High-resolution coastal modeling in Kerguelen Island for CAL/VAL activities

Y-T. Tranchant[1], M. Cancet[2], E. Sahuc[2], S. Millet[2], F. Lyard[3], L. Testut[1], V. Ballu[1], C. Chupin[1], G. Dibarboure[4], N. Picot[4], O. Laurain[5], P. Bonnefond[6]

1. LIENSs CNRS UMR 7266 –La Rochelle Université, France

2. NOVELTIS, Toulouse, France

3. OMP/CNRS/LEGOS, Toulouse France

4. CNES, France

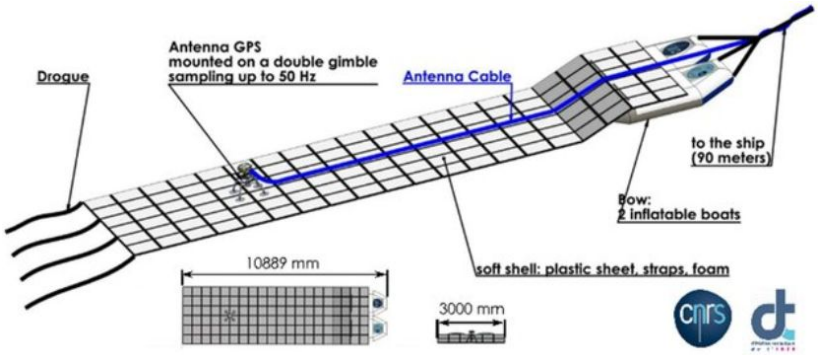
5. OCA-GEOAZUR, Valbonne, France

6. Observatoire de Paris – SYRTE, Paris, France

Motivation

In the context of the **FOAM** TOSCA project, a new CAL/VAL site is proposed on the Kerguelen Island, to complement already existing and historical sites (Corsica, Harvest, Bass Strait, Gavdos…) by monitoring the altimeter height measurements in different sea-state condition.

To link the altimeter and the local tide gauge observations, **CalNaGeo**, a GNSS towed sheet (see Chupin et. Al., 2020), has been designed to map the Sea Surface Height (SSH). Two campaigns were carried out in the Kerguelen Island in 2016 and 2018.



A general drawing of the original CalNaGeo offshore towed carpet with a double inflatable boat in front (© M.Calzas-DT-INSU)

CalNaGeo campaign, January 2018

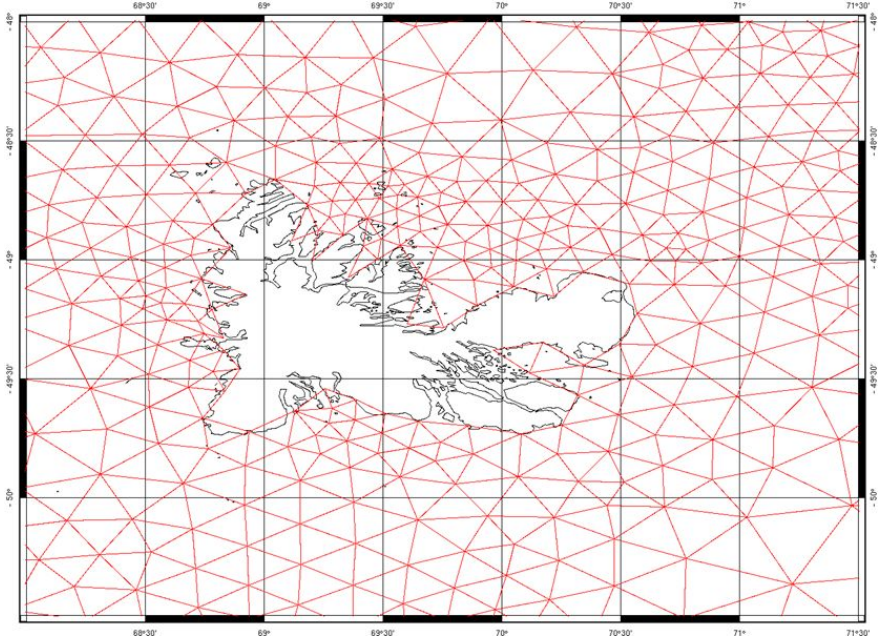
Motivation

To determine the precise local marine geoid from the CalNaGeo measurements, the contributions of the tide and the atmospheric forcing must be removed using accurate models.

$$\underbrace{SSH}_{CalNaGeo} = \underbrace{H_{Tide} + H_{Atm}}_{Model} + \boldsymbol{H_{Geoid}} + \delta H$$

The native spatial resolution of the most recent global tidal model FES2014 is of about 15 km in the region.

