
# NE Pacific Experimental Plan of the Moment

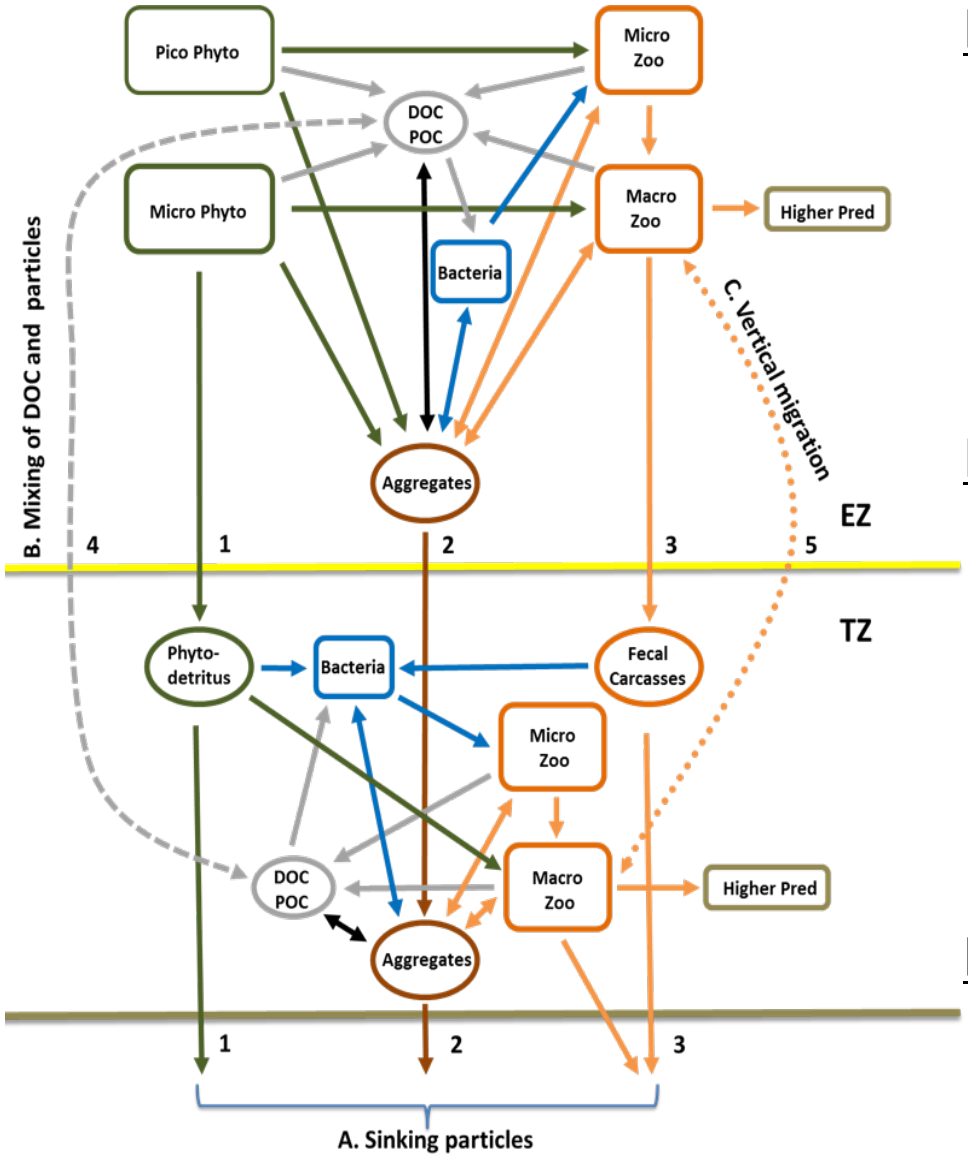
June 12, 2018

# EXPORTS Goal & Rationale

Goal: Predict the export, fates & C cycle impacts of ocean NPP from satellite (& other) observations

- Advances in remote sensing, genomics, in situ imaging & autonomous tools make achieving this goal possible
- EXPORTS' focus is on export pathways & NPP fates over different ecosystem states
- Emphasize a predictive understanding by measuring & modeling regulating processes

