National Aeronautics and Space Administration

Observing variability in significant wave height with SWOT

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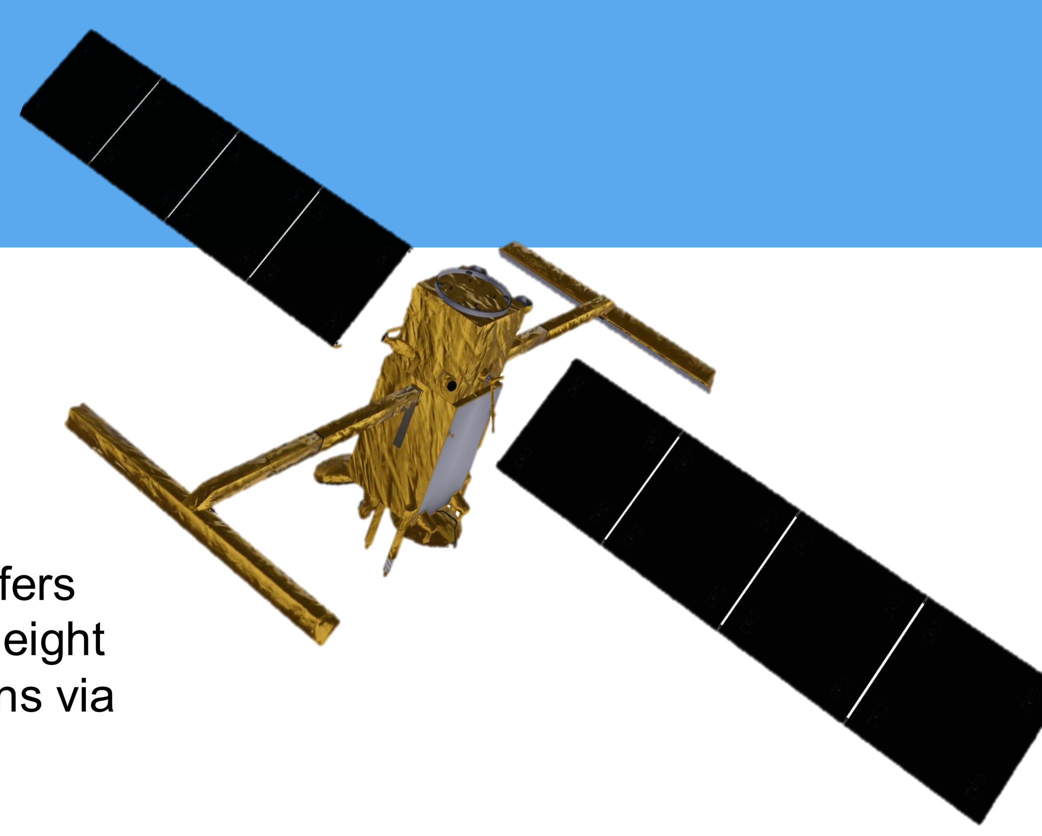
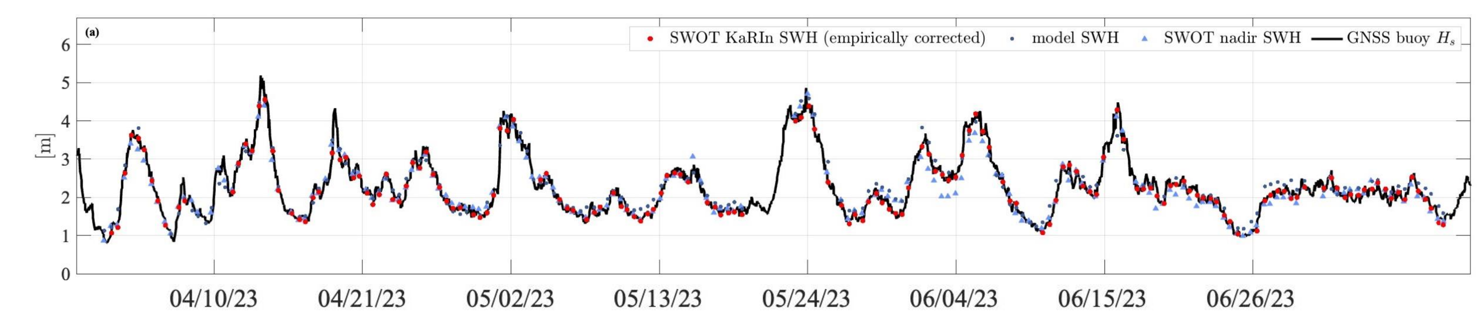


