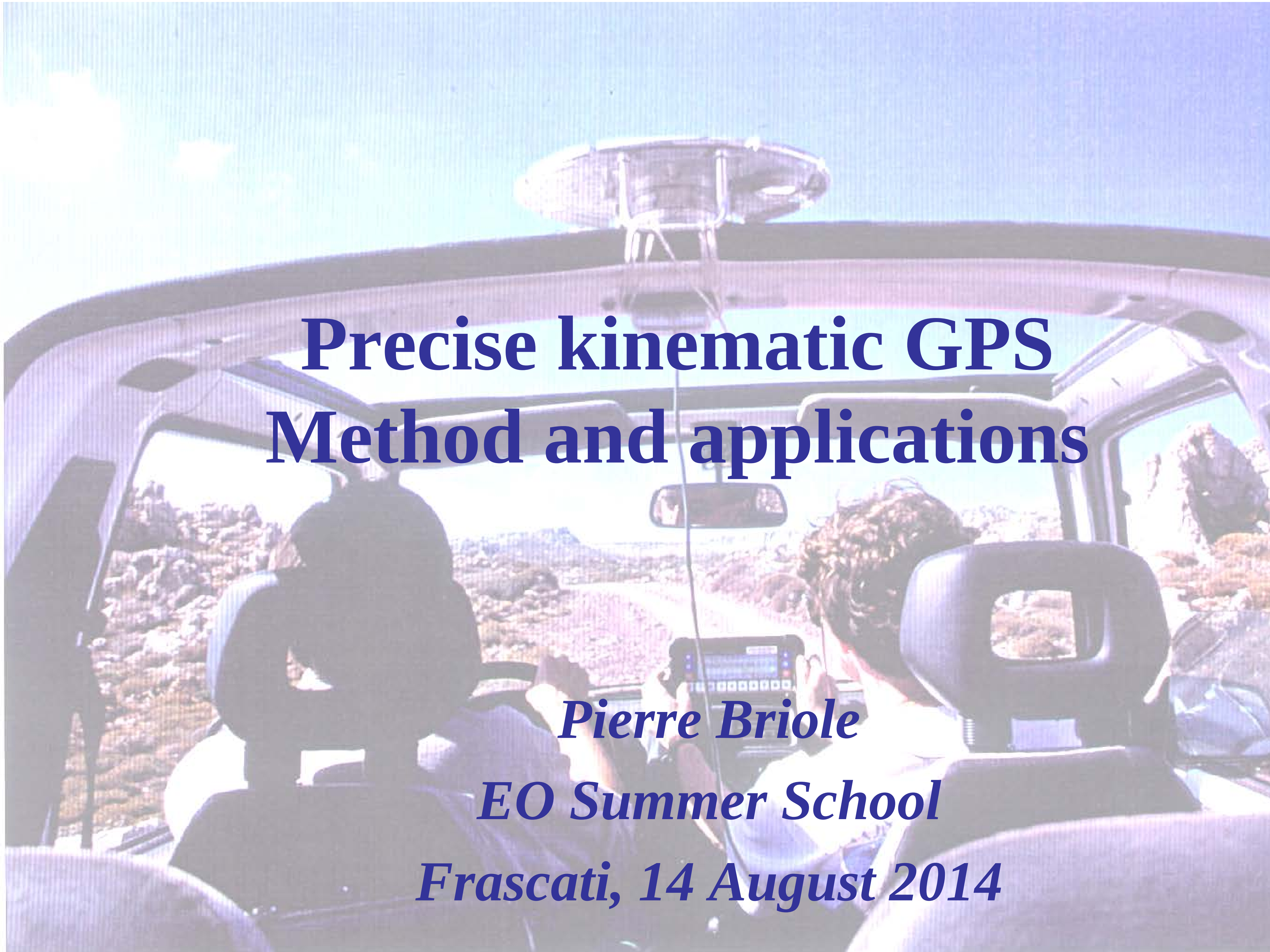


Precise kinematic GPS
Method and applications

Pierre Briole

EO Summer School

Frascati, 14 August 2014

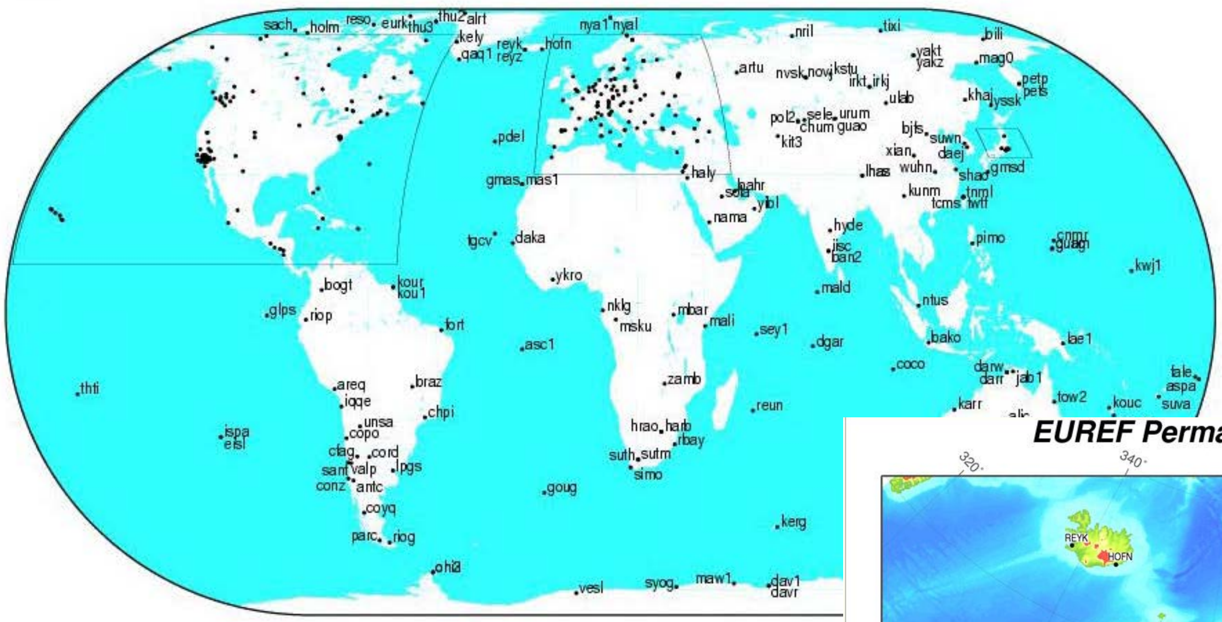
Content

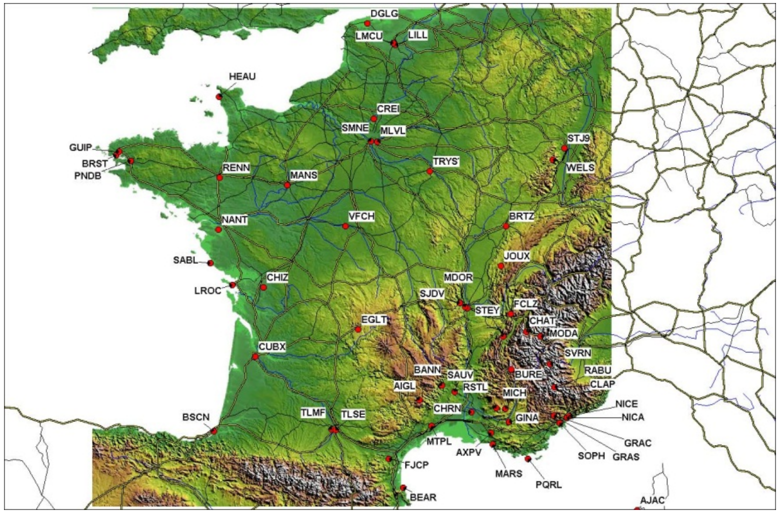
- GPS satellites and networks
- Basics of the principles
- Orbits (and their crucial role)
- Static (and continuous) observations
- Kinematic observations (not real-time)
- Analysis of the observations of August 12, 2014

