Preliminary results from GNSS processing at the Southern Ocean SOFS site

in preparation for SWOT validation

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The Southern Ocean Flux Station (SOFS)

What

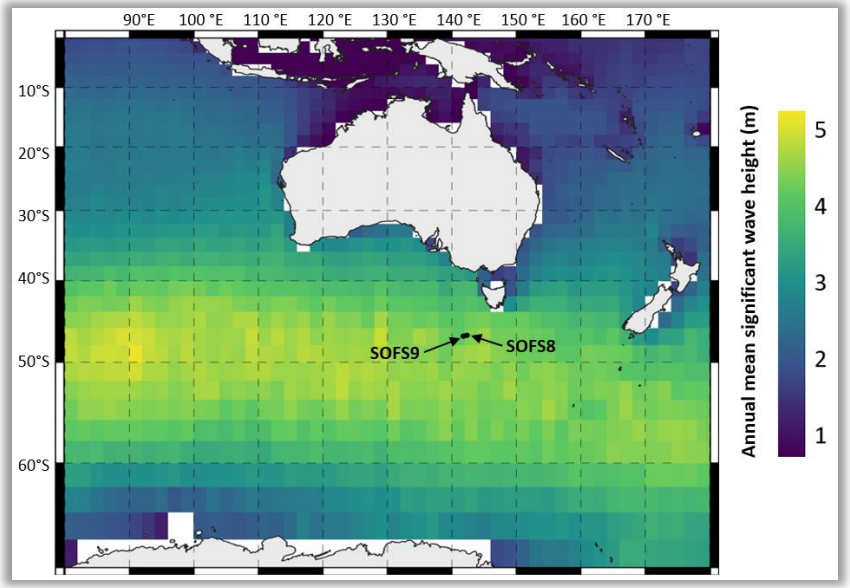
- SOFS is a deep sea mooring, first deployed in 2010, to measure air-sea fluxes in the extreme environment of the Southern Ocean.
- The addition of a GNSS receiver in 2019 gives us the opportunity to observe the sea surface position at a rate of 2 Hz.
- We use data from SOFS8 and SOFS9 deployments (2019-03 to 2021-04)

Where

- SOFS is redeployed every year in the sub-Antarctic Zone, ~500 km southwest of the island of Tasmania (Australia).
- The consistent westerly winds generate strong wave activity, with a mean SWH of 5 m during winter, and individual waves of over 20 m observed.