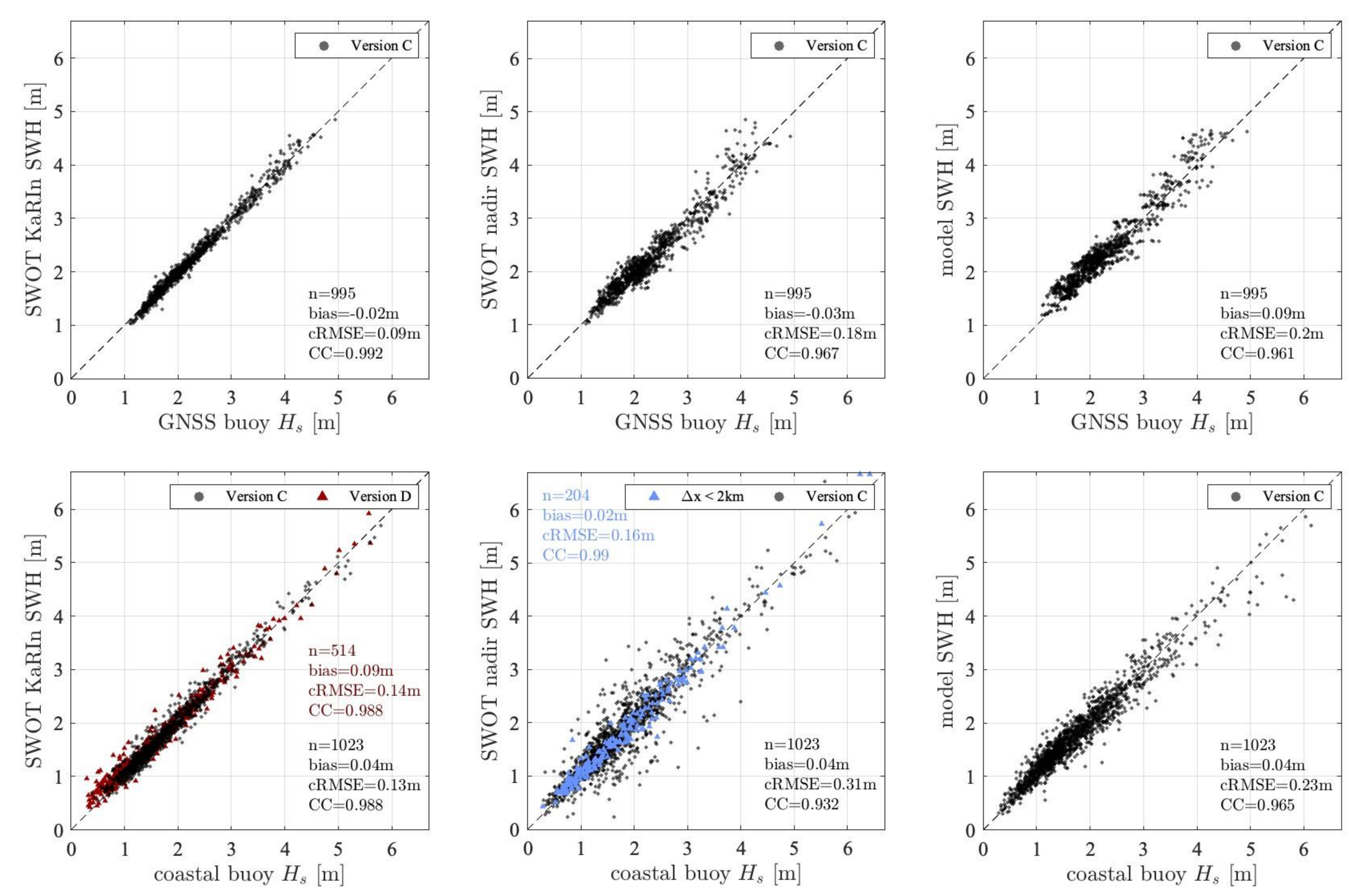
Background

Ocean surface wave climates are shaped by both atmospheric forcing and underlying ocean conditions. Variability in open-ocean wave heights subsequently reflects complex interactions occurring across a broad range of spatial and temporal scales. Many of the processes driving this variability take place at small spatial scales that have been previously poorly resolved by sparse altimetry observations and coarse global wave models. The Surface Water and Ocean Topography (SWOT) mission offers a new opportunity to observe variability at these scales with unprecedented two-dimensional measurements of significant wave height (SWH) from the Ka-band radar interferometer (Bohe et al. 2025). The objective of this work is to validate SWOT SWH observations via comparison to in-situ observations and connect the small-scale spatial variability observed with SWOT to ocean dynamics.

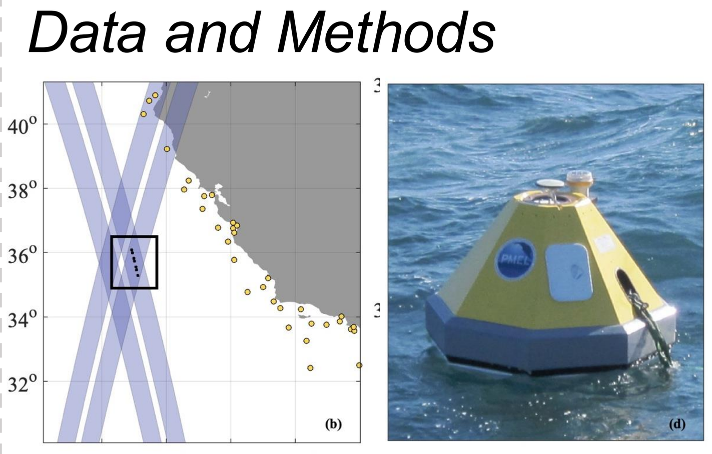
Validation to In Situ Wave Observations

We evaluate the accuracy of SWOT's KaRIn SWH estimates by comparison to in situ wave measurements. SWOT KaRIn SWH measurements are validated with high fidelity to in situ H_s from an array of GNSS buoys at the California crossover calibration site. Performance is consistant in additional comparison to a network of coastal wave buoys. After empirical correction for known biases in Version C products, the centered root-mean-square error ranges from 0.10 to 0.17 m across the various datasets and product versions, with correlation coefficients exceeding 0.98. The high resolution, two-dimensional observational coverage from SWOT better represents SWH than either SWOT's nadir altimeter or global numerical wave models run without currents.

