GEOCEAN-NC 2019 -

Sea level evolution in Noumea Lagoon, an approach using high-resolution along-track altimetry and in-situ measurements

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This presentation is a review of the scientific questions and processing carried out on data from the GEOCEAN-NC mission (Noumea Lagoon - New Caledonia - October 2019).

Summary

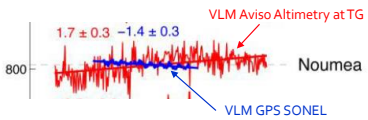
1. Context of the study
2. The GEOCEAN-NC mission (localisation, instrumentation, objectives, …)
3. First results : what is the quality of altimetry data in Noumea Lagoon ?
4. Conclusion & perspectives

1. Context of the study

Context of the study

Coastal sea-level evolution in Noumea lagoon is an unresolved issue, as altimetric, tide gauge and GNSS data on land do not provide consistent information (Aucan et al., 2017, Martinez-Asensio et al., 2019).

Vertical Land Movements (VLM) see by GNSS at land (blue) and by altimetry and tide gauge measurements* (red). Trends are in mm.y^{-1}.
[Martinez-Asensio et al., 2019]



Note that $VLM_{alt/TG}$ is the difference between altimetry and tide gauge measurements

Several explanations have been proposed:

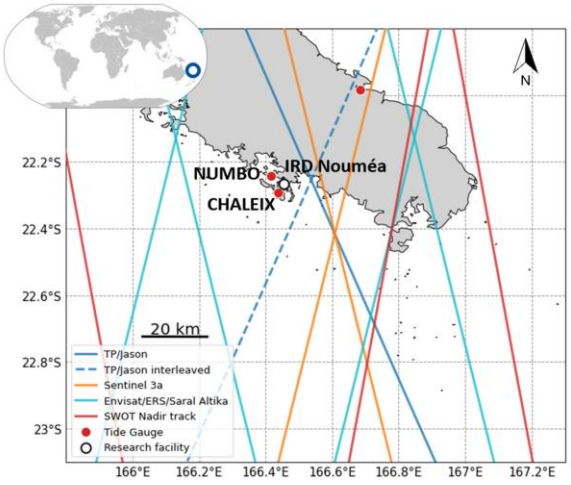
- ✓ **Altimetric data processing** doesn't integrate a local geoid model, any tropospheric correction other than the radiometer one, or a local hydrodynamic model.
- ✓ The trend of the local elevation of the water body (**setup**) linked to the waves and the wind may be different between the zone where the tide gauge is installed and that sampled by the altimetric products.
- ✓ There may be **errors in the determination of GNSS vertical land movements** due to mismodelled discontinuity (Ballu et al. 2019), or local movements at tide gauges not represented by permanent stations,…

The aim of the GEOCEAN NC mission is to investigate theses questions!

2. The GEOCEAN-NC mission

Localisation

- ✓ The GEOCEAN-NC mission took place in the **Noumea Lagoon, in New Caledonia** in the Pacific Ocean.
- ✓ This Lagoon is highly **covered by nadir altimetry** observations and will also be covered by the **future mission SWOT**.
- ✓ There is a large network of in-situ observations including permanent **Tide Gauges** (*long time series of CHALEIX-NUMBO tide gauges between 1957 and 2015*) and a network of **permanent GNSS stations** (*BANIAN – DITTT*)
- ✓ The **Noumea IRD laboratory** has resources (divers, sensors, operational hydrodynamic model,…) and experience in sea-level measurements.

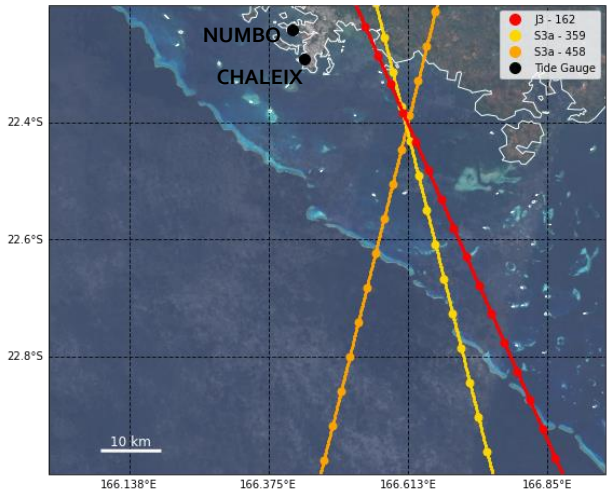


Localisation

- ✓ During the mission, we particularly focussed on the area where **3 nadir tracks intersect** (*see the map* ☞):
  - Jason 3 – Pass 162
  - Sentinel 3a – Pass 359
  - Sentinel 3a – Pass 458

- ✓ **4 altimetric satellite fly-bys** during the campaign
  - Jason 3 – 2019/10/04 23:38:55(HL)
    2019/10/14 21:37:26 (HL)
  - Sentinel 3a – Pass 359
    2019/10/12 22:07:48 (HL)
  - Sentinel 3a – Pass 458
    2019/10/16 09:39:22 (HL)

⇨ **We performed SSH in-situ measurements at the time of the fly-by for direct validation of the altimetry data.**



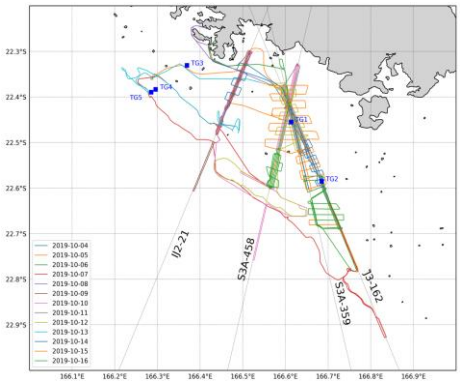
Instrumentation deployed during GEOCEAN-NC mission

Pointwise measurements

5 pressure sensors deployed in the lagoon ($TG_1 - TG_2 - TG_3 - TG_4$) and outside ($TG_5$). TG_1 is under the altimetry crossover points. They will be removed in Autumn 2020.

1 GNSS Buoy deployed at different locations

N/O ALIS trajectory during the GEOCEAN NC mission



Blue squares correspond to pressure sensors position, grey lines to altimetric tracks. All the colored lines represent ALIS trajectory during the cruise

Kinematic measurements

CalNaGeo GNSS coastal carpet towed by N/O ALIS during all the mission

A version of the Cyclopée system (GNSS antenna + acoustic altimeter) installed on N/O ALIS tender

Workplan during and after the GEOCEAN Cruise

Objectives	Data
Quantify the setup and its variations	- GNSS sea surface gradient measurements inside / outside the lagoon - Deployment of pressure sensors (1 year of data)
Improve sea-level kinematic mapping methodology along and across altimetry tracks in coastal area	- Static sessions at Tide Gauge with all instruments (Chupin et al., 2020) - Crossovers and repeated measurements in different conditions (weather,...) - Simultaneous measurements with several instruments
Altimetry cal/val	- Comparison of in-situ measurements at satellite fly-bys - Use of a local geoid model, precise tropospheric corrections and a local hydrodynamic model - Reprocessing of existing altimeter series and/or use of dedicated coastal altimetry products
Improve coastal altimetry processing	

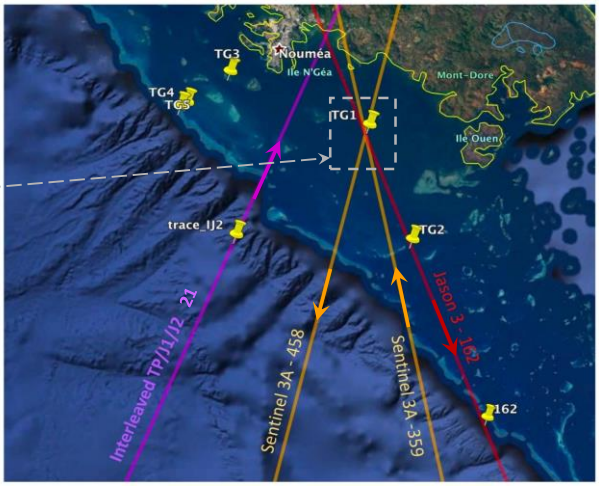
3. First results : What is the quality of the altimetry data in the Lagoon ?

Altimetric data in Noumea Lagoon

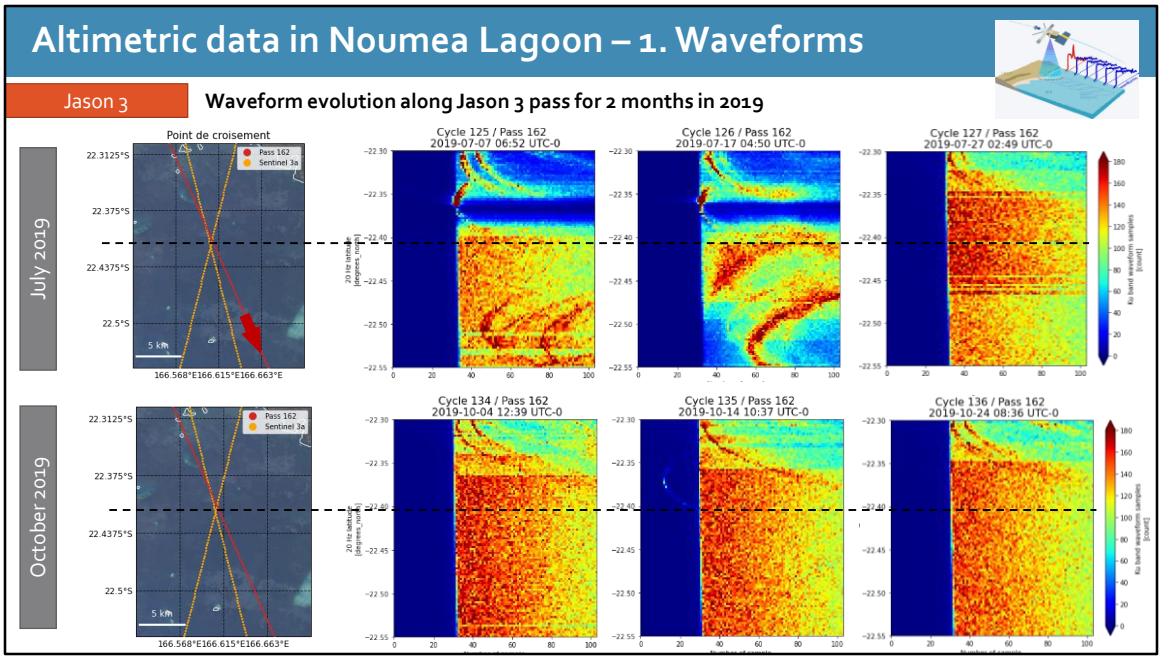
- ✓ For the moment, our objective is to determine the **quality of the available altimetry data in the Noumea Lagoon**
- ✓ We particularly **focused on the area where 3 tracks of 2 satellite missions intersect**
  (thereafter called "crossover area")

In the following, we look at :

1. Waveforms of Jason and Sentinel 3a in the area of the crossover point from S-GDR along track products
2. Long term altimetry trends in the lagoon from X-Track 1Hz data



3.1. Waveforms



Jason 3 – Pass 162 – Nadir altimetry waveforms from S-GDR products

We first analyze Jason 3 – Pass 162 waveforms in the area of the crossover point for the year 2019. In this slide, we present 6 radargrams of 6 passes of Jason 3 (3 passes in July 2019 and 3 passes in October 2019, Jason 3 has a repeatability of about 10 days). In a radargram, each waveform is projected onto a 2D space where the x-axis represents the range gate and the y-axis the latitude of the satellite (=satellite position along-track). Signal amplitude is represented with the colormap.

We see that the 3 radargrams corresponding to the October 2019 fly-bys are fairly similar. We don't present them here, but the radargrams for January and March are also similar. At the land approach (around latitude -22,36°), radargram show disturbances illustrating how the radar echoes may be impacted by the presence of land. In the area of the crossover point (black dotted line), waveforms display the typical form of the Brown model, which characterizes open ocean waveforms.

In July 2019, we see that the waveforms are disturbed even in the area of our crossover point. Our objective being to determine if we can use the altimetry data at the crossing point, we try to understand the cause of these disturbances. We investigate 2 hypotheses:

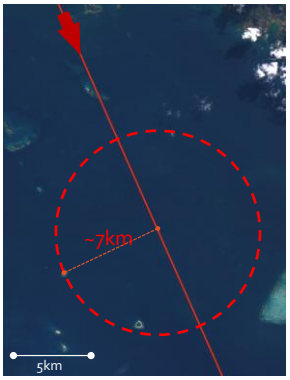
1. Is there a change in the scene seen by the satellite, which could be linked to the water height in the lagoon?
2. Is there a shift of the altimetric ground-track compared to the nominal trace that could impact the scene seen by the satellite?

Altimetric data in Noumea Lagoon – 1. Waveforms

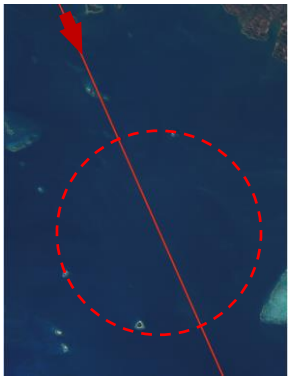
Jason 3

Sentinel 2 images – Jason 3 scene at the crossover point function of sea level at Numbo Tide Gauge

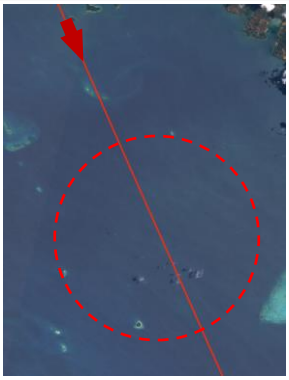
14 mai 2019 - H_{eau} NUMBO = 0,6 m



22 août 2019 - H_{eau} NUMBO = 1,0 m



24 janvier 2019 - H_{eau} NUMBO = 1,7 m

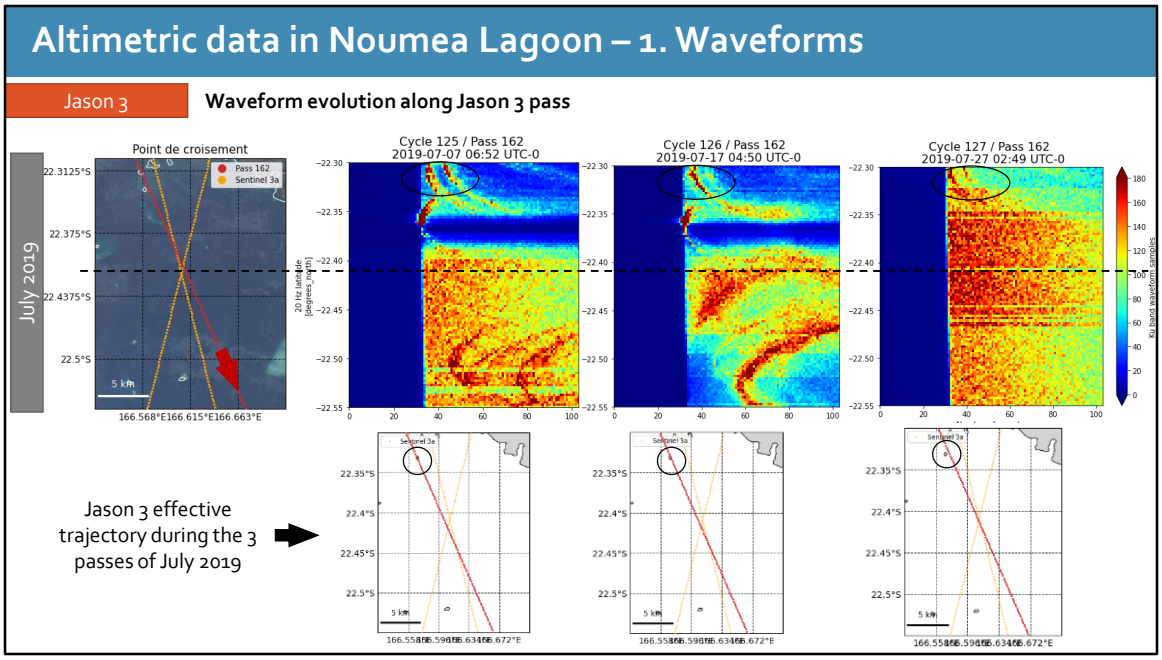


We conclude that there is no "visible" change in the satellite scene as a function of tide height variation. But it is always possible that an artifact (e.g. a quiet lagoon acting as a mirror) disrupts the signal from time to time and that the satellite images do not allow us to see it.

Jason 3 – Pass 162 – Nadir altimetry waveforms from S-GDR products

1. Is there a change in the scene seen by the satellite, which could be linked to the water height in the lagoon?

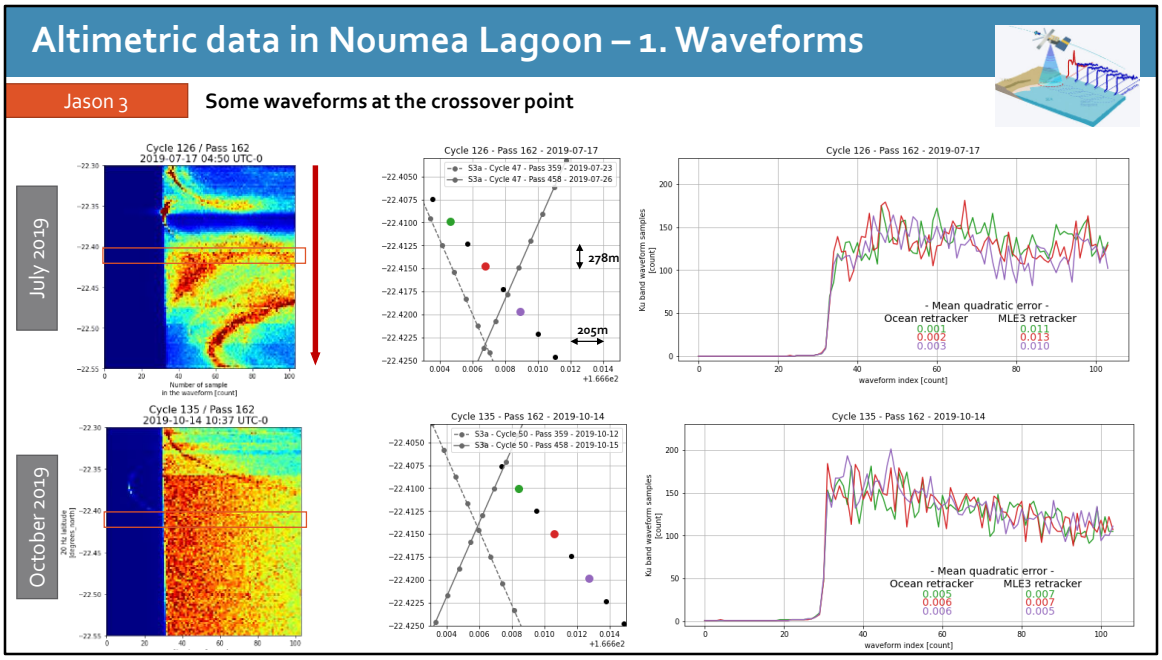
To answer this first question, we look at Sentinel 2 images. These images do not correspond to the actual passages of the altimetric satellites. However, we selected images corresponding to different water heights at Numbo tide gauge to get an idea of the evolution of the scene. We conclude that there is no "visible" changes in the satellite scene as a function of tide height variations. However, altimeter satellites observe in the range of radar wavelengths, which is not really comparable with optical images. It is possible that a ponctual artifact disrupts the signal and that the satellite images do not allow us to see it. For instance, a bright point such as still water in the inside of a lagoon could impact the radargram.



Jason 3 – Pass 162 – Nadir altimetry waveforms from S-GDR products

2. Is there a shift of the altimetric ground-track compared to the nominal trace that could impact the scene seen by the satellite?

Altimetry satellites have theorical ground tracks, but their real pass could be shifted from this nominal track. During July 2019, the satellite passed closer to small islands than in October. This may have disturbed the signal more than during other fly-bys.



Jason 3 – Pass 162 – Nadir altimetry waveforms from S-GDR products

To have a better idea of the waveform in the area of our crossover point, we look at a random sample of waveforms at different fly-bys. Here, we present 2 random samples for July 2019 and October 2019. We can see that even in July 2019, where the radargram is disturbed, we may still have exploitable waveforms in our area.

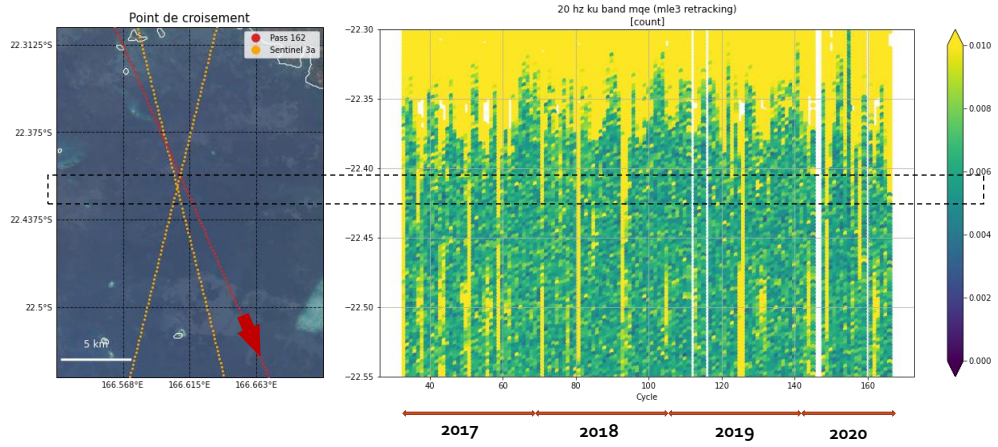
We also observe that the MQE parameter (that indicate the mean quadratic error between waveform and model) could give us a good information about the waveform quality. We note that the MLE3 retracker better highlights cycles where the signal is disturbed.

Altimetric data in Noumea Lagoon – 1. Waveforms

Jason 3

Evolution of MQE parameter along Jason 3 track 162 over 4 years

✓ The MQE parameter represent the Mean Quadratic Error between waveform and model (here, the MLE3 retracking).



<u>Jason 3 – Pass 162 – Nadir altimetry waveforms from S-GDR products</u>

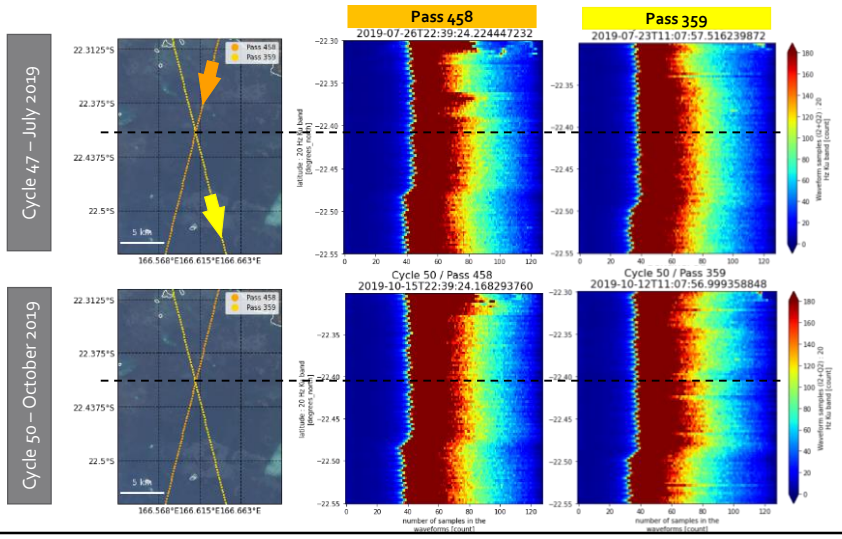
We represent the evolution of the MLE3 MQE parameter over 4 years of data. Approaching the coast, MQE parameter is bigger, but, most of the time, in the area of the crossing point, its value seem to be good. This parameter could help us to distinct cycles for which altimetry data need further investigation and those for which data are exploitable as is

⇒ **We conclude that we could have exploitable data from Jason 3 in the area of the crossover point, and that the MQE parameter could help us to distinct cycles for which data are exploitable as is.**

Altimetric data in Noumea Lagoon – 1. Waveforms

Sentinel 3a

Waveform evolution along Sentinel 3a passes



Sentinel 3a – Pass 458/359 – Waveforms analyse

We then analyze Sentinel 3a – Pass 458/359 waveforms in the area of the crossover point for the year 2019. In this slide, we present 4 radargrams of 4 passes of Sentinel 3a (2 fly-bys in July 2019 - 1 for the pass 458 and 1 for the pass 359 - and 2 fly-bys in October 2019 for the same passes).

These waveforms are different from Jason 3 waveforms. They seem to be conform to expected waveform for open ocean in the area of the crossing point, and less impacted by the proximity of land.

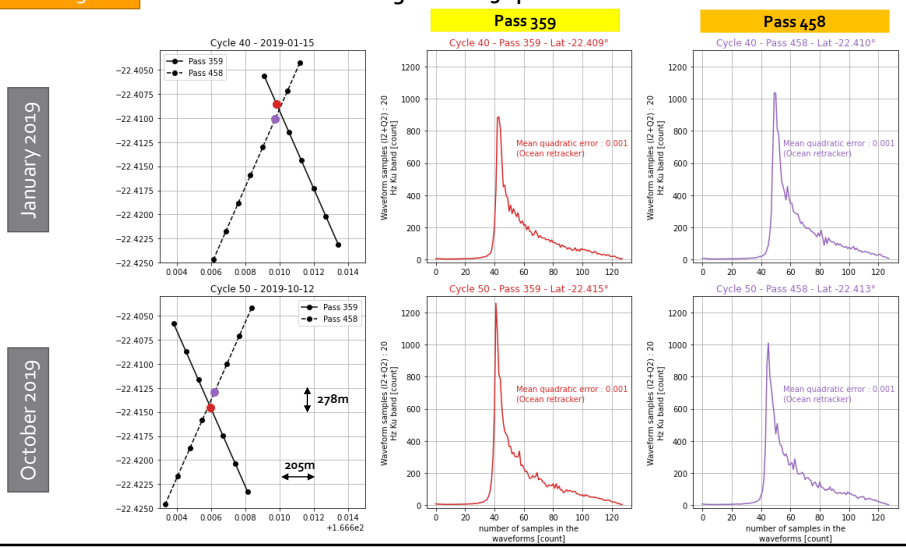
However we still have questions about these waveforms :

- How can we interpret Sentinel waveforms ?
- Are the Sentinel 3a waveforms used for the determination of altimeter parameters, or are they just a reconstruction to compare with nadir altimetry waveforms ?
- Why is there a step in the rising front of waveforms as a function of latitude ? Are there special treatments applied to Sentinel data that could create these steps?

Altimetric data in Noumea Lagoon – 1. Waveforms

Sentinel 3a

Waveform evolution along Sentinel 3a passes



<u>Sentinel 3a – Pass 458/359 – Waveforms analyse</u>

To have a better idea of the waveform in the area of our crossover point, we look at a random sample of waveforms at different fly-bys. Here, we present 2 random samples for January 2019 and October 2019, for the pass 458 (violet) and the pass 359 (red). We can see Sentinel 3 waveform exhibits a very clear peak and is probably not impacted by land contamination.

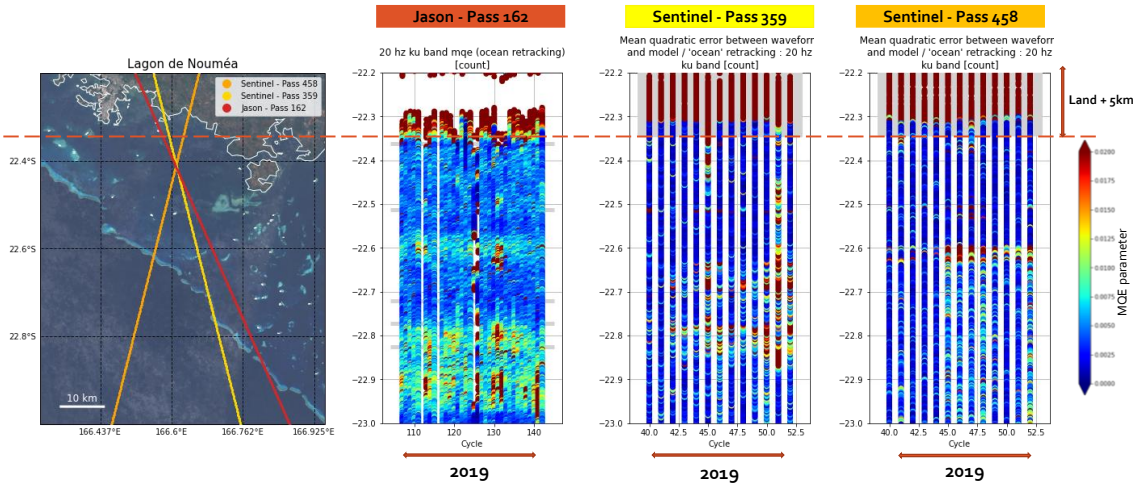
=> We observe that Sentinel 3 waveforms are not impacted by the presence of land and therefore, Sentinel 3 altimetry data in the area of the crossover point are fully exploitable.

Altimetric data in Noumea Lagoon – 1. Waveforms

Jason 3

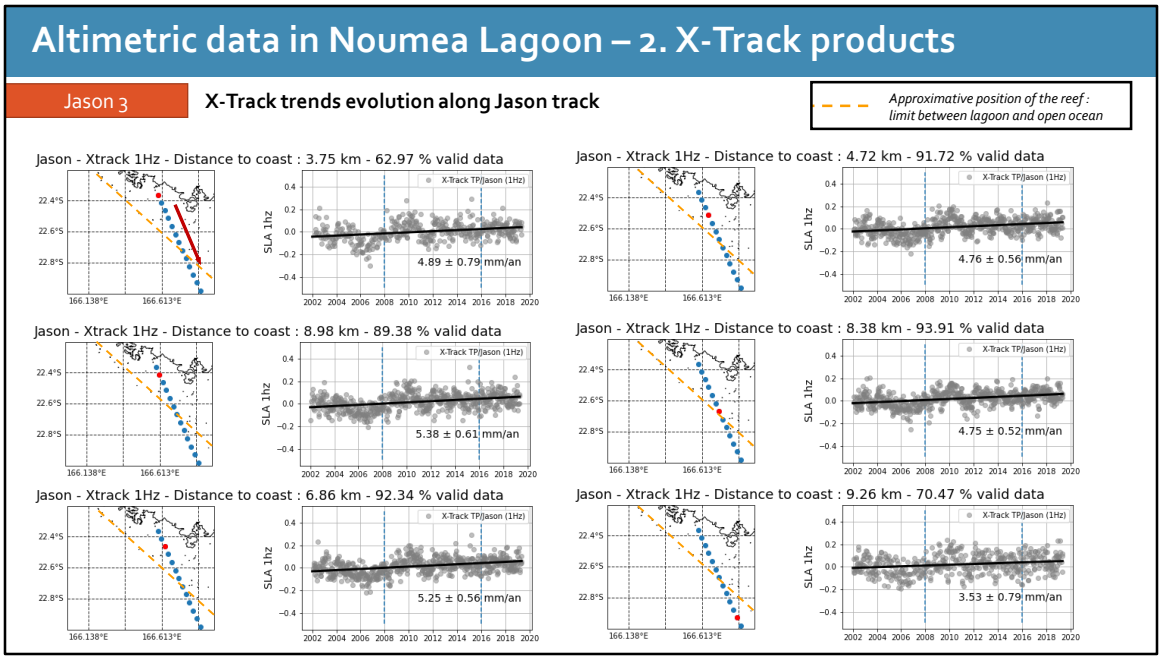
Sentinel 3a

Comparison of MQE parameters along Jason/Sentinel tracks



Jason/Sentinel 3a – Comparison of MQE parameter and data function of the distance to the coast

