Operational Highlights of the EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) North Atlantic 2021 Field Campaign

D. Siegel, L. Johnson, K. Buesseler, I. Cetinić J. Graff, C. Lee, H. Sosik, I. Soto Ramos, D. Steinberg & the EXPORTS Science Team

Goal & Science Questions

EXPORTS's goal is to improve predictions of the export and fate of ocean NPP using satellite data & numerical models.

Q1:How do upper ocean ecosystems determine the flux of organic matter from the surface ocean?

Q2: What controls the efficiency of vertical transfer of organic matter below the well-lit surface ocean?

Q3: How can the knowledge gained be used to reduce uncertainties in contemporary & future estimates of the export and fates of NPP?.

Overall Project Plans

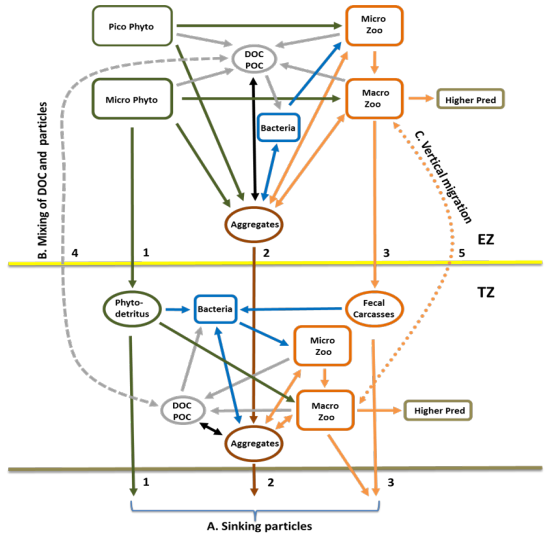
Two Phases: Field campaign followed by modeling & synthesis phase

Focus on Pathways & Fates:

Controls on the 3 dominant export pathways - sinking, migration & advection

Assess BGC impacts

Link to remote sensing variables for satellite algorithms



Field Program:

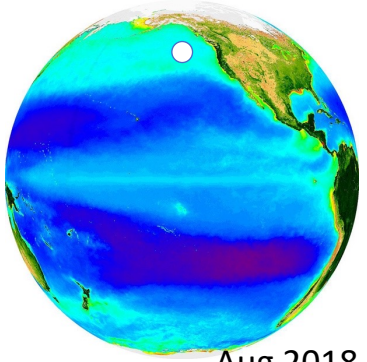
Two cruises: Station P & North Atlantic

Coordinated sampling with two ships & multiple AUVs

Dedicated data management team

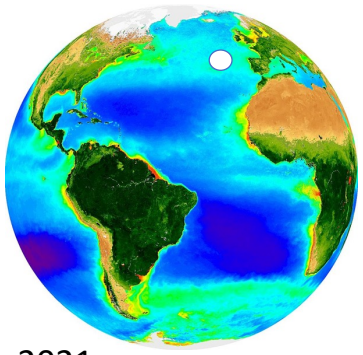
Documented protocols for all measurements

Station P



Aug 2018

PAP Observatory



May 2021

North Atlantic Field Program

Goals

- Contrasting endmember to 2018 NE Pacific cruise
- Big biomass & export signal & low flux attenuation
- Goal - observe the demise of the North Atlantic Spring bloom
- High mesoscale & sub-mesoscale energy driving patchiness in biomass & subduction

Siting & Observational Platforms

- Near NOC's PAP Observatory in a retentive eddy
- On site (~49N 15W) for 25 days of May 2021
- Three Ships - *RRS James Cook* (Process), *RRS Discovery* (Survey) & *R/V Sarmiento de Gamboa* (WHOI's OTZ)
- 3 Gliders, 2 BioARGOs, 1 Lagrangian Float, Sediment Trap & WireWalker arrays, & multiple NBSTs, & more…

Process Ship – RRS James Cook

Missions:

- Assess export pathways & their proximate causes over time in a Lagrangian frame of reference – following the Lagrangian Float (which sets experimental center)
- Integrate with other components to provide end-to-end assessment of the carbon cycle impacts of food web processes
- Link pathway / food web / BGC observations to remotely sensible quantities

Operations:

- Focus on sinking & active migrant carbon fluxes
- Characterize plankton / microbial community composition
- Make rate measurements to determine the flow of energy within upper ocean and mesopelagic food webs
- Address the roles of the food web in three export pathways

Survey Ship – RRS Discovery

Missions:

- Provide spatial/temporal-physical/BGC context from CTD/rosette & UW surveying,
- Complete the Process Ship's measurement suite,
- Collect optical & other data to ground truth & build satellite algorithms,
- Contribute to the assessment of advective export fluxes of POC & DOC, and
- Link sensor data thru sensor intercalibration exercises between the ships & the autonomous platforms.

Operations:

- Conduct spatial surveying & noon optics casts w/ CTD & UW systems,
- Conduct ^{234}Th flux, PSD, TMC sampling & incubations & high-volume pump profiles to support the Process Ship,
- Sample frontal features to assess advective export fluxes (incl. UCTD),
- Conduct 2-day "edge experiment" with the R/V Sarmiento, and
- Perform intercalibration casts among the various sensor data sets.

AUVs – Gliders, BioARGOs & the Lagrangian Float

Missions:

- Provide spatial/temporal physical/BGC oceanographic context on scales missing from ships (smaller space, longer time & broader extent),
- Lagrangian Float is the geographic center of the program,
- Contribute to the assessment of advective export fluxes of POC & DOC,
- Help assess the retentiveness of the eddy feature before ships arrive, and
- Link sensor data sets thru sensor intercalibration exercises.

Operations:

- Deploy three gliders from DY130 to three target sites,
- Deploy two BioArgo floats and the Lagrangian Float from DY131, and
- Coordinate operations with shore, ships, the WHOI OTZ and NOC.

Partnerships – NOC & the WHOI OTZ program…

Missions:

- Extend the trophic and space / time sampling of the experiment,
- Prove the utility of novel instrumentation for assessing twilight zone processes,
- Help quantify advective fluxes using OTZ's Stingray towed sled (edge experiment)
- Contribute data from PAP mooring (incl. deep sea sediment fluxes)
- PAP cruise (DY130) occurred before EXPORTS (collected samples & deployed gliders)

Operations:

