GPS-based systems for Sea Surface Height CalVal

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SWOT Science Definition Team meeting, 13-16 June 2013, Pasadena, USA

Difference between DGPS (Differential GPS) and PPP (Precise Point Positioning)

PPP		DGPS	
😃	😞	😃	😞
Everywhere, no need of a nearby reference receiver			Not too far (<~20-30 km) from reference receiver (at least during an initialization period for ambiguity resolution)
	Need to use very accurate orbits and clock and to solve for ionosphere and troposphere corrections	Cancellation of errors/corrections on short distance	

Difference between DGPS (Differential GPS) and PPP (Precise Point Positioning)

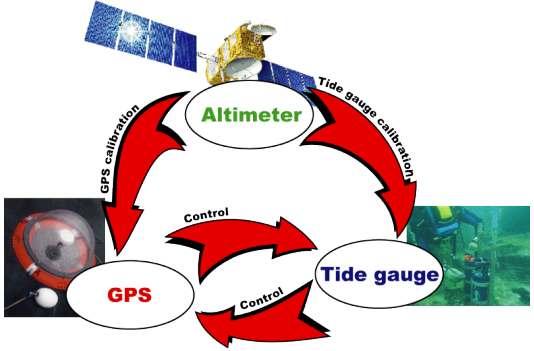
- Some of the basic difference between DGPS and PPP
  - The largest difference between DGPS and PPP is the way that the satellite orbit and clock errors are handled. Instead of estimating the satellite and clock errors (DGPS), PPP uses highly precise satellite clock estimates.
  - For the PPP user, no reference station is required.
  - Since no reference station is required in PPP, the coordinates are with respect to the satellite's reference frame. As a result, to obtain the coordinates in a different reference frame a transformation is required.
  - There are also differences in the mathematical model. In DGPS, the corrections are applied to the raw observations made at the mobile station. Where as in PPP, all error sources are required to be explicitly accounted for. These are typically modeled (relativistic effects,dry component of troposphere, ocean and earth loading, etc.), estimated (receiver clock error, wet component of the troposphere and ambiguity term) or eliminated (ionosphere).

Difference between DGPS (Differential GPS) and PPP (Precise Point Positioning)

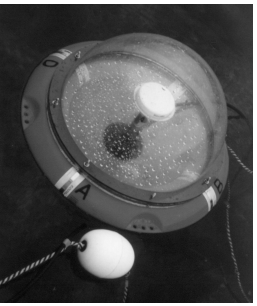
There are a few corrections which have to be applied to carrier-phase and pseudorange measurements in order to have a complete (adequate) observation model in PPP. This aspect is a limiting factor to achieve cm-level accuracy, as it is possible today, with PPP. Summarized in the table are all the corrections accounted for and the applied mitigation strategy.

Effect	Magnitude	Domain	Mitigation method	Residual error
Ionosphere	10s m	range	linear combination	few mm
Troposphere	few m	range	modelling; estimation	few mm
Relativistic	10 m	range	modelling	mm
Sat phase centre; variation	m - cm	pos; range	modelling	mm
Code multipath; noise	1 m	range	filtering	10s cm - mm
Solid earth tides	20 cm	position	modelling	mm
Phase wind-up (iono-free)	10 cm	range	modelling	mm
Ocean loading	5 cm	position	modelling	mm
Satellite orbits; clocks	few cm	pos; range	filtering	cm - mm
Phase multipath; noise	1 cm	range	filtering	cm - mm
Rcv phase centre; variation	cm - mm	pos; range	modelling	mm
Pole tide	few cm	position	modelled	mm
Receiver clock	10s m	range	estimated	mm
Atmospheric loading	cm - mm	position	modelling	cm - mm
Code biases	60 cm	range	modelling	mm
Ambiguity term	m – cm	range	estimated	mm

In situ instruments in Corsica

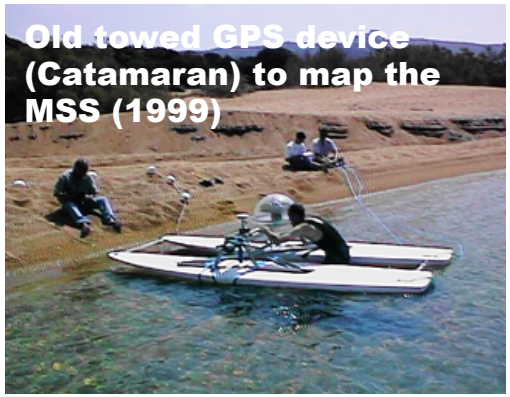


GPS buoys (not towed)



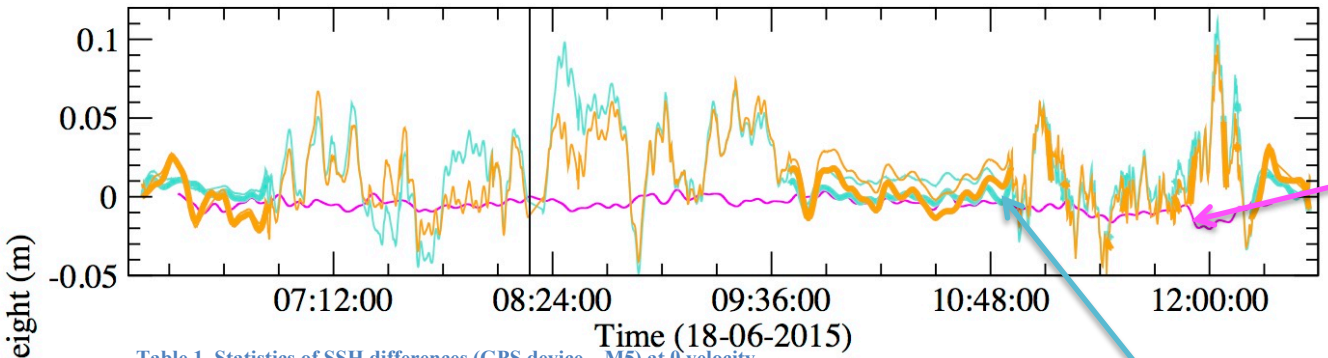
« in between »

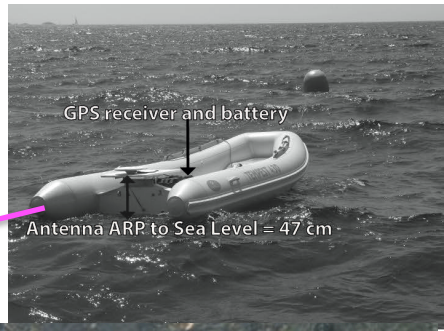
Towed GPS devices



2015: 16 years after the geoid computation

CalNavGeo experiment (Senetosa 18/06/2015): mode short (turquoise) / mode none + ambin (orange)





