Ocean GPS/GNSS CalVal sites

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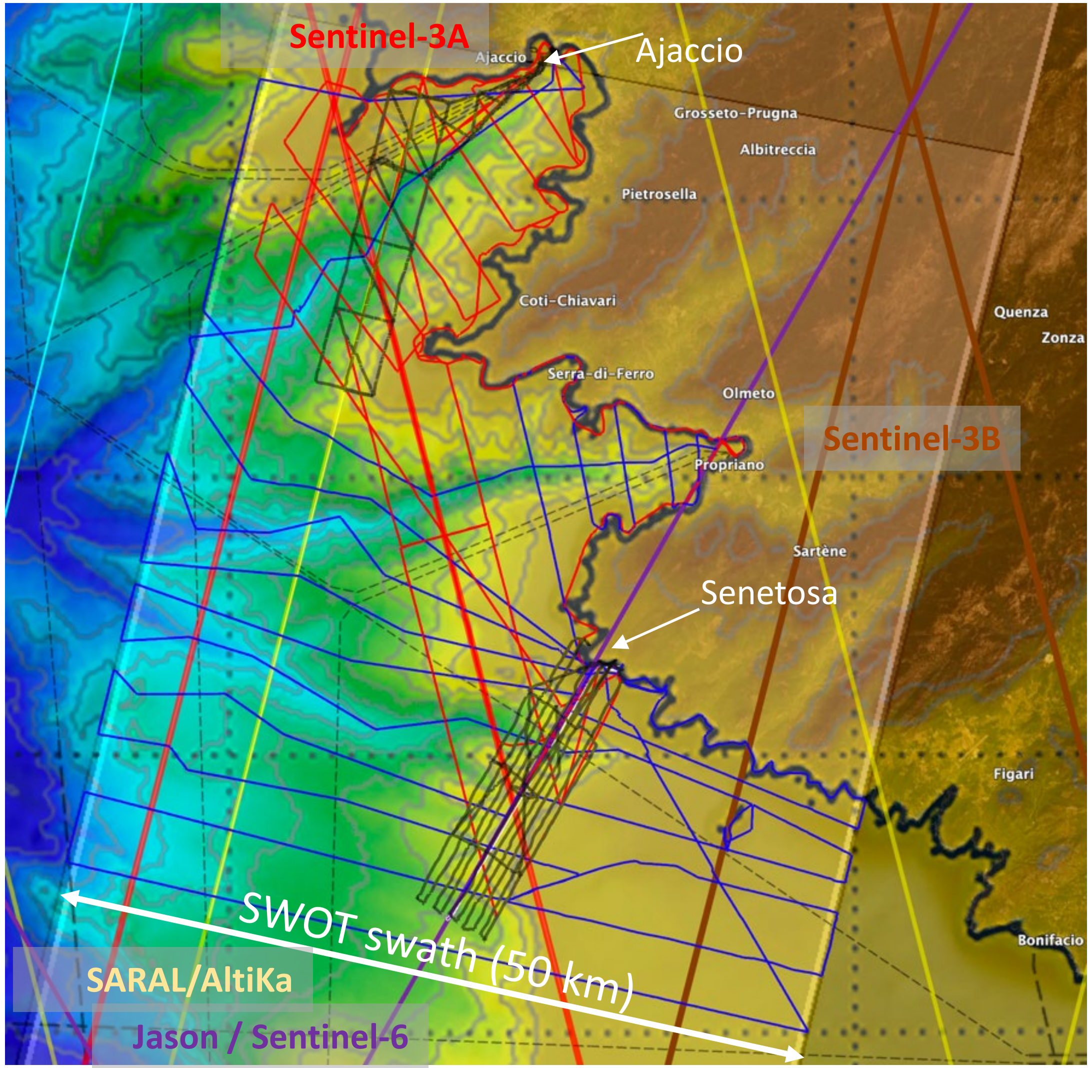
SWOT ST meeting, 19-22 Sep. 2023, Toulouse

Corsica – Campaign description



June 2021 and May 2022 surveys. Black lines for surveys of Ajaccio (2005) and Senetosa (1999) reference surfaces (bathymetry in background)

<u>Evolution of the Corsica facilities:</u>

- **Extension/unification of the reference surfaces**
  - Junction of the historical Senetosa and Ajaccio references surfaces following the Sentinel-3A ground track (**measurements in June 2021, 378 nautical miles**)
  - Extend and densify the reference surface in preparation of SWOT (**measurements in May 2022, 508 nautical miles**)
- **Preliminary results**
  - Measurements using **CalNaGeo and Cyclopée**: preliminary results show a **very good consistency** (few mm in average / 20 mm standard deviation)

Corsica – GNSS processing

GNSS data from the 2 instruments (CalNaGeo [cngc] and Cyclopée [cycl]) were processed with 2 kind of processing:

- **track**: Using TRACK software from MIT (**differential mode** only using GPS data, no clear improvement when adding Galileo data) -> **need a fix receiver in vicinity of the mobile one (less than few tens of km)**

- **ippp**: Using GINS software, from GRGS/CNES (**Precise Point Positioning** mode with integer ambiguity fixing, using both GPS and Galileo data improves the precision) -> **no need of a fix receiver**

- **Comparisons of the 2 processing modes for each instrument show a very good agreement (few mm in average / ~20 mm standard deviation) -> ippp having a similar precision it could allow to process GNSS data everywhere** (even very far from the coast)
- Comparisons of the 2 instruments with the same processing mode also agree well but exhibit larger biases (up to 34.5 mm) and larger standard deviations (up to 27.8 mm). The larger biases and standard deviations are for Cyclopée (cycl) in 2021: This is mainly because the sonic altimeter was not compensated for air temperature and the GNSS antenna had not the geodetic quality.

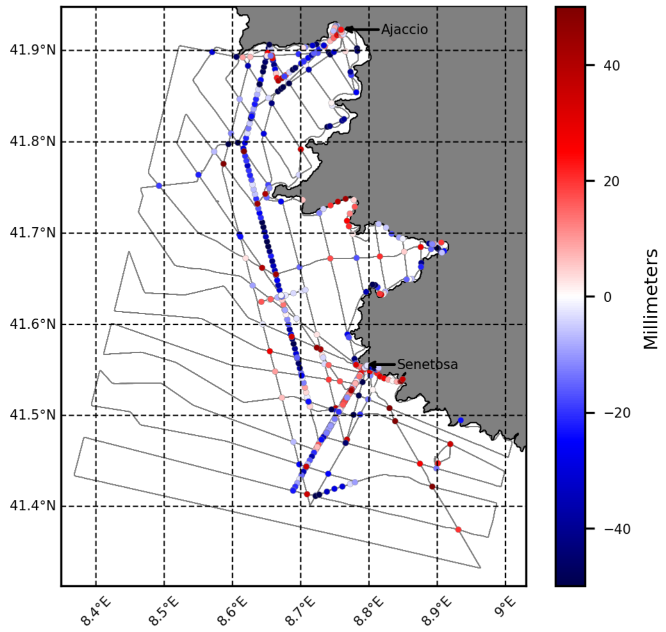
	cngc/track		cngc/ippp		cycl/track		cycl/ippp	
2021	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)
cngc/track	/	/	/	/	/	/	/	/
cngc/ippp	**0.7**	**18.1**	/	/	/	/	/	/
cycl/track	**14.5**	**24.0**	14.2	30.6	/	/	/	/
cycl/ippp	33.2	27.0	34.5	27.8	**18.8**	**19.2**	/	/

	cngc/track		cngc/ippp		cycl/track		cycl/ippp	
2022	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)	Mean (mm)	σ (mm)
cngc/track	/	/	/	/	/	/	/	/
cngc/ippp	**-2.7**	**18.3**	/	/	/	/	/	/
cycl/track	2.3	23.0	4.9	29.2	/	/	/	/
cycl/ippp	-6.7	26.1	**-4.0**	**22.8**	**-9.1**	**19.1**	/	/
	same instrument / different processing							
	different instrument / same processing							
	different instrument / different processing							

SSH differences @ crossover

Mean: -4 mm

σ: 21 mm



Comparisons with tide gauges:

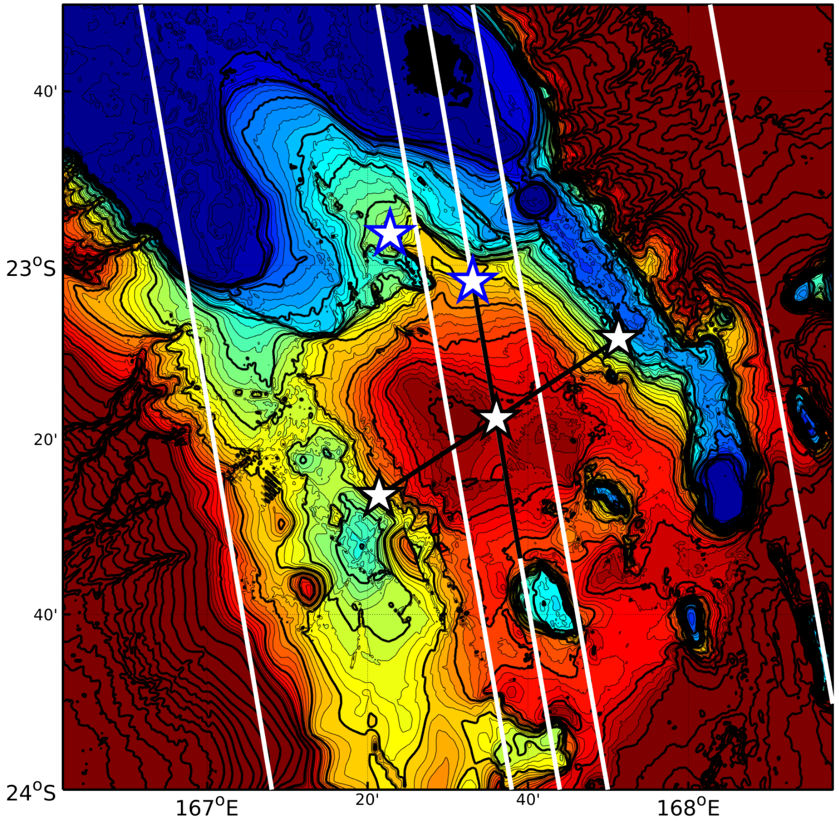
Standard deviation ranges from ~10 mm to ~20 mm

