The Near Real-time BGC/Physical 4D- Var DA system in the California Current

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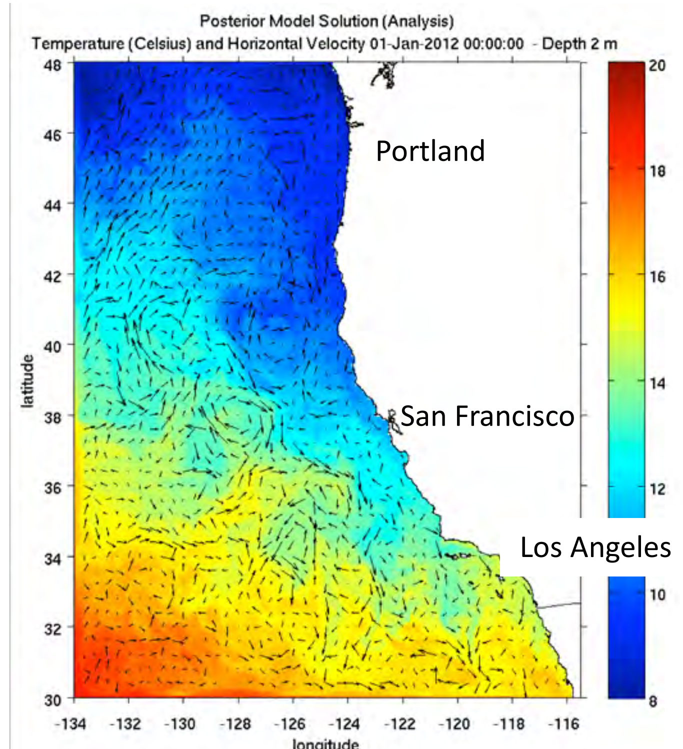


CeNCOOS NSF NOAA ONR SIMONS FOUNDATION GORDON AND BETTY MOORE FOUNDATION

Outline

- How to quantify ecosystem impacts of physical drivers
- Data assimilation: L4D-Var for BGC models
- NRT system
- Results from the warm blob

The recent warm blob, a major physical driver

- ~3°C multiannual marine heatwave
- What are the ecosystem impacts of this anomalous event?
- How would we quantify these?

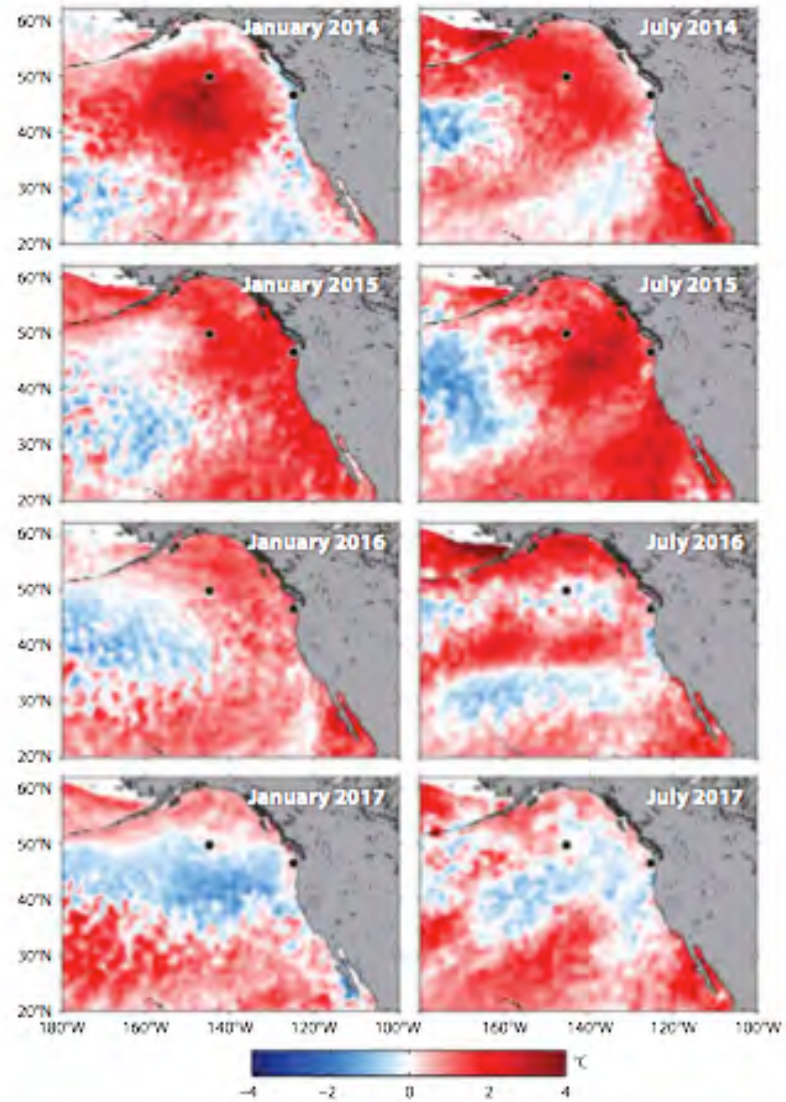
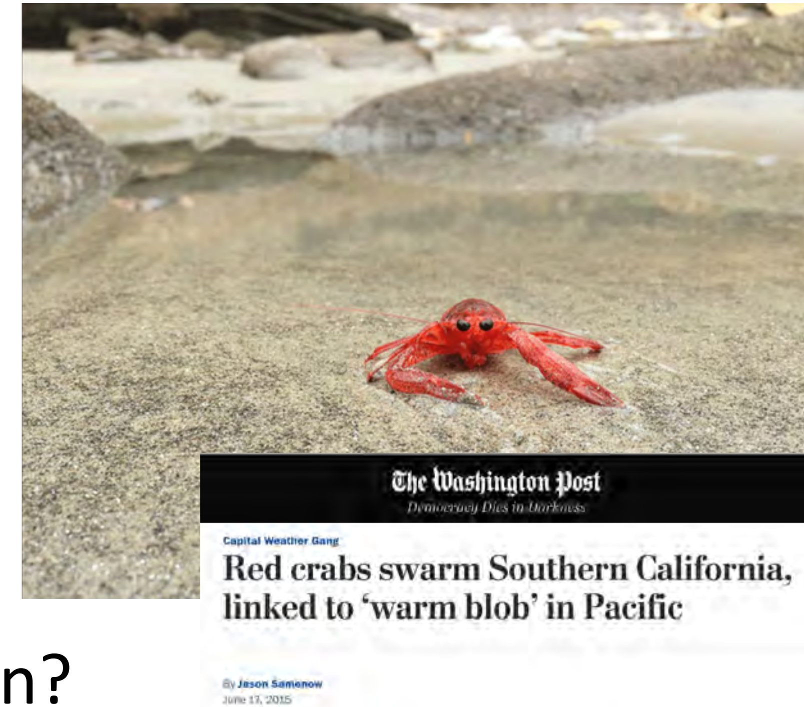


