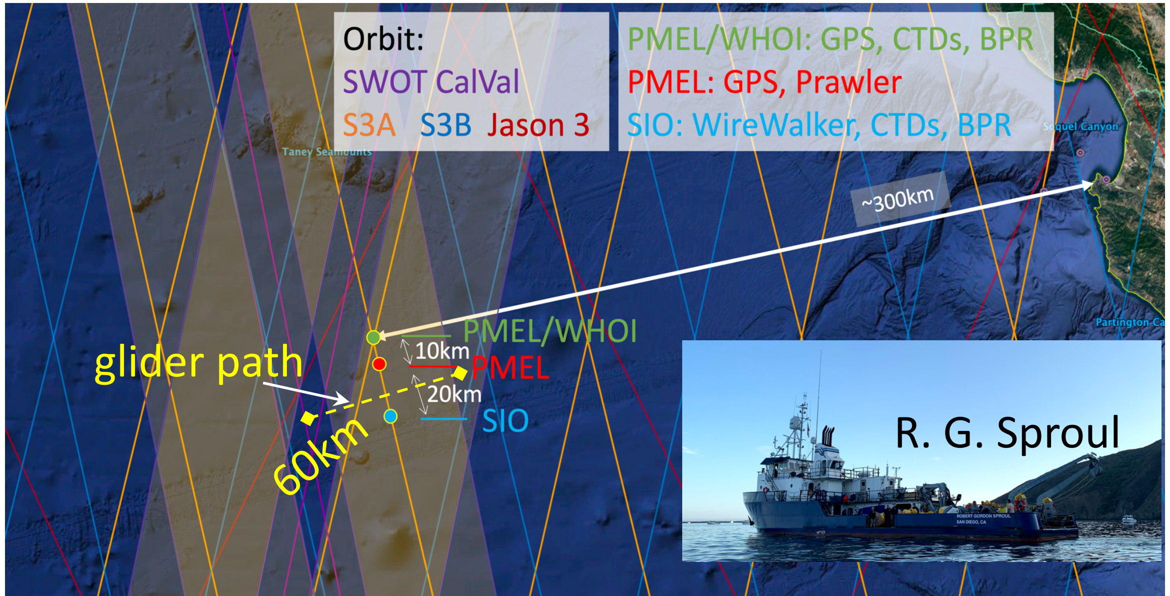
Measuring SSH at sub-centimeter level using in-situ platforms in preparation for the SWOT post-launch SSH Calibration and Validation

Jinbo Wang, Lee-Lueng Fu, Bruce Haines
Jet Propulsion Laboratory, California Institute of Technology

OSTST 2020, Splinter III

1. SWOT SSH calibration and validation is challenging because of the difficulty in reconstructing the ground truth of the small amplitude SSH at the SWOT scales (15 – 150km) for synoptic wavenumber spectrum calculation. One needs to capture the snapshots of the spatial SSH structure over a ~ 100 km distance within one hour of the satellite fly-by.
2. The mission has conducted pre-launch field campaigns to test the feasibility of different instruments and platforms in meeting the SWOT SSH CalVal requirement.
3. The 2019-20 pre-launch field campaign deployed three moorings with various instruments (Figure) in the open ocean 300 km off Monterey Bay, the location for the main post-launch CalVal campaign.
4. Based on the analyses of the observations, a minimum baseline design was proposed.

Related OSTST presentations:
Morrow et al., Archer et al., Li et al., Haines et al.



