Mesure du geoïde marin avec le système CalNaGEO (GNSS)

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1- Le projet: FOAM: From Ocean to inland waters Altimetry Monitoring

The determination of mean sea level variations with accuracy below 1 mm/yr is a central question in the current debate on climate change and its impact on the environment including oceanic circulation features [*Bindoff et al.*, 2007; *Cazenave and Nerem*, 2004]. To answer this, oceanography needs very accurate time series from satellite altimetry but also longer series from tide gauges data. In both cases, problems in geodesy are much more difficult to solve, taking into account the 2.5 cm overall accuracy objective for Jason/OSTM missions on Sea Surface Height.

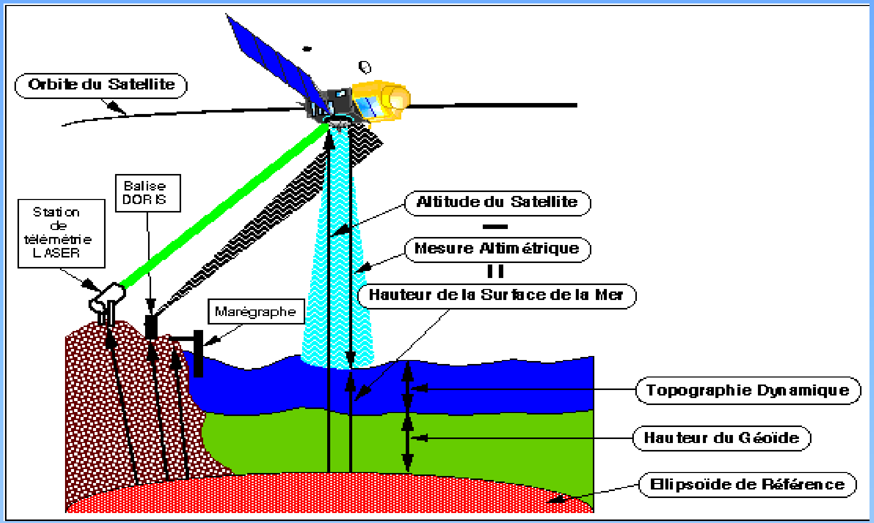
From the space point of view, orbit quality and reference system (e.g. ITRF) are of particular importance (~1 cm) but error budget on the altimetric measurements (~1.5 cm on range) is also at the same level. From the terrestrial point of view, the geodetic link of tide gauges into the space reference frame defined by satellite altimetry is also one of the most important problems in geodesy. These aspects lead us to develop ultra-precise validation and calibration techniques, including insitu absolute calibration experiment.

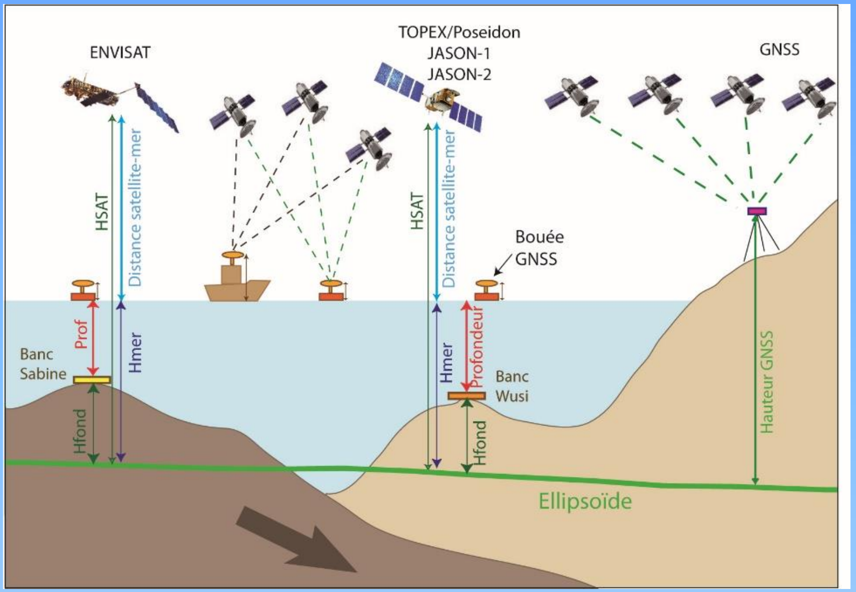
These components - orbit, measurements, corrections and their calibrations - form the basis of all the error budgets published in the framework of the TOPEX/Poseidon (T/P) and Jason-1&2 missions during both geophysical evaluation and scientific results phases [*Fu et al.*, 1994; *Ménard et al.*, 2003; *Lambin et al.*, 2010]. They have permitted: (i) to constrain the results of the mission giving limits to the interpretation of altimetric signals, (ii) to indicate the possible improvement sources and (iii) to contribute to the development of new evaluation, validation and calibration methods.

In collaboration with other investigators of the Ocean Surface Topography Science Team working at understanding the coupling effect between climate and global changes of sea level and inland water stocks, our contribution will be dedicated to a detailed error analysis that contribute to assemble a Climate Data Record from past, current and future missions. The system should be used for Jason 3, Sentinel and SWOT CAL/VAL satellites.

PI: Pascal Bonnefond, Astronome, Laboratoire Syrte, Observatoire de Paris

Projet financé par le CNES sur appel à projet CAL/VAL Altimetry





Par *définition*, le *géoïde* définit la surface de la Terre. ° Le *géoïde* est la surface équipotentielle de pesanteur qui coïncide avec la surface d'équilibre des mers prolongée dans les continents.

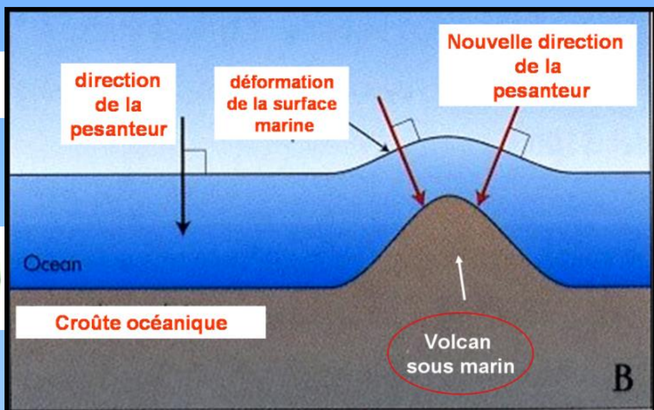
L'ellipsoïde de révolution ("sphère aplatie aux pôles") est un modèle mathématique utilisé pour exprimer des coordonnées géographiques afin d'effectuer des calculs sur une surface proche de celle de la terre. Il existe de nombreux modèles d'ellipsoïdes (ex WGS84 ou GRS80)

données hautes fréquences des GDR (Geophysical Data Record) Traitements OCA (Bonnefond/Laurain)

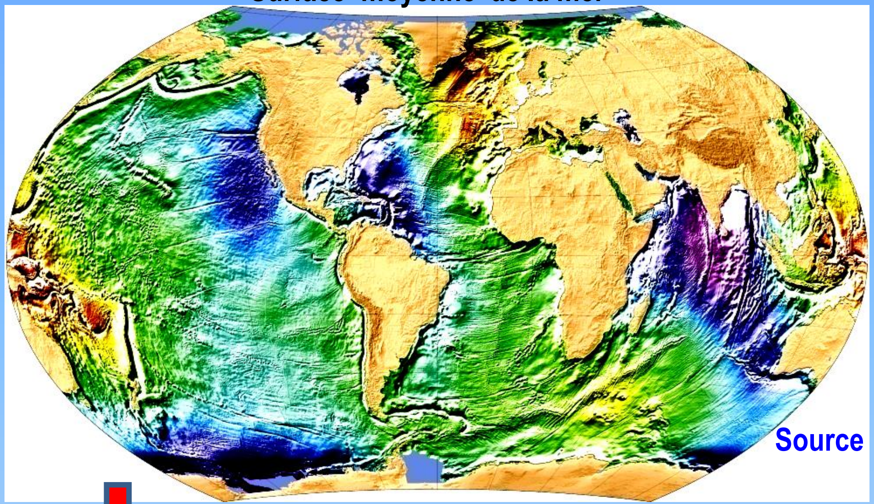
SSH = HSAT – (RANGE + IONO +WET +DRY + SSB).

- Orbite: standard GDR-C et GDR-D (champ de gravité variable)
- Range : retracker ocean, +/- 20 km (altimètre)
- Ionosphère :
  - dual frequency pour TP/J1/J2
  - Modèle GIM-KU pour Envisat
- Troposphère sèche: ECMWF
- Troposphère humide: radiomètres
- Ssb: basé sur des modèles empiriques
- Geoide: EGM08 (d'après Bouin et al. 2009)
- Marées terrestres, polaires et surcharge océanique (GDR)
- Pas de marée océanique, ni baromètre inverse.

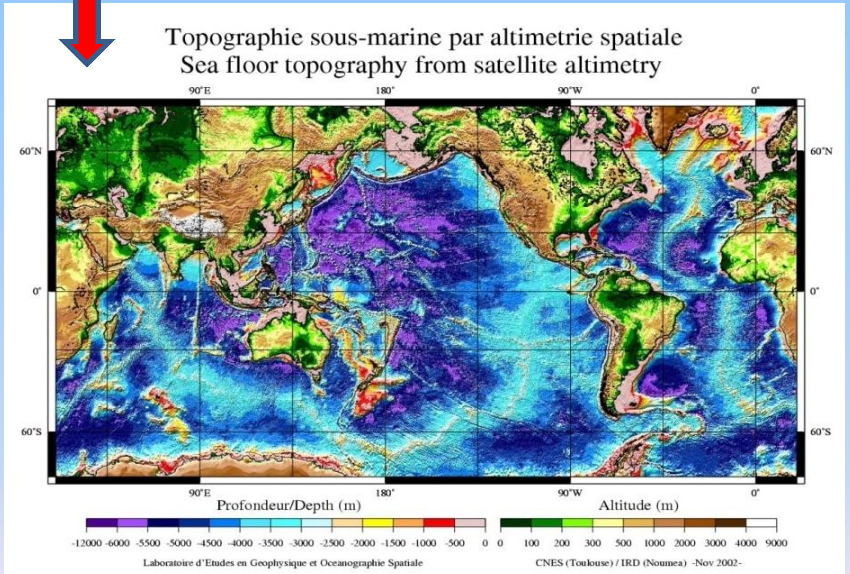
Ondulations permanentes de la surface ‘moyenne’ de la mer (géoide) → Bathymétrie



Surface ‘moyenne’ de la mer



Source : CLS



Bathymétrie

Specifications:

-towed up to 15 knots…whatever sea state…

-don’t lose satellite tracking

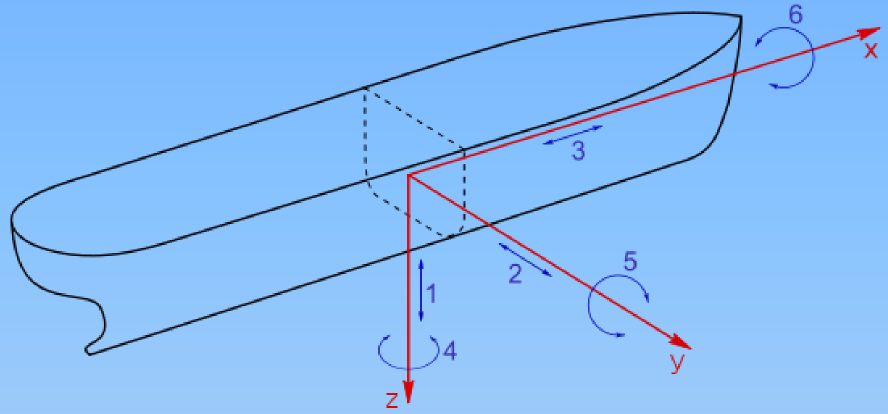
stability: as best as possible (<1 cm extra movement)

-autonomy: at least 5 days

-sampling: 1 to 50 Hz (to monitore waves)

Mouvements d'un bateau selon les trois axes, 6 degrés de liberté :

Translation:1- pilonnement, 2- embardée, 3- cavalement,
Rotation: 4- lacet, 5- tangage, 6- roulis.



Ship's movements with 3 axes, 6 freedom degrees :

Translation:1- heave, 2- sway, 3- surge
Rotation: 4- yaw, 5- pitch, 6- roll.

These movements introduce bias due to inertia's ship

1st solution: use a fixed Antenna on a ship

Advantage:
No problems for power and datalogging
Easy to install

Question:
How to deconvolve ship's movement of the signal?

Answer:
Use the inertial navigation system and gyrocompass of the ship

Question: ok, and how synchronise GPS Data with inertial navigation system Data?

Answer: with electronic and software device
but need post processing calculation
(need to wait 3 weeks for satellite data ephemeride)

2nd solution: tow an antenna fixed on a small rigid structure

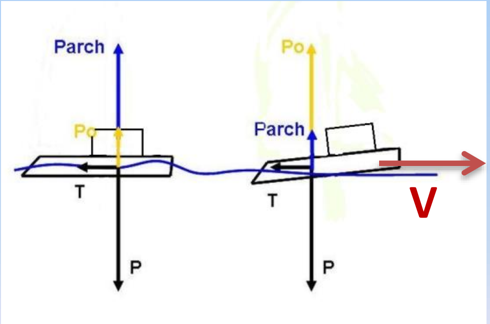
Advantage:
Avoid the ship mouvements

Question:
How to do for having power and datalooging for long time?

Answer:
Put energy supply and datalogger on the ship
or use a cable between the antenna and the ship

Question: At different speeds, the boat may sink or squat into the water (planning phenomena), thus changing the height of the antenna, how to monitore it?

Answer: calibrate the height at different speed:
monitore the speed for each satellite data…



3) Seaweed sheet concept:

Algae stay at the sea surface and follow exactly the swell and waves without extra movements

how to fix an antenna on seaweed and tow it?

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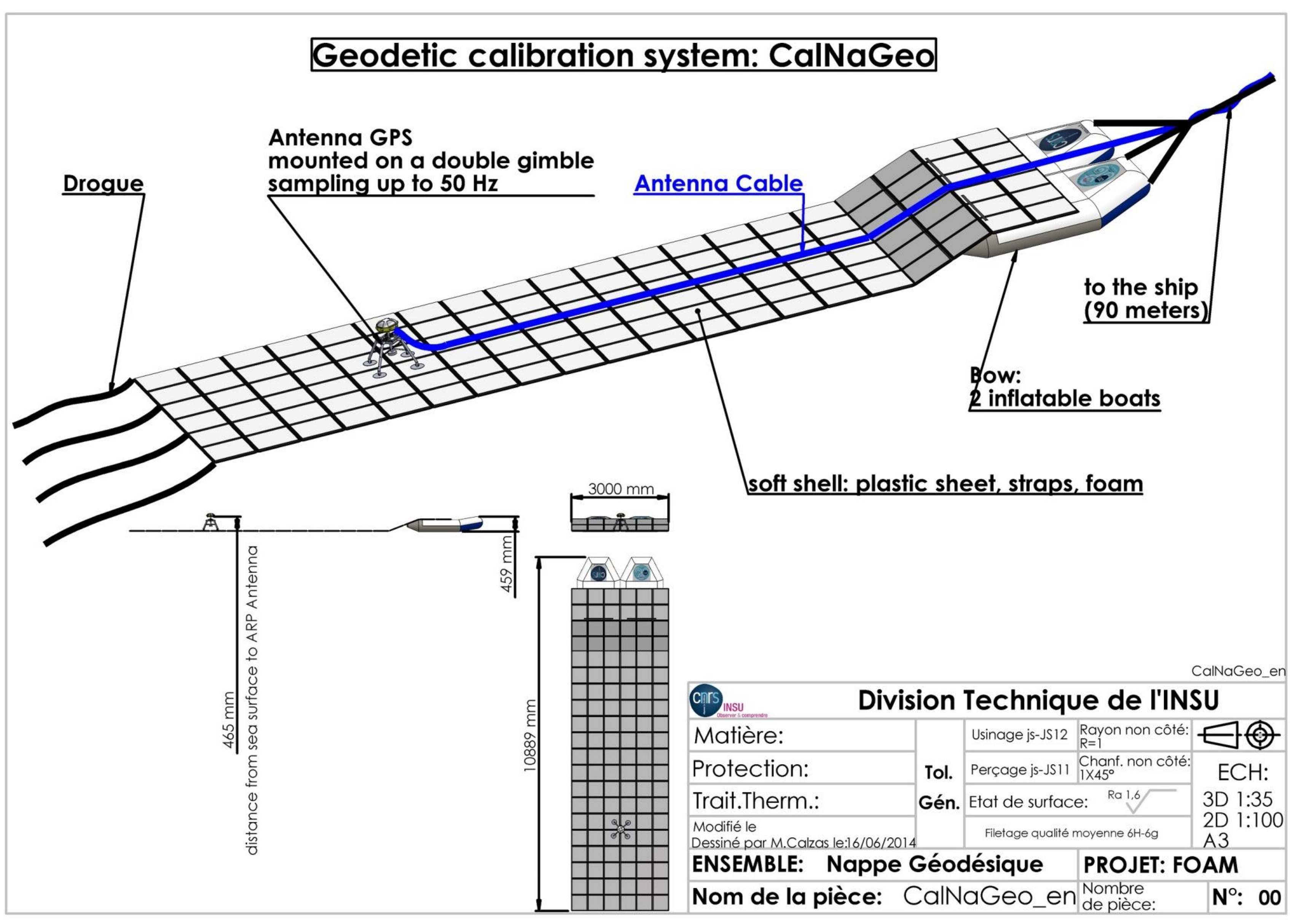
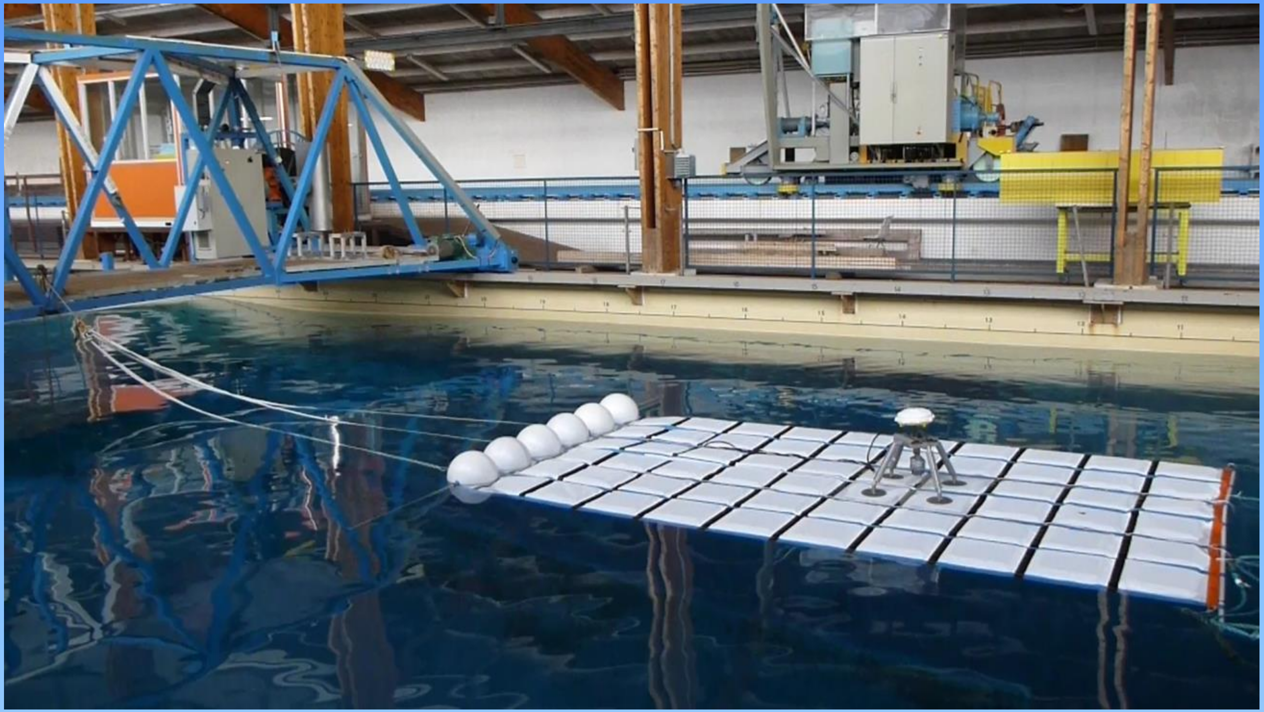
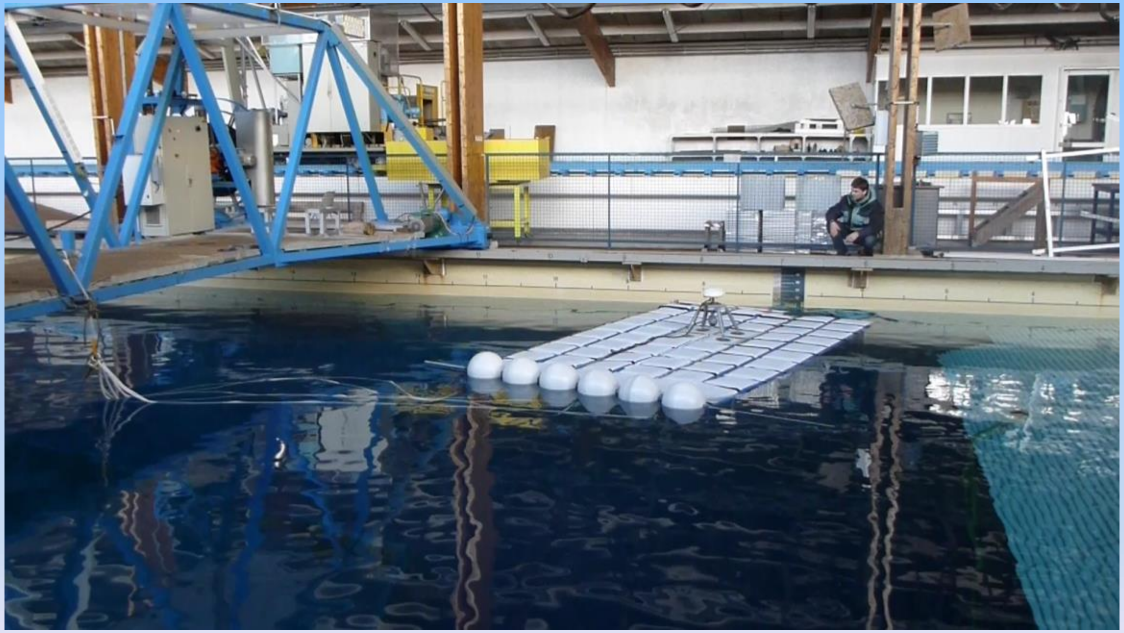
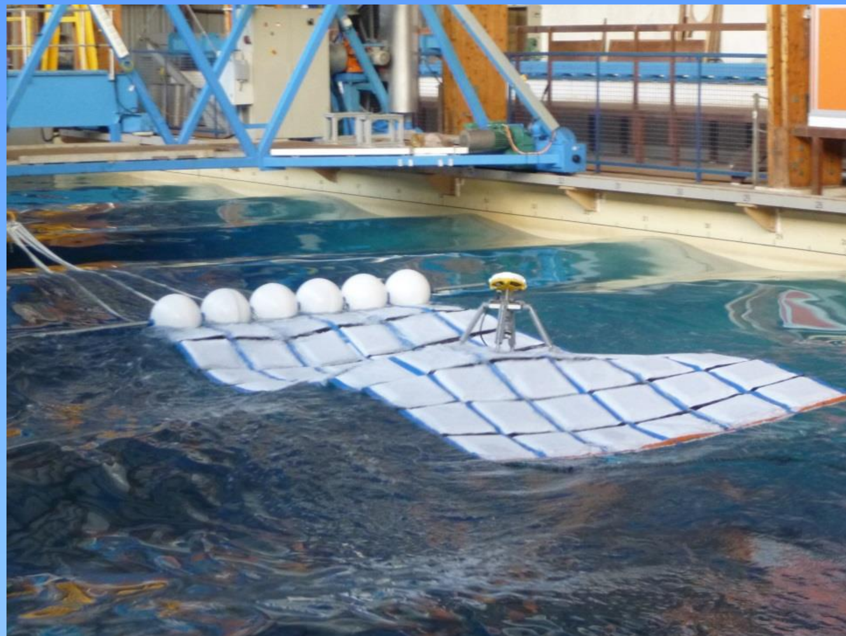
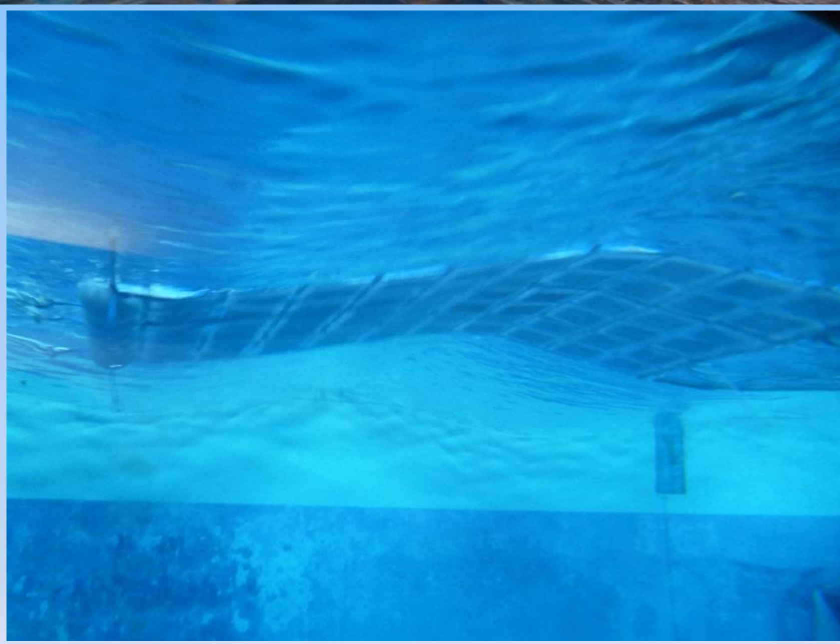