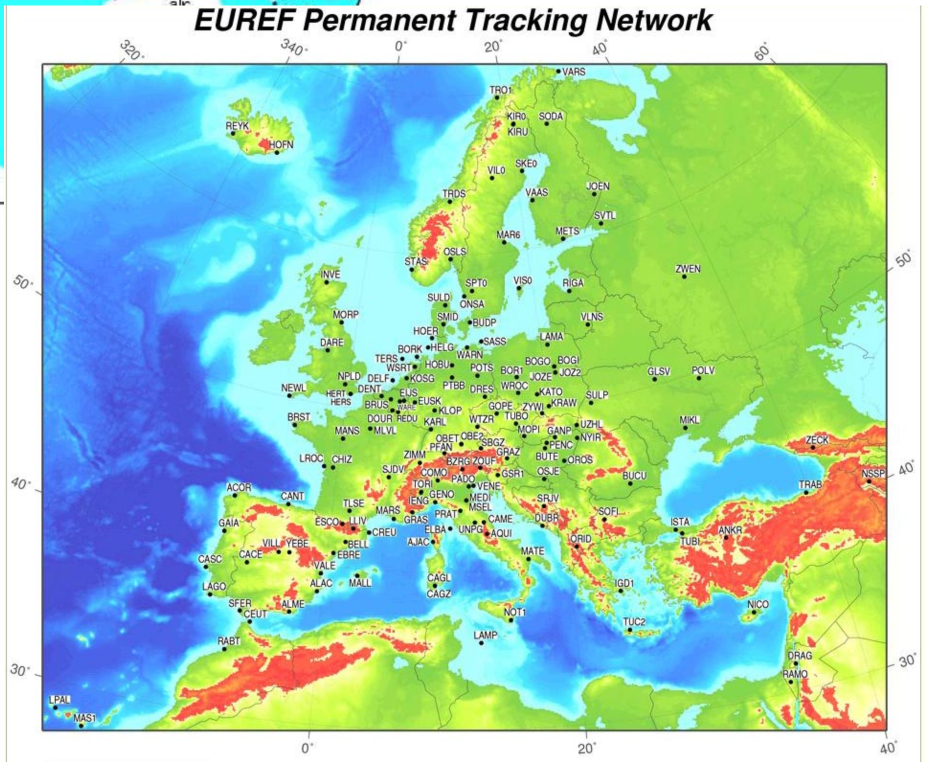
GPS – The space segment

- 24 satellites
- 26000km from the Earth centre
- 2 orbits/day
- Six orbital planes:
  - Inclination 55°
  - 4 satellites / orbite

GPS – The ground segment (control and users)



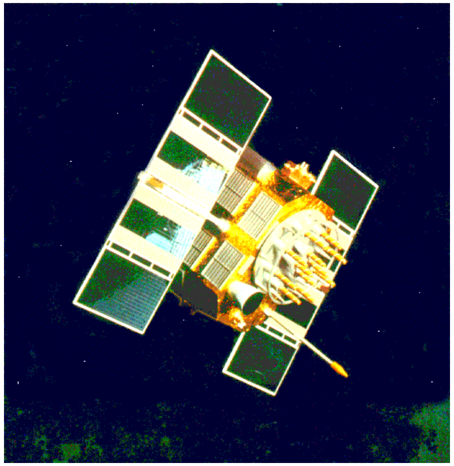




« Static » observations

- GPS antenna attached to the ground
- The measurements can be
  - continuous (permanent station)
  - repeated (campaign observations)

