

1 Key Points and View Forward

Our aim was to contribute to the validation of SWOT SSH (2), wet path delay (3) and waves (4) from the Bass Strait validation facility and the SOFS mooring in the Southern Ocean.

Our focus was using multiple surface buoys equipped with GNSS over the validation phase (Fig 1-1), with SSH validation over the science phase also utilising sub-surface in situ sensors (Fig 2-3).

Key Points Regarding Geometric GNSS Approach:

- GNSS devices can determine Sea Surface Height (SSH), Wet Path Delay (WPD) and Wave Parameters (e.g. SWH).
- Arrays of GNSS (Fig 2-1) provide a geometric approach to validation independent of knowledge of ocean properties.
- GNSS can assess spatial and temporal variability in SSH, WPD and SWH across the chosen spatial distribution of GNSS sites (e.g. along and/or across track).
- Double differencing SWOT and GNSS buoys over various separation distances is the key approach. Δ SSH uncertainty from pairs of GNSS ~ 4.6 mm.
- Important to utilise consistent buoys across the array to mitigate common mode error.

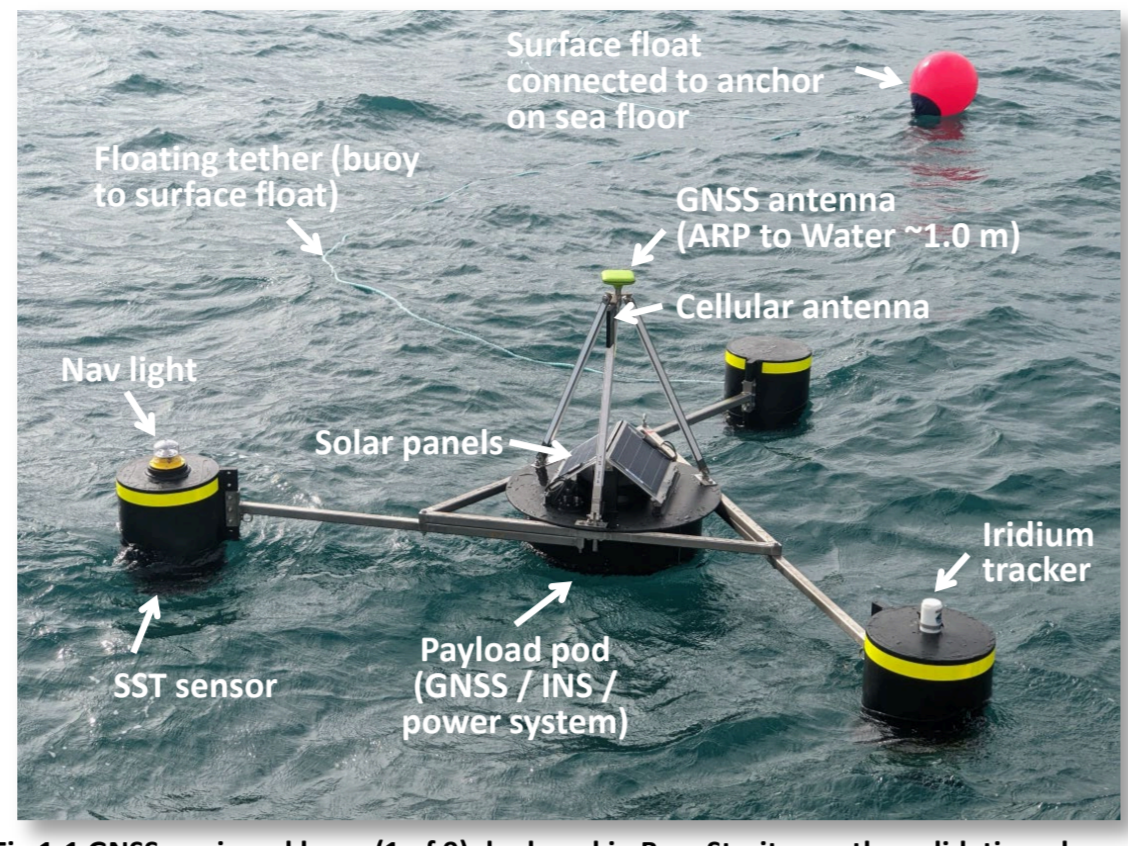


Fig 1-1 GNSS equipped buoy (1 of 9) deployed in Bass Strait over the validation phase

