PASS-SWIO Final Review

WP3000 – Sea Level Data Processing – Satellite Altimeter data

Work Packages

WP3200 – Satellite Altimeter Data Acquisition and initial processing.

WP3300 – Cross Validation of Satellite and Tide Gauge Data

WP3400 – Analysis of Tidal and Sea Level Variability Characteristics

Deliverables

D3.1 – Data Sets

D3.2 – Validation Report

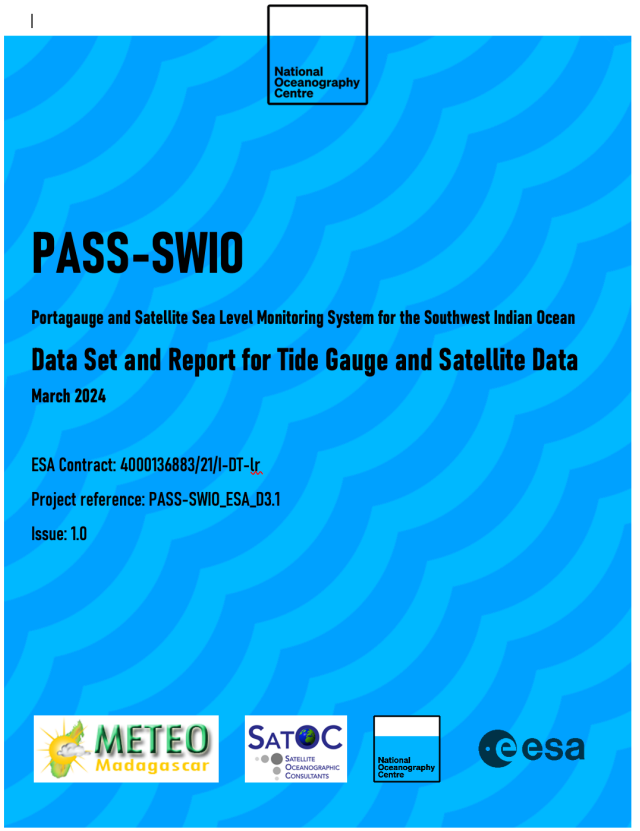
D3.3 – Report on Sea Level Variability

WP3200 – Satellite Altimeter Data

Three sets of satellite altimeter data used

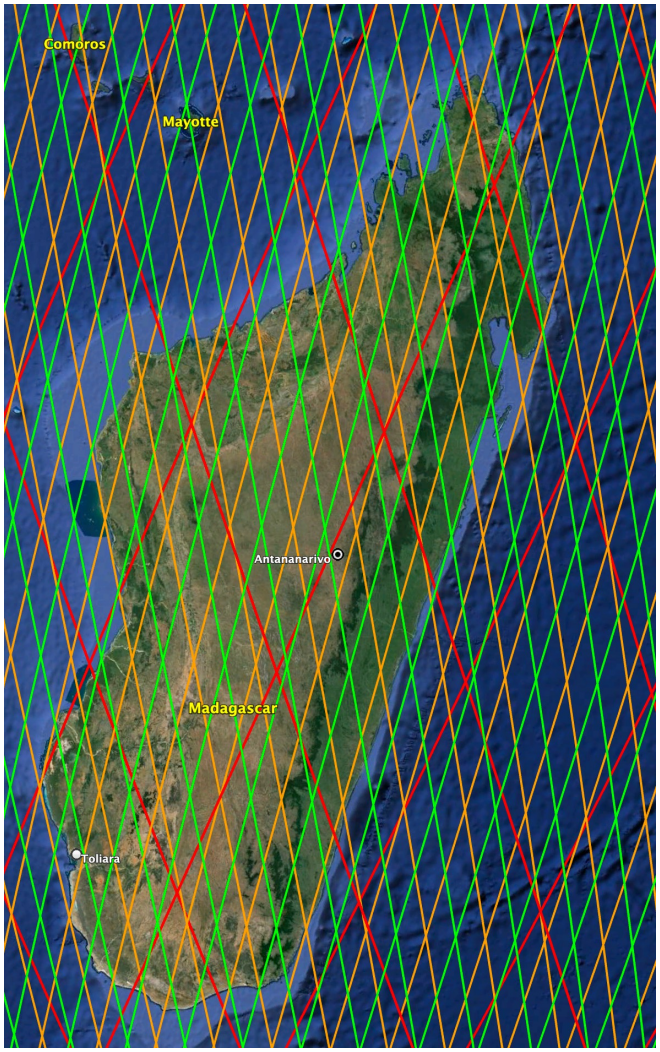
- Along-track time series satellite altimeter data (CMEMS L3)
  - Covering 2002-2022
  - For sea level variability analysis, and validation against historical Toamasina TG data
- Reprocessed satellite altimeter data (with coastal processor)
  - For assessing potential improvements using coastal processing
  - 2020-2021
- EUMETSAT L2 and L2P products
  - For validating Portagauge data
  - Covering June 2023 to January 2024

For more information see D3.1 “Data Set and Report for Tide Gauge and Satellite Data” and https://www.satoc.eu/projects/pass-swio/data.html



WP3200 – Satellite Altimeter Data

- Along-track time series satellite altimeter data (CMEMS L3)
  - CMEMS “SEALEVEL_GLO_PHY_L3_MY_008_062”
  - Jason-1, Jason-2, Jason-3 (2002 – 2022)
  - Sentinel 3A (2016-2022)
  - Sentinel 3B (2018-2022
  - Subsetted to Madagascar region and reformatted
    - 1 file per satellite track
    - Time series at each along-track location: Sea surface height anomaly, dynamic atmosphere correction

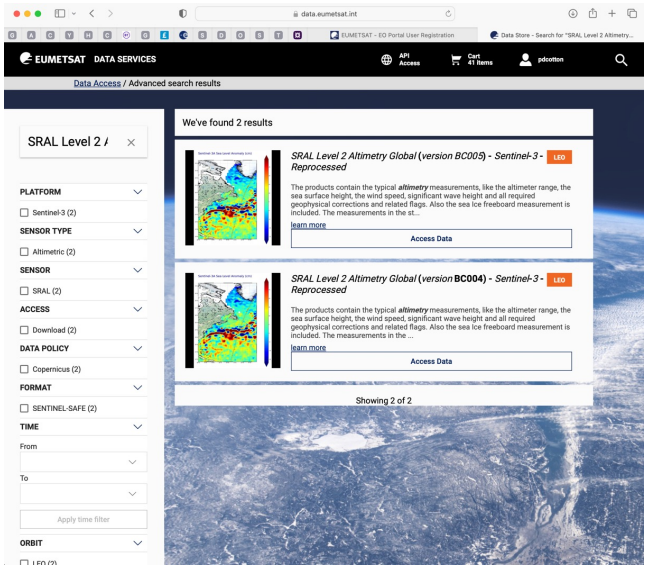


WP3200 – Satellite Altimeter Data

- Reprocessed Sentinel 3A and Sentinel 3B SRAL data
  - For assessing benefits of coastal processing
  - Sentinel 3A, Sentinel 3B (2020-2021)
    - Reference: EUMETSAT / ESA Level 2 marine product available through the EUMETSAT EO portal and data store (version BC005).
    - Coastal Processor: Reference data sets processed by Earth Console using SARvatore for Sentinel-3 service. Coastal processor settings, SAMOSA+ retracker. Funded by ESA Network of Resources.

WP3200 – Satellite Altimeter Data

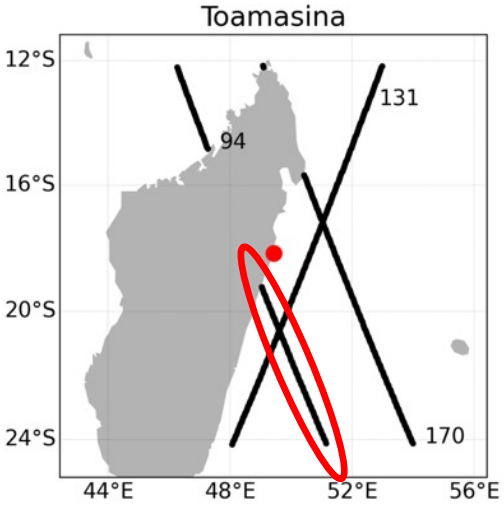
- EUMETSAT Sentinel-6A, Sentinel-3A and Sentinel-3B L2 products
- For cross validating against Portagauge data
  - 1st June 2023 – 31st January 2024
    - Sentinel 3A, 3B: *SRAL Level 2 Altimetry Global (version BC005) - Sentinel-3 – Reprocessed*
    - Relative orbits 041 and 362
    - Sentinel 6A-MF: *Poseidon-4 Altimetry Level 2 High Resolution (baseline version F08) - Sentinel-6 - Reprocessed*
    - Relative orbits 094 and 131

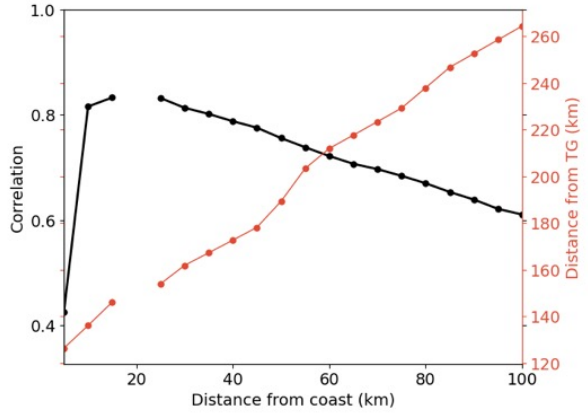


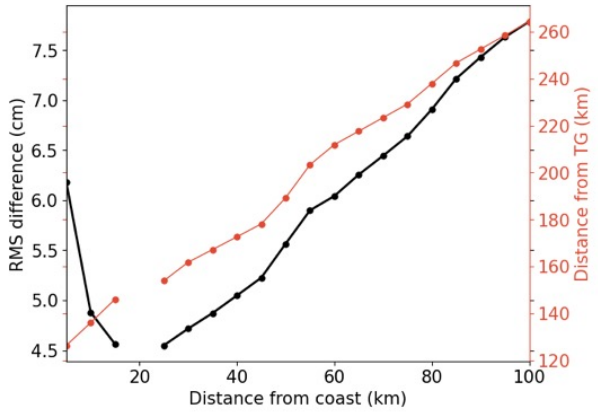
WP3300 – Cross Validation of Satellite and Tide Gauge Data (1) – Historical Data

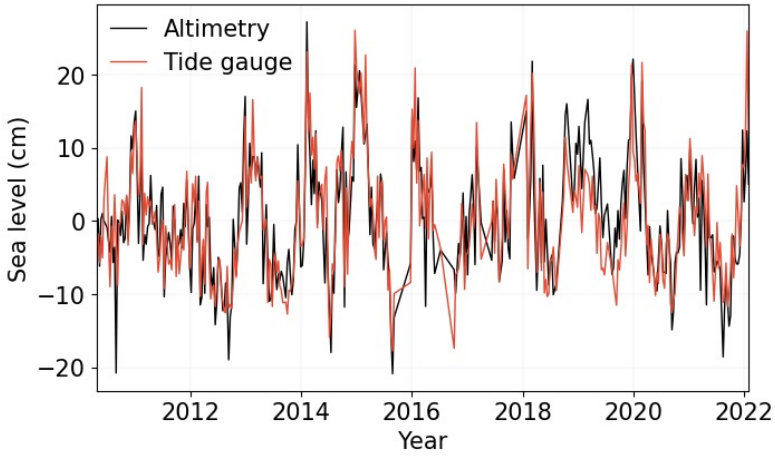
- Jason-2, Jason-3, Sentinel 3A, Sentinel 3B. 2010-2022
- Toamasina (SHOM) TG data (01/01/2010 to 29/03/2022)
- Satellite altimeter sea surface height anomaly against tide gauge residual sea level (measured sea level minus predicted tide)
- Code calculates correlation and rrms at each point along path and finds point of highest correlation.

WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Jason Series

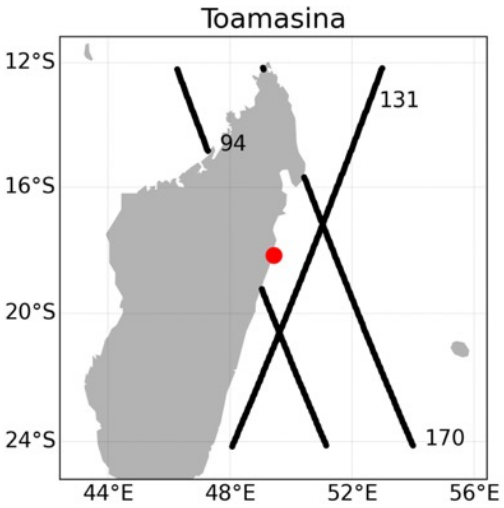




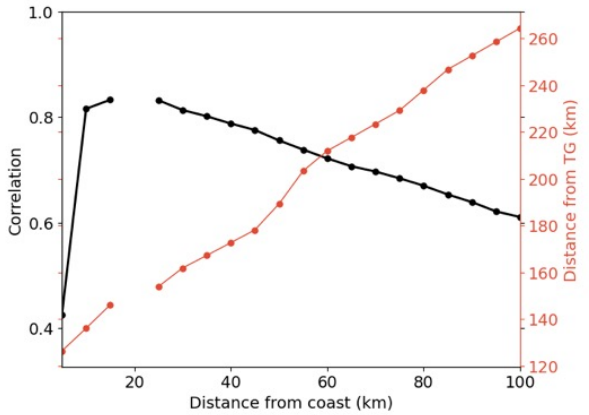




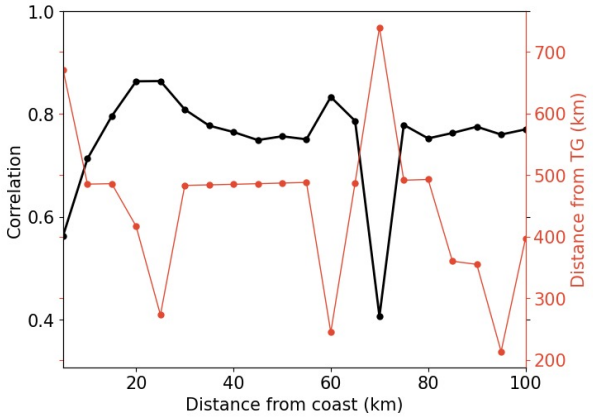
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Jason Series



Orbit 094



Orbit 170



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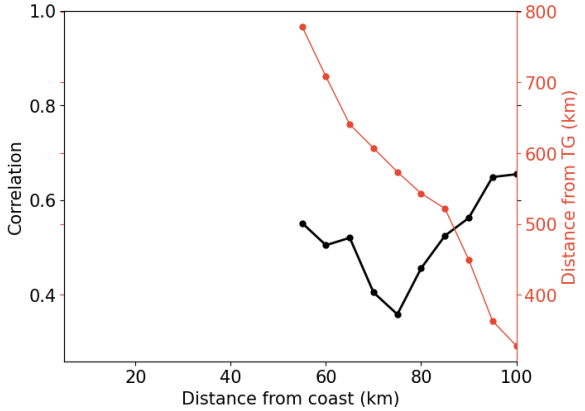
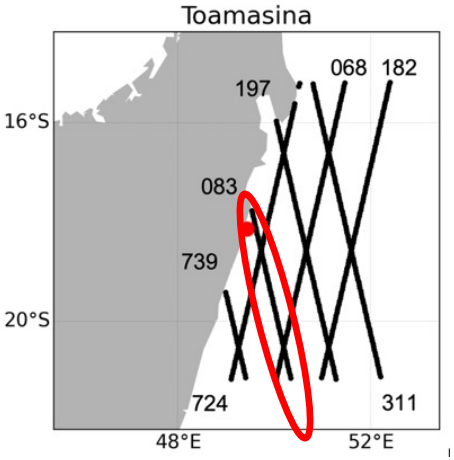
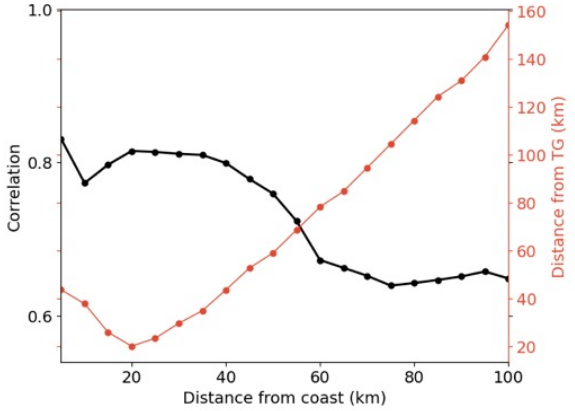
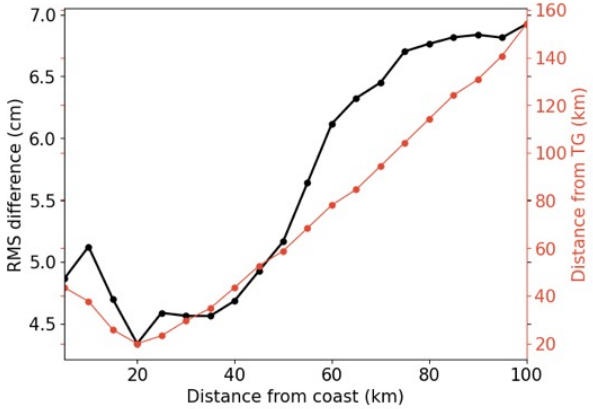
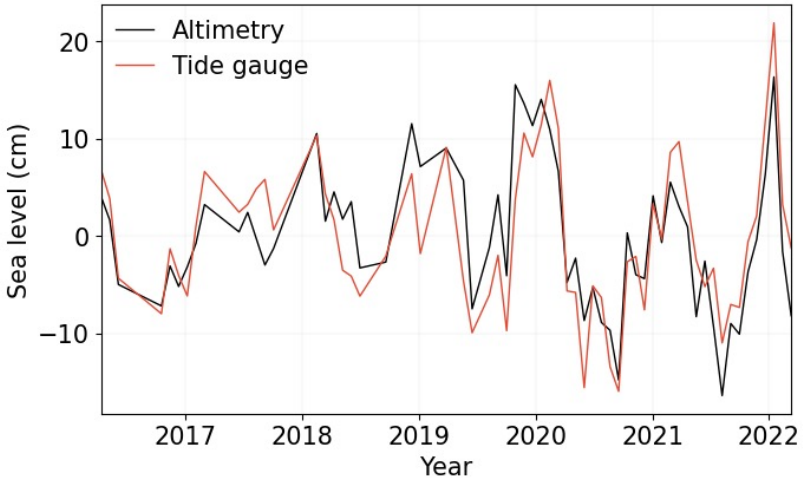


WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3A

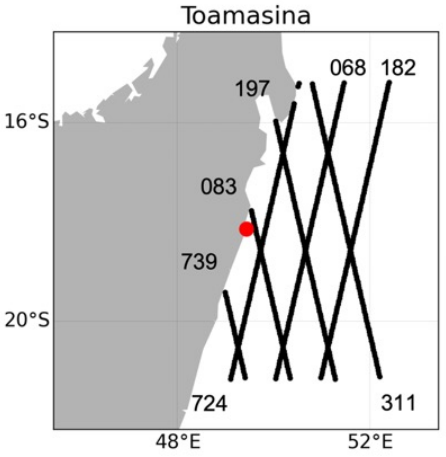




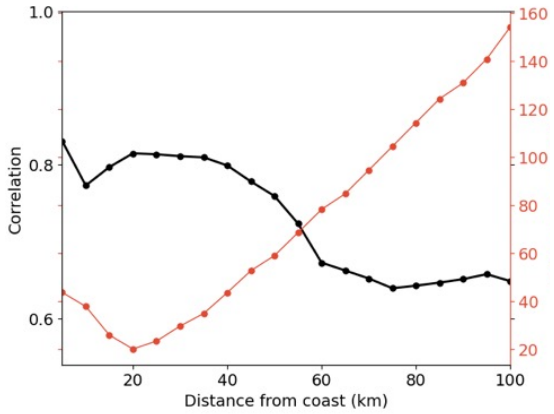




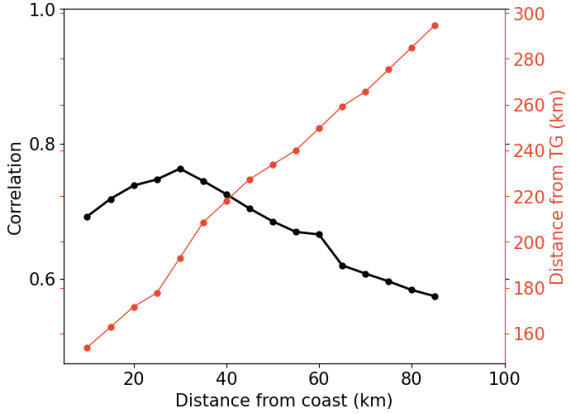
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3A



