An Assessment of the Observing System for the California Current

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Two Questions Posed by West Coast COMT Group

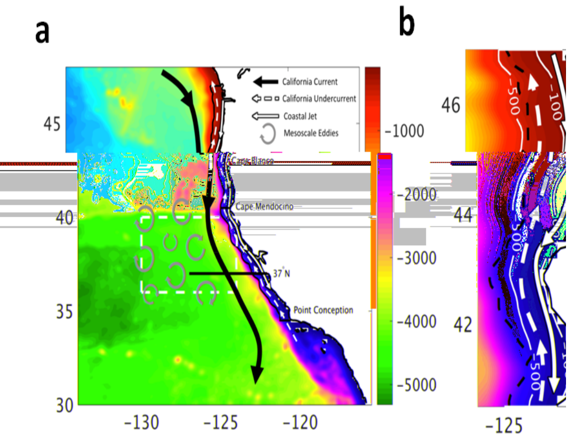
1) What is the impact of the current observing system on the CCS circulation?

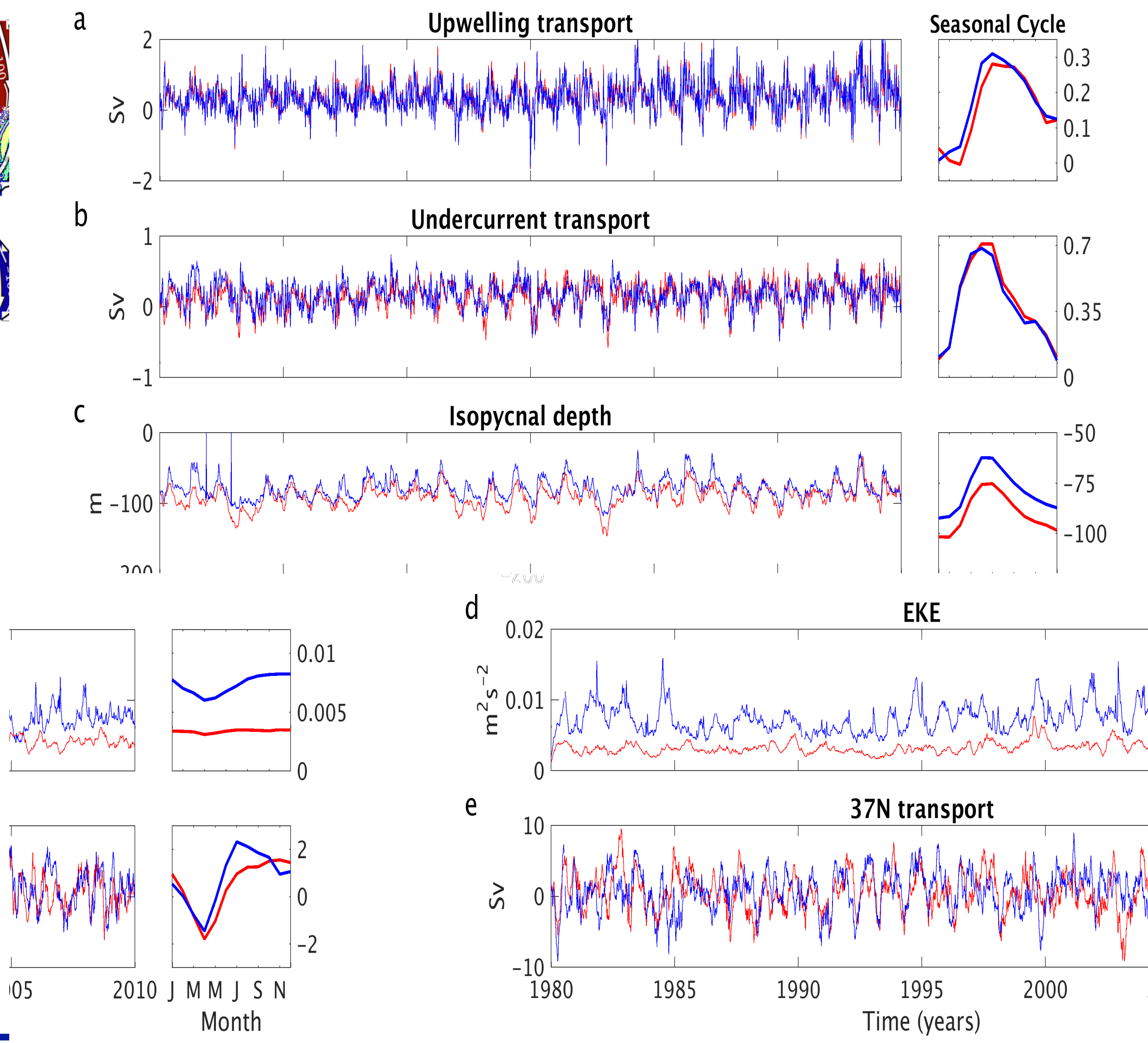
- Observation impact studies (presented previously)
- Metrics: upwelling transport
  undercurrent transport
  CCS transport along specific section
  eddy kinetic energy
  thermocline depth

2) How well do existing assets "observe" the CCS?

- Array modes (NEW)

1) Impact of 4D-Var DA on the Model circulation





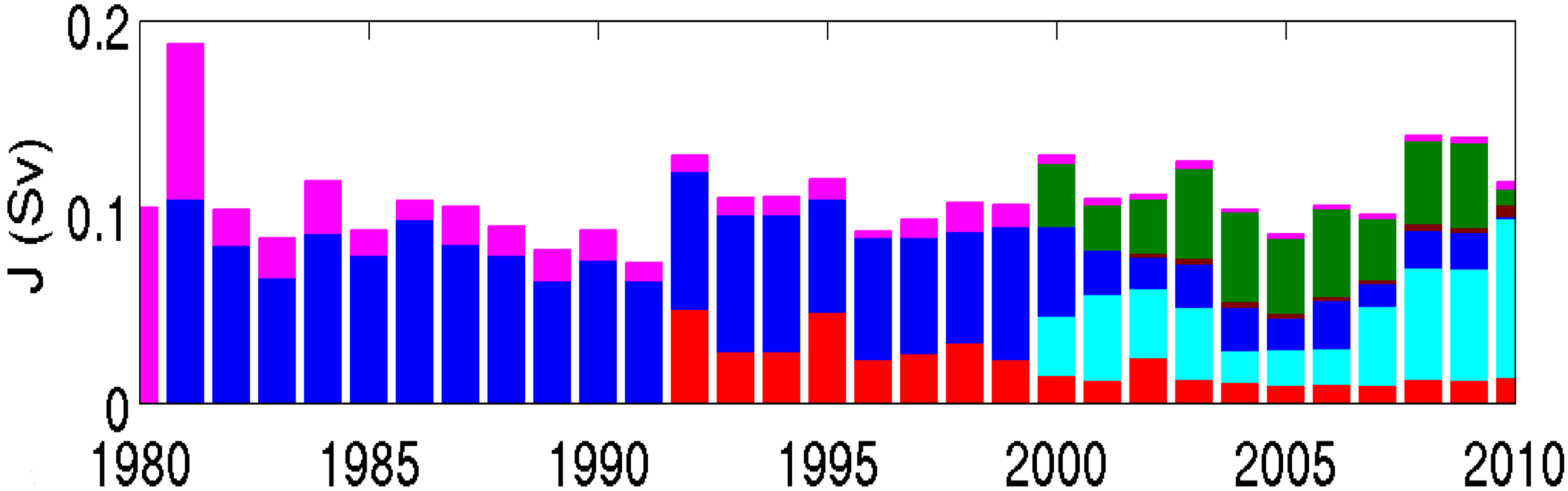
Time series of circulation indices:

Reanalysis (blue)

Forward model w/no DA (red)

Moore et al, 2017, *Progress in Oceanography*, 156, 41-60.

