Measuring and scaling net community production and carbon export in the Southern Ocean

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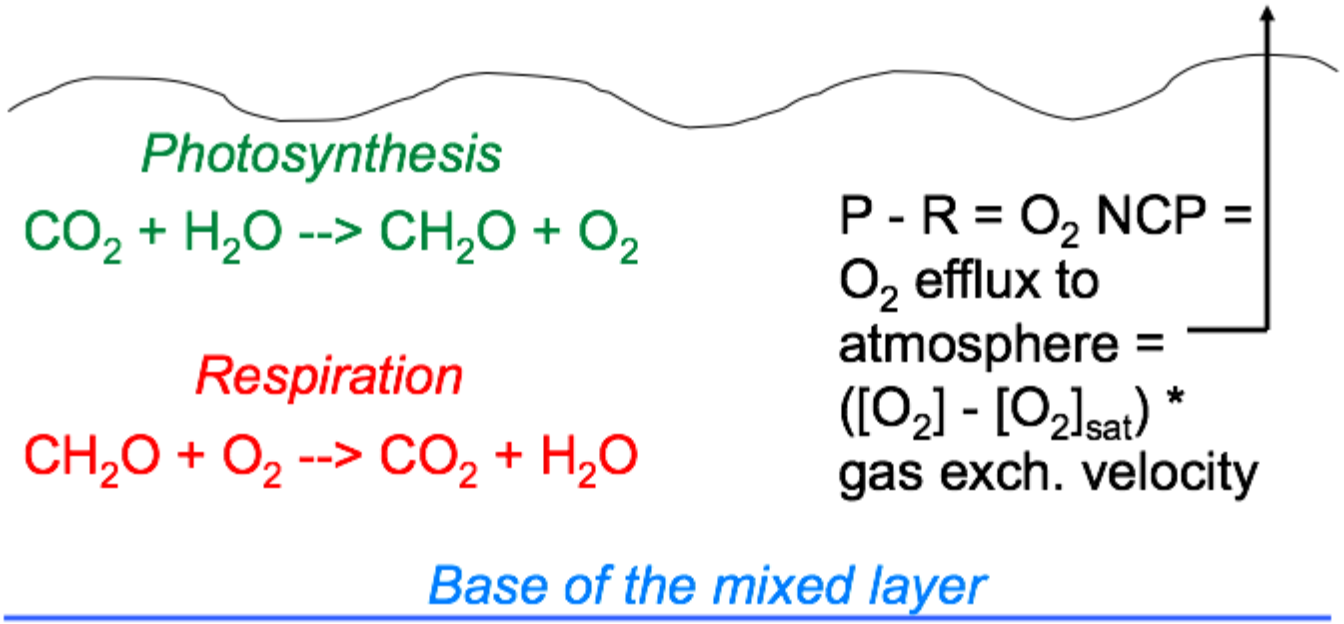
With experimental contributions and ideas from Nicolas Cassar

Many collaborators (especially Pedro Monteiro and Warren Joubert, and Bronte Tilbrook)

Outline

- Basis of net community production measurements by O_2/Ar
- Relation between chlorophyll-normalized NCP (mmol O_2 mg chl^{-1} day^{-1}) and average irradiance in the mixed layer
- Strategy for scaling up NCP measurements
- Other methods for accessing NCP and carbon export
  - Summary of methods
  - Global NCP variations estimated from different approaches

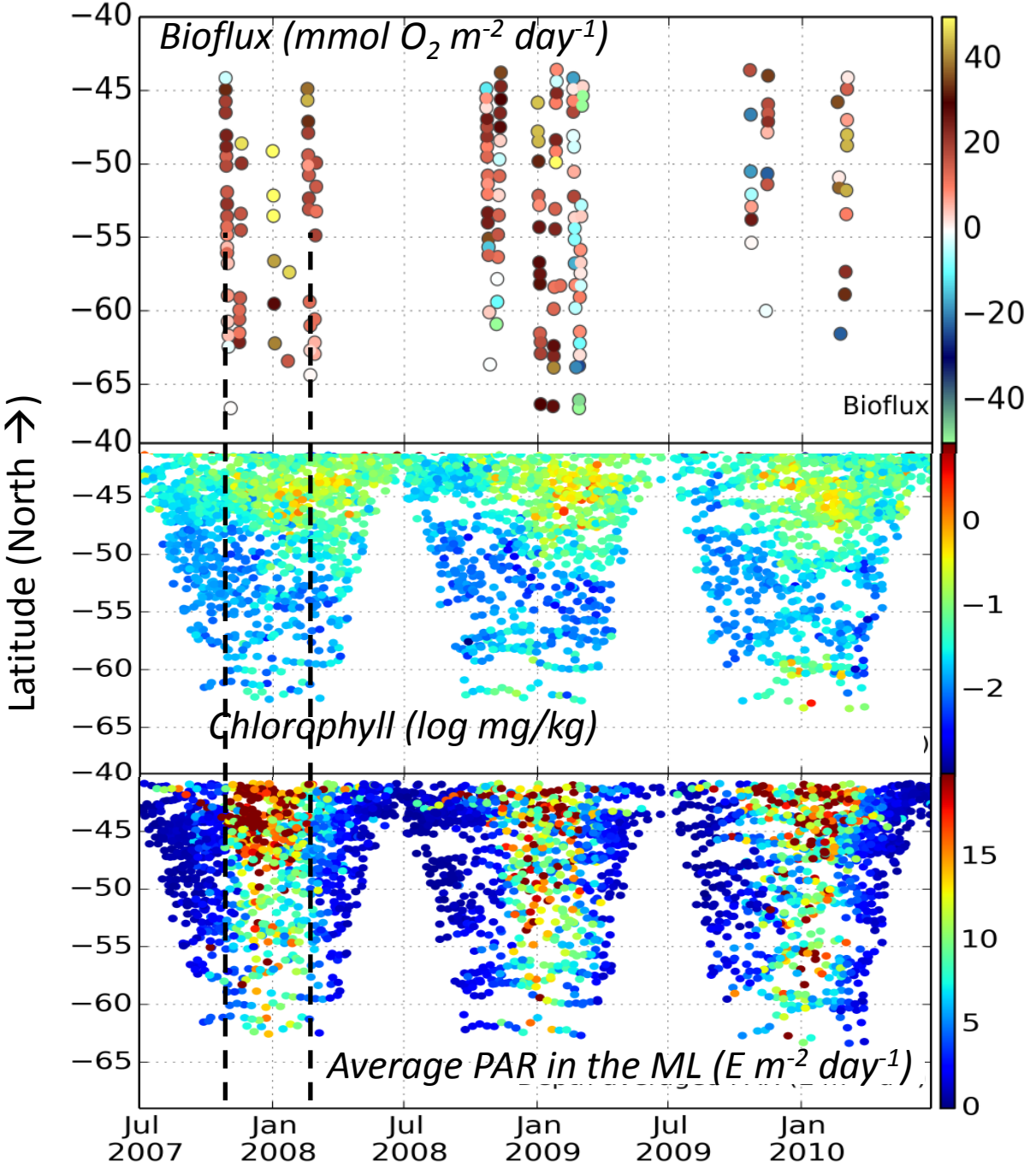
Mixed layer NCP and carbon export estimated from mixed layer O_2/Ar ratios