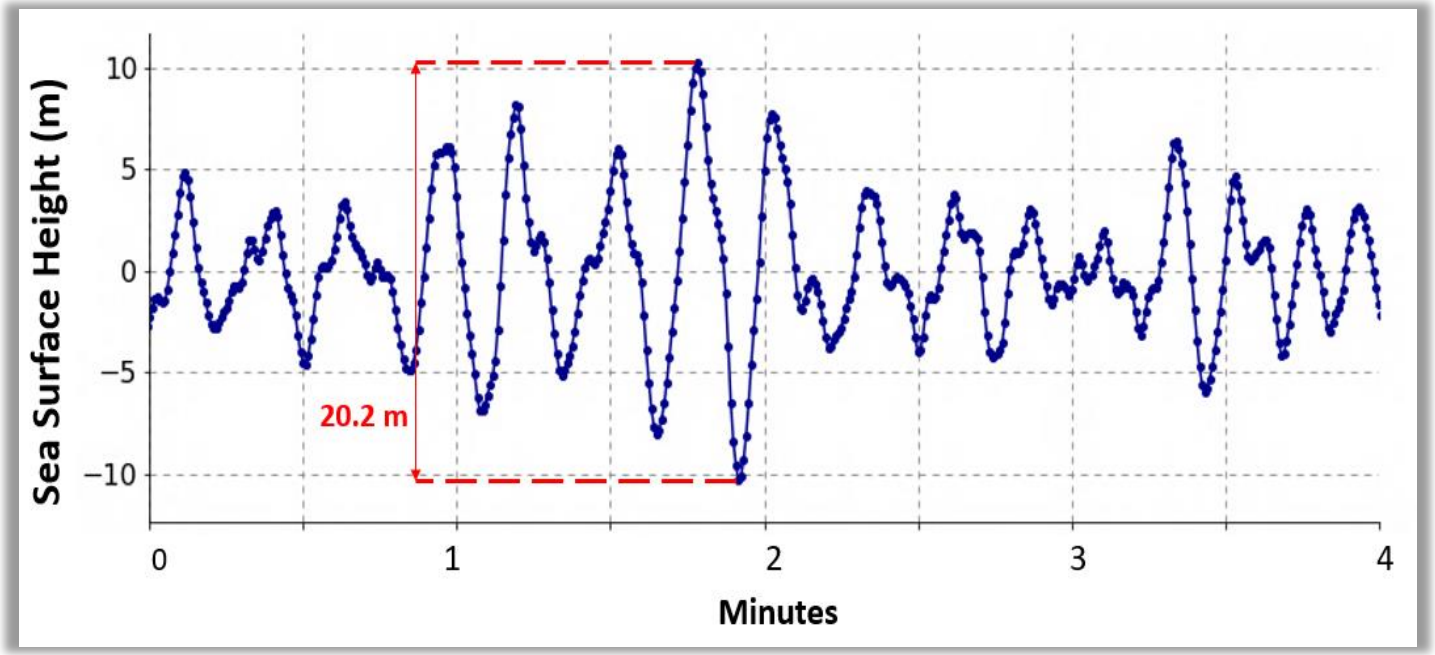
Objectives

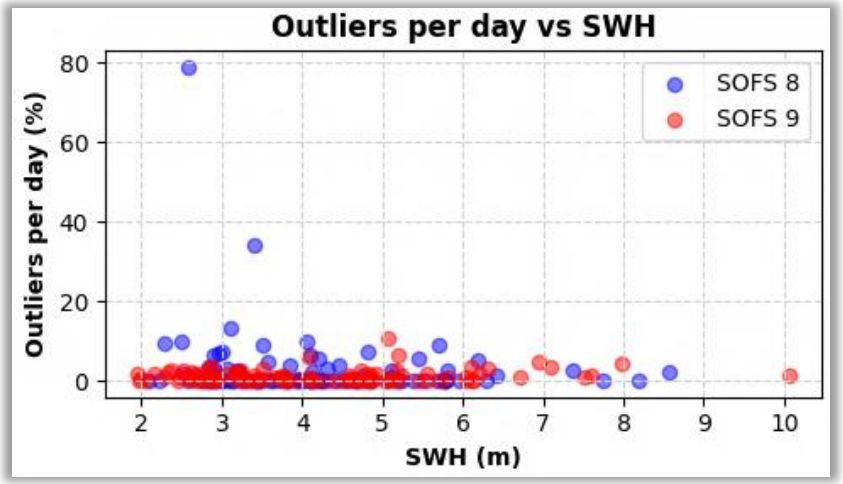
- Here we investigate the potential of this GNSS data as an in-situ validation point for satellite altimetry.
- We demonstrate the ability to estimate significant wave height (SWH), directional spectra and sea surface height (SSH) from the GNSS positions.
- Finally we show some preliminary comparisons to the CFOSAT SWIM and nadir altimetry products.



GNSS processing

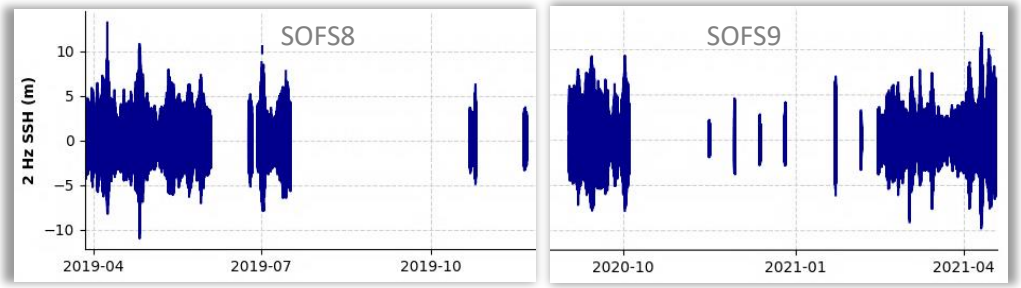
- We processed the GNSS data through GipsyX software (v2.0) using a kinematic Precise Point Positioning (PPP) approach.
- ~200 days of data were processed, with a median formal error of 21 mm in position.
- 2.1% of 2 Hz points discarded as outliers (identified as points with a formal error of greater than 40 mm).
- Data during extreme waves of over 20 m successfully recorded.





