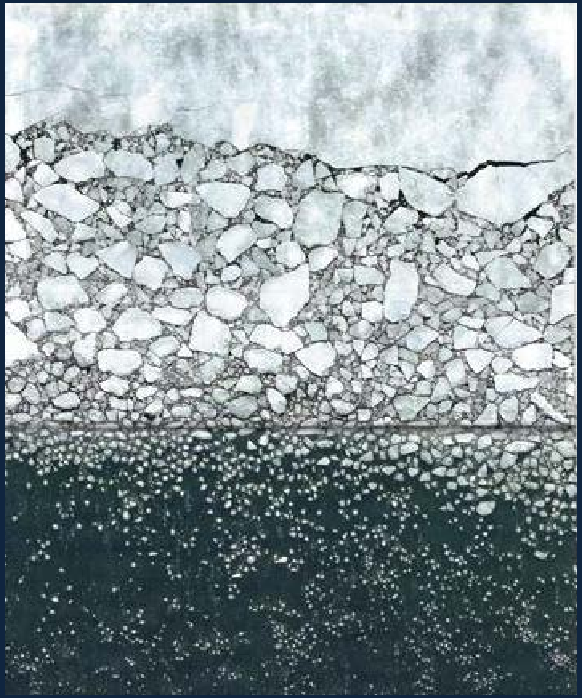
Instrument Robotic Platforms: Measurements in a Changing Environment

Luc Rainville

Applied Physics Laboratory, Univ. of Washington

… with input from Craig Lee, Eric D'Asaro, and several others.



1. Motivations and Challenges
   - Monitoring climate change
   - Physical and Biogeochemical systems
   - Sampling in remote areas
2. Platforms and sensors
   - Technology development (sensors and platforms)
   - New ways to use robotic platforms
3. Summary, thoughts, questions

Big Challenges for Autonomous Platforms

Monitoring the Planet in the context of **climate change**

Development of biogeochemical sensors to study the integrated **physical and ecological system**. Learning how to use platforms in a broader context.

- Understand the patchiness in time and space of primary production, carbon cycle, etc.
- How do patchy processes integrate to basin and global scales?

Using autonomous platforms to sample areas difficult or impossible to **access**

- Hurricanes, under ice, ice sheets, abyss, etc.

Why robotic platforms?

- Access- Regions far from human activity and transportation hubs.
- Risk- Unforgiving operating environment, extended development arc.
- Persistence- Resolve important timescales, transient events.
- Cost/Scalability- Sustain broad, long-term activity.
- Adaptability/Flexibility.
  - Needs evolve with changing environment and understanding.
  - Meet disparate stakeholder needs: climate to tactical.

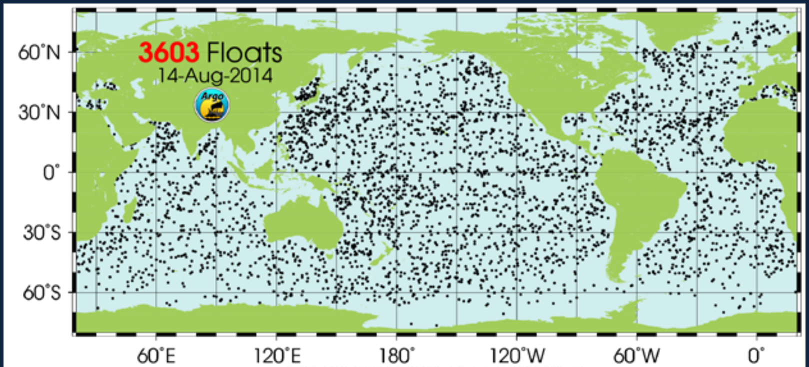
How do we build a sustainable observing capability that resolves a broad range of temporal and spatial scales (climate to process) and meets the needs of basic research, policy makers and stakeholders?

Global Observations

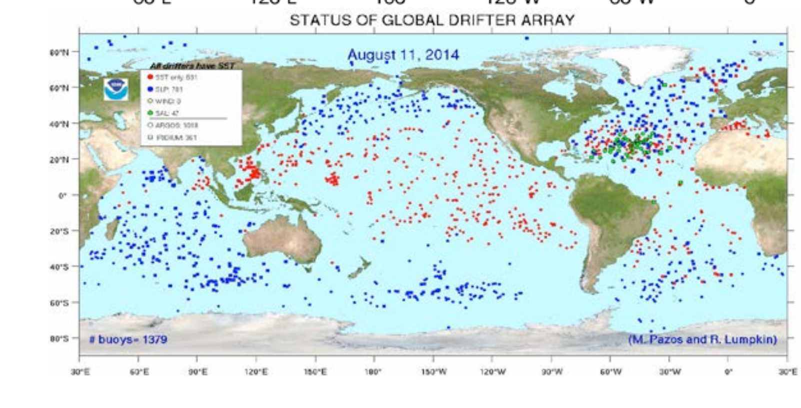
Key Attributes

- Access remote locations.
- Distributed & Persistent: low cost, light logistics, scales well, sustainable.
- *Requires acoustic infrastructure for working under ice.*

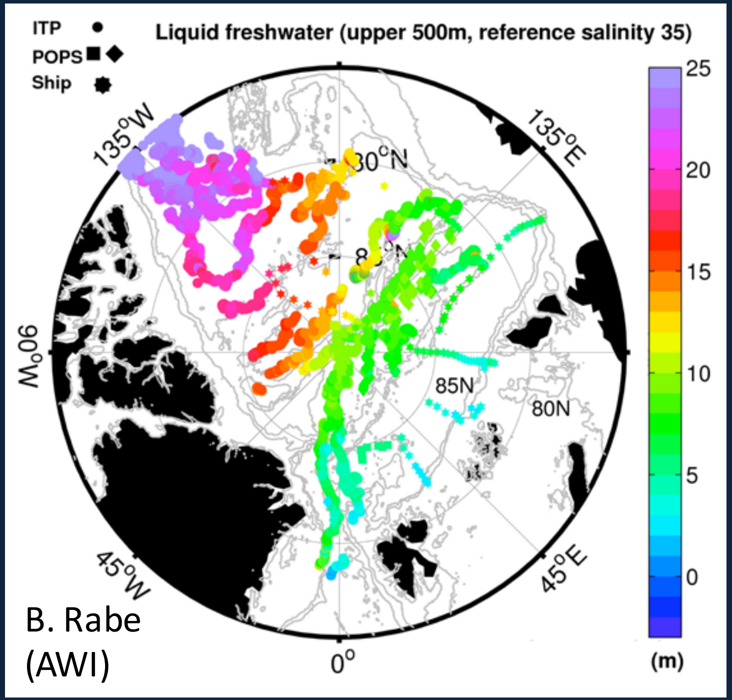
Global ARGO Array

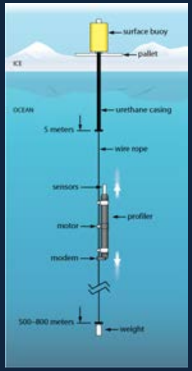


Global Drifter Program

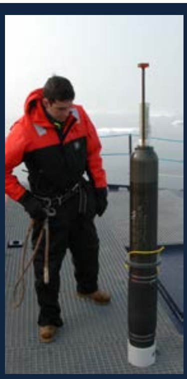


Arctic Observing System

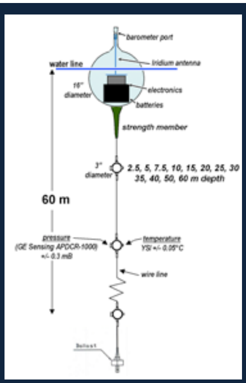




ITP



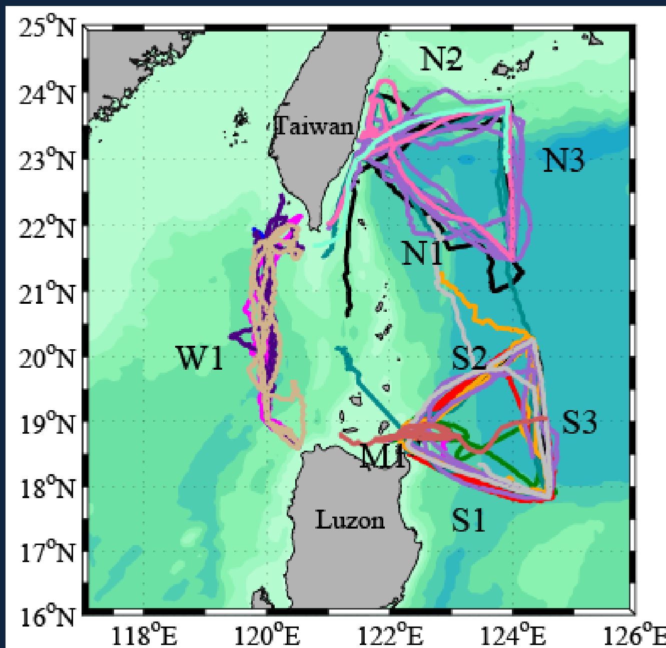
PPF

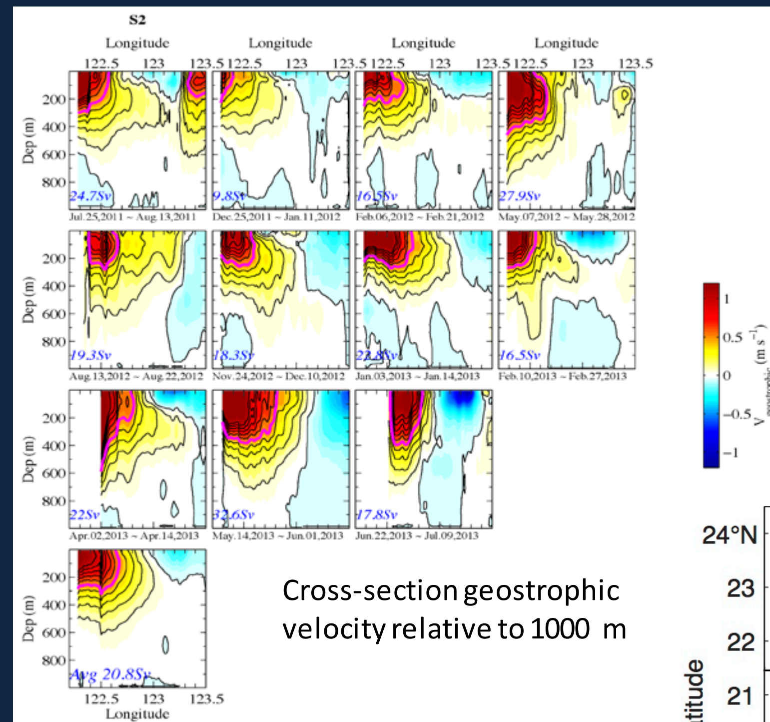


UpTempO

ULS Float

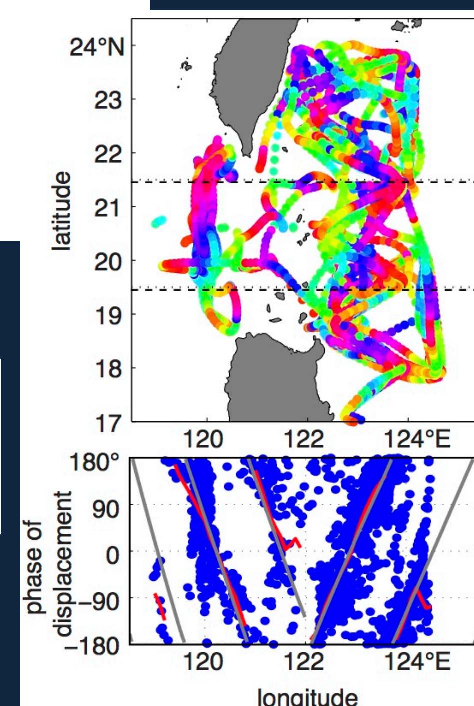
Persistence – Glider Observations of Boundary currents