# EXPORTS' Focus on Pathways




## Export from the Euphotic Zone

A: Sinking particles: 5-8 PgC $y^{-1}$

B: DOC/POC export: ~2 PgC $y^{-1}$

C: Vertical migration: ~1 PgC $y^{-1}$

Predictive skill remains poor

## Flux Attenuation in the Mesopelagic

Helps set global C sequestration

Disagreement over global patterns in remineralization depth scales

Observed imbalance between flux attenuation & mesopelagic C demand

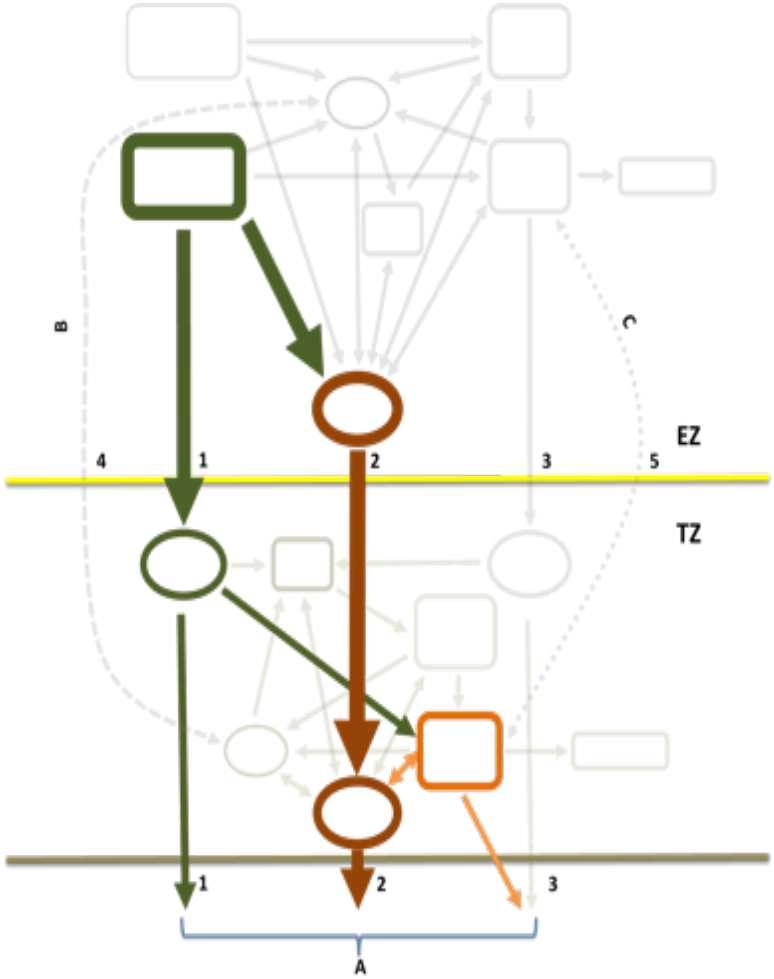
## Need a Predictive Understanding

Focus on mechanism

Requires observations over a range of "states" for model building

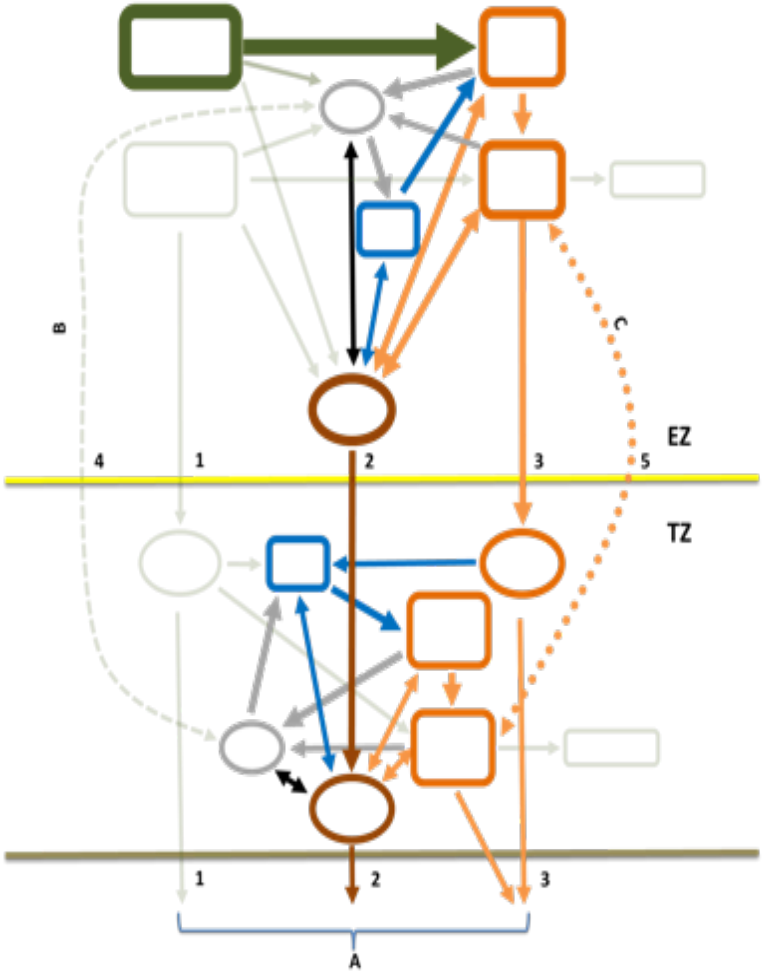
# Pathways for Different States

North Atlantic Bloom




Large phytoplankton
Big export from the EZ
Weak flux attenuation in TZ

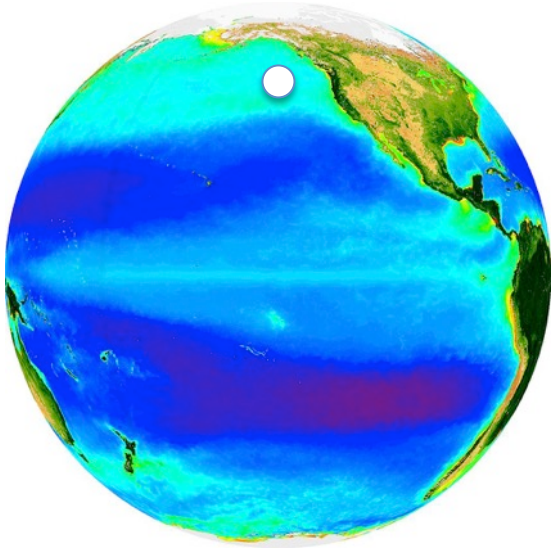
Summer Subarctic North Pacific

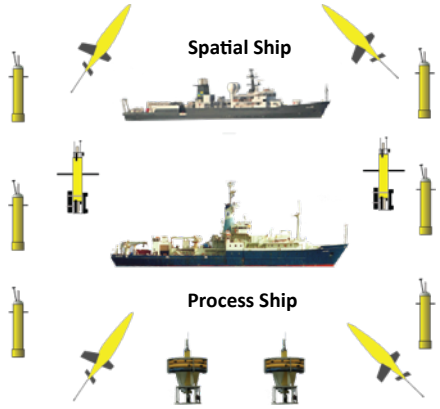



Small phytoplankton
Weak export from the EZ
Strong flux attenuation in TZ

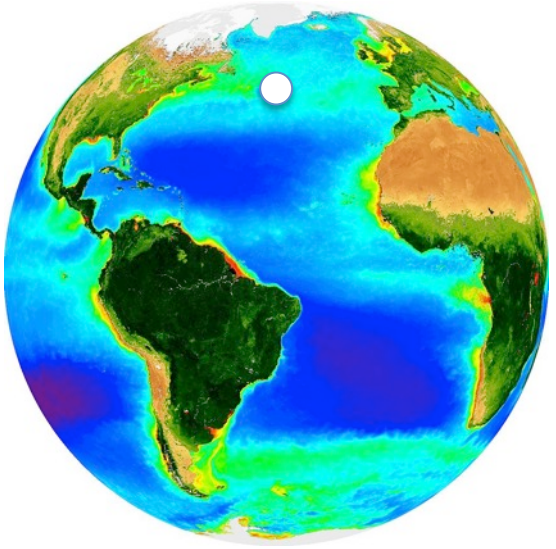
# High Level View

## Station P






## NAtlantic



**Cruise**: Aug/Sep 2018
**Duration**: 27d @ site
**Leverage**: Line P & OOI

**Cruise**: Mar/Apr, 2020
**Duration**: ~35d @ site
**Leverage**: internationals…

Will collect ~7 ecosystem / C cycling states

**Also data mining previous work** (ROSES 2015!!)

# High Level View

**Water-Following**
follow instrumented Lagrangian float

**Particle-Following**
from production to trap
Measure C cycling fluxes from 0 to 500 m (over ~8d)

**Process Ship**
Measure rates & stocks, deploy &recover traps, *in situ* cameras and zoop nets

**Survey Ship**
Meso-scale CTD & UW flow-thru surveys (1-200 km)
Large volume particle pumps

**Long Term Presence**
**Profiling Floats & Satellites**
BioARGO & optical export fluxes
**BGC fluxes via mass budgets**
$O_2$, $NO_3$, DOC, DIC, etc.

**Optimize Spatial Sampling**
**Gliders** surveying (1-200 km)
Bio-optical proxies
**Satellite** algorithm development
C cycling models for PACE

# Where are we?

- Team selected (12 NASA; 3 NSF; 43 PIs in total)
- Held 3 Science Team Meetings

  Sept 2017, 1 day before OSM and May 2018
- Planning for first cruise to Station P

  Aug10 to Sept 14 – Revelle & Ride – Seattle/Seattle
- Need to complete planning documents

  Platform (process & survey ships & AUV)

  Parameter (measurement protocols)

  Situational awareness (coordination while at sea)

  Data management (metadata, sample ID, etc.)

# EXPORTS Science Team

Plus Phoebe Lam (UCSC), Jong-Mi Lee (UCSC) & Olivier Marchal (WHOI)!!