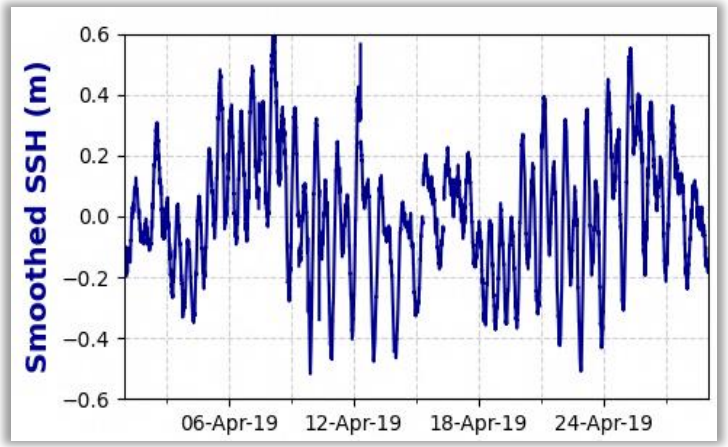
Data Summary

- Due to battery limitations, GNSS data could not continuously recorded for the whole initial deployments.
- Intermittent GNSS data was captured to prioritise altimetry over flights.



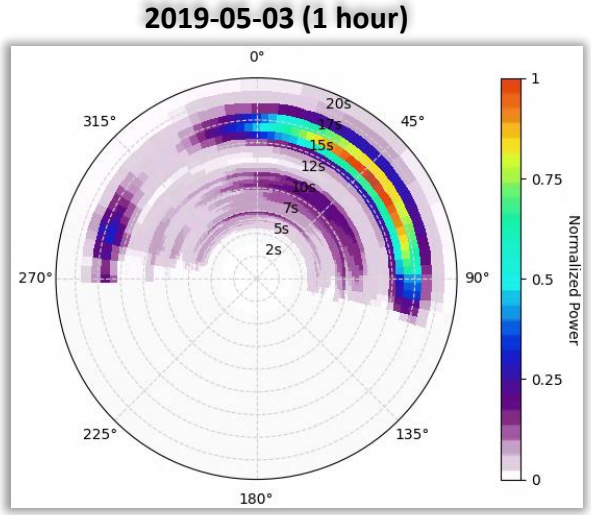
GNSS outputs and derived products

- From the 2 Hz positions, a range of products have been derived:



- **Smoothed sea surface height** from a 25 minute moving average filter to remove high frequency signals. From this, the tides, mean sea surface and inverse barometer has been removed to estimate **sea level anomaly**.

- **Significant wave height** calculated as four times the standard deviation of clean 2 Hz SSH estimates over a rolling one hour window.



- **Directional spectra** from the displacements in north and east, calculated over 5 minute segments and averaged over each hour. From this, **dominant direction** and **dominant wavelength** are determined.

SWH comparisons

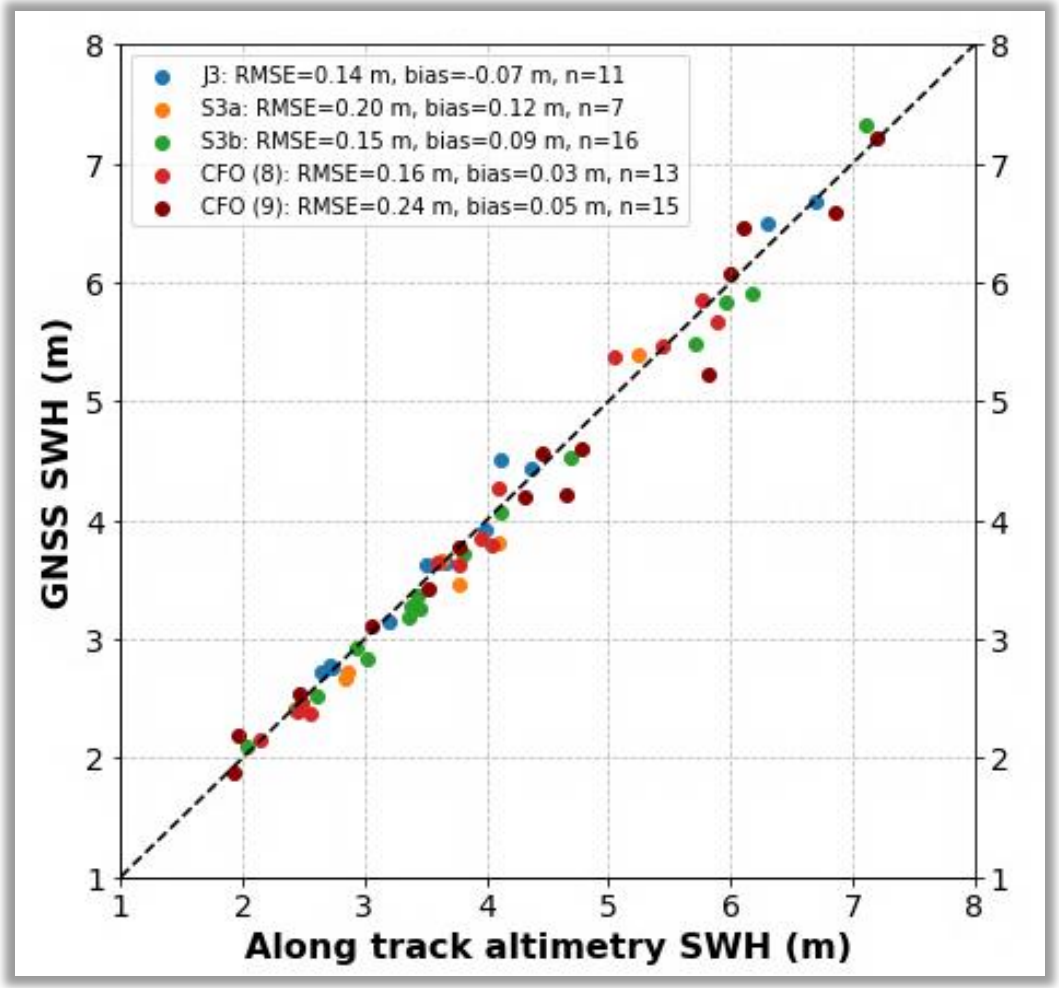
- The GNSS significant wave height (SWH) values were compared to the along track altimetry SWH estimates, and gridded altimetry SWH products

- The missions considered are:

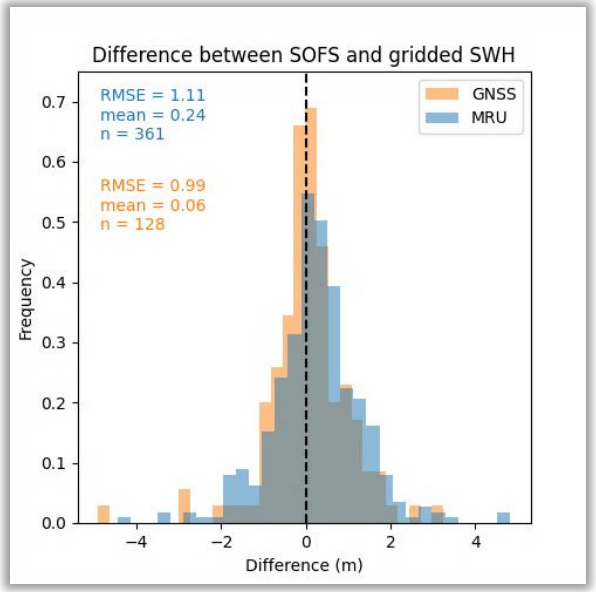
  SOFS8: Jason-3, Sentinel-3a, and CFOSAT (nadir altimeter)

  SOFS9: Sentinal-3b and CFOSAT (nadir altimeter)

- While acknowledging the sample sizes are small, **good agreement is seen for all missions**



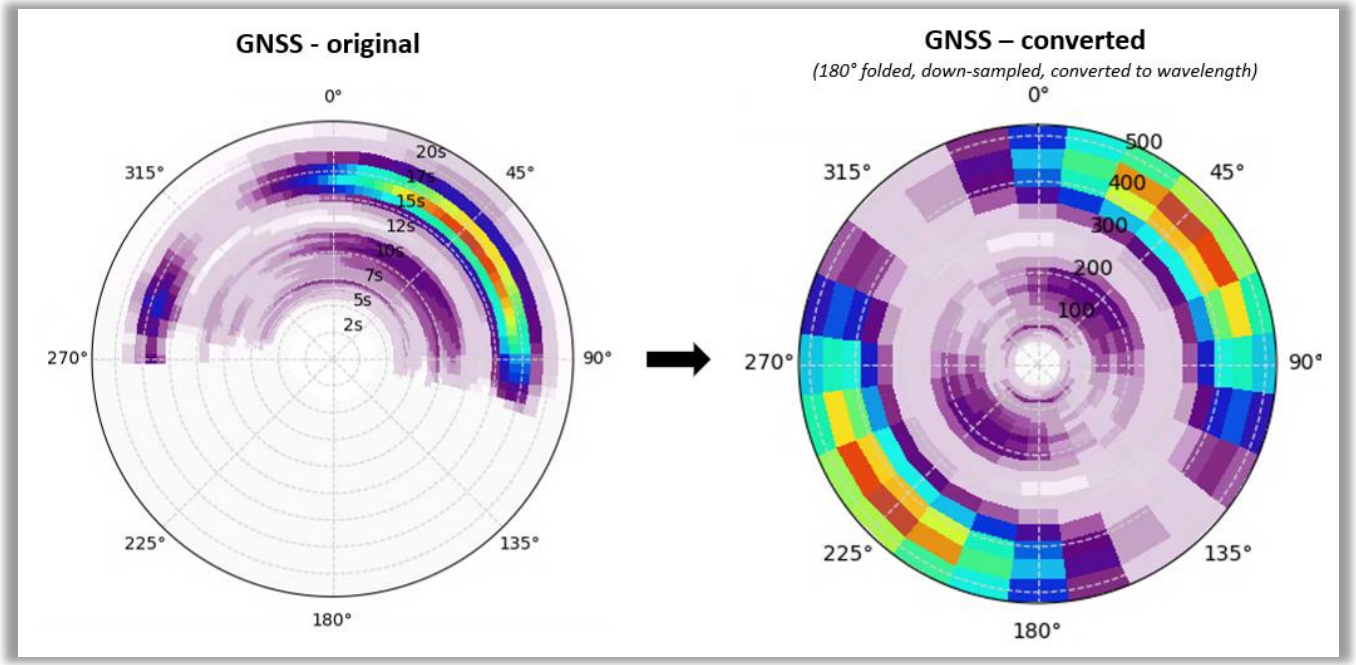
- The CMEMS gridded SWH product was compared to the GNSS SWH estimates, and to the *motion reference unit* (MRU) SWH estimates on board SOFS.
- Note the GNSS shows better agreement to the altimetry than the MRU.



SWIM comparisons

- Comparisons were made between the GNSS directional spectra and the CFOSAT SWIM ‘wave box’ product (L2PBOX).

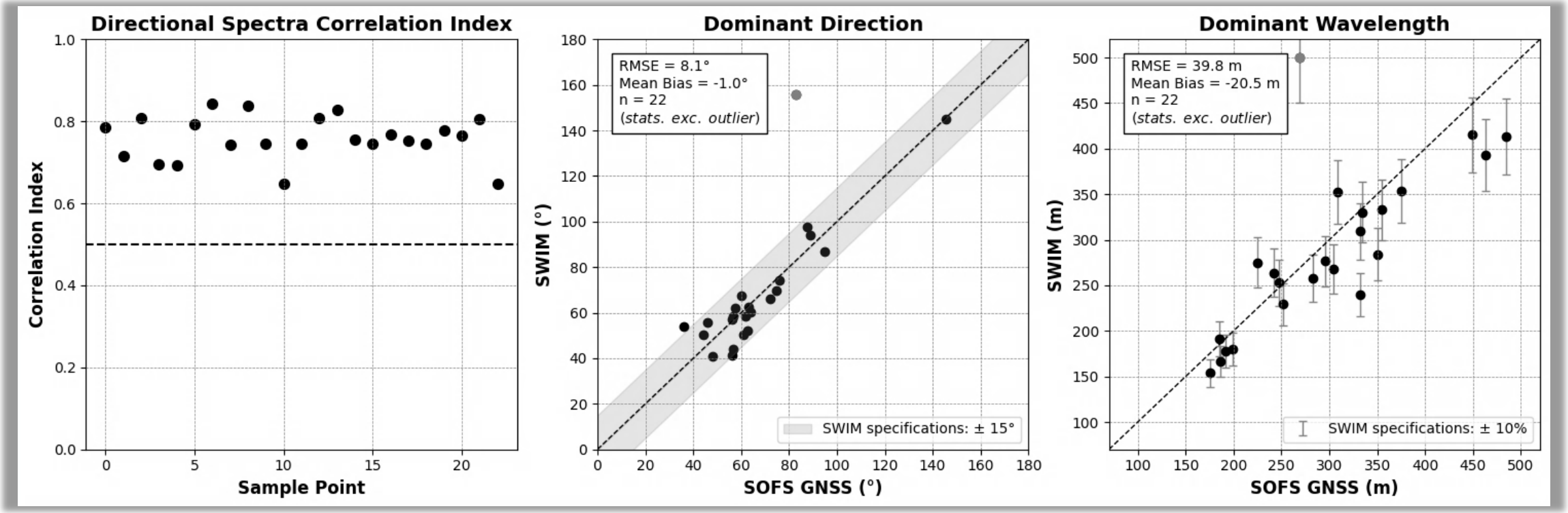
- The GNSS directional spectra was folded over 180°, converted from period to wavelength using the deep-water dispersion relation, and down-sampled to the SWIM resolution for comparisons.
- The agreement between SOFS GNSS and SWIM values was assessed using the correlation index, following Hauser et al. (2021).
- The dominant direction and wavelength were determined from the converted spectra using the weighted mean of the region around the peak that is at least 2/3 of the maximum energy value.