1) Observation Impacts for Central California Coast Upwelling Transport



Annual average rms impacts on the 4D-Var increments (analysis minus background) for each observing platform

Moore et al, 2017, *Progress in Oceanography,* 156, 41-60.

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- Array modes (NEW)

2) Array Modes

• The degree to which the EOFs of B are captured by the observing systems is described by the "array modes."

• The array modes depend *ONLY* on the observation locations, not the observation values.

$$\mathbf{x}_{\mathbf{a}} = \mathbf{x}_{\mathbf{b}} + \sum_{i=1}^{N} \alpha_i \mathbf{\Phi}_i$$

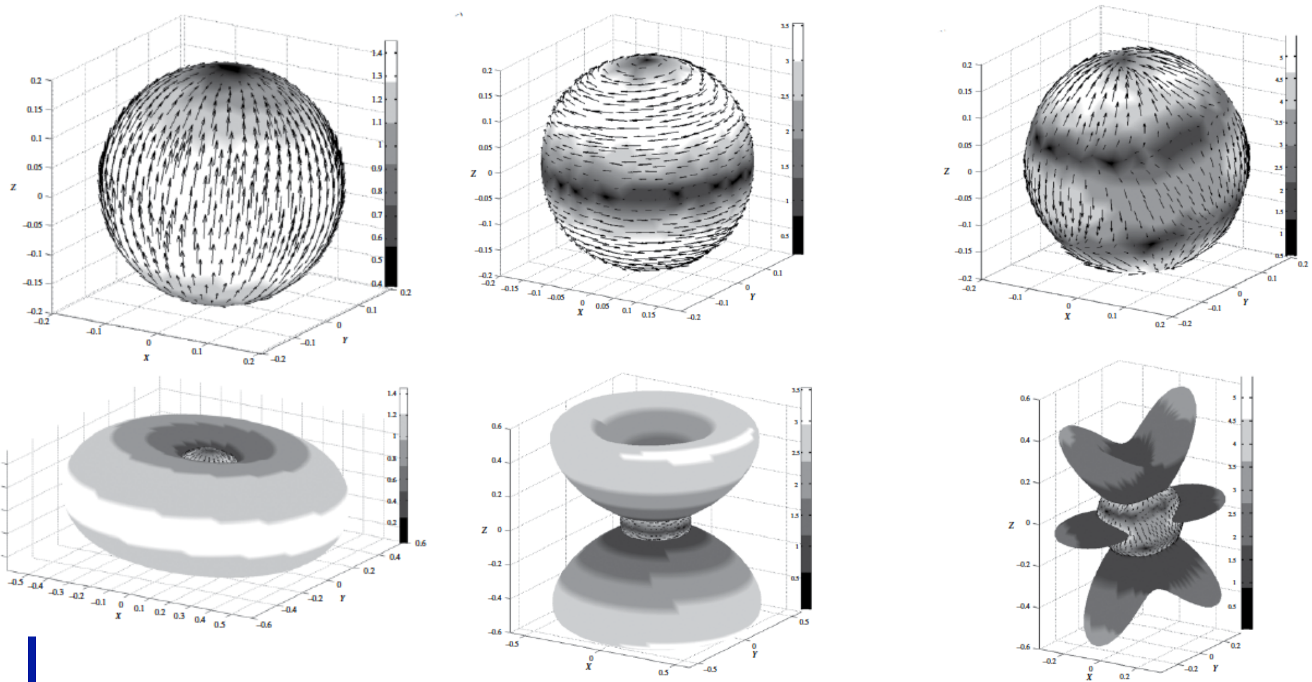
analysis — background

Weights (depend on obs values) → α_i

Array modes → $\mathbf{\Phi}_i$

Bennett (1985)

2) Array Modes



Examples the induced currents and electric and magnetic fields associated a selection of the leading eigenmodes of the impedance matrix of a perfectly conducting sphere (adapted from Chen and Wang, 2015).

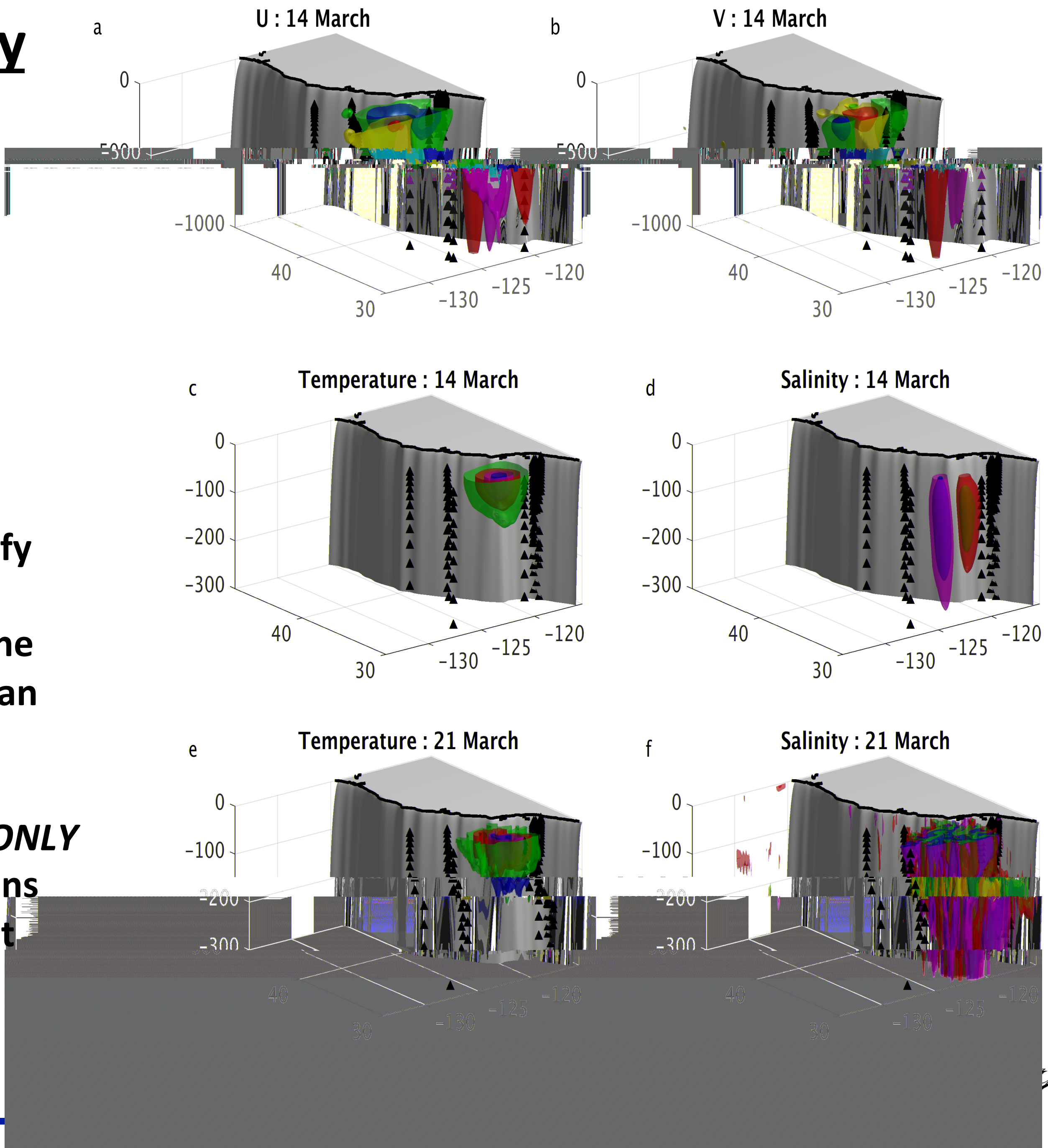
Array modes can be thought of the oceanic analog of the 4D-Var circulation "response" to observations

An Example Array Mode

Think of these as the circulation fields that are "excited" by observation values at the observation points.