FIGURE 2. North Pacific sea surface temperature anomaly showing the evolution of the "warm blob" from its origination in winter 2013–2014 through the following four years. Satellite temperature data are from AVHRR only Optimum Interpolation Sea Surface Temperature (OISST, https://www.ncdc.noaa.gov/oisst/data-access), and anomalies are computed relative to a 30 year climatology constructed from 1982 to 2011. The locations of the OOI Washington Offshore wire following profiler mooring and the OOI Station Papa (50°N, 145°W) mooring are shown as filled black circles.

Figure from Barth et al. (2018)

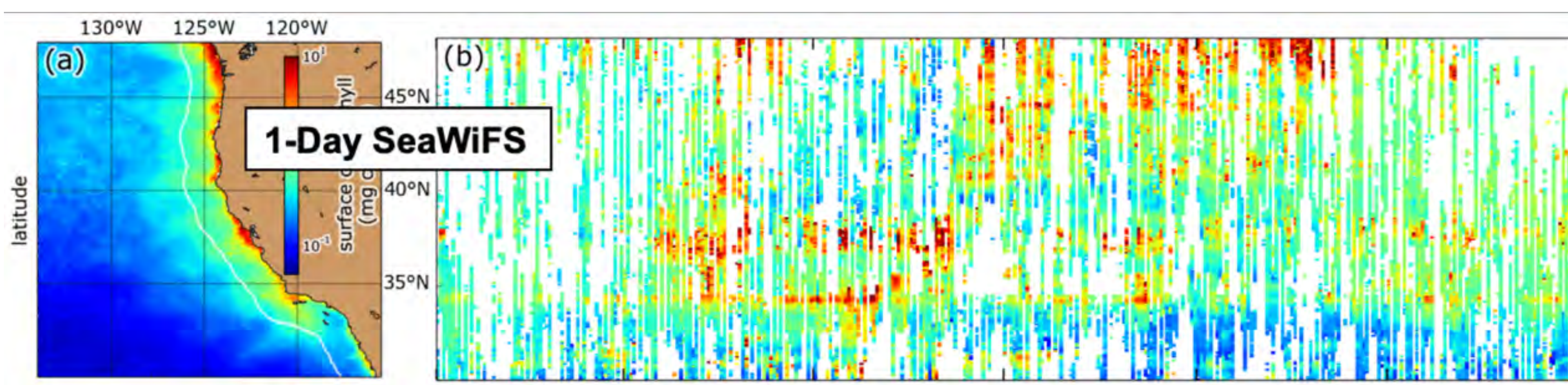
Ecosystem Impacts



- Observations showed unusual species cascading through region.

- What about primary production?

