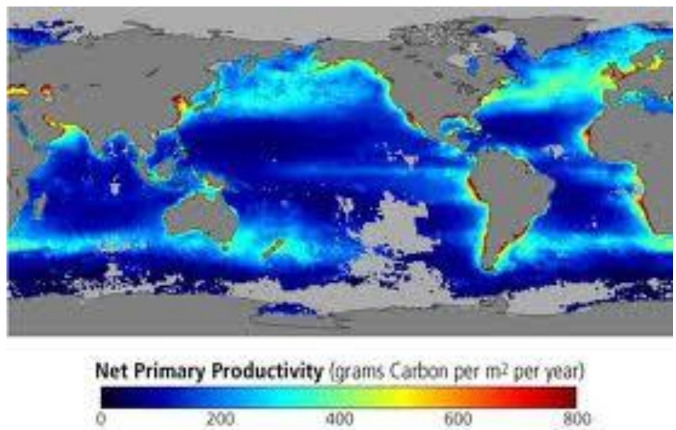
By making some assumptions, we can estimate GROWTH RATE (productivity) from space—we assume it is a function of light, temperature, and chlorophyll, all of which can be measured remotely



Side note: chlorophyll is BIOMASS and doesn't tell you anything about how fast the cells are growing, so chlorophyll is NOT the same as productivity (growth)

Common NPP Models

ESQRT Eppley 1985):

NPP = SQRT(CHL)

VGPM (Behrenfeld and Falkowski 1997):

NPP = 0.66125 x P^B_{opt} x Eo/(Eo+4.1) x Z_{eu} x CHL_{opt} x D_{irr}

Morel (1991):

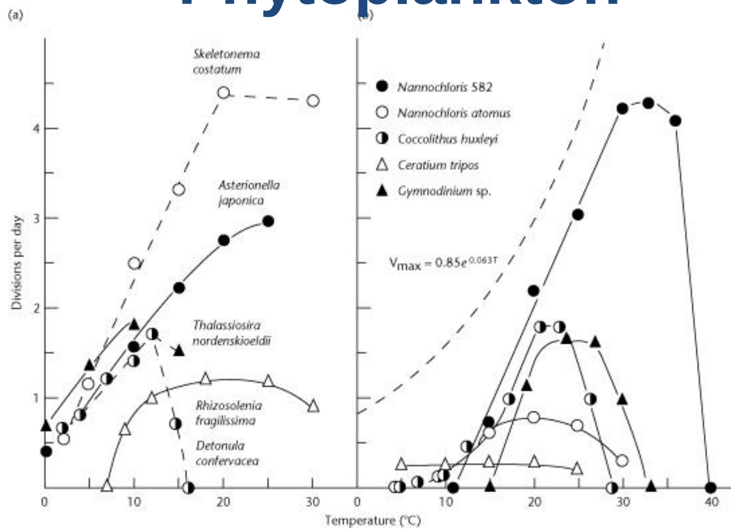
NPP = 12 x CHL x a* x PAR x PHI_c

CbPM (Westberry et al. 2008):

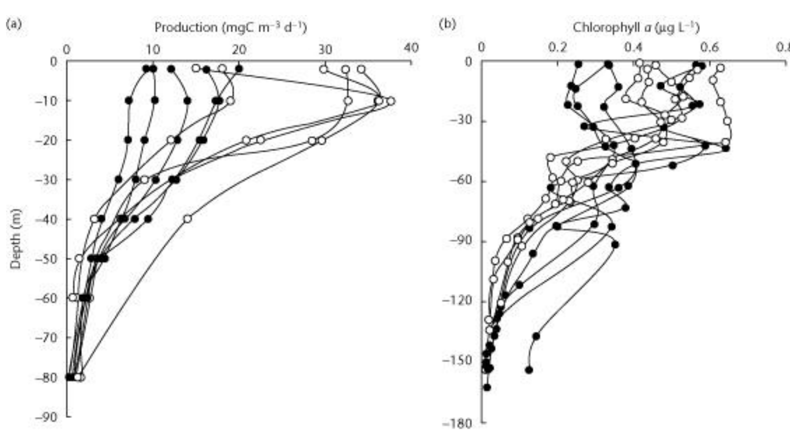
NPP = μ x C = μ x [(bbp(443)-bbp(443)$_{NAP}$) x SF]