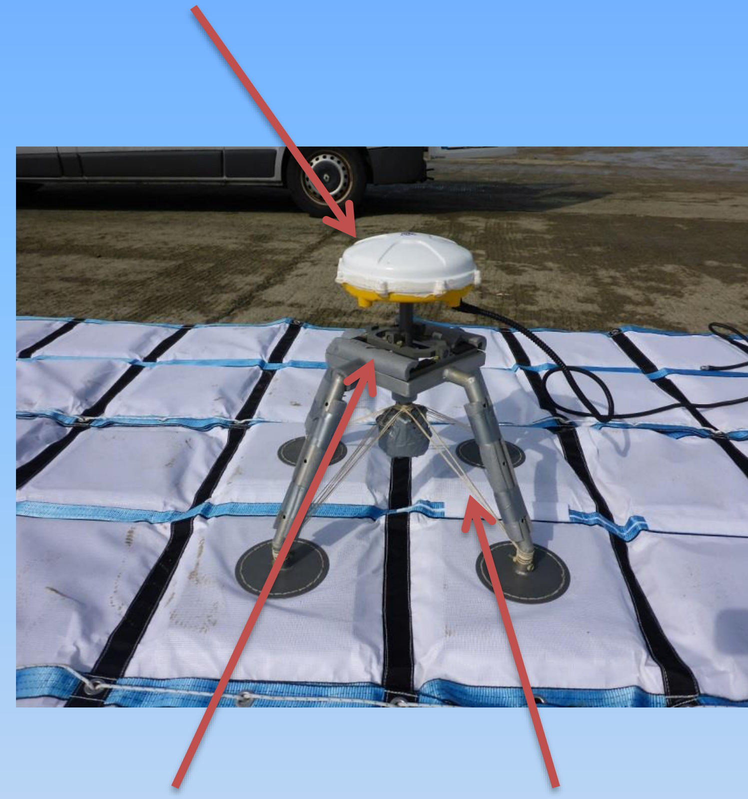
Geodetic calibration system: CalNaGeo
Antenna GPS
mounted on a double gimble
sampling up to 50 Hz
Drogue
Antenna Cable
to the ship
(90 meters)
Bow:
2 inflatable boats
soft shell: plastic sheet, straps, foam
3000 mm
459 mm
465 mm
distance from sea surface to ARP Antenna
10889 mm
CalNaGeo_en
Division Technique de l'INSU
Matière:
Protection:
Trait.Therm.:
Modifié le
Dessiné par M.Calzas le:16/06/2014
Tol.
Gén.
Usinage js-JS12
Perçage js-JS11
Etat de surface:
Ra 1,6
Filetage qualité moyenne 6H-6g
Rayon non côté: R=1
Chanf. non côté: 1X45°
ECH:
3D 1:35
2D 1:100
A3
ENSEMBLE: Nappe Géodésique
PROJET: FOAM
Nom de la pièce: CalNaGeo_en
Nombre de pièce:
N°: 00










Rugged antenna
Double gimbal
Suspension
(elastic wires)

Films tests bassins et en mer

Après quelques modifications (étrave, longueur, étanchéité électronique Transmission trame NMEA, lests, etc, etc) on a aboutit à ce système:

Version hauturière

Version côtière

Test rade de Brest

Mesures dans le Golfe du Bengale

Test large de la Rochelle

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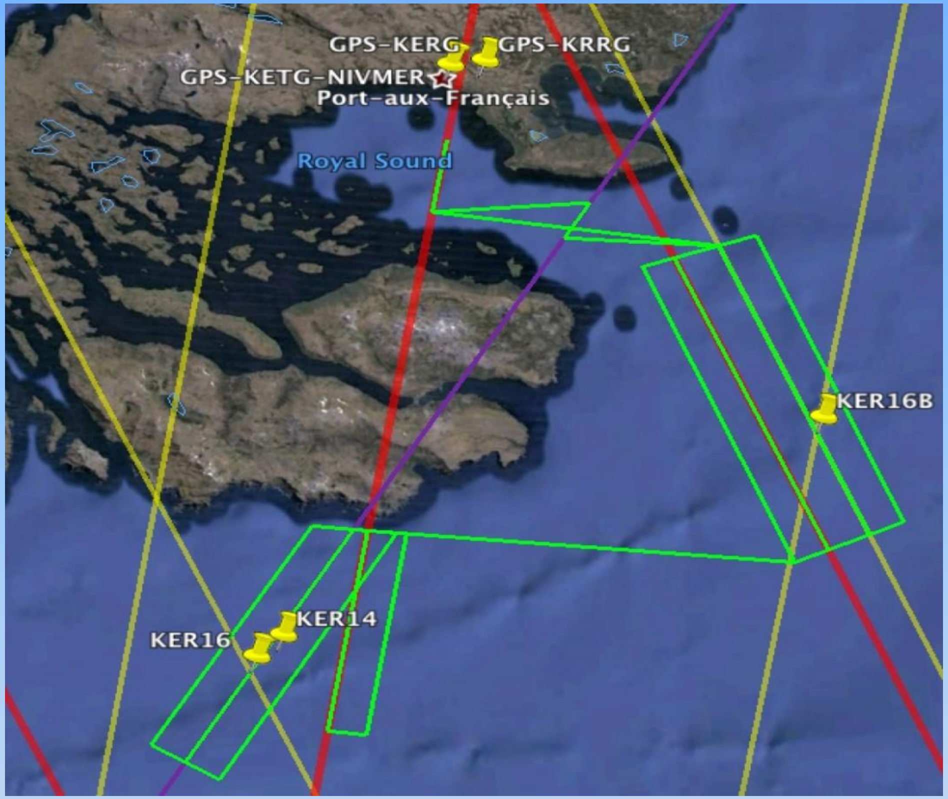
The towed GPS buoy: CalNaGEO

The system consists of a geodetic GNSS antenna on a soft shell (to avoid artefacts due to rigid structures) to follow the sea surface. The antenna is gimbaled and towed (up to 10 knots) by a ship. This is used for in-situ CAL/VAL calibration of altimetric height (SSH for ocean surfaces), geoid measurement and waves monitoring (up to 50 Hz).
These developments are founded by CNES (Centre National d'Etudes Spatiales) project FOAM (From Ocean to inland waters Altimetry Monitoring).

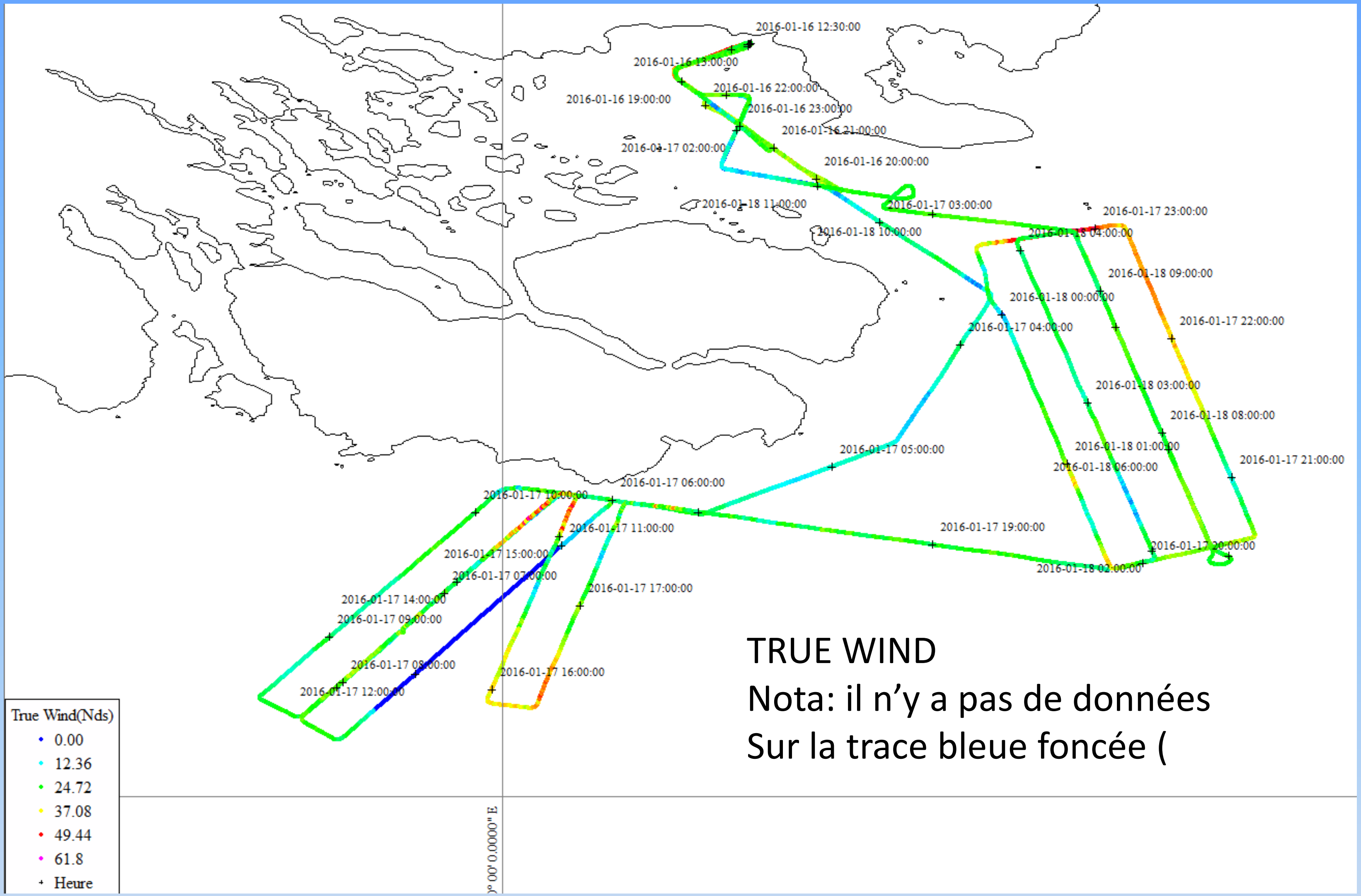
PI: Pascal Bonnefond, Astronome, Observatoire de Paris
Conception: DT INSU

<u>But de la mission FOAM:</u>

- Mesurer le géoïde local
- Rattacher les mouillages au point dé référence géodésique de PAF
- CAL/VAL satellite Jason 3-3, Sentinel 3, Saral-Altika
- Préparer CAL/VAL SWOT



Traces des satellites survolant Kerguelen (missions TOPEX/Poseidon et Jason en violet ; missions ERS-1&2, Envisat et SARAL/AltiKa en jaune ; mission Sentinel-3A en rouge) et trajet prévu par la nappe flottante CalNaGeo (en vert).



TRUE WIND
Nota: il n'y a pas de données
Sur la trace bleue foncée (

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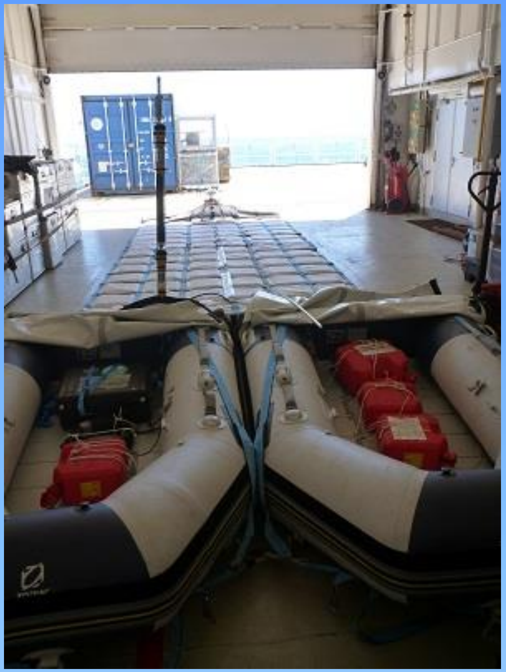
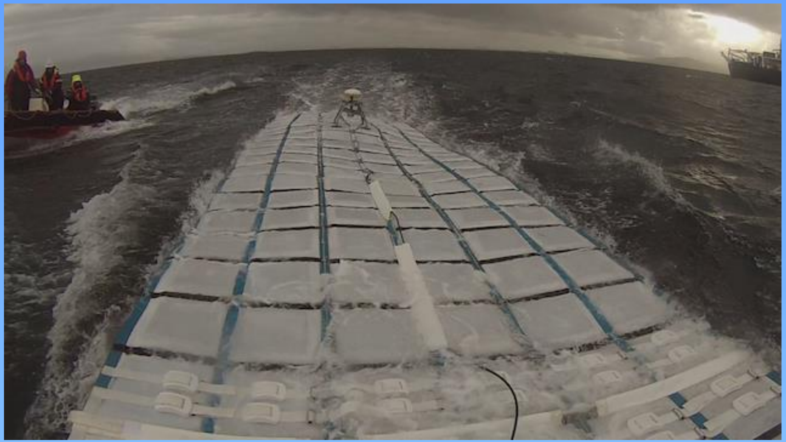
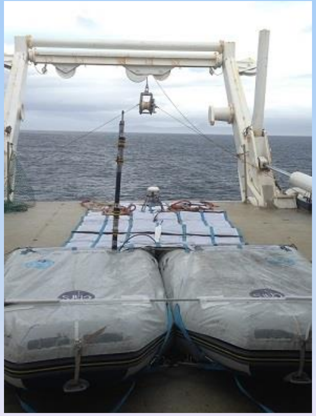
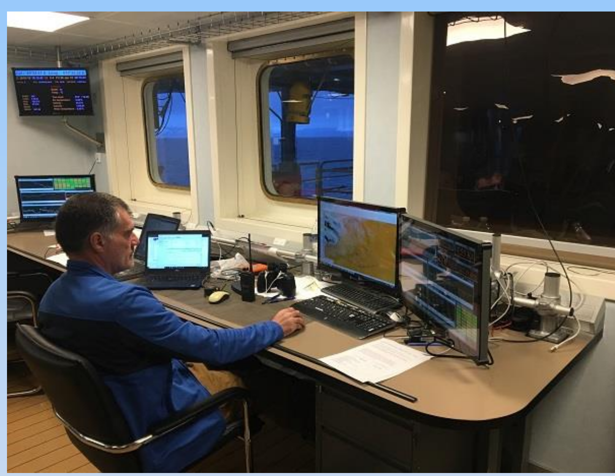


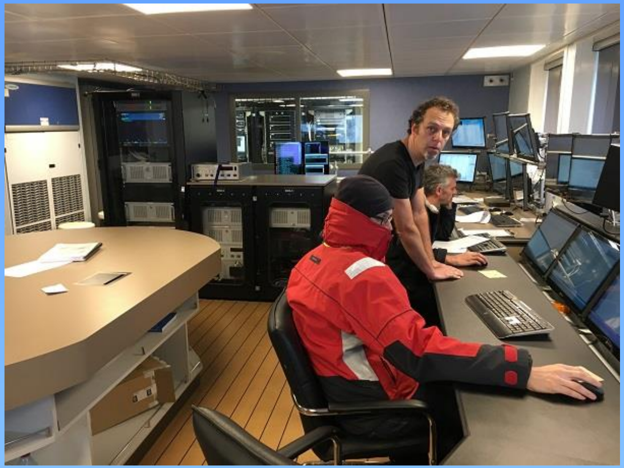




Film CalNaGEO aux Kerguelen



PC scientifique: écrans de contrôle pour CalNaGEO



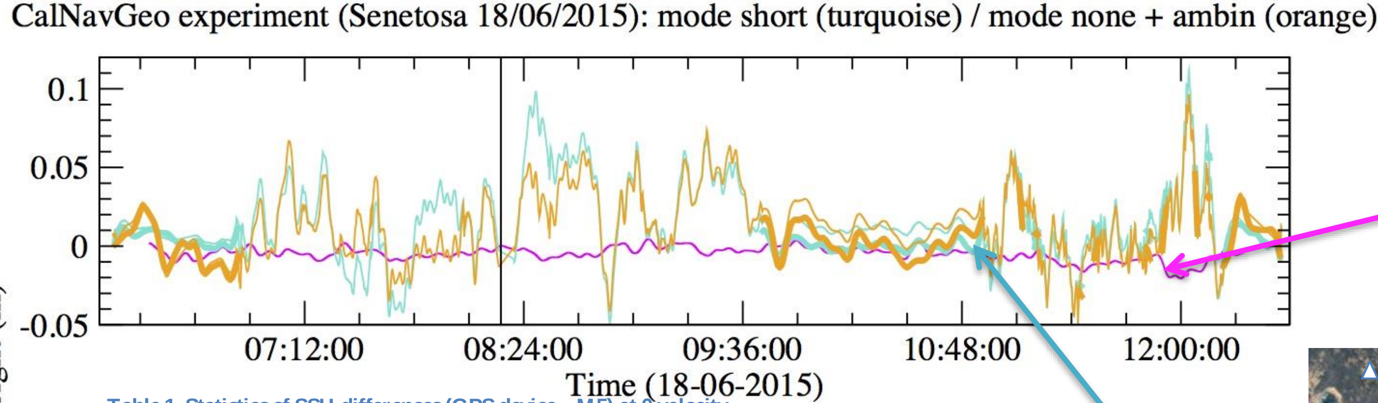
PC scientifique

Bouée GNSS au mouillage

Marégraphe à PAF

Station de base GNSS mobile

Corsica calibration site in 2015: 16 years after the geoid computation



zodiac

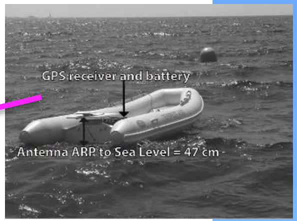


Table 1. Statistics of SSH differences (GPS device – M5) at 0 velocity

	Mean (mm)	Standard Deviation	Number of data
Zodiac	-5.0	4.4	21551
CalNaGeo	+1.4	4.2	5300

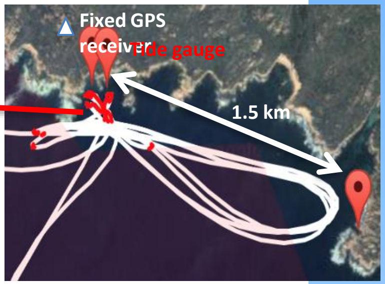
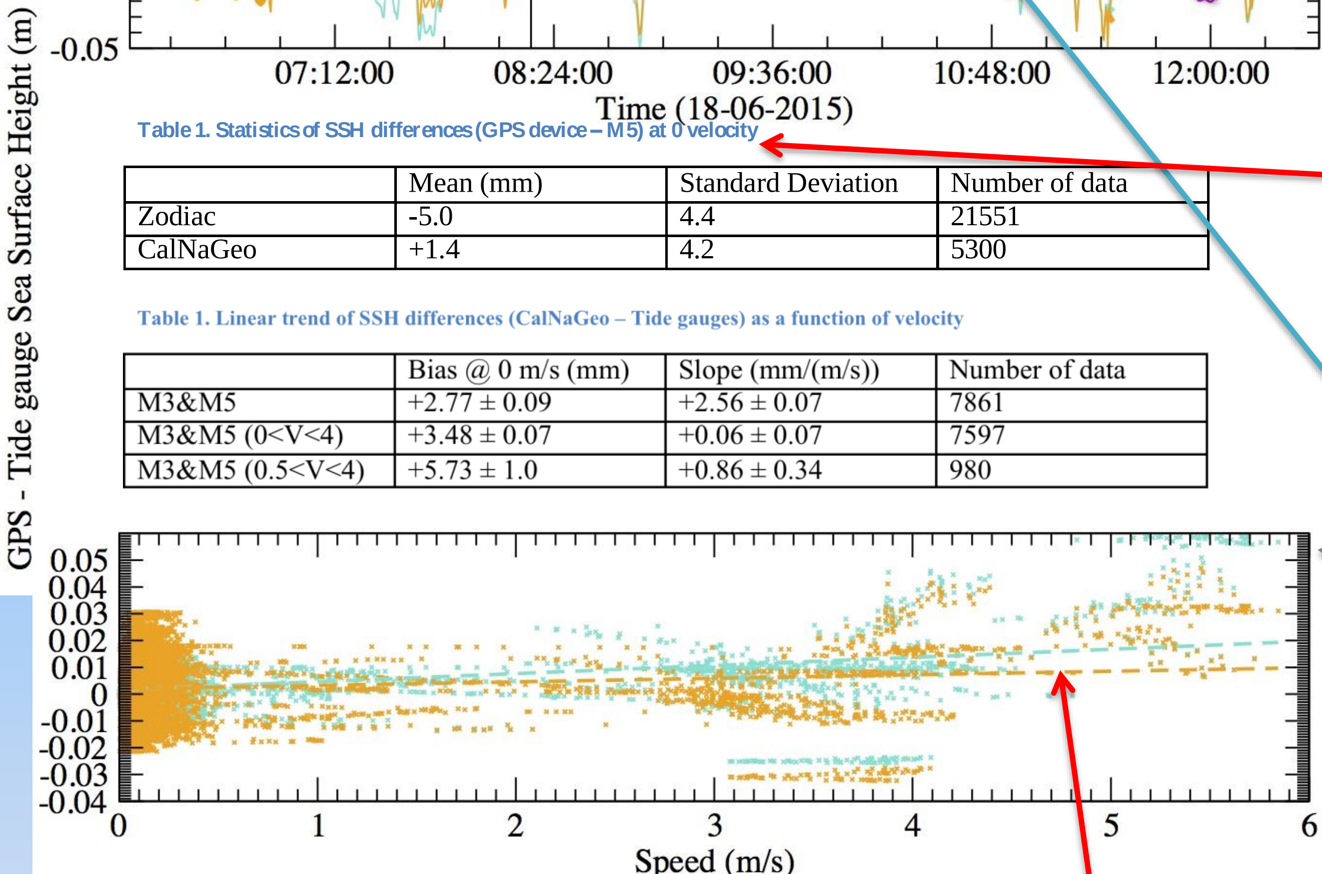


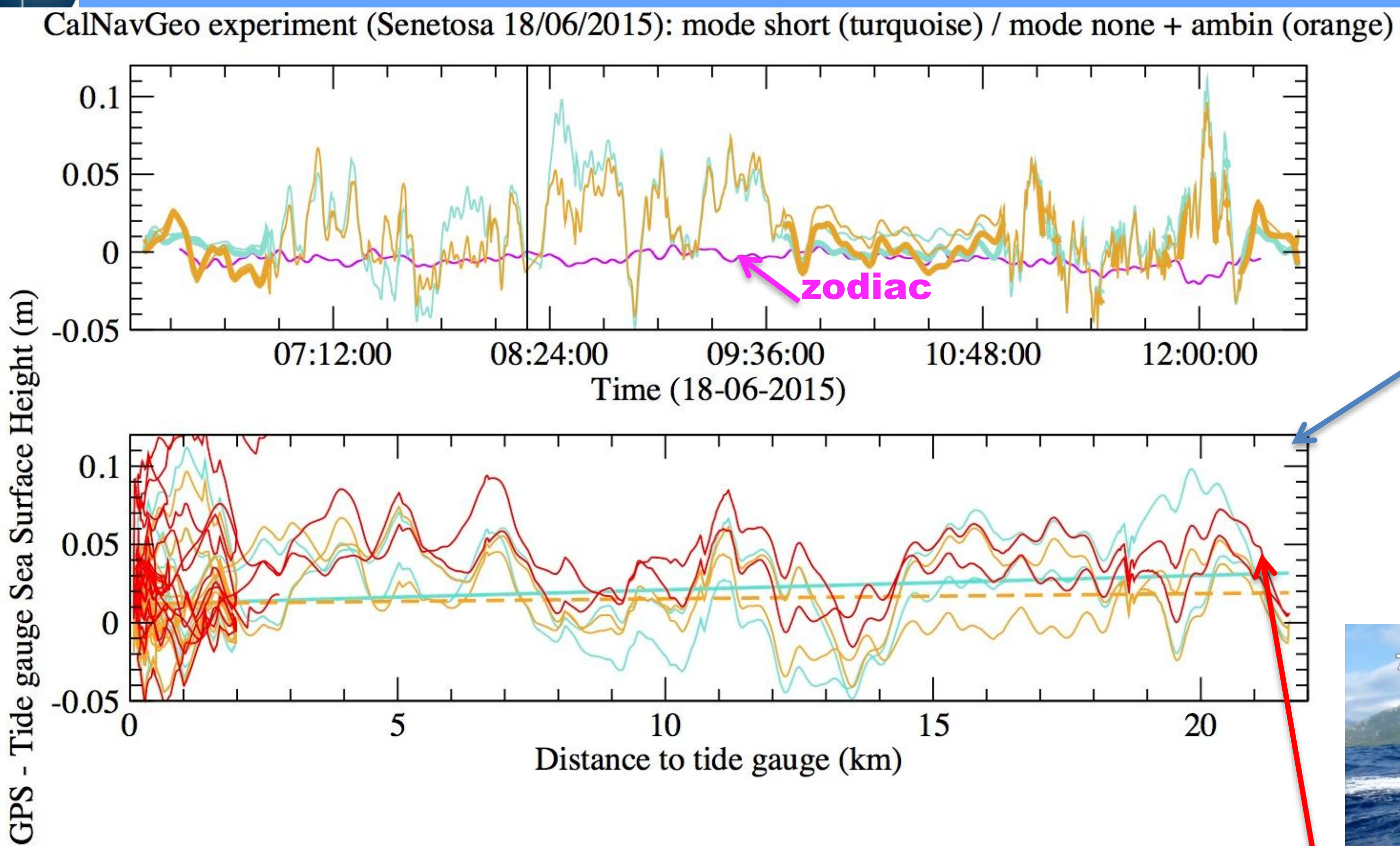
Table 1. Linear trend of SSH differences (CalNaGeo – Tide gauges) as a function of velocity

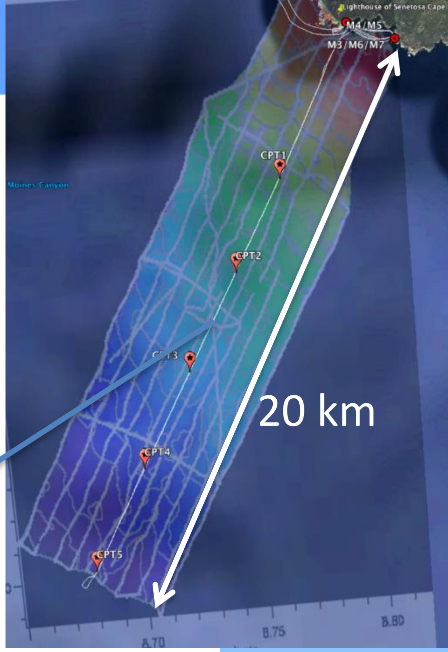
	Bias @ 0 m/s (mm)	Slope (mm/(m/s))	Number of data
M3&M5	+2.77 ± 0.09	+2.56 ± 0.07	7861
M3&M5 (0<V<4)	+3.48 ± 0.07	+0.06 ± 0.07	7597
M3&M5 (0.5<V<4)	+5.73 ± 1.0	+0.86 ± 0.34	980



No waterline dependency with the velocity (<1 mm / (m/s))

Corsica calibration site in 2015: 16 years after the geoid computation





Gipsy PPP solution:
Differences between the outward and the return journey are smaller

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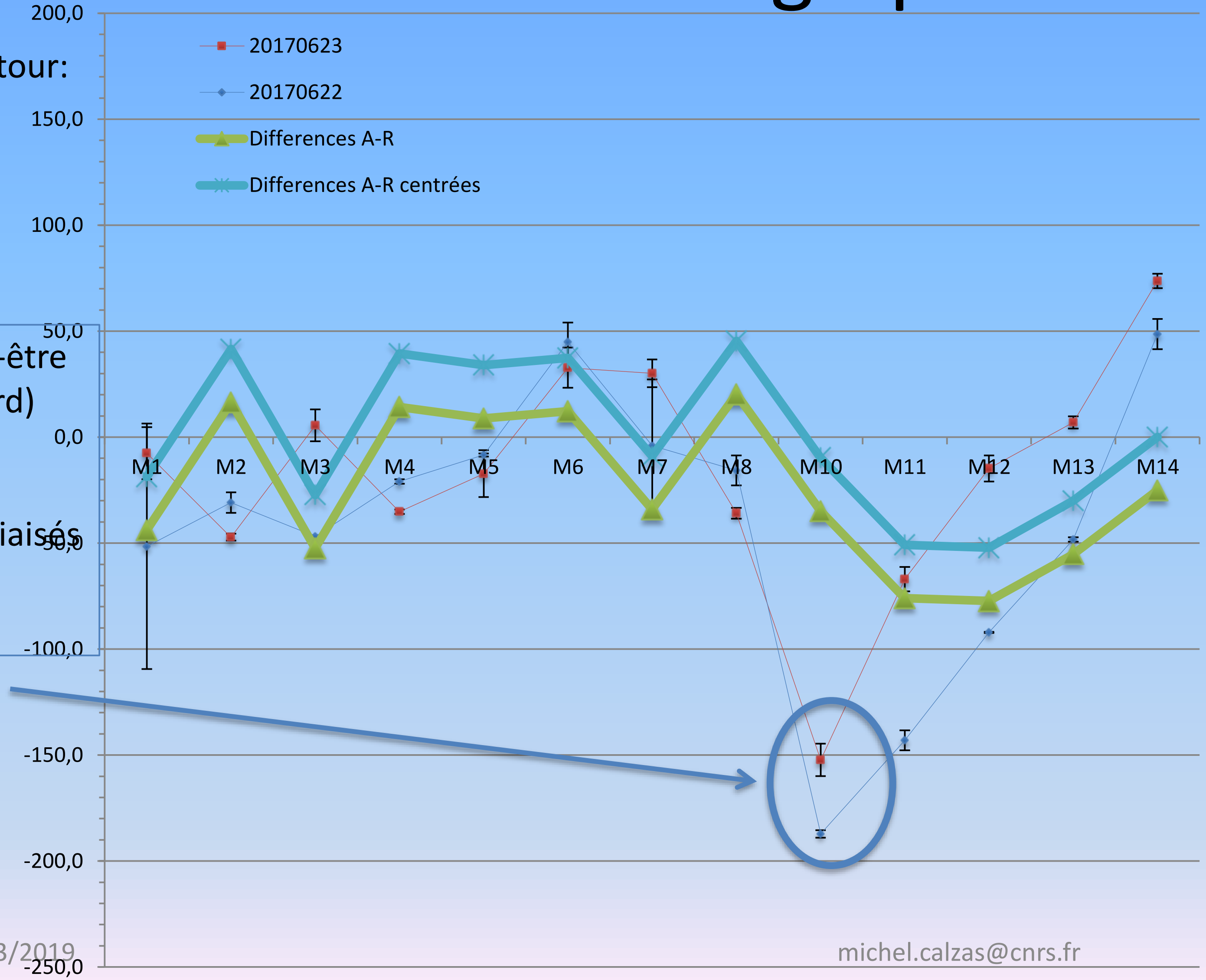
Campagne sur la Seine: Comparaisons avec les marégraphes

Différences Aller-Retour:
Moyenne: -25mm
Std: 36mm

M10 (Aizier) et peut-être aussi M11 (St Léonard) semblent avoir un problème de référencement car biaisés autant à l'aller qu'au retour



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Quelques chiffres:

RH: Depuis 2014: **1,5 ETPT/an** personnels DT INSU, soit 6 ETPT depuis le début du projet

Conception réalisée par:
Cédric Brachet, Antoine Guillot, Michel Calzas, Lionel Fichen **DT INSU**

Coût prototype (non consolidé): 100 k€
Coût (non consolidé) d'un système actuel: **40 k€**

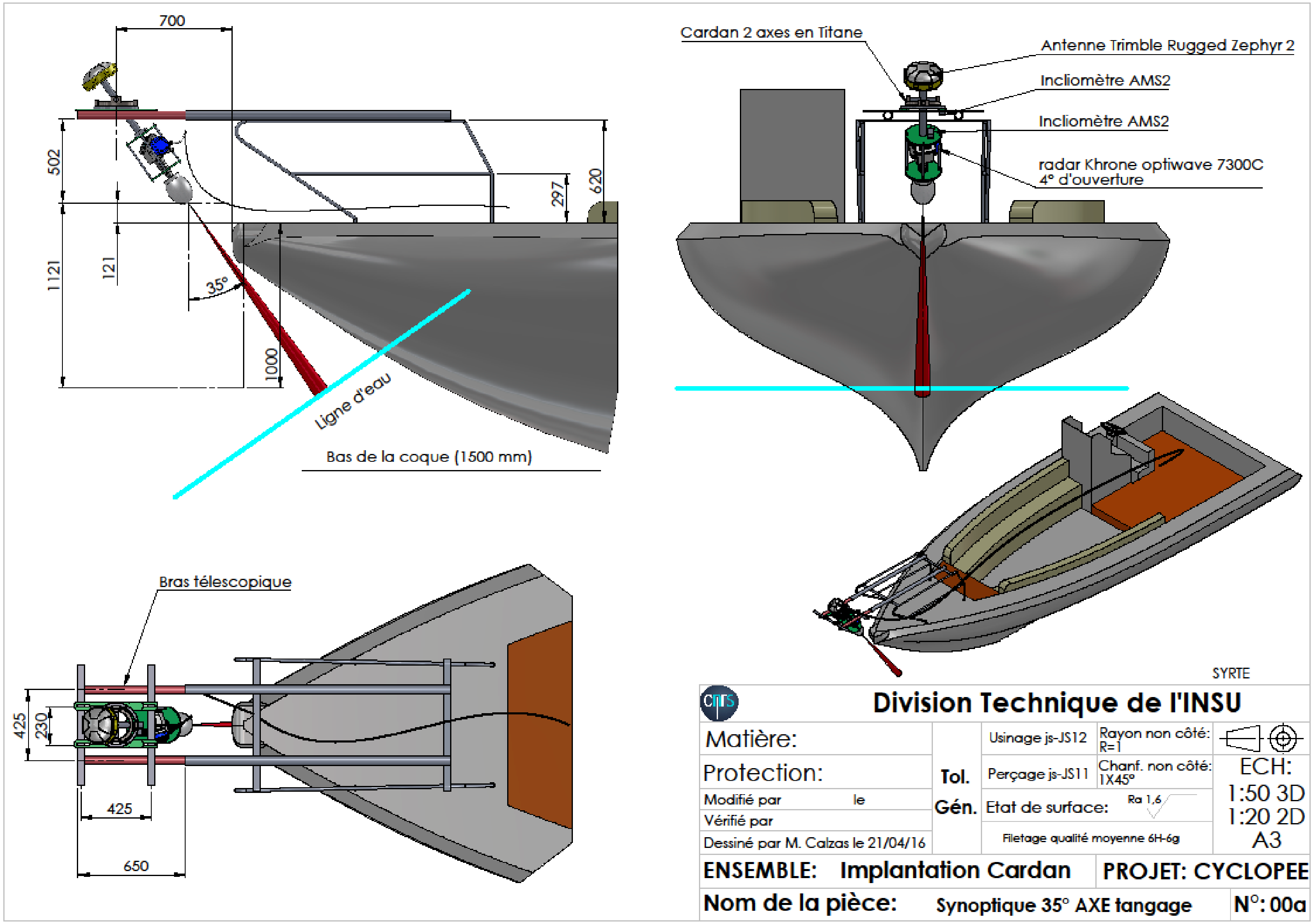
Sous-traitance: Réalisations mécaniques, maître voilier pour nappe, fabricant récepteur GNSS

Missions effectuées par: Christine Drezen, Cédric Brachet, Antoine Guillot, Michel Calzas, Pascal Bonnefond, Olivier Laurain, Claude Gaillemin, Stéphane Calmant, Etienne Poirier, Dominique Mahé

Lieux des missions: Senetosa (Corse), Rade de Brest, Pertuis, Golfe du Bengale, la Seine, la Gironde, Iles Kerguelen

Prévisions: Amazonie, Vanuatu, Lac Issy Kul, Baléares pour CAL/VAL Satellite SWOT

Nouveau système: Cyclopée



Merci de votre attention