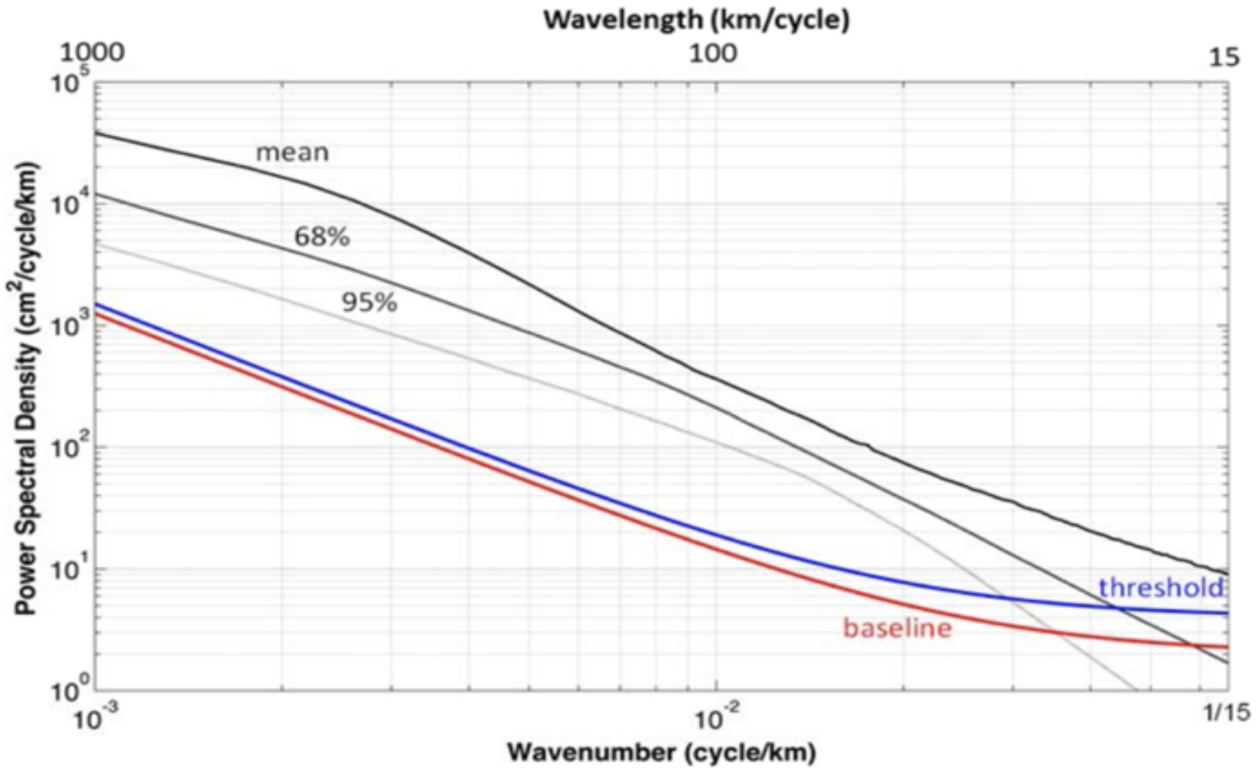
SWOT Pre-launch field campaign (Sep 2019 – Jan 2020)

Reference:
Wang et al., 2020, On the development of SWOT short-wavelength calibration and validation of the ocean topography based on in-situ observations (to be submitted)

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

SWOT mission science requirement

The mission CalVal target: the spectrum of the difference between satellite measurements and the ground truth is below the red (baseline) or blue (threshold) lines.



The SSH baseline error requirement spectrum (red line) as a function of wavenumber (Rodriguez, 2016; Desai, 2019). The thick black line is the mean spectrum of the Jason-2 altimeter track 159, which extends from the Southern Ocean to North Pacific. The 68% and 95% percentile are marked by the thin black line and the gray line. The red curve defines the baseline requirement represented by $E(f)=2+0.00125\ k^{-2}$.

