Triple Oxygen Isotopes for quantifying Gross Primary Production (GPP)

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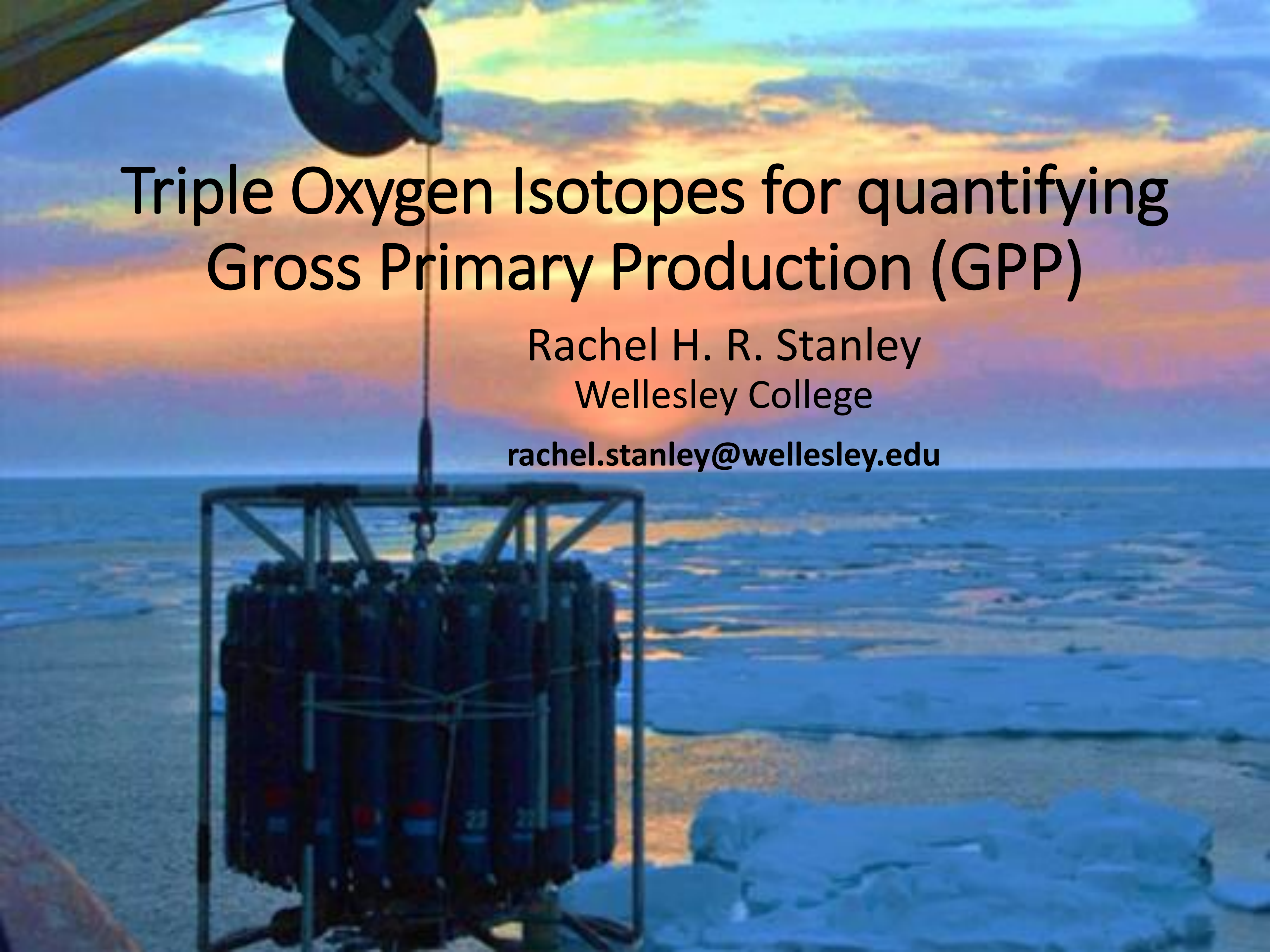
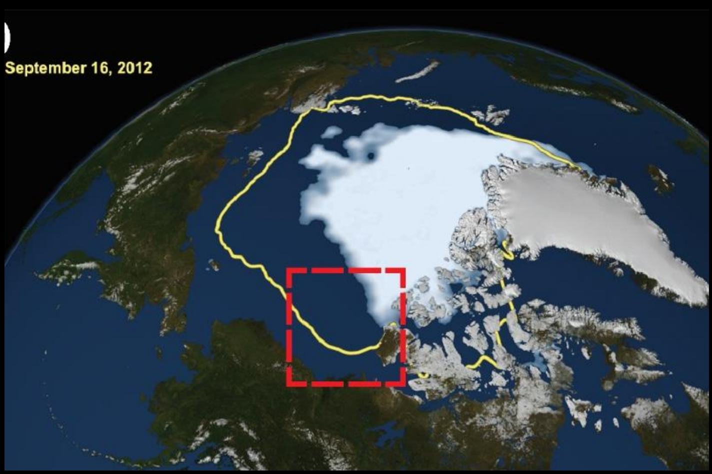


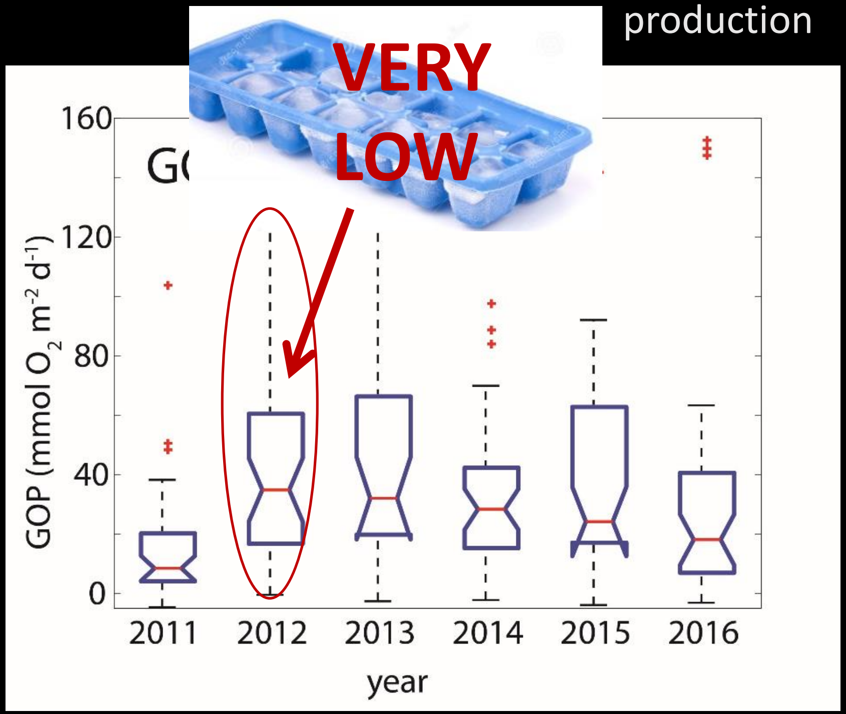
Why measure GPP?

- GPP represents total energy available for the ecosystem (maximal production)
- interesting dynamics in combination with NCP

GOP = gross oxygen production

Example: Response to melting sea ice





From Ji et al., submitted

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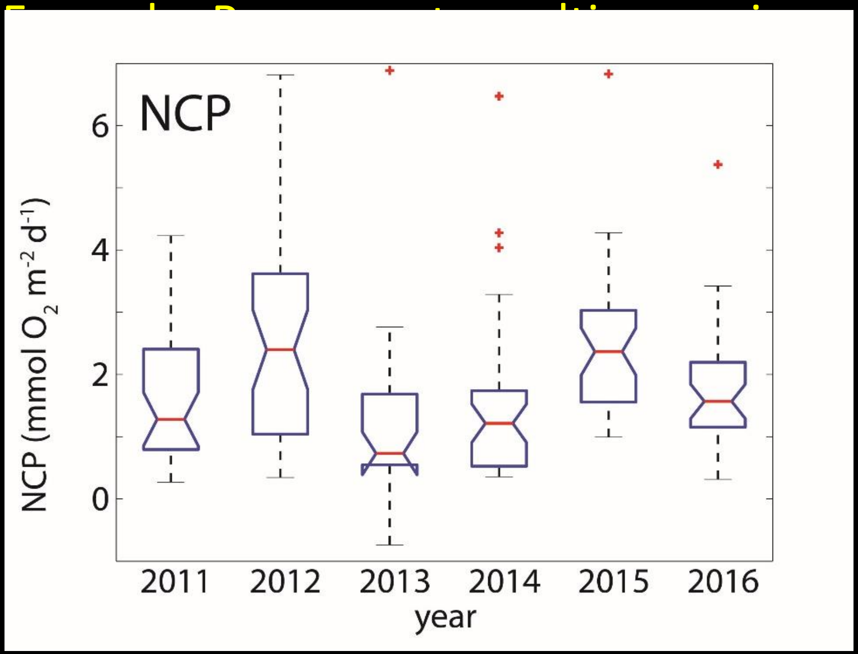
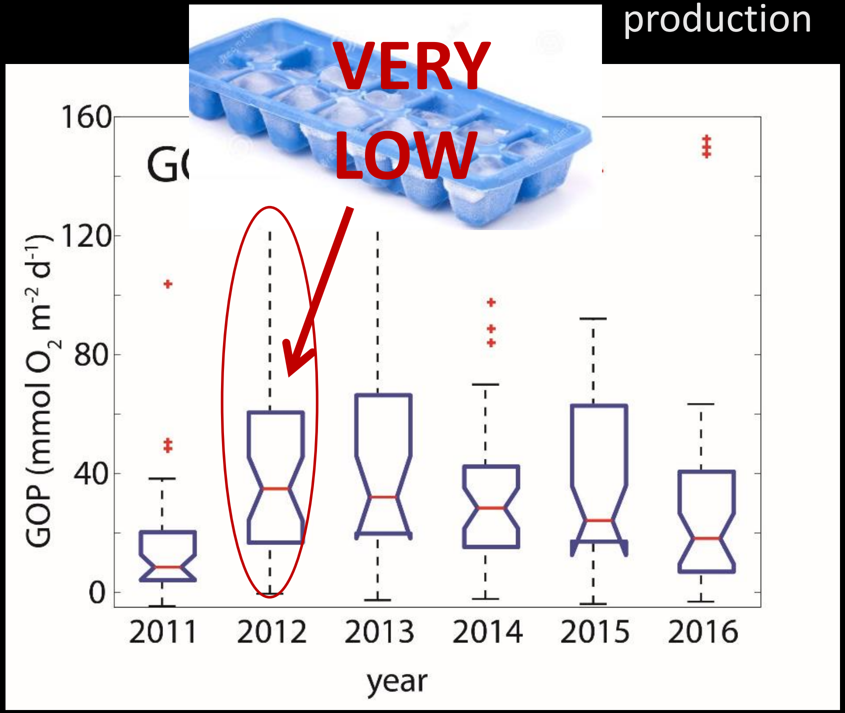
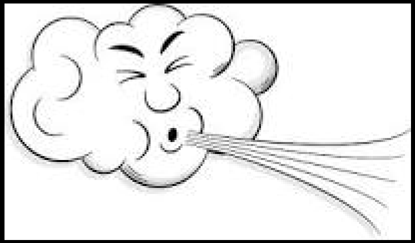




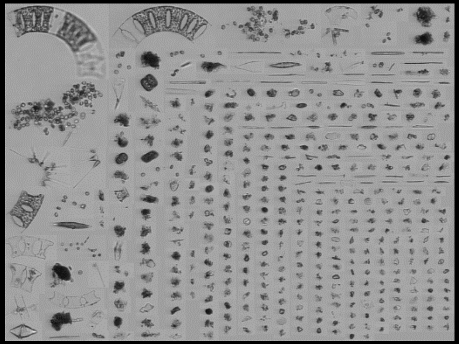
From Ji et al., submitted

How does the method work?

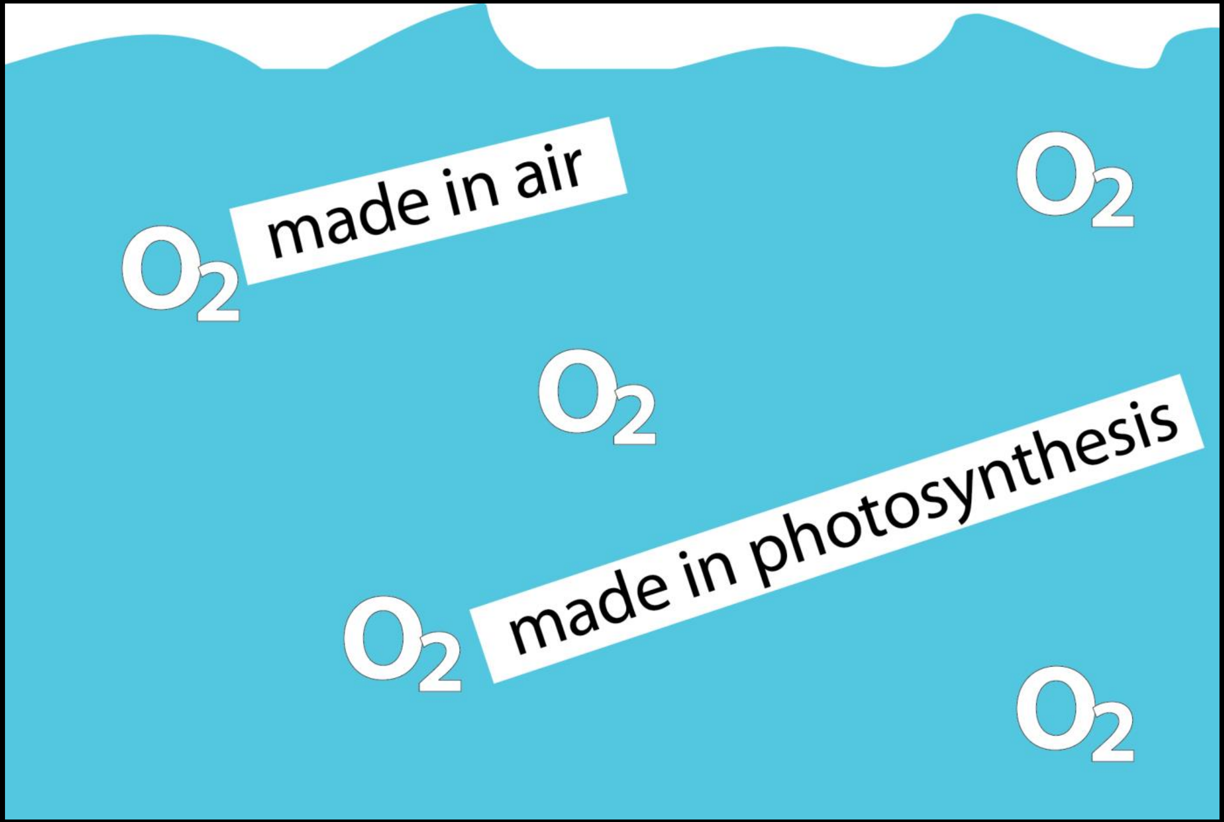
- Three isotopes of O: ^{16}O, ^{17}O, ^{18}O
- Ratio serves as a “made-in tag”



vs.



H. Sosik



GOP from Triple Oxygen Isotopes

$^{17}\Delta$ = measure of ratio of ^{16}O, ^{17}O, and ^{18}O
= $\ln(\delta^{17}O/1000+1) - 0.5179\ln(\delta^{18}O/1000+1) \times 10^6$

GOP = gross oxygen production

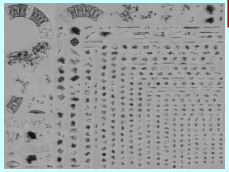
Atmosphere

UV Radiation → Mass

mo

$$\mathrm{GOP} = kO_{\mathrm{eq}} \frac{\dfrac{X^{17}_{\mathrm{dis}} - X^{17}_{\mathrm{eq}}}{X^{17}_{\mathrm{dis}}} - \lambda \dfrac{X^{18}_{\mathrm{dis}} - X^{18}_{\mathrm{eq}}}{X^{18}_{\mathrm{dis}}}}{\dfrac{X^{17}_{\mathrm{P}} - X^{17}_{\mathrm{dis}}}{X^{17}_{\mathrm{dis}}} - \lambda \dfrac{X^{18}_{P} - X^{18}_{\mathrm{dis}}}{X^{18}_{\mathrm{dis}}}}$$

Photosynthetic O_2 → Mass Dependent Fractionation
derived from H_2O *more ^{18}O than ^{17}O*

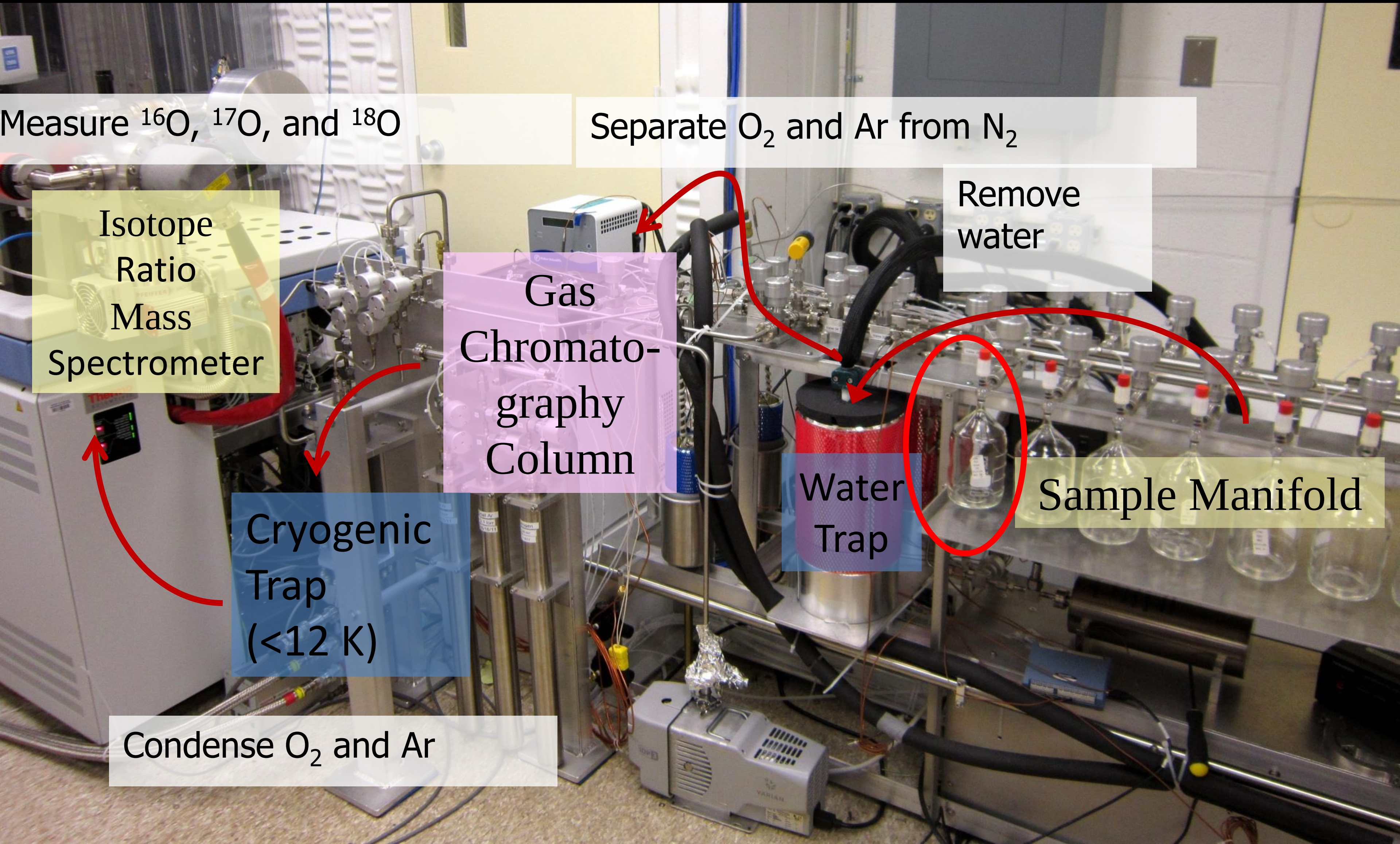


$^{17}\Delta$ of O_2 = 249 per meg

Calculate GOP

Ocean

Measuring Triple Oxygen Isotopes of O_2



Brief History

- Seminal papers by Luz et al. in 1999 and 2000 with simple equation
- Developed further by Michael Bender and Paul Quay in early 2000s…

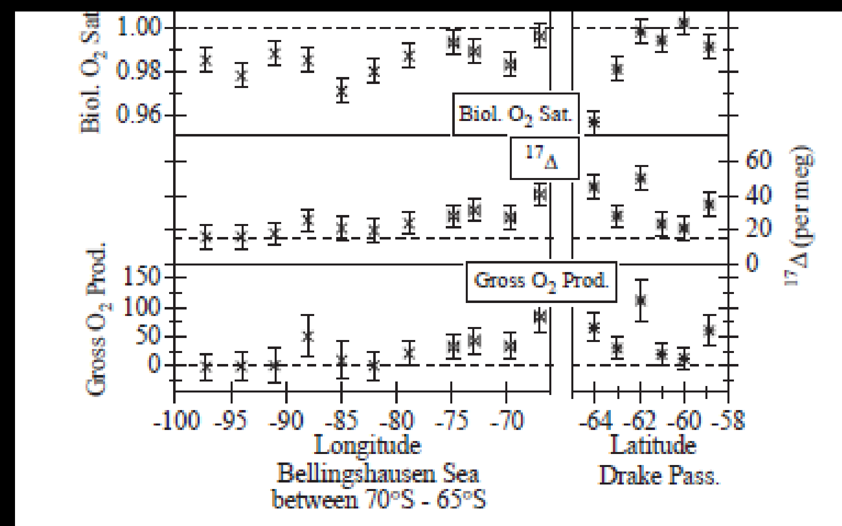
16 JUNE 2000 VOL 288 SCIENCE www.sciencemag.org

Assessment of Oceanic Productivity with the Triple-Isotope Composition of Dissolved Oxygen

Boaz Luz* and Eugeni Barkan

$$GP = KC_o(\Delta_{diss} - \Delta_{eq})/(\Delta_{max} - \Delta_{diss})$$

from Luz and Barkan, 2000



from Hendricks et al. 2004

Brief History

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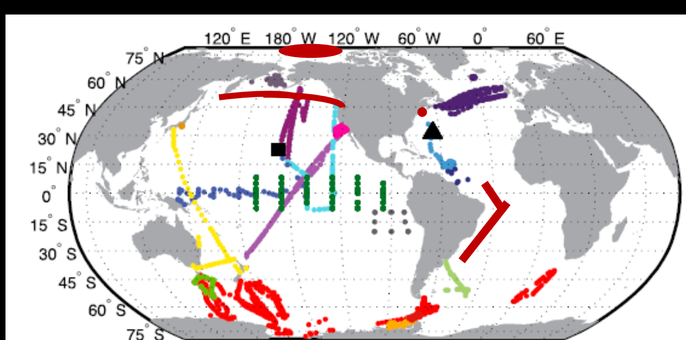
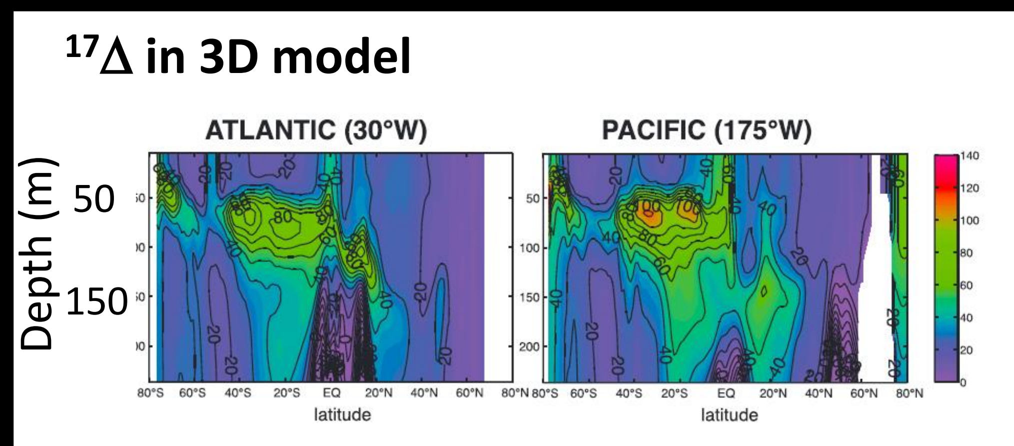
- Developed further by Michael Bender and Paul Quay in early 2000s…
- 2011 to present: equations developed further, 1D and 3D modeling, new considerations appear

from Prokopenko et al., 2011

$$hO_{dis}\frac{\partial^{17}\Delta}{\partial t} = G \bullet \left[\frac{X_p^{17} - X_{dis}^{17}}{X_{dis}^{17}} - \lambda\frac{X_p^{18} - X_{dis}^{18}}{X_{dis}^{18}}\right] - kO_{eq} \bullet \left[\frac{X_{eq}^{17} - X_{dis}^{17}}{X_{dis}^{17}} - \lambda\frac{X_{eq}^{18} - X_{dis}^{18}}{X_{dis}^{18}}\right]$$



from Nicholson et al., 2014

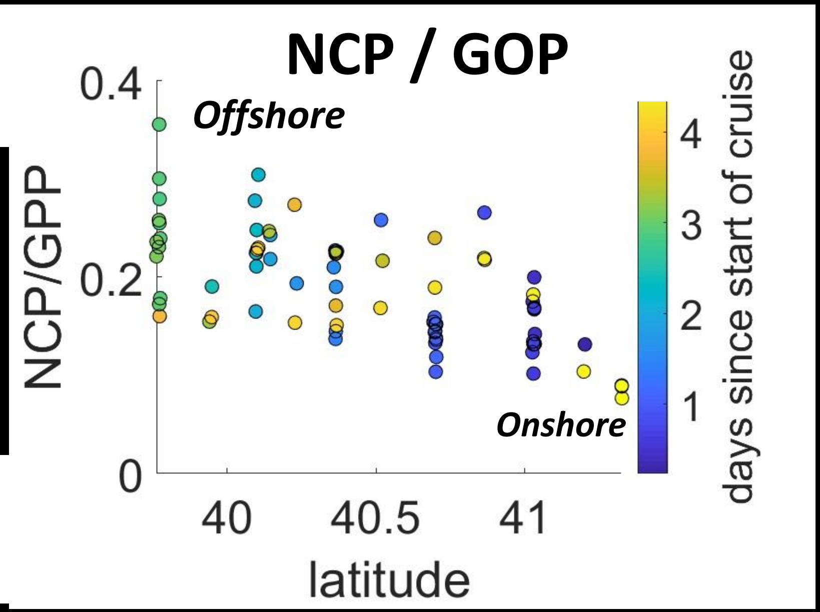


from Nicholson et al., 2014

Advantages of TOI for GPP

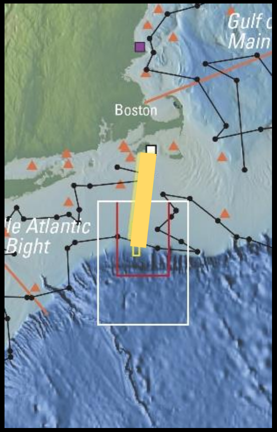
- In situ technique: Doesn't disturb the biology!
- Don't need assumption that light = dark respiration
- Integrates over large spatial and temporal scales
- Relatively easy to collect (but hard to measure!) → enables hundred(s) of GOP rates per cruise
- Provides the NCP/GOP ratio: a measure of carbon cycle efficiency

High Export = Leaky



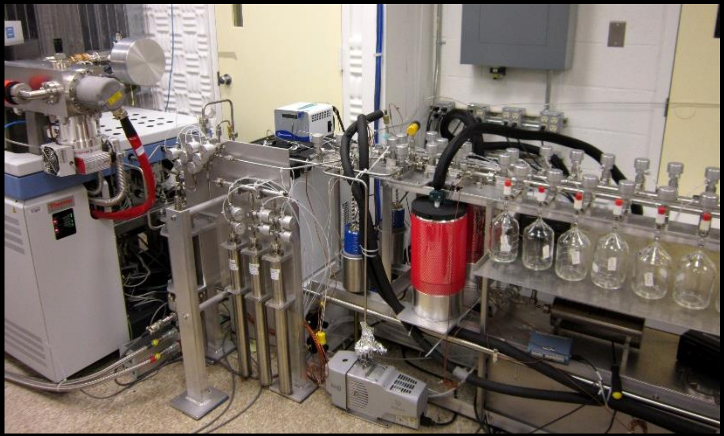
Low Export = Efficient Recycling

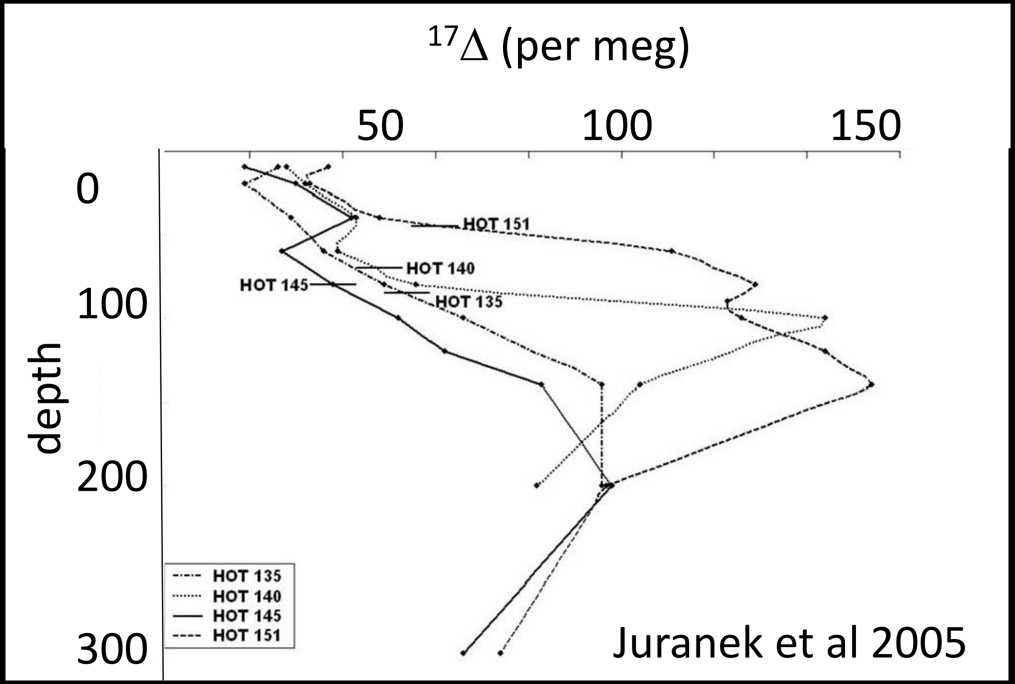
Productivity on summer New England shelf as part of NES-LTER



Disadvantages

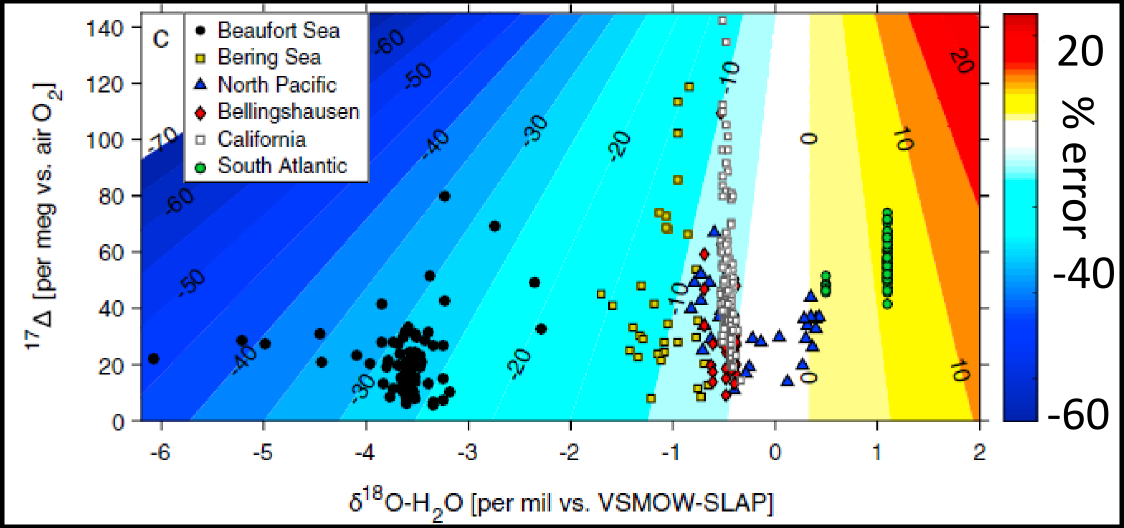
- Need specialized equipment to measure samples
- Biases caused by physical transport and steady state assumption
- Usually used only to give rate integrated over mixed layer





Special Considerations

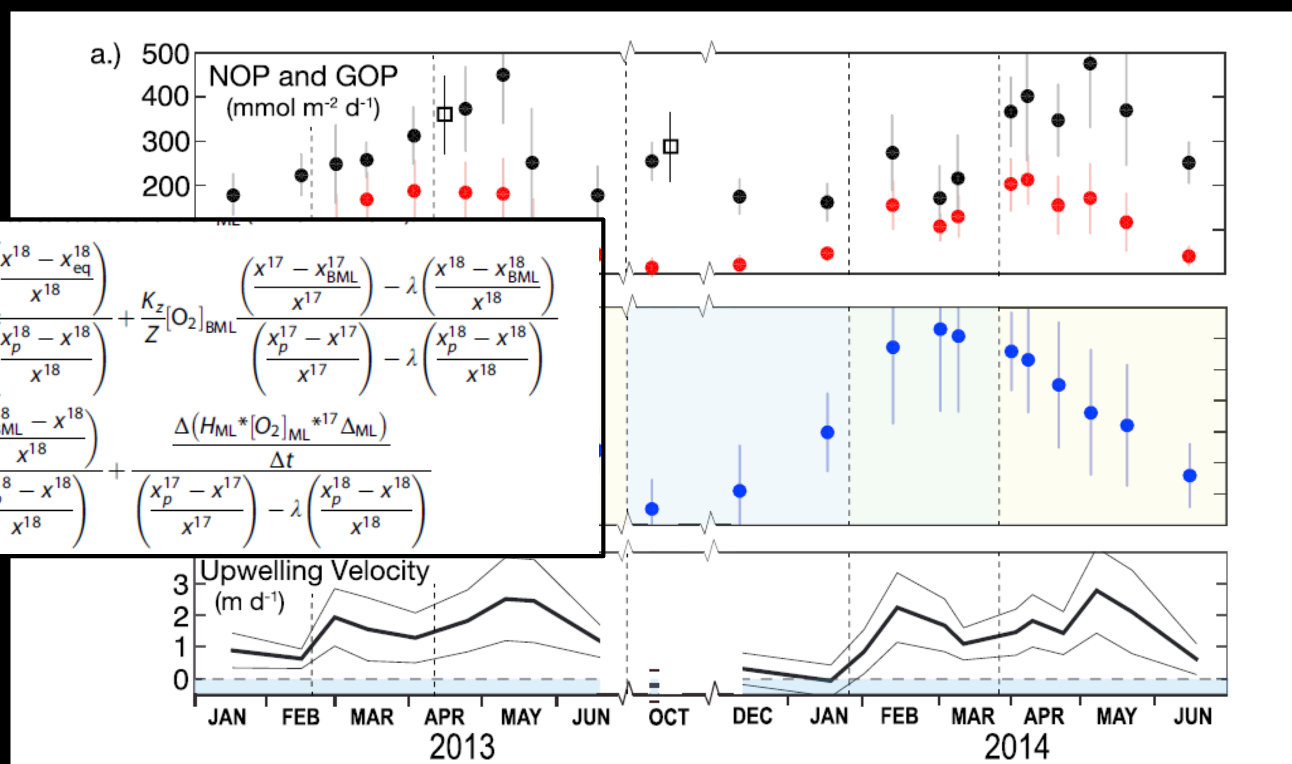
- Best to calculate photosynthetic end member from $\delta^{18}O$ of seawater (and $\delta^{17}O$ if possible)
- Cryogenic trapping really necessary in analysis
- Gives O_2 production → Mehler reaction and photorespiration need to be taken into account if want carbon production



from Manning et al., 2017

Outstanding Questions

- How best to correct for lateral (and vertical) physical transport?
- What is best factor to use to estimate NPP from GPP?
- Are there processes that affect the $^{17}\Delta$ signature? Bubbles? Non-standard metabolism?



$$\mathrm{GOP_{ML}} = k[\mathrm{O_2}]_{\mathrm{eq}} \frac{\left(\frac{x^{17}-x^{17}_{\mathrm{eq}}}{x^{17}}\right) - \lambda\left(\frac{x^{18}-x^{18}_{\mathrm{eq}}}{x^{18}}\right)}{\left(\frac{x^{17}_p-x^{17}}{x^{17}}\right) - \lambda\left(\frac{x^{18}_p-x^{18}}{x^{18}}\right)} + \frac{K_z}{Z}[\mathrm{O_2}]_{\mathrm{BML}} \frac{\left(\frac{x^{17}-x^{17}_{\mathrm{BML}}}{x^{17}}\right) - \lambda\left(\frac{x^{18}-x^{18}_{\mathrm{BML}}}{x^{18}}\right)}{\left(\frac{x^{17}_p-x^{17}}{x^{17}}\right) - \lambda\left(\frac{x^{18}_p-x^{18}}{x^{18}}\right)}$$

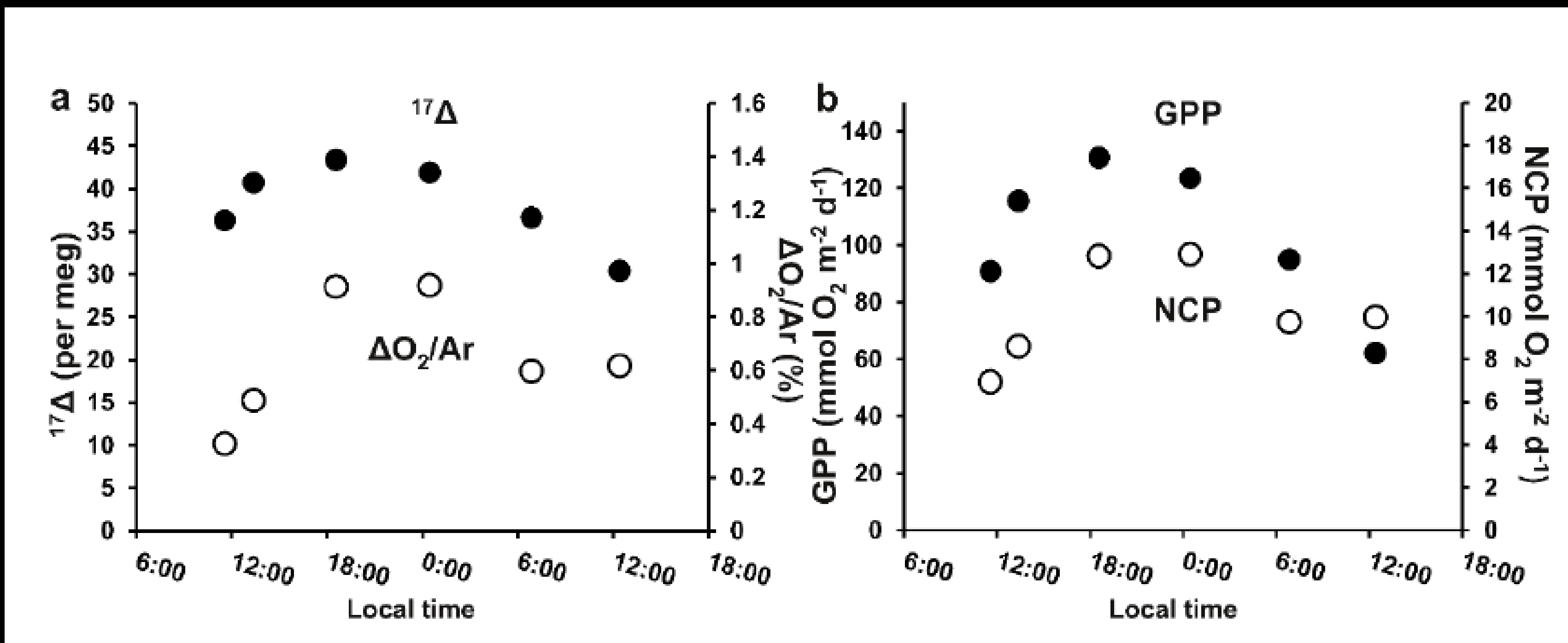
$$- w_H[\mathrm{O_2}]_{\mathrm{BML}} \frac{\left(\frac{x^{17}_{\mathrm{BML}}-x^{17}}{x^{17}}\right) - \lambda\left(\frac{x^{18}_{\mathrm{BML}}-x^{18}}{x^{18}}\right)}{\left(\frac{x^{17}_p-x^{17}}{x^{17}}\right) - \lambda\left(\frac{x^{18}_p-x^{18}}{x^{18}}\right)} + \frac{\frac{\Delta\left(H_{\mathrm{ML}}*[\mathrm{O_2}]_{\mathrm{ML}}*^{17}\Delta_{\mathrm{ML}}\right)}{\Delta t}}{\left(\frac{x^{17}_p-x^{17}}{x^{17}}\right) - \lambda\left(\frac{x^{18}_p-x^{18}}{x^{18}}\right)}$$

Haskell et al 2017

Extra slides

Diel Cycles in $^{17}\Delta$

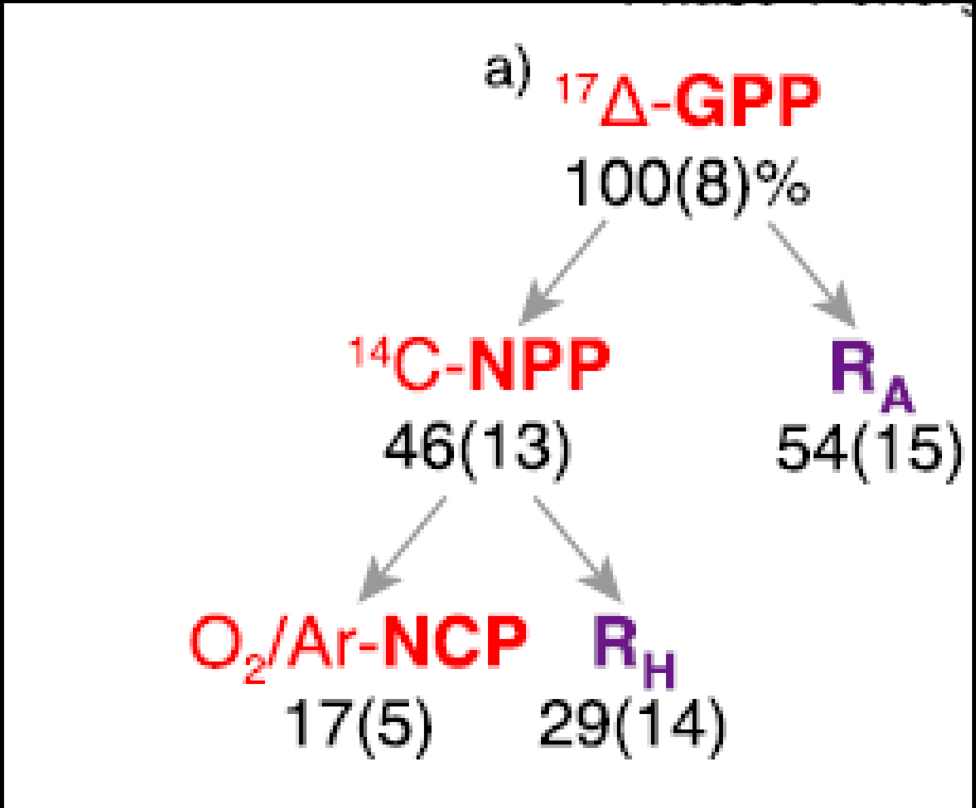
Sometimes diel cycles are observed despite expected time scale of O_2



