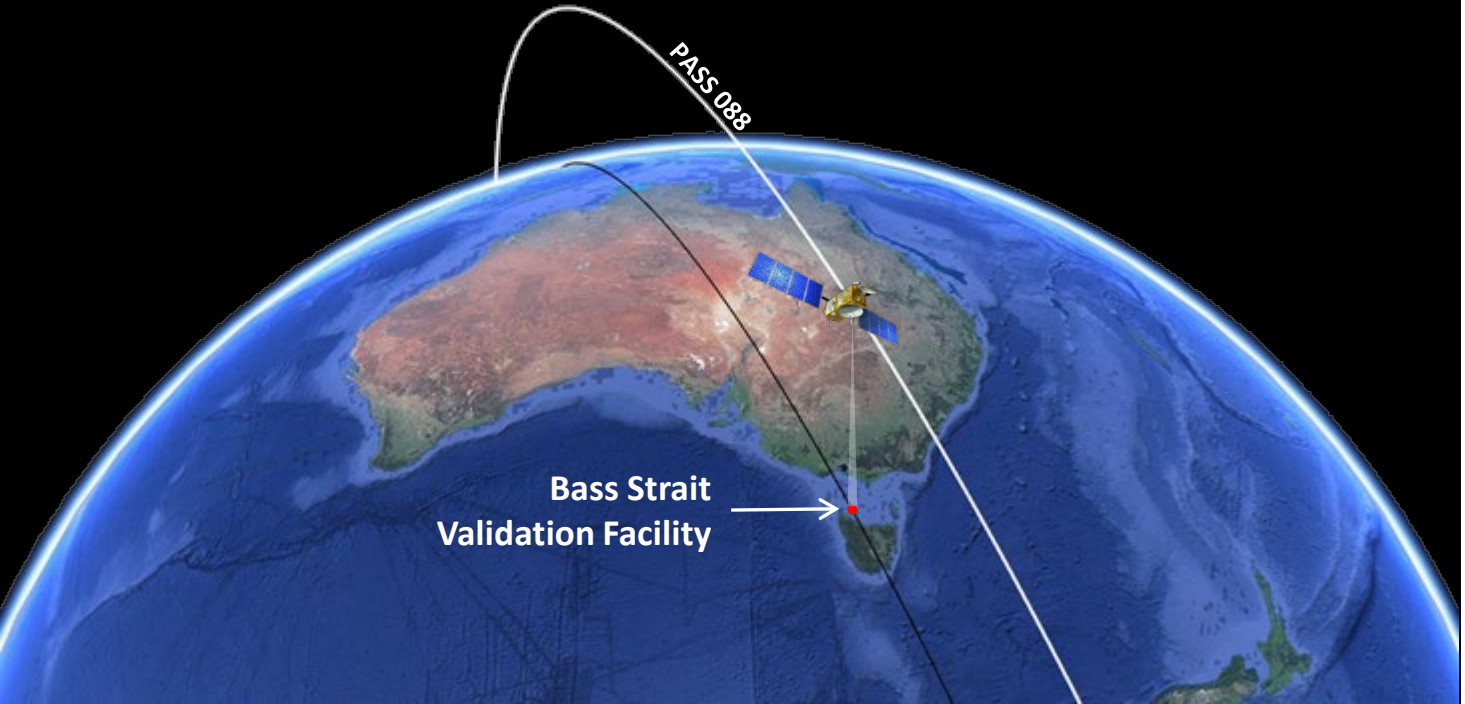
Updated S6MF validation results from the Bass Strait validation facility, Australia

Christopher Watson[1,2] (cwatson@utas.edu.au),
Benoit Legresy[3,2], (Benoit.Legresy@csiro.au),
Andrea Hay[1,3], Jack Beardsley[2], Boye Zhou[1], Matt King[1].

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



UNIVERSITY of TASMANIA

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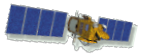
IMOS
Integrated Marine Observing System

S6VT Meeting
San Juan, Puerto Rico
November 7-11, 2023

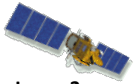
Bass Strait Validation Facility:

TOPEX / Poseidon
Aug 1992

Jason-1
Dec 2001

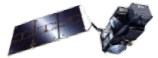


OSTM/Jason-2
June 2008

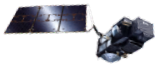


Jason-3
Jan 2016

- Sustained and independent monitoring of altimeter absolute bias in Bass Strait, Australia, since the launch of TOPEX/Poseidon in late 1992.
- Ongoing support received from the Australian Integrated Marine Observing System (IMOS) until June 2027.