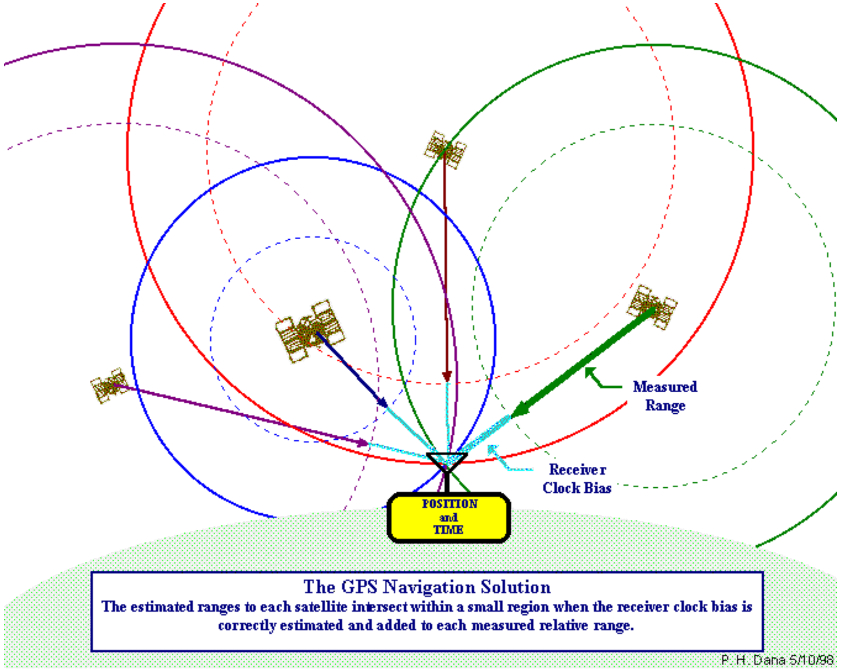
Basic principle of the GPS positioning



- The satellite have accurate clocks and each satellite transmits its time

- The positioning is based on the analysis of the difference of the arrival times of the signals at the receiver

- The satellites orbits must be known



Determination of the position of a receiver

The absolute coordinate of an antenna is determined using the following equations:

$(x_1 - X)^2 + (y_1 - Y)^2 + (z_1 - Z)^2 = c^2(T_1 - T - dT_r)^2$

$(x_2 - X)^2 + (y_2 - Y)^2 + (z_2 - Z)^2 = c^2(T_2 - T - dT_r)^2$

$(x_3 - X)^2 + (y_3 - Y)^2 + (z_3 - Z)^2 = c^2(T_3 - T - dT_r)^2$

$(x_4 - X)^2 + (y_4 - Y)^2 + (z_4 - Z)^2 = c^2(T_4 - T - dT_r)^2$

etc..

Parameters to be estimated:

- X,Y,Z: coordinates of the phase centre of the receiver antenna
- dTr : shift between the satellites time and the receiver clock

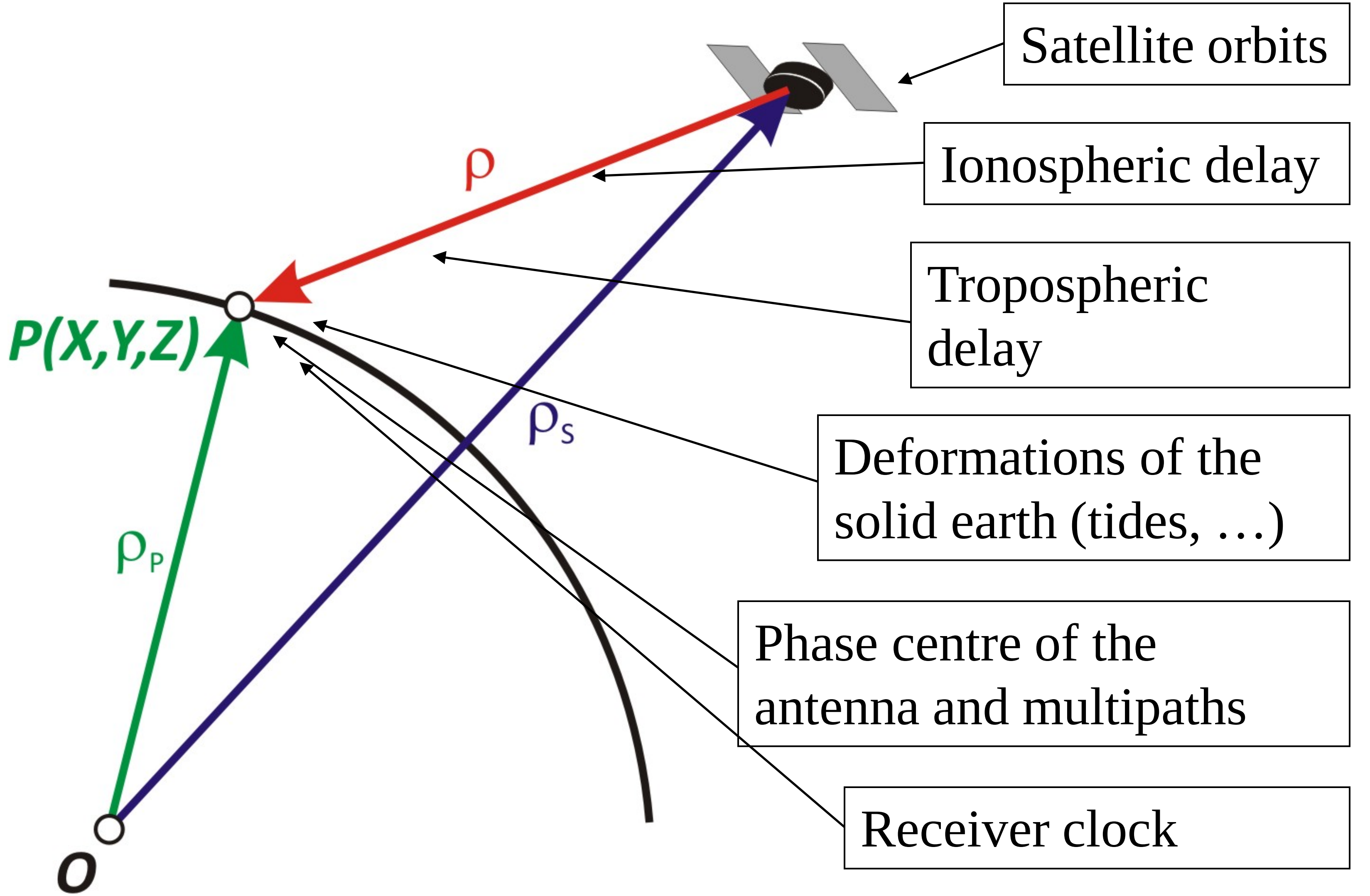
Data:

- x_i, y_i, z_i: coordinates of the satellites as a function of the « system » time T

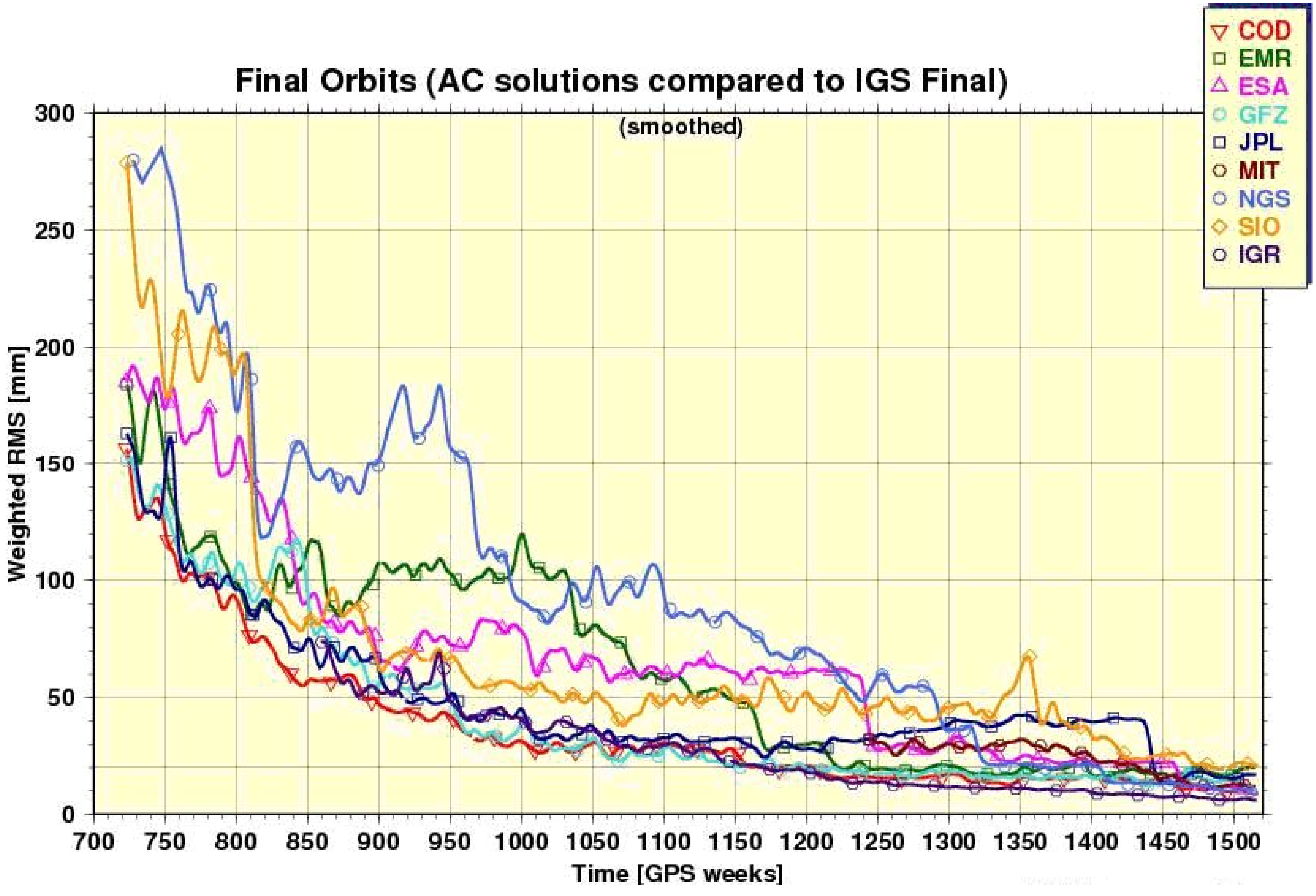
Observations made by the receiver:

- T_i : arrival time (in the receiver time scale) of the signals transmitted by the satellites at « system » time T

