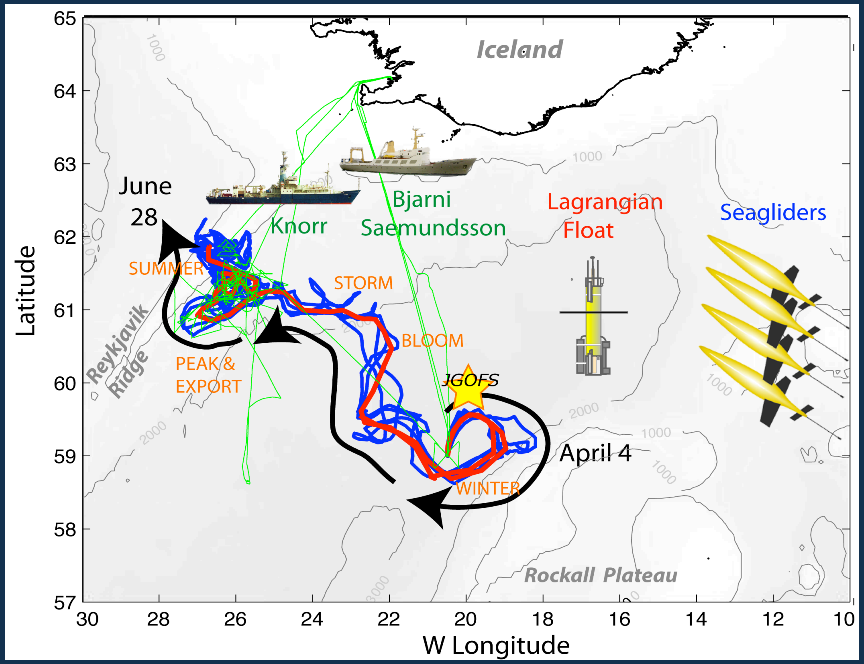
North Atlantic bloom dynamics: Insights from an interdisciplinary, multi-platform process study



Craig Lee and Eric D'Asaro
University of Washington

Mary Jane Perry
University of Maine

1) autonomous observing
2) NAB 08
3) looking forward

A Planning Workshop for an International Research Program on the Coupled North Atlantic – Arctic System

April 14-16, 2014

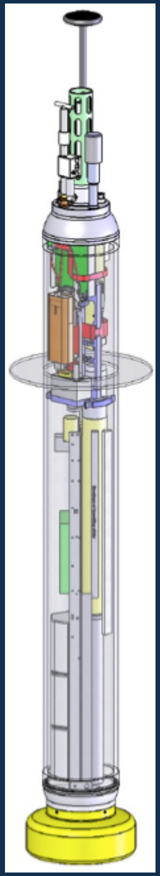
Why the North Atlantic – Subpolar and Arctic? Why now?

- **Coalescence of needs** – understand processes in changing oceans, predict ecosystem responses, and prepare for societal implications.

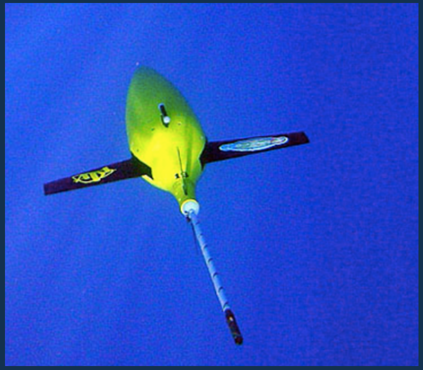
- Many of **science and management questions** demand long-term basin-scale approach, and access to inhospitable locations.

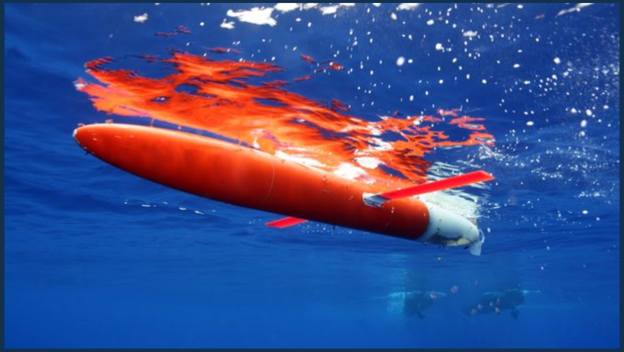
- Powerful new **observational capabilities** are mature; potential for synergistic international collaborations need to realized.

Autonomous platforms can act as the 'glue' for scaling up ship-based measurements and the' key' to data collection under clouds and ice, and in conditions inhospitable for ships.



Mature and evolving technologies

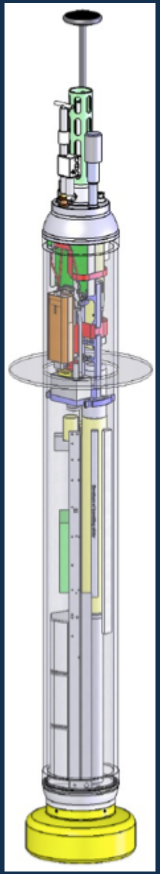


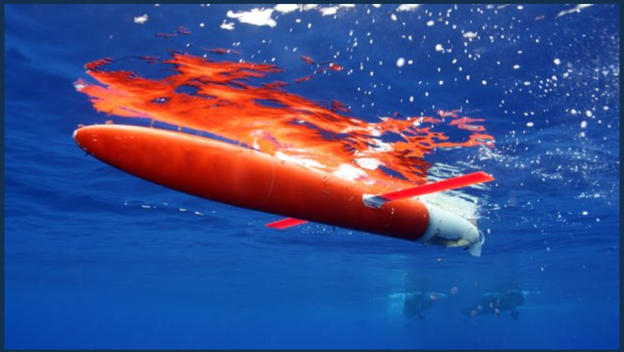


Autonomous platforms —

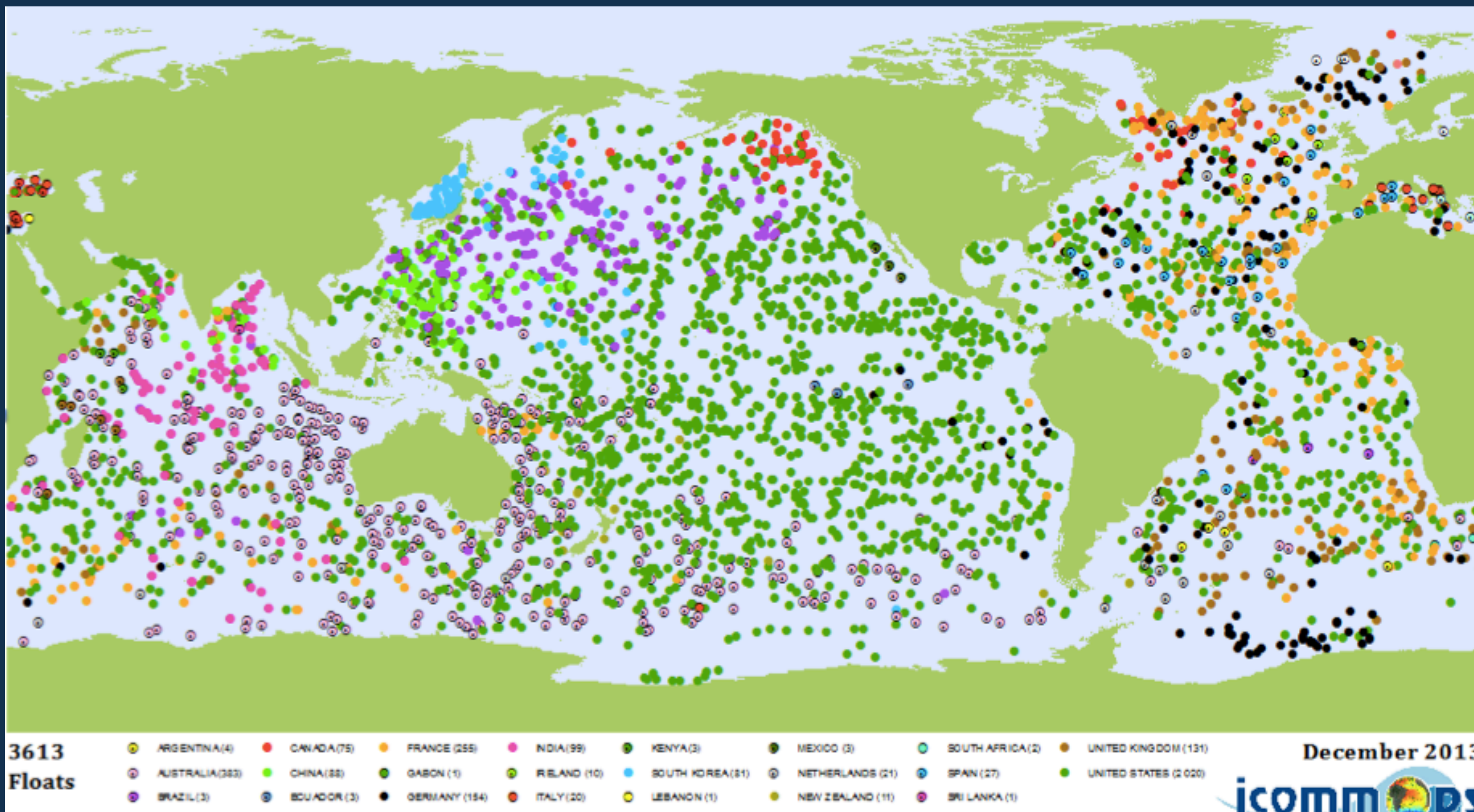
Diversity of platforms.
each with unique attributes
(match to the question)

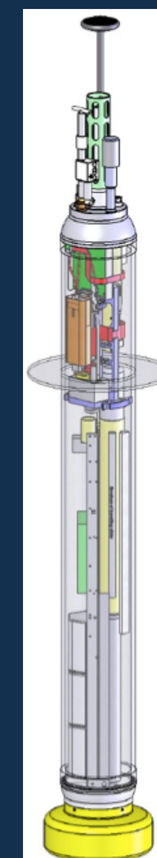
- persistence
- spatial scales
- sensor payload





Basin-scale ARGO floats – increasing number of floats with optics, O2,and a few with NO3 and pH (Bio Argo)

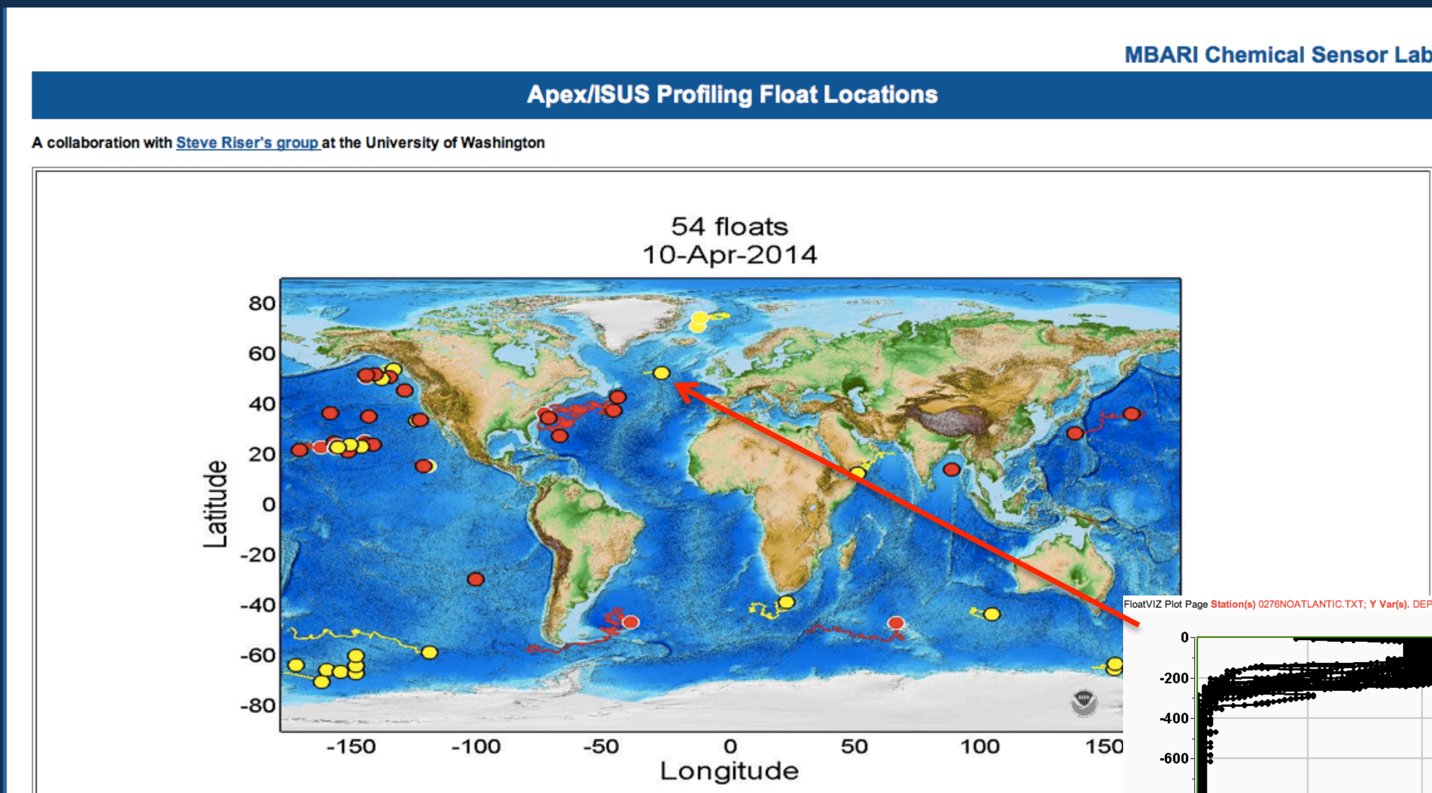


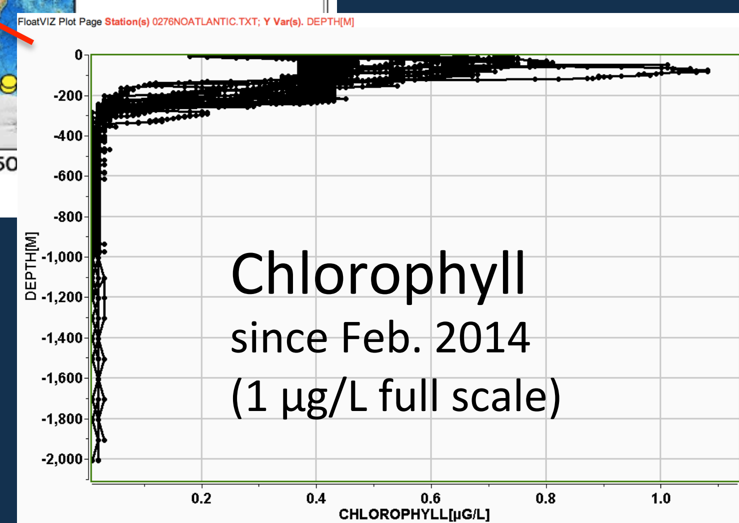


3560 floats on
13 April 2014

Slide courtesy of Ken Johnson and Hervé Claustre

Bio Argo float in North Atlantic at 53ºN, 32 W





Slide courtesy of Ken Johnson’ Float VIZ

Specialized floats – neutrally buoyant sediment traps


Contents lists available at ScienceDirect

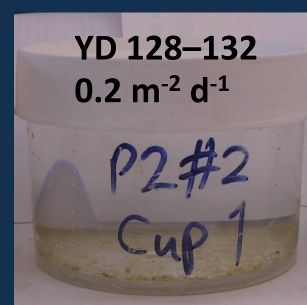
Deep-Sea Research I

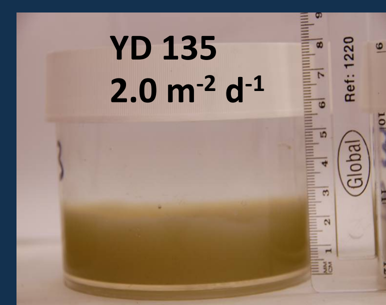
journal homepage: www.elsevier.com/locate/dsri

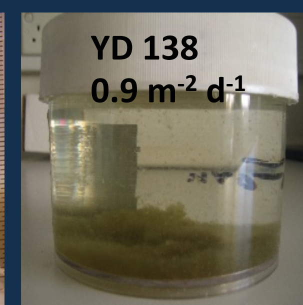
ELSEVIER

Export and mesopelagic particle flux during a North Atlantic spring diatom bloom

Patrick Martin[a,*], Richard S. Lampitt[a], Mary Jane Perry[b], Richard Sanders[a], Craig Lee[c], Eric D'Asaro[c]







Martin, Lampitt et al., 2011, DSR-I

Specialized floats – SOLOPC (zooplankton & aggregates)