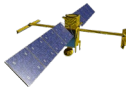


Sentinel-3A
Feb 2016



Sentinel-3B
Apr 2018

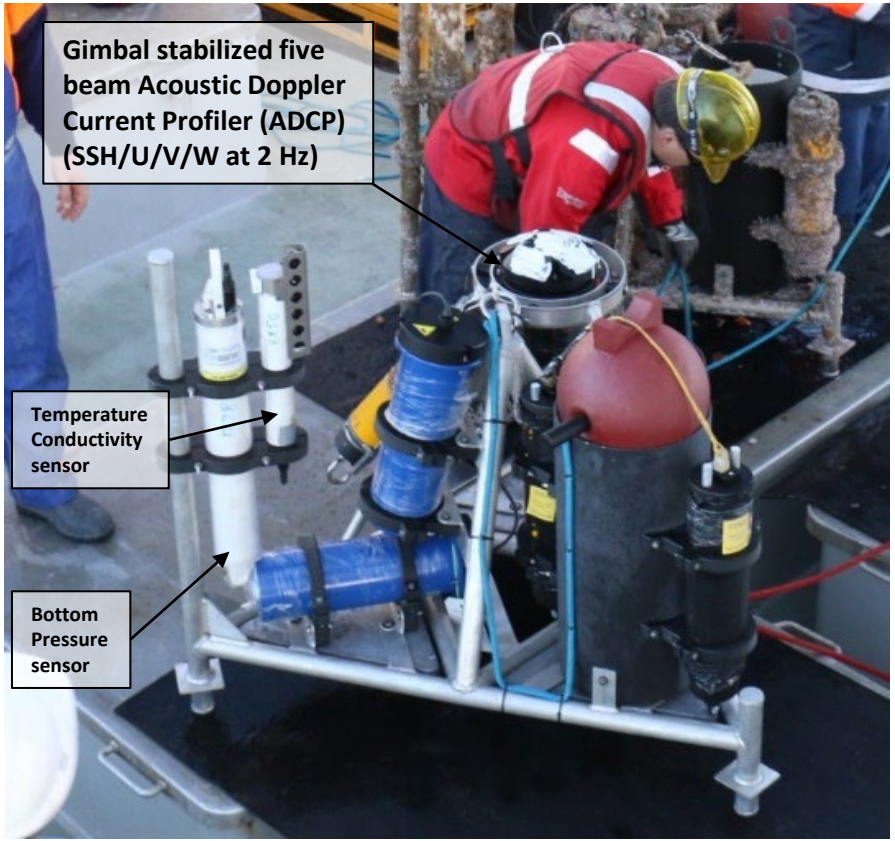
Sentinel-6 / Michael Freilich
Nov 2020



SWOT
Dec 2022

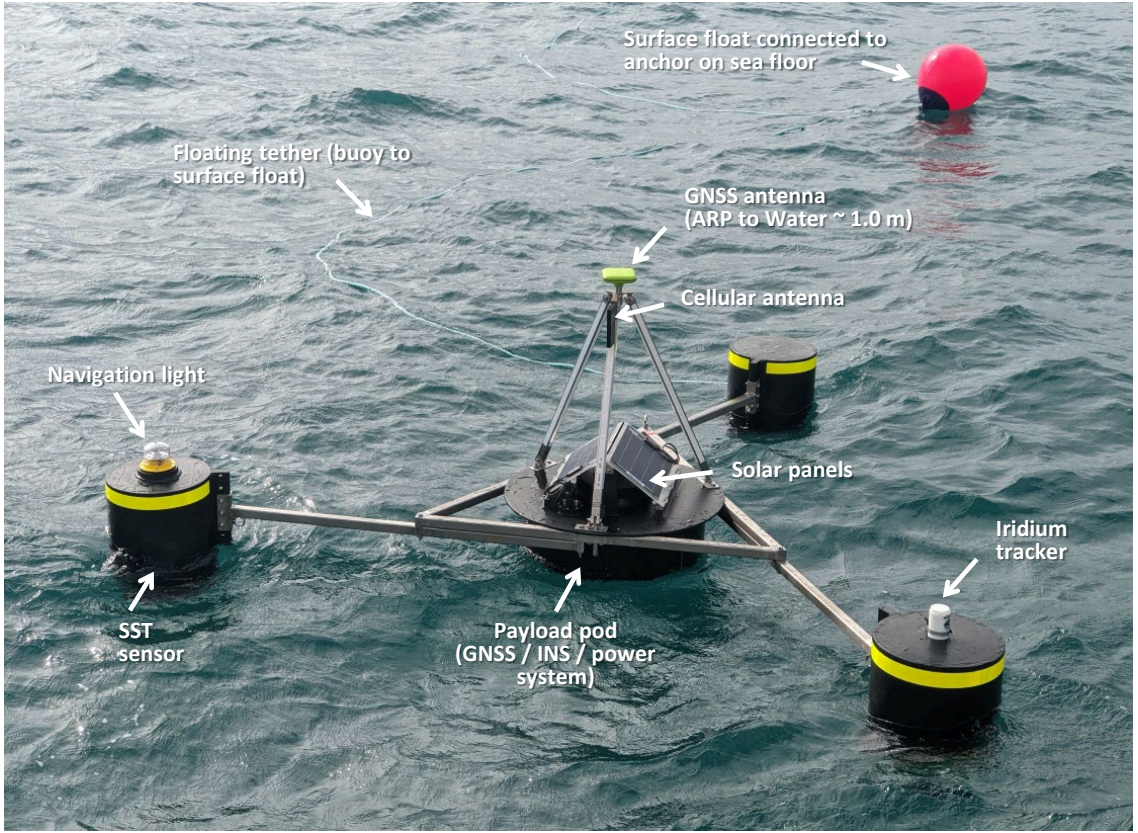
Bass Strait: Sensor Developments (CSIRO)

- Developments with altimeter technology means in situ approaches used to observe SSH need to evolve to keep pace. Sentinel-6 and SWOT key drivers for us.
- New CWPIES moorings add the acoustic approach to in situ SSH, overcoming imperfections in the ‘classic’ approach and helping to gain extra mm in precision.
- These new mooring also deliver new useful observations of 3D currents and waves.
- All of this continuously, year-round at our Sentinel-6, Senitnel-3A and 3B comparison points.
- Std dev against GNSS buoys < 2 cm.



Bass Strait: Sensor Developments (UTAS)

- New GNSS/INS equipped buoys to deliver sustained SSH in an absolute reference frame (ITRF).
- Now capable of sustained deployment (e.g. 9 buoys deployed in up to ~5 m SWH in Bass Strait over ~95 days for SWOT FSP).
- SSH (2 Hz), SWH and Wet tropospheric delay as outputs.
- Some tether induced bias evident against mooring SSH in SWH > 3 m.
- GipsyX PPP and TRACK DD solutions. Currently investigating differences with/without addition of INS in both solutions.

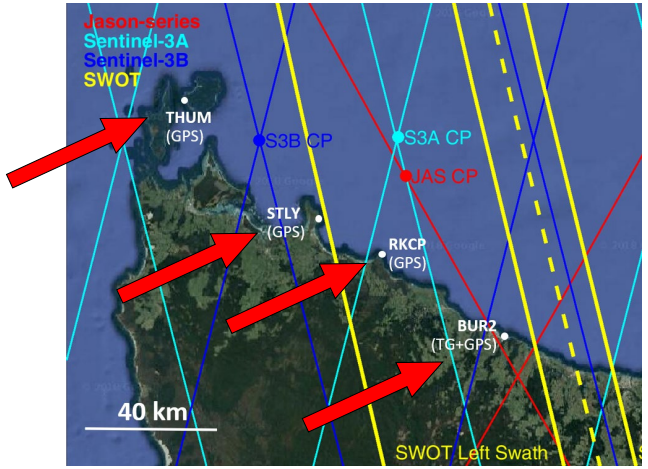


Bass Strait Datum

- Land based GNSS sites are critical to observe vertical land motion which influences relative sea level observations from the tide gauge and ocean moorings.

GNSS deployment at Rocky Cape (RKCP)

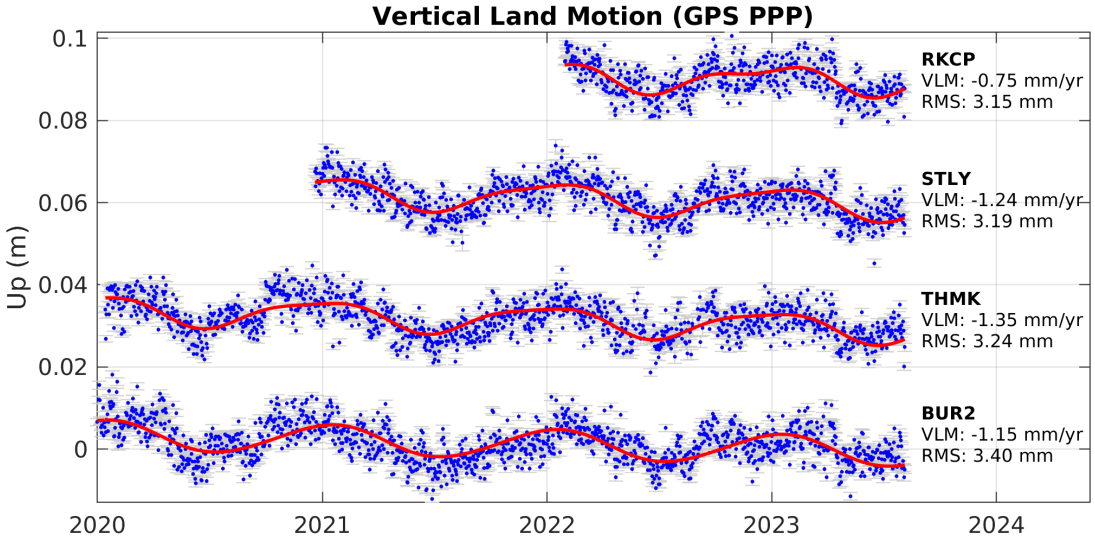
GNSS deployment at Stanley (STLY)



- GNSS sites are also used as reference stations in differential processing of buoys. Currently using both PPP and differential approaches.
- Additionally, they offer insight into the evolution of the wet tropospheric delay.

Bass Strait Datum

- Land based GNSS reveals widespread subsidence over SE Australia. All sites show excellent performance.
- Annual signal dominated by Terrestrial Water Storage (TWS) effects.
- Common mode signal and error – useful to consider in DD and PPP solutions.