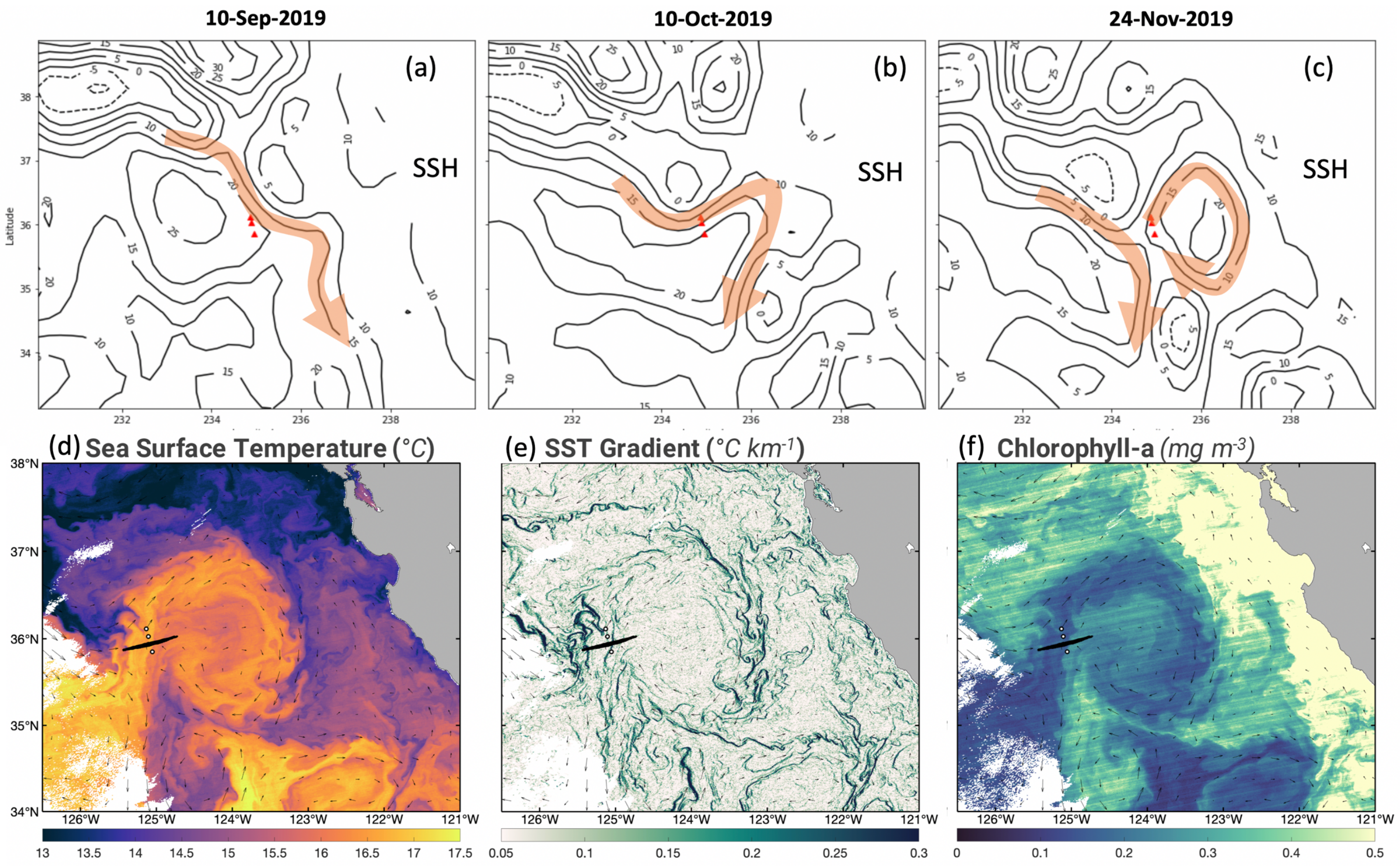
Prelaunch field campaign objectives

1. Test the SSH closure with GPS buoy, CTD mooring, and BPR
2. Evaluate the vertical scale of 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.

#1, 2, 4, 7 are presented here.

Large and mesoscale environment

1. (a)-(c) show the AVISO sea level anomaly (SLA) on 09/10/2019, 10/10/2019, and 11/24/2019 corresponding to the beginning, middle and end of the campaign.
2. The thick orange arrows indicate the formation of a coherent eddy from the meander of the California Current.
3. Panel (d) and (e) show the (VIIRS L2) SST and (MODIS) surface Chlorophyll-a on 11/24/2019 after the eddy was formed.
4. The SST is L2 without cloud removed. The three red triangles in panel (a)-(c) marked the three mooring locations. The black lines (60 km long) in (d) and (e) mark the glider flight path.



