

In situ geometric validation of SWOT satellite observations in Bass Strait, Australia

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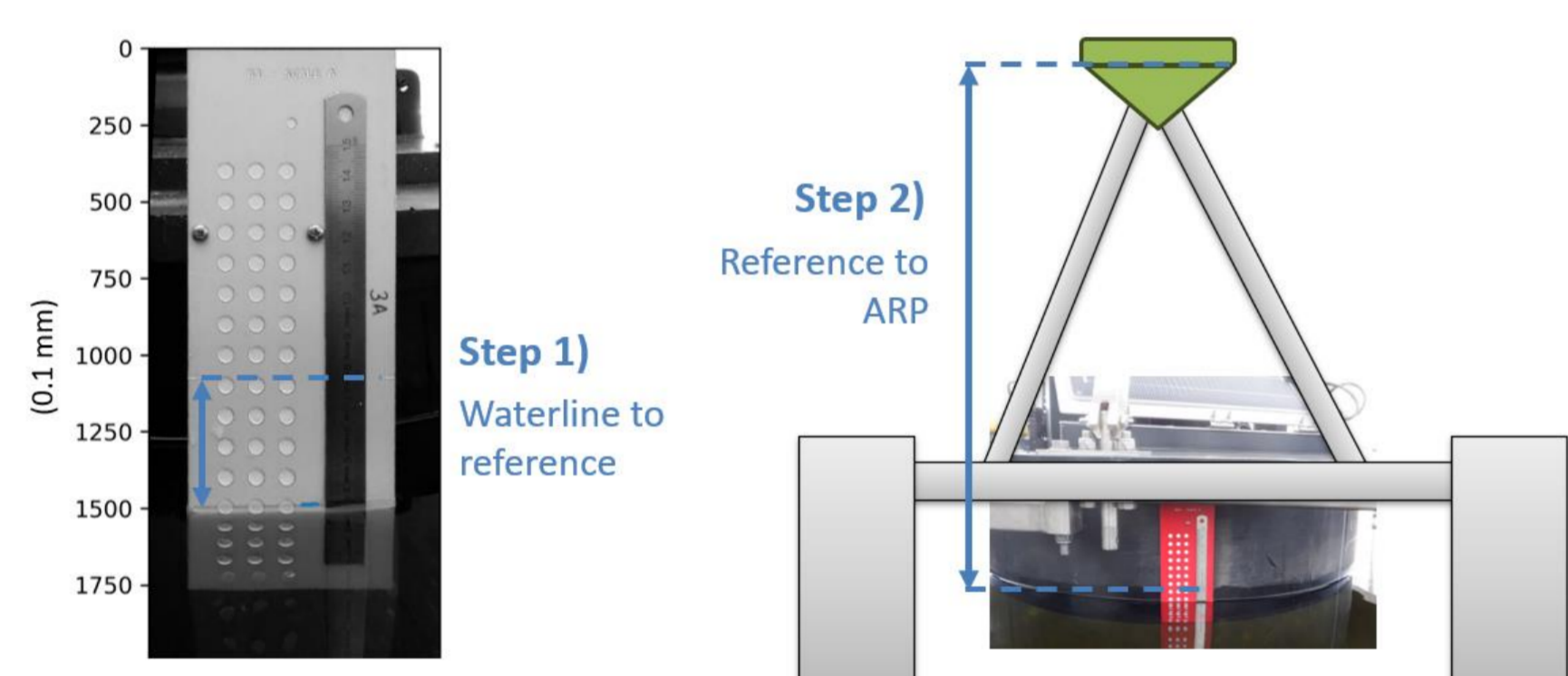
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SUMMARY

- Using nine GNSS buoys deployed for three months we find SWOT KaRIn SSH precision between 1.8 – 7.0 mm.
- This result is underpinned by our GNSS buoy differential-SSH uncertainty of 4.6 mm and requires differencing across each pair of buoys in the in situ array to minimize common mode errors.
- This is the product of over thirty years of development in buoy design and GNSS processing at this site.
- Results have recently been published – see QR code below!

