Seafloor geodesy : concepts & applications of acoustic distancemetry & GPS/A in the North Anatolian Fault & the Lesser Antilles

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Context

Observations of movements and deformations
on the Earth surface
using Global Navigation Systems

- 70 % of the Earth Surface is covered by water

- Oceans are the theaters of some of the most hazardous tectonic phenomea

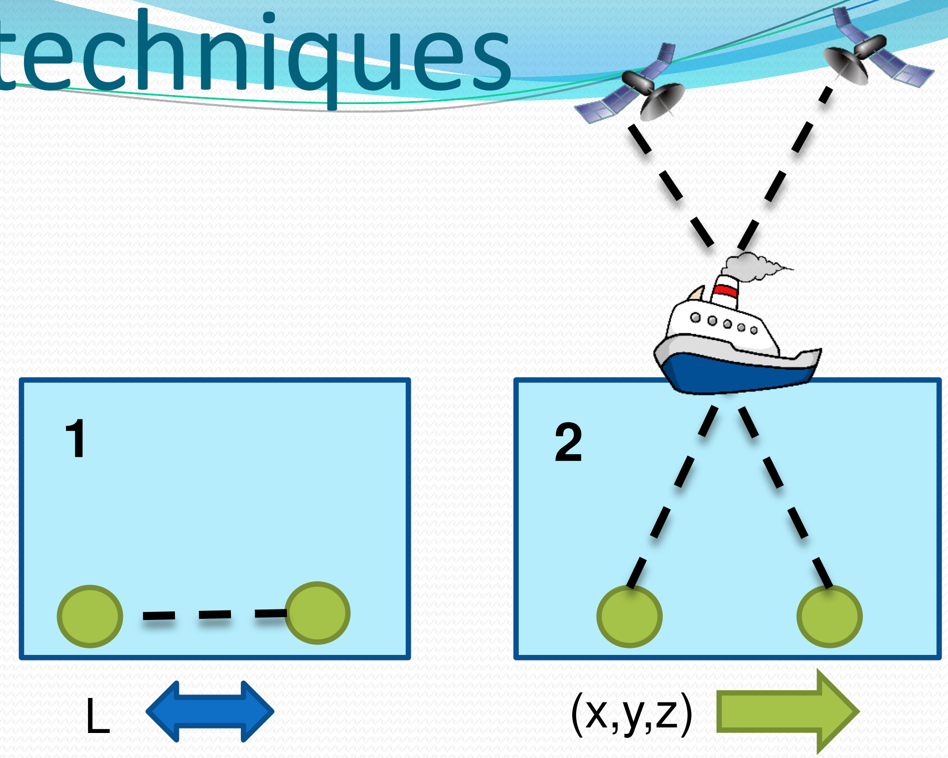
How to extend land observation networks offshore and perform precise geodetic measurements under the seas ?

Marine geodetic techniques

Monitoring horizontal movements :

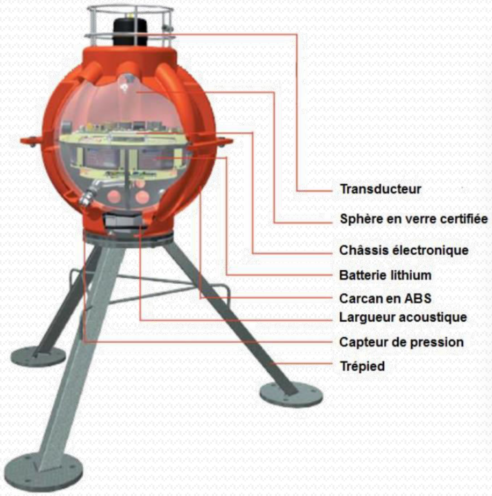
- **Relative (1) :** acoustic distancemetry between sea-floor Beacons [Chadwick et al. 1999]

- **Absolute (2) :** positioning combining acoustic and GNSS observations [Spiess et al. 1998]

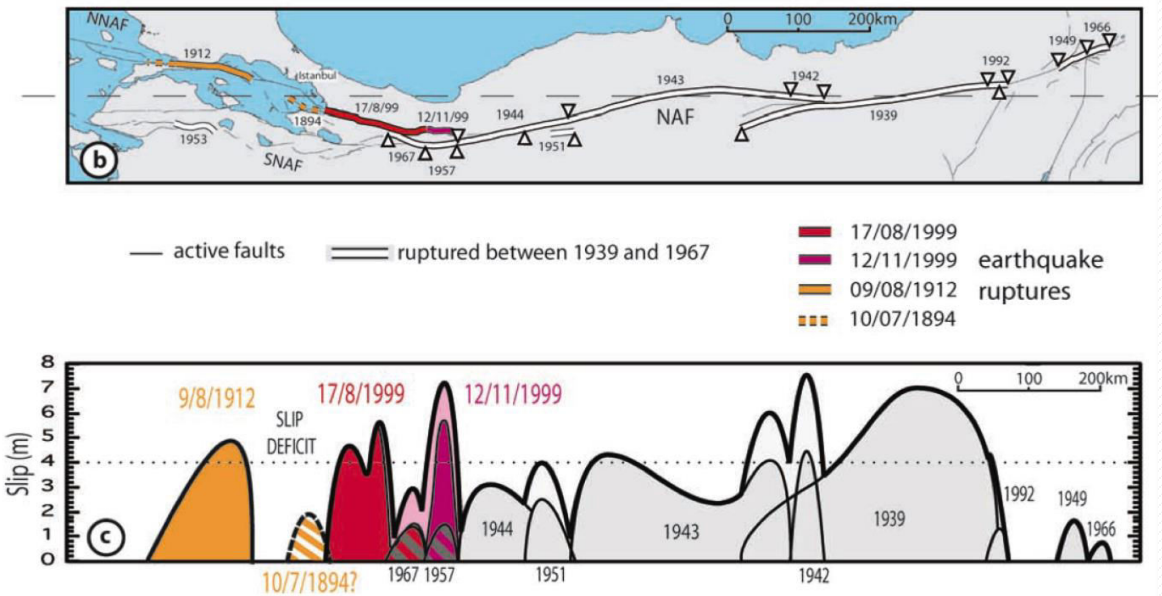


Substitution of electromagnetic waves by acoustic waves for time ranging

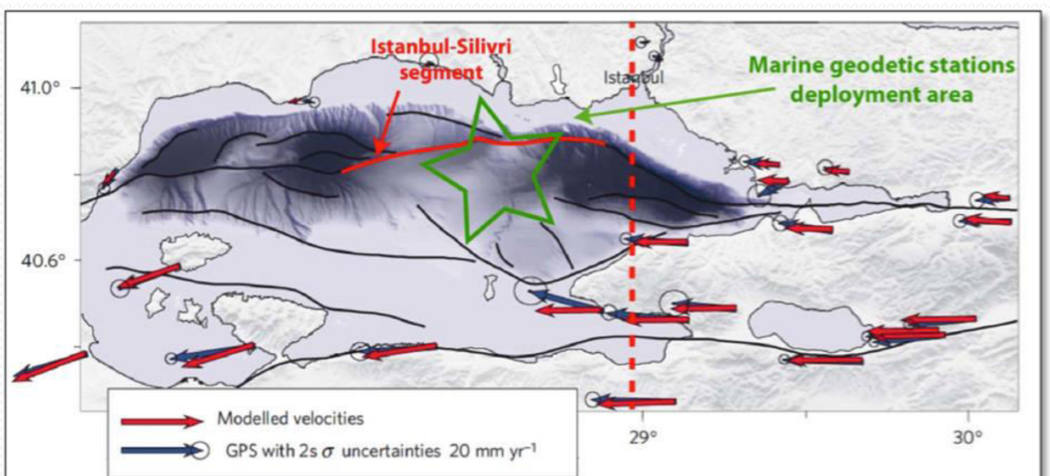
Main difficulty : modeling the sound velocity in the water for accurate ranges