The closure of the SSH equation

Integrating the hydrostatic equation $\frac{dp}{dz} = \rho g z$ from the sea surface to the ocean floor, the SSH budget equation can be written as

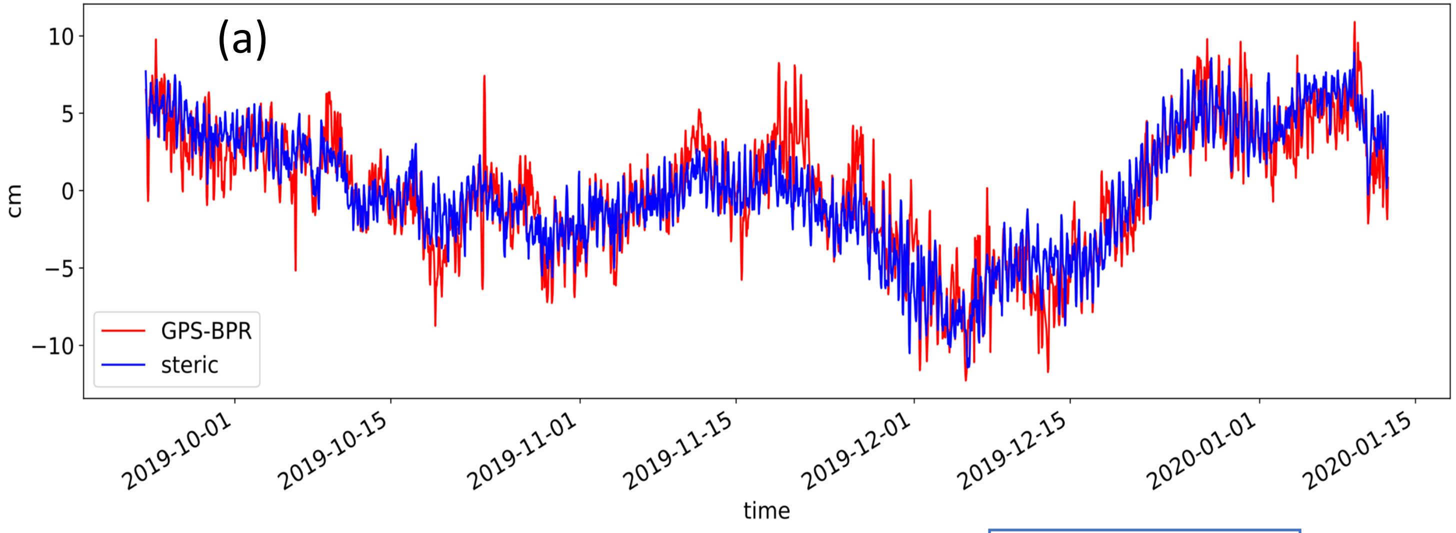
$$p'(-H) = \int_{-H}^{0} g\rho'\, dz + \rho_0 g\eta + p'_a, \qquad (1)$$

