Strategies for Autonomous Sensors

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With thanks to the NAB08 Team

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and

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WETLABS

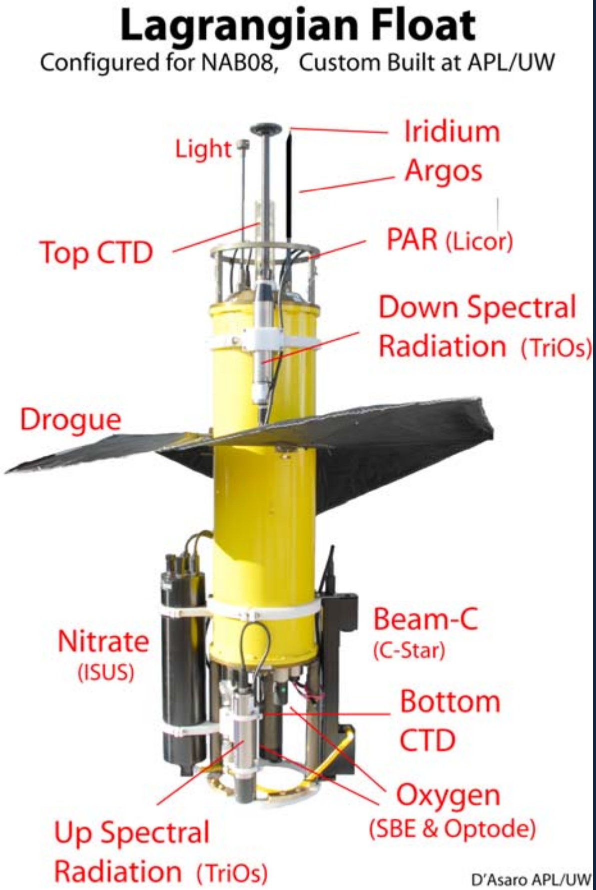
Autonomous Observing Network ‘Calibration’ Issues

1. Calibration- What does it measure? Uncertainties? Intercomparability? Stability?
   - Lab calibration (pre- and post-mission).
   - Direct in situ calibration (Winkler oxygen, bottle salinity).
   - Cross-calibration against known reference sensors.
   - Comparison with climatology.
   - Comparison with other data products (remote sensing?).
   - Redundant/related sensors.

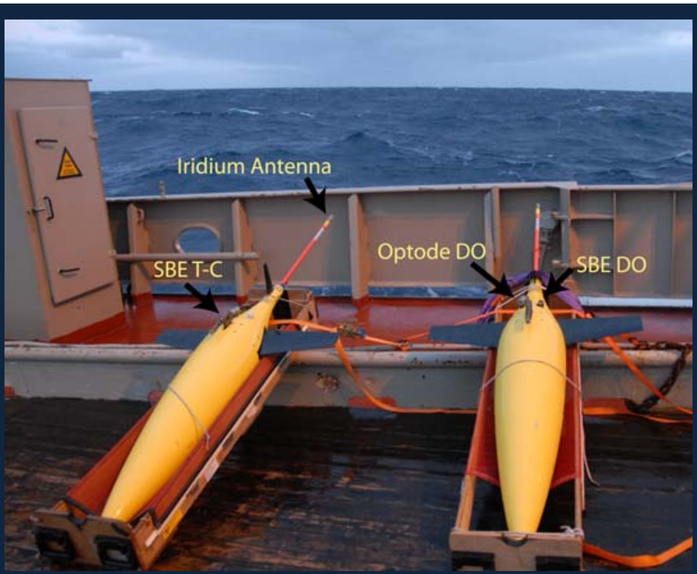
2. Interpretation (proxies: fluorescence → chlorophyll, backscatter/beam-c → POC)- Uncertainties? Stability (temporal & spatial)?
   - Lab characterization.
   - In situ measurements for proxy creation.

NAB08: Patch Scale Sampling Through the Spring Bloom

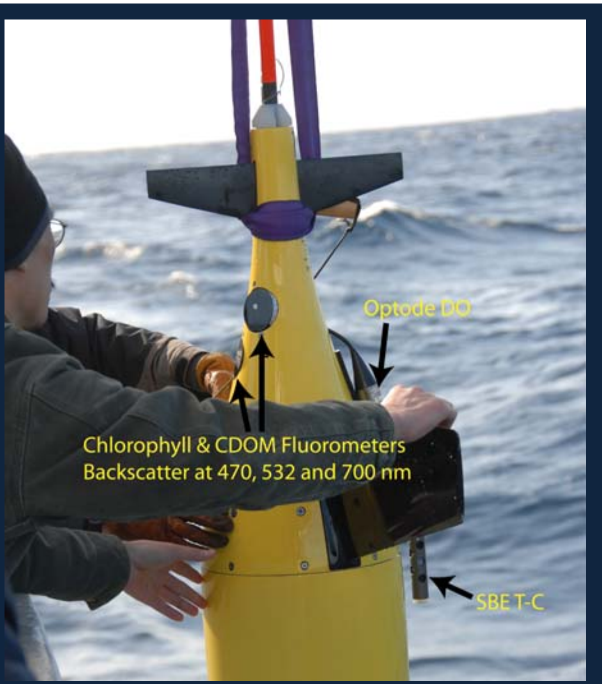
- Persistence- deploy before bloom, recover after.
- Floats- Lagrangian frame, quantify vertical fluxes.
- Gliders- spatial context around drifting floats.
- Proxy sensors for carbon-cycle components.
- Ship-based sampling- calibration, inform interpretation.
- Aggressive calibration efforts- lab, deployment, process and recovery cruises.
- Satellite remote sensing.
- Ecosystem and submesoscale circulation models.



Floats- Cycle within mixed layer. Profile to 250 m every 24-36 h.