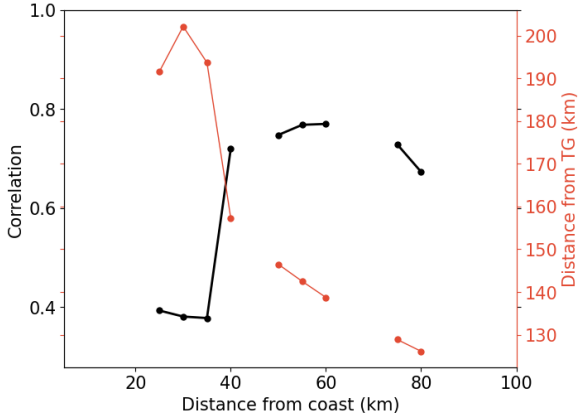
Orbit 083



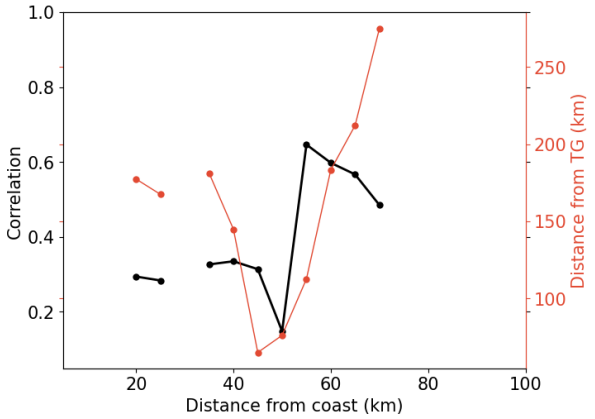
Orbit 739



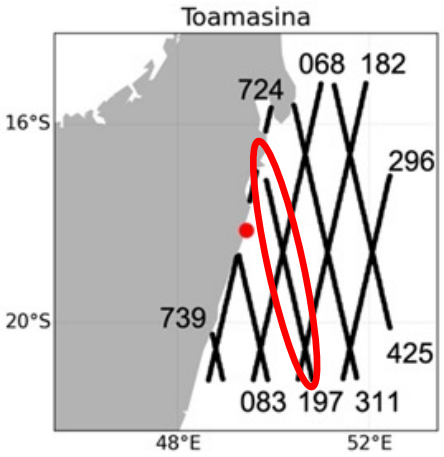
Orbit 197

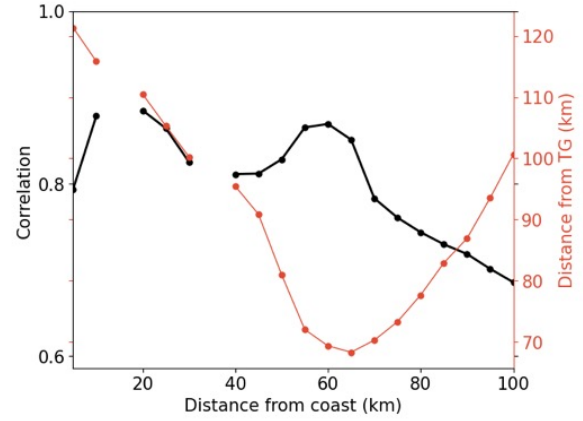


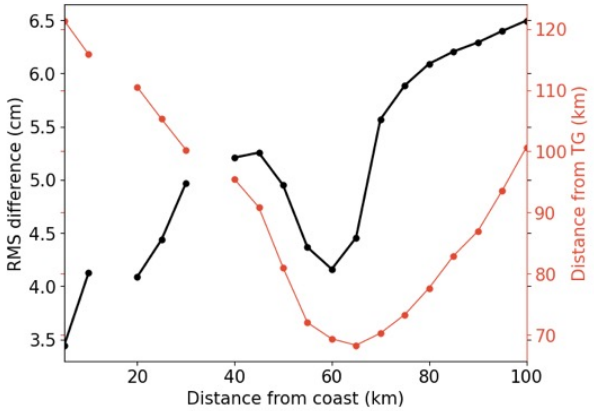
Orbit 724

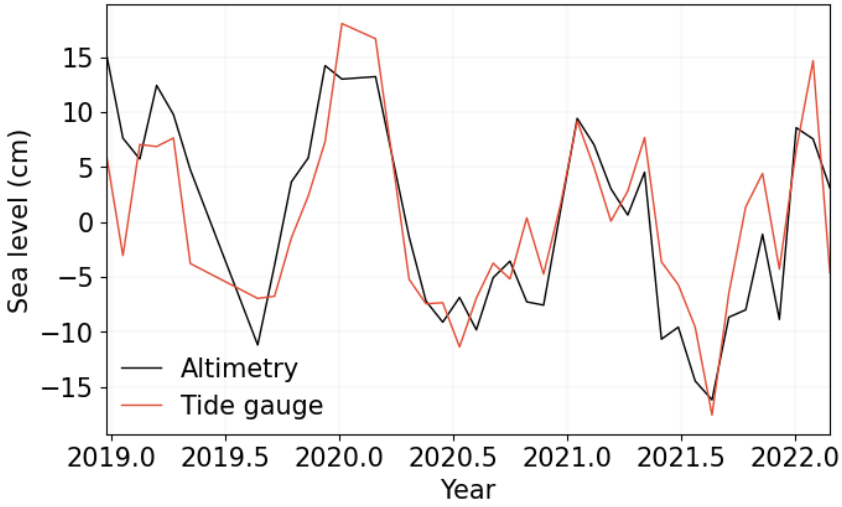


WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3B

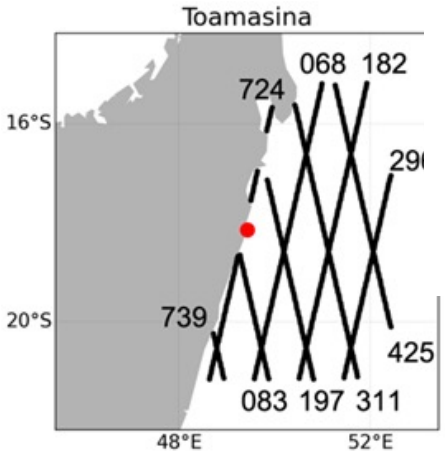




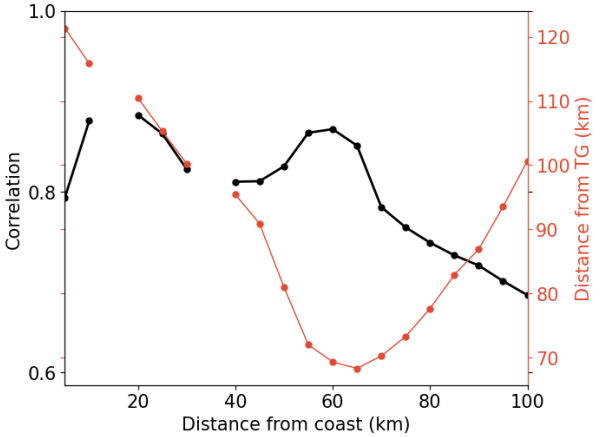




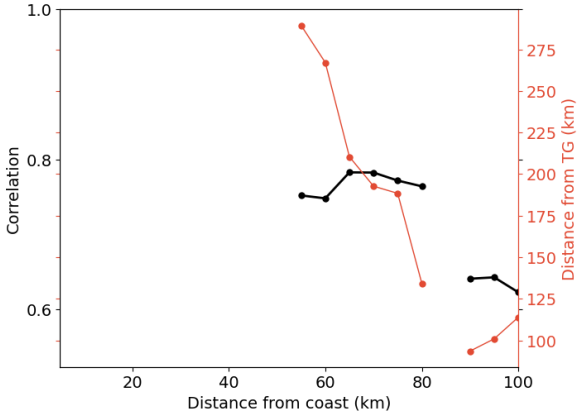
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3B



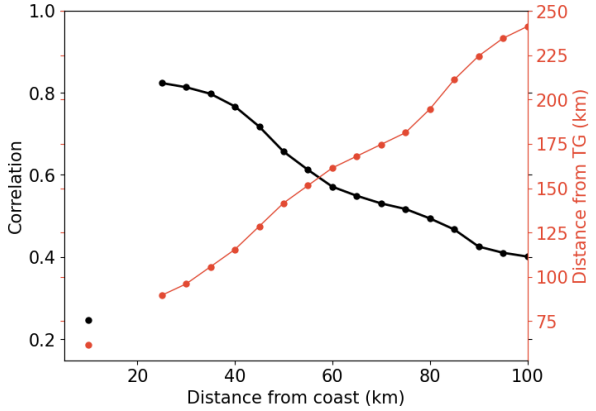
Orbit 197



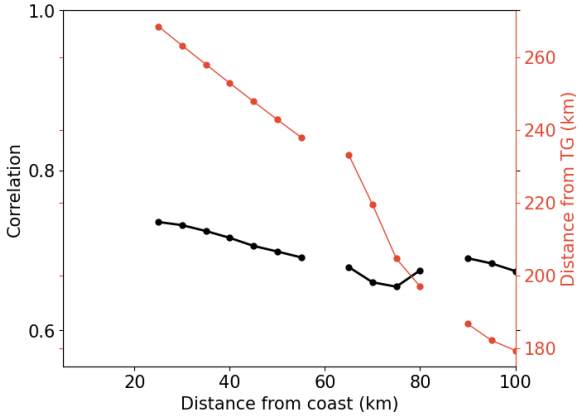
Orbit 068



Orbit 083



Orbit 311



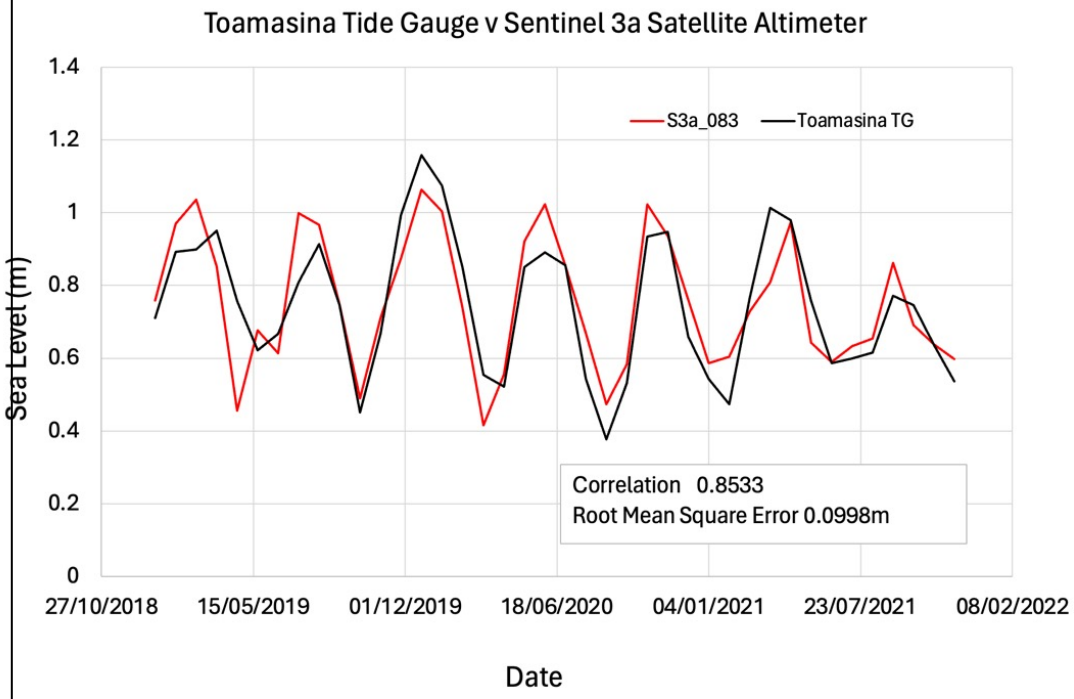
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3B

Satellite(s)	Relative Orbit No	Distance to Coast (km)	Distance to Tide Gauge	Correlation	RMS (m)	No of points
Jason series	094	14.8	146.0	0.8312	0.0422	365
Sentinel-3a	083	18.0	19.9	0.8224	0.0443	62
Sentinel-3b	197	48.0	81.0	0.8267	0.0494	39

- This is between SSHA and residual sea level (sea level - tide)
- Good agreement between satellite and tide gauge data (Correlation > 0.8 and RMS 4-5 cm)
- Compares to validations in HYDROCOASTAL project for southern Spain (correlation 0.56 to 0.70)
- Separation between satellite data point of highest correlation and tide gauge up to 146km
- Correlation stays high (> 0.6) along whole track
  - Suggests low natural variability in sea level in this region?