- In summer:
  - Photosynthesis > respiration
  - $[O_2] > [O_2]_{sat}$, lost to atmosphere
  - O_2 efflux = $([O_2] - [O_2]_{sat})$ * gas exchange velocity
- Net community O_2 production = flux to atmosphere
- Complication: $[O_2] > [O_2]_{sat}$ because of warming and bubble entrainment
- Measure Ar as inert analog to O_2 to correct for physical supersaturation (Jenkins, Quay, Emerson, Luz…)

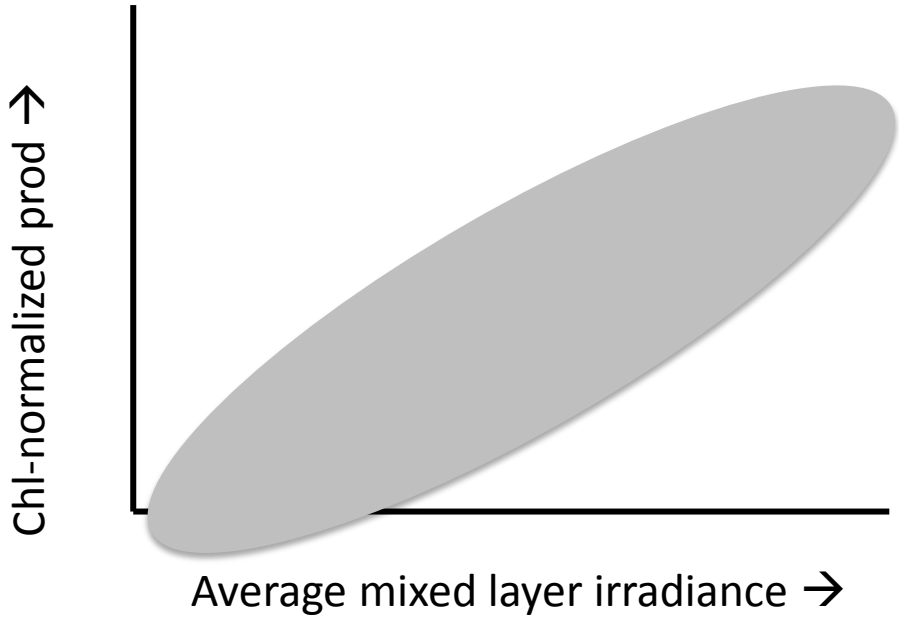
Net community production south of Australia

- Work on Astrolabe (French supply ship transiting between Hobart and Dumont d'Urvilles)
- Main collaborator: Bronte Tilbrook
- Data sources:
  - Bioflux from our O_2/Ar measurements
  - ML depth from Argo floats
  - Chl from satellite



Searching for a compact and scalable relation between O_2 bioflux (~NCP), MLD, chlorophyll, sea surface PAR and extinction coefficient