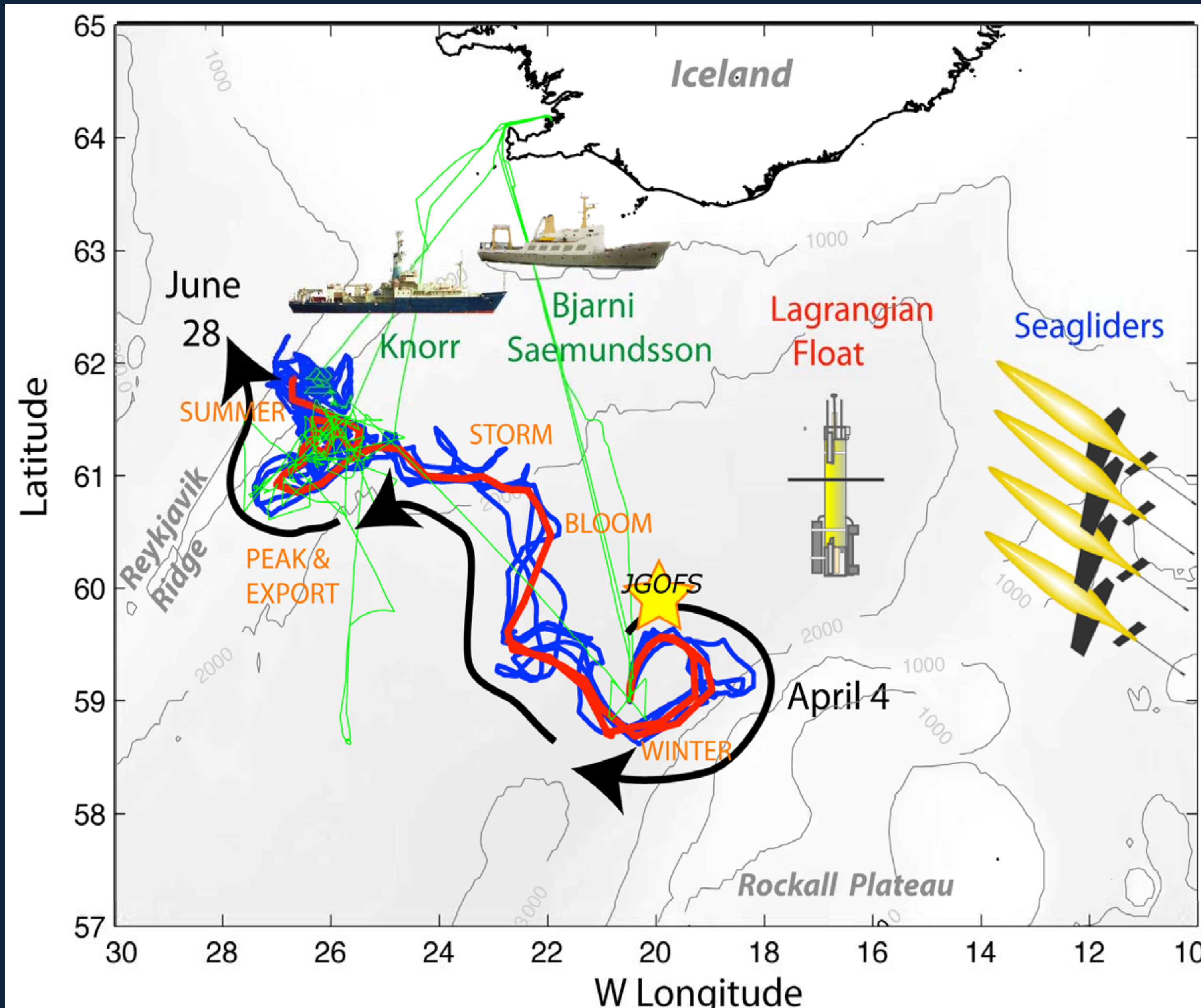


Gliders- Survey around floats. Profile to 1000 m every 4-5 h.



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

NAB08 Field Program



Platforms and Sensors

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} (3x)
• Chl fluor	□ Chl fluor	□ Chl fluor (2x)
• C-star	□ C-star	
• oxygen	□ Oxygen (2x)	□ Oxygen (2x)

NAB08 Calibration Approach

- Cross-calibration required to exploit large array of sensors.
- Pre- and post-deployment lab calibrations.
- Aggressive program of direct calibration and cross-calibration against common reference sensors using tightly co-located, contemporaneous hydrographic casts (20 profiles)
- Cross-calibration using collocated glider-glider and float-glider profile pairs (40 profiles).
- Additional ship-based measurements support proxy creation.
- Methodical- calibration reports.

The 2008 North Atlantic Bloom Experiment

Calibration Report #

**Intercalibration of the C-Star Beam Transmis
48, Knorr cruise and the Bjarni Sæm**

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Preliminary Version 1.3: January 15,

Abstract

Five WET Labs C-Star beam transmissometers were deployed during the 200
(NAB008). Floats 47 & 48 (CST-1062, CST-1063), the R/V Knorr cruise 19
three cruises on the R/V Bjarni Saemundsson (CST-284, CST-1090) are comp

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Calibration Report #3

Calibration of the Dissolved Oxygen Sensors from Float 48 and Winkler bottle samples from Knorr Cruise

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Version 1.1 March 11, 2009

Summary

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

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Calibration Report #7

Intercalibration of the Backscatter sensors from Float 47 & Knorr cruise

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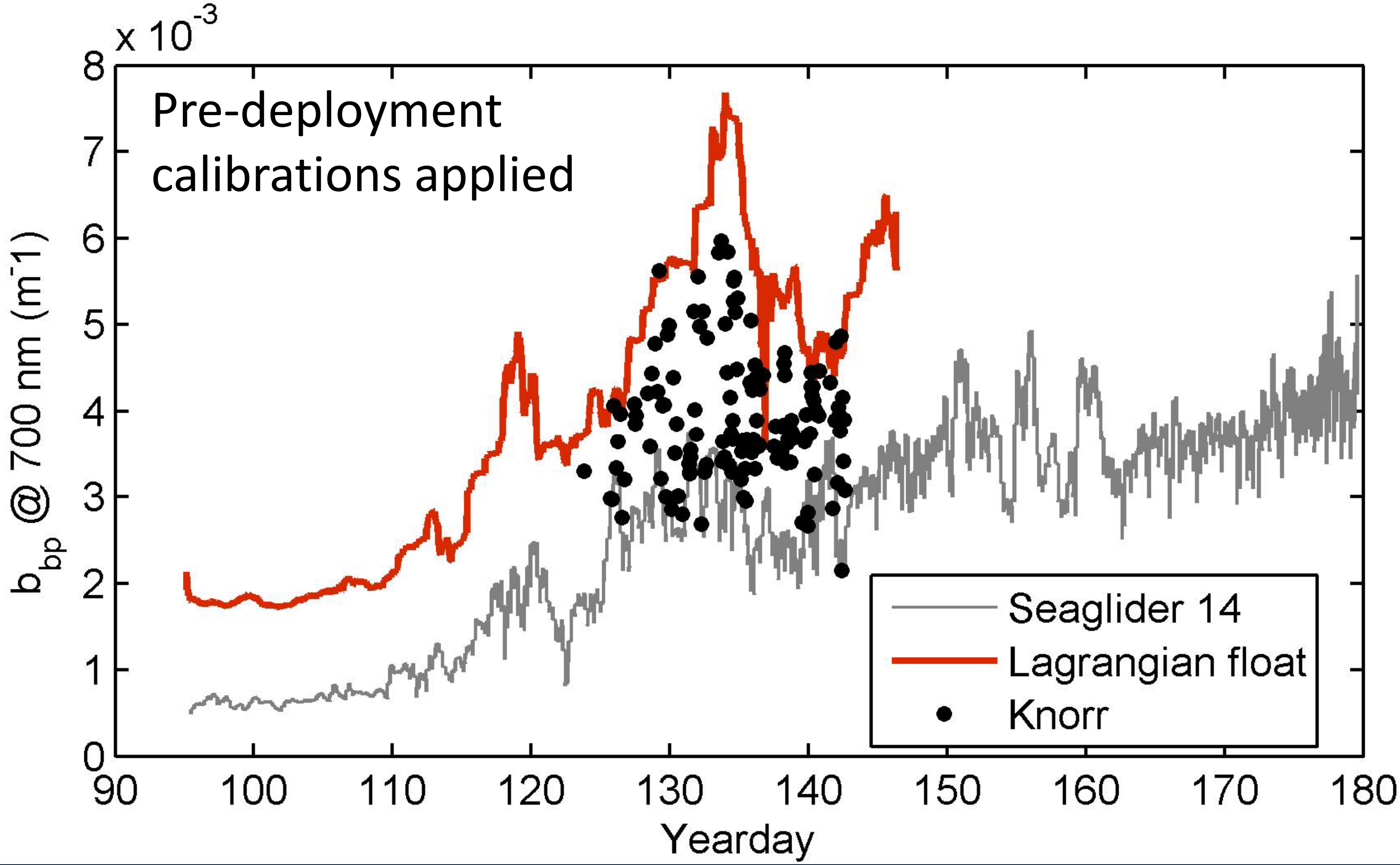
Version 0.5: October 15, 2009

uments that estimate backscatter at 700nm were deployed during the
loom experiment (NAB08). There was one on each of the two floats,