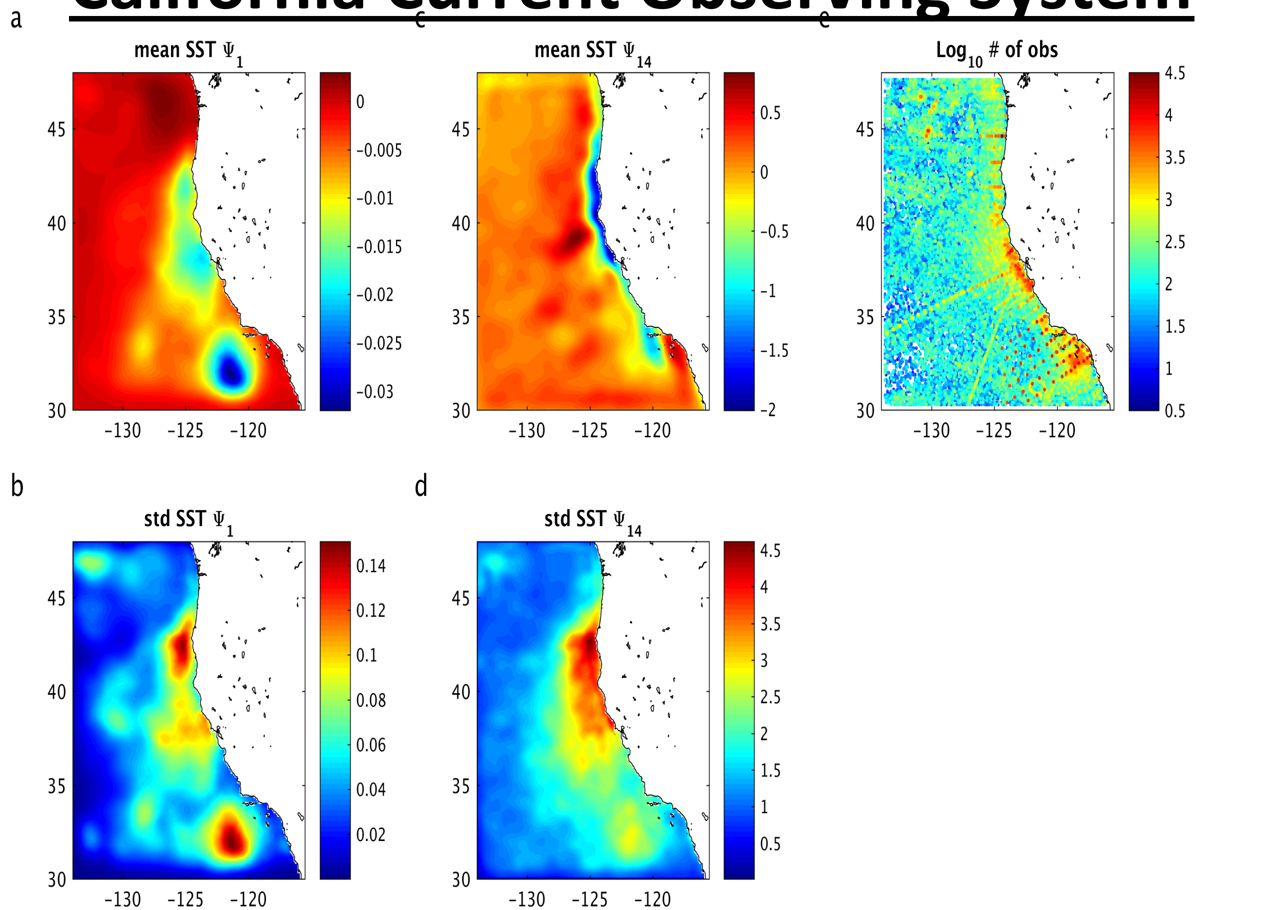
They can be used to identify which parts of the model space are "activated" by the observations collected by an observing system.

The array modes depend *ONLY* on the observation locations and *NOT* the measurement values.



Moore et al., submitted.

2) 1st and 14th Array Modes for SST of the California Current Observing System



The mean and standard deviation of SST for the first and last members of the array mode spectrum averaged over all 4D-Var cycles (1980-2010). Also shown is the number of *in situ* observations which appears to exert a strong control on the array mode structures (more so that than satellite observations). **Moore et al., submitted.**

Summary and Conclusions

- Observation impact calculations have been used to quantify the influence of the existing observing system on the CCS circulation (Moore et al., 2017).

- Assessment of the ability of the Observation System to "observe" the California Current System is based on array modes.

- Array modes depend on observation locations only, with particular modes excited depending on observation values.

- Ability to "observe" is also dependent on background error covariance matrix **B**, which is not very well known.

- In 30-year reanalysis, modes show an apparent relationship to in situ observations despite the relative paucity of such obs.

2) The Importance of the Background Error Covariance Matrix

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{B}\mathbf{G}^{T}\left(\mathbf{G}\mathbf{B}\mathbf{G}^{T} + \mathbf{R}\right)^{-1}\left(\mathbf{y} - H(\mathbf{x}_b)\right)$$

