Floats and Boats: Rectifying productivity results across methods, space, and time

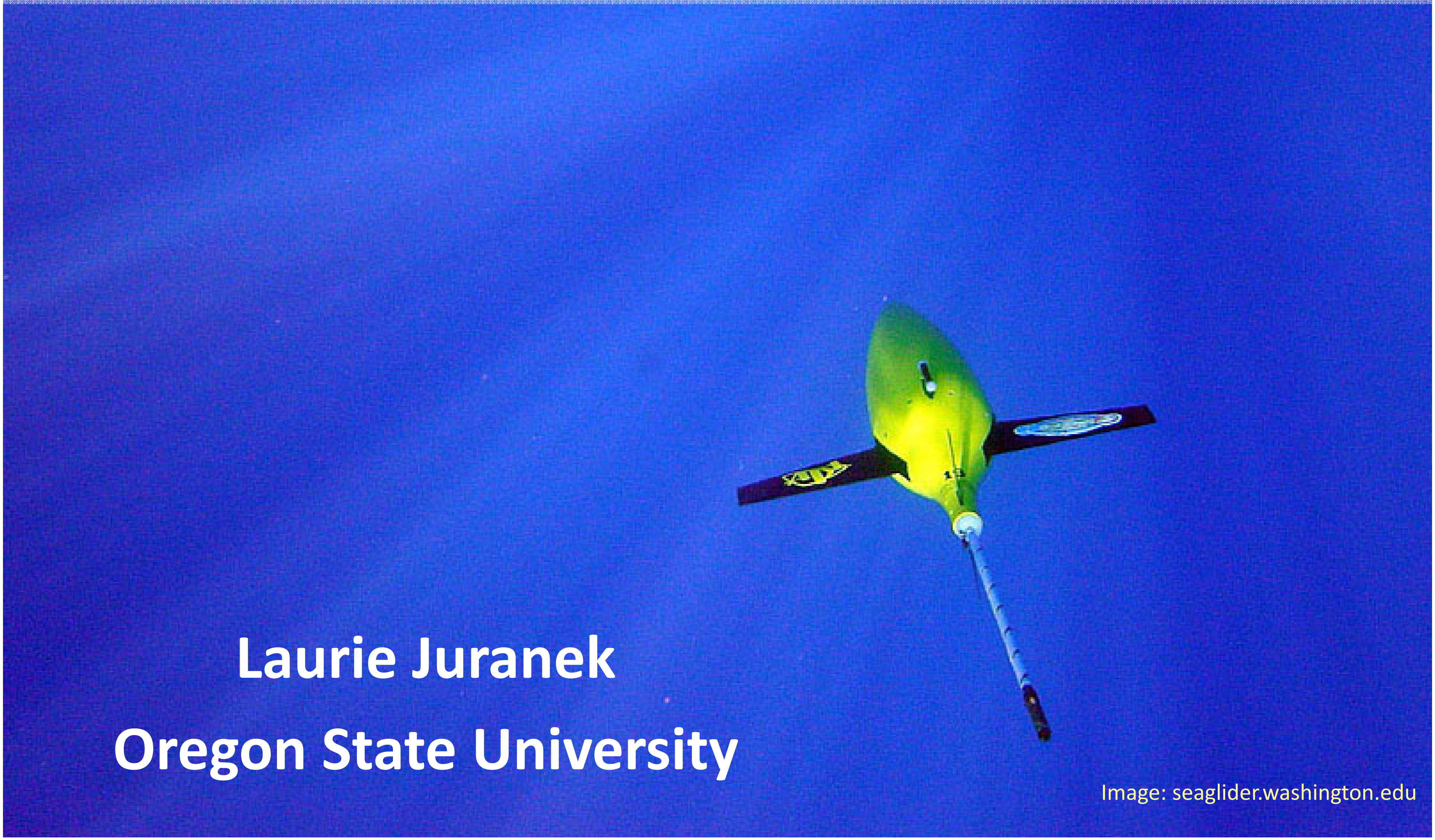

Image: seaglider.washington.edu

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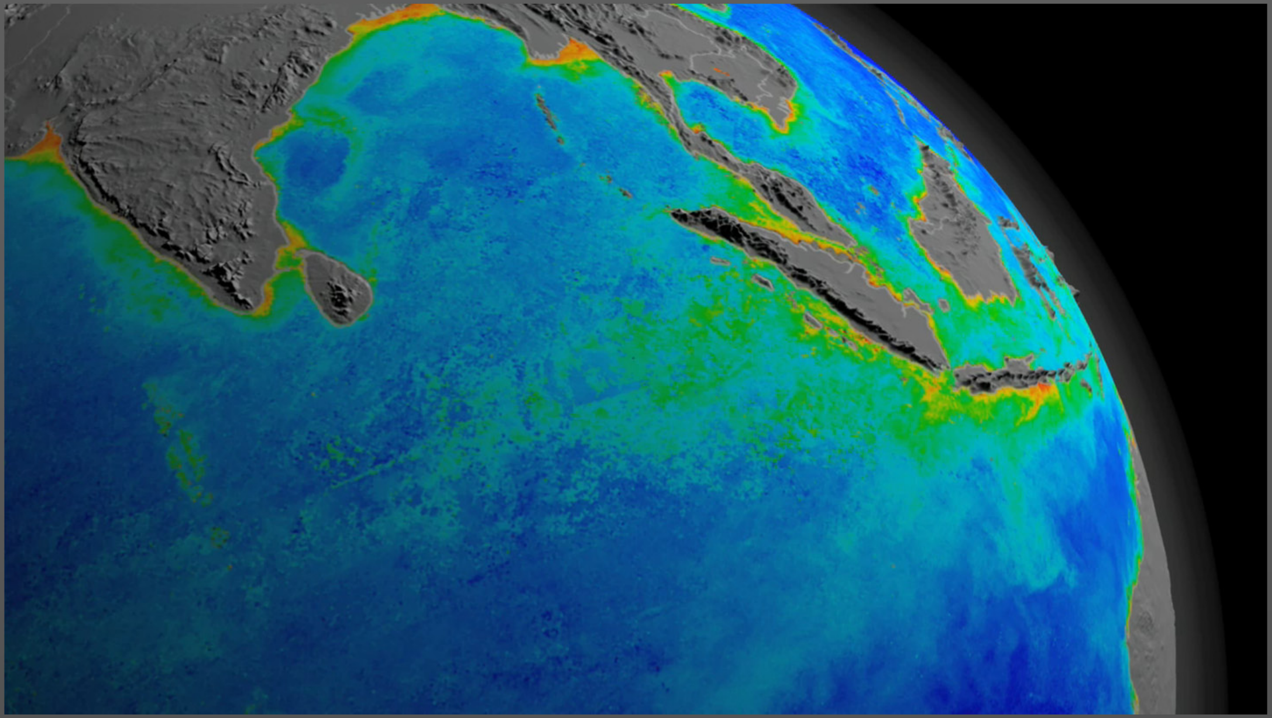
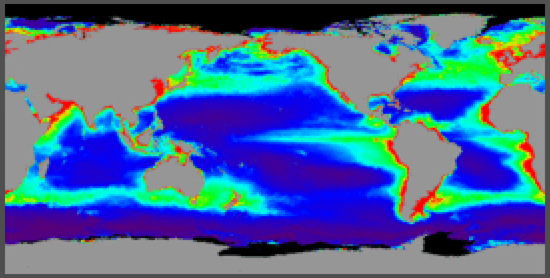
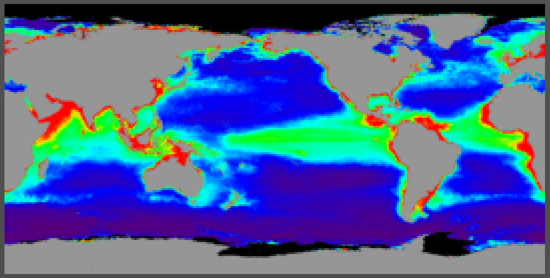
Why even measure productivity?



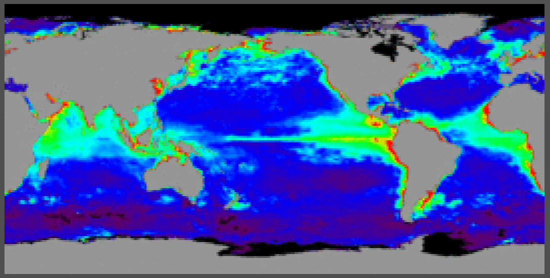
NASA/GSFC: https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=3387



VGPM

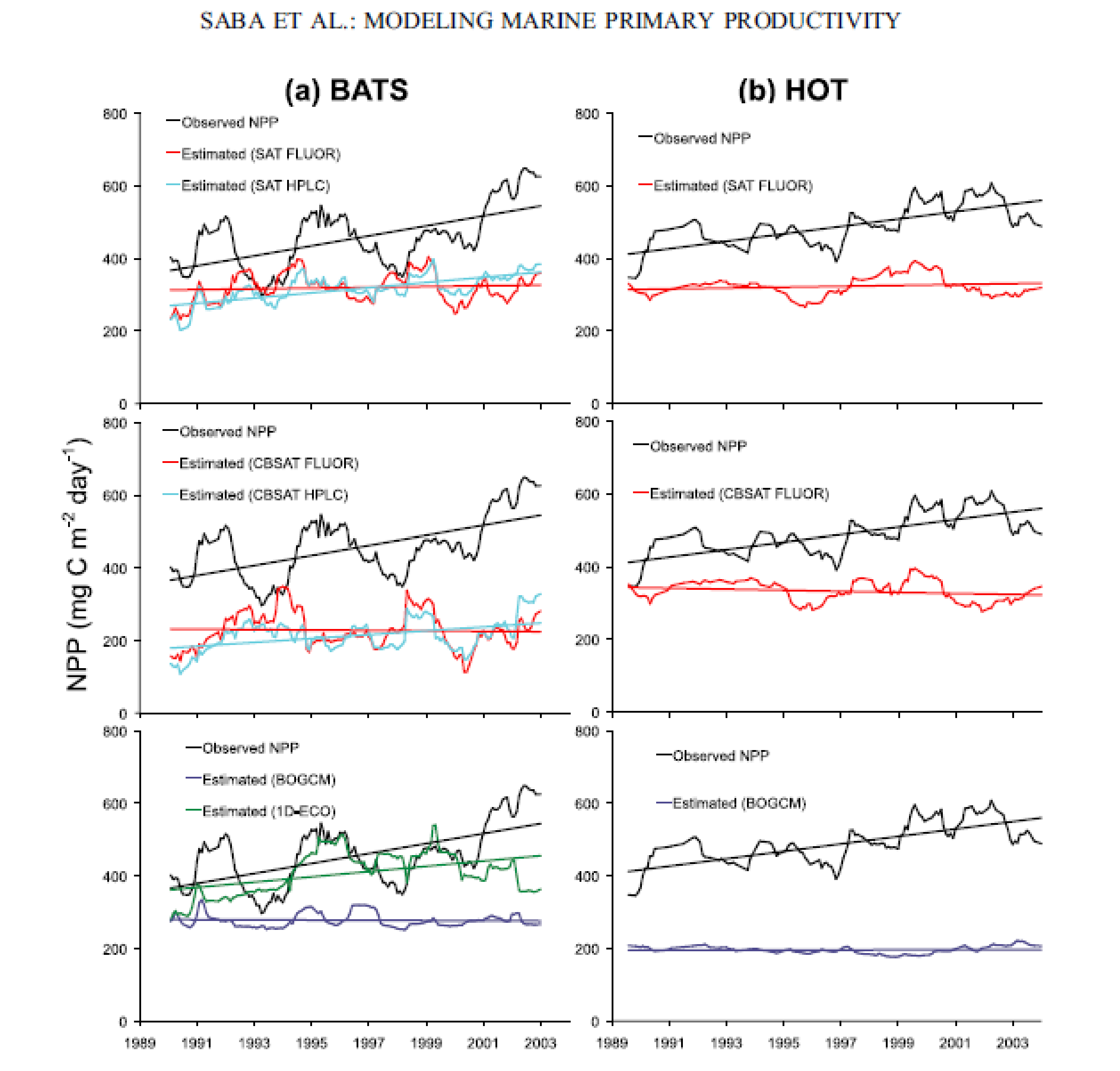


VGPM-Eppley



CbPM

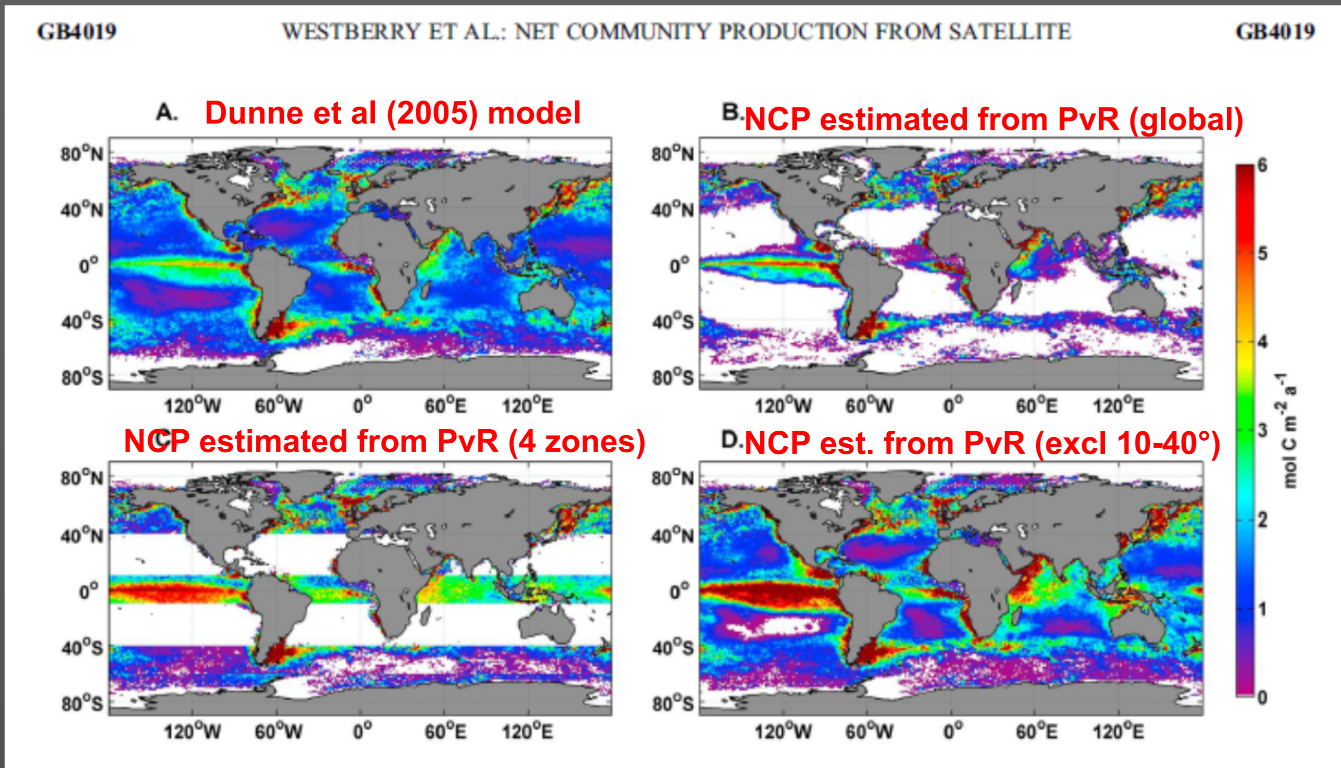
We need field data to constrain/validate model-based observations



most models significantly underestimate mean productivity rate and its variability at HOT and BATS, and most fail to detect multi-decadal trends