# Funded NASA EXPORTS Projects

- Behrenfeld – Phyto stocks, type & rates w/ links to RS & export (coPIs - Boss, Karp-Boss, Guidi, Graff & Halsay)
- Buesseler – Export via $^{234}$Th (coPIs – Benitez-Nelson & Resplandy)
- Carlson – DOC cycling & export (coPI – Hansell)
- Estapa – Sinking particle export (coPIs – Buesseler, Durkin & Omand)
- Lee – Robotic observations of export processes (coPIs d'Asaro, Nicholson, Omand, Perry & Thompson)
- Marchetti – Phyto / prok rates & taxa & links to NCP (coPIs – Gifford & Cassar)
- Menden-Deuer – grazing on phyto (coPI – Rynearson)

# Funded NASA EXPORTS Projects

- Roesler – PFT optics (coPI Sosik)
- Santoro – RESPIRE traps & N remin (coPI Boyd)
- Siegel – PSD dynamics, export & remote sensing (coPIs Burd, McDonnell, Nelson & Passow)
- Steinberg – Zoop & active C transport (coPI Maas)
- Zhang – Optics, PSD & export (coPIs Gray, Guidi & Huot)

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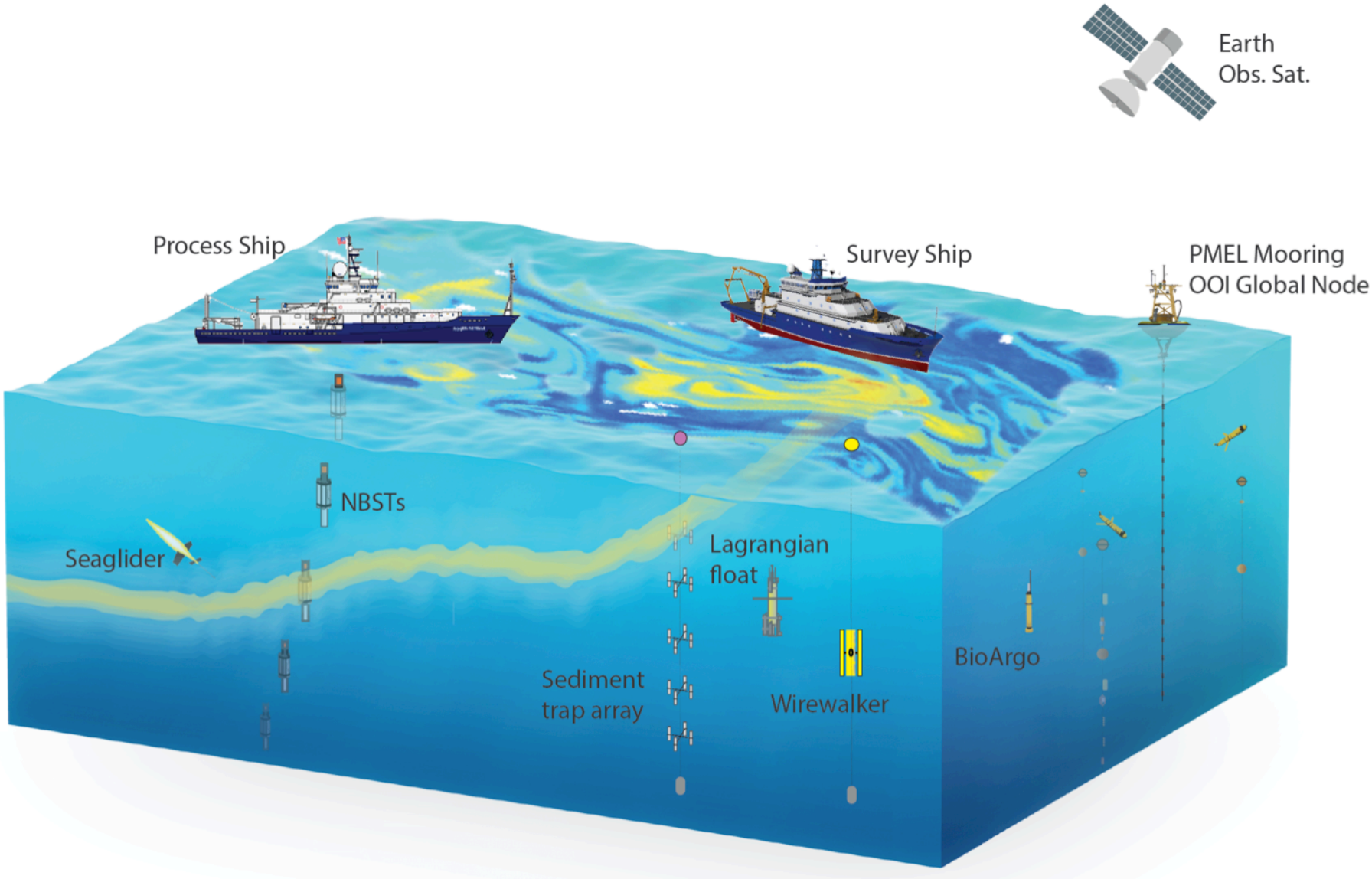
- Siegel – EXPORTS Science Lead
- Cetinic – EXPORTS Project Scientist
- UCSB Hydro– Basic obs (Nuts, POC, Chl, HPLC, BSi, etc.)
- NASA GSFC – Data management & field support
- NASA ESPO – Field logistics support

# Funded NSF EXPORTS Projects

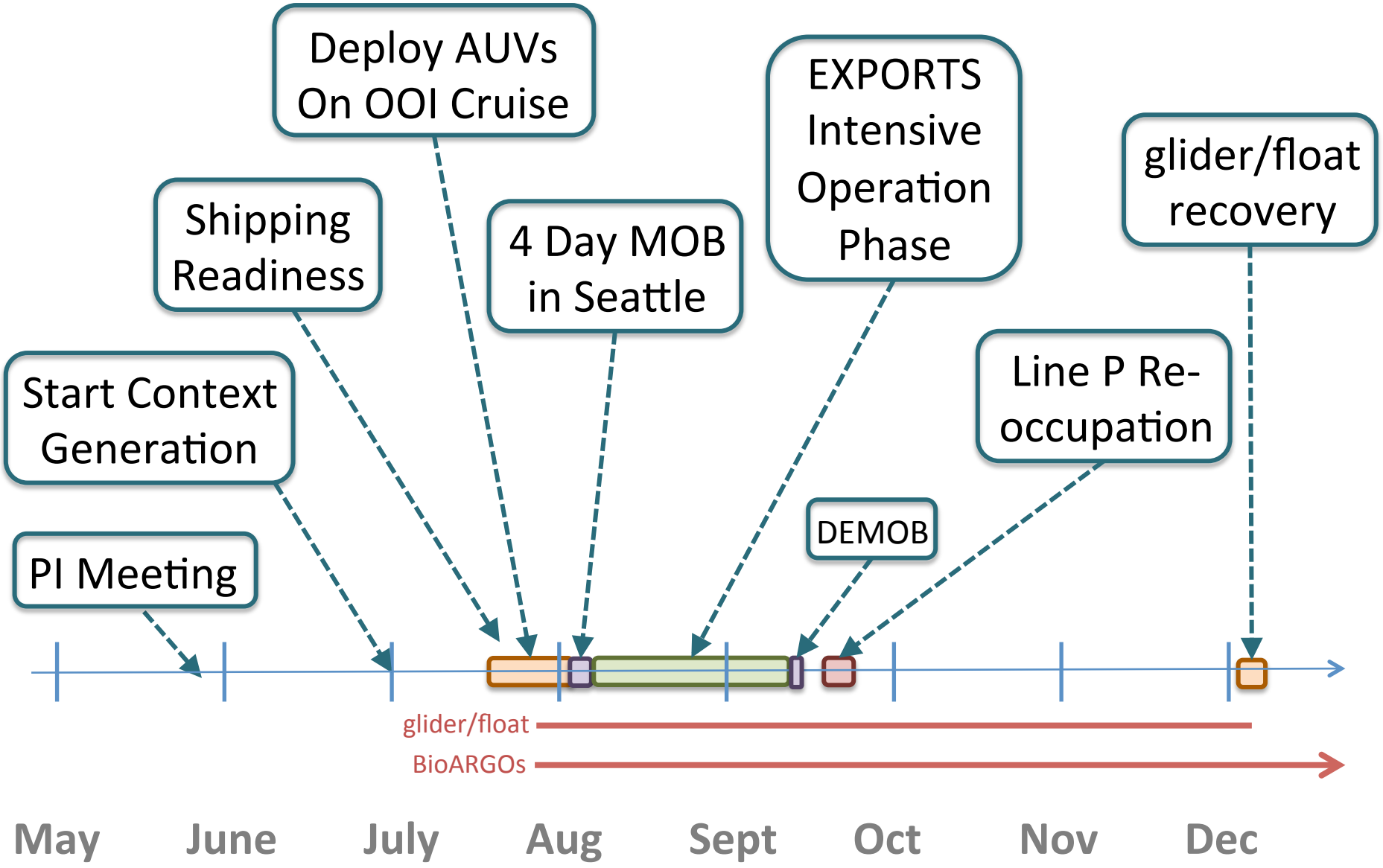
- Fassbender – Multi-year BioARGO profiling observations at Station P
- Jenkins – Diatom growth dynamics & affects on biogeochemistry (coPIs – Brzezinski & Buck)
- Van Mooy – Lipidomics of sinking and suspended particulates
- *Lam – Geochemical assessment of particle aggregation & disaggregation (coPIs – Lee & Marchal)