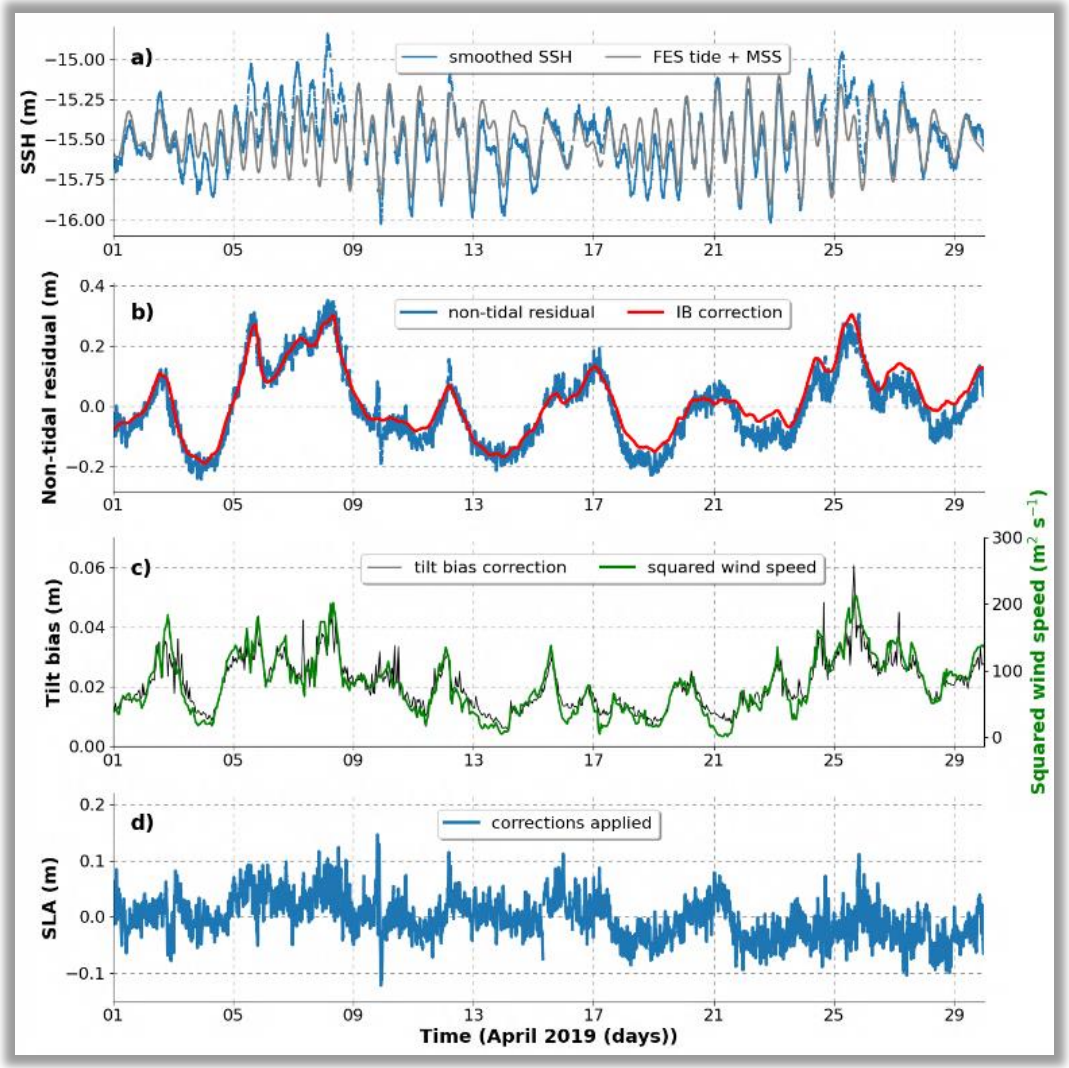
Hauser, D., Tourain, C., Hermozo, L., Alraddawi, D., Aouf, L., Chapron, B., Dalphinet, A., Delaye, L., Dalila, M., Dormy, E., Gouillon, F., Gressani, V., Grouazel, A., Guitton, G., Husson, R., Mironov, A., Mouche, A., Ollivier, A., Oruba, L., Piras, F., Rodriguez Suquet, R., Schippers, P., Tison, C., Tran, N., 2021. New Observations From the SWIM Radar On-Board CFOSAT: Instrument Validation and Ocean Wave Measurement Assessment. IEEE Trans. Geosci. Remote Sensing 59, 5–26. https://doi.org/10.1109/TGRS.2020.2994372

SWIM comparison results

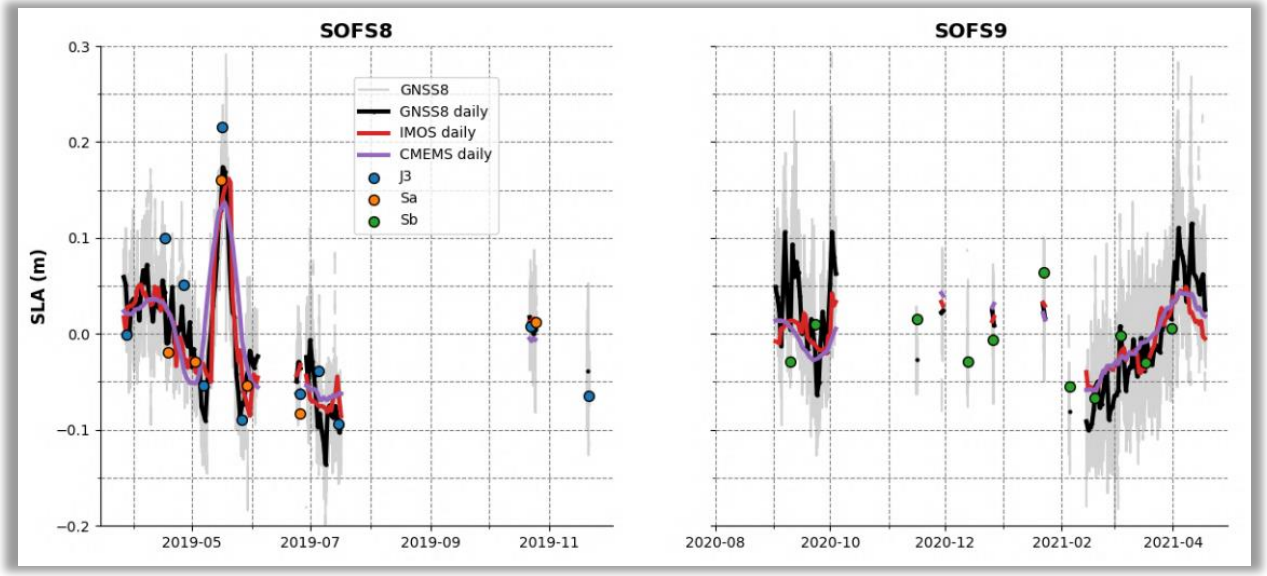
- The directional spectra show good agreement between the GNSS and the SWIM instrument, with all 23 comparisons having a correlation index greater than 0.5.
- There is also good agreement between the GNSS and SWIM dominant directions, with most points meeting the SWIM specifications which state an accuracy of 15°.
- *See additional slides for example SOFS GNSS and SWIM directional spectra comparisons.*



SLA comparisons



- In addition to the calculation of wave parameters, the sea level anomaly (SLA) was estimated from the GNSS on SOFS.
- To estimate SLA, the following corrections were applied to the GNSS smoothed sea surface height record:
  - modelled tide (FES2014b) and mean sea surface (CNES CLS15)
  - inverse barometer (from SOFS on board air pressure measurements)
  - tilt bias (derived from SOFS on board motion reference unit (MRU))
    - *measured wind speed plotted to show relationship between antenna tilt and wind speed*
- **Preliminary comparisons** to the gridded SLA products from IMOS and CMEMS have RMSE values of 32 mm and 37 mm respectively (n = 195 in each case).
- Along-track altimetry estimates have RMSE values of 40 – 50 mm.



Summary

- The preliminary processing of GNSS data at the SOFS mooring shows we can successfully observe in-situ waves in the extreme conditions of the Southern Ocean, with ~200 days of data processed containing ~2% of identified outliers, and obtain robust measurements in all wave regimes.
- Significant wave height comparisons to altimetry estimates show good agreement, with a combined RMSE of 0.18 m and a mean bias of 0.04 m (for 62 comparison points over the four missions considered).
- Directional spectra comparisons to the SWIM instrument also show good agreement, with all 23 comparisons having a correlation index of > 0.5, and dominant directions having an RMSE of 8.1°.
- Further work to understand the uncertainties in the GNSS SWH and directional spectra will enable the SOFS mooring to provide valuable in-situ validation results in this under sampled region of the open ocean. With additional work to improve the sea level anomaly estimates, SOFS will also be positioned to provide co-located wave and SLA measurements in high wave states to assist with the validation of the upcoming SWOT mission.

Questions: please add to the forum or send via email to andrea.hay@utas.edu.au

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Additional

- Examples of the directional spectra for SOFS GNSS and SWIM wave box are shown below for the month of May, 2019.