3.2 Jason 3 trends using X-Track 1Hz products



Jason 3 – Pass 162 – Trends using X-Track 1Hz products

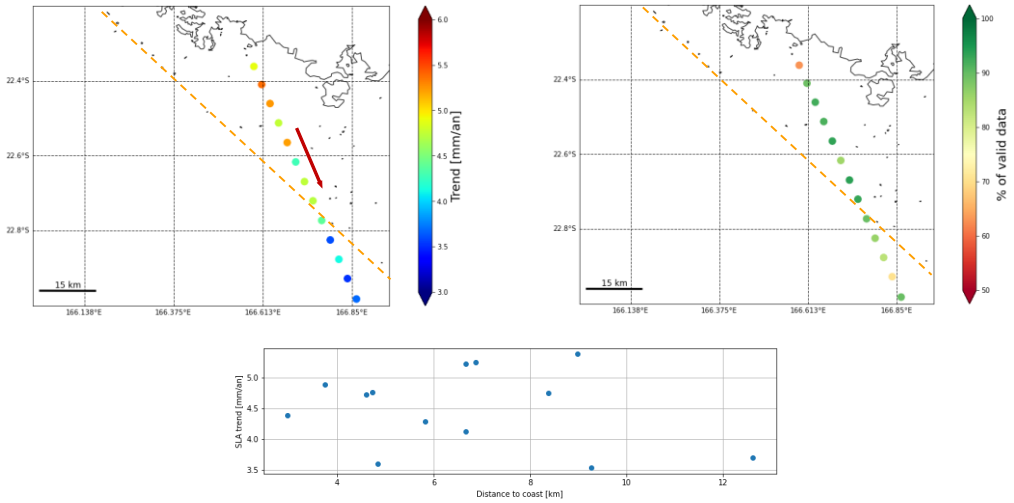
To better understand the evolution of sea level seen by altimetry in the Lagoon, we look at the SLA trend evolution along Jason 3 track. To this end, we use 1Hz data from X-Track products (Birol et al., 2017), and we focused on the period [2002-2019] (Jason 1/2/3). In this slide, we present the complete X-Track SLA time series at several points of the track (red point on the maps). For each time series, we also compute the trend (black line on the plots). We indicate the point distance to closest coast and the percentage of valid data in the SLA time series.

Altimetric data in Noumea Lagoon – 2. X-Track products

Jason 3

X-Track trends evolution along Jason track

Approximative position of the reef : limit between lagoon and open ocean



Jason 3 – Pass 162 – Trends using X-Track 1Hz products

- ✓ If we represent the trends at each 1Hz point of the track (figure on the left), we see that trends are variable. We observe that in the lagoon, trends are between 4.7-5.4 mm/y, and they seem to be smaller outside the lagoon (around 3.5 mm/y).
- ✓ There is a good percentage of valid data along the track (always better than 60%).
- ✓ When we represent trends as a function of the distance to the coast (figure at the bottom), we do not observe a particular pattern.

For the moment, we only use a 1Hz dataset. Our objective is to improve these results using 20Hz X-Track/ALES data to have a better understanding of the evolution of the trend along Jason 3 track.

4. Conclusions & perspectives

Conclusions and perspectives

Conclusions :

- ✓ **The Noumea Lagoon is well-suited for cal/val activities.** It is highly covered by past and current nadir altimetry missions and the future SWOT mission.
- ✓ The data from the GEOCEAN NC mission should help us to **better understand the dynamic of the area,** and hopefully to reconcile the altimetry, tide gauges and GNSS observations.
- ✓ First analyses on the altimetry data show that :
  - There is an area where **1 Jason track and 2 Sentinel track intersect**. This crossing point is an opportunity to compare data from different altimetry missions.
  - The analyse of the waveforms show that we could have **exploitable data in the area of the crossing point**.
  - Long term altimetry trends in the lagoon seem to be variable. A more complete study should be carried out using 20hZ data.

Perspectives :

- ✓ Use 20Hz X-Track/ALES products to compute a long term altimetry trend
- ✓ Compare altimetry data with in-situ measurements, in particular at the point of crossover between Sentinel and Jason 3 missions where a pressure sensor has been deployed during GEOCEAN-NC and should be recovered next month.
- ✓ Compute a new GNSS long term time series for VLM
- ✓ Compute a local model geoid with CalNaGeo GNSS observations
- ✓ …

Acknowledgments

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- ✓ We thank the LEGOS team for their help with altimetry data and the computation of high-resolution along track data.
- ✓ For the GEOCEAN-NC mission in Noumea lagoon in October 2019, we want to thank the captain and crew of the R/V Alis. We also thank Etienne POIRIER for the management and deployment of the equipment.
- ✓ We also thank the CNFC and CNFH (Commission Nationale de la Flotte Côtière et Hauturière), Ifremer, IRD and the Government of New Caledonia for rapidly adjusting and obtaining permissions for the new cruise plan.
- ✓ Funding for C.Chupin PhD is provided by the Direction Générale de l'Armement (DGA) and the Nouvelle Aquitaine region.

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