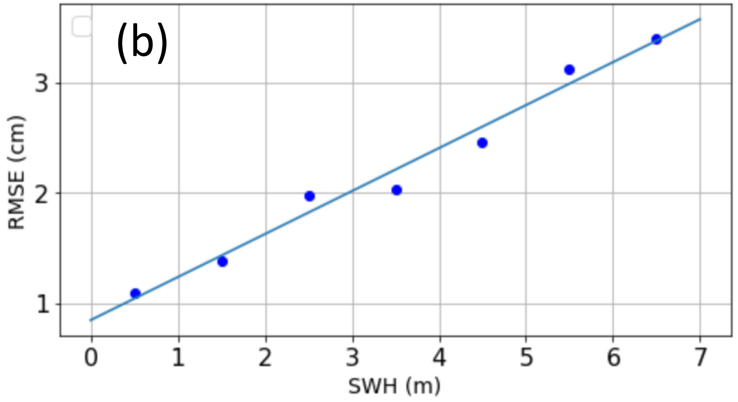
in which $-H$ is the depth of the ocean floor, ρ_0 the mean density, η is the sea surface height deviation from $z = 0$ with an amplitude of meters, ${p_a}'$ the atmospheric pressure anomaly. The anomalies are deviations from the time mean. The four terms in Eq. (1) represent bottom pressure anomaly, dynamic height anomaly, surface pressure anomaly due to the free surface, and atmospheric pressure anomaly. They are observables by BPR, moorings with CTDs, GPS and barometer, respectively. With the instrumentation in the pre-launch field campaign, we can examine the closure of this equation to calculate the error budget and test the instruments' capability.

Hypothesis: The SWOT-scale SSH that is related to ocean circulation is the upper-ocean steric height.

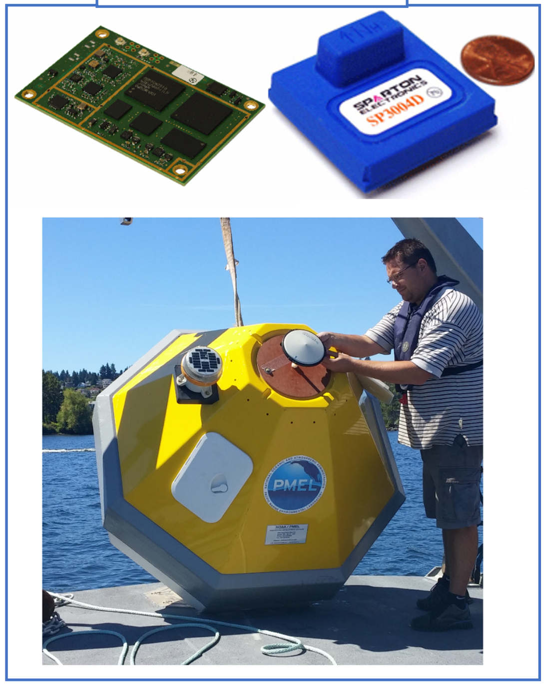
GPS evaluation

1. Panel (a) GPS-BPR together with atmospheric pressure and high-resolution geiod correction can largely match the CTD-derived full-depth steric height.
2. The difference between the red line (GPS-BPR) and the blue line (full-depth steric height) is a function of SWH (panel b).
3. Panel b: the GPS-BPR can derive a full-depth steric height with ~ 1 cm error for calm seas (SWH<1m).
4. These errors come from periods of 1-10 days (figure not shown) most likely due to the influence of transient weather systems and sea state on the GPS measurements.





(c) The GPS buoy



Vertical scales

How deep do we need to measure?

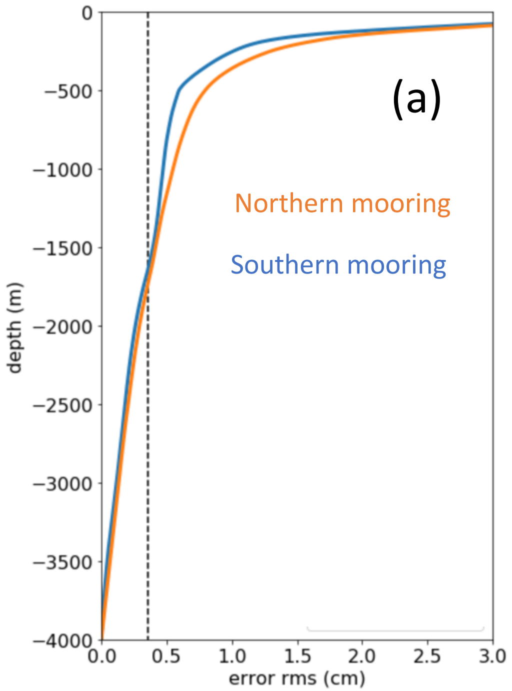
1. Using the upper 1600m steric height to represent the full-depth steric height introduces 0.36 cm error RMS (dash line in Panel a), meeting the SWOT baseline requirement (convert 2cm^2/cpkm to single0station error rms).
2. The RMS difference between the upper 500m and full-depth steric height is 0.85 cm and 0.6 cm for the northern and southern mooring, respectively.
3. Most these RMS difference is from high-frequency motions such as the M2 tide (panel b), which has large spatial scales (>100 km).