analysis

background

adjoint obs operator

background error cov matrix

obs error cov matrix

obs

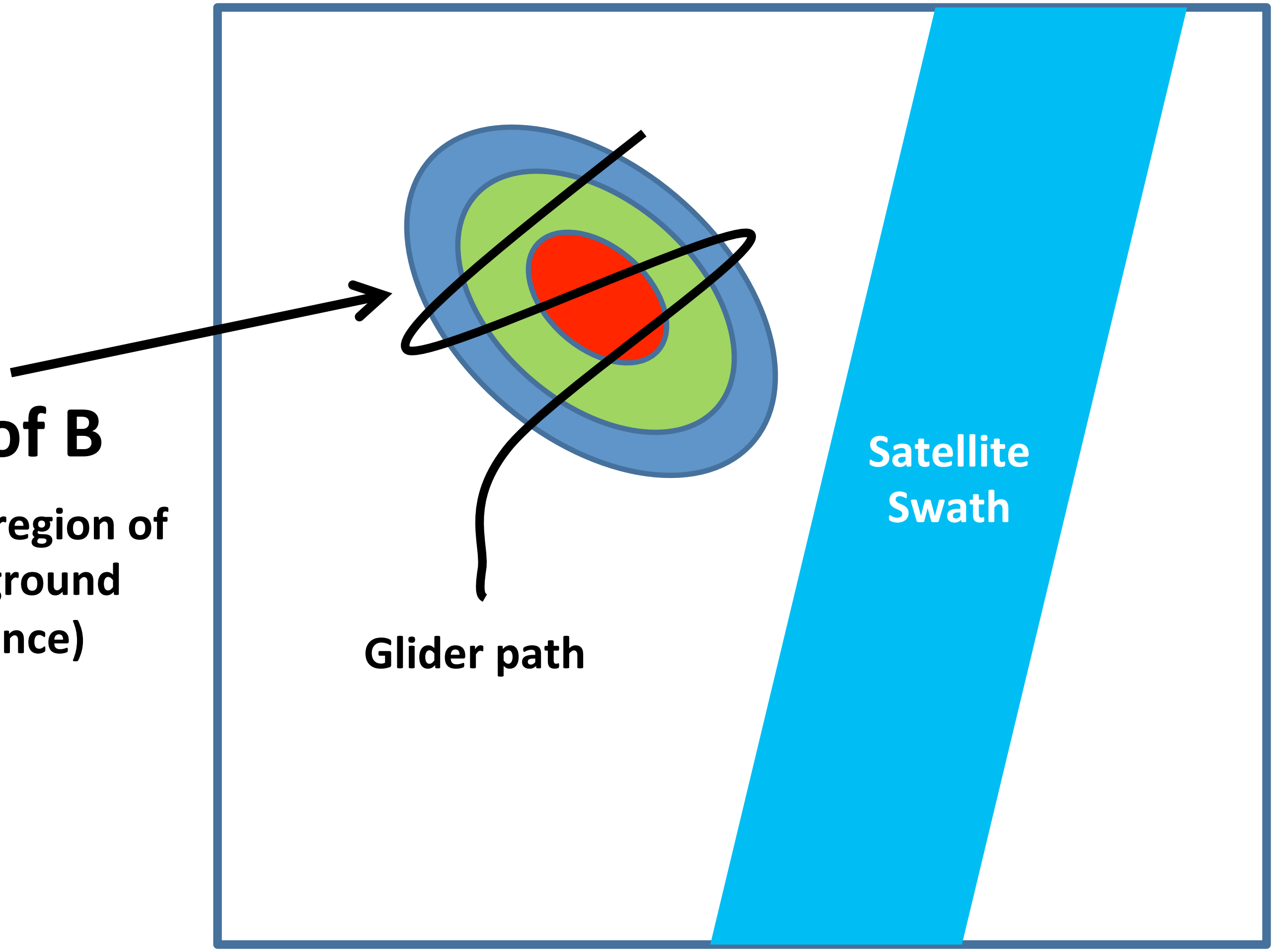
obs operator

Analysis increment

The analysis increment "lives" in the space spanned by B !!!

Therefore, to reduce errors in x_b, the observing system must effectively observe (directly via G or indirectly via G^T) the dominant EOFs of B.

2) An Illustrative Examples



EOF1 of B

(localized region of high background error variance)

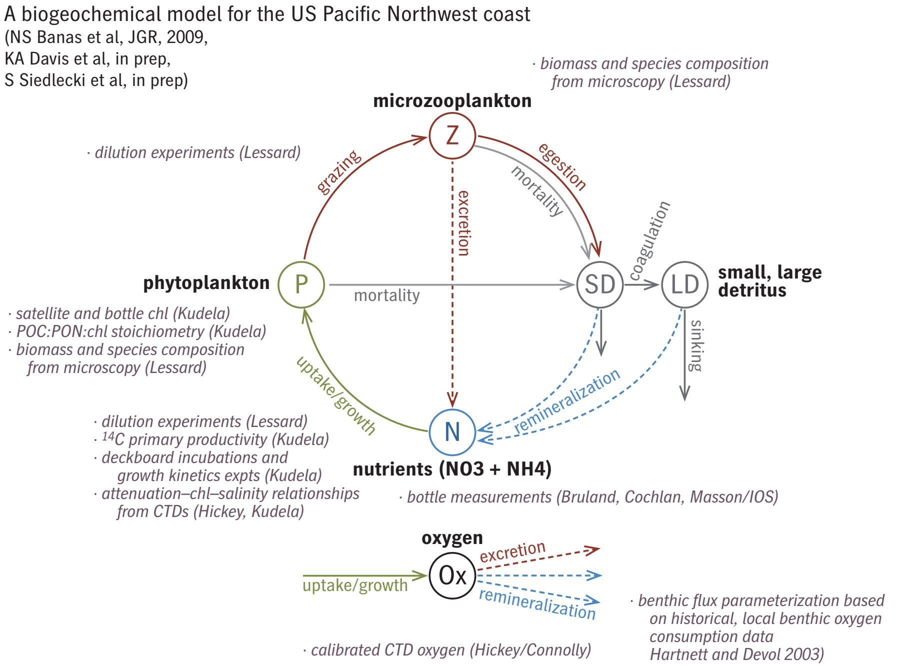
The glider path does directly observe the region of high error background error variance associated with EOF1 of B, so errors in this regions will be corrected during data assimilation by the glider.

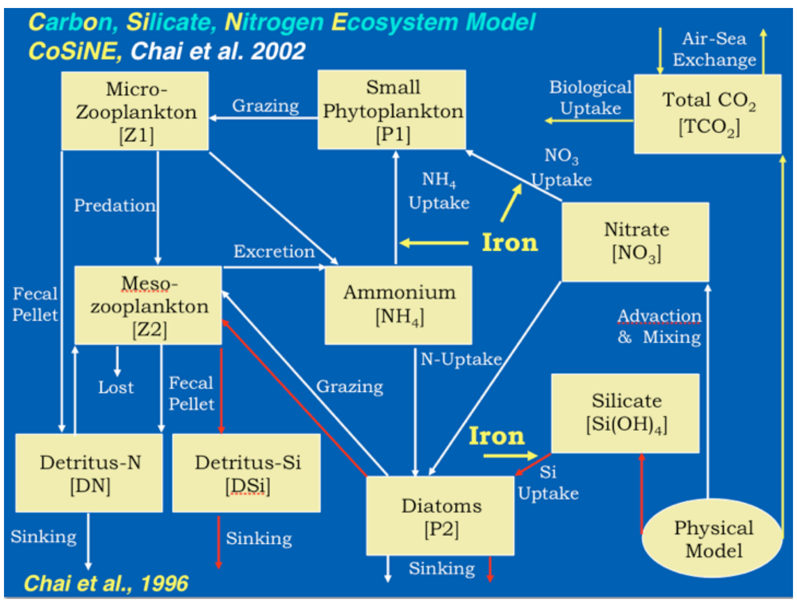
Biological intercomparison in the California Current System: Objective