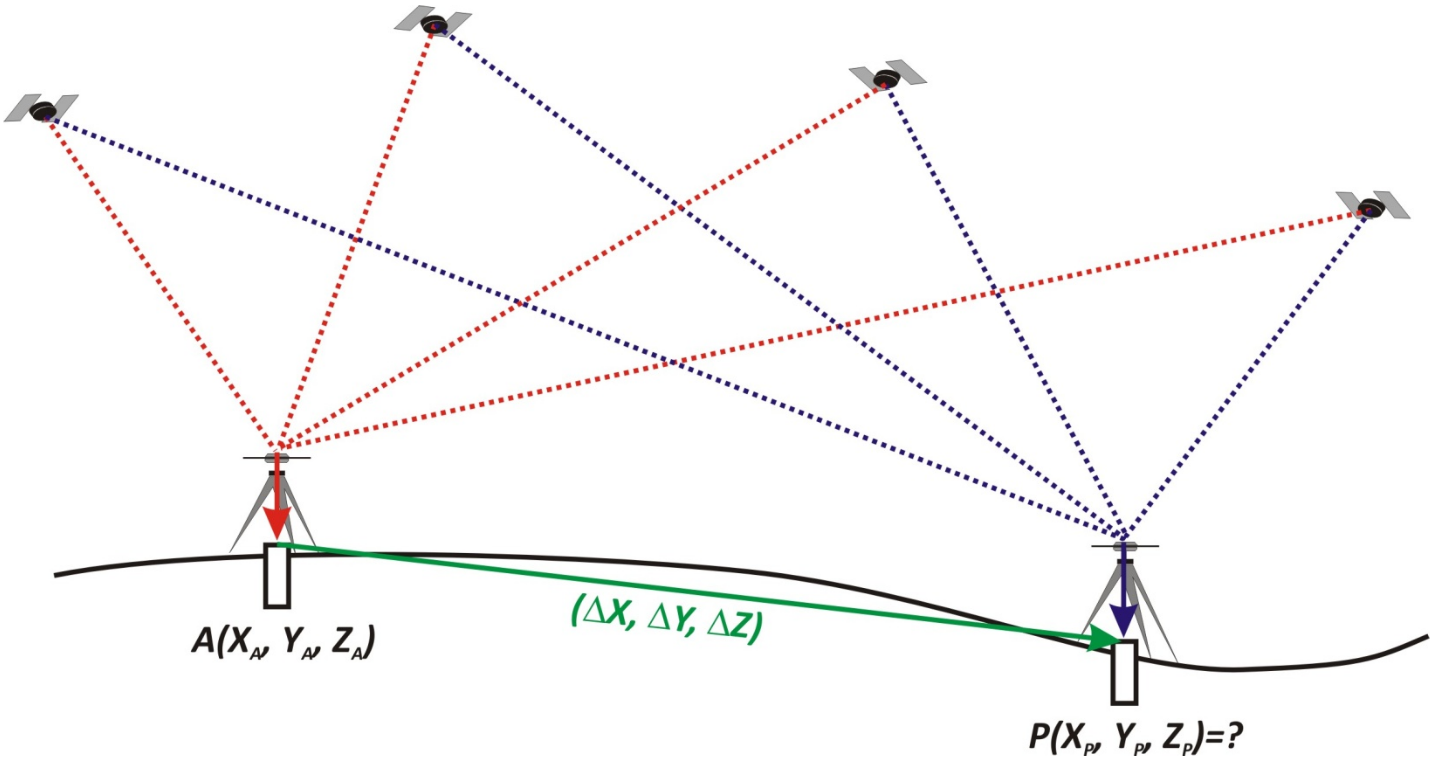
The propagation of the signal must be accurately modelled



Evolution of the accuracy of the GPS orbits
(calculated with the data of a « core » GPS network)