=> SSH precision at centimeter level

More details in the poster:
Extending the Corsica facilities up to SWOT swath

New Caledonia - SWOTALIS

Internal tide/meso-submesoscale interactions in the Caledonian region



- Zoom on the southern tip of New Caledonia, where the SWOTALIS campaign was done. Bathymetry in color, SWOT swath in white trace.
- The 3 moorings are aligned across the swath (stars).
- The black line connecting them corresponds to the repeated sections with the UCTD and the **2 GNSS instruments (CalNaGeo and Cyclopée)** described in the Corsica slides.
- The other black line below nadir corresponds to the glider trace.
- Fixed stations for measuring turbulence are located at the central mooring and to the north as you move up towards the lagoon (stars).

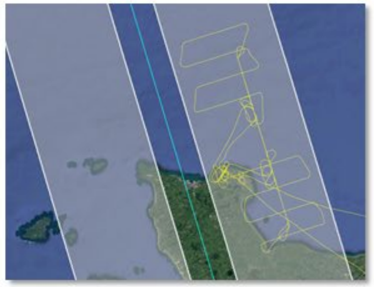
~17 days of continuous GNSS data with CalNaGeo and Cyclopée instruments:
=> processing with Precise Point Positioning is ongoing…

Normandy coasts – LIDAR - GNSS processing on airplane

Trajectory processed by **GINS** and integer Precise Point Positioning (**iPPP**)
⇒ **centimetric accuracy on antenna position**

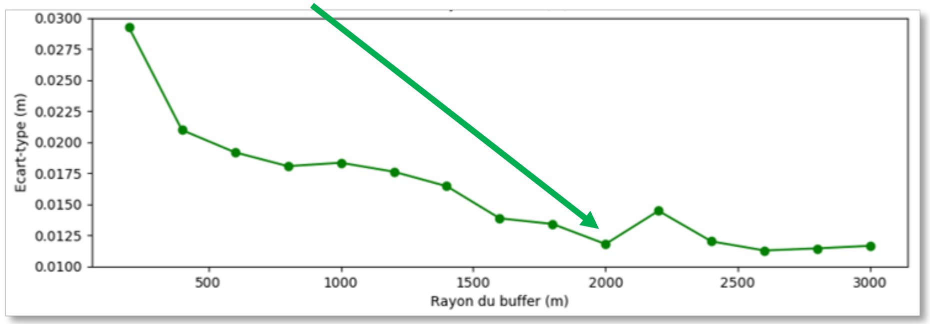
Calibration on Ground Control Points (GCP) close to Cherbourg
⇒ LiDAR calibration between 5 to 8 cm to GCPs

	Plane GNSS position (cm)		LiDAR calibration (cm)
Flight Name	Phase RMS (cm)	Mean standard deviation of h from the covariance matrix (cm)	dZ standard deviation between LiDAR and GCPs
SWOT1	1.0	0.9 +/- 0.4	5.7
SWOT3	1.1	1.2 +/- 0.4	6.9