WP3300 – Cross Validation of Satellite and Tide Gauge Data – Historical Data – Sentinel 3A (L2)

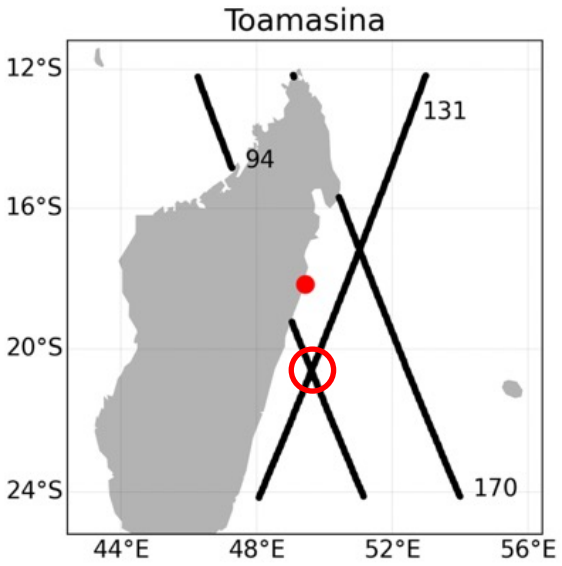
- Additional validation of historical Toamasina TG data against L2 S3a (Orbit 083) data (01/2019 – 02/2022)
- Total Water Level: SSHA + tide (GOT4.1) + mss (DTU21) against measured TG water level
- Average of 5 x 1Hz data points across location of highest correlation.
- TG data interpolated to time of overpass
- Correlation 0.8533, rms 0.0998m
- Offset of 10.28m between data sets

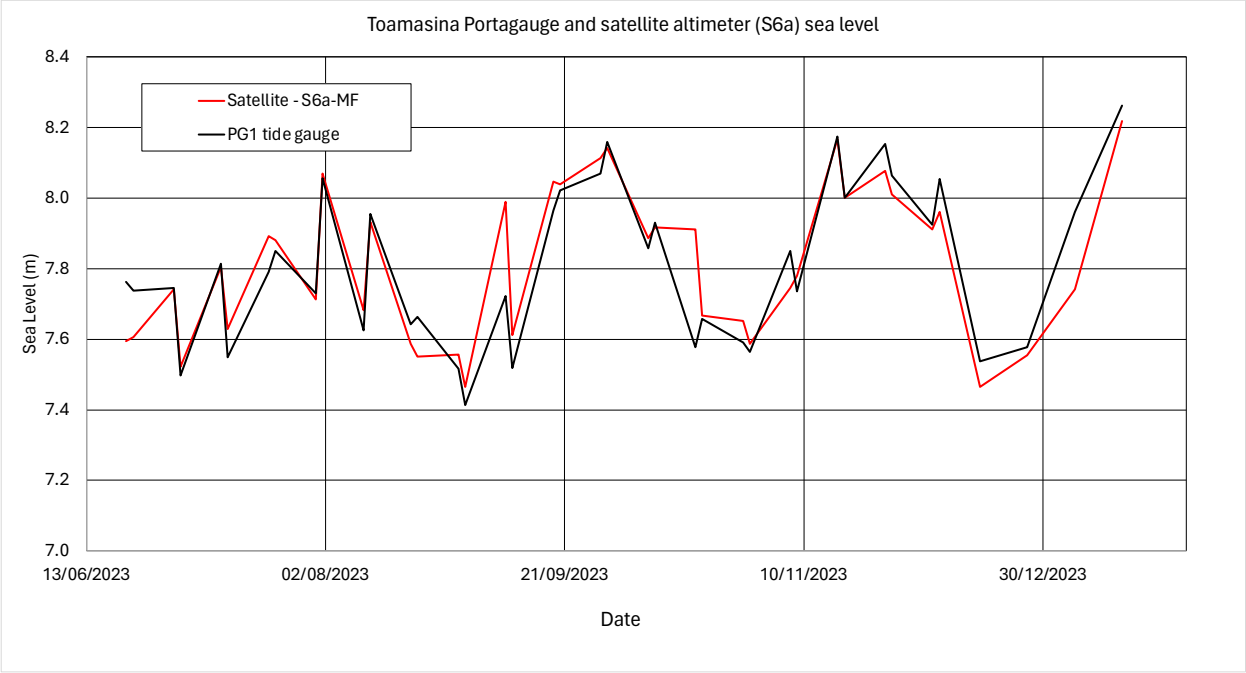


WP3300 – Cross Validation of Satellite and Tide Gauge Data – Portagauge

- Sentinel-6A MF, Sentinel-3A, Sentinel-3B, EUMETSAT L2
- Toamasina Portagauge data (13/06/2023 to 31/01/2024)
- Total Water Level: SSHA + tide (GOT4.10) + mss (DTU18/21) against measured TG water level
- Average of 5 x 1Hz data points at satellite track cross-over point (to double available sampling.
- TG data interpolated to time of overpass

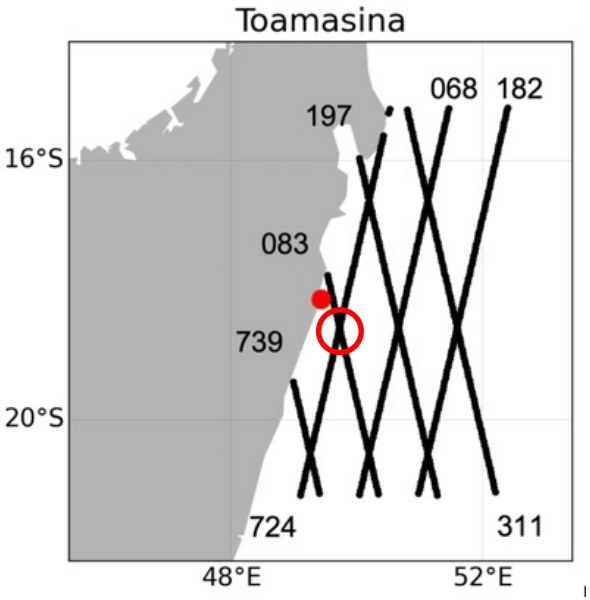
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Portagauge S6a MF

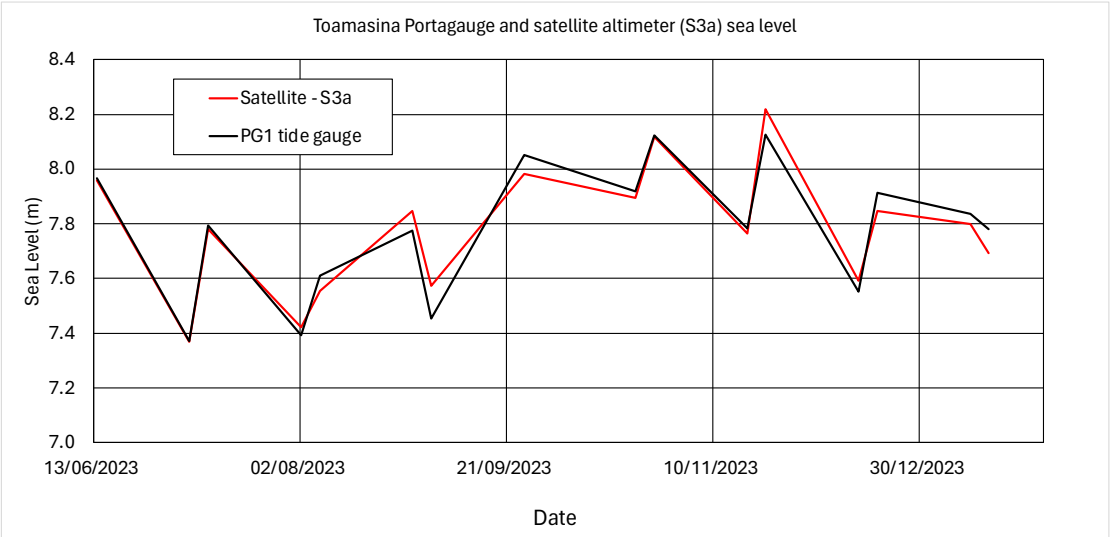




Sentinel 6a: At cross-over point of orbits 094 and 131

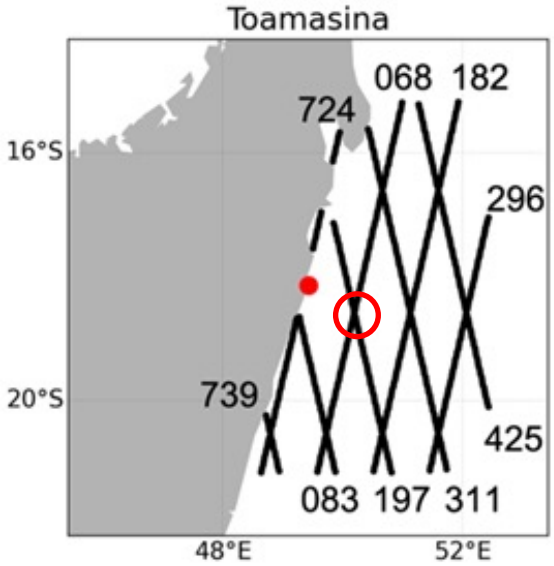
WP3300 – Cross Validation of Satellite and Tide Gauge Data – Portagauge – S3a