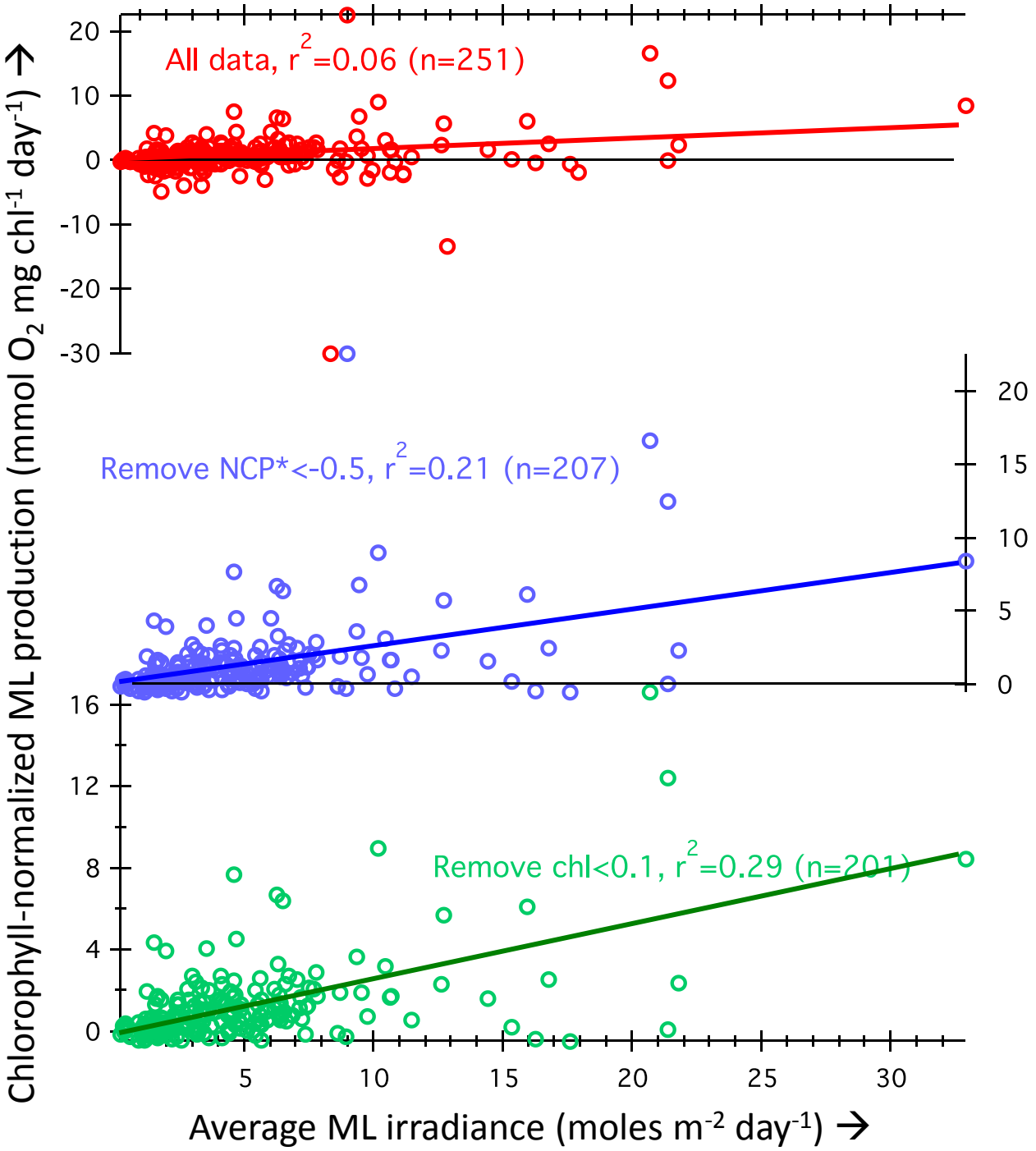
- Average mixed layer irradiance = ∫Sea Surface PAR * exp(-kz) dz / MLD
  - Units: E m^{-2} day^{-1})
  - K = extinction coefficient
- Chlorophyll-normalized production in ML = O_2 bioflux / (MLD*chl)
  - Units: mmol O_2 mg chl^{-1} day^{-1}



Data sources for plots of chlorophyll-normalized volumetric production vs. average ML irradiance

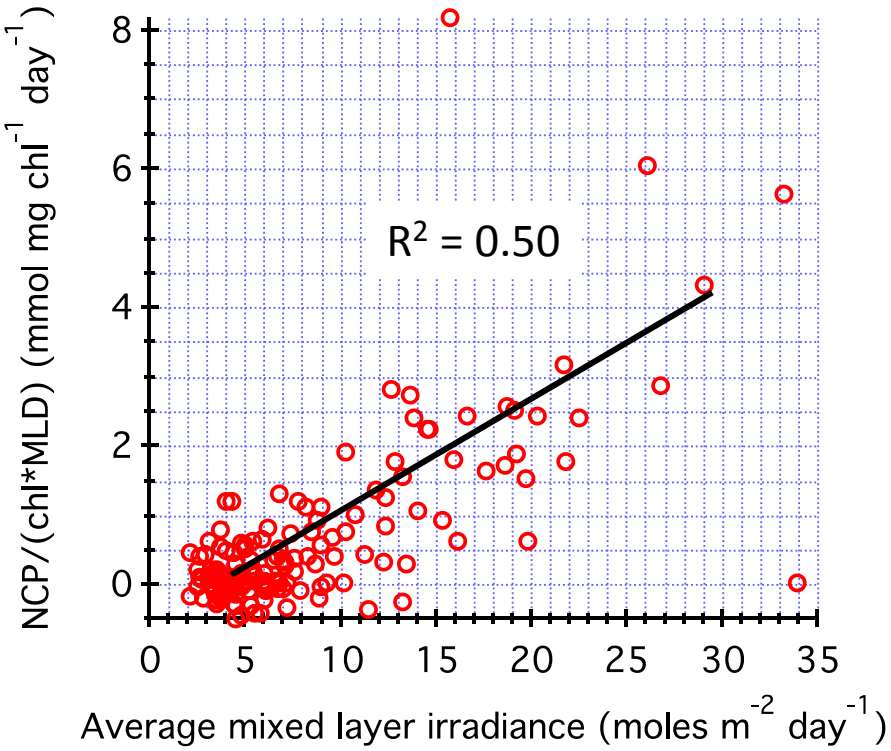
- O_2/Ar, chlorophyll, and mixed layer depth are measured
  - Satellite chlorophyll for Astrolabe
- Winds, sea surface PAR, and extinction coefficient are remote-sensing products
  - Morel equation for Astrolabe

