High resolution in situ sampling in Bass Strait and surrounds: Early perspectives on validation of SWOT Fast Sampling Phase data.

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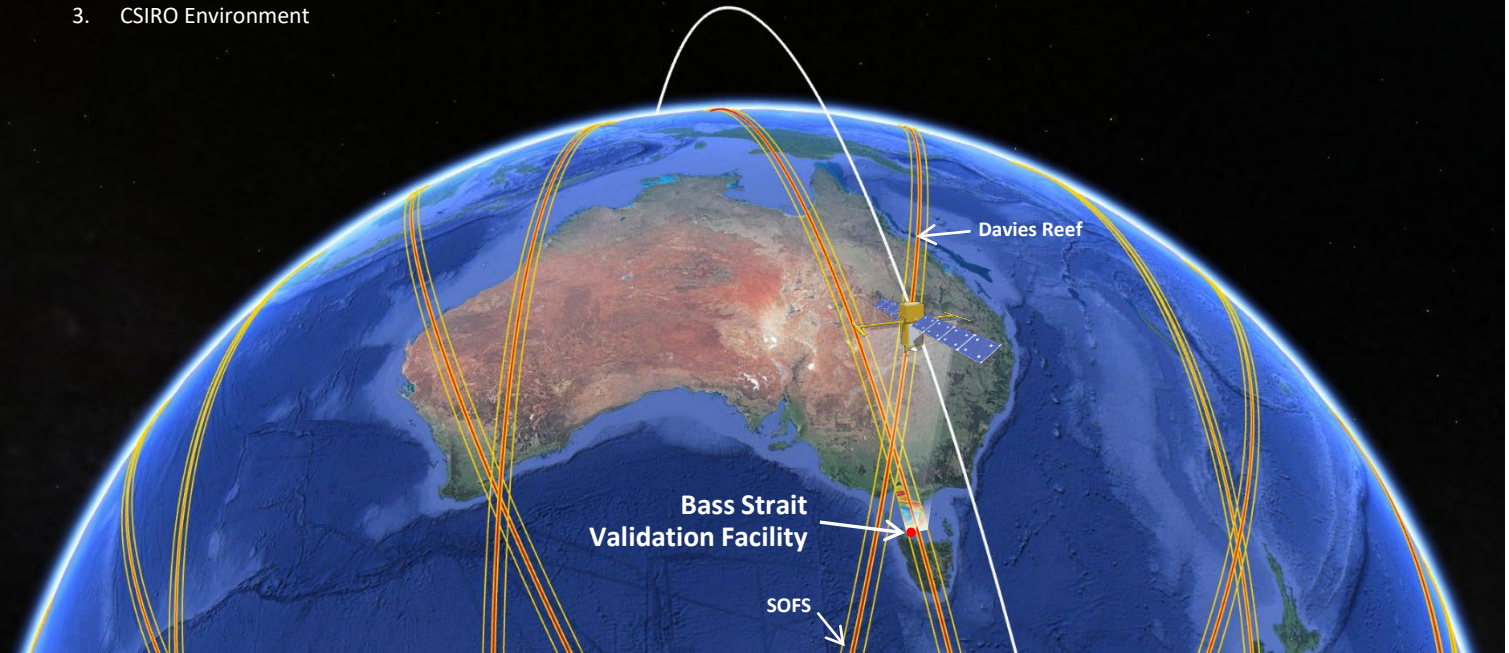
1. University of Tasmania
2. Integrated Marine Observing System
3. CSIRO Environment

Acknowledgements:

- Bass Strait field team
- CSIRO moorings team
- CNES



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OSTST Meeting
San Juan, Puerto Rico
November 7-11, 2023

Bass Strait Validation Facility:

- **SWOT launched in Dec 2022 and undertook a ~90-day Fast Sampling Phase (FSP) over April/May/June 2023.**
- **Our aim is to provide a validation target that is complementary to other studies.**
- **Bass Strait presents a shelf sea region, near coast to offshore, along and across swath sampling – and heritage in altimeter validation back to TOPEX.**

Geometric Approach to In Situ SSH:

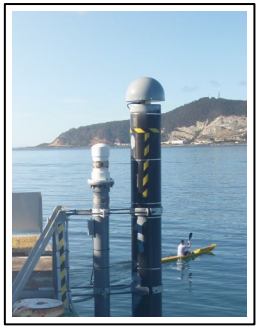
- **Direct, geometric approach to in situ validation. Instantaneous observation of SSH at multiple locations in ITRF.**
- **In situ observations at offshore comparison points, no reliance on ocean tide, DAC or MSS models.**

GNSS/INS Equipped Buoys

- 9 buoys deployed over SWOT FSP (thanks to CNES for support of 2).
- Iridium & cellular comms.
- 2 Hz GNSS SSH, SWH and wet troposphere.
- Includes sea surface temperature and inertial sensors.

Moored Sensors

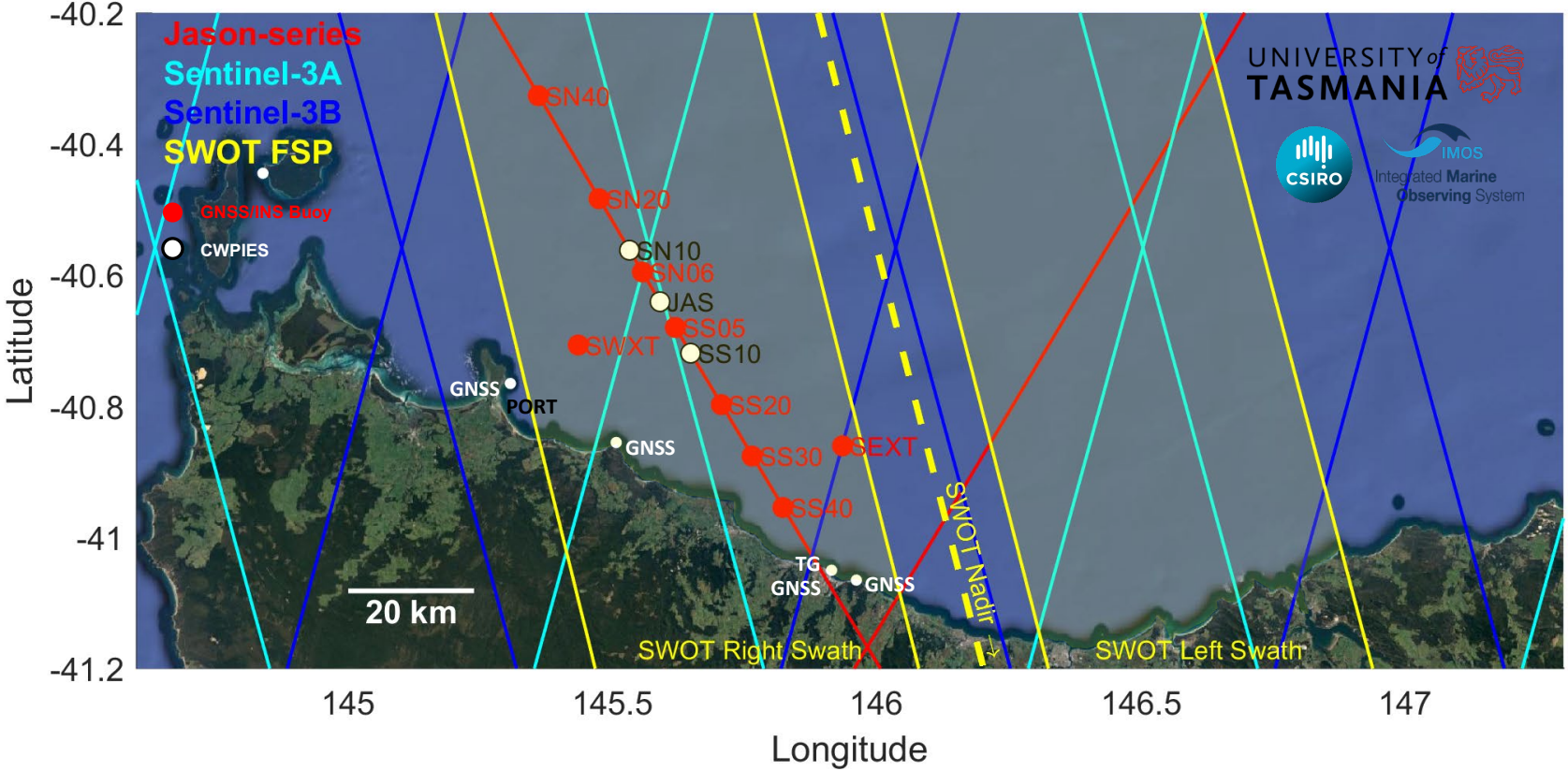
- Bottom pressure, temp and salinity to determine continuous SSH time series (datum defined by GNSS buoys).
- Current, waves, pressure inverted echo sounders (CWPIES) yield 2 Hz SSH as well as wave spectra and currents.