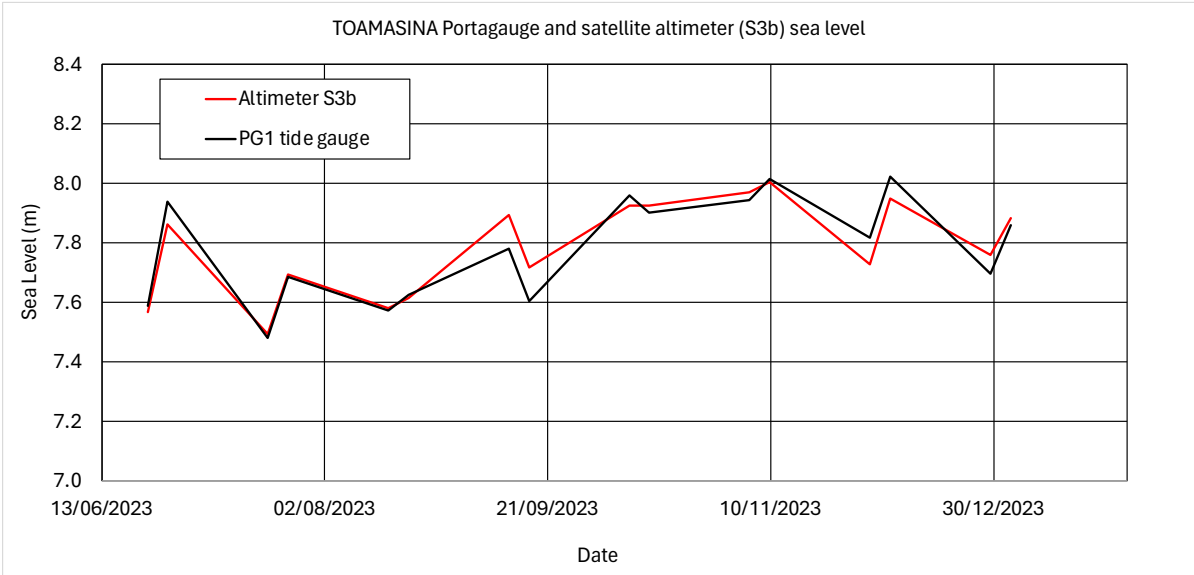




Sentinel 3a: Cross-over point orbits 724 & 083

WP3300 – Cross Validation of Satellite and Tide Gauge Data – Portagauge S3b





Sentinel 3b: Cross-over point orbits 197 & 068

WP3300 – Cross Validation of Satellite and Tide Gauge Data – Portagauge

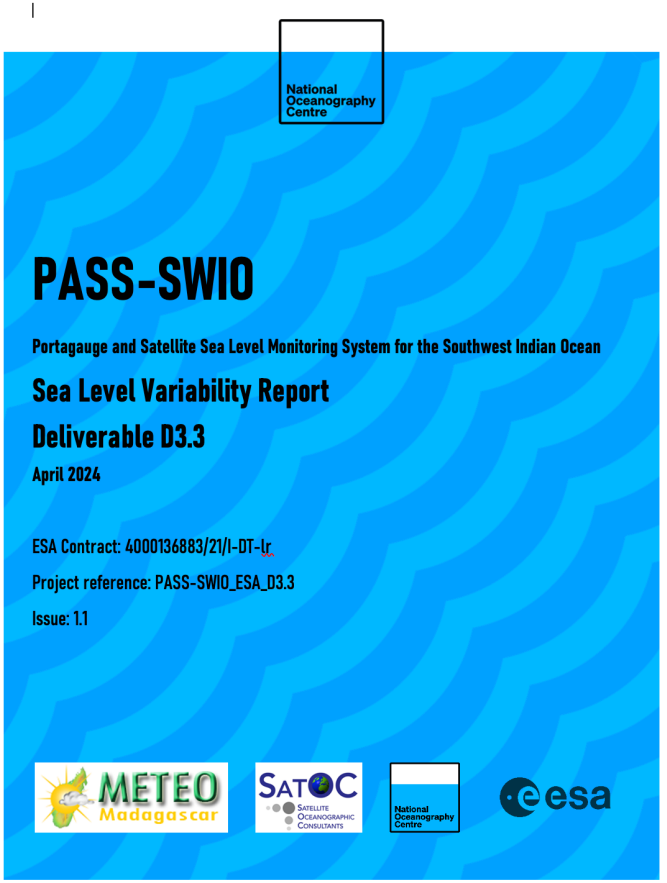
Satellite(s)	Relative Orbit Nos	Distance to Coast (km)	Distance to Tide Gauge (km)	Correlation	RMS (m)	Offset applied to satellite data (m)	No of points
Sentinel-6a	094 / 131	106	273	0.8987	0.0976	18.66	40
Sentinel-3a	724 / 083	42	61	0.9703	0.0571	18.45	16
Sentinel-3b	098 / 034	92	93	0.9225	0.0638	20.15	16

- Validation of total water level
- Low number of passes (hence the use of cross over points) in 8 months
- Correlation still high (0.89 to 0.97), rms 5.7cm to 9.8 cm.

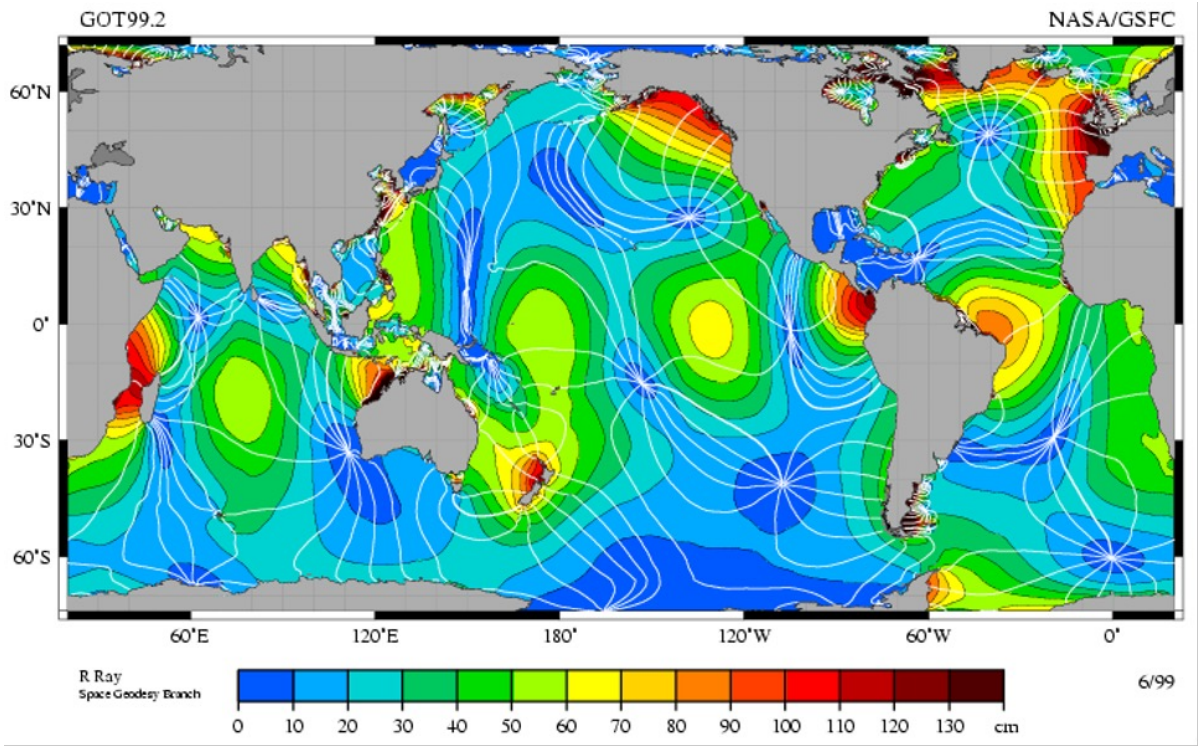
- Offset 18.66 to 20.15 m. Compares to 10.28m for SHOM gauge.
- No benchmarking for Portagauge. Reference plane 9.804m below radar arm
- Mean sea level with respect to reference plane 7.807m

WP3400 – Sea Level Variability Analysis – Satellite Altimeter Data

- Sea Level Variability Report. Deliverable D3.3
- Overview of tidal and non-tidal variability in South-West Indian Ocean
- Aim to identify regions of coherent characteristics of variability.
- This presentation includes analysis of Jason-1, Jason-2, Jason-3, Sentinel-3A and Sentinel-3B data for PASS-SWIO.



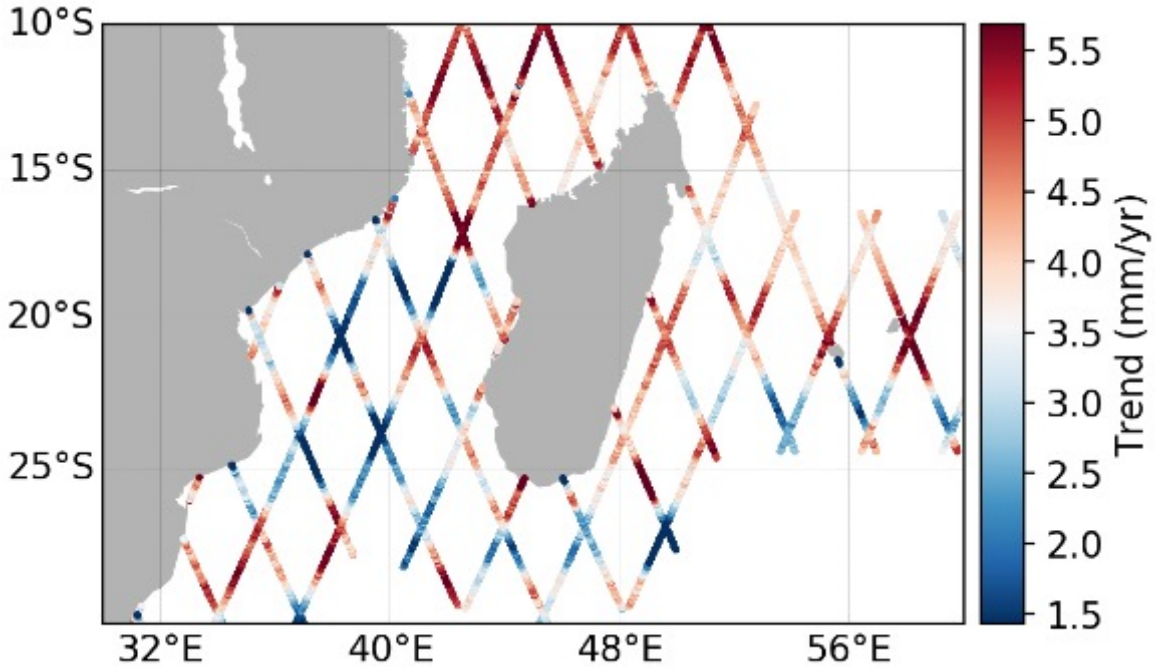
WP3400 – Sea Level Variability Analysis – Tides