Astrolabe data (Hobart to Antarctica): integrate and scale

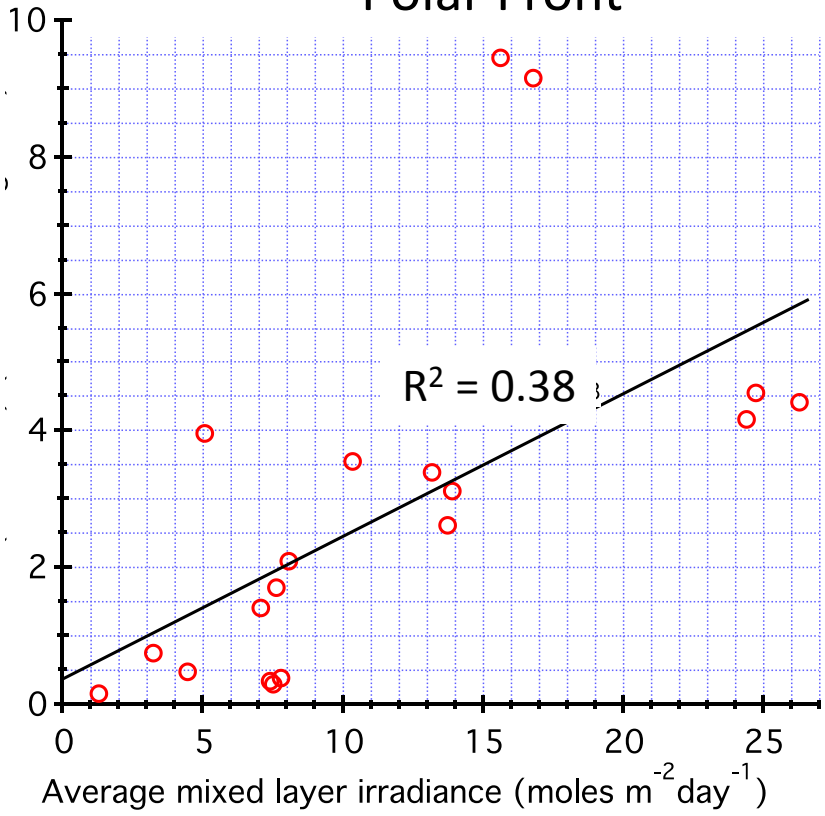


Agulhas and SAZ-SENSE data

Agulhas: Cape Town to Antarctica



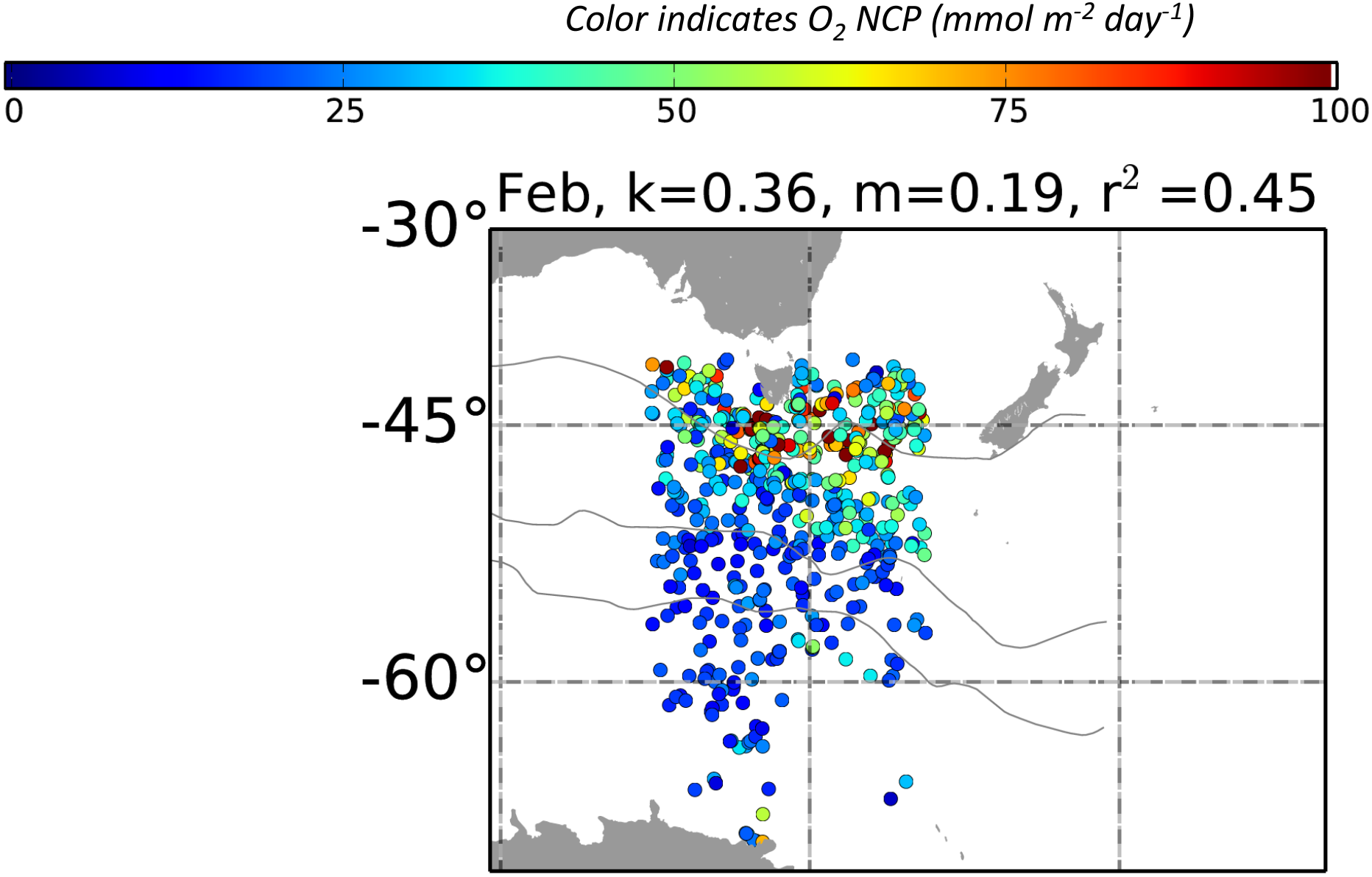
SAZ-SENSE: Hobart south below Polar Front



