Exploring Ocean Iron Solutions- fieldwork planning workshop report out
May 29-31 at WHOI

Participants

Small invited group

*Note that participants contributed to ideas to draft an implementation plan as outlined in Paths Forward report and are **not** necessarily PI's for eventual fieldwork*

In-person: *K. Buesseler, F. Chai, J. Cullen, M. Estapa, M. Honda, D. McGillicuddy, P. Morris, M. Omand, D. Siegel, S. Smith, Y. Takeshita, B. Twining, M. Wells, A. White*

Remote: *P. Boyd, S. John, J. Nishioka*

Funding from the Astera Institute for travel/logistics and WHOI for the meeting facilities

ASTERA INSTITUTE

WOODS HOLE OCEANOGRAPHIC INSTITUTION

ExOIS field planning workshop

Workshop objective

To develop a structure for what the first fieldwork deployment will look like, and to formulate a roadmap and work plan for launching a series of pilot studies, under different levels of funding.

ExOIS overall objective

To conduct research to evaluate if OIF is an efficient and responsible approach to reducing atmospheric CO_2. *And if so*, provide research results that enable society to conduct OIF at scale.

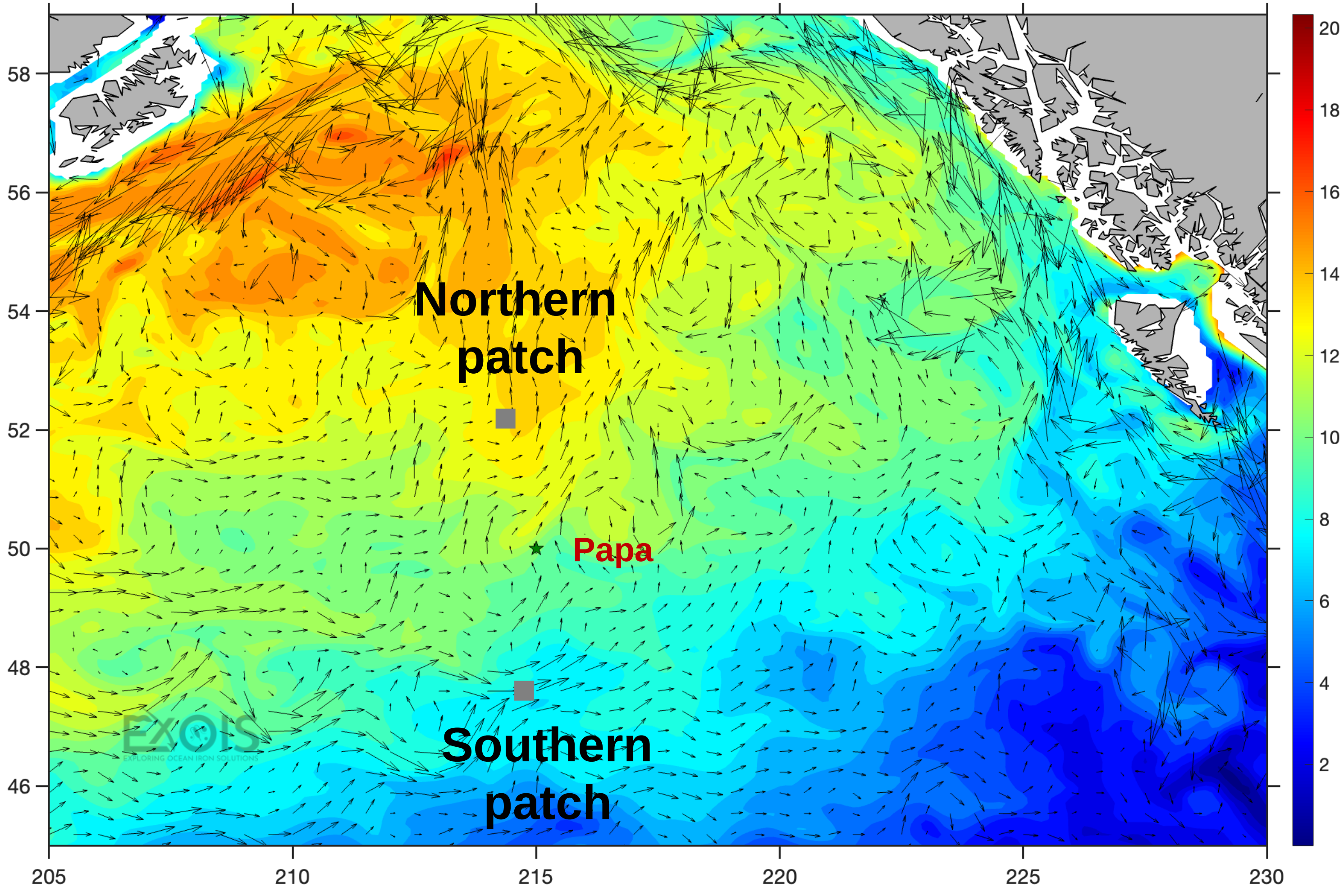
ExOIS overall aim (outcome)