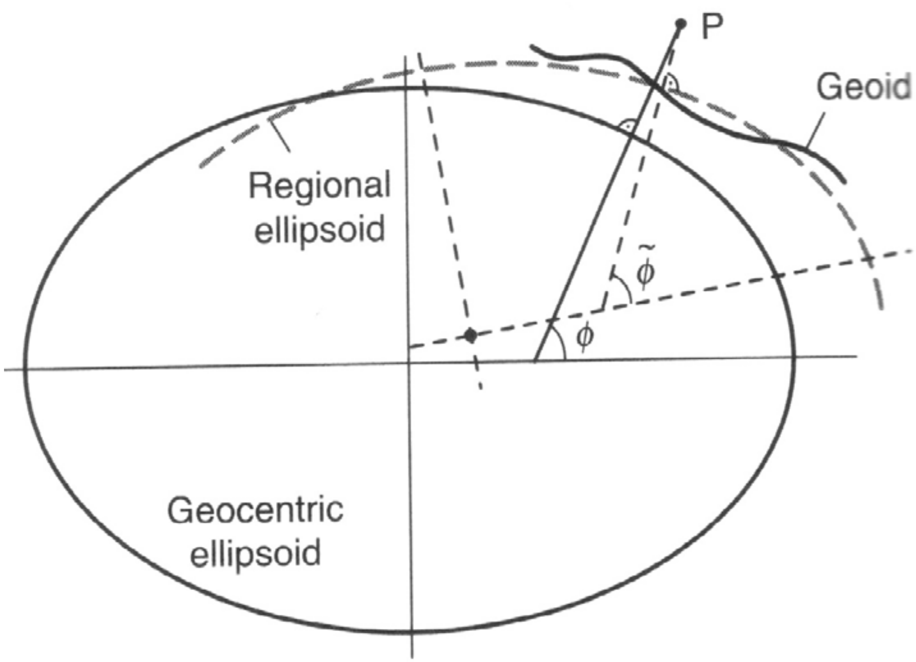
Differential (relative) positioning

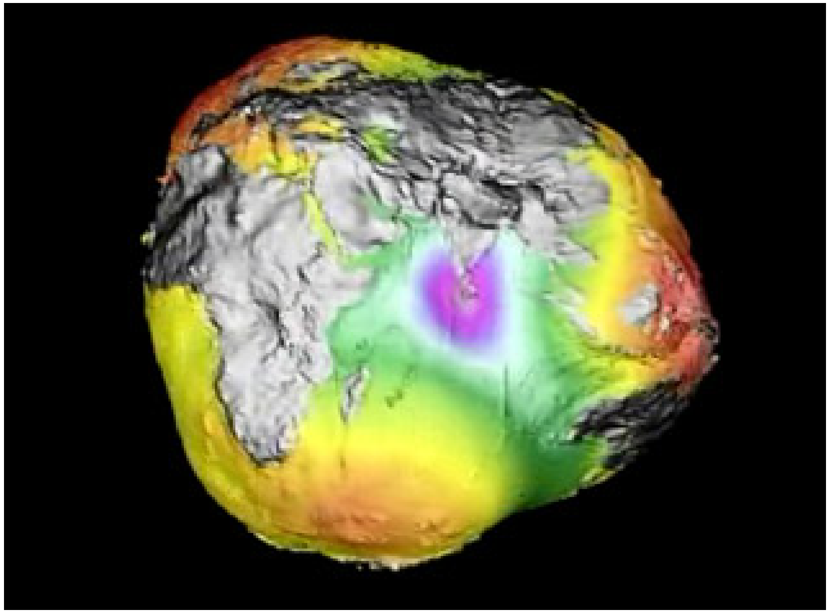


Eliminates (or reduces) the effect of error sources, like:

- orbit and clock error;
- tropospheric error (for short baselines)