Data sources for simulated NCP field

- Chl, sea surface PAR, extinction coefficient from satellite product
- MLD from “colocated” Argo float
- NCP calculated from the relationship between chl-nomalized volumetric NCP and averaged ML irradiance

Scaling NCP in the Australian sector

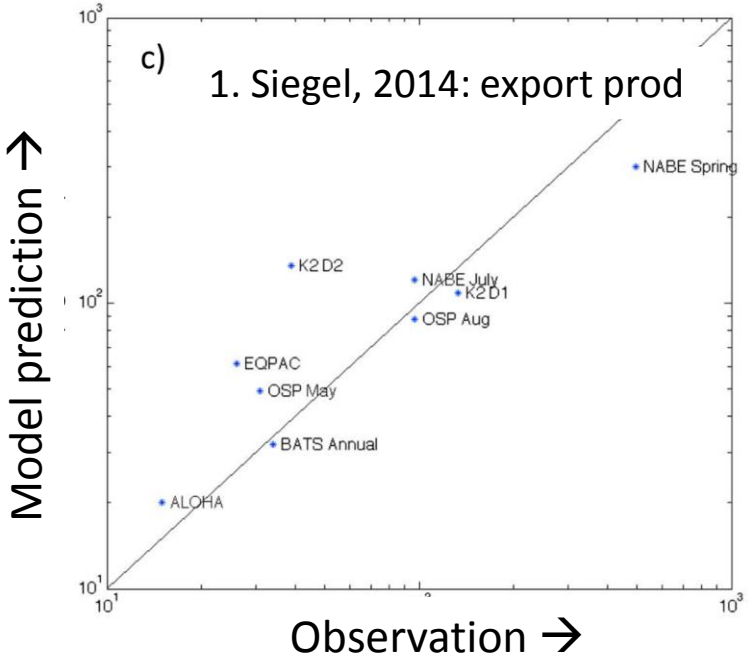


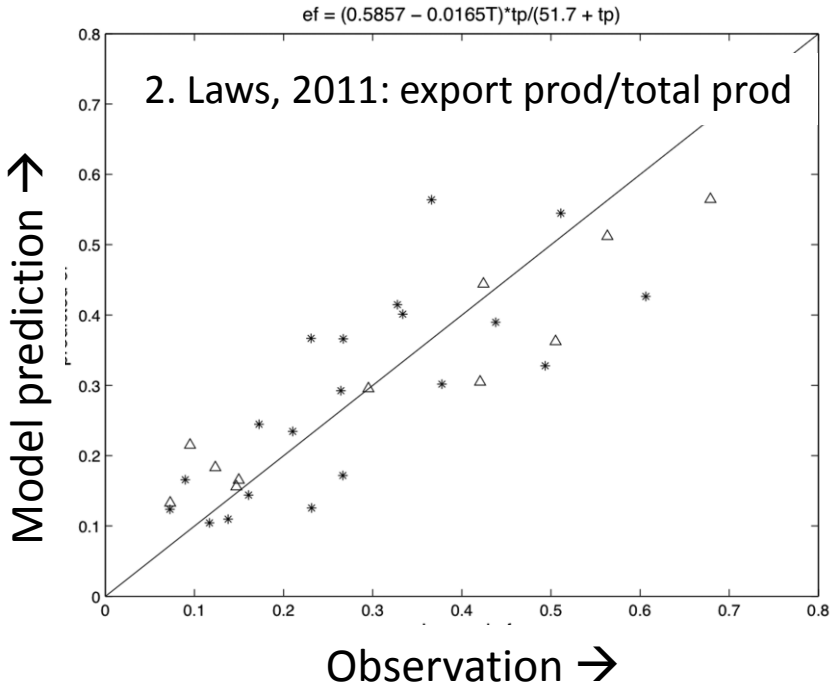
Methods for measuring net community production and carbon export