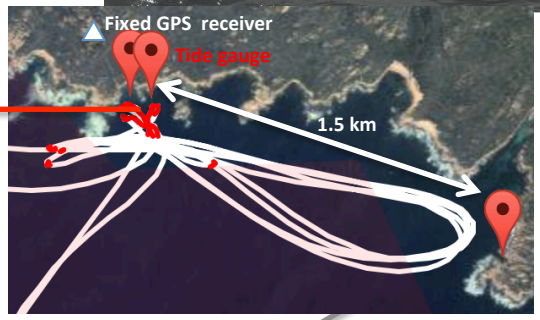
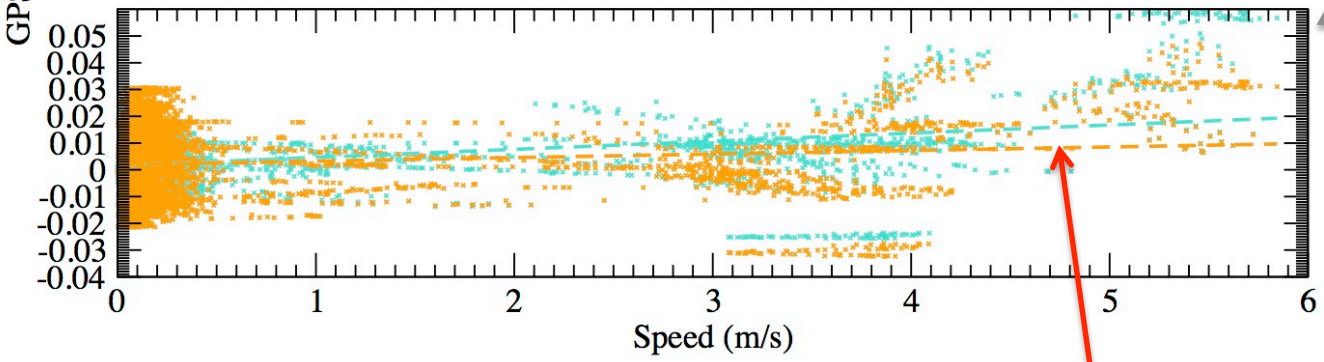


Table 1. Statistics of SSH differences (GPS device – M5) at 0 velocity

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

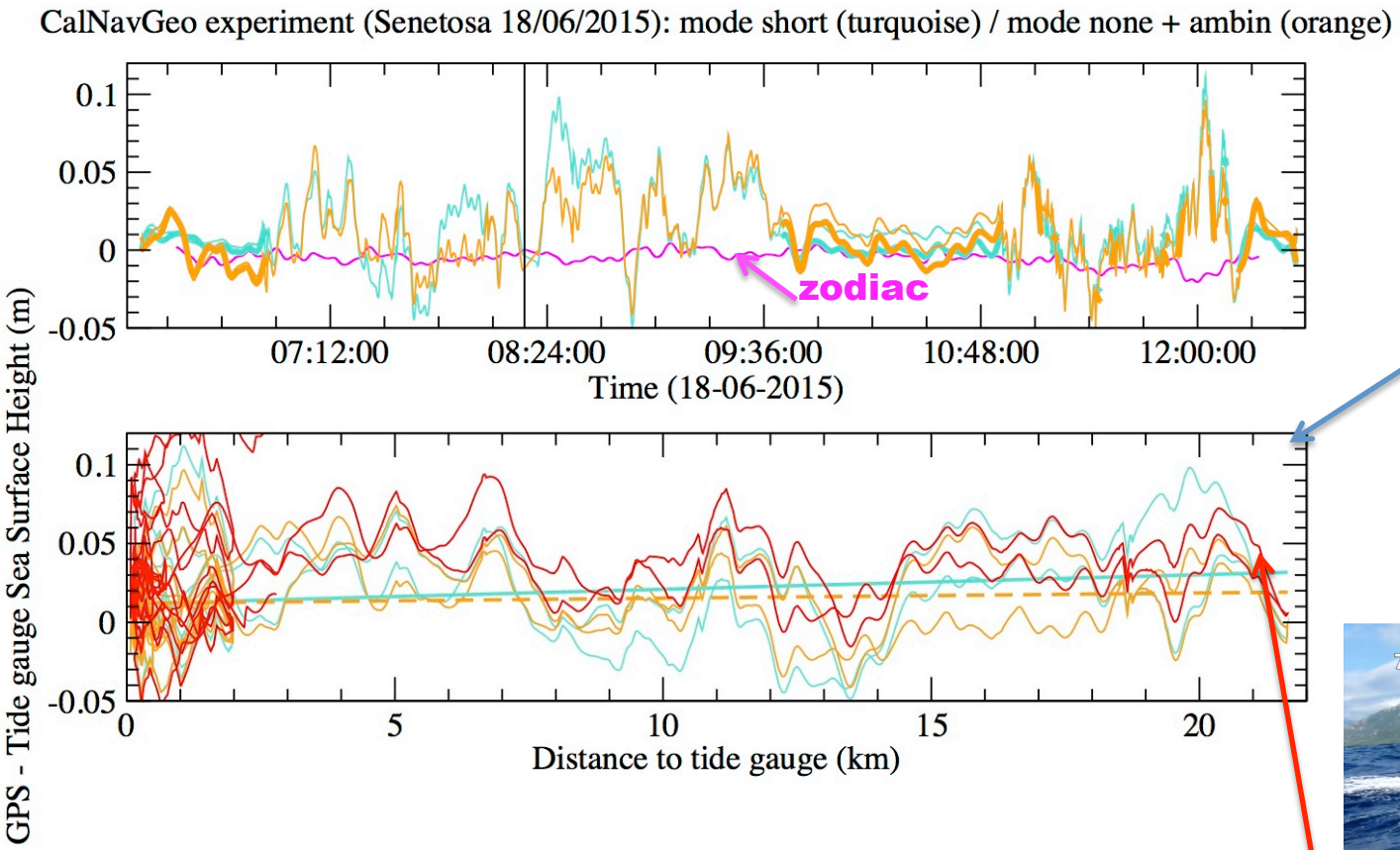
Table 1. Linear trend of SSH differences (CalNaGeo – Tide gauges) as a function of velocity