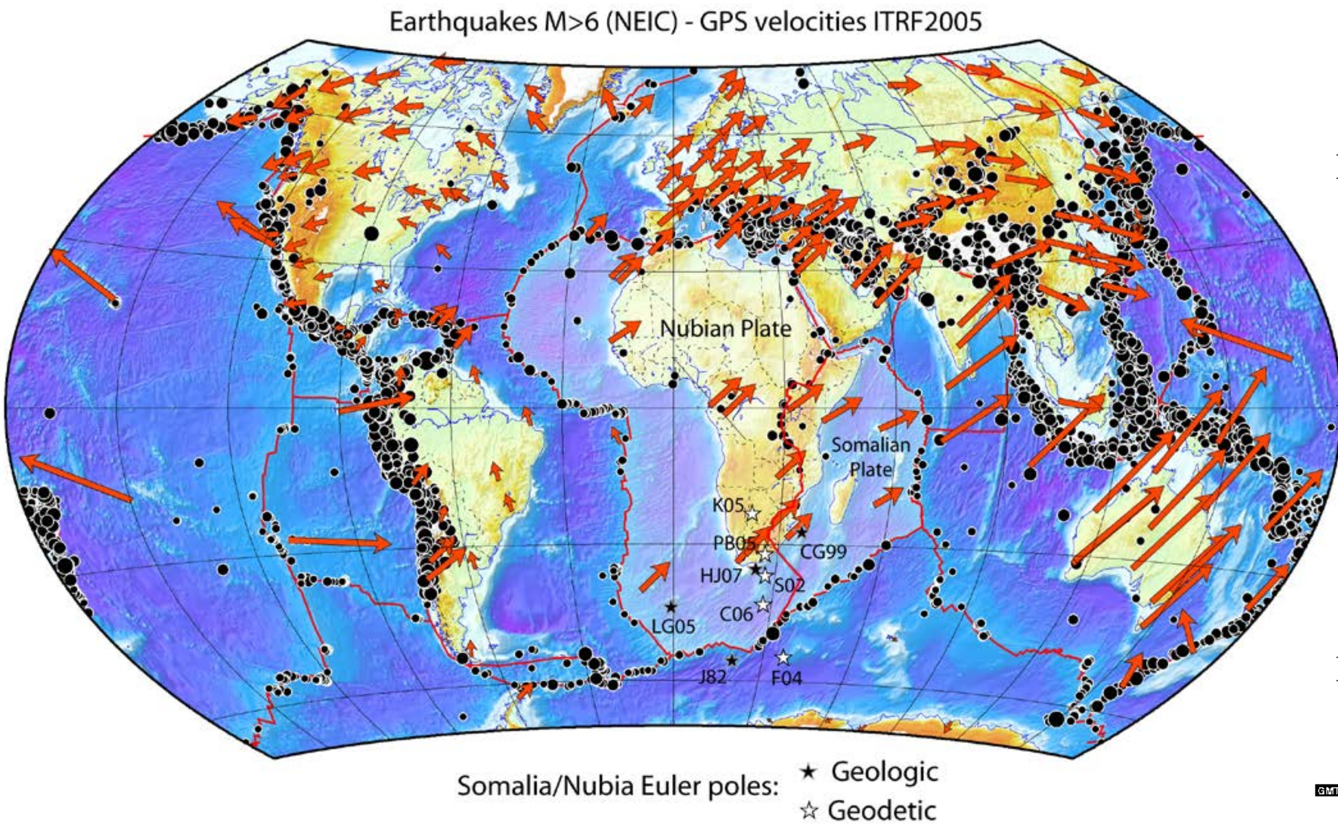
Ellipsoid v/s Geoid

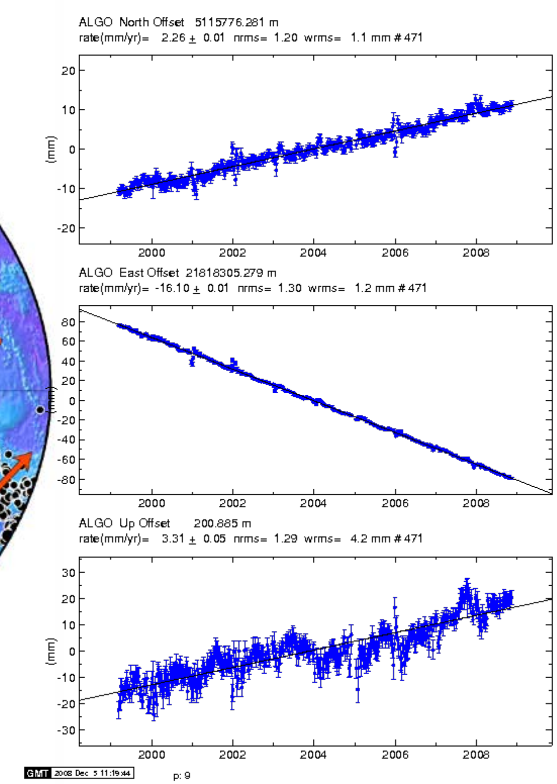




- Géoide = equi-potential surface (complex shape) : 0 ~ mean sea level
- Ellipsoïd = simple mathematical surface used in the definition of the global coordinates systems
- For a given point, latitude, longitude and altitude (elevation) are different from an ellipsoid to another
- Ellisoidal height and Altitude (above Geoid) are different

Plate velocities determined with GPS

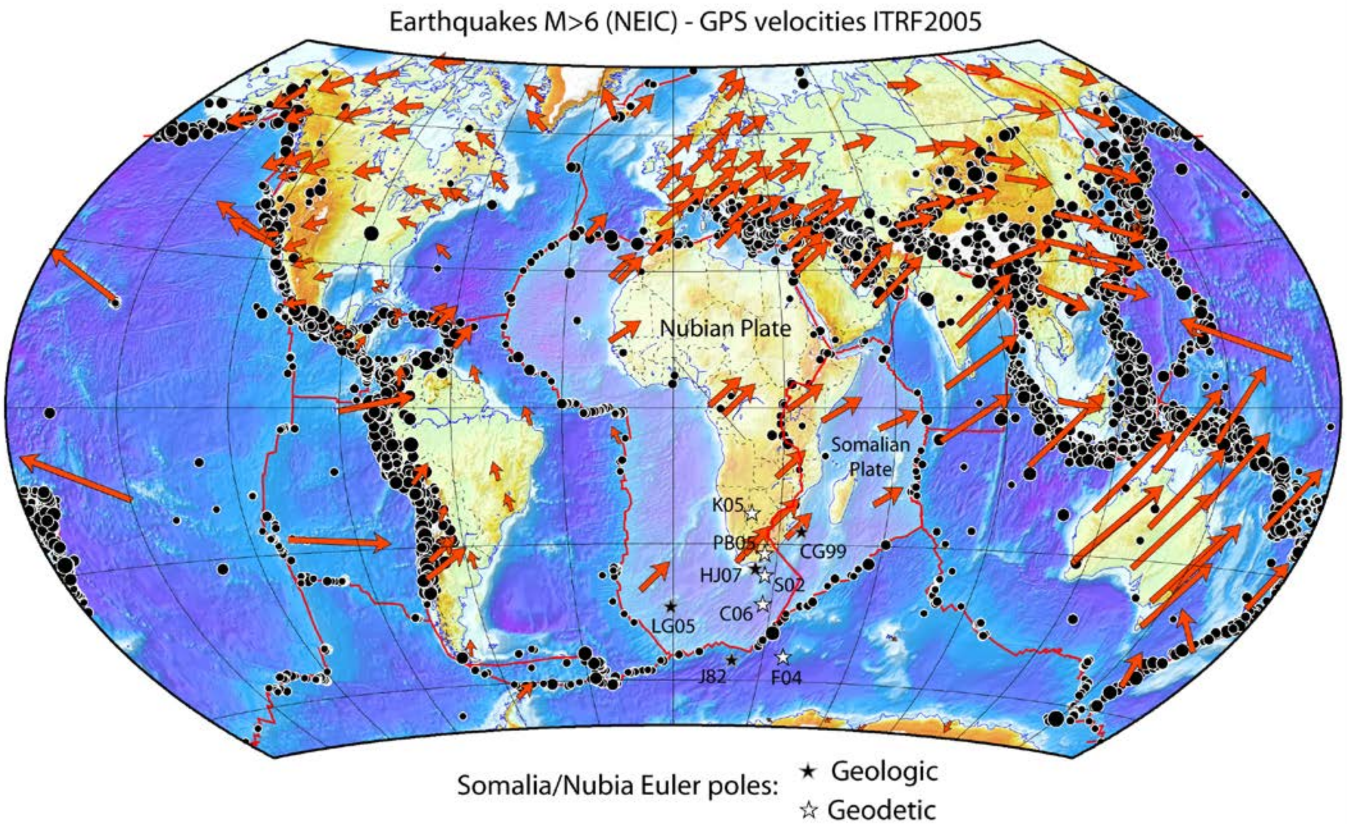


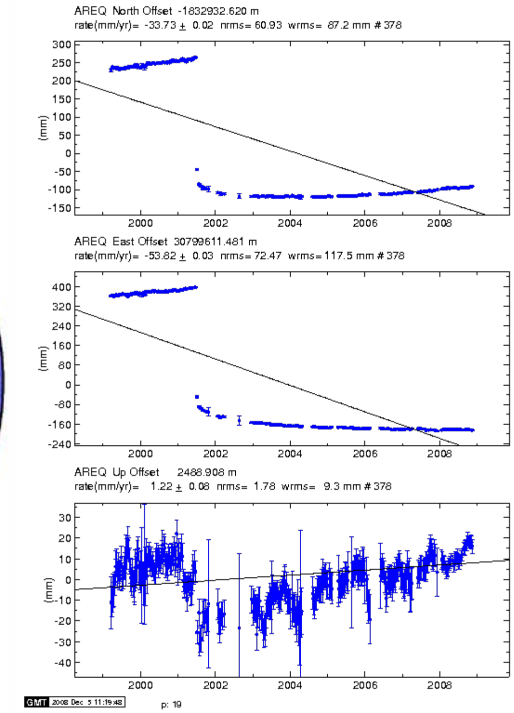


The available time series of coordinates at several thousands of permanent stations allow th map the global plate tectonics of Earth