*Recommended for support

# EXPORTS Cruise – Aug/Sep 2018



# EXPORTS' 2018 Timeline



# Process Ship Measurements

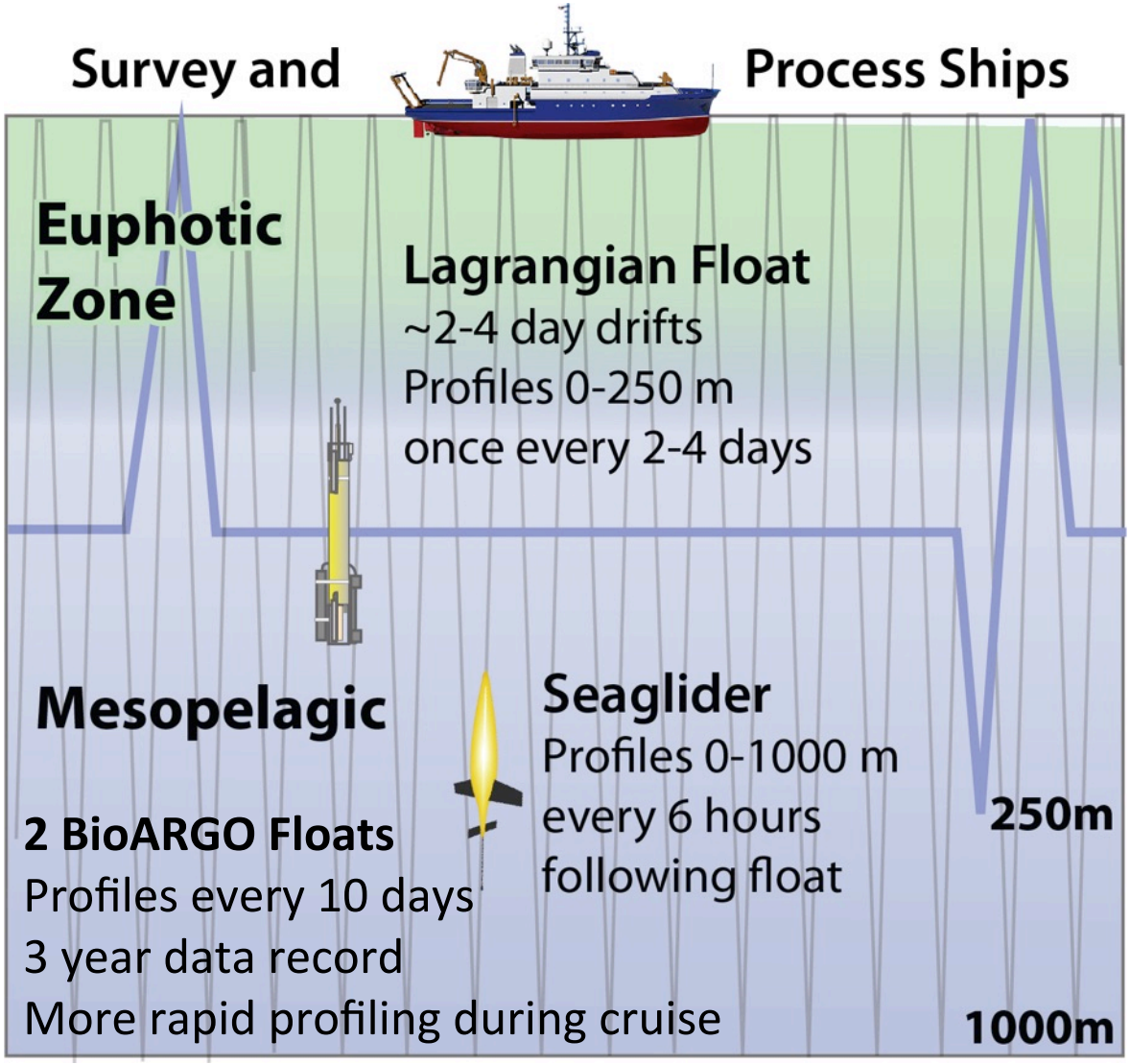
- Optics
  - Profiling & UW IOPs (incl. discrete), C-OPS & HyperSAS reflectance, LISST-Deep PSD, …
- NPP / Rates
  - NPP ($^{14}C$ & $^{15}N$ ), NCP ($O_2$/Ar), Community resp, Phyto growth / grazing, Zoop grazing, bacterial prod, …
- Taxa & Particle Characteristics
  - MOCNESS, HPLC, iFCB, UVP, FloCam, genomics for Pro's & Euk's, …
- Export pathways
  - Sediment traps, DOM/POM remin, aggregate char, diel zoop migration, …
- BGC stocks
  - Nuts, Chl/HPLC, DOC/N POC/N, $O_2$, BSI, PIC, PSD, …

# Survey Ship Measurements

- Optics
  - Multispectral / multi angle scattering, nanoparticle PSD, profiling & UW IOPs (incl. discrete & size frac), HyperSAS reflectance, submicron PSD, C-OPS & LISST-Deep, …
- NPP / Rates
  - NCP (by $O_2$/Ar)
- Taxa & Particle Characteristics
  - iFCB, UVP, HPLC, acoustics for zoop, genomics for Pro's & Euk's, …
- Export pathways
  - $^{234}$Th export, UVP-sinking flux
- BGC stocks (also act as the calibration link to AUVs…)
  - Pump & Niskin POC/N/PIC/Bsi/etc. profiles, Nuts, Chl/HPLC, DOC/N, $O_2$, PSD, …

# Autonomous Sampling Near OWS-P

July - December 2018 (& beyond)




- **One Lagrangian Float**
  T, S, $O_2$ ,$NO_3$, Chl, bbp
  Optical sediment trap
  Target depth = 95 m
- **Seaglider following float**
  T, S, $O_2$, PAR, Chl, $b_{bp}$
  Acoustic backscatter (zoop)
- **Two BioARGO Floats**
  T, S, $O_2$, $NO_3$, Ed, Chl, $b_{bp}$
  Provides long term record
- **Intercalibrate sensor data**
  with EXPORTS & Line P cruises
- **Wirewalker profiler**
  Deployed each epoch
  T, S, $O_2$, $NO_3$, Ed, Chl, $b_{bp}$, ...