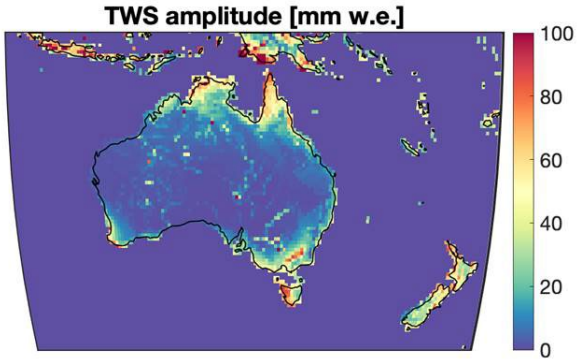


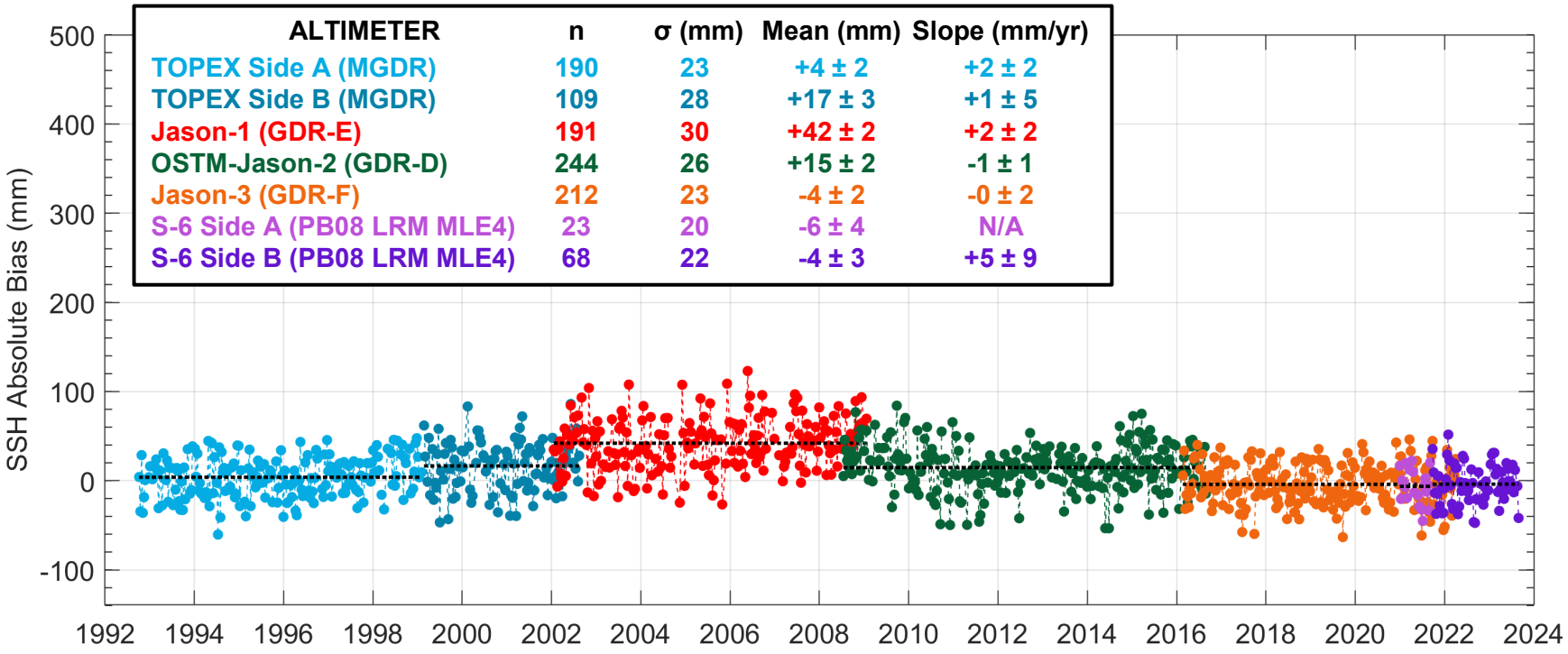
Image from Carsten Ludwigsen, DTU

Results Part I:

Absolute Bias at Nominal CP

Absolute Bias Time Series

- PB08 for Sentinel-6 MF
- Mooring or TG used for in situ



Absolute Bias Time Series

- S6 bias indistinguishable from zero.
- S6 HR std dev now clearly < 2 cm.

ALTIMETER	n	σ (mm)	Mean (mm)	Slope (mm/yr)
TOPEX Side A (MGDR)	190	23	+4 ± 2	+2 ± 2
TOPEX Side B (MGDR)	109	28	+17 ± 3	+1 ± 5
Jason-1 (GDR-E)	191	30	+42 ± 2	+2 ± 2
OSTM-Jason-2 (GDR-D)	244	26	+15 ± 2	-1 ± 1
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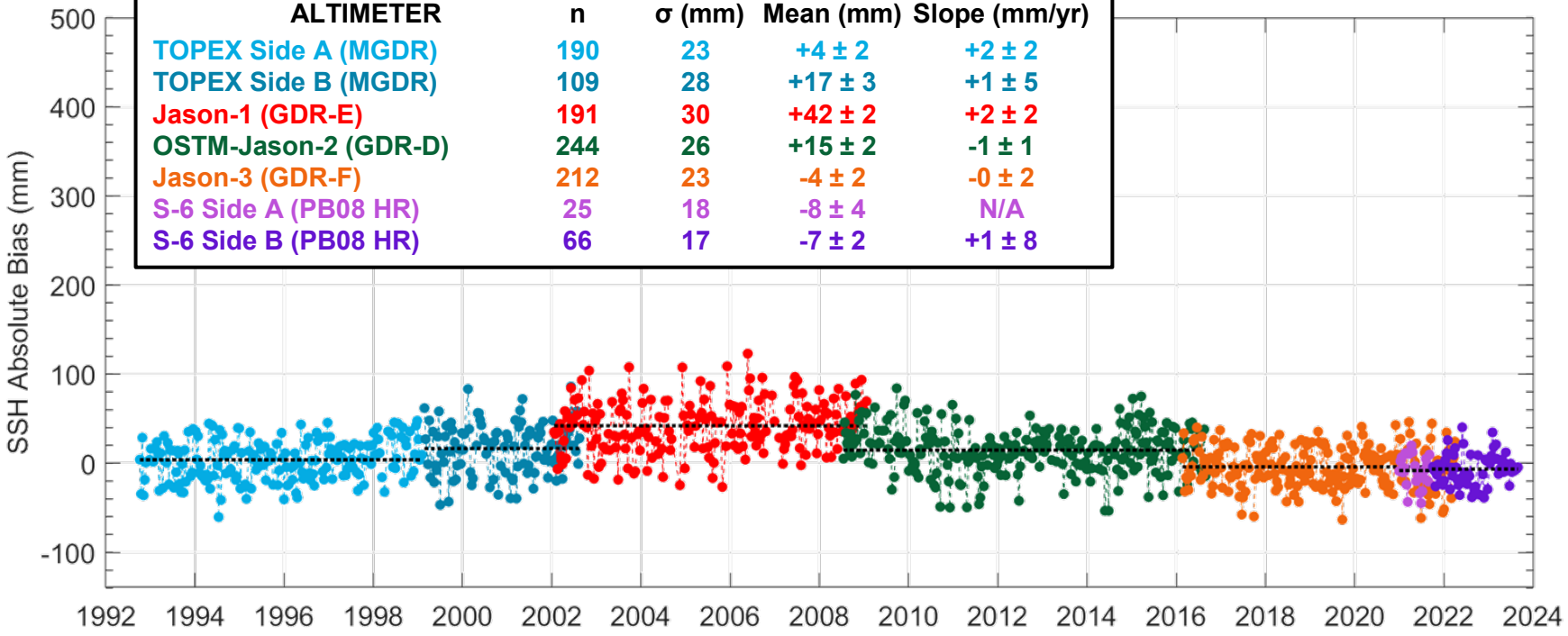
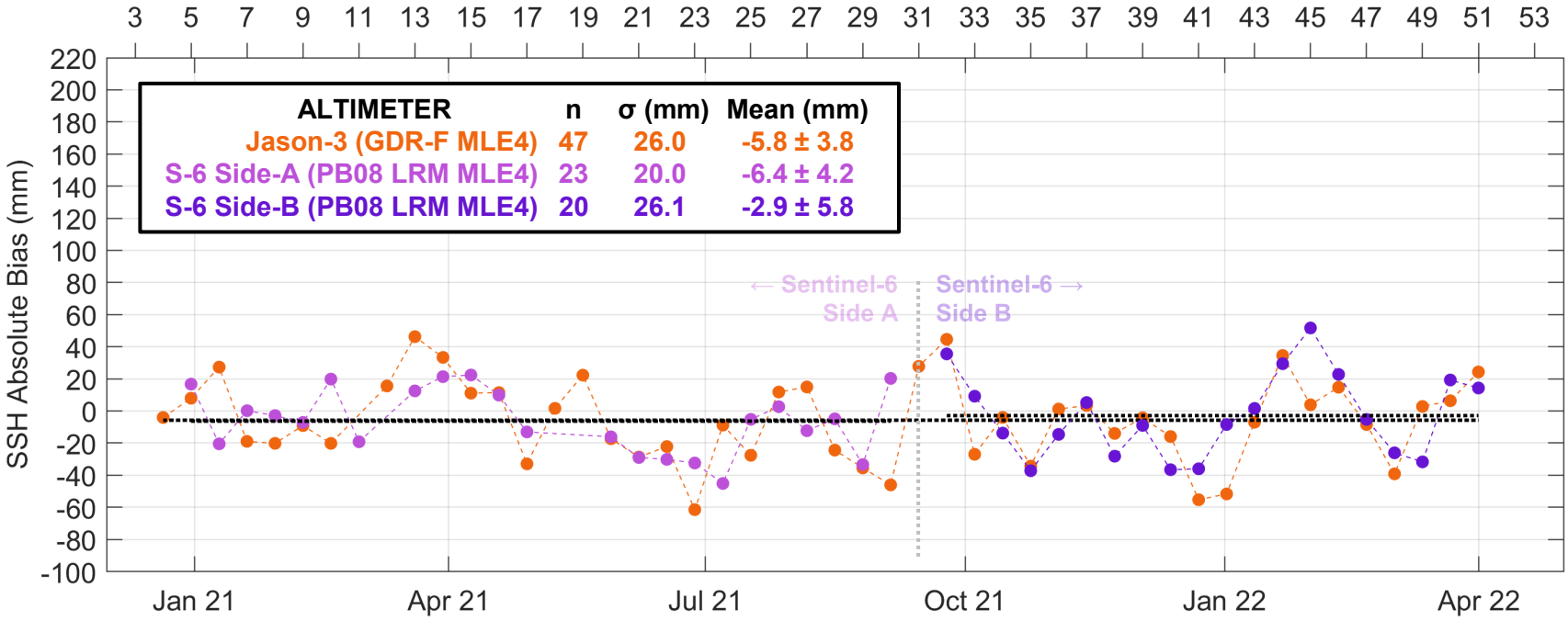
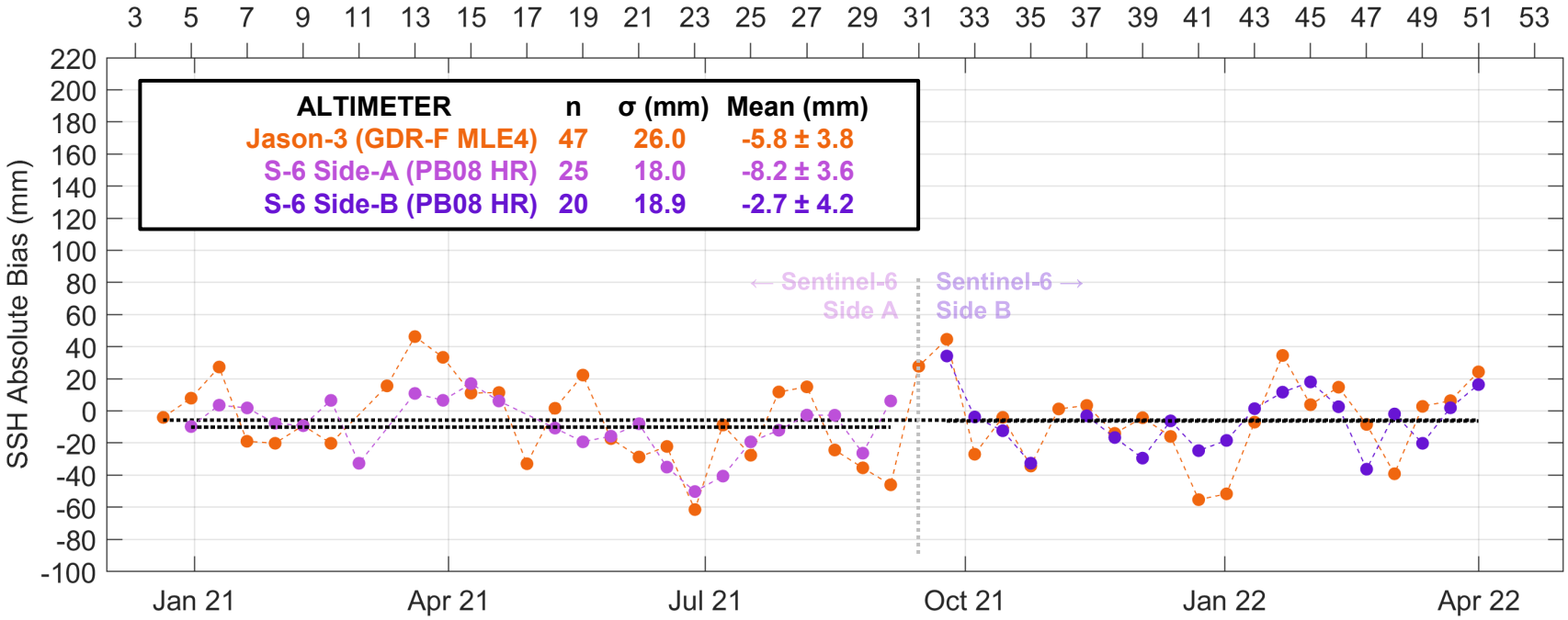