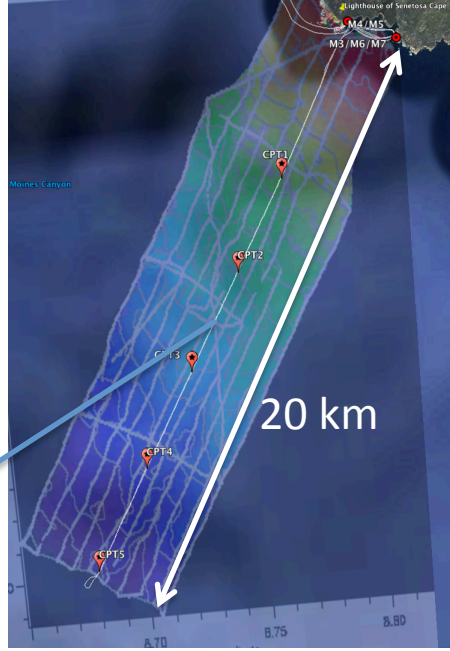
	Bias @ 0 m/s (mm)	Slope (mm/(m/s))	Number of data
M3&M5	+2.77 ± 0.09	+2.56 ± 0.07	7861
M3&M5 (0<V<4)	+3.48 ± 0.07	+0.06 ± 0.07	7597
M3&M5 (0.5<V<4)	+5.73 ± 1.0	+0.86 ± 0.34	980



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

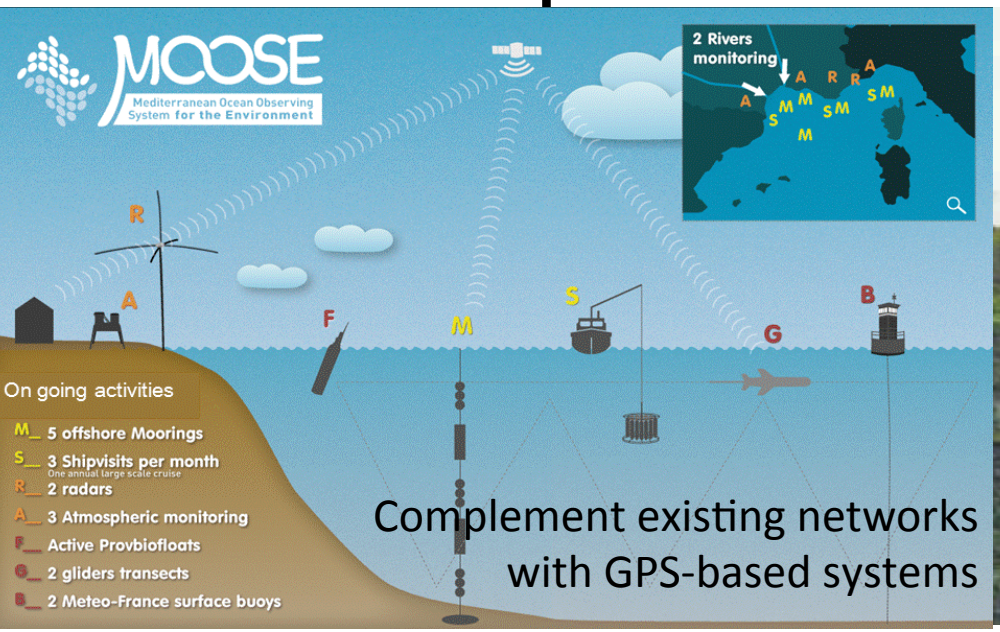
2015: 16 years after the geoid computation



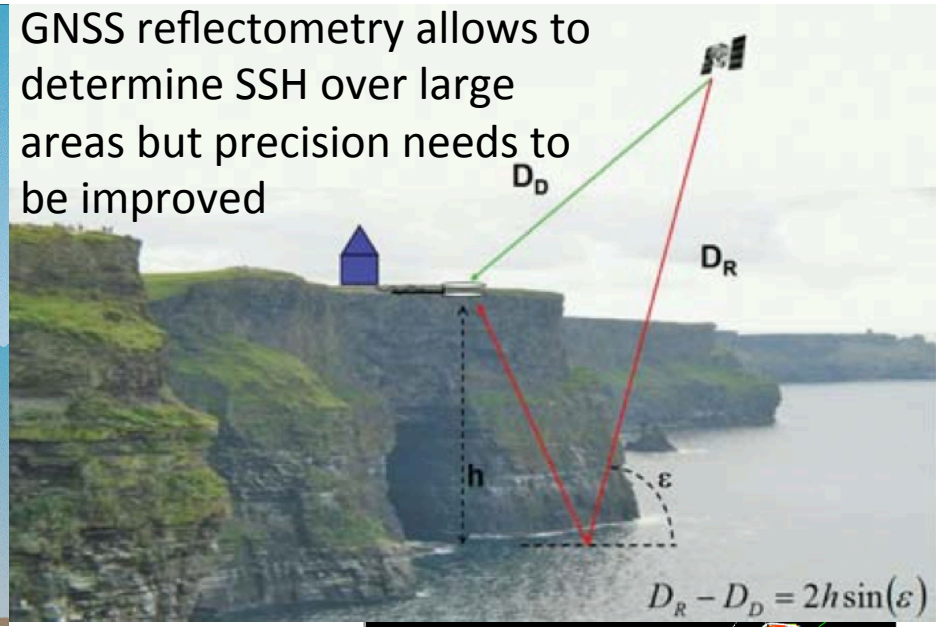


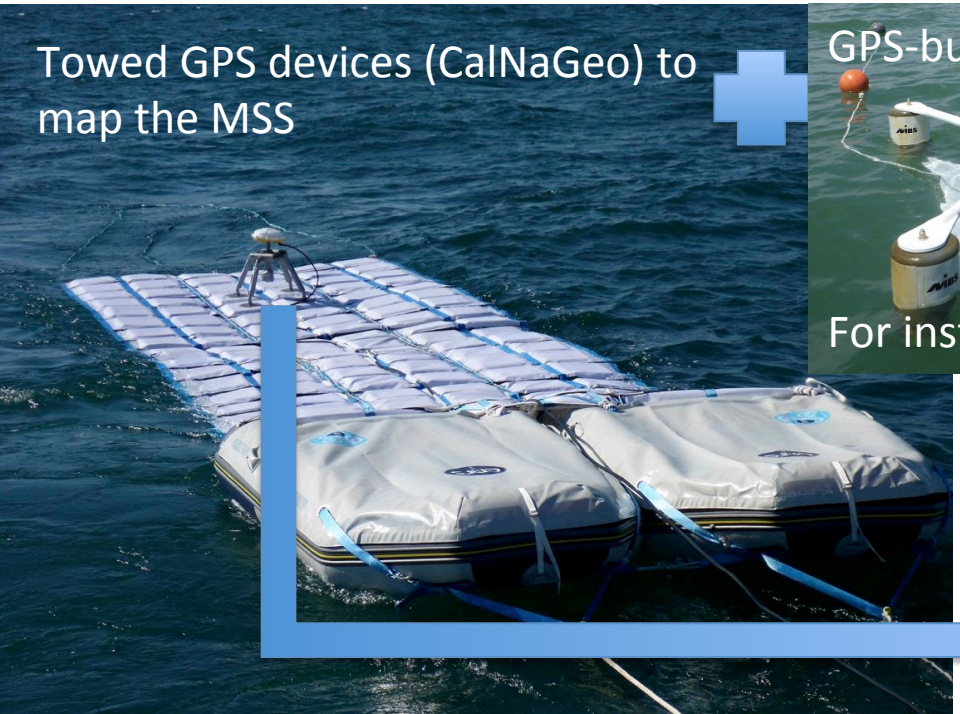
Gipsy PPP solution:
Differences between the outward and the return journey are smaller