To provide an open-source description of the protocols that would be needed for the implementation of at-scale OIF implementation

Priorities for first field experiment in the NE Pacific *(set ahead of workshop)*

- ✓ Create and track a coherent and large bloom
- ✓ Track export and fate of the additional particulate C to at least 100 yr (500 m) scales, and over months/season
- ✓ Assess surface DIC drawdown with observations and track with models air/sea exchange
- ✓ Document ecosystem and environmental impacts (eMRV)
- ✓ Use the observations made during the field experiment to assess MRV technologies and to develop and validate MRV model
- ✓ Use the field data (obs and models) to assess scalability, costs, and with models, regional and climate impacts
- ✓ Learn from the field study to design future studies to maximize mCDR potential, evaluate variability and reduce costs at this site and other regions

ROMS – CoSINE
Mean NO_3 (0-50 m) and mean current in July



Experiment setups:

Season

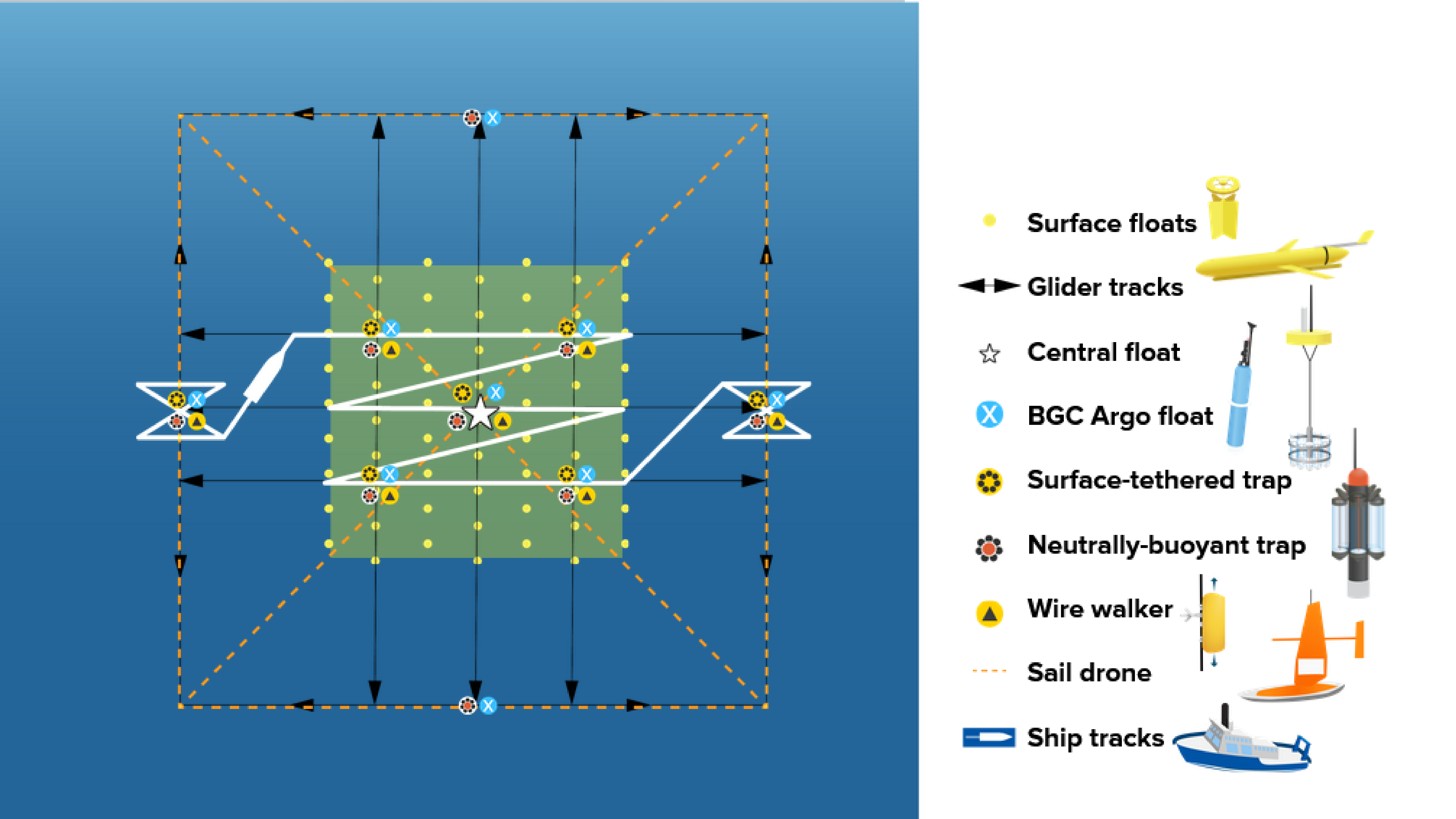
- Starting from July 1
- Continuous release for 10 days

Size