Absolute Bias at Bass Strait – J3/S6 LRM FFP



Relative bias: S6A (PB08 LRM MLE4) – J3 (GDR-F MLE4) = +1.3 ± 4.8 mm
S6B (PB08 LRM MLE4) – J3 (GDR-F MLE4) = +1.0 ± 4.2 mm

Absolute Bias at Bass Strait – J3/S6 HR FFP

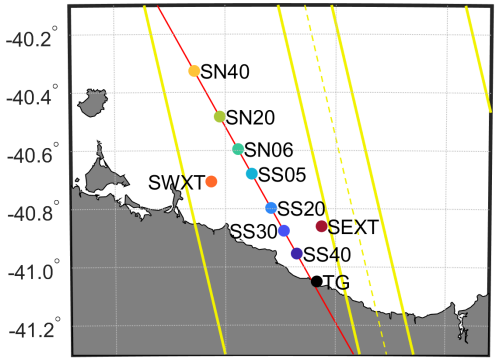


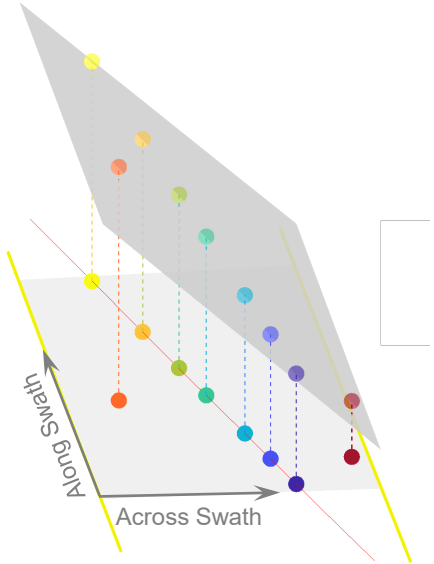
Relative bias: S6A (PB08 HR) – J3 (GDR-F MLE4) = -1.2 ± 5.2 mm
S6B (PB08 HR) – J3 (GDR-F MLE4) = +3.8 ± 4.0 mm

Results Part II:

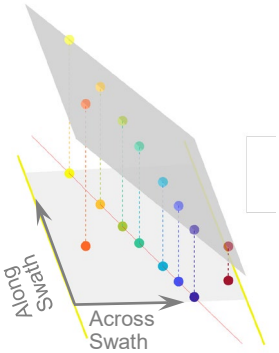
Early Comparison with SWOT

- Seven GNSS buoys along ~80 km of Sentinel-6 Pass 088 over SWOT FSP





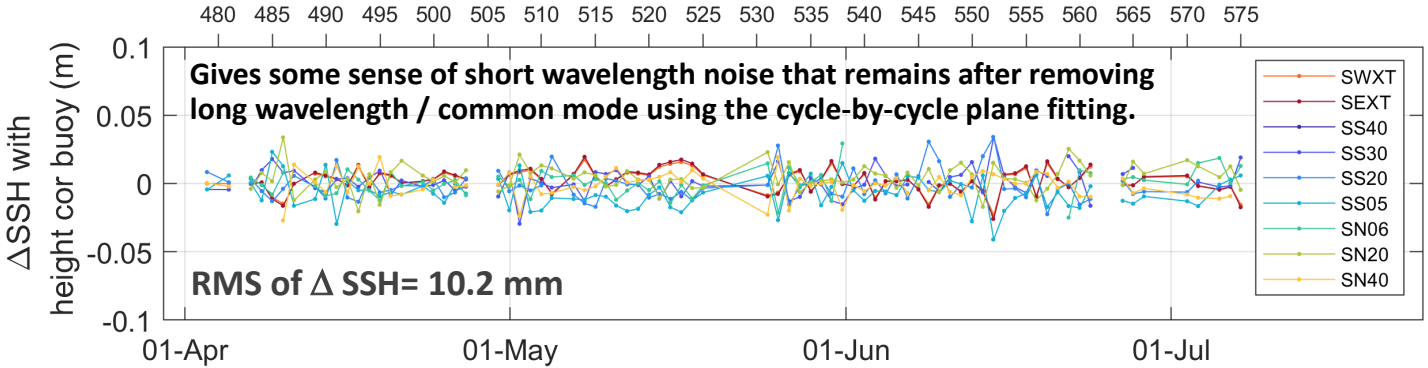
Comparisons: SSH SWOT – SSH Buoy = ΔSSH

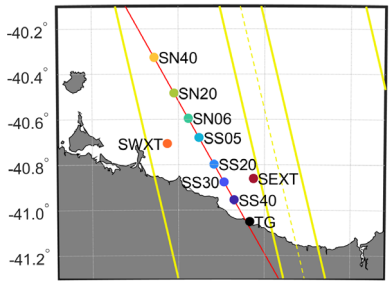


L2, LR (2 km), PGE 4.3.0
Product SSH includes wet radiometer and SSB corrections.
- Solid Earth Tide
- Pole Tide (solid part only)
- Load Tide (FES)

- height cor buoy (derived from GNSS buoys)

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



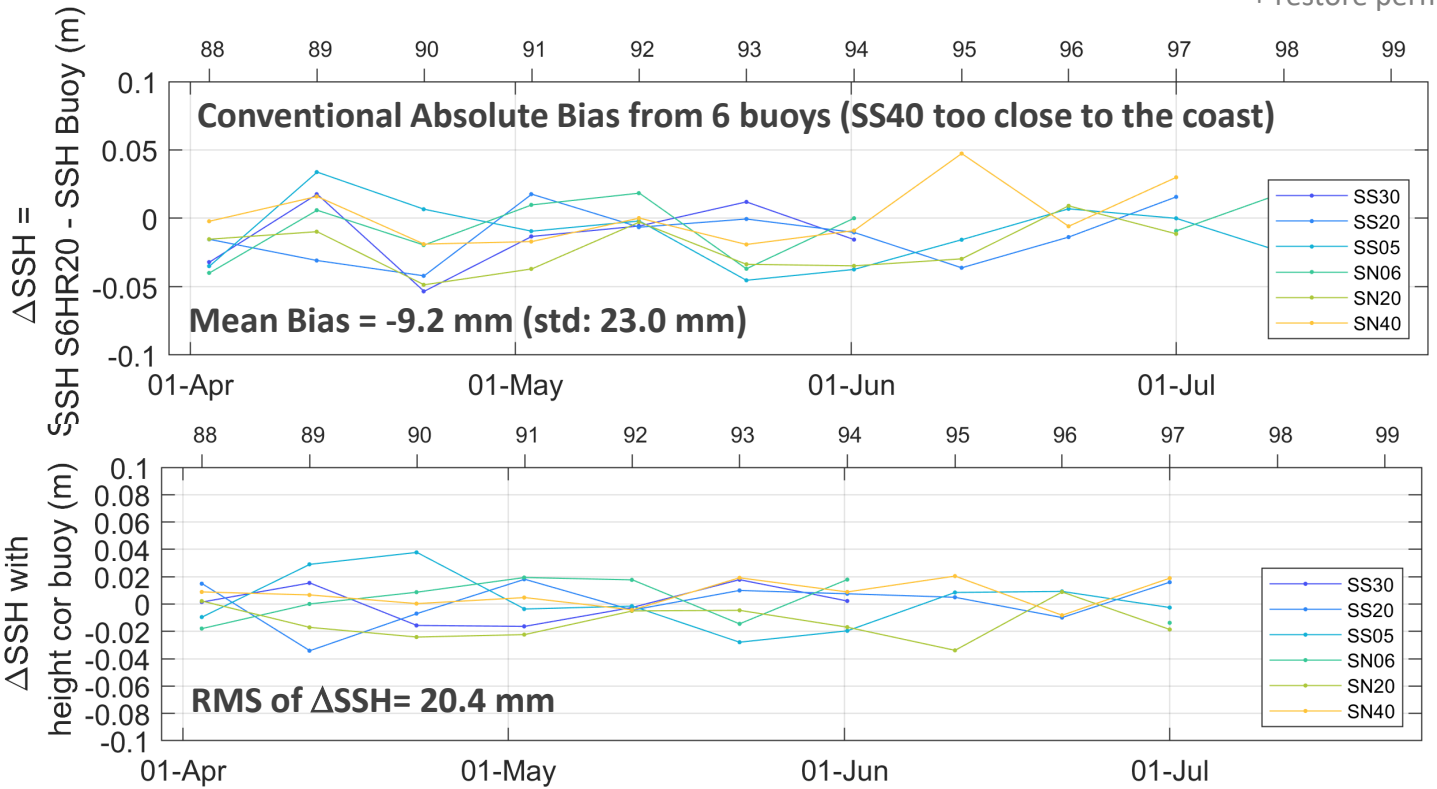


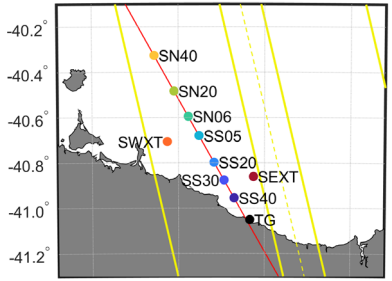
Are there any useful comparisons to make with Sentinel-6 HR data here?