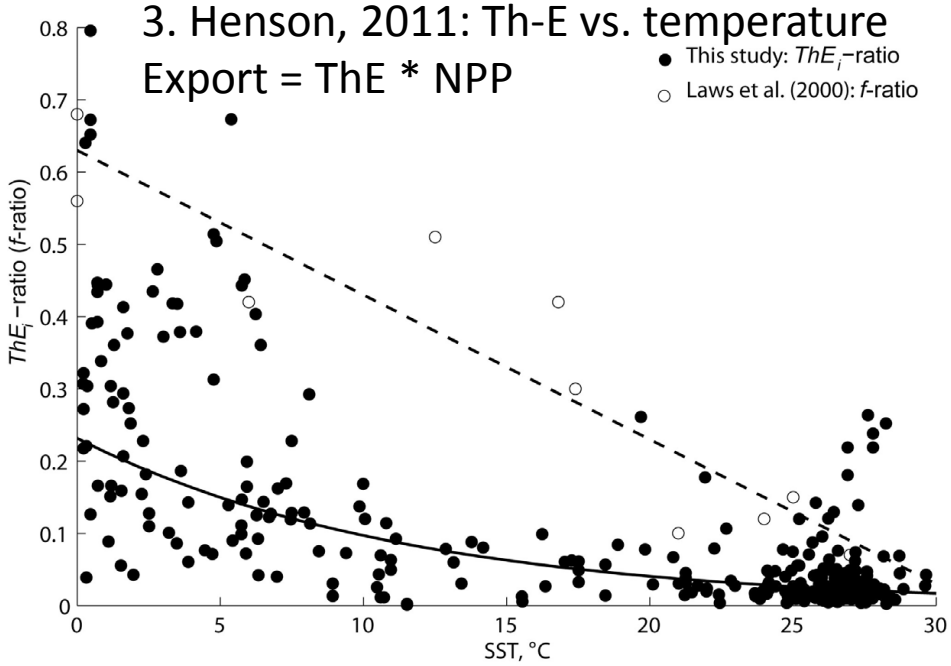
- Day to month scale
  - O_2/Ar: Uncertainties due to vertical mixing, gas exchange estimate; ML only
  - $^{15}NO_3^-$ assimilation: bottle effects, depends on day's irradiance; ML or EZ
  - ^{234}Th /C ratios: ML or EZ or arbitrary control depth
- Seasonal time scale
  - DIC or NO_3^- drawdown: lateral and vertical mixing; ML

4 recent statements about the global-scale pattern of variability NCP and export

- Laws et al: simple model based on temperature dependence of photosynthesis and respiration
- Siegel et al: Simple 1-D ecosystem model
- Henson et al: empirical model relating The e-ratio to temperature