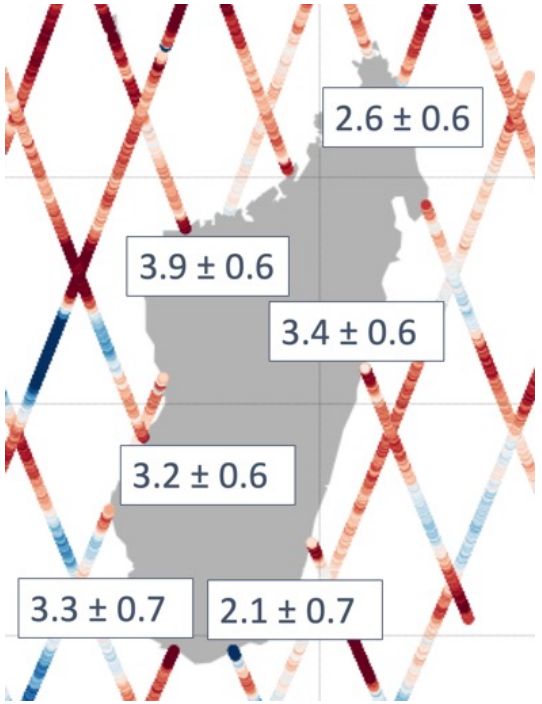
Amplitude of M2 tidal constituent, from GOT99/2 tidal model. NASA/GSFC

Maximum tidal ranges from POLTIPS

WP3400 – Sea Level Variability Analysis (Trend)

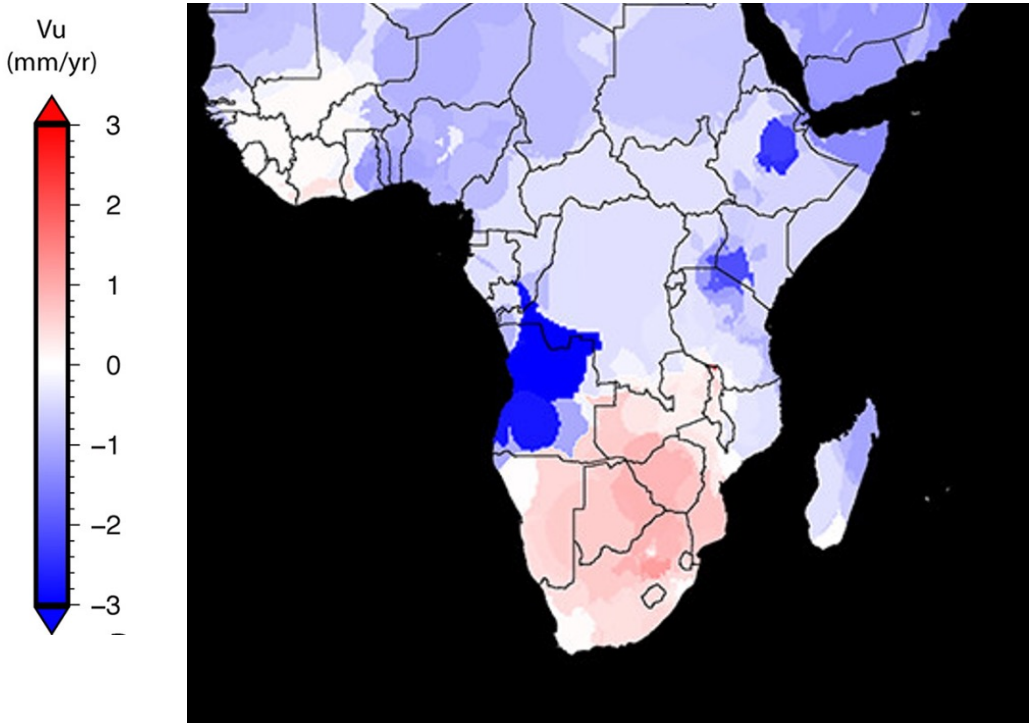


Annual trend (Jason Series) 2000 -2020



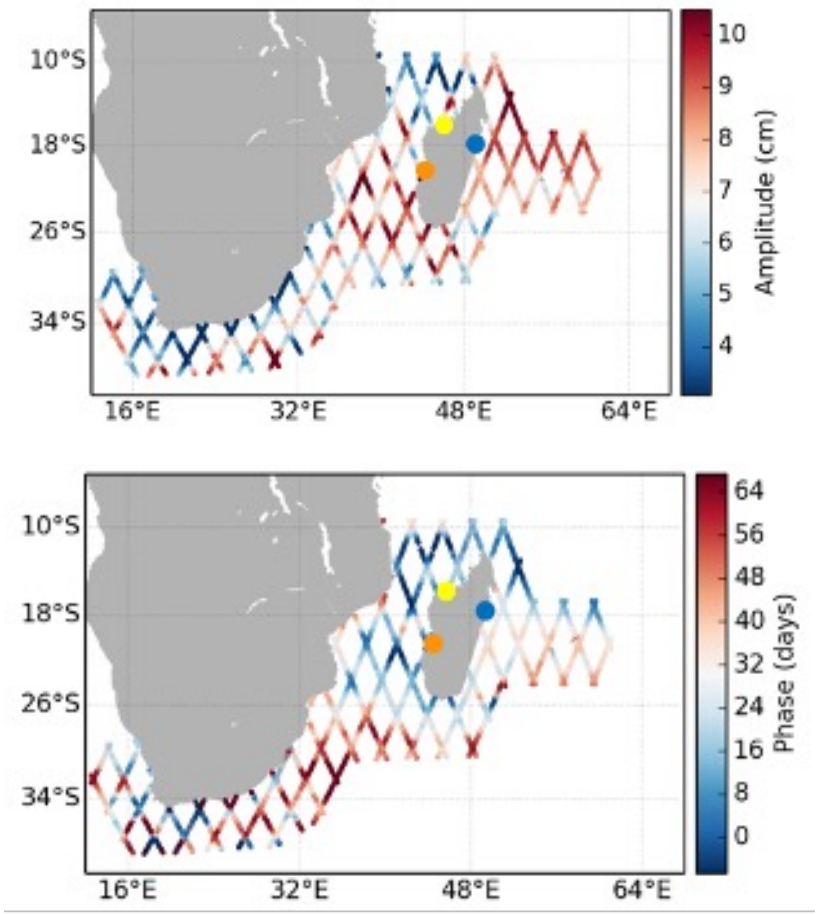
Zoom of left panel.
Inset values from CCI+ project

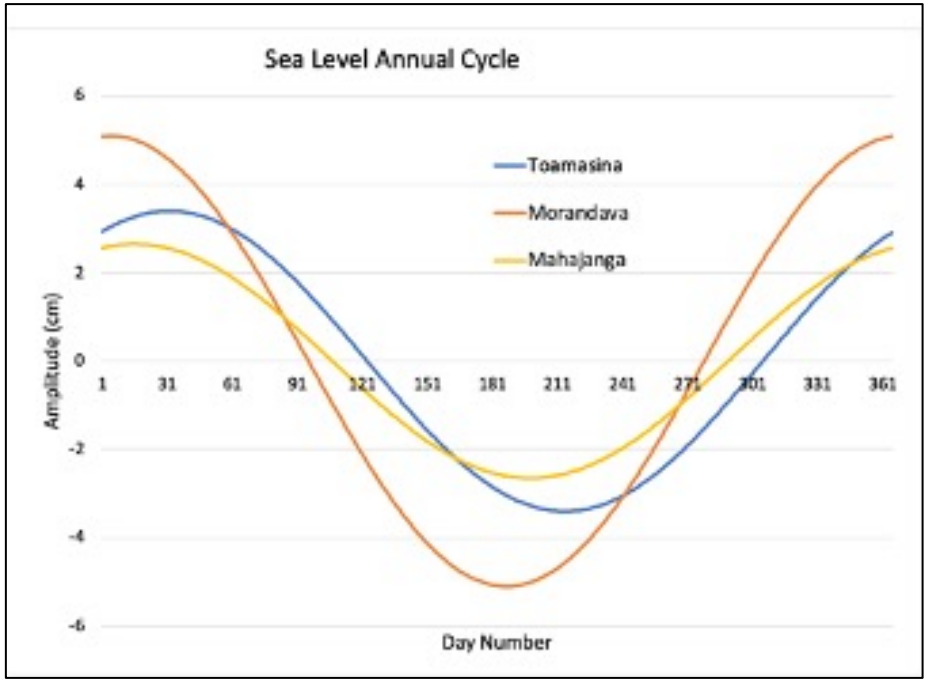
WP3400 – Sea Level Variability Analysis (VLM)



Satellite values do not take into account vertical land motion. GPS data indicates range from 0 in the South to -1 mm yr^{-1} in the North. Hammond et al. 2021

WP3400 – Sea Level Variability Analysis (Seasonal)