It is thus necessary to implement a high-resolution regional model in the region.



Extract of the unstructured mesh of the global tide model FES2014 around the Kerguelen Island

Motivation

To meet this objective, a high-resolution barotropic configuration has been implemented for two different hydrodynamic models, SCHISM and TUGO-m.

Each model has specificities in terms of physical approximations and numerical schemes and the **main objective** of this exercise is to **identify the driving processes** in the area by comparing the simulation results, and thus be able to provide a relevant correction for the CalNaGeo measurements.

This study is also an opportunity to **prepare the future global tide model FES2022** in the region, with the local refinement of the mesh, the integration of new local bathymetry data and the local tuning of the TUGO-m model.

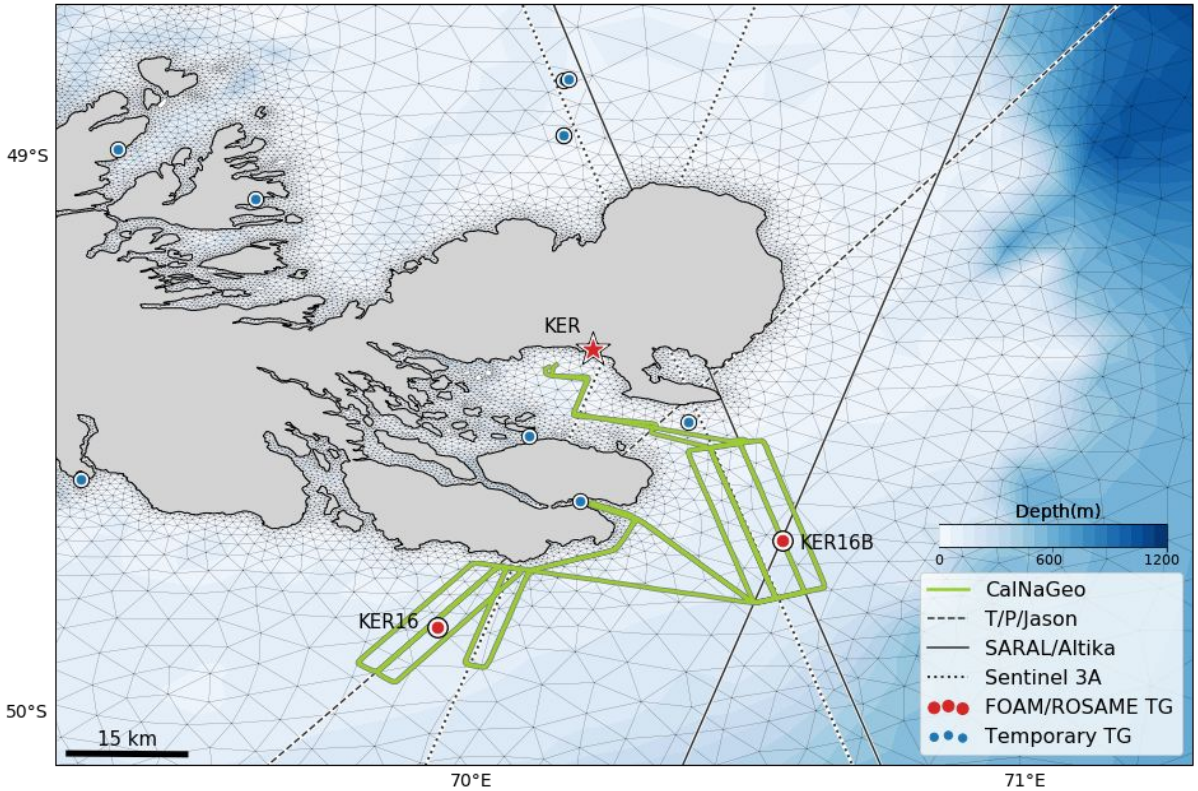
Infrastructure

The site of Kerguelen is overflown by many altimetry missions including TP/J, SARAL/AltiKa and Sentinel-3A.