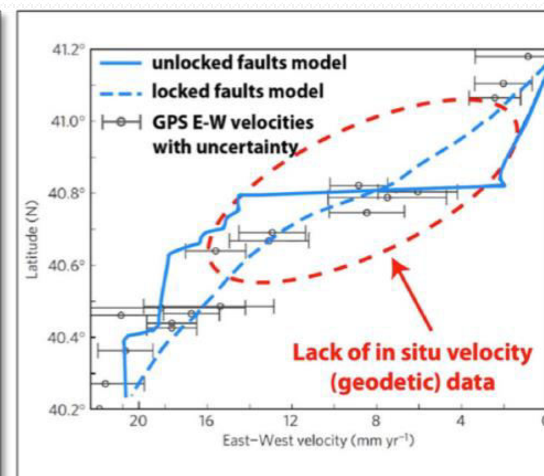


Marmara Sea tectonic context



[Stein et al. 1996] & [Armijo et al. 1999]



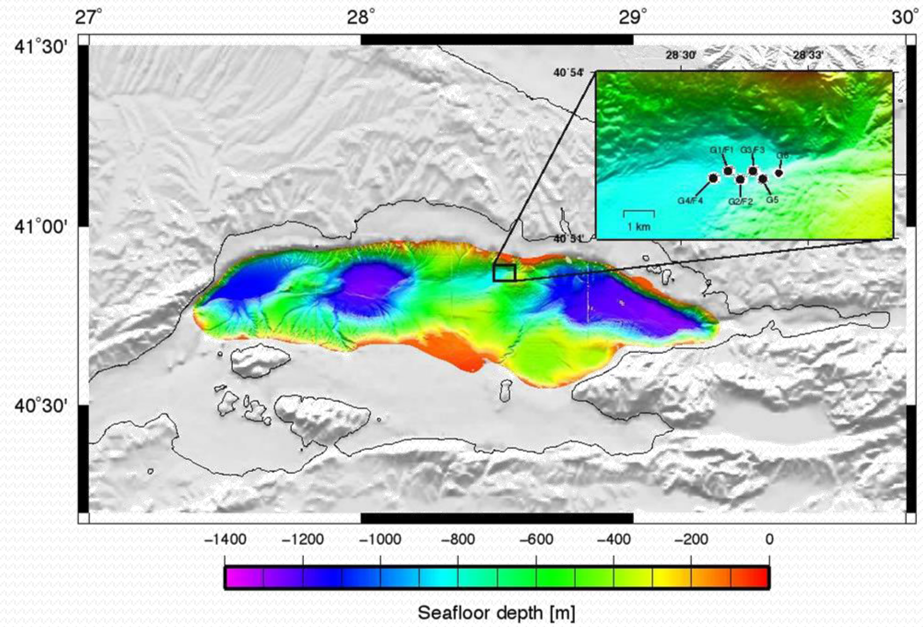


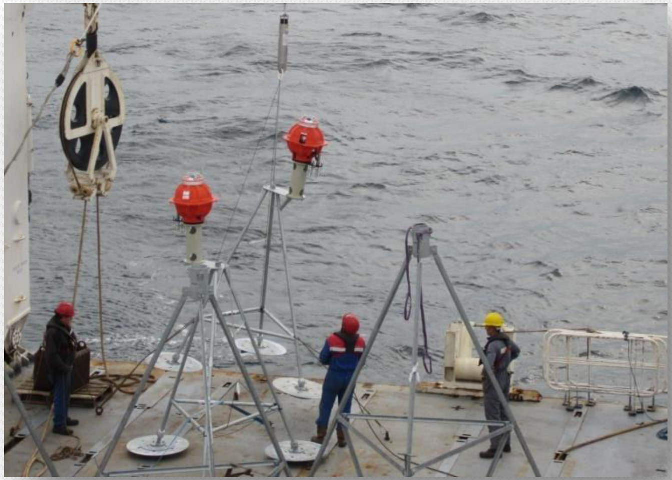
[Hergert & Heidbach 2010]

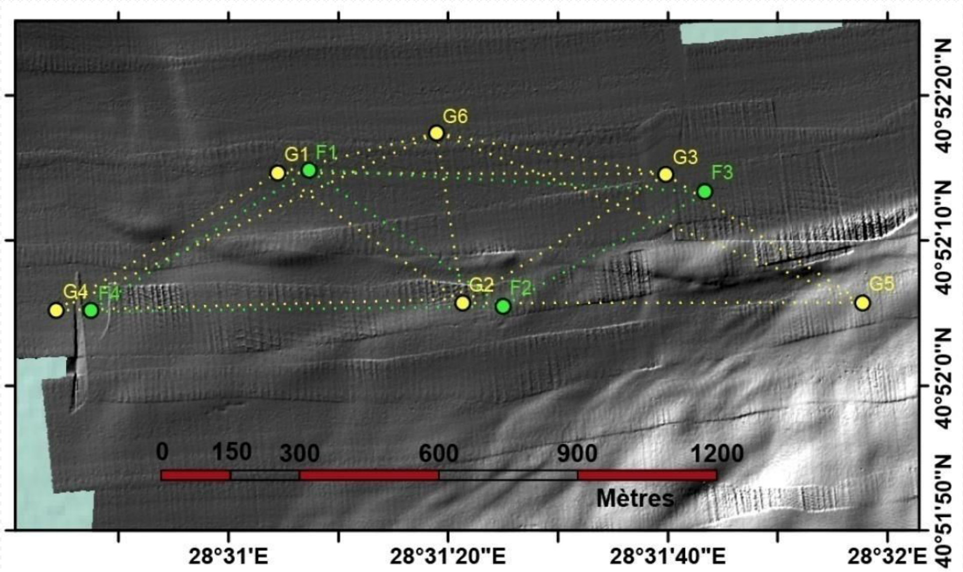
MARSITE campaign

- Offshore campaign from 28th October to 3th November on board of R/V *Pourquoi Pas ?*
Join Campaign with Geomar – Kiel