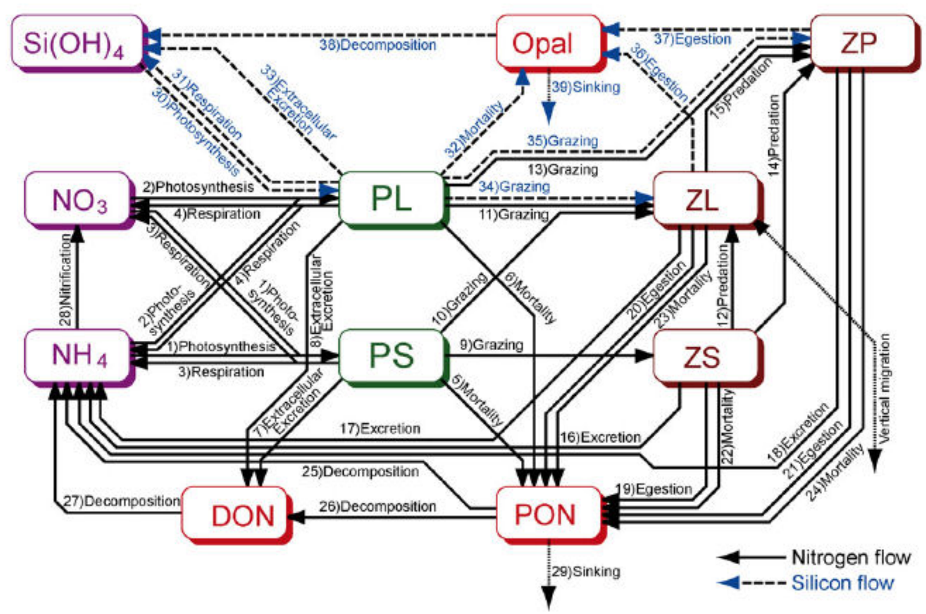
- To compare performance of 3 different established ecosystem models within a single physical circulation system
- First 3 years, UCSC domain
- Last 2 years, WCOFS domain
- Focus on
  - State variables
  - Rate processes
- Approach: A Latin Hypercube sampling of model rate parameters to optimize models to one configuration
- Summary statistics from 1-year (Monte Carlo) and 6-year (rate process) runs
- Collaborations: Edwards, Banas/MacCready, Chai

3 models

- Cascadia (Banas)
- CoSiNE (Chai)
- NEMURO (Edwards)







A challenge: Multiple fields of interest

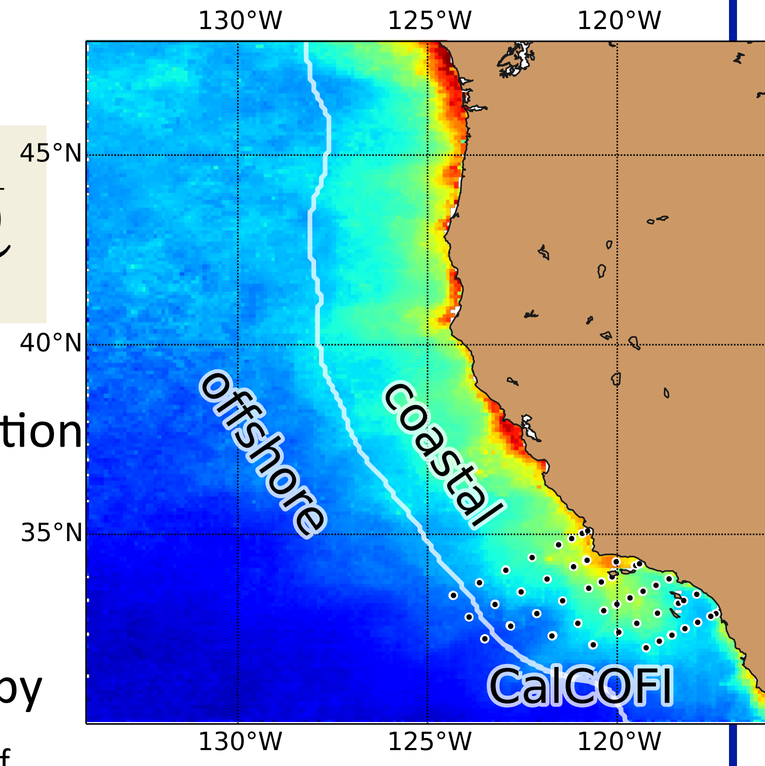
- Phytoplankton biomass
- Zooplankton biomass
- Primary production
- Oxygen
- pH
- Nutrients
- Stratification
- Export

Optimization

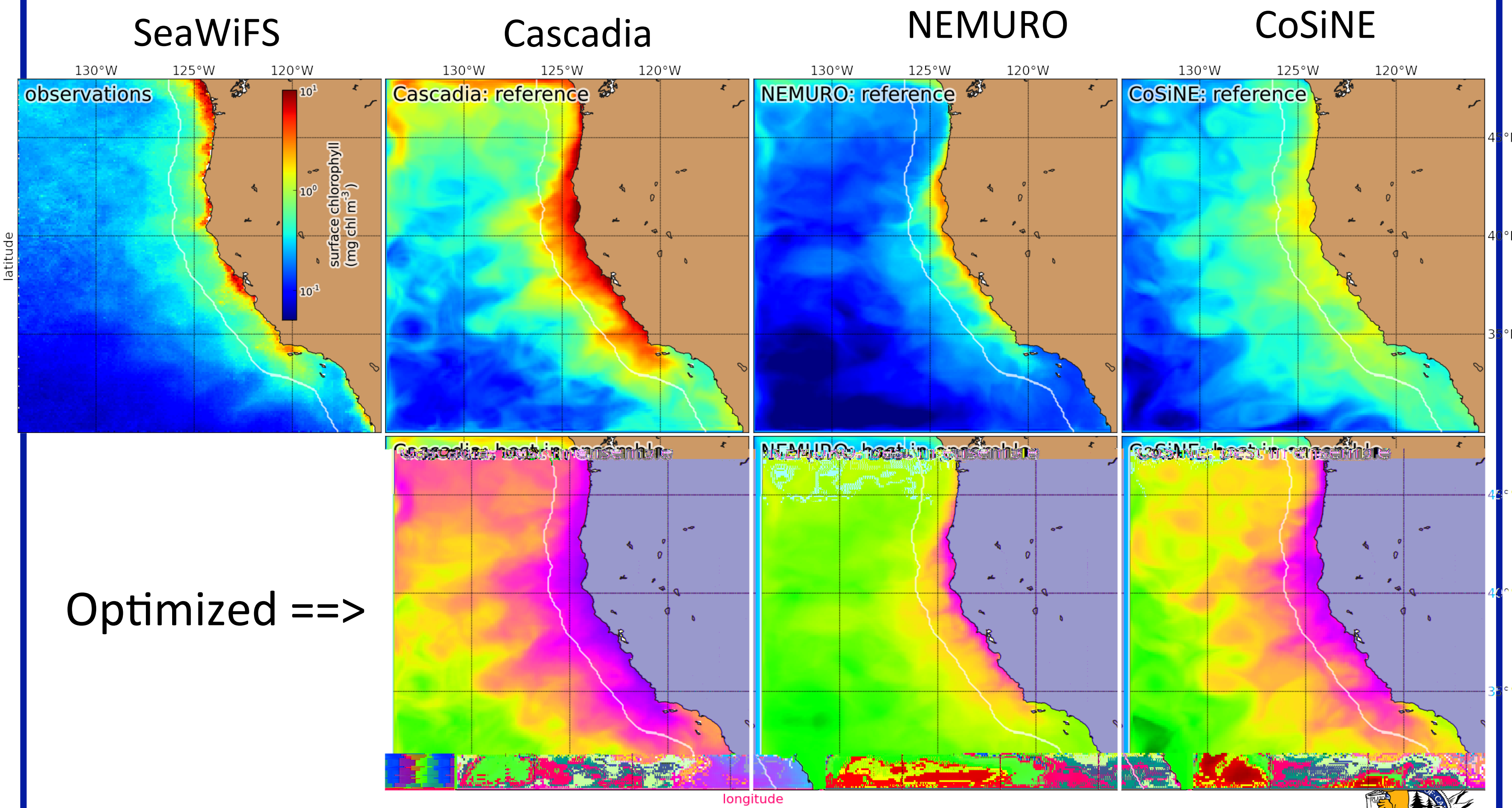
- The cost function J(q) summarizes model performance in one number

$$J(\theta) = \underbrace{\frac{1}{3}\frac{J_{nut}(\theta)}{J_{nut}(\theta_{\mathrm{ref}})}}_{NO_3\text{-based}} + \underbrace{\frac{1}{3}\frac{J_{\mathrm{coastal}}(\theta)}{J_{\mathrm{coastal}}(\theta_{\mathrm{ref}})} + \frac{1}{3}\frac{J_{\mathrm{offshore}}(\theta)}{J_{\mathrm{offshore}}(\theta_{\mathrm{ref}})}}_{\text{Chl-based}}$$