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

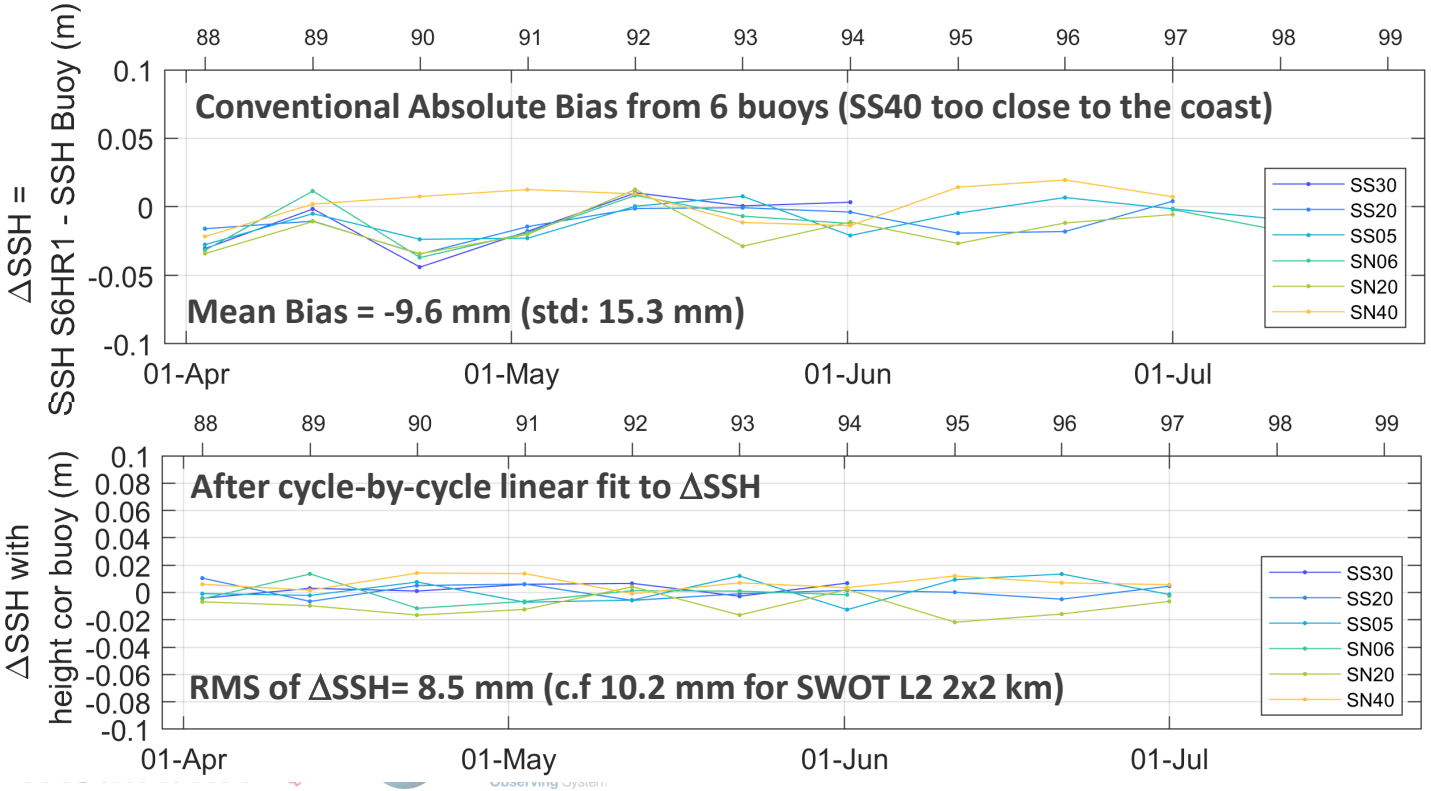


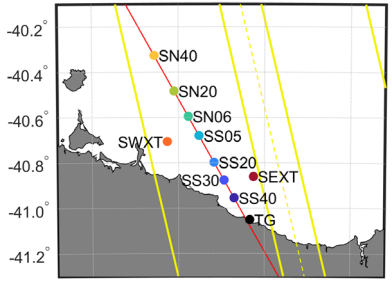


Comparisons: SSH S6 HR 1 Hz - SSH Buoy = ΔSSH

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

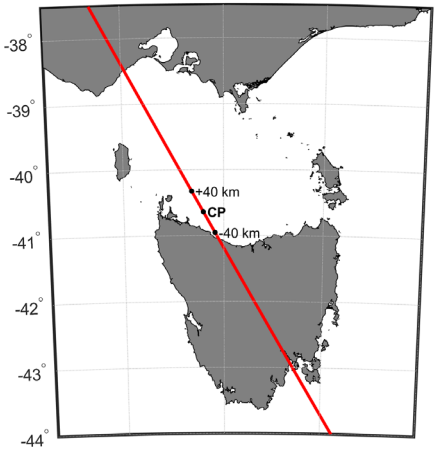
GipsyX, ITRF14, GRS80 Ellip Ht at 2 Hz
- corrections as per SWOT
+ restore permanent tide

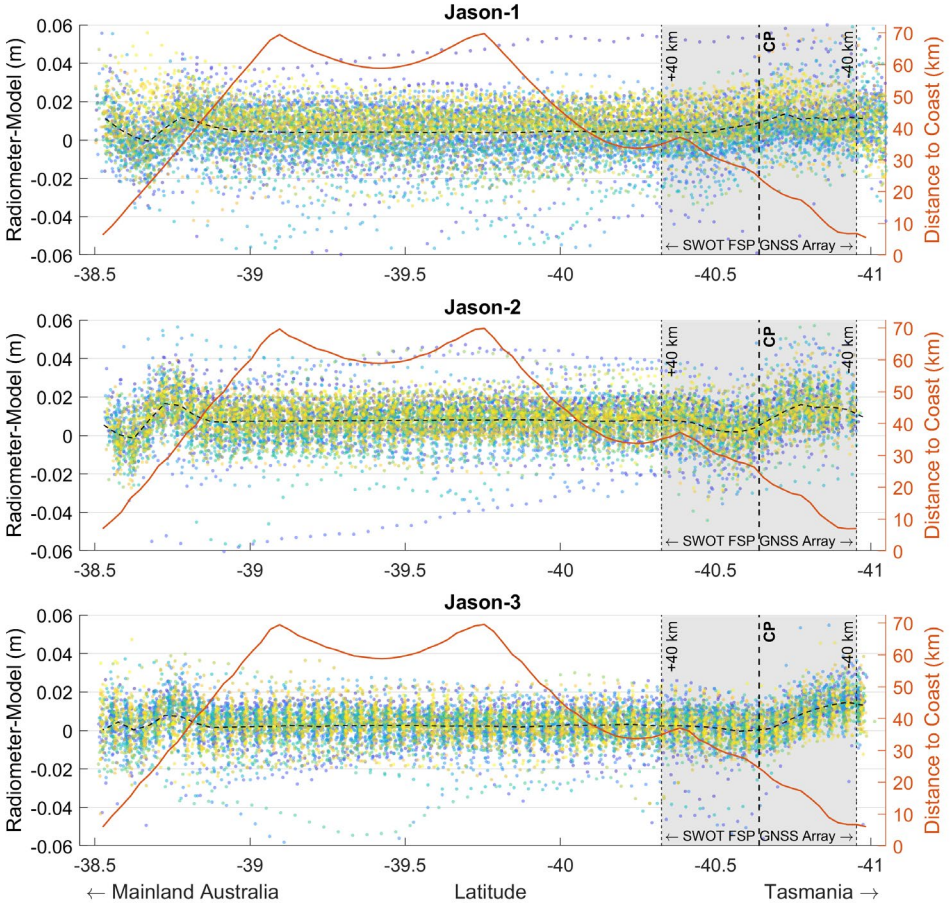




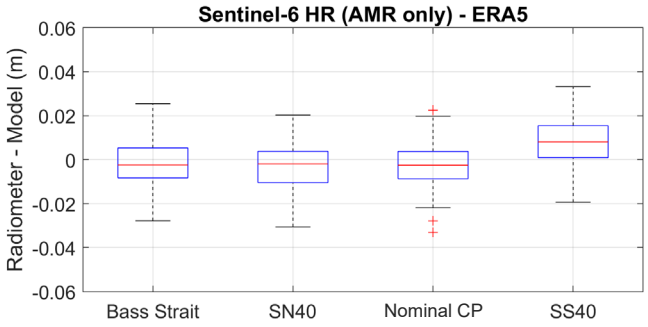
Coastal Effects

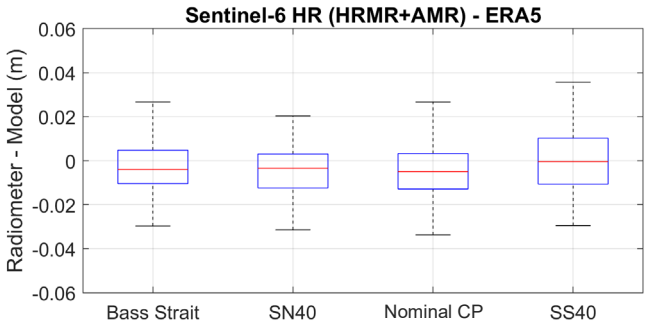
- Cycle-by-cycle radiometer minus modelled wet delay for Jason-series 1 Hz data as function of latitude gives sense of residual land contamination.
- How does this look for S6 AMR and HRMR data?