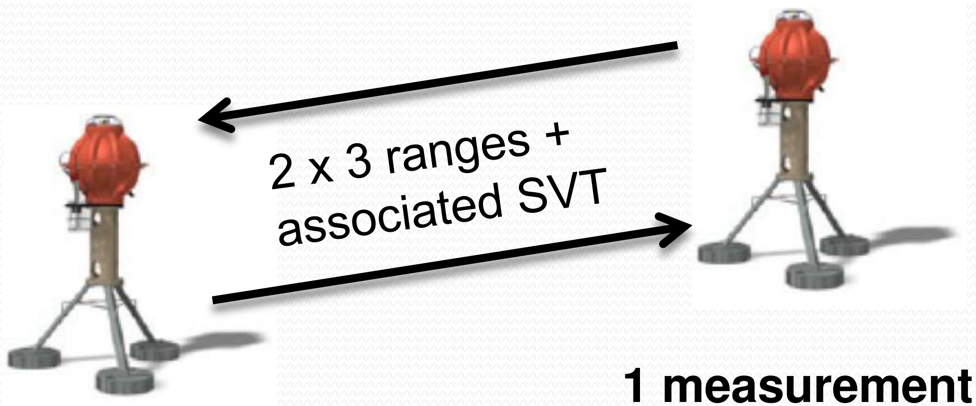
- Deployment of 4 **F**rench and 6 **G**erman beacons on both side of the main fault







MARSITE : measurement strategy



1 measurement session / hour

$$D = V * \frac{T \text{ - buffer}}{2}$$

Determination of the mean sound speed

$$V_{harm} = \left(\frac{1}{L} \cdot \int_{X_a}^{X_b} \frac{1}{v(s)} ds \right)^{-1} \qquad \tilde{V}_{harm} = \frac{1}{\frac{1}{V_a} + \frac{1}{V_b}}$$

2 strategies :

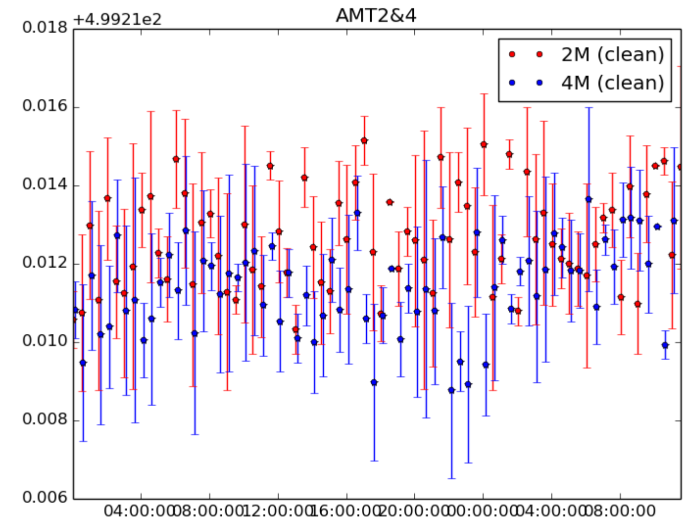
- Raw processing by determination of each range associated at every acoustic shot
- Determination of the mean range for each session with average S.V. and average

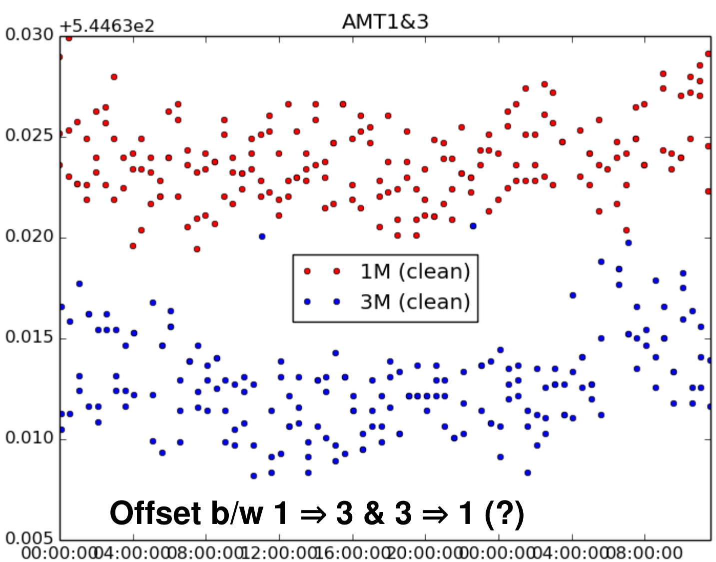
Frequency of acquisition - number of samples	
Logging Period	1h
Battery	2 days
Inclinometer	1 h
Pressure	1 h
Baseline	1h - 3 samples
Soundspeed and Temperature (SVT)	1h + Log When Woken
Other parameters	
Blocking period	0 s
Offset from start time	3 min
Multiple sample interval	5 s
Number of measurements	
Total number of mes . of a given baseline during one cycle with the 4 fetchs	6
Total number of SVT during one cycle with the 4 fetchs	8
Daily total number of measurements of a given baseline	144
Memory	
Daily number of pages	11
Memory used during 1 year of acquisition	2.06 Mo
Duration of downloading of 1 year of measurements, at a 6000 bps speed	5.71 min
Battery expense (as estimated by Monitor)	
Yearly battery expense	28.17 Ah
Total duration of battery	6.39 years

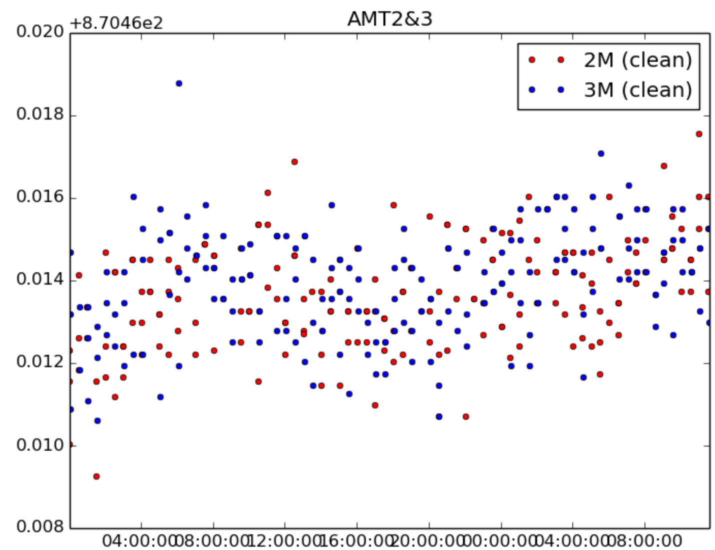
MARSITE : preliminary results

1.5 days (30 & 31/10/2014) of observations with 30min spaced sessions

ID of AMT		# of mes.	D final	Std. Dev. (1 σ)
1	2	206+206	506,5884	0,0009
1	3	200+202	544,6488	0,0058 *(0,0021 / 0.0016)*
1	4	194+185	846,6028	0,0033 *(0,0021 / 0.0018)*
3	2	191+197	870,4746	0,0014
4	2	204+208	499,222	0,0013