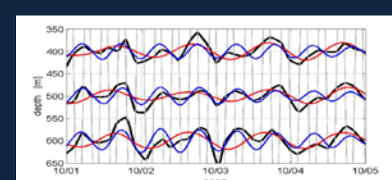
Cross-section geostrophic velocity relative to 1000 m

Craig Lee, Barry Ma,
Ren-Chieh Lien, Luc Rainville



OKMC – Kuroshio
(2011 – 2013)

- 3 Years
- 20 missions
- 1,774 Days
- 8,705 Dives



Glider-Based Characterization of Internal Tides

Luc Rainville, Craig Lee, Dan Rudnick

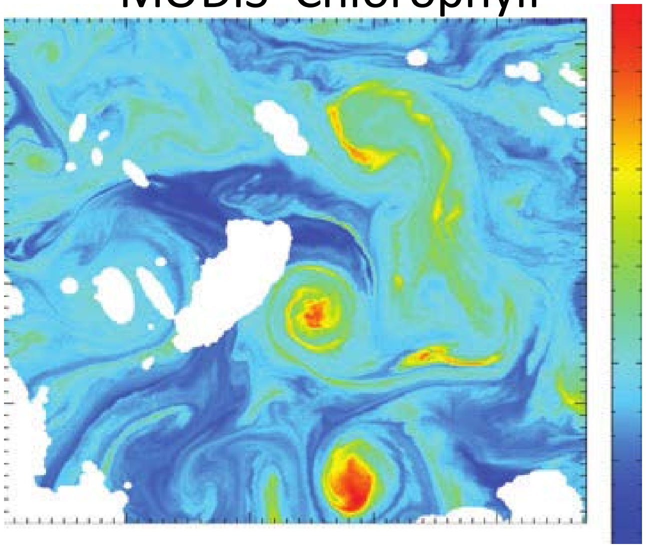
Physical Controls of Biology / Biogeochemistry

Blooms and **patchiness** characterize primary productivity and plankton communities

We need to measure on the small temporal and spatial scales of these fields!
We need to resolve the complexity of biological communities

MODIS SST

MODIS Chlorophyll



Klein and Lapeyre 2009

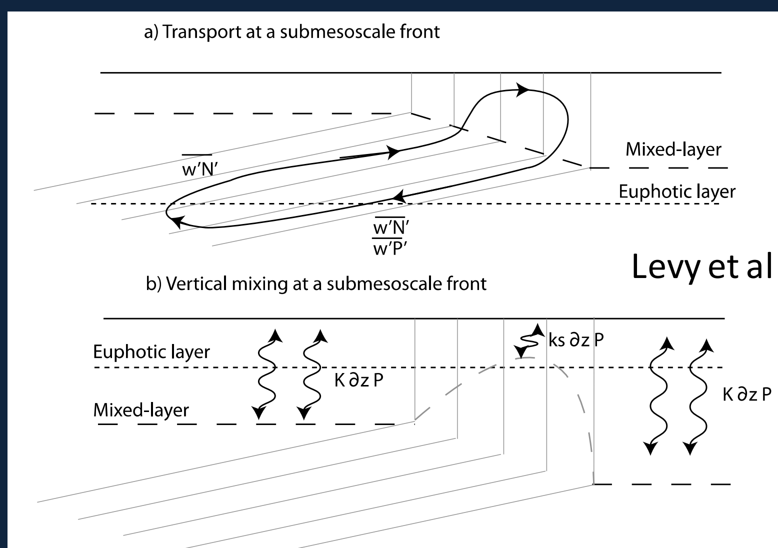
Inherently interdisciplinary- many scientists and technologists with diverse skills required to drive advances in complex problems like these.

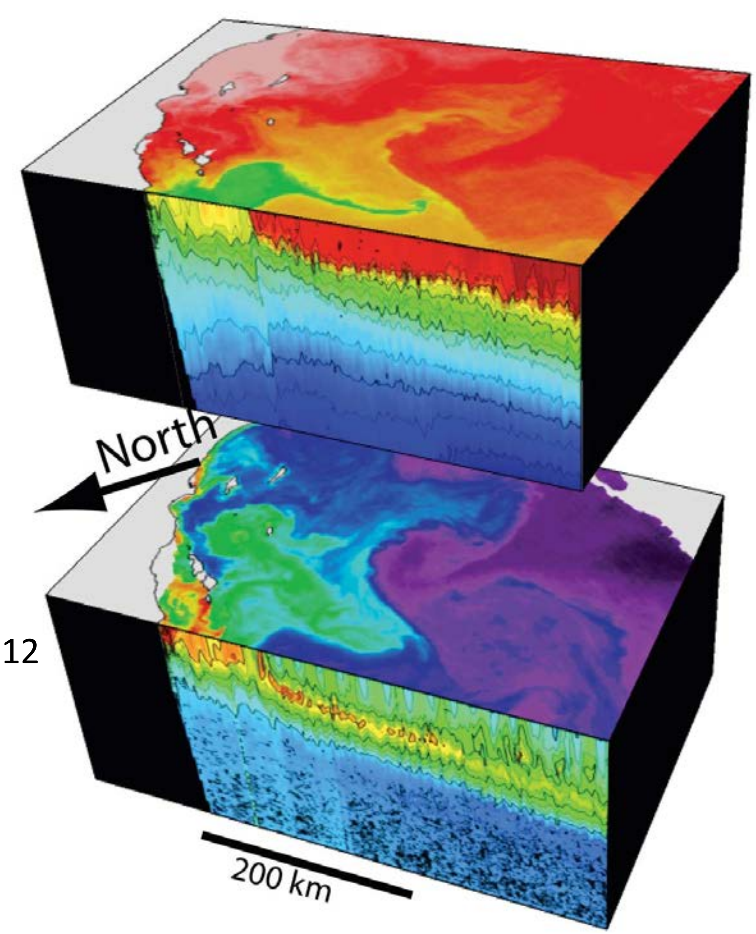
Patch dynamics to climate- Must understand the details of these small scale processes to predict system response to climate variability.

Physical Controls of Biology / Biogeochemistry

Eddy boundaries, mesoscale fronts show *submesoscale* structures 100 m – 10 km. Fronts, filaments, eddies. Elevated chlorophyll.

- Nutrient supply – mixing, advection
- Light – stratification, vertical exchange
- Export (flushing, sinking)
- Encounter rates
- Community structure





Levy et al 2012

Physical Controls of Biology / Biogeochemistry

Ship-based and ship-supported sampling

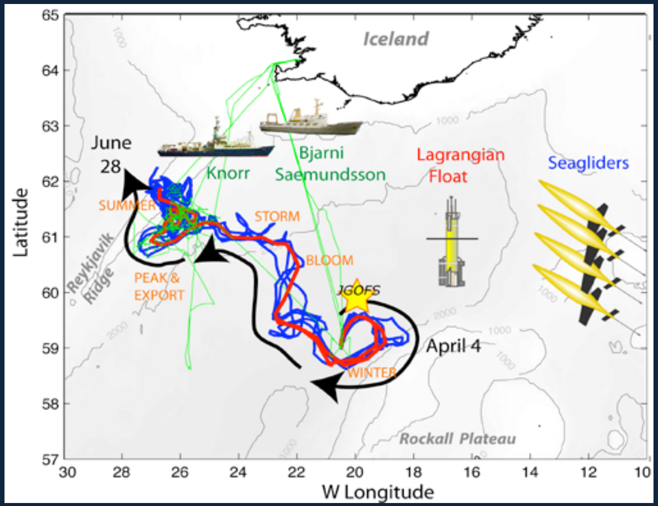
Composition of falling particles

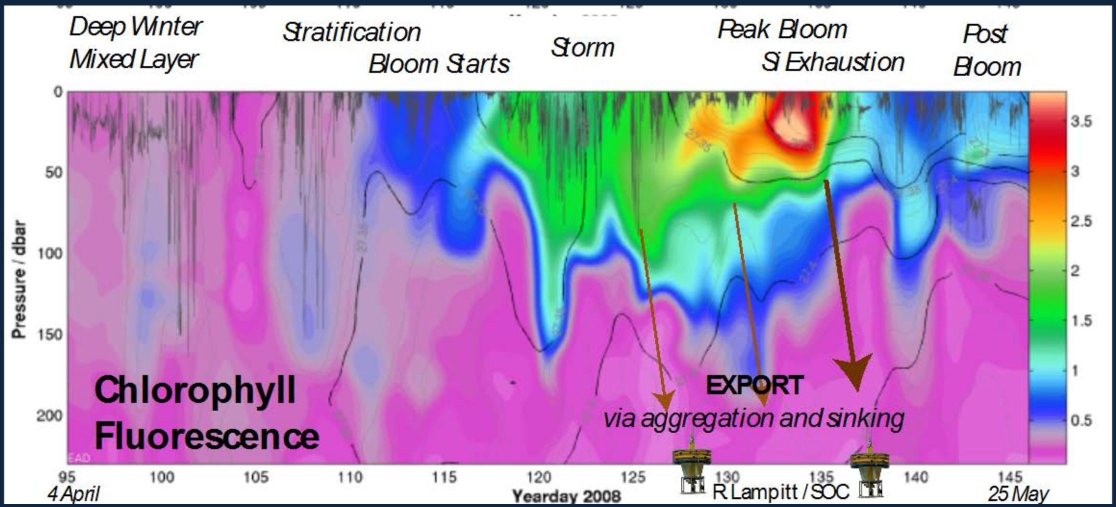
Extensive biological and chemical measurements, calibration data, scale check.

