In situ methods to measure Primary Production and Net Community Production

What have we learned?

Time Series Sites

- Time series sites provide:
  - test bed for new PP methods
  - evaluation of the <u>annual</u> carbon budget
  - other relevant characteristics of the system

- How do time series sites bias our thinking about the biological pump?
  - spatial context

In-situ PP and NCP Methods

- Estimate gross primary production (GPP) using triple isotopes (^{18}O:^{17}O:^{16}O) of dissolved O_2
  - O_2 mass and isotope ($^{17}\Delta$) mixed layer budgets

$$Z_{ml}*d(^{17}\Delta\text{-}O_2)/dt = k_{gas}*[O_2]*(^{17}\Delta - {}^{17}\Delta_{eq})/(^{17}\Delta_p - {}^{17}\Delta) + GPP + Mixing$$

  - respiration does not change $^{17}\Delta$

- Estimate net community production (NCP) using ratio of dissolved O_2 and Ar gases (O_2/Ar)
  - combined O_2 and Ar mixed layer budgets

$$Z_{ml}*d(O_2/Ar)/dt = k_{gas}*[O_2]*[(O_2/Ar)/(O_2/Ar)_{sat} -1] + NCP + Mixing$$

  - O_2/Ar insensitive to temperature and bubbles

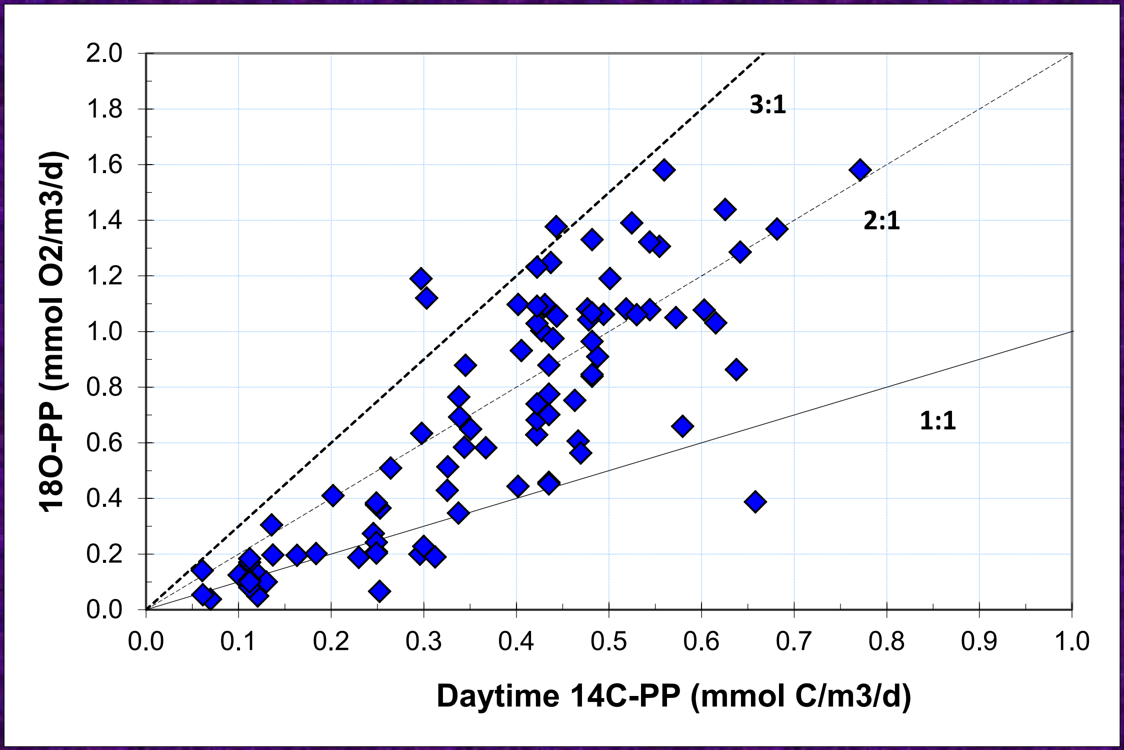
- Estimate NPP and GPP using diurnal cycle in O_2/Ar

In-situ PP and NCP Methods

- Advantages
  - no bottle incubations (biases, time intensive)
  - longer integration time (1-2 weeks)
  - only water sample collection
  - measured continuously underway (O_2/Ar)
  - allow us to evaluate in vitro PP methods

- Disadvantages
  - biases, primarily due to mixing/entrainment and non steady-state conditions
  - substantial uncertainties (±30%)
  - converting production rates of O_2 to C

In vitro ^{18}O-GPP vs ^{14}C-NPP at HOT (23ºN 158º W)



^{18}O-GPP/^{14}C-PP (12hr) = 1.9±0.1 (HOT) (24 months)
-however, depth trend

^{18}O-GPP/^{14}C-PP (24hr) = 2.7±0.2 (JGOFS- Marra, Bender)
(12hr) = 2.0 (JGOFS- Marra, Bender)

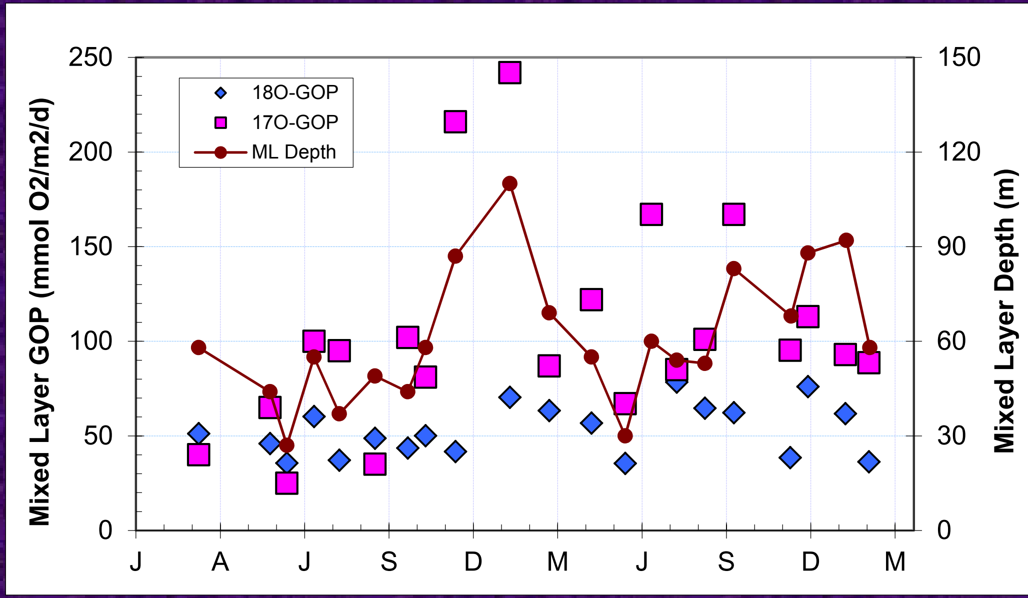
- Use these results to convert from GPP-O_2 to NPP-C production rates