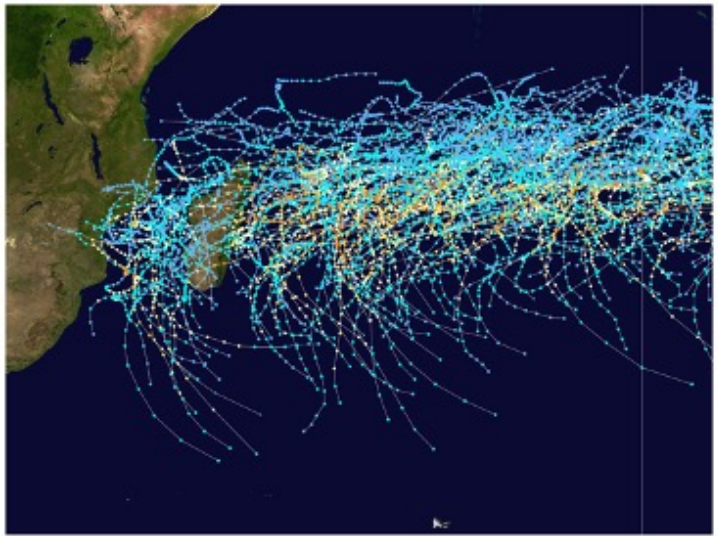


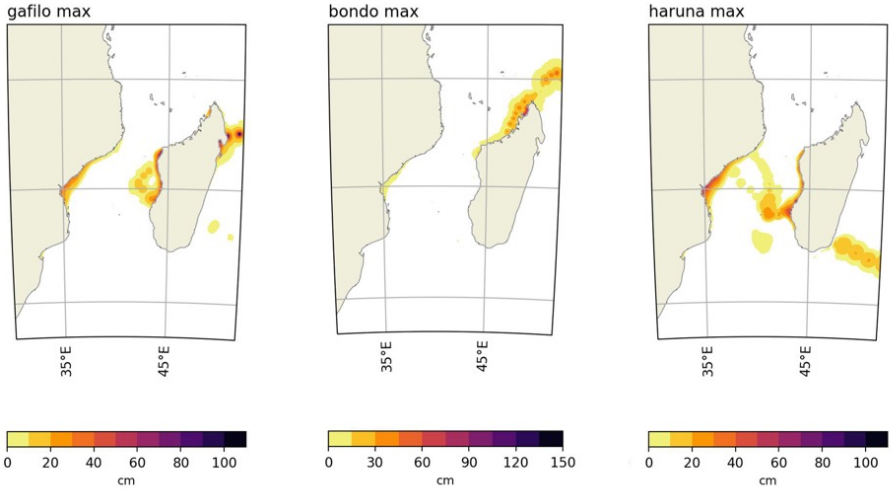


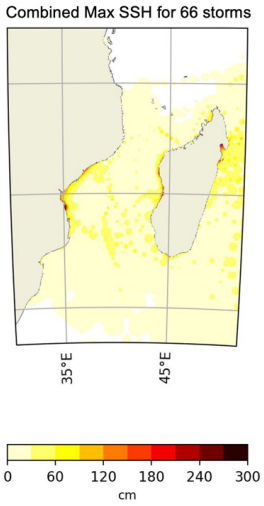
Seasonal Cycle from Jason series data

WP3400 – Sea Level Variability Analysis (Extremes)

SW Indian Ocean Cyclone Tracks 1980-2005







Storm surge from Tropical Cyclones
Cyclone tracks from Météo France (above).

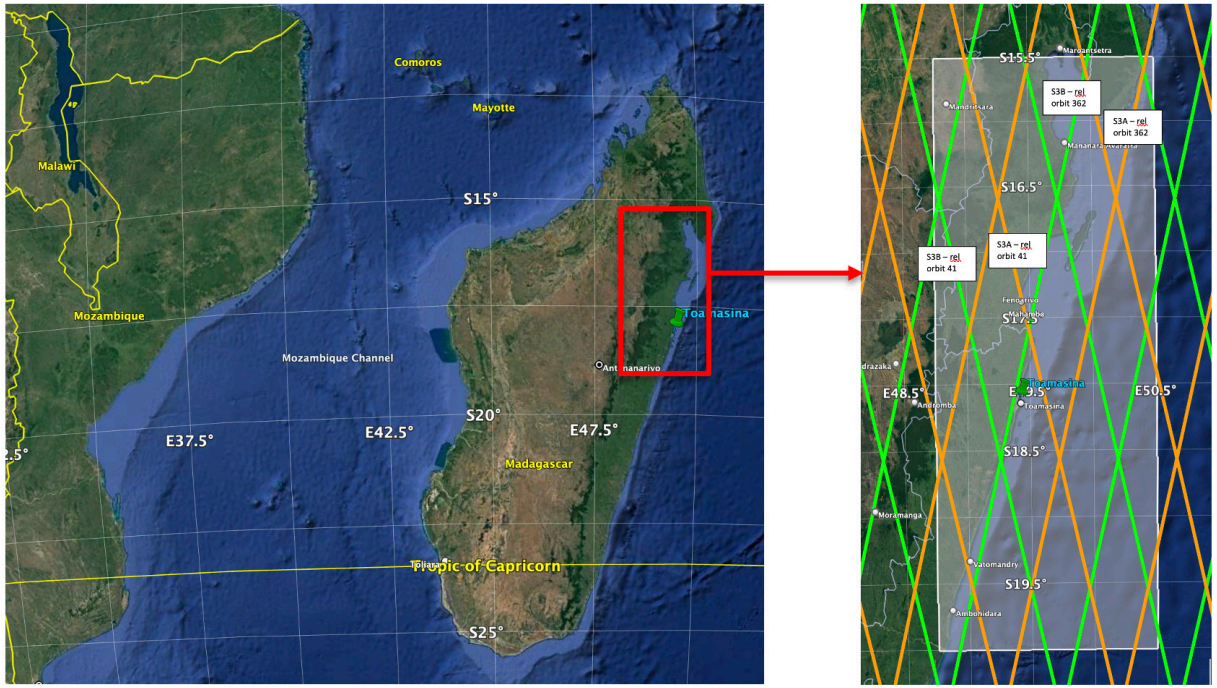
Maximum modelled sea surface height residual from C-RISC modelled storms (right)

WP3400 – Sea Level Variability - Summary

- The tidal range varies from 4m in the northwest to less than 1m on the east coast.
- Long term trends in sea level vary from 3.9 mmyr-1 in the northwest to 2.1 mmyr-1 in the southeast. This does not include the effect of any vertical land movement at the coast, which should be investigated.
- The seasonal cycle in sea-level is 5-10 cm
- Extremes:
  - Storm surge associated with tropical cyclones can be up to 2m. Impact of storm surges at all locations on the Madagascar coast. Northeast and central west coast at highest risk.
  - The maximum runup from the 26/01/2004 Indian Ocean Tsunami was 5.4m at Betanty in the south.

Coastal Processor Analysis

Assess difference in performance between ”Standard” EUMETSAT L2 product, and data produced by specific coastal processor



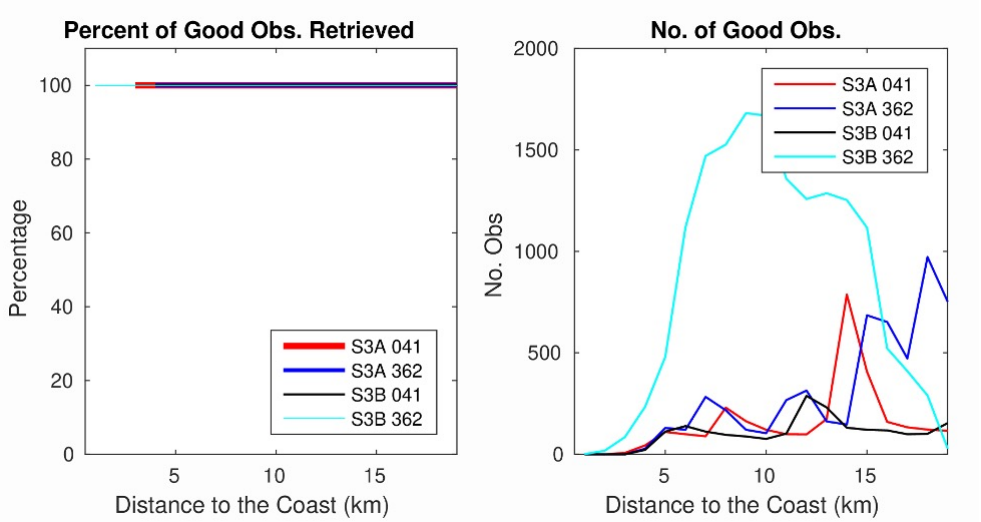
S3A and S3B data, orbits 362 and 041 close to Toamasina.

1) “Standard” EUMETSAT / ESA Level 2 marine product (BC005)

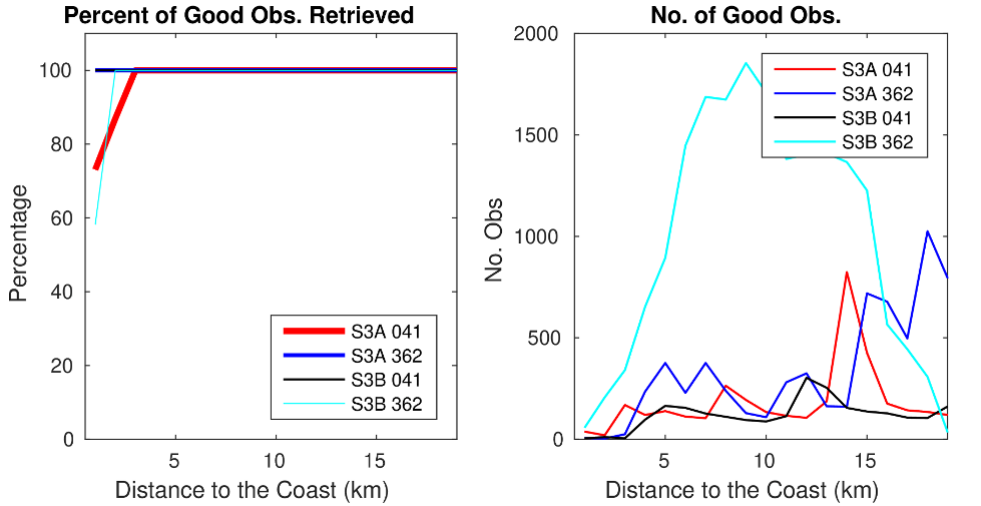
2) Processed using SARvatore for Sentinel-3 on Earth Console, SAMOSA+ retracker and coastal settings. Funded by ESA NOR sponsorship