Limited footprint, expensive.

Patch-Scale Dynamics in the Subpolar North Atlantic Spring Bloom – NAB08

Craig Lee, Eric D'Asaro, Mary Jane Perry, et al.





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

2) **Productivity measurements** –

Phytoplankton, Net Community

Export, Sequestration

3) **Calibrated optical proxies** –

Allow projection of expensive ship measurements to larger spatial scales

The NAB08 Story

Phytoplankton growth highest in regions of strong stratification (increased light exposure).

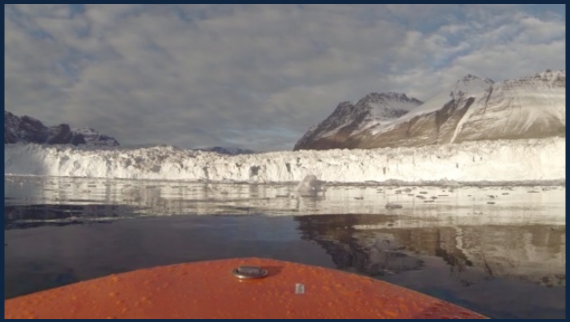
Instabilities of the ML lateral density gradient initiate restratification, accelerates bloom onset by 20-30 days (than would occur with surface warming alone).

Community type (diatoms/PN) also patchy, but can be mapped mapped with Chl-F/bb ratio

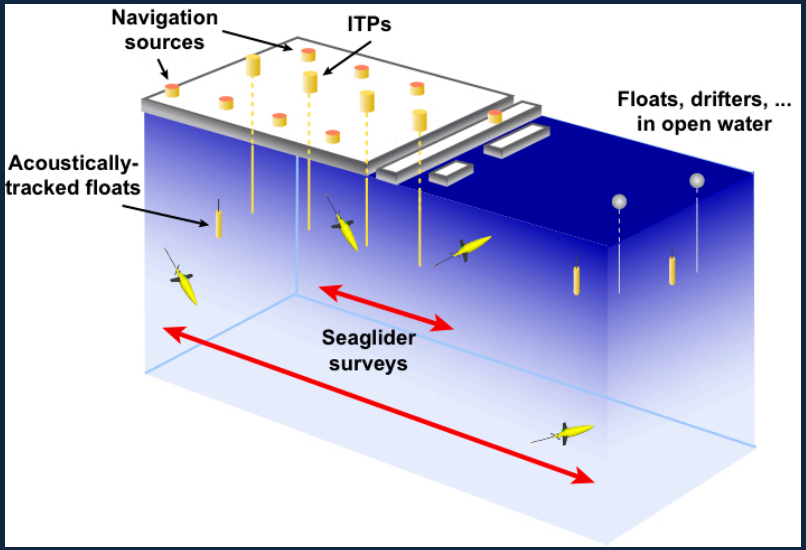
Export efficiency depends on community (12% vs 2%).

Need better grazing estimates to determine patch dynamics.

Sampling in Difficult Environments



Remotely operated boat with ADCP and CTD winch
Schroyer, Sutherland, Nash (Oregon State)

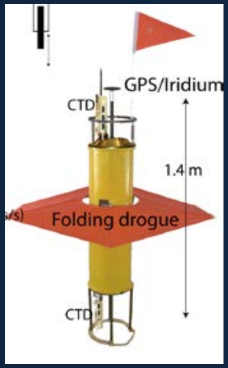


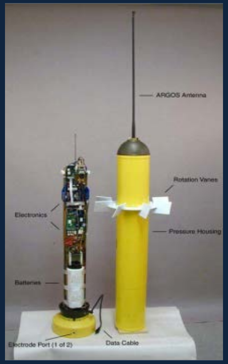
ONR Marginal Ice Zone DRI

Sampling in Difficult Environments

Deployment of Lagrangian float from C-130 during ITOP 2010

79 floats and drifters air-deployed





Eric D’Asaro, Luca Centurioni, Tom Sanford, et al.

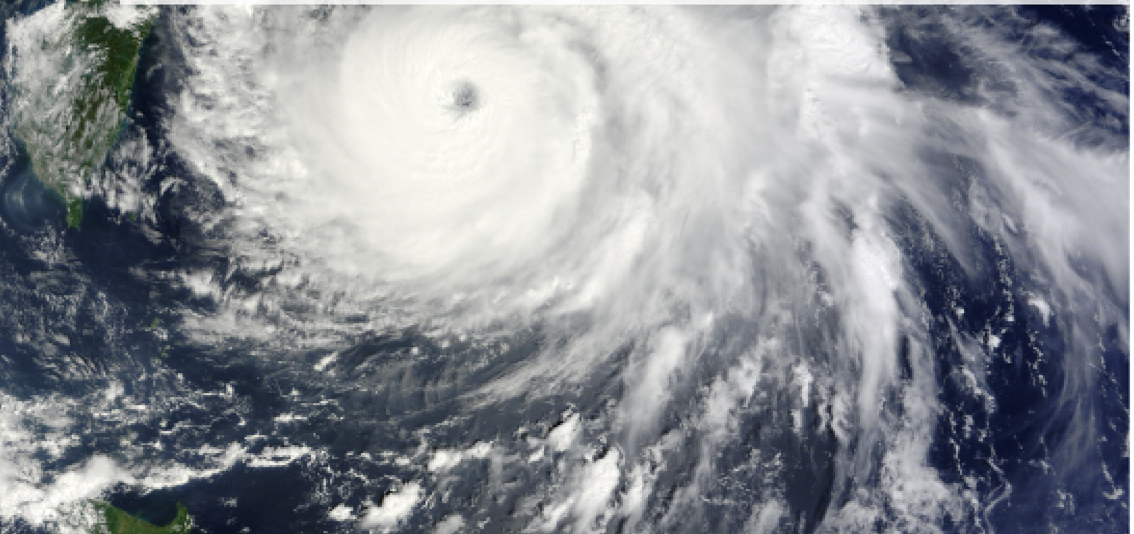
Adaptive and Integrative Sampling during ITOP 2010

10 Seagliders: 3100 dives over 1 month (including 580 χ-profiles from 3 gliders).

Underway-CTD (ship): 3162 profiles over 20 days.