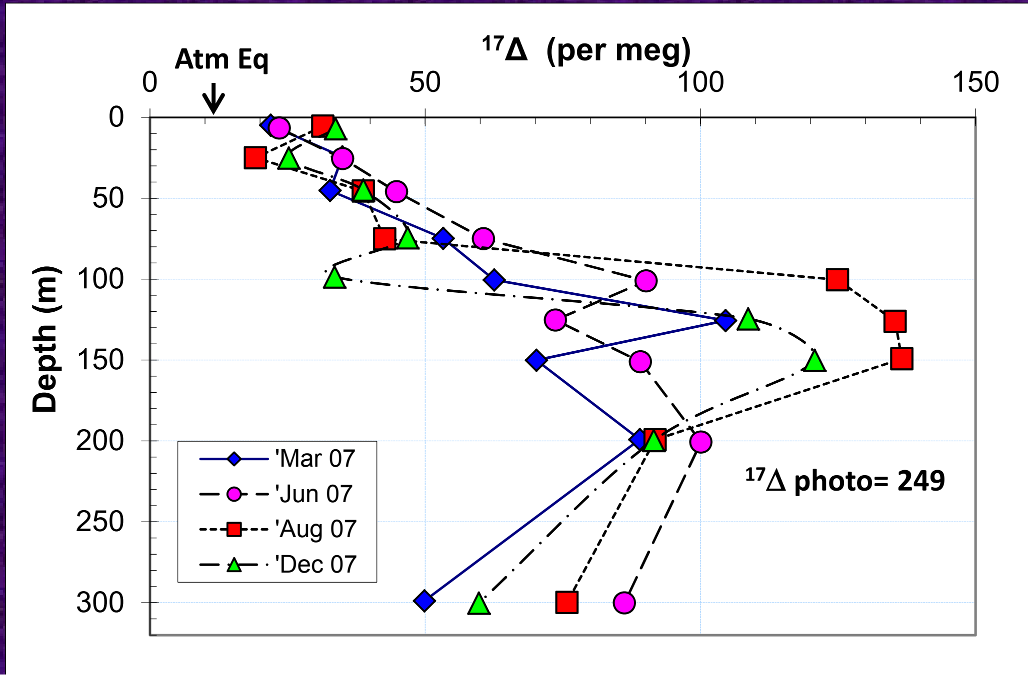
In-situ $^{17}\Delta$-GOP estimates at HOT

- Estimates of $^{17}\Delta$-GOP varied much more than concurrent in vitro ^{18}O-GOP.

- $^{17}\Delta$-GOP significantly overestimated in fall and winter due to entrainment of subsurface water with high $^{17}\Delta$.

- Mixed layer $^{17}\Delta$-GOP budget approach is not always applicable.

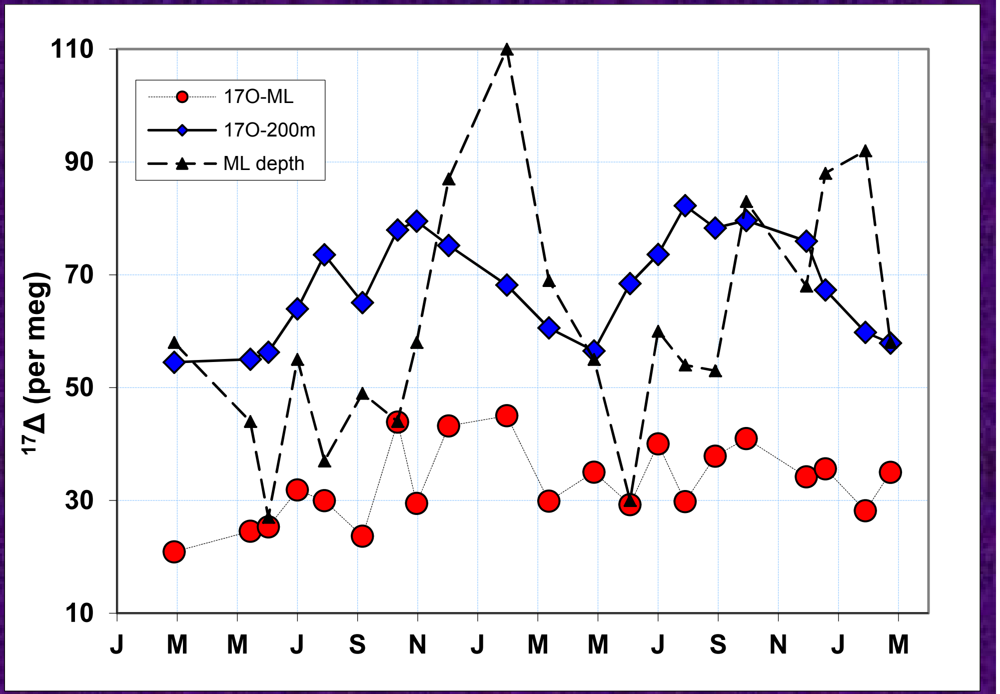




$^{17}\Delta$-GOP using depth integrated $^{17}\Delta$ change

$^{17}\Delta$-GOP$_{PL}$	$^{17}\Delta$-GOP$_{int}$	^{18}O-GOP$_{int}$
	Summer	
136±51	123±44	89±18
	Winter	
140±58	83±42	67±13