Substantial instrumentation:

- Permanent TG at Port-aux-Français (KER) since 1993 (ROSAME).
- KER16 and KER16B deployed during FOAM campaign of 2016. Replaced by KER18 and KER18B during the 2018 campaign.
- Tidal constituents computed from 10 temporary tide-gauges

⇒ 4 years of in situ measurements under Jason and SARAL tracks.

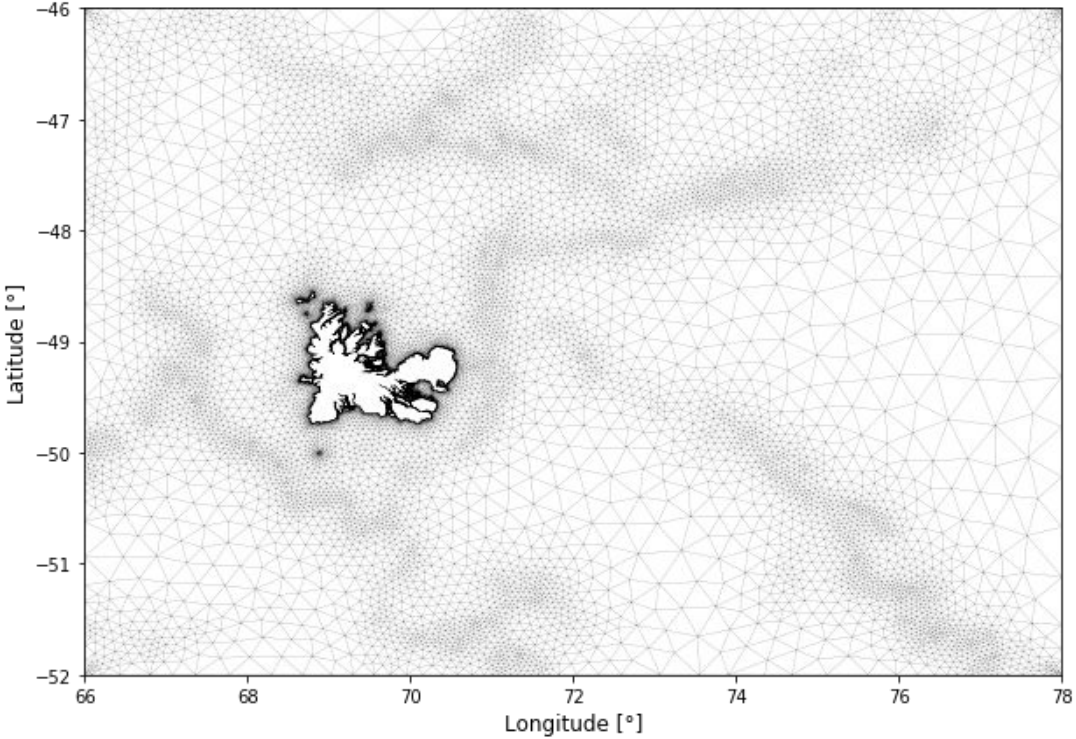


In-situ deployment and altimetry tracks over Kerguelen

Model configuration

The grid used for both hydrodynamic models (SCHISM and TUGO-m) is an unstructured mesh, with a resolution ranging from 10 km in the deeper ocean to 100 m near the coastline, providing a coastal/open ocean continuum.

Both models are forced by tides from the global tide model FES2014 at their open boundaries.



High-resolution unstructured mesh implemented around the Kerguelen Island

Validation

For the two regional models, the tide validation is performed classically by computing **complex errors** at 13 in situ stations (temporary dataset and FOAM/KER tide gauges).

After performing harmonic analysis on observed and modeled water levels, **complex errors** rely on the vector difference between both tidal constituents (with A and φ the amplitude and phase lag obtained by harmonic analysis):

$$|\Delta z| = |A_{obs} e^{\varphi_{obs}} - A_{mod} e^{\varphi_{mod}}|$$

Then, the Root Sum Square (RSS) can be derived, giving the combined error of each model.