# EXPORTS' Sampling Asset Interactions

- Process ship – pathways, rates & stocks
  - The 8-day "epoch" sampling schedule is key
    - Need to assess how we adapt to issues as they arise
  - Follows subsurface float/glider AUV pair
- Survey ship – spatial sampling
  - Defined four spatial sampling modes
    - Large-scale, small-scale, AUV cals, particle pump profiles & noon optics casts
- AUVs– extends experimental timeline
  - Float/glider pair – anchor for Process ship
  - BioARGOs – extends Station P BGC time series

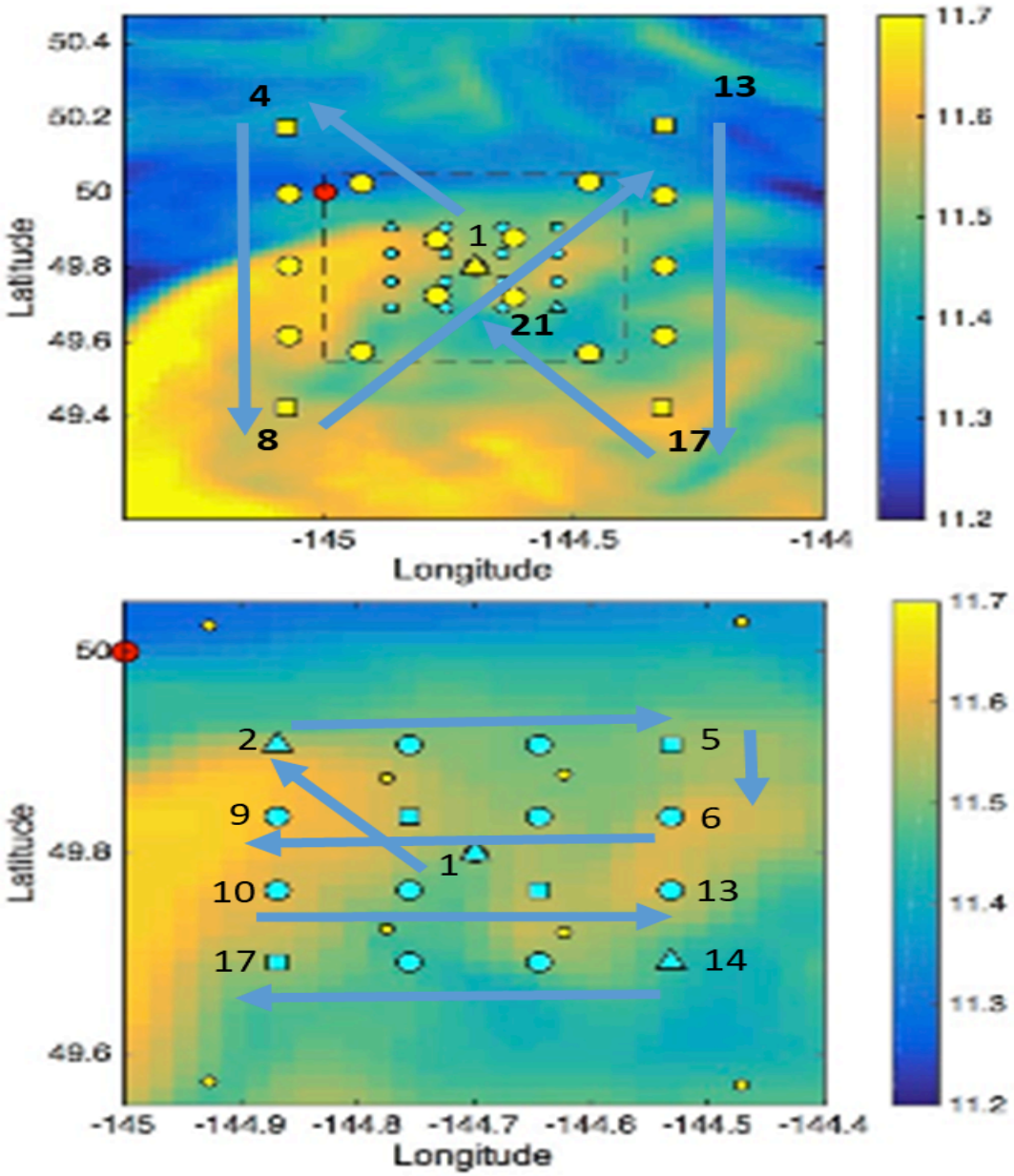
# Process Ship Planning for an Epoch

| Day | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0000-0100 | | SIO CTD - 1000 m | SIO CTD - 1000 m | Mocness | SIO CTD - 1000 m | zoo tow | SIO CTD - 1000 m | zoo tow | Mocness |
| 0100-0200 | | (UVP n, uz, expts) | (UVP n, uz, expts) | | (UVP n, uz, expts) | (fp, resp) | (UVP n, uz, expts) | (fp, resp) | |
| 0200-0300 | | TMC Towfish | TMC CTD 1 | Mocness | TMC CTD 1 | TMC CTD 1 | TMC CTD 1 | SIO CTD - 150 m uz | Mocness |
| 0300-0400 | | | | | | | | | SIO CTD - 150 m uz |
| 0400-0500 | | | TMC CTD 2 | | TMC CTD 2 | TMC Towfish | TMC CTD 2 | | TMC CTD 1 |
| 0500-0600 | | | | | | | | | |
| 0600-0700 | | Deploy Traps | | | | | | | TMC CTD 2 |
| 0700-0800 | | & wire walker | | zoo tow (63 um-day) | | | Poop run | zoo tow | |
| 0800-0900 | | | SIO CTD 150m (NC,expt) | zoo tow | zoo tow | SIO CTD - expts | | (fp) | Poop run |
| 0900-1000 | | | TMC CTD- 150m BJ | (fp) | (graze) | zoo tow | SIO CTD 150m (NC,expt) | | |
| 1000-1100 | | TMC CTD- 150m KH | Mocness | | TMC CTD- 150m BJ | (fp) | TMC CTD- 150m BJ | Mocness | TMC CTD- 150m BJ |
| 1100-1200 | | Optics | | Optics | Optics | Optics | Optics | | Optics |
| 1200-1300 | NBST test deploy | | Mocness | | | | | Mocness | |
| 1300-1400 | | zoo tow | | SIO CTD - 1000 m | SIO CTD - 1000 m | SIO CTD - 1000 m | SIO CTD - 1000 m | | SIO CTD - 1000 m |
| 1400-1500 | | (fp) | Mocness | | (UVP d) | (UVP d) | | Mocness | (UVP d) |
| 1500-1600 | SIO CTD - 500 m | SIO CTD - expts | | Mar snow catchr | Poop run | TMC CTD- 150m KH | Mar snow catchr | | |
| 1600-1700 | (trap water) | SIO CTD - 1000 m | SIO CTD - 1000 m | | | Poop run | | SIO CTD - 1000 m | Recover Wire walker |
| 1700-1800 | (expt. water) | | | | | | | | |
| 1800-1900 | NBST test recover | Mar snow catchr | | | | | | | SIO CTD - 500 m |
| 1900-2000 | | | poop run | poop run | SIO CTD - 500 m (expt) | | zoo tow (MSC) | Poop run | (trap water) |
| 2000-2100 | | | | | Recover 3-day traps | Recover 4-day traps | Recover 5-day traps | | (expt. water) |
| 2100-2200 | zoo tow | | Mocness | zoo tow (63 um-night) | | | | Mocness | zoo tow |
| 2200-2300 | (fp ,resp) | Poop run | | zoo tow | | | (incudes STT) | | (fp, resp) |
| 2300-2400 | | | Mocness | (fp, resp) | | | | Mocness | |