- Four cases: 10 km x 10 km, 30 km x 30 km, 50 km x 50 km, 100 km x 100 km
- Add Fe to the upper 5 meters
- both south & north of station Papa

Iron amount

- Total **25 ton** of FeSo4 7H2O (about 5 t of Fe) for the *50km patch*, (~daily added Fe concentration would be 0.72 nM/day; constant injection flux)
- Total **1 ton** of FeSo4 7H2O (about 0.2 t of Fe) for the *10km patch*, (~daily added Fe concentration would be 0.72 nM/day; constant injection flux)


Surface floats
Glider tracks
Central float
BGC Argo float
Surface-tethered trap
Neutrally-buoyant trap
Wire walker
Sail drone
Ship tracks

Discussion today on ***selected*** workshop topics

1. **Modeling in support of field trials**
2. **Core measurements/parameters** (general and particle fate)- ***Ben Twining***
3. **Observations for eMRV**
4. **Go/no-go criteria**- ***Sarah Smith***
5. **International collaborations-** ***Paul Morris***
6. **Patch tracking and field plan** (including Fe delivery)
7. **Resources needed**
8. **Next steps to action**

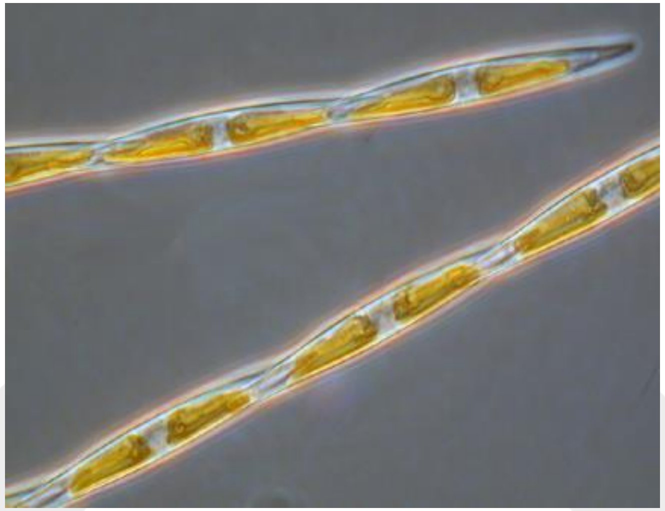
Core measurements/parameters

Some key questions/ideas that were considered:

- Key measurements that were integral in past studies
- Is an overall carbon budget / characterization of carbon fluxes that don't reach the "100-year horizon" necessary? *No. Focus on gravitational and migrant fluxes*
- Need to measure fate of trace metals, as well as carbon (& N, P, bSi)
- Coarse prioritization of parameters and methods
  - Priority 1 = Minimum viable plan – measurements needed to achieve project priorities 1,2,3
  - Priority 2 = Needed to develop models and predictions beyond the direct observation (all project priorities)
  - Priority 3 = Would be nice (for scientific completeness)

List of eMRV concerns

1. Harmful algal blooms (Domoic Acid production)
2. Hypoxia (or "deoxygenation")
3. Nutrient Robbing/Redistribution
4. Generalised concern about impact on **fisheries**
5. Impacts on higher trophic levels, including things like:
    a. Food web restructuring (changes to all biota - inc. pelagic ocean microbiome)
    b. Impacts on whales and birds
    c. Benthic communities
6. Greenhouse gases produced in the water column and emitted to the atmosphere (N_2O, CH_4), and production of other climate-relevant gases like DMS



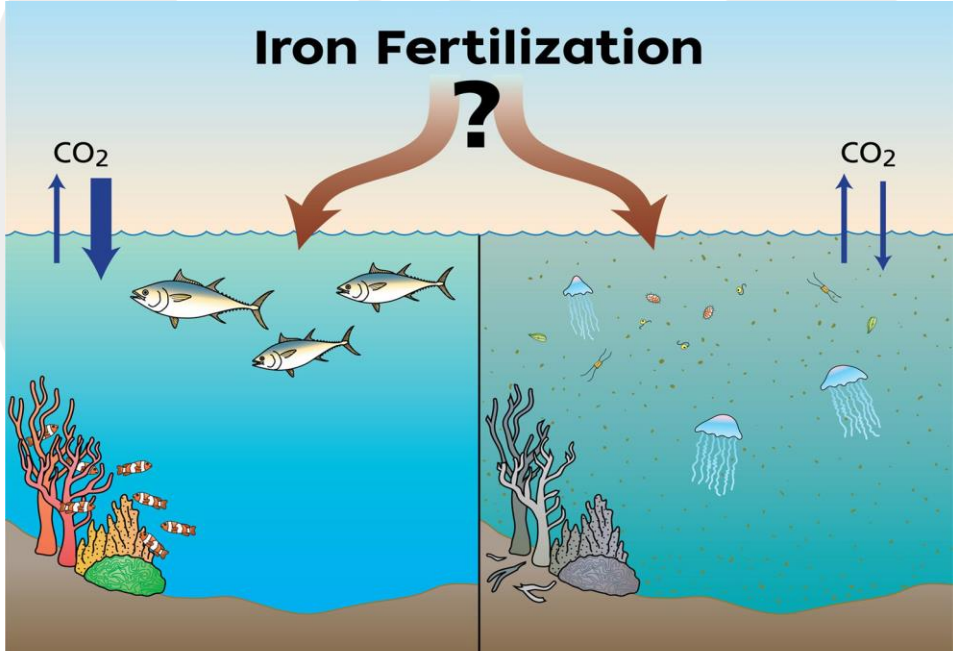


Illustration by Jack Cook, ©Woods Hole Oceanographic Institution

Group	Parameter	Method	Platform *depth*
SHIP-BASED			
A	T,S,Chl F, O2, NO3, BBP, PAR	Ship's underway mounted se	shipUW
A	Fv/Fm indication of physiology	FV/FM underway	shipUW
A	Particle absorption and attenuation - acs	absorption/attenuation/backs	shipUW
A	Plankton Imaging (pico-nano) underway	plankton imaging (PSD, ID, a	shipUW
A	pCO2	pCO2	shipUW
A,C	T,S,Chl F, O2, NO3, BBP, PAR	Rosette mounted sensors, C	ship