- Ocean color data is useful, but has real gaps

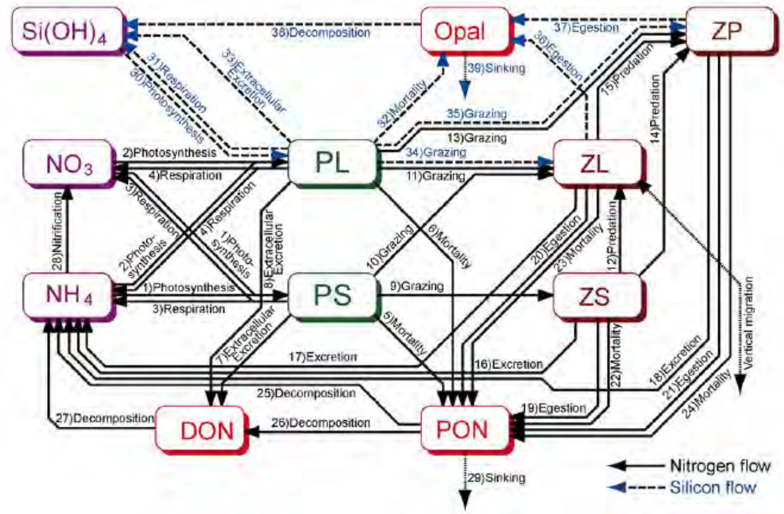


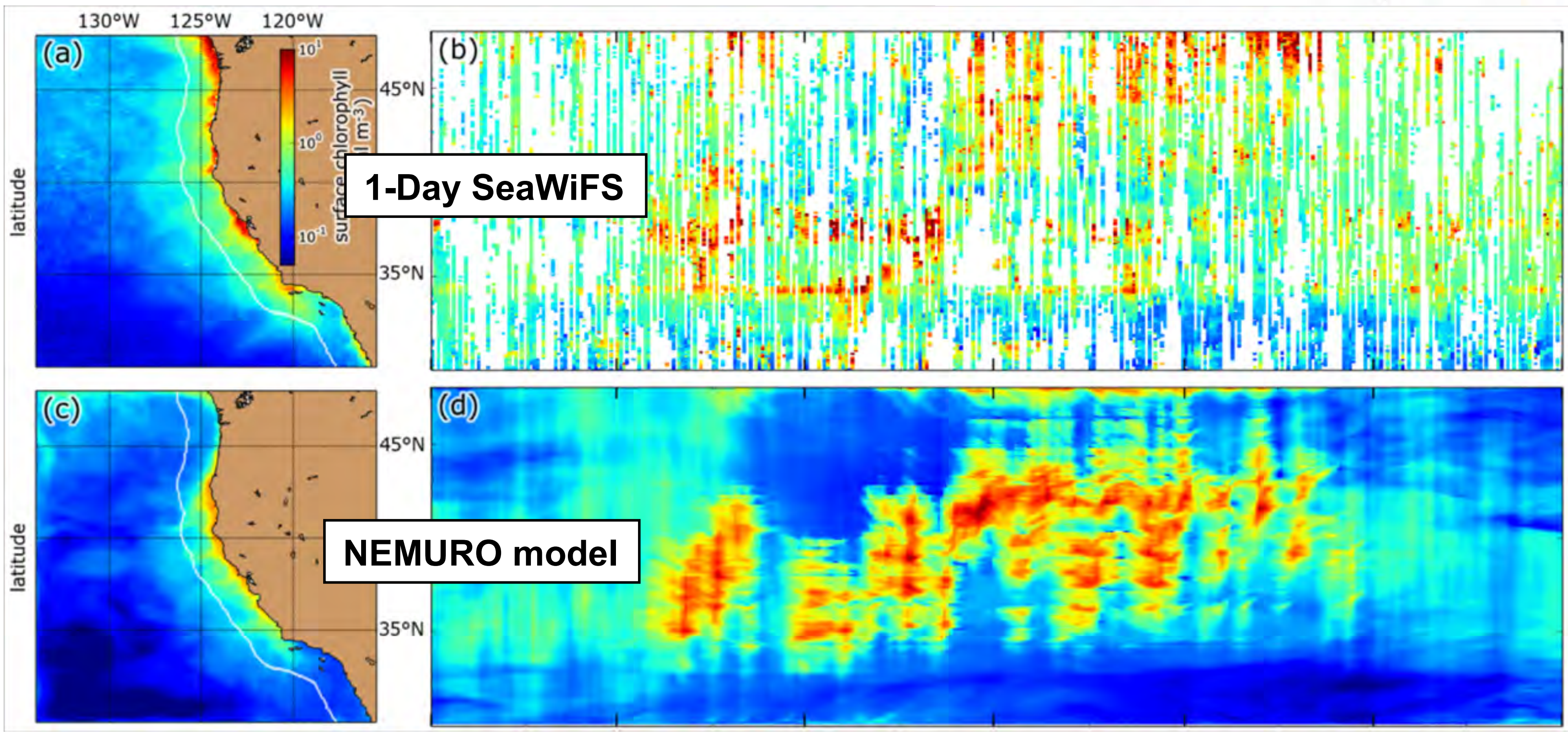
Model the ecosystem

But no matter how good the model is, unavoidable errors exist due to uncertainty

- initial conditions
- lateral and surface forcing
- model error

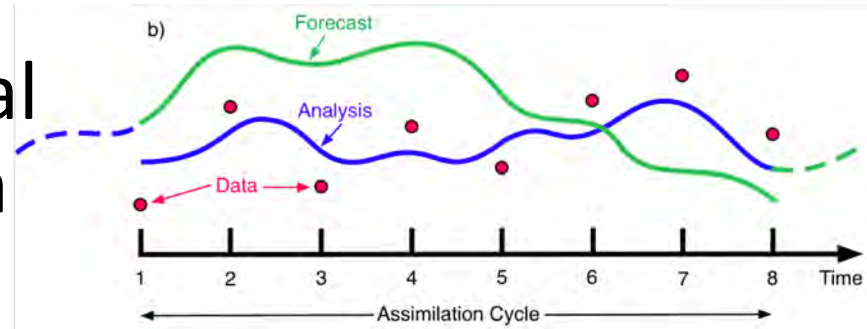
NEMURO





One approach to reduce uncertainty is to use data assimilation

- We use 4-dimenionsional variational (4D-Var) data assimilation



- With BGC model, we assume variables are lognormal (when transformed, errors are normal)

Logarithm transformation Surface chl-a

CAMPBELL: LOGNORMAL VARIABILITY IN BIO-OPTICS

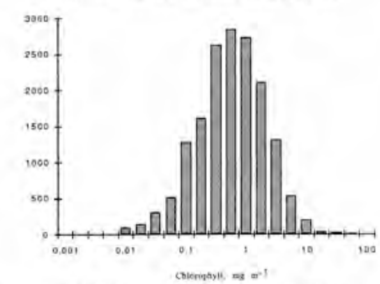


Figure 1. Histogram of 16,364 in situ measurements of ocean chlorophyll concentration from a compilation by *Balch et al.* [1992]. The data are global in scope, but sampling was concentrated at midlatitudes in the northern hemisphere, and central ocean gyre regions were undersampled.

Campbell (1995)

Combined G4DVar and L4DVar using augmented state vector

Gaussian Cost function

$$J_G(\delta \mathbf{x}_0) = \frac{1}{2}\delta \mathbf{x}_0^T \mathbf{B}^{-1}\delta \mathbf{x}_0 + \frac{1}{2}\sum_{i=1}^{N_o}(\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_{i,0}\delta \mathbf{x}_0)^T \mathbf{R}_i^{-1}(\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_{i,0}\delta \mathbf{x}_0),$$

Lognormal Cost function

$$J_L(\delta \mathbf{g}_0) = \frac{1}{2}\delta \mathbf{g}_0^T \mathbf{B}_L^{-1}\delta \mathbf{g}_0 + \frac{1}{2}\sum_{i=1}^{N_o}\left(\mathbf{p}_i - \mathbf{L}_i\mathbf{H}_i\mathbf{M}_{i,0}\mathbf{X}_{b,0}\delta \mathbf{g}_0\right)^T \mathbf{R}_{L,i}^{-1}\left(\mathbf{p}_i - \mathbf{L}_i\mathbf{H}_i\mathbf{M}_{i,0}\mathbf{X}_{b,0}\delta \mathbf{g}_0\right),$$

- Cost functions can be combined in terms of augmented state vector and error covariances

$$\delta \mathbf{z} = \begin{bmatrix} \delta \mathbf{x}_G \\ \delta \mathbf{g}_L \end{bmatrix}$$