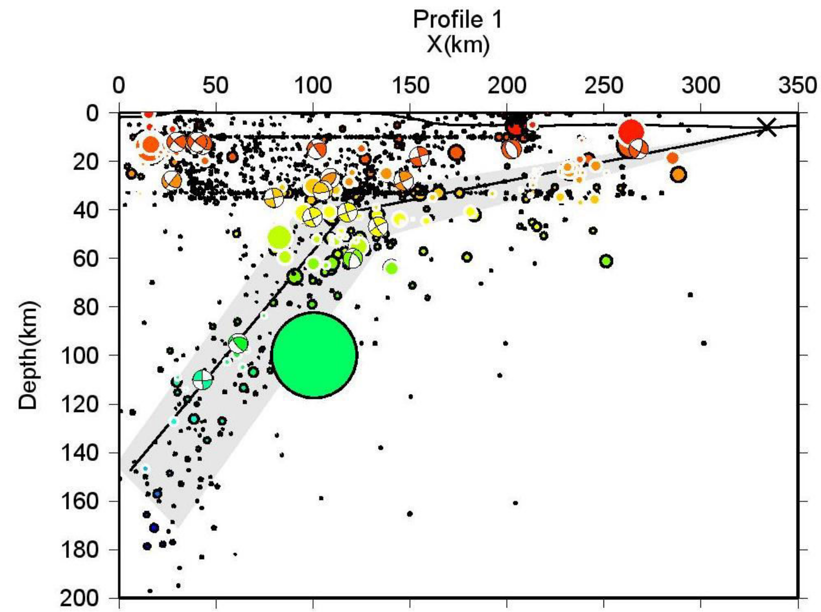


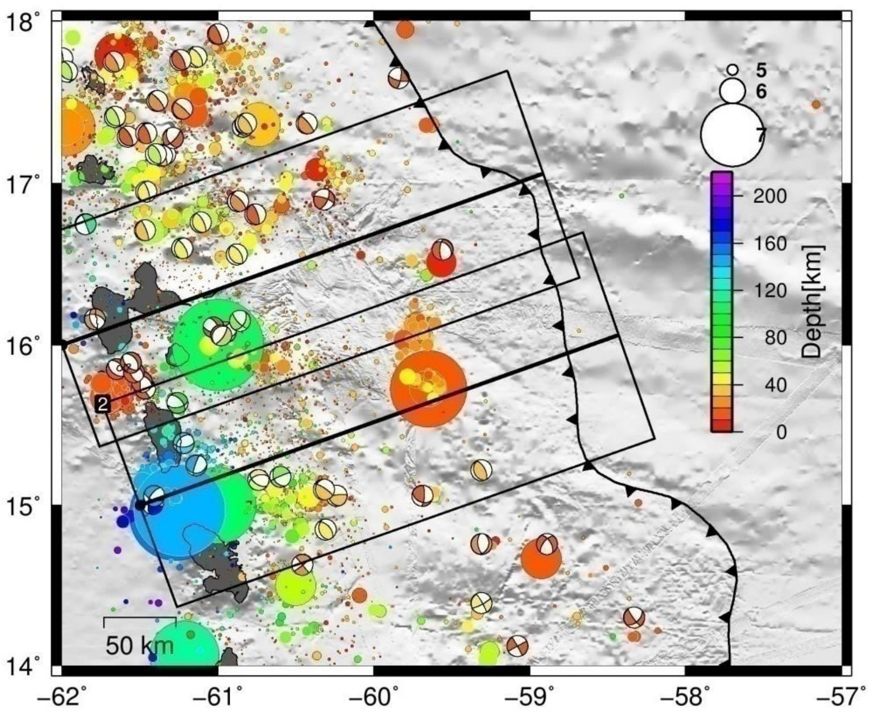


The case of Lesser Antilles

The Archipelago is too far from the trench for observing a significal signal with on shore GNSS

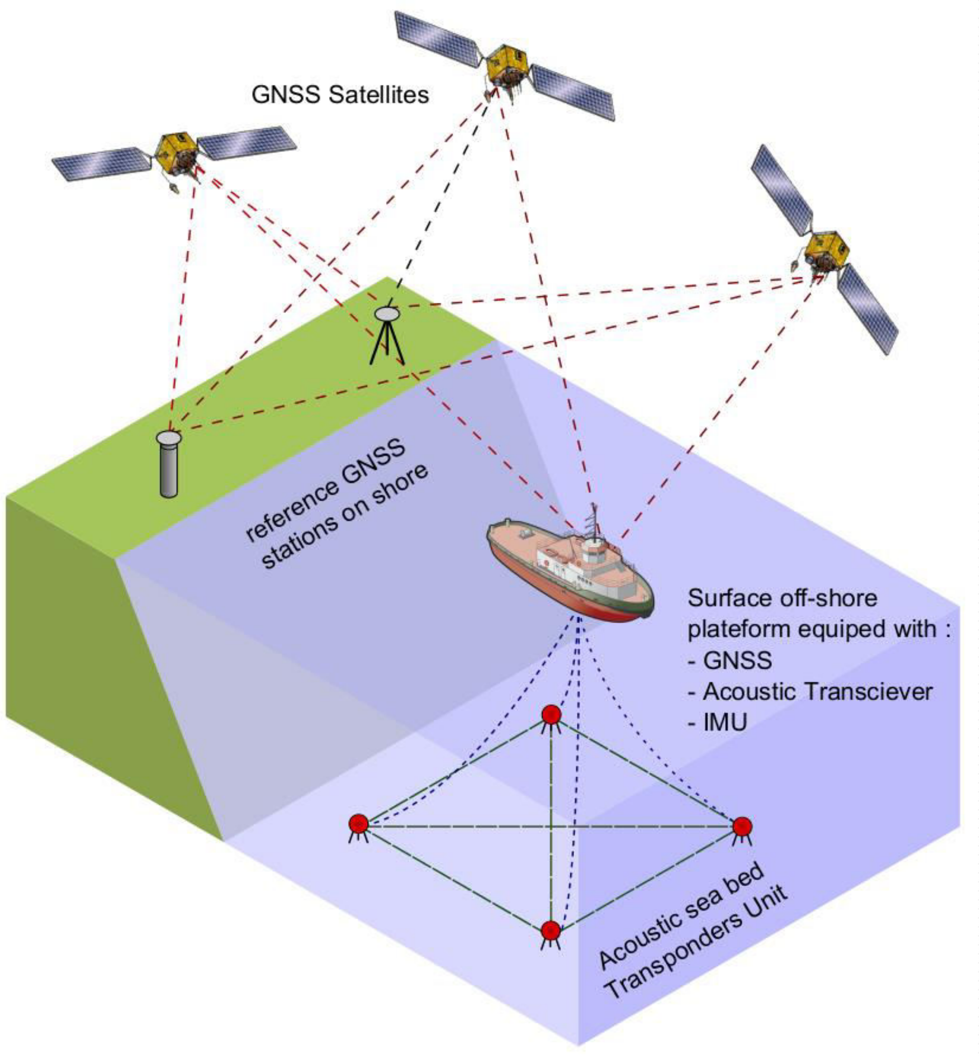
Tsunamigenic Earthquake is possible (but *e.g.* 1843 event didn't broke up to the trench)





- Trench is 500km far from the islands
- ~ 5000m depth
- Distancemetery is inappropriate in this context : **need of absolute positioning**

GPS/Acoustics



- Spiess et al. 1998 : Deployment of anchored beacons on the sea-floor in order to monitor the displacement in an **absolute** reference frame

- regular visits of the array with a surface platform (boat, glider) or continuous measurements with a buoy