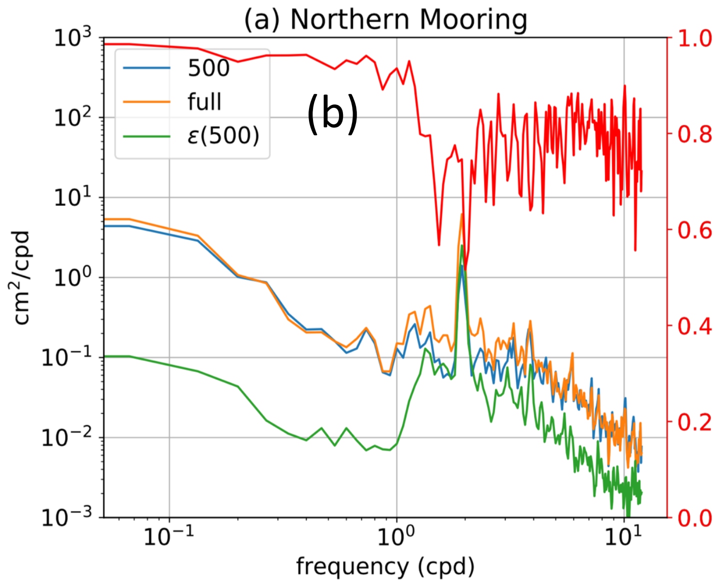
We quantify the error of the approximation $\epsilon(z)$ using the difference between upper ocean steric height integrated from surface to a certain depth z (denoted as ξ_z), and the full-depth steric height (denoted as ξ_b):

$$\epsilon(z) = \mathrm{rms}(\xi_z - \xi_b),$$

$$\xi_z = -\int_{-z}^{0} \frac{\rho'(z')}{\rho_{ref}}\, dz',$$

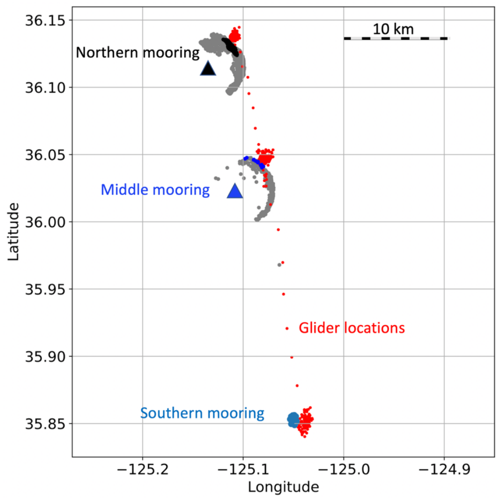
where ρ' is the in-situ density anomaly deviate from a reference density ρ_{ref}, which is set to 1035 kg/m^3 here. $\epsilon(z)$ is also equivalent to the contribution of the deep ocean (<z) to the full-depth steric height. The $\epsilon(z)$ based on the northern and southern mooring is shown in panel (a).