# Survey Ship Planning for an Epoch

- Large-Scale Survey
  - Mesoscale context, ~100 km crossed transect, 19 stations, ~20 km spacing, adapt to NRT data, 1 per epoch
- Small-Scale Survey
  - Resolve SMS gradients, ~25 km box centered on float / glider w/ 8 km spacing, 18 stations, 1 per epoch
- AUV Calibrations
  - Improve AUV data, simultaneous cast within 1 km of AUV, typically 1-2 per epoch (BioARGO 2 per cruise)
- Pumping Profiles
  - Sinking particle collections, @ trap depths & 750 m, 4 per epoch, both near and far from Process Ship
- Pre-dawn and noon-time optics cast
  - Link to ocean color obs, needed daily if possible

# Survey Ship Planning for an Epoch




Large-scale survey – ~100 km, oriented cross/along SST/Chl gradients, centered on float, niskin sampling on diagonals, 19 stations, 1 per epoch

Small-scale survey – ~25km, oriented cross/along SST/Chl gradients, centered on float, some niskin sampling, 17 stations, 1 per epoch

Optics & AUV cals – sampling based on time of day / rendezvous, will be largely integrated into large/small-scale survey

Red dot – Station P

# Survey Ship Planning for an Epoch

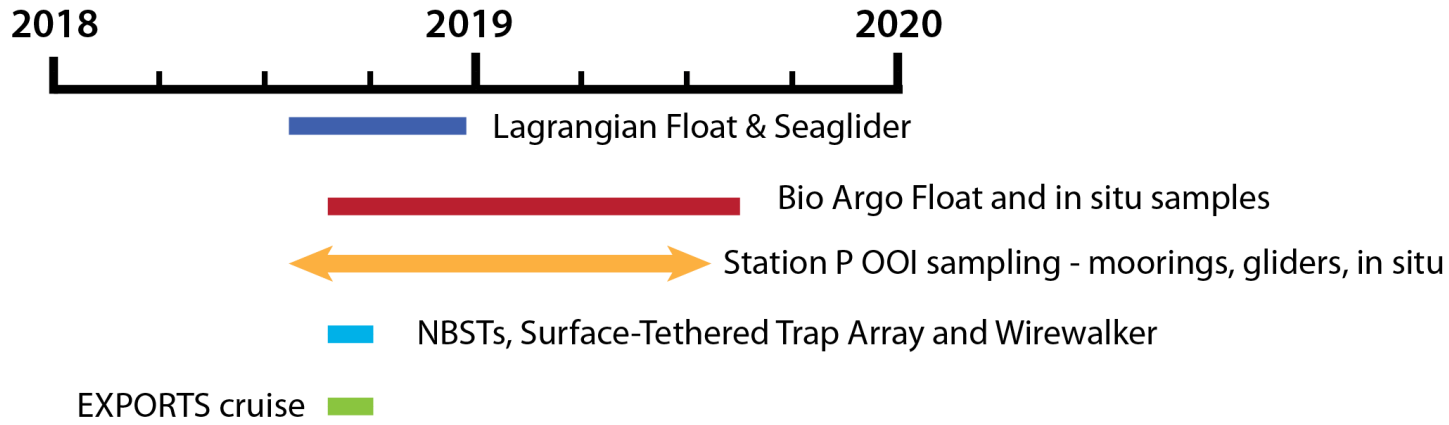
| | | | |
|---|---|---|---|
| | AOP | | Pumping |
| | IOP | | Poop run |
| | CTD w/ water optics + Th | | Open (Cals / target a front / other?) |
| | CTD w/ water Th/DOM | | Deep Cast |
| | CTD no water | | |

| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 |
|---|---|---|---|---|---|---|---|---|
| 00:00 | Poop / transit | PUMPING | PUMPING | CTD SS13 | PUMPING | Poop / transit | Poop / transit | CTD LS18 |
| | Poop / transit | PUMPING | PUMPING | CTD SS13 | PUMPING | Poop / transit | Poop / transit | Poop / transit |
| 01:00 | Poop / transit | Poop / transit | PUMPING | Poop / transit | PUMPING | Poop / transit | Poop / transit | Poop / transit |
| | transit | Poop / transit | PUMPING | Poop / transit | PUMPING | Poop / transit | Poop / transit | Poop / transit |
| 02:00 | transit | Poop / transit | PUMPING | Poop / transit | PUMPING | CTD LS8 | CTD LS12 | Poop / transit |
| | transit | Poop / transit | PUMPING | Poop / transit | PUMPING | CTD LS8 | CTD LS12 | CTD LS19 |
| 03:00 | CTD SS1 | CTD SS3 | PUMPING | CTD SS14 | PUMPING | CTD LS8 | CTD LS12 | CTD LS19 |
| | CTD SS1 | CTD SS3 | PUMPING | CTD SS14 | PUMPING | CTD LS8 | CTD LS12 | |
| 04:00 | CTD SS1 | CTD SS3 | PUMPING | CTD SS14 | PUMPING | transit | transit | |
| | CTD SS1 | CTD SS3 | PUMPING | CTD SS14 | PUMPING | transit | transit | |
| 05:00 | IOP | transit | IOP | transit | transit | IOP | IOP | |
| | IOP | IOP | IOP | IOP | IOP | IOP | IOP | |
| 06:00 | CTD SS1 | IOP | CTD SS8 | IOP | IOP | CTD LS9 | CTD LS13 | |
| RISE (aug) | CTD SS1 | CTD SS4 | CTD SS8 | CTD SS15 | CTD LS1 | CTD LS9 | CTD LS13 | |
| 07:00 (sep) | CTD SS1 | CTD SS4 | CTD SS8 | CTD SS15 | CTD LS1 | CTD LS9 | CTD LS13 | |
| | CTD SS1 | CTD SS4 | CTD SS8 | CTD SS15 | CTD LS1 | CTD LS9 | CTD LS13 | |
| 08:00 | transit | CTD SS4 | transit | CTD SS15 | CTD LS1 | transit | transit | |
| | CTD SS2 | transit | CTD SS9 | transit | transit | transit | transit | |
| 09:00 | CTD SS2 | CTD SS5 | CTD SS9 | CTD SS16 | CTD LS2 | CTD LS10 | CTD LS14 | |
| | CTD SS2 | CTD SS5 | CTD SS9 | CTD SS16 | CTD LS2 | CTD LS10 | CTD LS14 | |
| 10:00 | CTD SS2 | CTD SS5 | CTD SS9 | CTD SS16 | transit | transit | transit | |
| | IOP/AOP | CTD SS5 | transit | CTD SS16 | transit | transit | transit | |
| 11:00 | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | |
| | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | |
| 12:00 | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | |
| | CTD SS2 | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | IOP/AOP | |
| 13:00 | CTD SS2 | CTD SS6 | CTD SS10 | CTD SS16 | CTD LS3 | CTD LS11 | CTD LS15 | |
| | CTD SS2 | CTD SS6 | CTD SS10 | CTD SS16 | CTD LS3 | CTD LS11 | CTD LS15 | |
| 14:00 | CTD SS2 | CTD SS6 | CTD SS10 | CTD SS16 | CTD LS3 | CTD LS11 | CTD LS15 | |
| | CTD cal LF | CTD SS6 | CTD SS10 | CTD SS16 | CTD LS3 | CTD LS11 | CTD LS15 | |
| 15:00 | CTD cal LF | transit | CTD WW | CTD BA1 | transit | transit | transit | |
| | CTD cal LF | CTD SG | CTD WW | CTD BA1 | transit | transit | transit | |
| 16:00 | CTD cal LF | CTD SG | CTD WW | CTD BA1 | CTD LS4 | PUMPING | CTD LF | |
| | CTD cal LF | CTD SG | CTD WW | CTD BA1 | CTD LS4 | PUMPING | CTD LF | |
| 17:00 | transit | CTD SG | CTD WW | CTD BA1 | transit | PUMPING | CTD LF | |
| | PUMPING | CTD SG | transit | transit | transit | PUMPING | CTD LF | |
| 18:00 | PUMPING | transit | CTD SS11 | CTD SS17 | CTD LS5 | PUMPING | CTD LF | |
| | PUMPING | CTD SS7 | CTD SS11 | CTD SS17 | CTD LS5 | PUMPING | transit | |
| 19:00 | PUMPING | CTD SS7 | CTD SS11 | CTD SS17 | transit | PUMPING | transit | |
| | PUMPING | CTD SS7 | CTD SS11 | CTD SS17 | transit | PUMPING | CTD LS16 | |
| 20:00 | PUMPING | CTD SS7 | transit | transit | CTD LS6 | PUMPING | CTD LS16 | |
| | PUMPING | transit | CTD SS12 | transit | CTD LS6 | PUMPING | transit | |
| 21:00 | PUMPING | PUMPING | CTD SS12 | PUMPING | transit | PUMPING | transit | |
| | PUMPING | PUMPING | CTD SS12 | PUMPING | transit | PUMPING | CTD LS17 | |
| 22:00 | PUMPING | PUMPING | CTD SS12 | PUMPING | CTD LS7 | PUMPING | CTD LS17 | |
| | PUMPING | PUMPING | transit | PUMPING | CTD LS7 | PUMPING | transit | |
| 23:00 | PUMPING | PUMPING | CTD SS13 | PUMPING | transit | PUMPING | transit | |
| | PUMPING | PUMPING | CTD SS13 | PUMPING | transit | PUMPING | CTD LS18 | |