Height above waterline/datum

- Precise SSH from GNSS buoys requires accurate determination of the antenna reference point (ARP) to waterline distance.
- This was achieved by filming scales fixed to the buoys, extracting the waterline, relating this to a reference mark, and accurately measuring the distance from reference to ARP (see https://github.com/AndreaHay/buoy_waterline).



- For comparisons to SWOT SSH a consistent height datum is needed. This requires ensuring the same ellipsoid is used (GRS80), reinstating the permanent tide to GNSS, and applying equivalent corrections to SWOT using the formula below.

$$\text{SWOT SSH for comparison to GNSS} = \text{swot_ssh} + \text{height_cor_xover} - \text{solid_earth_tide} - \text{load_tide} - \text{pole_tide (solid component only)}$$

SWOT absolute SSH accuracy

Standard deviation: **33 mm**
Mean bias: **unlikely to be statistically different from zero**

- The SWOT L2 PGC SSH data was compared to GNSS buoy SSH. Absolute heights are important for hydrography applications, however there are no oceanography requirements over > 1000 km scales for KaRIn.
- The mean bias of -11 mm and standard deviation of 33 mm seen is slightly poorer than Bass Strait validation results for nadir missions.
- Errors in absolute SSH are strongly driven by errors in the cross-track correction which varies geographically. The dramatic improvement between PIB and PGC absolute SSH in Bass Strait (Fig 4) can be largely attributed to improvements in the cross-track correction.