Tide Gauge / GNSS

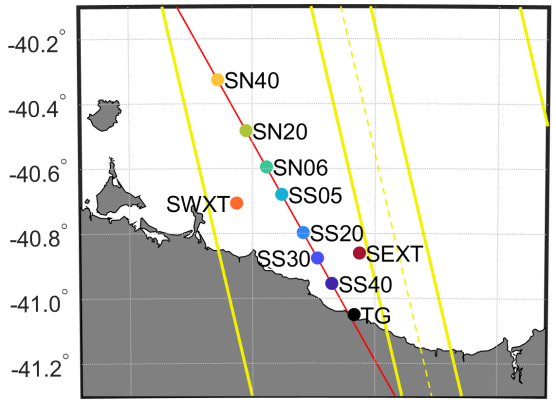
- Climate quality coastal tide gauge.
- Numerous inland GNSS to provide vertical land motion (VLM).
- Inland GNSS used in differential processing of buoys given favourable geometry.
- GNSS offer insight into spatial/temporal evolution of troposphere.

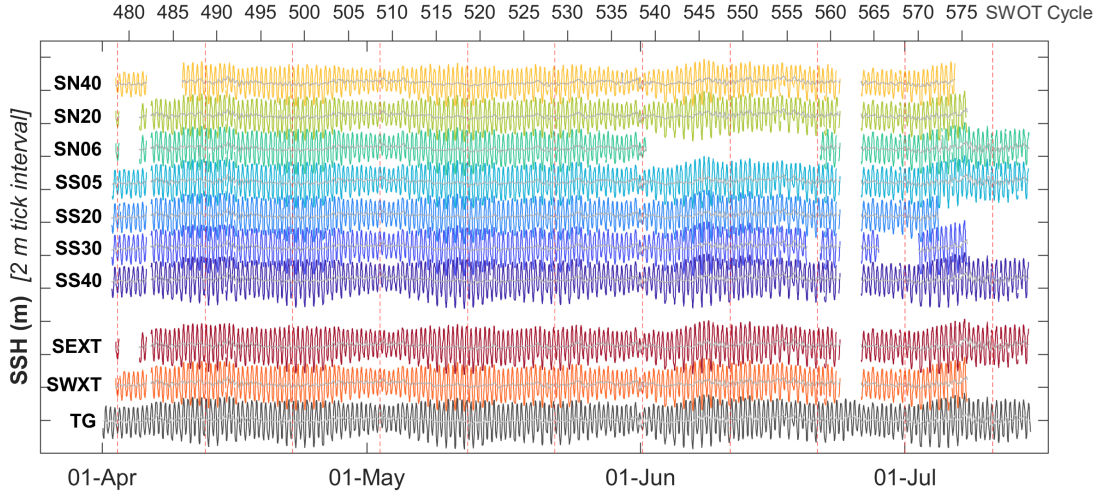
Bass Strait SWOT FSP Configuration:

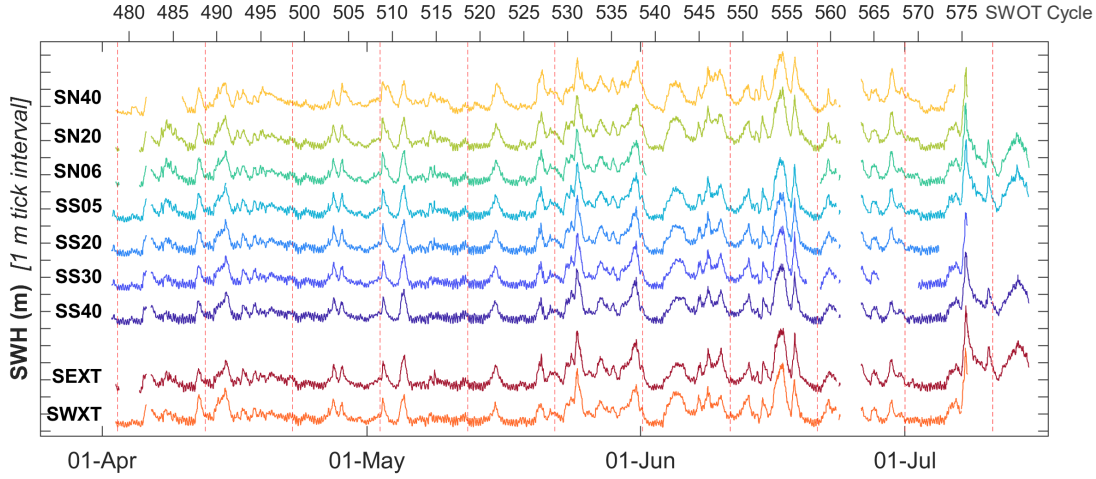


Buoy: SSH and SWH

- Almost complete coverage over the SWOT FSP period from 9 GNSS buoys at 2 Hz.
- Delivers SSH, SWH, Wet troposphere.
- Austral winter and cloudy conditions made solar charging marginal at the end of the deployment.
- DD and PPP GNSS (+INS) solutions underway.



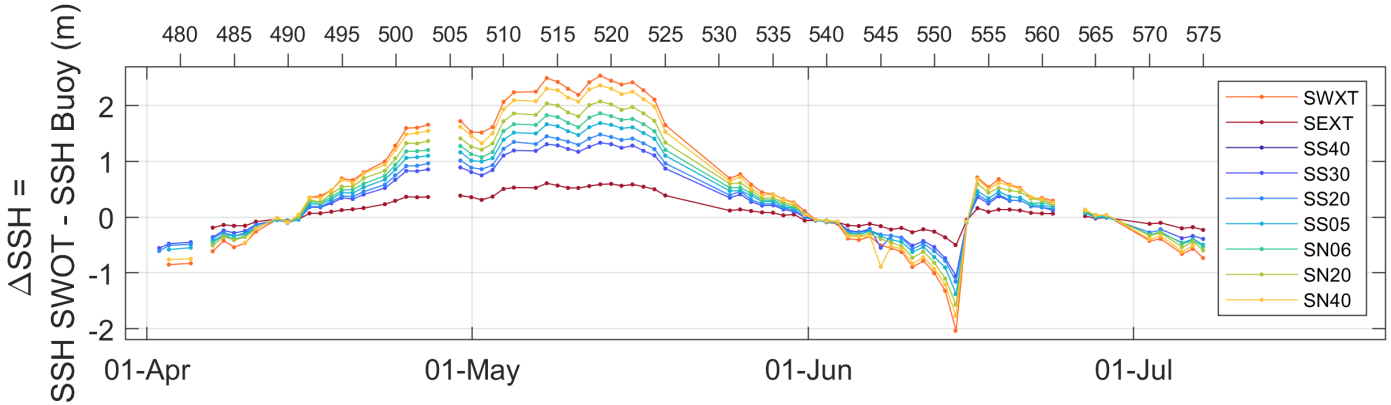


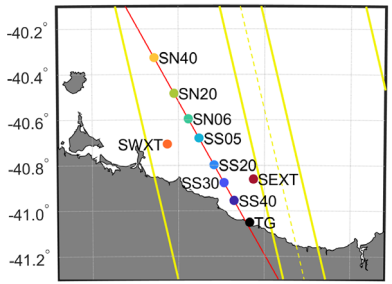


Comparisons: SSH SWOT – SSH Buoy = ΔSSH

L2, LR (2 km), PGE 4.3.0
Product SSH includes wet radiometer and SSB corrections.
- Solid Earth Tide
- Pole Tide (solid part only)
- Load Tide (FES)

GipsyX, ITRF14, GRS80 Ellip Ht at 2 Hz
(Moving avg over 20 mins)
- Solid Earth Tide
- Pole Tide (solid part only)
- Load Tide (FES)