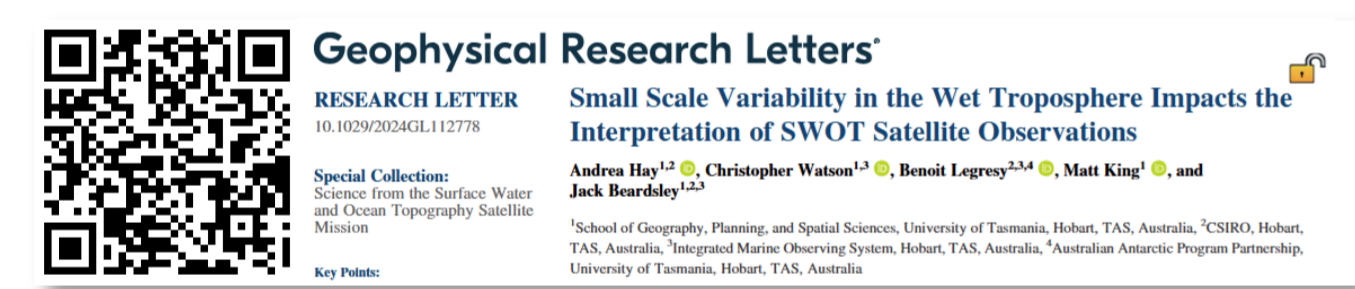
Key Points Regarding SWOT:

- We derived bounds on KaRIn SSH precision between 1.8 and 7.0 mm [2 km product] over length scales of ~ 10 km in Bass Strait, well within the mission requirements of 9.1 mm.
- Sustained validation of SSH during science phase shows negligible absolute bias and precision consistent with the validation phase.
- Variability of up to a few cm in WPD of over short spatial scales is not resolved by the radiometer or modelled product, hence can impact SWOT interpretation.
- Land contamination of SWOT radiometer yields biases of ~ 1 -2 cm within ~ 50 km of the coast.
- Negligible SWOT SWH bias and high precision for SWH > 1 m. Still some challenges with low wave states and very close to the coast.

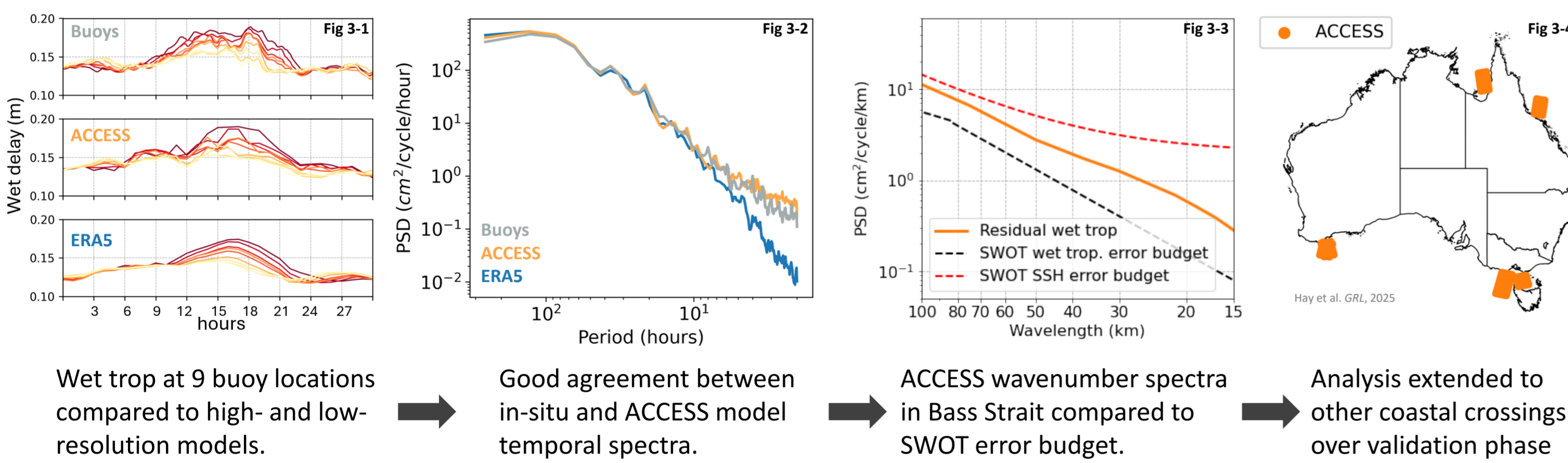
View Forward:

- GNSS equipped arrays of surface platforms have been demonstrated as a viable approach to geometric validation of swath altimetry.
- The Bass Strait array remains a useful coastal test case for assessing refined KaRIn algorithms and new product releases.
- Next step is to integrate our long-term in situ time series from the S3B location (Fig 2-2) into the ongoing validation of science phase data.

3 Troposphere



- Nine GNSS buoys and high-resolution (~ 1.5 km) ACCESS atmospheric model used to investigate wet path delay up to 100 km scales during validation phase (92 SWOT repeats). See Hay et al. *GRL*, 2025.
- Comparable temporal variability in the path delay between GNSS buoys and high-res ACCESS model was observed, with high frequencies poorly captured in the low-resolution model (Fig 3-1, 3-2).
- Wavenumber spectra for ACCESS shows variability up to 100 km scales often exceeds SWOT error budget in Australian coastal regions during the validation phase (Fig 3-3). Case studies (Fig 3-4) provide interesting insights including the effects of atmospheric wave propagation.



- SWOT radiometer (or global low-resolution WPD models) is insensitive to any short scale signal in the troposphere, hence these express in SSH. Atmospheric waves over Bass Strait provide an interesting example (Fig 3-5, 3-6).

- Wavelike phenomena occasionally observed in SWOT SSHA (~ 2 cm wave height, 9 km wavelength, Fig 3-5). Near contemporaneous data from Sentinel-3A clouds band (Fig 3-6) suggests this feature is related to wet troposphere.
- Other examples include high frequency frontal systems in Northern Australia (not shown here) not captured by the radiometer, nor low-resolution models, leaving SSHA errors of ~ 3 cm.

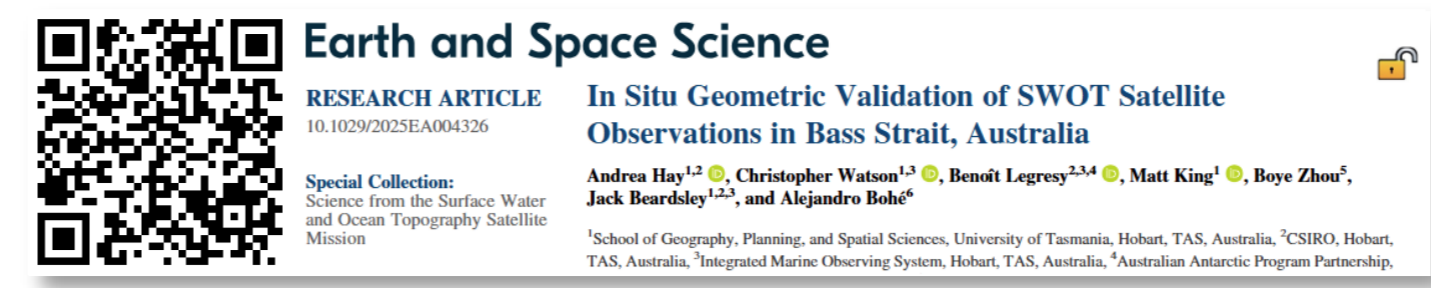
- Our GNSS buoy array also provides a rare opportunity to validate SWOT radiometer land contamination in situ, without extrapolating data from coastal GNSS sites. Fig 3-7 shows contamination commencing ~ 50 -55 km from the coast.

Contributions to SWOT validation from Bass Strait and the Southern Ocean

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Christopher Watson^{1,2} (cwatson@utas.edu.au)
Andrea Hay¹, Benoit Legresy^{3,2}, Jack Beardsley²,
Boye Zhou⁴, Matt King¹ and Alejandro Bohé⁵.

