Vertical Mixing Rates from Autonomous Profiling Floats

902108 Scoping Project (1 year):

To evaluate and determine the feasibility of integrating microstructure sensors on MBARI's Coastal Profiling Float (CPF)

MBARI Team

Andrea Fassbender (PI) → Yui Takeshita
Magdalena Carranza (Lead Scientist)
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Ken Johnson (Scientist)
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Yanwu Zhang (Research Engineer)
Tom O'Reilly (Software Engineer)

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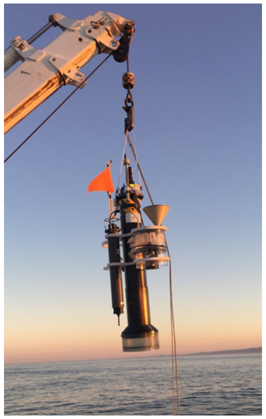
CPF



\+

MicroRider (RSI)

=

Outcome

concomitant vertical profile data of BGC properties + dissipation rates of turbulent kinetic energy, ε (z)

Potential External Collaborators

Judah Goldberg (RSI)
Peter Franks (SIO-UCSD)
Rob Pinkel (SIO-UCSD)
James Girton (APL-UW)

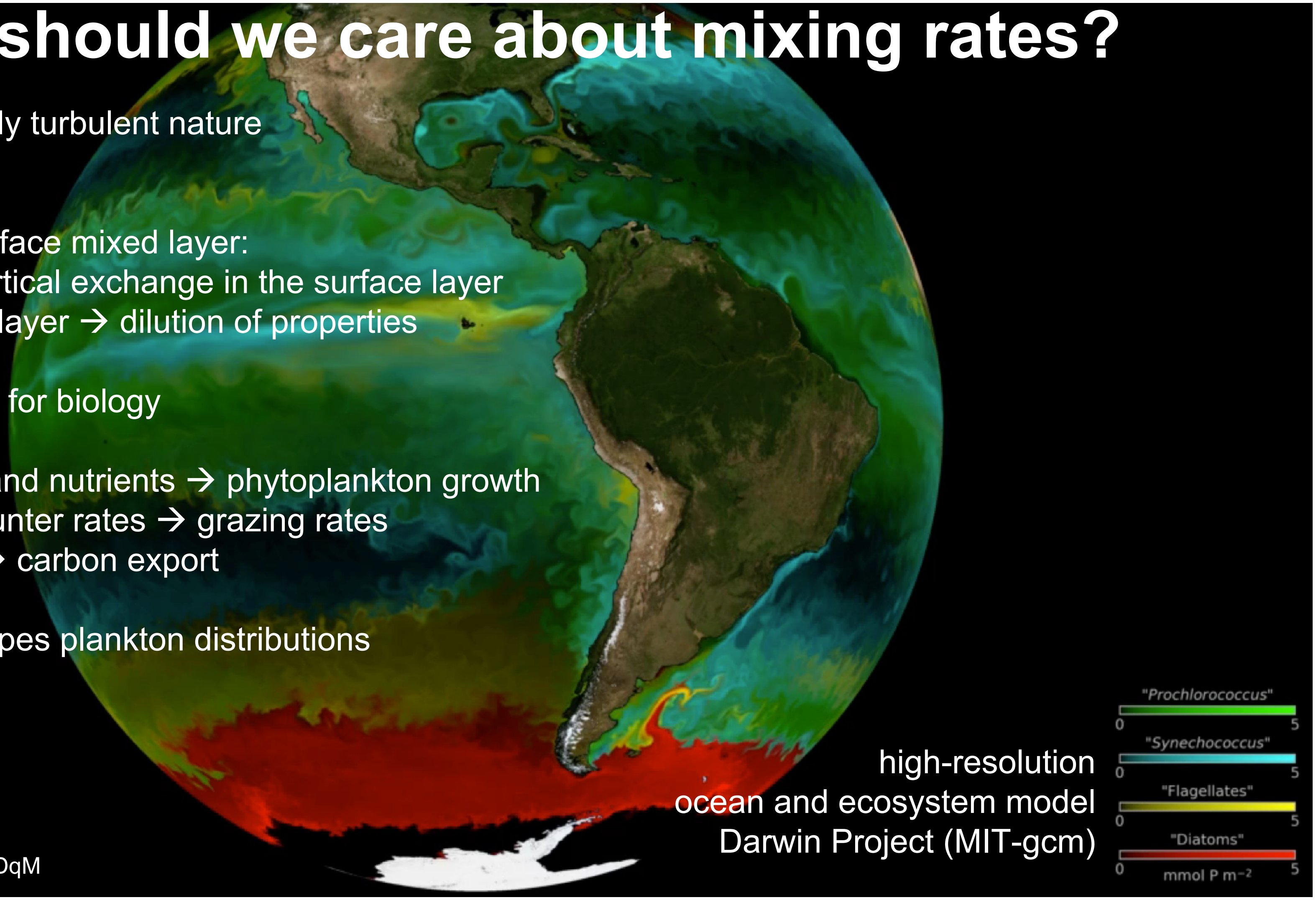
Why should we care about mixing rates?

e ocean's inherently turbulent nature

rbulence in the surface mixed layer:
najor forcing for vertical exchange in the surface layer
leepens the mixed layer → dilution of properties

rticularly important for biology
d biogeochemistry:
listribution of light and nutrients → phytoplankton growth
rey-predator encounter rates → grazing rates
ggregation rates → carbon export