Note: The comparison between the global FES2014 model and the tide gauge stations is not shown as it is biased by the fact that observations from some of the tide gauges as well as altimetry points located close to some tide gauges were assimilated in this model.

Exploration of the models dynamics

In one of the two models, TUGO-m, the Self-Attraction and Loading (SAL) term is fully integrated in the momentum equation. It allows to assess the impact of this parameter on the accuracy of the tide modelling in the Kerguelen area.
The contribution of the tide potential is also expected to be non-negligible due to the extent of the model domain.
In order to quantify the impact of these two terms in the hydrodynamic simulations, comparative runs were made, from which combined complex errors were computed against 13 stations (temporary data set and FOAM tide gauges):

TUGO-m - Sensibility to SAL and Tide potential:

RSS (cm)	M2	S2	K1	O1
Without pot.	2.01	0.37	1.18	0.95
Without LSA	1.72	0.81	0.54	0.44
With LSA & pot	0.72	0.49	0.64	0.46

Sensibility to SAL and Tide Potential - TUGO-m

Each of these two terms (SAL and tide potential) has a non-negligible impact. For instance, the M2 main tidal component is improved by more than 1 cm when considering both terms in the simulation.

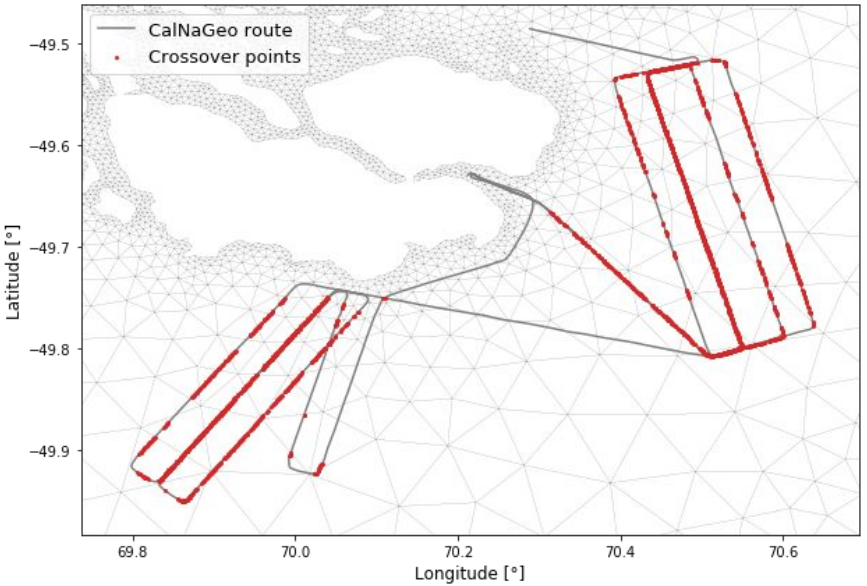
CalNaGeo campaign crossover points

Methodology

The route of the CalNaGeo campaign in 2018 was designed in 2 mirror parts. Each part is designed to revisit given points, and the second part of the CalNaGeo campaign (Jan. 25-27, 2018) is an overlapping of the outward journey (Jan. 23-25, 2018).

An indicator of the model ability to remove the non-stationary part of sea-level in CalNaGeo measurements is to investigate the differences at crossover points before and after corrections.

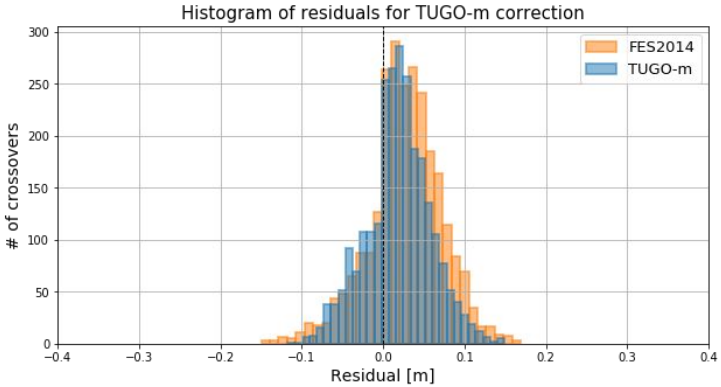
Before computing residuals at crossover points, raw height measurements are corrected from the inverse barometer and from the tide correction from the studied model. For these preliminary results, the tide reconstruction is based on 16 constituents.