172 VMP profiles (ship).

7 EM-APEX, 4 Lagrangian Floats.

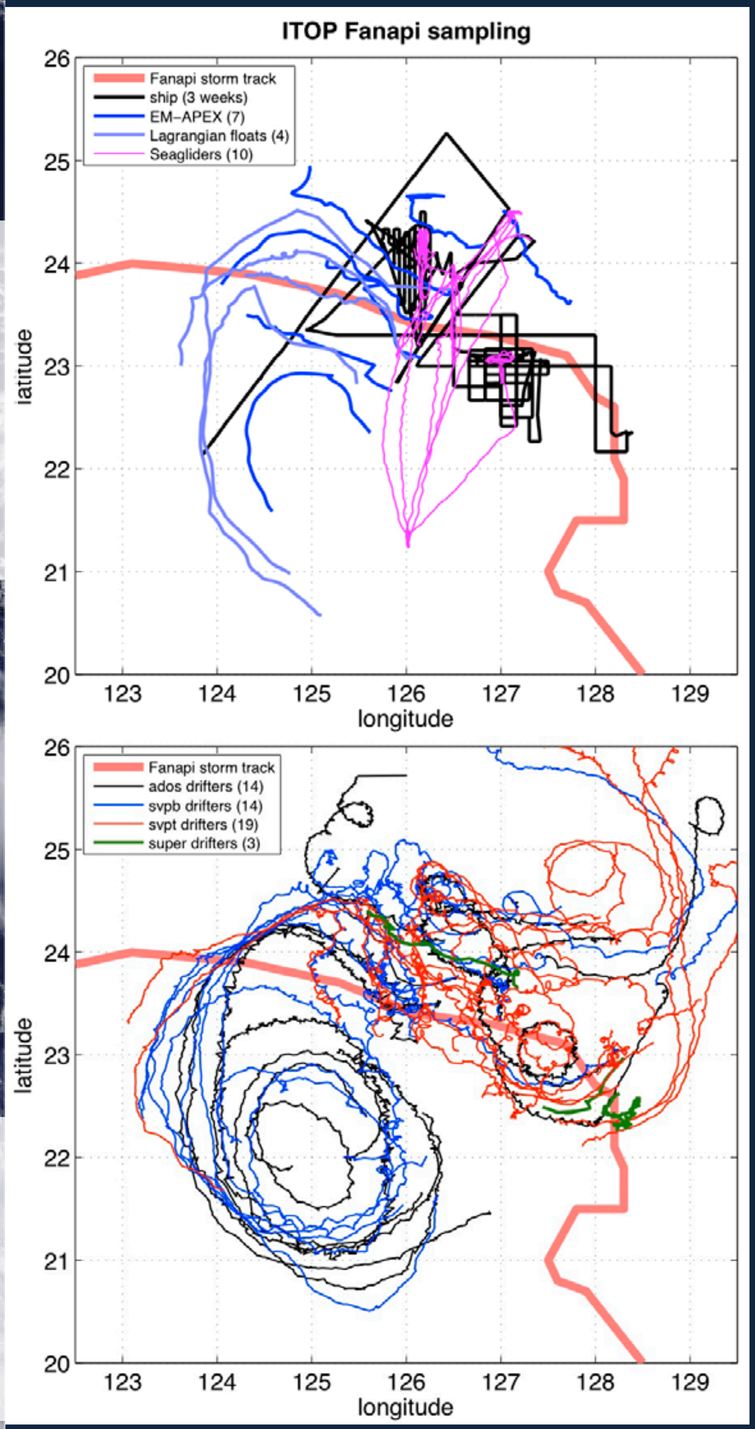


28 surface drifters

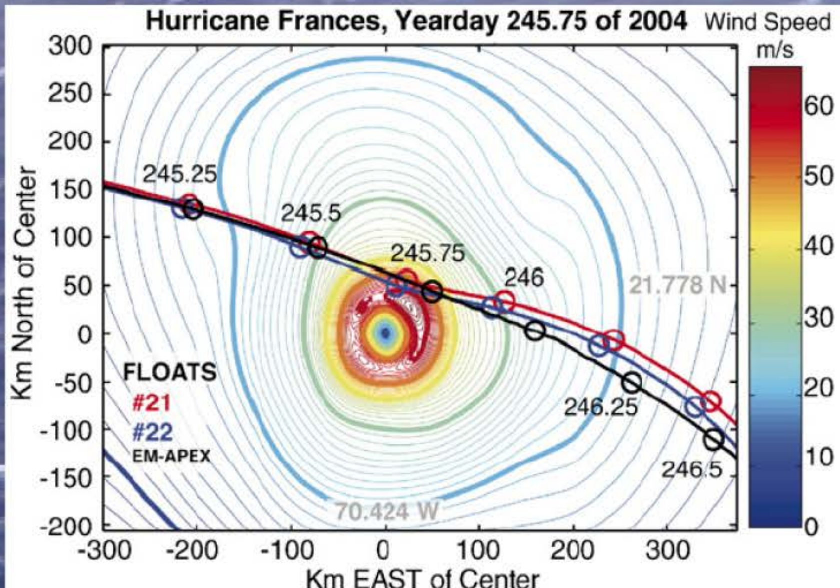
19 surface drifters with T-chains

3 surface drifters with T-chains and ADCPs

+ MOORINGS and other observations

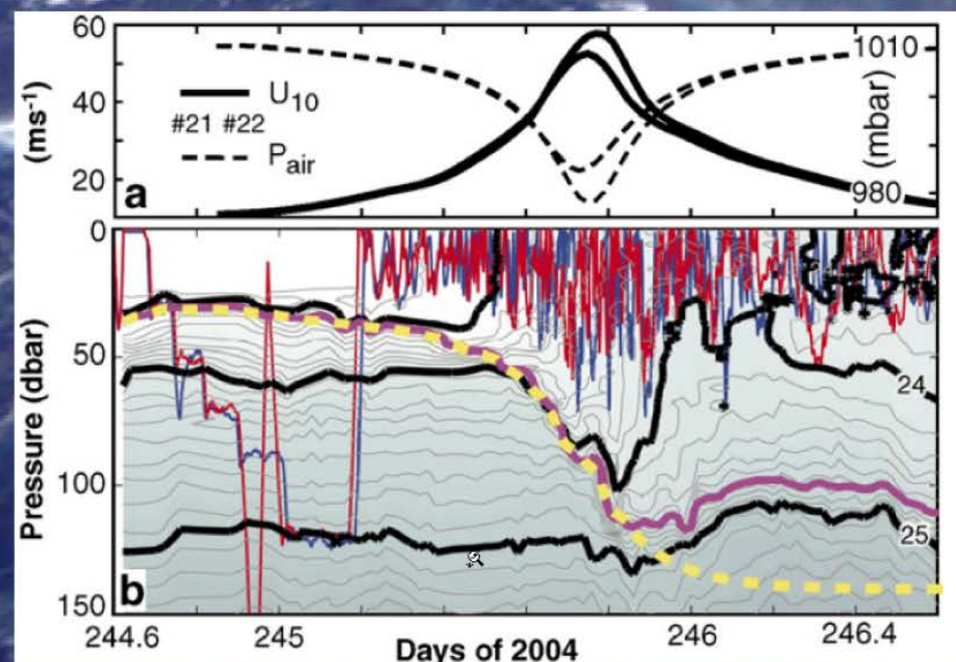


Hurricane Frances



2 floats into maximum winds 55 m/s

Observe intense mixing and mixed layer deepening

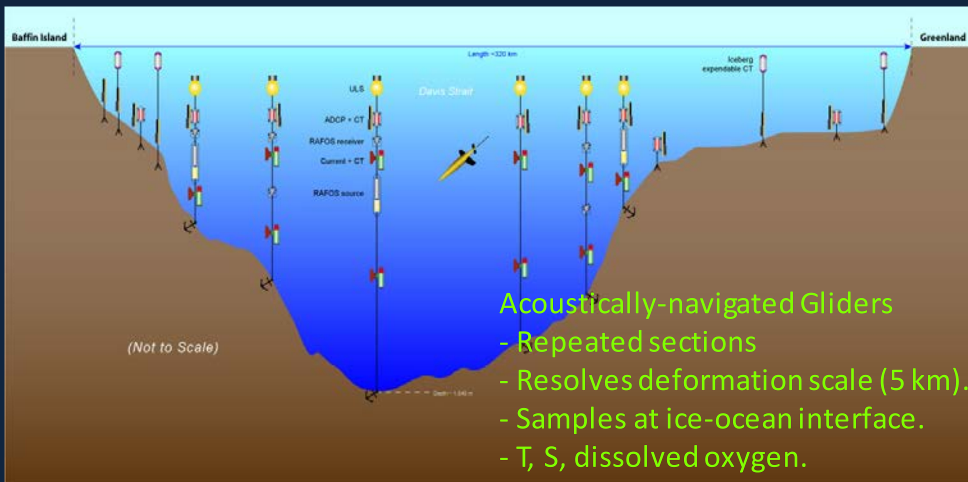


Sampling in Difficult Environments

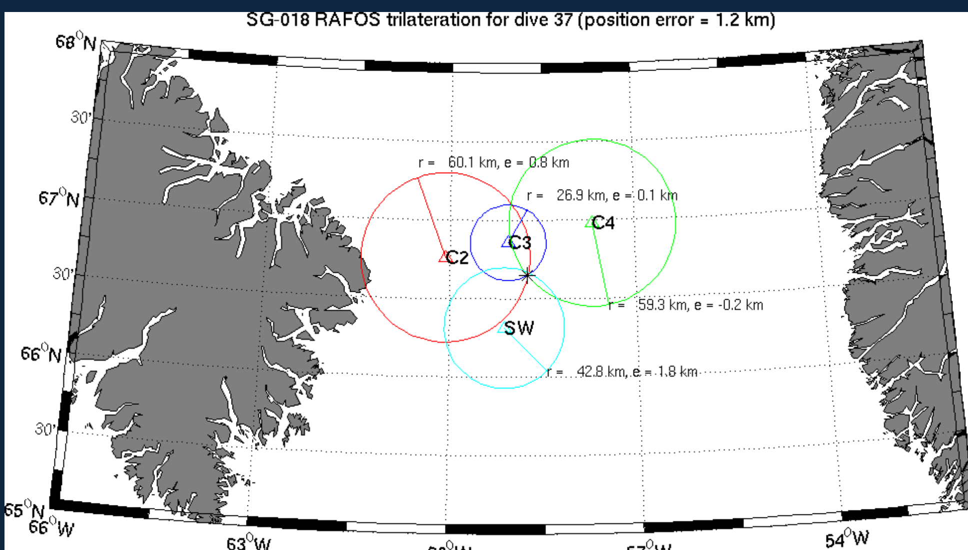
Extended Operations Under Arctic Ice

Craig Lee, et al.

Davis Strait Array

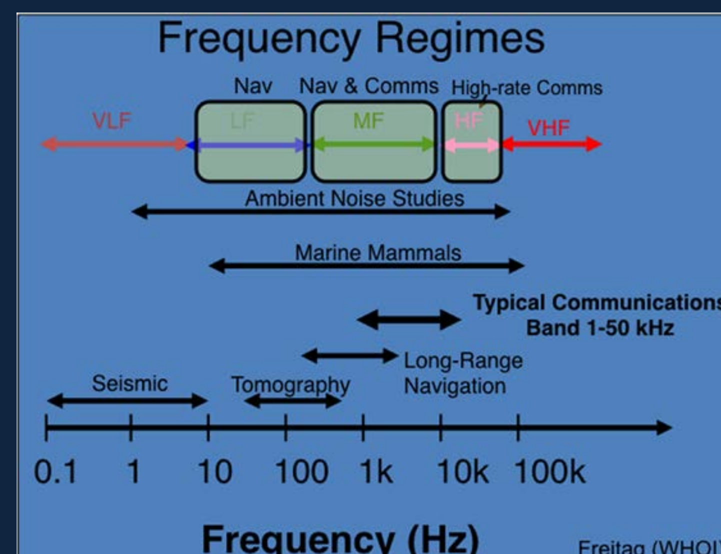


Acoustically-navigated Gliders
- Repeated sections
- Resolves deformation scale (5 km).
- Samples at ice-ocean interface.
- T, S, dissolved oxygen.



Sample in full ice cover, marginal ice zone, ice-ocean interface

- Enhanced endurance, reliability
- Compass calibration/check procedures for high-latitudes ops
- Real-time acoustic navigation.
- Ice detection- ice climatology, temperature, altimeter.
- Enhanced autonomy.
- Acoustic communication for data transfer