Calibration, Correction and Proxy: NAB08 b_{bp} Example

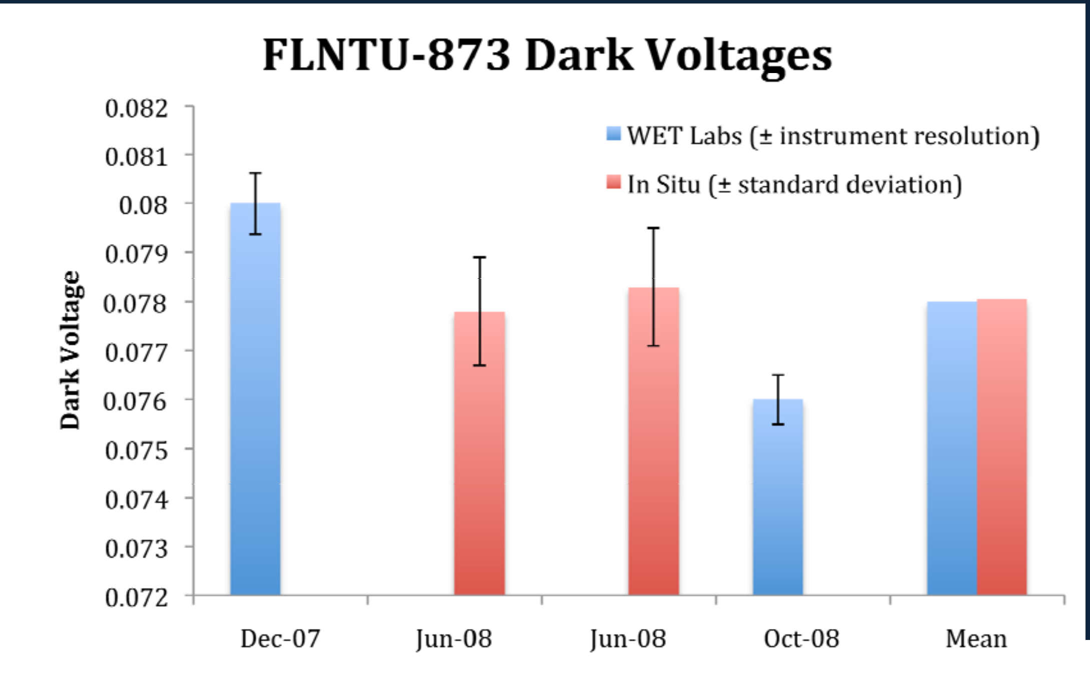
- Bulk laboratory calibrations- all backscatter sensors (1 ship, 4 glider, 2 float) undergo joint pre-deployment calibration.



Calibration, Correction and Proxy: NAB08 b_{bp} Example

- Bulk laboratory calibrations- all backscatter sensors (1 ship, 4 glider, 2 float) undergo joint pre-deployment calibration.
- Chose reference- ship.
- Direct in situ calibration.
- Cross calibration against common reference.
- Map b_{bp} to POC.

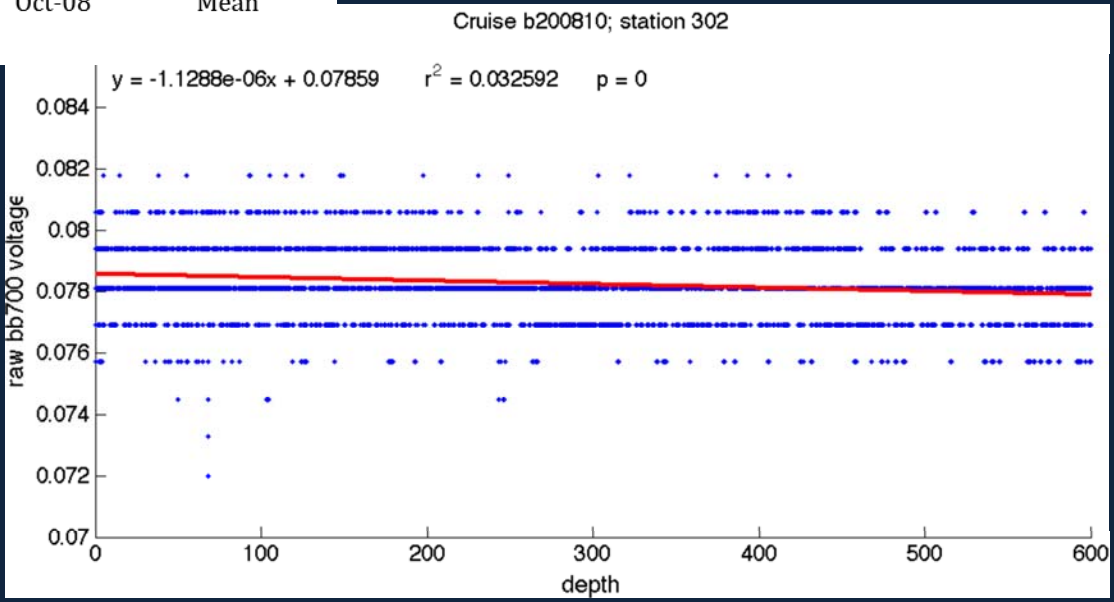
Calibration of Reference (ship) β_{700}



$$\beta_{700} = A(\beta_{raw} - \beta_{dark})$$

- Pre- and post-mission lab calibration differ.
- Mean consistent with in situ cal.

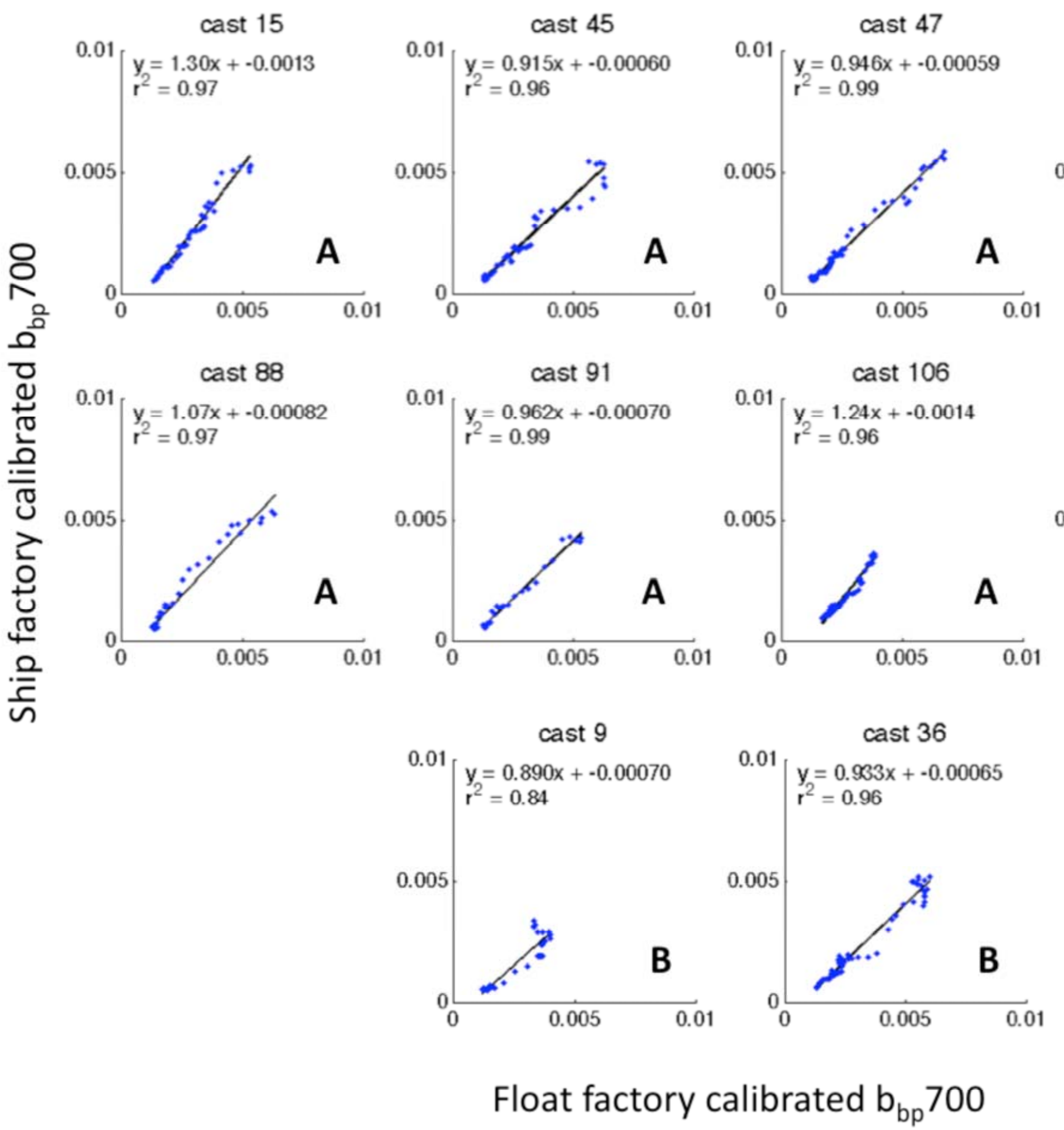
Small hint of depth-dependent bias...



Float – Ship Calibration Casts

'Class A' (<0.5 km)

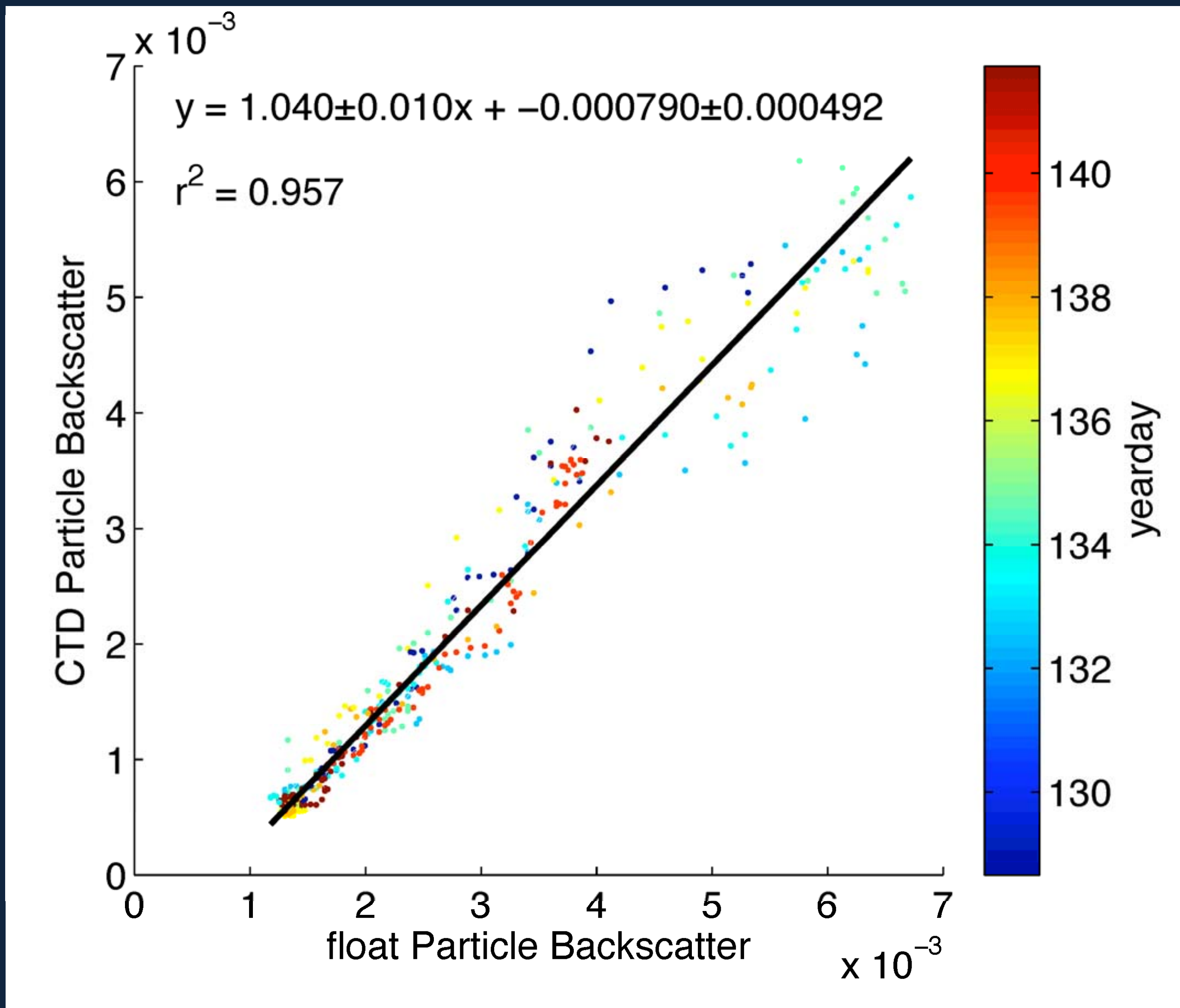
'Class B' (>0.5 km)