- University of Tasmania
- Integrated Marine Observing System
- CSIRO Oceans and Atmosphere
- University of Newcastle
- Centre National D'Études Spatiales



- The long running Bass Strait altimeter validation facility provides heritage back to TOPEX-Poseidon. The site was significantly augmented for SWOT (Fig 2-1) – see poster by Hay et al for validation phase results. Here we show L2 SSH validation for the science phase (Fig 2-2, 2-4).

Validation phase (1-day orbit) configuration

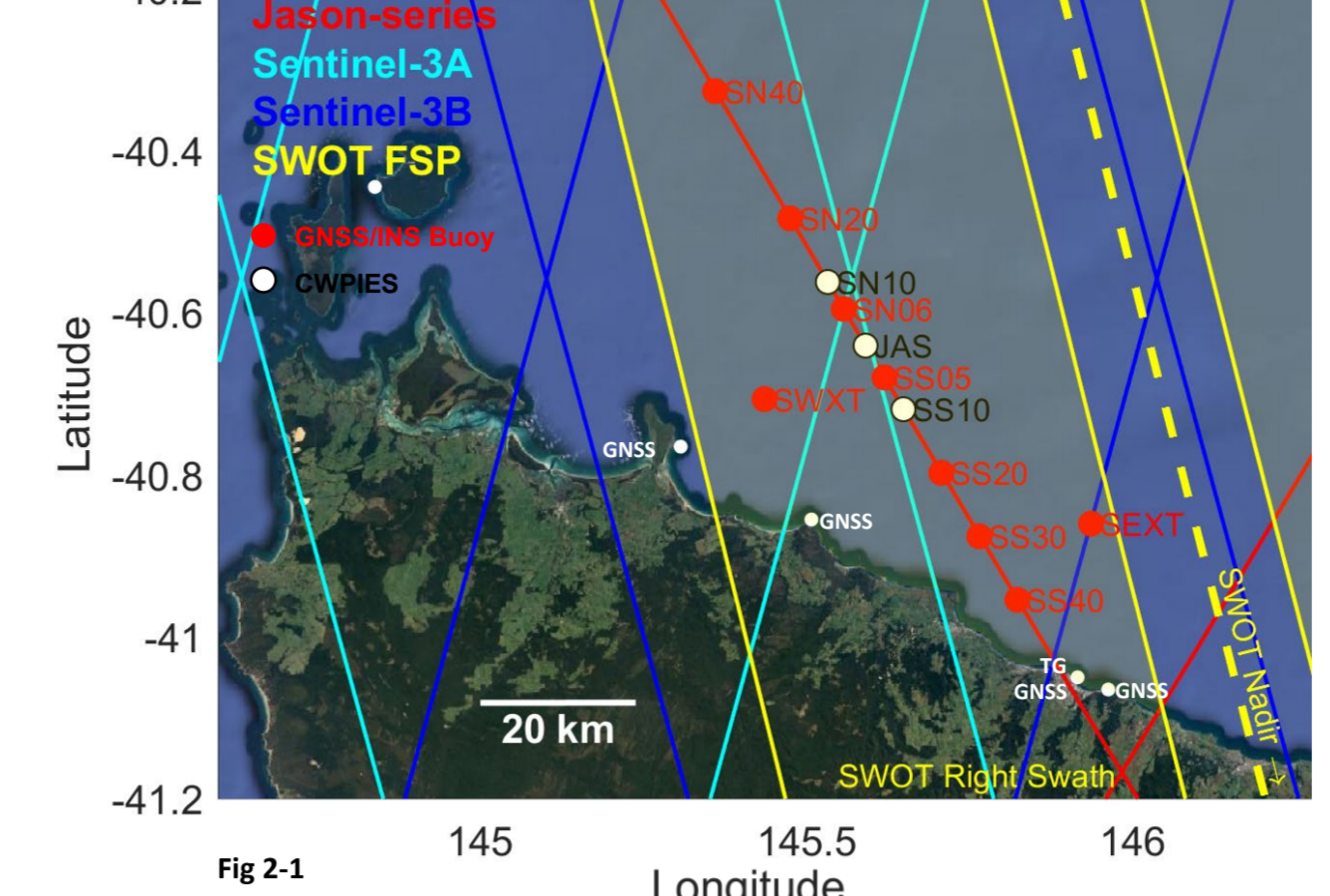


Fig 2-1

Science phase configuration

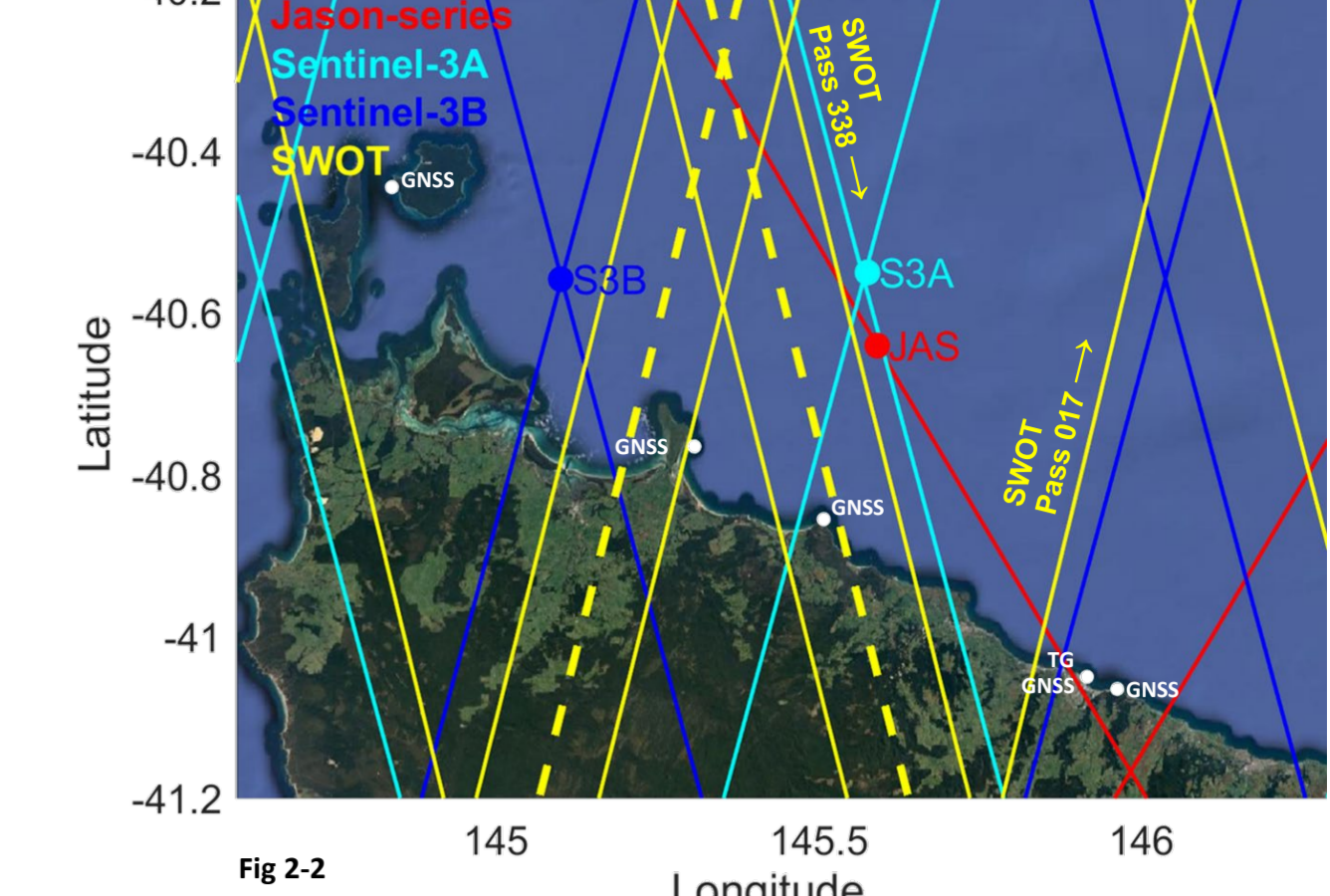