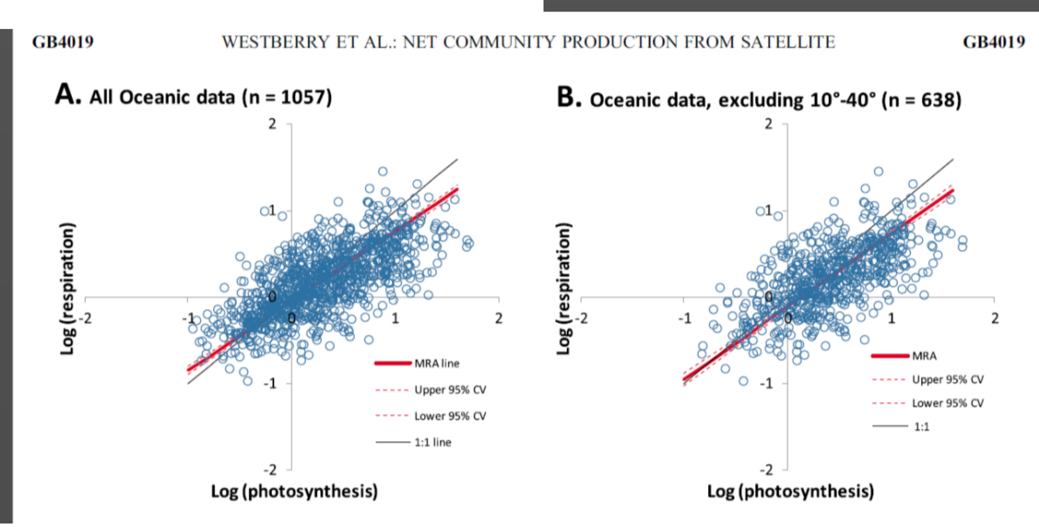
Saba et al., 2010

But what data are most appropriate for validation/calibration?



Need to omit all bottle data from 10-40° in order to get a realistic prediction of carbon export !

Westberry et al (2012) say likely an underestimation of P rather than overestimation of R.

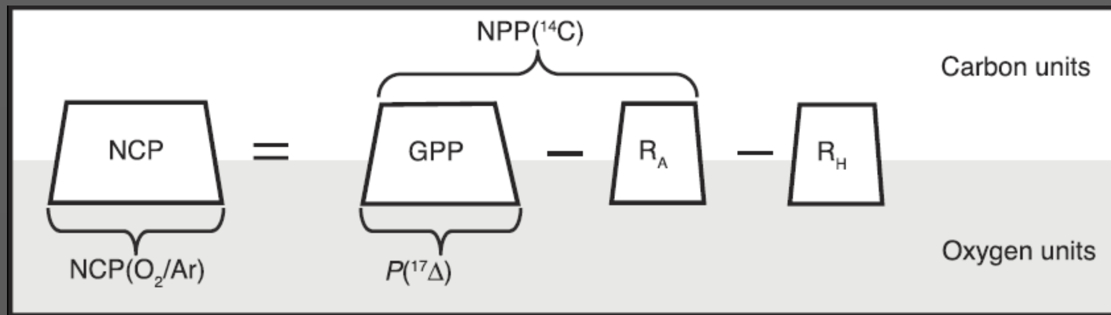


We have several ways of measuring productivity, and many results disagree.

Options:

A. **Pick your favorite method, ignore all others**
B. **Pick your favorite method, attribute differences in others to method artifacts, space, or time differences**
C. **Use the unique traits of each method to contribute to a holistic view of productivity**

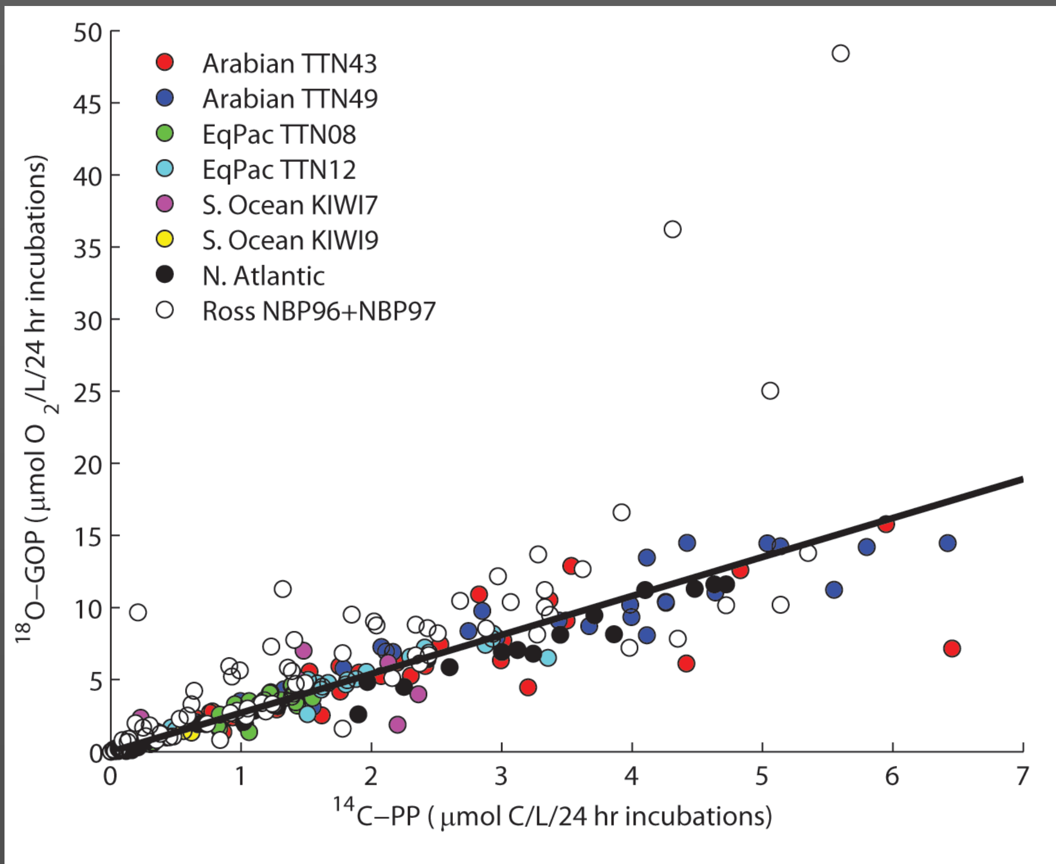
Step 1: be clear about what we are (are not) measuring…



Nicholson et al., 2012

- (Gross or Net) Primary Production
  - Incubation-based approaches (^{14}C NPP, ^{18}O-GPP, O_2 light/dark)
  - In situ approaches (O_2 isotope budgets)
- Net Community Production (NCP)
  - incubation-based approaches (light/dark O_2)
  - in situ approaches (O_2/Ar)
- Annual NCP (ANCP)
  - geochemical budgets (nutrients, carbon, oxygen)

Step 2: Evaluate differences in terms of potential physiological mechanisms



Juranek and Quay, 2013

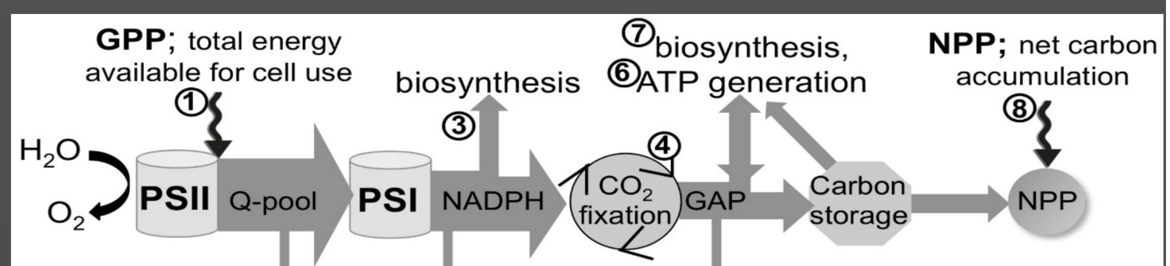
If we look at concurrent GOP and ^{14}C-PP in bottles:

$$GOP = 2.7*(^{14}C\text{-}PP)_{24hr}$$

(where GOP is mol O_2 and ^{14}C-PP is mol C)

O_2 evolution and C-fixation are decoupled by:

1) Light-dependent respiration
2) nutrient assimilation
3) Use of energy/reductant for cell metabolism, and short-term turnover of fixed carbon



courtesy K. Halsey

What might explain additional variability in GOP:NPP?

Table 1 Summary of previously published comparisons of concurrent mixed-layer integrated $^{17}\Delta$-GOP (mol O_2 m^{-2} day^{-1}), ^{18}O-GOP (mol O_2 m^{-2} day^{-1}), ΔO_2-GOP (light + dark bottle, mol O_2 m^{-2} day^{-1}), and ^{14}C-PP (mol C m^{-2} day^{-1})

Location	$^{17}\Delta$-GOP/ ^{18}O-GOP	$^{17}\Delta$-GOP/ ΔO_2-GOP	$^{17}\Delta$-GOP/^{14}C-PP	^{18}O-GOP/^{14}C-PP	^{14}C-PP incubation length (h)	Reference(s)
Global (all JGOFS sites)	—	—	—	2.7[a] 2.0[a]	24 12	Bender et al. 1999, 2000; Laws et al 2000b; Dickson & Orchardo 2001; Marra 2002
Subtropical Pacific (HOT)	1.9 ± 0.9[b]	—	3.3 ± 2.0[b]	1.8 ± 0.4[b]	12	Juranek & Quay 2005
Subtropical Pacific (HOT)	1.2 ± 0.7 (winter) 1.4 ± 0.6 (summer)	—	2.2 (winter) 2.7 (summer)	1.8 ± 0.4[c] (winter) 2.0 ± 0.5[c] (summer)	12	Quay et al. 2010
Subtropical Atlantic (BATS)	—	—	3.5 (spring) 7.9 (late summer)	—	12	Luz & Barkan 2009
Equatorial Pacific	—	—	8.2 ± 4.0 (WEP) 3.1 ± 2.8 (CEP)	—	24	Stanley et al. 2010
Southern Ocean	—	—	4.2 ± 2.5	—	24	Hamme et al. 2012
Southern California Bight	—	—	5.5 ± 0.4[d]	—	6 (scaled to 24)[d]	Munro et al. 2012
Sagami Bay	1.0 ± 0.2	1.8 ± 0.5	—	—	—	Sarma et al. 2005, 2006
Celtic Sea	—	—	—	4.5 ± 1.2	24	Robinson et al. 2009
Sea of Galilee	1.0 ± 0.1	—	—	—	—	Luz & Barkan 2000
Lake Kinneret	—	—	—	1.9 (nonbloom)[e] 7.6 (bloom)[e]	3 (scaled to 24)[e]	Luz et al. 2002

(in situ budget:bottles)

(bottles:bottles)

Juranek and Quay, 2013

Bottle-based rates GOP:NPP is 2-4(ish), with some exceptions

Much more variability in budget:bottle ratio

Resource allocation to understand variability in gross/net PP

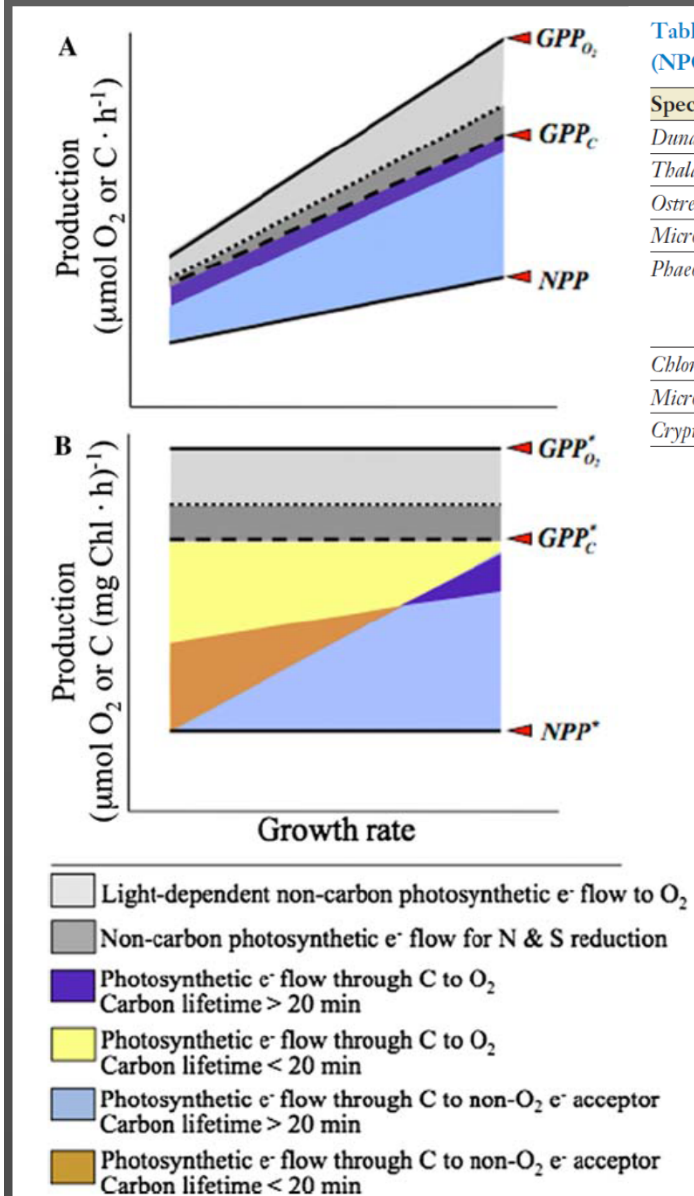
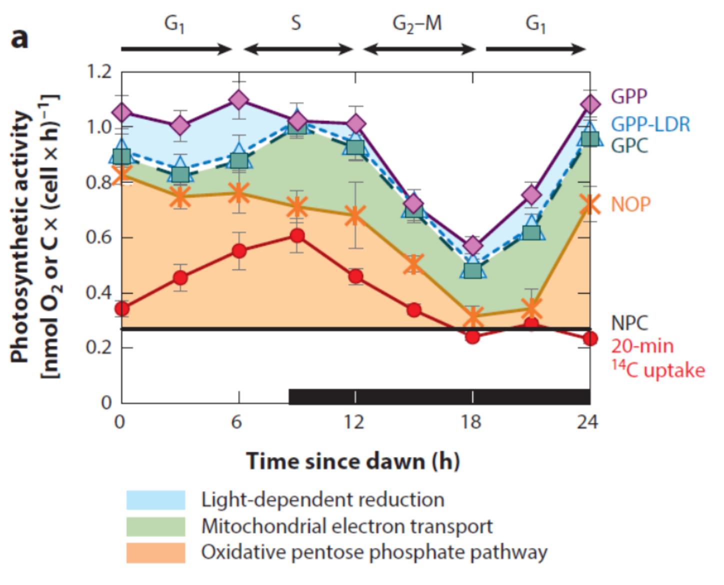


Table 1 Gross-to-net energy conversion efficiencies [ratios of gross primary production (GPP) to net carbon production (NPC)] measured in different species under various growth conditions

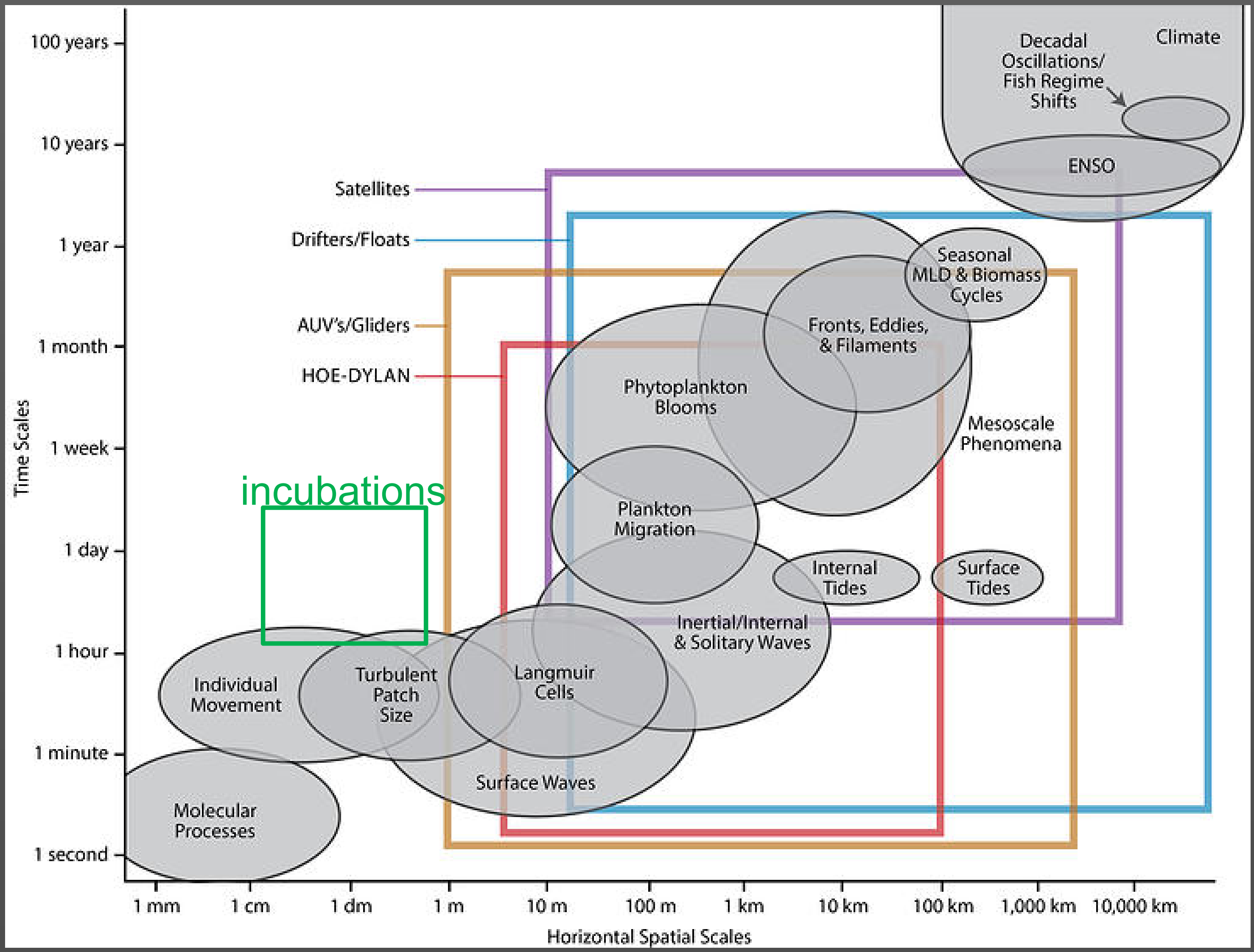
Species	Taxonomic class	Growth condition	GPP:NPC	Reference
Dunaliella tertiolecta	Chlorophyceae	Nitrogen limited	3.3	Halsey et al. 2010
Thalassiosira weissflogii	Coscinodiscophyceae	Nitrogen limited	3.5	Halsey et al. 2013
Ostreococcus tauri	Prasinophyceae	Nitrogen limited	3.3	Halsey et al. 2014
Micromonas pusilla	Prasinophyceae	Nitrogen limited	1.8–2.7	Halsey et al. 2014
Phaeodactylum tricornutum	Bacillariophyceae	Dynamic light	1.2–2.8	Wagner et al. 2006
		Nitrogen limited and dynamic light	4.0–7.0	Jakob et al. 2007
Chlorella vulgaris	Trebouxiophyceae	Dynamic light	3.0–3.1	Wagner et al. 2006
Microcystis aeruginosa	Cyanobacteria	Dynamic light	3.2	Kunath et al. 2012
Cryptomonas ovata	Cryptophyceae	Dynamic light	6.4	Kunath et al. 2012



Take home: resource allocation can vary due to growth rate, cell cycle, and taxonomic adaptation.

Halsey et al., 2010; Halsey and Jones, 2015

Step 3: Consider the space and timescales we're observing and work to bridge gaps



Wilson and Karl, 2013

Bridging timescales and rates with new approaches

Table 1. *Prior* and *Diel* Rates at Station ALOHA

Prior-NCP

Day[a]	MLD[b] (m)	kw^c ($m\ d^{-1}$)	$\Delta(O_2/Ar)^b$ (%)	$[O_2]_{eq}{}^b$ ($\mu mol\ L^{-1}$)	*Prior*-NCP[d] ($mmol\ m^{-2}\ d^{-1}$)	*Prior*-NCP[e] ($mmol\ m^{-2}\ d^{-1}$)
13–14	60 ± 5	4.4	0.82 ± 0.03	214.6 ± 0.1	7.9 ± 0.3	7.9 ± 0.3
14–15	45 ± 2	5.0	0.74 ± 0.03	213. 8 ± 0.3	7.8 ± 0.4	7.8 ± 0.4
17–18	104 ± 2	6.8	0.58 ± 0.03	215.5 ± 0.2	8.5 ± 0.4	12.3 ± 0.4
19–20	100 ± 3	6.8	0.59 ± 0.04	215.4 ± 0.1	8.7 ± 0.6	12.5 ± 0.6
20–21	99 ± 1	6.9	0.71 ± 0.03	215.6 ± 0.1	10.6 ± 0.4	14.5 ± 0.4
21–22	92 ± 4	7.0	0.65 ± 0.02	215.5 ± 0.1	9.8 ± 0.3	13.6 ± 0.3
22–23	86 ± 3	7.0	0.67 ± 0.03	215.7 ± 0.1	10.1 ± 0.4	13.8 ± 0.4

Diel Rate Estimates

Day[a]	MLD[b] (m)	$d[O_2]_{bio}/dt^f$ ($mmol\ m^{-3}\ d^{-1}$)	$F_{GE}{}^g$ ($mmol\ m^{-3}\ d^{-1}$)	*Diel*-CR ($mmol\ m^{-3}\ d^{-1}$)	*Diel*-GOP ($mmol\ m^{-3}\ d^{-1}$)	*Diel*-NOP ($mmol\ m^{-3}\ d^{-1}$)
13	60 ± 8	0.83	0.09		1.20 ± 0.17	−0.28 ± 0.17
13–14	53 ± 6	−1.56	0.07	−1.48 ± 0.19		
14	47 ± 2	1.19	0.19		1.20 ± 0.39	0.18 ± 0.39
14–15	40 ± 2	−0.84	0.29	−0.55 ± 0.37		
17	105 ± 2	0.87	0.07		1.06 ± 0.25	−0.19 ± 0.25
17–18	104 ± 2	−1.31	0.06	−1.25 ± 0.24		
20	103 ± 3	1.15	0.09		1.31 ± 0.30	0.42 ± 0.30
20–21	94 ± 3	1.00	0.11	−0.89 ± 0.21		
21	95 ± 6	0.97	0.08		1.00 ± 0.27	−0.03 ± 0.27
21–22	85 ± 2	−1.23	0.08	−1.16 ± 0.49		
22	90 ± 4	1.34	0.07		1.18 ± 0.34	0.16 ± 0.34
22–23	79 ± 2	−0.96	0.08	−0.88 ± 0.25		
23	83 ± 8	1.84	0.12		1.36 ± 0.35	0.48 ± 0.35
Mean ± SE				−1.04 ± 0.13	1.19 ± 0.05	0.11 ± 0.11

[a]Day in March 2014.
[b]Mean ± standard error (SE) during the 24 h (*Prior*-NCP) or 12 h (Diel Rate Estimates) periods.
[c]Weighted gas transfer velocity, calculated using *Wanninkhof* [2014] wind speed relationship.
[d]*Prior*-NCP before the entrainment correction.
[e]*Prior*-NCP corrected for entrainment.
[f]Rate of change of biological O_2 during the 12 h period considered.
[g]Air-gas exchange correction (second term in equation (4)).

Ferrón et al 2015

Diurnal measurements of O_2/Ar at HOT averaged to yield an estimate of NCP (daily), as well as GPP and R for the observation period

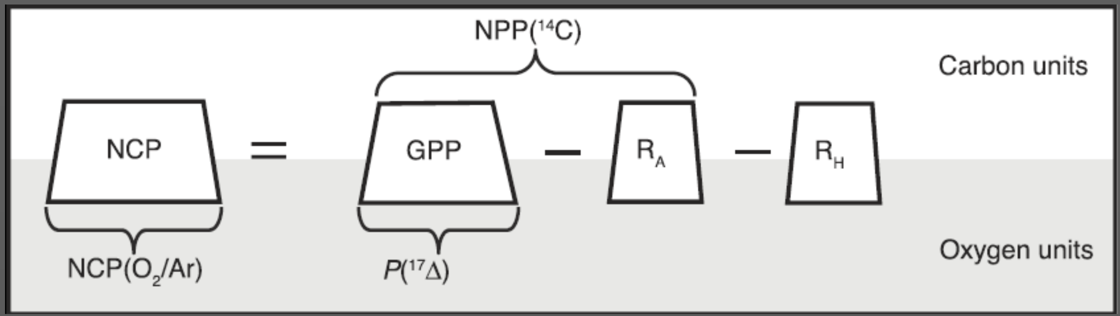
Take home summary:

1. Diel-GPP was close to prior estimates determined via $^{17}\Delta$ tracer, slightly higher than ^{18}O-bottles.

2. Very small variability in Diel-GPP

3. Variability in diel -NOP driven by respiration (at night)

Lets be clear about what we are trying to measure…



Nicholson et al., 2012

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Seaglider diel-O_2 observations at HOT (Nicholson et al., 2015)

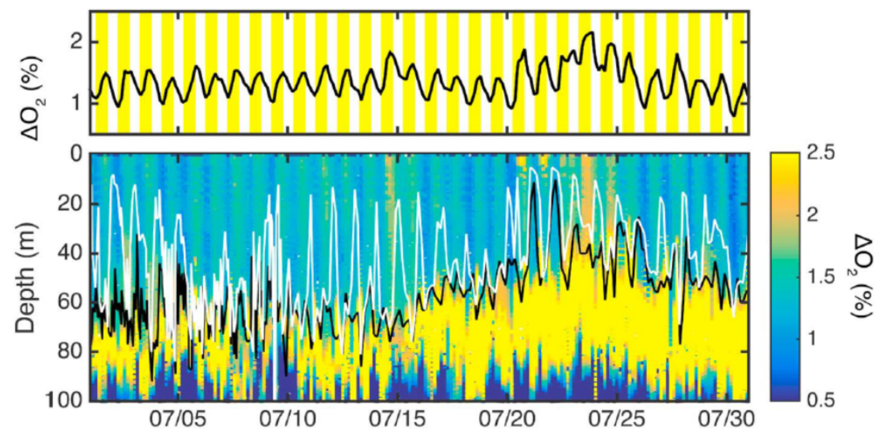
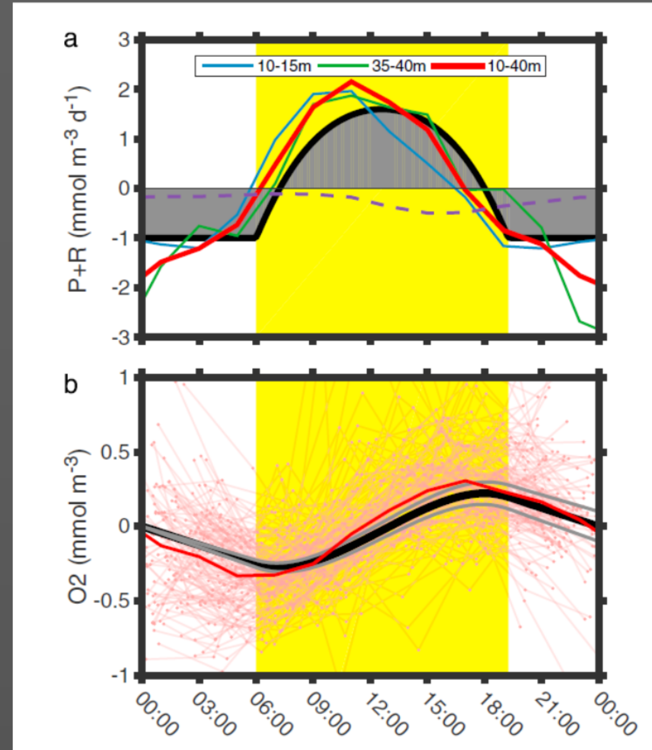
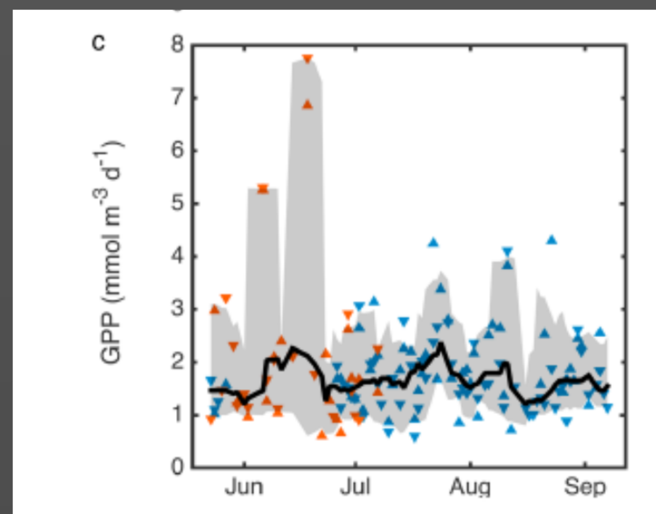


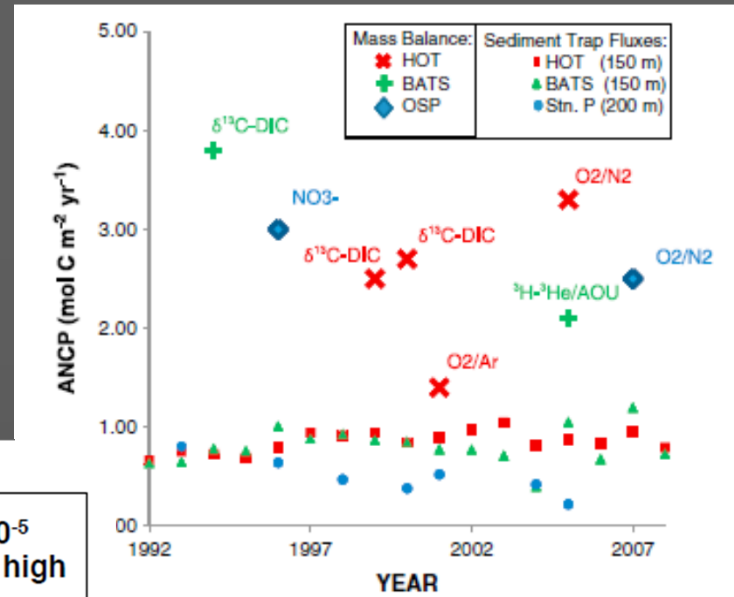
Figure 1. Oxygen saturation anomaly (%) is shown averaged over the upper 40 m (above) and through the upper 100 m (below) for the month of July 2012. Yellow bars (above) show daylight hours. Below, mixed layer depth using a density threshold ($\Delta\sigma_\theta$) of 0.03 kg m^{-3} and 0.125 kg m^{-3} is plotted in white and black, respectively.



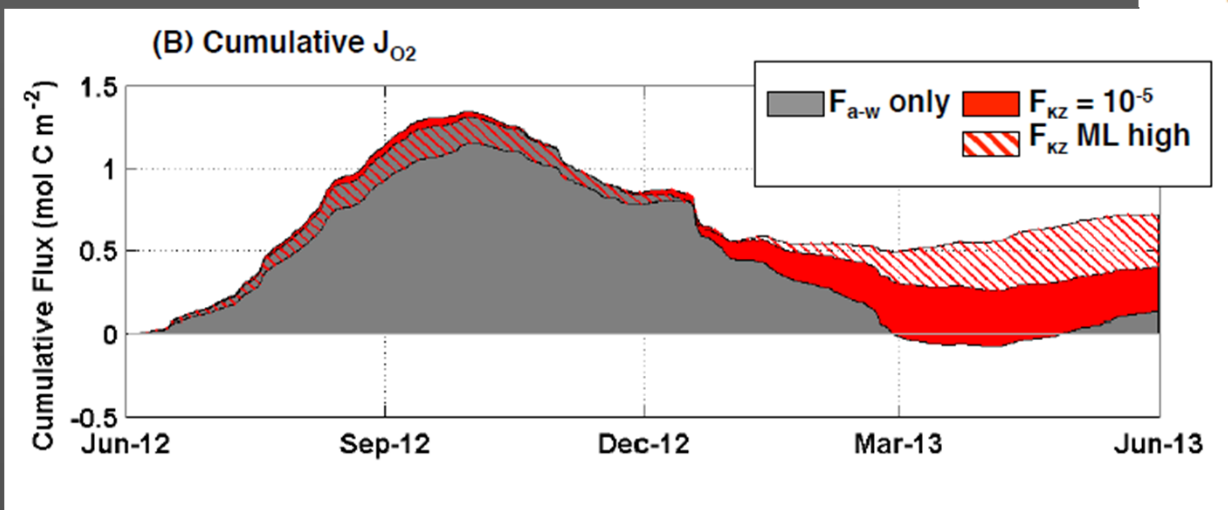
- NOP averaged 1.7 mol m^{-2} yr^{-1}
- GPP-O_2 averaged 1.7 mmol m^{-3} d^{-1}
- GPP:^{14}C-PP ratio of ~3



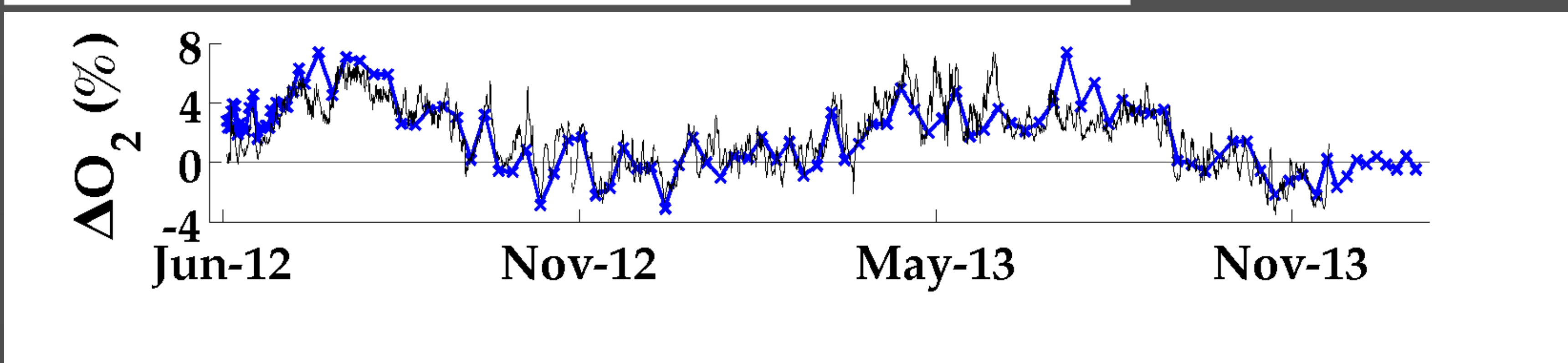
...And one more example (linking seasonal NCP to ANCP with Argo floats at Station P)



Emerson (2014)



Bushinksy and Emerson (in prep)



A few take home points

We are finally starting to develop the tools necessary to evaluate differences in productivity methods in greater detail

- better understanding of potential physiological underpinnings to a variable GOP/NPP ratio
- better understanding of the temporal variability in rate terms (gross and net O_2 production, respiration) and how this influences budget-based approaches

There's more to 'productivity' than ^{14}C! We now have an array of tools that enable us to address questions at various time/space scales; combination of autonomous and ship-based approaches will broaden our perspective of marine productivity