- Technique divided in 2 parts :
  - *surface segment :*
    accurate localisation of the platform with GNSS and IMU
  - *underwater segment :*
    Extract a position from multi-shoots two-ways travel time measurements
    Dealing with the sound speed variations (multiple CTDs, polygonal array)

Precise Positioning Experiment

Aim :

1. Positioning a moving plateform (ship) with the best accuracy

2. Locating the acoustic head in a absolute frame

3. Using multiples receivers on bord
   - Avoid technical failure
   - Make the best of each receivers, by elimination of uncorrelated errors
   - Using GNSS as IMU

4. Necessity to use a PPP approach (in view of Carabean configuration)

5. Need of (good) topometric ties between the instruments

GNSS post-processing :

- Differential approach
  - *Track*
  - *RTKLIB*
  - IGS BRST station as reference
- PPP approach :
  - *GINS* (CNES)
  - *GIPSY* (JPL/NASA)

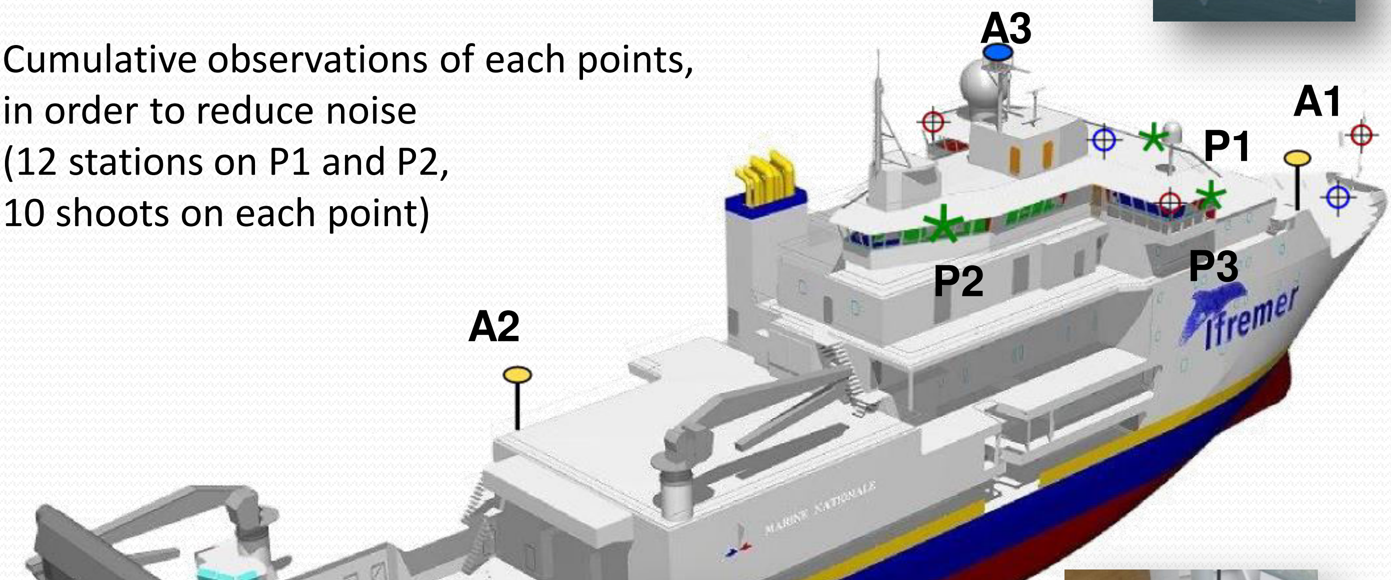
- 1 Hz acquisition rate
- Tropospheric model GPT2/GMF2
- Antex IGS week 1798
- IGS/CLS/JPL final orbits

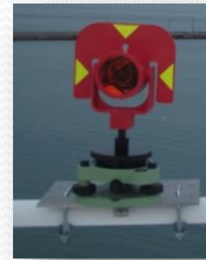
Precise Positioning Experiment

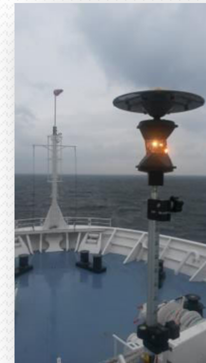
Temporary GNSS configuration on R/V *Pourquoi Pas ?*

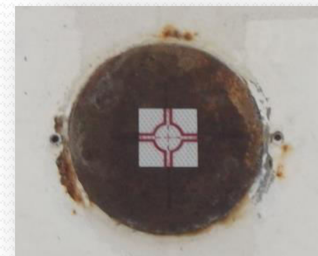
Surveys on 2 points (P1 & P2), sighting reflectors on antennas, reference points of the ship & controls points

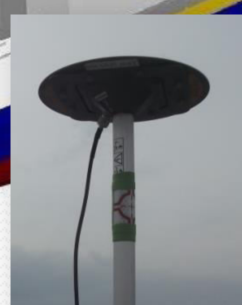
Cumulative observations of each points,
in order to reduce noise
(12 stations on P1 and P2,
10 shoots on each point)