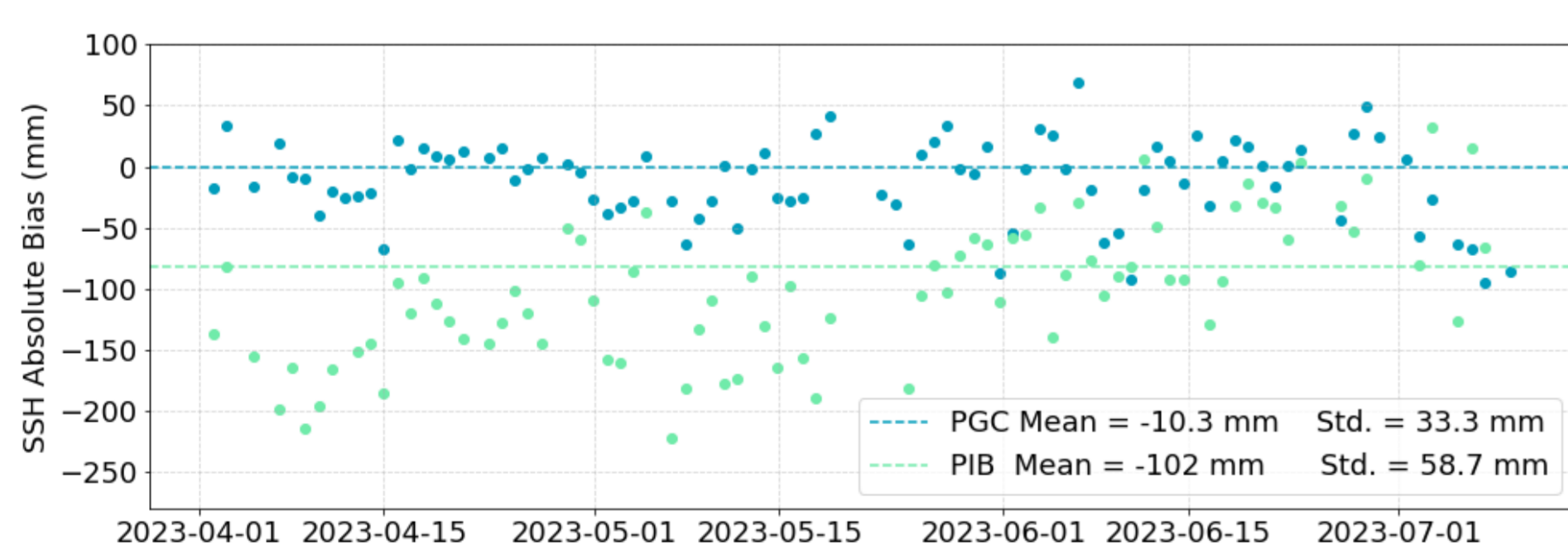


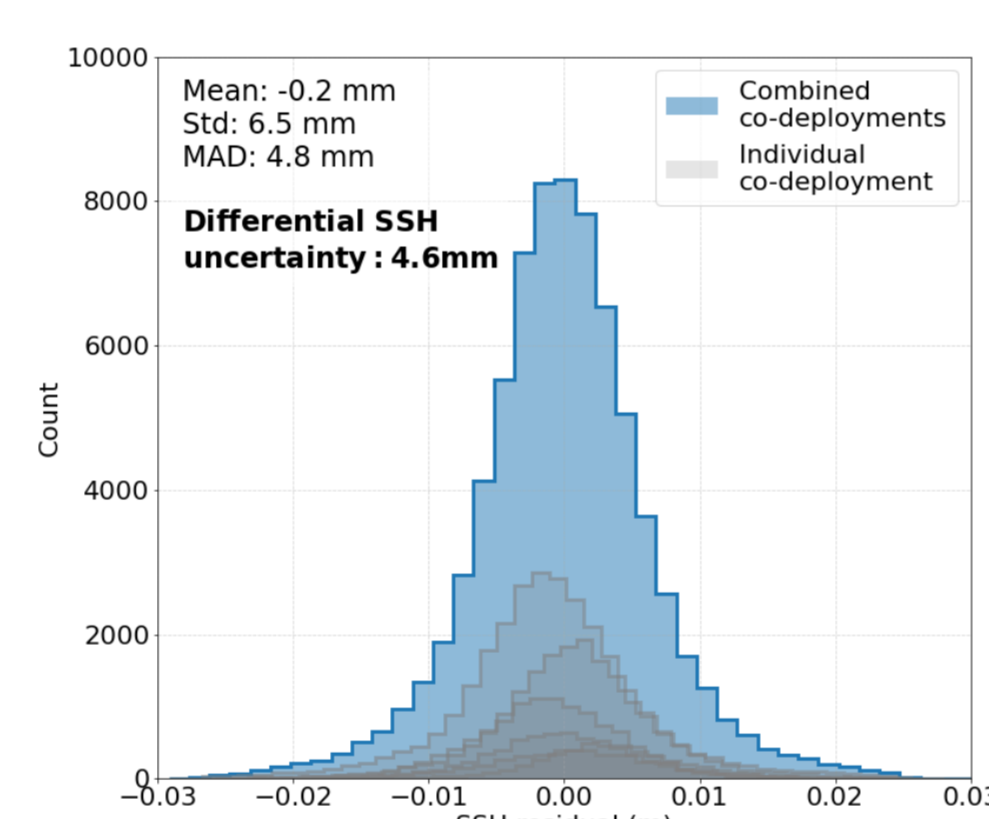
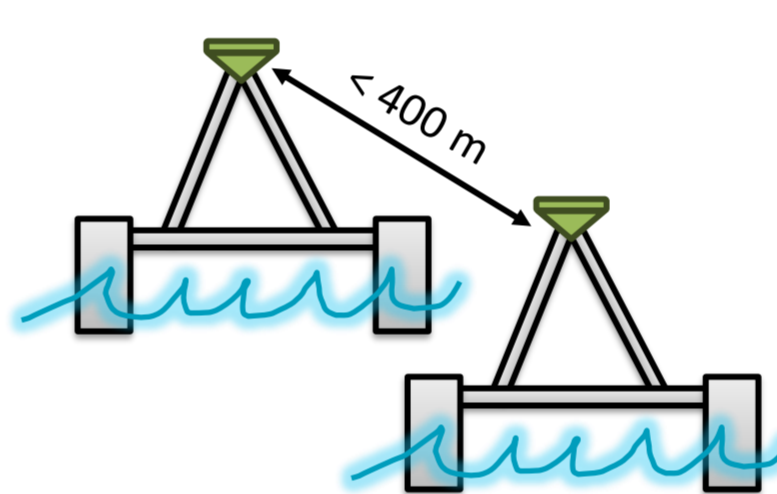
Fig 4: SWOT minus GNSS buoy SSH averaged across the nine points for each cycle. PIB (forward processed) and PGC (reprocessed) differences highlight the impact of cross-track correction on absolute heights.