Difference Z (LiDAR) and SSH_KaRIn

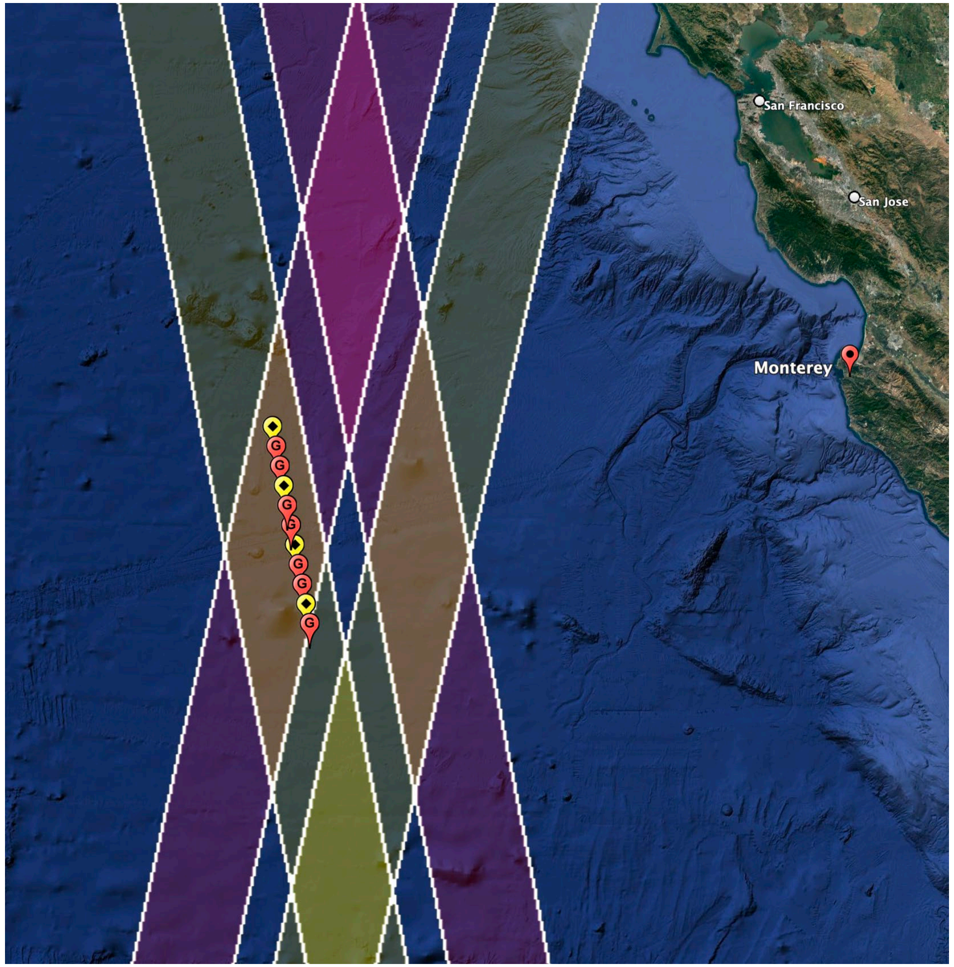
- 2*2 km LiDAR buffer size
- centimetric standard deviation



Presentation made this morning in Deltas, Estuaries and Coastal (DEC) WG session, contact the authors for details:
Normandy coasts, France, B. Laignel, L. Froideval, J. Deloffre, E. Salameh

Project In-situ Ocean Campaign:
GPS/GNSS Contributions at California Crossover

- Crossover for SWOT 1-d repeat orbit.
  - Approximately 300 km west of Monterey CA in 4500 m of water.
- Main campaign: March-July 2023
- Eleven total moorings spanning 100 km, complemented by gliders.
  - Primary observation is steric height from CTDs (Wang et al.).
- Seven moorings (NOAA) carry precise GPS/GNSS payloads as experiments.
  - Operated continuously.
  - Low-rate (1-min) observations telemetered via Iridium.
  - High-rate (1-Hz) observations for cm-level SSH stored onboard for recovery.
  - Performance demonstrated over multiple campaigns and long-term occupations (at Harvest platform).
- Overflights of Lidar/MASS (Lenain et al.) provide airborne GPS/GNSS.
  - Presents opportunities for unique network solutions (e.g., Buoys + aircraft).
- GPS/GNSS buoys will be re-deployed in California bight for long-term observations.



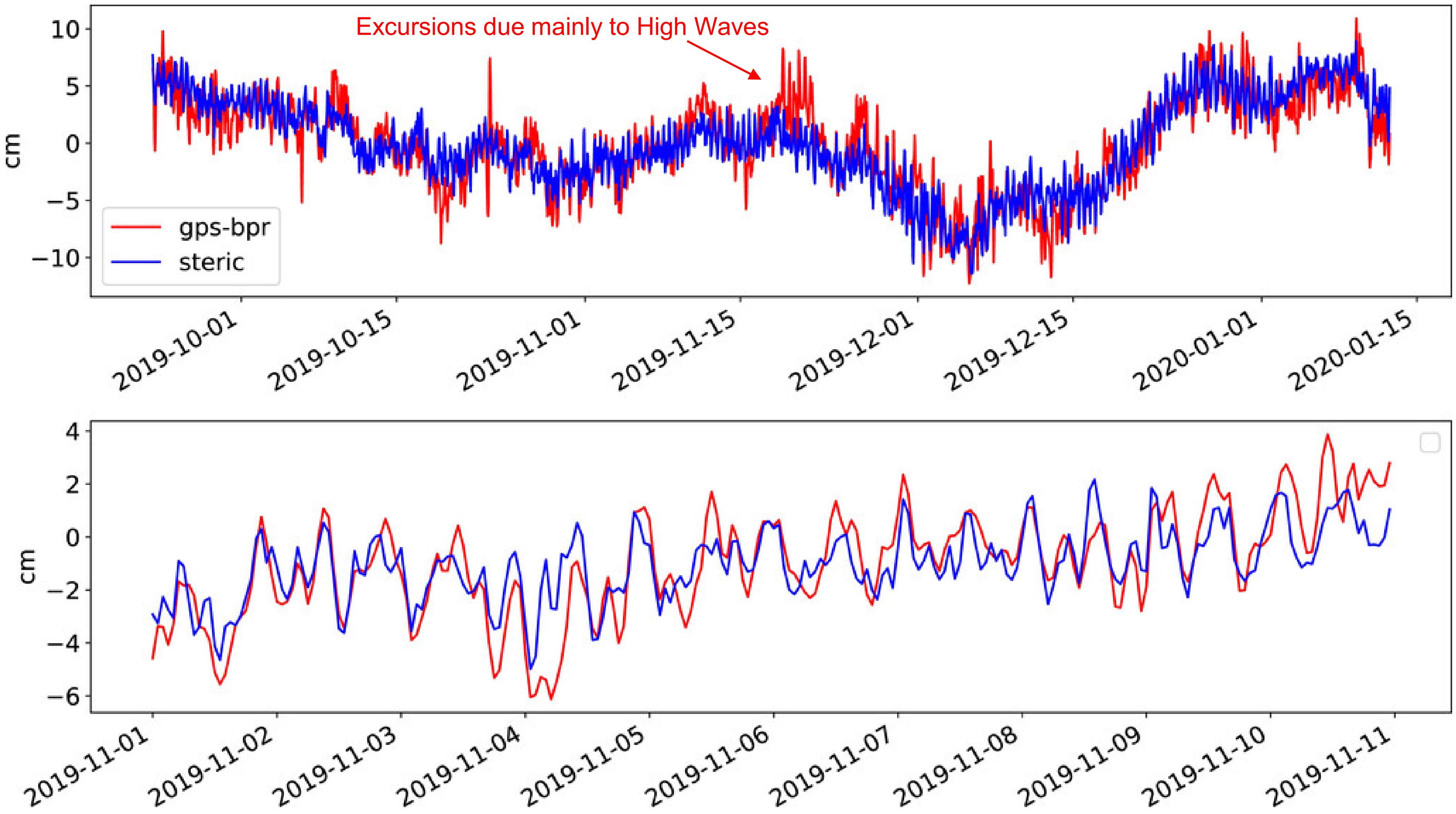

NOAA Moorings with GNSS buoys + Prawlers


SIO Hybrid Moorings with Wirewalkers and fixed CTDs

SWOT Prelaunch Campaign (2019–20)

Sea Surface Height Closure: Geodesy vs. Hydrography

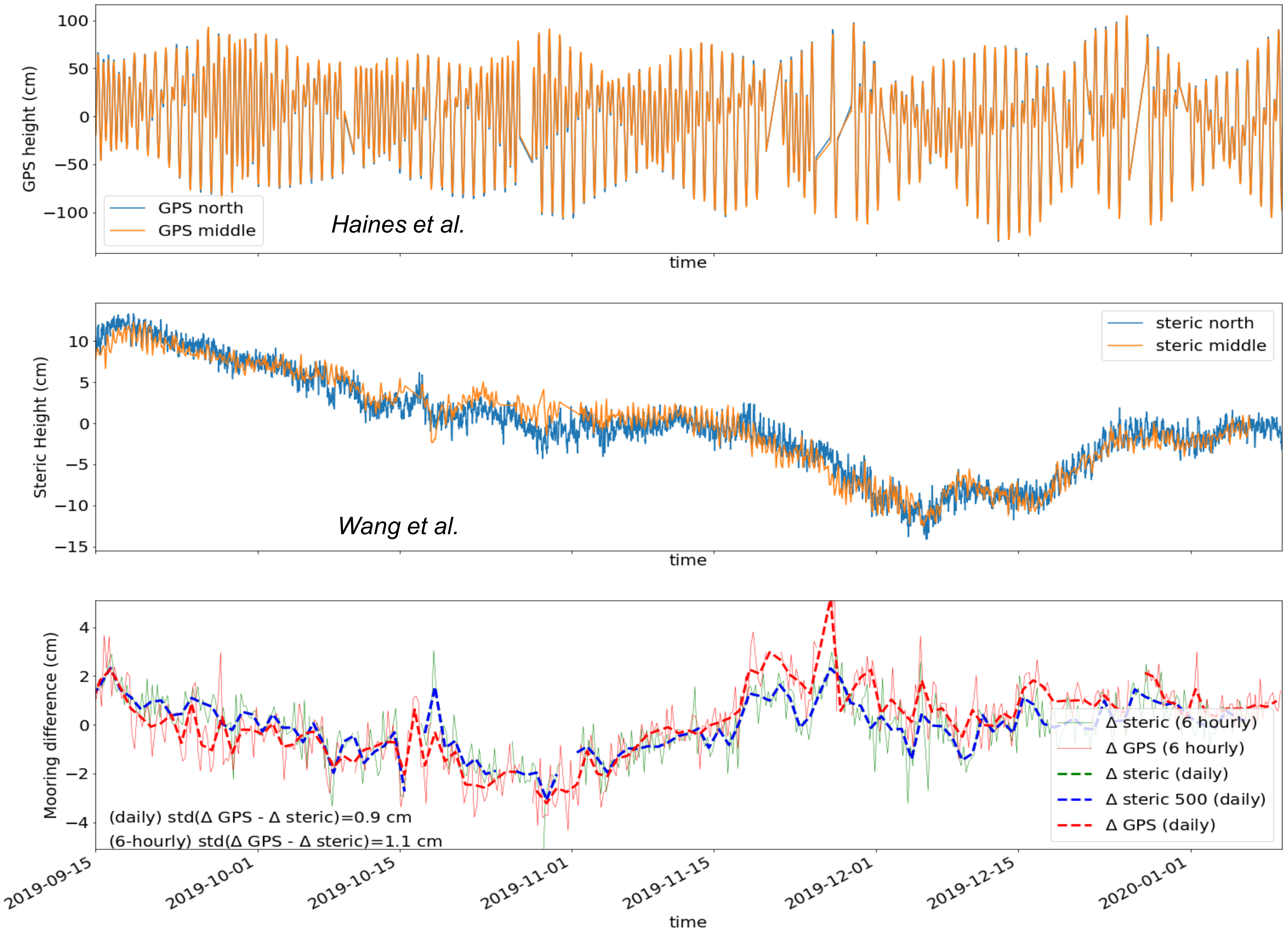
GPS – Bottom Pressure vs. Dynamic Height



Wang et al. (2022)

SWOT Prelaunch Campaign (2019–20)

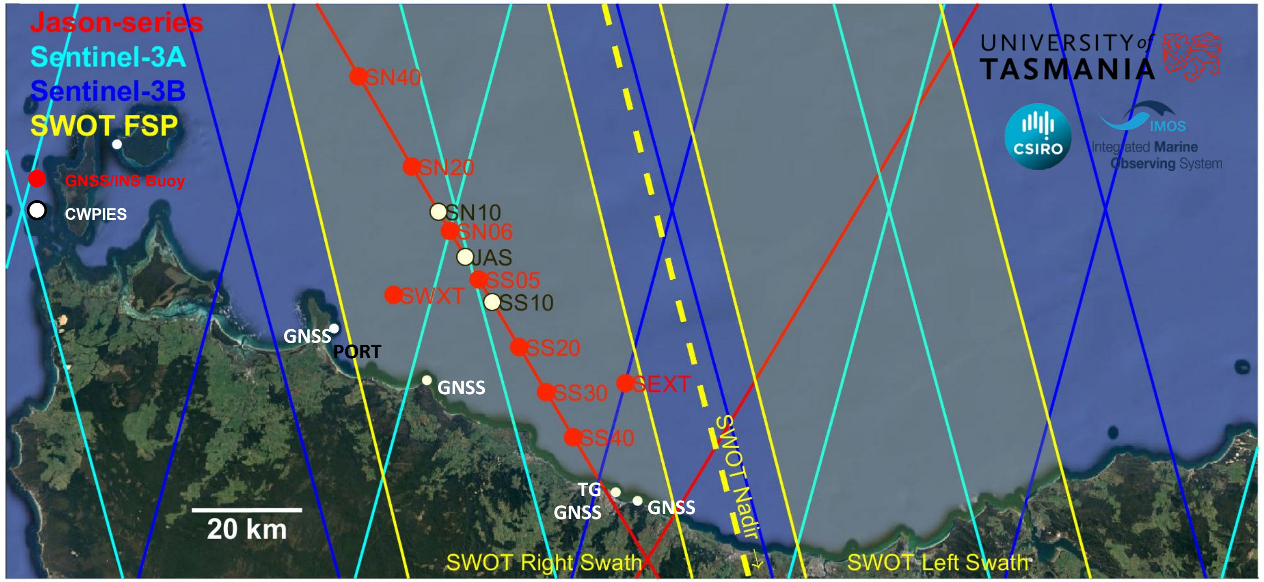
ΔSSH over 10-km Baseline: Geodesy vs. Hydrography

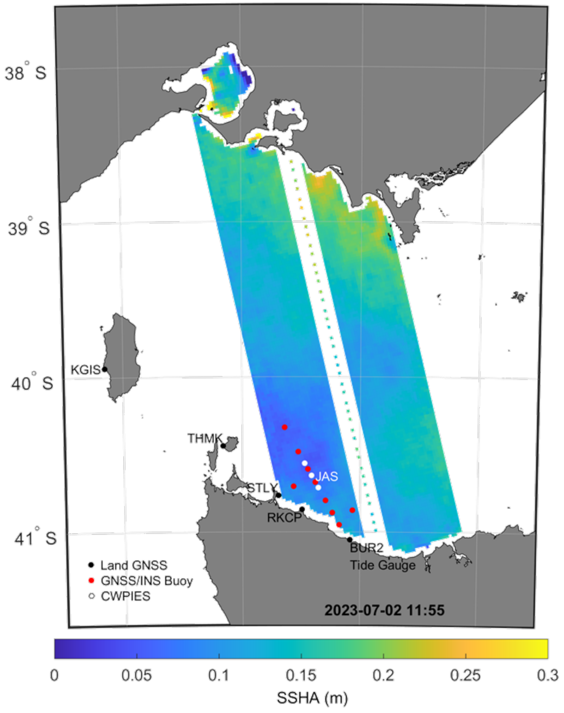


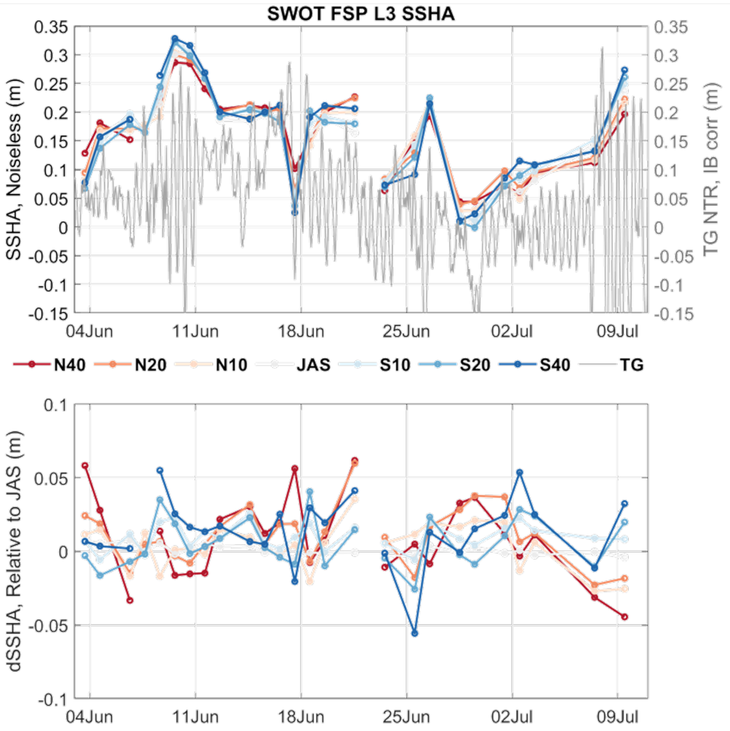
Bass Strait and Surrounds

- Aim: Geometric in situ validation over the SWOT fast-sampling phase (FSP) at the Bass Strait validation facility.
  - Complementary targets to other campaigns.
  - Focus on intra-swath variability (SSH, SWH, wet delay), plus near coastal targets.
- In situ instrumentation for Bass Strait over the FSP:
  - 9 x GNSS/INS equipped buoys (SSH, wet trop, waves, SST).
  - 3 x CWPIES moorings (SSH, U, V, waves, T, S).
  - 3 x Bottom pressure moorings (SSH, P, T, S).
  - Processing of all data is now well underway and looking good. GNSS processing using GipsyX (PPP) and TRACK (DD). All data to be made available to those interested.
- Modelling effort:
  - 3D finite difference SHOC model nested within the Australian OceanMaps model. In various configuration to support facility planning, SSH signals interpretations and applications.
- Early SWOT L2 and L3 SWOT data over Bass Strait looks highly promising. In addition to fine scale features, we are seeing likely contribution from changes in the M2 resonance across Bass Strait driven by wind forcing.

See poster: SWOT validation activities in Bass Strait and surrounds







Bass Strait and Surrounds

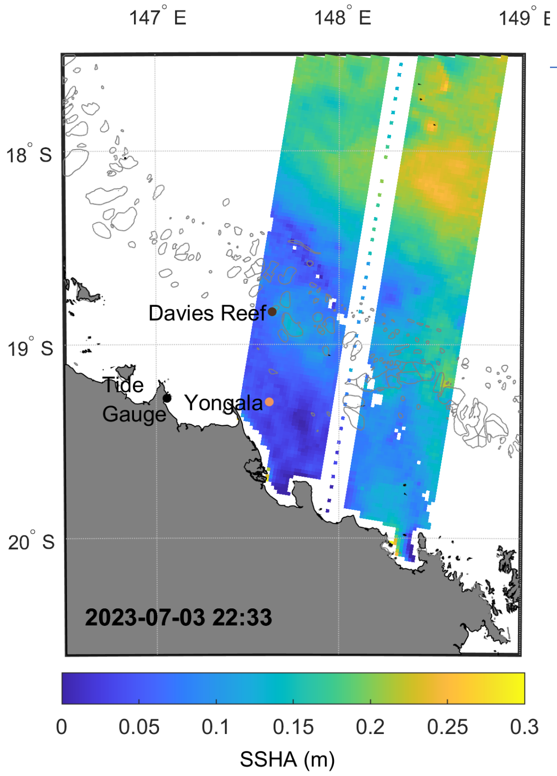
We have an additional two validation targets at other sites of interest within the fast-sampling phase:

1) Davies Reef / Yongala – Great Barrier Reef.
   - Approximately ~3,100 km NE along the FSP track from SOFS, Davies Reef and Yongala have been instrumented (separation between sites ~52 km).
   - Davies Tower includes GNSS-IR, radar TG, bottom P/T sensors. Yongala includes 5-beam ADCP with a short GNSS equipped buoy deployment for defining datum. Same GNSS processing workflow as Bass Strait.

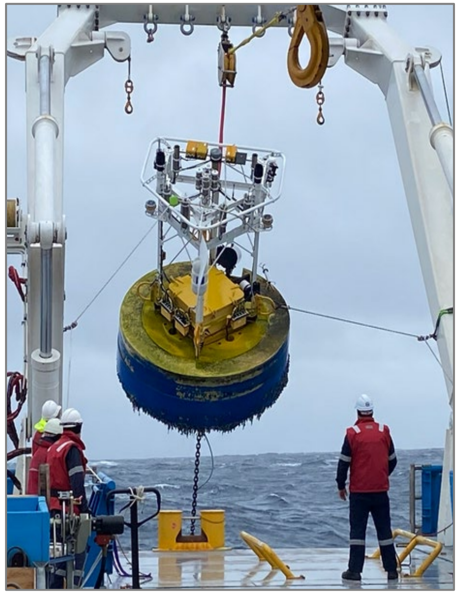
2) Southern Ocean (SOFS) – deep water mooring in a high wave environment.
   - GNSS added to the mooring since 2019.
   - New paper: *Hay et al. 2023 "In-Situ Validation of Altimetry and CFOSAT SWIM Measurements in a High Wave Environment" Journal of Atmospheric and Oceanic Technology.*
   - GNSS data over the first half of SWOT FSP already processed (GipsyX PPP).
   - See poster for first comparisons of with SWOT SWH!

See poster: In situ validation of altimetry in a high wave environment

Davies Reef Tower



SOFS Mooring



GNSS derived SWH within SWOT FSP in high wave environment – see poster for first results!

Conclusion and food for thoughts

- **Data acquisition worked well**
- Processing on going with **very promising preliminary results**
- **Precise Point Positioning** (PPP) is now very mature and competitive in precision compared to the differential approach
  => **PPP allows to process GNSS data everywhere even far from any fixed receiver**
- **Adding other constellations** (Galileo, GLONASS) to GPS **improves the solution** but needs further tuning and improvement of consistency between them
- **Multi sensors and multi techniques** (e.g. moored instrumentations, GNSS-R, acoustic ranging,…) **offer new independent information** to further interpretation of signals and noises.
  - Comparisons with independent observations (e.g. altimetry and tide gauges) **suggest absolute accuracies of SSH are 1–2 cm** (ΔSSH < 1 cm).
- **The experiments bring tremendous datasets to validate aspects of SWOT**, and SSH signals. They also drive processing strategies and testing and intercomparison approaches.
- **Impact of waves on SSH precision < 1 cm** (for SWH up to 4 m). Some evidence of systematic sea-state errors of ~2% (akin to altimeter SSB).
- **Many emerging applications**
  - Altimeter calibration/validation.
  - Sea level monitoring ("open ocean tide gauge")
  - Sea-floor geodesy and natural hazards
  - Tsunamis (direct detection and traveling ionospheric disturbances).
  - Atmospheric river monitoring (continuous, integrated precipitable water from GPS).
- **Adaptable to several platforms** (e.g., wavegliders, SailDrones).