A-B	Large particle PSD & Plankton Imaging (Phyto-Zoo)	UVP	ship
C	N2O gas	Rosette Niskin	ship
A,C	Nutrients (NO3, NO2, SiON, PO4)	water samples	ship
A-B	Iron (dissolved and particulate)	TMC rosette	ship
A-C	Particle concentration (Chl, POC, PON, PIC, bSi, POP)	Bottle filter	ship
A, C	Pigment suites - Chl	water samples	ship
A	Carbonate system	water samples (pH, DIC, TA)	ship
A	Physics- Currents	ADCP	ship
B	Sinking and migrant POC fluxes	234Th	ship
C	Particulate Domoic Acid PP	ELISA	ship
C	eDNA - community composition	Particulate DNA/RNA Filters	ship
AUTONOMOUS PLATFORMS SUPPORTED BY SHIP DURING CRUISE			
A	Lagrangian Following Drifters	patch COM location, dispersi	drifters
B	Gravitational C, N, P flux and remineralization profiles	trap	drift moorin
B	Sinking particle characteristics	gel trap	drift moorin
B	Gravitational C, N, P flux and remineralization profiles	trap	autonomou
AUTONOMOUS PLATFORMS DEPLOYED BEYOND CRUISE			
A-B	Glider: T,S,F,O2,BBP, PAR, currents	Glider mounted sensors, calit	glider
A	Glider: NO3	Glider mounted sensors, calit	glider
A-C	Floats + remin fluxes: T,S,F,O2, NO3, BBP, PAR, pH	Variety of sensors	float
A	waveglider sensors	pCO2	waveglider
MULTIPLE PLATFORMS			
A	Air-sea fluxes	meteorological obs	multiple
SATELLITE REMOTE SENSING			
A	SSH, geostrophic velocity, FTLEs	merged altimetry	satellite
A	Chl, BBP, PhytoGroups, Fluor	Ocean color	satellite
A	SST	Infrared	satellite
A	SST	Microwave	satellite

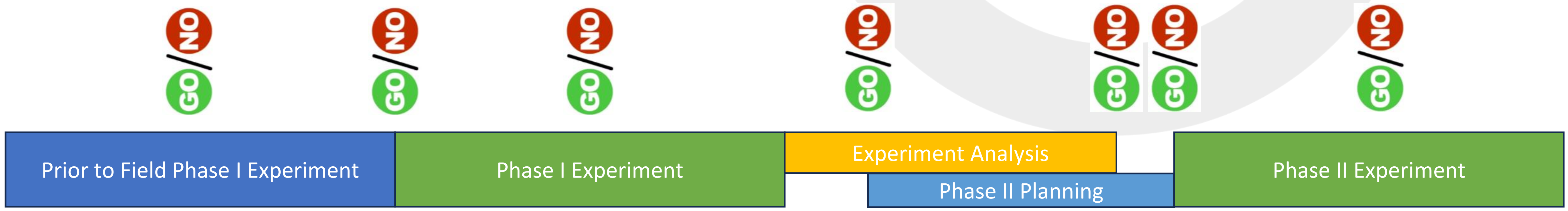
Core measurements/parameters MRV and eMRV

"Minimum viable plan 1" (=priority 1)

- Platforms required: ships, ship-supported autonomous platforms, long-lived autonomous platforms, and satellites
- Many measurements spanned multiple discussion areas

