

Satellite Products

Summary

- OOI data is extraordinarily useful for various modeling applications
- Pioneer and Endurance array glider and mooring data provides rich information for ocean circulation
- Demonstrations for non-DA model evaluation: UW LiveOcean, J-SCOPE, WCOFS
- Demonstration for DA at submesoscale: Rutgers triply nested Pioneer Array domain
- Optical data potentially useful for estimating phytoplankton community structure from radiative transfer ideas (work still in progress)