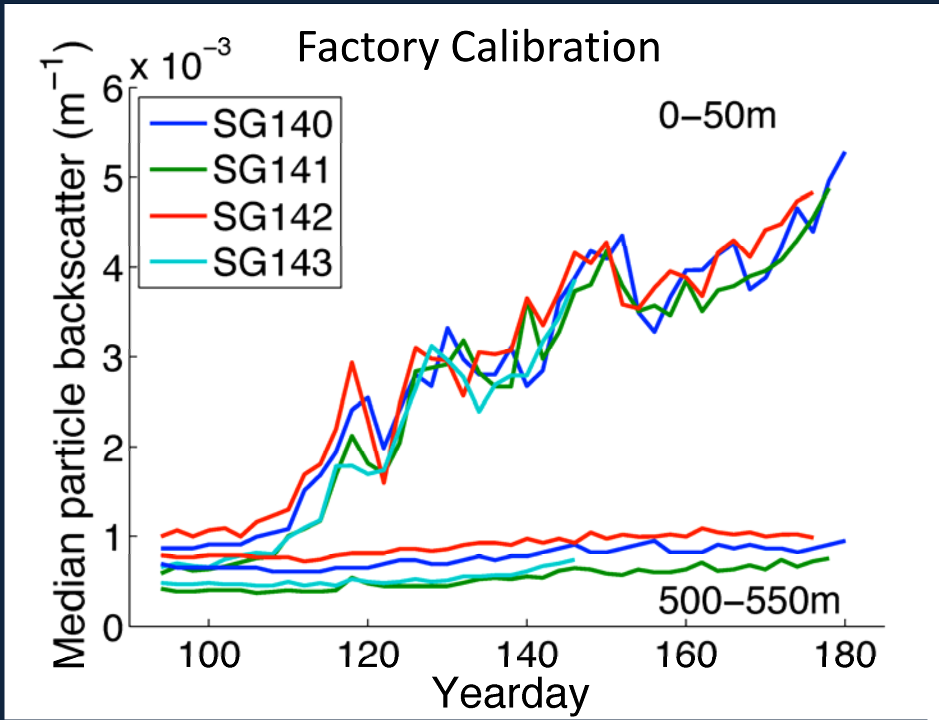
Proximity Matters:

regressions degrade with separation (space, time)

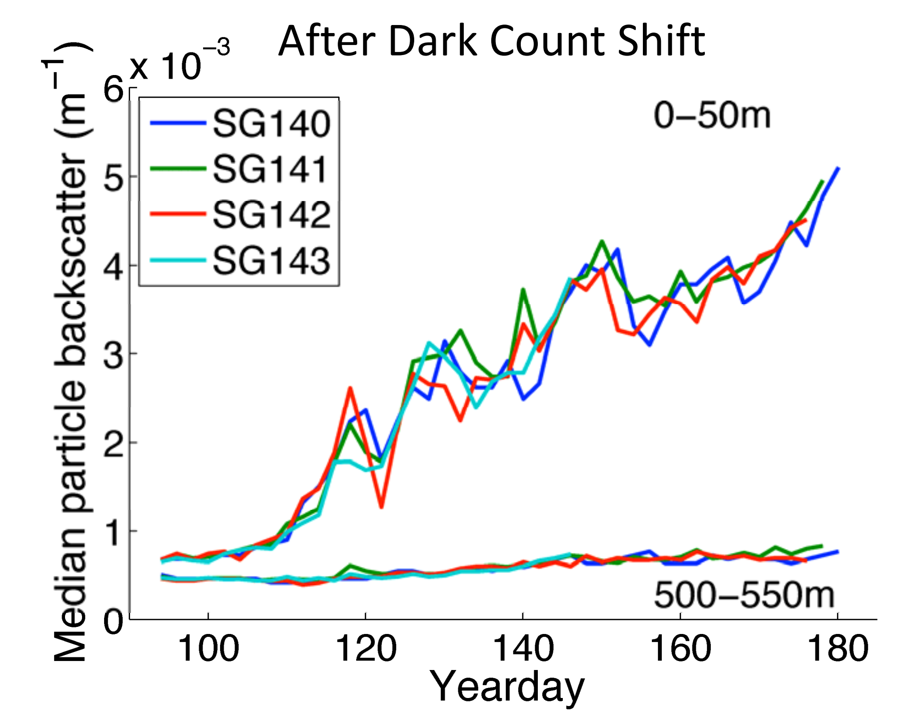
Float Cross-cal to Ship Reference



Glider: Deep Misalignment

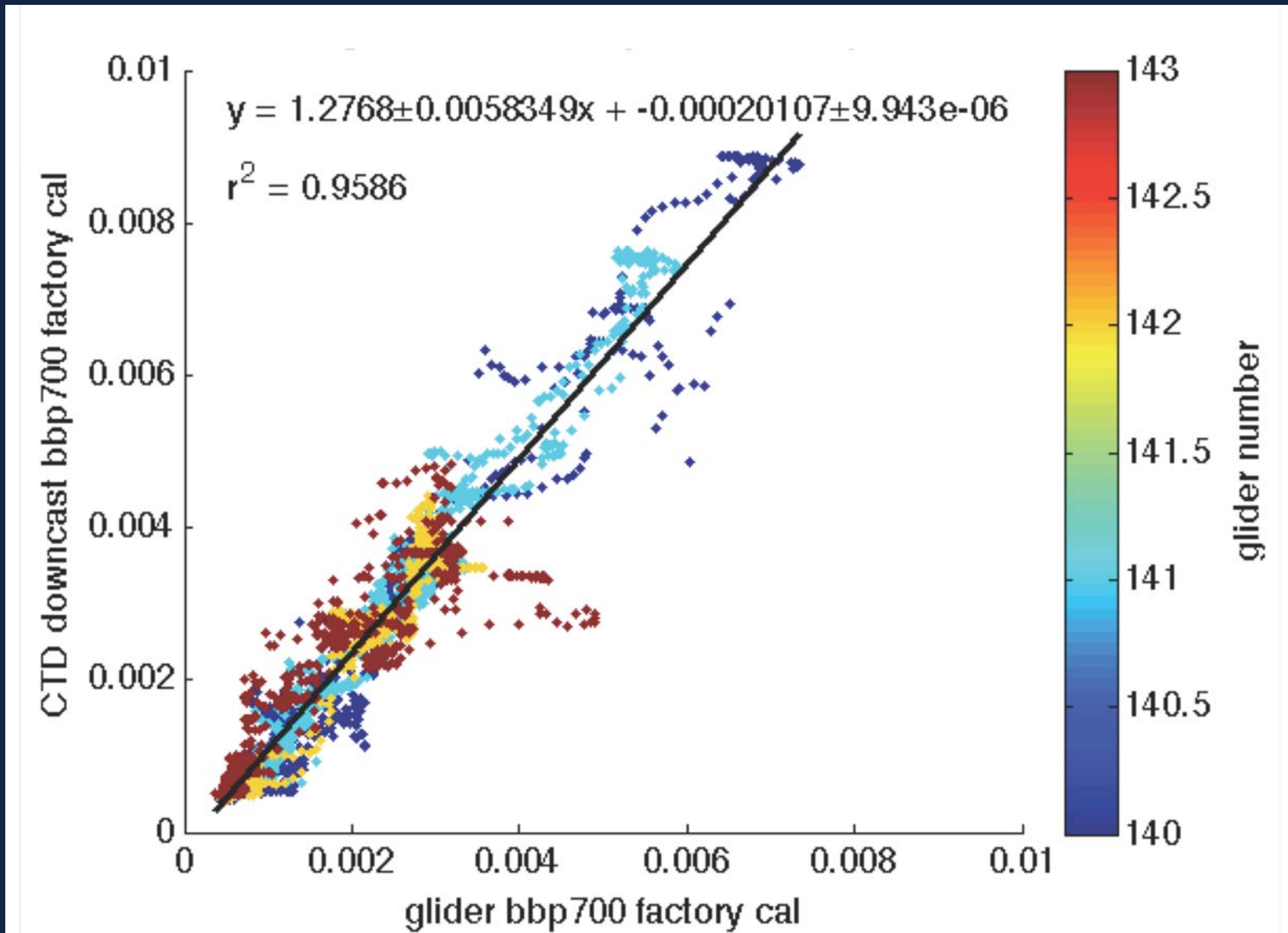


- Clear biases at depth-uncertainty in dark cals.
- Shift baseline to adjust: $\beta_{700} = A(\beta_{raw} - \beta_{dark})$
- Calculate b_{bp}

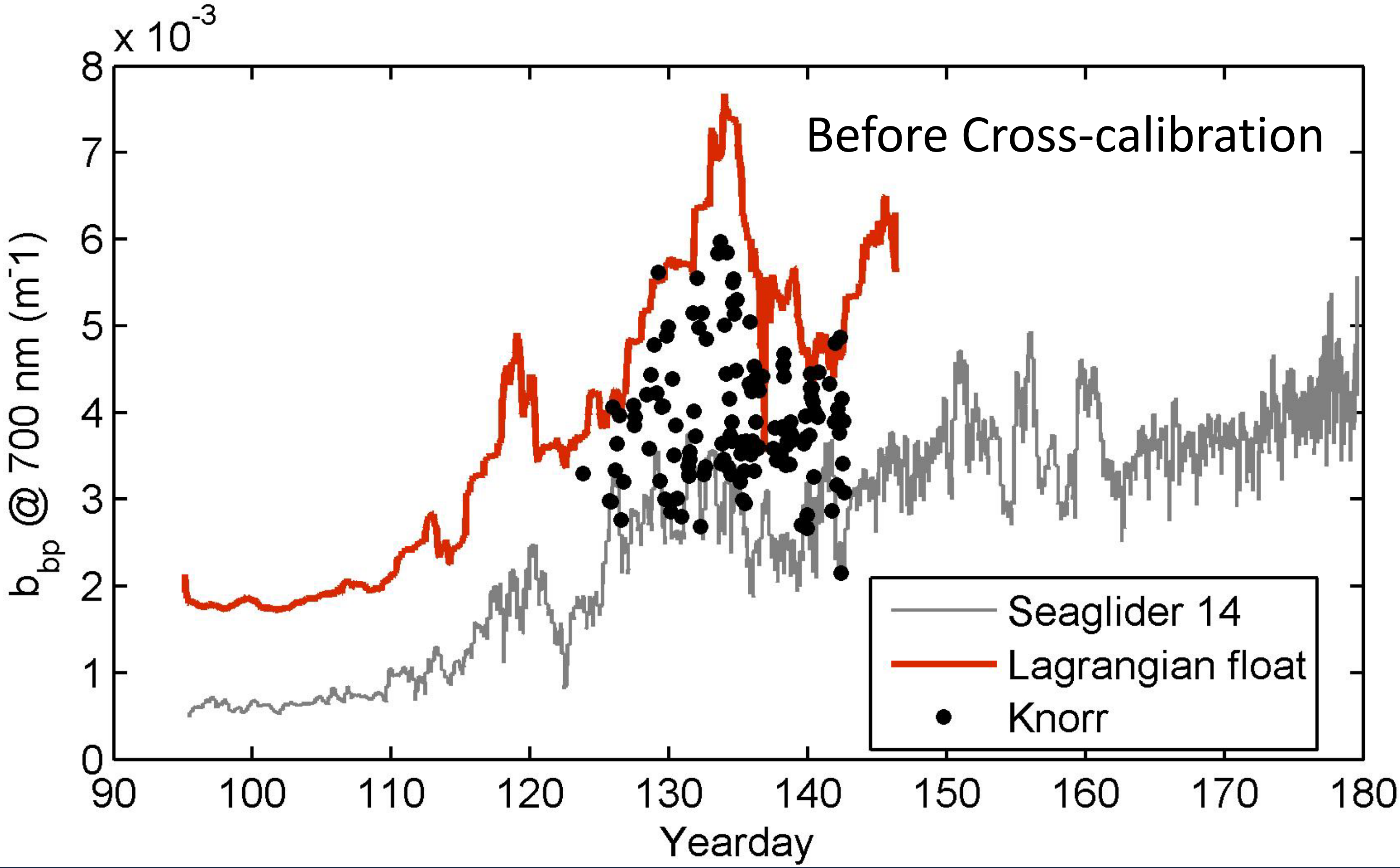


- Collapses deep and early (shallow, before YD120) b_{bp} across the 4 gliders.
- No clear scale (A) error.

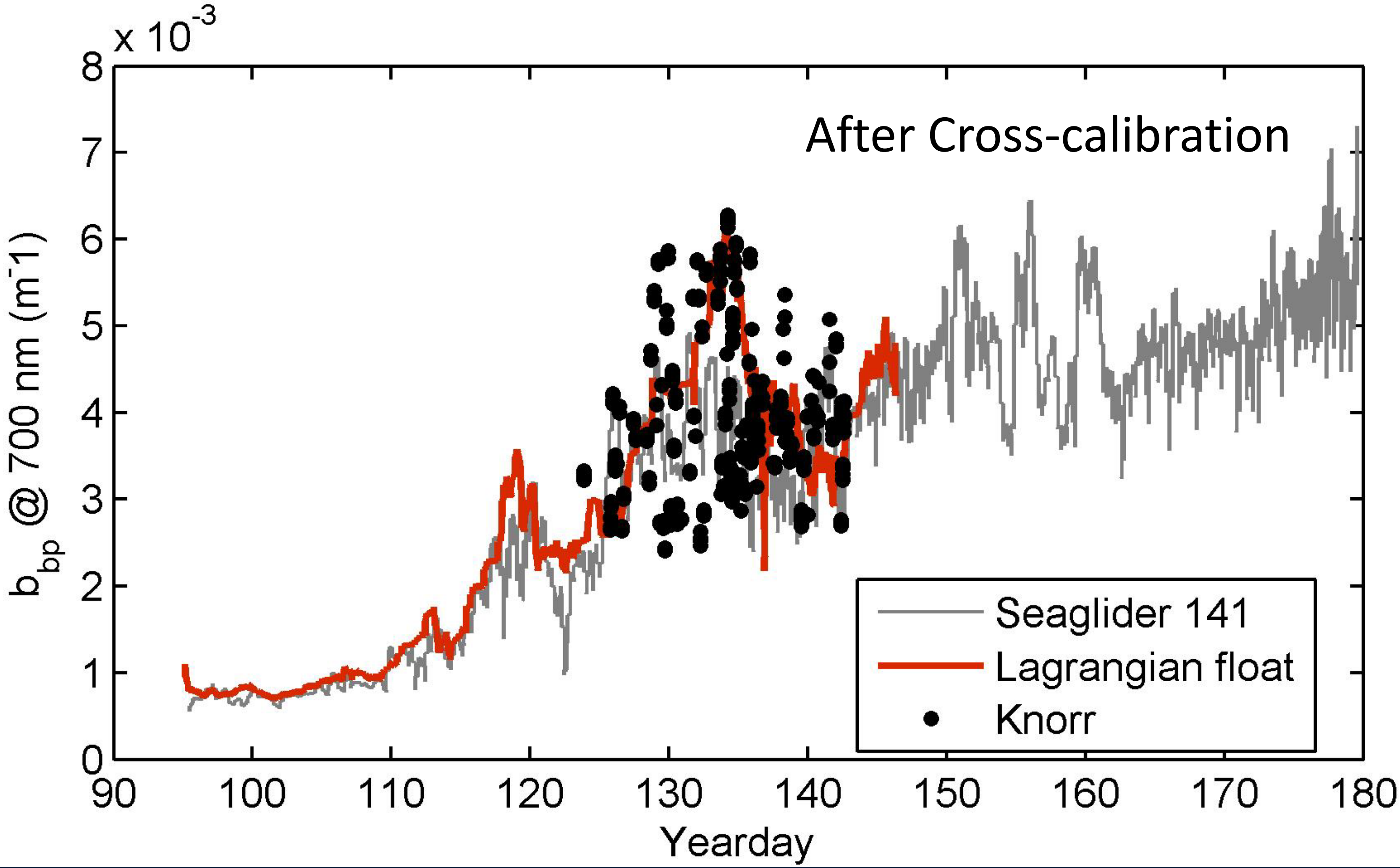
Glider Cross-cal to Ship Reference



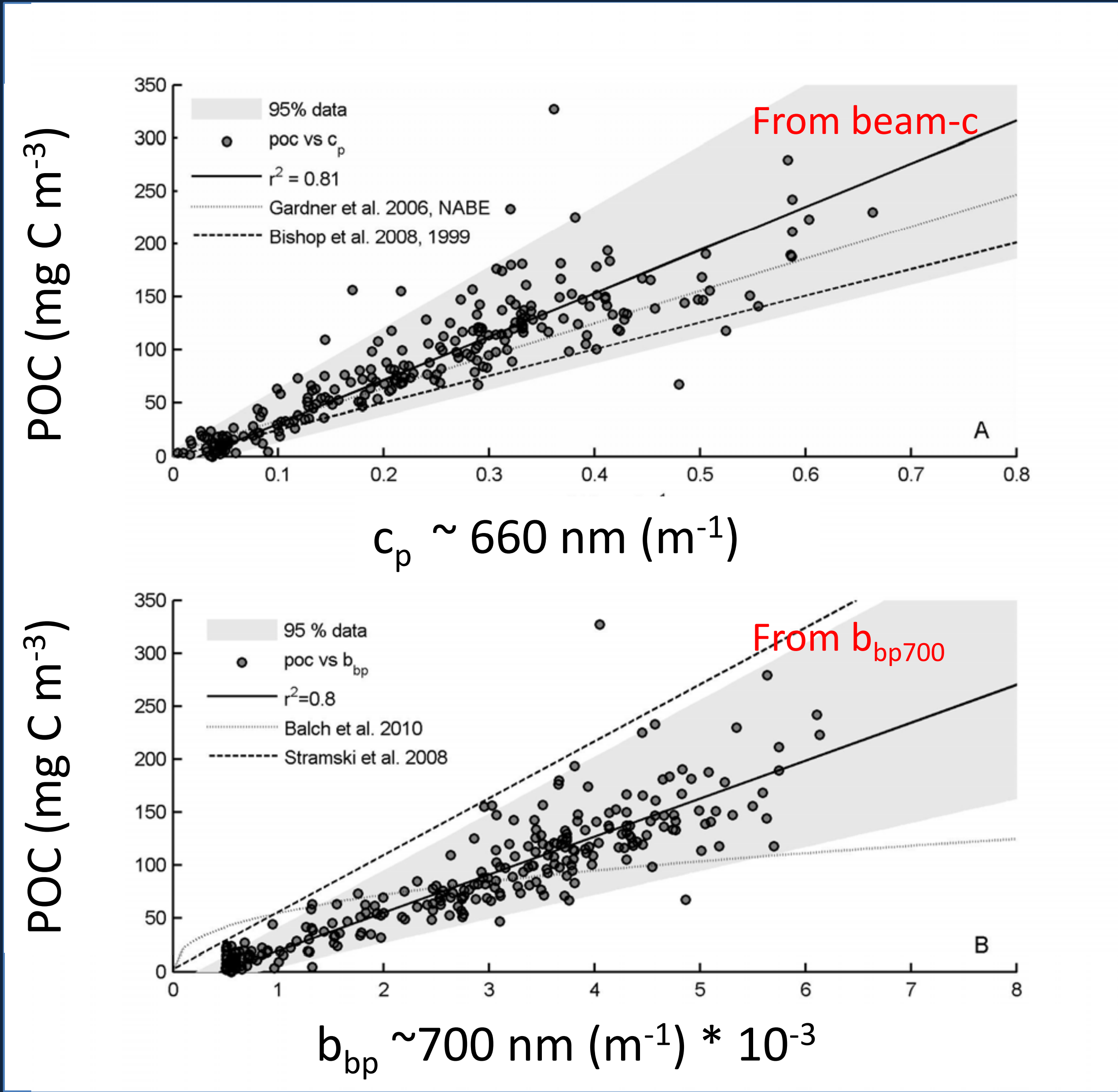
Before Calibration to Common Reference



After Calibration to Common Reference



POC Proxies: c_p and b_{bp} (>300 samples)



Cetinic et al.

NAB08 Lessons

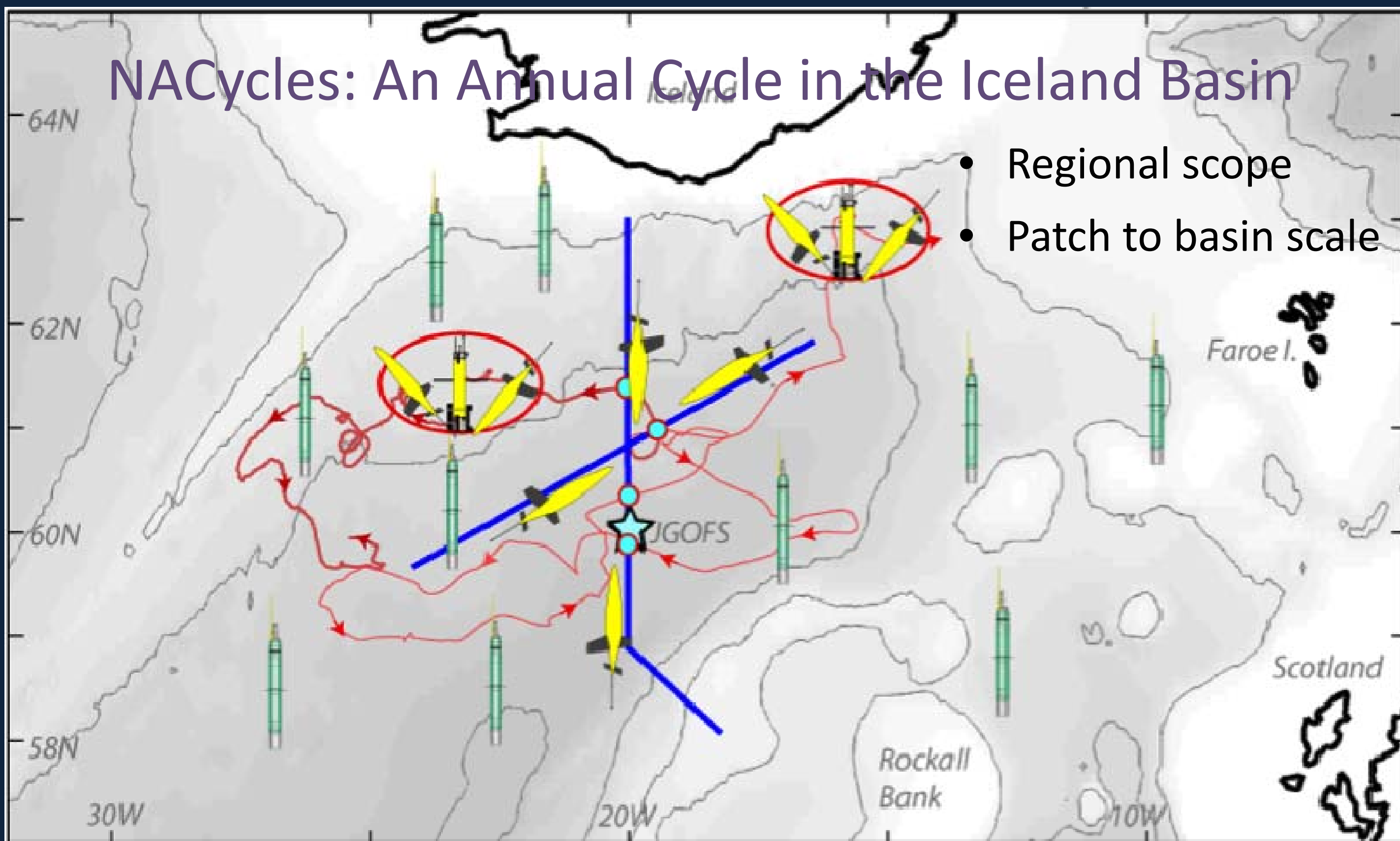
- Quantitative analyses (e.g. budgets) require in situ and cross-calibration of biogeochemical sensors- lab calibration is insufficient.
- However, there are other important questions that place less stringent requirements on data quality.
- Multiple calibration opportunities required for robust correction.
- Calibration at recovery risky (instrument issues).
- Spatial and temporal variability may limit utility of climatological calibration in many areas (‘proximity matters’).
- Intensive ship-based measurements may be leveraged onto more numerous autonomous observations.

- Direct calibration does not scale to large numbers of platforms, highly distributed networks.

Looking forward…

- Experience (e.g. salinity) → sensors *can* improve enough to greatly reduce calibration problems.
- Direct calibration of limited number of reference sensors on mobile autonomous platforms.
- Mobile platforms propagation direct calibrations via cross-calibration ‘visits’ and engineered encounters.
- Further cross-calibration through chance encounters.
- Possible calibration using localized (time & space) reference sensor data.
- Empirical vs. mechanistic proxy relationships.
- Continued need for ships and in situ work (calibration and interpretation in systems undergoing change).

Autonomous Biogeochemical Network- Pilot Projects



Key Elements:

- Compelling science
- > Process study
- < Ocean scale
- Test system components & concepts

Autonomous Sensors

O_2, NO_3, Chl, PAR
Optics (POC),
Acoustics (MesoZooplankton)

Intercalibration Opportunity

Glider Lines:
4 Gliders
20-30 days transit

BioArgo Array
~10 floats

Lagrangian Arrays

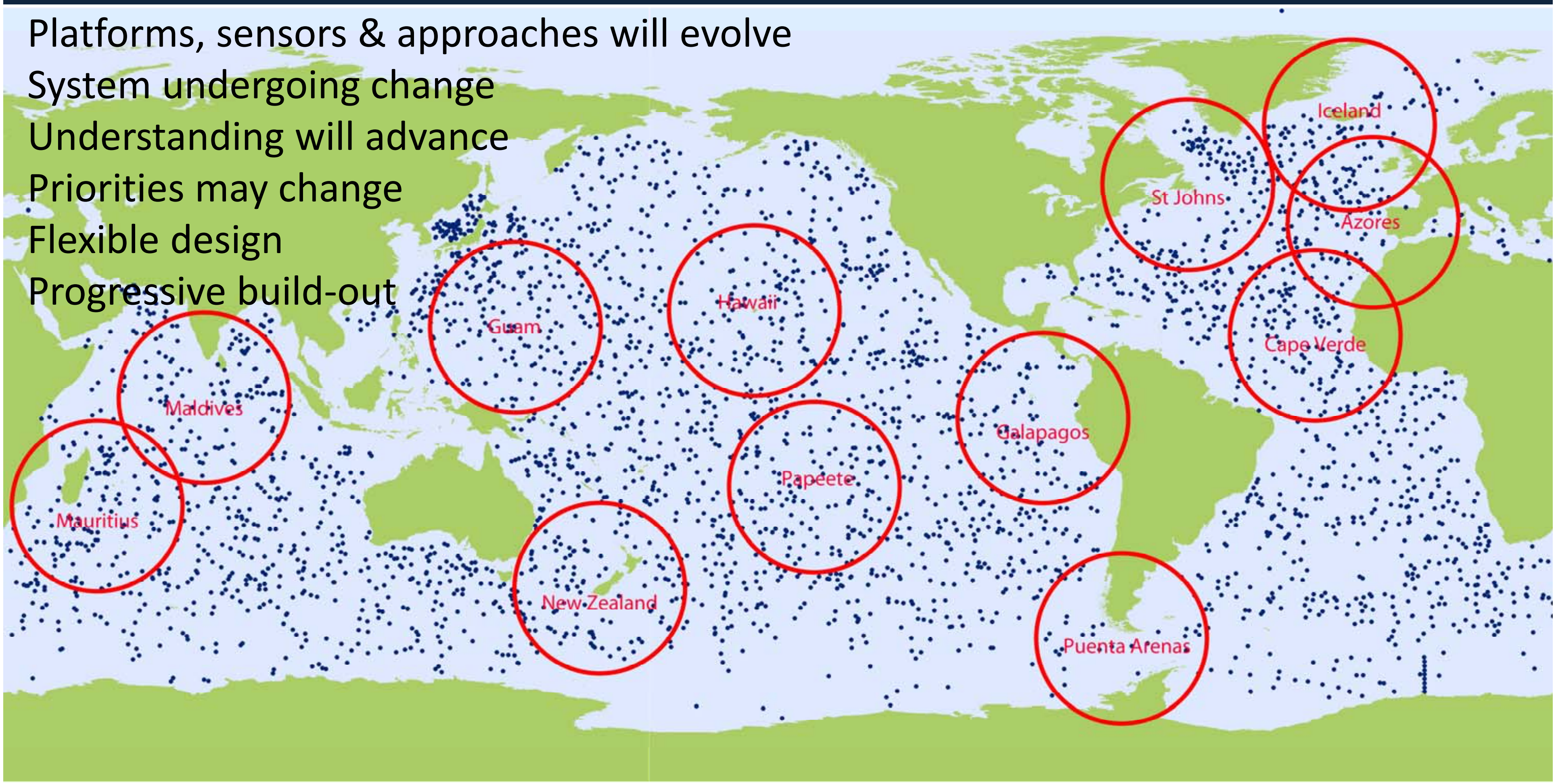
120 day deployments

Ships

~9 Cruises
UNOLS Charter BASIN

Mobile Autonomous Platforms in a Biogeochemical Network

Platforms, sensors & approaches will evolve
System undergoing change
Understanding will advance
Priorities may change
Flexible design
Progressive build-out



3308 Active Floats **May 2011**

~1800 km range circles = ~6-month operating scope of today's gliders
Can loiter and drift to extend endurance, time on station

Future mobile platforms: Tethys LR AUV (1-2 kts, 3000+ km, extensive payload)
ER and Deep gliders