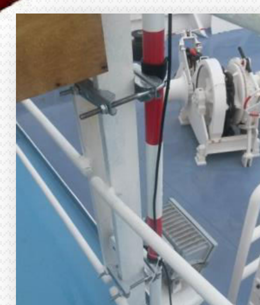






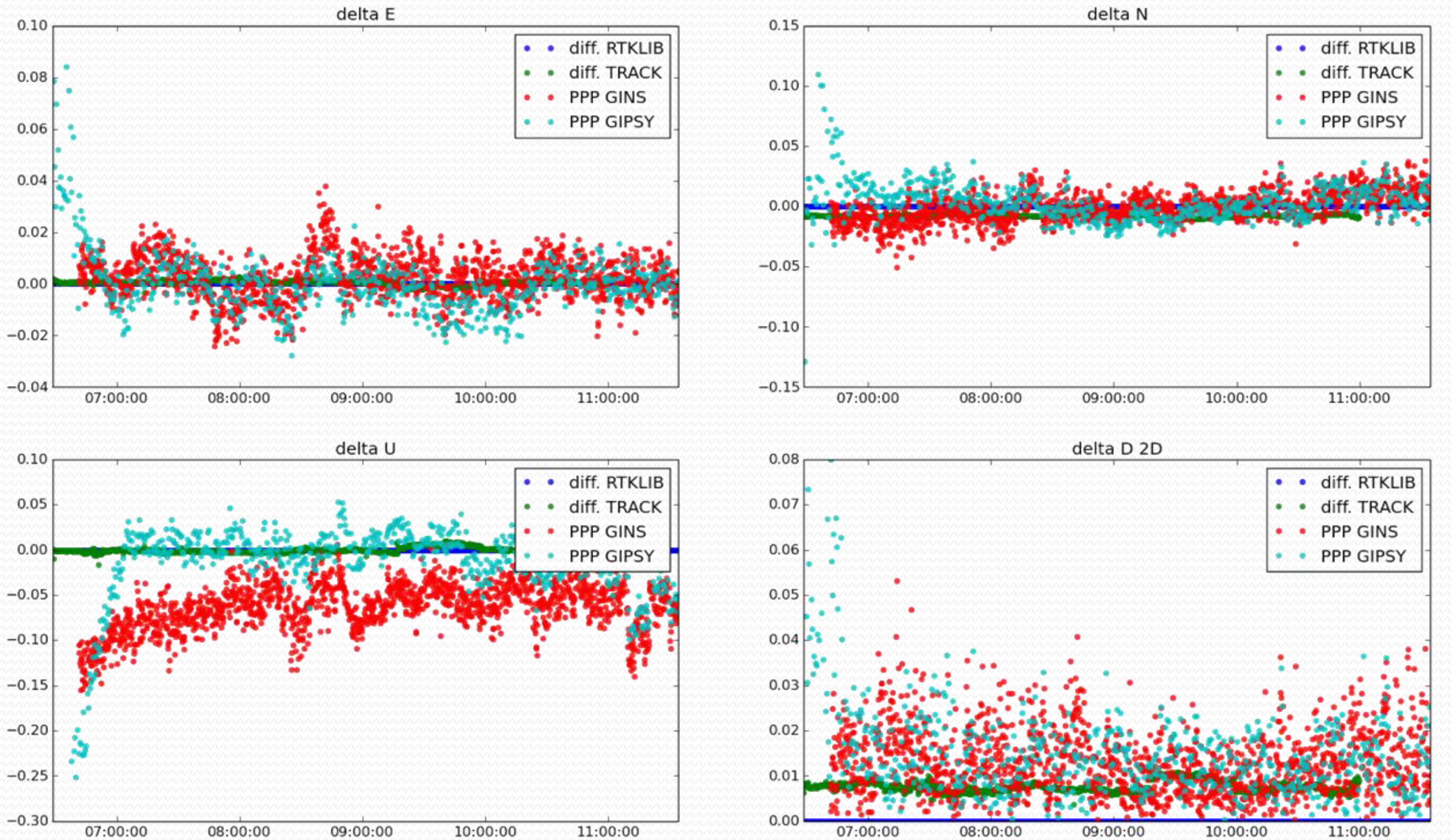






Precise Positioning Experiment

results on *Albert Lucas* : **GAV1 (GNSS « Avant » / Bow) results**



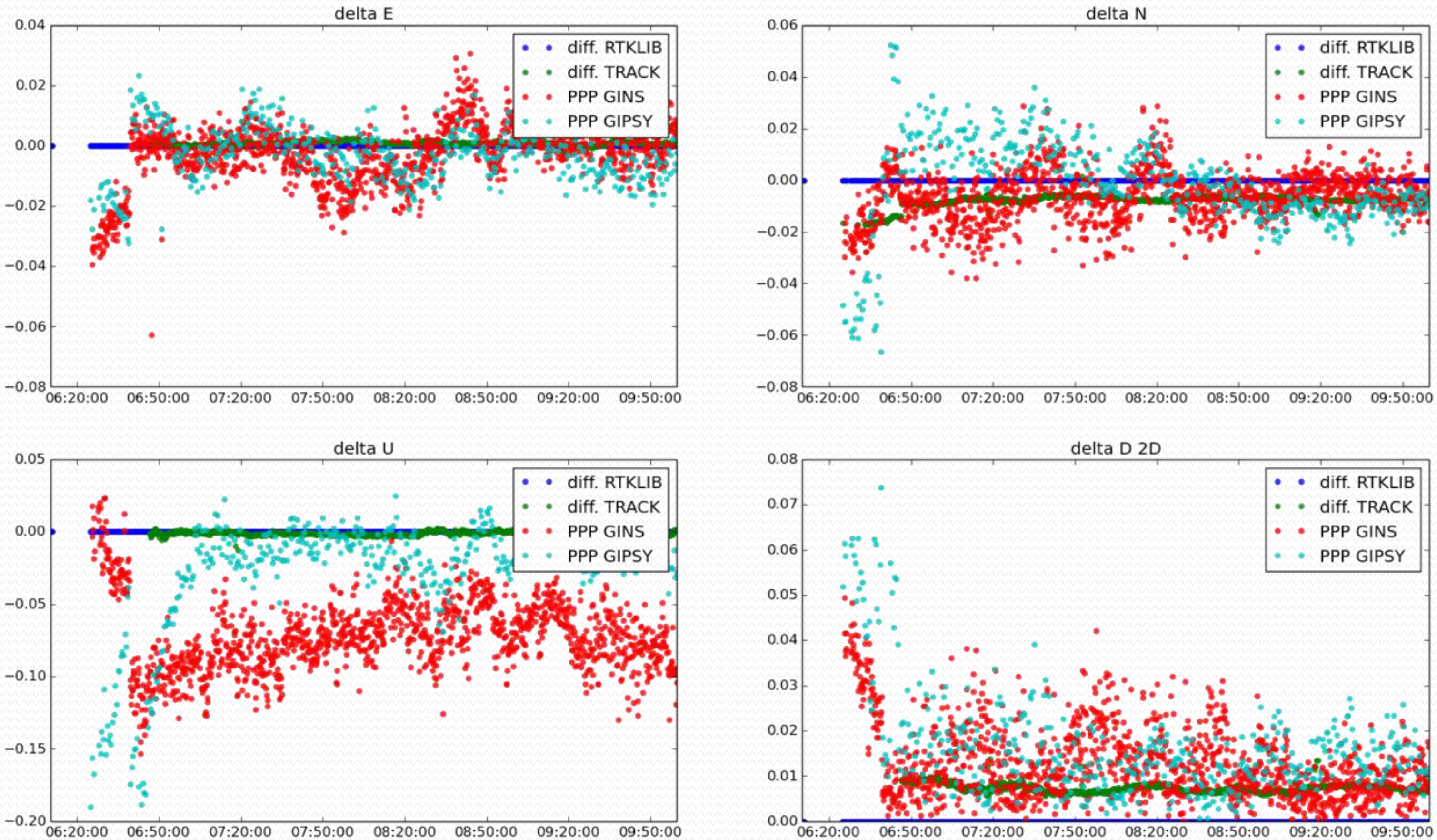
Using RTKLIB solution as reference

(m)	RMS 3D	RMS 2D	σ 3D
TRACK	0,0050	0,0059	0,0013
GINS	0,0443	0,0098	0,0196
GIPSY	0,0303	0,0144	0,0255

Thanks to P. Bosser – ENSTA/IGN for GIPSY run

Precise Positioning Experiment

results on *Albert Lucas* : **GTR1 (GNSS « Tribord » / starboard)**



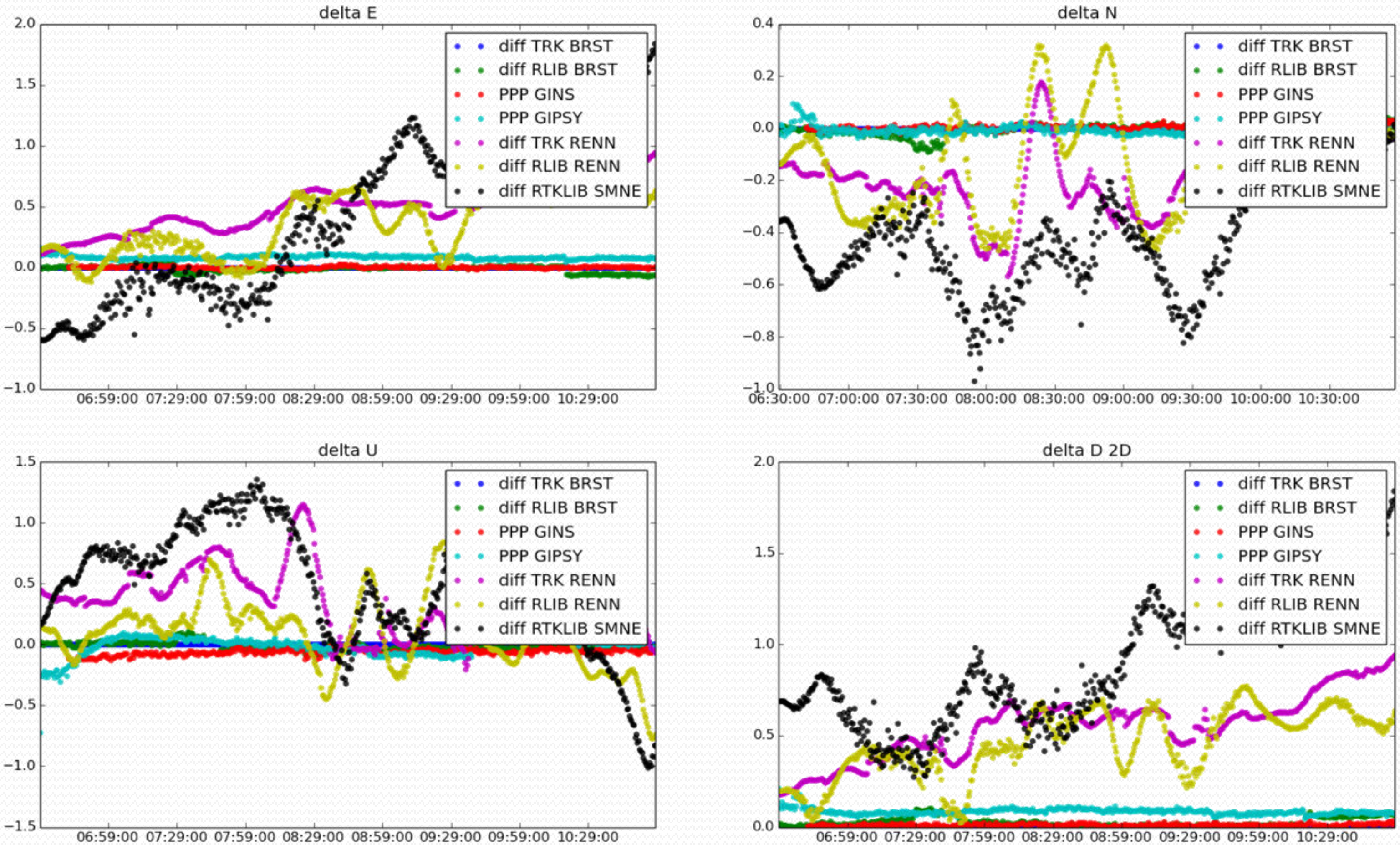
Using RTKLIB solution as reference

(m)	RMS 3D	RMS 2D	σ 3D
TRACK	0,0048	0,0055	0,0017
GINS	0,0398	0,0092	0,0249