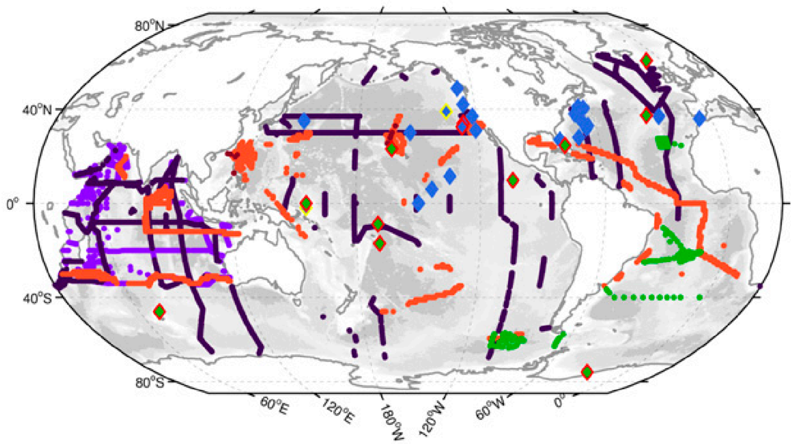
us, turbulence shapes plankton distributions



high-resolution
ocean and ecosystem model
Darwin Project (MIT-gcm)

tps://youtu.be/wAsNzQ2RDqM

The Fundamental Problem

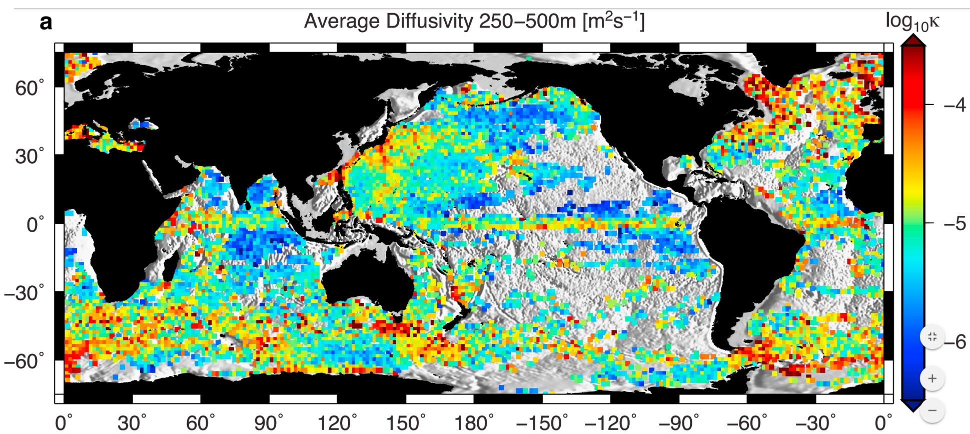


(c) Observations of mixing

- From microstructure measurements (◆, ◆) on Vertical Microstructure Profiler, VMP
- From acoustic measurements (◆, ◆)

→ very expensive, and thus sparse

Argo float data (fine-scale parameterizations):



Whalen et al. 2012, Waterhouse et al. 2014

Mixing rates in the top surface layer
or coastal oceans are hard !!!
from physical grounds

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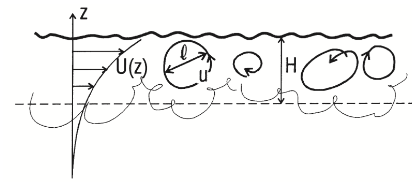
How do we quantify and measure vertical mixing rates?

Reynolds' Decomposition (mean + turbulent flow): $u = \overline{u} + u'$

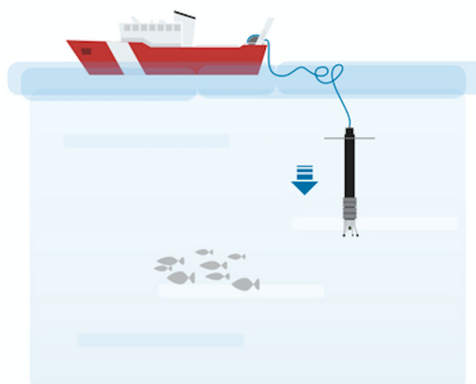


Turbulent fluxes of properties:

$$-\frac{\partial \overline{w'p'}}{\partial z} \sim \frac{\partial}{\partial z}(K_z \frac{\partial P}{\partial z})$$

- Turbulent eddy diffusivity, K_z (variable in time and space) times a vertical gradient dP/dz (in analogy to viscous diffusion)

Microstructure shear sensors (cm-scale) on Vertical Microstructure Profilers (VMPs)



Invoking "theory":

$$K_z = \frac{\Gamma}{\overline{N}^2}\epsilon \quad [m^2 s^{-1}]$$ *Osborn (1980)*

ϵ *dissipation rate (from microstructure obs)*

$\Gamma = 0.2$ *mixing coefficient*

$\overline{N}^2 \sim \frac{\partial \rho}{\partial z}$ *stratification*

Breaks in low stratification conditions (N~0), like the surface mixed layer!

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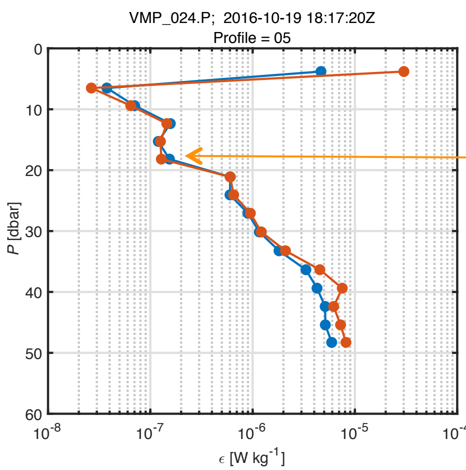
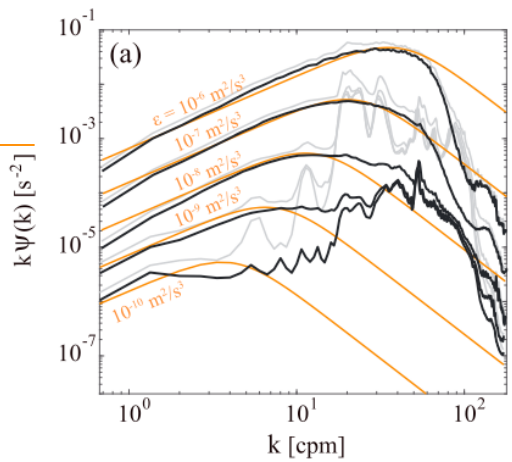


cm-scale u,v shear spectra



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Fisher et al. (2008)

Invoking "theory":

$$K_z = \frac{\Gamma}{\overline{N}^2}\epsilon \quad [m^2 s^{-1}]$$ *Osborn (1980)*

ϵ *dissipation rate*
(from microstructure obs)

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Breaks in low stratification conditions (N~0), like the surface mixed layer!