Route of the CalNaGeo campaign in 2018 and crossover points considered for the analysis in red.

CalNaGeo campaign crossover points

Preliminary results – All crossover points



The histograms of the residuals obtained over the whole area with the two regional models (SCHISM and TUGO-m) clearly show less dispersion around 0 than the residuals histogram obtained with the FES2014 global model.

The RMSE and the variability of the residuals obtained with both regional models are also smaller than for the FES2014 results, which shows that the regional models provide more accurate tide corrections than the global model in the region.

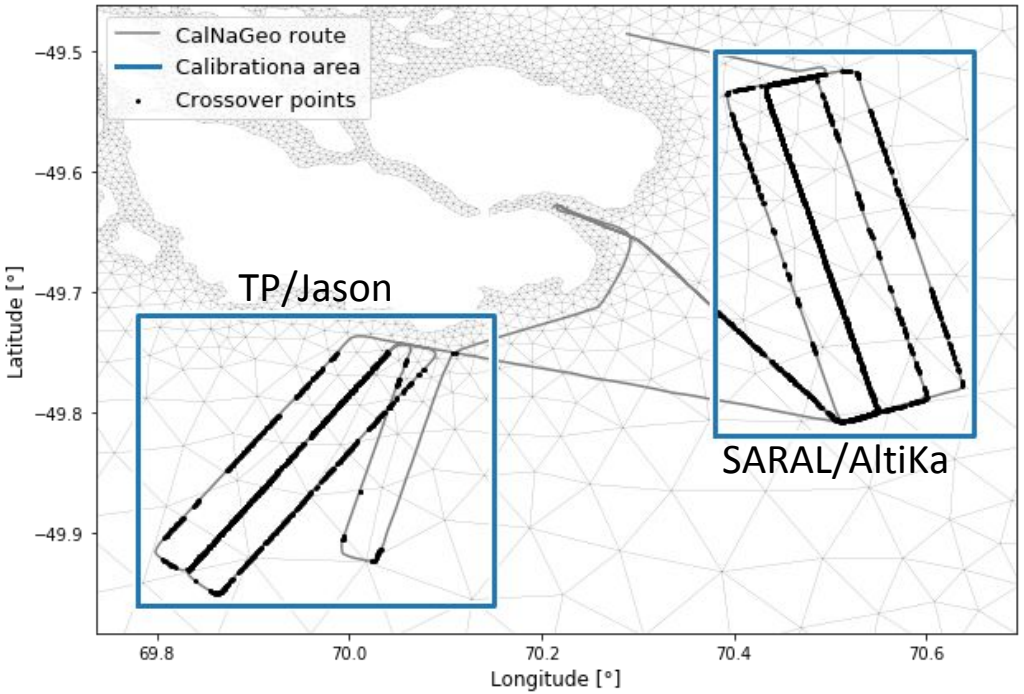
	SCHISM	TUGO-m	FES2014
RMSE [cm]	4.42	4.38	5.31
STD [cm]	4.26	3.98	4.58

CalNaGeo campaign crossover points

Calibration area

In order to make a more specific assessment of the quality of the model for CAL/VAL operations, the computed differences at crossover points were split in 2 areas, the **TP/Jason** and the **SARAL/AltiKa** calibration areas.