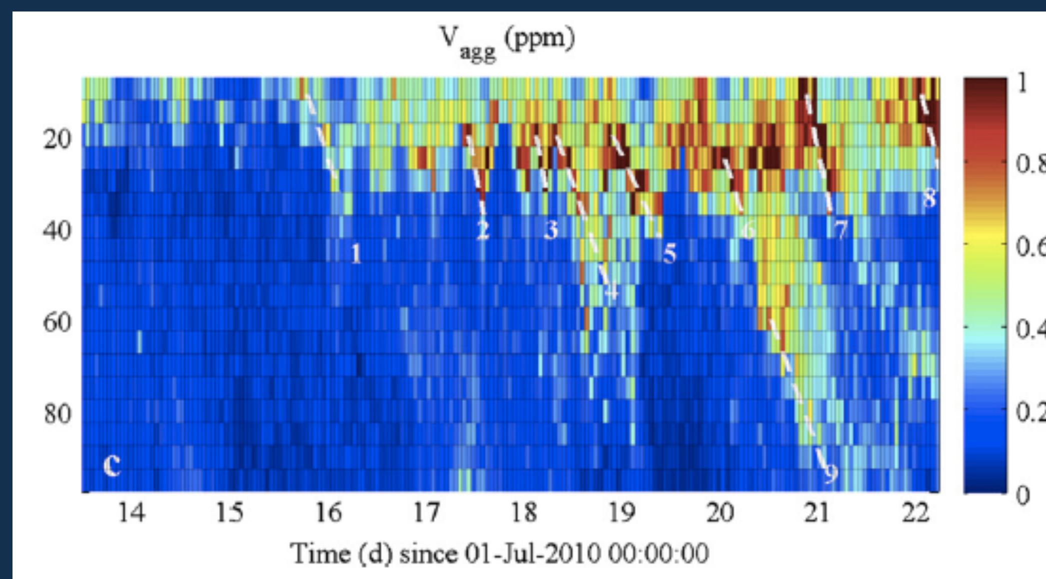
Contents lists available at SciVerse ScienceDirect

Deep-Sea Research I

journal homepage: www.elsevier.com/locate/dsri

Aggregates and their distributions determined from LOPC observations made using an autonomous profiling float

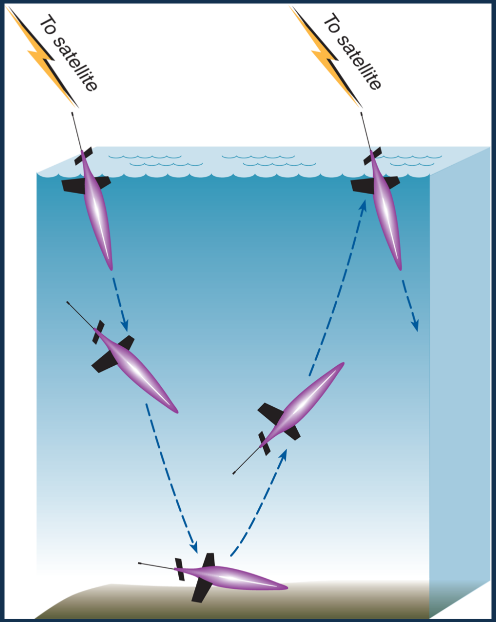
Colleen M. Petrik [a,*,1], George A. Jackson [a], David M. Checkley Jr. [b]

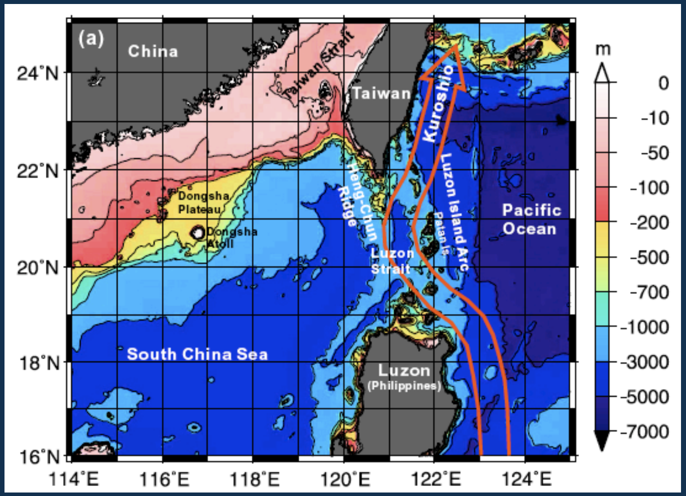


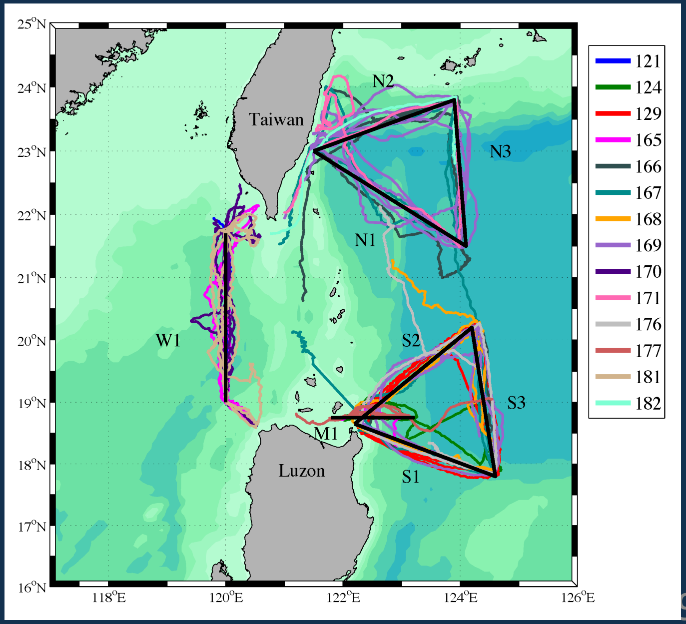
Aggregate volumes, Monterey Bay; depth to 100 m.

Sinking trajectories as white dotted lines.

Gliders – persistence and adaptable navigation





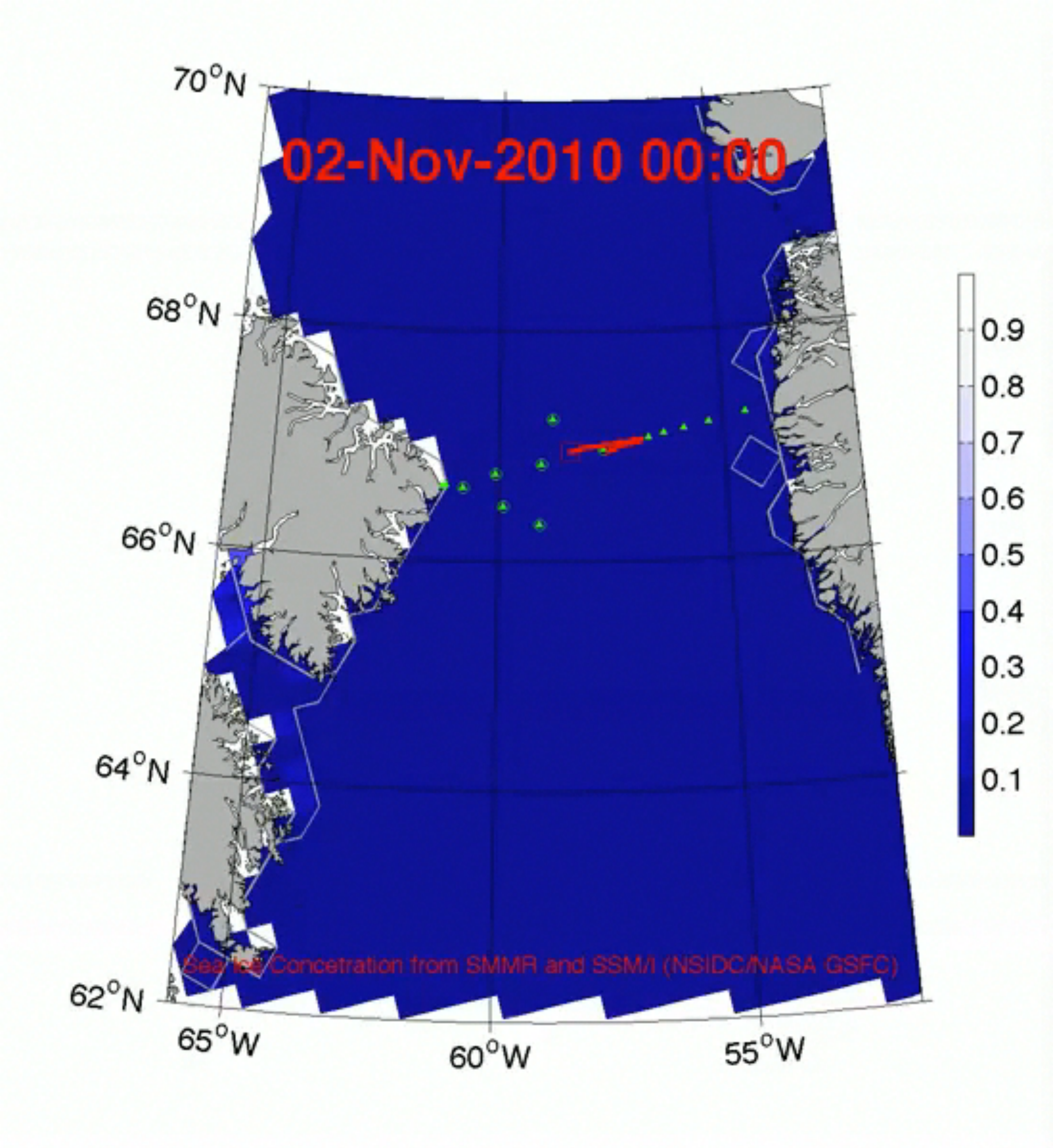


Lee – two years

STATION KEEPING IN KUROSHIO

- 2+ Years (2011 – 2013)
- 14 Seagliders; 20 missions
- 1,774 Days; 8,705 Dives

Gliders in Davis Strait– Operations Under Ice with Acoustic Navigation



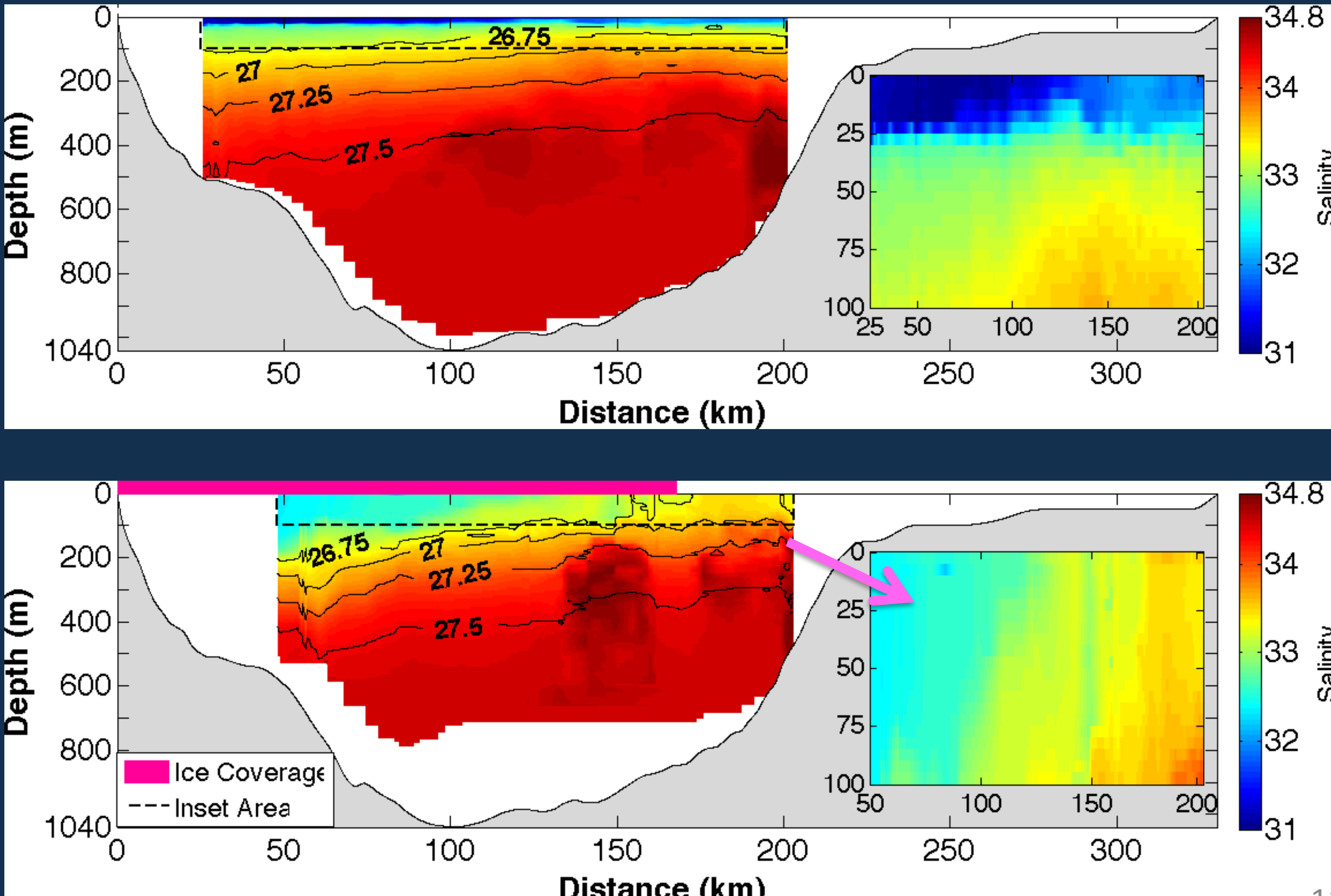
Lee

Jan-May: ice-covered
Jun: transition
Jul-Nov: ice-free
Dec: transition

For 2011 experiment:

- 34 sections
- 2113 profiles
- 1762 w/ ice autonomy

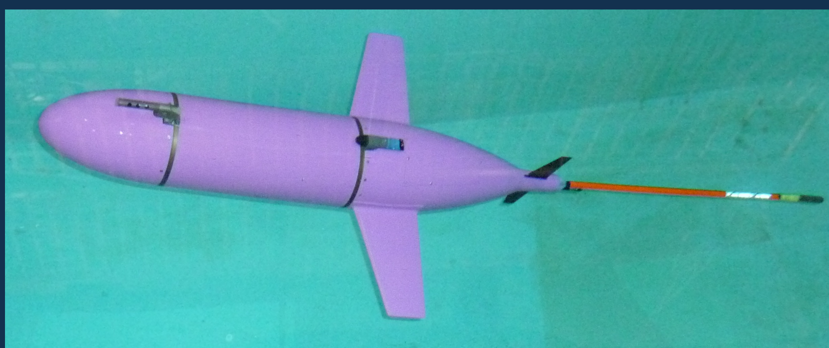
Davis Strait – September (ice-free) / December (ice-covered)



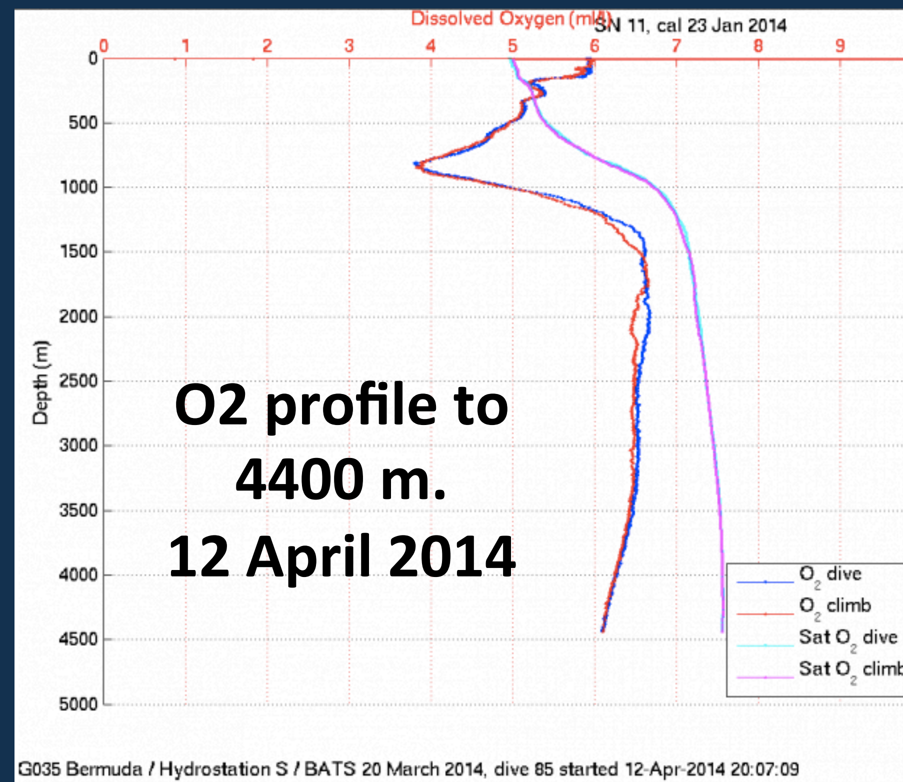
Eriksen Deepglider – current mission at Bermuda

Maximum depth – **6 km**
Range – **10,000 km**

Endurance – **18 months**
Expected # Dives – **275 dives**



SG035 completed dive 85 at 13/04/14 17:08 to 4438 m in 1260 minutes, covering 20.8 km over ground. 0 errors, 0 retries. Next call due 14 Apr 14:09. Battery remaining 62.3% (high)/86.6% (low).