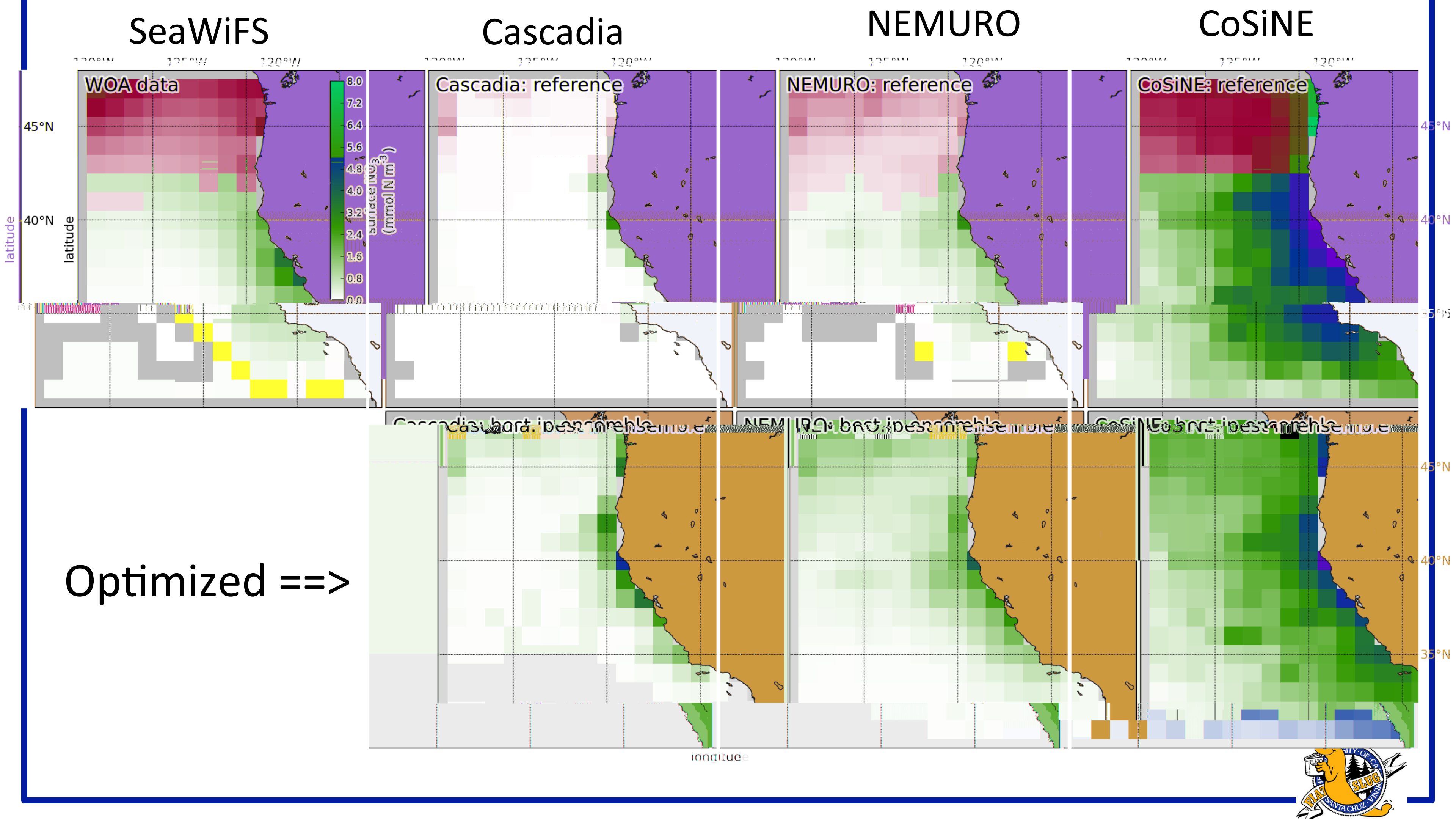
- Measures model-observation misfit as a function of select biological parameters q
- Based on real satellite Chlorophyll and climatological nitrate from WOA
- Individual cost contributions are normalized by the reference simulation with parameters q_{ref}



Annual Average performance, Surface Chlorophyll



Average Annual Performance, Surface Nitrate



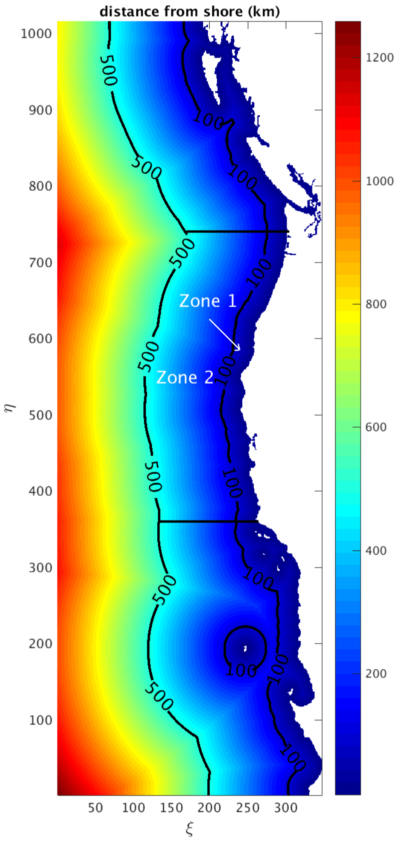
Summary: Intercomparison of Cascadia, NEMURO and CoSiNE within UCSC CCS model

- State variables:
  - NEMURO has lowest RMS error against satellite-derived chl and climatological nitrate
  - CoSiNE leaves high nitrate near surface, cannot be removed through optimization
  - Cascadia arguably suffers in terms of state-variable metric due to only one phytoplankton

