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

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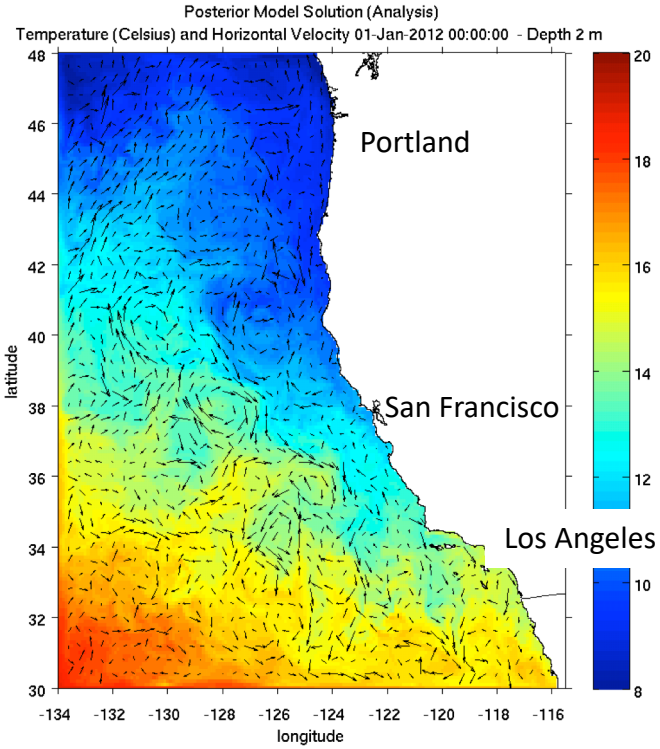


6th COSS-TT Meeting

Puertos del Estado, Madrid, Spain

19-21 September 2018

Outline

- Review of L4D-Var for BGC models
- NRT system
- Ecosystem responses to physical drivers in coastal regions
  - Recent warm period in the CCS

BGC L4D-Var Review

- Gaussian data vs skewed data
- Positive and negative variables vs positive definite concentrations
- We assume **lognormal** variables
- For 4D-Var, requires additional linearizations

Logarithm transformation
Surface chl-a

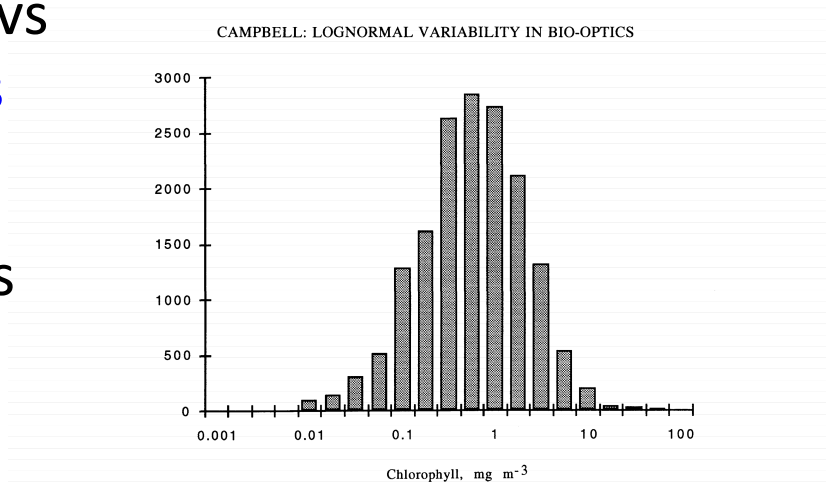


Figure 1. Histogram of 16,364 in situ measurements of ocean chlorophyll concentration from a compilation by *Balch et al.* [1992]. The data are global in scope, but sampling was concentrated at midlatitudes in the northern hemisphere, and central ocean gyre regions were undersampled.

Campbell (1995)

BGC Review – Fully Coupled 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

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

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

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

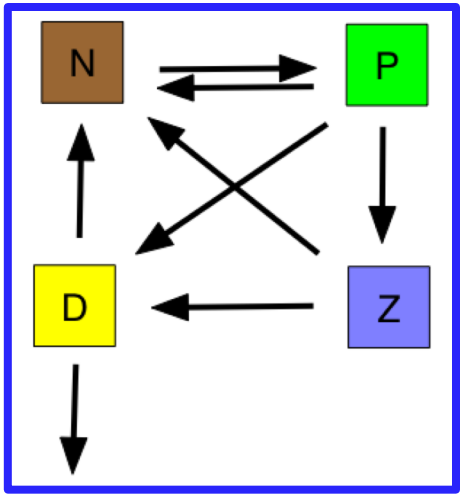
Song et al. (2012, 2016b)

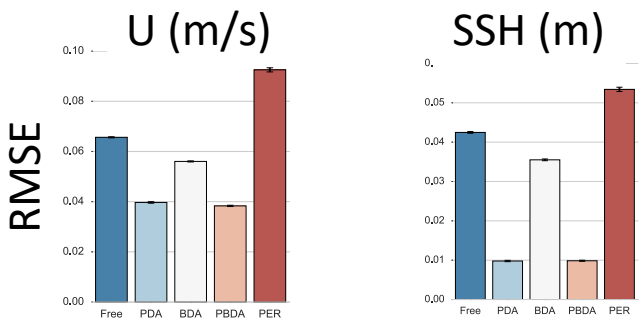
Fully coupled or not Fully coupled?

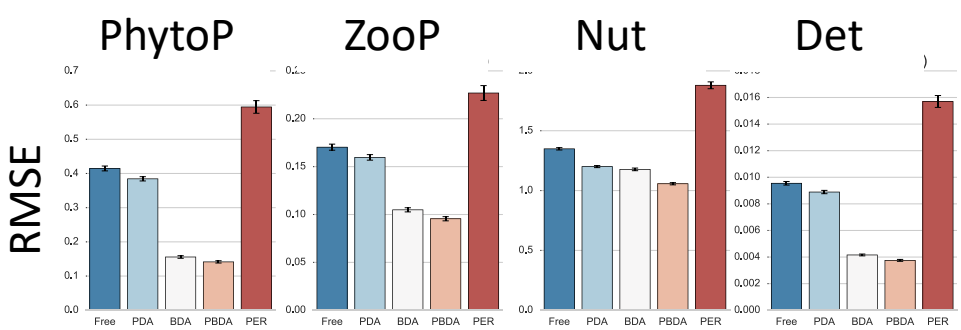
In principal, bio obs should feed back on physics and vice versa

Demonstrated here in model twin experiment

- Statistics from 30 1-month runs.
- Assimilating physical data and surface Phytoplankton
- Lowest error from combined PBDA (<u>not</u> yet demonstrated with real data)







Free Run

Physical DA

Biological DA

Physical and biological DA

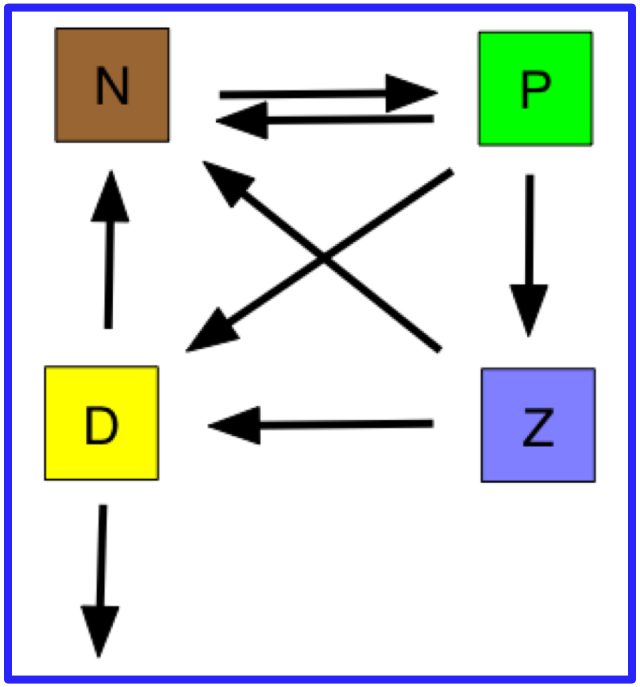
Persistence (1 month)