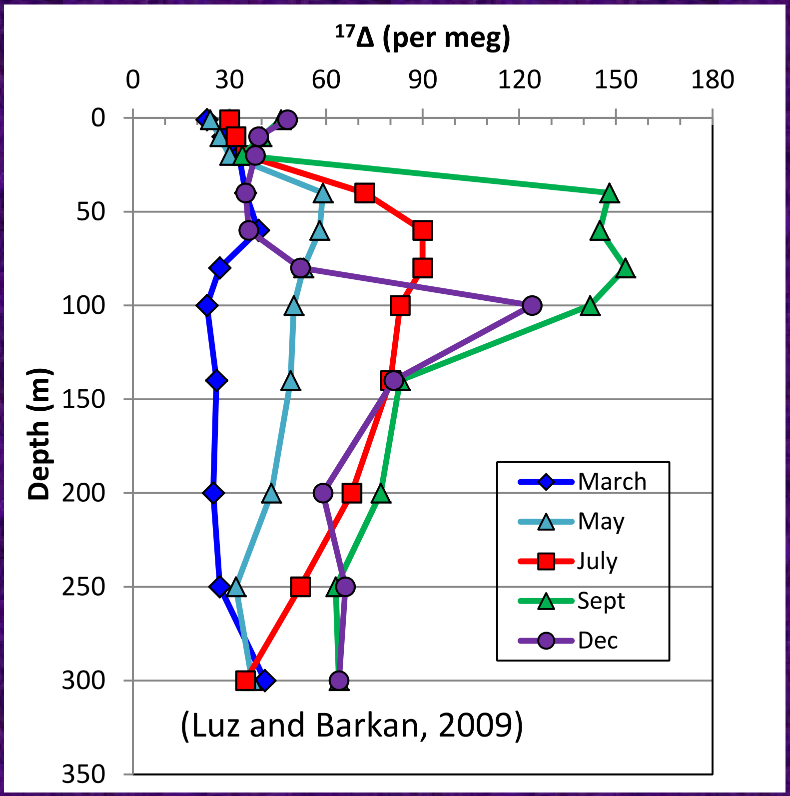
(mmol O_2/m^2/d)



- The steady-state $^{17}\Delta$-GOP estimates equaled integrated 17D-GOP estimates during summer (stratified) but were substantially greater in winter (entrainment).
- Depth-integrated $^{17}\Delta$-GOP (0-200m) are 20-30% higher than depth-integrated bottle ^{18}O-GOP (but within ±40% uncertainty)

Situation at BATS: similar to HOT but different

- Summer $^{17}\Delta$ increase is twice as great and twice as deep compared to HOT.
- Along isopycnal ventilation and mixing affecting $^{17}\Delta$. (and what other properties?)
- Yet, depth integrated $^{17}\Delta$-GOP yields NPP rates about equal to measured ^{14}C-PP.



$^{17}\Delta\text{-GPP}_{140m}/2 = {}^{14}\text{C-PP}_{eqv}$ = 54±21 mmol C/m^2/d (650±250 mg C/m2/d)

$^{14}\text{C-PP}_{meas}$ = 49±11 mmol C/m^2/d (590±130 mg C/m2/d)

$^{17}\Delta$-GOP at Sta PAPA (50ºN 145ºW)

August 2009, 2010, 2012 (Z_{ML}=25m)

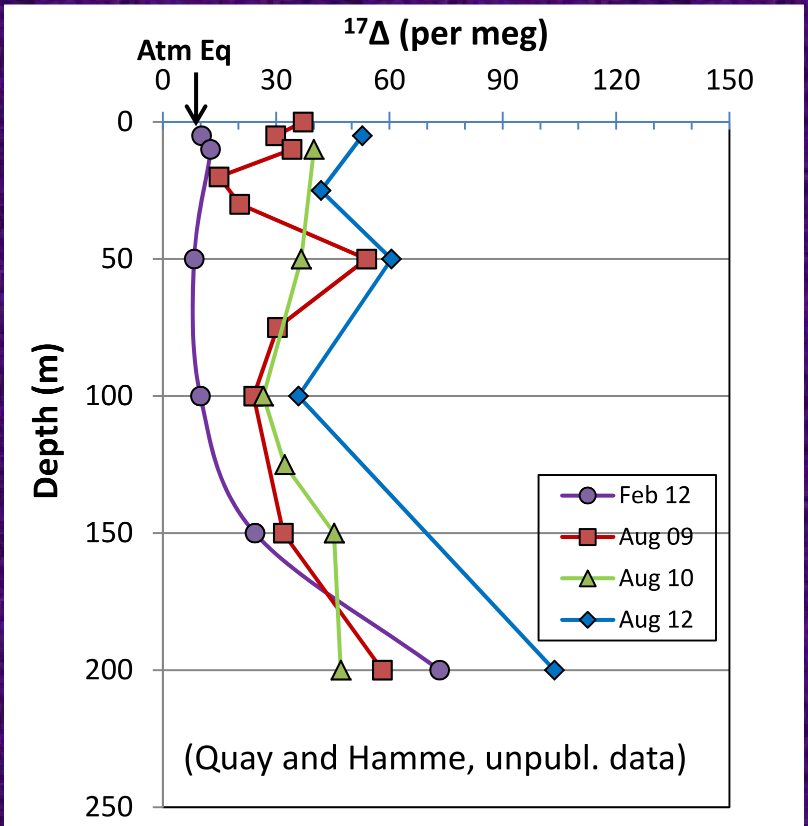
$^{17}\Delta$-GOP = 113±42 mmol $O_2/m^2/d$