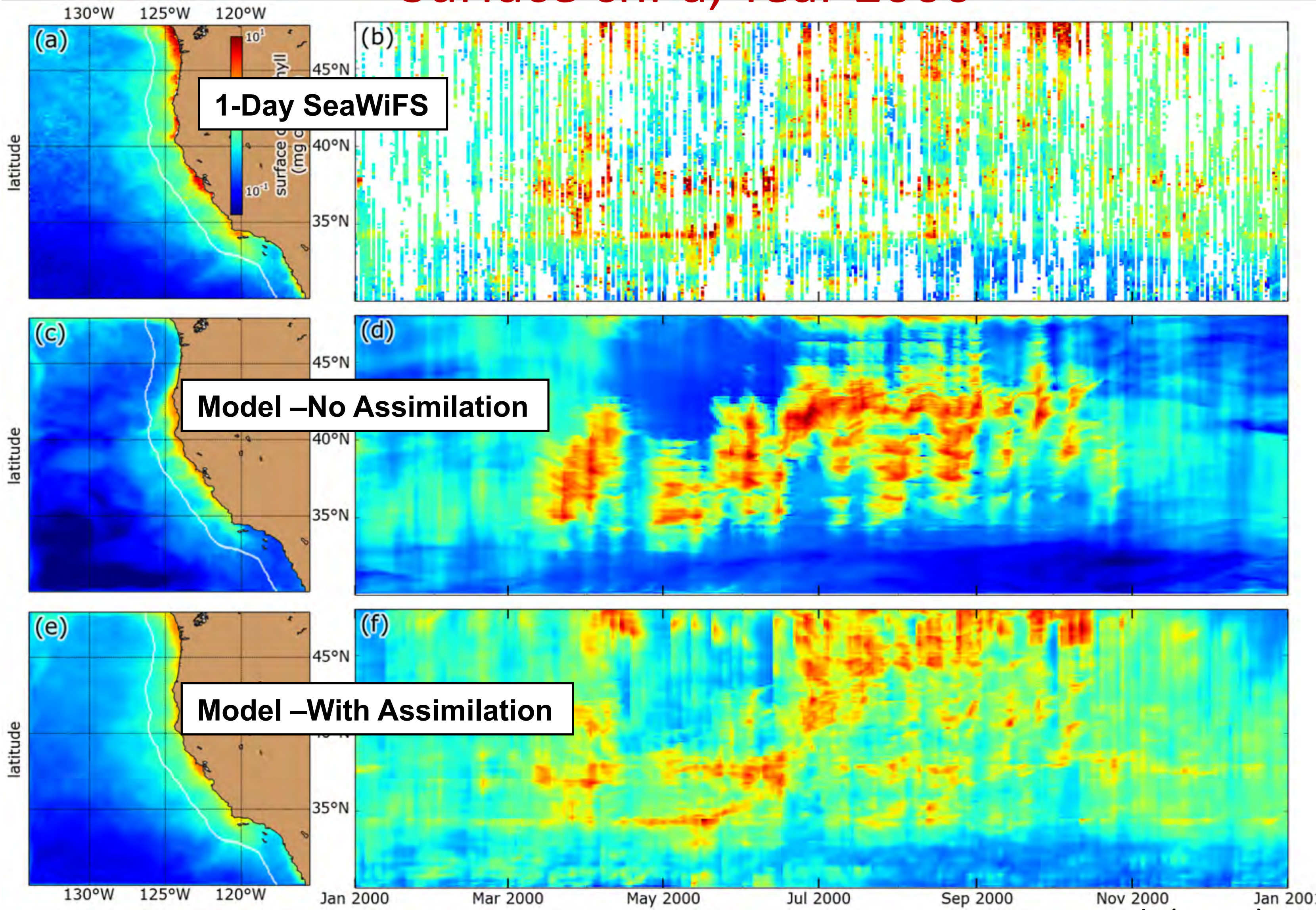
$$\mathbf{B} = \begin{bmatrix} \mathbf{B}_G & \mathbf{0} \\ \mathbf{0} & \mathbf{B}_L \end{bmatrix}$$

$$\mathbf{R} = \begin{bmatrix} \mathbf{R}_G & \mathbf{0} \\ \mathbf{0} & \mathbf{R}_L \end{bmatrix}$$

Song et al. (2012, 2016b)

Fully coupled 4D-Var using NEMURO

Surface chl-a, Year 2000

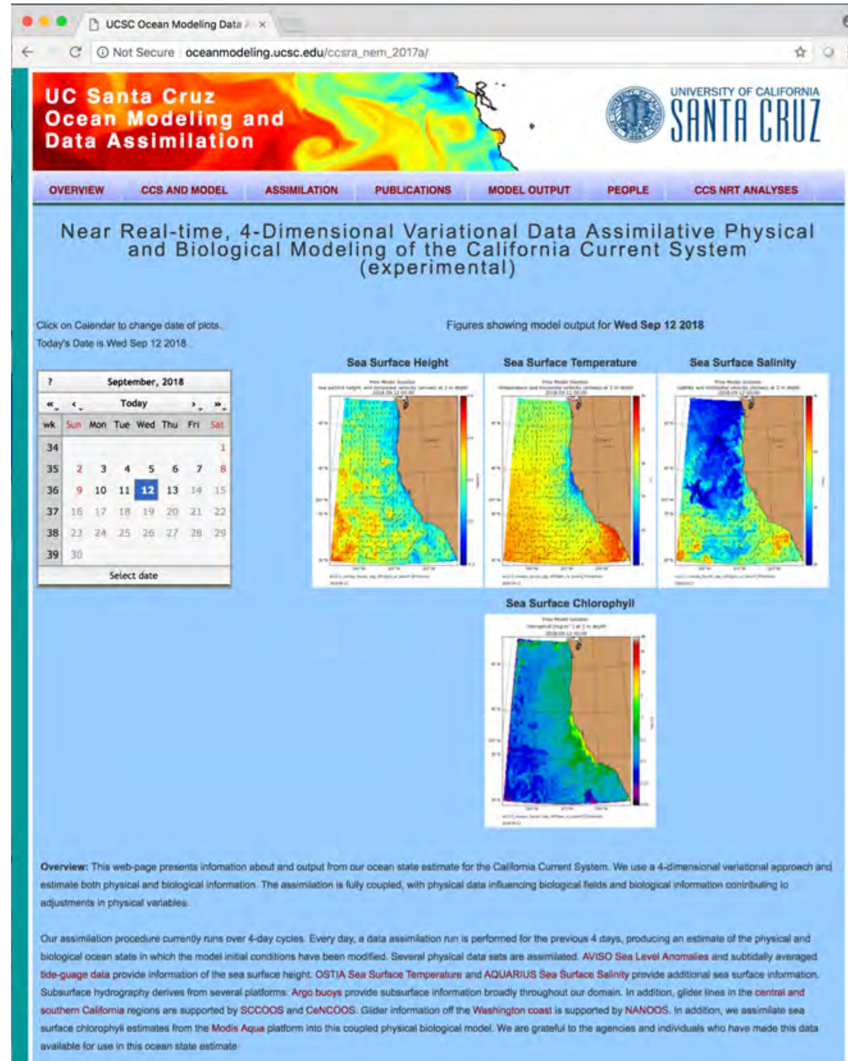


Mattern et al. (2017)

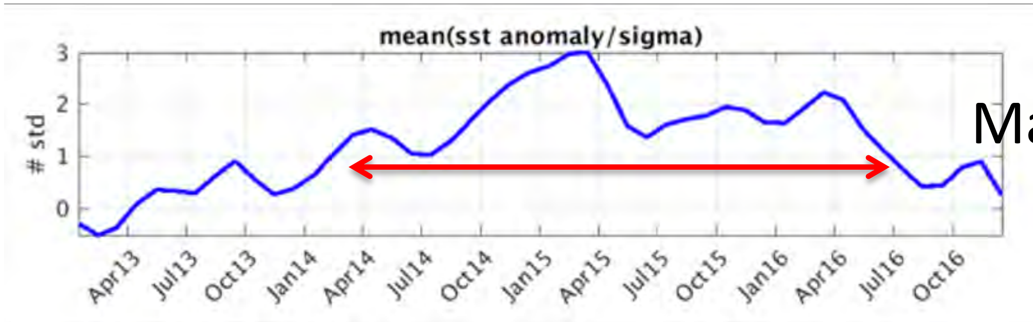
UCSC Coupled Physical/Biogeochemical System ROMS 4D-Var, 2011-present

(http://oceanmodeling.ucsc.edu/ ccsra_nem_2017a/)

- 1/10° CCS ROMS configuration
- Online since July 2014
- 4-day assimilation cycles
- Assimilates SST, SSH, SCHL, glider T/S, Argo T/S, HF RADAR velocities
- Model output available on a TDS
- Figures of model fields posted
- Calendar searchable

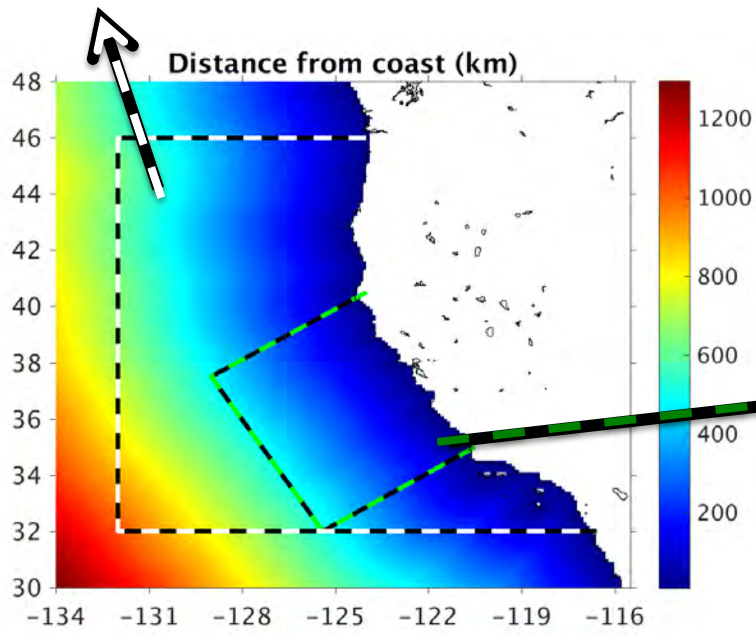


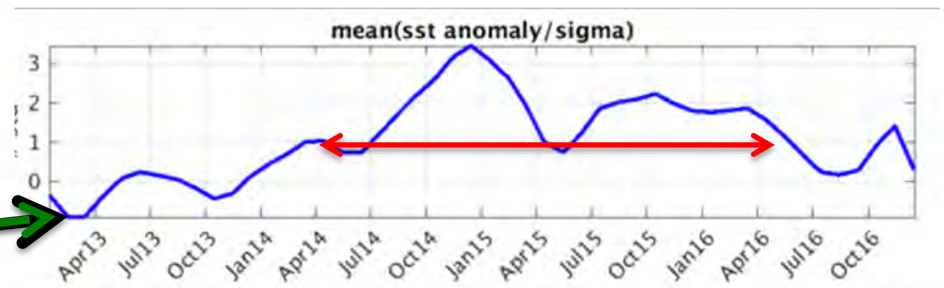
The Blob and El Niño as seen by a bgc/physical reanalysis



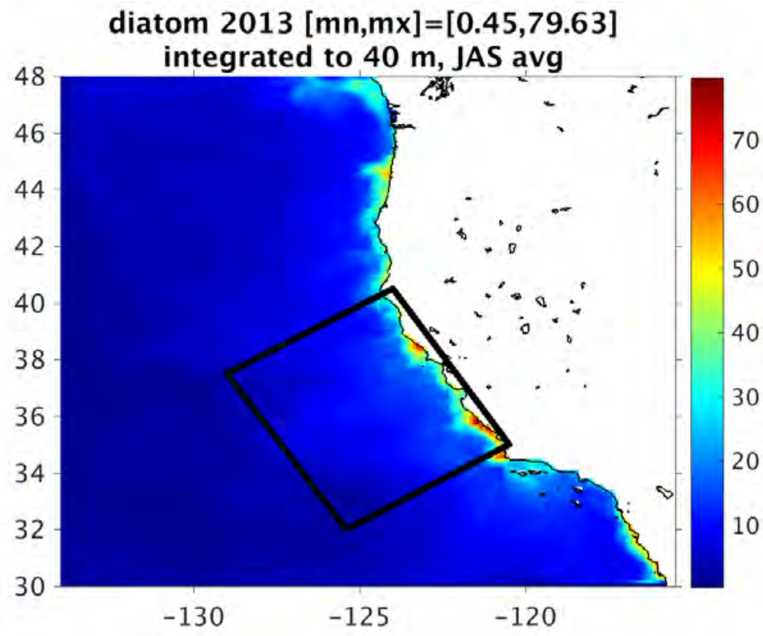
SST > 1 σ

March 2014 until June 2016

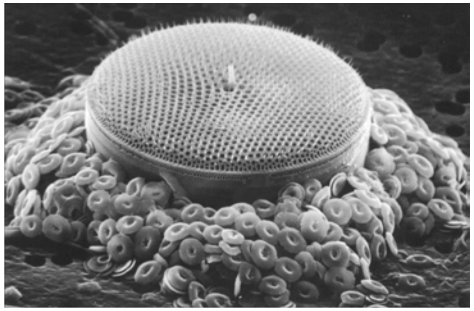




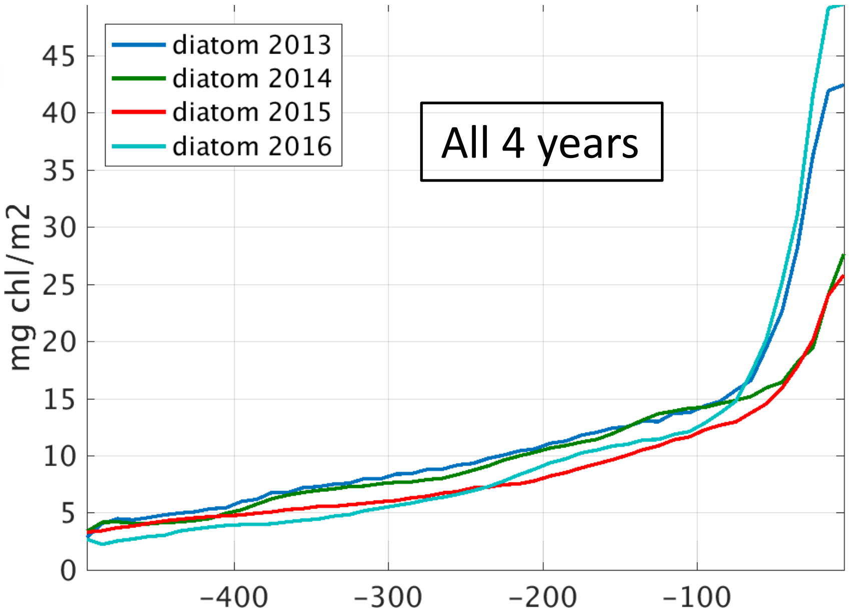
Central CCS Diatom fields, July-Sept Averages



Annual average diatom stock low during 2014-2015



Average in time (JAS) and in space (cross-shore distance)



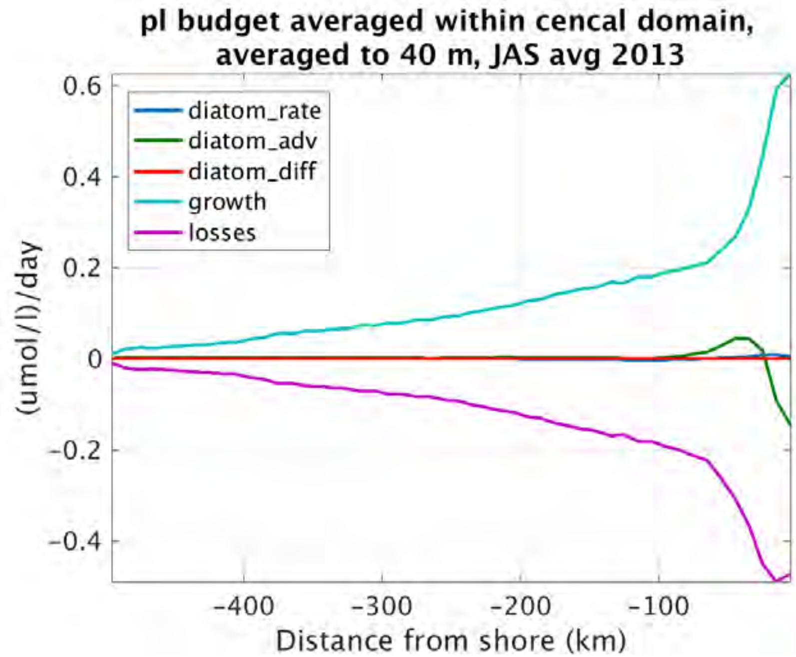
Distance from shore

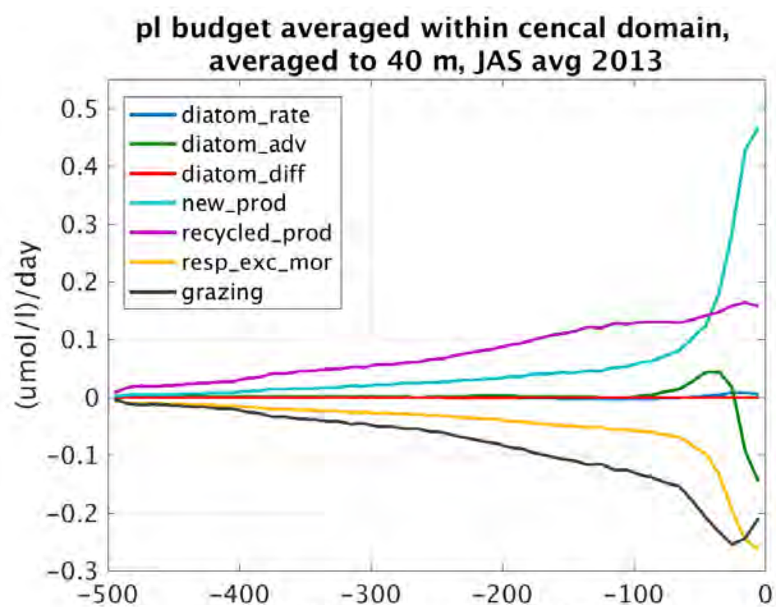
Diatom budget (summertime average)

dP/dt = advection + diffusion + growth + losses

Mostly a <u>balance</u> between <u>growth</u> and <u>losses</u> with a small contribution by advection nearshore.

dP/dt = advection + diffusion + new production + recycled production + grazing + excretion + respiration + mortality

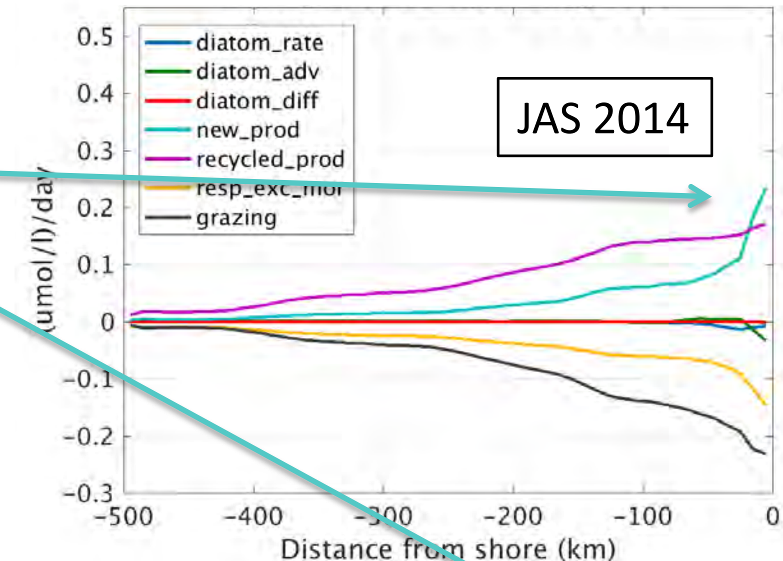


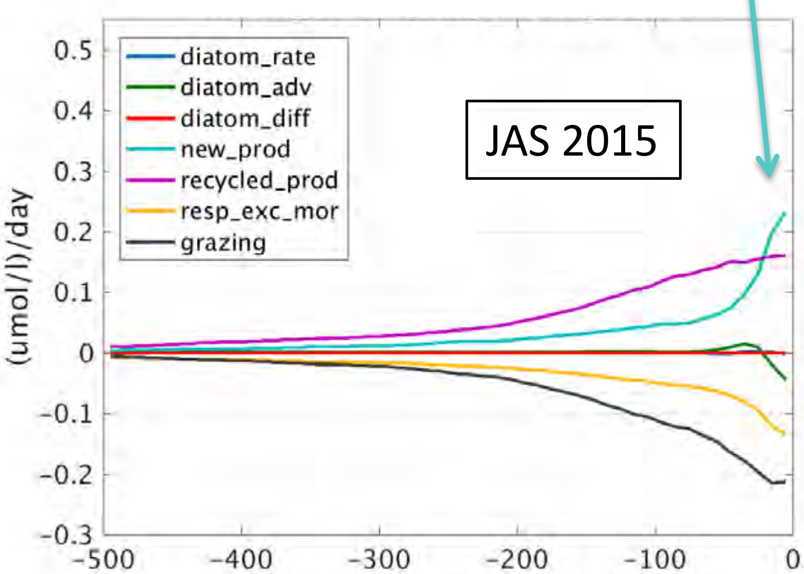


Distance from shore

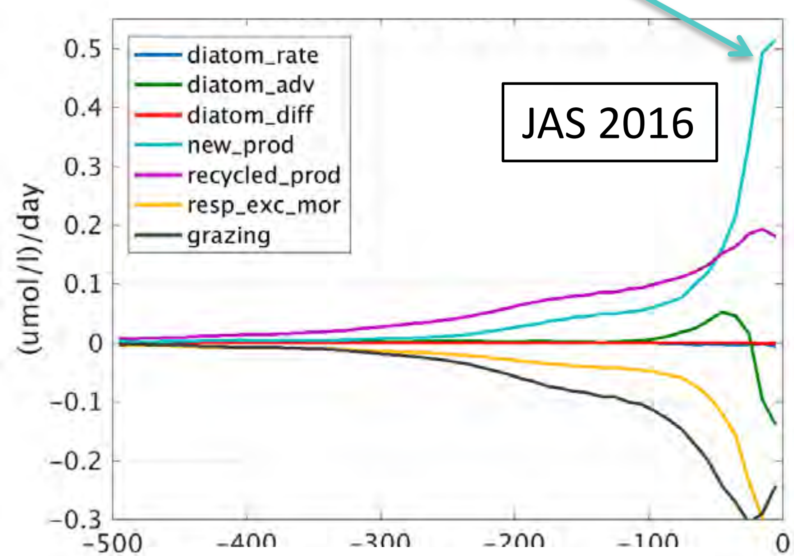
Summertime dynamical balances reveal starkly different new primary production

dP/dt = advection + diffusion + new production
+ recycled production + grazing + excretion
+ respiration + mortality





Distance from shore

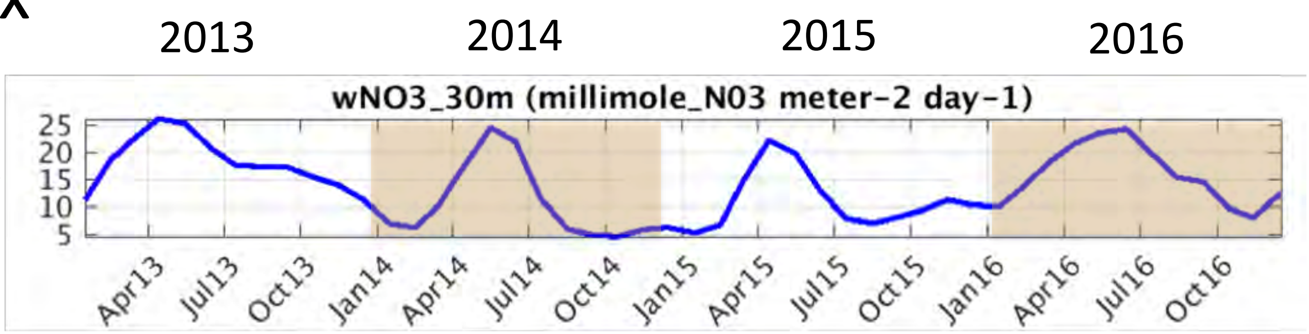


Distance from shore

Explanation

- Changes in new production can be due to changes in
  - light
  - temperature
    - higher temp -> higher growth rates
  - nutrient flux

Vertical nitrate flux across 30 m depth



- Note anomalous summer lows in 2014/2015

Physical nitrate transport

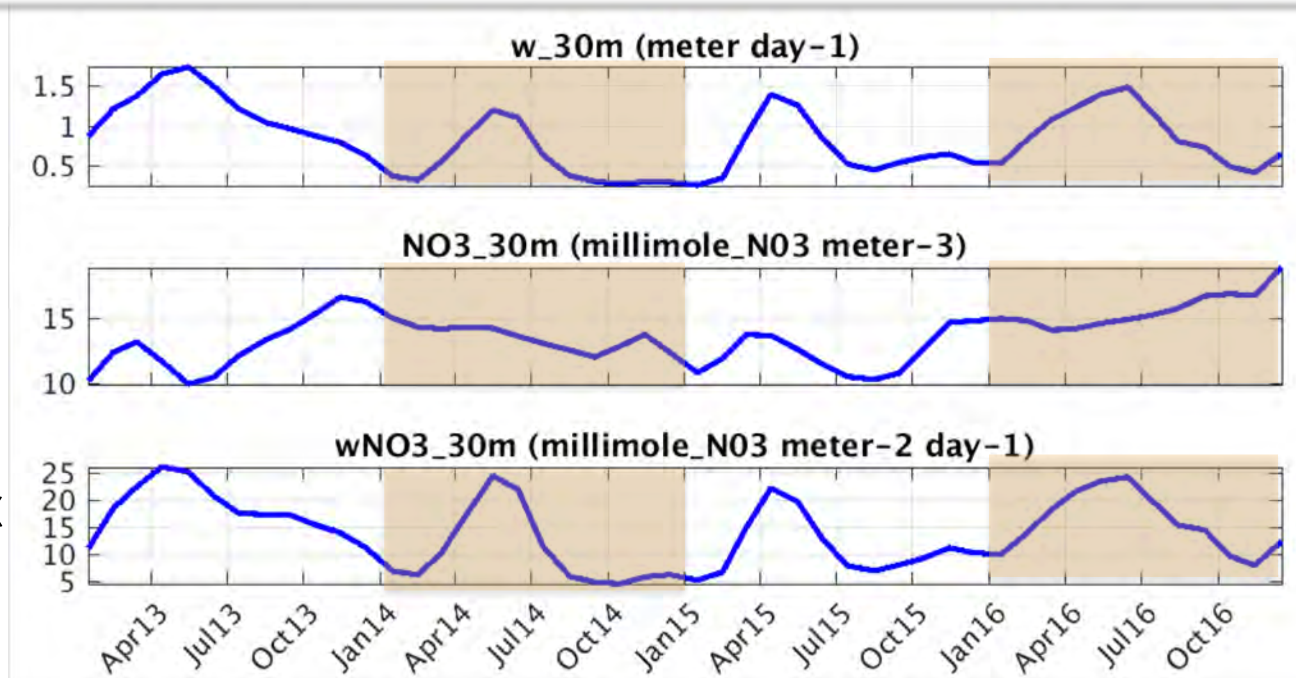
(monthly averages, averaged to 50km from shore)

