Spanning the scales: Multi-platform approaches for integrated studies of biogeochemistry and physics

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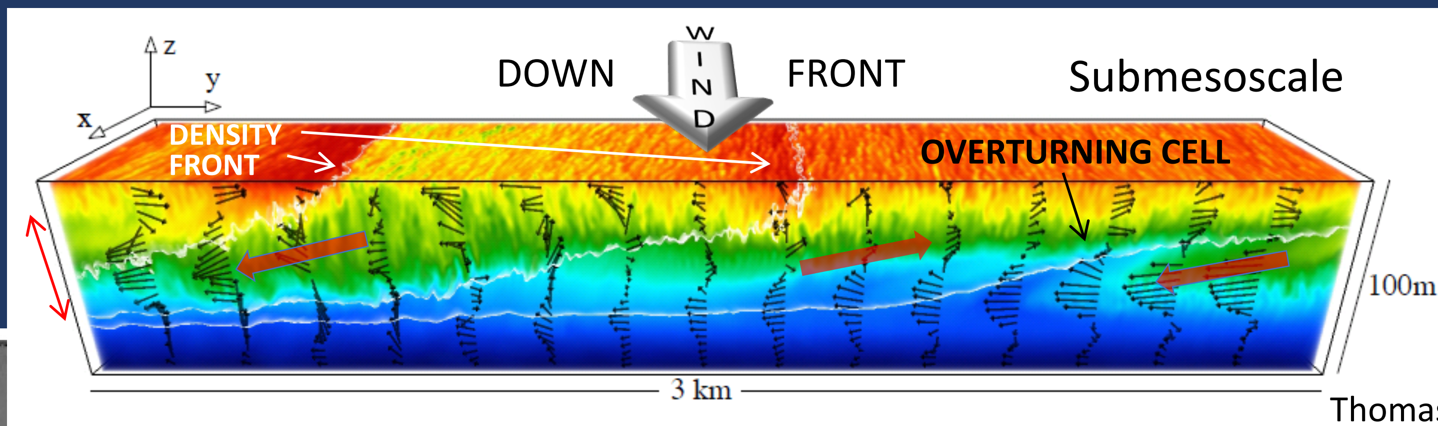
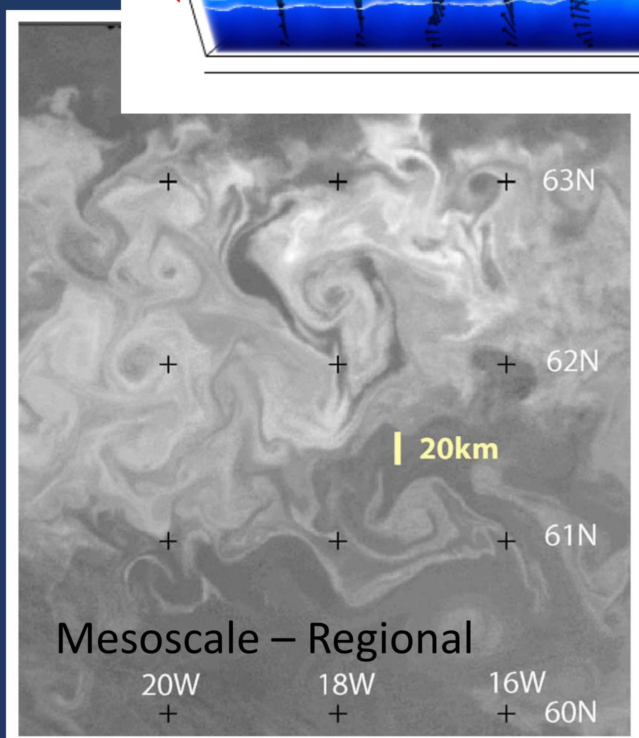
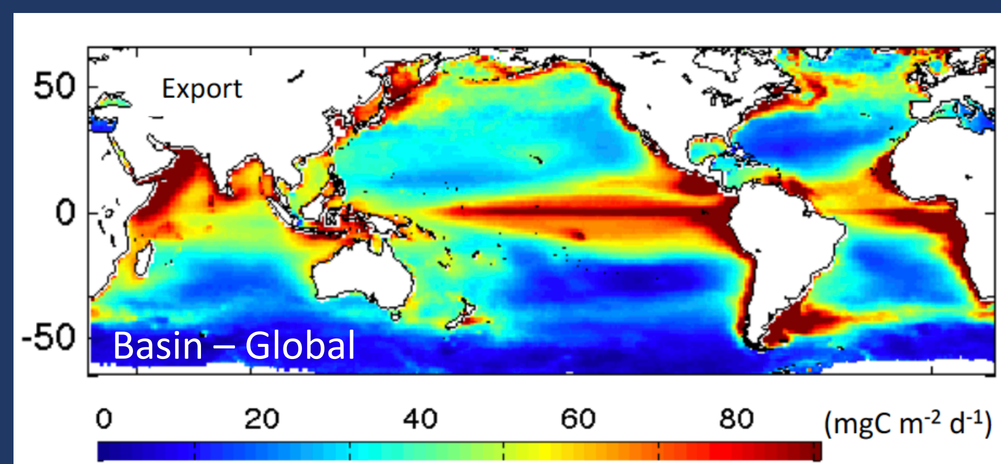
Dan Rudnick (SIO), Ken Johnson (MBARI), Tom Farrar (WHOI)

STRATIFIED,
TURBULENT
SI LAYER

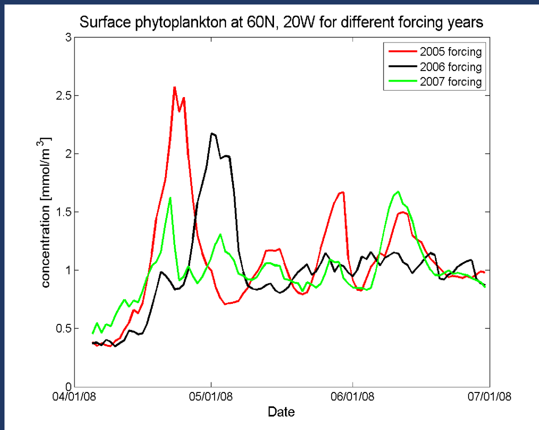




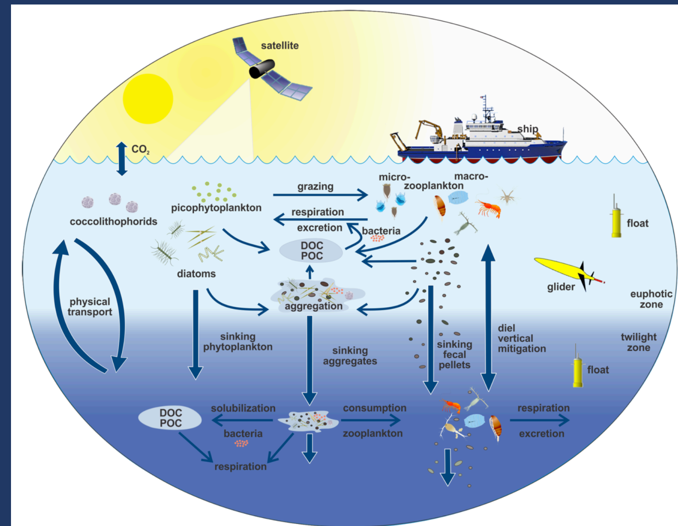


Siegel et al., 2014

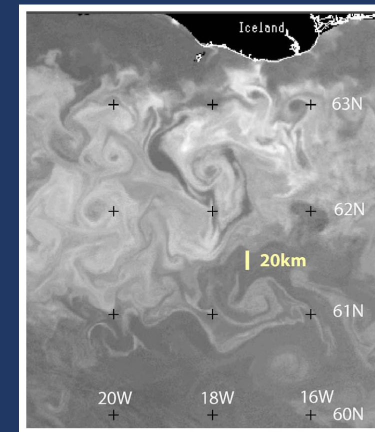
Observational Challenges



Episodic evolution (K. Fennel)



Steinberg et al. (2016)



Small patch scales, 4D physics

Synoptic 4D sampling

- Sampling speed vs. timescales of dynamics
- Tradeoffs… temporal resolution vs. spatial resolution

Persistence

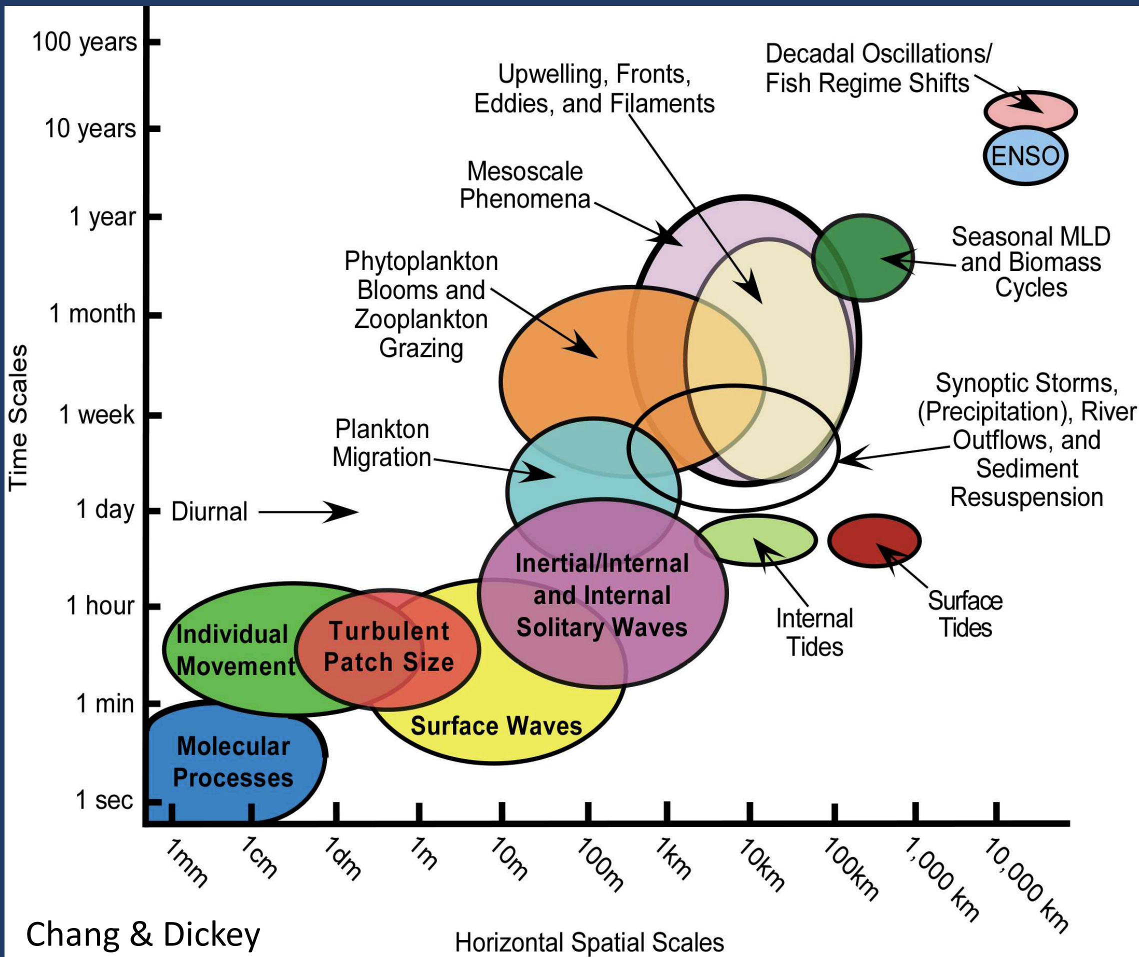
- Episodic events, multiple realizations
- Extended timescales