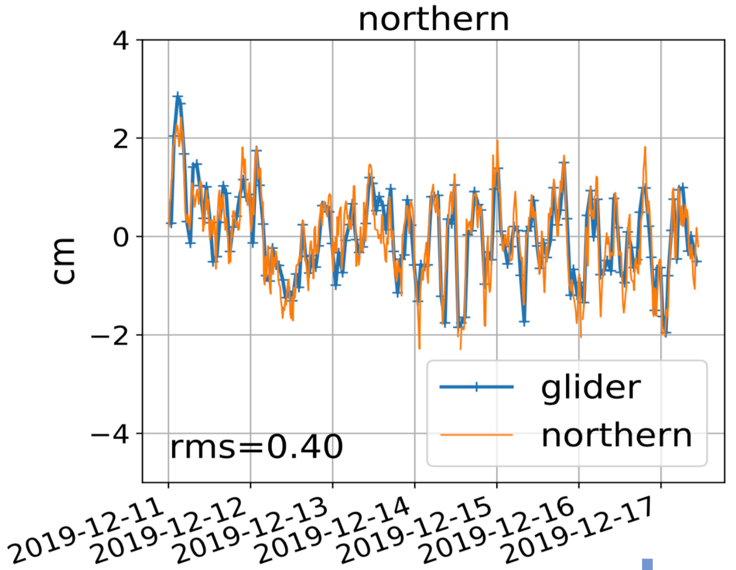
The frequency spectra of 500m (blue), full-depth (orange) steric height and their difference (green) and coherence (red). The difference (green) is the *ϵ500*.

Station-keeping glider as a virtual mooring

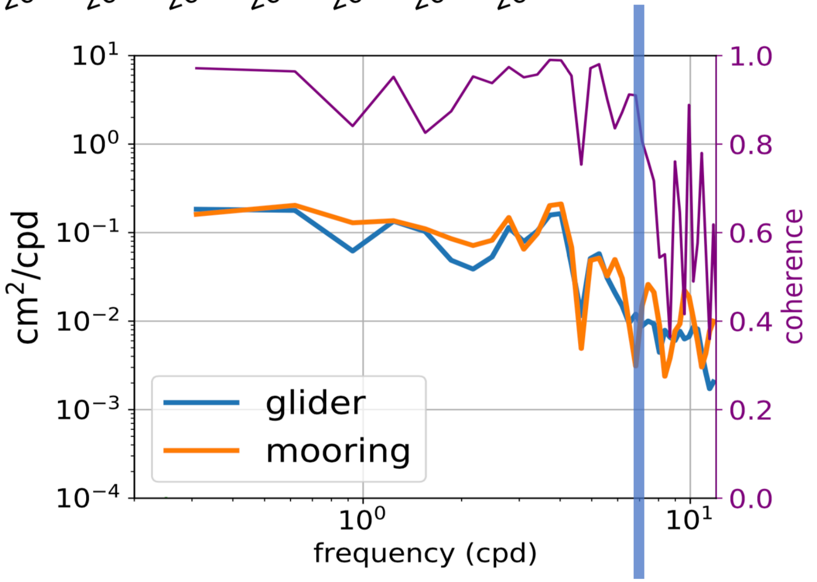


The locations of the glider (red) and the northern (black), the middle (green, to add) and the southern mooring (blue) during the glider station-keeping phase 11/27/2019 - 12/17/2019. The mean separation distances during station keeping phase are 0.9 ± 0.2 km, 0.8±0.4 km, and 1.2 ± 0.2 km for the northern, middle and southern mooring, respectively. The two triangles indicate the anchor locations of the middle and northern moorings. The mooring watch circle indicated by the gray dots has radius about 4 km.

The northern mooring has high temporal resolution. The glider reproduced the northern mooring upper-500m steric height with a small RMS different of 0.4 cm.



The purple line shows the coherence between glider and mooring steric heights. The glider reconstruction can reproduce the mooring steric height to high frequency (6 cycle/day).



SWOT Post-launch field campaign minimum baseline

- Based on the 2019-20 prelaunch field campaign results, the design of the minimum baseline will consist of four full-depth moorings with 30km separation (orange triangles), seven profiler moorings sampling the upper 500m (blue squares), two gliders (arrow lines), and a barometer at the center of the array.
- The full-depth mooring will capture the large-scale, deep-reaching, high-frequency variabilities, mostly from baroclinic tides.
- 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.