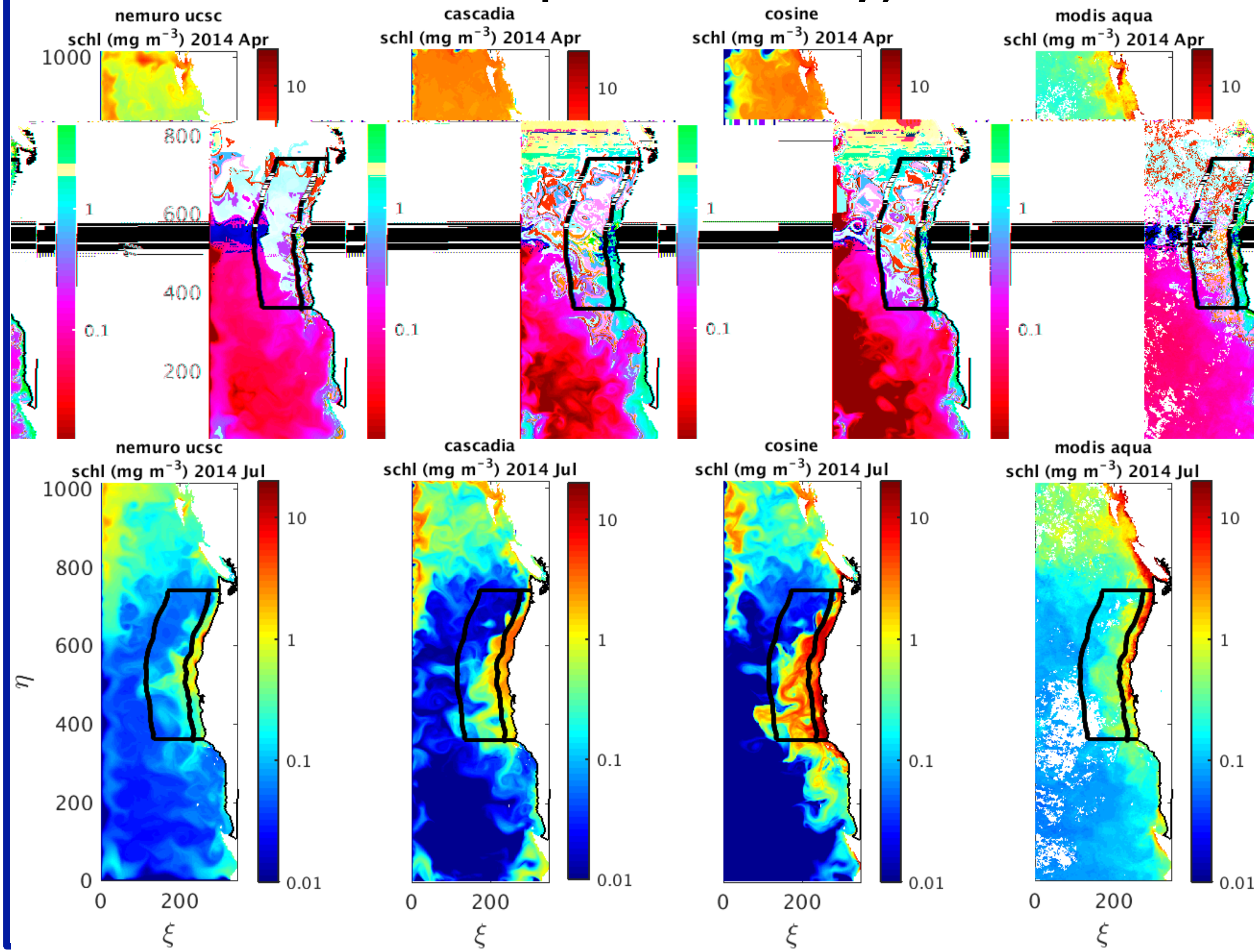
- Rate process investigation reveals
  - CoSiNE exhibits grazing-limited production, limiting nitrate uptake
  - NEMURO and Cascadia are more consistent with observations, showing a shift from high phytoplankton growth in nutrient-replete conditions, shifting to a growth/grazing balance in low nutrient conditions
  - NEMURO rate processes reasonably span range of available observations
  - Cascadia does not yield high phytoplankton growth portion found in observations

WCOFS Domain

- Configure realistic but coarse resolution (4km) WCOFS
  - 1/8 cost of full WCOFS 2km grid
  - Realistic mean and mesoscale
  - No tides
  - No precipitation
  - No rivers
- Oct 1, 2013 Through December 31, 2014
- Initial conditions:
  - WOA nutrients
  - Low values for other variables
- ~30 times computational cost of UCSC domain



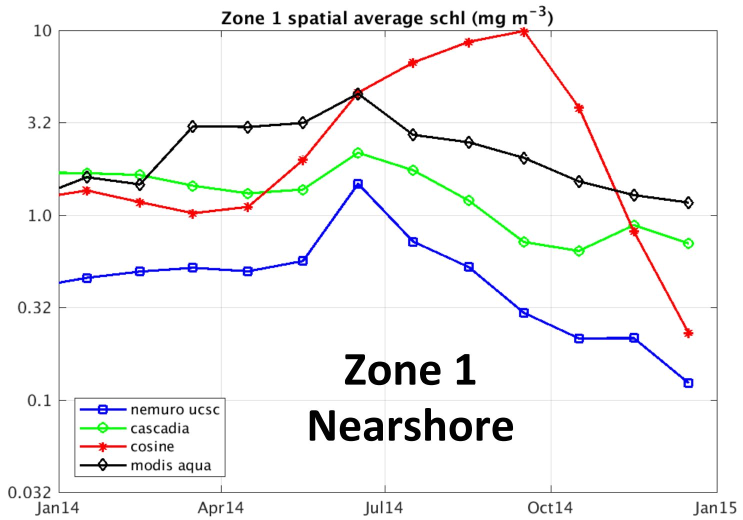
Example $\log_{10}$(Monthly Average Surface Chl-a) April and July, 2014

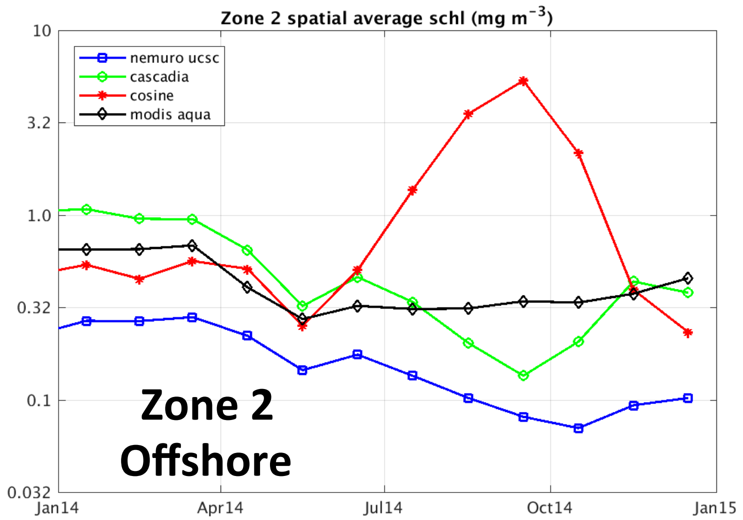


April

July

Time series $\log_{10}$(Surface Chl)