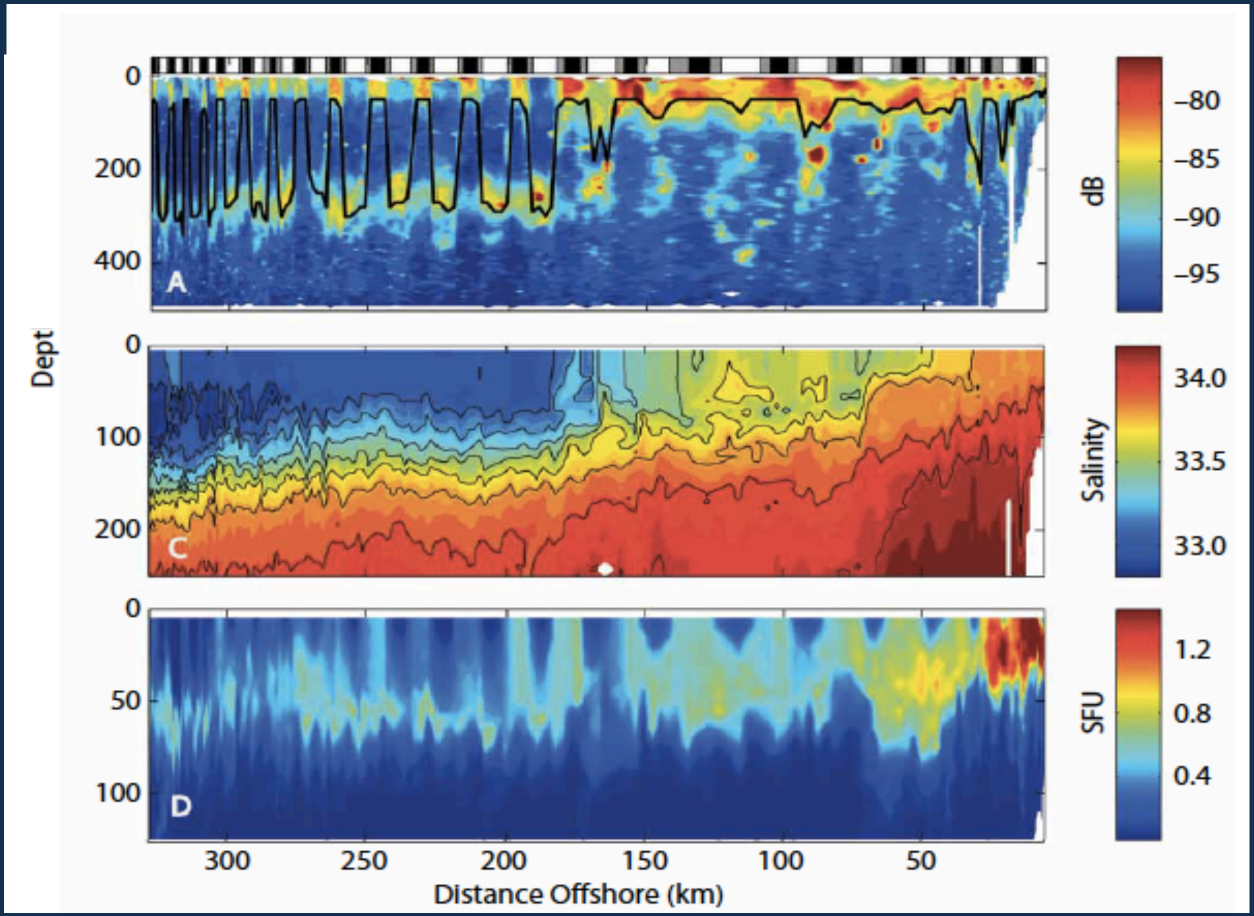


Zooplankton community off Southern California since 2006

Zooplankton from acoustics

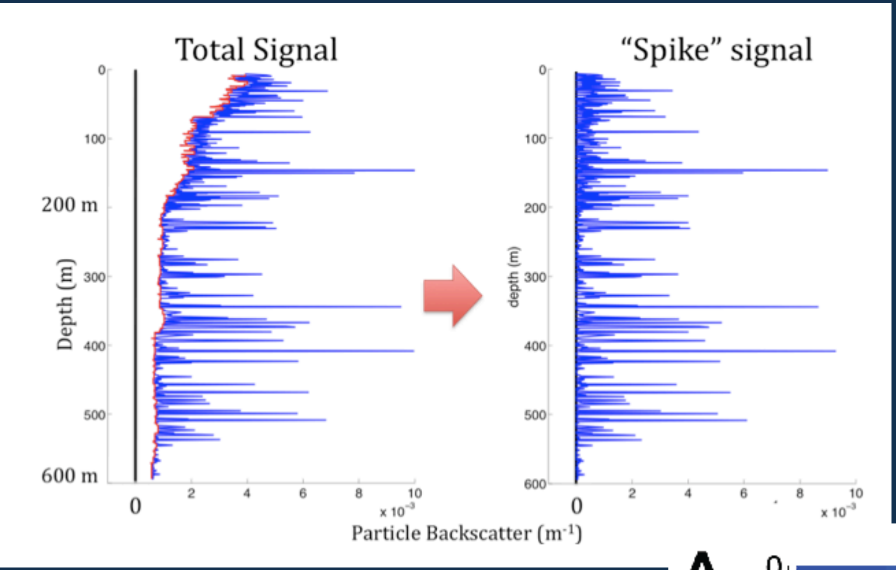
Salinity

Chlorophyll fluorescence



Ohman, Davis, et al. (2013) Oceanography

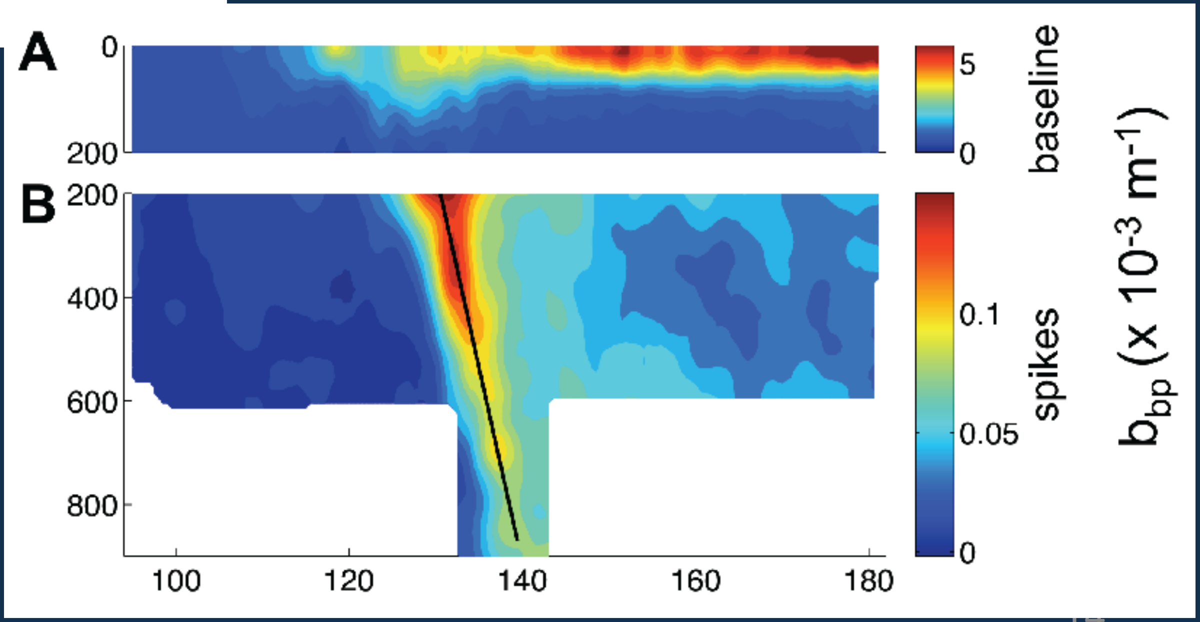
Gliders observe large scale carbon flux event



Sinking of diatom aggregates (optical spikes).

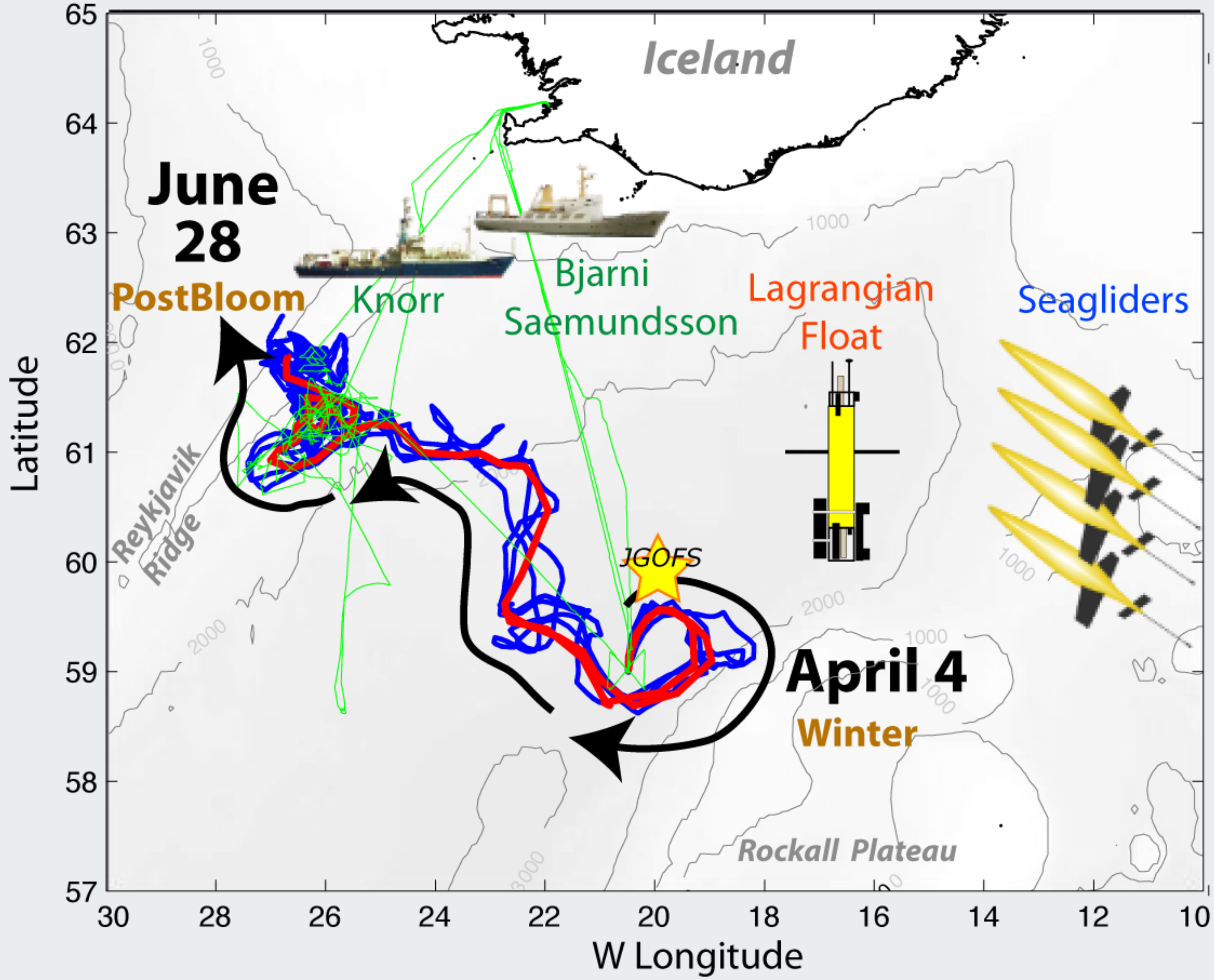
How much carbon passes through the twilight zone?

Briggs et al. (2011)
Deep-Sea Research



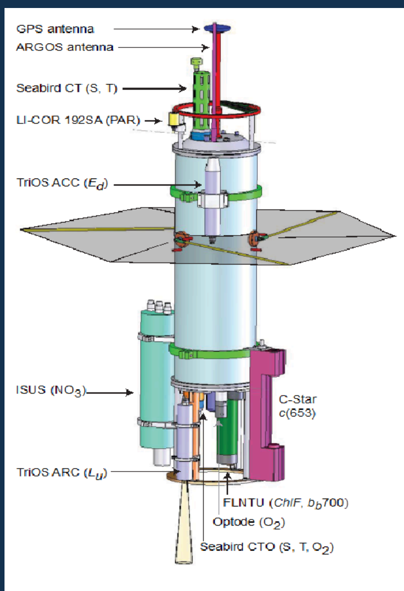
The 2008 North Atlantic Bloom Experiment

Craig M. Lee, Eric A. D'Asaro, Mary Jane Perry, Katja Fennel
Matthew Alkire, Witold Bagniewski, Nathan Briggs, Ivona Cetinic, David Checkley, Giorgio Dall'Olmo, Amanda Gray , Kritstinn Gudmundsson, Jan Kaiser, Emily Kallin, Richard Lampitt, Amala Mahadevan, Patrick Martin, Nicole Poulton, Eric Rehm, Katherine Richardson, Ryan Rykaczewski, Tatiana Rynearson,

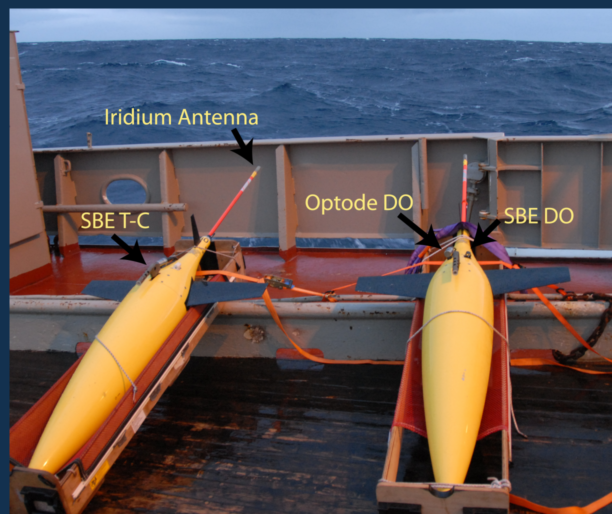


NAB08 (April – June)

- Persistence- deploy before bloom, resolve entire evolution
- Cooperative sampling by different vehicles
- Satellites & models



Mixed Layer Float- Define Lagrangian frame of the mixed layer. Daily profiles to 250 m.



Gliders- Spatial context. Survey around floats. Profile to 1000 m every 4-5h

R/V Knorr
R/V Sæmundsson
Calibration, proxy data. Extensive biological and chemical measurements, calibration data, scale check

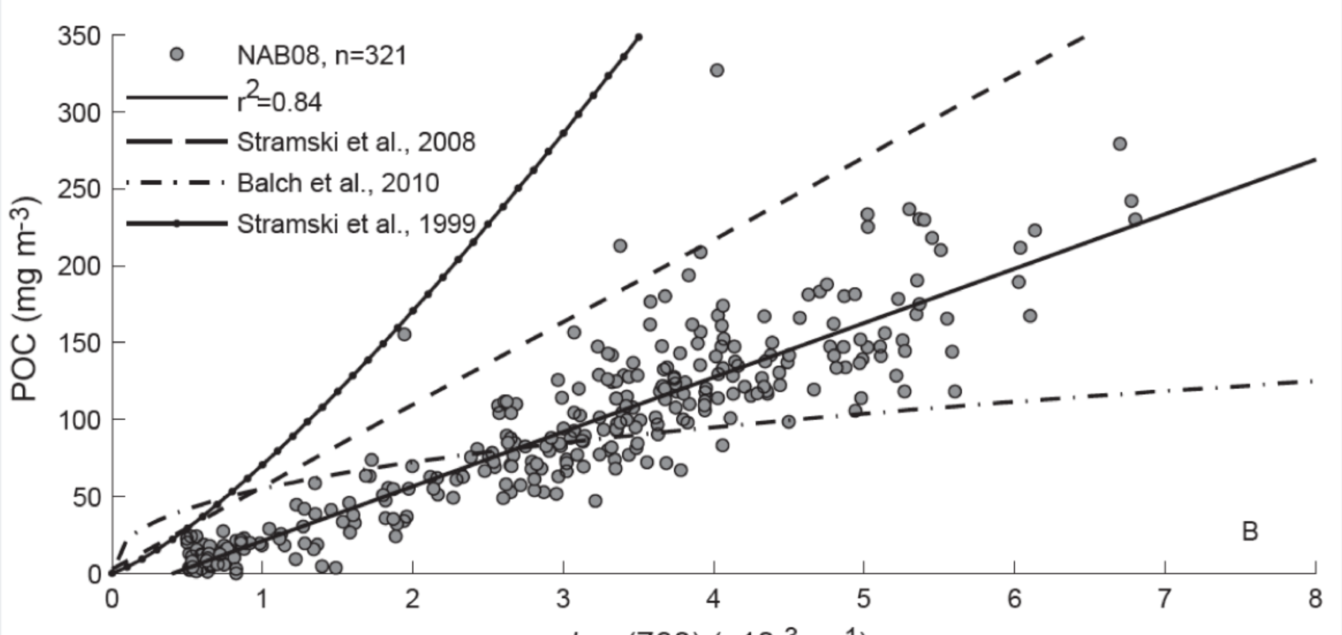
Calibration and Proxy Creation

"Autonomous sensors need the same attention to data quality as laboratory sensors"

Example - Estimating Particulate Organic Carbon from 700 nm optical backscatter

Calibration - Make 7 different backscatter sensors agree
Pre/post cruise mass calibrations. Cross-calibrations between sensors.

Proxy creation - Relate backscatter to POC
CTD calibration casts <1 km from a float or glider
321 POC samples with careful attention to blanks



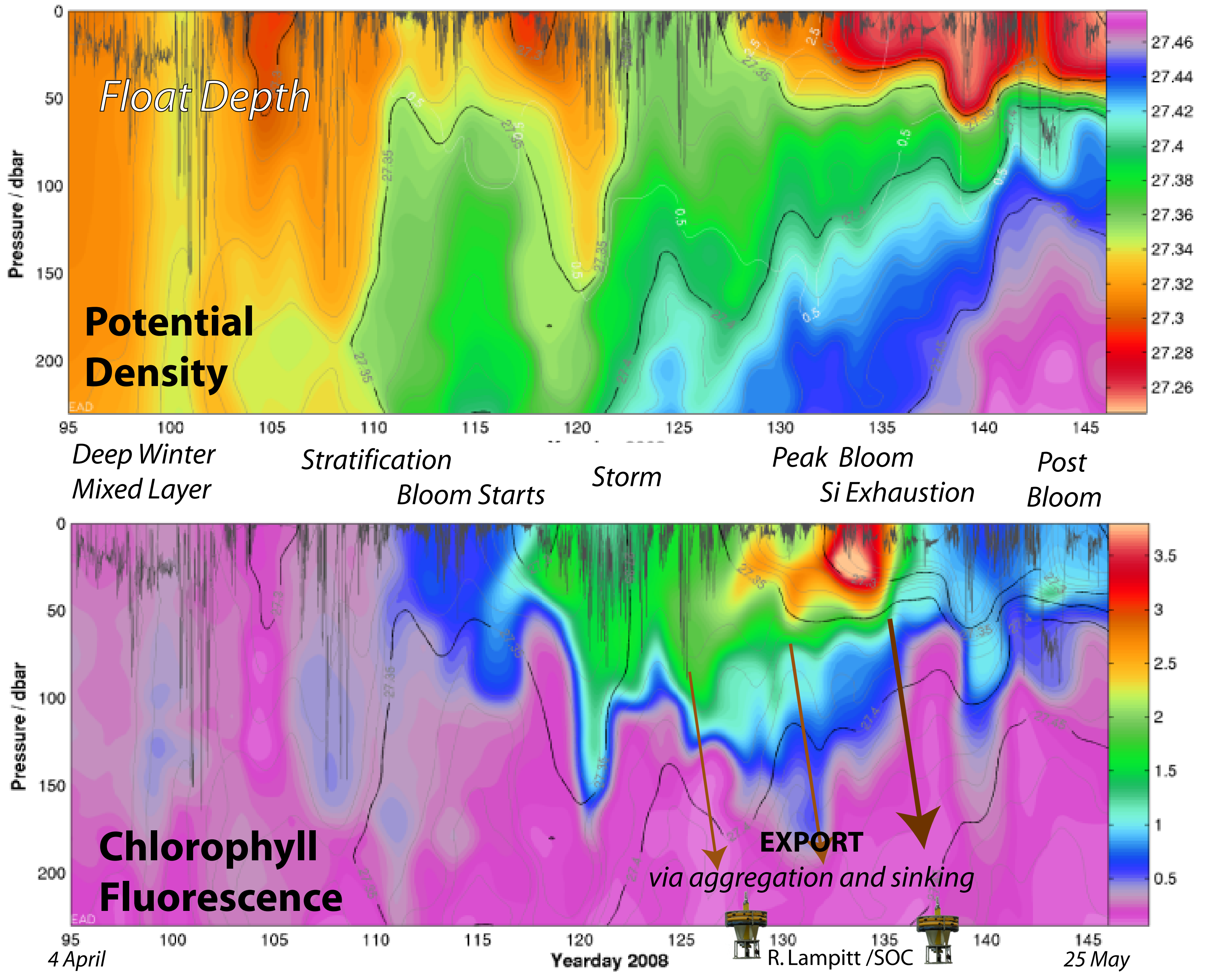
Centinic et al. 2012

321 POC samples
+
3 million bbp
=
3 million POC

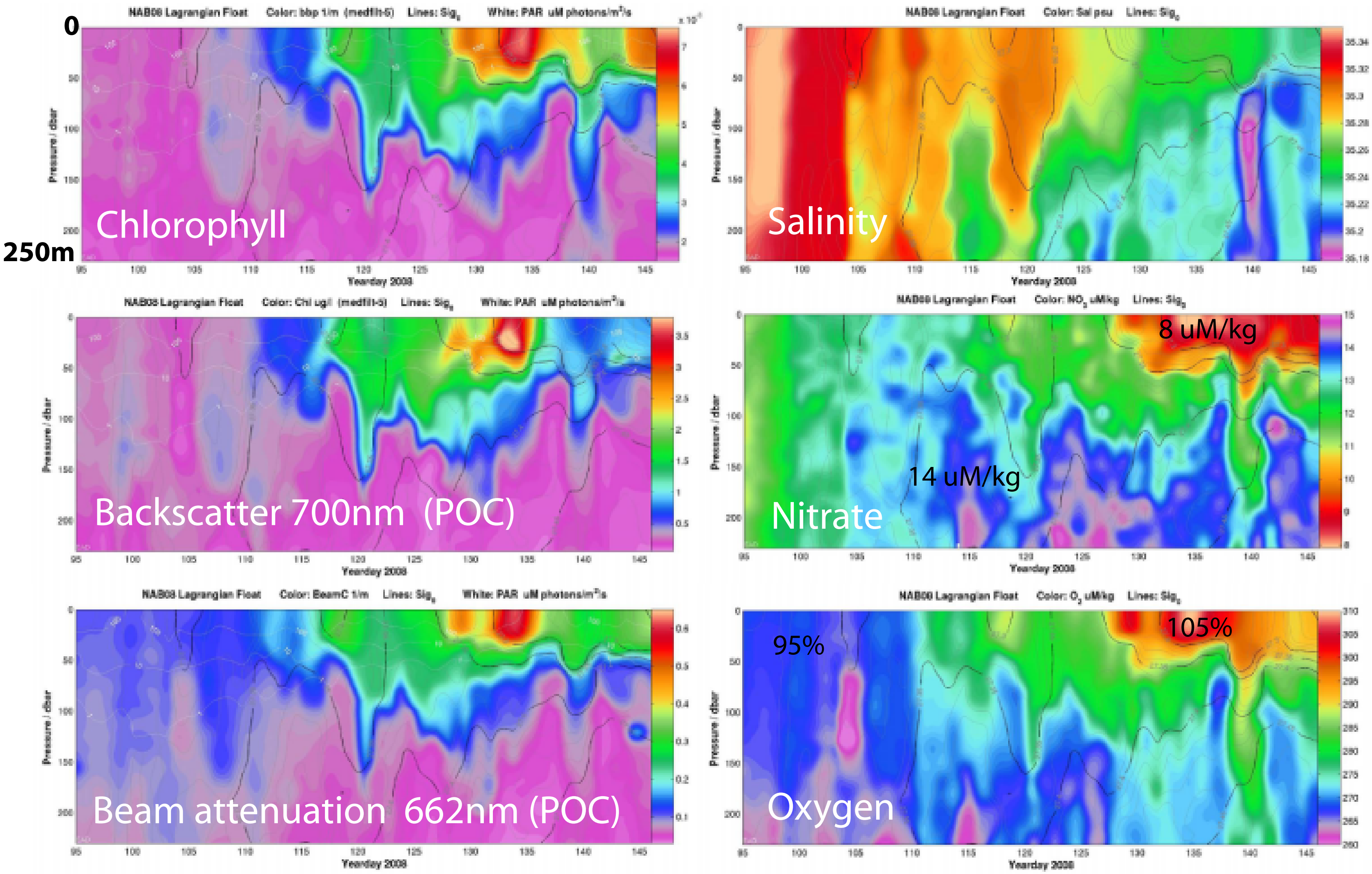
Oxygen

Chlorophyll

beam-c


Float Depth
Potential Density
Pressure / dbar
Deep Winter Mixed Layer
Stratification
Bloom Starts
Storm
Peak Bloom
Si Exhaustion
Post Bloom
Chlorophyll Fluorescence
EXPORT
via aggregation and sinking
Yearday 2008
4 April
25 May
R. Lampitt /SOC
0
50
100
150
200
95
100
105
110
115
120
125
130
135
140
145
27.46
27.44
27.42
27.4
27.38
27.36
27.34
27.32
27.3
27.28
27.26
3.5
3
2.5
2
1.5
1
0.5

Other float variables show similar patterns



Not showing PAR, hyperspectral light

Net Community Production and Export

(From float data)

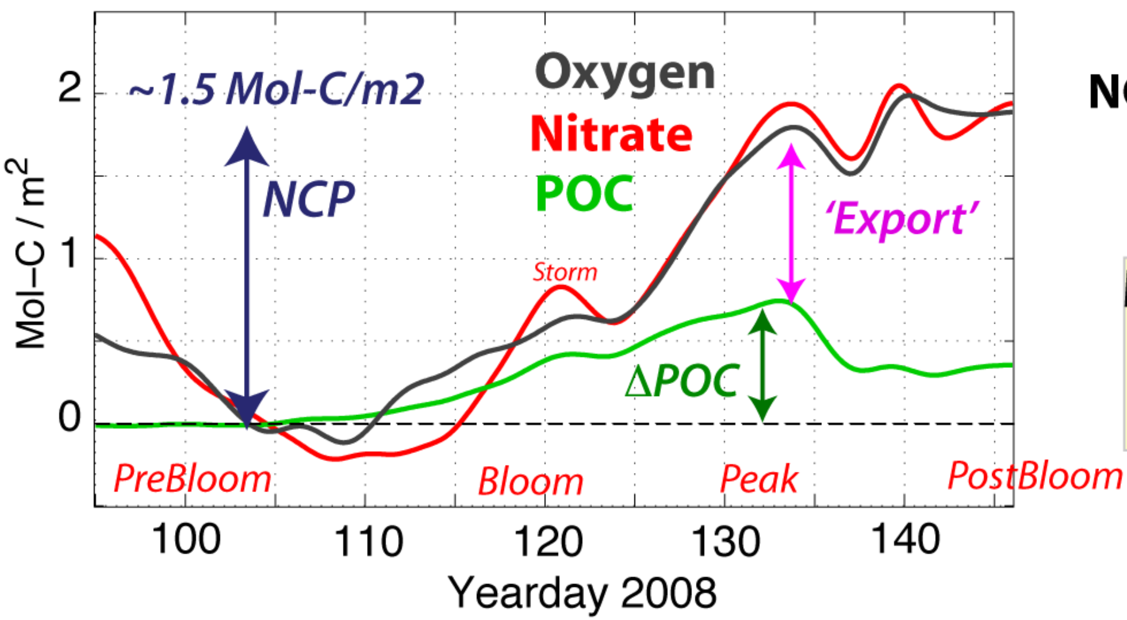
NCP= Primary Production - Respiration

= 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]

0-100m Integrated Carbon at float



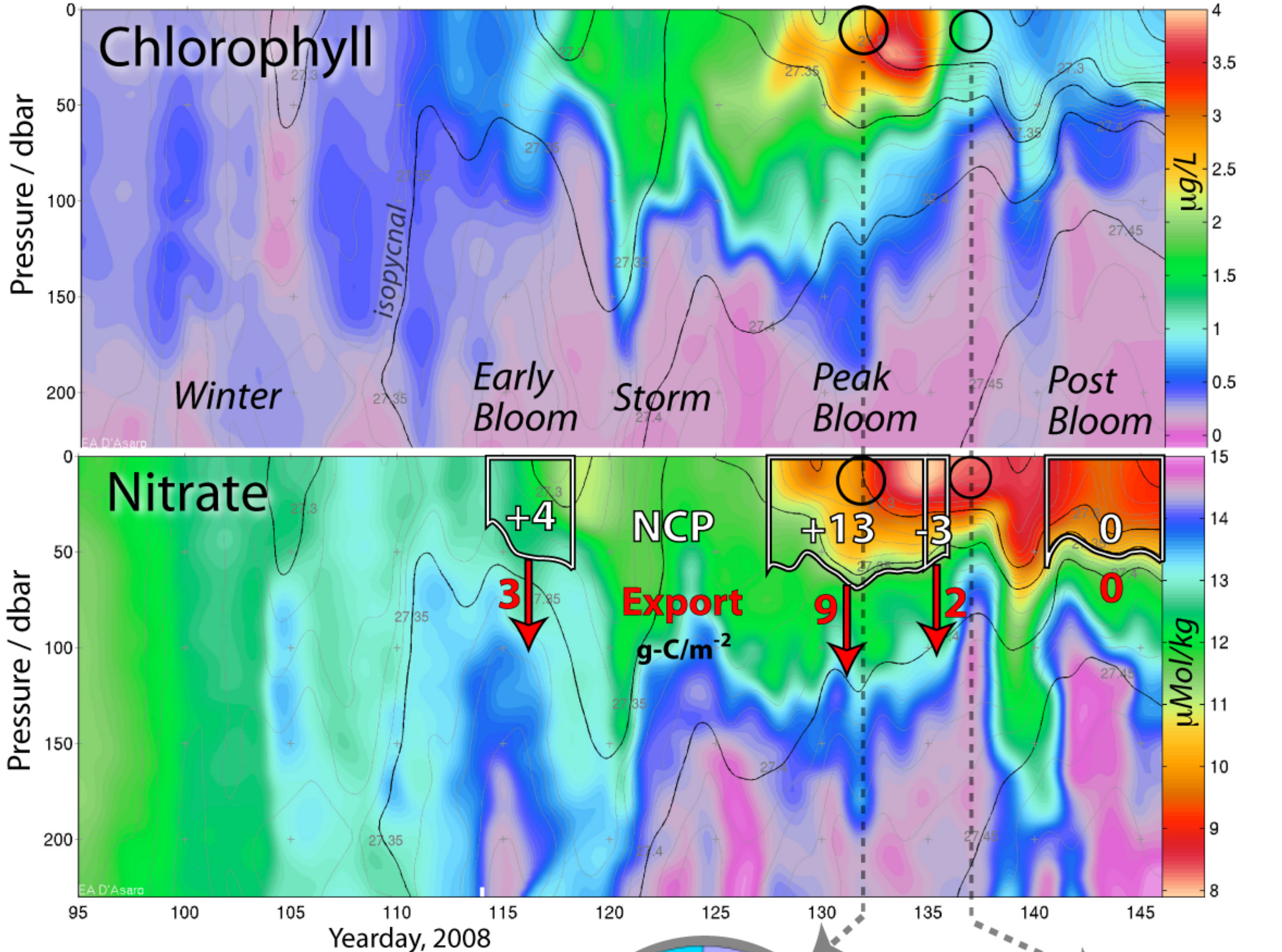
NCP from NO_3 and O_2 agree well

Much of the net carbon fixed --> Export or DOC

Alkire et. al (2012) estimates DOC from literature

e=Export/NCP = 30-70%

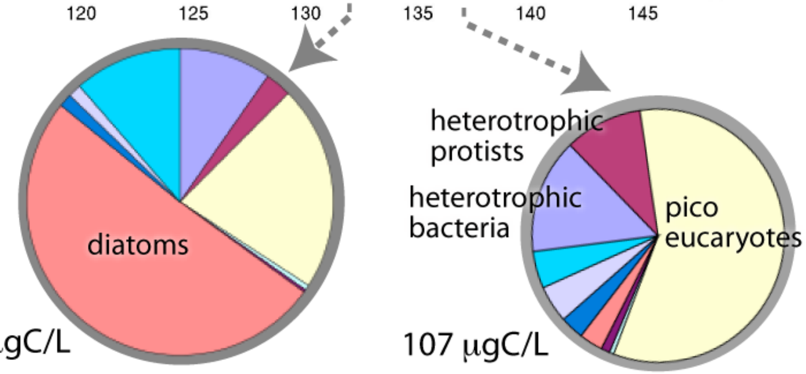
Export and Community Structure



Community Structure

FlowCam
Flow cytometer

N. Poulton M. Sieracki
Bigelow Labs



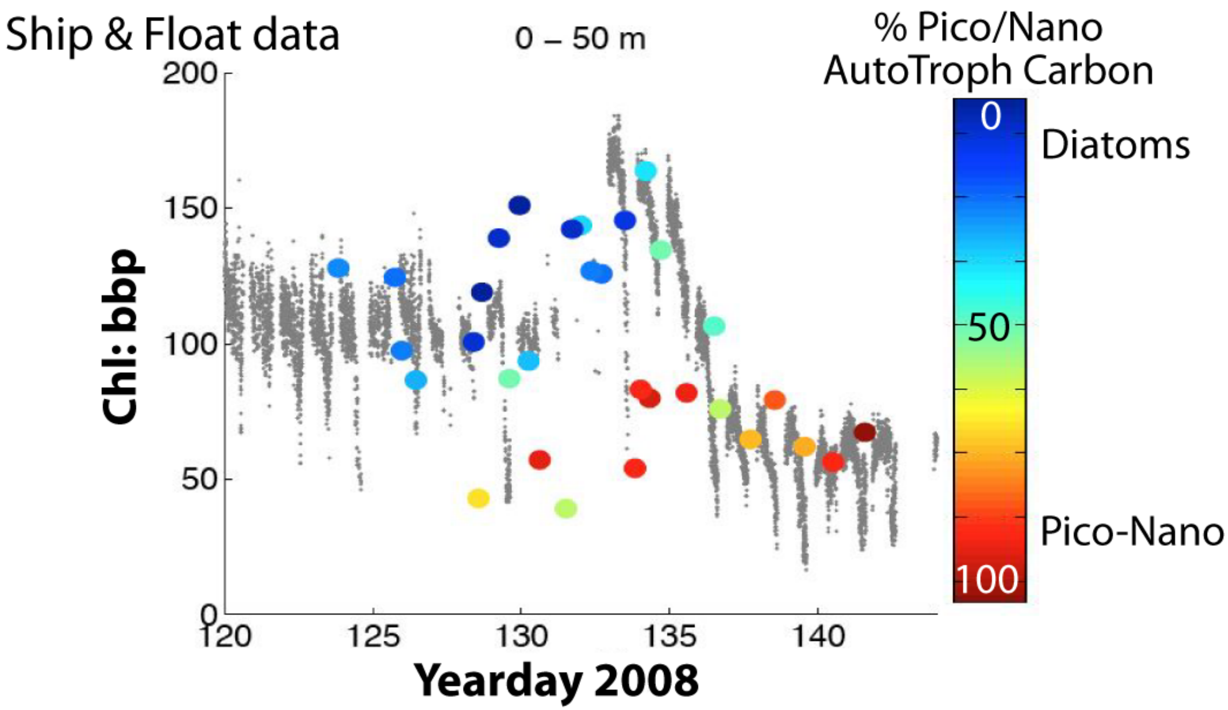
Optical Indices of Planktonic Community

Measuring community type from autonomous platforms

Biology: Chlorophyll:Carbon ratio plankton varies with type of plankton (diatoms > picoplankton > heterotrophs) and with their physiological state

Optics: Fluorescence ~ Chl   Backscatter ~ POC

Tool: Fluorescence : Backscatter ratio = Optical Index = **OI**



Clear Community Shift as Silicate runs out

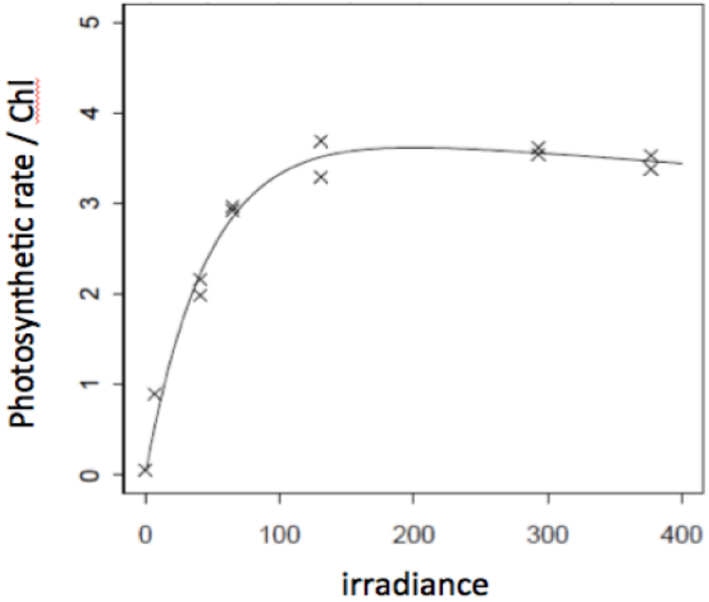
OI detects this shift

It doesn't happen at all places at the same time

Net Primary Productivity

Photosynthesis - *Phytoplankton Respiration*

2 hr ^{14}C Incubations
P-E curves



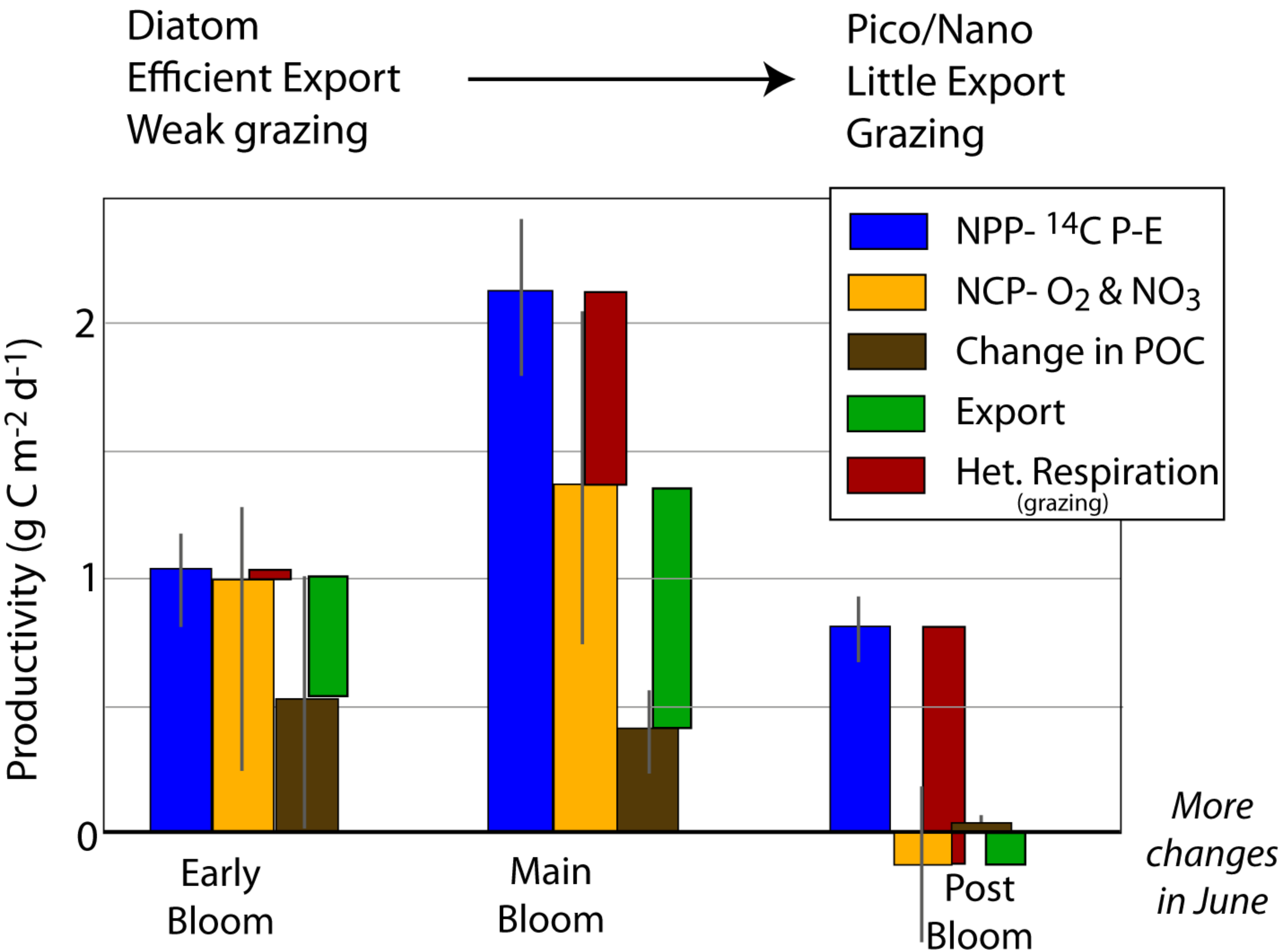
+ PAR Measured on Float = NPP

Ship data projected onto autonomous data

Community, Export and Grazing

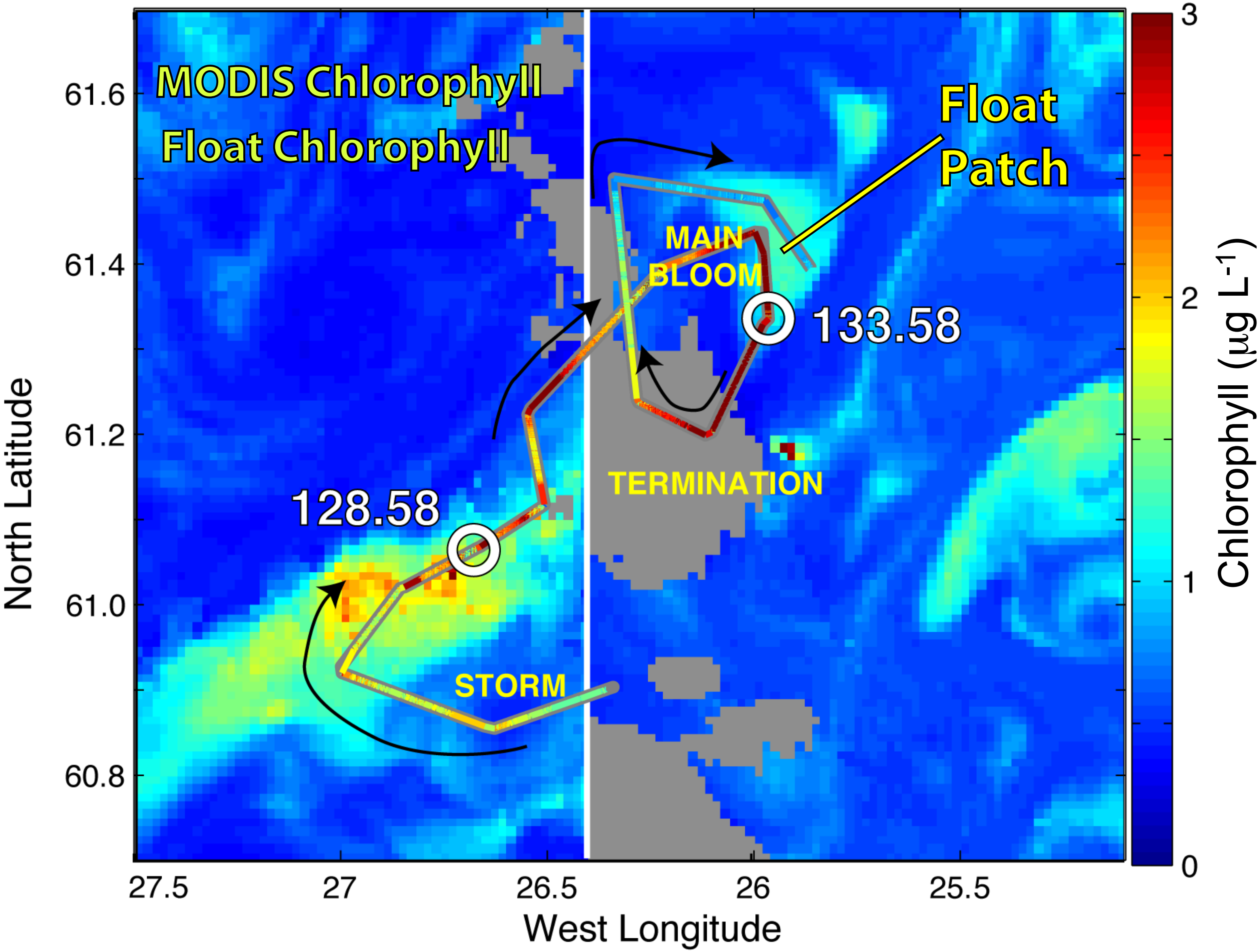
(Float data)

Large changes through NAB08



There Really Is Spatial Structure

Satellite images are infrequent here



Map the Patch using Gliders, Float and Ship

Patch

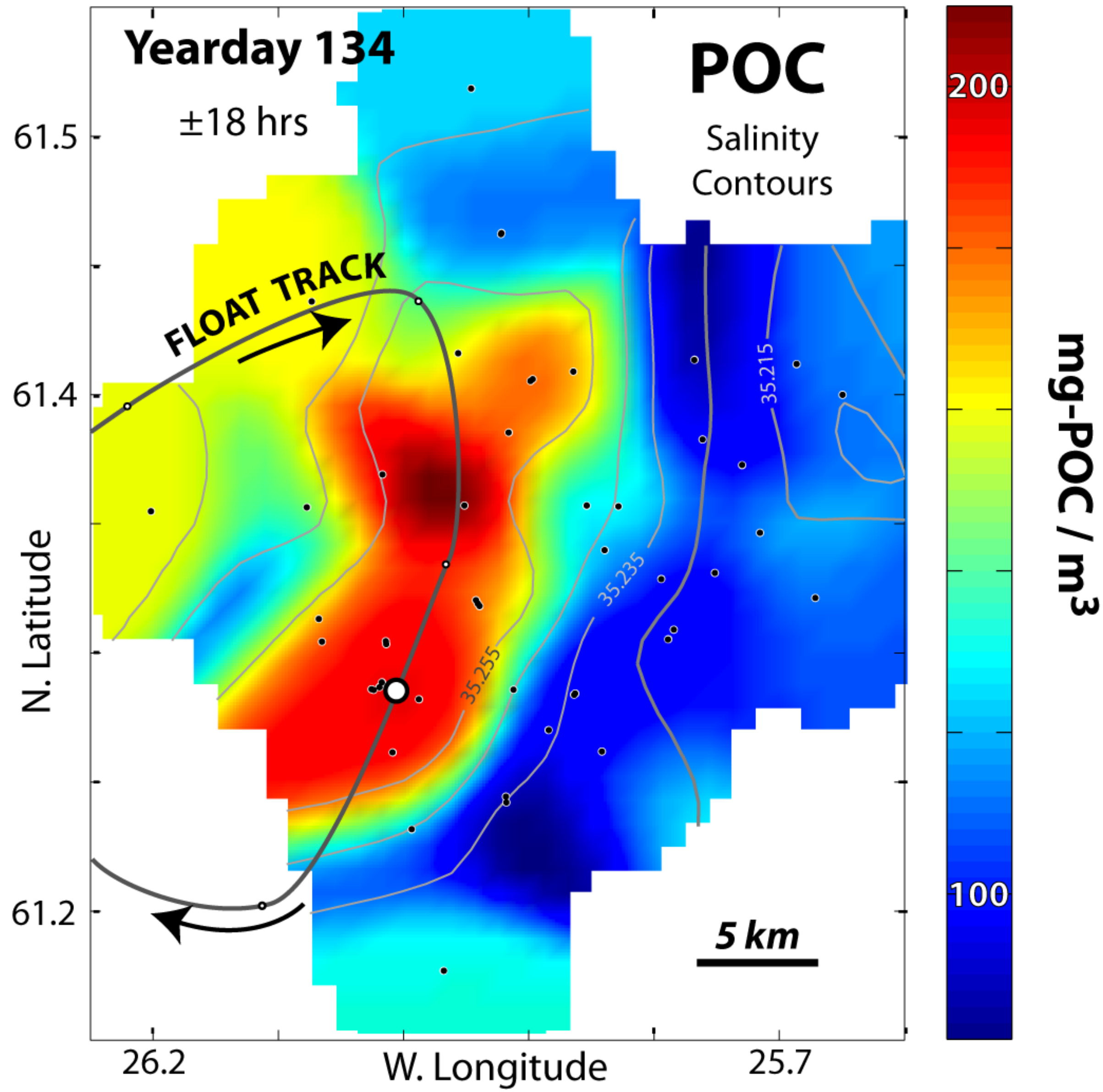
Higher POC

Higher Salt *(0.02 psu)*

More diatoms

Decays rapidly over next 2 days

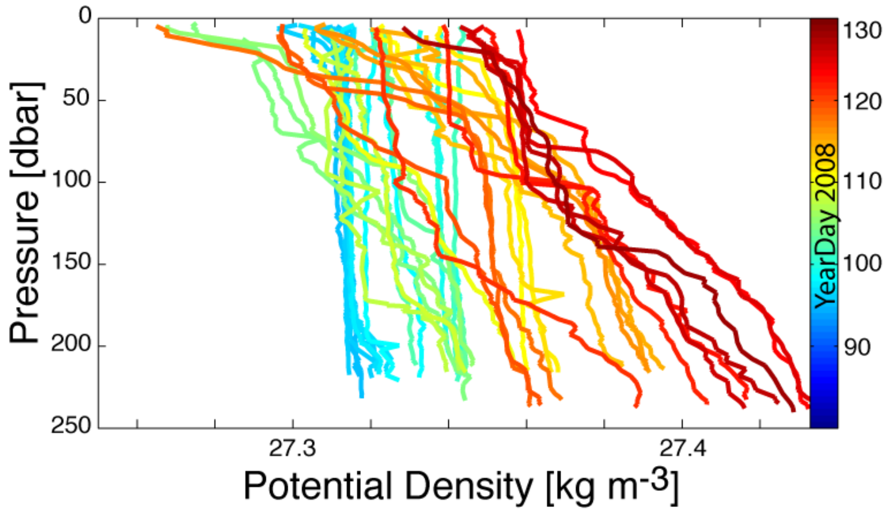
"the last piece of the diatom bloom"



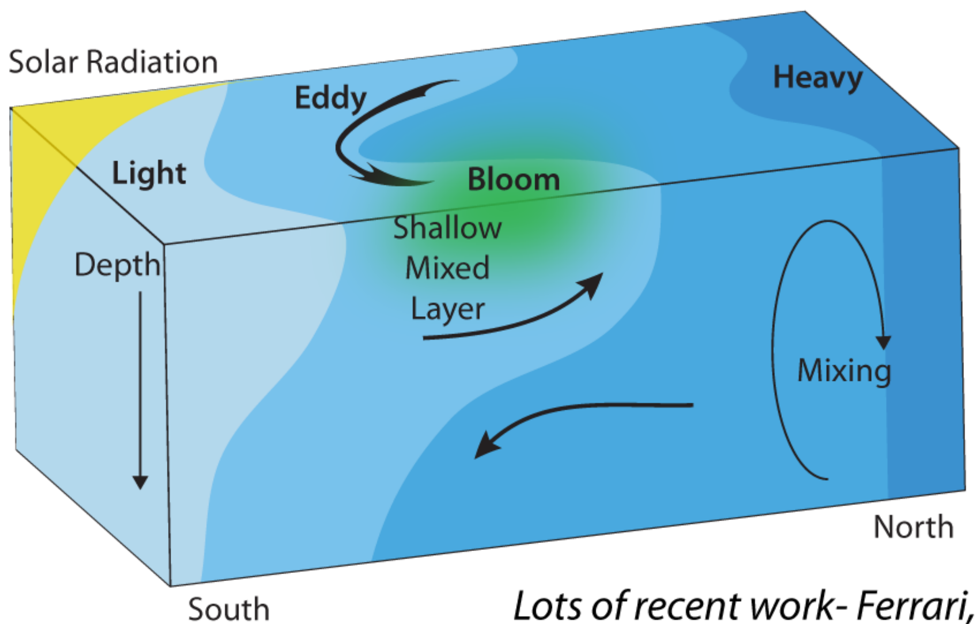
Why patchy? Who cares?

Mixed Layer Eddy Restratification & Bloom Initiation

'Sverdrup 1953 + Submesoscale Physics'



Clue:
The entire Winter Mixed Layer Restratifies, not just the surface
This is not surface warming

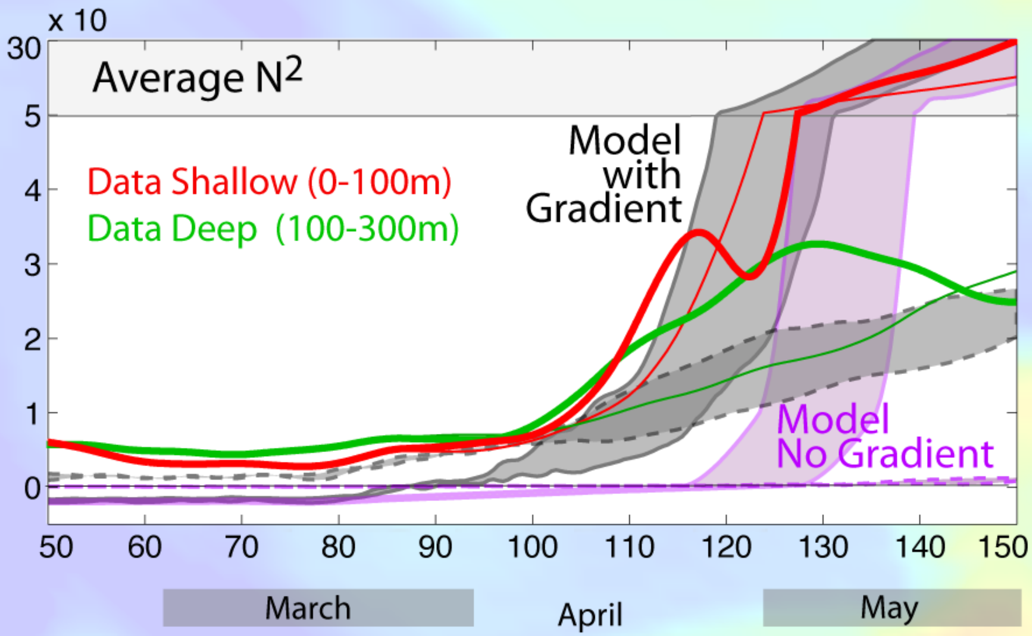


Mechanism:
Slumping of lateral density gradients within the winter mixed layer

Lots of recent work- Ferrari, Fox-Kemper Mahadevan, Boccaletti

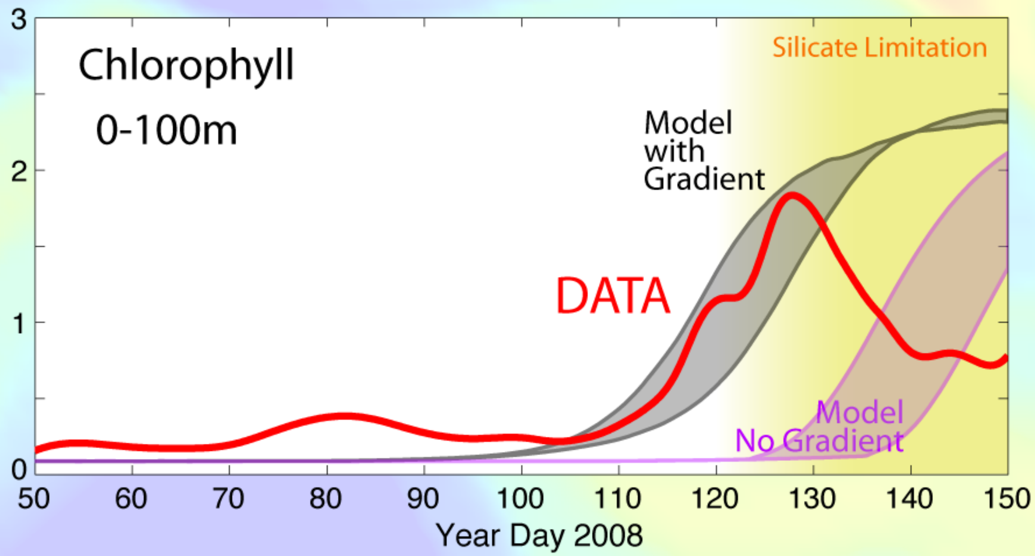
Mixed Layer Eddy Restratification Advances the Spring Bloom

Mahadevan, D'Asaro, Lee, Perry (2012)



Submesoscale physical model
Predicts:
- Earlier restratification across entire winter mixed layer
- Due to lateral gradient
- Later surface stratification

Consistent with data



Simple phytoplankton model
(light limited, tuned to float data)

Predicts:
- Earlier bloom (~20 days)

Consistent with data
(until silicate limitation occurs)

Some Lessons from NAB08

- A cooperative float/glider/ship sampling system
- Calibration of sensors
- Optical proxies for POC and community type
- Submesoscale patchiness
- Quantitative analysis and model evaluation
- Coordinated multidisciplinary scientists & engineers

Some Results

- Community structure, export and grazing rates are linked, spatially variable, and evolve during the spring
- Patchiness changes bloom timing

Toward an Interdisciplinary Observing System

Policy- climate driven

- Focus: Document & understand environmental change, planning.
- Time scale: Decades, value placed on long records.
- Spatial scale: Distributed.
- Data: Real-time data return not necessary. Long, consistent records.

Strategy- process studies, develop predictive capability

- Focus: Process-level understanding, planning for high-risk activities.
- Time scale: Seasons to years, long records valued.
- Spatial scale: Limited geographic scope.
- Data: Rapid data access (near real time) may be required.

Tactical- ‘stakeholder’ driven collection

- Focus: Support for specific activities.
- Time scale: Rapid spin-up, spin-down. Flexible design,.
- Spatial scale: Tightly focused, often near regions of human activity.
- Data: Useful products delivered in real time.

Design Goals

- Measurements physics, biogeochemistry and biology at multiple spatial and temporal scales.
- Integrate over (and thus resolve) annual cycle to estimate many key carbon variables.
- Evaluate and refine predictive capability by testing over many realizations (10+) years.
- Process studies measure broadly and limited set of sustained core observations.
- Sustained calibration of broad, interdisciplinary sensor suite.
- Proxy development – in situ and satellite

Challenges

- Access
  - Distributed operations.
  - Remote, frequently inhospitable.
- Risk
  - Resilience to component failure.
- Persistence
  - Resolve important timescales, transient events.
- Adaptability/Flexibility
  - Needs evolve with changing environment and understanding.
  - Meet disparate stakeholder needs: climate to tactical.
- Interoperability
  - Coordinated operation of broad mix of platforms and sensors
  - Cross-calibration, data in ‘common currency’
- Cost/Scalability

Scaling Up:
Leveraging Onto an Autonomous Sensor Network

More Variables → More Measurements

Ships

Discrete samples
- Pigment analysis
- Phytoplankton
- POC
- absorption(λ)
- Nutrients

Community Structure

Rates

Sensors
- CTD + velocity
- PAR (Ed)
- b_{bp}
- Chl fluor
- Beam Attenuation
- Oxygen
- many others…

Many more…

Moorings/IBOs

CTD + velocity
Microstructure
Nutrients (autoanalyzer)
Zooplankton (image, acoustic)
PAR (Ed)
Spectral Irradiance
b_{bp}
Chl, CDOM fluor
Beam Attenuation
Oxygen
pH
Meteorology
Genomics

Floats & Gliders

CTD + velocity
Microstructure
Nitrate (SUNA)
Zooplankton (acoustic)
PAR (Ed)
Spectral Irradiance
b_{bp}
Chl, CDOM fluor
Beam Attenuation
Oxygen
pH

Calibration- interoperability between platforms

Proxies- biogeochemical/biological variables from autonomous sensors

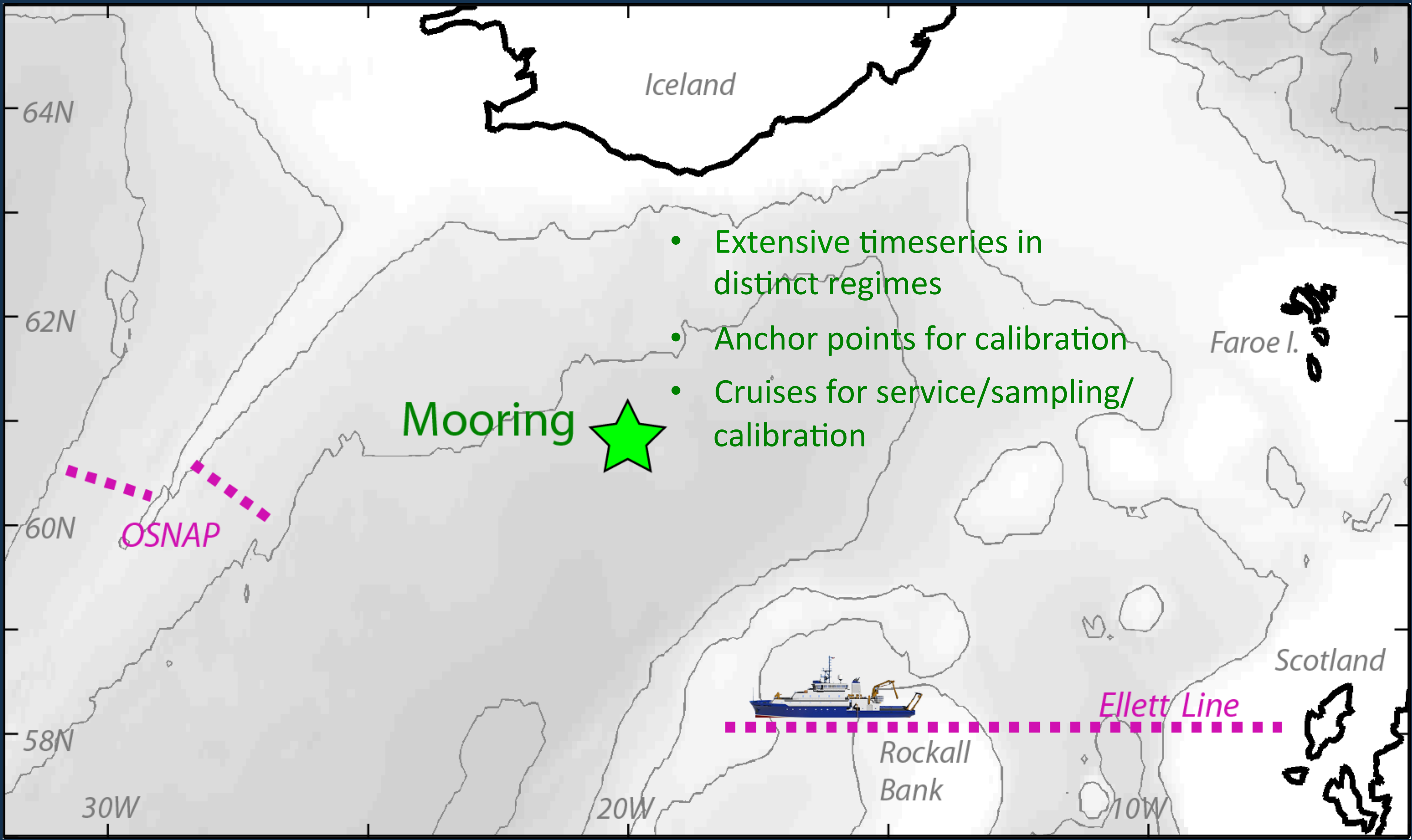
Calibration

- Proximity (engineered or opportunistic)
- Direct or through propagation of reference calibrations
- Sensors *can* improve enough to greatly reduce calibration problems (e.g. salinity). Biogeochemical sensor not at this level of maturity.

Proxies

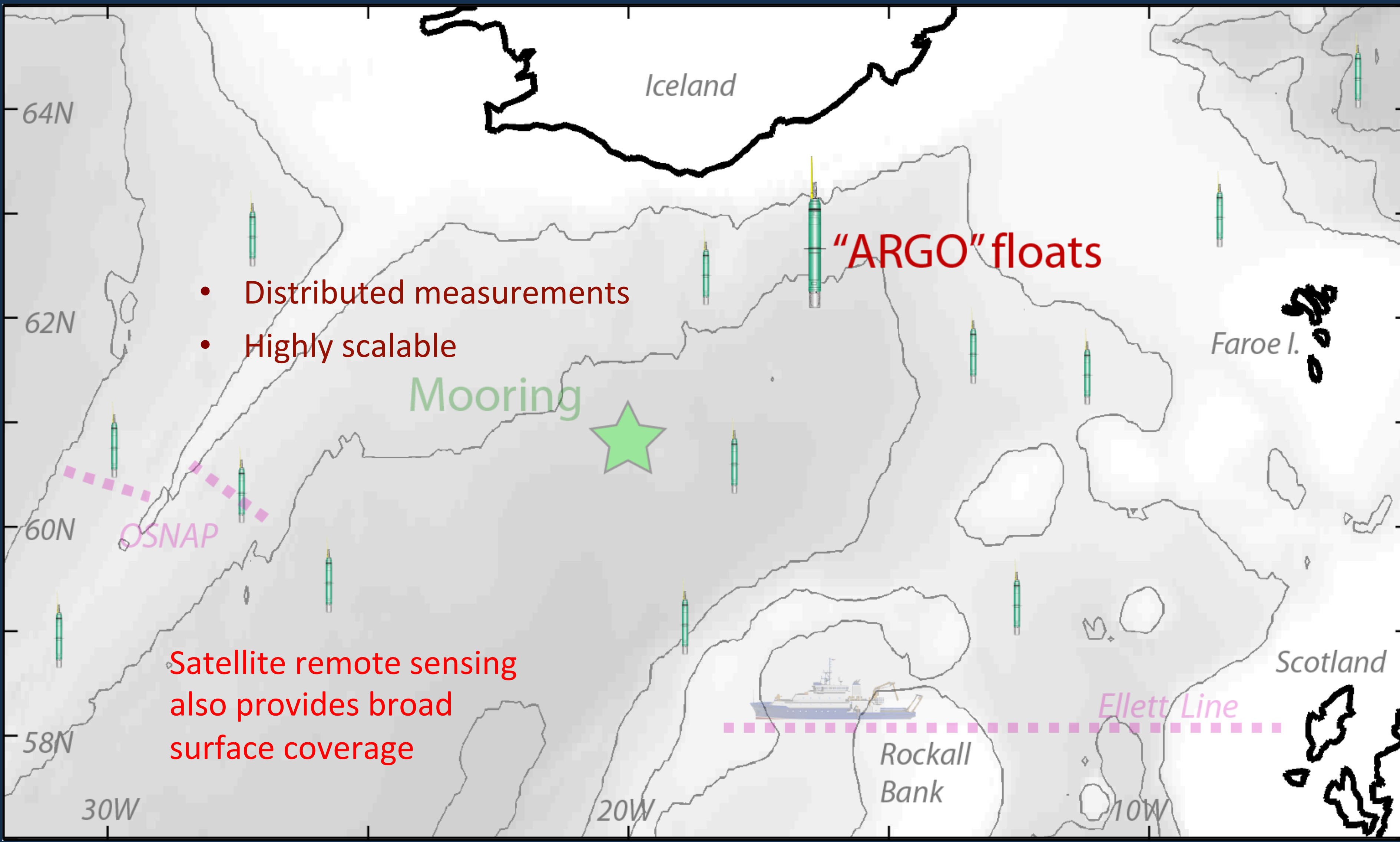
- Spatial and temporal validity.
- Empirical vs mechanistic proxy relationships.

Basin-Scale System- High-Resolution Timeseries

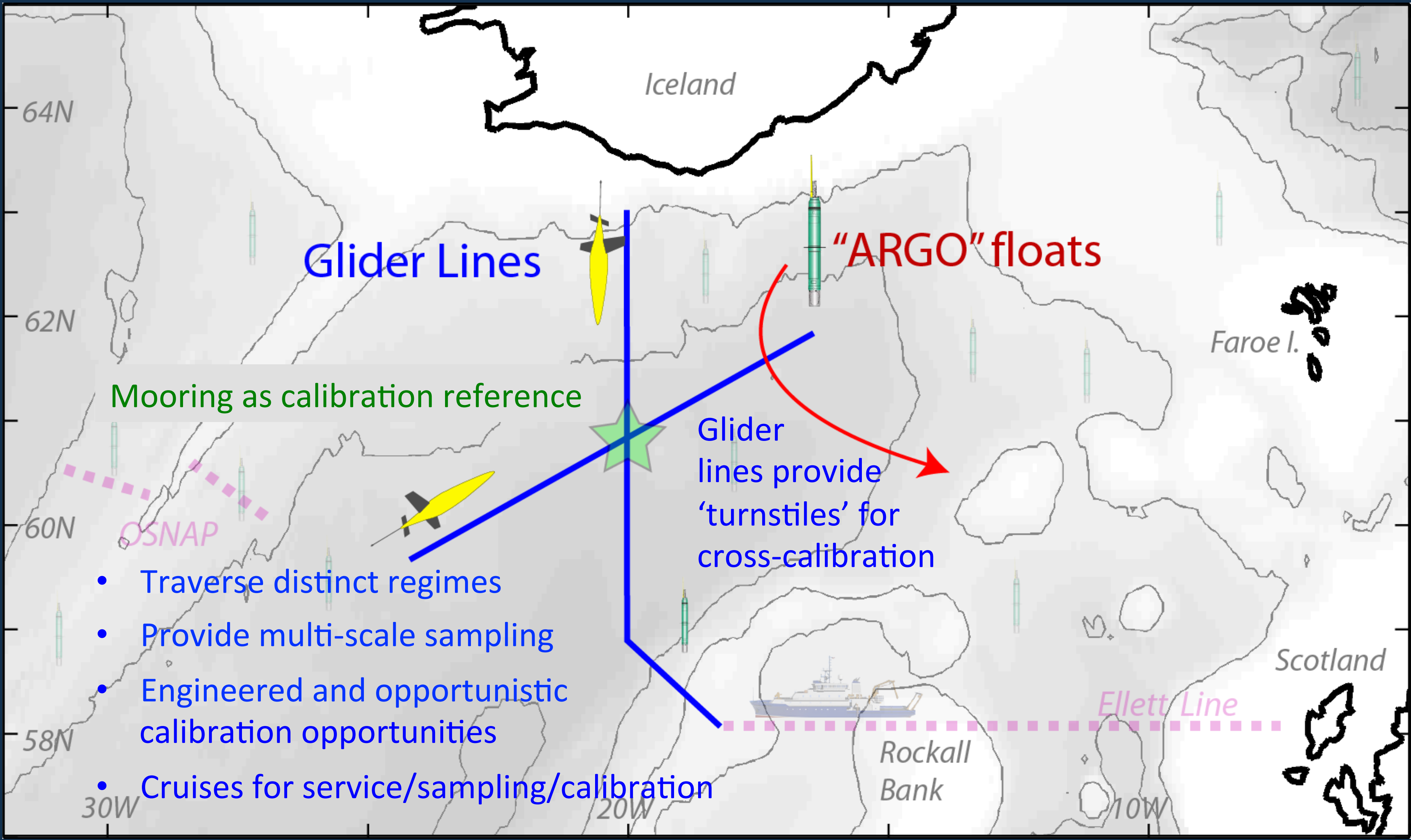


- Extensive timeseries in distinct regimes
- Anchor points for calibration
- Cruises for service/sampling/calibration

Floats for Distributed Measurements



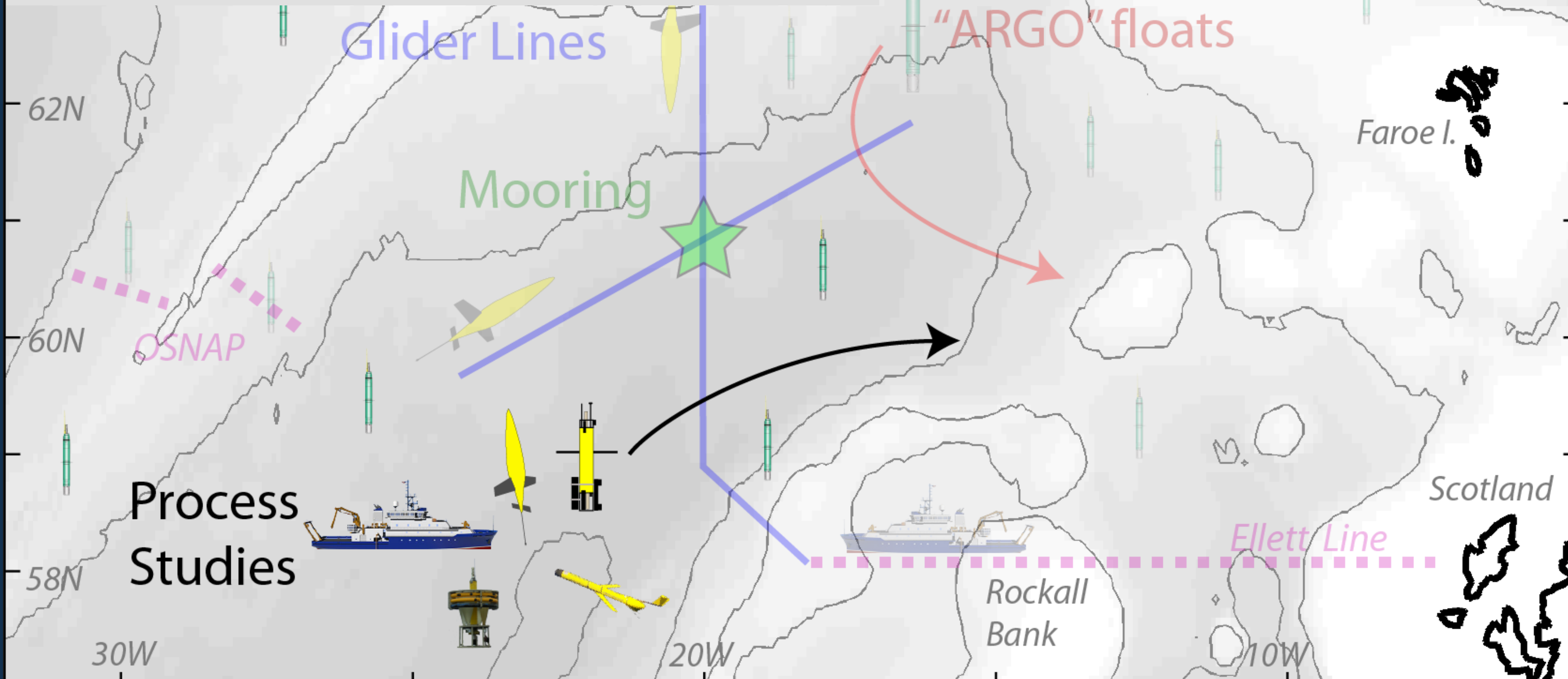
Glider Sections Tie System Together



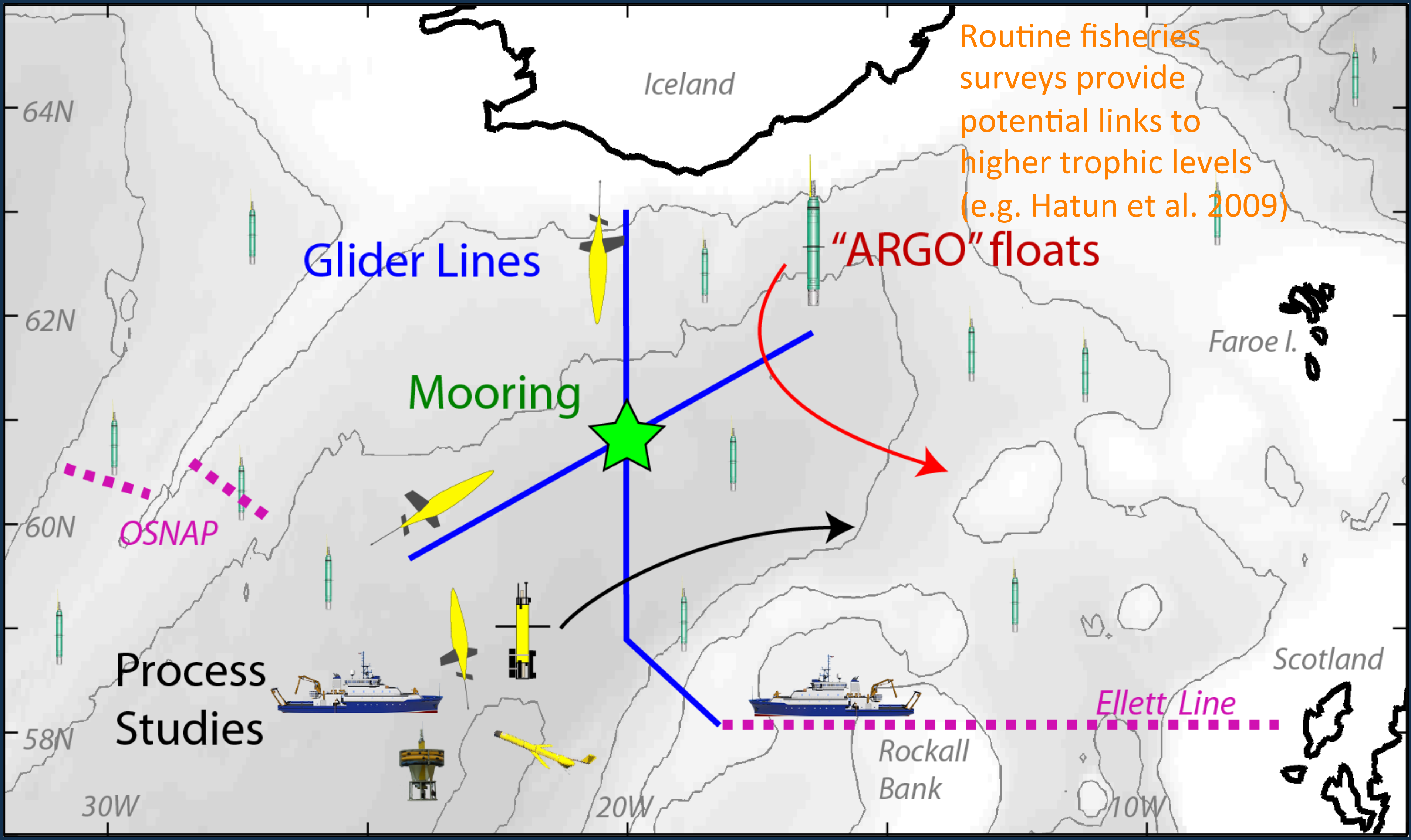
- Traverse distinct regimes
- Provide multi-scale sampling
- Engineered and opportunistic calibration opportunities
- Cruises for service/sampling/calibration

Embedded Process Studies

- Focus on key processes, regimes, seasons
- Improve models, predictive capability
- Build proxies for leveraging autonomous sensors
- Evaluate new technologies



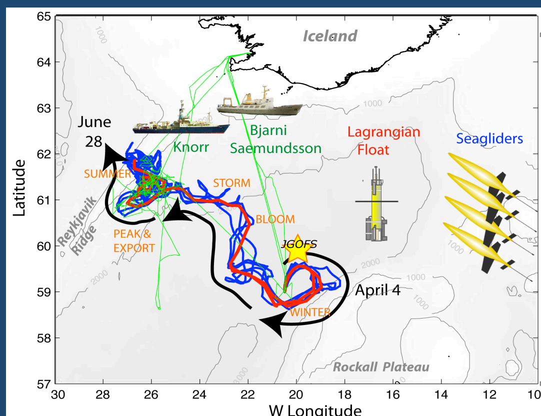
Straw-plan for Sustained, Multi-Scale System



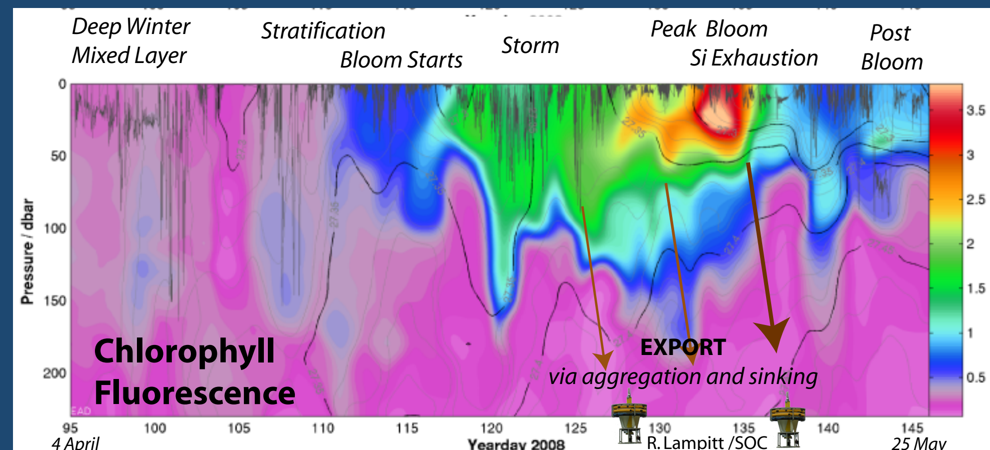
2008 North Atlantic spring bloom experiment —

combination of 5vautonomous platforms, ships, satellites & models

Craig Lee, Eric D'Asaro, Mary Jane Perry



BCO-DMO: NAB 2008



1) **Persistence** – floats & gliders provide longer term observations than ships; followed bloom evolution and demise; rare but important events

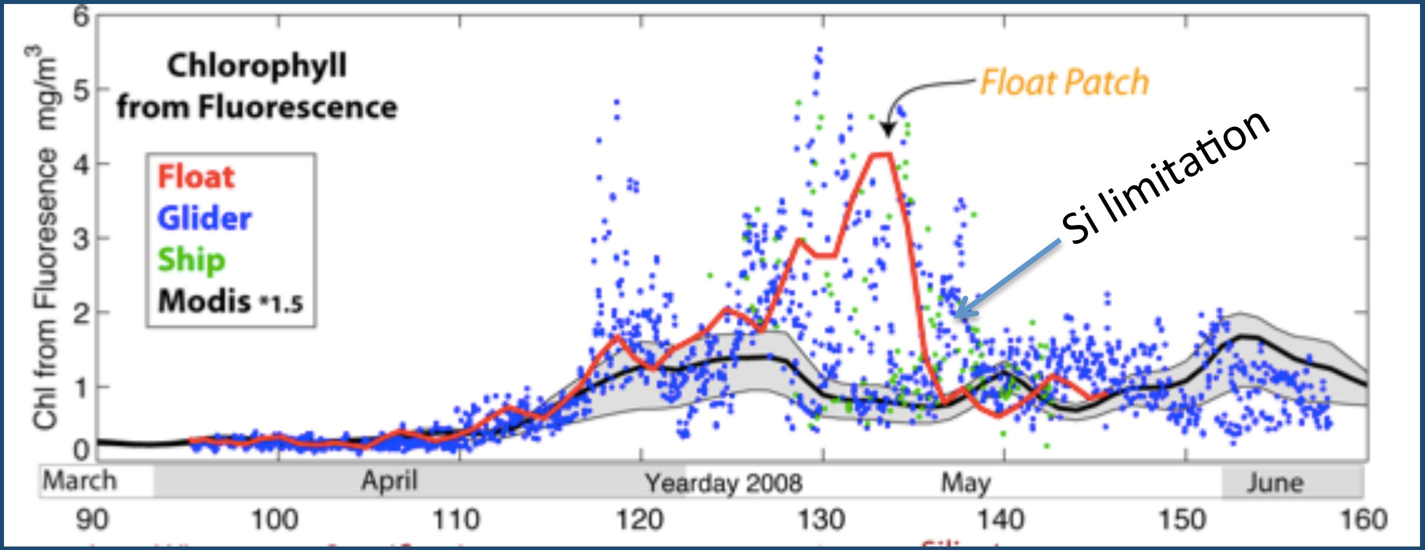
2) **Calibrated sensors & proxies –** allow projection of expensive ship measurements to larger spatial scales

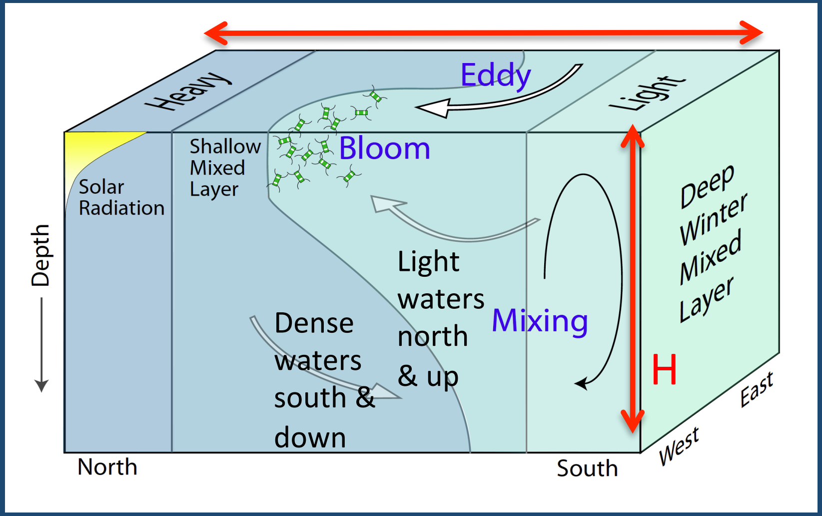
3) **Productivity –** Phytoplankton, Net Community, Export, Sequestration

Mixed layer shallows rapidly and bloom begins ~ YD 110

Increase in Chl, POC, O_2

Decrease in NO_3





Mahadevan el al., 2012

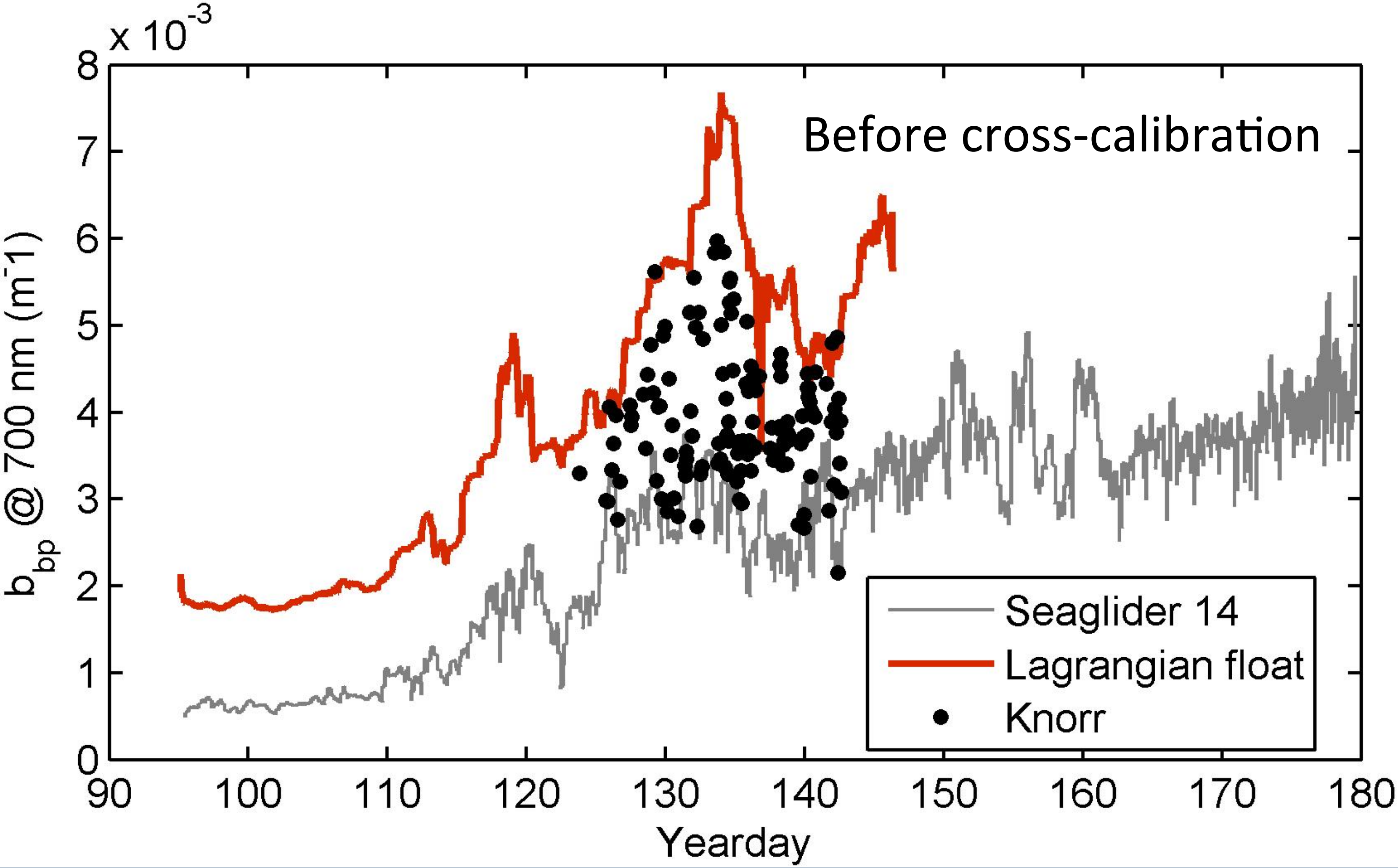
- ML cools during bloom initiation
- Eddy-driven slumping of basin-scale North-South density gradient results in PATCHY BLOOMS; bloom starts **20-30 d EARLIER** than would occur by warming.
- Process level mechanisms (physics & biology) required for predicting responses to climate change.

Calibration is ESSENTIAL (and once is not enough)

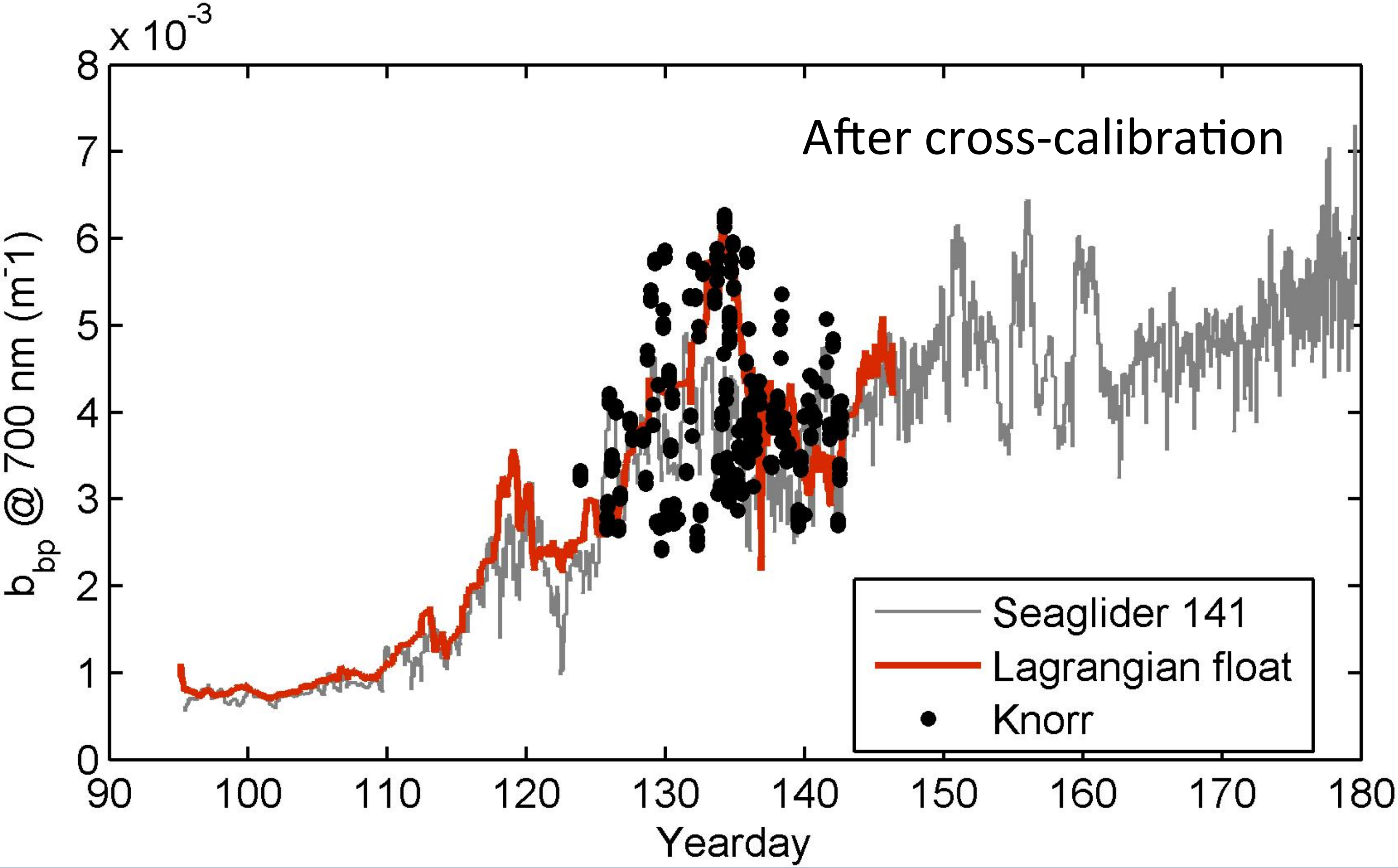
- Pre-mission calibrations
- During mission – deliberate w/ ship; in situ encounters
- Post-mission bulk factory calibrations
- Redundant/related sensors
- Documentation and data at BCO DMO – NAB 2008

Seaglider calibration by ship

Before calibration to common reference



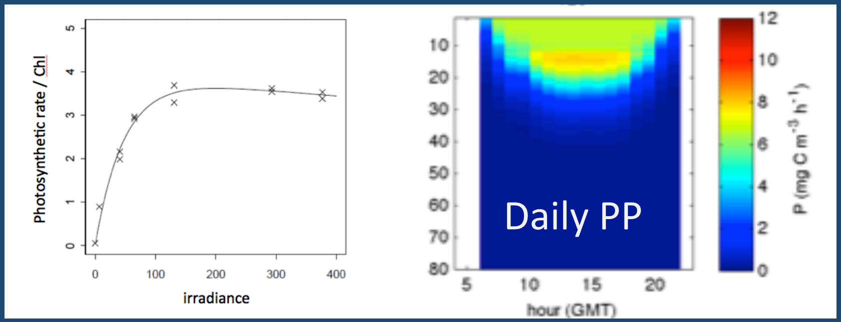
After calibration to common reference



1) Phytoplankton Productivity

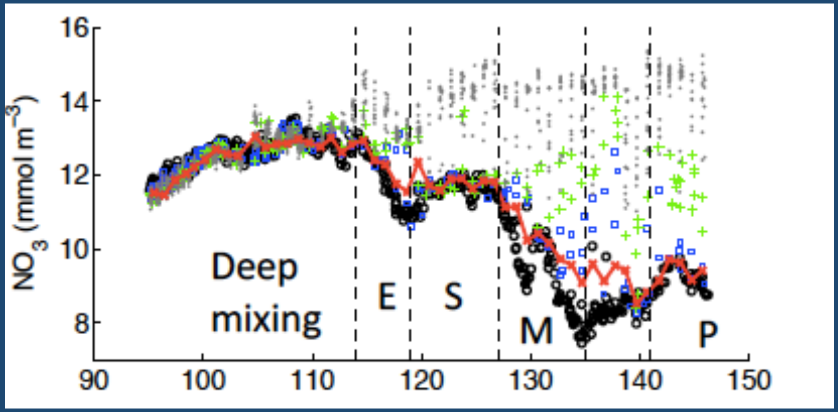
Ship ^{14}C P vs. E + float hourly Chl & PAR

Float diel cycle analysis



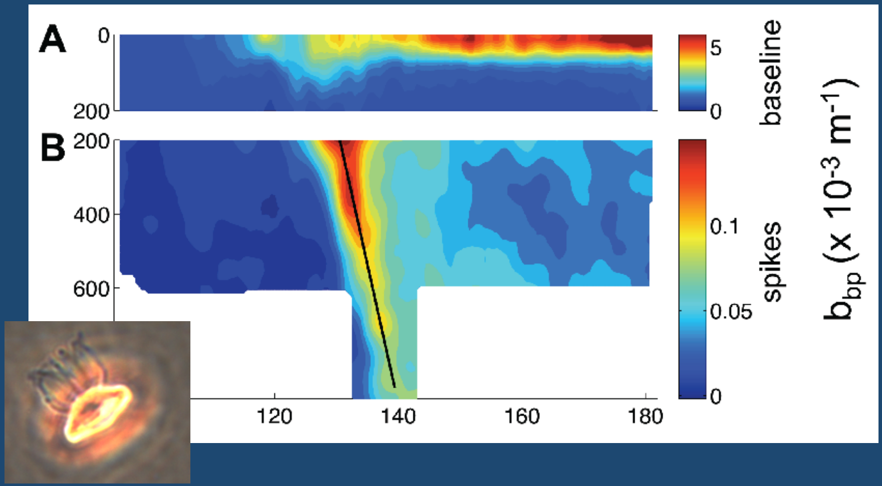
2) Net Community Productivity –

2 mo Lagrangian float observations of NO3 drawdown and O2 evolution



4) ~ Sequestration Productivity

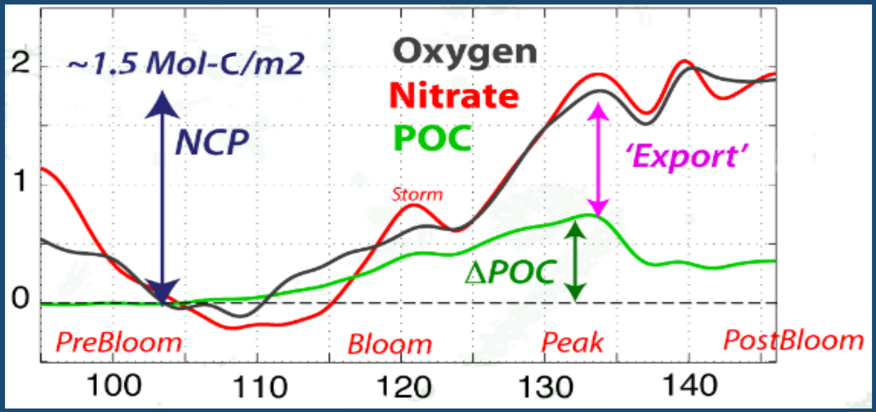
Event – sinking of diatom aggregates



3) Export Productivity –

= Δ NCP (O2 or NO3) – d POC/dt;

~30 - 70%

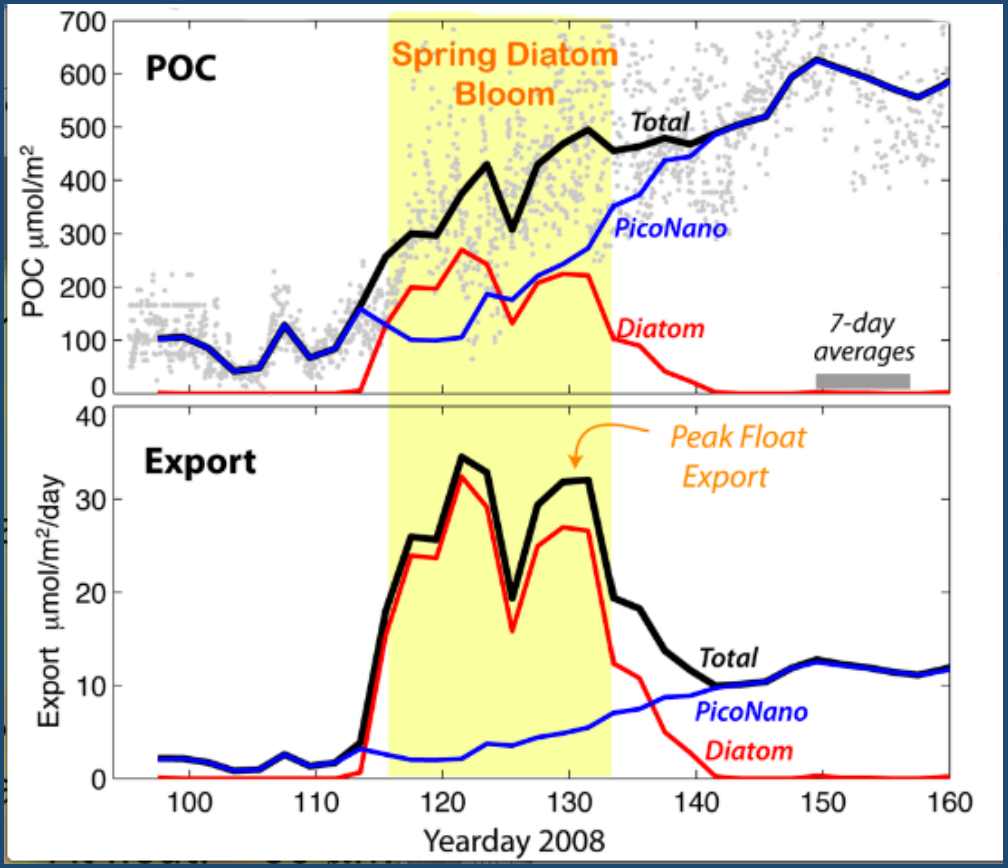


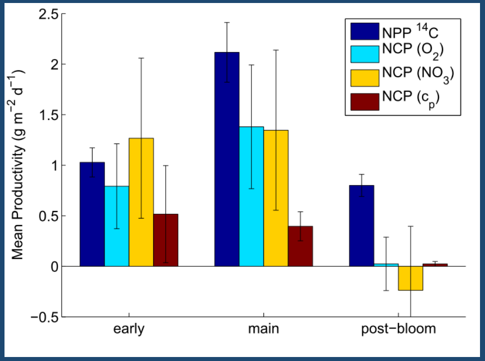
0 –100 m integrated Carbon (mol C m^{-2})

Calibrated, validated optical proxies allow projection of expensive ship results to larger spatial scales scales.

Particulate organic carbon, partitioned into two blooms:
- diatom spring bloom
- later picoplankton bloom

EXPORT is the fate of carbon from diatom spring bloom





Export rate diatoms community ~ 12% / d
Export rate for picoplankton ~ 3% / d

Where are we going in the next 31 years ?

- More sensors, particularly for ecosystems and biochemistry
- More calibrations
- More long-term sustained operations
- More coupled ship – multiple autonomous process studies
- More truly autonomous operations (robotic intelligence)
- Better data systems

Why do we need to get there?

- For pure scientific discovery and understanding
- For understanding climate change and its consequences
- For mitigation of problems with immediate impact on society