Only an example…

# Autonomous Sampling in North Pacific EXPORTS

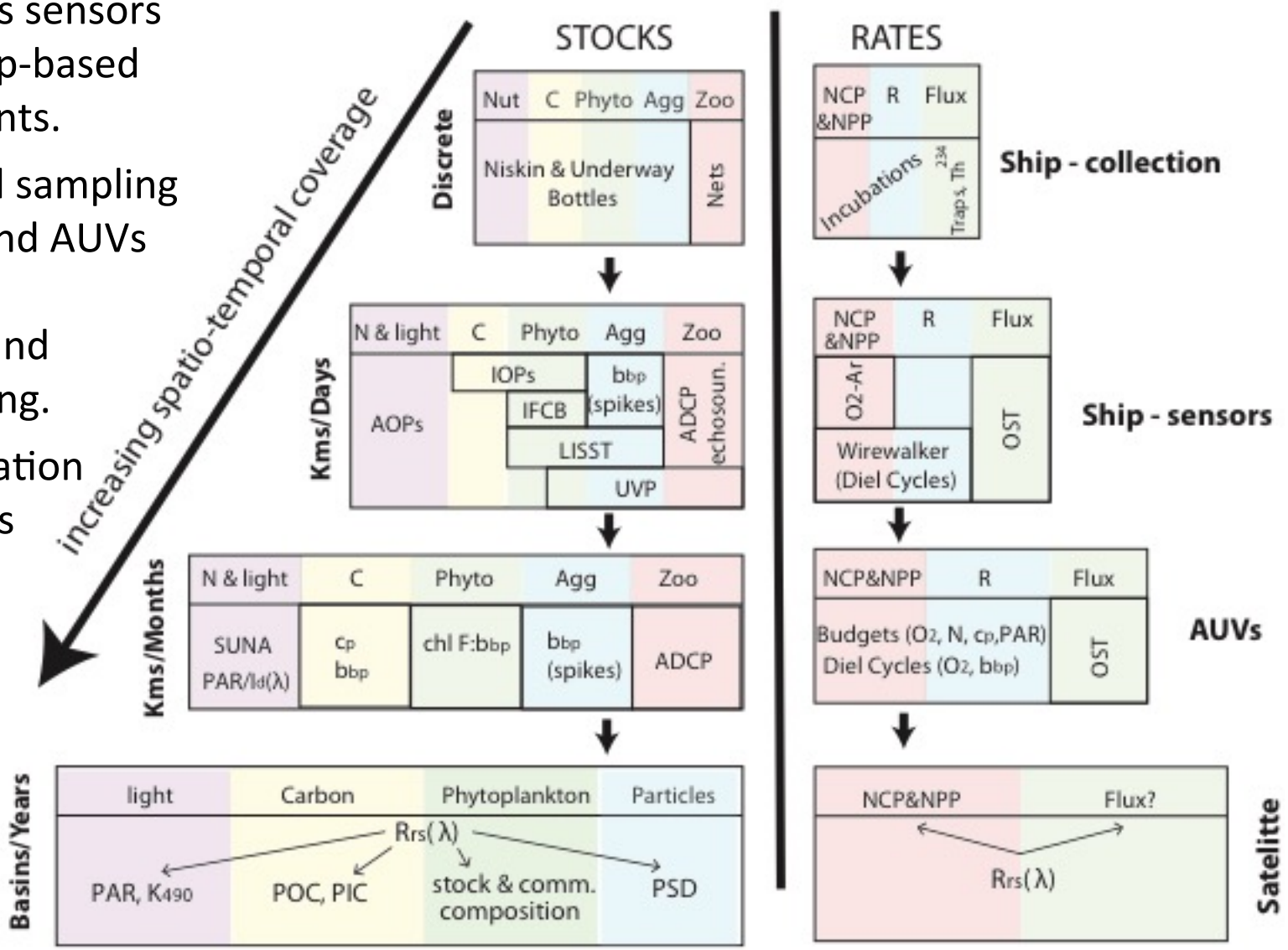
Craig Lee, Eric D'Asaro, Mary Jane Perry, Melissa Omand, David Nicholson and Andy Thompson (Lagrangian Float and Seaglider)
Meg Estapa, Ken Buesseler, Colleen Durkin, Melissa Omand and Pat Kelly (NBSTs, Trap Array and Wirewalker)
Andrea Fassbender, Ken Johnson, Yui Takeshita and Sophia Johannessen (Bio-Argo floats)




- One **Lagrangian float** and one **Seaglider**, ~ 6 months
- **Bio-Argo Floats**, 2 floats to span 1+ year
- On-going in situ and moored observations (OOI)
- Drifting **NBST**, **Surface-Tethered Trap Array** and **Wirewalker**, operated as part of EXPORTS cruise
- Autonomous Observations Provide:
  - Temporal context
  - Targeting for ship-based efforts
  - Lagrangian reference frame
  - Sensor-based proxies
  - Additional states

# Autonomous Sensors Expand Range of Sampled Temporal & Spatial Scales

- Autonomous sensors leverage ship-based measurements.
- Coordinated sampling with ships and AUVs required for calibration and proxy-building.
- Cross-calibration of all sensors critical to EXPORTS success.



