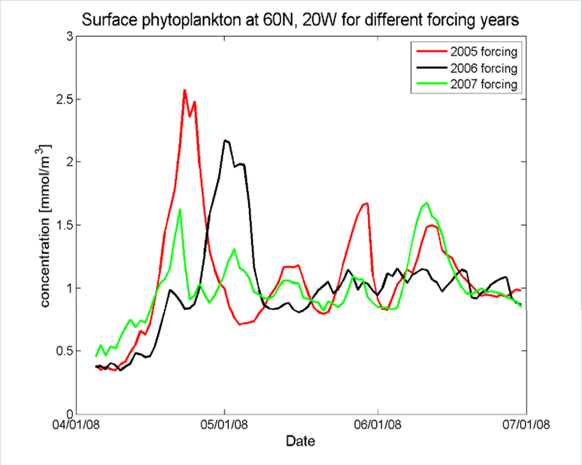
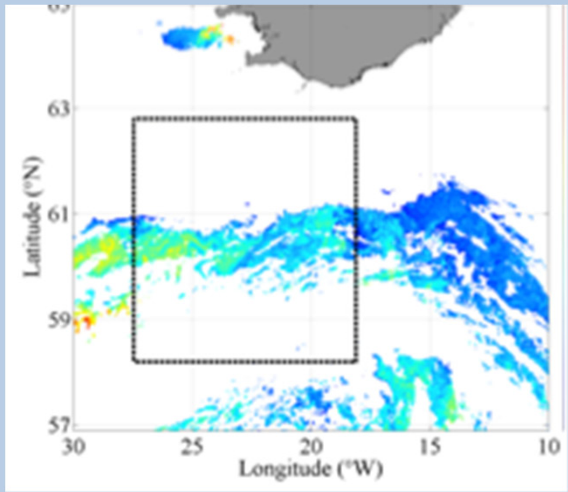
How do autonomous assets expand the temporal and spatial footprint of a shipboard process study?

Mary Jane Perry, Univ. Maine
Craig Lee & Eric D'Asaro, Univ. Washington

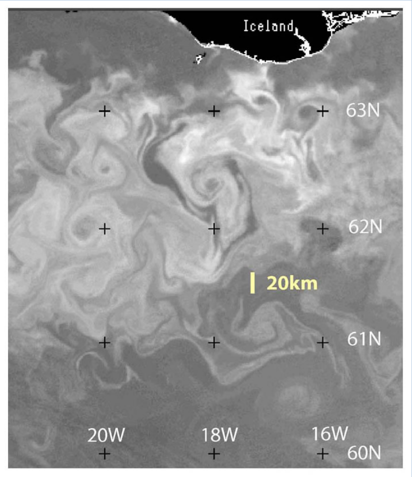
Challenges & the Limits of Conventional Approaches



Initiation & episodic evolution
(K. Fennel)

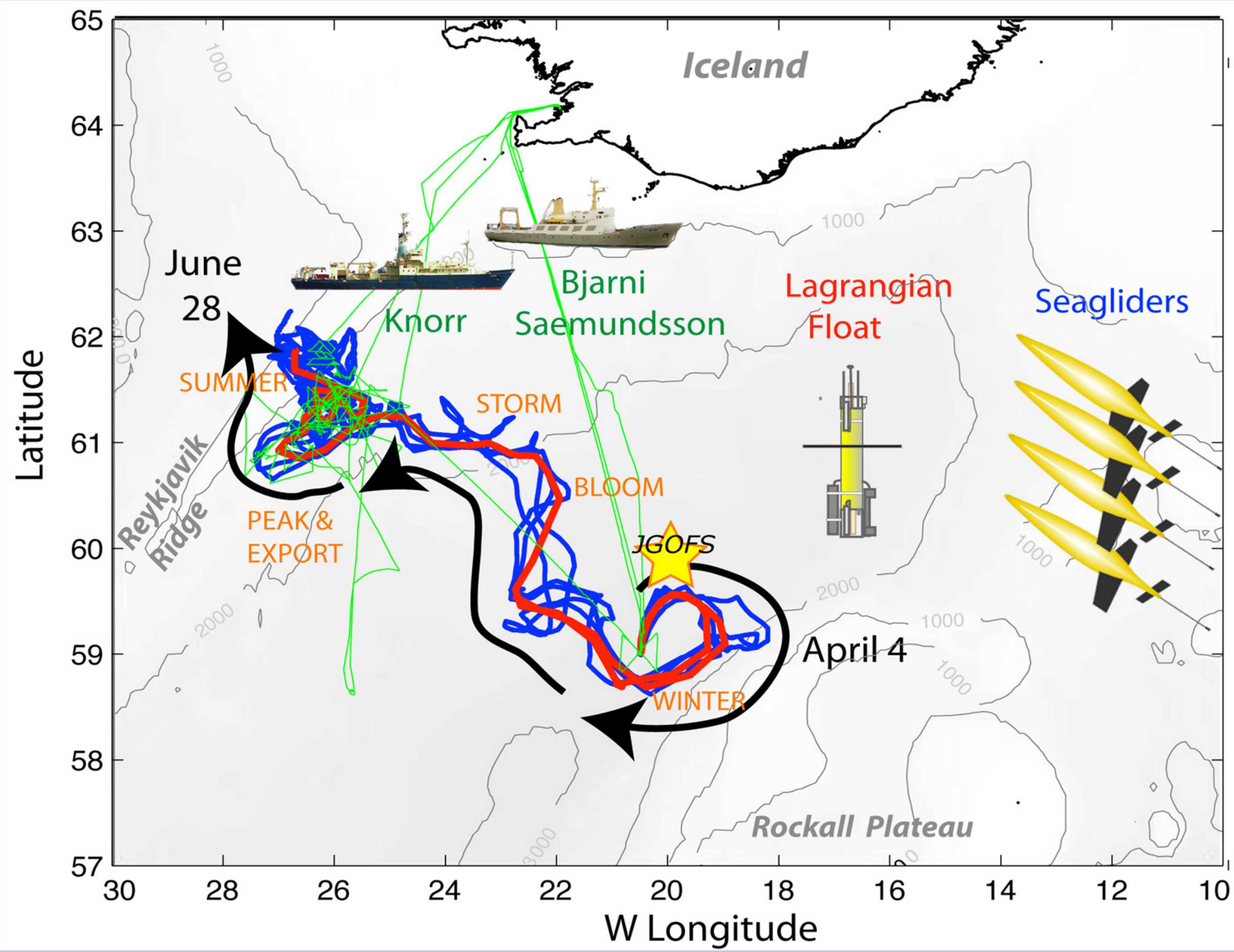


Clouds and surface bias
(B. Sackmann)



Small patch scales
4D physics

- **Ships** – broad measurement suite, but timing difficult and persistence impractical.
- **Moorings** – persistence good, but submesoscale sampling difficult.
- **Remote Sensing** – broad (x,y,t) coverage (selected variables), but clouds limit utility, no subsurface structure.
- **Models** – need improved understanding of processes.



NAB 2008: April – June

Autonomous Study of the Subpolar North Atlantic Bloom

Why the subpolar North Atlantic?

- responsible for 20% of global ocean's net uptake of CO_2
- undergoing significant changes

Why an autonomous approach?

Wide range of space and time scales

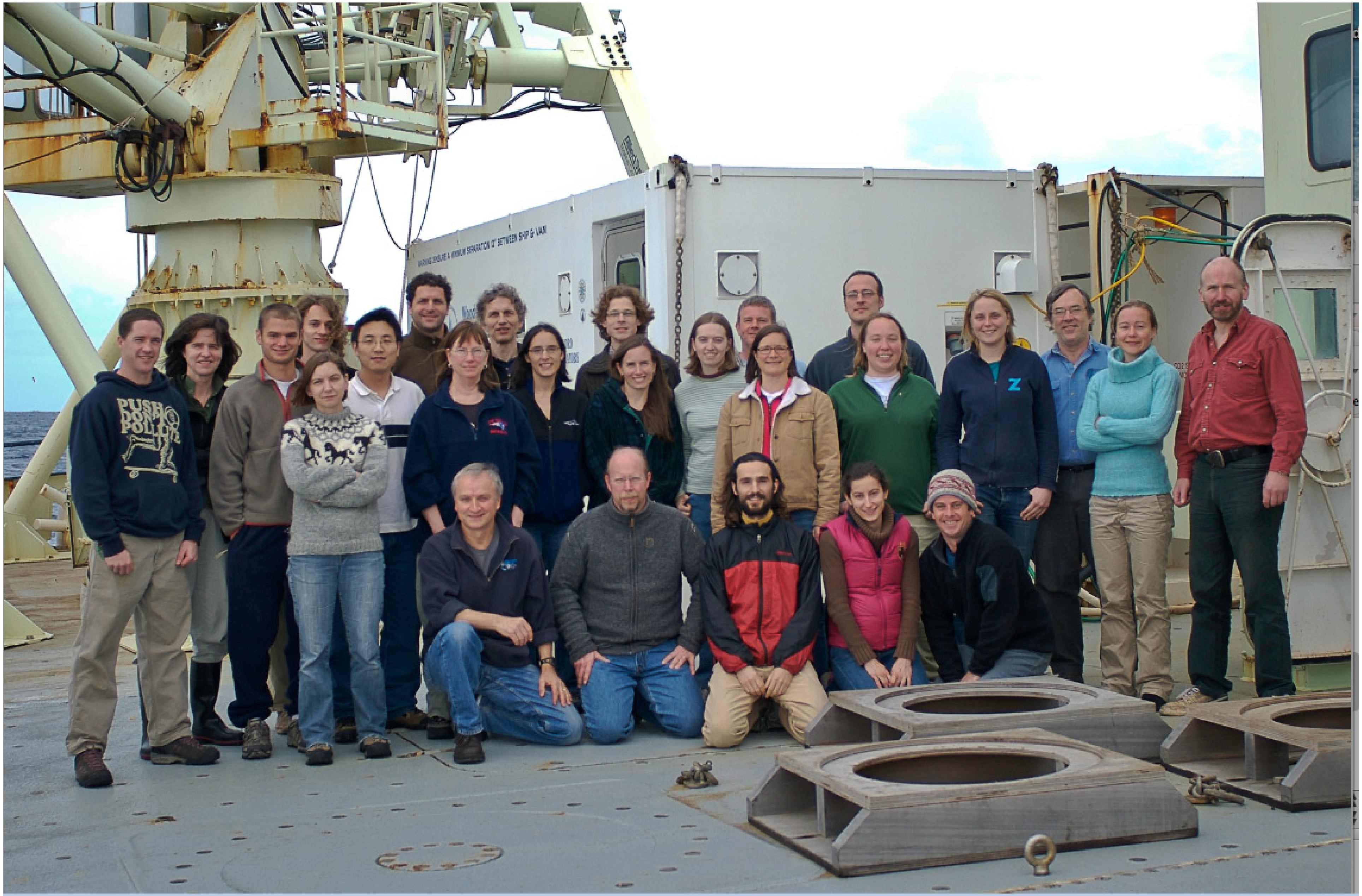
- ocean is **patchy** from meters to kilometers
- blooms are **ephemeral**, difficult to 'catch' a bloom
- understand as much of annual cycle in open ocean

What did we try to resolve?

– complexity of space and time scales

– mechanisms for bloom initiation (climate change & phenology) – changes in phytoplankton community composition in S & T

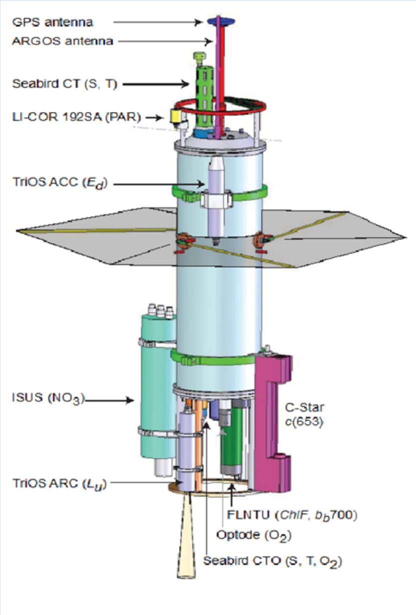
– variety of carbon productivities



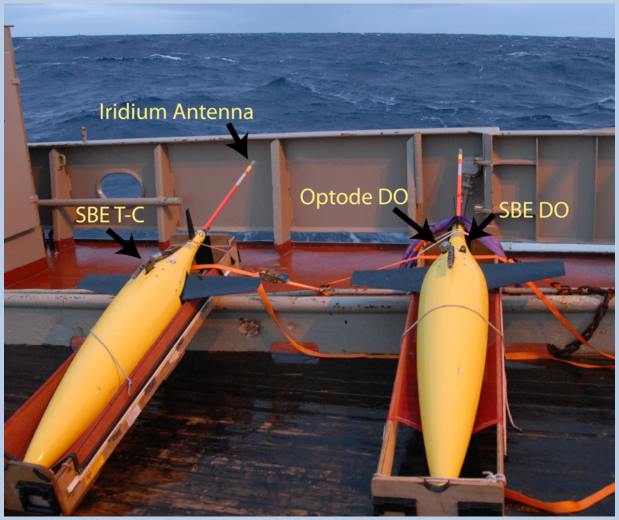
***R/V Knorr* with 28 scientists (half were students) – 7 countries**

- **Combination** of autonomous assets, ships, satellites, models
- **Persistence** – deploy before bloom, resolve entire evolution
- **Cooperative** sampling by different vehicles and lots of data

Mixed layer float – defined Lagrangian frame. Daily profiles to 230 m.



Gliders – spatial context. Survey around floats. Profile to 1000 m ~ 5 hr.



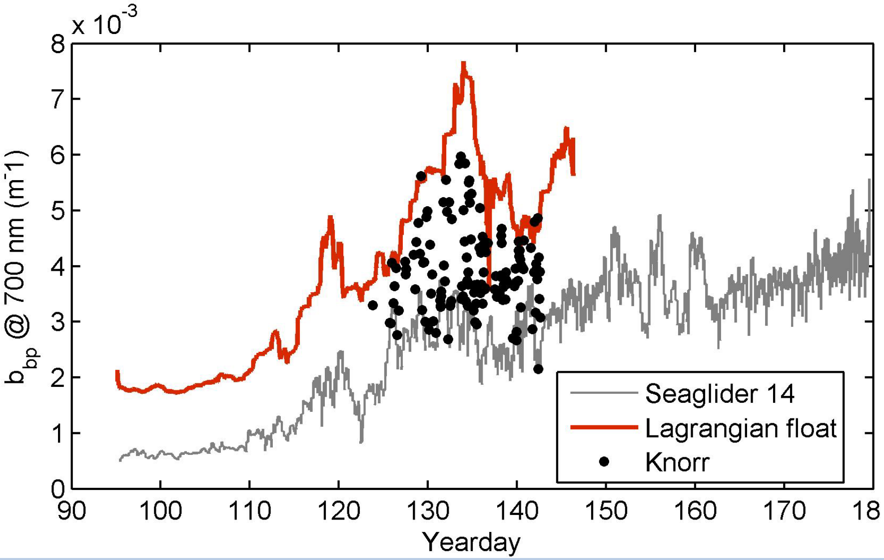
R/V Knorr & Sæmundsson – calibration, proxy data. Extensive biological and chemical measurements.

More Variables → More Measurements

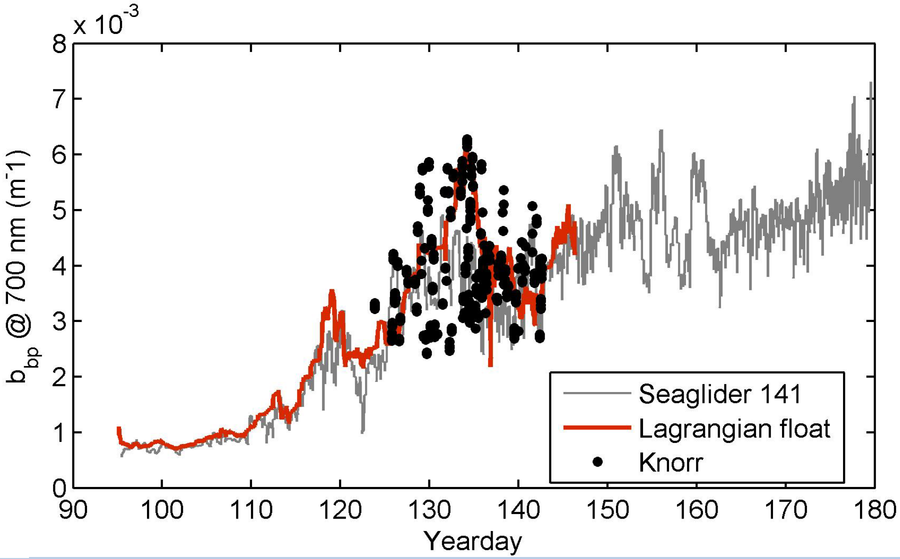
CTD/Rosette	Lagrangian Float	Seagliders
• Discrete samples – Pigment analysis – Phytoplankton – POC – absorption(λ)		
• CTD	☐ CTD	☐ CTD
• PAR (Ed)	☐ PAR (Ed)	
• b_{bp}	☐ b_{bp}	☐ b_{bp}
• Chl fluor	☐ Chl fluor	☐ Chl fluor
• Oxygen	☐ Oxygen	☐ Oxygen
• C-Star	☐ C-Star	

Careful calibration of all sensors

1. Mass factory calibration – before and after experiment
2. In situ calibration – simultaneous profiles of ship CTD and float or glider, multiple times, proximity matters
3. Made six to ten different sensors agree **(bb**, c, Chl, O2, NO3)

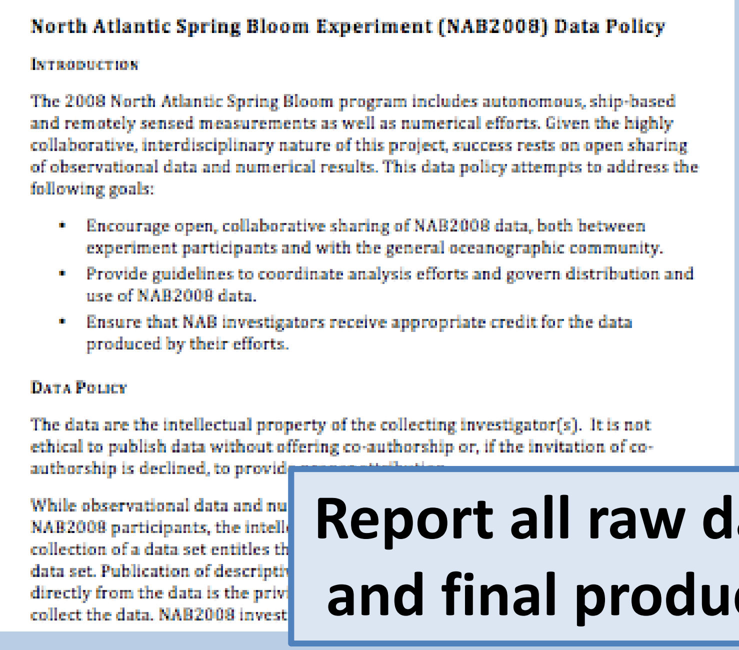


Before cross-calibration



After cross-calibration

Highly detailed documentation of data – in BCO-DMO



North Atlantic Spring Bloom Experiment (NAB2008) Data Policy

INTRODUCTION

The 2008 North Atlantic Spring Bloom program includes autonomous, ship-based and remotely sensed measurements as well as numerical efforts. Given the highly collaborative, interdisciplinary nature of this project, success rests on open sharing of observational data and numerical results. This data policy attempts to address the following goals:

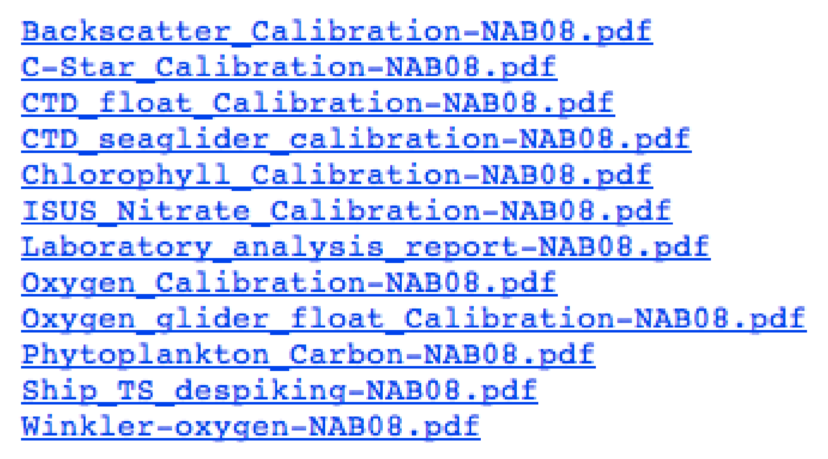
- Encourage open, collaborative sharing of NAB2008 data, both between experiment participants and with the general oceanographic community.
- Provide guidelines to coordinate analysis efforts and govern distribution and use of NAB2008 data.
- Ensure that NAB investigators receive appropriate credit for the data produced by their efforts.

DATA POLICY

The data are the intellectual property of the collecting investigator(s). It is not ethical to publish data without offering co-authorship or, if the invitation of co-authorship is declined, to provid

While observational data and nu
NAB2008 participants, the intell
collection of a data set entitles th
data set. Publication of descripti
directly from the data is the priv
collect the data. NAB2008 invest

Report all raw data and final products

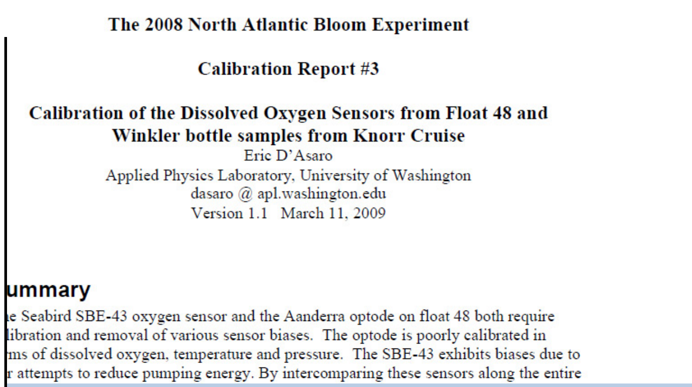


Backscatter_Calibration-NAB08.pdf
C-Star_Calibration-NAB08.pdf
CTD_float_Calibration-NAB08.pdf
CTD_seaglider_calibration-NAB08.pdf
Chlorophyll_Calibration-NAB08.pdf
ISUS_Nitrate_Calibration-NAB08.pdf
Laboratory_analysis_report-NAB08.pdf
Oxygen_Calibration-NAB08.pdf
Oxygen_glider_float_Calibration-NAB08.pdf
Phytoplankton_Carbon-NAB08.pdf
Ship_TS_despiking-NAB08.pdf
Winkler-oxygen-NAB08.pdf

The 2008 North Atlantic Bloom Experiment
Calibration Report #7
Intercalibration of the Backscatter sensors from Float 47 & Knorr cruise

Nathan Briggs (nathan.m.briggs@maine.edu)
Darling Marine Center, University of Maine, Orono
.5: October 15, 2009

ite backscatter at 700nm were deployed during the
(NAB08). There was one on each of the two floats,

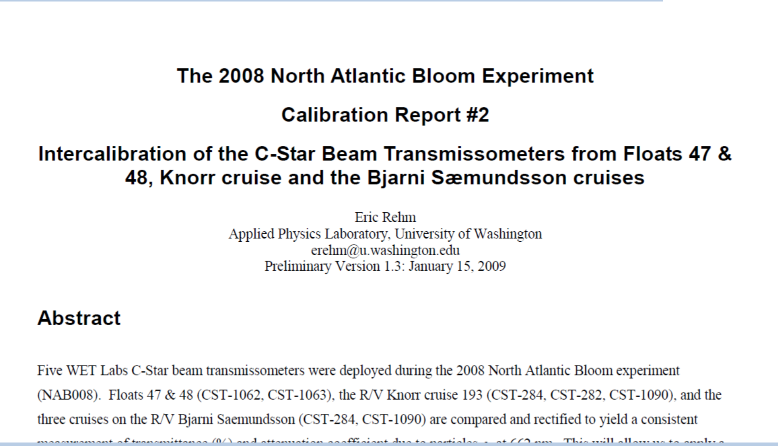


The 2008 North Atlantic Bloom Experiment

Calibration Report #3

Calibration of the Dissolved Oxygen Sensors from Float 48 and Winkler bottle samples from Knorr Cruise
Eric D'Asaro
Applied Physics Laboratory, University of Washington
dasaro @ apl.washington.edu
Version 1.1 March 11, 2009

ummary
e Seabird SBE-43 oxygen sensor and the Aanderra optode on float 48 both require
ibration and removal of various sensor biases. The optode is poorly calibrated in
ms of dissolved oxygen, temperature and pressure. The SBE-43 exhibits biases due to
r attempts to reduce pumping energy. By intercomparing these sensors along the entire



The 2008 North Atlantic Bloom Experiment

Calibration Report #2

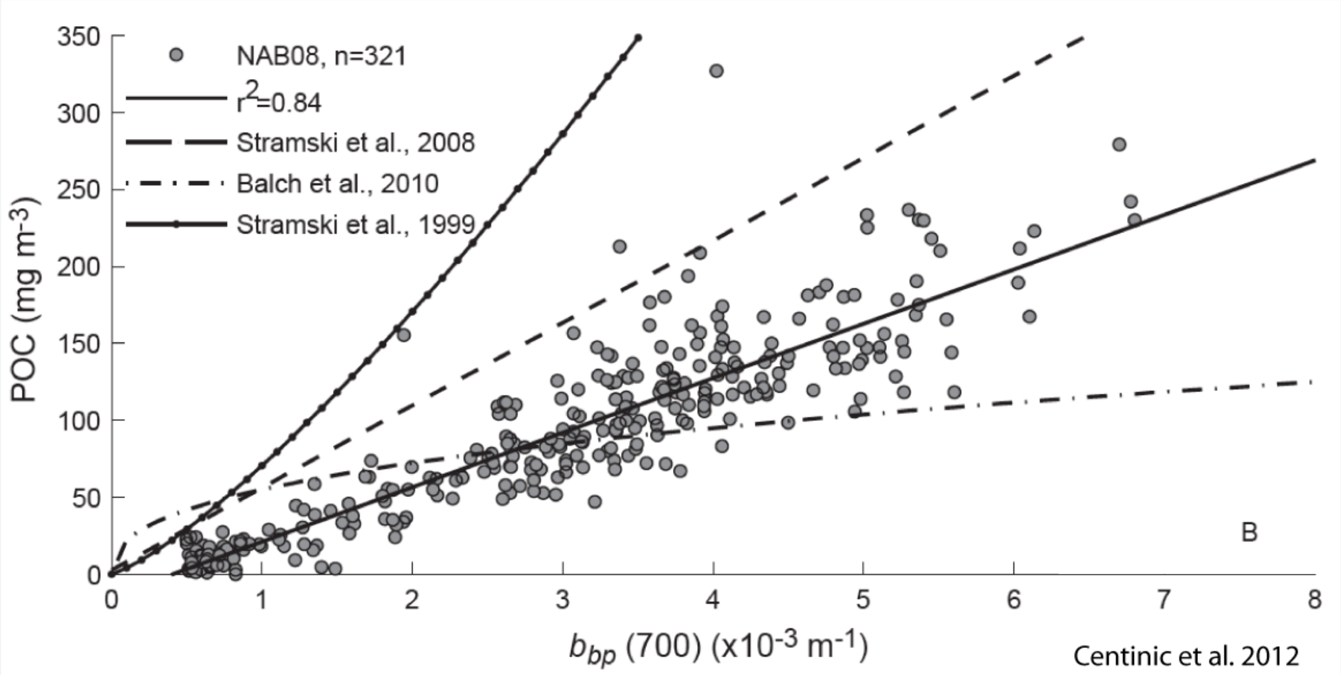
Intercalibration of the C-Star Beam Transmissometers from Floats 47 & 48, Knorr cruise and the Bjarni Sæmundsson cruises

Eric Rehm
Applied Physics Laboratory, University of Washington
erehm@u.washington.edu
Preliminary Version 1.3: January 15, 2009

Abstract

Five WET Labs C-Star beam transmissometers were deployed during the 2008 North Atlantic Bloom experiment (NAB008). Floats 47 & 48 (CST-1062, CST-1063), the R/V Knorr cruise 193 (CST-284, CST-282, CST-1090), and the three cruises on the R/V Bjarni Saemundsson (CST-284, CST-1090) are compared and rectified to yield a consistent

Build proxies to project $$$ ship measurements to simple optical measurements



Centinic et al. 2012

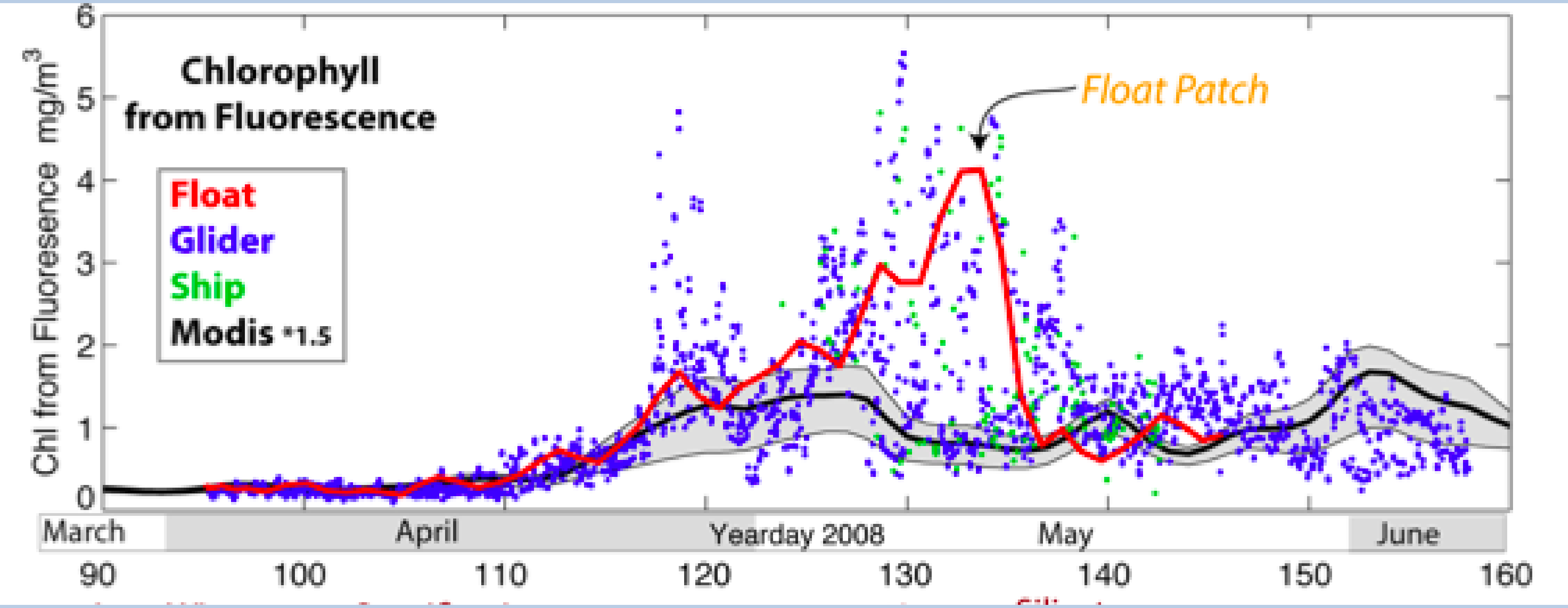
321 POC samples
+
3 million bbp
=
3 million POC

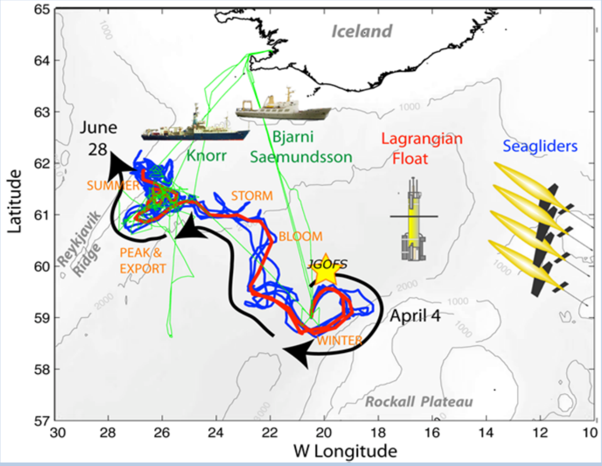
Optical
backscatter
to POC

All ~~models~~ proxies are wrong but some are useful;

bulk measurements are not obsolete.

Cetinic et al., 2012



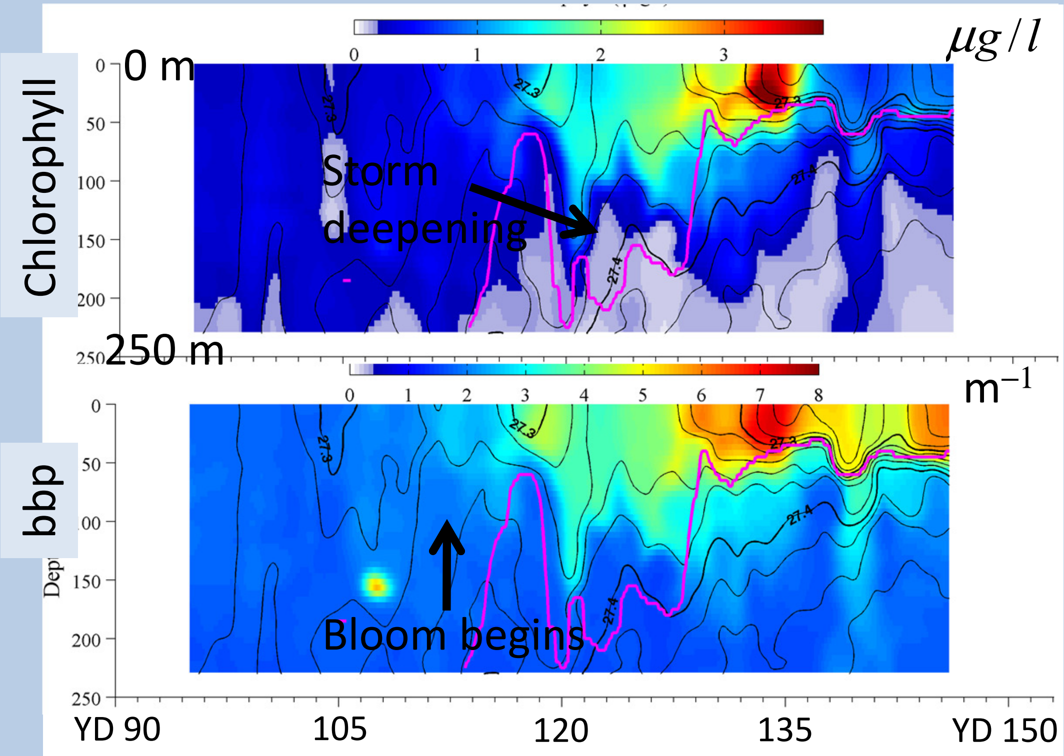


The spring bloom:

- began before ship arrived
- diatom bloom
- patchy

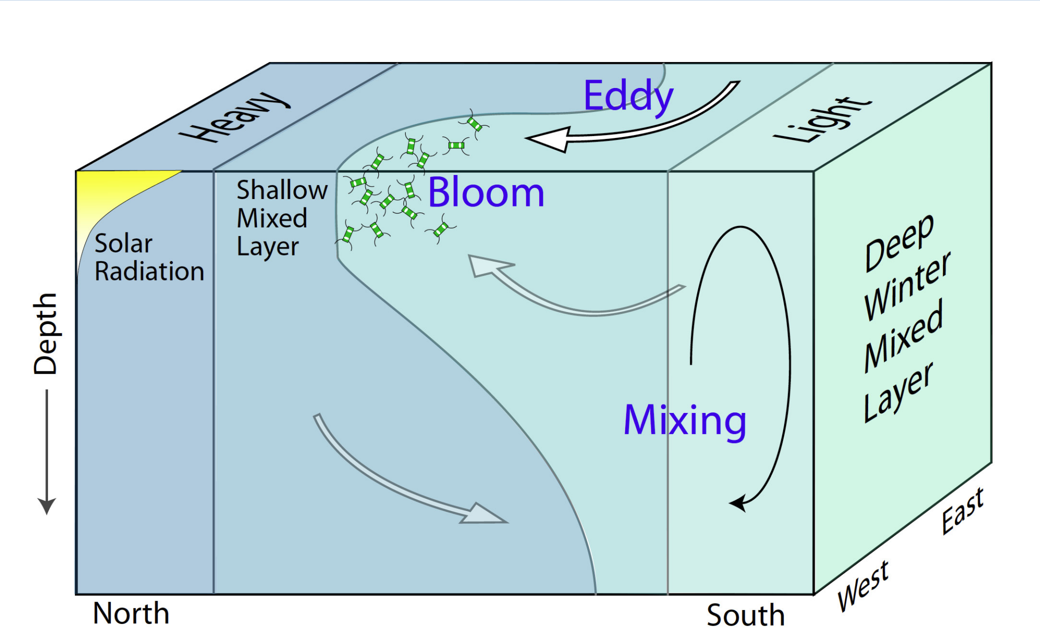
Mahadevan el al. 2012

Bloom evolution as seen by Lagrangian float

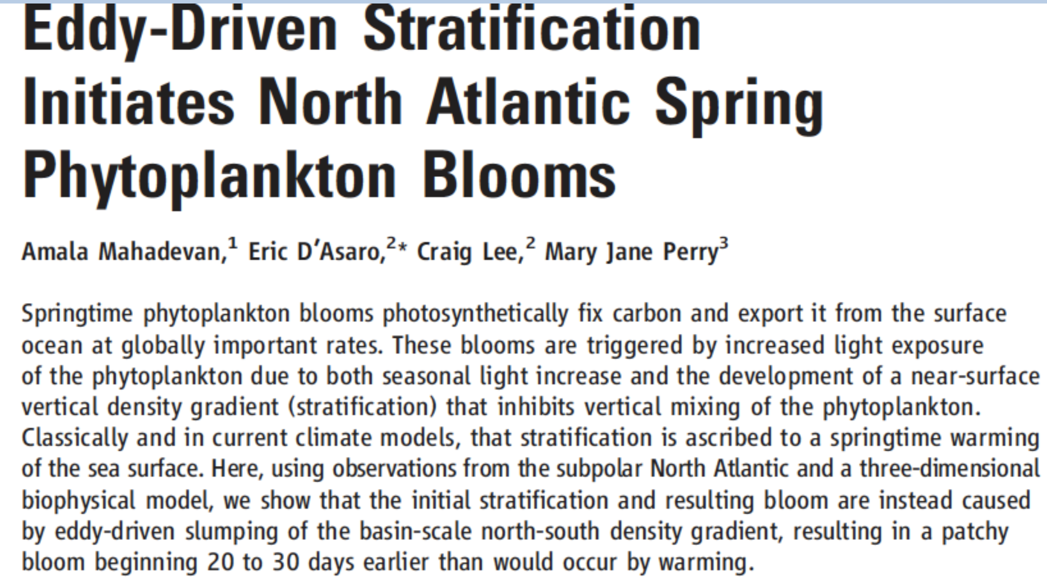


- ML shallows rapidly and bloom begins YD 110.
- Backscatter and beam attenuation rise.
- Dissolved oxygen concentration rises, ML nitrate decreases.
- ML restratification typically attributed to solar warming, but…
- ML cools during bloom initiation.
- What initiates bloom?

Alkire el al. 2012



Mahadevan el al. 2012



Eddy-Driven Stratification Initiates North Atlantic Spring Phytoplankton Blooms

Amala Mahadevan,[1] Eric D'Asaro,[2]* Craig Lee,[2] Mary Jane Perry[3]

Springtime phytoplankton blooms photosynthetically fix carbon and export it from the surface ocean at globally important rates. These blooms are triggered by increased light exposure of the phytoplankton due to both seasonal light increase and the development of a near-surface vertical density gradient (stratification) that inhibits vertical mixing of the phytoplankton. Classically and in current climate models, that stratification is ascribed to a springtime warming of the sea surface. Here, using observations from the subpolar North Atlantic and a three-dimensional biophysical model, we show that the initial stratification and resulting bloom are instead caused by eddy-driven slumping of the basin-scale north-south density gradient, resulting in a patchy bloom beginning 20 to 30 days earlier than would occur by warming.

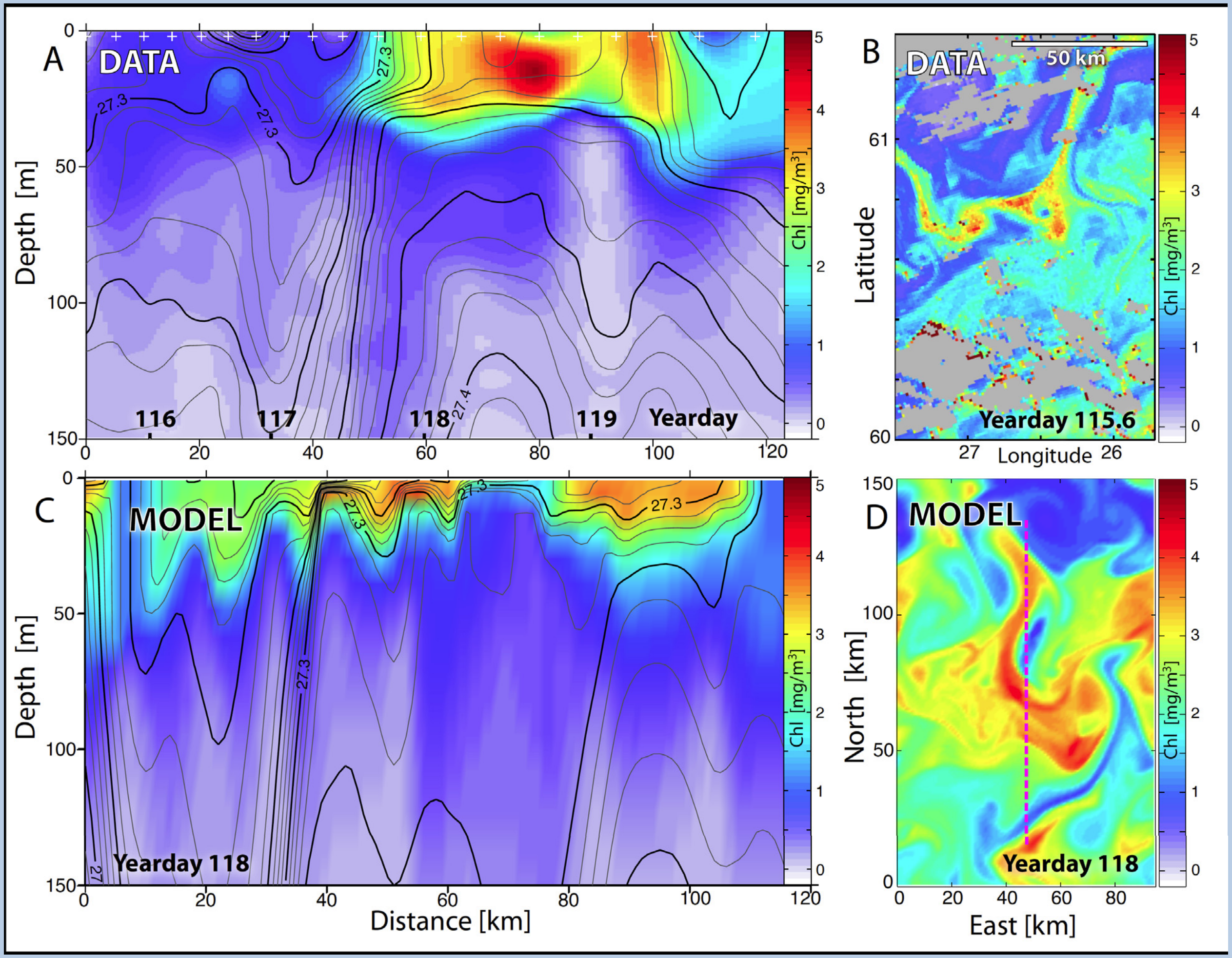
Eddy-drive Restratification:

- submesoscale (1-10 km) ML eddies 'slump' lateral density gradients.
- converts horizontal density contrasts to vertical stratification.

Bloom initiation:

- onset coupled stratification.
- without ML eddies, stratification & bloom delayed 20-30 days.
- similar timing across all platforms.
- termination when silicate is exhausted.

Patchy bloom due to patchy stratification



Mahadevan el al. 2012

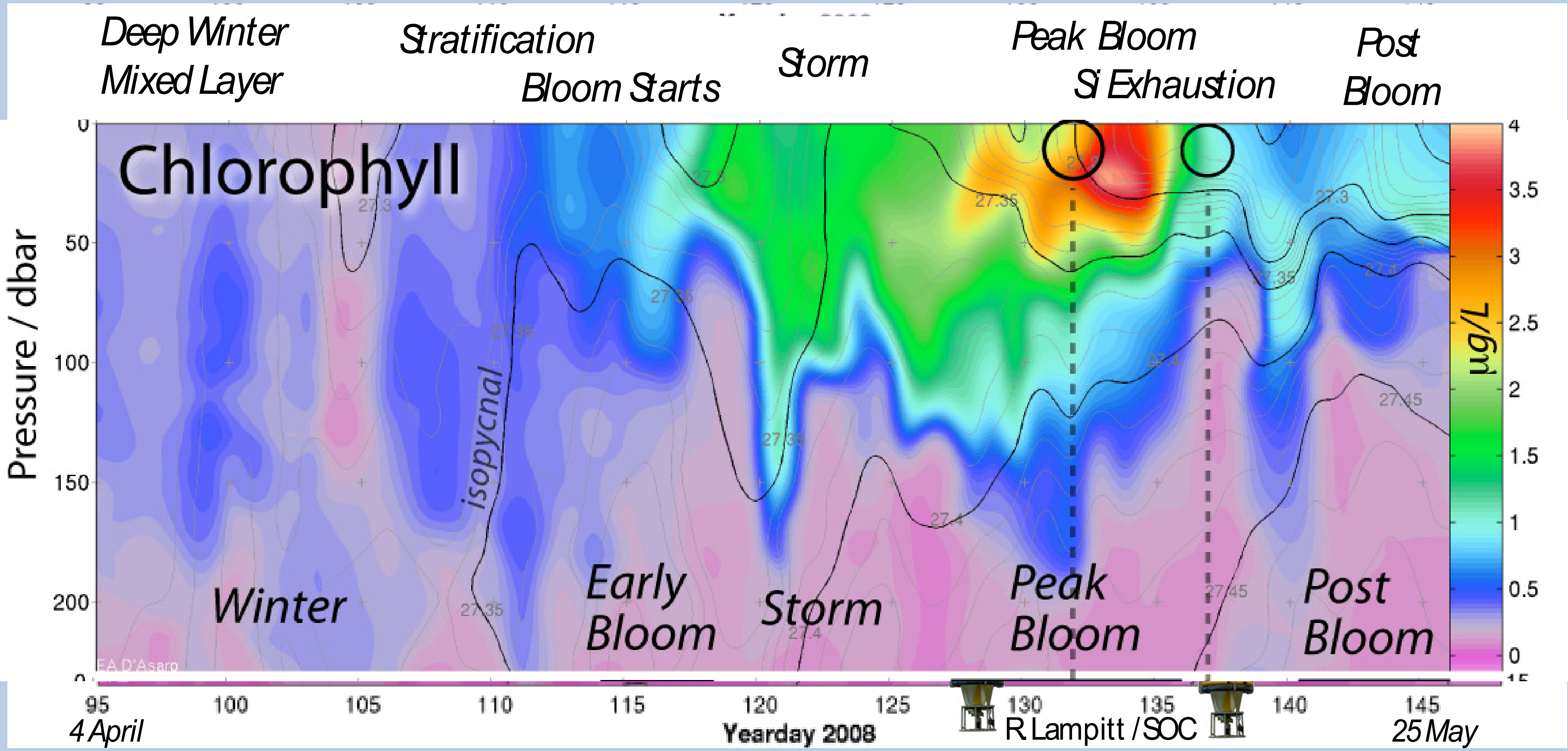
Phytoplankton growth highest where stratification is strongest (increased light exposure).

Stratification controls bloom patchiness…. Scales and shapes contain information about dominant processes.

ML eddies produce patchy (1-10 km) stratification, straining into elongated filaments. Consistent with NAB08 observations & simulations.

Other factors (e.g. differential nutrient supply, grazing) may also drive patchiness.

Lagrangian float followed a patch in April and May, measuring NO3, O2, POC (float sensors well calibrated by ship)



Alkire et al., 2012

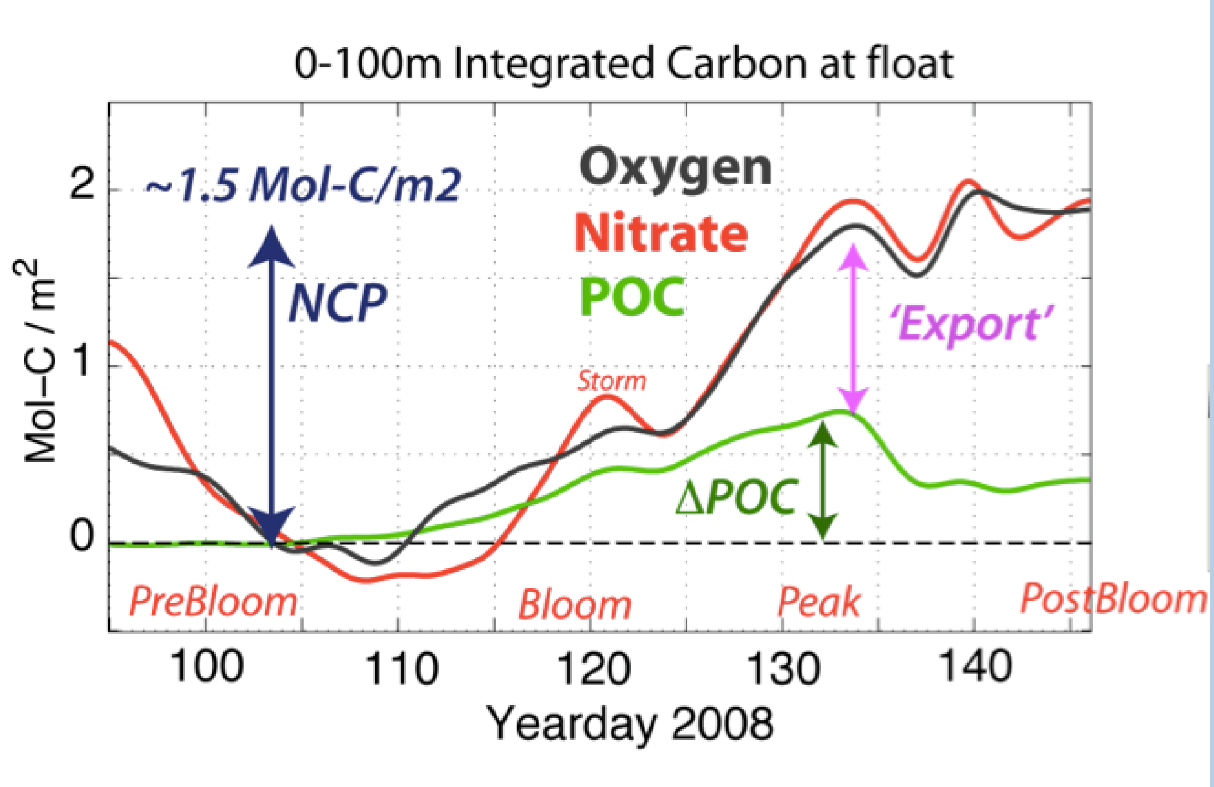
Net Community Production from Lagrangian O2 and NO3

NCP= Primary Production - Respiration

= Decrease in NO_3 x C:N Redfield

= Increase in O_2 + O_2 loss to atmosphere x O:C (PQ)

= Increase in POC - Carbon Export + [increase in DOC]

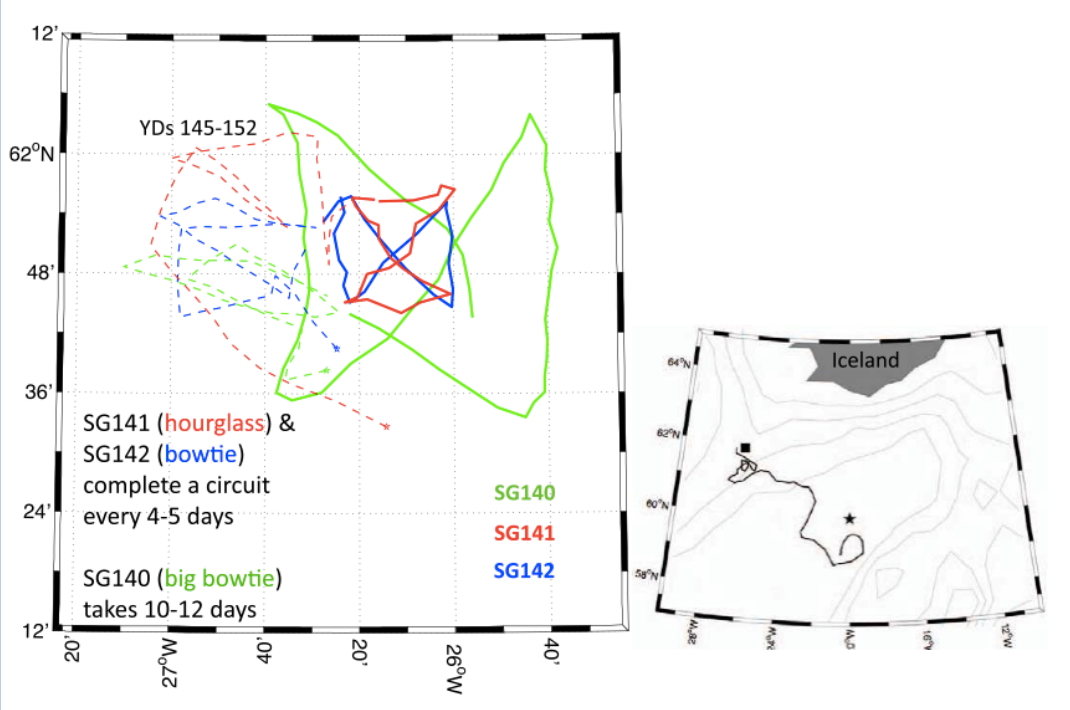


Much of net fixed carbon is exported.

Export ratio
= Export / NCP
~ 30 – 70%

Alkire et al., 2012

Net Community Production from Eularian measurements of O2 & POC from 3 gliders in June

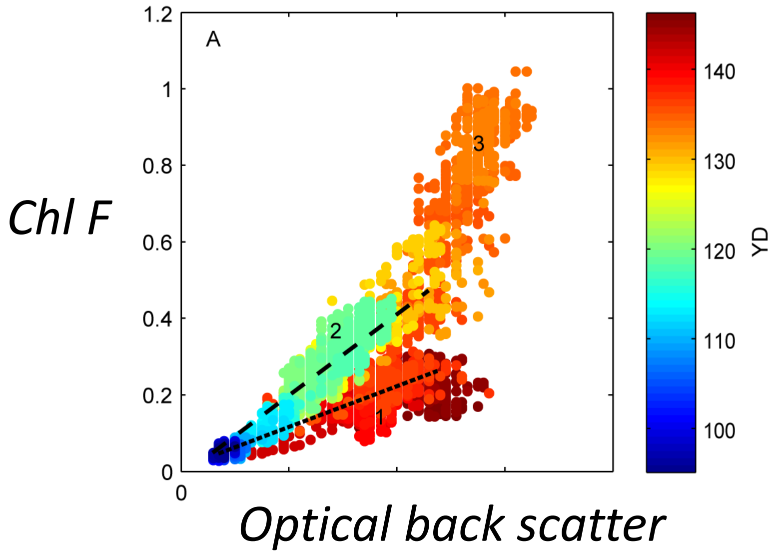


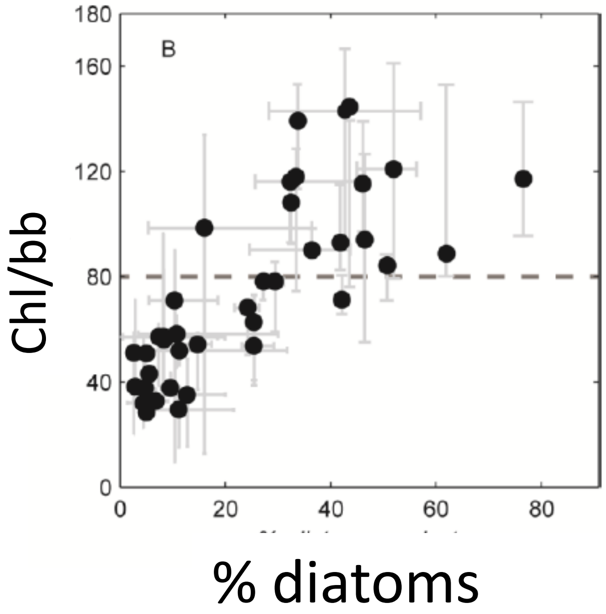
(glider sensors well calibrated by ship)

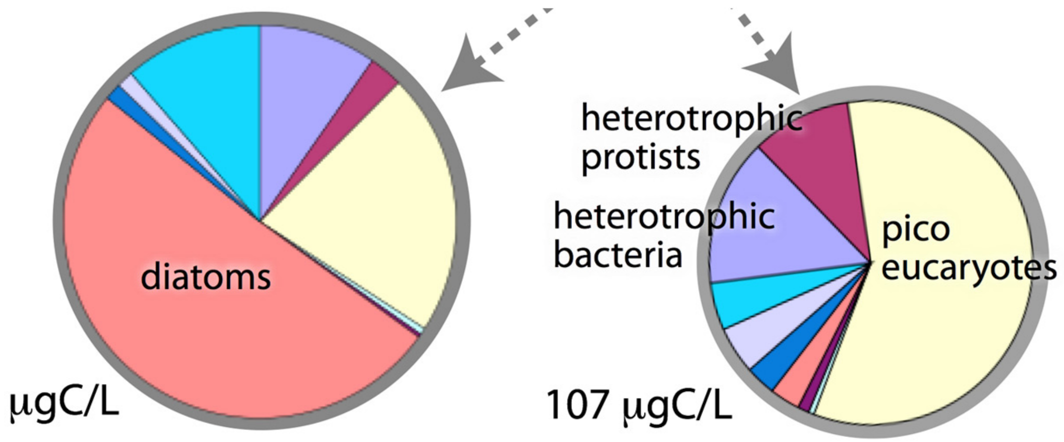
- Eulerian reference frame – great care to account for local rate of change, vertical mixing, air-sea exchange, and horizontal advection.
- NCP for O2 ~ 1.0 mol C m-2
- POC export ~ 0.6 mol C m-2
- carbon production and export was comparable to that during diatom spring bloom.

Alkire et al., 2014

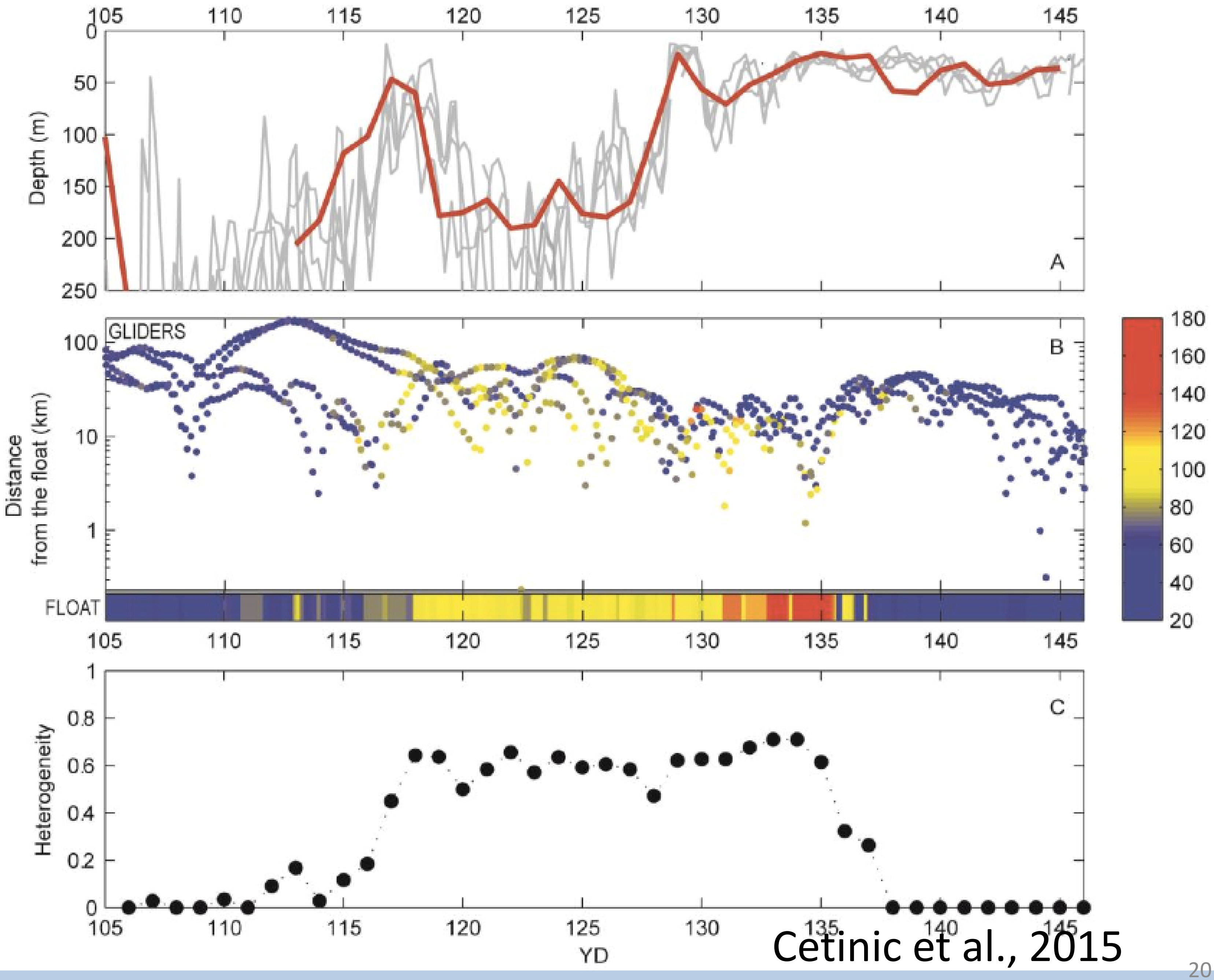
Optical proxy for community composition: *Chl F/bbp*





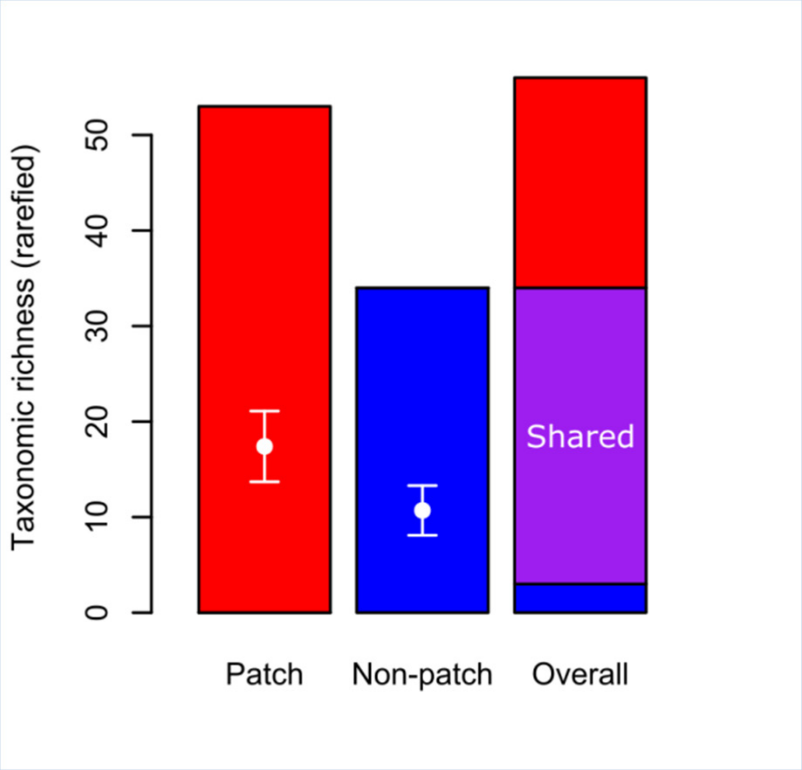


Cetinic et al., 2015



Cetinic et al., 2015

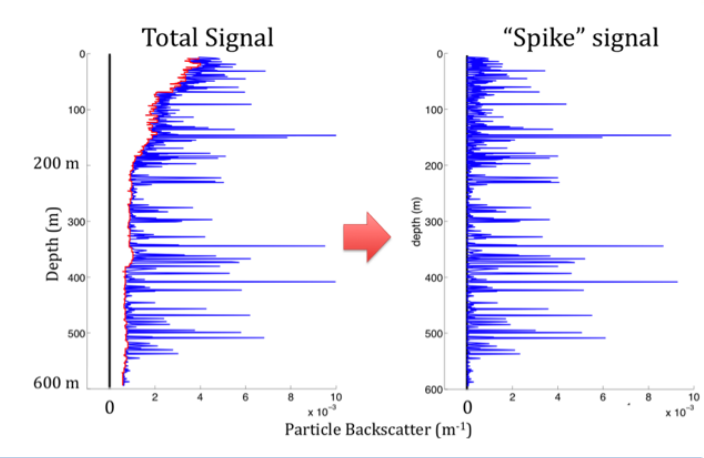
Sub-mesoscale fronts structure spatiotemporal patterns in marine phytoplankton diversity

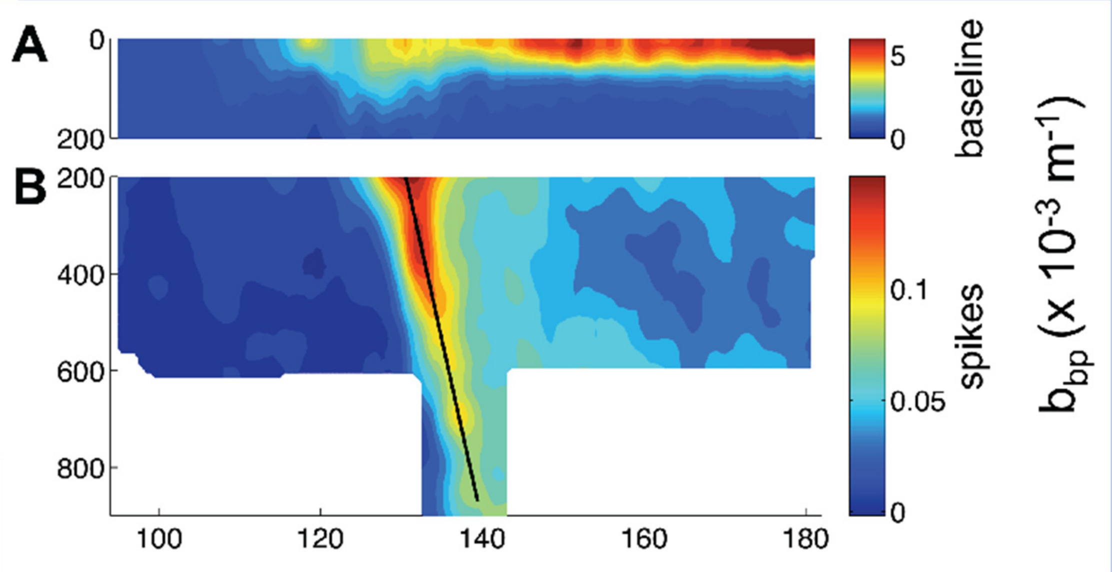


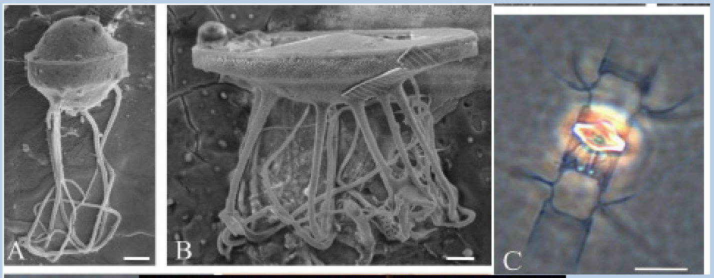
Similarities in community composition within and outside the patch were driven by small generalist taxa whereas **differences** were driven by typical bloom species (especially of the genus *Chaetoceros*), resulting in two functionally different communities despite very similar environmental conditions.

Mousing et al. (submitted)

Gliders observe large scale carbon flux event below 200 m



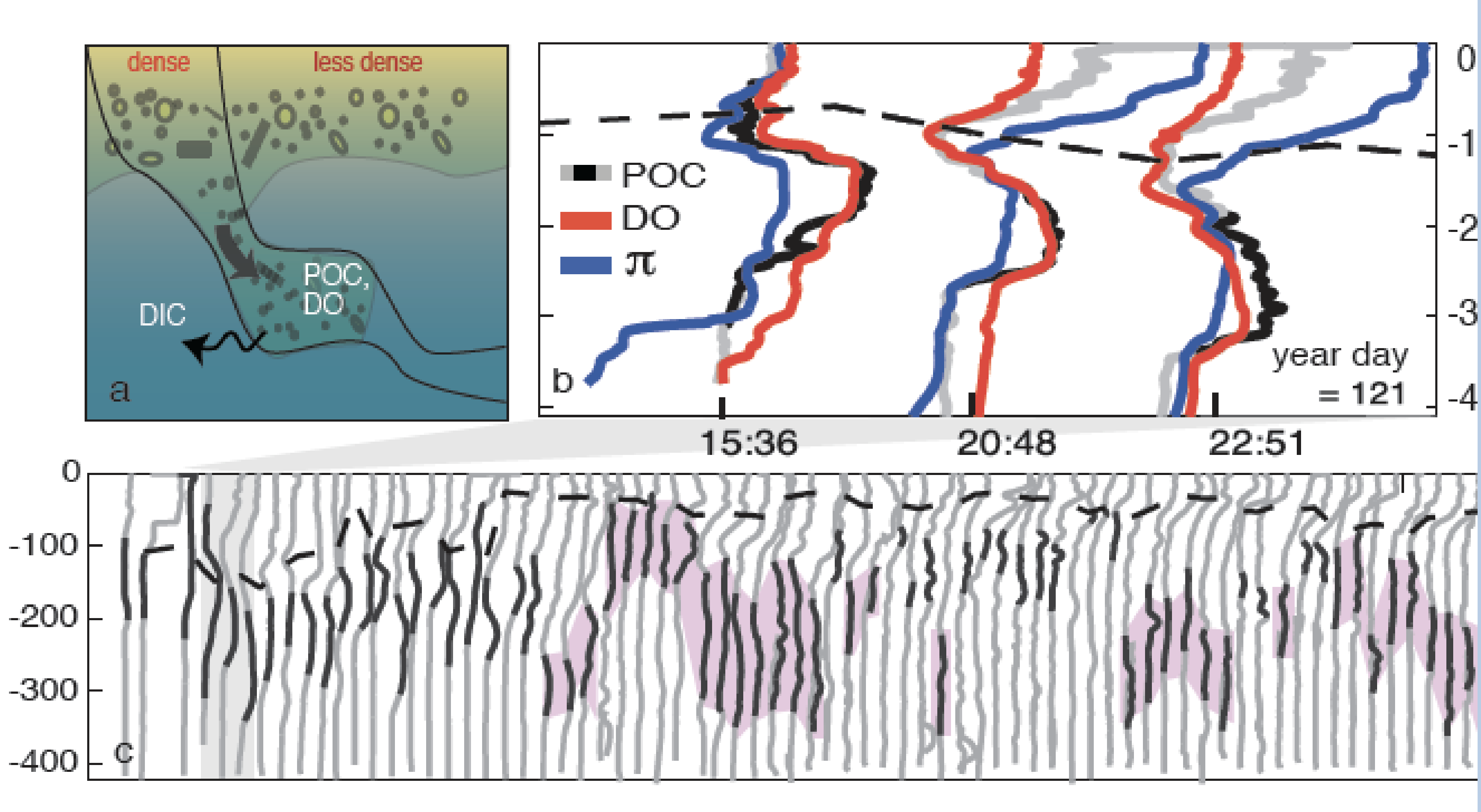




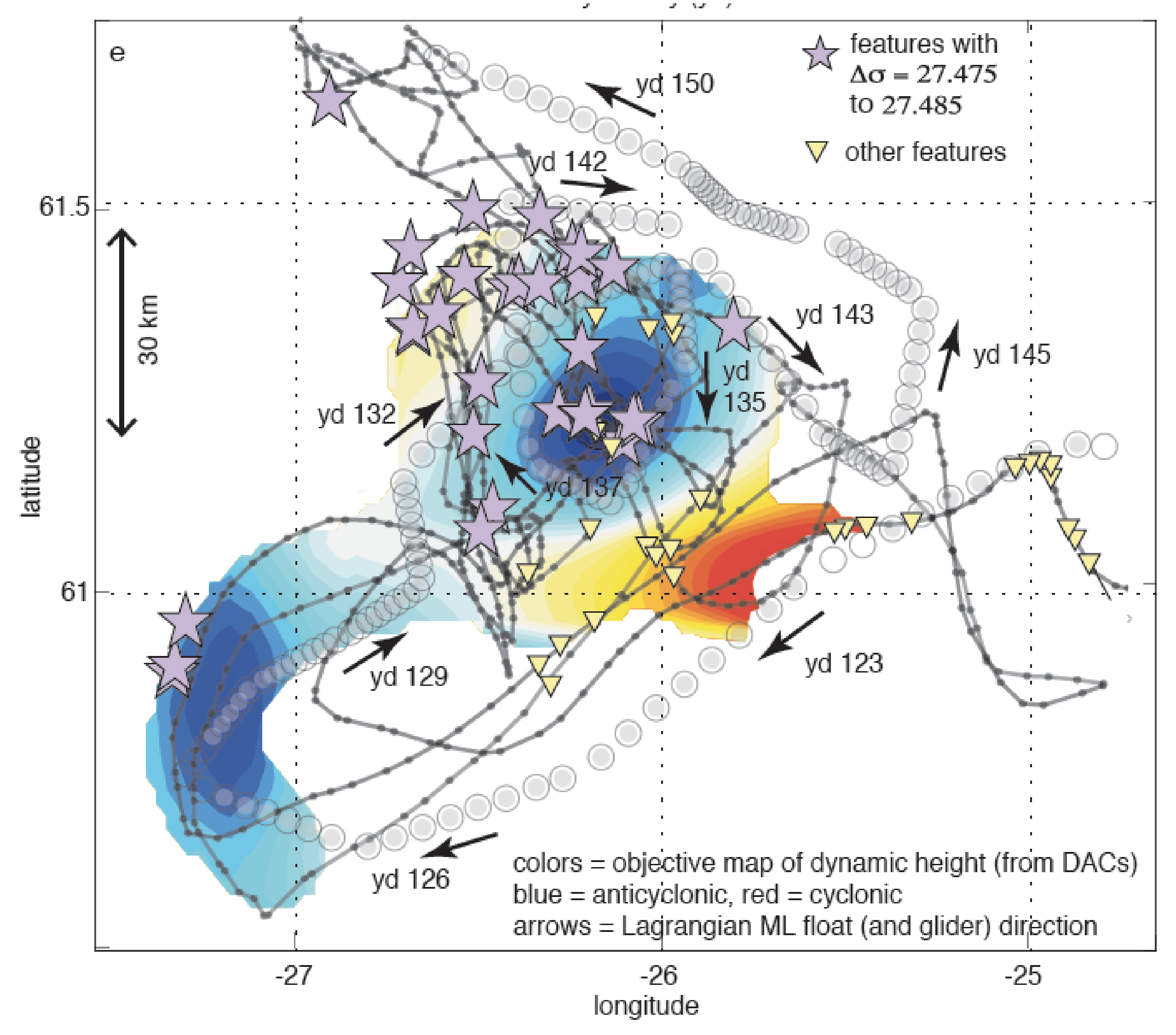
- Sinking of diatom aggregates (optical spikes).
- How much carbon passes through the twilight zone?
- Diatom spores are resistant.

Briggs et al., 2011
Martin et al., 2011
Rynearson et al., 2013

Eddy-driven subduction exports particulate organic carbon from the spring bloom



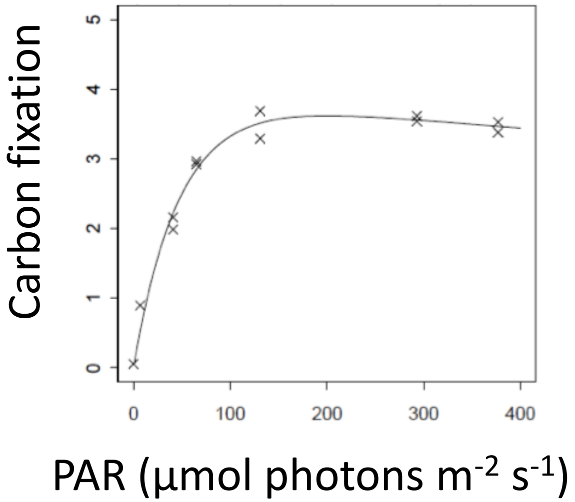
Omand et al., 2015



Omand et al., 2015

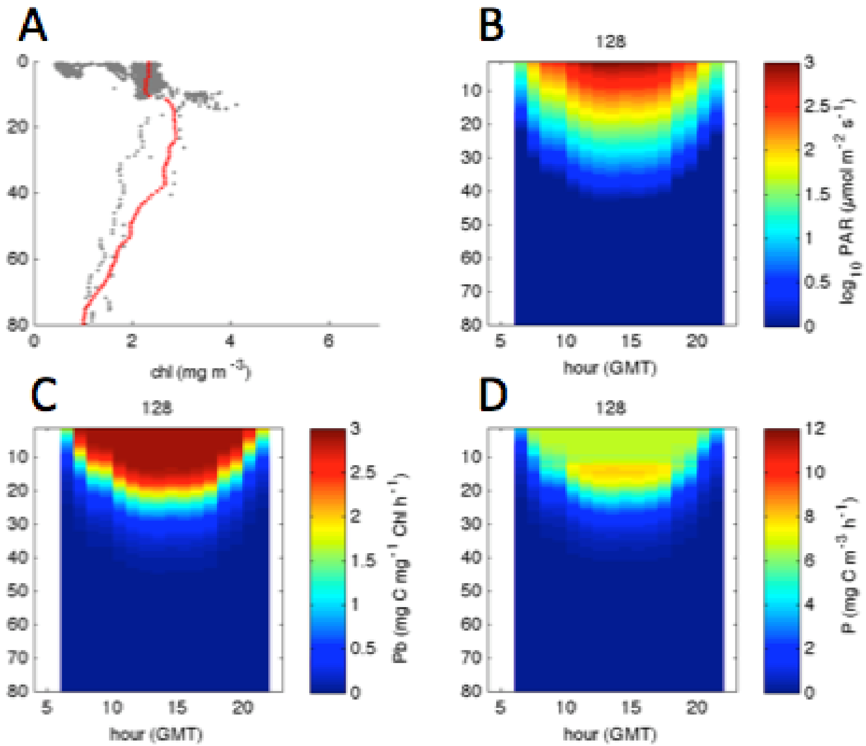
Net phytoplankton productivity

Ship-based P vs. E
normalized to Chl



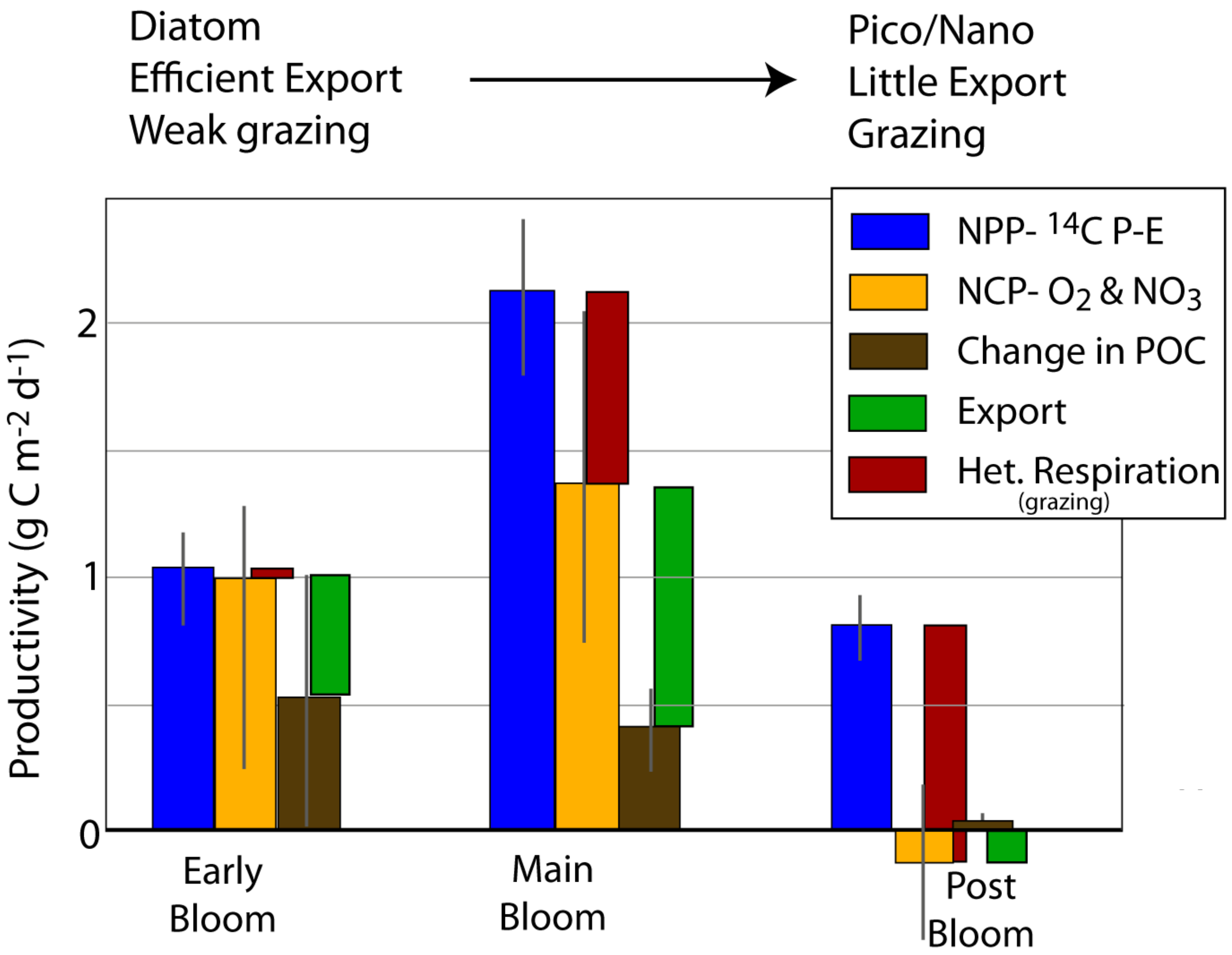
(K. Gudmundsson et al., in prep.)

Hourly from float –
Chl, PAR, PP/Chl, PP



Daily estimates of water column PP

Characterize the state of the carbon cycle – autonomously



D’Asaro et al.

How do autonomous assets expand the temporal and spatial footprint of a shipboard process study?

This is still a research question.

In NAB 2008, learned how to do the patch,
but not the basin. There's more to learn.