Go/No-go criteria

- Project “Go/No-Go” points come out of lexicon used by some funding agencies (DOE for example) and can represent points early on in project funding, and at the mid-way for project funding
    - Designating situation in which one must decide whether or not to continue with a particular course of action, or the moment when such a decision must be made.
- Go/No-Go criteria considered for ExOIS pilot experiments and whether one recommends future OIF work broadly
    - What are the go/no-go criteria for the experiment
    - What are the go/no-go criteria to move to Phase II



Some Go/No-Go Considerations Identified

Milestones that we define for ourselves in advance of fieldwork

- Environmental Harm (EPA CDR thresholds exceeded – no-go)
  - Domoic acid thresholds exceeded
  - Toxic heavy metal thresholds (if trace metals other than Fe used to track patch, or if contaminants are present)
  - GHG production
  - Oxygen depletion
- Lack of social license established (?)
  - Requirement for public input and engagement before, in between, and after experiments working *towards* social license through open sharing of outcomes
- Development of an Open Data Policy
- Require standards of success (clearly define what a successful experiment would look like)
  - Measured, additional export quantified to a satisfactorily constrained level of confidence
  - Minimized ecological harm
  - Life-cycle assessment of the technology at scale (hard) vs. the C footprint of the pilot experiment (more tractable)

International collaboration

- Formalizing international collaborators
    - USA, Canada, Japan, China, Europe, Australia/NZ.....
    - International collaboration for science sampling platforms (ships, gliders, floats etc.)

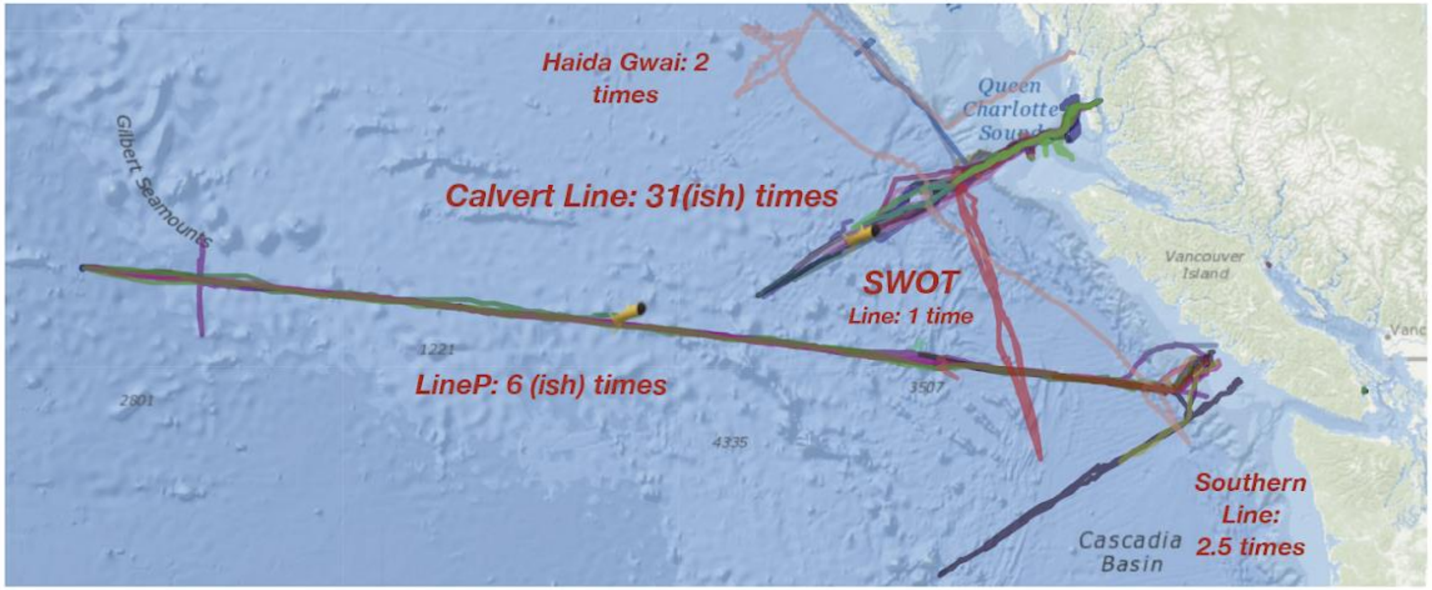
Some examples of ship plans for NE Pacific 2026