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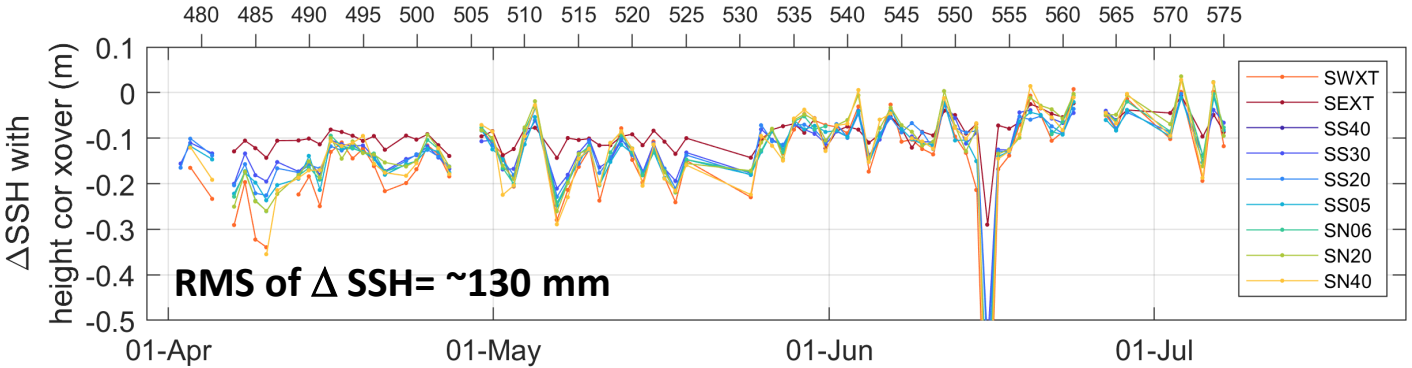

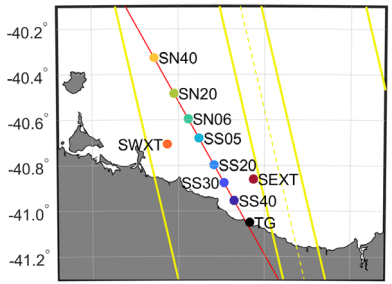

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Product SSH includes wet radiometer and SSB corrections.
- Solid Earth Tide
- Pole Tide (solid part only)
- Load Tide (FES)
- height cor buoy (derived from GNSS buoys)

GipsyX, ITRF14, GRS80 Ellip Ht at 2 Hz
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- Solid Earth Tide
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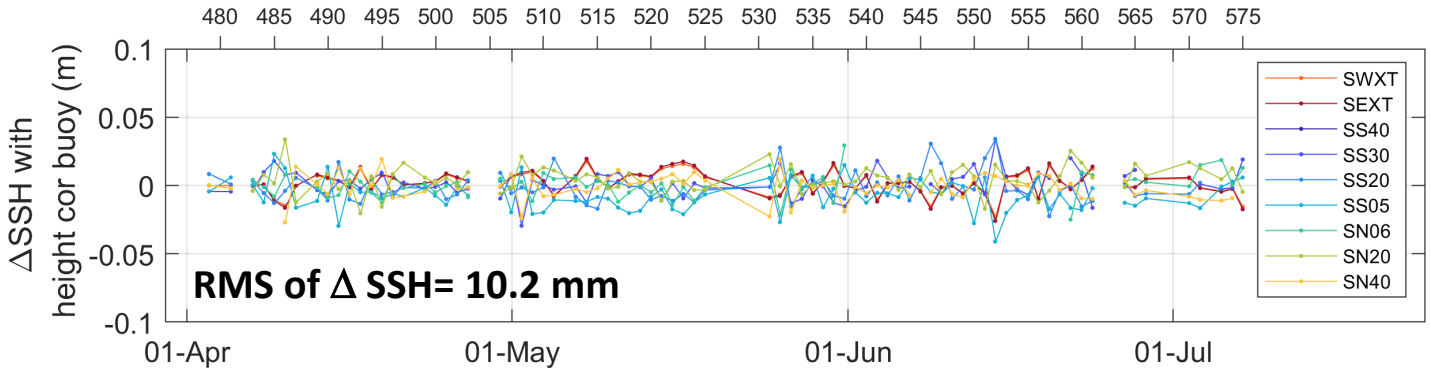
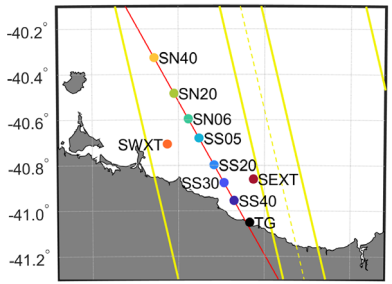
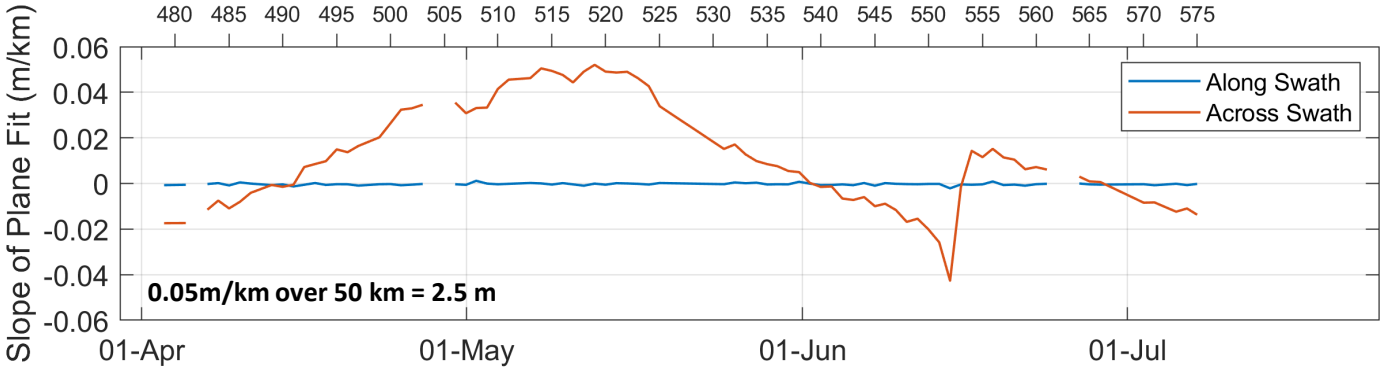
- Load Tide (FES)

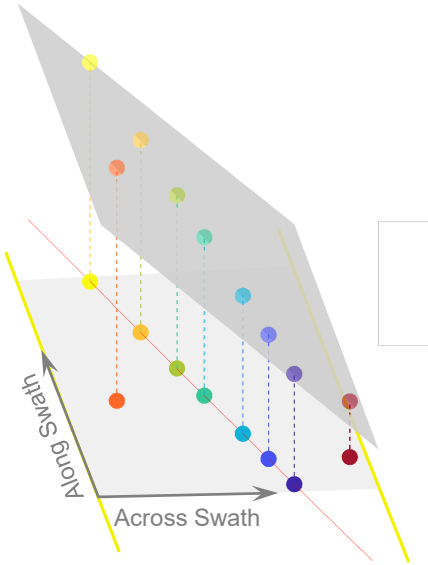




Buoy derived SWOT correction

- The SWOT product “height cor xover” accounts for various calibrations and remains work in progress (currently v4.3). In Bass Strait, the correction is large (up to 2.5 m) and predominantly an across swath feature that evolves in time (as expected).
- Our “buoy derived” version simply fits a plane to ΔSSH (linear in along and across swath directions), for each cycle. Soaks up common mode contributions in SWOT and GNSS buoys. Note sample size per fit is small (up to 9 buoys).

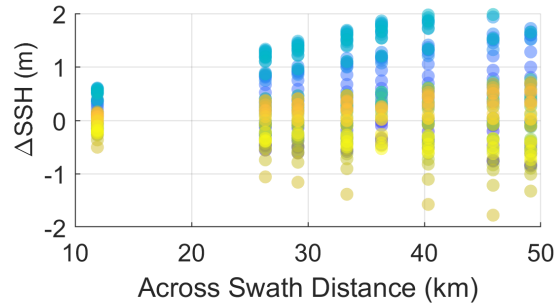




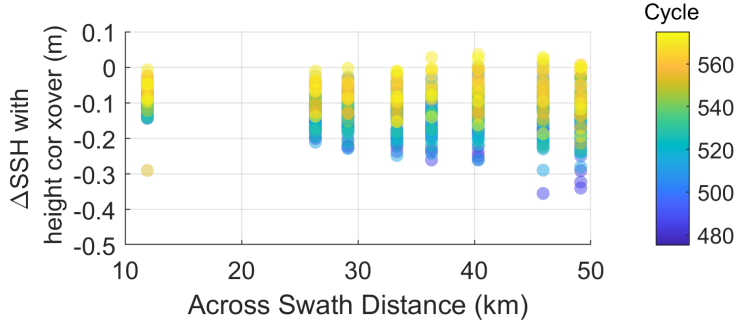
SSH SWOT - SSH Buoy = ΔSSH

- The buoy derived correction attenuates the long wavelength signal that otherwise dominates – this leaves the high frequency component that includes error contributions from GNSS buoys and SWOT (**RMS = 10.2 mm**).
- Comparing this to the RMS of differences between pairs of closely separated buoys is informative (**RMS = 7 to 12 mm**, Zhou et al. 2023).
- Applying the buoy derived correction suggests very small short wavelength noise contribution from SWOT. Work remains in progress.

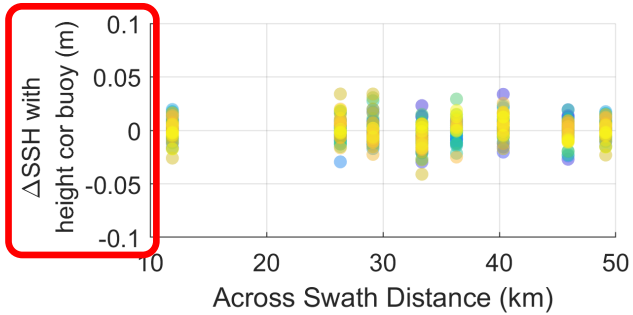
No correction →



with correction from SWOT product (v4.3) →

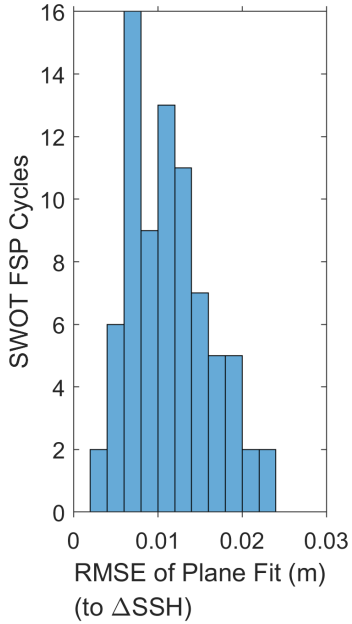


with buoy derived correction (v1) →



Quality of Cycle-by-Cycle Fits

Can we make any comparisons with Sentinel-6 HR data given 7 buoys were deployed along S6 Pass 088? Very cautiously…



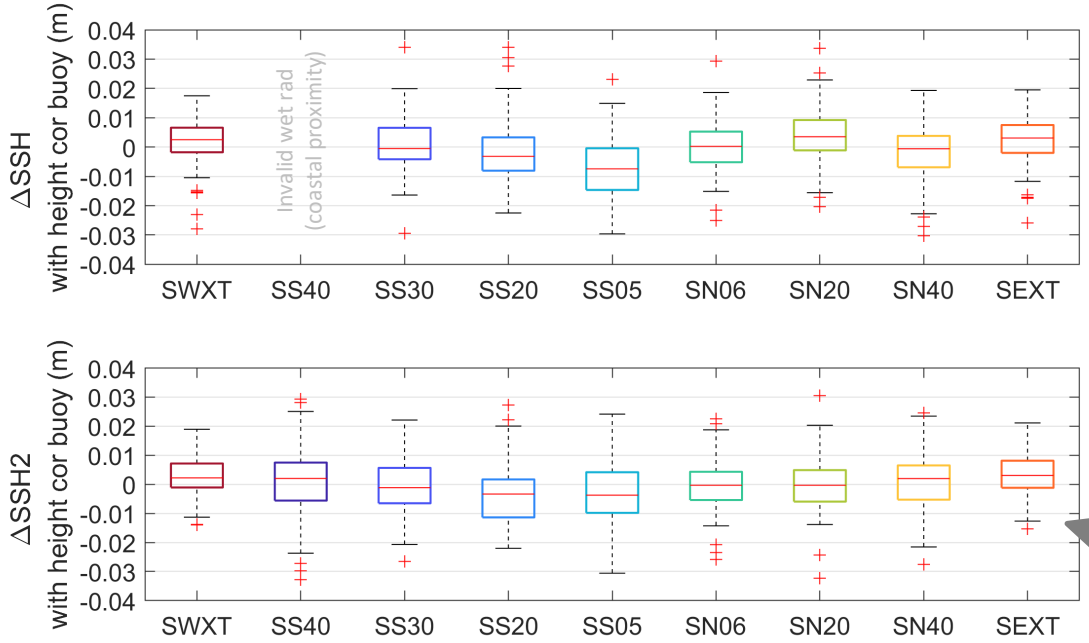
SWOT L2 LR (95 cycles, up to 9 buoys per fit)
- 2 x 2 km
- Mean RMSE of plane fit = **11.7 mm**

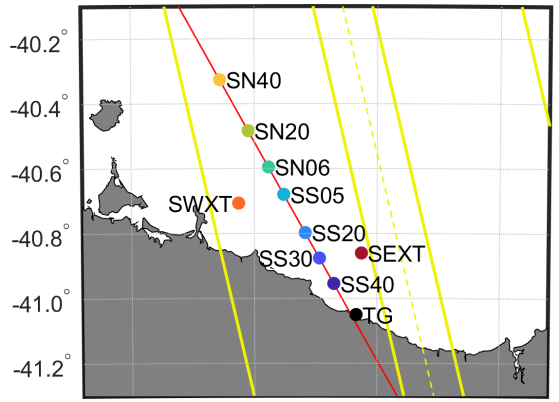
Sentinel-6 L2 HR 20 Hz (10 cycles, up to 7 buoys per fit)
- 350 m x ~7 km
- Mean RMSE of linear fit = **19.2 mm**

Sentinel-6 L2 HR 1 Hz (10 cycles, up to 7 buoys per fit)
- 7 x ~7 km
- Mean RMSE of linear fit = **10.6 mm**

Site Specific ΔSSH over SWOT FSP:

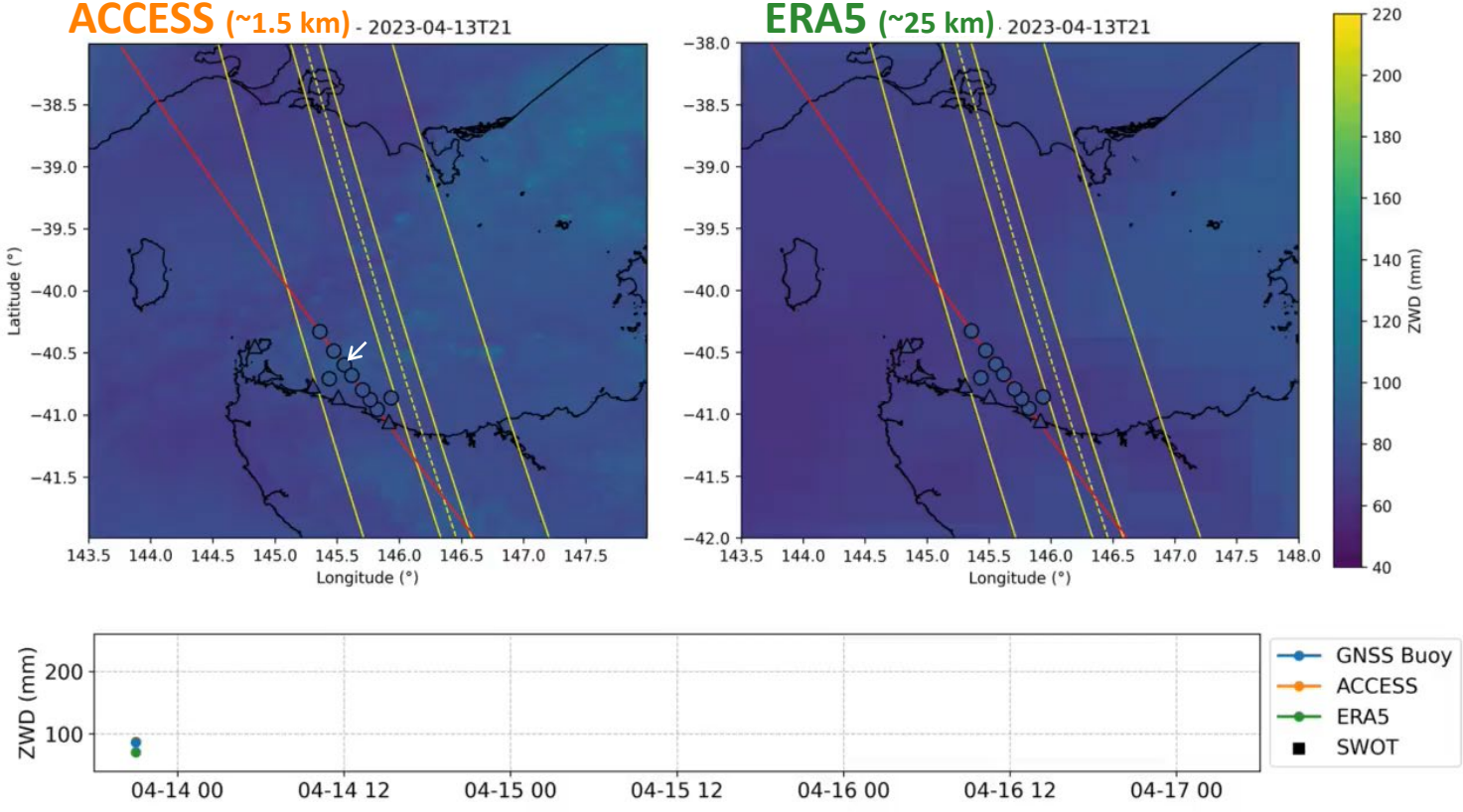
Top Panel: ΔSSH, SWOT using observation-based corrections (rad wet cor, ssb)
Bottom Panel: ΔSSH2, SWOT using model-based corrections (model wet cor, wave model ssb)





Possible evidence for the need for 2nd order term in xcal from in situ data?

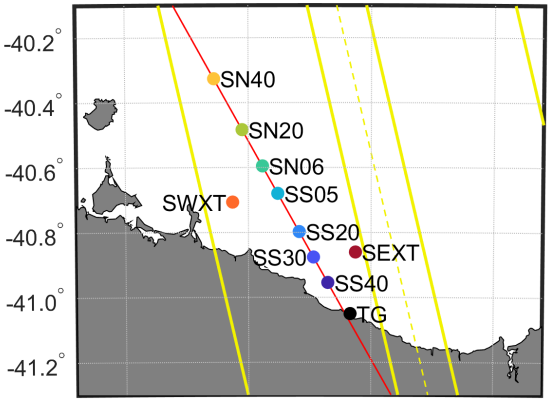
Wet Tropospheric Delay

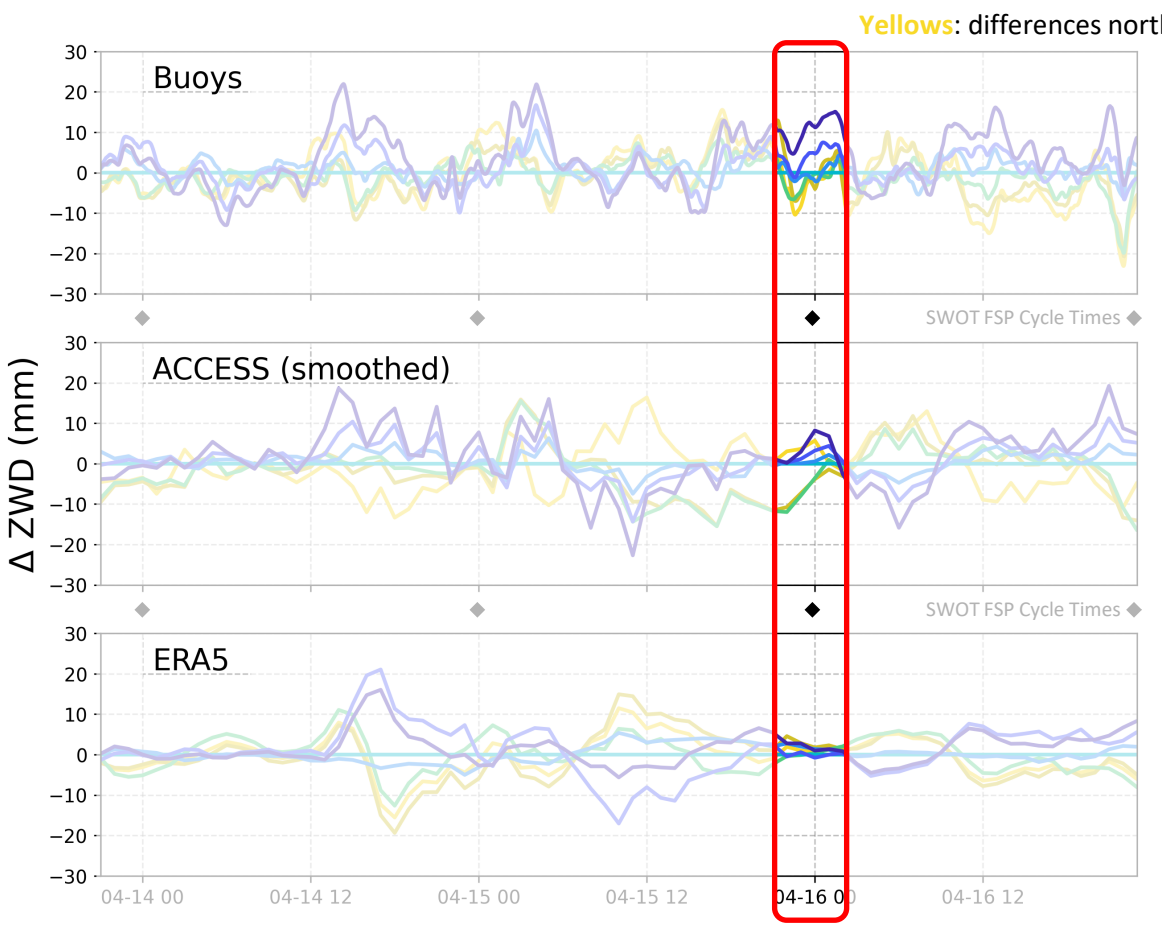


Wet Trop Delay

(Differenced against site SS05)

- High resolution model gives some insight into intra-swath variability.
- Some ability to quantify possible short wavelength errors in SWOT (particularly in the coastal zone) using GNSS v model.





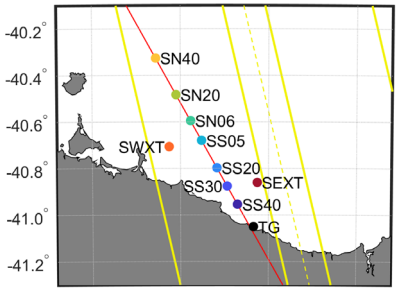
SWOT SWH:

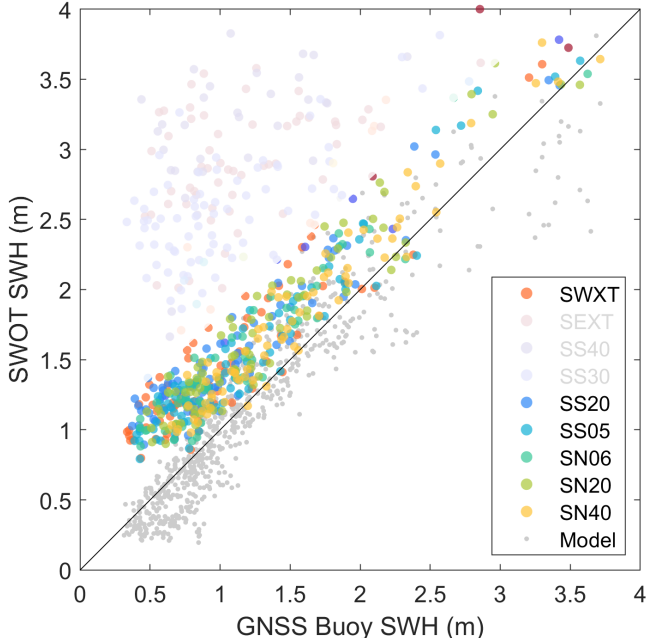
Model – Buoy SWH:

- Mean: -0.05 m, Std: 0.25 m

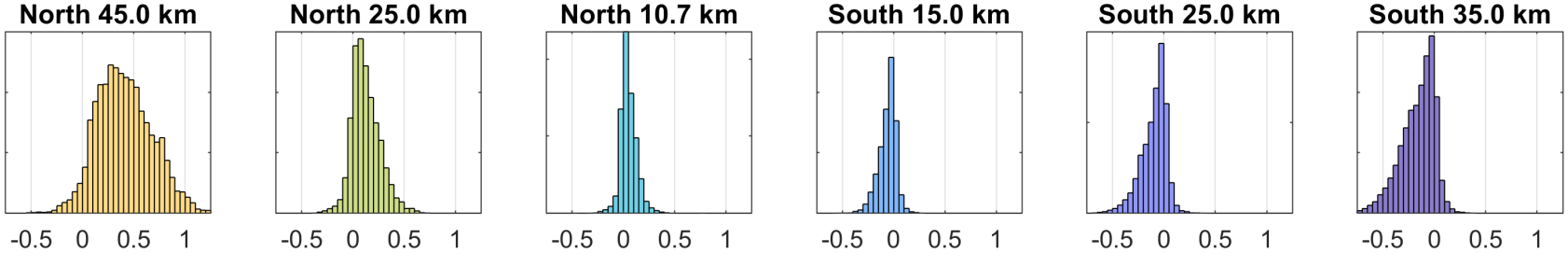
SWOT – Buoy SWH:

- Mean: 0.41 m, Std: 0.22 m
  (outliers / flagged removed)





Buoy SWH variation from centre location:



← Rougher to North

GNSS Buoy SWH differenced against centre site

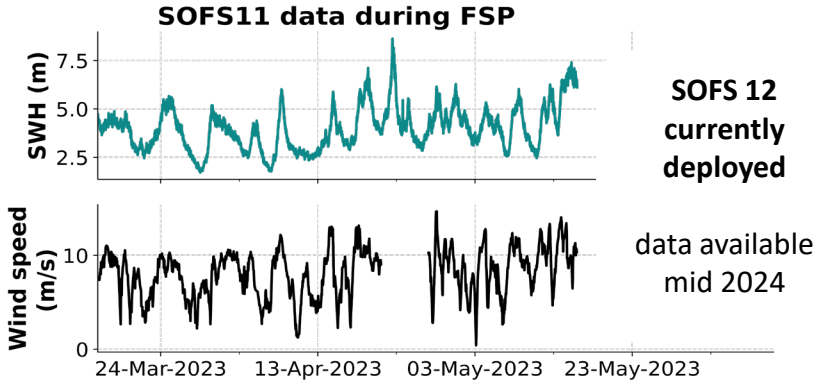
Calmer to South →

SWOT v SOFS GNSS

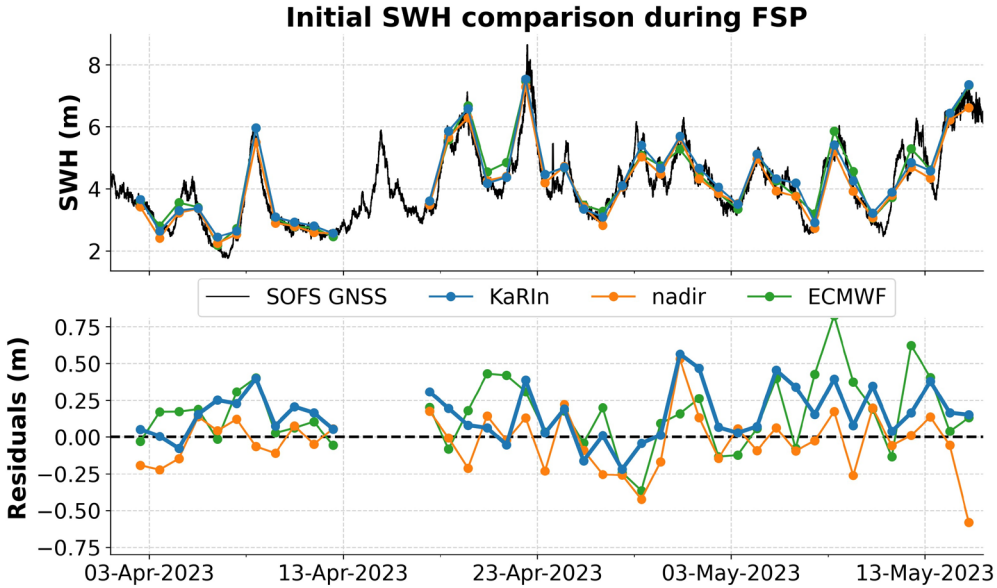
- SOFS mooring has been deployed annually in the Southern Ocean (~47S, 141E). Augmented with geodetic GNSS (2 Hz) since 2019.

- Provides a point target within the SWOT FSP in a high wave environment. Data now available for first 47 days of FSP, with subsequent period still deployed.

- New paper! Hay et al. 2023, JTECH, In-Situ Validation of Altimetry and CFOSAT SWIM Measurements in a High Wave Environment.



SWOT v SOFS GNSS



SWOT KaRIn	**RMSE = 0.25 m**	**mean bias = 0.16 m**	
SWOT Nadir	RMSE = 0.20 m	mean bias = -0.04 m	← (Comparable with results from other nadir missions, see Hay et al., 2023)
ECMWF	RMSE = 0.28 m	mean bias = 0.15 m	

(n = 41 for all, residuals are SWOT – SOFS GNSS)

Conclusions and Future Directions

- GNSS buoy array in Bass Strait is providing useful insight into SWOT over the FSP. Useful tool to probe intra swath variability and validity of corrections.

- Early SWOT data (v4.3) over Bass Strait shows large variance at long wavelengths due to limitations in x-over calibration during FSP (not unexpected).
  - Buoy approach offers a means to attenuate this and focus on short spatial scales and the validity of correction terms.
  - Here, in terms of SSH SWOT is performing very nicely (~1 cm over 80 x 40 km including contribution from in situ noise).

- Current activities and future directions:
  - Expand our analysis to SWOT HR data (250 x 250 m). Investigate in situ smoothing and intra-swath variability (across SSH/SWH/wet trop) from observations and models.
  - Comprehensive analysis of GNSS DD/PPP (+INS) solutions underway, plus investigations of sea state dependence.
  - Integration of mooring data (SSH / currents / waves) at interleaved locations along track. Ongoing analysis of SSH and SLA.

Questions?

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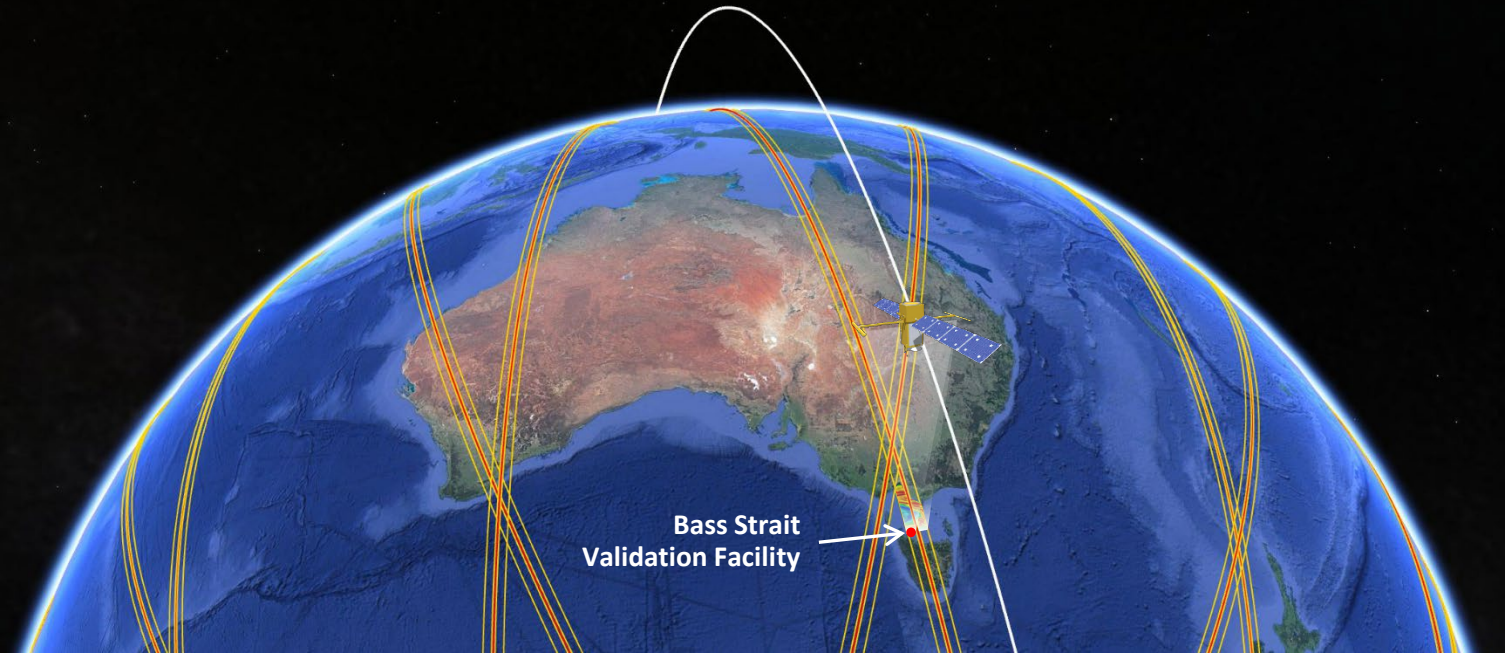

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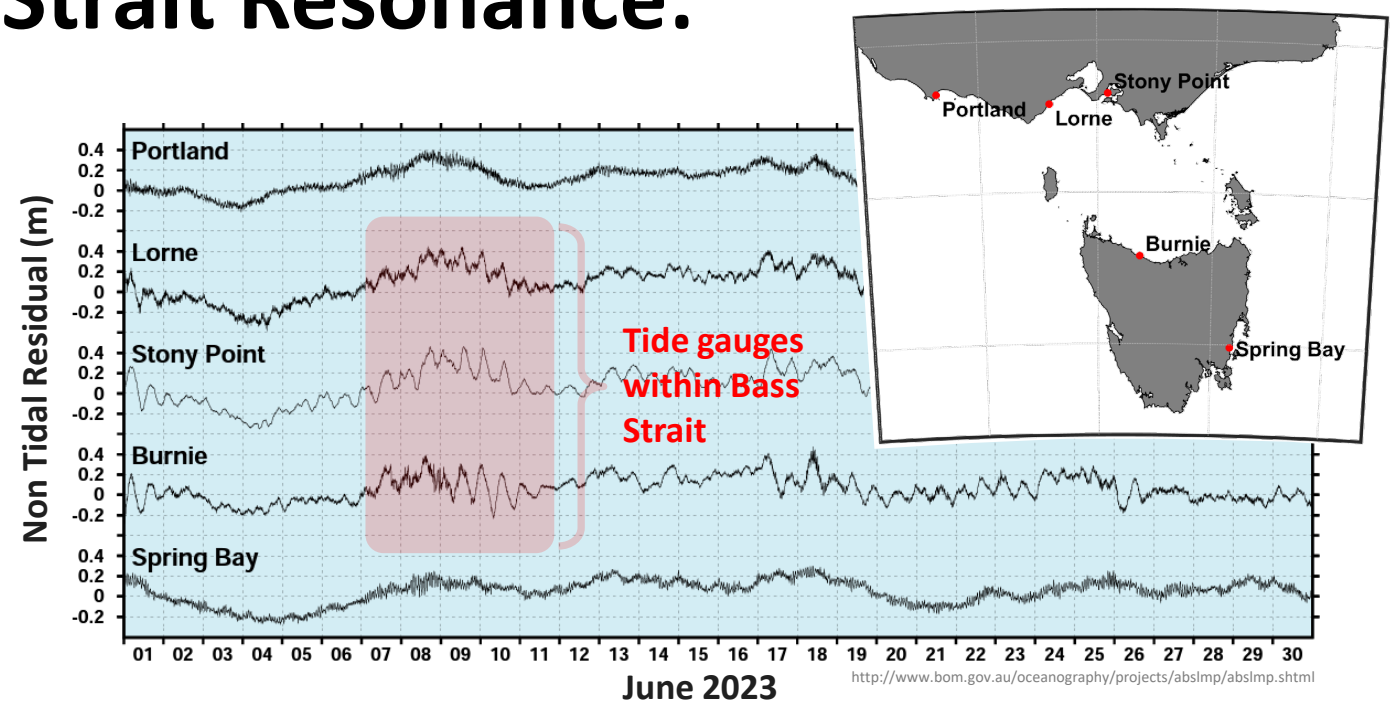
Spares

Bass Strait Resonance:

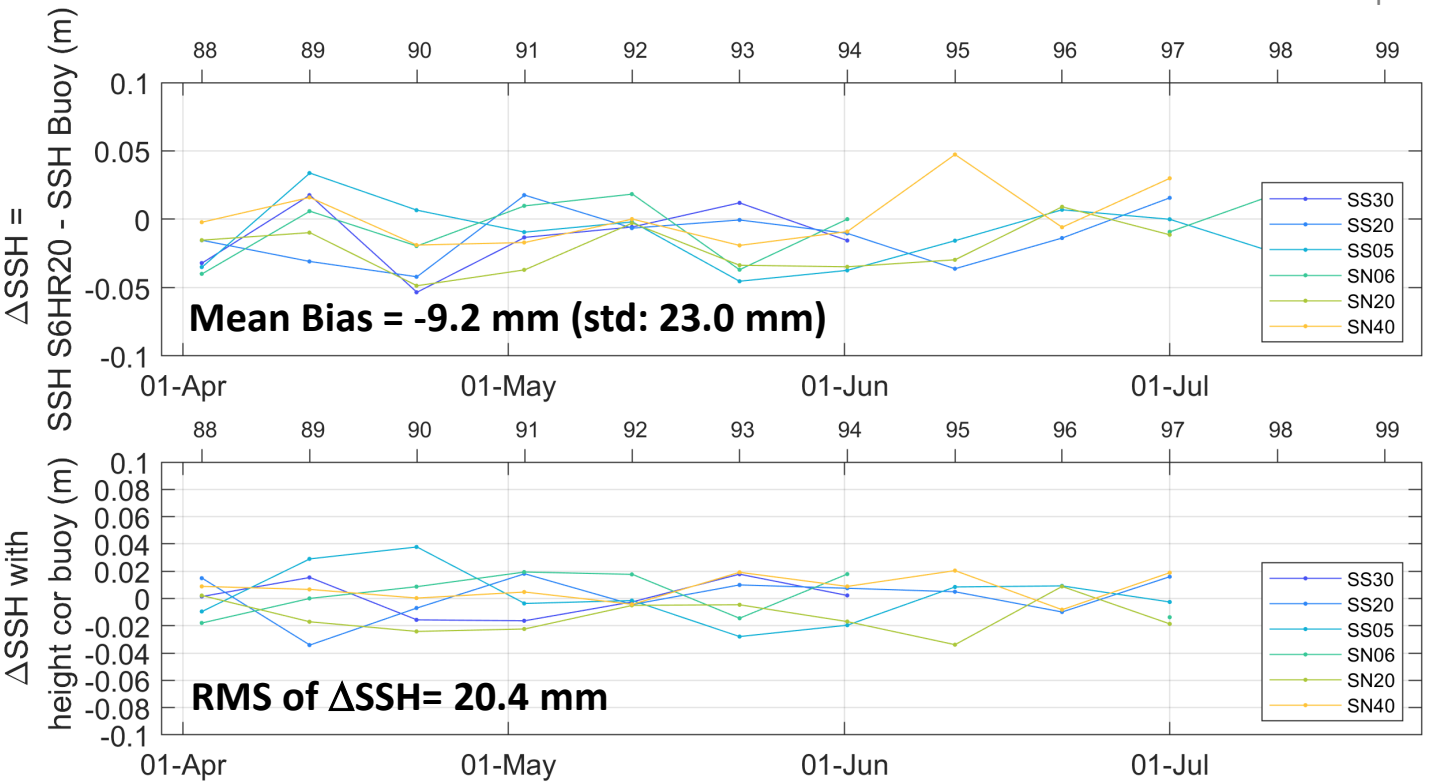


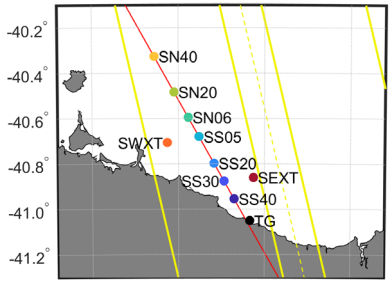
- Non tidal residuals in Bass Strait frequently show excitation around the M2 frequency.
- Typically correlated well with wind events.
- Atmospheric excitation of a seiche and/or atmospheric induced tidal damping? (Hargous, 2023).
- Direct gravitational attraction important in modelling (Wijeratne et al., 2012).