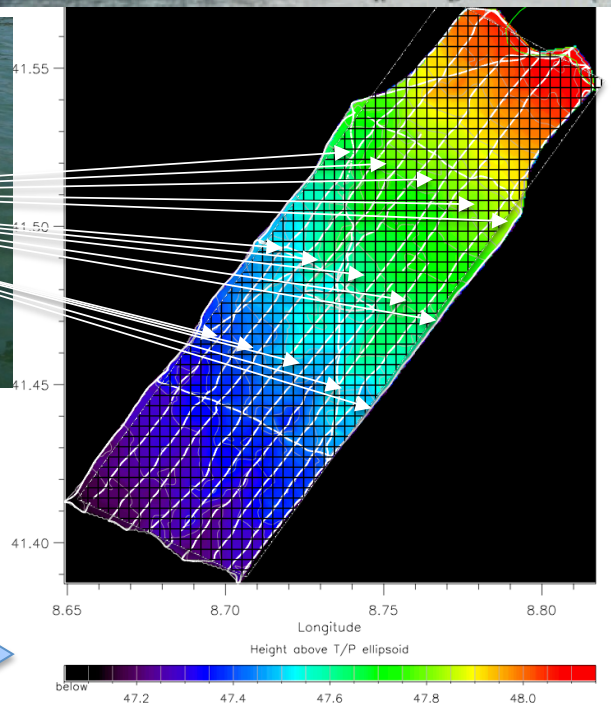
Some possibilities for GPS-SSH…



GNSS reflectometry allows to determine SSH over large areas but precision needs to be improved

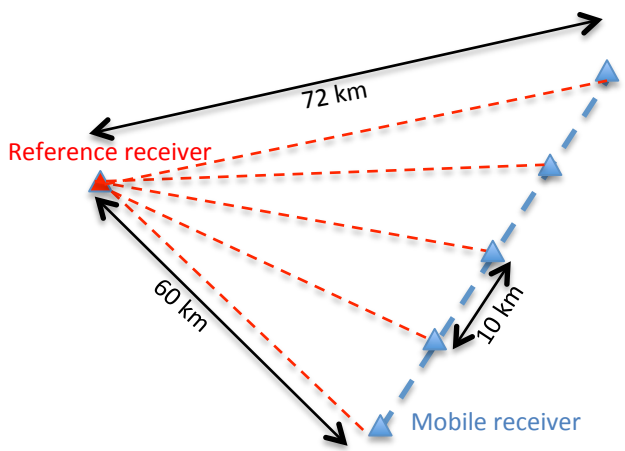






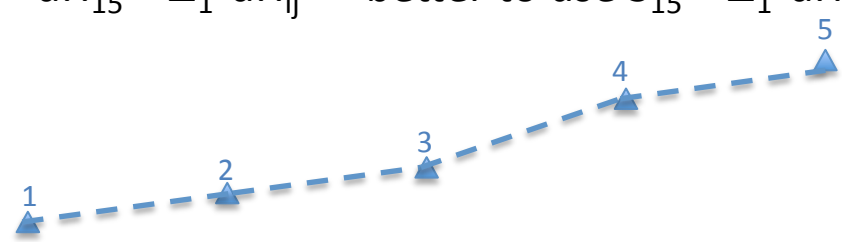
Absolute versus Relative accuracy

- Common errors are affecting the GPS accuracy over distances < few tens of km
- If only SSH differences (slope) are concerned then comparing nearby GPS-buoys could give enough precision (~cm) to validate SWOT measurements



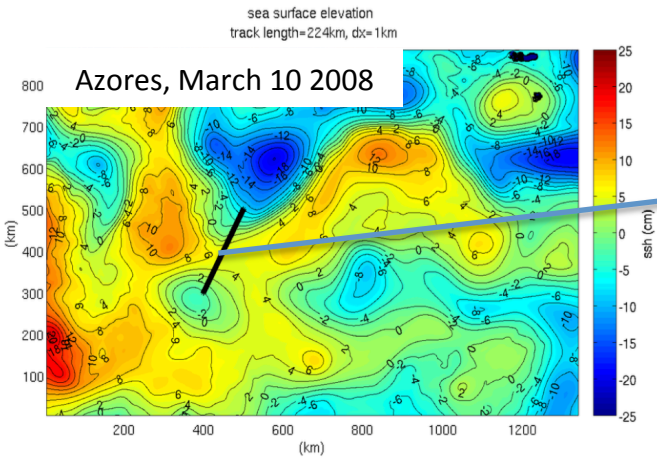
$dH_{ij} = H_j - H_i$

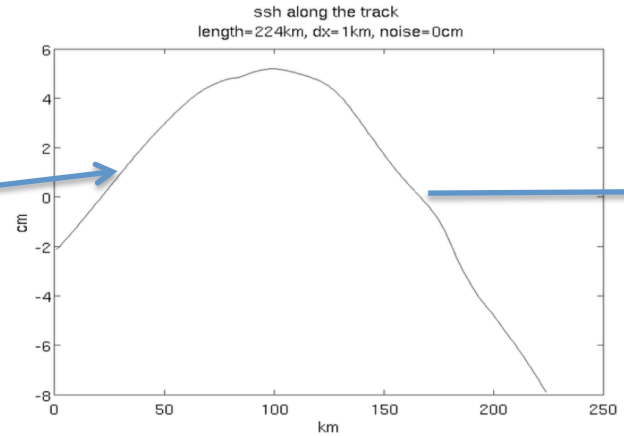
$dH_{15} \neq \Sigma_1^5 dH_{ij}$ => better to use $S_{15} = \Sigma_1^5 dH_{ij} / d_{15}$

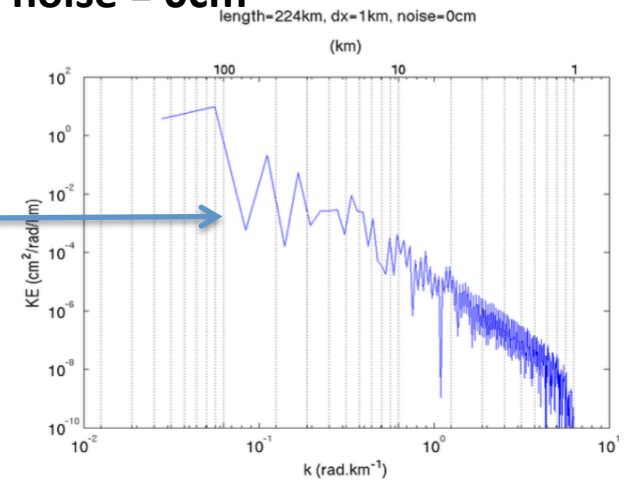


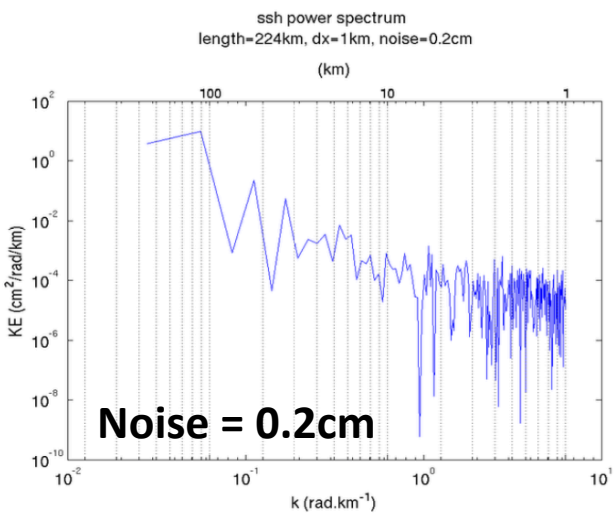
Numerical experiments of SSH spectra from “GPS-like” measurements
see more in « French modeling activities » presentation at 2pm (F. d'Ovidio)

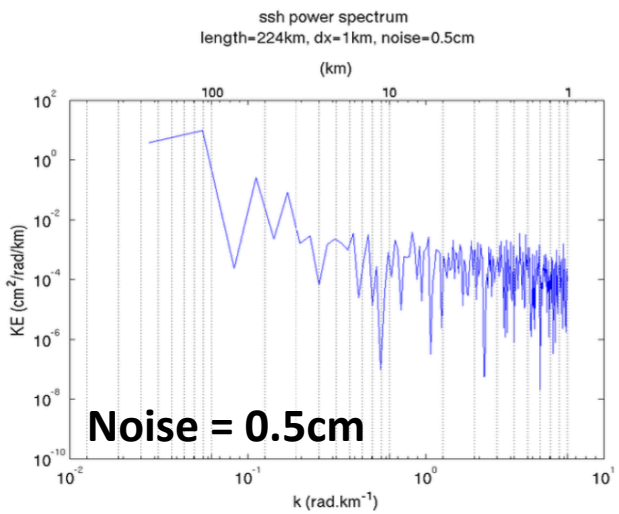
Track length = 224km, resolution = 1km, noise = 0cm

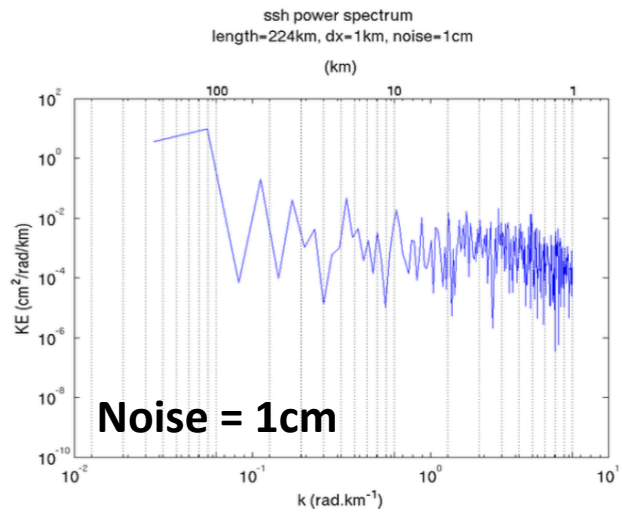












Even 1cm precision is still challenging in current GPS-SSH processing…

Future with GPS+Galileo (+GLONASS)

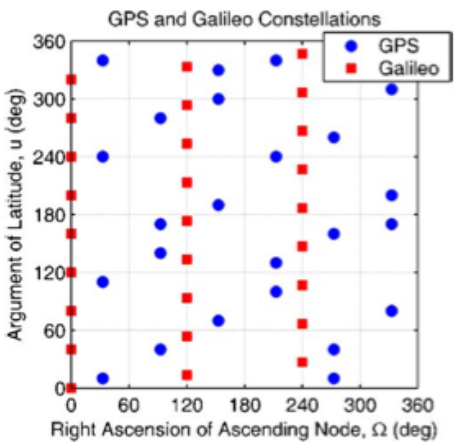


Fig. 1. GPS and Galileo constellations.

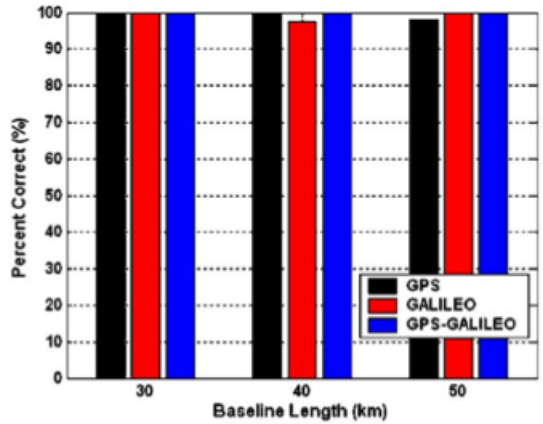


Fig. 15. Percentage of correctly fixed ambiguities for GPS/Galileo, GPS-only and Galileo-only for the 30-, 40- and 50-km baselines.

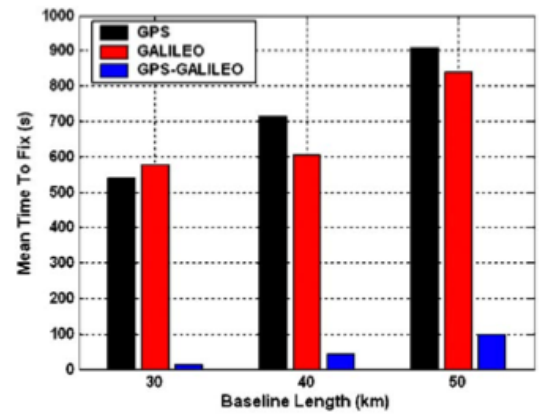


Fig. 16. Mean time to fix ambiguities for GPS/Galileo, GPS-only and Galileo-only for the 30-, 40- and 50-km baselines.

Table 3
Number of times the ambiguity process did not succeed within 1500 s baseline length (km) for GPS-only, Galileo-only, GPS/Galileo

Baseline length (km)	GPS-only	Galileo-only	GPS/Galileo
30	14	13	0
40	19	22	0
50	21	27	0

Table 4
3D position error standard deviation for GPS/Galileo, GPS-only and Galileo-only for the 30, 40, and 50 km baseline (in cm)

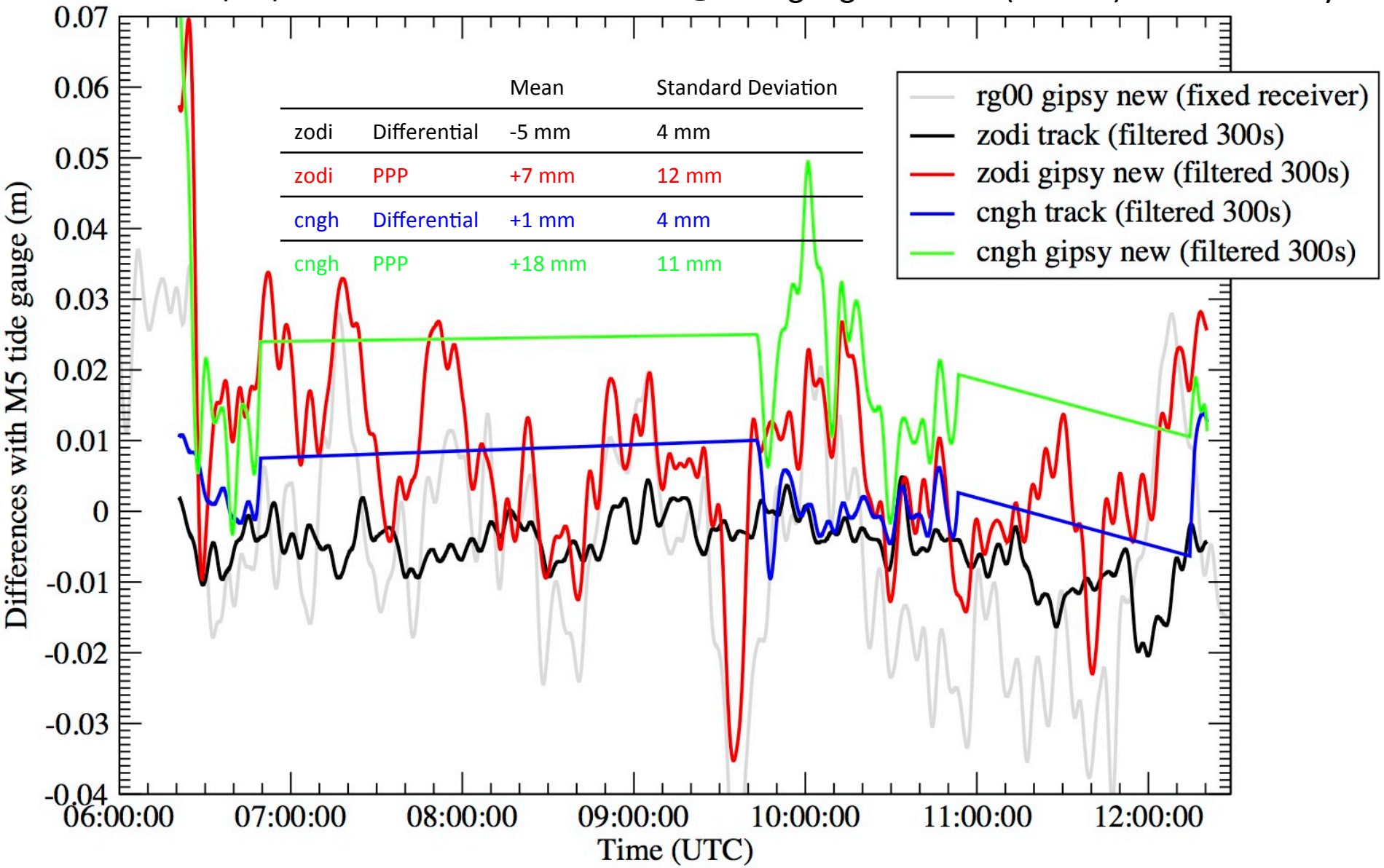
Baseline length (km)	GPS-only	Galileo-only	GPS/Galileo
30	22.4	1.1	0.8
40	9.5	1.1	0.8
50	14.3	1.2	0.9

Availability, accuracy, reliability, and carrier-phase ambiguity resolution with Galileo and GPS
K. O'Keefe, O. Julien, M.E. Cannon, G. Lachapelle
Acta Astronautica 58 (2006) 422–434

Conclusion

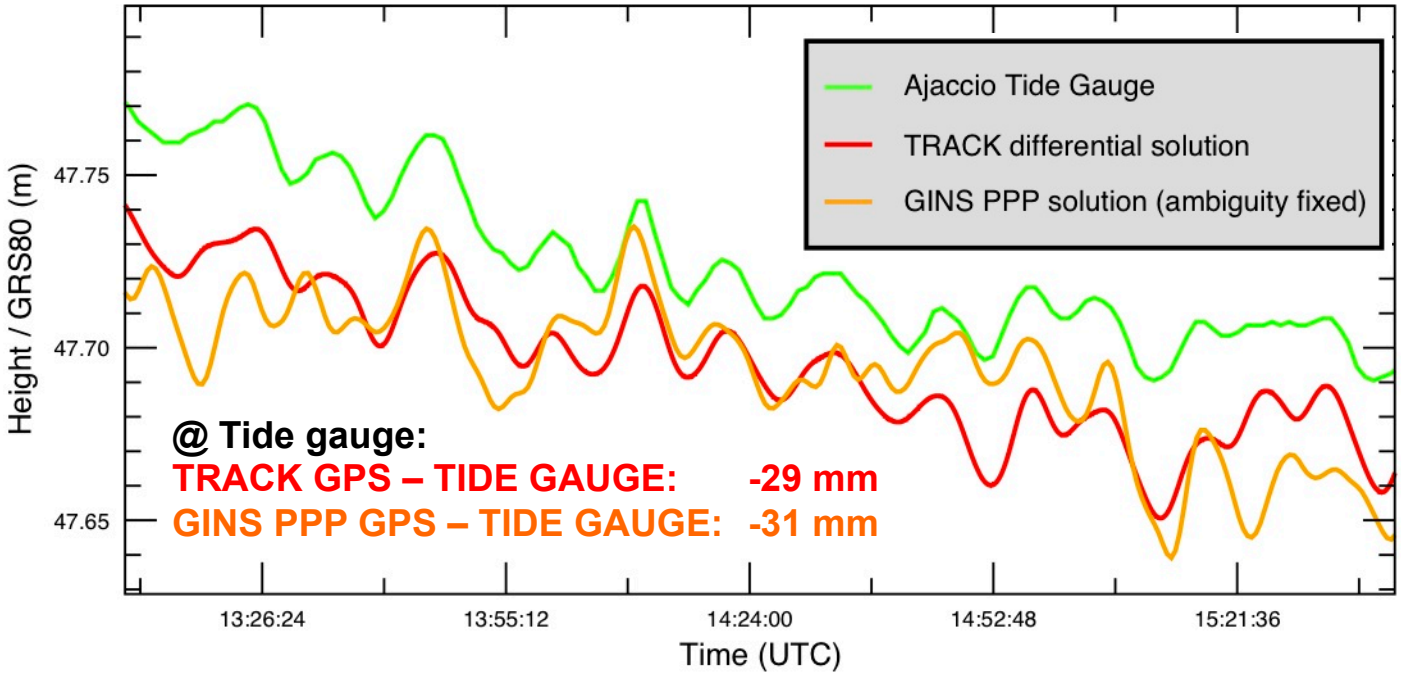
- **Can** GPS calval meet the requirements?
  - Yes on very short distance (few kilometers) from a reference receiver
- **Will** GNSS calval meet the requirements?
  - Probably with the addition of Galileo and the orbit and clocks improvements that will allow PPP to reach the cm accuracy
  - Troposphere correction error will still remain challenging but hopefully highly correlated on short distance (<10 km, in stable meteorological conditions)

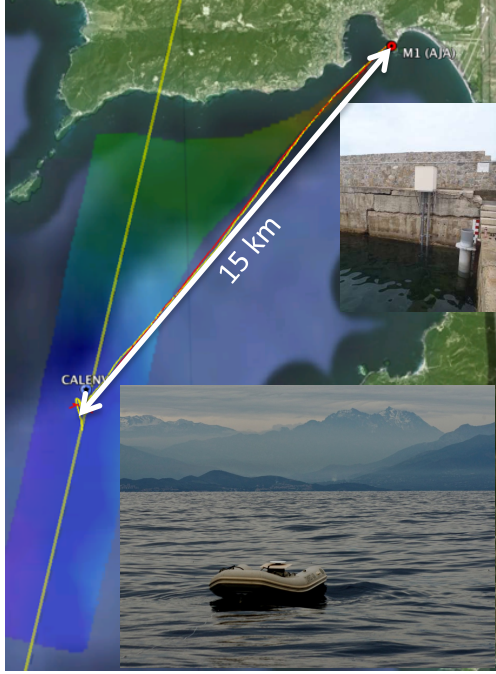
Senetosa 18/06/2015: Zodiac and CalNaGeo @ tide gauge location (<250m) with 0 velocity

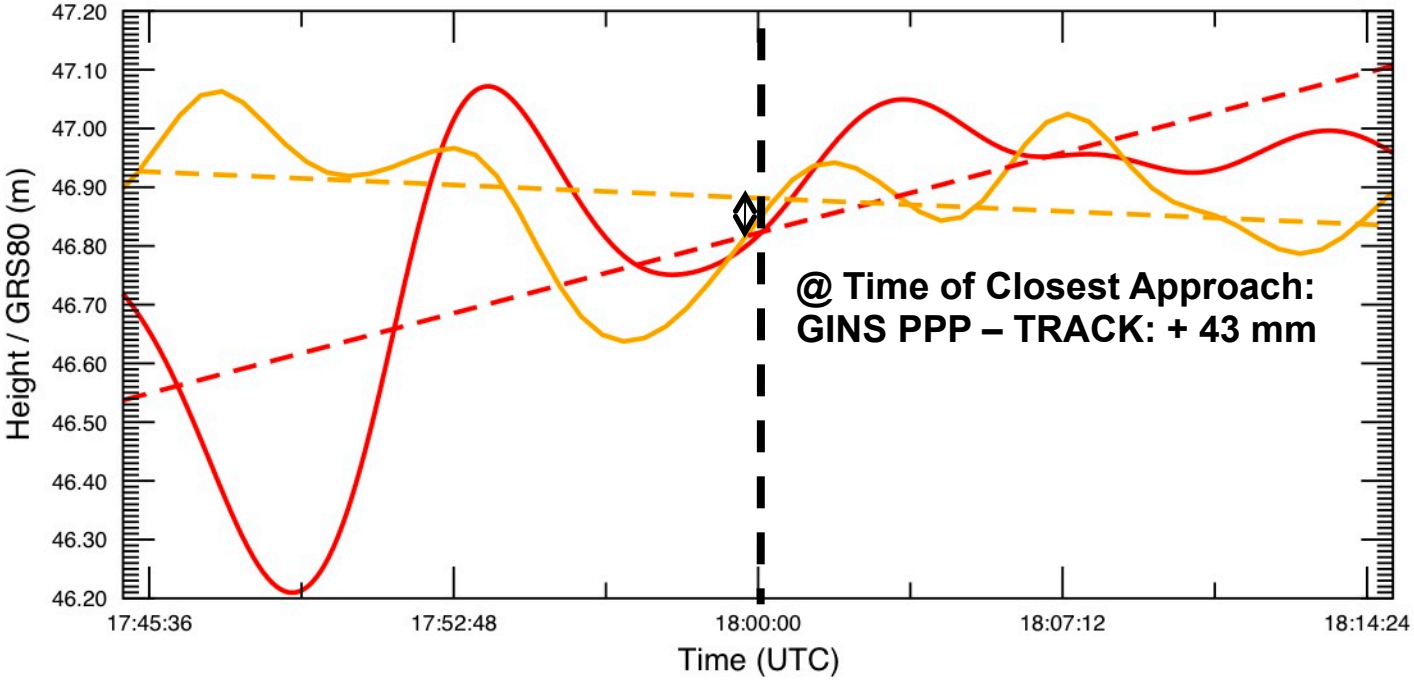


		Mean	Standard Deviation
zodi	Differential	-5 mm	4 mm
zodi	PPP	+7 mm	12 mm
cngh	Differential	+1 mm	4 mm
cngh	PPP	+18 mm	11 mm

On very short distance the differential solution is far better in term of standard deviation. The tide gauge being leveled / rg00 (reference receiver) the mean is very small because it is the same local frame.

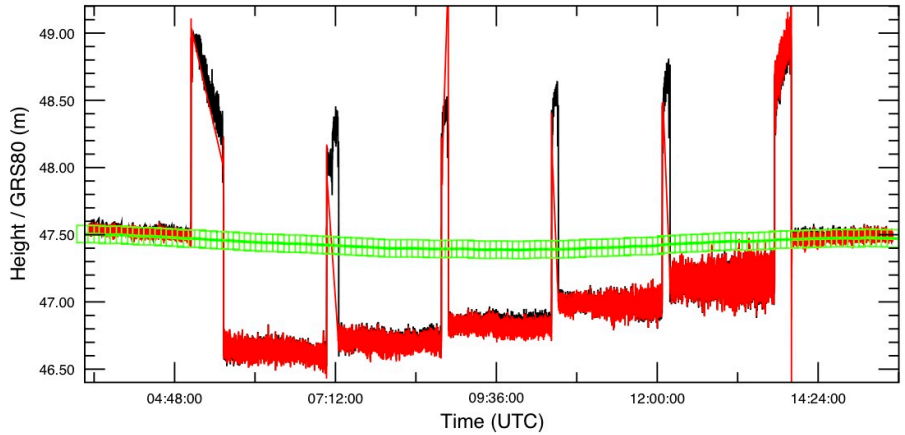
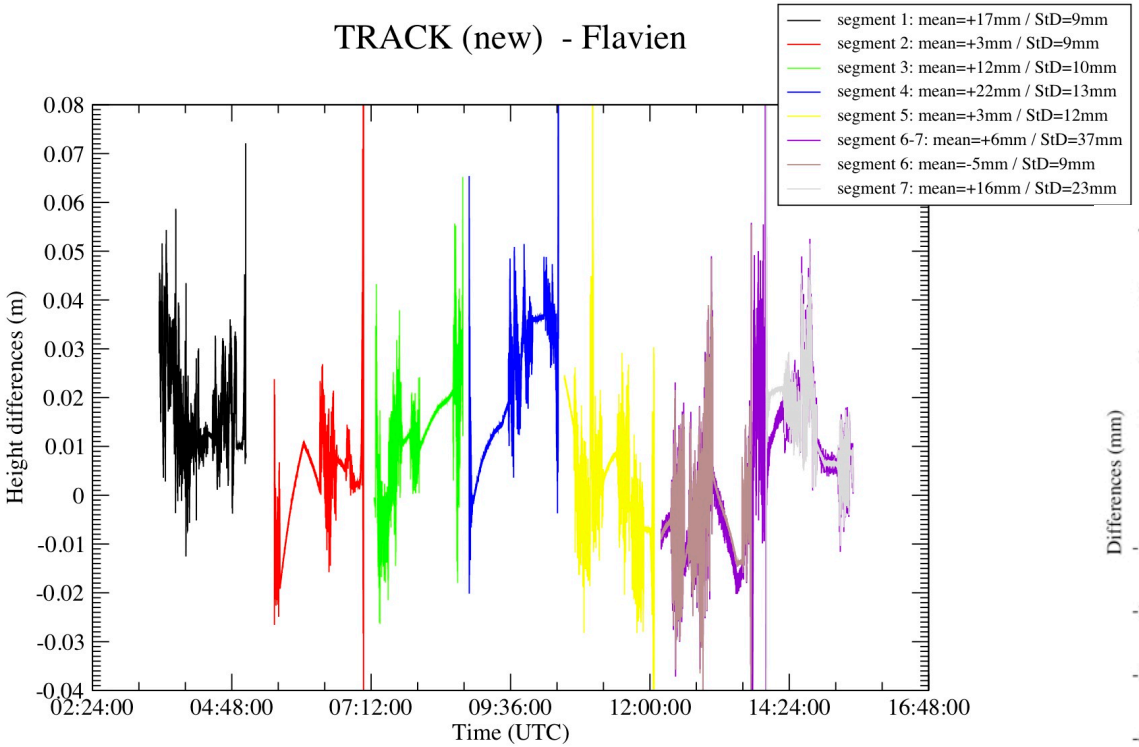
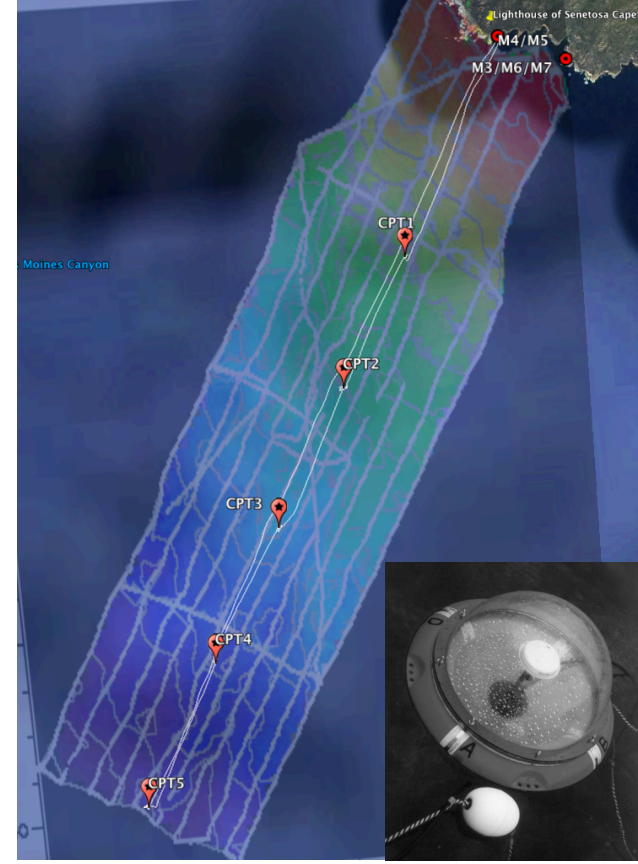
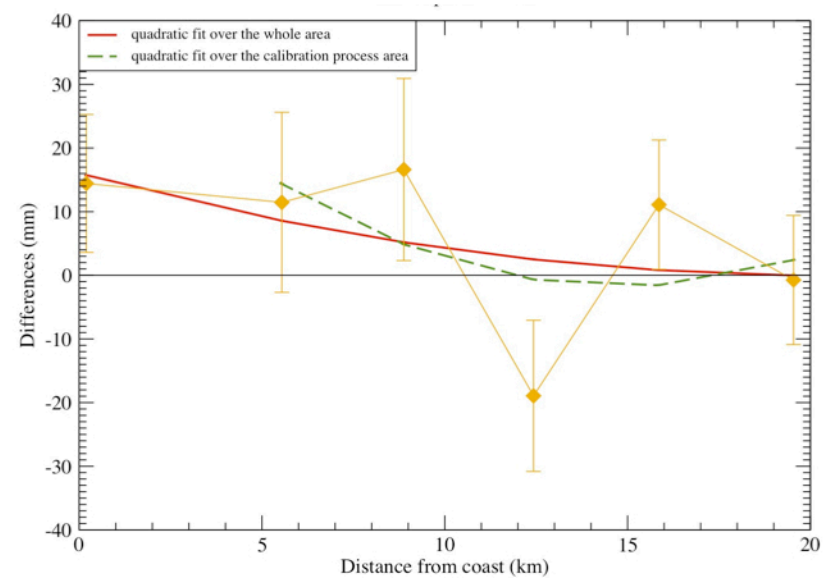






SARAL/AltiKa
Overflight
05/27/2013

2010: 11 years after the geoid computation

Raw data (LC)
Flavien (segments)
Tide gauge (M5)

Flavien Mercier (CNES) = PPP integer ambiguity resolution