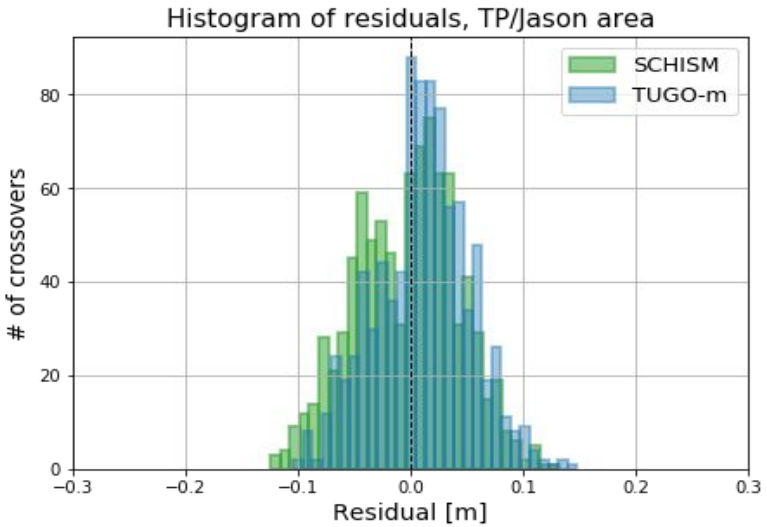
For each of those areas, the distribution of the residuals is determined and statistical indicators are derived as before.



CalNaGeo campaign crossover points

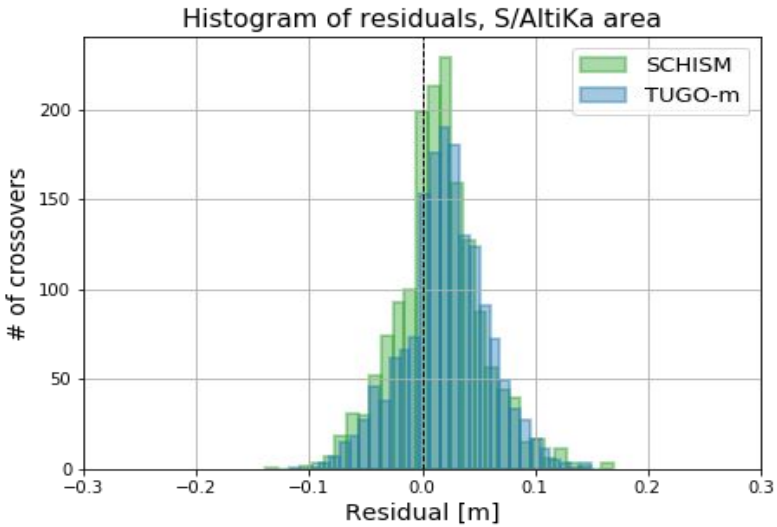
Preliminary results – Residuals for each calibration area

TP/Jason area



	SCHISM	TUGO-m	FES2014
RMSE [cm]	4.63	4.32	5.11
STD [cm]	4.61	4.18	4.94

SARAL/AltiKa area



	SCHISM	TUGO-m	FES2014
RMSE [cm]	4.10	4.28	5.27
STD [cm]	3.82	3.73	4.09

CalNaGeo campaign crossover points

Discussion

From these preliminary results, the two regional models present a gain in accuracy (from 0.8 to 1.2 cm) in comparison to FES2014 in its assimilated version over the whole area.

On the 2 calibration areas, TUGO-m correction exhibits a more constant RMSE on residuals (4.28 and 4.32 cm) than residuals issued from the SCHISM correction (4.10 cm and 4.63 cm). On the other hand, residuals are more dispersed in the SCHISM correction than for TUGO-m.

Investigating those spatial disparities and differences in the model results is one objective of this study, and should help us understand the main driven processes in the area.

***Remind**: These preliminary results are based on a pure tidal reconstruction based on 16 constituents, for each model.*

Conclusions

Although still preliminary, these results already highlight the **strong interest of high-resolution modelling in the Kerguelen Island region** to produce more accurate ocean tide estimates than the recent global tide model FES2014.

The cross-comparison of simulations provided by two different hydrodynamic models (SCHISM and TUGO-m), with their own specificities in terms of physical approximations and numerical schemes, is a **powerful approach to identify and better understand the driving processes** in the area. In particular, these analyses will be very useful to optimize the tuning of the models' parameters in the region.

Next steps:

Continue to explore the results and extend the analysis on more tidal components.

Use atmospheric forcing to produce a more complete correction for the CalNaGeo measurements, including the ocean tide and the atmospheric effects on the sea surface height (inverse barometer and high frequency processes).