GIPSY	0,0297	0,0152	0,0199

Precise Positioning Experiment

results on *Albert Lucas*

GOR1 differential cinematic positioning, with differents reference stations
(BRST ~5km, RENN ~100km, SMNE ~500km)



« off-the-shelf » solution ?

Off shore positioning materials developped by privates compagnies

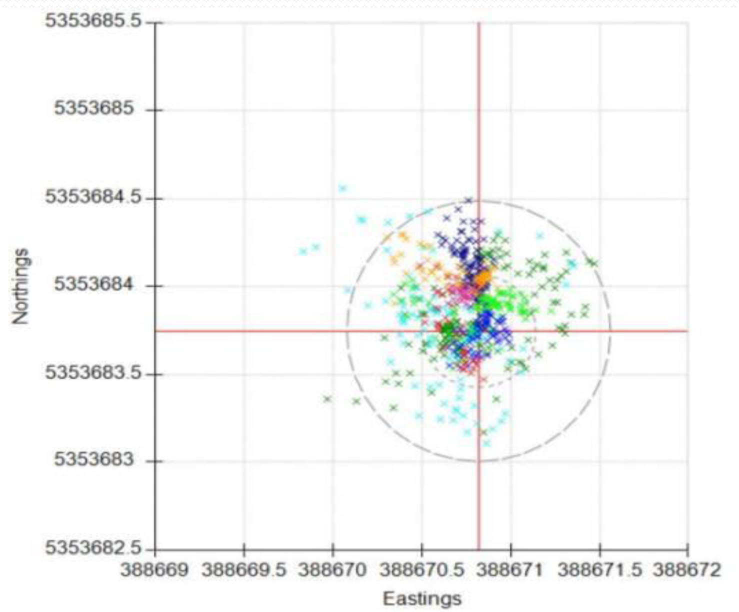
Results:

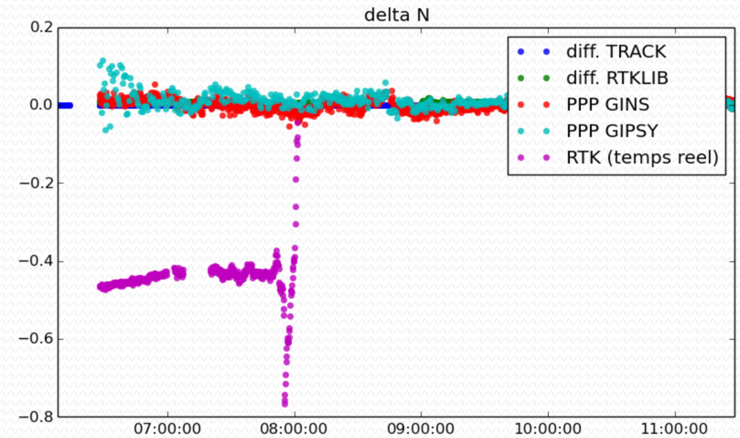
Beacon BoxIn	Beacon Eastings	Beacon Northings	Beacon Depth	Sound Velocity	Transceiver Starboard Offset	Transceiver Forward Offset
Before	388670.95m	5353683.72m	34.68m	1492.64m/s	0.00m	0.00m
Calculated	388670.82m	5353683.75m	34.91m	1495.68m/s	0.13m	-0.05m
Calculated Accuracy	0.01m	0.01m	0.01m	0.19m/s	0.01m	0.01m