^{14}C-PP_{eqv} = 42±16 mmol $C/m^2/d$

^{13}C-PP_{meas} = 28±8 mmol $C/m^2/d$

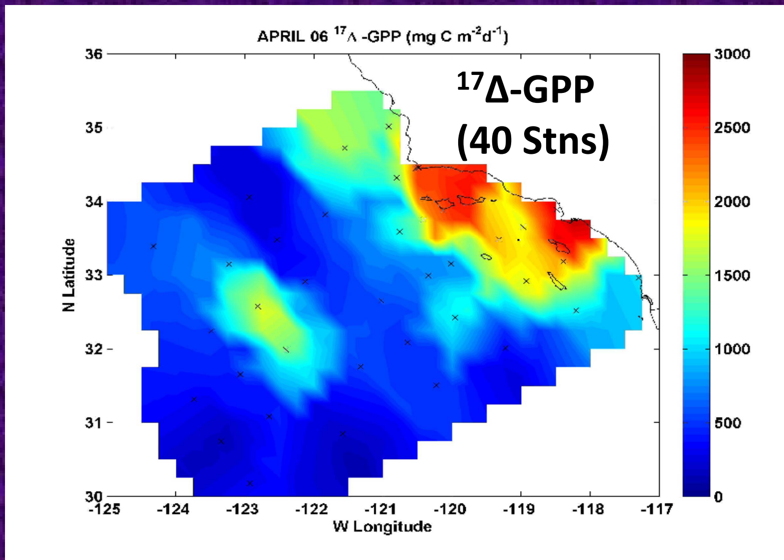
(Giesbrecht et al., 2012)

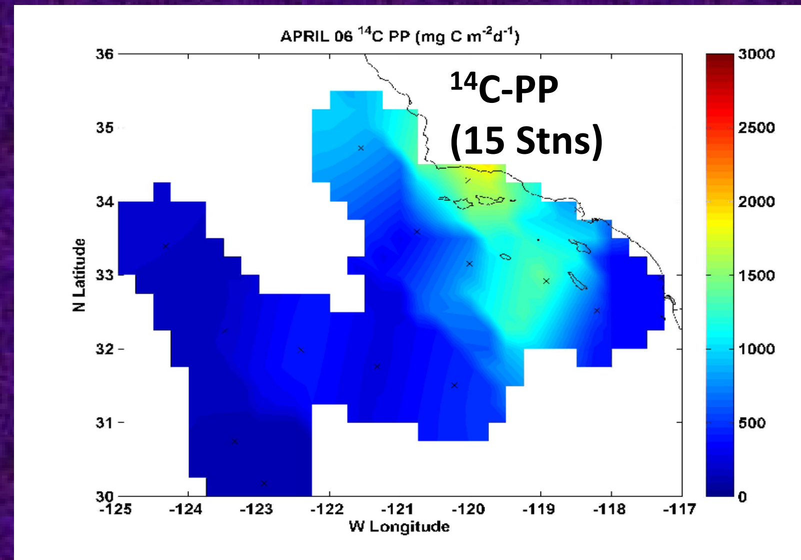
^{14}C-PP_{eqv}/^{14}C-PP_{meas} = 1.3 (PAPA)
= 1.3 (HOT)
= 1.1 (BATS)



- In subpolar (non-N limited) regions the $^{17}\Delta$-GOP mixed layer budget method is less sensitive to entrainment biases.
- In situ PP rates higher than in vitro PP rates. Why?

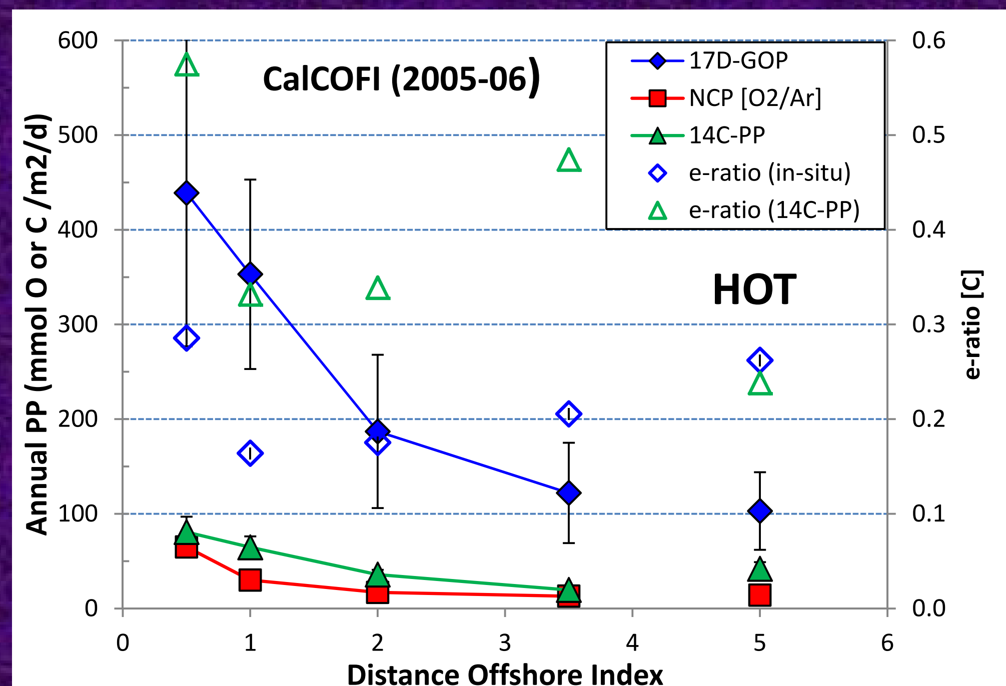
CalCOFI: $^{17}\Delta$-GOP and ^{14}C-PP