Scalability Assessment: Can we infer mixing rates in the upper-ocean from "coarse" resolution BGC float data?

Exploit the observation that biogeochemical tracer's distributions show vertical gradients within the mixed layer (i.e. homogenized in density) to infer vertical eddy diffusivities in the surface layer

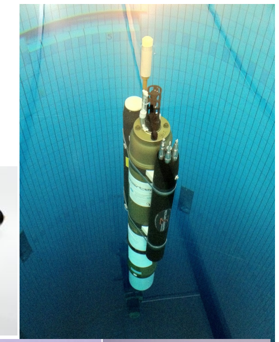
Tools and Approach

1. Phytoplankton production and nutrient demands → vertical diffusivities, Kz(z)
(*Eppley et al. 1979, King and Devol 1979, Lewis et al. 1986)*

2. Photo-adaptation principles/theory in a turbulent layer → bulk mixed-layer diffusivity Kz
(*Lewis et al. 1984a, 1984b, Cullen and Lewis 1984, Falkowski 1983)*

3. From vertical velocity variance (Large-eddy scales) → estimate dissipation rates → Kz(z)
(Gargett, et al. 1994, *Rudnick et al. 2013; Beaird et al. 2012)*

New Technology: Microstructure Sensors on Autonomous Platforms



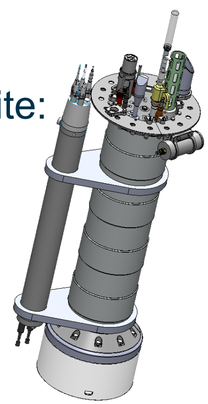
1. Microstructure sensor's Solutions from Rockland Scientific International (RSI):

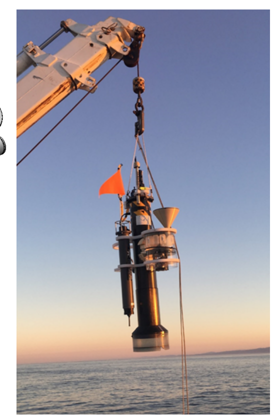
MicroRider Package (RSI):

✓ 2 shear probes, 2 fast-response thermistors (FP07s, or χ-pods)
✓ 2 vibrational sensors and inclinometer
✓ self-powered, self-logging → minimal engineering effort
✓ still expensive, but can be leased for a month (~13K)

2. MBARI's own Coastal Profiling Float (CPF)

✓ full control on profiling speeds
✓ higher payload capacity, full BGC sensor suite:
CTD, nitrate, bio-optics (FLBB),
radiometer (4 channel OR), pH and oxygen





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Strategy – Test Deployments

1) Integrate a MicroRider (full microstructure sensor package) on the CPF to evaluate:
   - float's behavior
   - quality turbulence signal (noise removal from additional sensors)

Perform stability tests of CPF-MicroRider in the tank
CPF float deployments and instrument recovery
(from R/V Paragon or R/V John Martin)

2) Evaluate the feasibility of full integration
   - Power & data telemetry integration
   - OEM Float Kit (in development by RSI for float manufacturers), would require significant engineering efforts

Scalability Assessment: Can we infer mixing rates in the upper-ocean from "coarse" resolution BGC float data?

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3. From vertical velocity variance → estimate dissipation rates → Kz(z)
   (*Rudnick et al. 2013; Beaird et al. 2012)*

Vertical velocities from glider's CTD data and steady flight model

- ✓ Merckelbach et al. (2010) for a Slocum glider
- ✓ Frajka-Williams (2011) for a Seaglider
- ✓ Rudnick et al. (2013) for a Spray glider

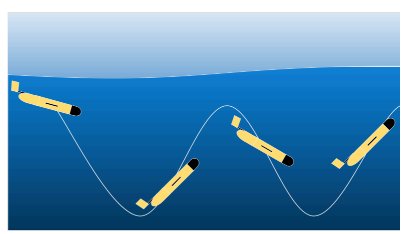
Basic assumption: $w = w_{ctd} - w_{steady}$

w → water vertical velocity

$$w_{ctd} = \frac{dp}{dt}$$

→ Low freq ~ flight
High freq ~ water motion

w_{steady} vertical velocity that the glider would have if going through still water



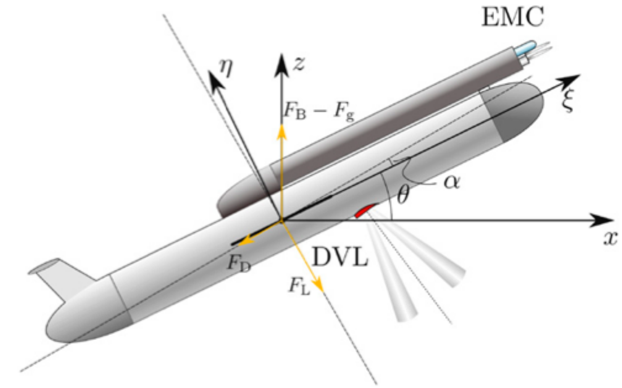


FIG. 1. Schematic representation of a glider, defining an orthogonal coordinate system with x and z axes, and an orthogonal glider referenced coordinate system (ξ, η). The latter originates from the former after a rotation of the pitch angle. The glider path (dashed line) makes a small angle, equal to the angle of attack, with the glider's principal axis, which coincides with the ξ axis. The forces resulting drag, lift, and net buoyancy are drawn by the yellow vectors. The positions of the EMC sensor and the DVL are in blue and red, respectively. The DVL is mounted such that the principal axis of the DVL (dashed) makes an 11° angle with the η axis.

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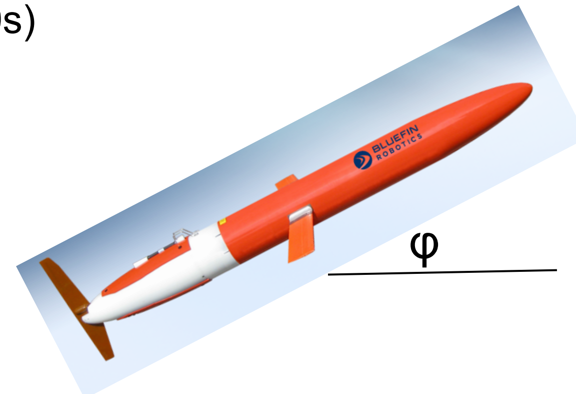
Vertical velocities from a Spray Glider

1) $w = w_{ctd} - w_{steady}$ from a steady flight model along the glider's path
+ additional filtering (to remove effects from model imperfections):
detrending (quadratic polyfit) + low-pass filtering (cutoff 100s)

Buoyancy ~ Drag

$$(\rho V - M) g \sin\varphi = \tfrac{1}{2} \rho A C_d q^2, \qquad q = \frac{w_{gw}}{\sin\varphi}$$

$$V = V_0[1 - \alpha p + \beta(T - T_0)] + V_b,$$



Solve for q: glider's velocity (along its path)

2) detrending (quadratic polyfit) + low-pass filtering (cutoff 100s) + high-pass filtering (cutoff 5400s)

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Rudnick et al. (2013), w from Spray Glider

Vertical velocities from a Spray Glider

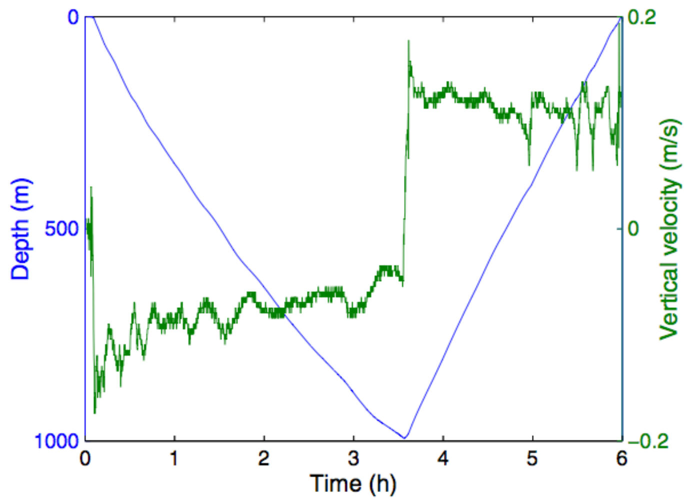


Figure 2. Depth and vertical velocity as a function of time for dive 100 of mission 074020. Note the small fluctuations in depth along the relatively smooth path. These fluctuations, caused by internal waves, are made more evident by calculation of vertical velocity.

RMSE for w ~ 0.005 m/s

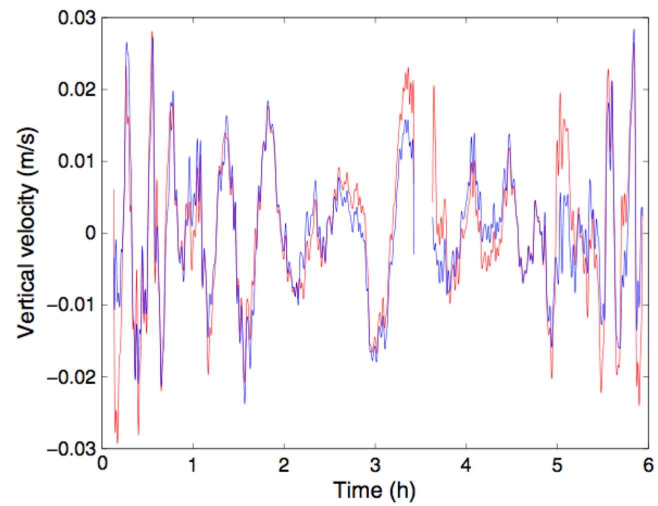
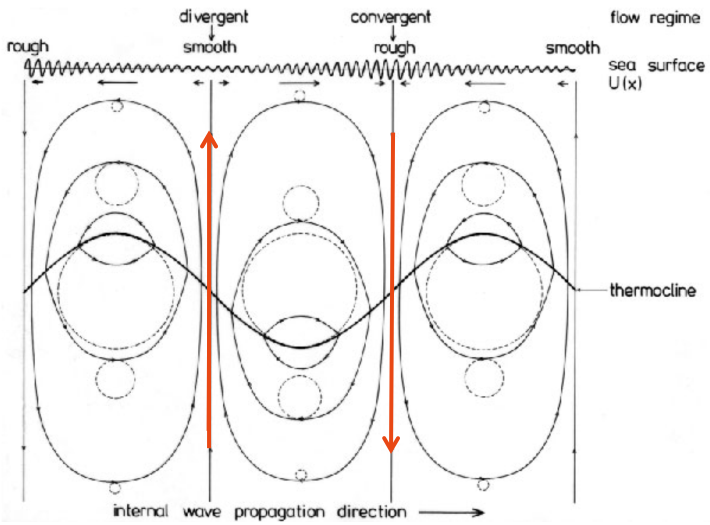


Figure 7. Vertical velocity derived from the model (blue, same as in Figure 6) and from a high-pass at 1/5400 Hz (red) for dive 100 of mission 074020. In each case, data have been detrended and low-passed at 0.01 Hz.

Rudnick et al. (2013), w from Spray Glider

Internal Wave induced vertical motion

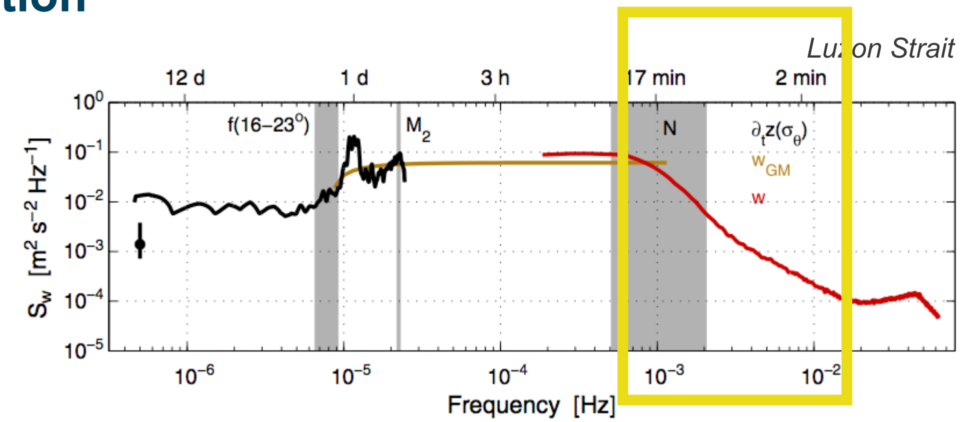
Orbital velocities



Inertial
T ~ h

$$\frac{1}{f} < freq < \frac{1}{N}$$

Buoyancy
T ~ min



Monterey Bay: T ~ 20 h – 15-50 min

Non linear waves: Solitons, internal bores

BREAKING internal waves → turbulent fluxes

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Dissipation rate estimates from w

Large Eddy Method (LEM):

$$\varepsilon \sim \frac{(q')^2}{\tau} \sim \frac{(q')^3}{l}, [\frac{m^2}{s^3}] \qquad K \sim q'l, [\frac{m^2}{s}]$$

q' velocity scale of the largest (energy-containing) eddies
τ time it takes to overturn once
l their length scale

For stratified flow, $l \sim L_{Oz} = N^{1/2}\epsilon^{3/2}$
(Ozmidov Scale)

$$e = c_\epsilon N(q')^2$$

c_ϵ calibration coefficient (determined from MR casts)
N buoyancy frequency/stratification

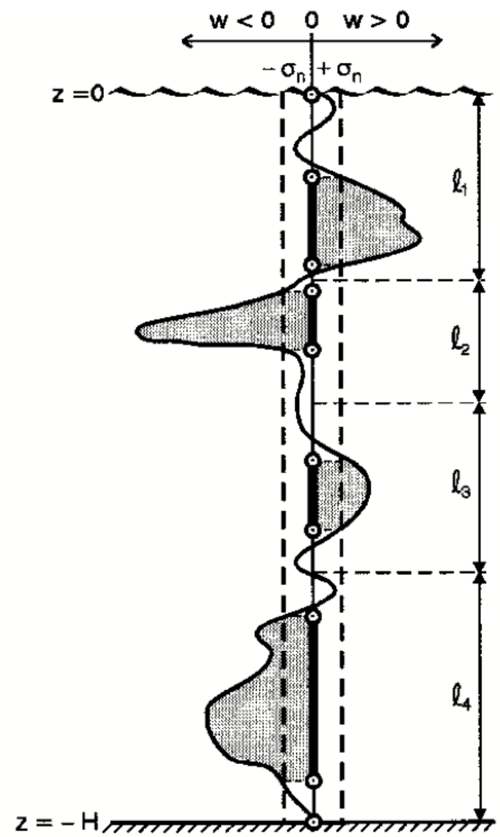

FIG. 6. Schematic of the zero crossing algorithm used for local determination of a (vertical) length scale associated with the large eddies of the turbulent velocity field. For discussion see text, section 3.

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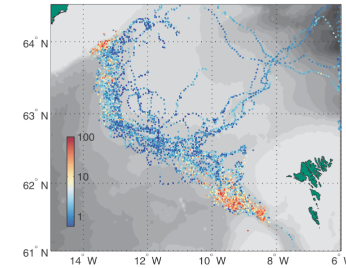
Following Beaird et al. 2012; Greene et al., 2015; Gargett (1994,1999)

Dissipation rate estimates from glider's CTD data



dissipation rates over the plume m^{-2}), from all Seaglider data.

Large Eddy Method (LEM):

$$\varepsilon \sim \frac{(q')^2}{\tau} \sim \frac{(q')^3}{l}\,.$$

q' velocity scale of the largest eddies

τ time it takes to overturn once

l their length scale

For stratified flow, $l \sim L_{Oz} = N^{1/2}\epsilon^{3/2}$
(Ozmidov Scale)

$$e = c_\epsilon N(q')^2$$

c_ϵ calibration coefficient

N buoyancy frequency

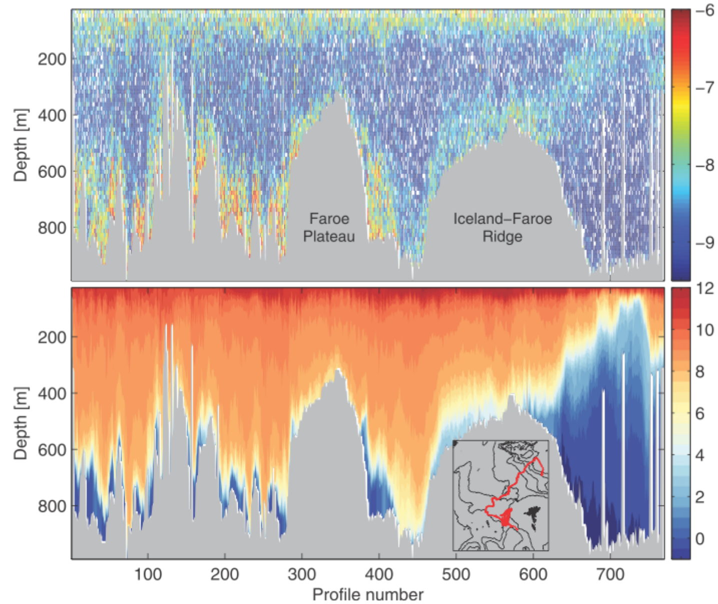


FIG. 9. (top) Depth vs profile number section of dissipation, $\log_{10}(e)$ [W kg^{-1}], from the entire sg005 deployment for which where each dive and climb is counted as a profile, and (bottom) corresponding temperature section (°C). Inset map shows the dive locations in red; the FBC dives may be seen in more detail in Fig. 2.

Following Beaird et al. 2012

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Dissipation rate estimates from vertical velocity variance: Glider Survey in MB

Large Eddy Method (LEM):

$$\varepsilon \sim \frac{(q')^2}{\tau} \sim \frac{(q')^3}{l}.$$

q' velocity scale of the largest eddies
τ time it takes to overturn once
l their length scale

For stratified flow, $l \sim L_{Oz} = N^{1/2}\epsilon^{3/2}$ (Ozmidov Scale)

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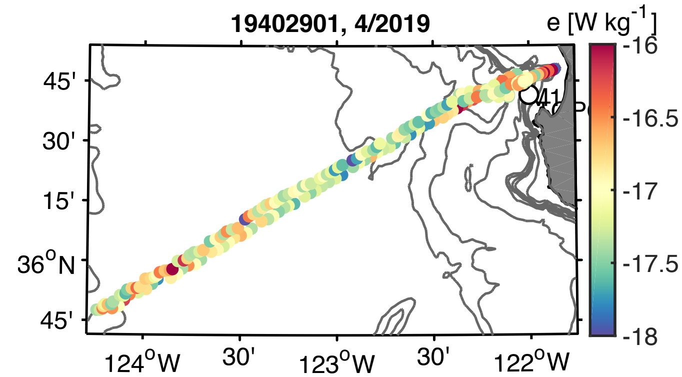

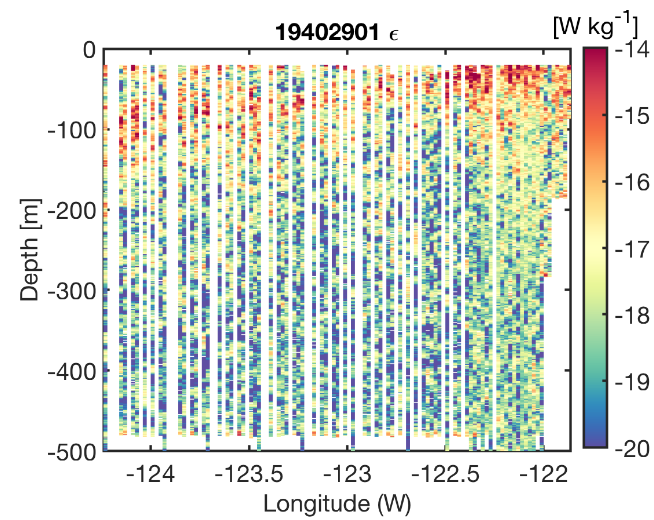

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Basic requirements for microstructure turbulence measurements

- Sensor placement (unperturbed flow, extremely fragile sensors)
- Platform moving smoothly, at profiling speeds ~ 0.2 - 1 m/s
  (Taylor's "frozen" turbulence hypothesis + freq response of the probe, $f = V * k$)
- Quiet platform: minimal mechanical vibrations & electronic noise
  in the dissipation range
- Angle of attack: +/- 10 deg

MicroRider-1000-WW Specifications

Dimensions: ~ 1m (w/probes)

Weight: 5.5 kg in air, ~0 kg in water

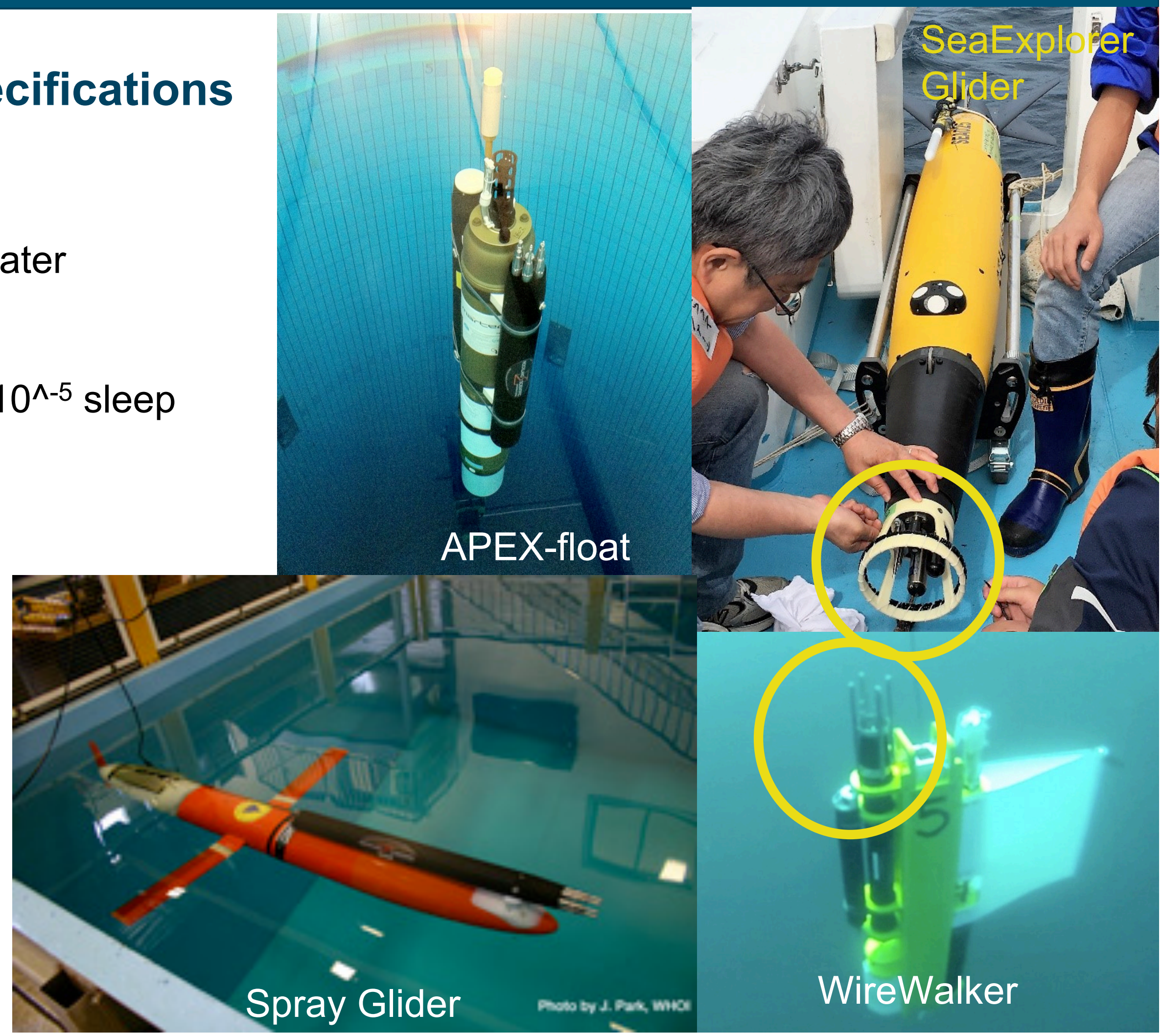
Power: 9-18 DVC supply,
Consumption ~ 1 W sampling, 10^$^{-5}$ sleep