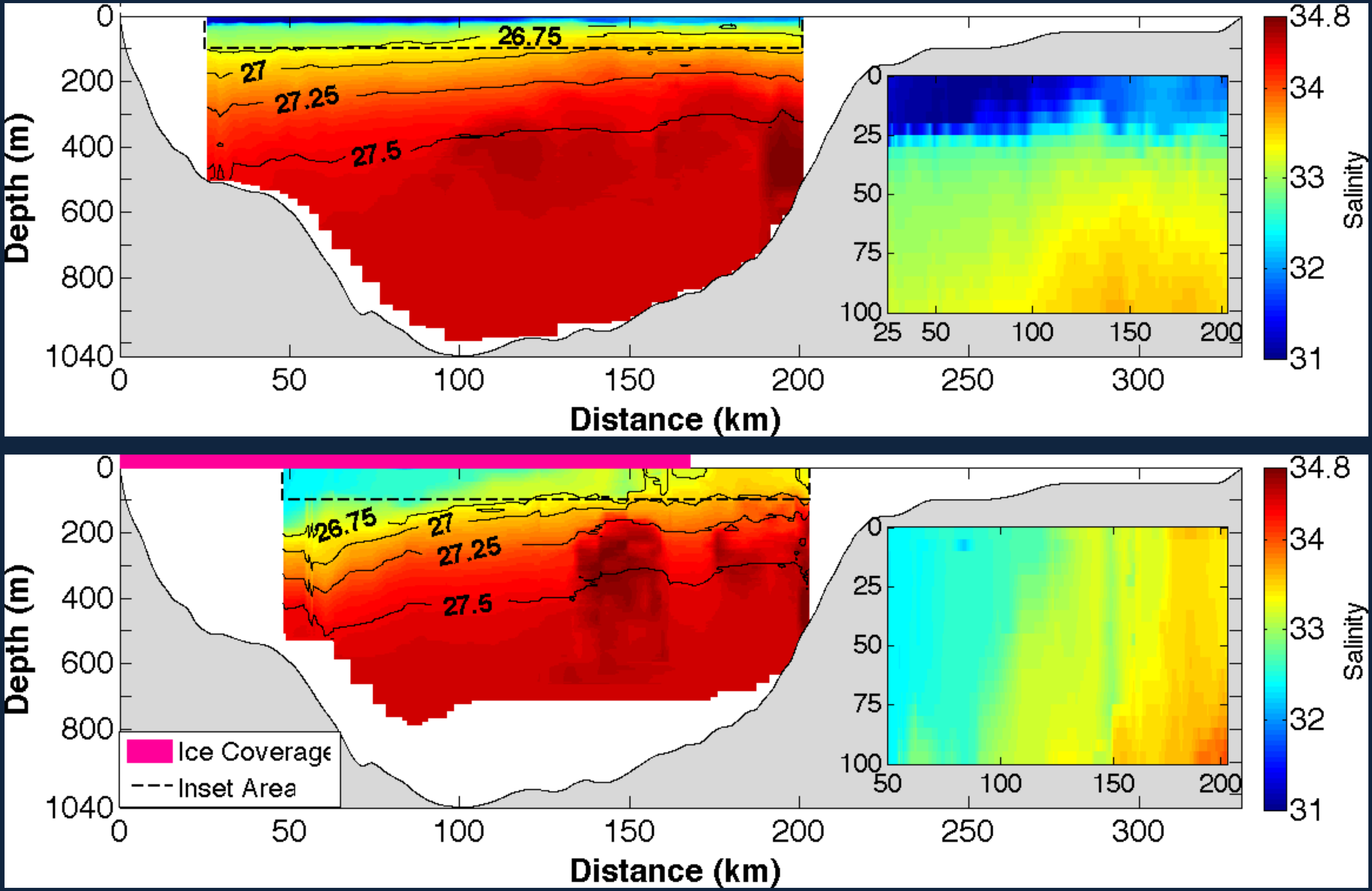


Sampling in Difficult Environments

Extended Operations Under Arctic Ice

Craig Lee, et al.

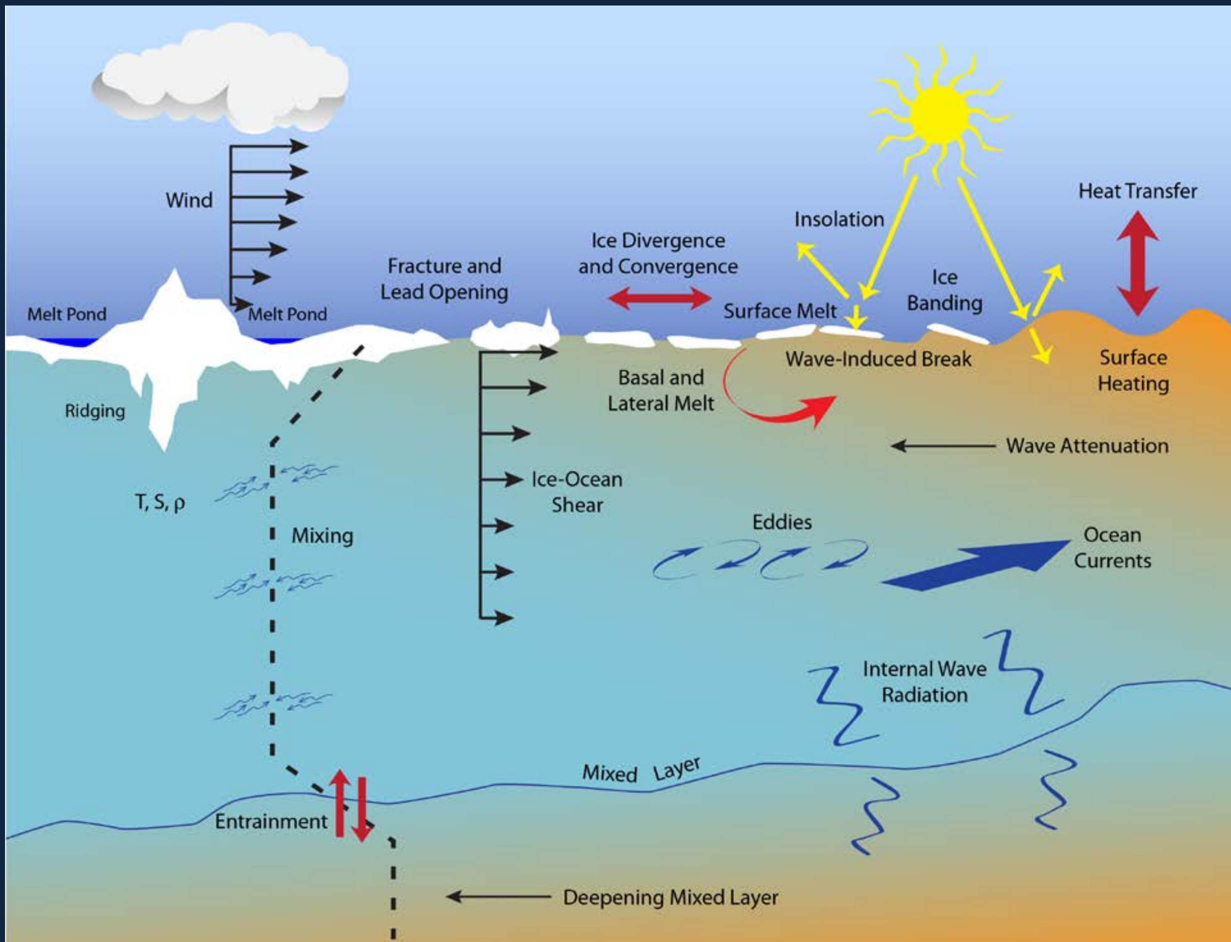
September (ice-free) and December (ice-covered) 2008



Seaglider is the only long-endurance AUV capable of multi-month operations under ice.

Collaboration Example: Autonomous Study of the Marginal Ice Zone

2014 (APL, WHOI, NPS, BAS, …)



Understand

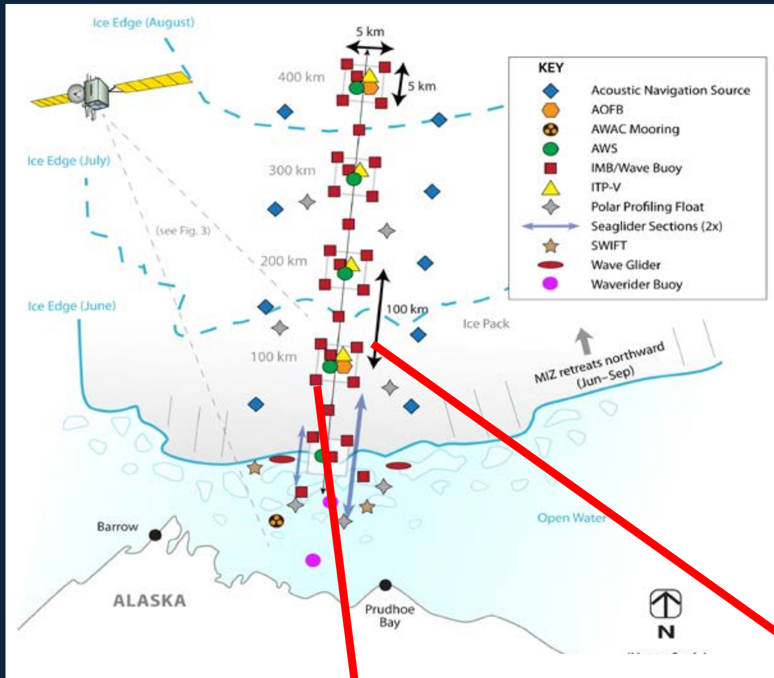
- Processes that govern MIZ evolution.
- Key interactions & feedbacks.
- Potential changes with increased seasonality in Arctic sea ice.

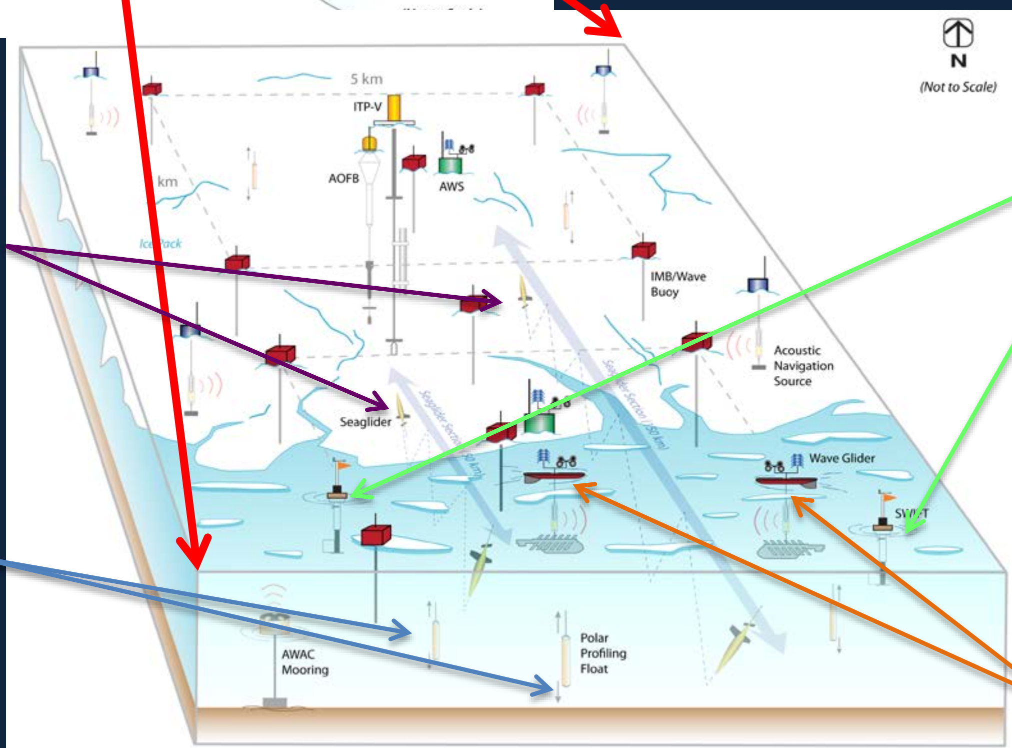
Improve process parameterizations to enhance seasonal forecast capability.

Collect benchmark dataset.

MIZ Approach

- Follow retreating ice edge, continuous sampling across MIZ, from open water to ice-covered interior.
- Mobile, drifting and ice-based platforms.
- New drifting and mobile (Waveglider-mounted) navigations sources (Freitag). Broadband, encode source position.





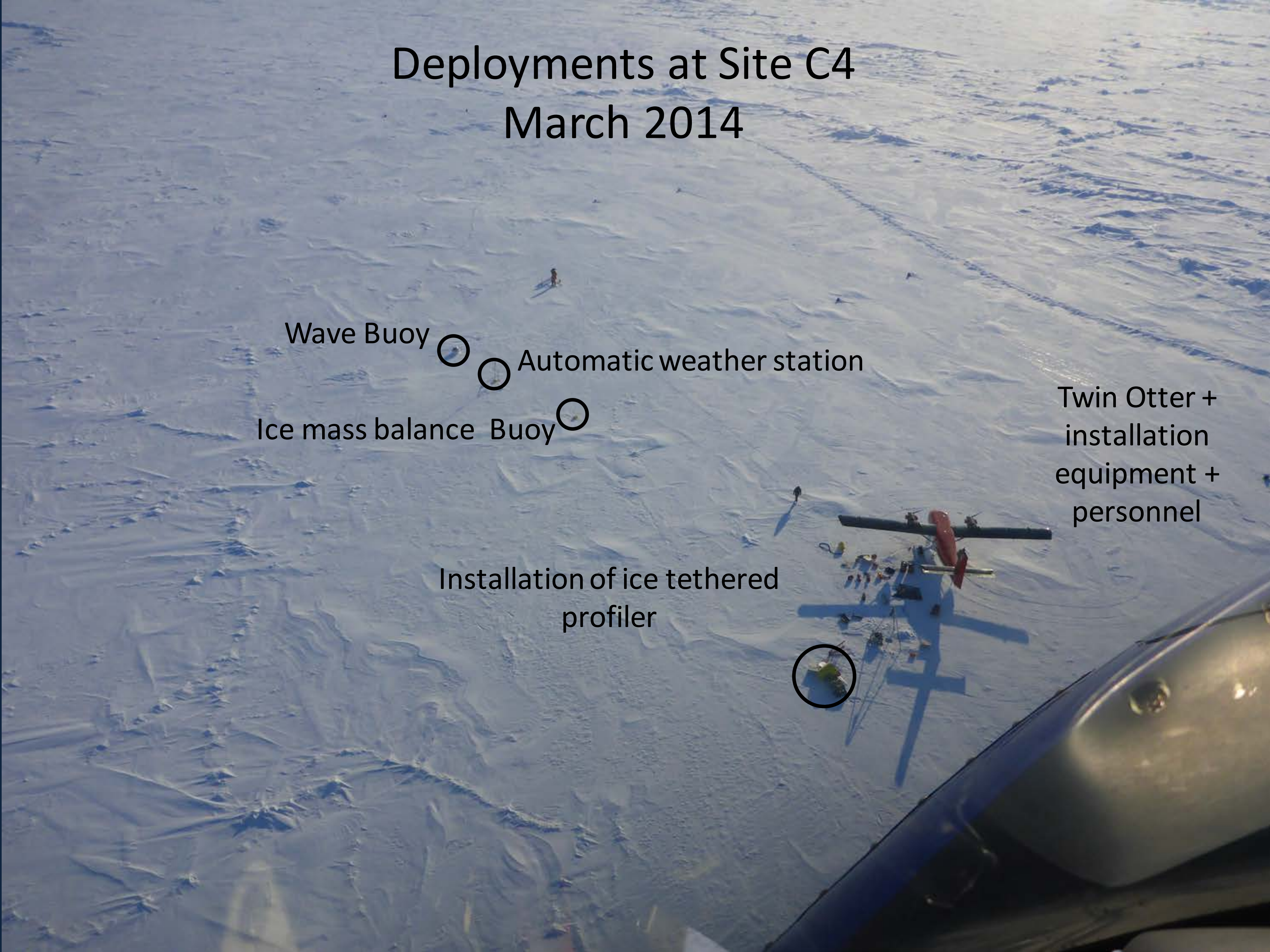
SWIFT floats

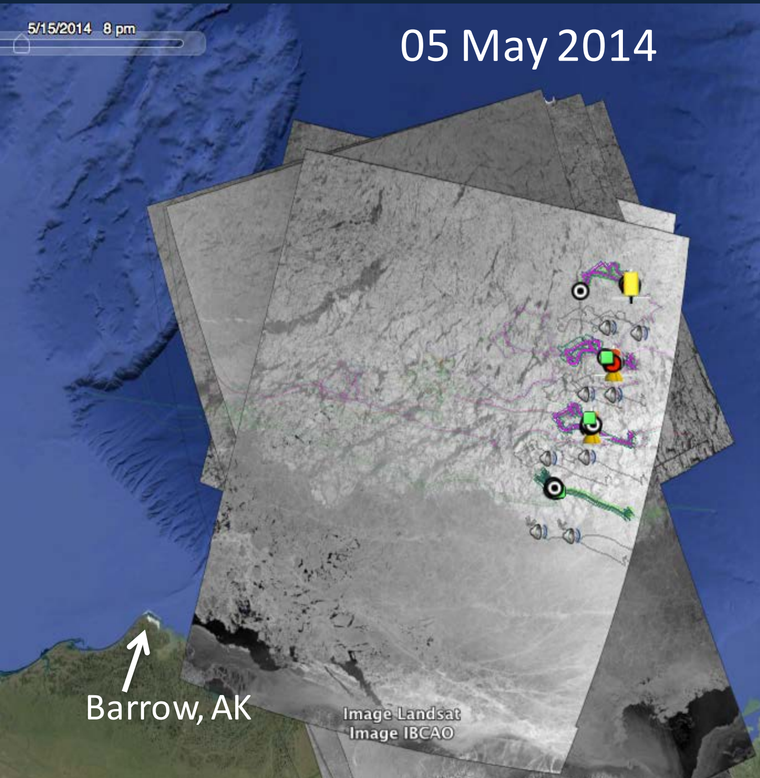
Seagliders

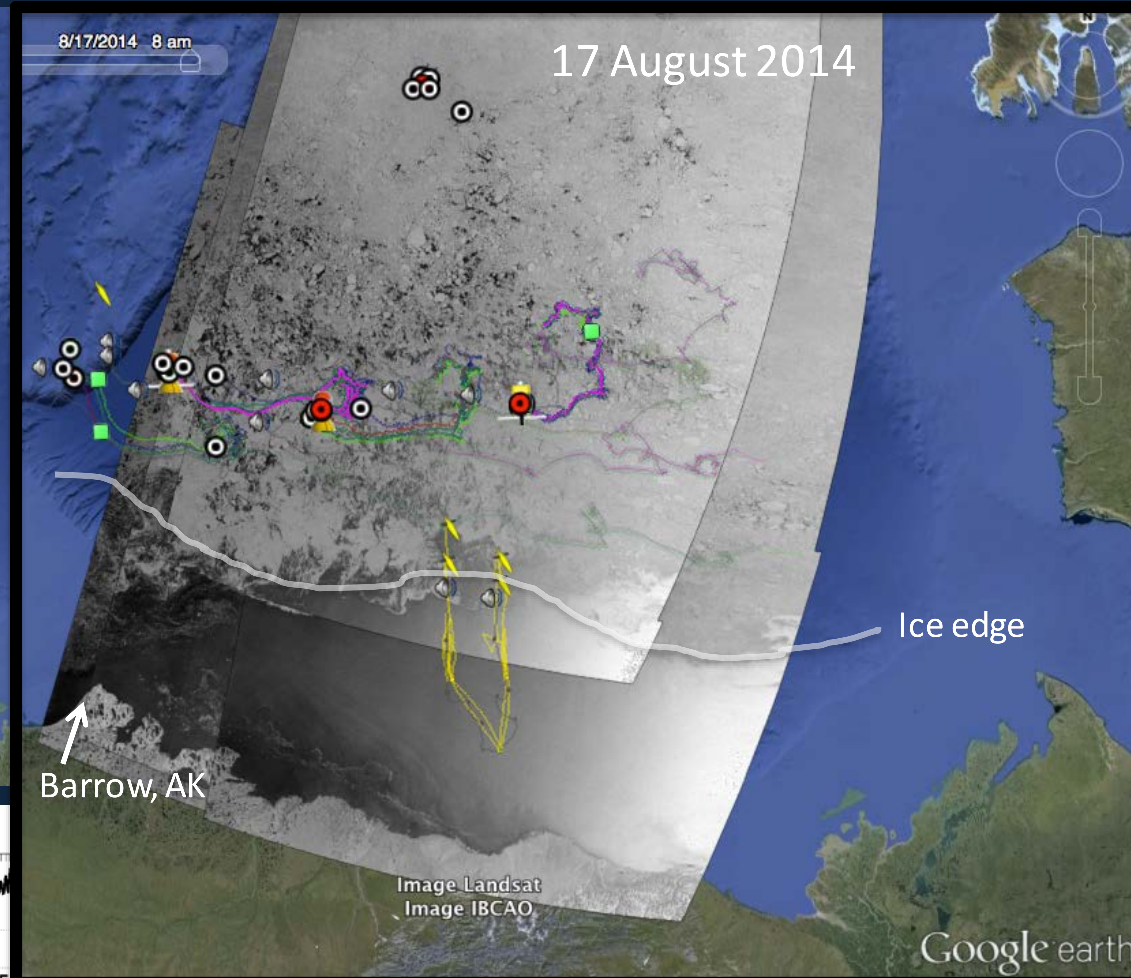
Profiling floats

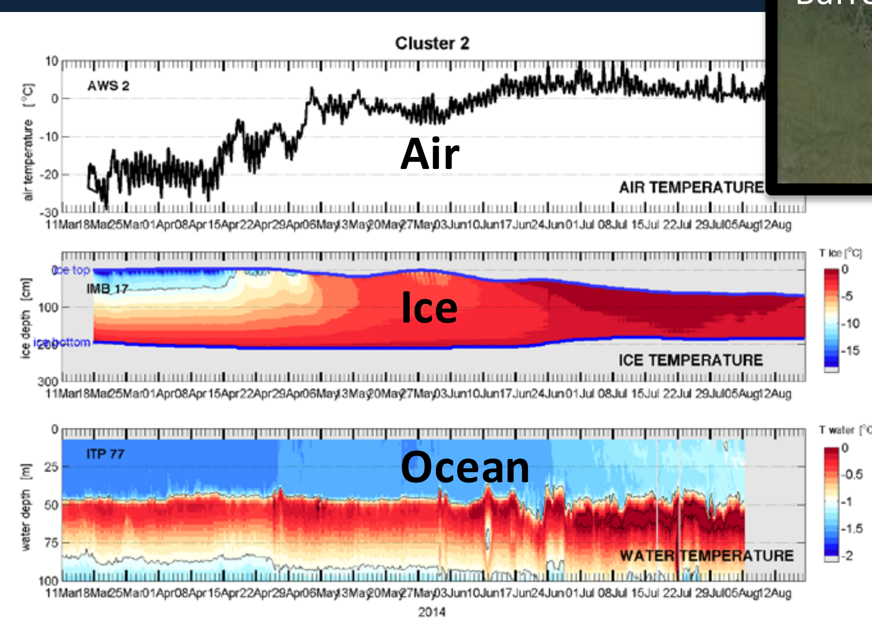
Wavegliders

Deployments at Site C4
March 2014





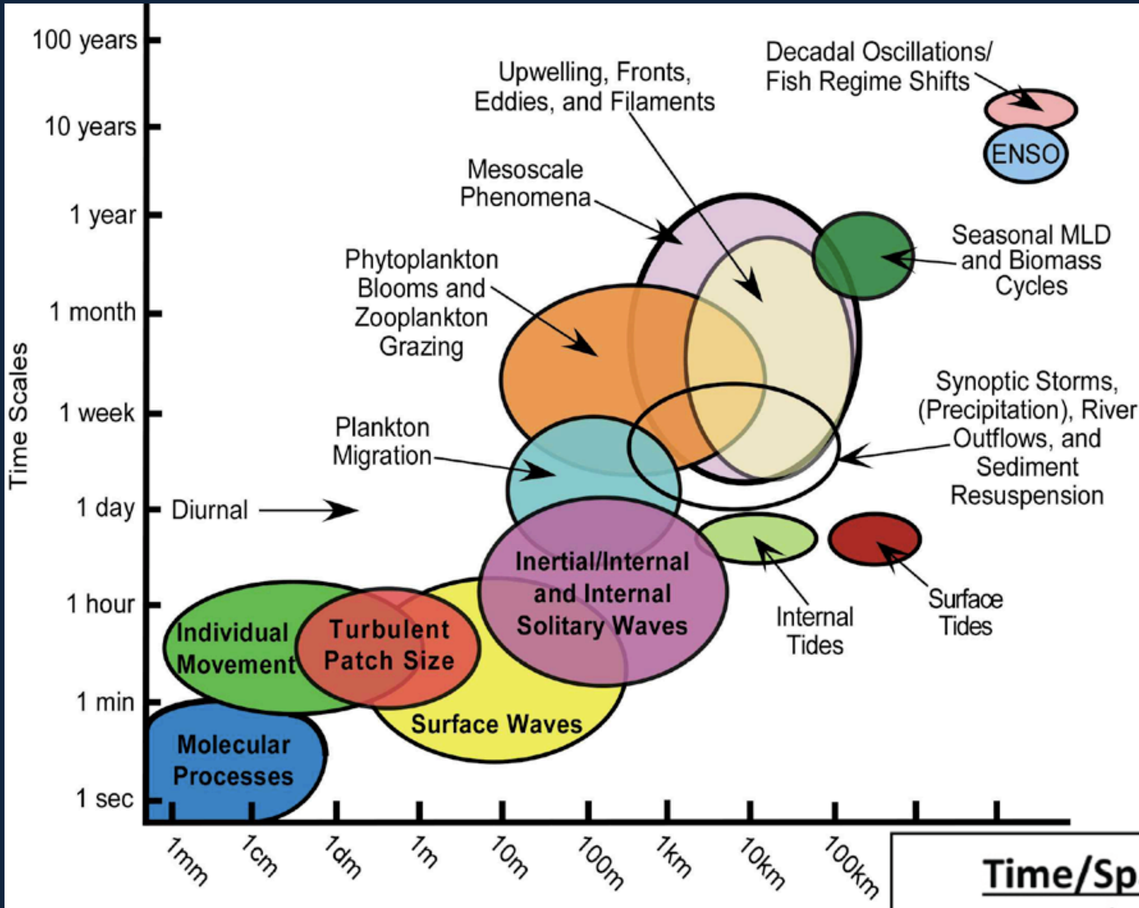




Sampling the atmosphere-ice-ocean system

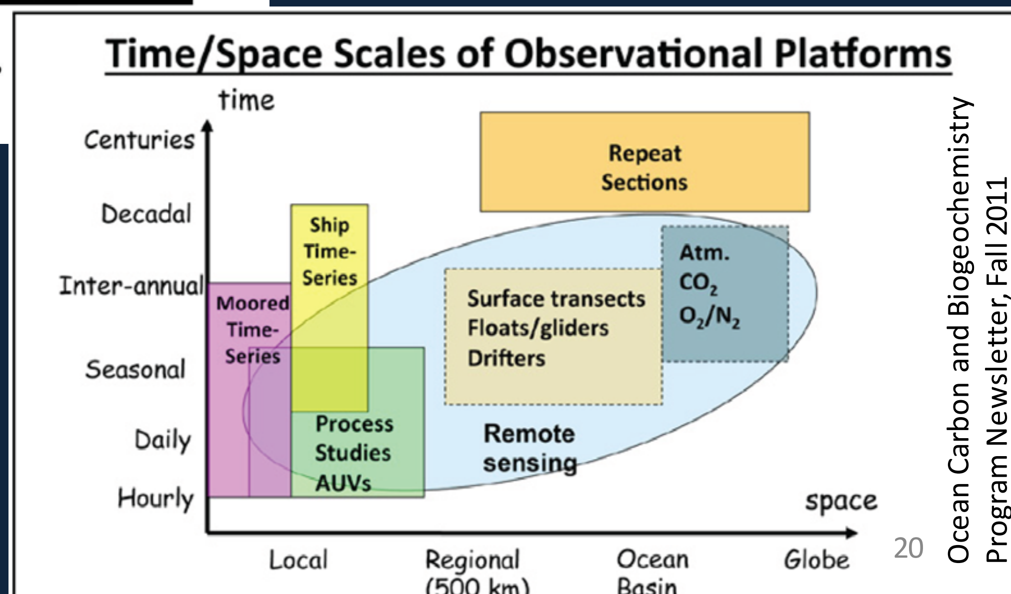
- SAR and visible images
- ITPs, IMBs, WBs
- Seagliders
- SWIFTs and AWAC
- models

Match Approach, Technology to Physical, Biological and Biogeochemical Scales



Chang & Dickey

Practical constraints: logistics, resource availability impact these decisions.



Ocean Carbon and Biogeochemistry Program Newsletter, Fall 2011