Coastal Processor Analysis – valid data

EUMETSAT L2

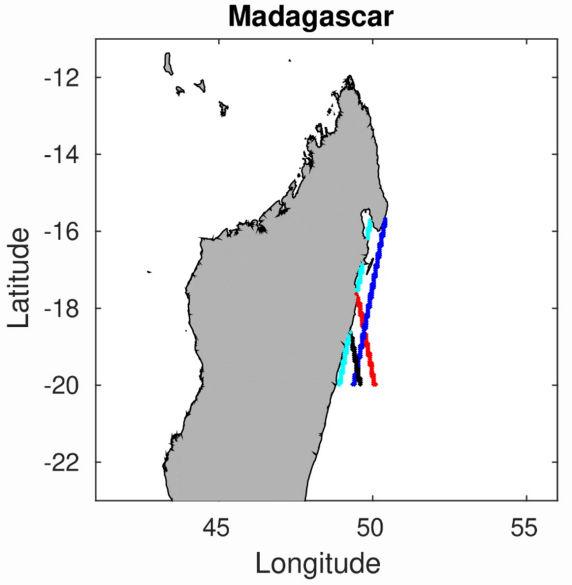


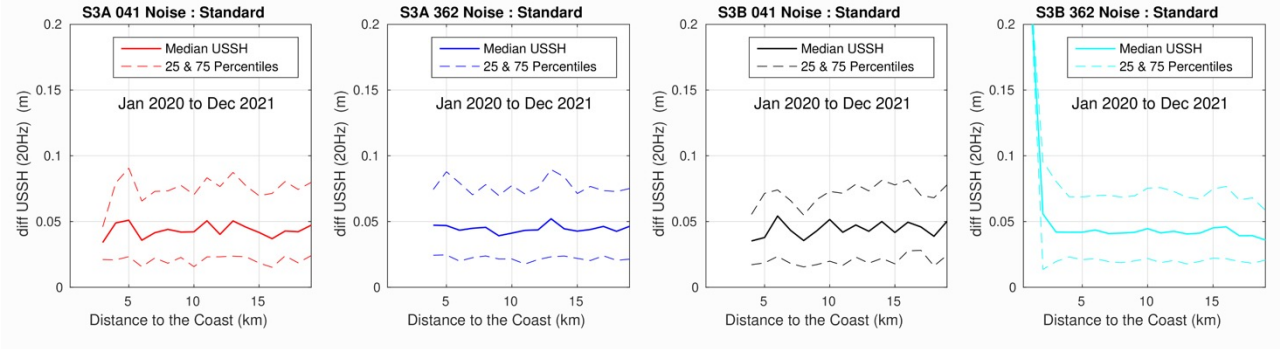
Coastal Processor



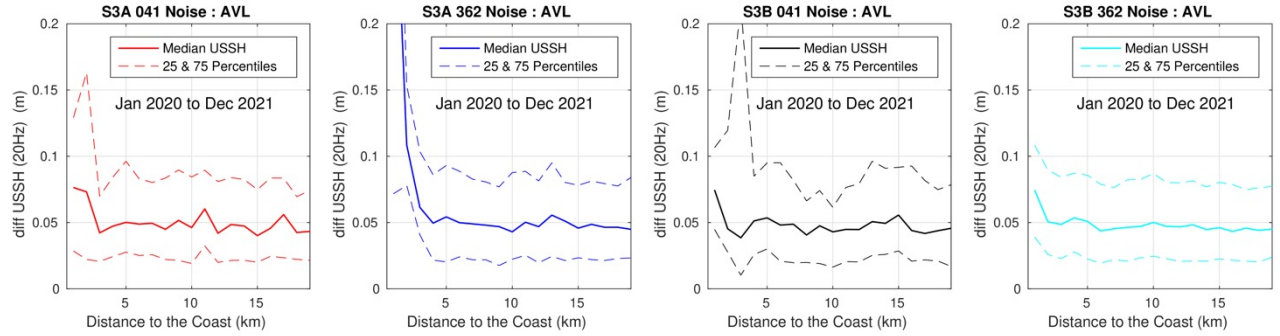
Coastal Processor Analysis – Along track noise

EUMETSAT L2 “Standard

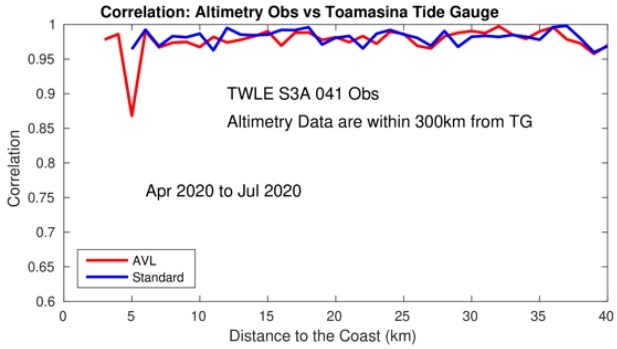


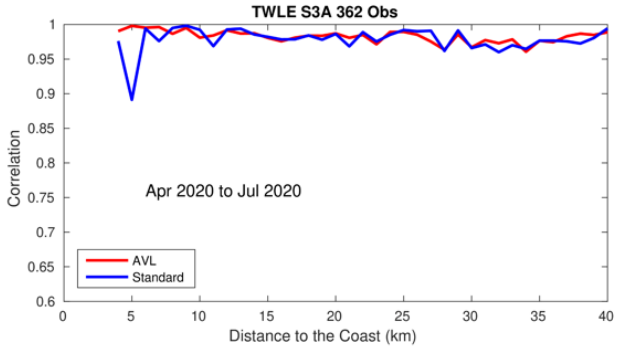


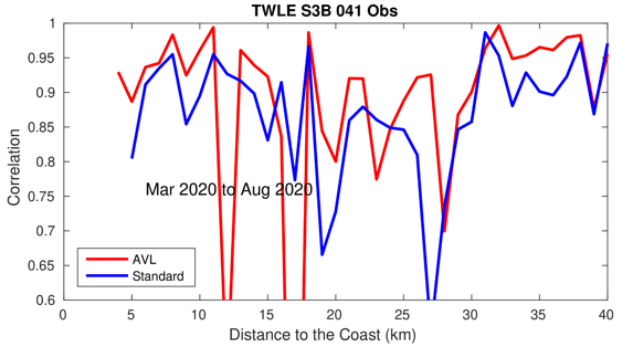
AVL Coastal Processor

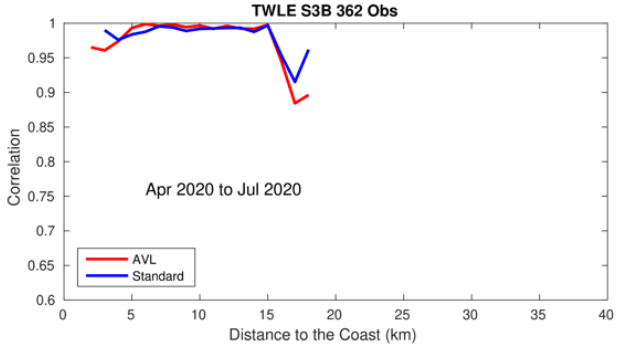


Coastal Processor – Validation against Tide Gauge









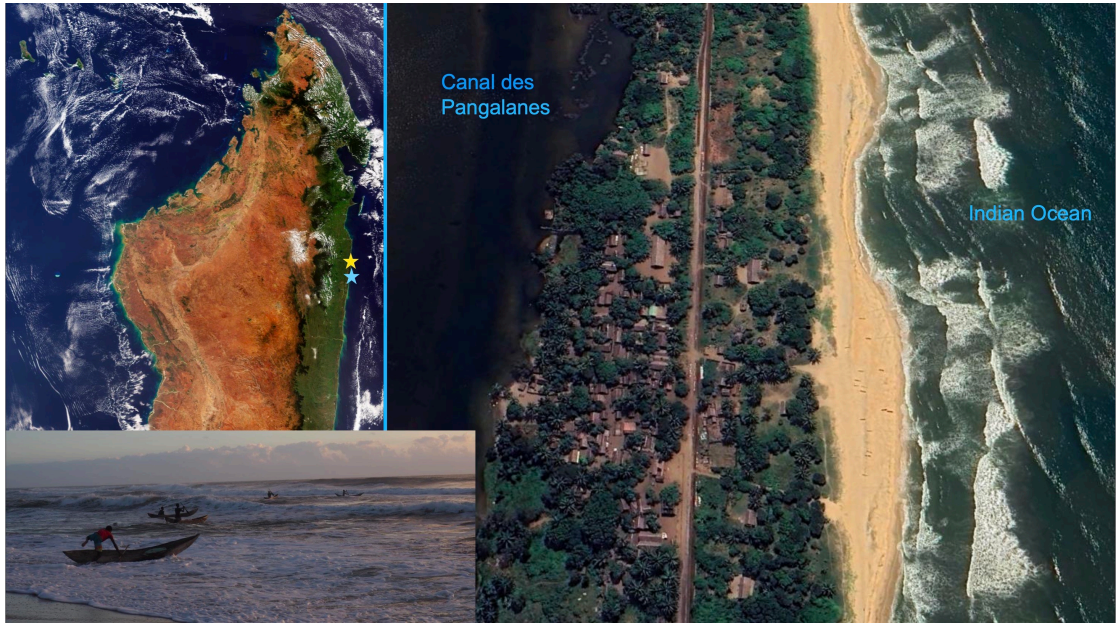
Correlation against distance to the coast. Standard Product, and Coastal Processor data

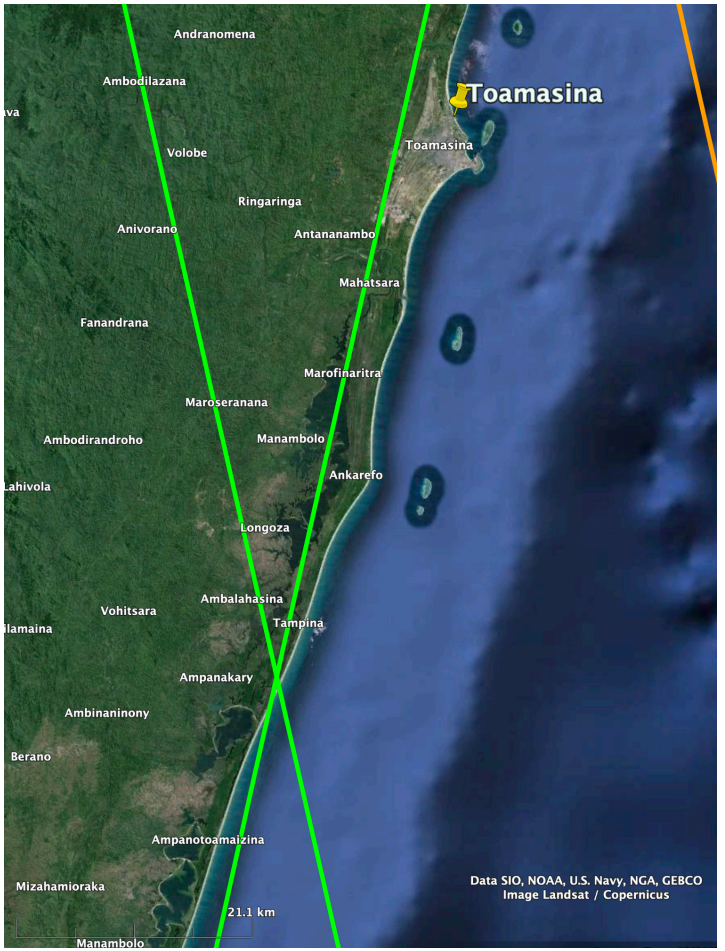
Coastal Processor Analysis – Summary

- Specialist coastal processor (SAMOSA+) data were not seen to provide more accurate sea surface height measurements than those from the standard L2 EUMETSAT/ESA product (SAMOSA2 retracker) in the range 5-10km from the coast.

- However, the specialised coastal processor does provide more data in near coastal locations (within 5km of the coast) than the standard product. Therefore of greatest interest close to the coast and where there is complex coastal topography.

Finally…
Pangalanes Canal – Interesting for FFSAR?





- Pangalanes Canal: connected lakes and waterways for 400 km.
- Provides safe transportation parallel to exposed E coast
- Subject to changes in water level following prolonged rain, which can flood coastal villages.
- Sentinel 3B track runs along canal
- Could FFSAR processing provide accurate water levels?