How can we validate SWOT SSH to sub cm precision?

GNSS processing and precision

Approach: **Precise Point Positioning (PPP)**
Differential SSH uncertainty: **4.6 mm**

- Careful GNSS processing and in situ precision assessment is important for achieving sub cm validation results.
- We process 2 Hz GPS observations using PPP with the GipsyX software (Bertiger et al., 2020). This does not require nearby base stations and provides 3-dimensional coordinates from which sea surface height (SSH) and wave parameters can be derived, as well as an estimate of wet tropospheric delay.
- To assess in situ differential-SSH precision we deployed pairs of buoys separated by a maximum of 400 m.



- SSH residuals from over 2000 hours of data across six co-deployments show a mean bias of 0.2 mm and a standard deviation of 6.5 mm.
- We divide this by $\sqrt{2}$ to find the differential-SSH uncertainty of 4.6 mm at a single point.

SWOT ΔSSH precision

SWOT SSH noise (2 km product): **7.0 mm**
SWOT SSH noise (unsmoothed product): **13.0 mm**

- We consider double differences (SWOT ΔSSH - buoy ΔSSH) over 10 km to assess KaRIn noise. The double differencing approach is taken to minimize common mode error between points (Fig 5).
- This gives a standard deviation $\sqrt{2}$ of 8.4 mm for the 2 km product and 13.8 mm for the unsmoothed product.