Representative spatial/temporal coverage

- Scaling from patches to basins, seasons to years

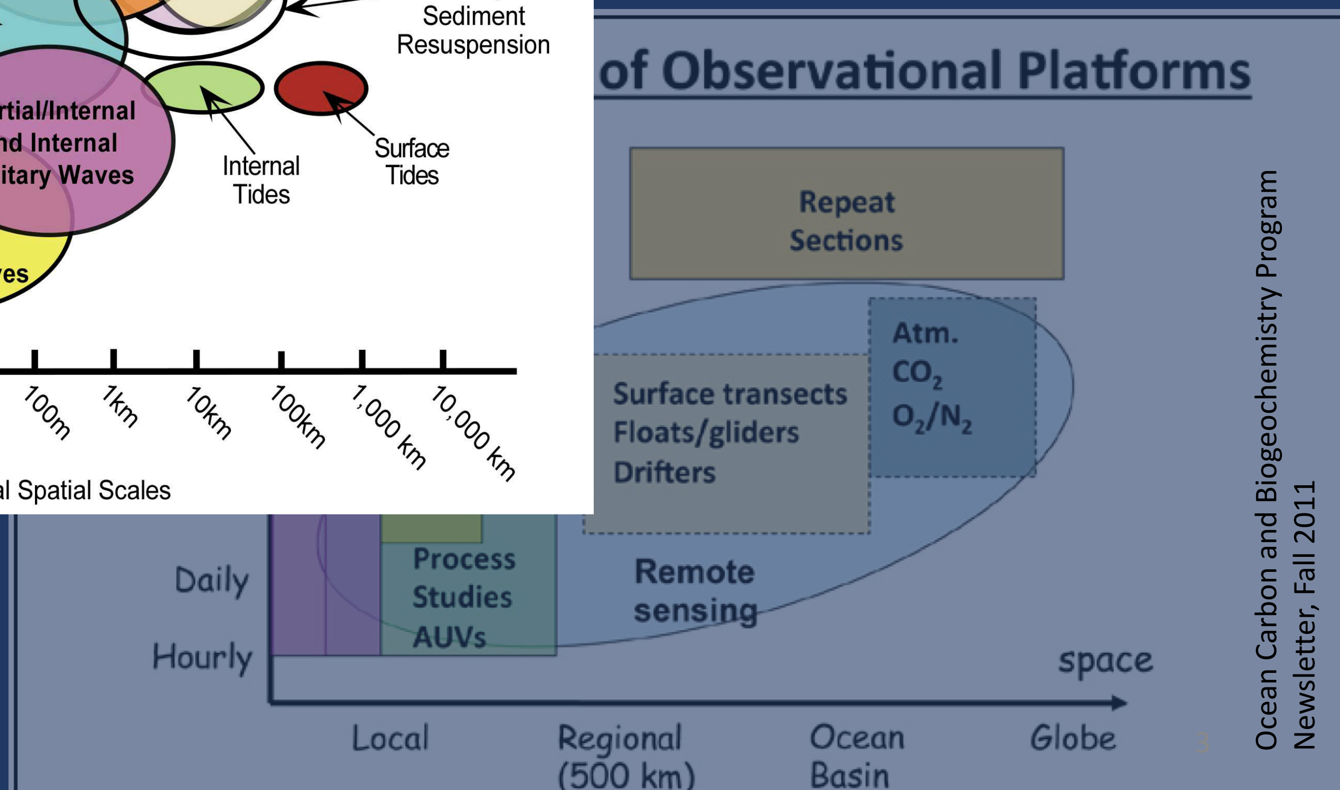
Recent autonomous technologies provide access scales that were previously difficult or impractical to sample.

Match Approach, Technology to Spatial and Temporal Scales



Chang & Dickey

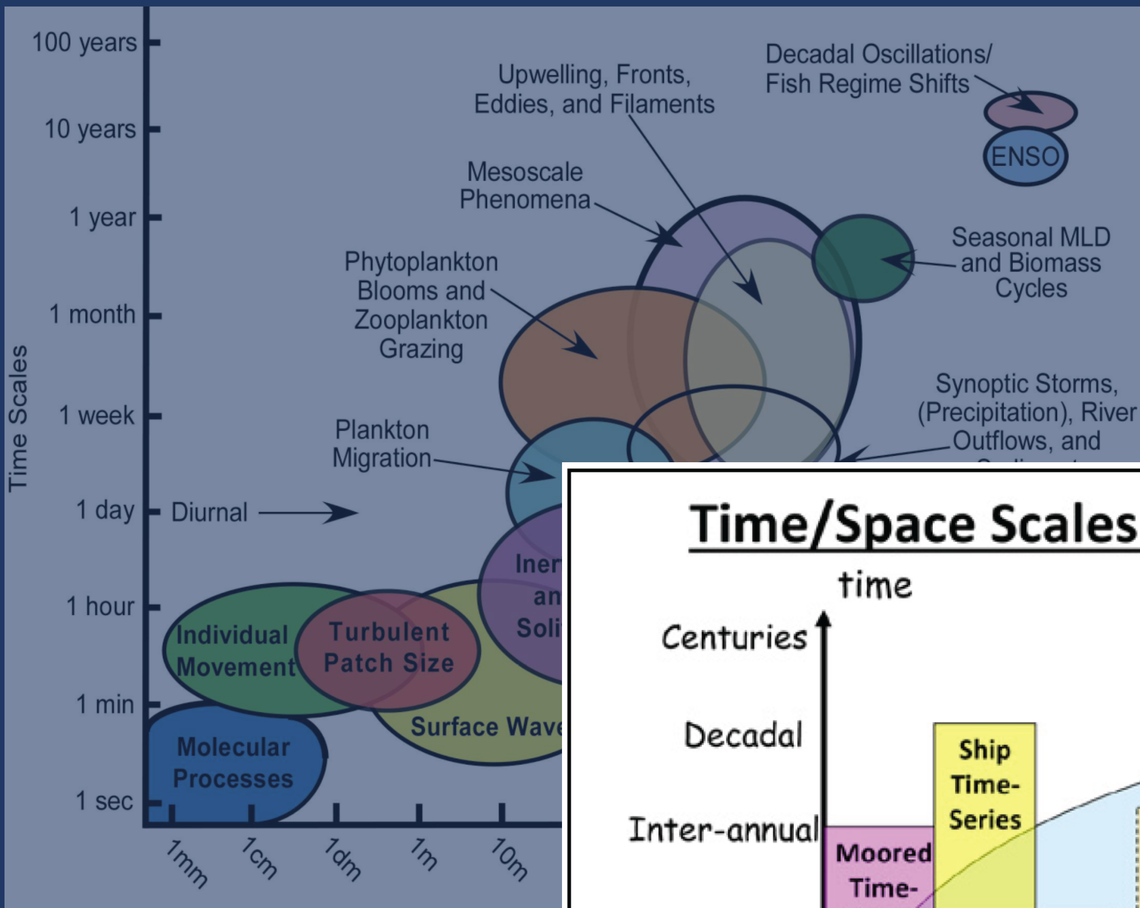
Most problems involve interactions between processes across multiple scales.



Ocean Carbon and Biogeochemistry Program Newsletter, Fall 2011

Practical constraints: logistics, resource availability impact these decisions.

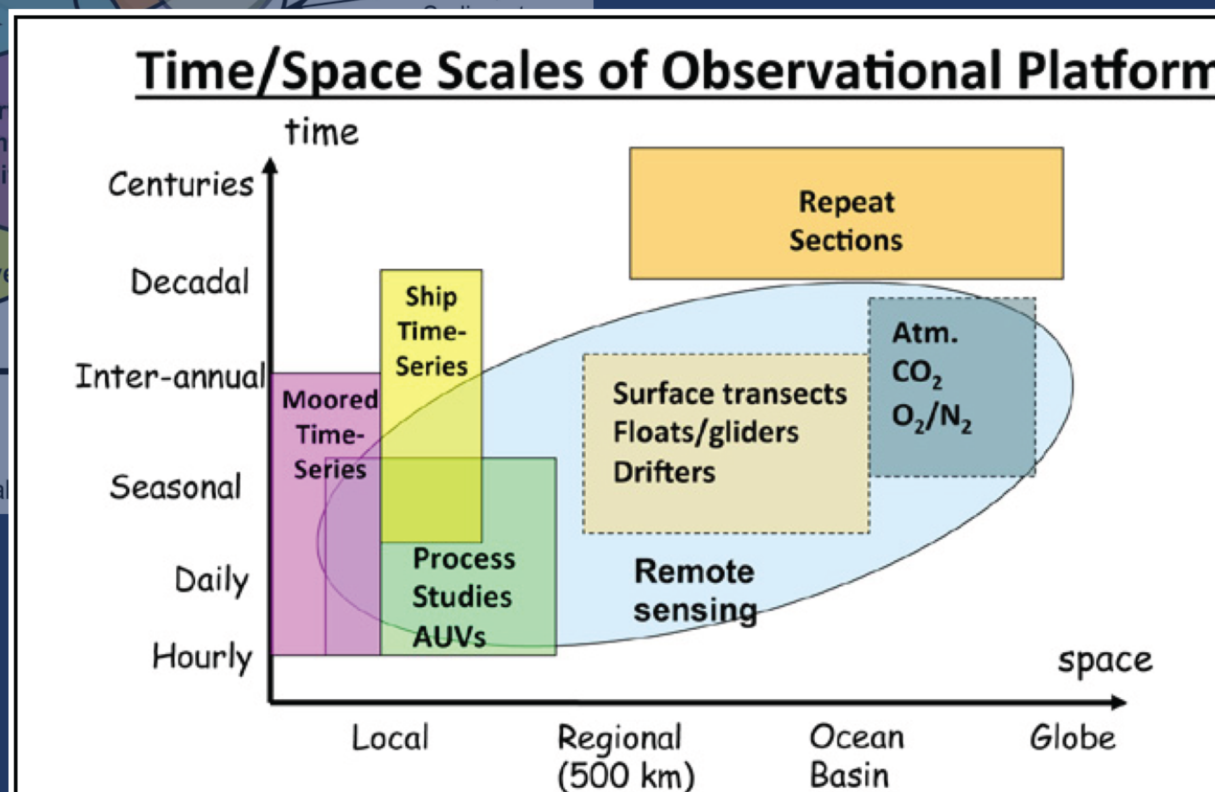
Match Approach, Technology to Spatial and Temporal Scales



Chang & Dickey

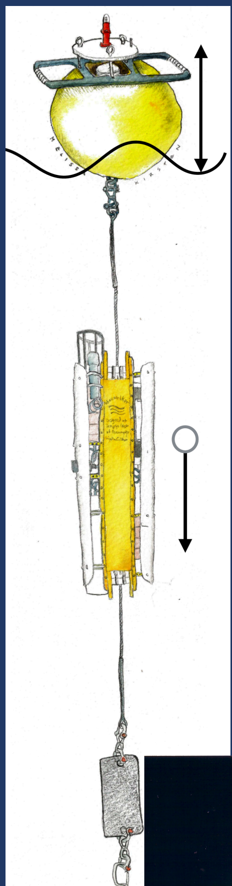
Solutions often involve complementary combinations of platforms

Practical constraints: logistics, resource availability impact these decisions.

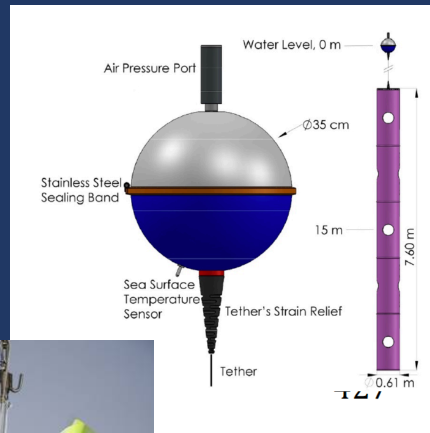


Ocean Carbon and Biogeochemistry Program Newsletter, Fall 2011

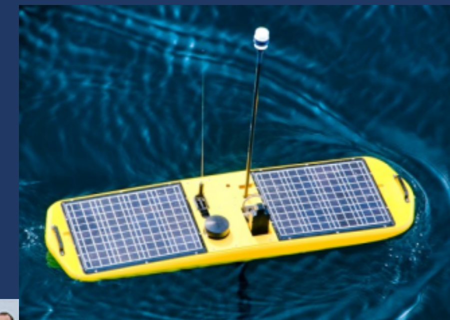
Many Platforms, Complementary Capabilities

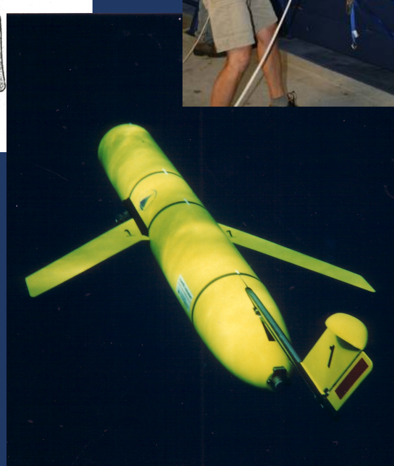


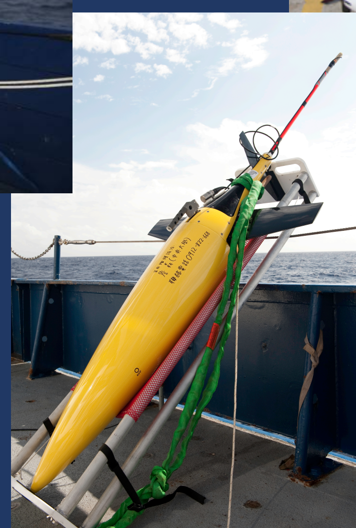
Reliability
Logistics
Cost
Scalability

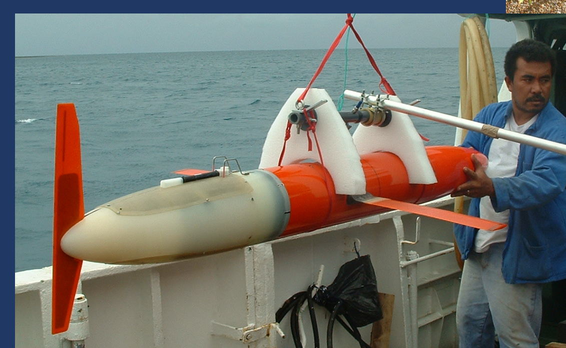


Speed
Endurance
Payload
Depth range



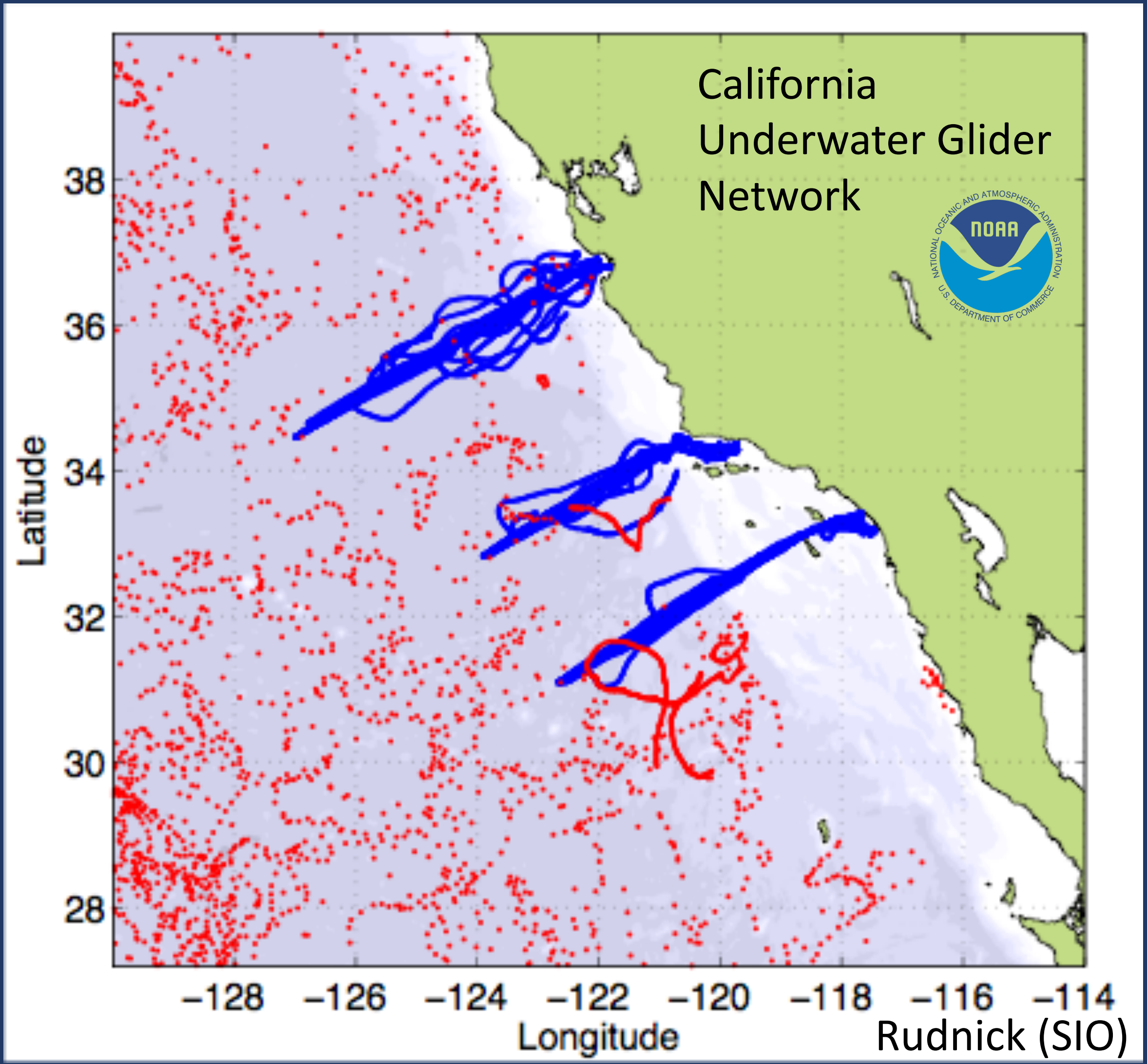






What are They Good For?

Boundary Current Example…



- Area defined by regional model
- 28893 glider profiles
- 2482 Argo profiles
- Similar per-profile cost ($20k/200 profiles, $100k/1000 profiles), but usage differs
- Floats- distributed, mapping
- Gliders- concentrated, small scales, string gradients

What are the physical processes responsible controlling the upper ocean salinity balance: air-sea interactions, mixing, oceanic transport, etc.

SPURS programs involve coordinated field work, numerical models, and remote-sensing:

Towed Surface Salinity Profiler, Asher et al., UW
SPURS Data Management System, Bingham et al., UNC
Multi-scale Modeling and Data Assimilation, Chao et al., RSS
Near-surface Turbulence: Lagrangian Floats, D'Asaro et al., UW
Toward a Salinity Budget (flux mooring), Farrar et al., WHOI
Multiscale Autonomous Surveys, Fratantoni et al., WHOI
Characteristics SSS Fluctuations, Gordon et al., LDEO
Upper Ocean Salinity from Glider Surveys, Lee et al., UW
Multi-Scale Modeling and Data Assimilation, Li et al., JPL
Measurements of T, S, Wind Speed, and Rainfall (floats), Riser et al., UW

Microstructure and Mixing, Schmitt et al., WHOI (NSF)
SSS Drifters for SPURS, Centurioni et al., SIO (NOAA)
Prawler Mooring, Kessler et al., NOAA/PMEL (NOAA)
Sustained Ocean Observations, Goni et al., NOAA/AOML (NOAA).

Lagrangian Floats: Shcherbina, D'Asaro, Harcourt, Maximenko
Wave Gliders: Hodges, Schmitt
Towed Surface Salinity Profiler: Asher, Jessup, Drushka
Surface meteorology: Clayson, Edson
Data management: Bingham, Li, Li
Hydrography: Sprintall
Sea snake: Schanze
Surface drifters: Centurioni, Chao, Maximenko
Seagliders: Rainville, Eriksen, Drushka, Lee
Argo floats: Riser, Yang
Mooring: Farrar, Plueddemann, Edson, Zhang, Yang, Kessler
Modeling: Li, Bingham, Li

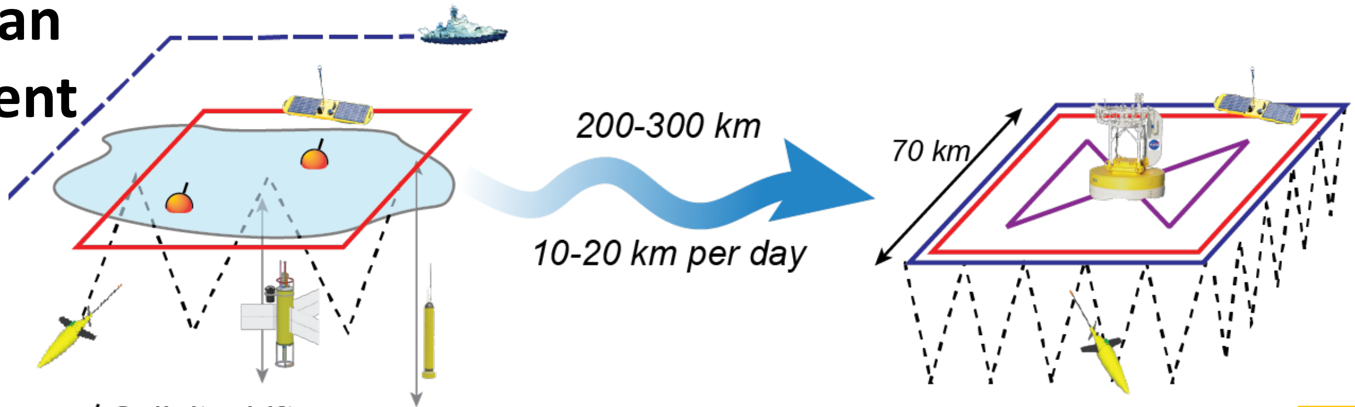
PICO moorings: Kessler (NOAA)
Rain lenses: Drushka, Asher, Jessup, Rainville (NSF)

SPURS - 2

Salinity Processes in the Upper Ocean Regional Study

Lagrangian component

Eulerian component



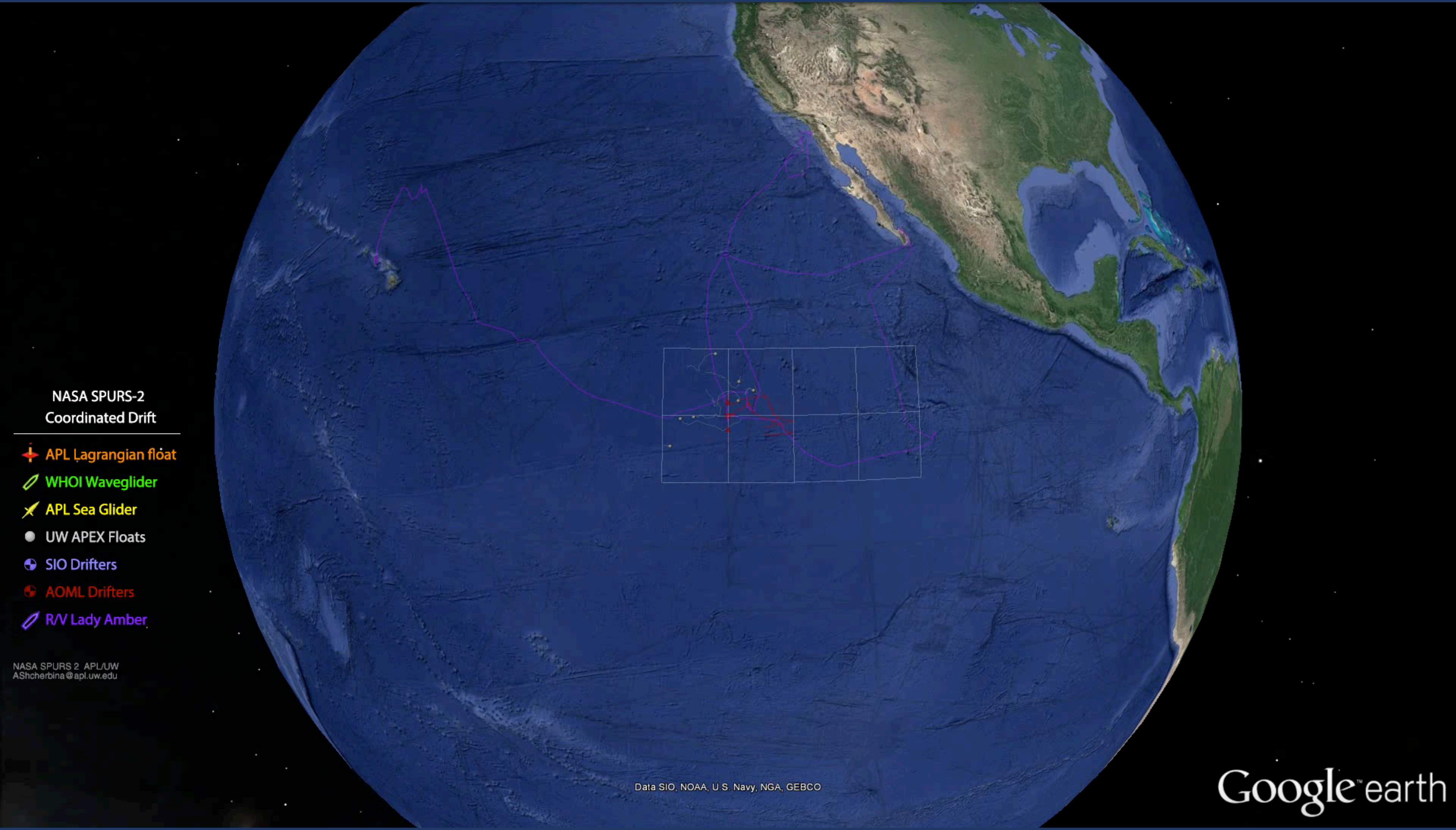
- Salinity drifters
- Lagrangian float (MLF)
- Profiling (APEX) floats
- Seaglider*
- Waveglider*
- Shipboard/SSP surveys

* return to mooring after ~2 weeks

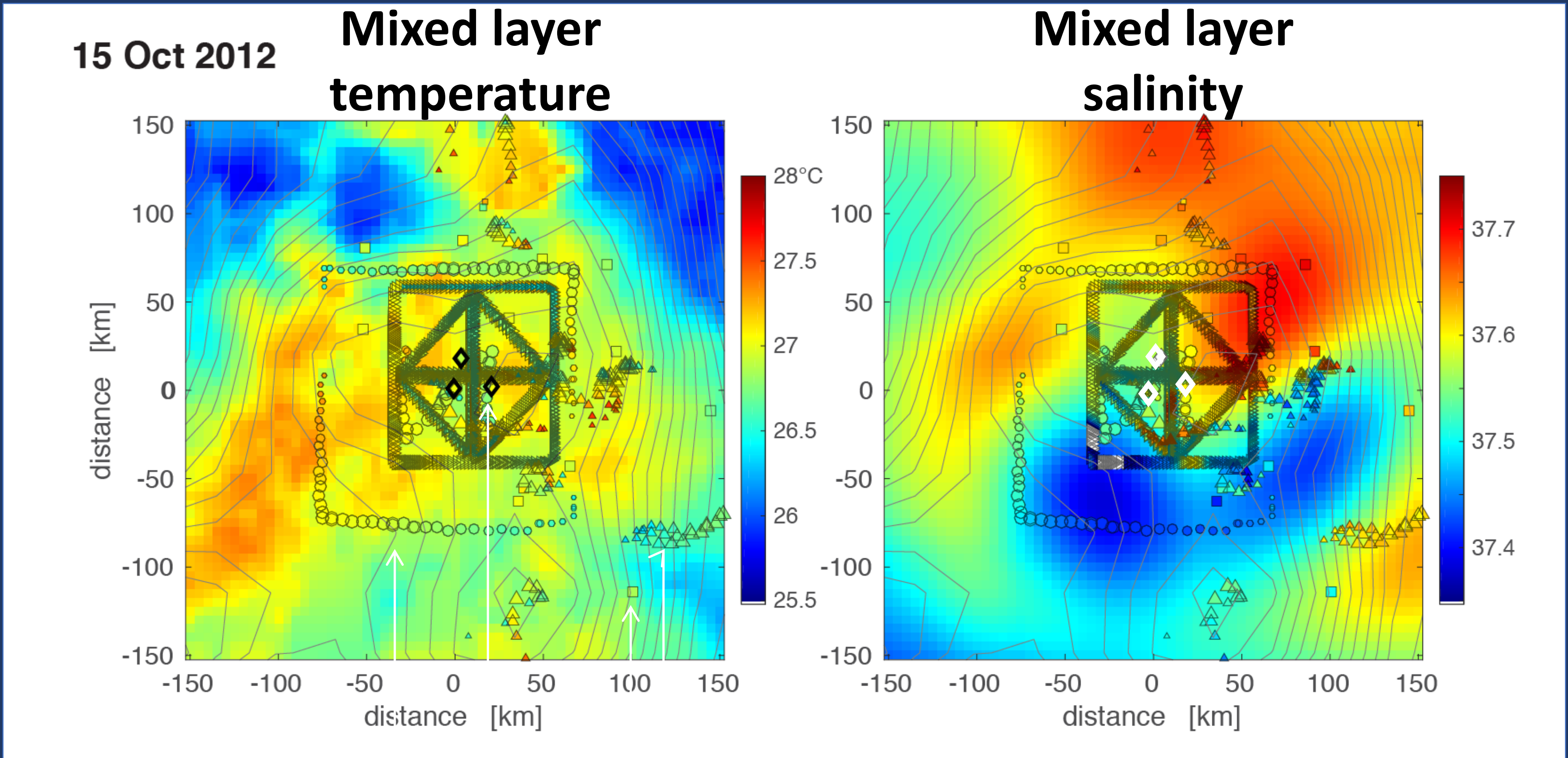
- Moorings
- Seagliders
- Wavegliders

Low-cost deployments and recoveries using schooner Lady Amber

SPURS - 2
Salinity Processes in the Upper Ocean Regional Study



Shcherbina (APL-UW)



- Moorings
- Drifters
- Seagliders
- Argo floats
- UCTD

Decorrelation scales: 75 km and 5 days mapped as perturbations from remote sensing

Note: Size of data marker is scaled by when it was collected relative to the map time.

Salinity and temperature budgets of the mixed layer

For the 3-week averages:

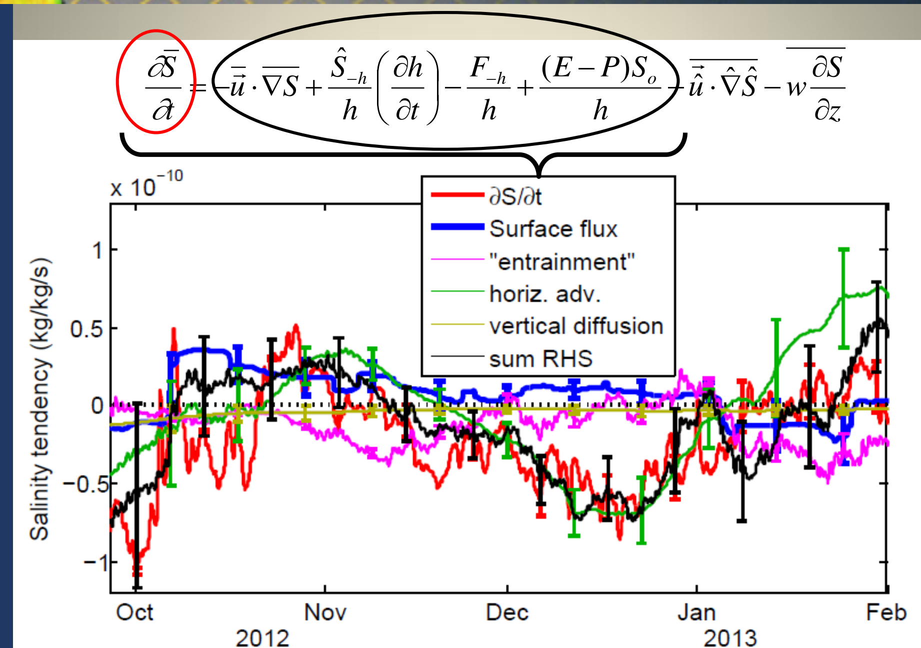
Salinity tendency mostly due to mesoscale advection.

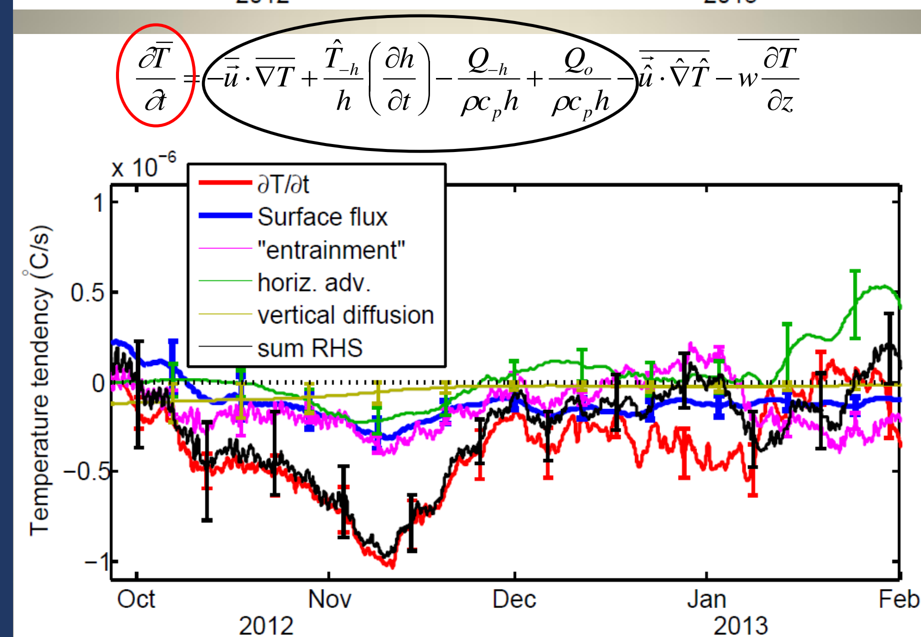
Temperature balance has similar contributions from surface fluxes, entrainment, and advection.

Not perfect…

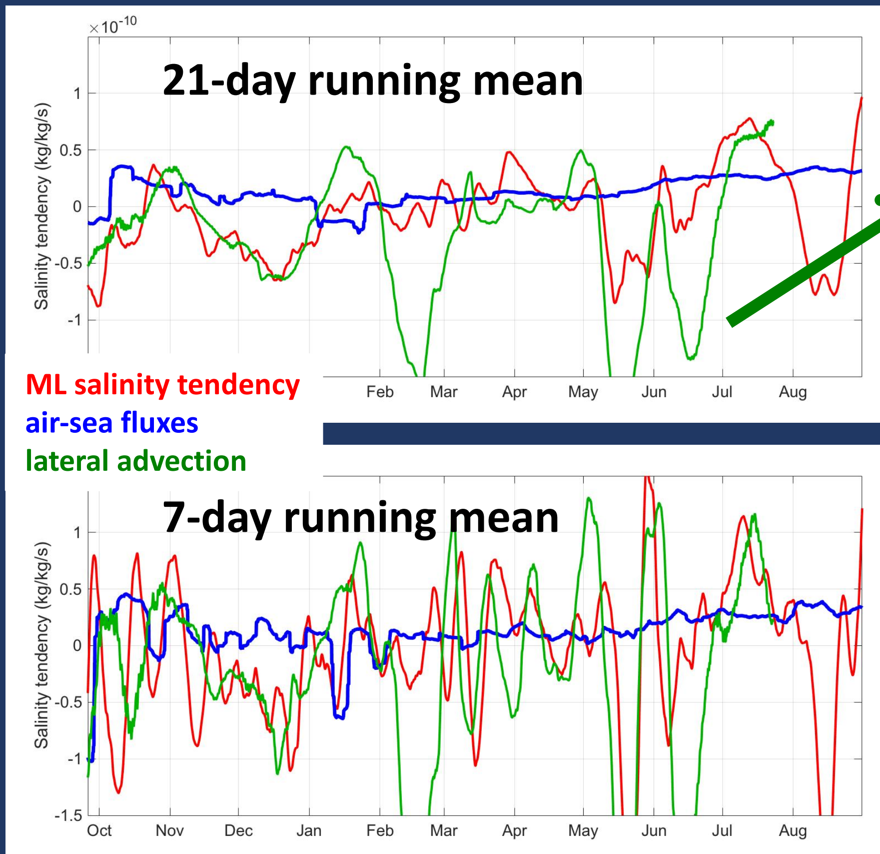
- Physics representation in terms
- **Temporal and spatial scales**

Farrar et al. (2015)





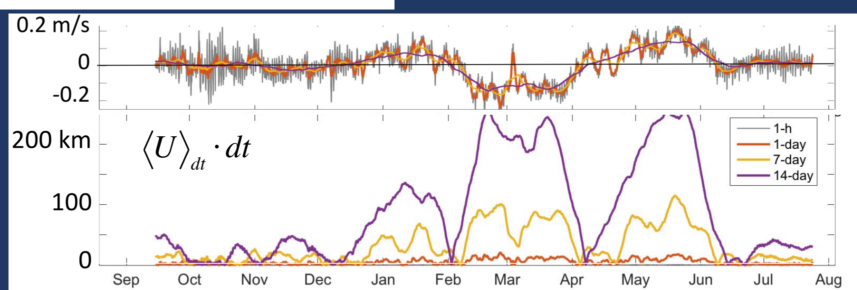
Different scales emphasize different processes.

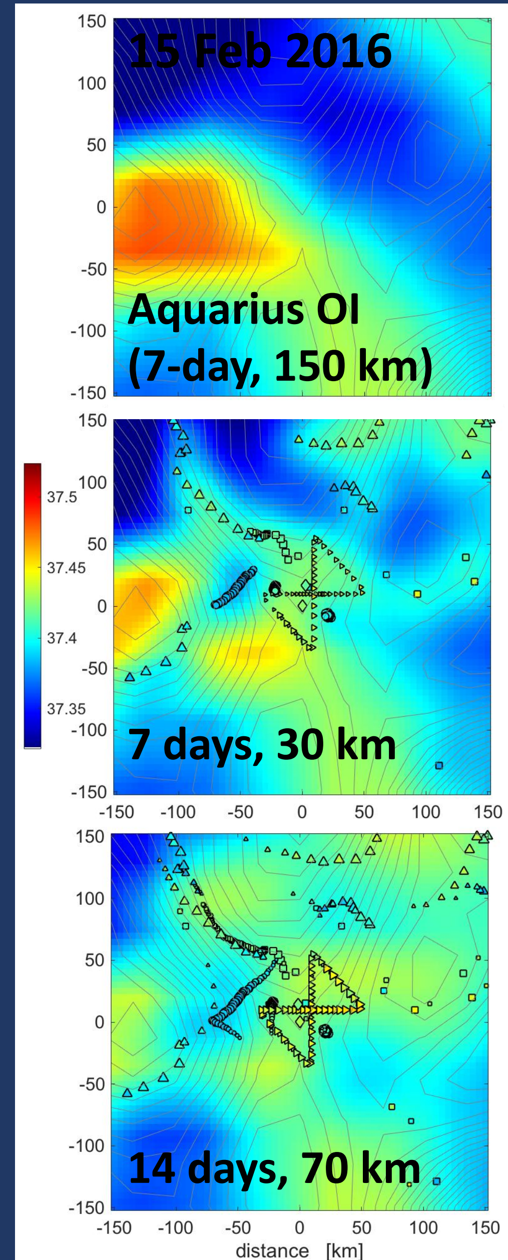


$$\langle -\vec{u} \rangle \cdot \langle \vec{\nabla} S \rangle$$

Average over a time scale

Assume a spatial scale





BGC Observations: 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

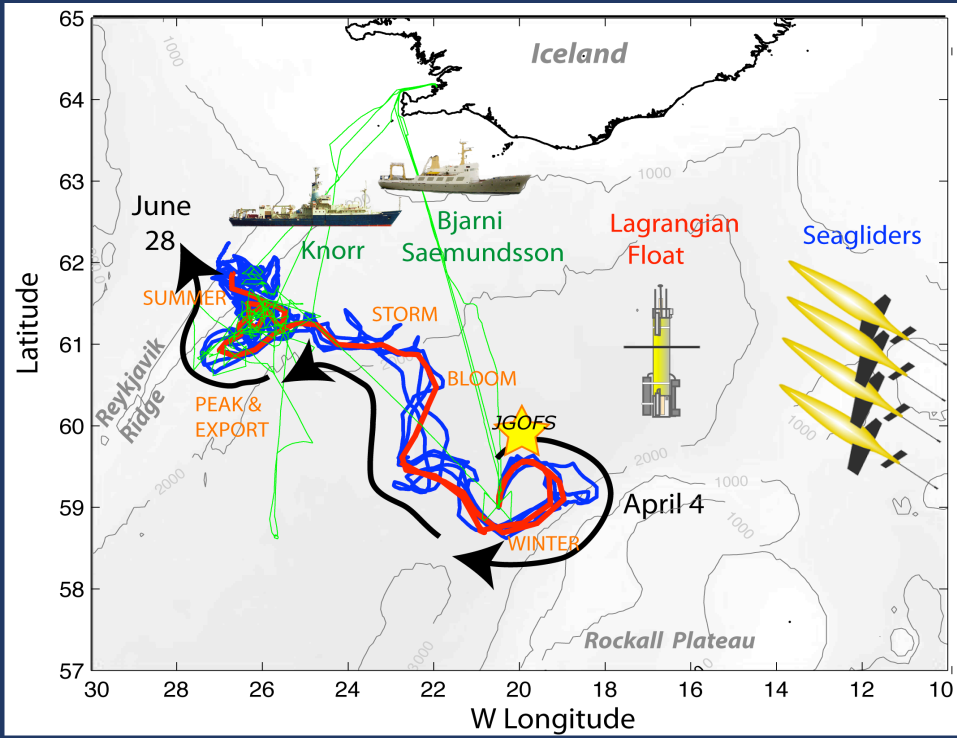
Coupled Physical-Biogeochemical Processes- NAB08

Craig M. Lee, Eric A. D'Asaro, Mary Jane Perry, Katja Fennel

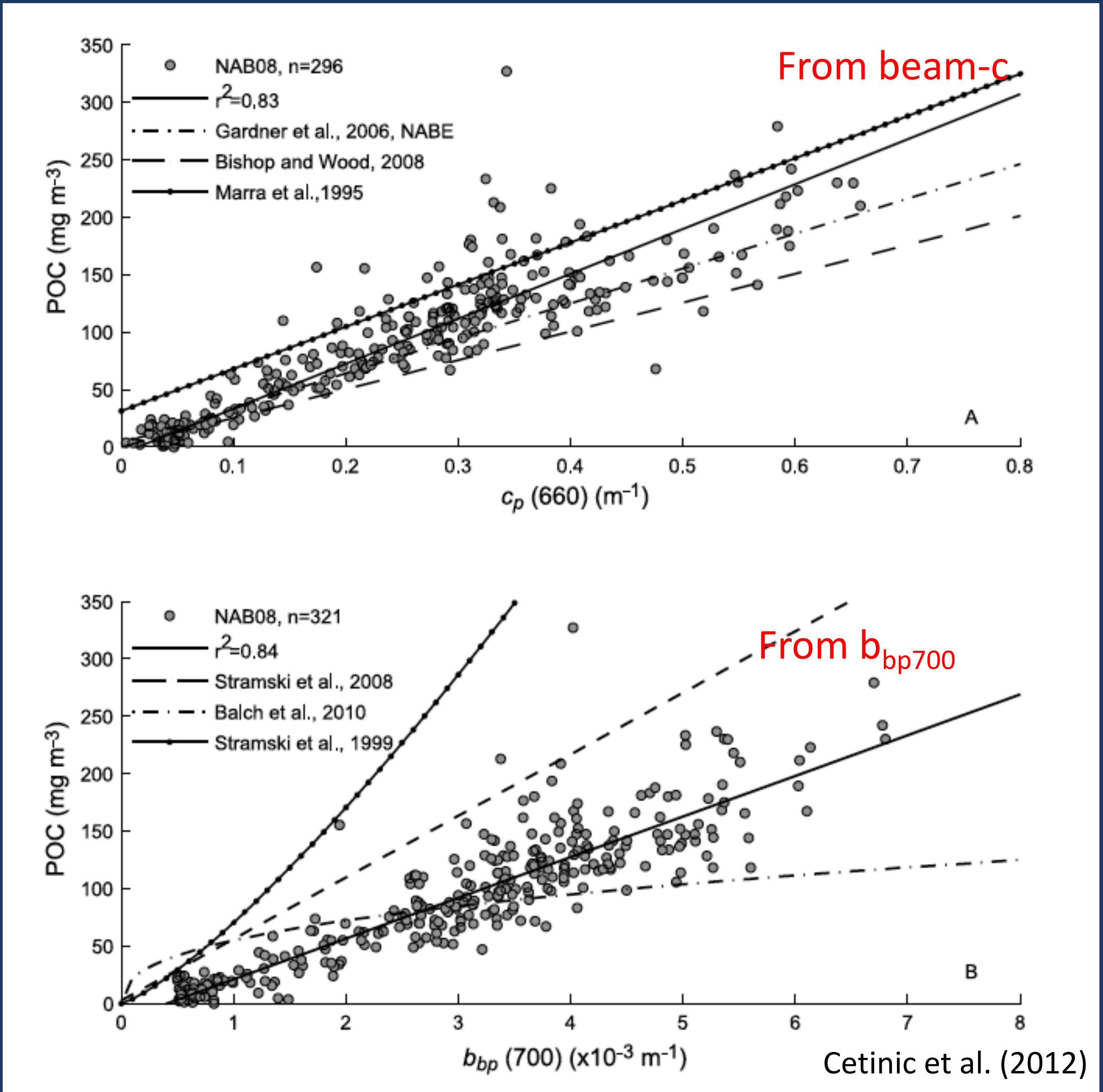
Matthew Alkire, Witold Bagniewski, Nathan Briggs, Ivona Cetinic, David Checkley, Amanda Gray, Kritstinn Gudmundsson, Jan Kaiser, Emily Kallin, Richard Lampitt, Amala Mahadevan, Patrick Martin, Nicole Poulton, Eric Rehm, Katherine Richardson, Ryan Rykaczewski, Tatiana Rynearson, Brandon Sackmann, Michael Sauer, Michael Sieracki, Toby Westberry

Spring Phytoplankton Bloom Initiation and Evolution in the Subpolar North Atlantic

- Timing – deploy before the bloom.
- Persistence – measurements before, during, after bloom.
- Float – Lagrangian frame.
- Seagliders – spatial context.
- Real-time data – adaptive sampling.
- Proxy sensors – for carbon-cycle components.
- Ship-based sampling – calibration, inform interpretation.
- Aggressive calibration efforts – (lab, deployment, process & recovery).
- Satellite remote sensing – ocean color, SST, Aviso SSH, NCEP winds.
- Models – ecosystem, productivity, submesoscale circulation.



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



- Dual POC proxies.
- Empirical relationship derived from 296 (c_p) & 321 (b_{bp}) - POC pairs.

Redundancy

- Regions where c_p and b_{bp} POC records are identical provide confidence.
- Regions where c_p and b_{bp} POC records differ provide diagnostic.

Net Community Production and Export

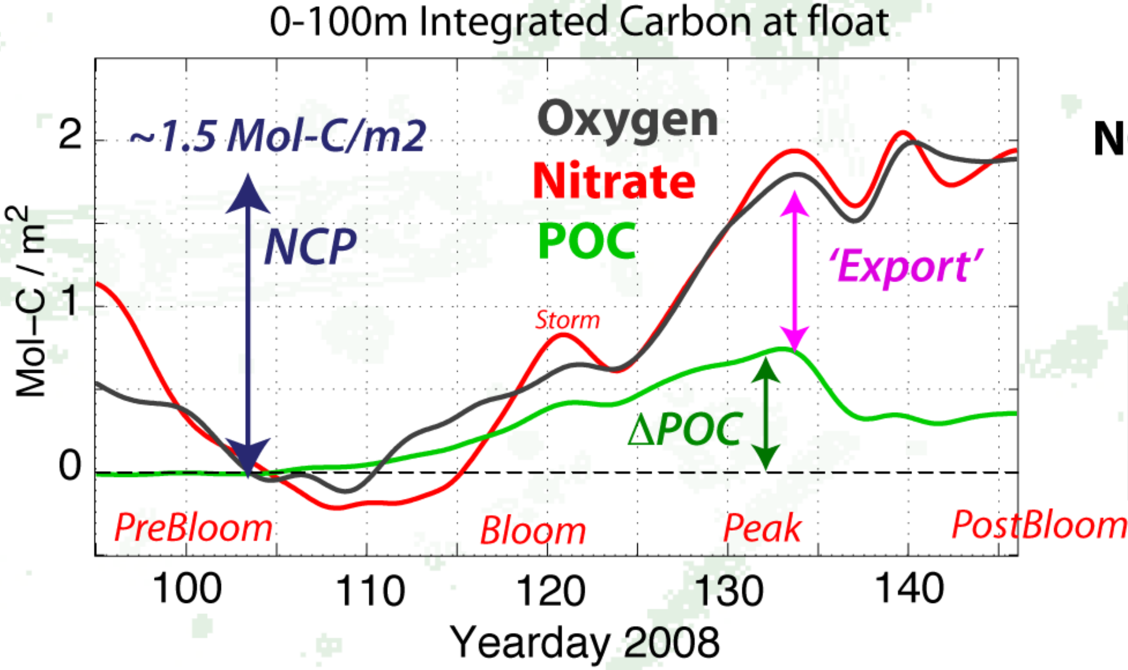
Matthew Alkire
APL/UW

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]



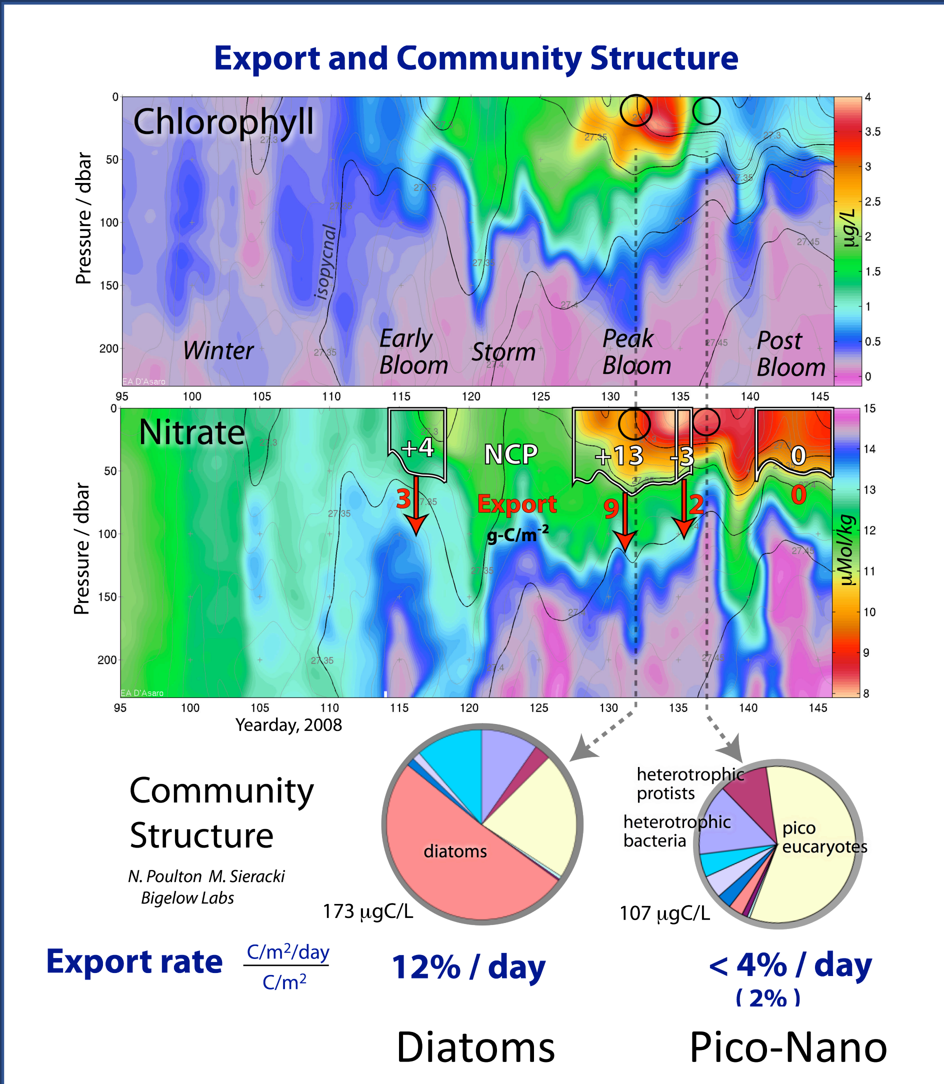
NCP from NO_3 and O_2 agree well

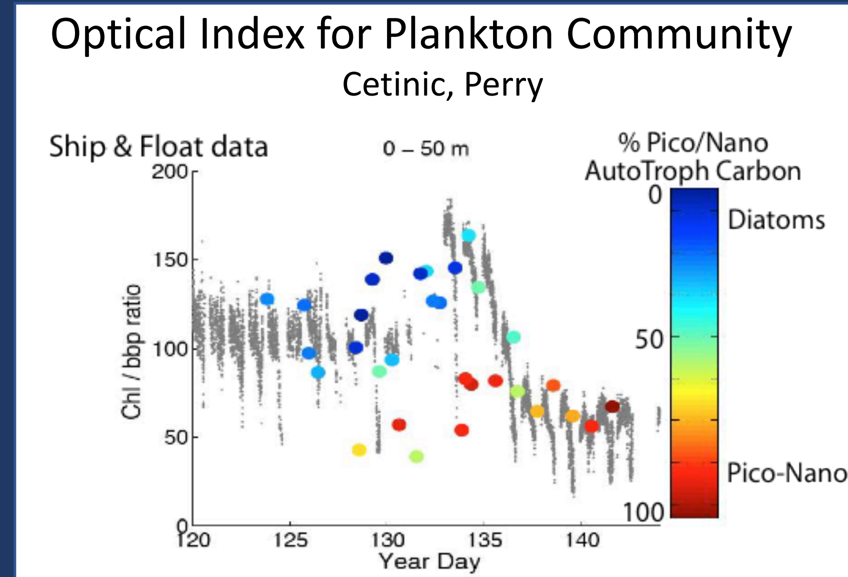
Much of the net carbon fixed --> Export or DOC

Alkire et. al (2012) estimates DOC from literature

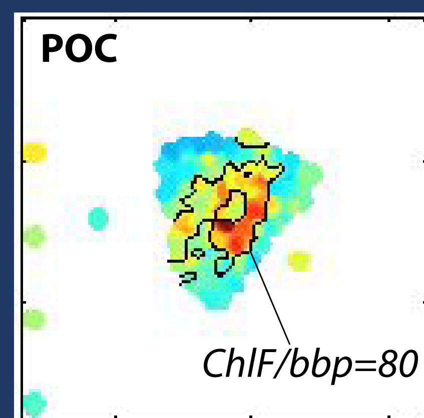
e=Export/NCP = 30-70%

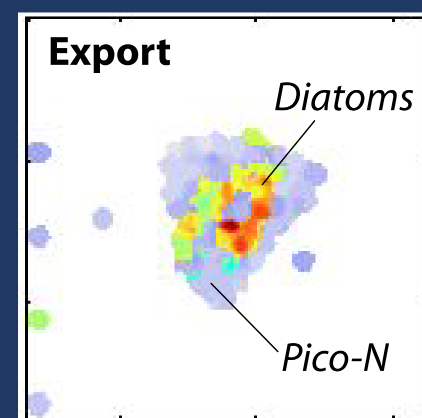
Export Maps from Glider-based Measurements and Optical Proxies





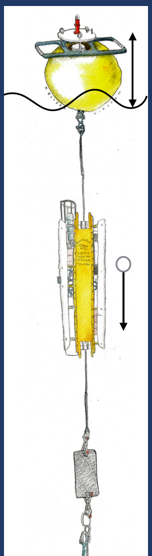
- Map POC, Chl/bbp (community index)
- Combine to map export

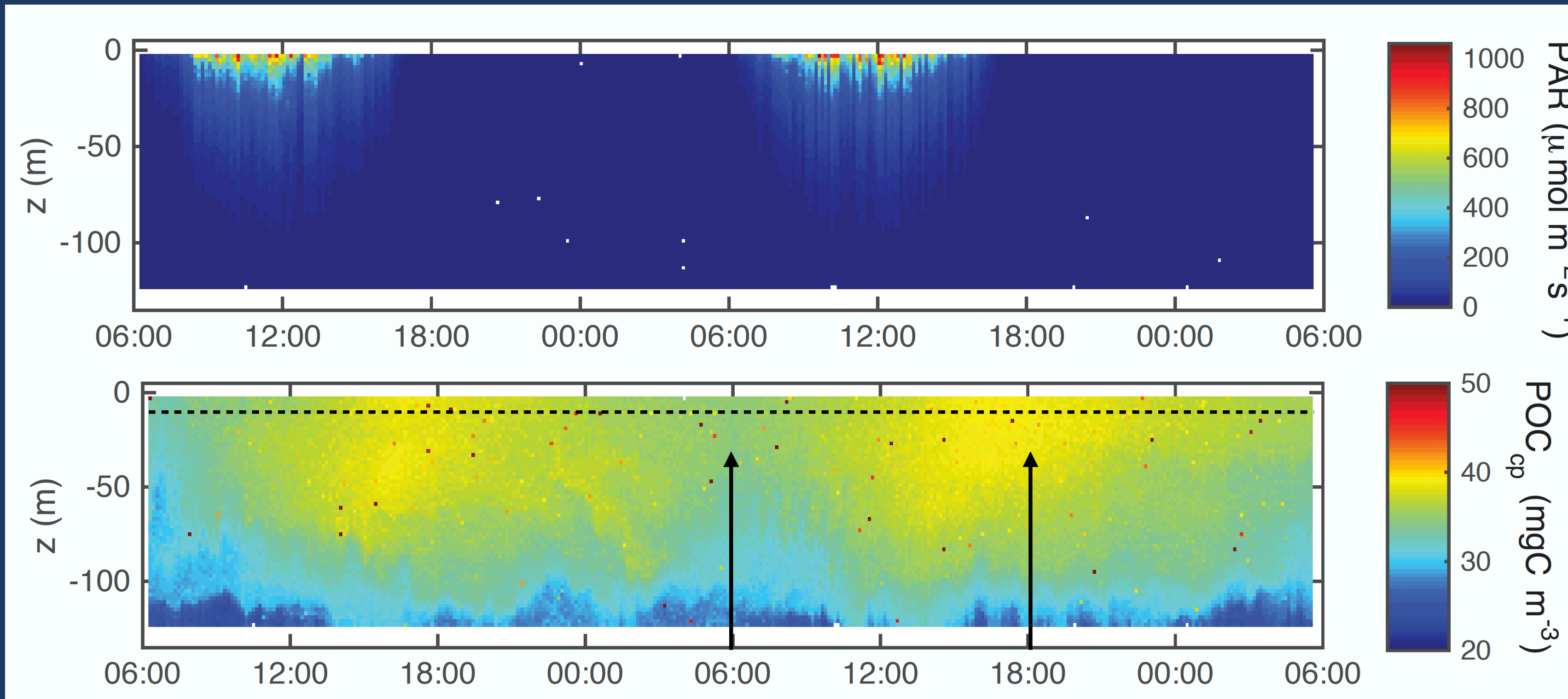




Growth Rates from Diel Cycles

Melissa Omand (URI)





POC_{cp} minimum pre-dawn, peaks near dusk

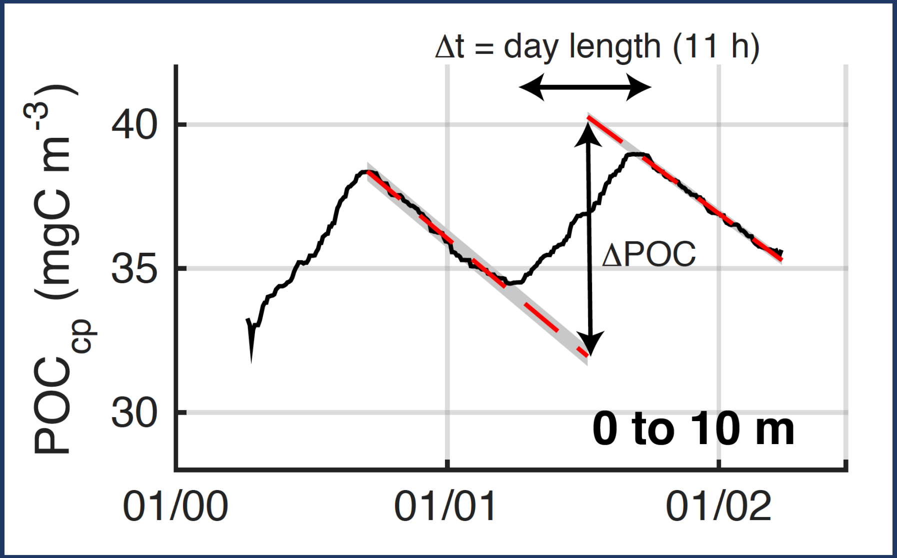
Overnight – assume no photosynthesis, only phyto loss

Daytime – phyto growth and loss

POC_{cp} was calculated from a linear fit between filtered POC samples and Cp on the CTD Rosette (ie. *Claustre et al. 1999, Cetinic et al. 2012*).

Growth Rates from Diel Cycles

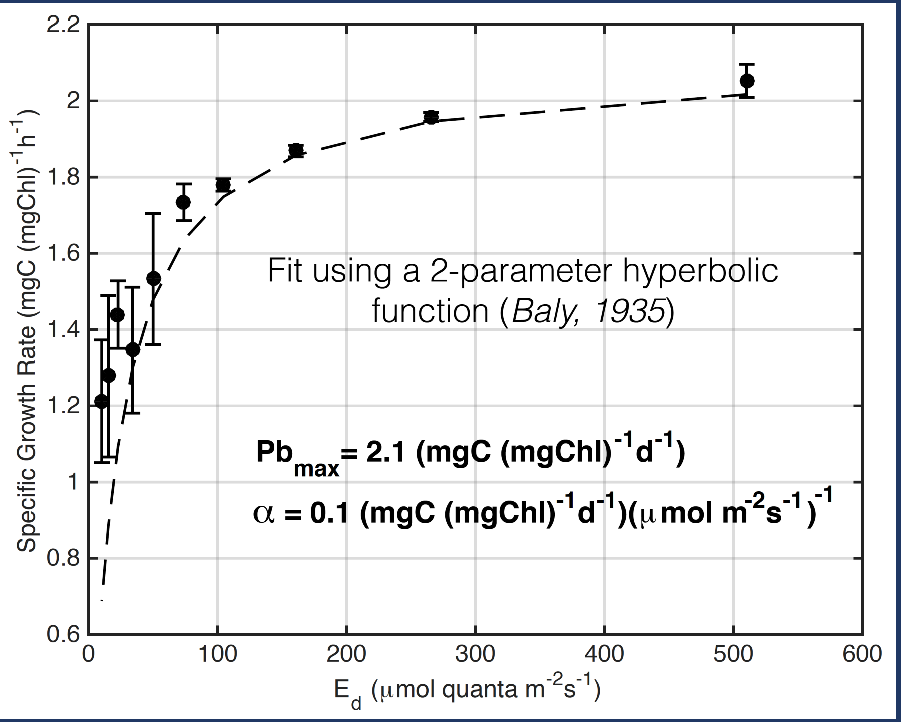
Melissa Omand (URI)



- Take vertical average (10 m bin)
- Linearly fit night-time POC
- Specific growth rate is calculated from the extrapolated POC difference = 2.03 $mgC(mgChl)^{-1}h^{-1}$
- Compute growth rate at multiple depths

Growth rates calculated at each depth versus the average PAR measured over daylight hours at that depth

Resembles lab-based photosynthesis-irradiance curves



Southern Ocean Carbon and Climate Observations and Modeling

Goals:

- Quantify and understand the role of the Southern Ocean (everything south of 30°S) in carbon cycling, acidification, and nutrient cycling on seasonal, interannual, and longer time scales.

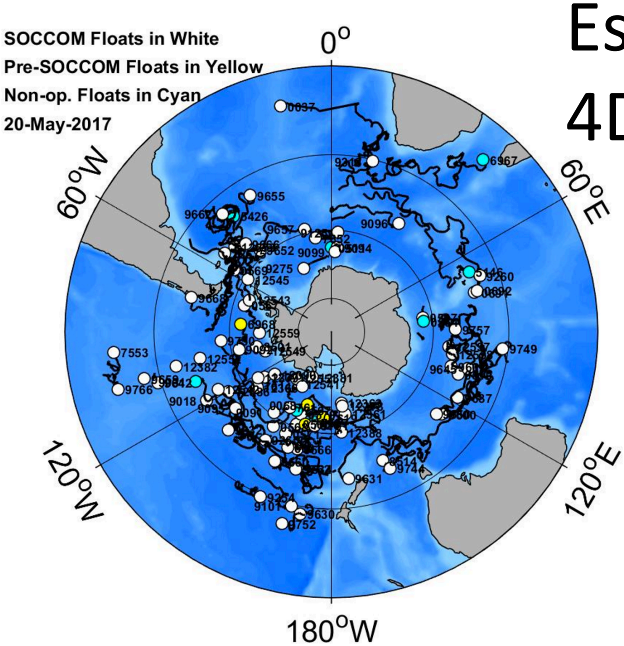
- Develop the scientific basis for projecting the contribution of the Southern Ocean to the future trajectory of carbon, acidification, and nutrient cycling.

SOCCOM

SOCCOM Strategy

~200 profiling floats over 6 years with pH, NO_3^-, O_2, biooptics

Southern Ocean State Estimate model to get 4D fluxes



Improved coupled climate model (GFDL) predictions of Southern Ocean role in carbon and climate

SOCCOM

BGC Argo

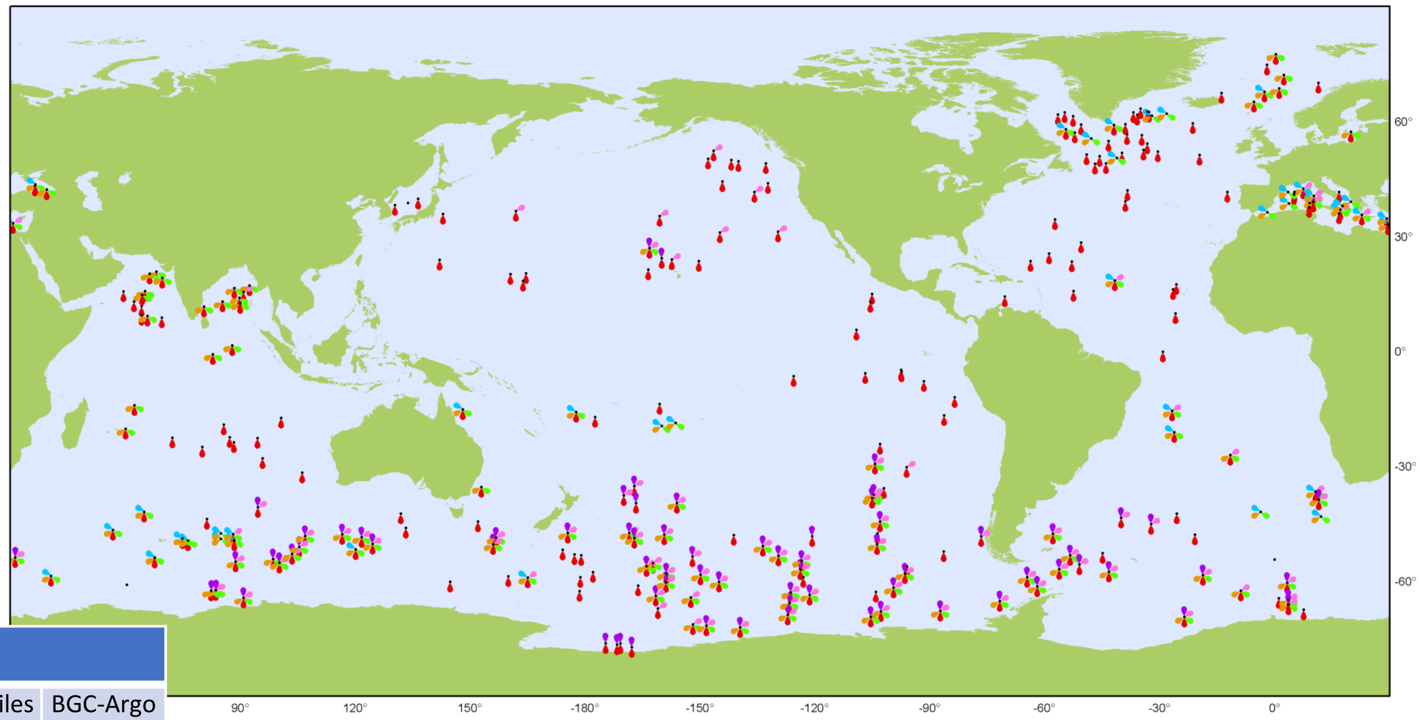


Table 1. Profiles to depth > 900 m.

Parameter	Ship Profiles per year (2001-2010)	BGC-Argo Profiles per year (2016)	BGC-Argo /Ship
Oxygen	1730	11332	6.5
Nitrate	1231	3835	3.1
pH direct	460	1862	4.0
pH (TA/DIC)	540		3.4
Source	US NODC	Argo GDAC	

Summary

- Creative, multi-platform approaches offer great power.
- Match target spatial and temporal scales to system of platforms.
- Leverage autonomous sensors through BGC proxies.
- Understand process-level physics, biology and biogeochemistry.
- Scale up – process knowledge + observations + remote sensing + models.
- Ship-based observations critical for calibration, proxy building. An application for long-range AUVs?
- New logistical approaches- flexible vessels, over-the-horizon deployments to access remote/dangerous locations, …
- Expendable platforms. Aim for low-cost/long-endurance, easy logistics.
- How do we define expendable? Gliders and floats have similar cost per profile…