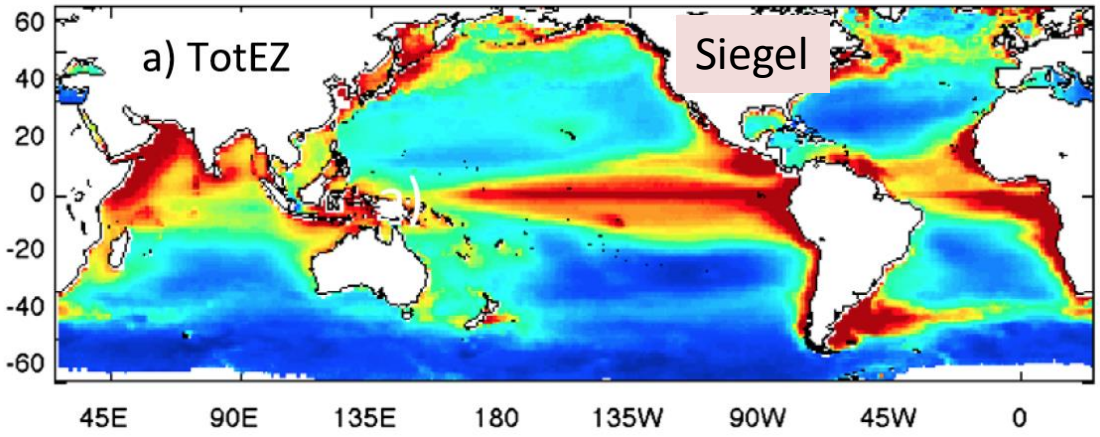


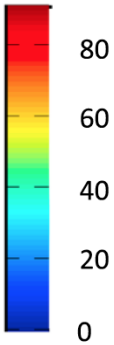


4. New production estimates from O_2/Ar or DIC balance show little variability

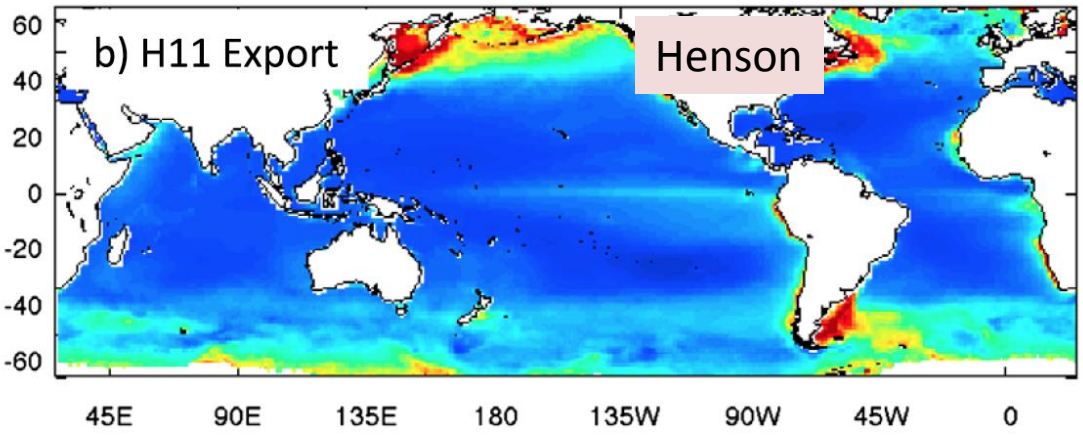
- Annual NCP based on ML O_2 or DIC balance (Emerson, 2014): NCP is in the range of 1-4 moles m^{-2} yr^{-1} in the
  - Southern Ocean
  - Equatorial Pacific Ocean
  - Subtropical north and south Atlantic
  - Subtropical North Pacific and western South Pacific
  - Subpolar North Pacific and North Atlantic

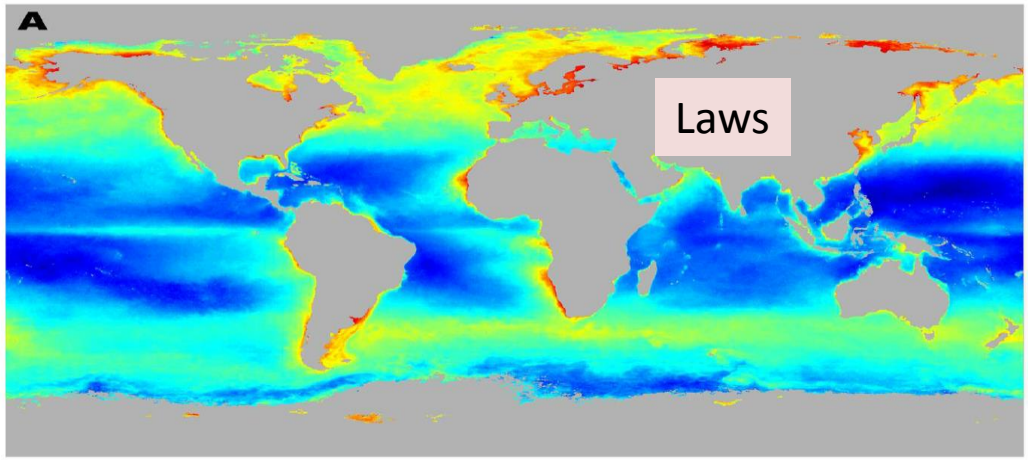
Inferred global patterns of new production or carbon export

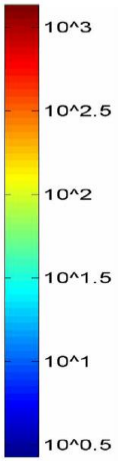




Gas or DIC estimate







Gas or DIC estimate

Comments and conclusions

- Plots of chl-normalized NCP vs. average ML irradiance look like good candidates for scaling NCP observations
- It matters what depth domain NCP and carbon export are reported (e. g., ML or euphotic zone)
- Models should report ML carbon fluxes in addition to fluxes for other domains
- Extensive remineralization in the lower euphotic zone will lead to increasing DIC, decreasing O_2