Fig 2-2

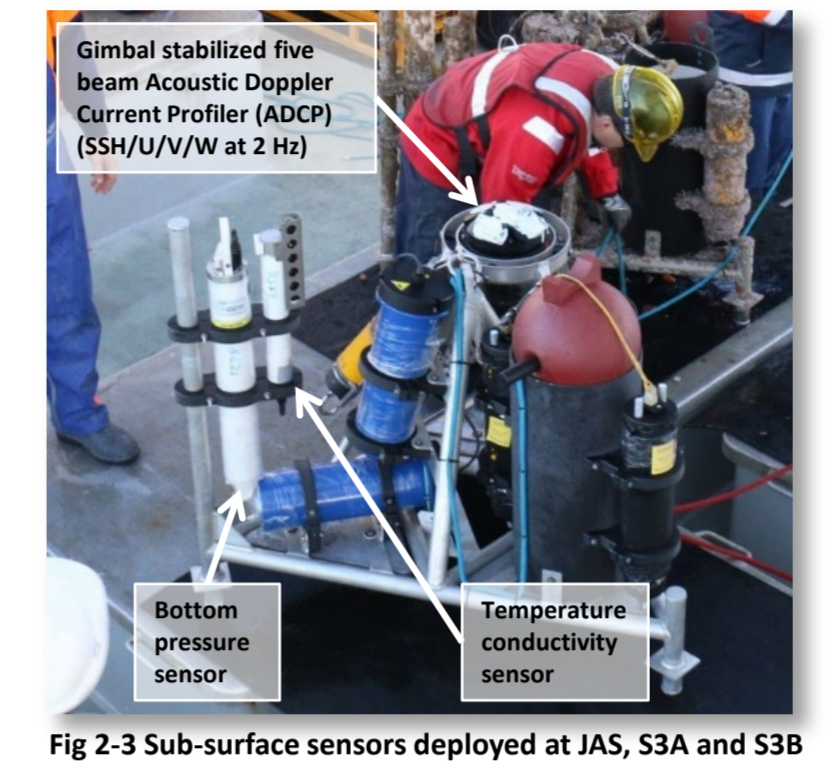


Fig 2-3 Sub-surface sensors deployed at JAS, S3A and S3B

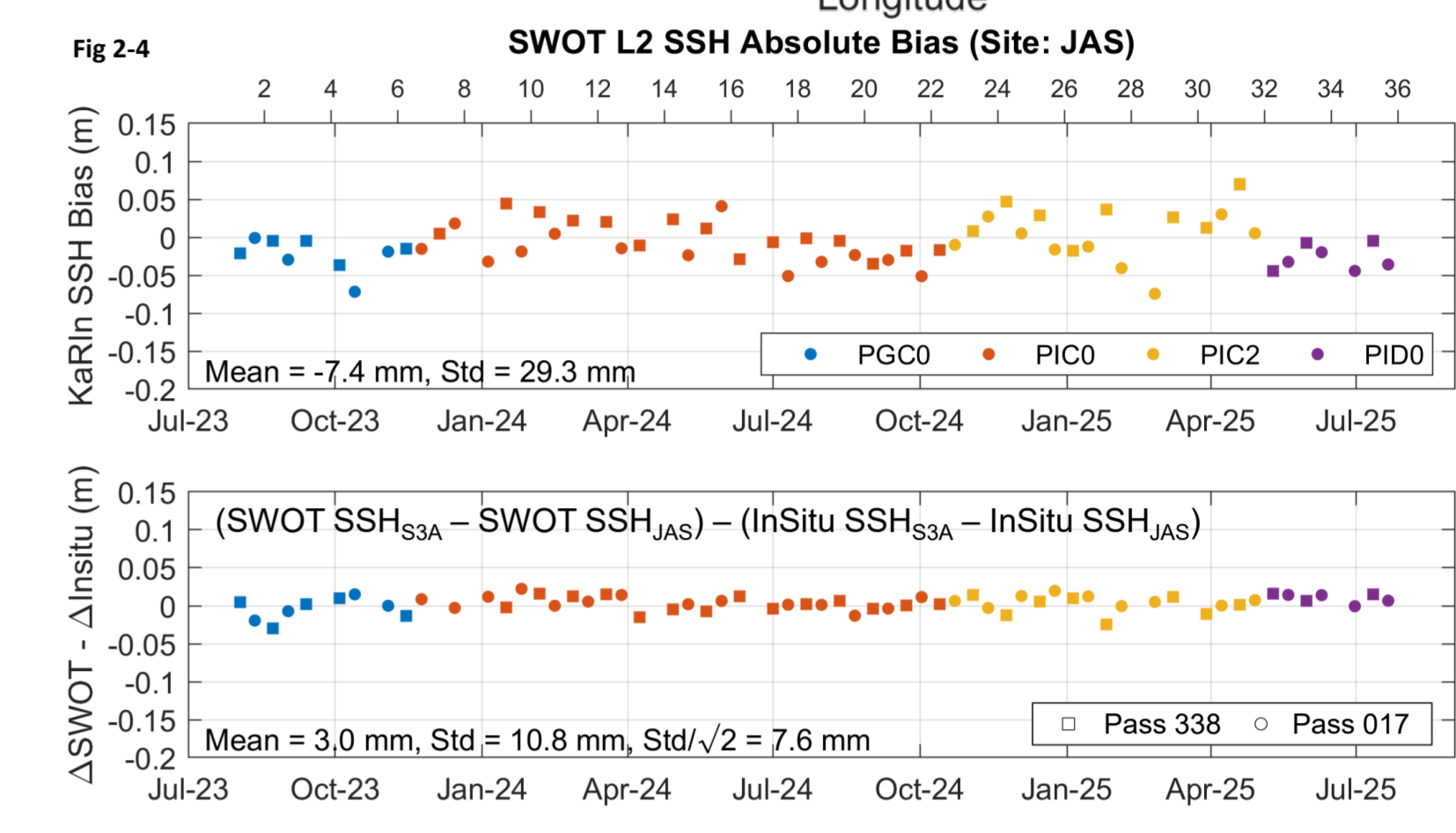
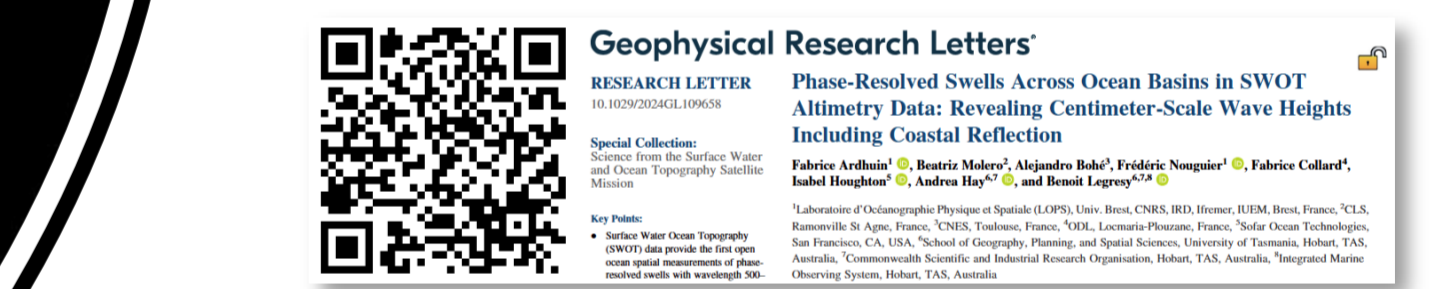