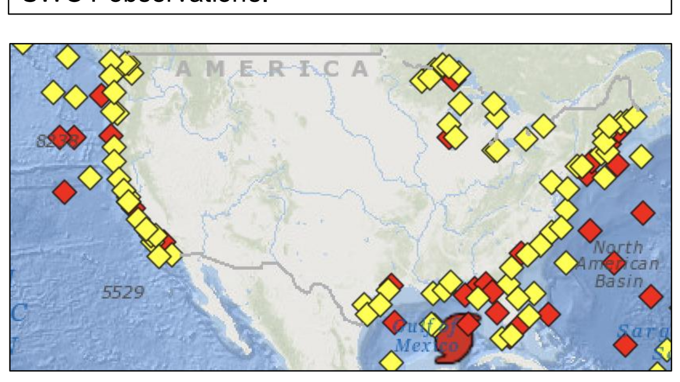




Data and Methods



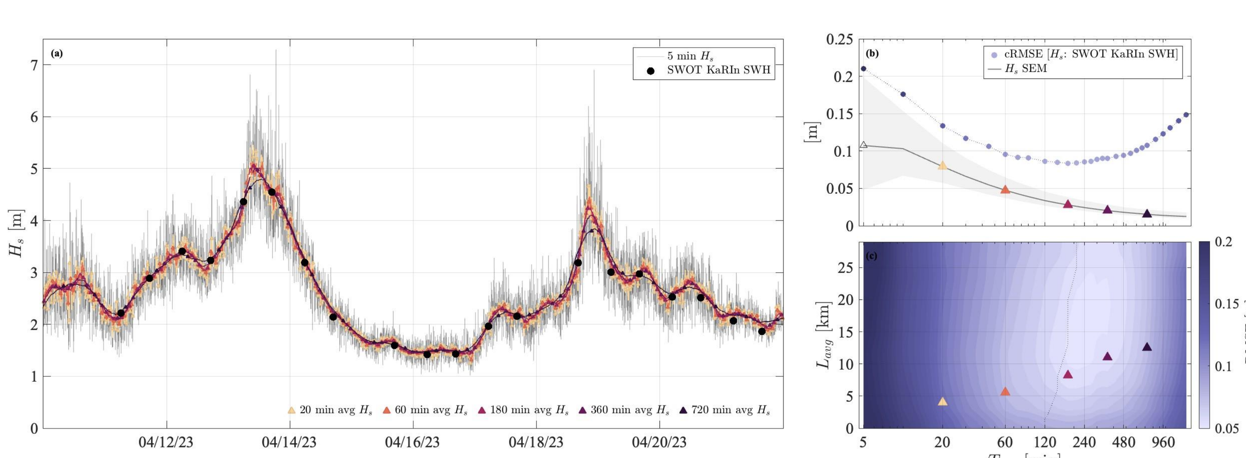
7 GNSS buoys at California crossover during Cal/Val orbit resolve scales 10-90km, 3 months of twice-daily SWOT observations.



Over 200 NDBC moored coastal accelerometer - based wave buoys in deep and shallow water, 1.5+ years SWOT observations.

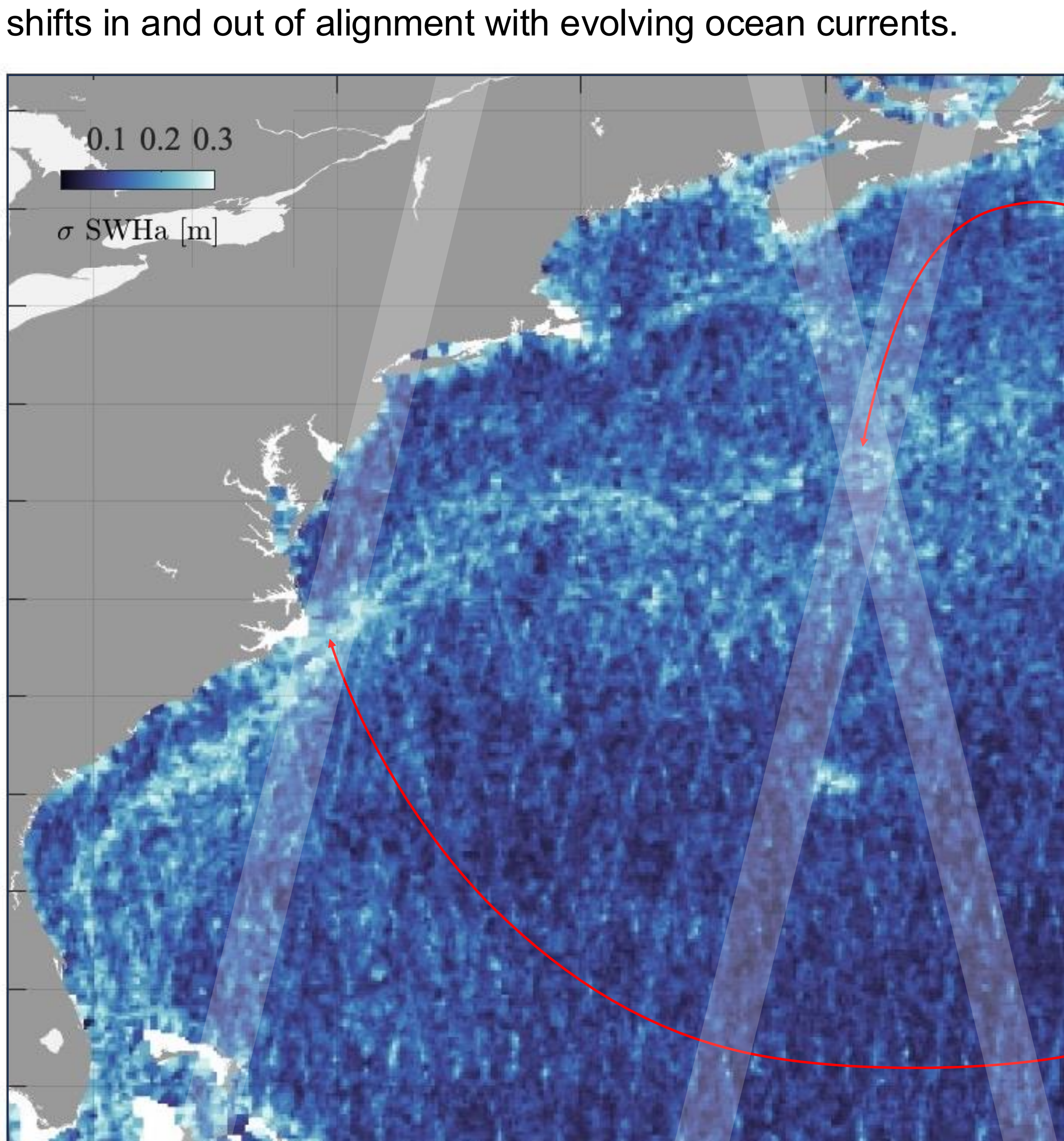
In Search of a 'Ground Truth'

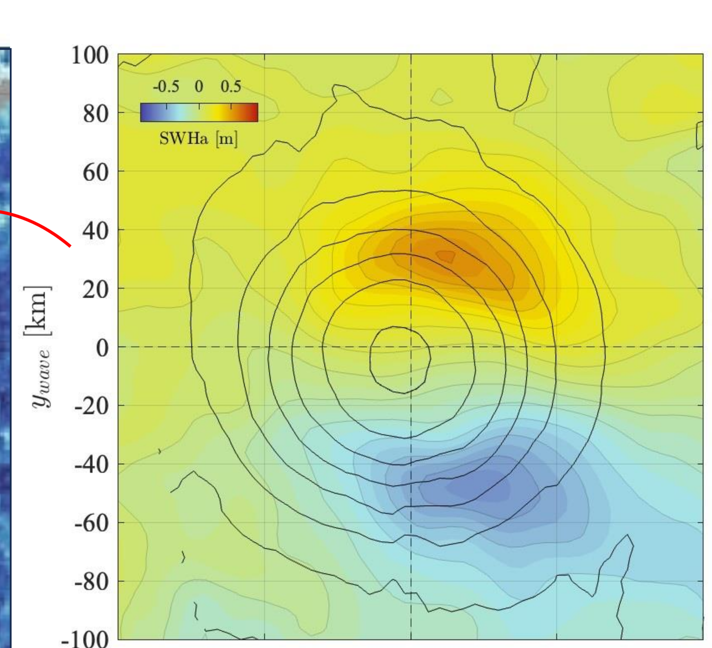
SWH and H_s and are computed from distinct methods that sample different aspects of a temporally and spatially varying wave field. Agreement between SWOT KaRIn and GNSS buoy observations of significant wave height is sensitive to both spatial and temporal averaging scales. The cRMSE between SWOT KaRin *SWH* and GNSS buoy H_s is minimized for temporal averaging windows T_{avg} between 2 to 8 hours and spatial averaging windows L_{avg} between 5 to 30 km. Optimal spatial averaging scales increase with longer temporal averaging windows.



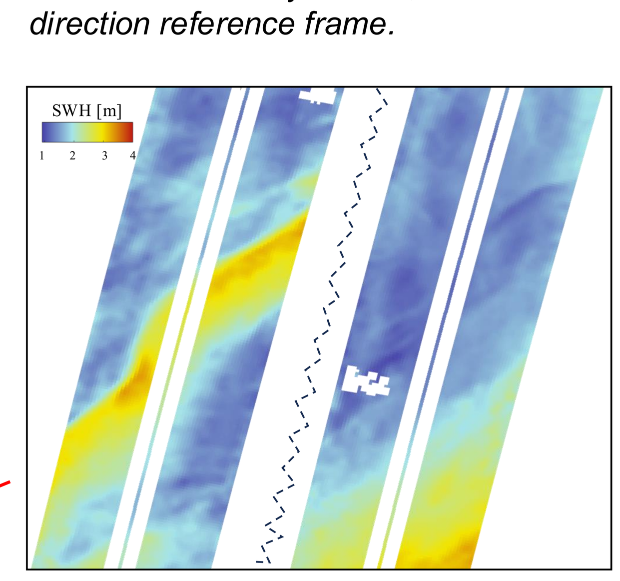
Observing Variability and Intermittency in SWH with SWOT

Small-scale variability in SWH has been linked to interactions with submesoscale ocean currents. SWOT KaRIn observations of SWH and SSHA enable direct collocation of wave variability with underlying circulation for exploration of wave-current interactions (e.g. Boas et al. 2025). SWOT reveals enhanced gradients and variance over boundary currents and other energetic regions. This variability is intermittent, appearing and disappearing as the incident wave direction shifts in and out of alignment with evolving ocean currents.





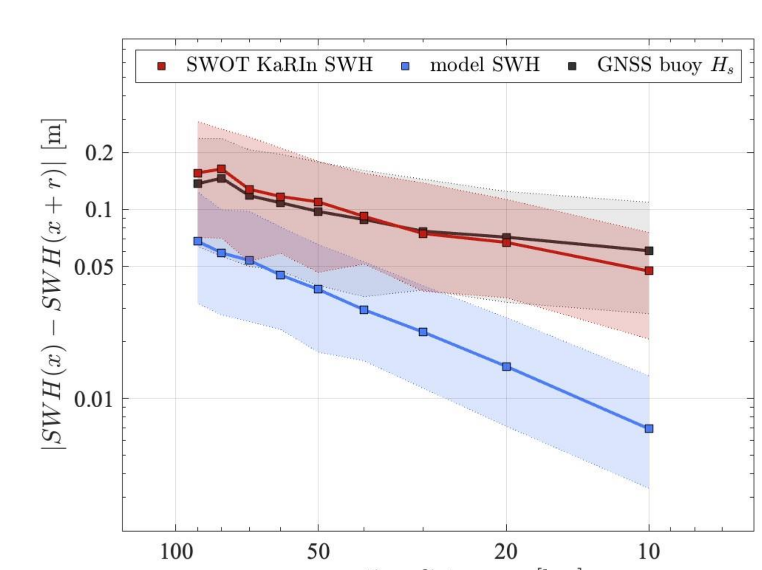
SWH modulation by mesoscale eddy, rotated into to eddy-centric, wave-direction reference frame.

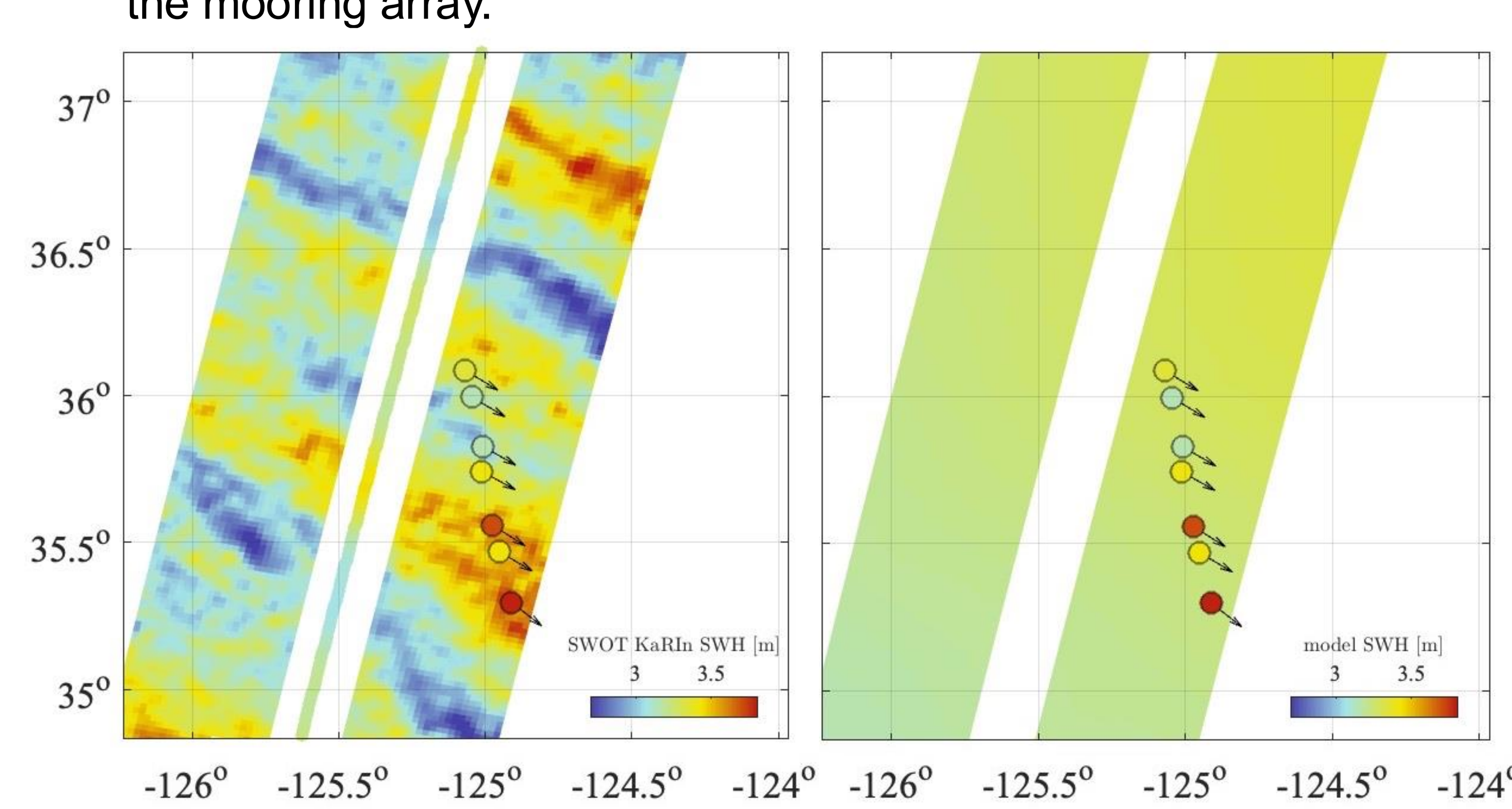


SWH amplification over Gulf Stream observed 5 days apart.

Fine-Scale Spatial Gradients

SWOT resolves small-scale spatial features in wave height observed across the GNSS buoy array but not captured in coarse global wave model. Structure function analysis finds SWOT KaRIn successfully captures in situ SWH variance down to scales of 10 km, the resolution limit of the mooring array.





References

Ho A, Wang J, Haines B, Wu A, Stalin S (in review) In situ validation of small-scale spatial variability in significant wave height observations from SWOT.

Bohé, A., Chen, A., Chen, C., Dubois, P., Fore, A., Molero, B., Peral, E., Raynal, M., Stiles, B., Ardhuin, F. and Hay, A., 2025. Measuring Significant Wave Height fields in two dimensions at kilometric scales with SWOT. IEEE Transactions on Geoscience and Remote Sensing.

Bôas, A.B.V., Marechal, G. and Bohé, A., 2025. Observing Interactions Between Waves, Winds, and Currents from SWOT.

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