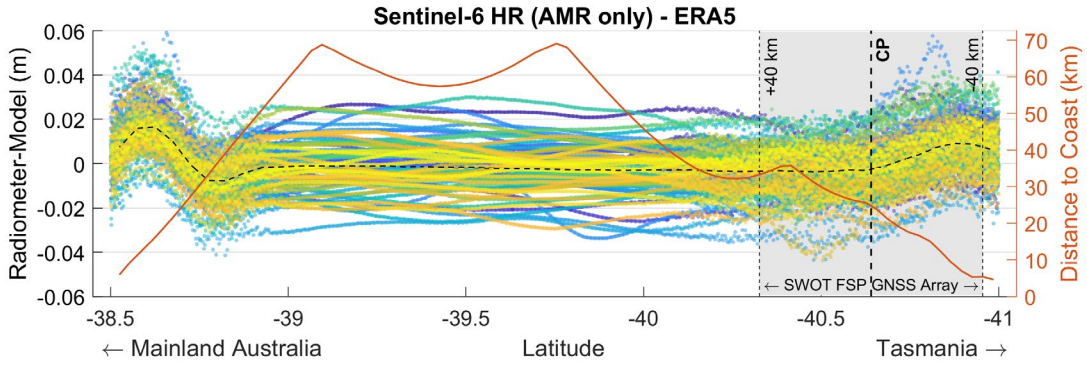


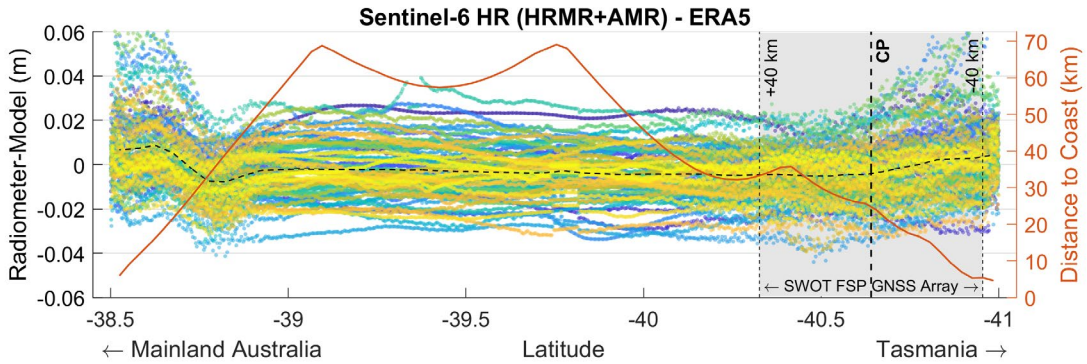


S6 v ERA5: AMR Only and HRMR+AMR



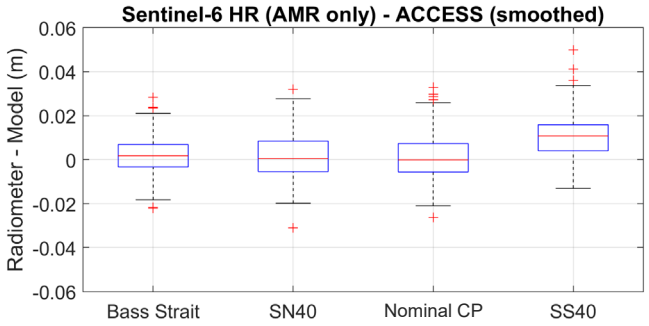


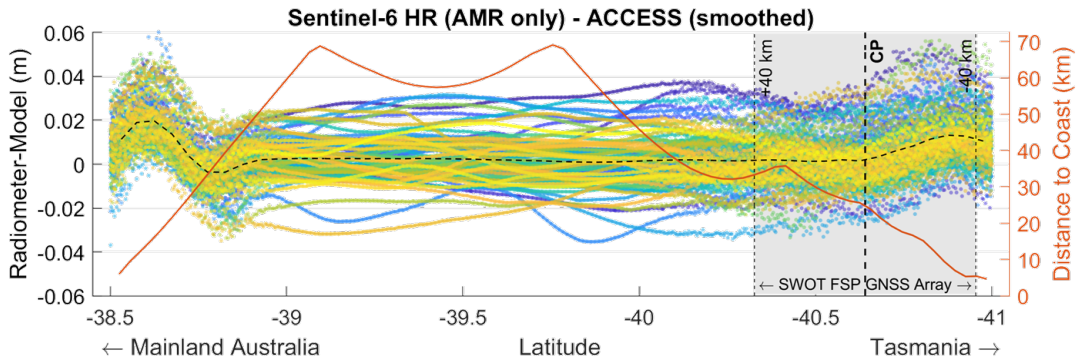


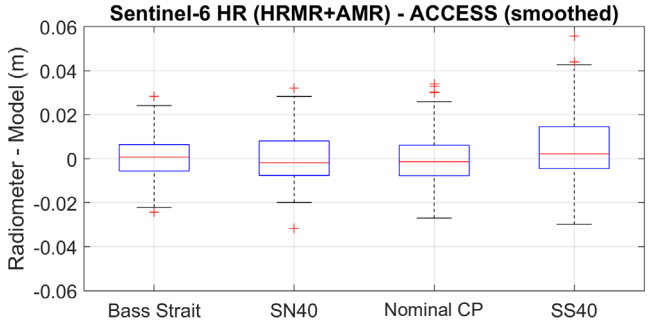


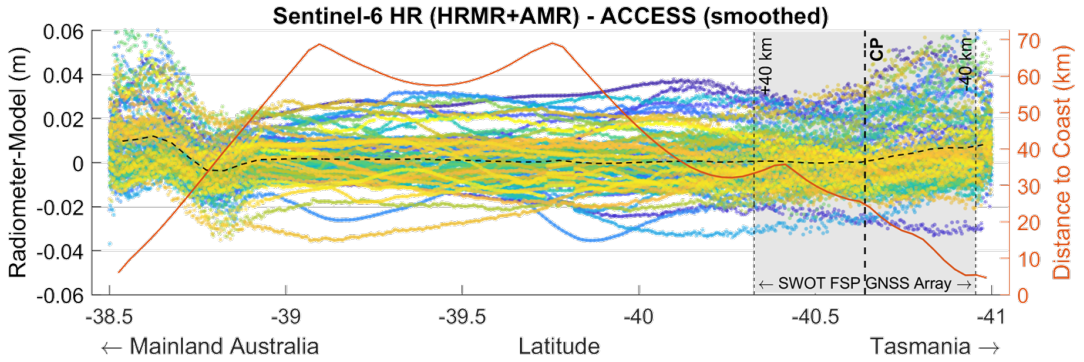
S6 v ACCESS: AMR Only and HRMR+AMR

- ACCESS is the Australian ~1 km resolution operational atmospheric model



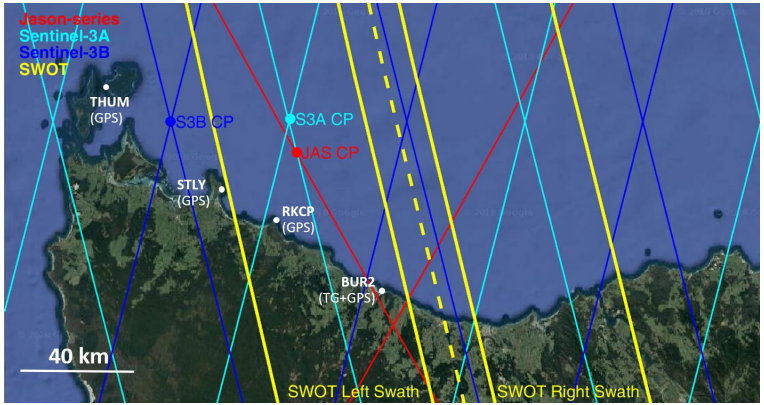






Conclusions

- Very low variability in bias estimates at Bass Strait highlights the evolution of altimetry and the high quality in situ data in use at the facility.
- Sentinel-6 bias estimates are indistinguishable from zero. Variability of HR data is now < 2 cm. Short wavelength contributions (including contribution from in situ is < 1 cm).
- All trends are indistinguishable from zero. Negligible difference between retrackers.
- Non-averaging errors likely limit absolute bias uncertainty to ±10 mm.



Current work in progress:

- Buoy array and CWPIES v Sentinel-6 and SWOT over FSP right up to the coast.
- Part of this includes an investigation of intra swath (SWOT) variability in wet delay – this will include a focus on AMR v HRMR v GNSS and models.