Song et al. (2016b)

We have developed L4D-Var for ROMS with two ecosystem models

NPZD

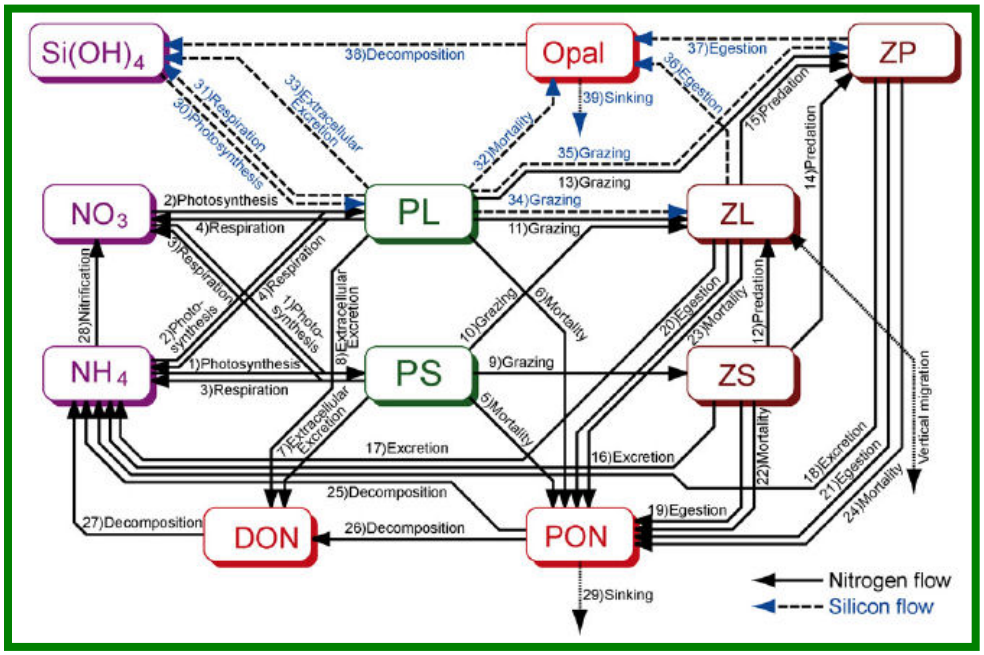
(Powell et al. 2006)



4 boxes

NEMURO

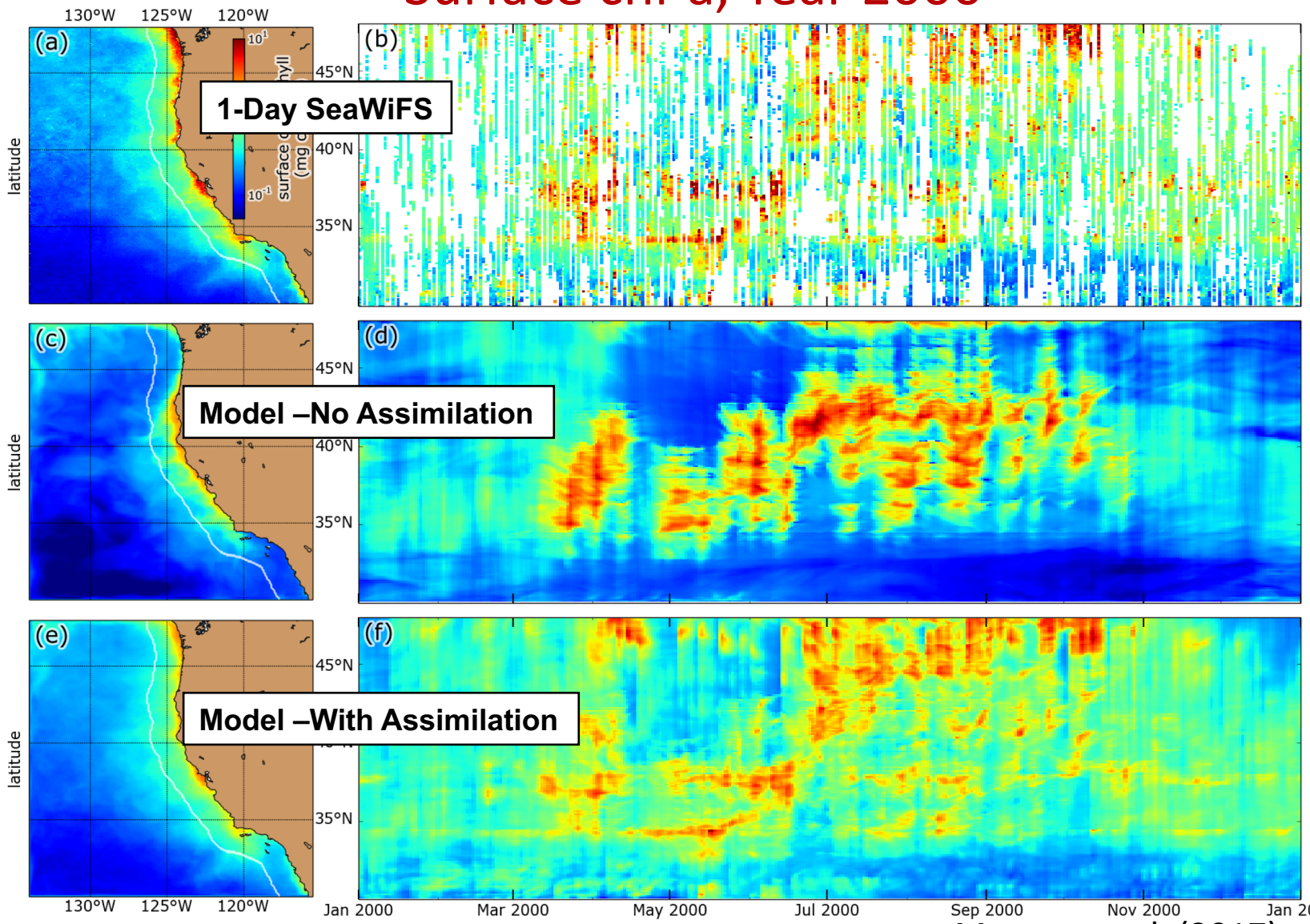
(Kishi et al. 2011)



11 boxes

Fully coupled 4D-Var using NEMURO

Surface chl-a, Year 2000

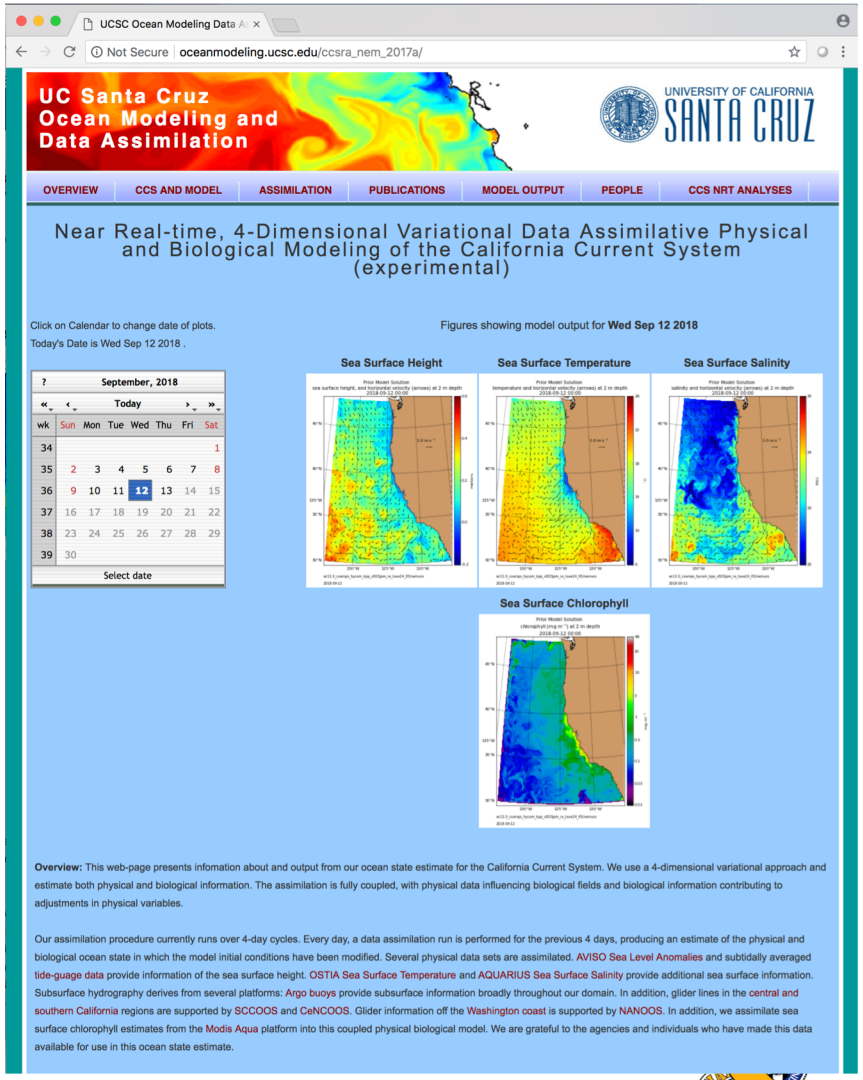


Mattern et al. (2017)

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



An application: The recent warm blob in the Pacific

- ~3°C multiannual marine heatwave
- What are the ecosystem impacts of this anomalous event?

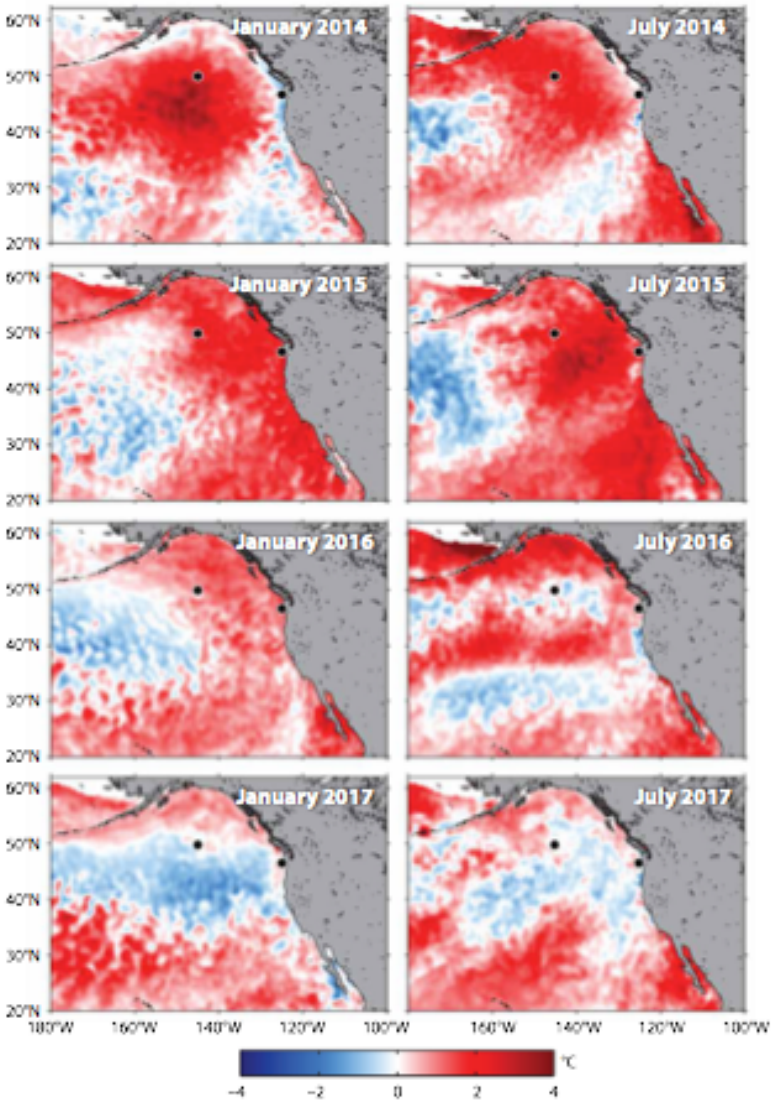
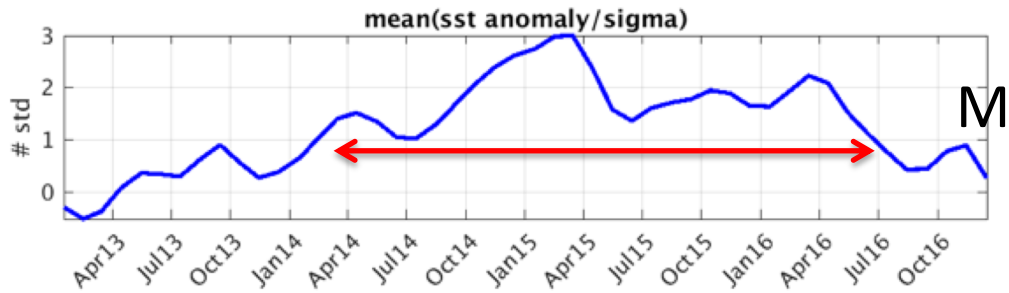


FIGURE 2. North Pacific sea surface temperature anomaly showing the evolution of the "warm blob" from its origination in winter 2013–2014 through the following four years. Satellite temperature data are from AVHRR only Optimum Interpolation Sea Surface Temperature (OISST, https://www.ncdc.noaa.gov/oisst/data-access), 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.

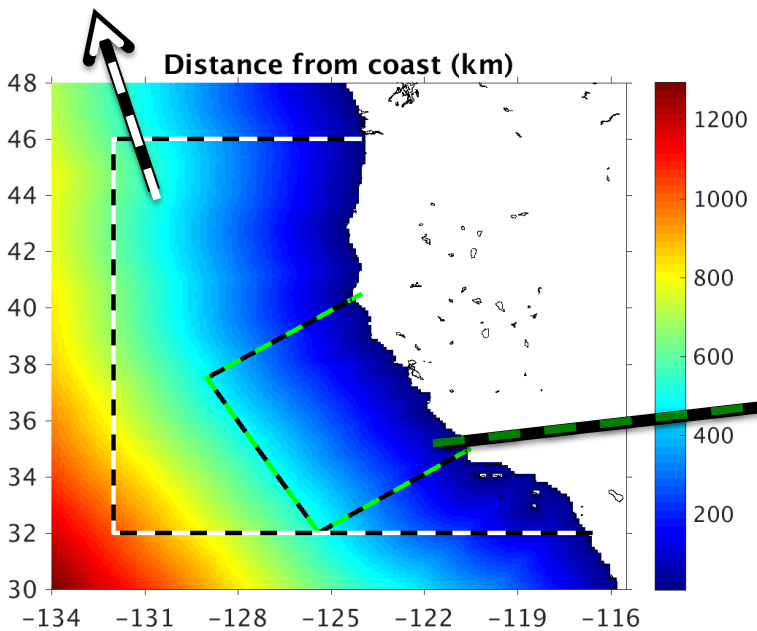
Figure from Barth et al. (2018)

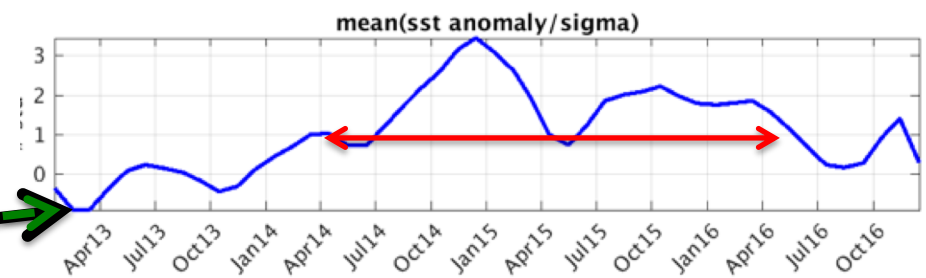
The Blob and El Niño as seen by a bgc/physical reanalysis



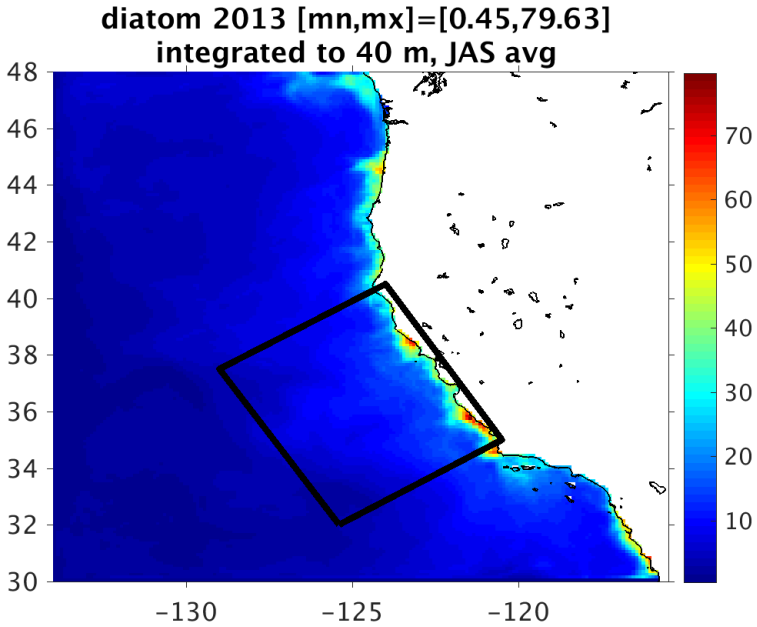
SST > 1 σ

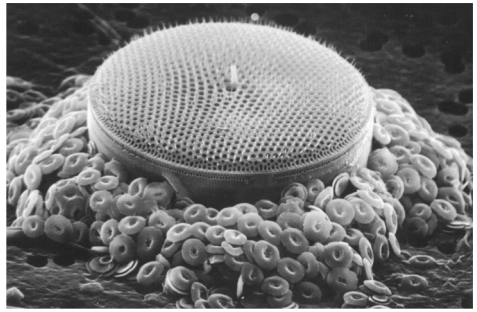
March 2014 until June 2016



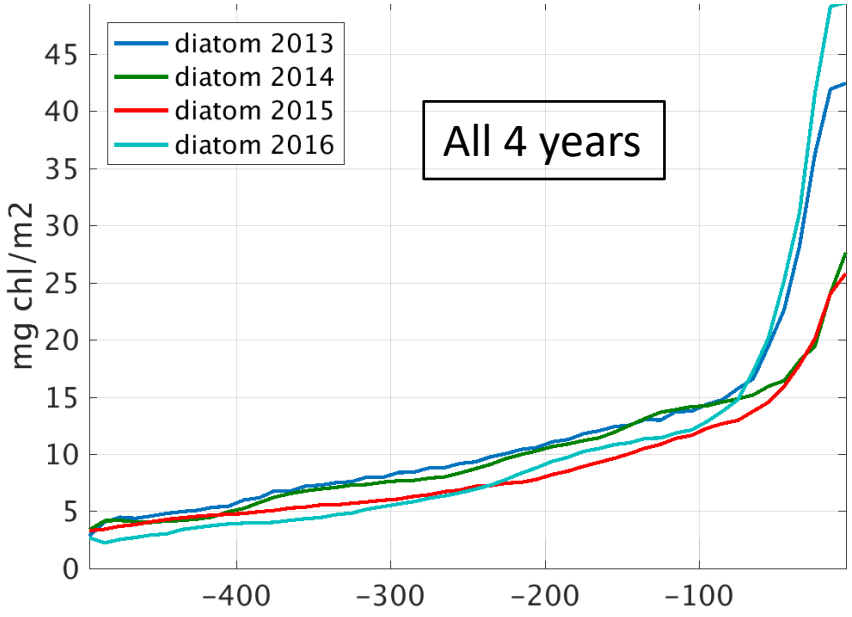


Central CCS Diatom fields, July-Sept Averages





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



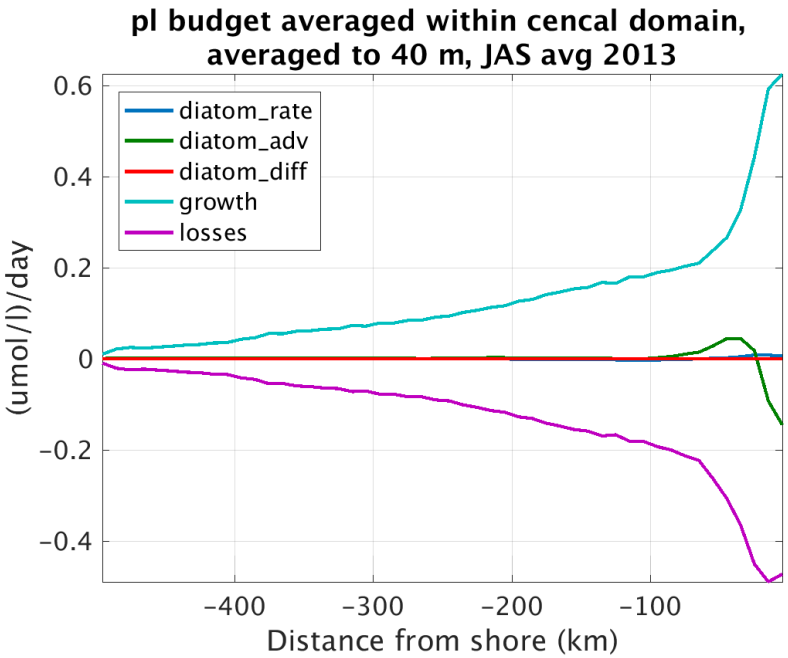
Annual average
diatom stock low
during 2014-2015

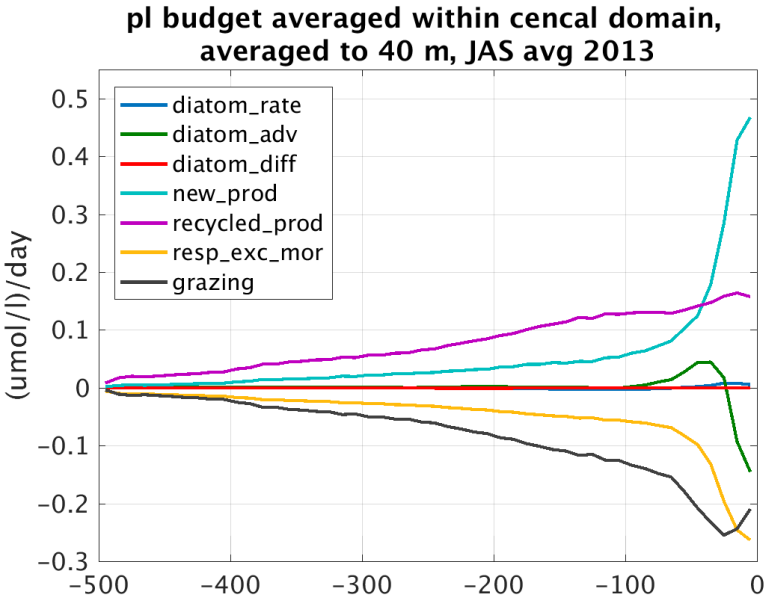
Diatom budget (summertime average)

dP/dt = advection + diffusion + growth + losses

Mostly a balance between growth and losses with a small contribution by advection nearshore.

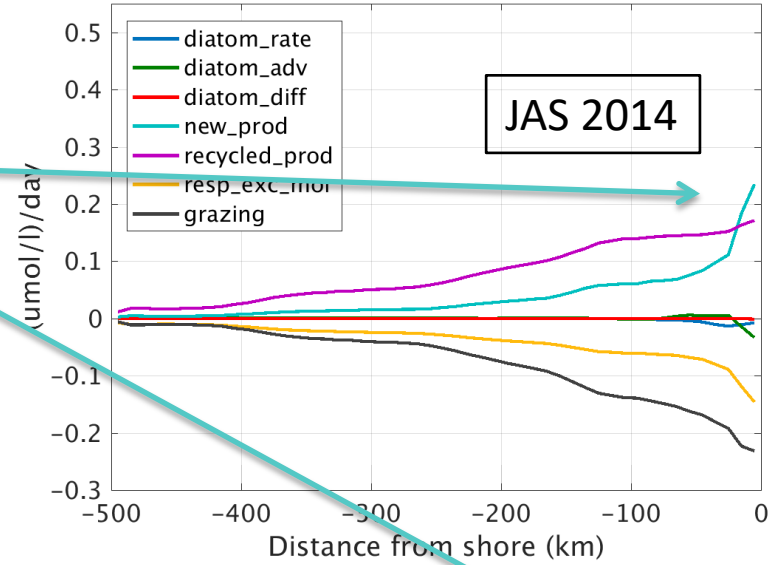
dP/dt = advection + diffusion + new production + recycled production + grazing + excretion + respiration + mortality

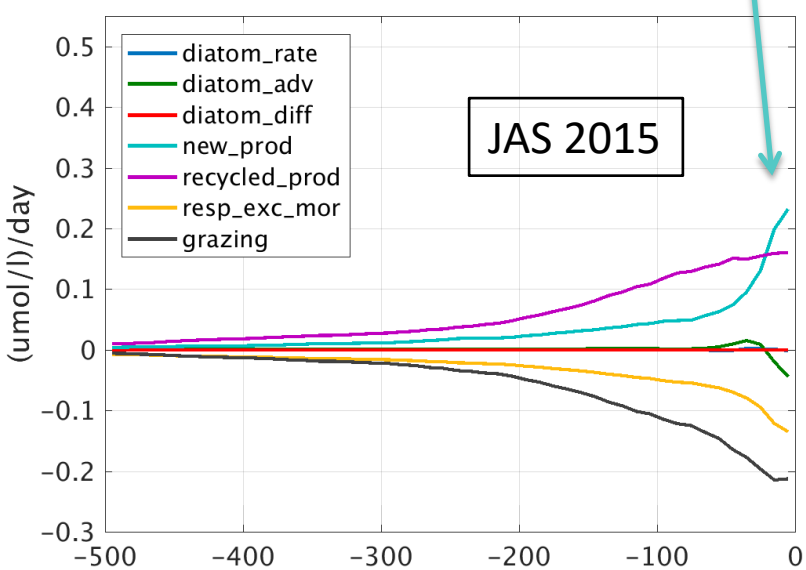




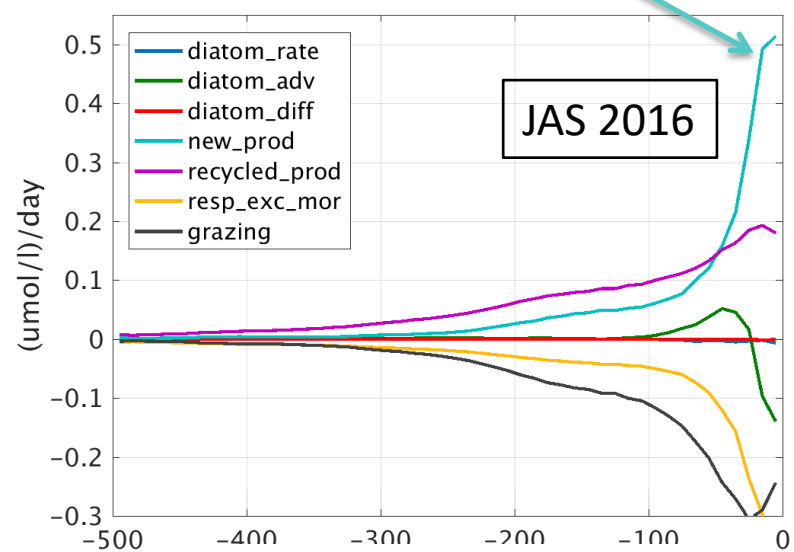
Summertime dynamical balances reveal starkly different new primary production

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





Distance from shore

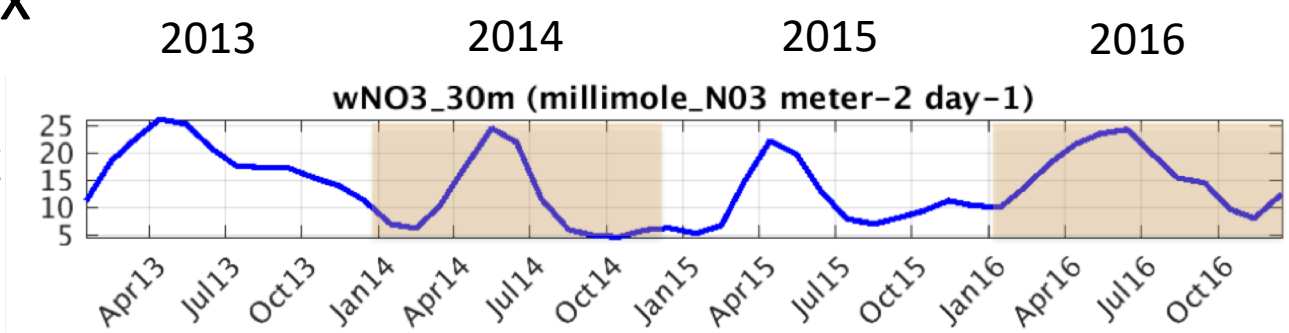


Distance from shore

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

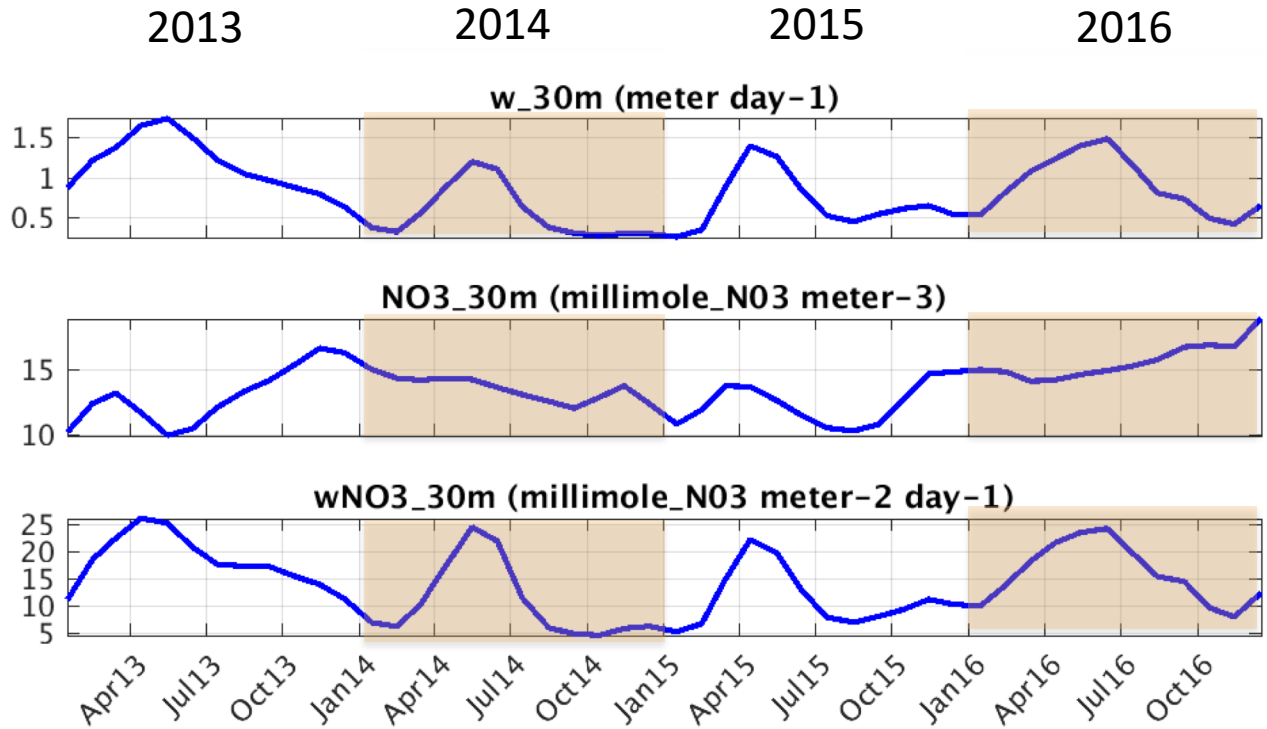
Physical nitrate transport

(monthly averages, averaged to 50km from shore)

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)

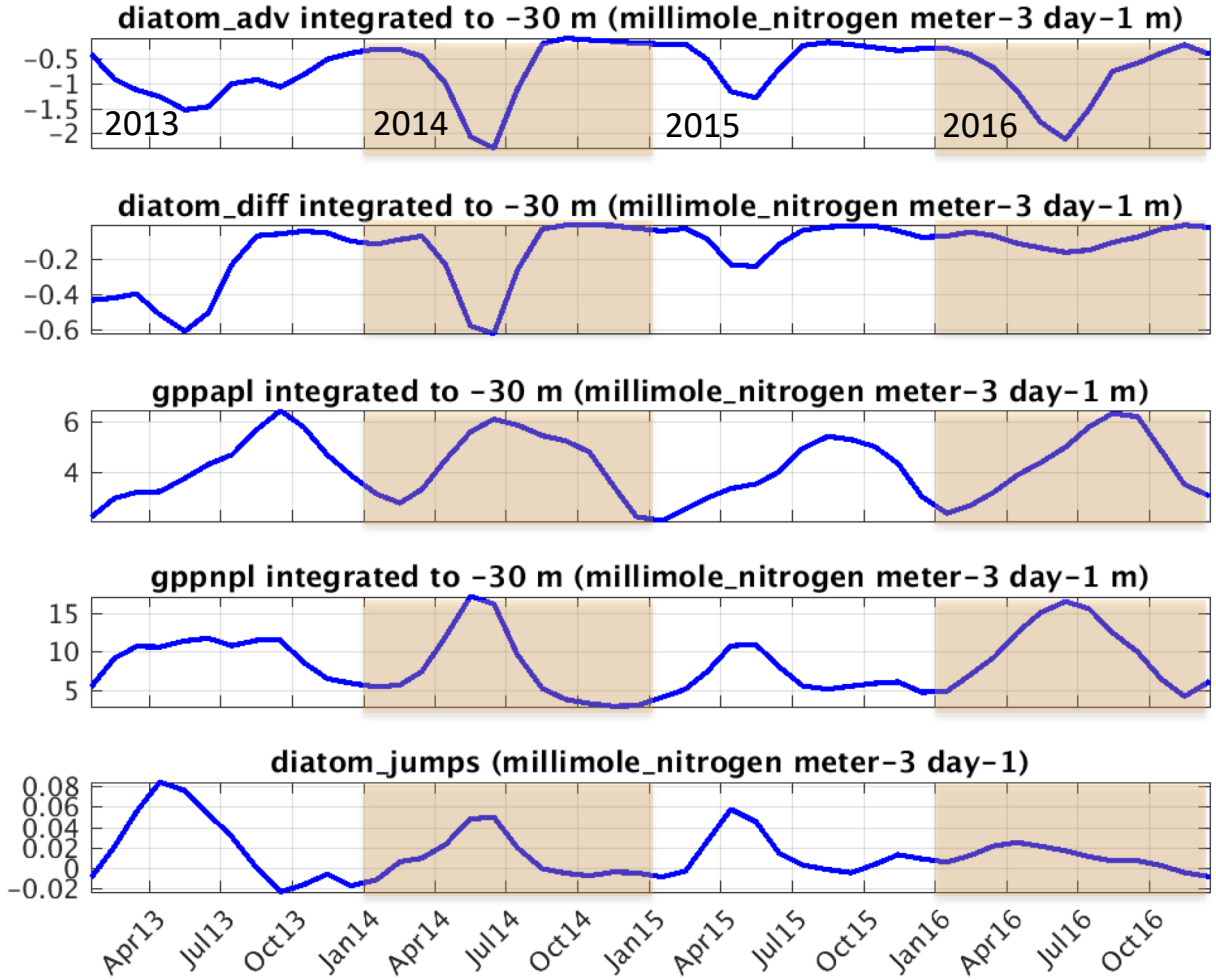
advection

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

- NRT L4D-Var, physical and BGC data assimilation underway in the CCS for years.

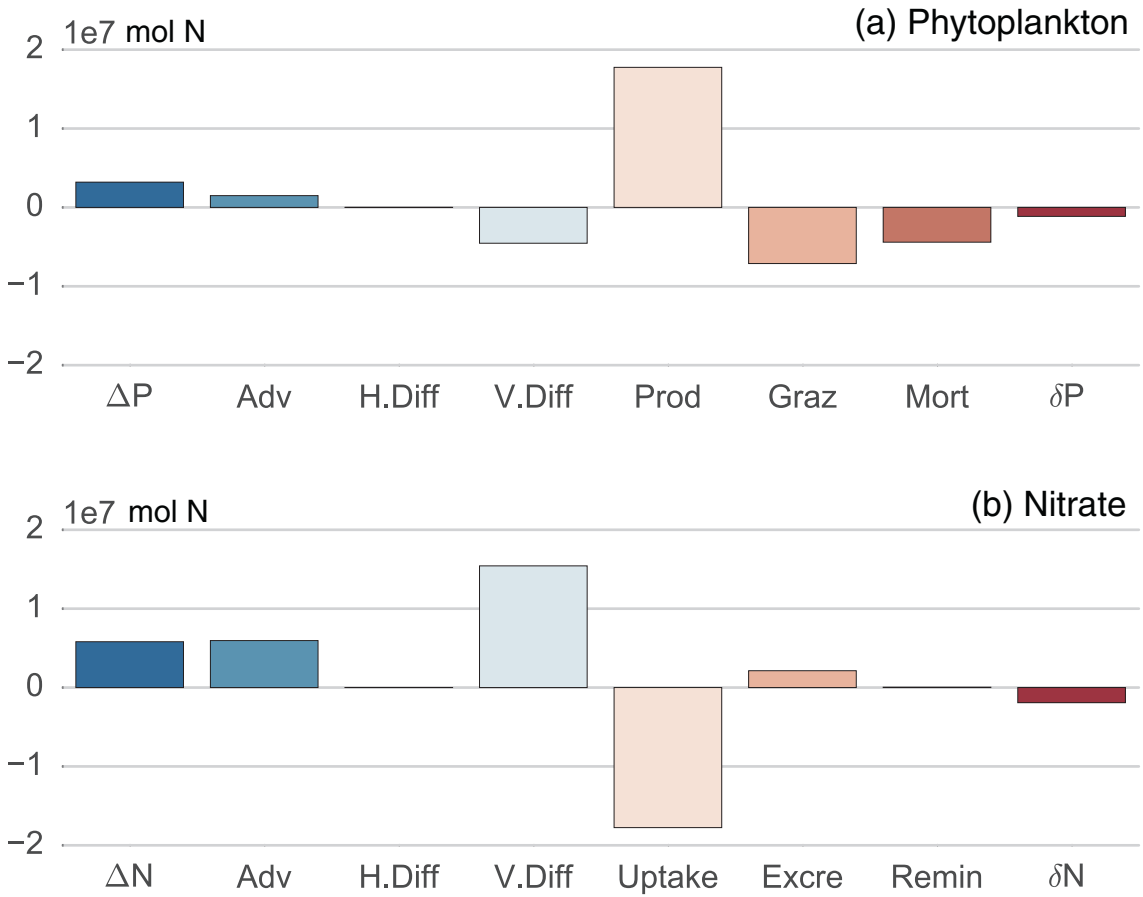
- Reanalysis provides a sensible dynamical interpolation from sparse data and offers a platform for dynamical analysis to understand ecosystem impacts of physical drivers.

- 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

Flux estimates (npzd model)

(coastal zone average, April-September)

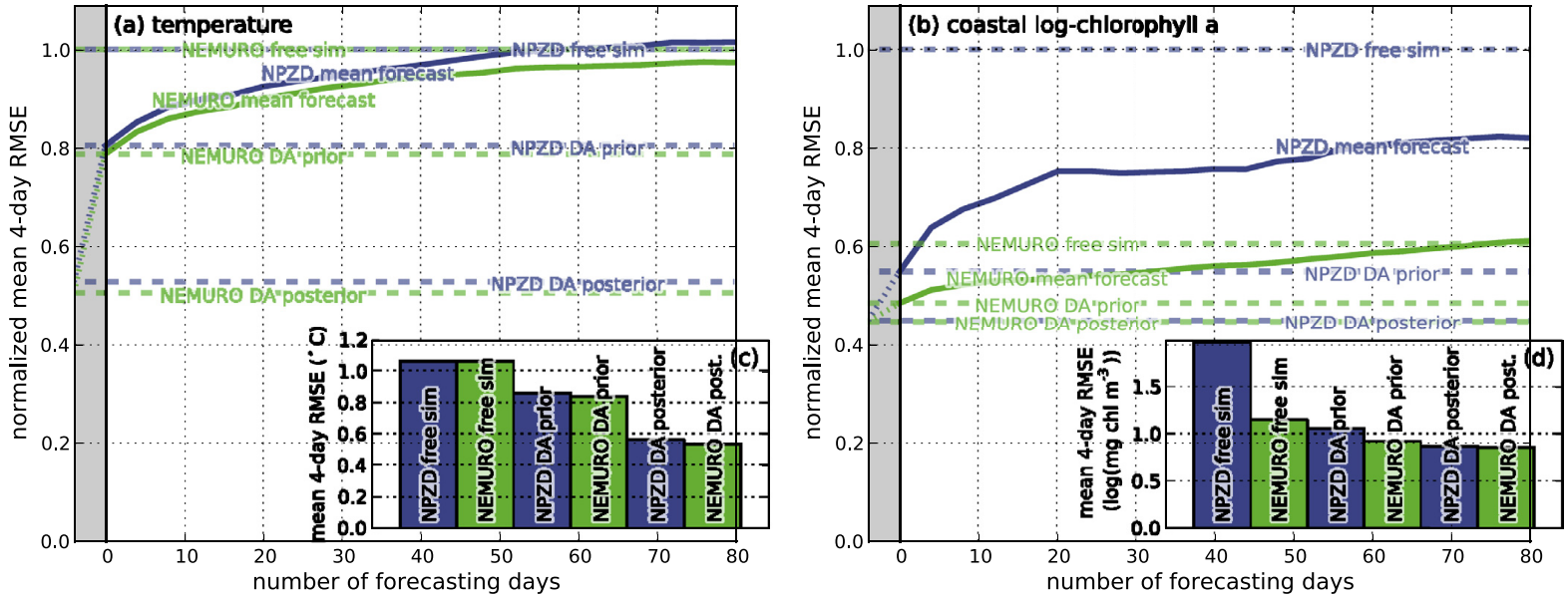
- δP and δN are adjustments due to assimilative jumps
- Small compared to dominant biological and physical processes



Song et al. (2016c)

Forecasting skill

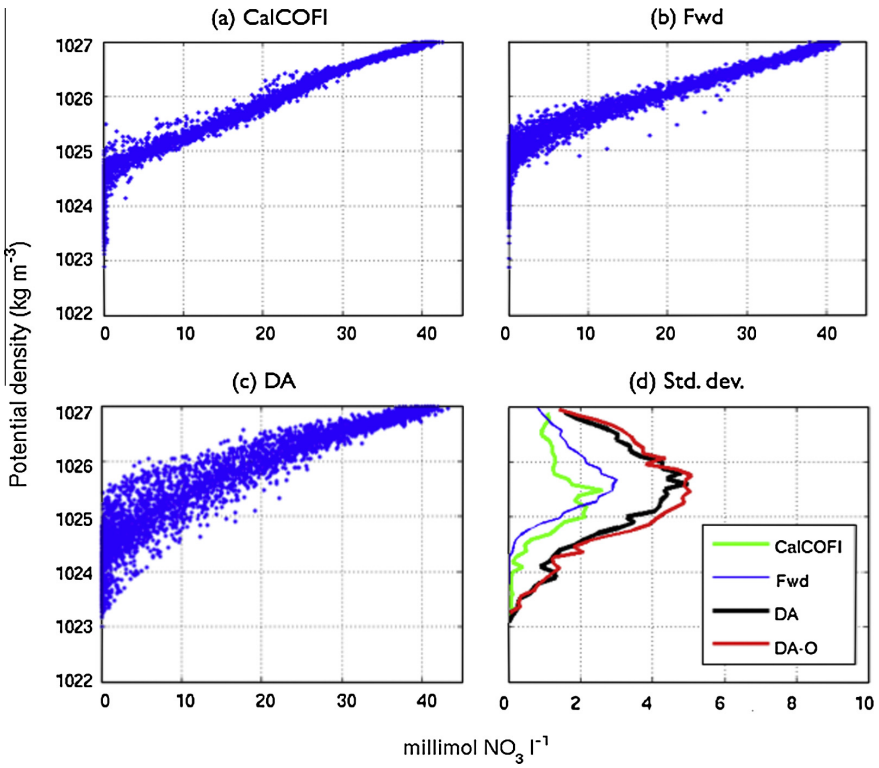
Improvements out to at least 10 arguably 30 days



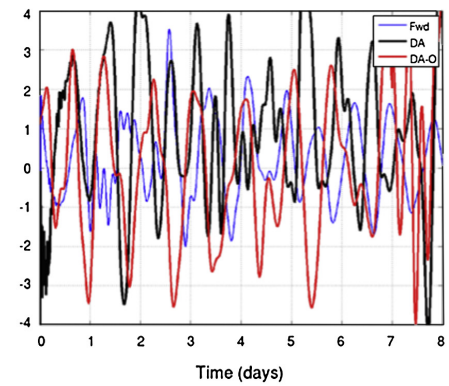
Mattern et al. (2017)

2 negative impacts of physical assimilation on ecosystem response

Nutrient/density relation

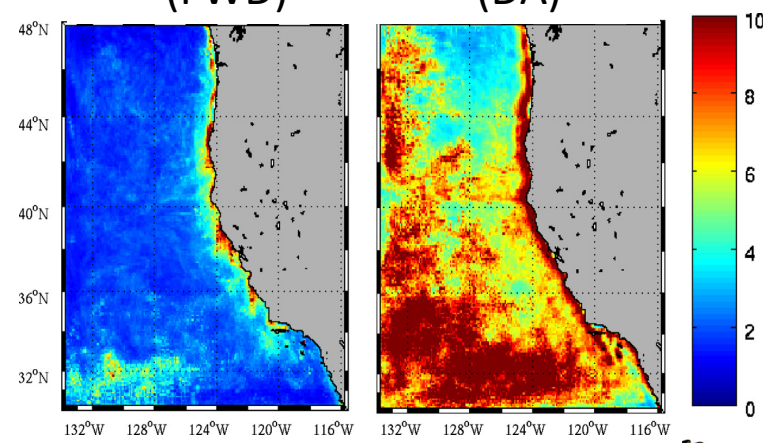


w @ 50 m (m/day)



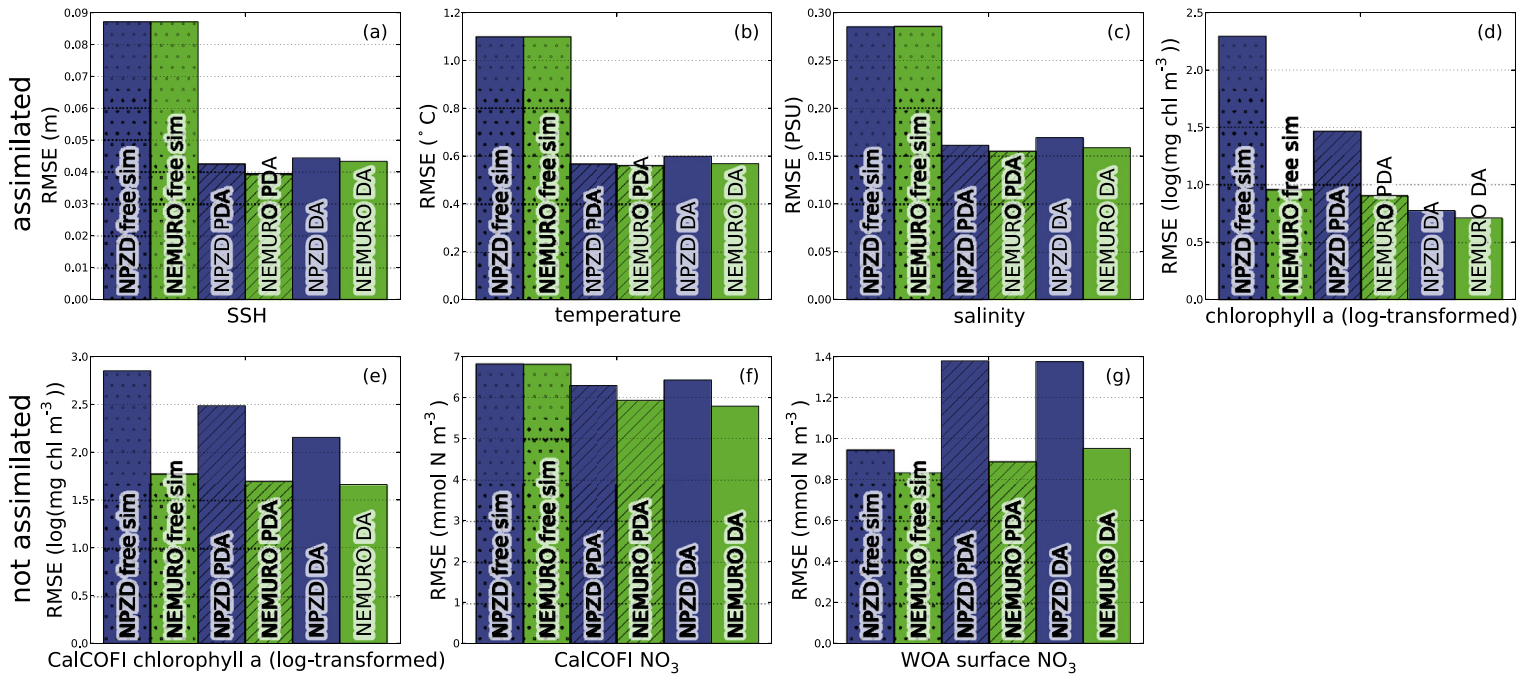
RMS w @ 50 m (m/day)

(FWD) (DA)



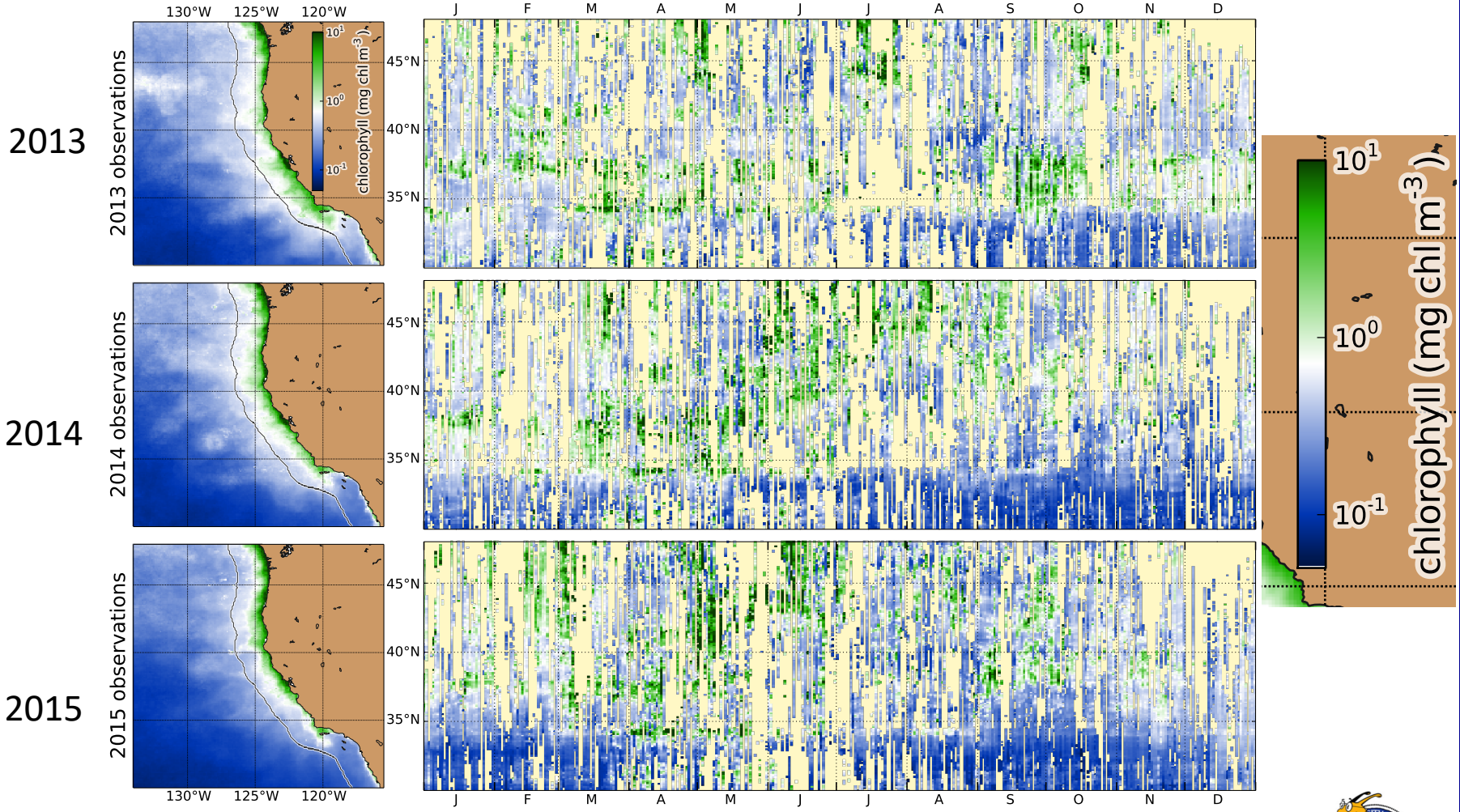
Raghukumar et al. (2015)

Assimilation improvement for assimilated and unassimilated data



Mattern et al. (2017)

2013-2015 MODIS AQUA CCS Surface chlorophyll-a (mg chl-a/m^3)



2013-2015 Reanalysis CCS Surface chlorophyll-a (mg chl-a/m^3)