- Japan: Jun Nishioka, M. Honda- proposal submitted for use of R/V Hakuho-Maru in 2026-2028. Kazutaka Takahasi (biological oceanographer lead The Univ. Tokyo). First priority July-Aug 2026
- China: Fei Chai, M. Dai- R/V Tan Kah Kee – Xiamen University, China, ship time funds needed, personnel would be available
- US: submit UNOLS ship time request?

Canada: CCGS Tully, Dept of Fisheries and Ocean run a program with 3 trips per year (Feb, May, Sept) of roughly 16 days each. Scheduling happens in March/April each year

- CCGS Sir Wilfrid Laurier, Great circle Vancouver to Dutch Harbor, north in July and south in October

C-PROOF: *Canadian-Pacific Robotic Ocean Observing Facility*



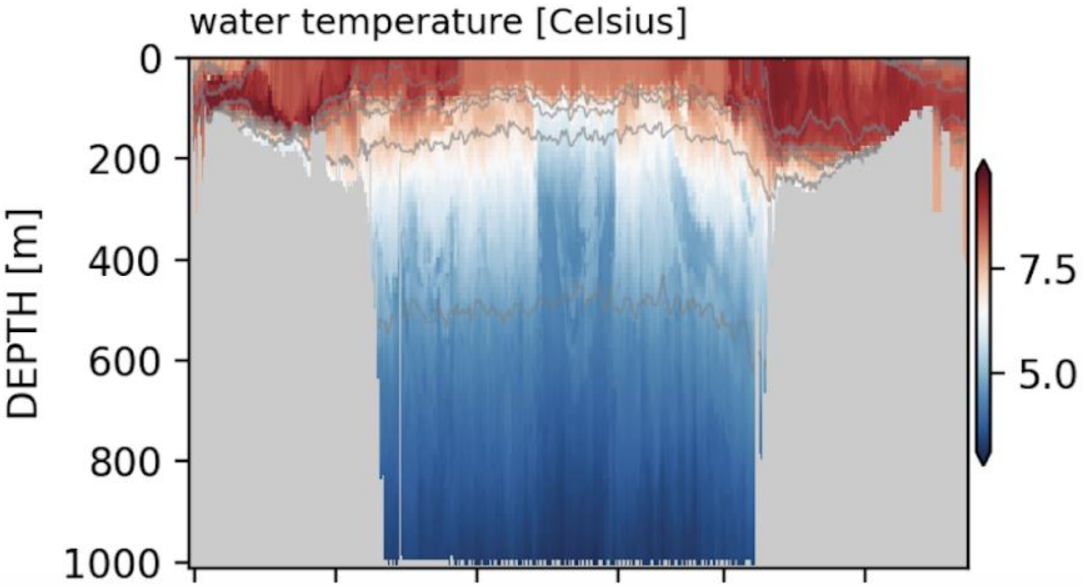
Fisheries and Oceans Canada

Hakai
Science on the Coastal Margin

TELEDYNE MARINE
Everywhereyoulook

ROCKLAND SCIENTIFIC

C-PROOF



- Essential Data:
  - 12 Gliders and >20 Floats: temperature, salinity, oxygen, chlorophyll.
  - Goals: Improved weather and seasonal forecasting, ecosystem health
- Big Data:
  - 58 glider missions since 2019
  - 56,854 km; 62,463 CTD casts; 1782 glider days at sea
- Open Data:
  - Realtime locally: https://cproof.uvic.ca
  - Internationally: Global Telemetry System; International Ocean Observing System; Coriolis Operational Oceanography (EGU)

International collaboration

- What programs are we missing?
- Who else should ExOIS be talking to?
- Ships of opportunity