From Howard et al., 2017

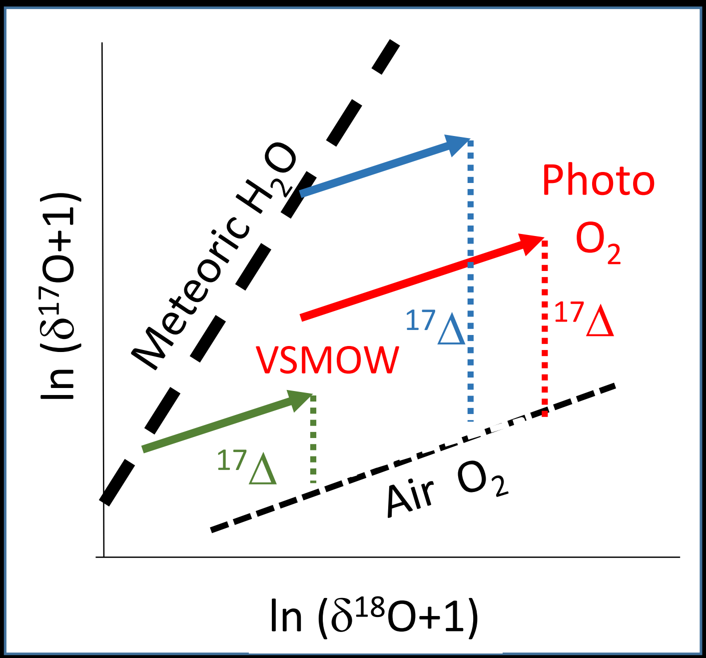
Energy flow diagrams

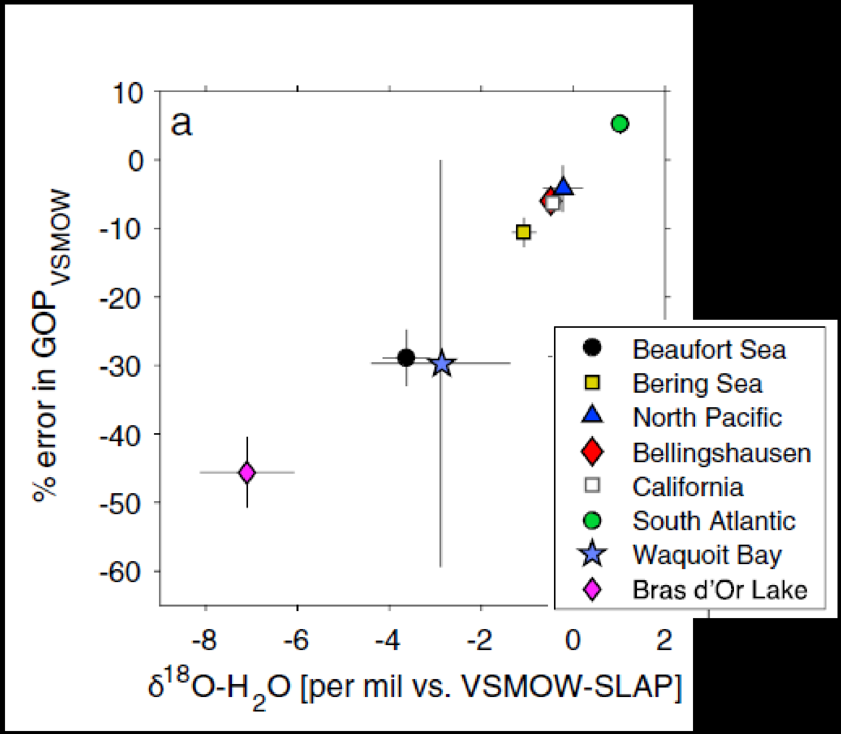
- Can be constructed if GPP, NPP and NCP are all measured



from Manning et al., 2017b

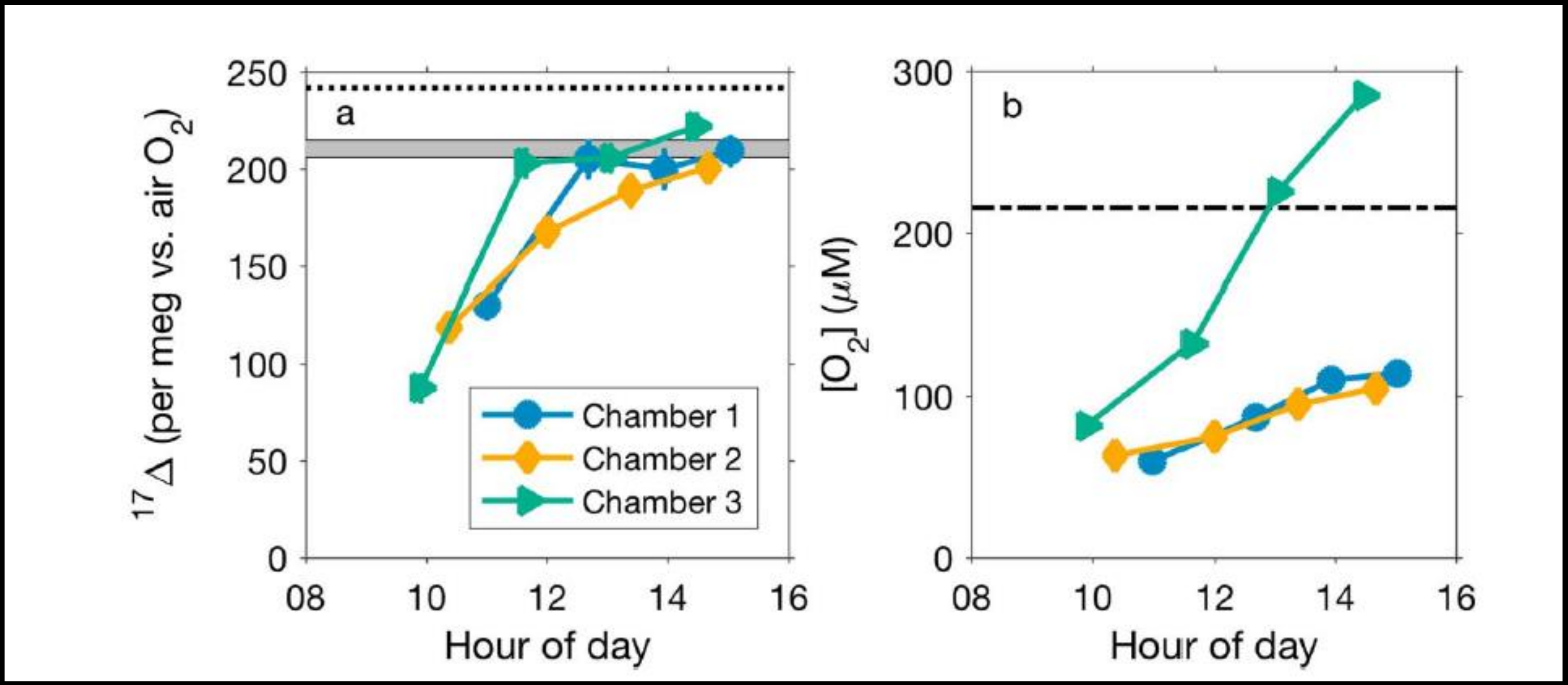
Why the isotopic composition of seawater matters





modified from Manning et al., 2017

Photosynthetic End Member



modified from Manning et al., 2017

Biases in GOP from $^{17}\Delta$ method

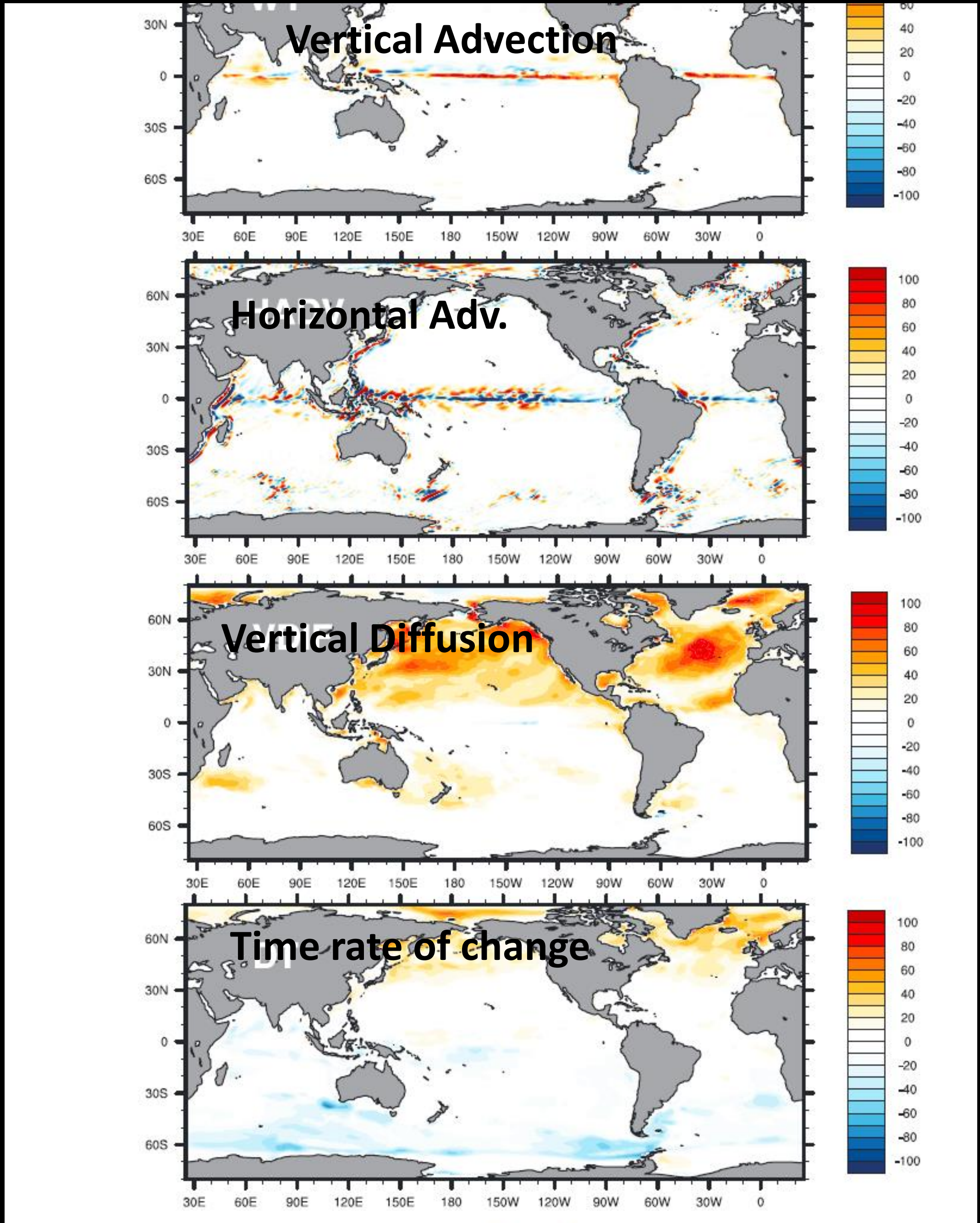
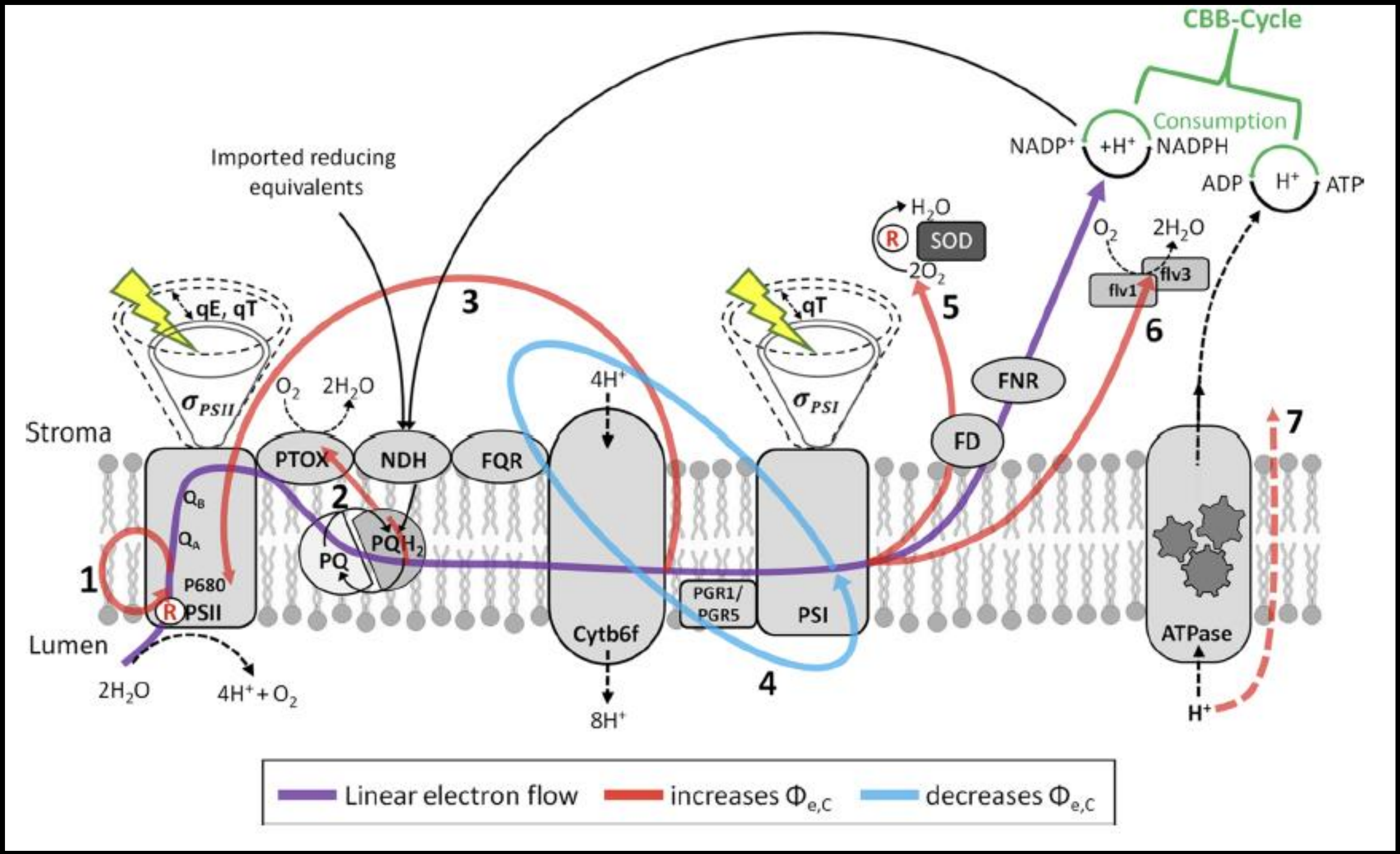


Figure 9

from Nicholson et al., 2014

Photosynthetic Electron Flow



From Hughes et al. 2018