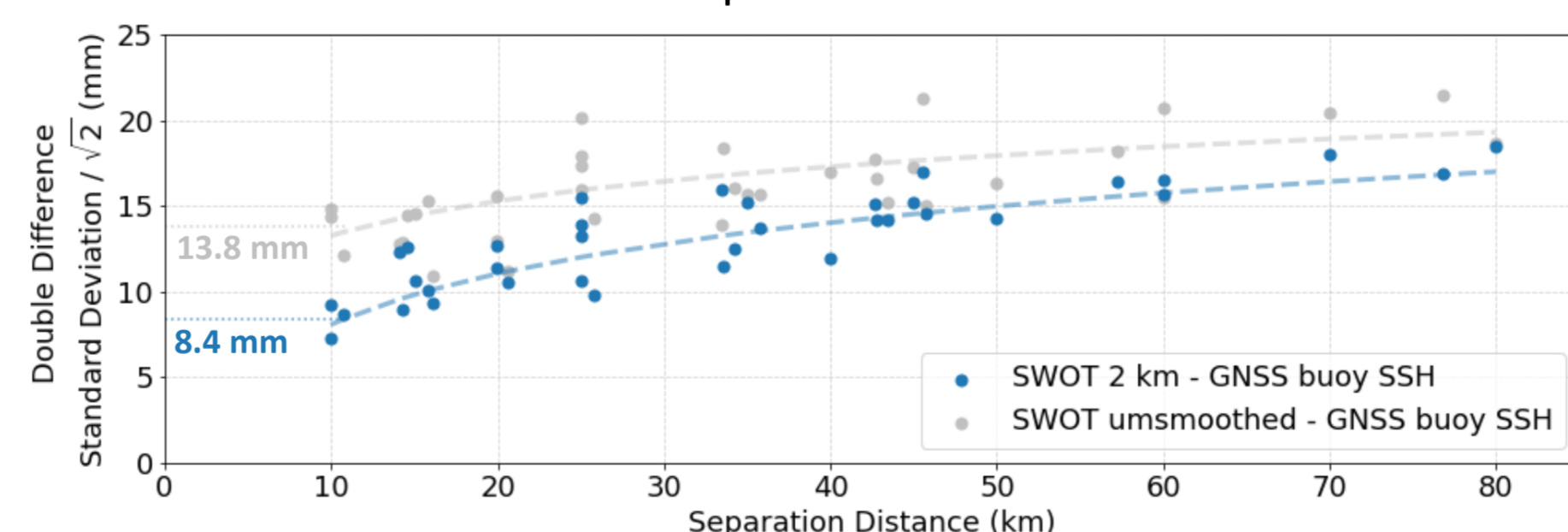


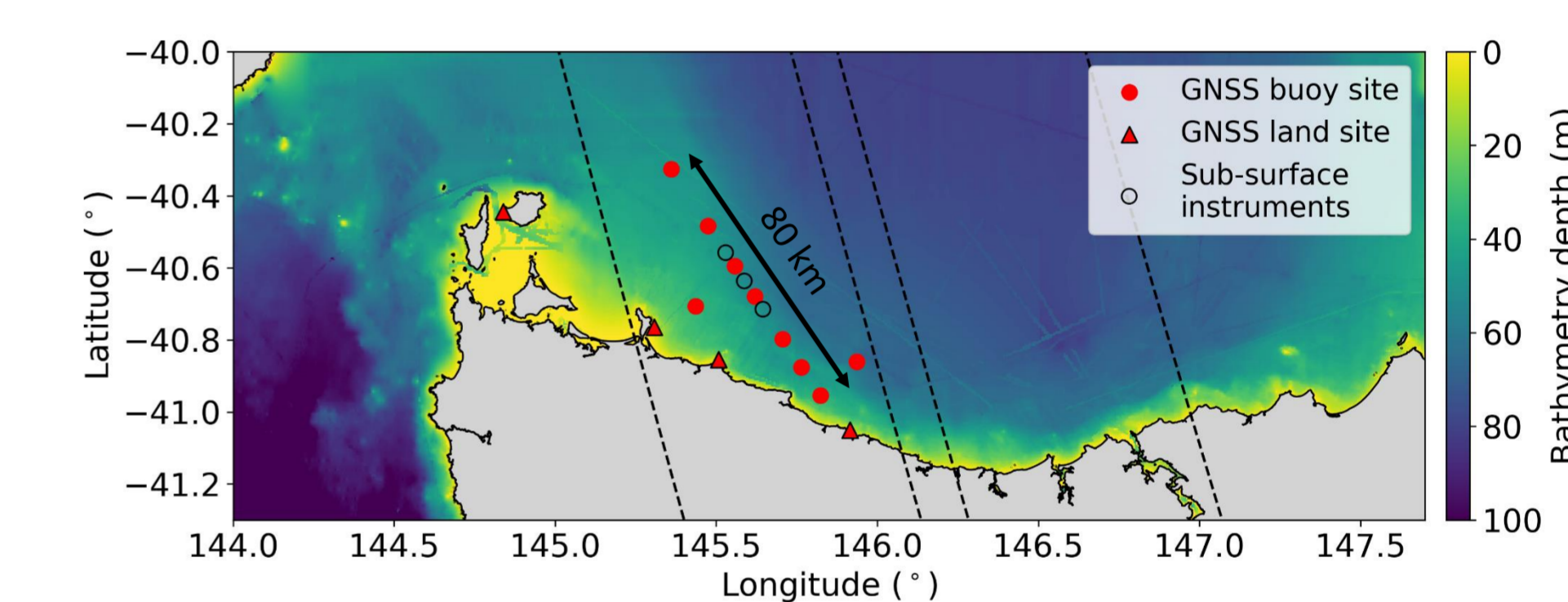
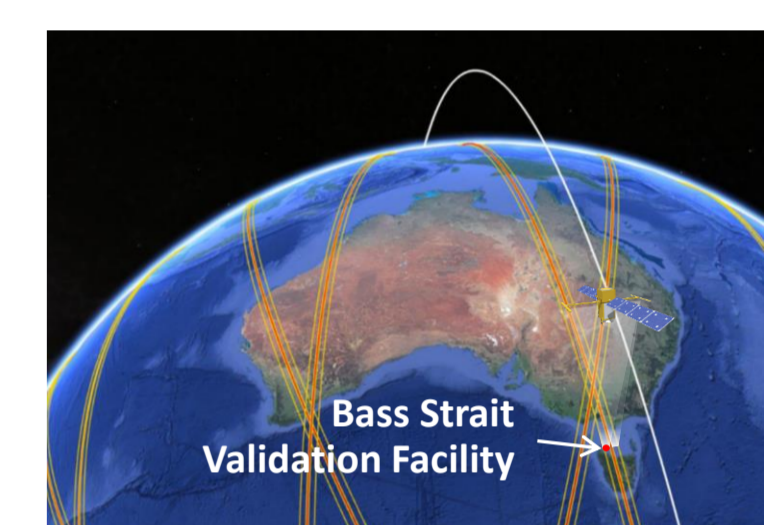
Fig 5: Double differences (SWOT ΔSSH - buoy ΔSSH) calculated over the 3 month validation phase.