- WHOI OTZ - R/V Sarmiento de Gamboa on site May 6-18

  CTD/rosette/UVP, MOC-10 nets & Stingray towed system

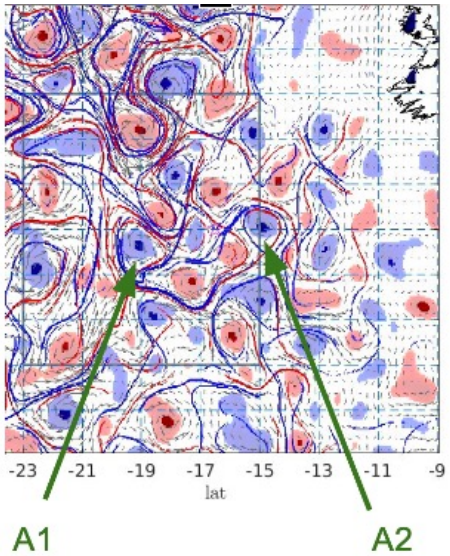
  Focus on higher trophic levels & novel instrumentation - Minions & Twilight Zone Explorer
- DY130 cruise was March 25-April 14 (DY130) - benthic science focus – turnaround BGC mooring – will help extend the EXPORTS time baseline
- Operate NOC's Slocum glider & provide real-time data for mission planning

Site Selection & Sampling

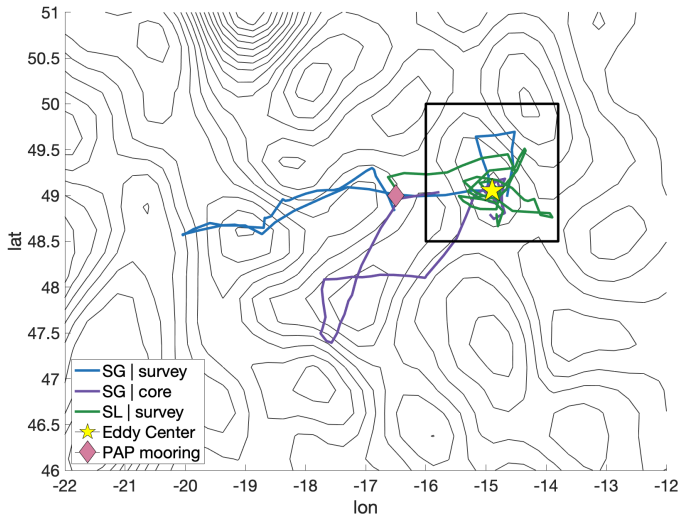
Chose a retentive eddying feature near PAP

- Logistically simpler & reduce roles of advection on the interpretation of rate / stocks measurements
- Created "eddy selection" team with selection criteria & democratic process – became "shore team"
- Assessed many eddies in 2021 as well as "dry lab" feature selection process using previous years
- Deployed 3 gliders to sample potential targets from DY130 (first deployed April 1)
- Conducted a consensus feature selection process and elected feature (A2) was an anticyclone
- All assets were tracked (N=49) - locations & ship/AUV data shared with shore & ships

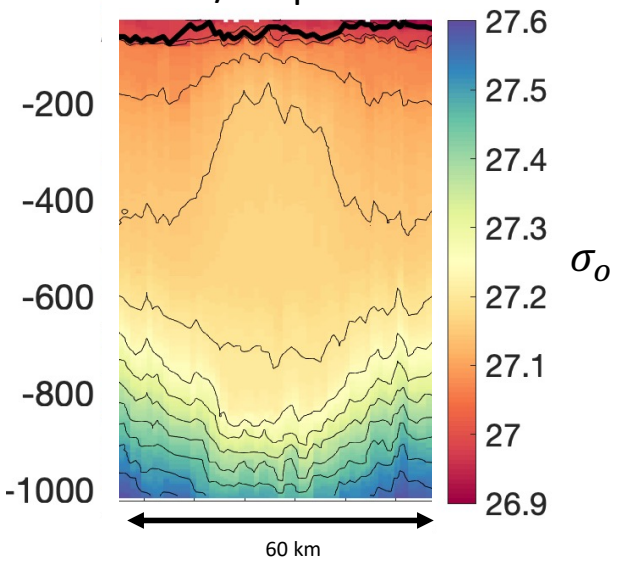
Pre-Cruise Eddy ID'ing

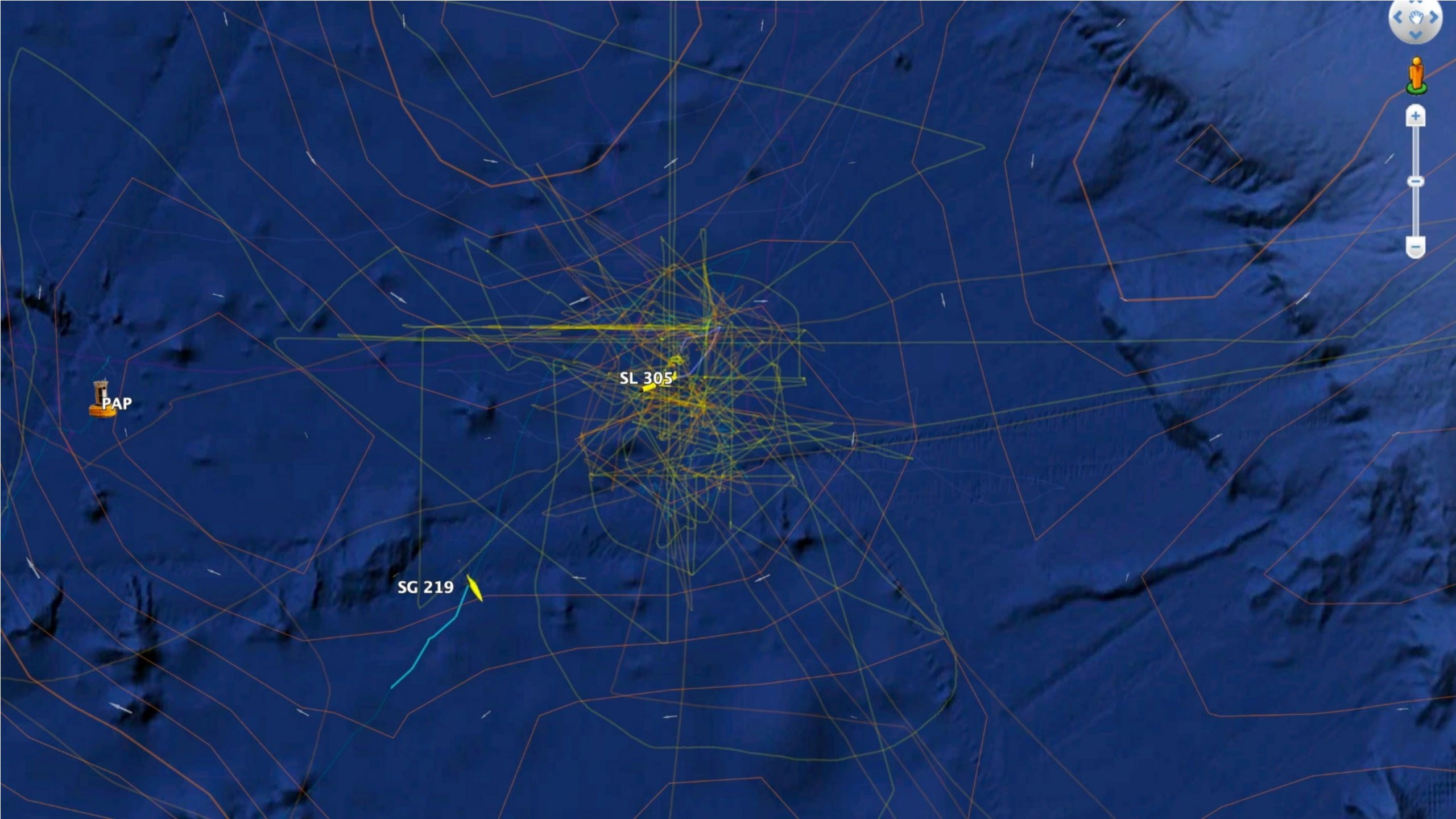


Gliders Pre-Cruise



Glider / Ship Section

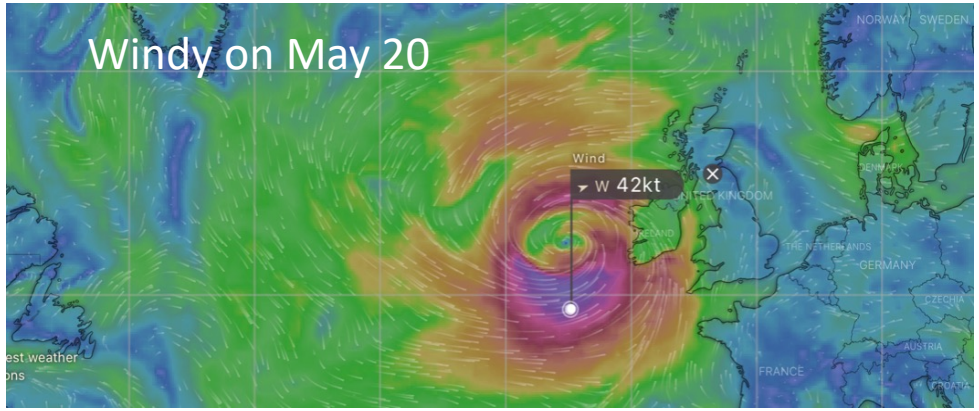



SL 305
PAP
SG 219

Way Too Soon Science Nuggets

Anticyclone A2

- A2 remained coherent & retentive throughout
- Lagrangian float stayed at the eddy center

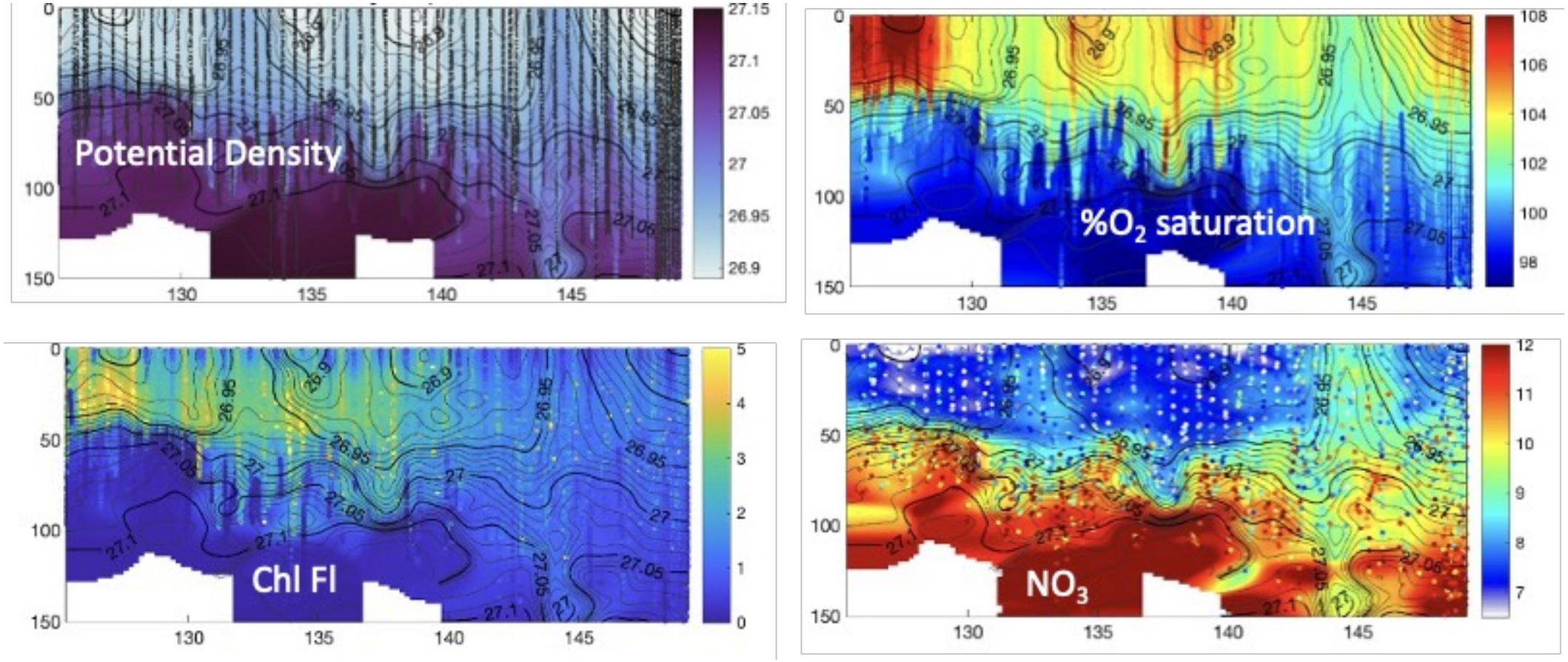


Weather

- Four major storm events (≥ 40 kts)
- Lost 7.5 days of sampling (>7 m SWH!)

Upper Ocean Evolution

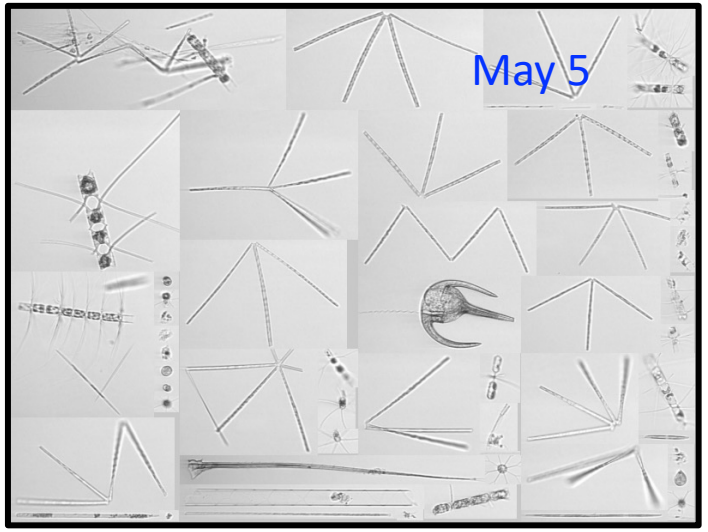
- Mixed layer deepened & Chl Fl decreased over time
- Vertical mixing in response to the storms was apparent in σ_θ, $O_{2\ sat}$ & NO_3

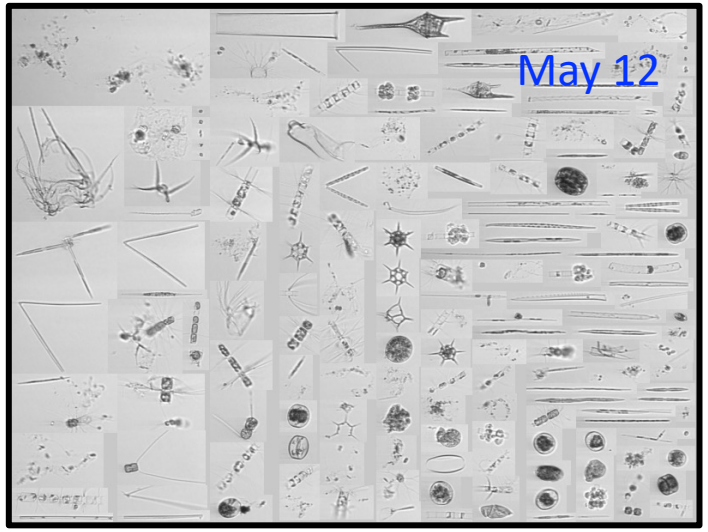


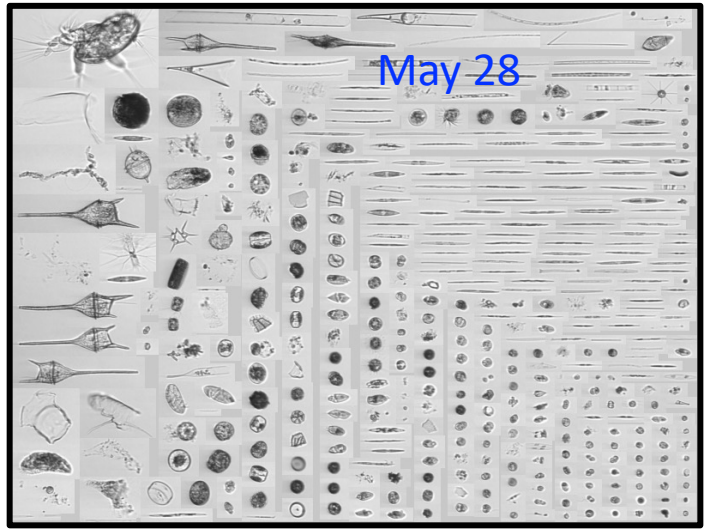
Lagrangian float daily profiles before final calibration – D'Asaro

Surface Biology

- Arrived as intense diatom bloom was just ending
- Initial surface SiO_4 / NO_3 ratios were very low (SiO_4 ~ 0.1 µM)
- Surface phyto community evolved to smaller taxa in time



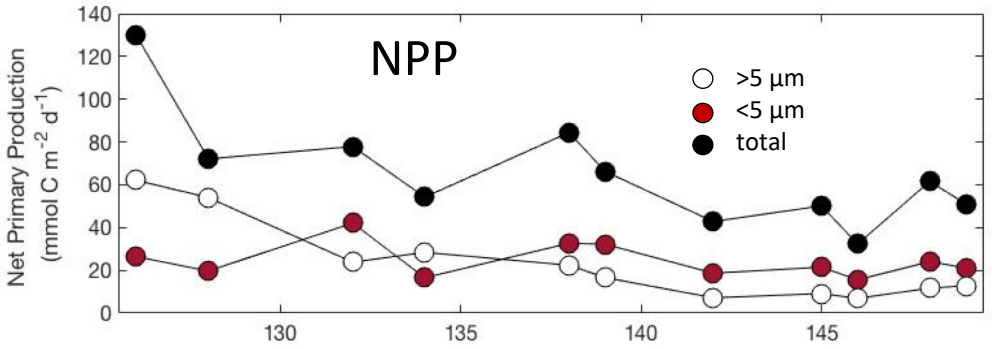


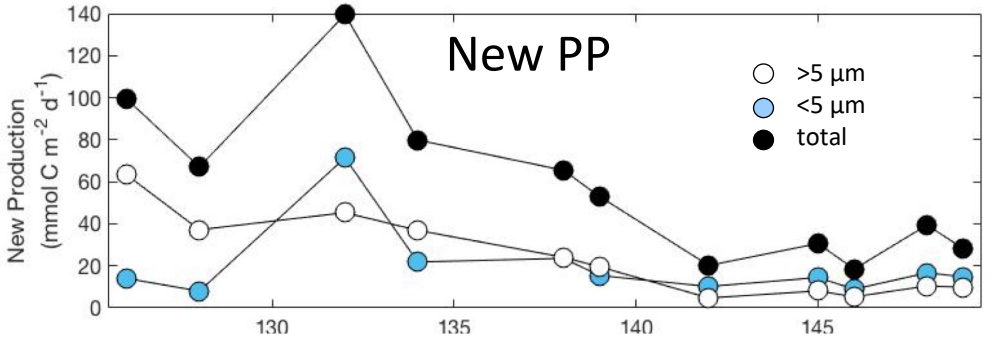


DY131 IFCB dashboard – Sosik/Roesler

Net Primary & New Primary Production Rates

- NPP by ^{13}C-DIC & New PP by ^{15}N-NO_3 incorporation
- NPP rough partition between large (>5 µm) & small fractions
- NPP dominated by new production (regenerative prod was small)



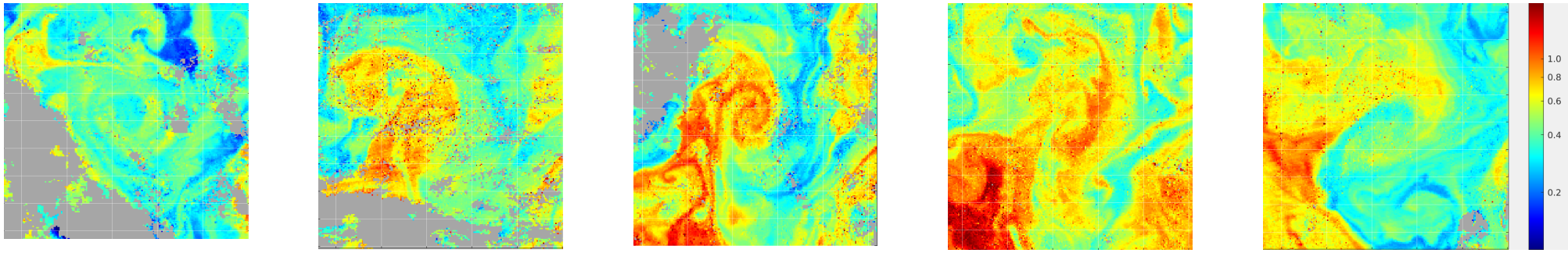


JC214 - Meyer/Marchetti

Spatial – Temporal Changes

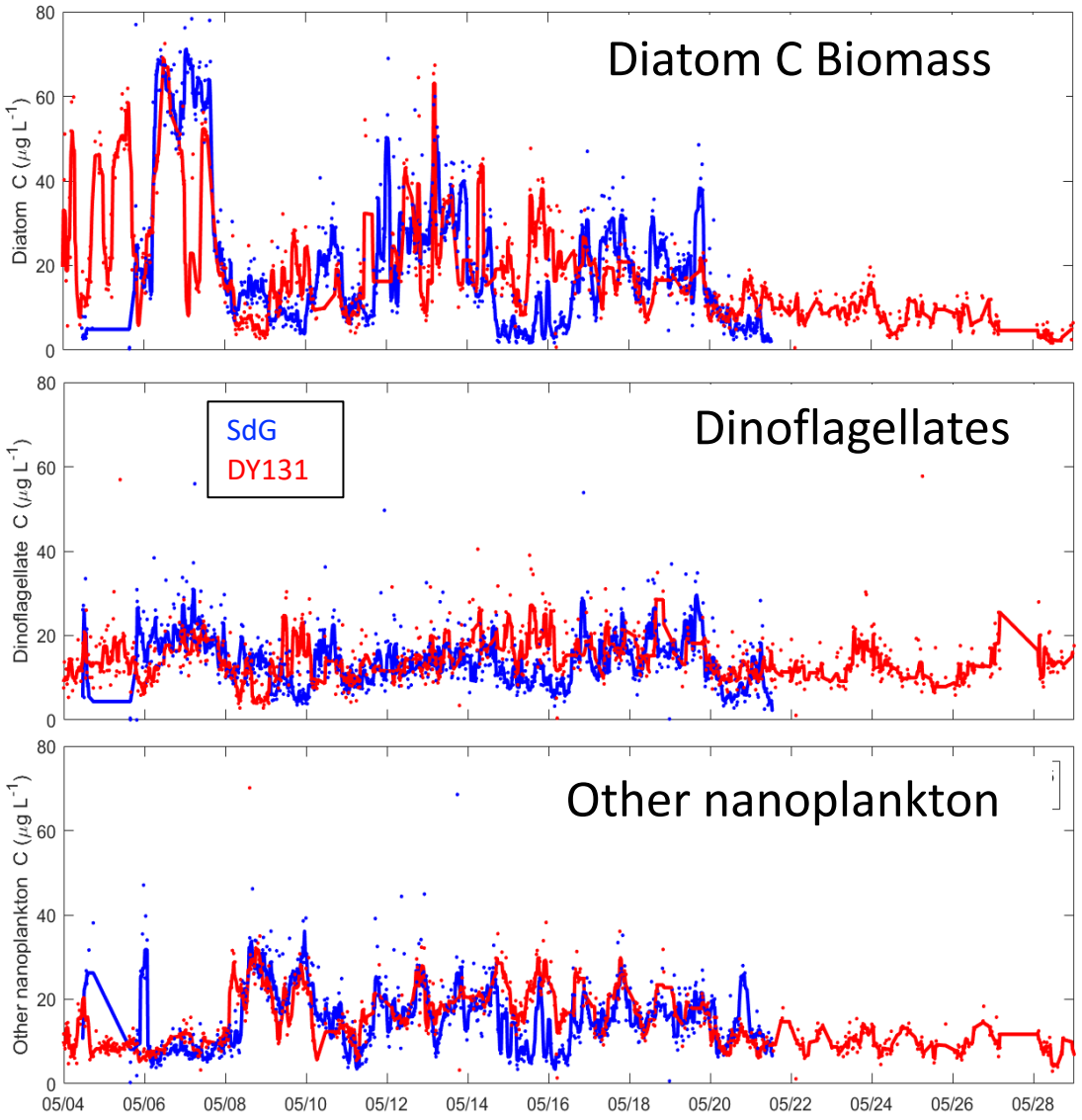
- Lots of meso/submeso-scale variations in Chl

May 2 May 10 May 13 May 18 May 28

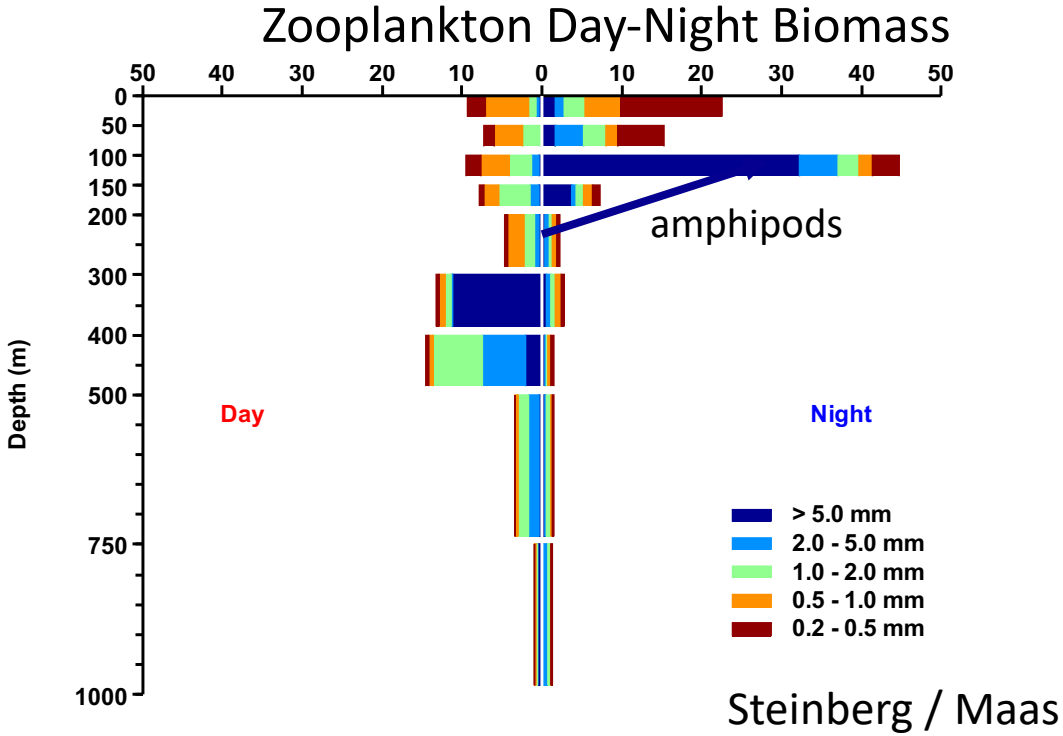


Merged daily satellite Chl for a 200 km box centered on A2

Plankton Composition



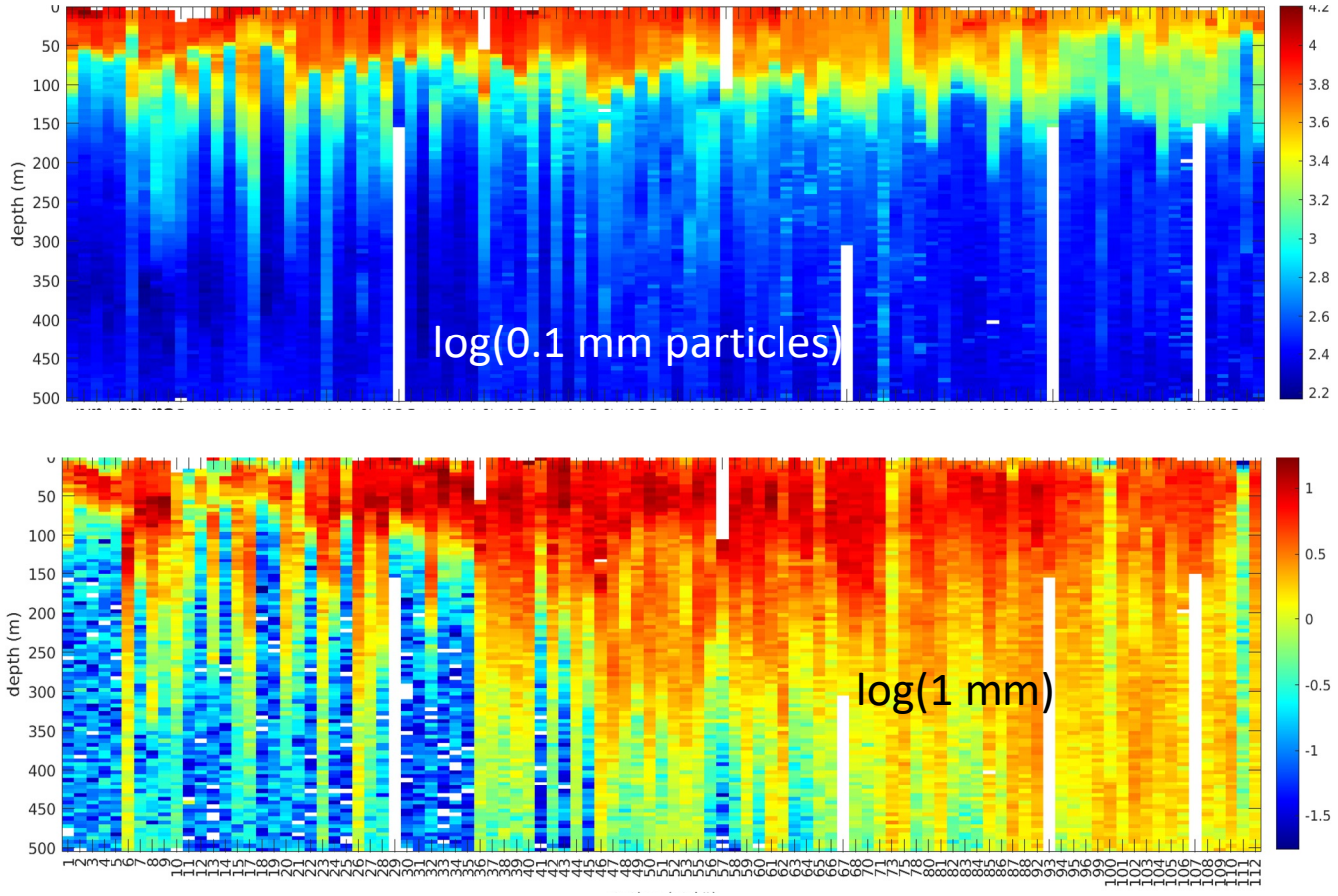
IFCB C biomass - Sosik/Roesler



Steinberg / Maas

- Large changes in Phyto biomass in time
- Zoop day/night differences shows large migrant biomass
- Large pelagic snails (pteropods) were conspicuous & abundant

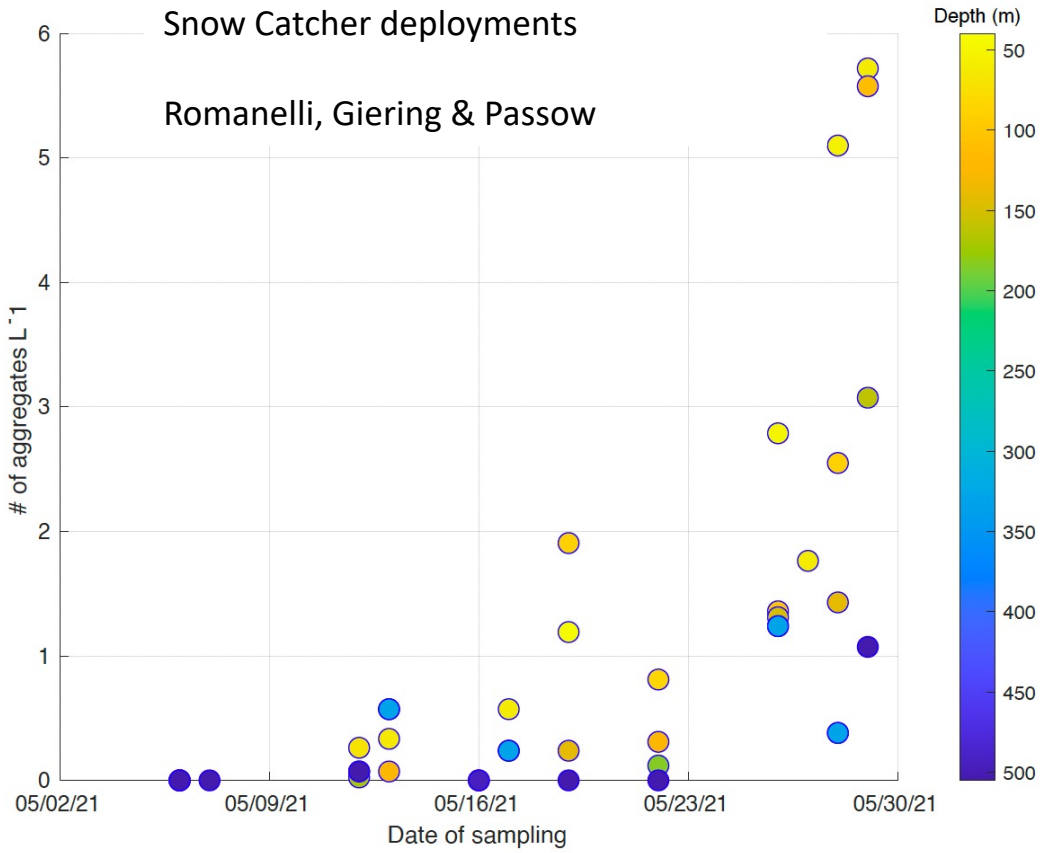
Sinking Particles & Marine Snow



DY131 UVP5 PSD in cast sequence – McDonnell / Siegel

Aggregate concentrations from Marine Snow Catcher deployments

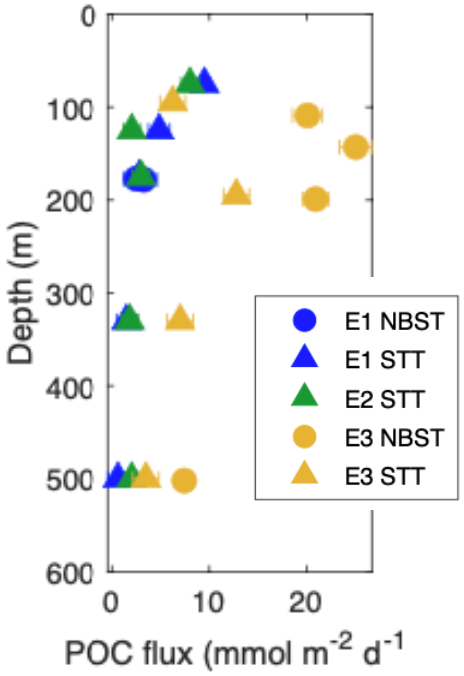
Romanelli, Giering & Passow



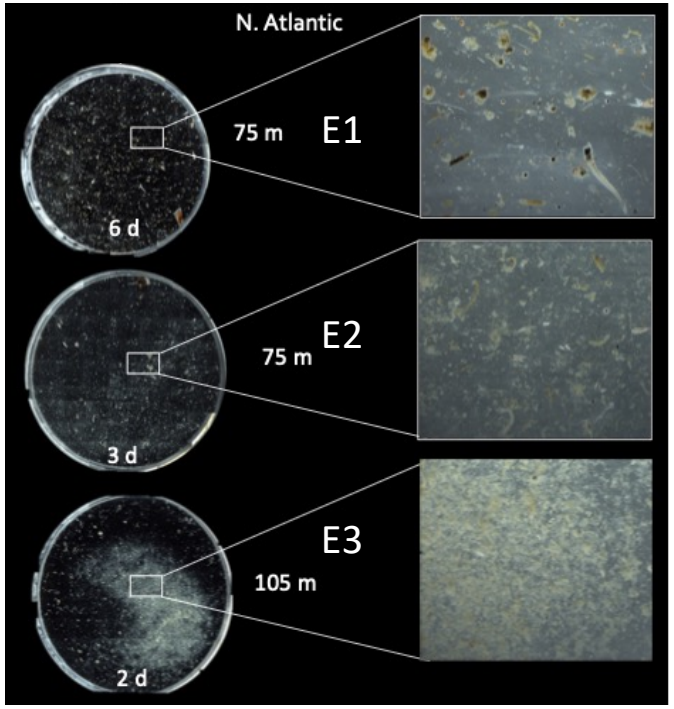
- UVP-5 PSD show decrease of small particles in mixed layer but a substantial increase in large particles especially at depth
- Number of marine snow aggregates collected show large increase in time

Sinking Particle Export Fluxes

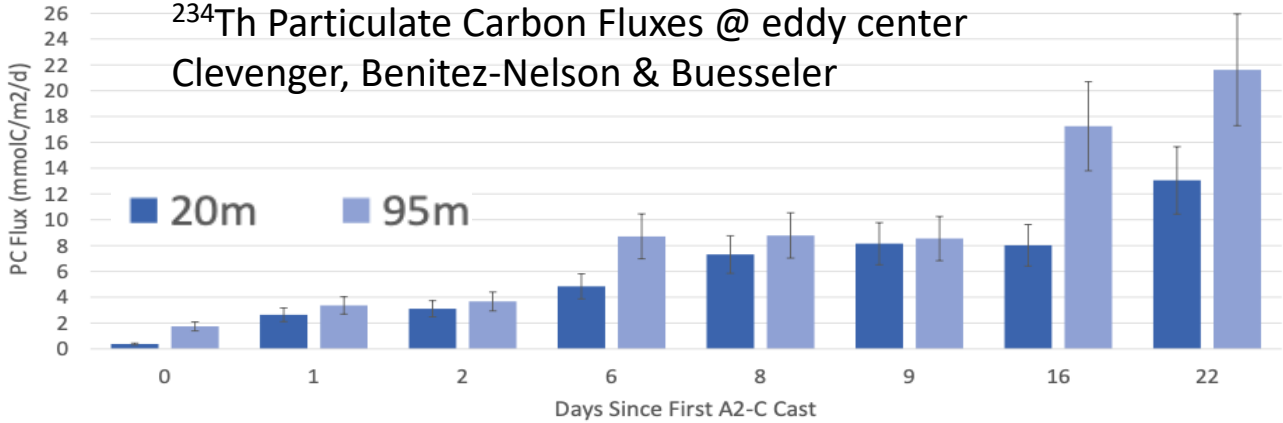
Trap POC fluxes – Estapa

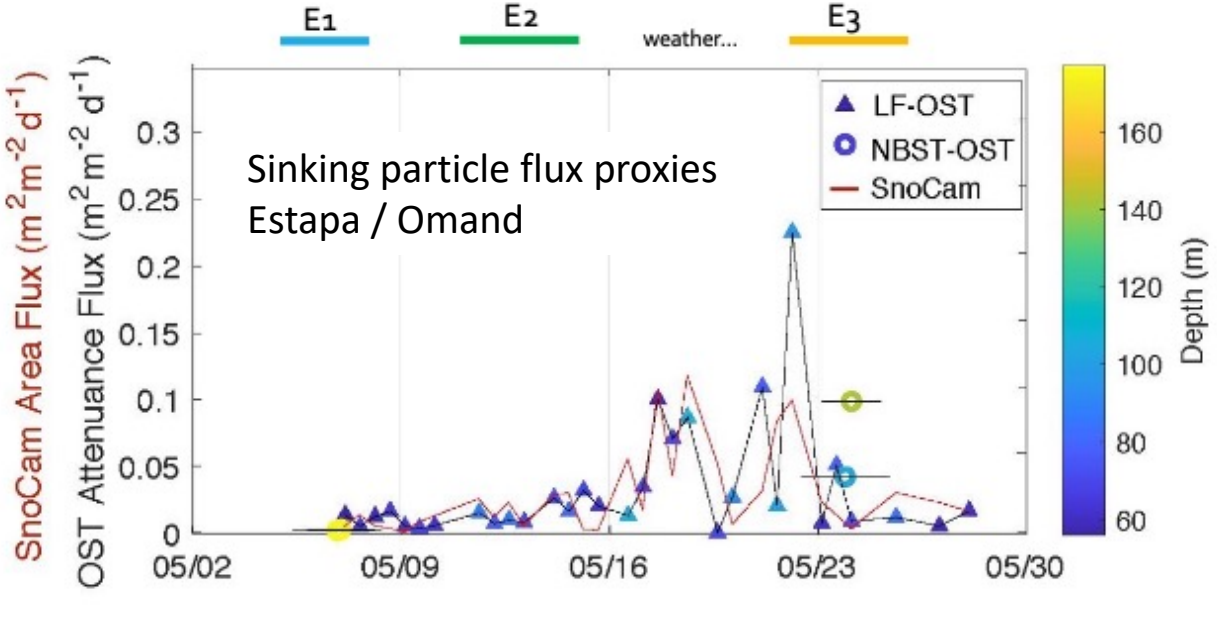


Gel Trap Images - Durkin



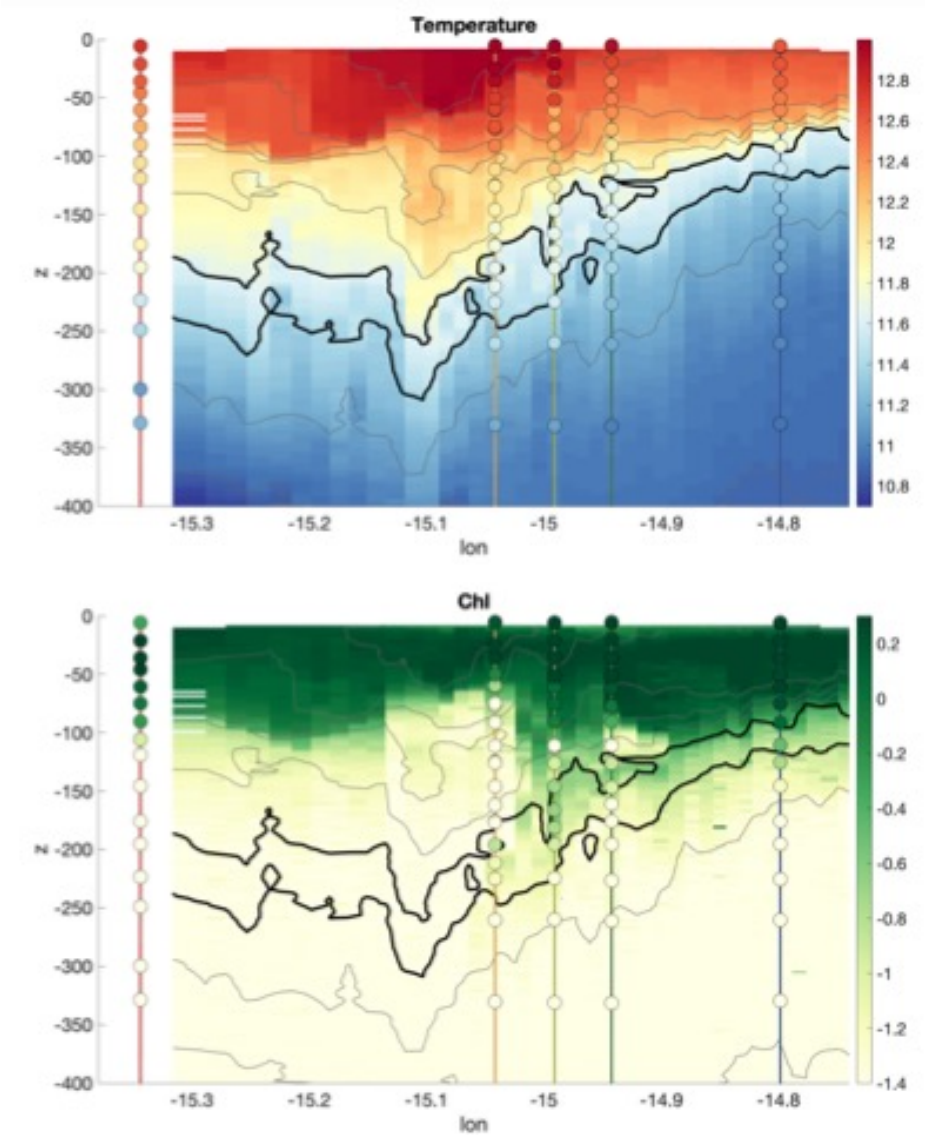
^{234}Th Particulate Carbon Fluxes @ eddy center
Clevenger, Benitez-Nelson & Buesseler



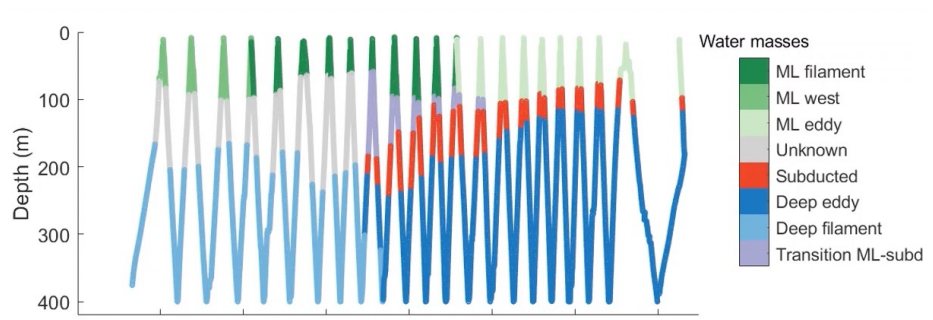


- Export increases over time in both trap, 234Th & optical proxy fluxes (esp. Epoch 3)
- Active fluxes by migrating zooplankton were very large (~30% sinking POC fluxes)

Edge Experiment…



- Conducted an "edge experiment" at a strong front at the edge of the eddy to assess the mixing pump component
- Front was identified by remote sensing, 5+ glider surveys & several uCTD sections from the RRS *Discovery*
- Two-day intensive survey with the R/V *Sarmiento* & RRS *Discovery*
- R/V *Sarmiento* towed a profiling sled with CTD & an ISSUS shadowgraph camera system
- RRS *Discovery* followed behind & targeted sampling based on real-time info from the Sarmiento
- In the subducting waters, there were elevated Chl, anomalous nutrient ratios, shallow microbial communities (via 16S) & very large (2-16 mm) aggregates



Johnson & Sosik - leads

Concluding Thoughts…

EXPORTS North Atlantic was successful (beyond our dreams…)

- Planning (eddy selection, situational awareness, governance, COVID) was critical
- Saw demise of a diatom bloom & enhancement of export as cruise went on
- Should be able to assess all 3 export pathways
- Focus now on interpreting physical oceanographic context (retentiveness of the eddy, entrainment from storms, etc.) and synthesis among observables

It wasn't cheap for one month of observation…

- 3 ships * 30 days * $50K/d = $4.5M
- ~10 science teams funded at $250K/y for 3 years = $7.5M
- Shipping, travel, data management, sample analysis, contingency, etc. = $1M?
- Lots of existing institutional hardware was deployed & recovered

And it takes a long time to get data analyzed & synthesized…