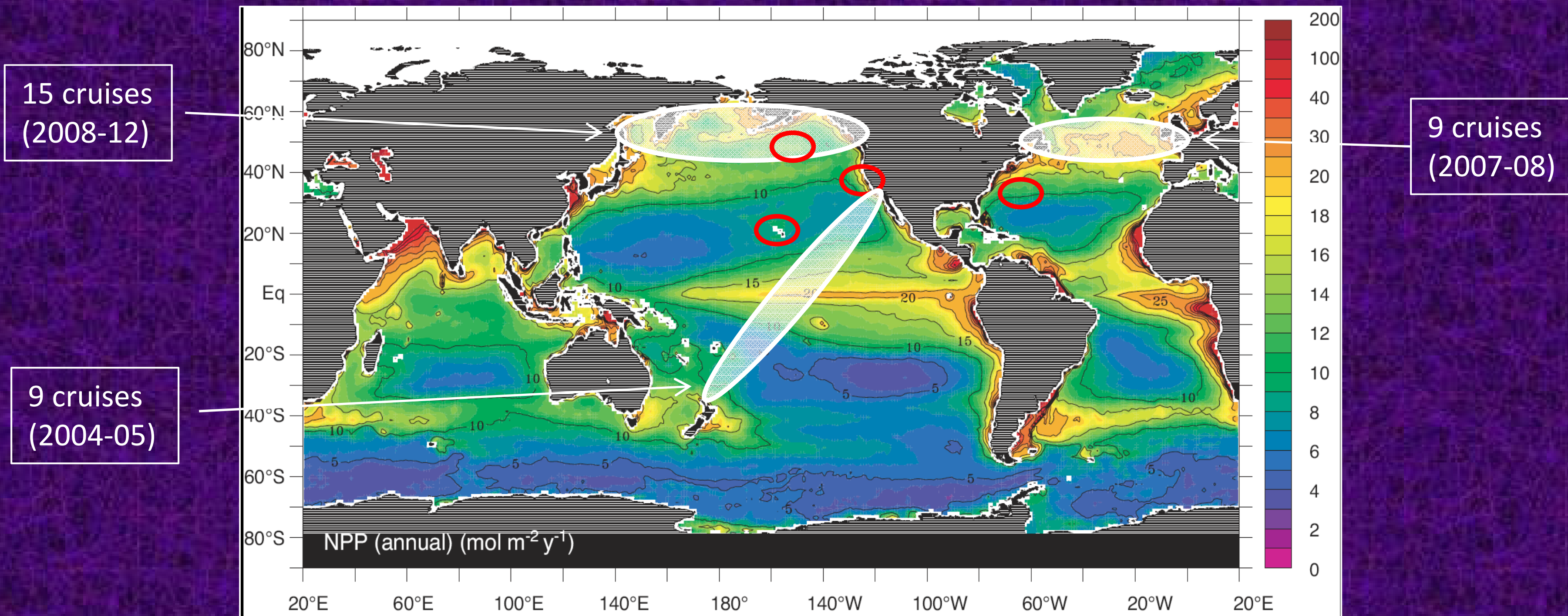


(Dave Munro, L&O, 2013)

- Six cruises 2005-08.
- Better spatial resolution with $^{17}\Delta$-GOP than ^{14}C-PP.
- Offshore PP decrease by 4x.
- Problems with ^{14}C-PP?
- No offshore or productivity trend for in-situ e-ratio (0.20±0.05).



Time Series using Container Ships

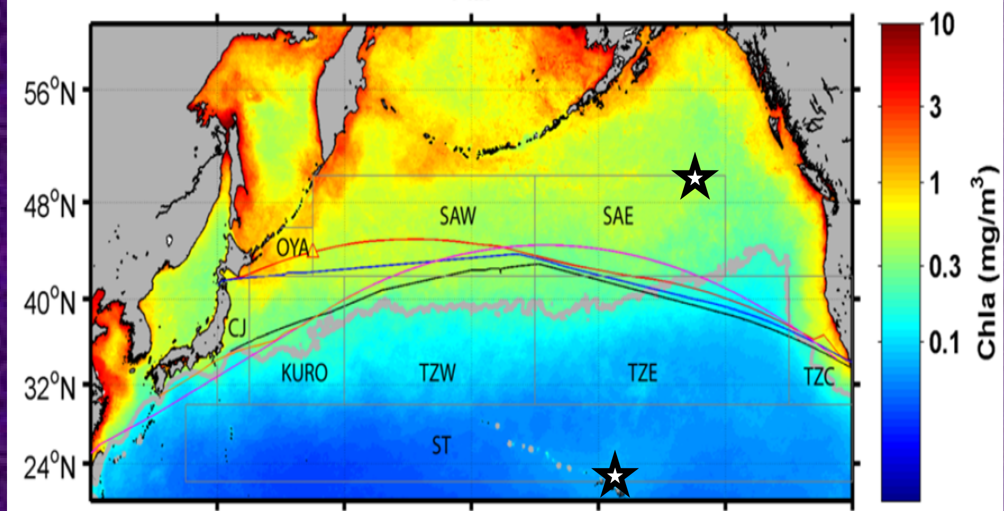


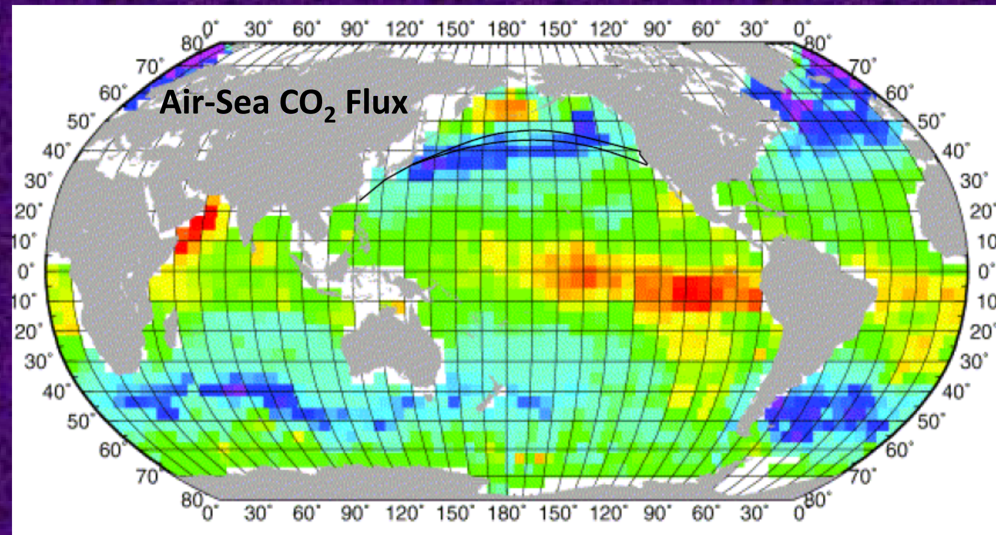
Underway measurements of T, S, pCO_2, O_2, O_2/Ar, nitrate, chlorophyll, (plankton abundance by flow cytometry) in mixed layer along repeated cruise tracks. Discrete samples for $^{17}\Delta$ and calibration.