$$\mu=\mu_{max}\times \frac{\frac{Chl}{C}-\left[\frac{Chl}{C}\right]_{\mu=0}}{\left[\frac{Chl}{C}\right]_{N-T\max}-\left[\frac{Chl}{C}\right]_{\mu=0}} \left[1-e^{(-5PAR(z))}\right]$$

Temperature & Phytoplankton



P^B_{opt} & Temperature



P^B_{opt} & Temperature

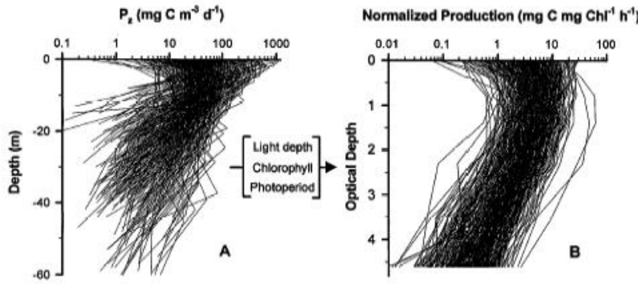


Fig. 1. Profiles of phytoplankton carbon fixation for 500 randomly chosen stations from the MARMAP dataset. A. A large degree of variability was observed in the vertical distributions of daily primary production (P_z, mg C m^{-3} d^{-1}). B. Normalizing P_z in panel A to chlorophyll concentration at each depth, photoperiod, and optical depth resulted in a consistent pattern in the vertical structure of productivity, which was modeled as a function of surface irradiance by the structural components of the VGPM (Eq. 8).

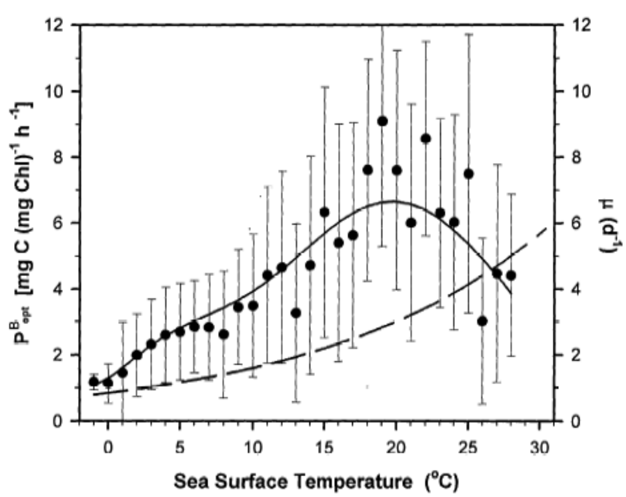


Fig. 7. Measured (●; ±SD) and modeled (——; Eq. 11) median value of the photoadaptive parameter, P^B_{opt}, as a function of sea surface temperature. Dashed curve indicates the theoretical maximum specific growth rate (μ; d^{-1}) of photoautotrophic unicellular algae described by Eppley (1972), which is used in a variety of productivity models (e.g. Balch and Byrne 1994; Antoine et al. 1996).

Modifications to NPP models

1) For regionally tuned models, the Pbopt relationship is often modified, including use of a seasonal or annual average (i.e. removing the temperature dependence)

2) Addition of different size classes
   - Kameda & Ishizaka, 2005
   - Hirata et al. 2009

3) Addition of Phytoplankton Functional Types
   - Uitz et al. 2010

Does it Matter?

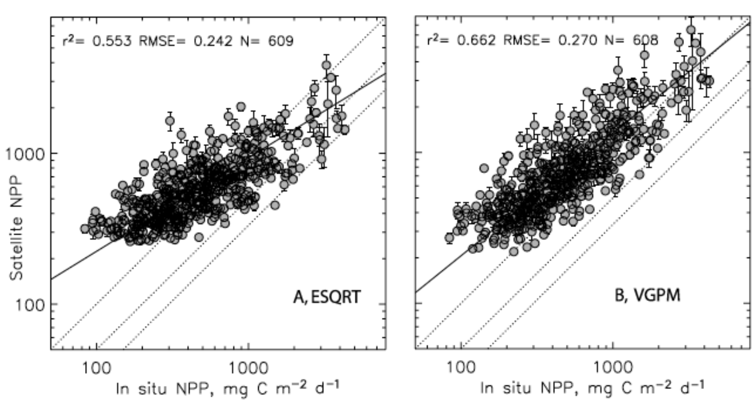


Figure 2. Satellite-estimated NPP versus in situ CalCOFI measurements. The solid black line is the least squares linear regression (in log-log space), and the dotted lines show the one-to-one line, the 1/2, and the 1/3 lines, respectively. The circles are centered at the mean of each 3 × 3 pixel satellite pixel window, and the vertical lines show the 1 standard deviation for the same window. If standard deviation is small, then the vertical line becomes invisible. (a) ESQRT model, (b) VGPM model.

Kahru et al. 2009

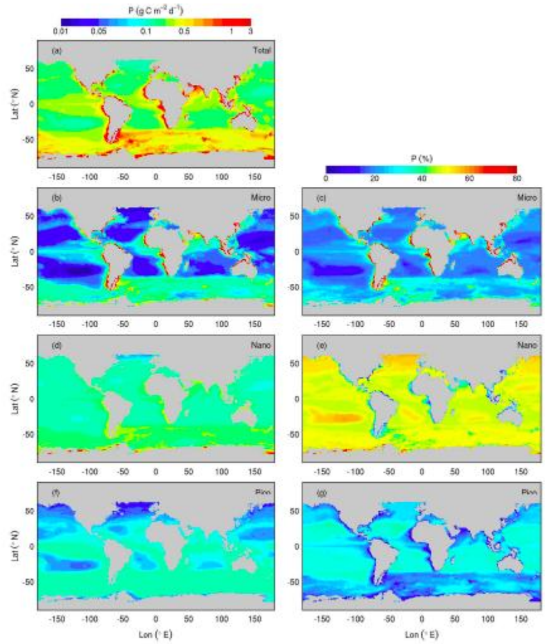
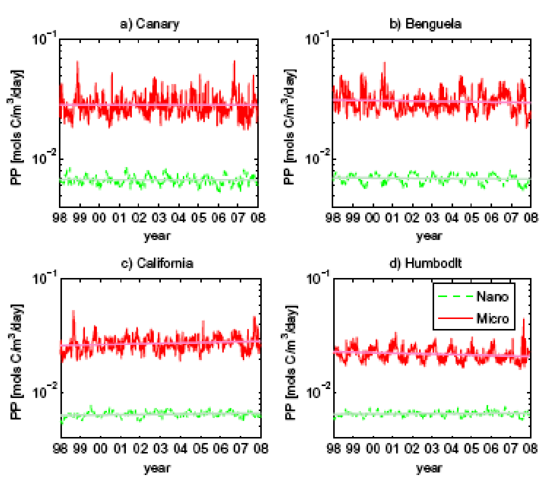


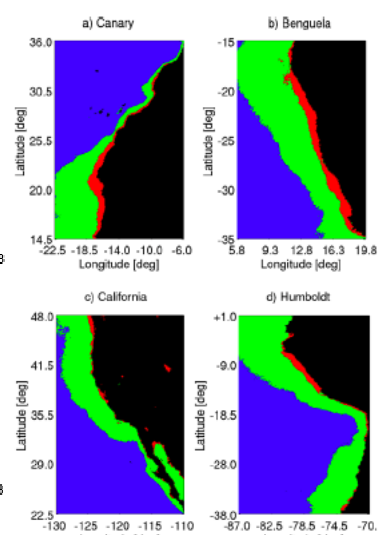
Figure 2. Seasonal climatology (1998–2007) of total and phytoplankton class-specific primary production for the December–February period (boreal winter/austral summer). The left-hand panels show the primary production in absolute units of g C m^{-2} d^{-1}, and the right-hand panels show the percent contribution of class-specific production to total primary production.

Size-based primary prodcution (note that coastal waters were excluded)

Uitz et al. 2010, GBC 24: GB3016

Size-based NPP, Upwelling Only





Hirata et al. Prog. Oceanogr. 83: 393-397

Does it Matter?

Saba et al., 2011 (Biogeosciences, 8, 489-503)

- Tested 21 Ocean Color models
- Found that model complexity does NOT increase skill
- Most models did reasonably well globally

Largest errors associated with CHL (35%) and the in situ NPP data (36%)

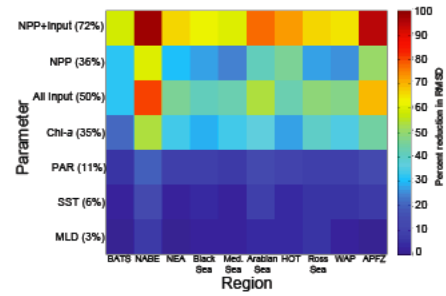


Fig. 5. Reduction in RMSD at each region based on uncertainties in individual input parameters, all input parameters, NPP measurements, and both the input parameters and NPP measurements. Values in parentheses are mean reductions in RMSD across all regions.

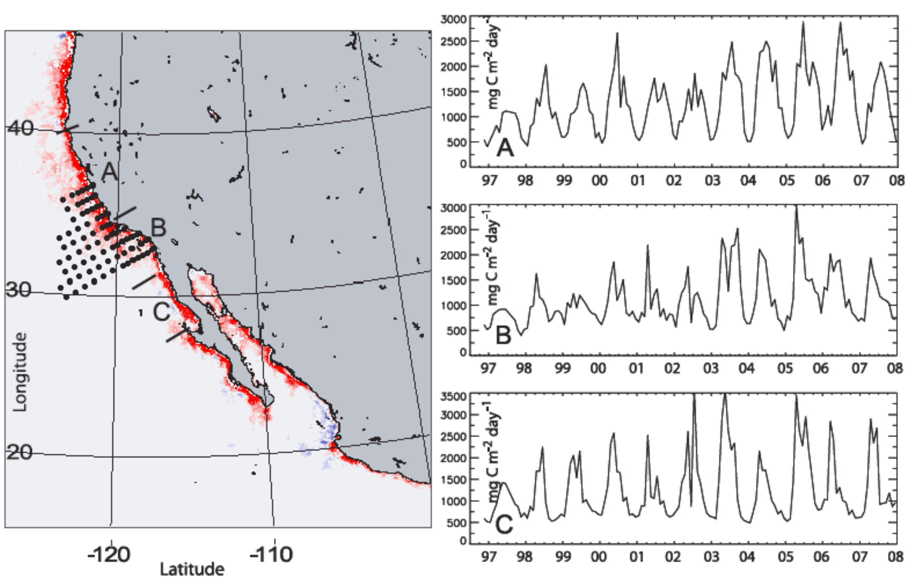
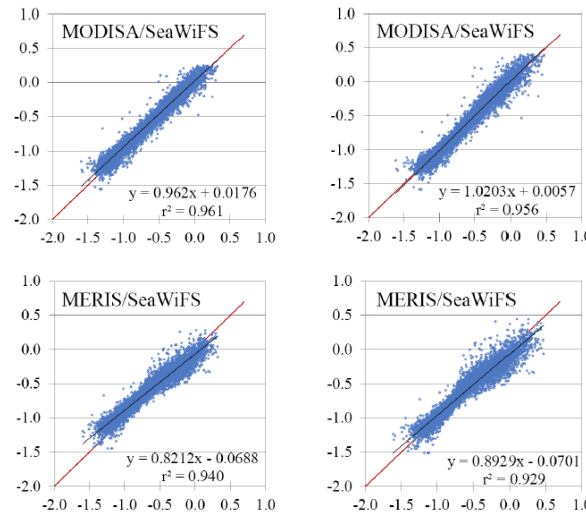


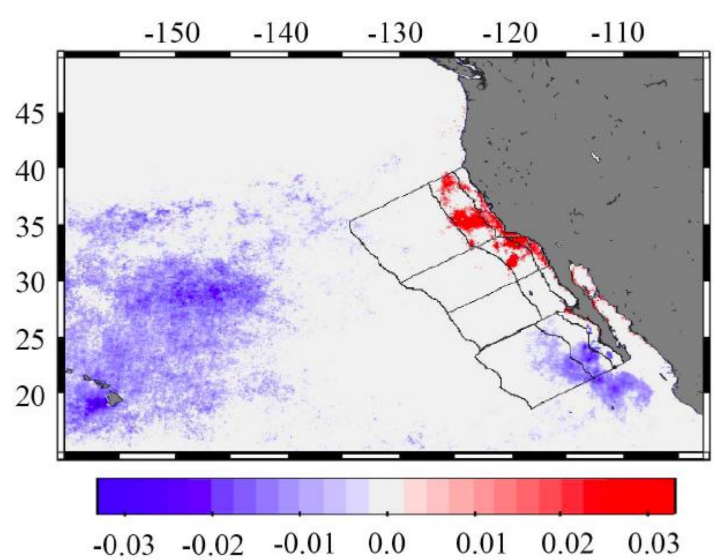
Figure 4. Map of the change in annual maximum primary production (calculated with the VGPM-CAL algorithm) during last 11 years (1997–2007). Red areas show significant increase detected by the Sen slope, a few blue areas have had significant decrease, and light gray areas have no detectable trend. The grid of the CalCOFI stations with in situ NPP measurements is shown as black filled circles. (right) Monthly time series of NPP in 50 km coastal strip off (left) Central California (area A), Southern California (area B), and Northern Baja California (area C).

Start by fixing Chlorophyll

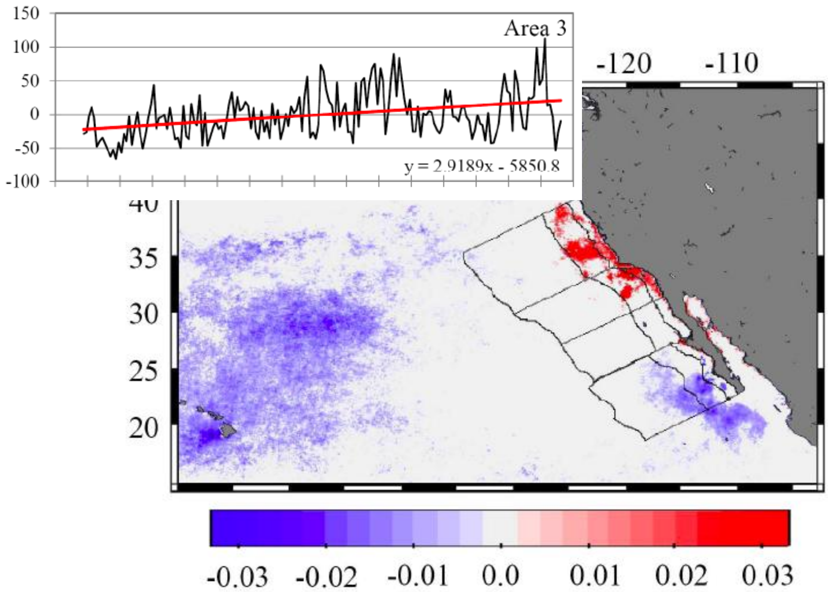
~10,500 matchups from the California Current used to create an optimized band-ratio algorithm for multiple sensors



Chlorophyll trends, 1996-2011



Chlorophyll trends, 1996-2011



Summary

- Satellite-based productivity models are readily available—depending on your region, some do better than others but there is no “perfect” model
- Several models exist that can partition NPP into size classes or Phytoplankton Functional Types
- The largest errors are due to Chlorophyll and the NPP matchup data sets