Sampling rates:
Shear probes, 512 Hz
CTD, 64 Hz

Mode of Operation
(continuous vs cyclic sampling)

Data Storage ~ 64 GB

Outputs ~ 8192 bytes/s



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High-energy Battery Pack

Length: ~ 1 m (w/probes)

Weight: ~ 0 kg in water

14.8 VDC (Li-Ion), rechargeable

~ 48 hours of continuous sampling
(# of upcast profiles to ~ 200m depth?)

CPF

w_p ~ 0.4 m/s

Dynamic model

CTD + full set of BGC sensors (ISUS, bio-optics, transmisometer)

External battery power

Target depth/ sampling?

Mission length?

Drift vs anchored mode

Spray Gliders

w_p ~ 0.2 m/s (suboptimal)

Dynamic model/filtering

CTD + fluorescence + Oxygen, but no ISUS

Spray powered?

Targeted sampling, deep MLD

Longer Science Mission

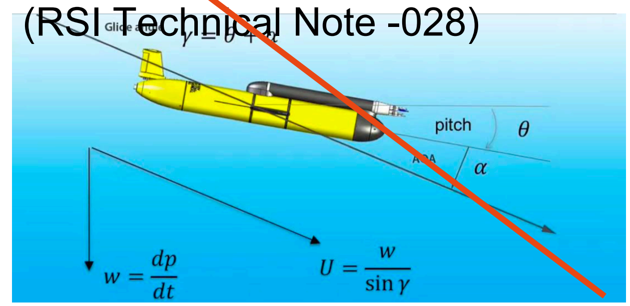
Minimize pitch/roll and buoyancy adjustments

Angle of attack : ~+/3 deg

Test deployments:
Minimize potential sources of vibrations & electronic noise

Stability can be compromised

Removal of coherent noise (RSI Technical Note -028)



Schematic, courtesy of RSI Technical Note-022

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Discussion

Platform (Plan A: CPF, Plan B: BOG-CPF, Plan C/Z!?: Spray glider, LRAUVs?)
(profiling speeds, sensors on board, range/recovery, targeted sampling, mission length)

Deployment Strategy
(eng lab/at-sea test deployments vs science missions)
get as many ε(z) profiles as possible, capturing the diurnal cycle

Deployment Sites
upper water column (target depth ~200m), ideally deep mixed layers

Timeline
Phytoplankton blooming season, spring/fall (not too stratified or strong upwelling)

Pre-MR arrival Tasks

- CPF readiness, buoyancy control adjustments? Output for w_water?

- Sensor placement
- Design brackets (MR and battery pack)
- Protective cage?
- Cables, connectors
- Tools

- Battery Power: # of profiles to 200m in cyclic mode, how long to fully recharge?

- ~~Data Telemetry?~~ (Evaluate/Discuss before May Proposal deadline)

- Go through the MicroRider-1000-WW Manual
- Instrument Communication protocols
- Familiarize with processing software: ODAS MATLAB Library and Zissou Essentials (Windows only)
- Data visualization and post-processing (VMP-250 Workshop Materials)
- Identification of mechanical noise & removal

Bench Tests

- Instrument communication
- RSI checklist

Tank Tests

ideally,
2 weeks max

- Float's stability
- Optimal profiling speed
- Consistent angle of attack
- Vibrations & electronic noise
- Clock's syncing for cyclic sampling