Platform developments

Saildrone LLC
(MSTF)

Z-boat
(OceanScience)

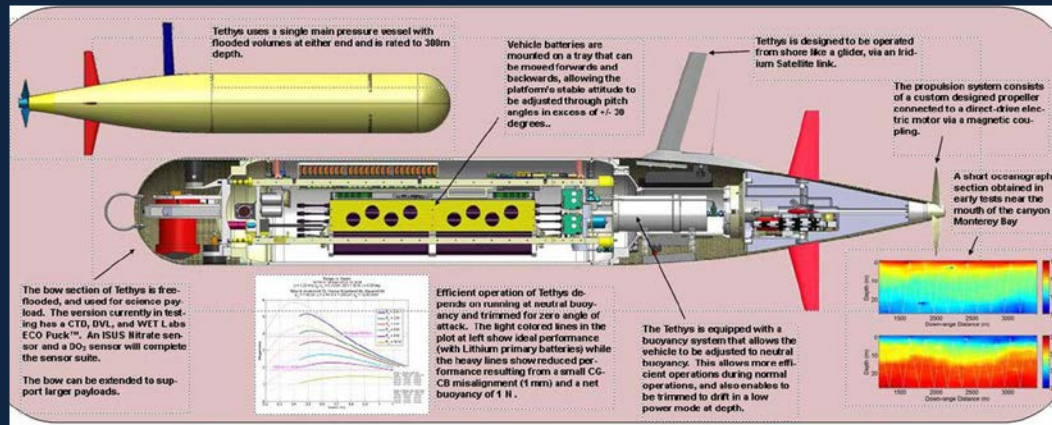
Waveglider
(LiquidRobotic)

Use renewable energy:
Wind, wave, solar

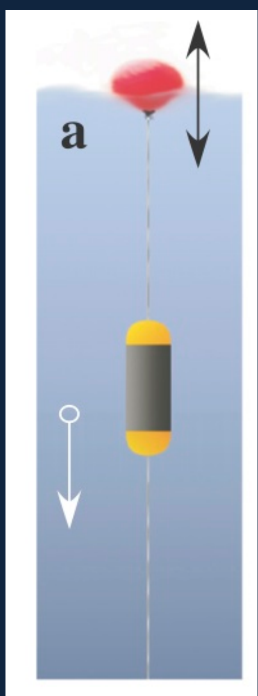
Platform developments

Tethys (MBARI)
Long Range AUV

1000 km, 2 weeks

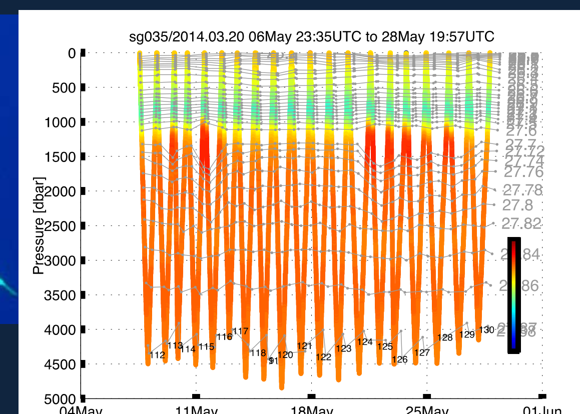


Wirewalker
(Pinkel, SIO)

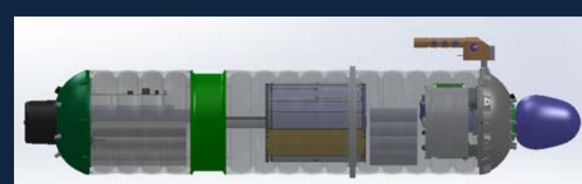


Deepglider (Eriksen, UW)

6000 m,
18 month projected endurance,
2 days per dives



1-year Seaglider
(Lee, Gobat, et al., APL/UW)

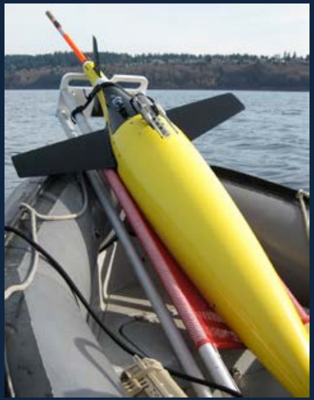


1000 m,
3-4 dives per day
20 km per day

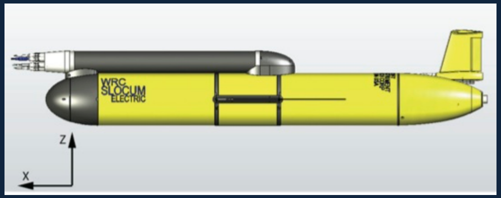
Sensor developments

Physics is 'easy'

- Turbulence microstructure from gliders

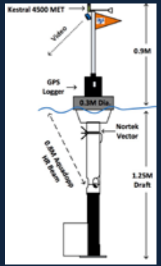


Rockland, APL/UW,
OSU, WHOI,



- Velocity measurements:
  Differential pressure sensors – pitot tubes
  (Moum, OSU)

- Surface turbulence
  SWIFTs (Thomson)



Biology and Biochemistry is hard.