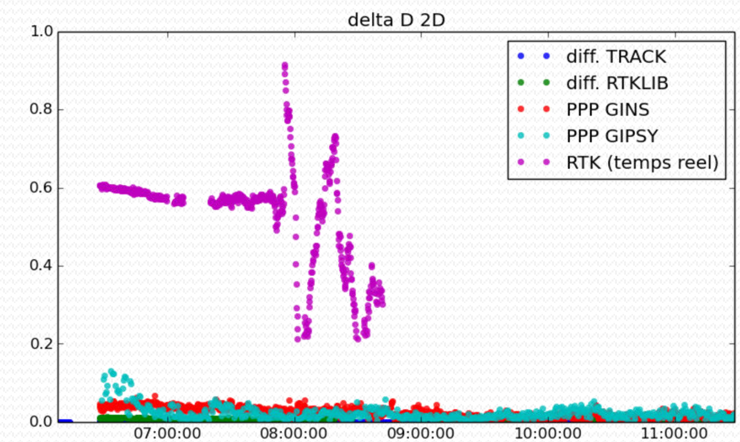
Transceiver Attitude	Pitch Correction	Roll Correction	Heading Correction
Before	-0.12º	-0.19º	0.28º
Calculated	-0.09º	-0.03º	0.47º
Calculated Accuracy	0.01º	0.01º	0.03º

Statistics:

	Before CASIUS (distance)	After CASIUS (distance)	Before CASIUS (% depth)	After CASIUS (% depth)
39.4% Beacon Positions (1 sigma)	0.4m	0.2m	1.03	0.65
50.0% Beacon Positions (CEP)	0.4m	0.3m	1.20	0.76
63.2% Beacon Positions (1 Drms)	0.5m	0.3m	1.38	0.92
86.5% Beacon Positions (2 sigma)	0.7m	0.5m	1.94	1.43
98.2% Beacon Positions (2 Drms)	1.0m	0.7m	2.73	2.13



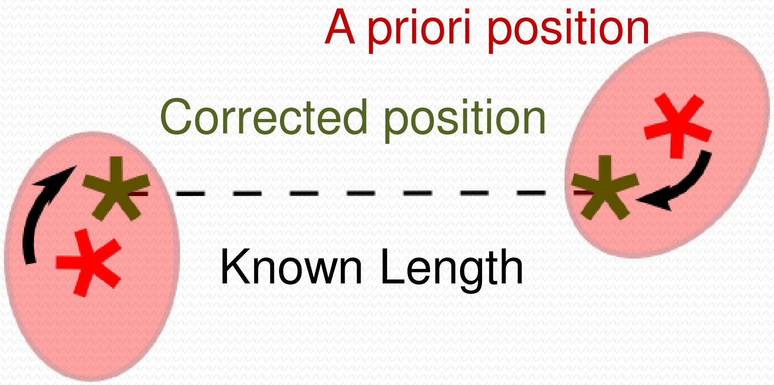


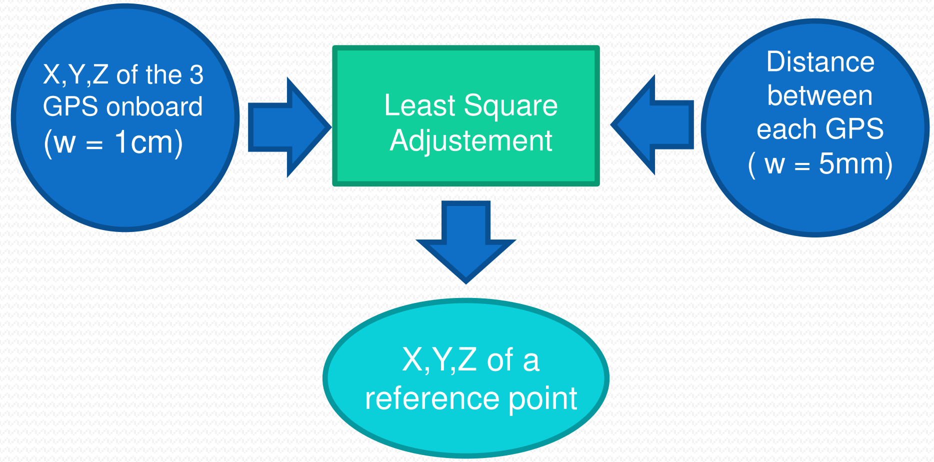


Powerful processing chain but
Insufficient accuracy of absolute positionning

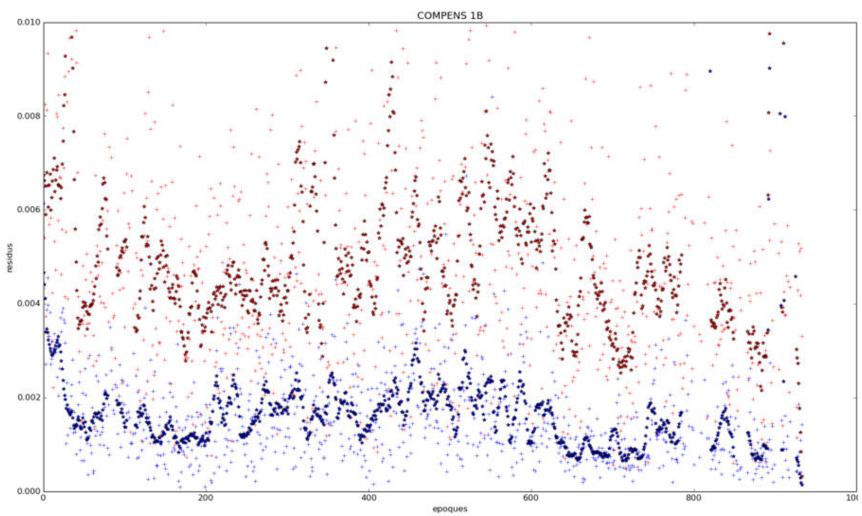
Final position compensation

Concept

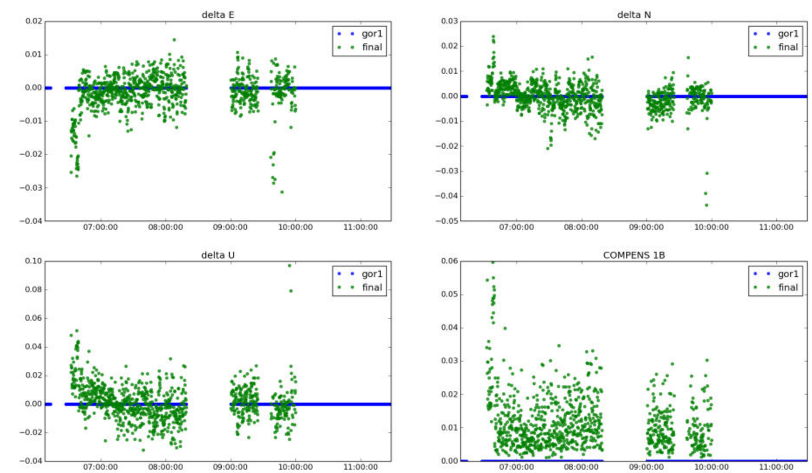




Residuals before and after adjustment on the distances



Difference between adjusted position and a priori position



Missing orientation constraint

Perspectives

- **Precise Positioning Validation**
  - ➢ Processing of the topometric and GNSS data of the MARSITE campaign
- **Acoustics ranging simulations**
- **Tectonic deformation modelisation**
  - ➢ Using *Pylith*
  - ➢ Testing different scenarios : position and size of the blocking zone & configuration of the slab (angle, thickness, accretionary prism)