Fig 2-4

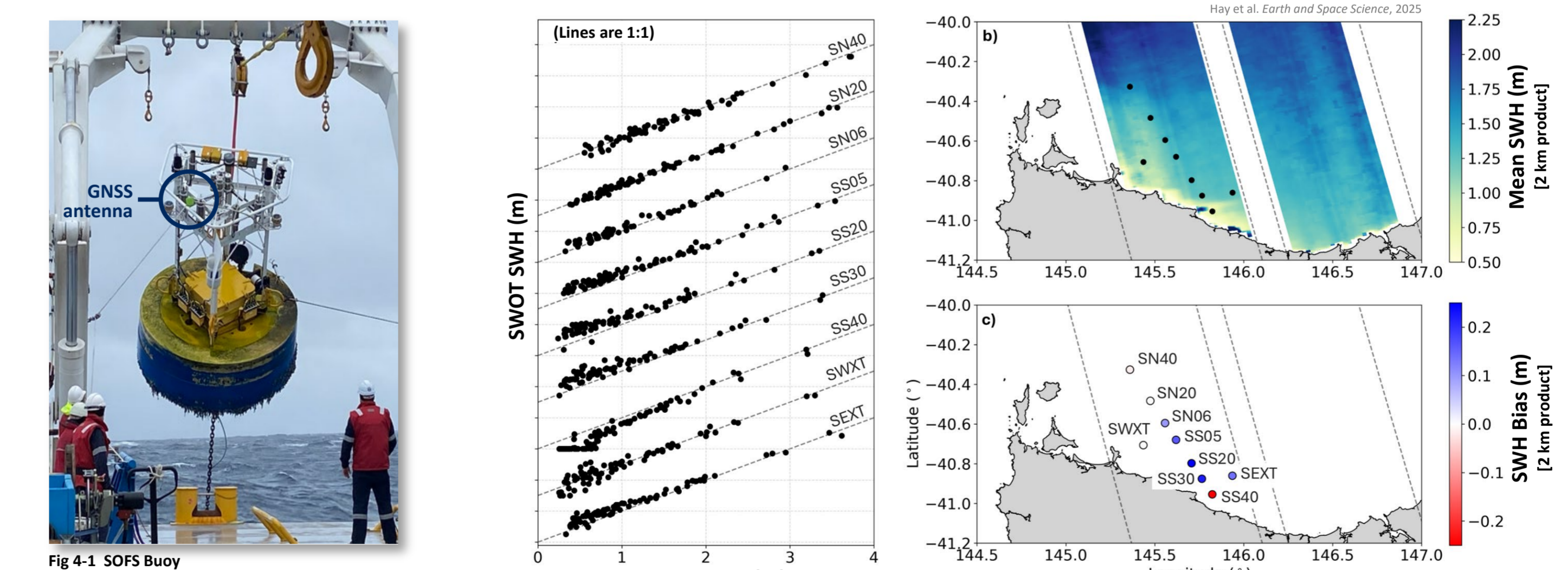
- Fig 2-4 (top) shows absolute bias time series (SWOT – in situ) from SWOT passes 017 and 338 at the JAS CP (see Fig 2-2), computed using an in situ series derived using sub-surface sensors (see Fig 2-3) with datum connection from GNSS buoy deployments.
 - Mean and standard deviation remain consistent with results from validation phase. No clear dependence on pass or PGC0 / PIC0 / PIC2 / PID0.
- Fig 2-4 (bottom) shows double differenced SSH between SWOT and in situ SSH at S3A and JAS sampling locations (~ 9.2 km separation, locations in Fig 2-2).
 - Differential noise of 7.6 mm over ~ 9 km is likely dominated by in situ noise. Assuming equal contribution from SWOT and in situ implies KaRIn noise of ~ 5.4 mm.



4 Waves



- GNSS observations at 2 Hz from the SOFS mooring (Fig 4-1) in the Southern Ocean (~ 47 S, 141E) were used to derive wave parameters and compared against nadir altimetry and CFOSAT SWIM measurements (Hay et al. *JTECH*, 2023).
- Over the validation phase, SWOT 2D wave fields were compared to SOFS (Bohé et al. *TGRS*, 2025), showing negligible biases and std deviations of 0.15 m (@ 5 km) and 0.20 m (@ 2 km).
- SOFS data also used in validating long period cm-scale swell signals (Arduin et al. *GRL*, 2024).



- Our array of 9 GNSS buoys in Bass Strait (Fig 4-2) provided a coastal shallow-water target for SWOT wave validation over the validation phase (Hay et al. *ESS*, 2025). Mean bias of 0.06 m, standard deviation of 0.21 m (n=683), reduces to 0.03 m and 0.11 m when considering SWH > 1 m (n=308). Gradient in bias approaching the coast (Fig 4-2c), and near coast performance (i.e. SS40, Fig 4-2c) remains under investigation.
- Inter-site SWH differences confirm SWOT and GNSS observe comparable variability over 10-80 km scales. The ECMWF global model also captures the gradient in SWH yet doesn't capture as much energy over the shortest scales (Figure 4-3).