- nutrients
- Mesozooplankton
- carbon 'master variables' (DIC, pCO2, pH).

Gulper
(MBARI)
Water samples from AUV

"Swarms" of AUEs
(Jaffe, Franks, SIO)

Summary

- Autonomous vehicles can successfully sample across the broad range of space and time scales needed to resolve physical and biogeochemical processes.
- Creative, multi-platform approaches offer great power.
- Technology development directly tied to science interests.
  - Identify important science questions where availability of observations impedes understanding – develop new observing technologies and approaches.
- Calibration is critical
  - Need in situ and cross-calibration of biogeochemical sensors. Still need ships: lab calibration is insufficient.
  - Empirical vs. mechanistic proxy relationships.
  - Direct calibrations of limited number of reference sensors on mobile autonomous platforms, and propagate these via cross-calibration 'visits' and engineered or random encounters.

A few thoughts and questions…

Technology development: tied to science interests, require integrated teams of scientists and engineers.

How to encourage and promote risk and novel ideas?

Interdisciplinary problems: scientists and technologists with diverse skills required to drive advances in complex problems.

How to encourage and promote cross-discipline collaborations?

Availability of 'proven' technology: many new nice, expensive, platforms

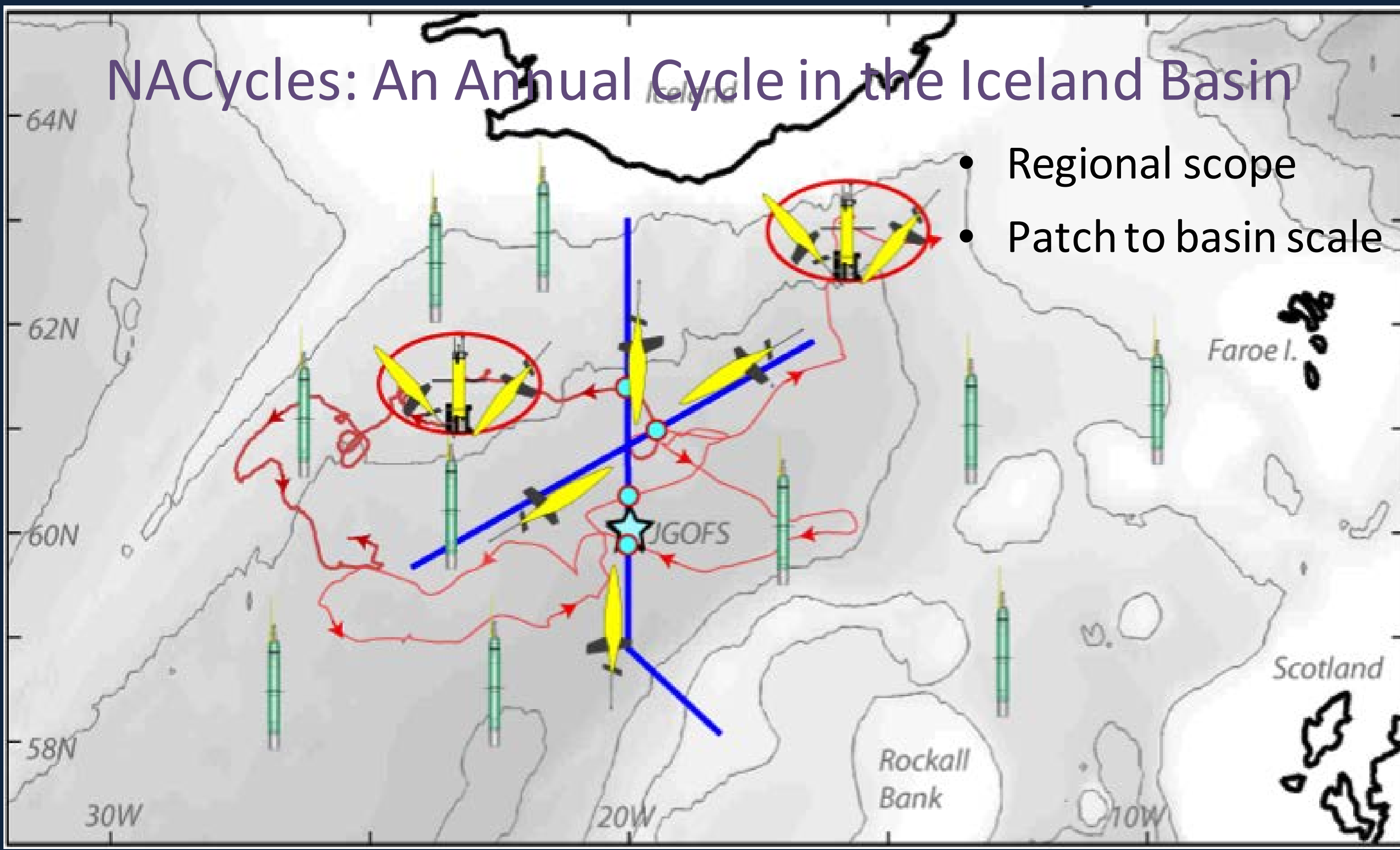
How to provide access for use, and for sensor development & integration?

Learning and teaching integrated science: no single instrument resolves everything.

How do we use best coordinate multi-platform programs, and how to synthesize data from autonomous platform, remote sensing, ship assets, etc.?

How to learn/teach how to use the technology?

Autonomous Biogeochemical Network- Pilot Projects

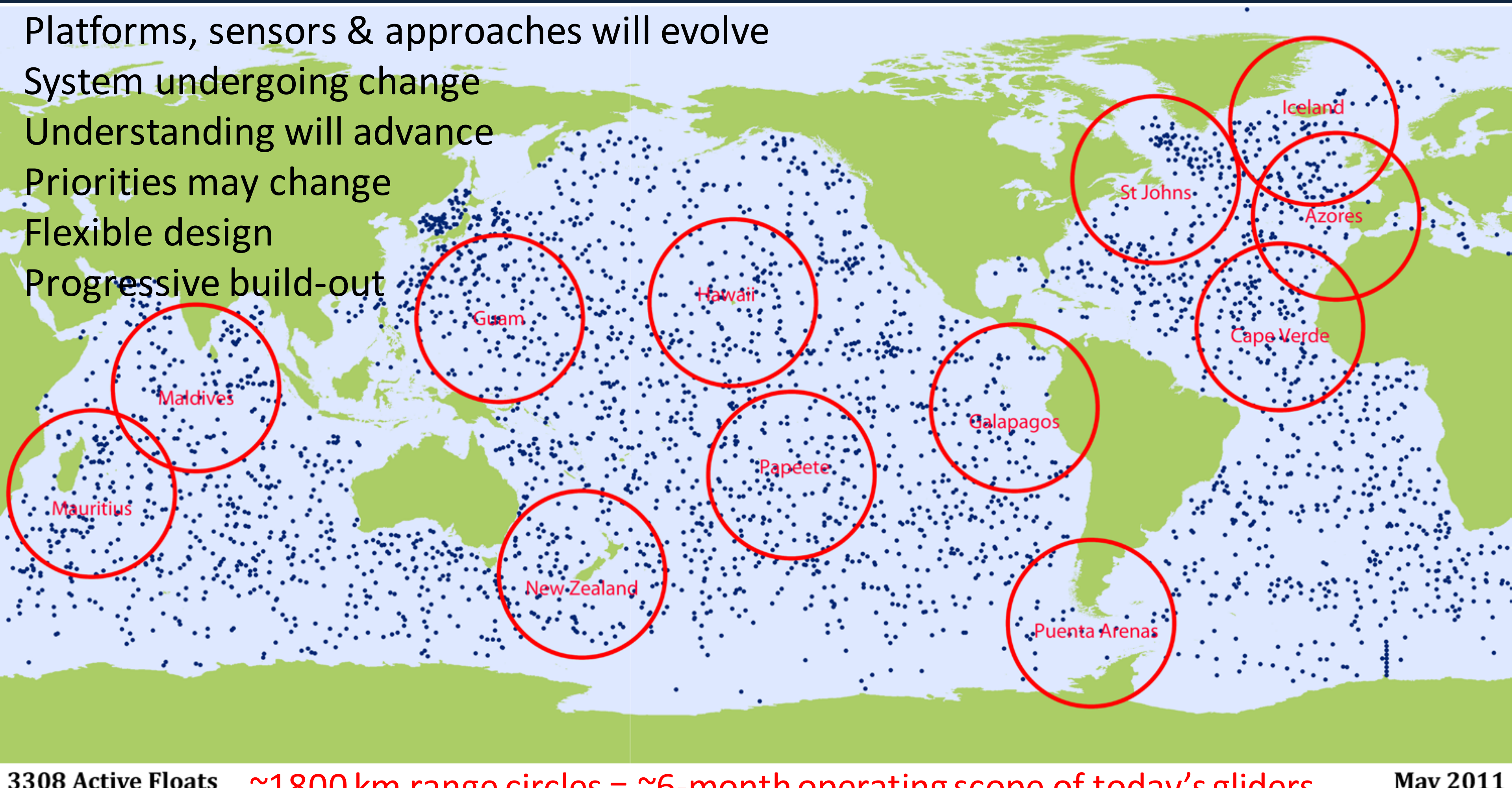


Key Elements:

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

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



~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