KEY POINTS

1) Our GNSS buoys achieve a differential-SSH uncertainty of 4.6 mm. This is due to accurately determining antenna heights, processing using PPP at 2 Hz, and using an array of identically manufactured GNSS buoys to allow the removal of common mode errors through differencing.

Buoy array configuration

- The Bass Strait facility between Tasmania and mainland Australia was located within descending pass 006 of SWOT's one day validation phase.
- During this phase, nine GNSS buoys, three oceanographic sub-surface instruments, and four GNSS land sites were operating near continuously.
- The GNSS array spans 80 km, with the shortest separation distance between buoys of 10 km.
- The coastal shelf sea location and combination of both along and across track sampling allows us to address a variety of validation questions. See poster by Watson et al. for results regarding wet path delay and wave parameters – here we focus on SSH.



Separating noise contributions

- Taking a simple approach to separate total error into noise contributions, we can estimate some bounds for SWOT noise

$$\text{Total}^2 = \text{In situ noise}^2 + \text{KaRIn noise}^2$$

Upper bound (assuming only GNSS noise from in-situ, holding GNSS fixed)

$$\text{2 km product: } 8.4^2 = 4.6^2 + 7.0^2$$

$$\text{Unsmoothed product: } 13.8^2 = 4.6^2 + 13.0^2$$

Lower estimate (assuming independent 500 m KaRIn samples, holding ratio of KaRIn noise fixed)

$$\text{2 km product: } 8.4^2 = x^2 + \left(\frac{1}{\sqrt{16}}y\right)^2$$

$$\text{Unsmoothed product: } 13.8^2 = x^2 + y^2$$

(solving simultaneously for x and y)

$$\text{2 km product: } 8.4^2 = 8.2^2 + 1.8^2$$

$$\text{Unsmoothed product: } 13.8^2 = 8.2^2 + 11.1^2$$

VALIDATION
We send them out into Bass Strait wave-riders, sea-sensors, tethered there to tell tales of how satellites arc across their sky

We listen carefully
tease out the trace of tides and swell the water above and below a chorus of oscillations

We stitch them to graphs,
hold swaths up to the light it's true – we say – we see it too paying homage to the marvel

The ocean's mysteries
shift in hue and float a little closer to our lips

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Earth and Space Science

RESEARCH ARTICLE
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