At-sea engineering tests

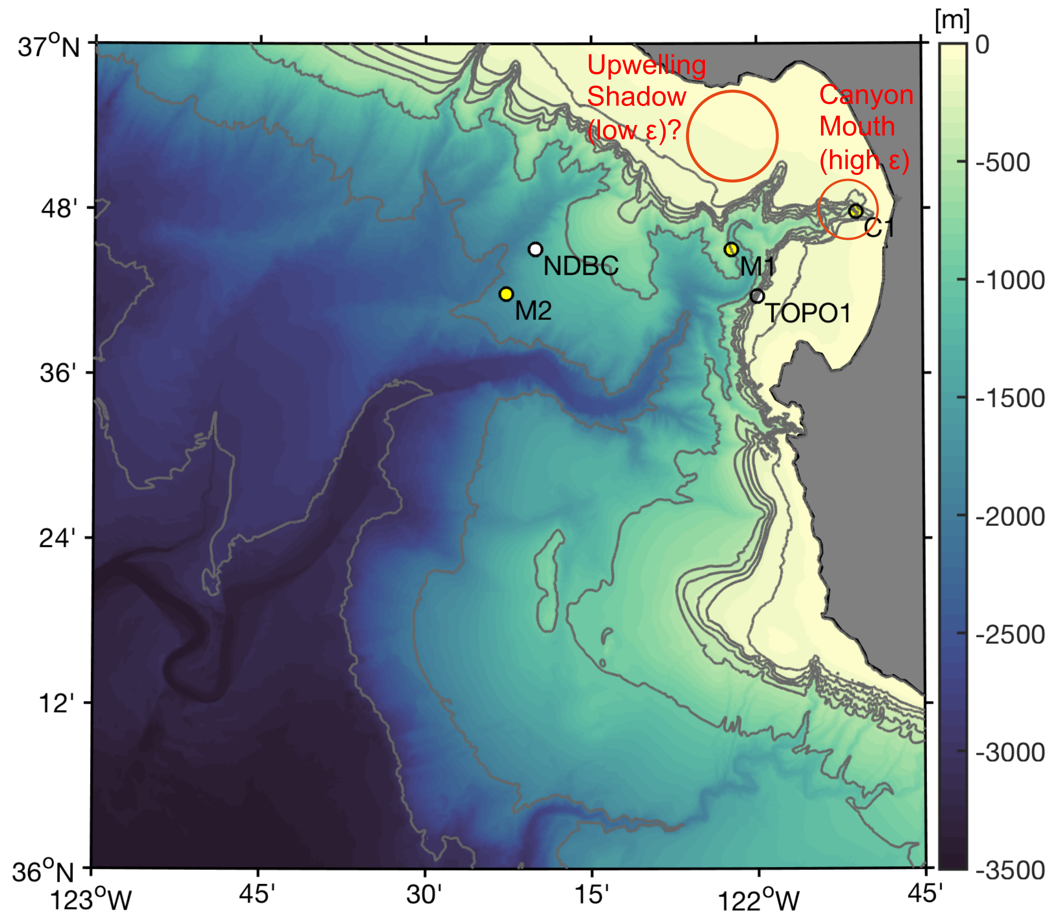
- Deploy nearby, within the canyon axis for 2 days
  (recover to ensure data acquisition, data quality)
- Recharge battery overnight, redeploy the next day for 2 days

Science Missions (2 weeks)

- Gather as many $\varepsilon(z)$ profiles as possible, 1-2 week deployments (MR battery-power dependent)
- As many BGC sensors as possible (optics, radiometer, isus would be a plus)
- Target depth ~200 m
- Capture the diurnal cycle (~ 1 profile every 1-2h)
- Phytoplankton blooming season, spring/fall when mixed layers can be deep (storms)
- High and low turbulence environments (e.g. Canyon axis and @ or past M1)
- CPF: “drift” vs “anchoring” mode?

Timeline MR Lease for ONE month

April	Spring CANON cruise
May	
June	Original Target Date (CPF)
July	
Aug	
Sep	
Oct	Fall CANON cruise
Nov	
Dec	



/atlas.shore.mbari.org/ProjectLibrary/Mixing Rates – 902108
/Rockland_VMP-250 : Workshop Materials

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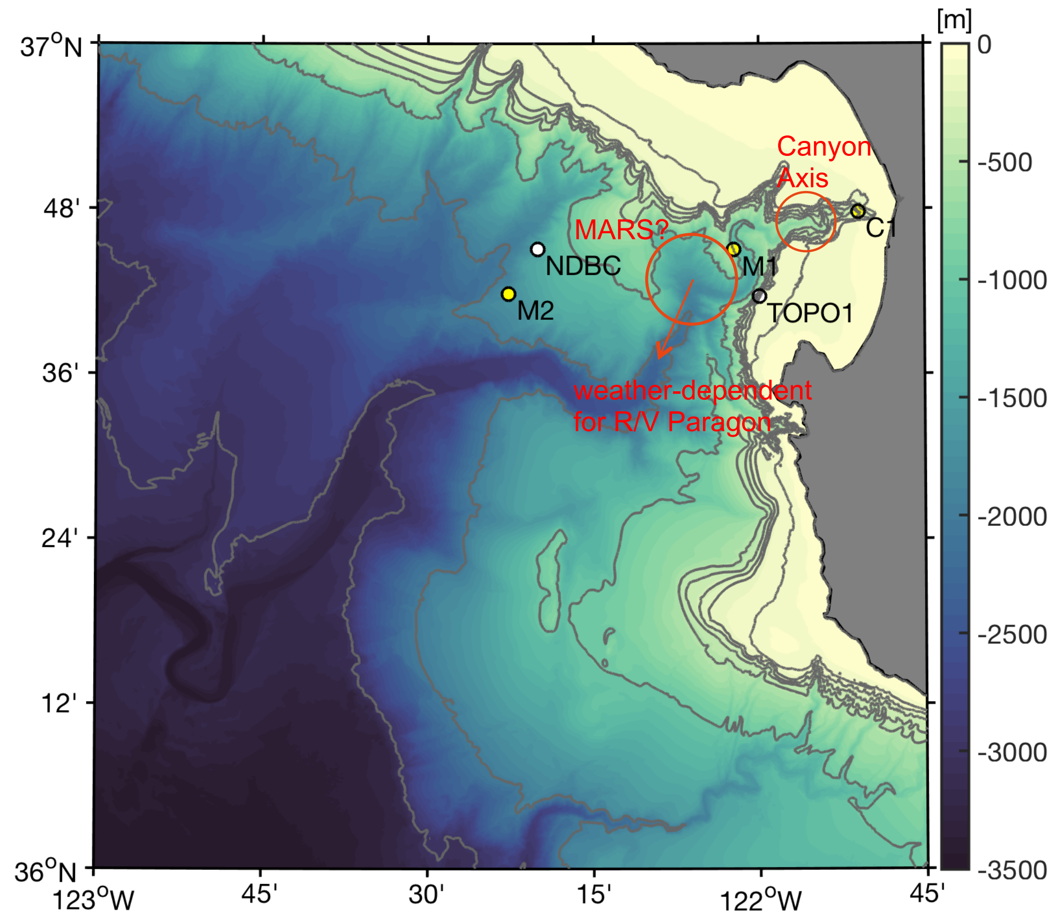
Tasks TO DO
to meet June deadline

Feb Mar	CPF Buoyancy control adjustments?
April	brackets?
May	protective cage?
June	Target for Deployments (CPF)
…	
Oct	
Nov	
Dec	



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