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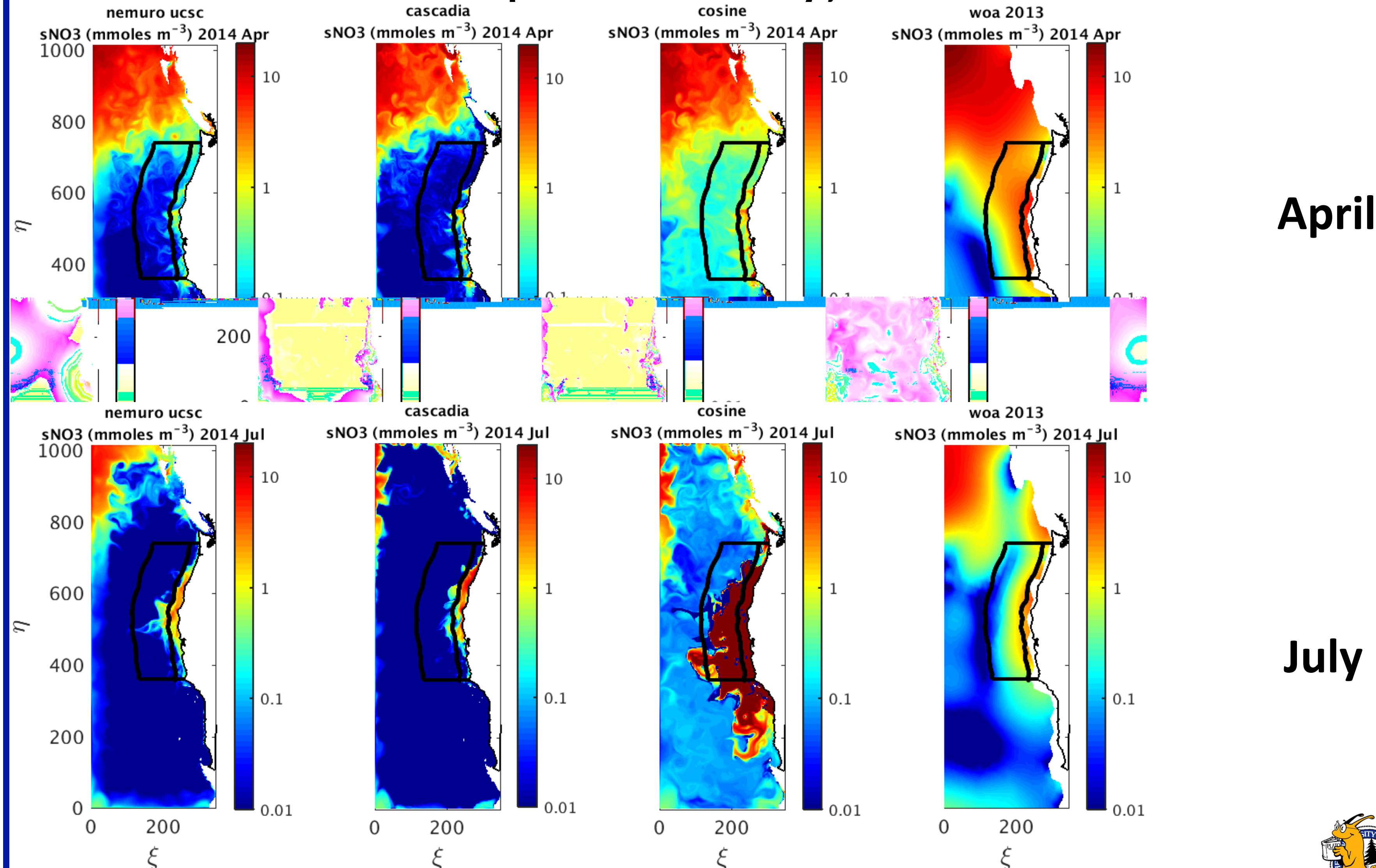


Summary: Intercomparison of Cascadia, NEMURO and CoSiNE within WCOFS 4km

- Cascadia
  - Right magnitude nearshore stock
  - Low offshore stock
  - Low offshore nutrients

- CoSiNE
  - Right magnitude nearshore and offshore stock
  - High nutrient concentrations

- NEMURO
  - Low nearshore stock
  - Right magnitude offshore stock
  - Low offshore nutrients

Development

Common issues

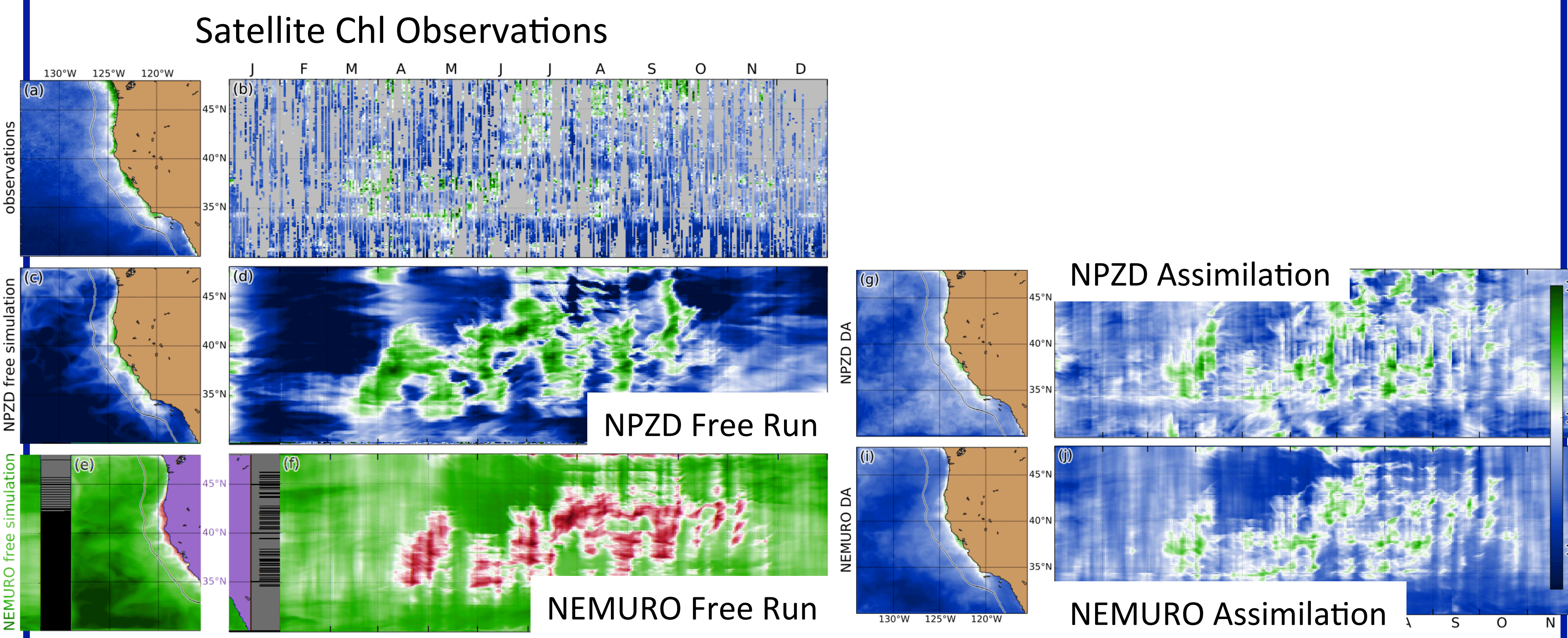
- Iron limitation in northern part of domain
- Uncertain C:Chl ratio
- 2014 anomalous year
- Sensitivity to advection scheme
- Spinup

Work plan involves all parties

- Operate with physical circulation from "typical" period (2013)
- Add one year spinup (2012)
- Distribute tuning and optimization effort among expert groups
- Groups can add particular enhancements (e.g., C:Chl, oxygen) available now to those models

Long-term vision:
Have performed 4D-Var data assimilation using NPZD and NEMURO models.

Evaluation for Year 2000 in UCSC domain



Song et al. (2015a,b,c), Mattern et al. (2017)