Time Series: Container Ships

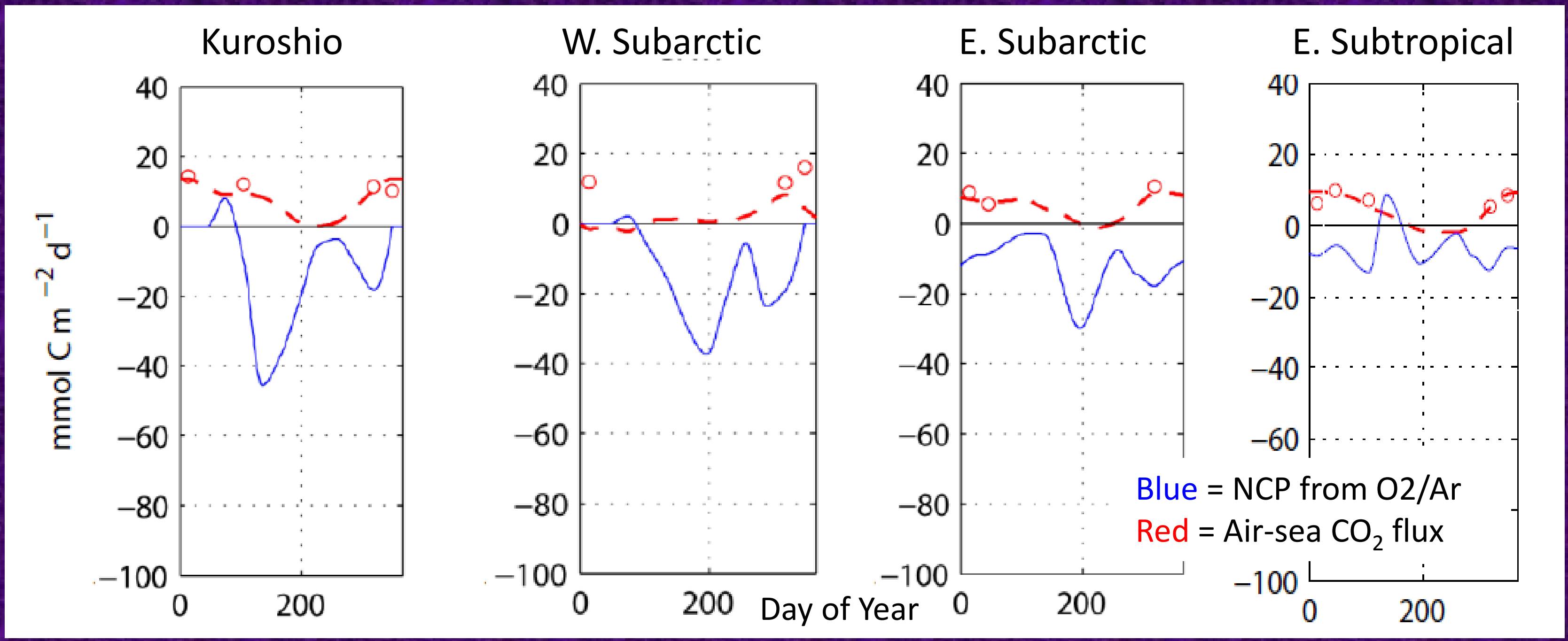
- How does biological pump affect atmospheric CO_2 uptake rate?
- What is the spatial variability of NCP in the region? (How do the locations of time series stations (HOT, PAPA) bias our understanding?)

OOCL Tianjin (15 cruises 2008 to 2012)





Impact of NCP and physical CO_2 supply on annual CO_2 uptake rates



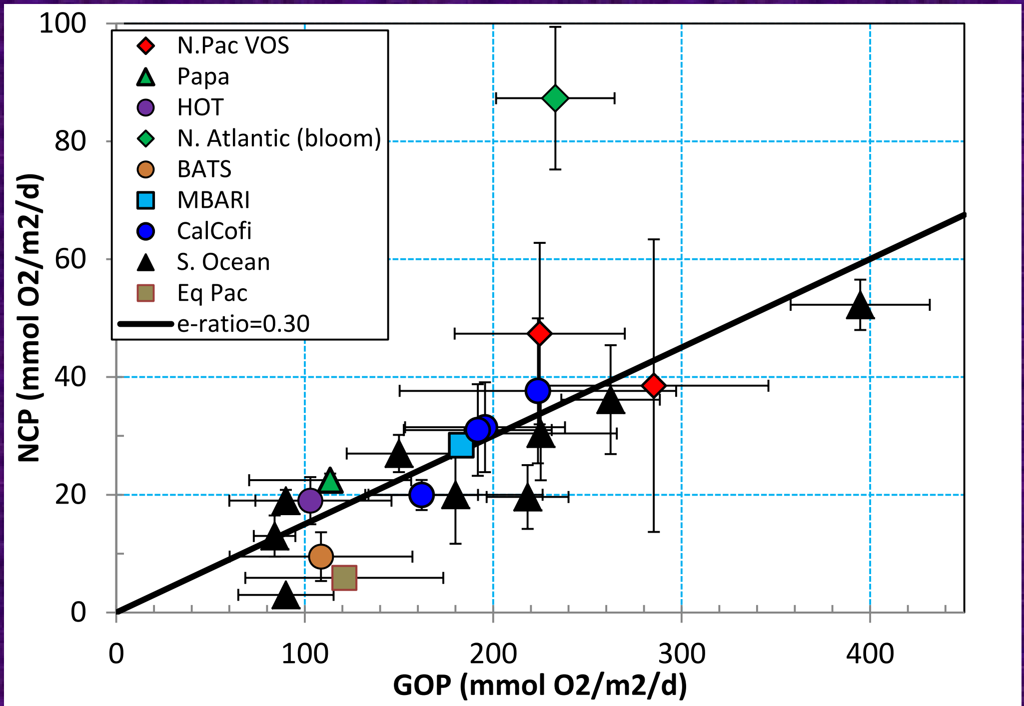
	Kuroshio	W. Subarctic	E. Subarctic	E. Subtropical
NCP (mol C/m^2/yr)	-4.5±3.3	-4.8±2.1	-4.5±1.5	-2.5±1.0
Atmos CO_2 Uptake	+2.7	+0.6	+1.7	+0.9
Phys Supply*	+1.8	+4.2	+2.8	+1.6

In regions of high productivity and high seasonality (e.g., western subarctic N. Pacific and N. Atlantic) deep winter mixed layers reduce the effective annual OC export rate and enhanced physical supply reduce air-sea CO_2 uptake rate. (Deirdre Lockwood, 2013)

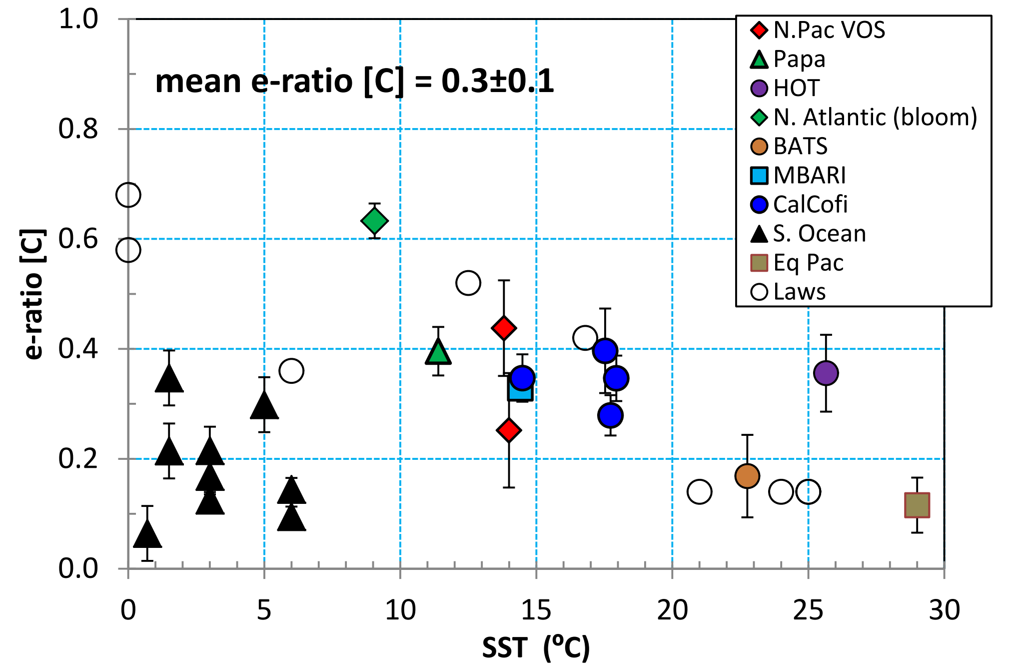
e-ratio in the Ocean

e-ratio(O) = $NCP_{(O2/Ar)}$/ $GPP_{17\Delta}$

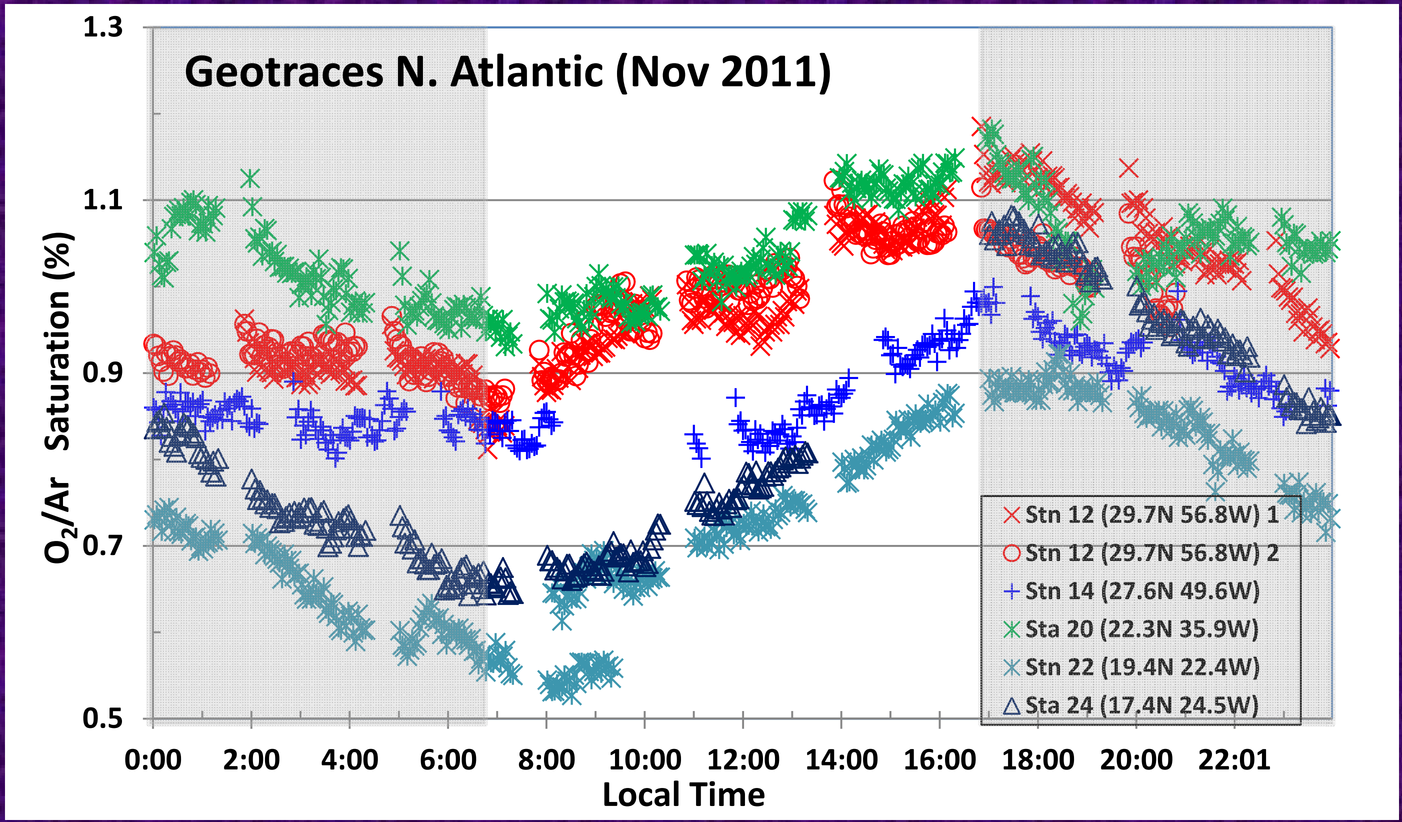
e-ratio(C) = e-ratio(O)*2.7/1.4



- $^{17}\Delta$ and O_2/Ar provide bottle-free estimates of e-ratio
- e-ratio doesn't appear to depend on productivity or temperature
- Mean ocean e-ratio [C] = 0.30± 0.07, fairly constant



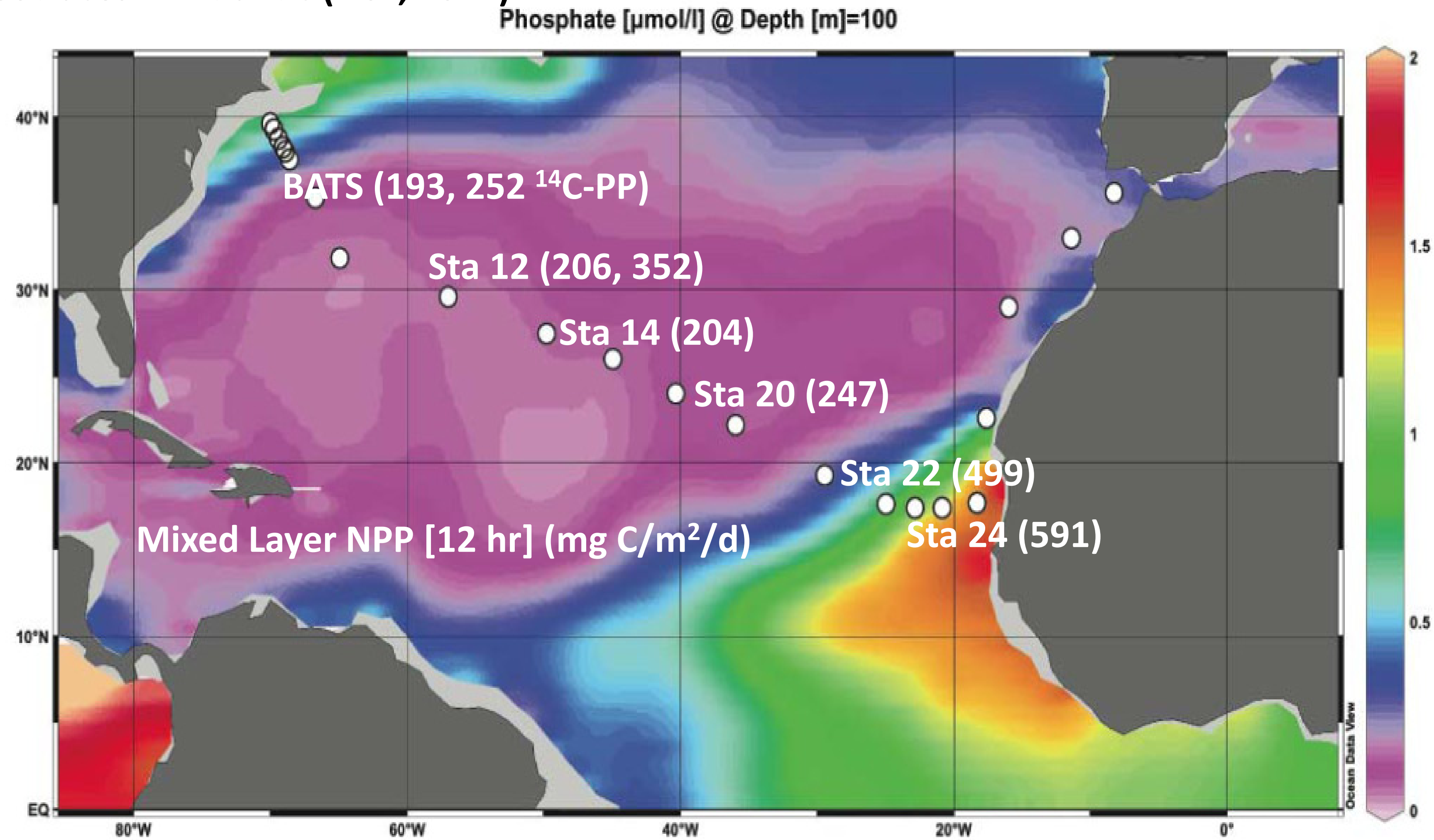
PP from Diurnal in-situ O_2/Ar Cycle



- Zml*d(O_2/Ar)/dt = GPP – Resp (comm) + Gas exchange + Mixing
- Respiration (comm) = nighttime dO_2/Ar decrease – Gas loss
- Net PP = daytime dO_2/Ar increase + Gas loss
- Gross PP = daytime NPP + nighttime Respiration (comm)
- Net Comm Prod (NCP) = Gas loss (2 week integration)

PP across the subtropical N. Atlantic

Geotraces N. Atlantic (Nov, 2011)



Conclusions

- Time-series stations are excellent sites to test PP methods.
- In situ $^{17}\Delta$-GOP mixed layer estimates are most accurate under summer stratified conditions especially in subtropics.
- In situ $^{17}\Delta$-GOP yields 30±20% higher rates than concurrent in vitro ^{18}O-GOP (and ^{14}C-NPP after O to C conversion). Method biases, if so, which one?
- Although $^{17}\Delta$ at HOT looks “1-D Vertical”, not at BATS.
- Annual cycle in NCP necessary to understand impact of physical CO_2 supply and biological pump on atmospheric CO_2 uptake.
- Ocean-wide e-ratio is ~0.3 and doesn’t vary much.
- Measuring diurnal O_2/Ar cycle provides another way to estimate in situ GPP, NPP and e-ratio. Compare to $^{17}\Delta$-GOP.