ALTIMETER	n	σ (mm)	Mean (mm)	Slope (mm/yr)
TOPEX Side-A (MGDR)	190	23	+4 ± 2	+2 ± 2
TOPEX Side-B (MGDR)	109	28	+17 ± 3	+1 ± 5
Jason-1 (GDR-E)	189	29	+41 ± 2	+2 ± 2
OSTM-Jason-2 (GDR-D)	244	26	+15 ± 2	-1 ± 1
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S-6 Side-A (PB08 LRM MLE4)	23	20	-6 ± 4	N/A
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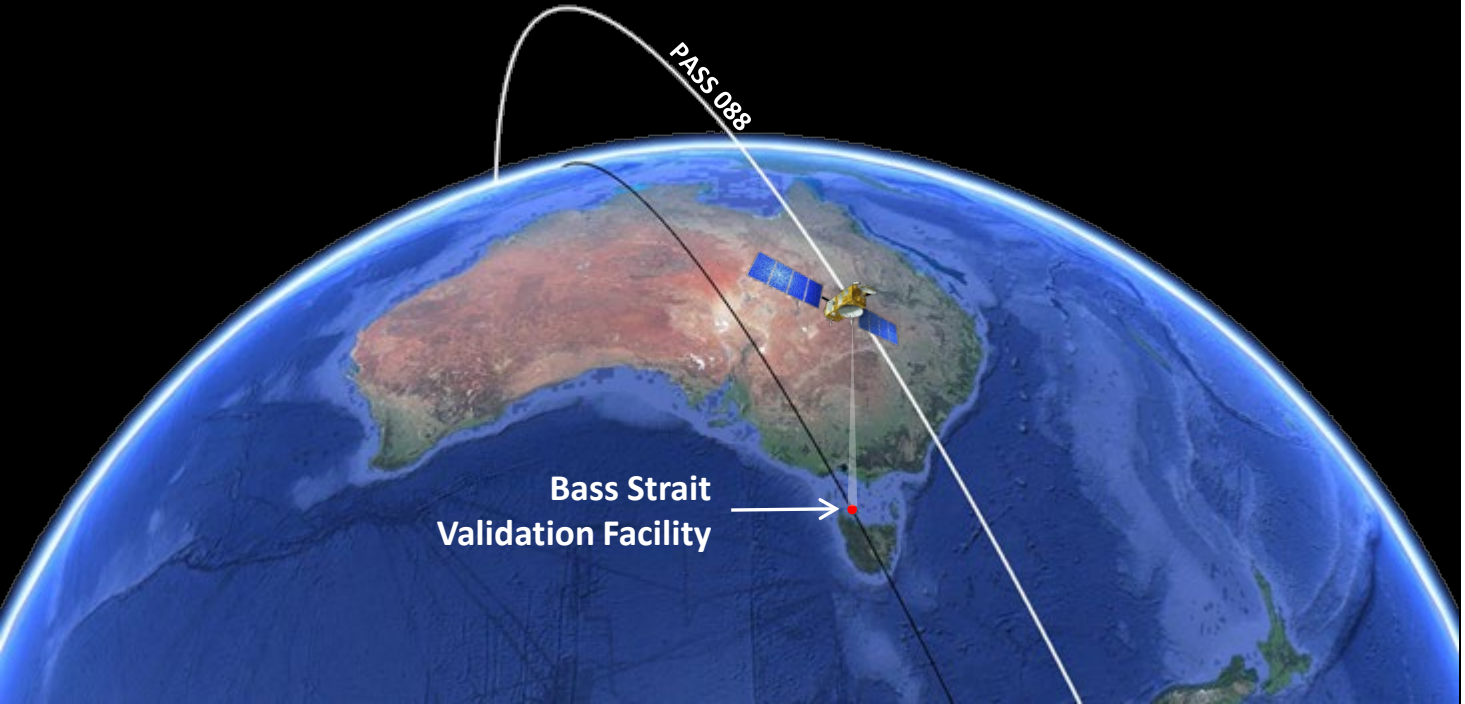

UNIVERSITY of TASMANIA

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IMOS
Integrated Marine Observing System

S6VT Meeting
San Juan, Puerto Rico
November 7-11, 2023

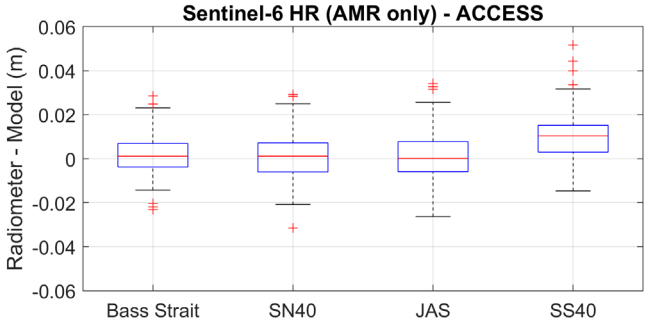
Spares

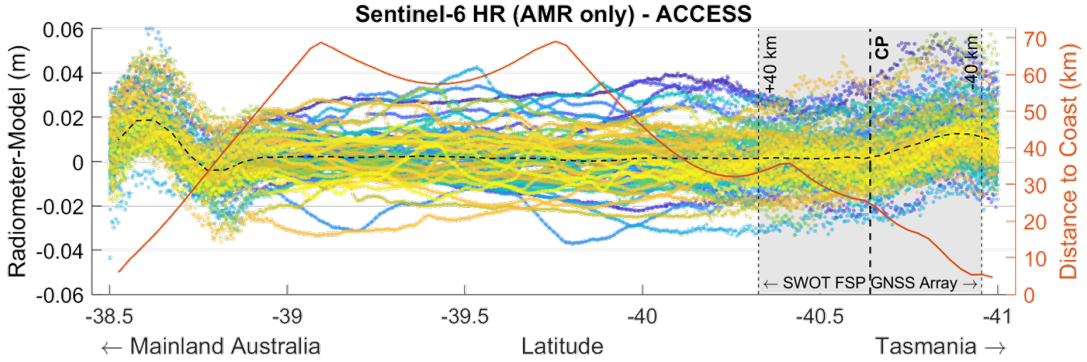
Sentinel-6 LRM Retrackers

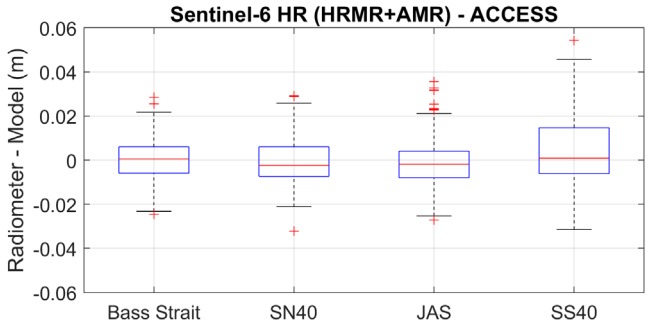
- Insignificant difference in Sentinel-6 LR bias statistics using MLE3 / MLE4 / NR retrackers.
- Further analysis of very near coast SS40 comparison point may prove interesting using the NR retracker.

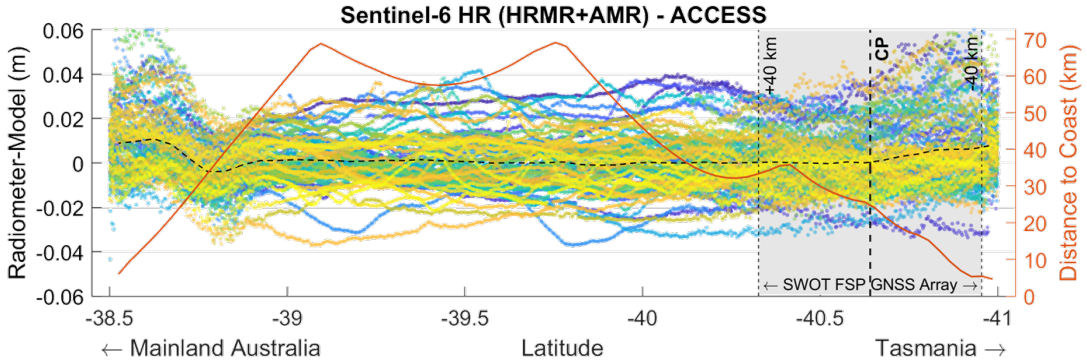
ALTIMETER	n	σ (mm)	Mean (mm)	Slope (mm/yr)
PB08 LRM MLE3				
Sentinel-6 Side A	23	21	-7 ± 4	N/A
Sentinel-6 Side B	67	23	-7 ± 3	+6 ± 10
PB08 LRM MLE4				
Sentinel-6 Side A	23	20	-6 ± 4	N/A
Sentinel-6 Side B	68	22	-4 ± 3	+5 ± 9
PB08 LRM NR				
Sentinel-6 Side A	23	20	-8 ± 4	N/A
Sentinel-6 Side B	67	21	-8 ± 3	+4 ± 9

S6 v ACCESS (unsmoothed): AMR Only and HRMR+AMR









Bass Strait “Standard” Configuration: