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Evaluating SWOT's capability in observing small-scale (<100km) sea surface height

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SMODE: 4 gliders **Luke Rainville** (UW), 5 gliders **Gregg Jacobs, Joseph M D`Addezio** (NRL)
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Ocean Surface Topography Science Team meeting, Puerto Rico
November 10th, 2023

URS321260

Wang et al., 2023; in prep

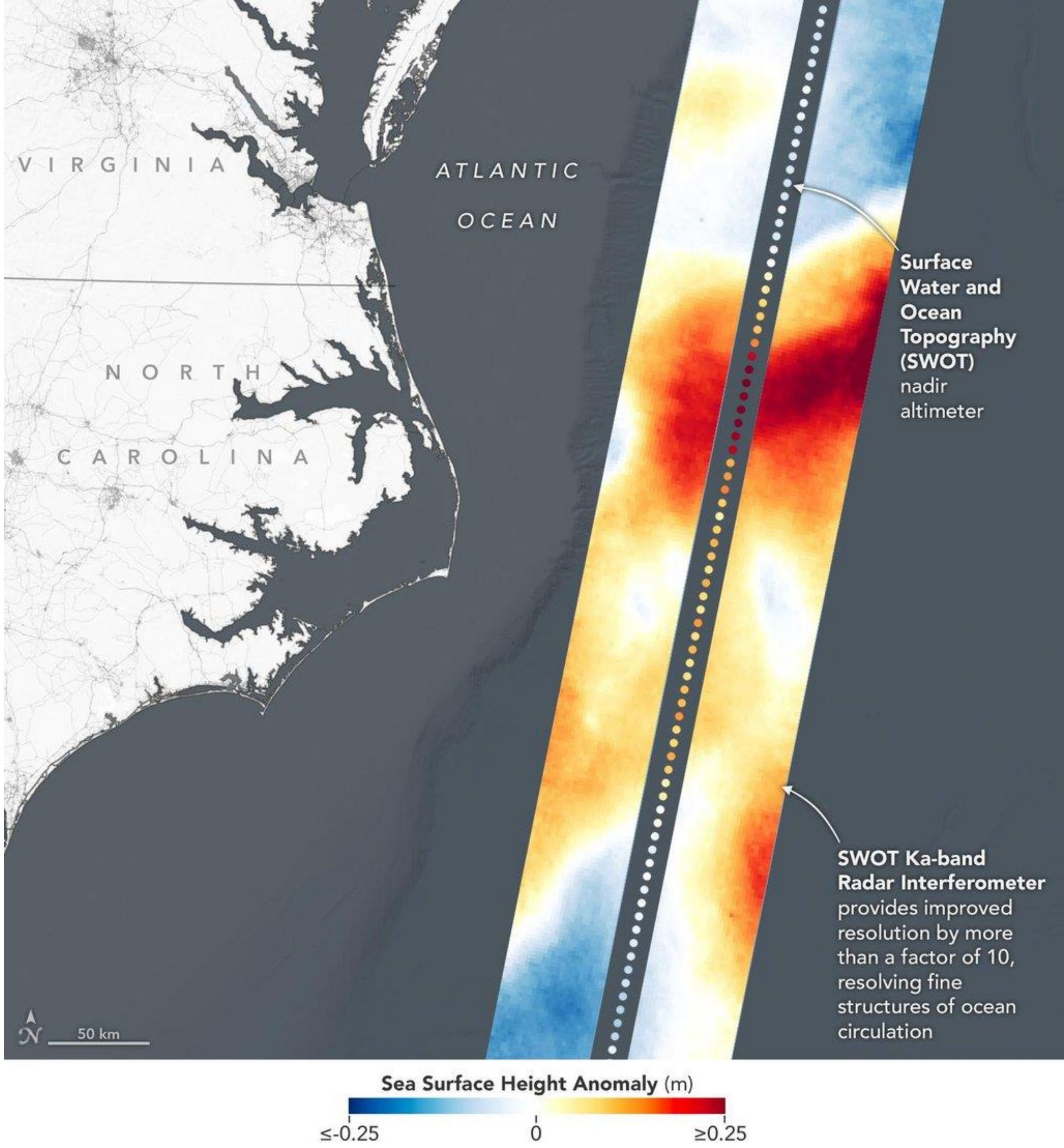
Outline

- Objective
- Overview of the development
  - Prelaunch
  - Postlaunch
- Postlaunch results
  - Process of SWOT KaRIn and in-situ data
  - Comparison
- Conclusion

SWOT calibration and validation (Cal/Val)

- Our SWOT analysis has revealed some promising high-resolution imagery.
- To what extent do SWOT measurements at <100km scales represent ocean physics?

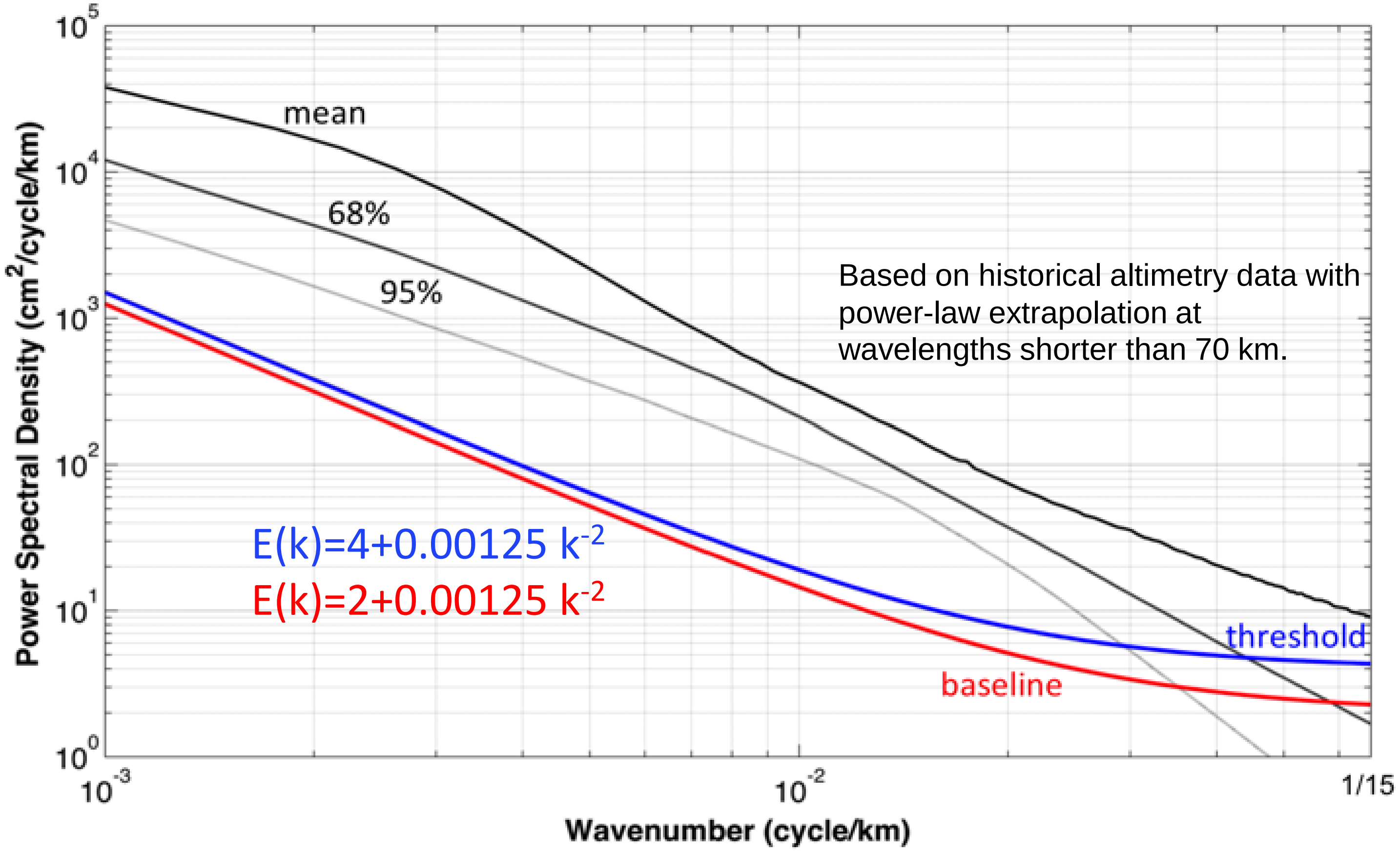
Validation against the ground truth is crucial.



SWOT Ocean Cal/Val objectives

- Geodetic validation – validate the measurement of SSH to meet the wavenumber spectrum requirement

- Oceanographic validation – validate the utility of the SSH measurement to meet the science objectives



Recap of the past development

- 2016-2017 Observation System Simulation Experiment
  - Identified the utility of steric height
  - An array of 20 mooring will be sufficient, but too expensive
  - Array of station-keeping gliders marginally meet the requirement
  - Underway CTDs and PIES does not meet the requirement
- 2017-2018 Pilot field campaign near MBARI M1 mooring
  - Station keeping gliders can reconstruct mooring steric height for periods longer than 6 hours
  - Could not match GPS-BPR with mooring steric height partially due to the local large spatial gradient in geoid
- 2019-2020 pre-launch field campaign (planning, execution)
  - California Xover location, deep ocean
  - GPS-BPR matches steric height with 1-3 cm rms difference
  - Quantification of the steric height composition
  - Demonstrated the feasibility of an array of moorings as the baseline
- 2020-2023 (post-launch calval campaign planning)
  - Create baseline
  - Team formation
  - Plan execution
- 02/2023 - 09/2023 (postlaunch campaign)
  - 11 moorings, 2 gliders
  - 9 gliders from NAVO/APL, >100 drifters (SMODE)

Theoretical basis

Steric height is a hydrographic approach to measuring SSH when the correction for the inverted barometer effects and barotropic signals is made.

$$\frac{dp}{dz} = \rho g$$

$$p'(H) = \int_H^0 g\rho' \, dz + \rho_0 g \eta' + p'_a$$

Bottom pressure recorder

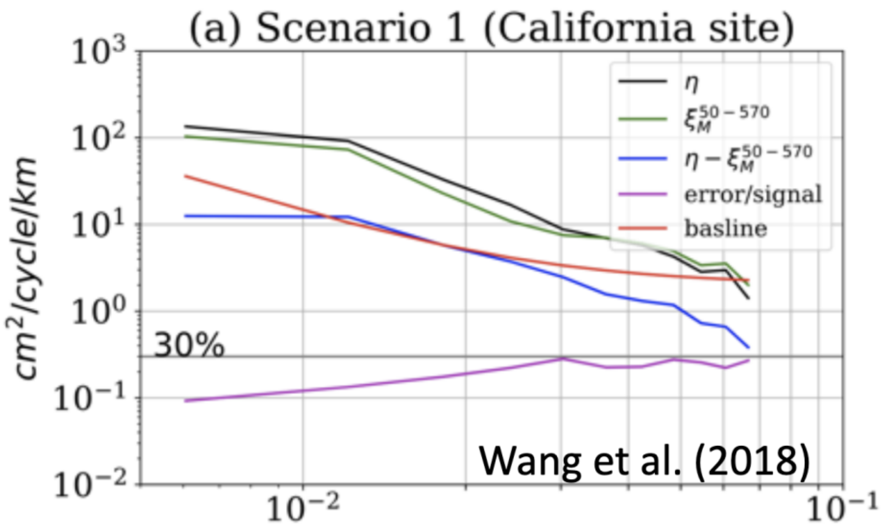
CTD mooring

GPS/SWOT

Barometer/reanalyses

Wang et al., 2018

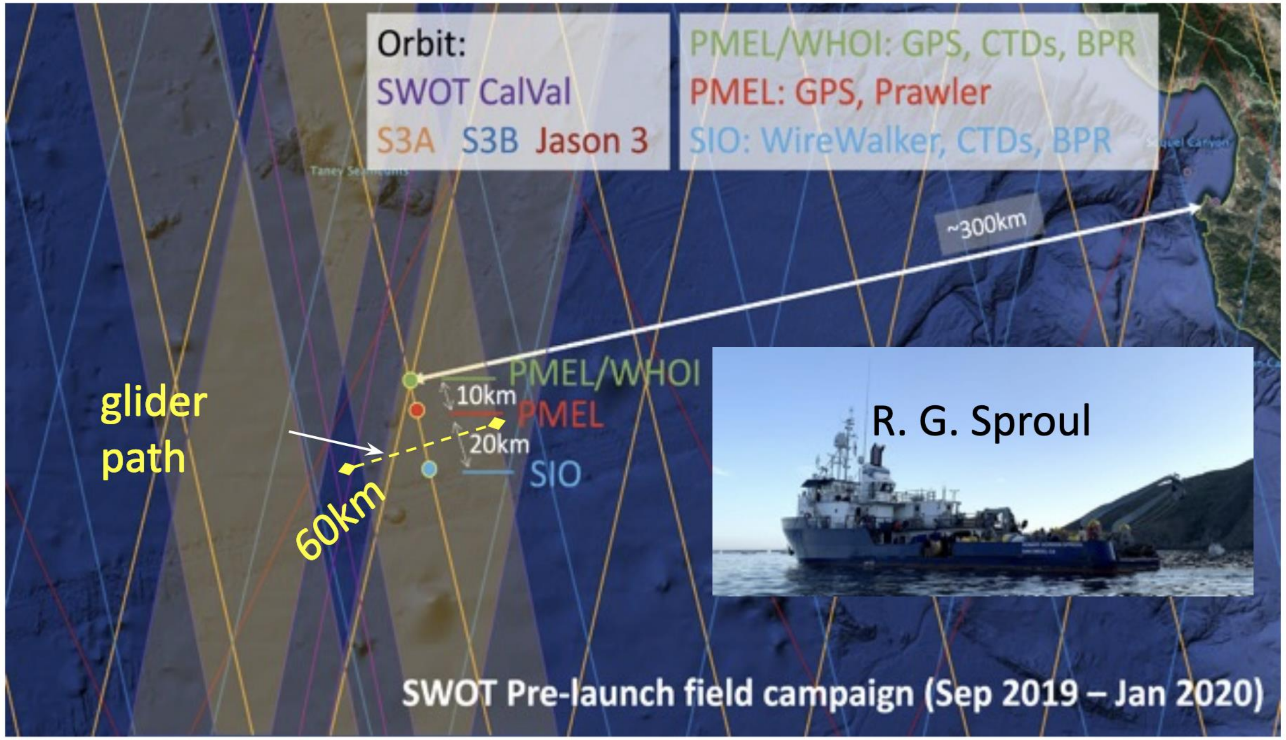
An OSSE of an array of 20 moorings



2019-20 SWOT pre-launch Campaign

objectives

1. Test the SSH closure with GPS buoy, CTD mooring, and bottom pressure recorder (BPR)
2. Evaluate the vertical scale of the steric SSH at the SWOT scales for different frequency bands
3. Evaluate the roles of bottom pressure in SWOT SSH signals
4. Assess the information content of the in-situ observations
5. Continuation of the SSH wavenumber spectrum from Sentinel 3A to SWOT regime
6. Evaluate the reconstruction of the upper ocean circulation
7. Provide information for the design of the post-launch in-situ observing system.



Campaign participants: Christian Meinig, Scott Stalin, Mike Craig, Danny Devereaux, **Yi Chao**, **Oscar Schofield**, John Kerfoot, David Aragon, **Uwe Send, Andrew J. Lucas**, Rob Pinkel, Matthias Lankhorst, Jeff Sevadijan, Ethan Morris, Riley Baird, Romain Heux, Tyler Hughen, Paul Chua, Drew Cole, Bofu Zheng, **J. Thomas Farrar**, Sebastien Bigorre, Ray Graham, Emerson Hasbrouck, Ben Pietro, and Al Plueddemann, **Bruce Haines, Lee-Lueng Fu**, Jinbo Wang

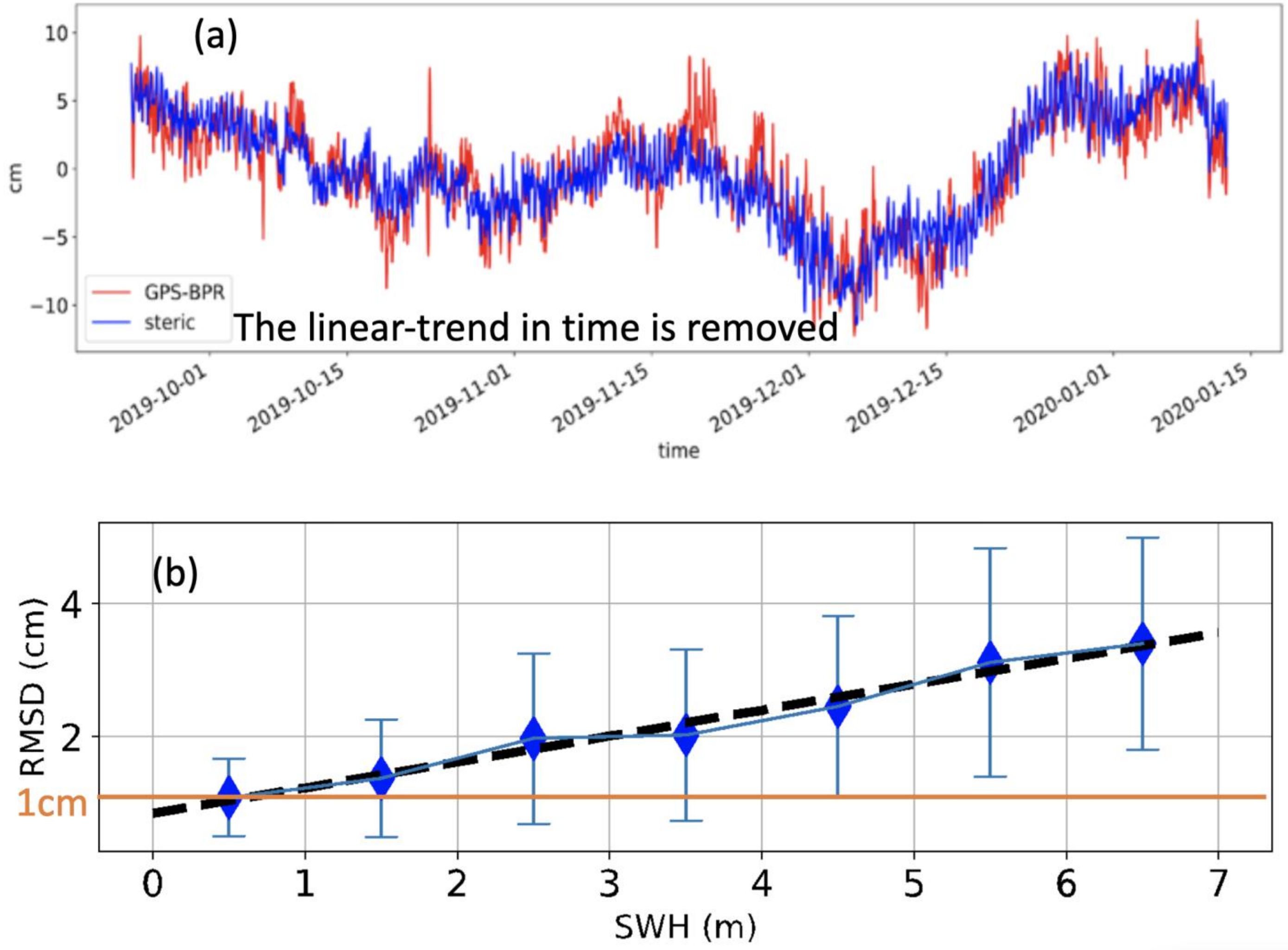
Acknowledgment: Matthew Archer, Richard Ray, David Sandwell, Hong Zhang, Anna Savage, Marie Eble, George Mungov

SSH budget can be closed with ~ 1-3 cm RMS residual.

Wang et al., 2022

$$\frac{-p'_b}{g\rho_b} + \eta'_{GPS} - \eta_{IB}$$

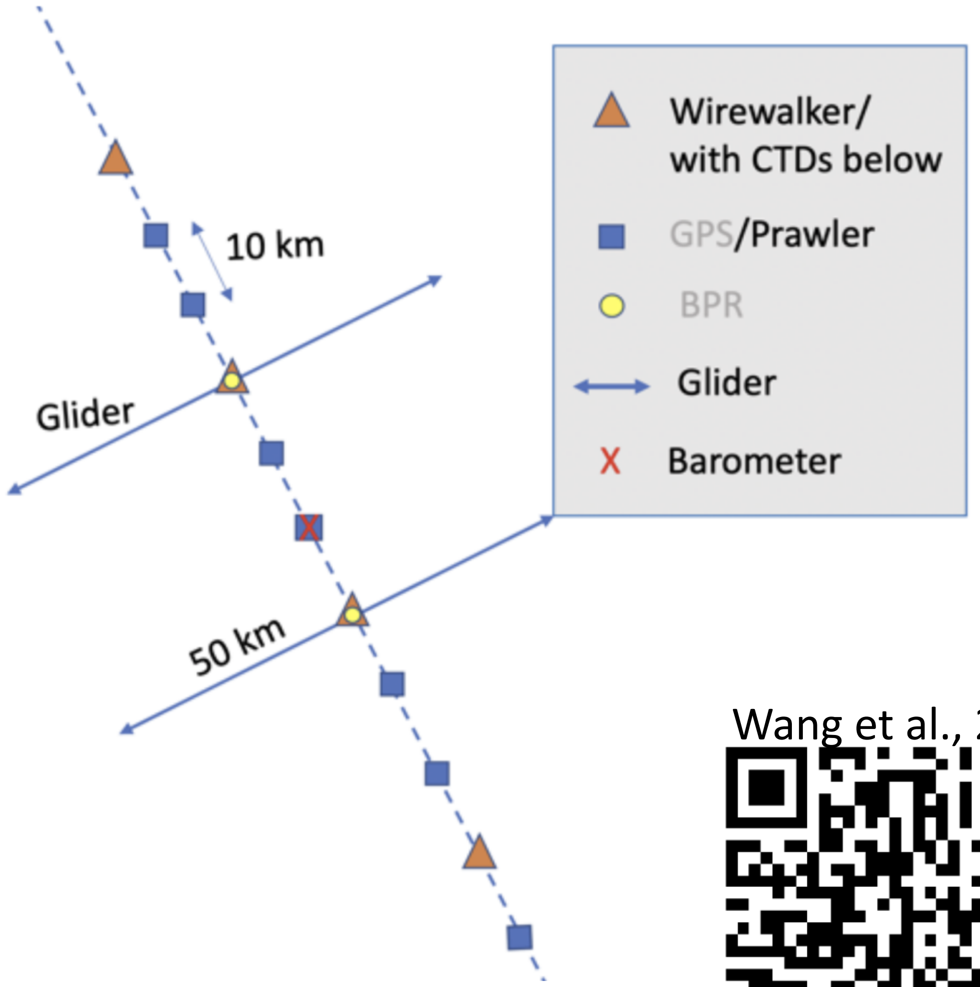
$$\int_H^0 \frac{-g\rho'}{\rho_0} dz$$



1. The hydrostatic equation is closed with GPS, BPR, and CTDs, confirming the SSH equation and the utility of CDTs in reconstructing the truth.
2. The differences between blue and red is a function of surface wave condition, indicating the error source from GPS retrieval, which is believed to be of long-wavelength and less relevant to <100km scales. On-going investigation.

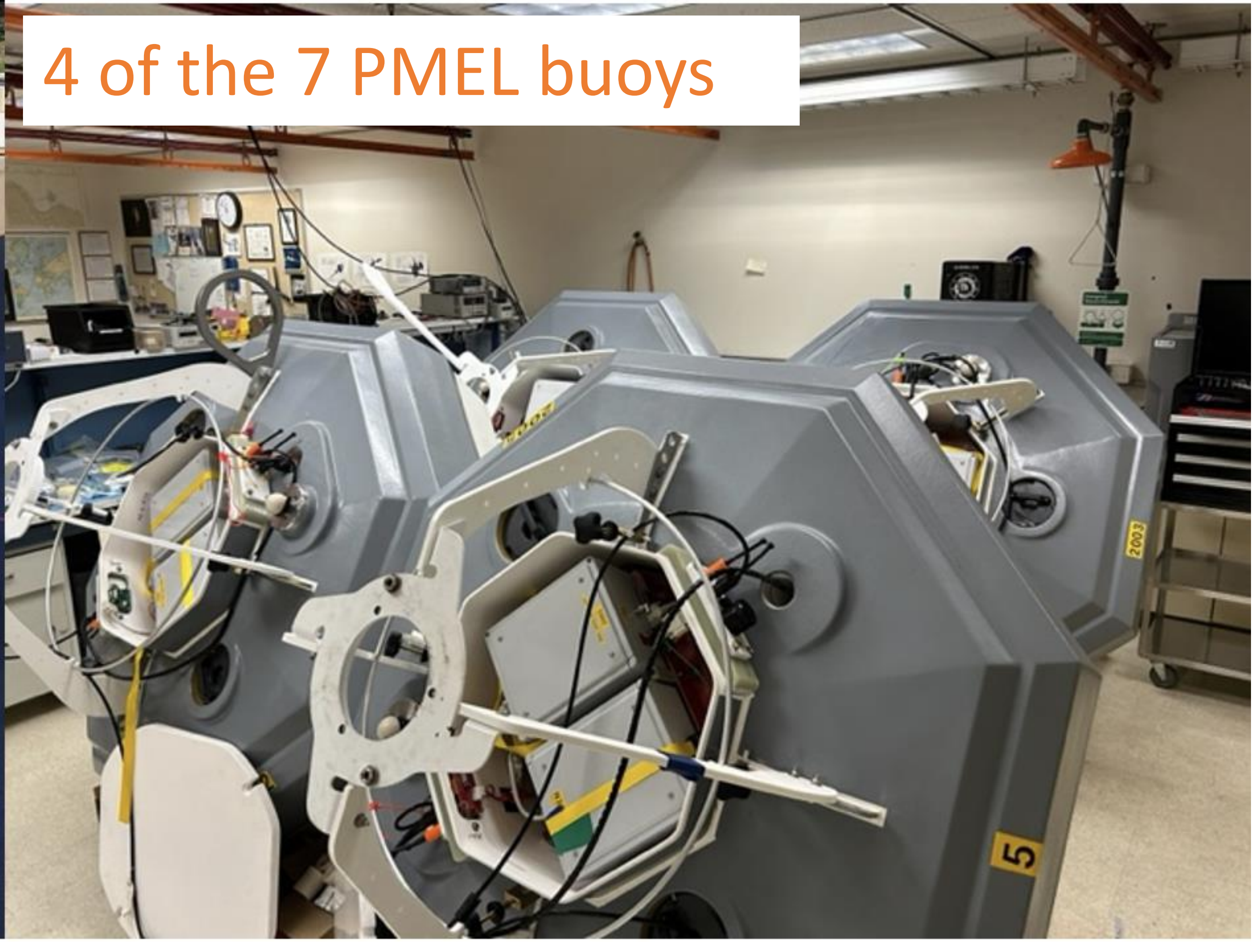
SWOT Post-launch Cal/Val campaign minimum baseline

- Four full-depth moorings with 30km separation
- Seven profiler moorings sampling the upper 500m
- Two gliders cross swath
- A barometer at the center of the array.
- The full-depth mooring will capture the large-scale, deep-reaching, high-frequency variabilities
- The gliders will sample the cross-swath direction to provide two-dimensional measurements, but also serve as a contingency for failed moorings.
- The barometer will provide high-frequency atmospheric pressure for IB corrections.
- GPS and BPR are not in the minimum baseline but considered as valuable upgrades.
- The array will be under a SWOT swath along a Sentinel 3A ground track as done in the 2019-20 prelaunch field campaign.



Wang et al., 2022


4 SIO buoys


4 of the 7 PMEL buoys

Argo floats

2 Rutgers gliders

3 PIES under S moorings

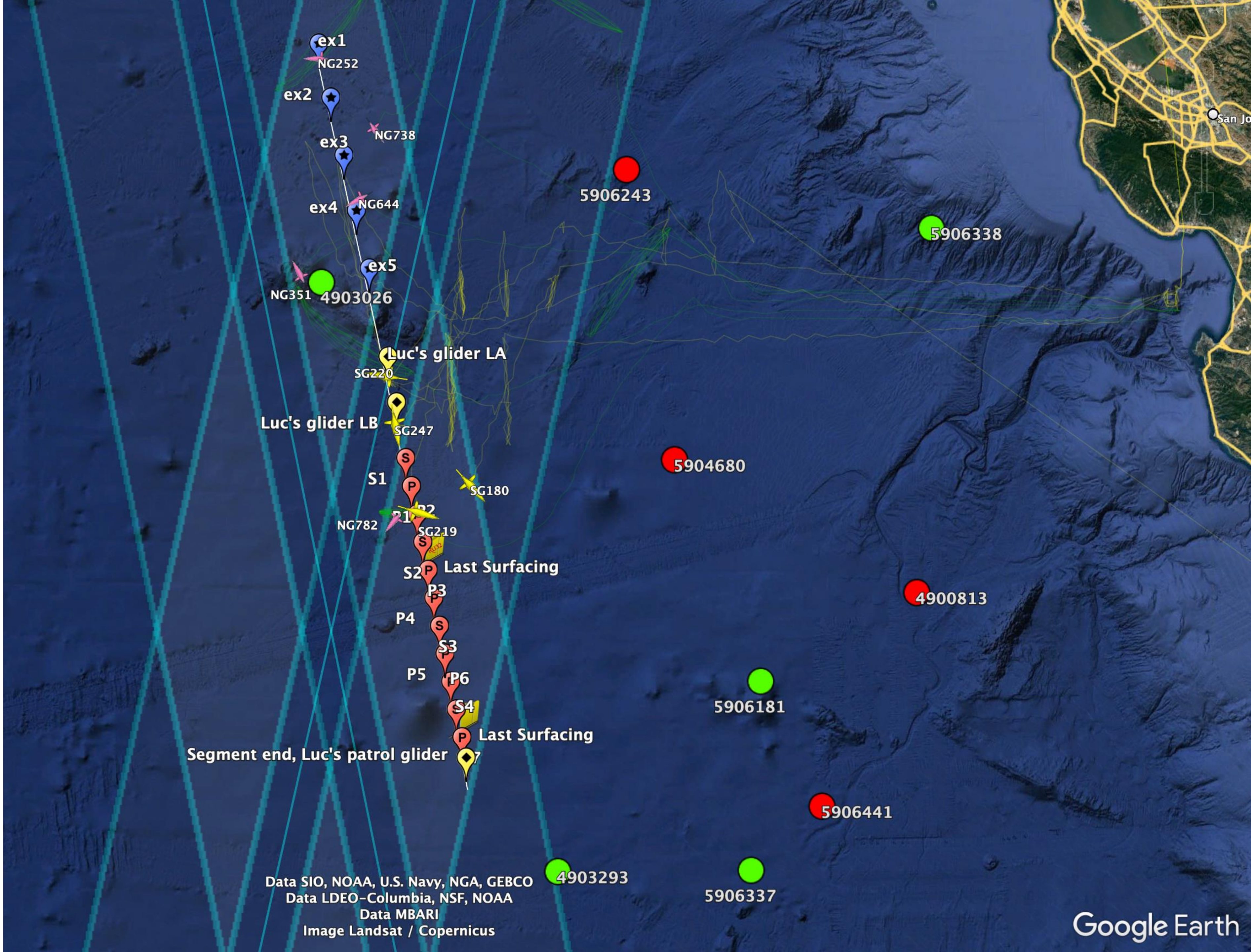
4 UW gliders

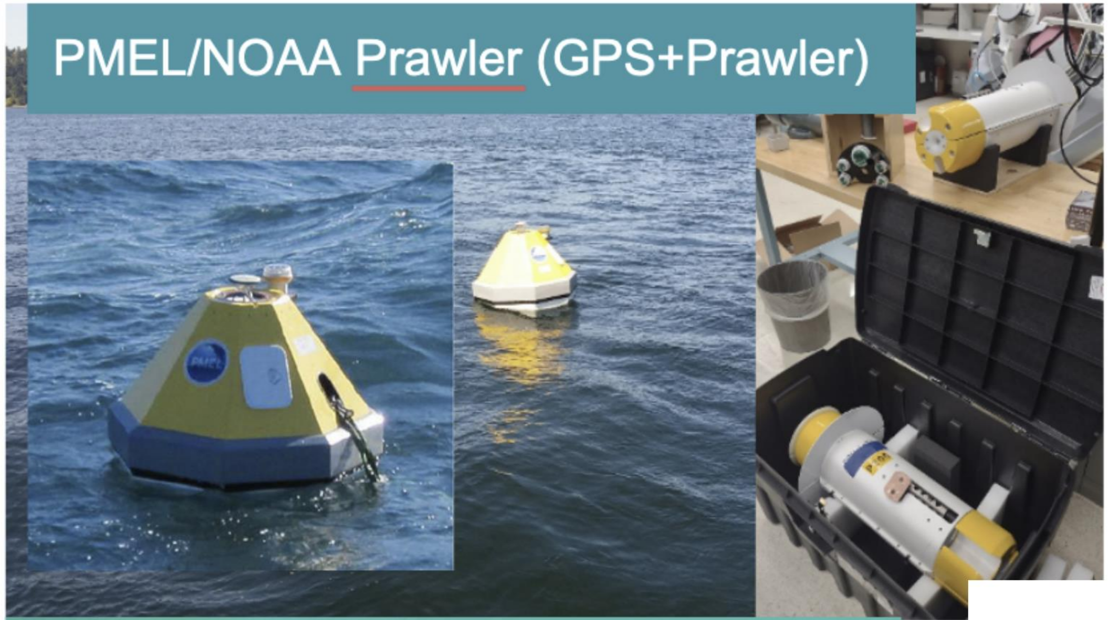
4 SIO deep moorings

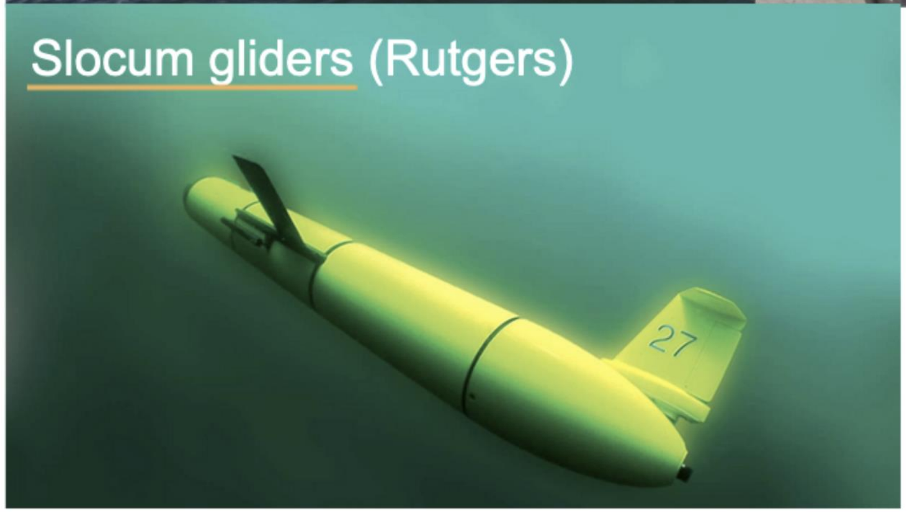
5 NAVO gliders

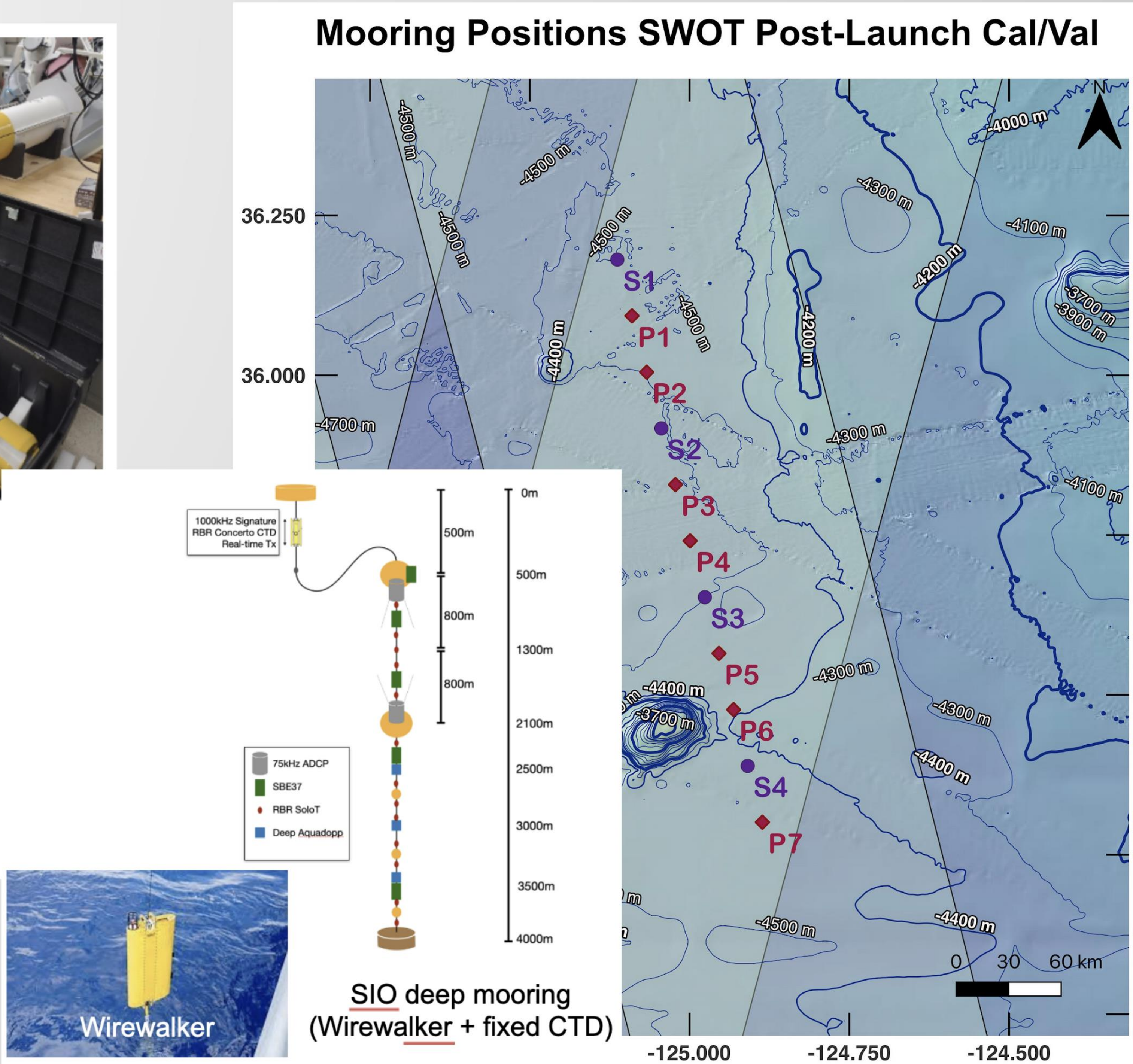
7 NOAA/PMEL moorings

Numerous drifters
(not shown)

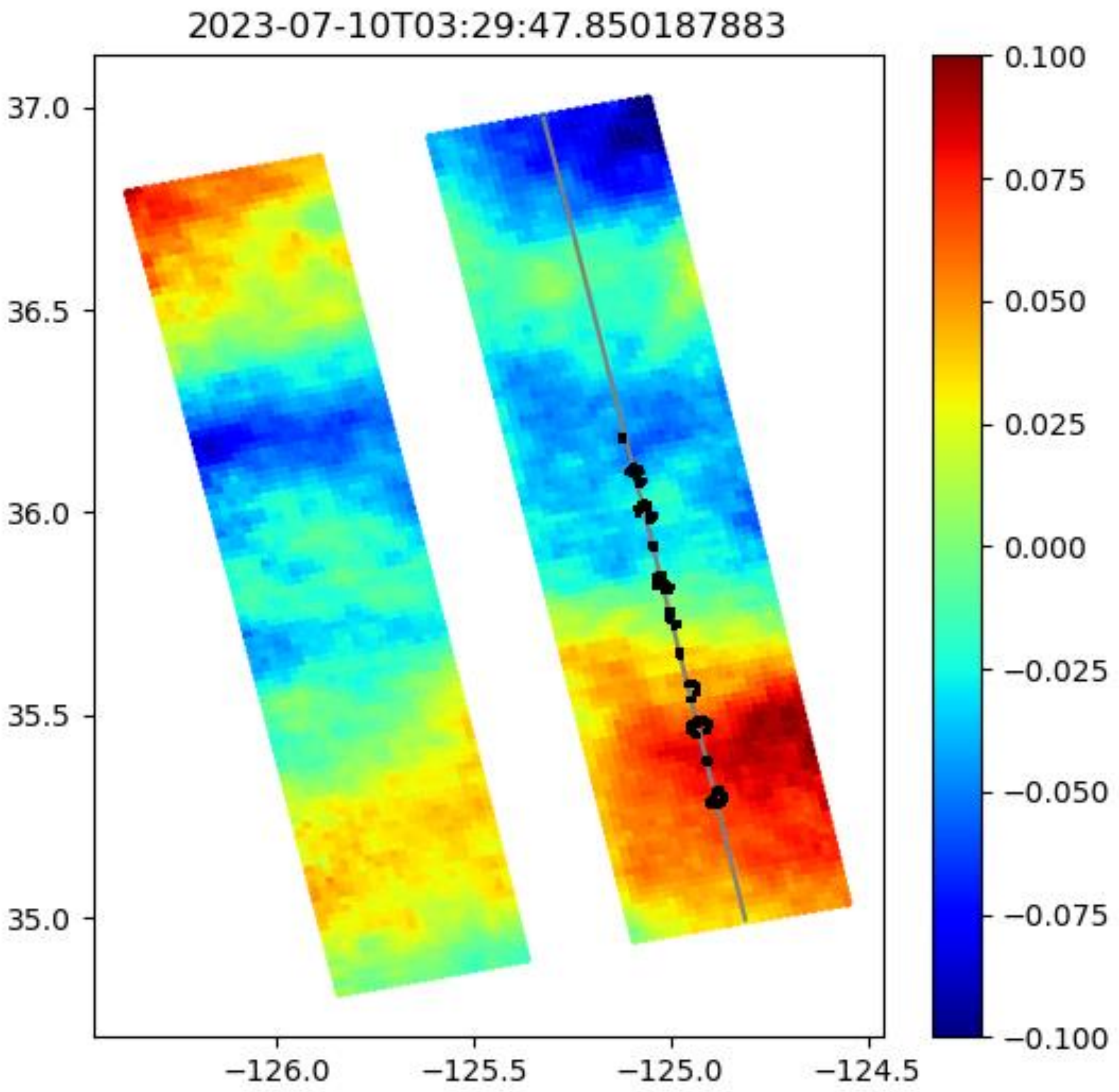



PMEL/NOAA Prawler (GPS+Prawler)


Slocum gliders (Rutgers)
27

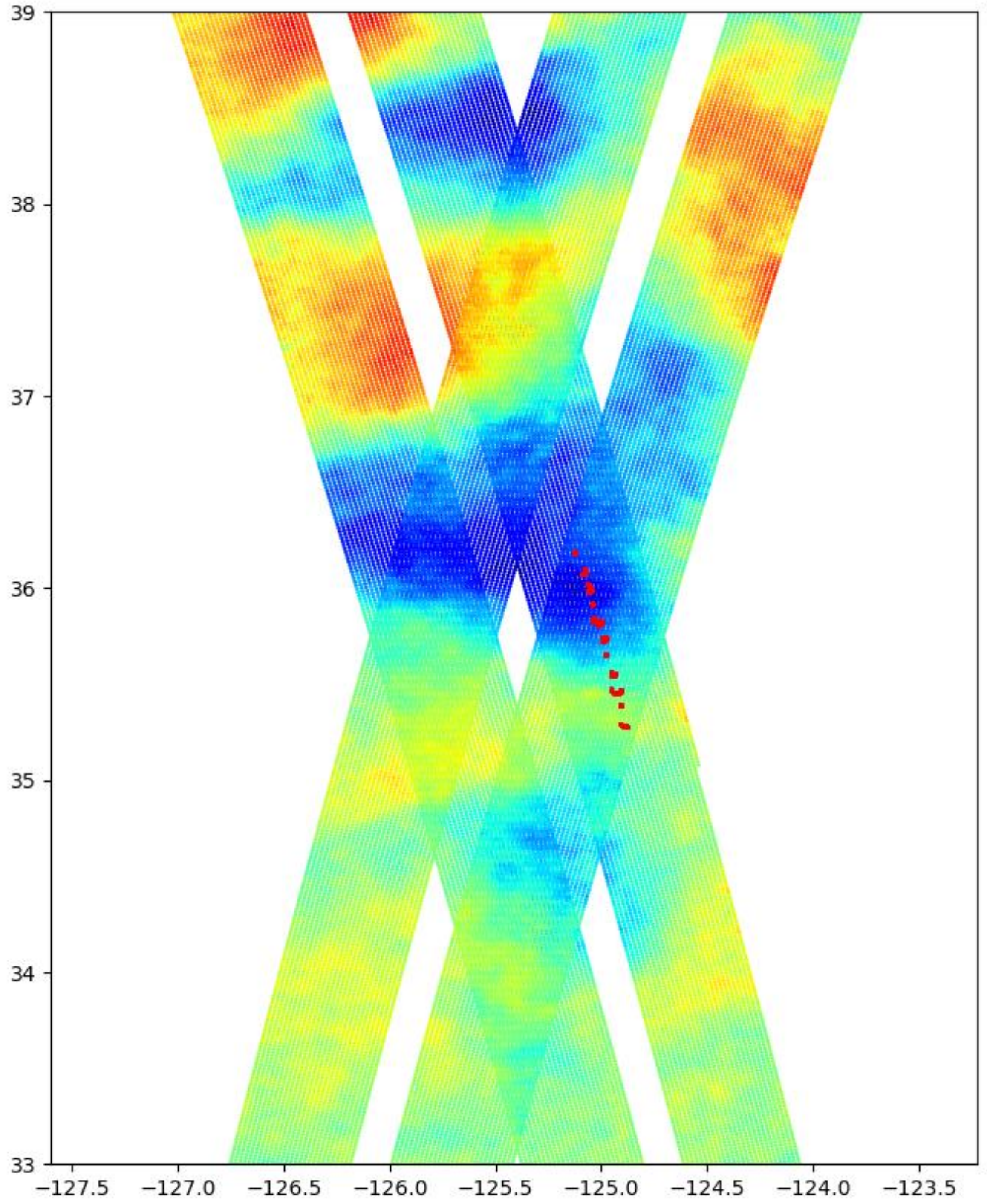

1000kHz Signature
RBR Concerto CTD
Real-time Tx
500m
800m
800m
0m
500m
1300m
2100m
2500m
3000m
3500m
4000m
75kHz ADCP
SBE37
RBR SoloT
Deep Aquadopp
Wirewalker
SIO deep mooring
(Wirewalker + fixed CTD)
Mooring Positions SWOT Post-Launch Cal/Val
36.250
36.000
-125.000
-124.750
-124.500
S1
P1
P2
S2
P3
P4
S3
P5
P6
S4
P7
-4500 m
-4400 m
-4300 m
-4200 m
-4100 m
-4000 m
-4700 m
-3700 m
-3900 m
0
30
60 km

1. The black dots are the buoy GPS positions over three months.
2. They were placed along the center of the swath
3. Spatial deviations (watch circle) are less than 4km.



Put together

1. Interpolate KaRIn on to mooring locations
2. Interpolate mooring steric height on the KaRIn time axis
3. Use both passes (~12 h sampling)

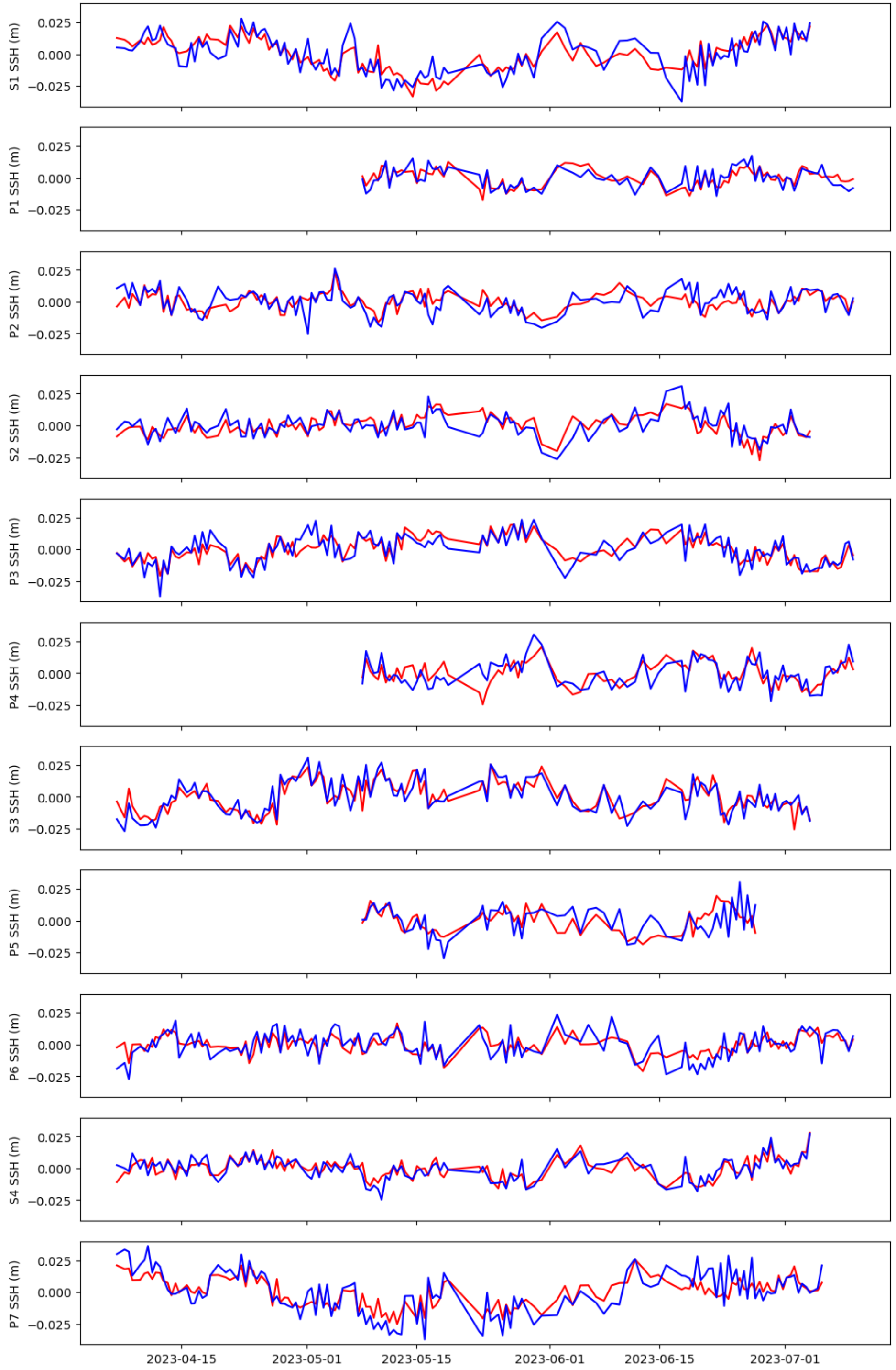


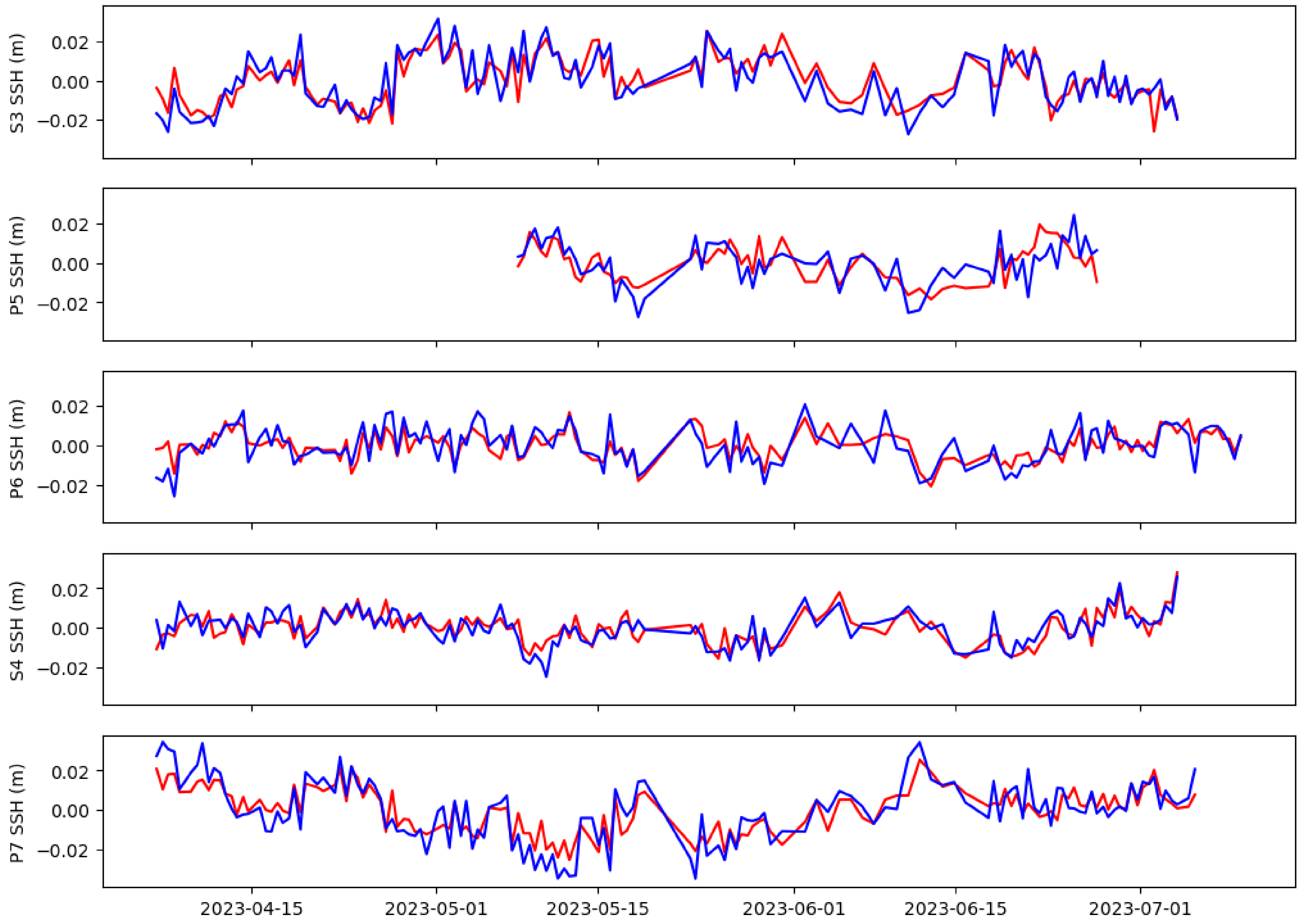
Blue: SWOT KaRIn
Red: In-situ mooring steric height

Two time series exhibit a mm-level difference in their covariation

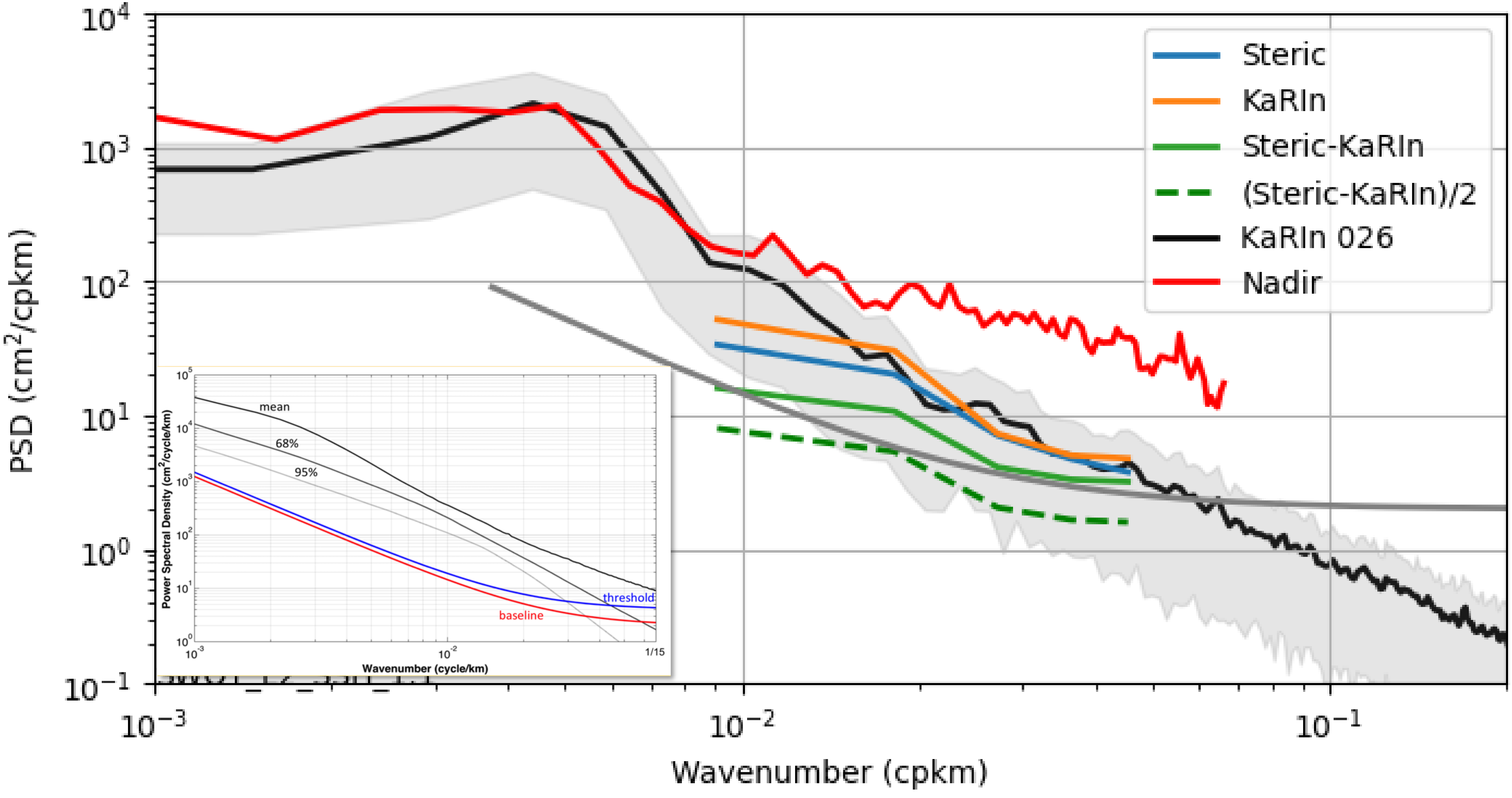
RMS difference: 0.74±0.19 cm
For spatial scales <100km

SWOT_L2_LR_SSH_1.0





S3 SSH (m)
P5 SSH (m)
P6 SSH (m)
S4 SSH (m)
P7 SSH (m)
0.02
0.00
−0.02
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01



PSD (cm^2/cpkm)
Wavenumber (cpkm)
Steric
KaRIn
Steric-KaRIn
(Steric-KaRIn)/2
KaRIn 026
Nadir
mean
68%
95%
threshold
baseline
Power Spectral Density (cm^2/cycle/km)
Wavenumber (cycle/km)
1/15

Conclusion

1. SWOT KaRIn meets the science requirement for wavelength <100km
2. SWOT SSH at <100km is connected to ocean dynamics
3. Spatial and temporal separation is sufficient to remove KaRIn errors
4. Science orbit data do not yet have a record long enough to construct a time mean. Residual small-scale MSS can be a challenge.
5. Small-scale wet tropo correction and SSB are unknown but less likely to be an order-one threat for <100km
6. Correlated error needs more scrutiny for ~100-500km scales.

Future work

1. Recalibrate S and P moorings using the recovered data and ship CTD casts
2. Use 11 gliders to extend the wavelength range to 2km – 150km wavelength
3. GPS for SSH, wet tropo, swh validation
4. Two barometers for IB correction evaluation
5. Package the in-situ and swot data for regional validation and other SWOT working groups
6. Process-oriented studies (tides, internal waves, eddies, the vertical structure of different processes), how can SWOT SSH be used for studying those processes?
7. Go beyond spectra, enjoy the benefit of wide-swath!