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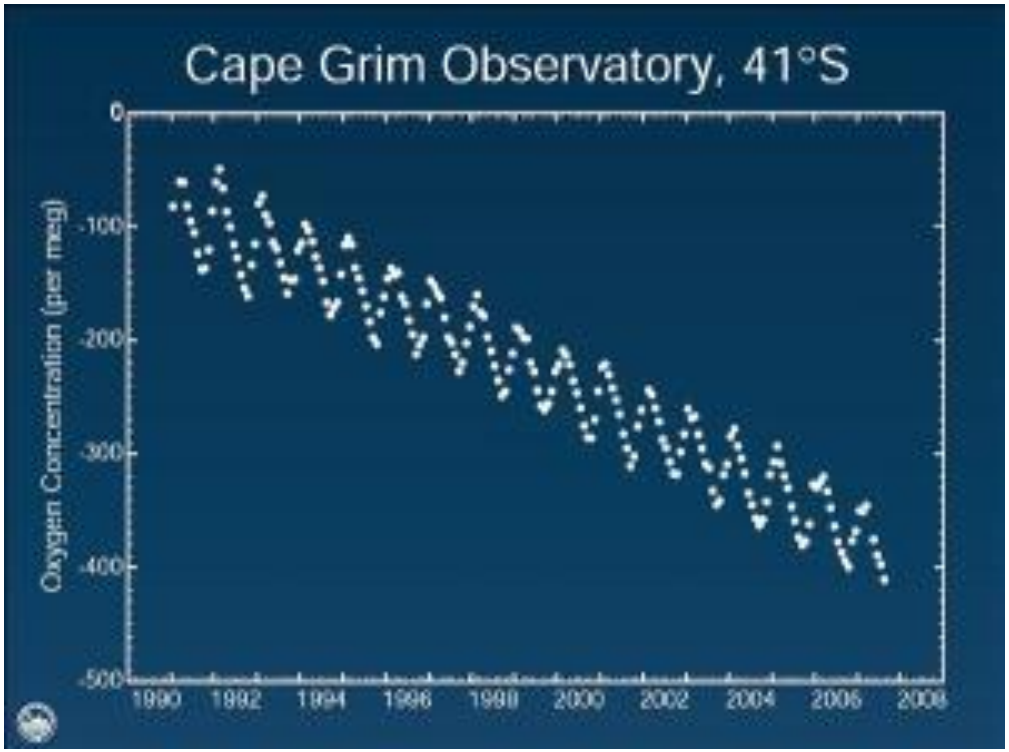
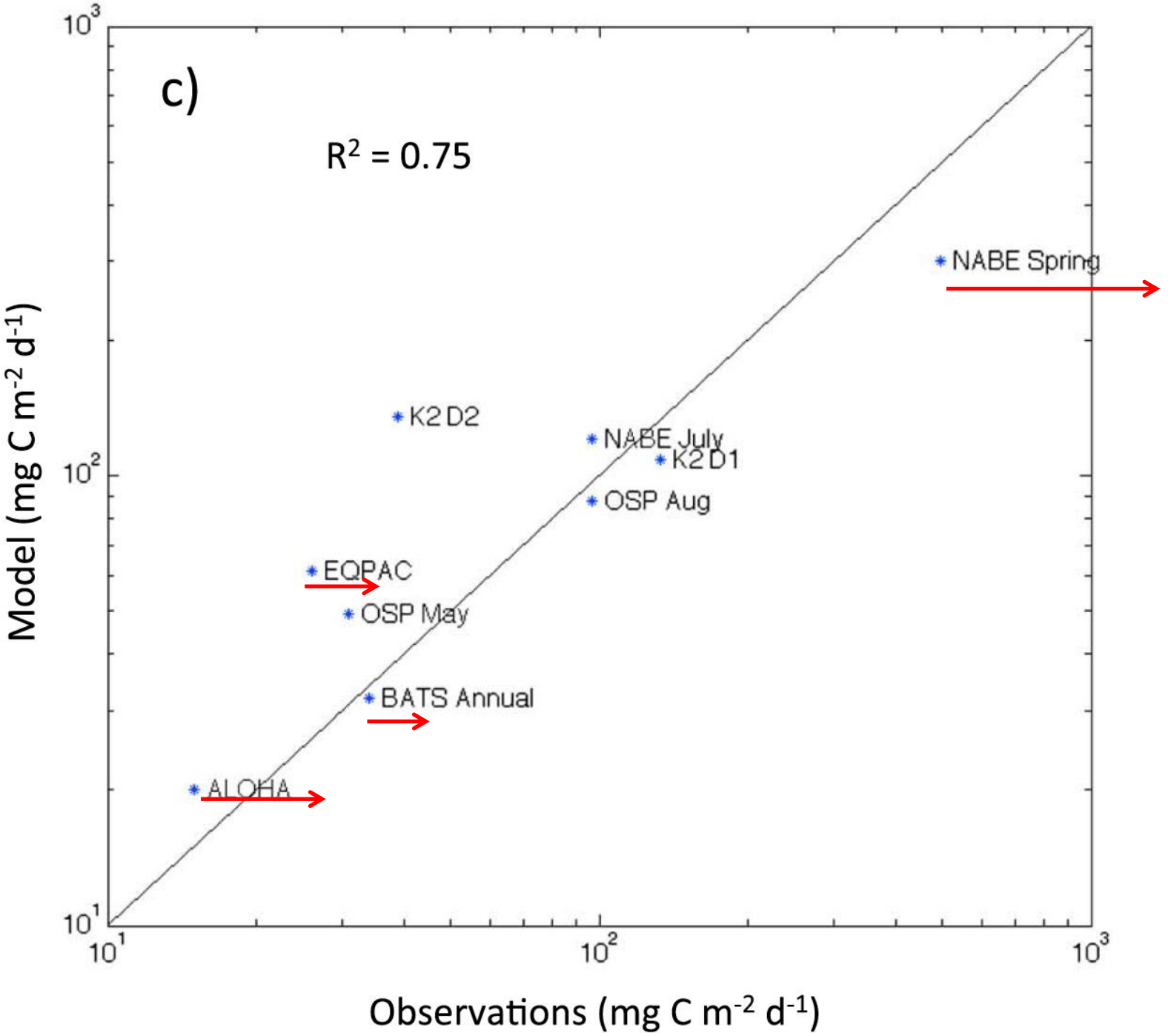
- Models should report ML carbon fluxes in addition to fluxes for other domains
- Extensive remineralization in the lower euphotic zone will lead to increasing DIC, decreasing O_2
- Global models of upper ocean carbon fluxes should be tested vs. atmospheric O_2/N_2 data

Atmospheric O_2 concentration →



1990 1998 2006


c)
$R^2 = 0.75$
NABE Spring
K2 D2
NABE July
K2 D1
OSP Aug
EQPAC
OSP May
BATS Annual
ALOHA
Model (mg C m^{-2} d^{-1})
Observations (mg C m^{-2} d^{-1})
10^1
10^2
10^3