2013 2014 2015 2016

Vertical velocity across 30 m depth

Nitrate at 30 m depth

Vertical nitrate flux across 30 m depth



Vertical nitrate flux predominantly results from vertical velocity (94% of variance)

Diatom budget terms

(monthly averages, averaged to 50km from shore)

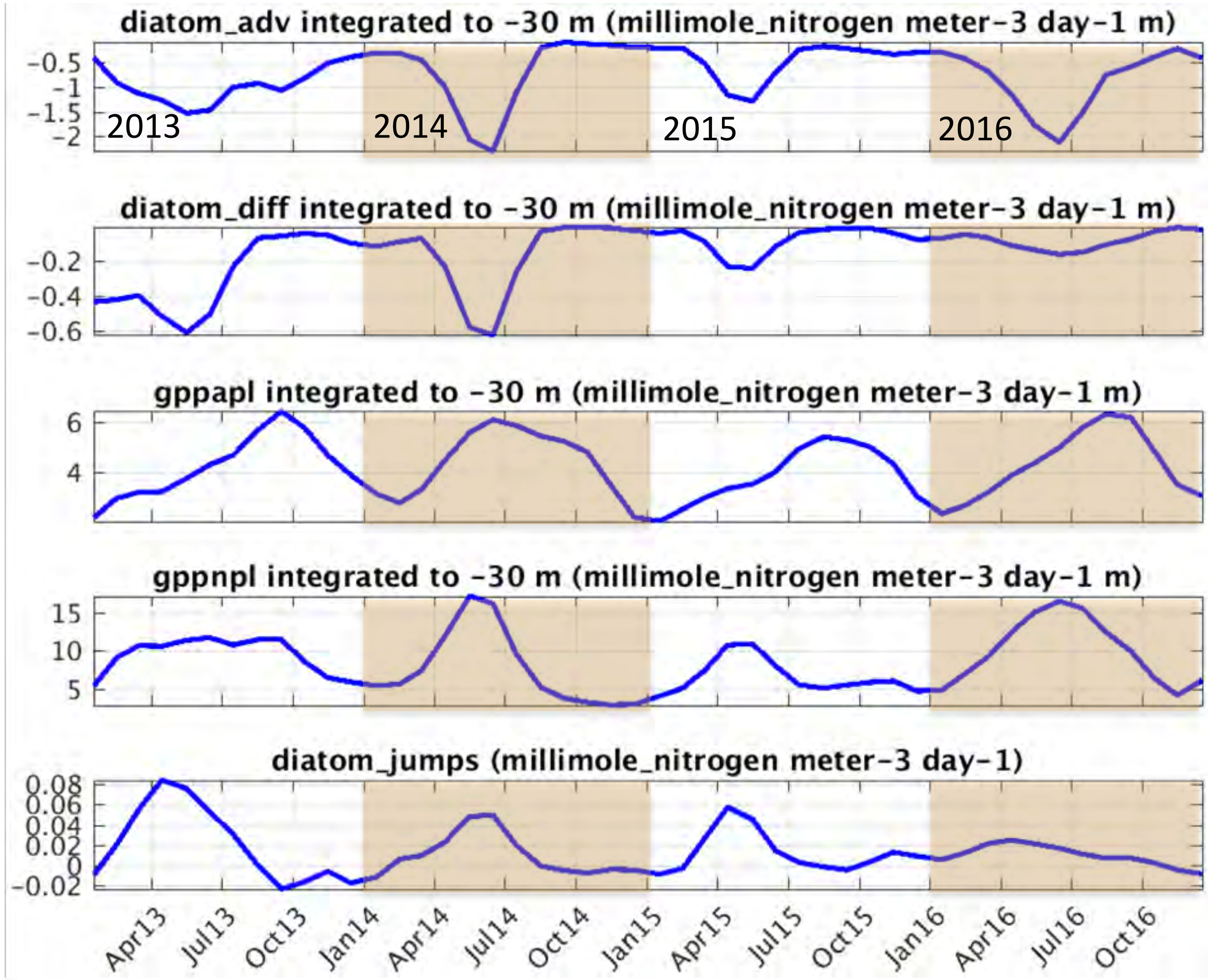
advection

diffusion

Recycled production

New production

Non-conservative changes due to assimilation cycles



79% of variance in new production accounted for by nitrate flux, 67% by wind stress

Summary

- ROMS 4D-Var BGC data assimilation operating routinely in the CCS.
- A sensible dynamical interpolation from sparse data
- Offers a platform for dynamical analysis to understand ecosystem impacts of physical drivers.
- During 2014-2015 (Blob)
  - **Low Diatom** annual average concentration
  - Recycled production not particularly anomalous.
  - **New production** was anomalous.
  - **Springtime** new production not significantly impacted
  - **Summertime** new production significantly lowered
  - Vertical nitrate flux dominated by **vertical velocity** (and wind sress), not nutricline depth
- A multi-decadal reanalysis is underway (1997 to present)
- See H. Song talk on Friday for more on L4D-Var DA