# Autonomous Platform Calibration Cast Procedure

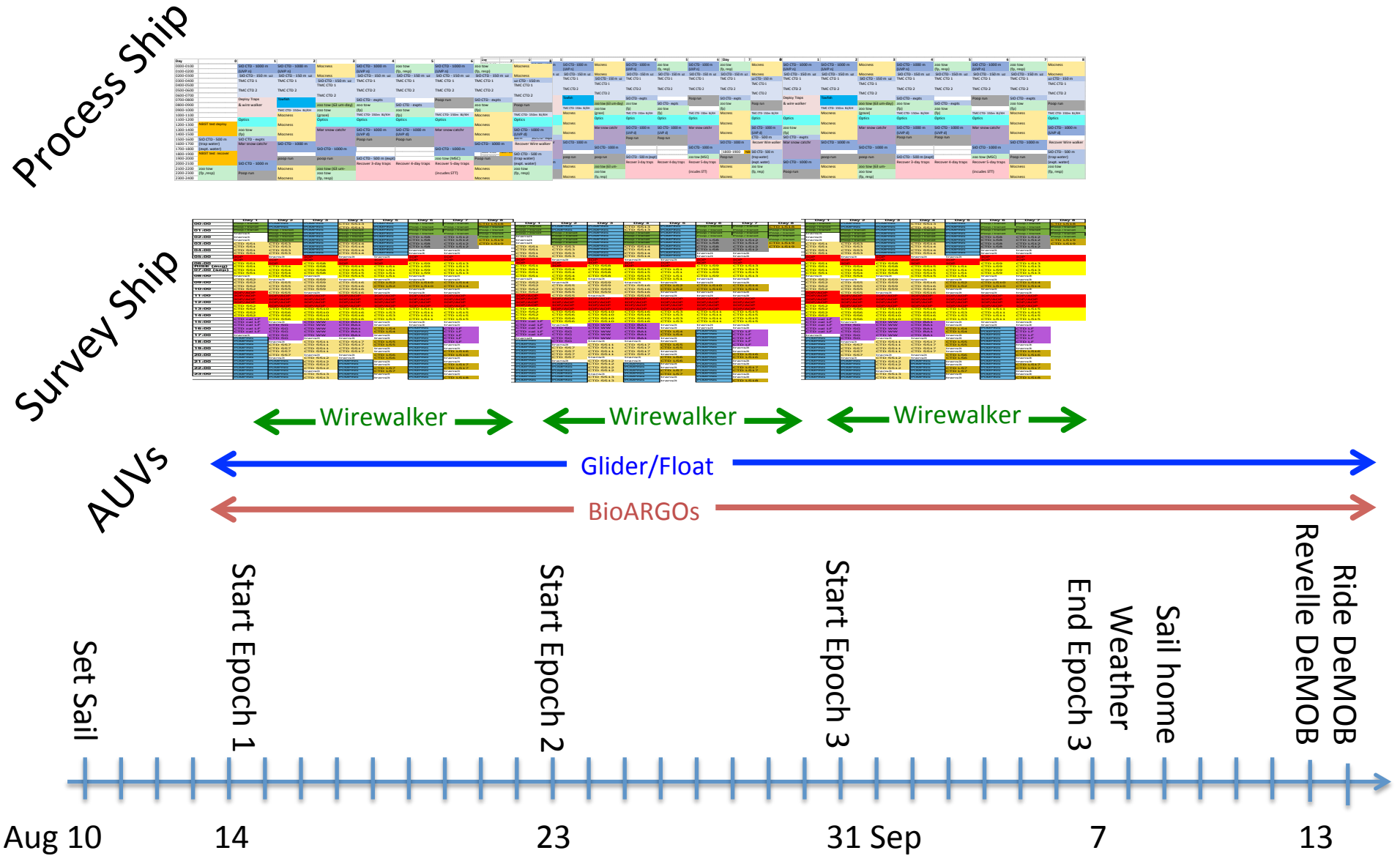
| When | Actions | Notes |
|---|---|---|
| 2-3 days prior | Obtain projected position of asset.<br>Negotiate timing of cal cast with operator. | Communication via email and/or IM.<br>Operator sets dive schedule to put asset on surface prior to planned time. |
| 1 day prior | Ship and operator confirm timing.<br>Operator provides new projected position. | Communication via email and/or IM.<br>Shift to IM once inside 24-h window |
| 6 hours prior | Ship and operator confirm timing & position. | Communication via IM, both ship and shore should monitor and respond. |
| Cal Cast | Asset on surface and held.<br>Operator updates to ship with positions.<br>Ship establishes visual contact with asset.<br>Close to within 100-200 m.<br>Prepare CTD, notify asset operator when ready for cast.<br>Asset operator initiates dive.<br>CTD cast begins as asset leaves surface. | Frequent communication between operator and ship via IM.<br>Close coordination with bridge and CTD crew required.<br>Proximity matters (though maybe not as critical here as in other places) – get close! |

- Need watch lists for both ship and shore-side operations – names, email, phone and IM.
- Choose IM clients and test connectivity prior to sailing.
- Iridium phones as backup – need to run external antennas on ships.

# Platform Calibration Needs

| Platform | No. | Frequency | Total Cal Casts | Notes |
|---|---|---|---|---|
| BioArgo Float | 2 | Beginning and end of cruise. Or one deep cast with replicates. | 4 | Target each float at start and end of EXPORTS cruise period. Or one deep cast with replicate samples. |
| Lagrangian Float | 1 | Beginning and end of cruise plus one per epoch. | 5 | Could share cal casts with Seaglider, if platforms in close proximity. |
| Seaglider | 1 | One per epoch. | 3 | Could share cal casts with float, if platforms in close proximity. |
| WireWalker | 1 | One per epoch. | 3 | |
| NBST | 6 | One (density profile) | 1 | From Process ship |
| Process Ship | 1 | Min. one cast | 1 | Perform at least one intentional calibration cast with Ride and Revelle in close proximity. |

# EXPORTS' Intensive Operation Phase



# Situational Awareness Plan Goals

- Needed to coordinate the EXPORTS NE Pacific field program's sampling assets
- Enable input from all EXPORTS PIs allowing a democratic decision making process
- Keep track of progress conditions from all platforms
- Respond effectively to opportunities / disasters
- Work effectively without requiring high bandwidth communication
- Will be available for coordinating with Line P

# Situational Awareness Plan Elements

- Four reports are produced daily (~6pm local)
  - Context (weather, imagery, etc.) - Dave/Ivona
  - Process ship – Deb / Jason
  - Survey ship – Norm / MJ
  - AUV – CraigL / Andy / Eric / Andrea
- Reports daily accomplishments, plans for tomorrow, plans for the next 3 days as well as system & ocean status
- Future plans are discussed for 24 h
- Lightweight report templates have been created
- Context reporting will start July 1

# Remaining Issues To Resolve

- Viewing in-water asset locations from the ships
  - We can provide text/graphical data - need to get output to the bridge easily
- Ship-to-ship & ship-to-AUV calibration casts
  - We have process – need to work with Captains on exact implementation (& its sea state dependent)
- Reliable low bandwidth comms for coordination
- MOB / DeMOB issues
  - DeMOB is especially short & complicated for the Reveille
  - NASA PAO Media Affair - Aug 9 (last day of MOB)