Comparisons: SSH S6 HR 20 Hz - SSH Buoy = ΔSSH

L2, HR 20 Hz (350 m x ~7 km), PB08
- standard corrections

GipsyX, ITRF14, GRS80 Ellip Ht at 2 Hz
- corrections as per SWOT
+ restore permanent tide

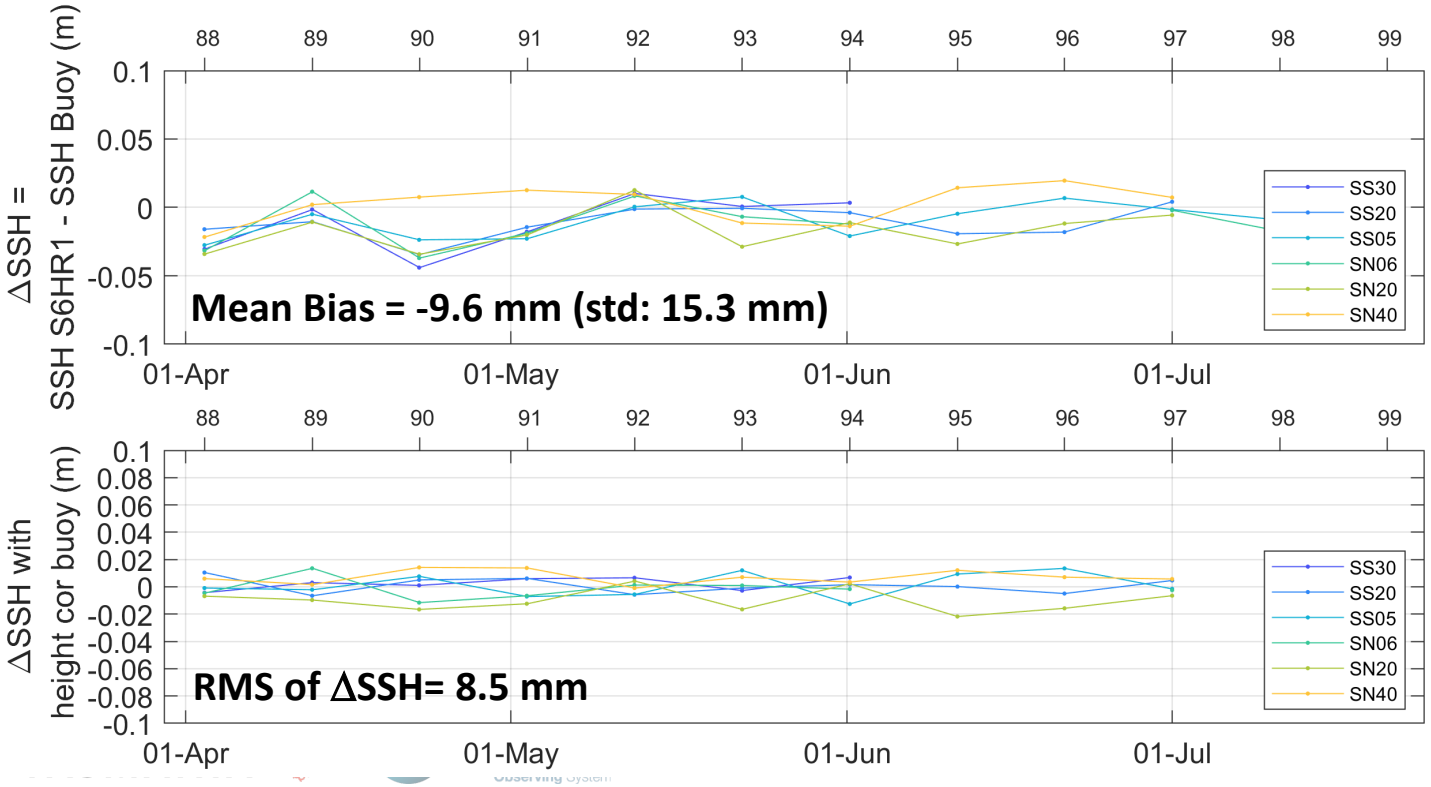


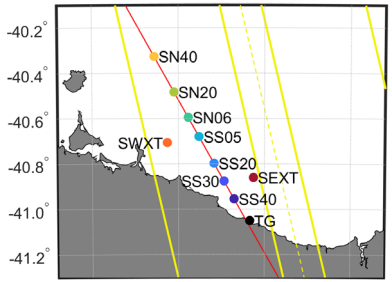


Comparisons: SSH S6 HR 1 Hz - SSH Buoy = ΔSSH

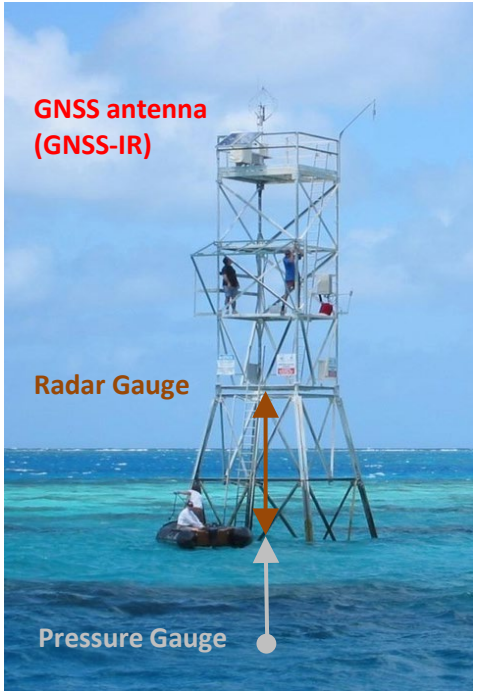
L2, HR 1 Hz (7 km x ~7 km), PB08
- standard corrections

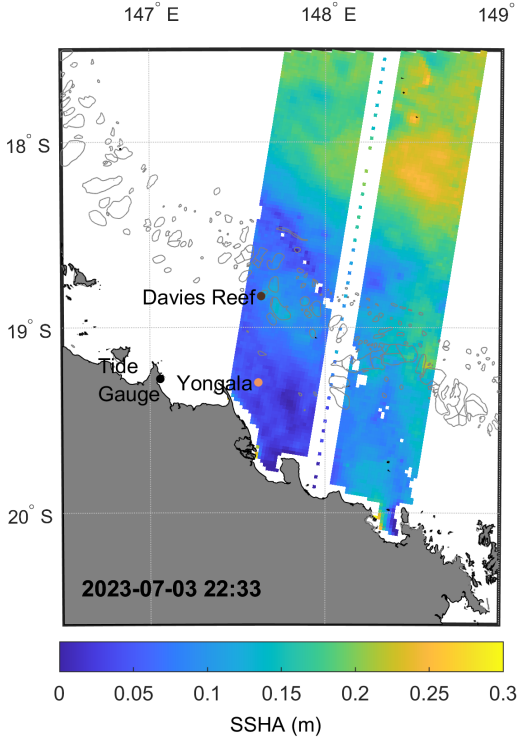
GipsyX, ITRF14, GRS80 Ellip Ht at 2 Hz
- corrections as per SWOT
+ restore permanent tide

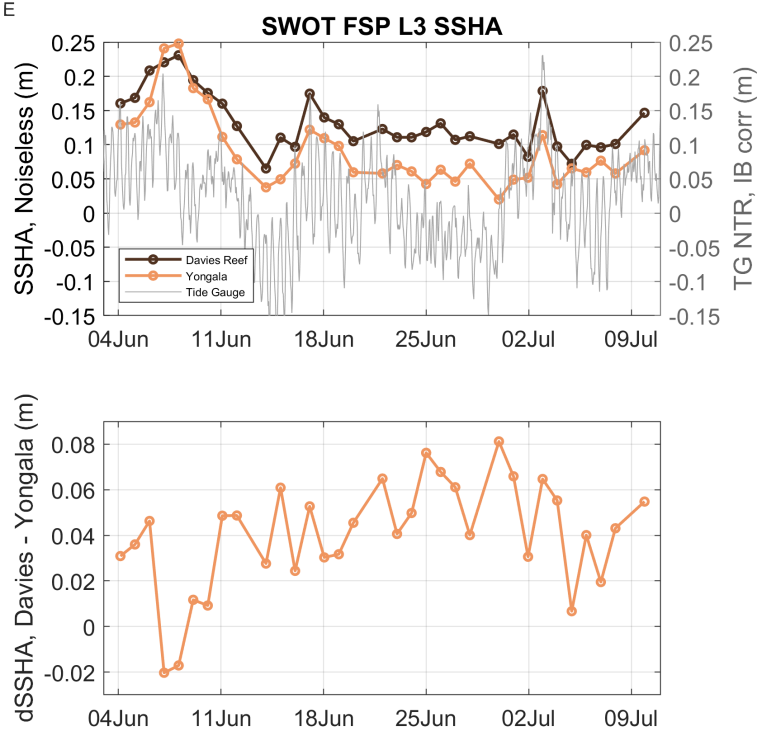




Davies Reef / Yongala







Davies Reef Reflectometry