Velocities plotted with respect to a « Earth mantle » reference frame (defined using the location and trajectory of the hot-spot volcanoes

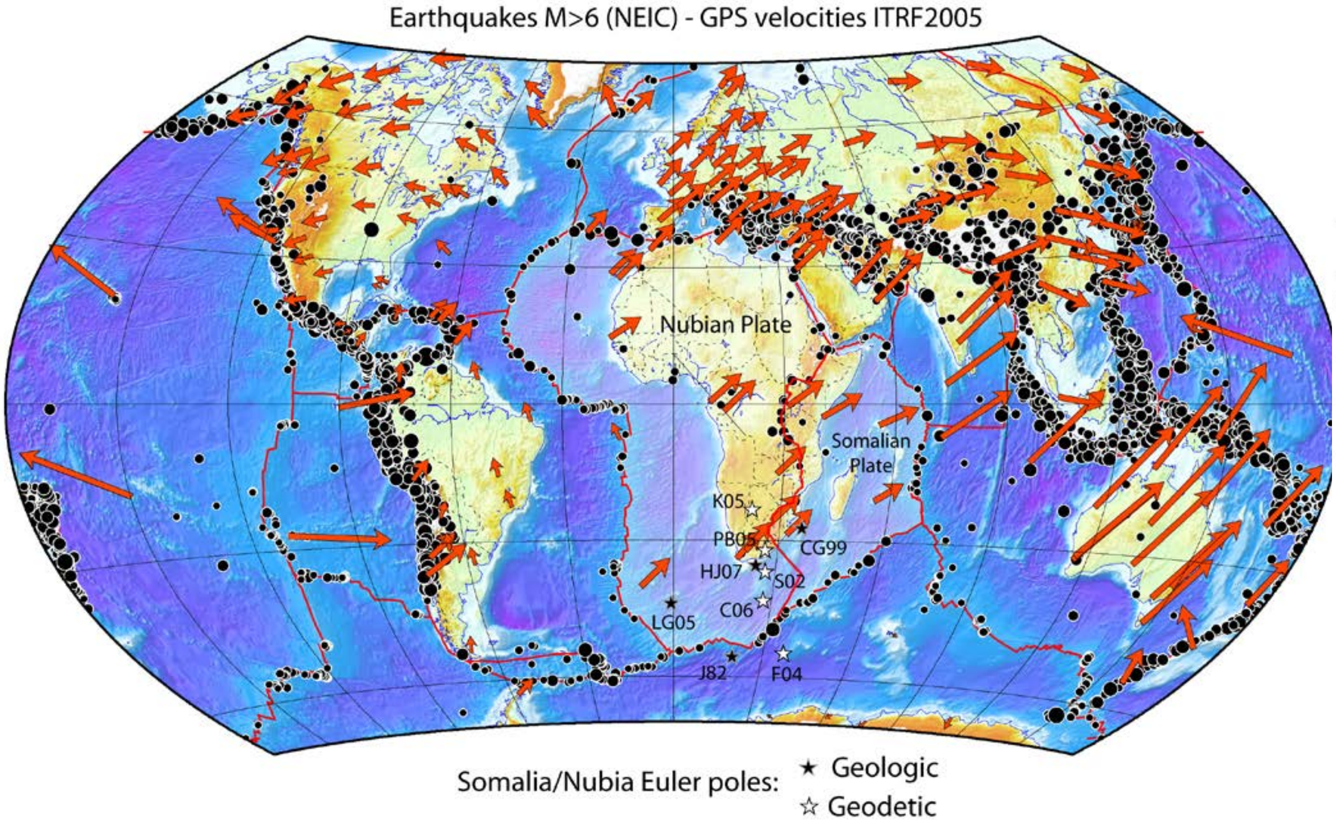
There are velocity transients

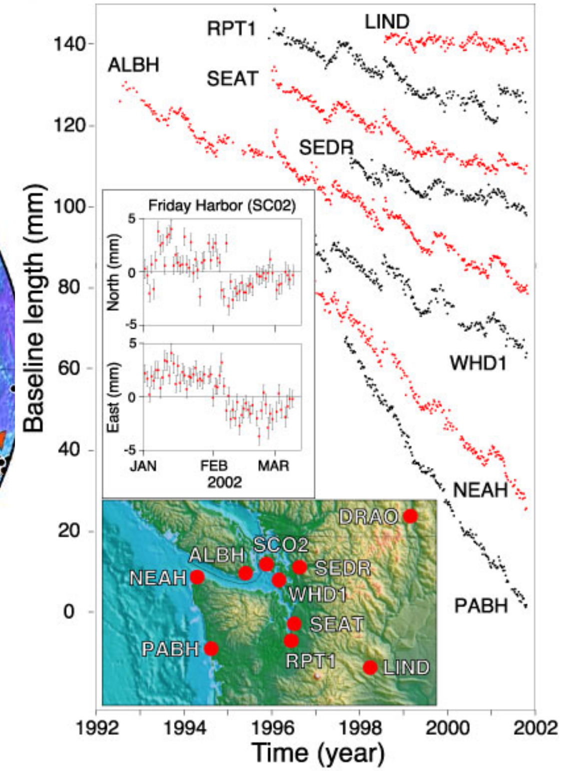




Associated with earthquakes (here a subduction earthquake in Peru in 2001)

There are velocity transients

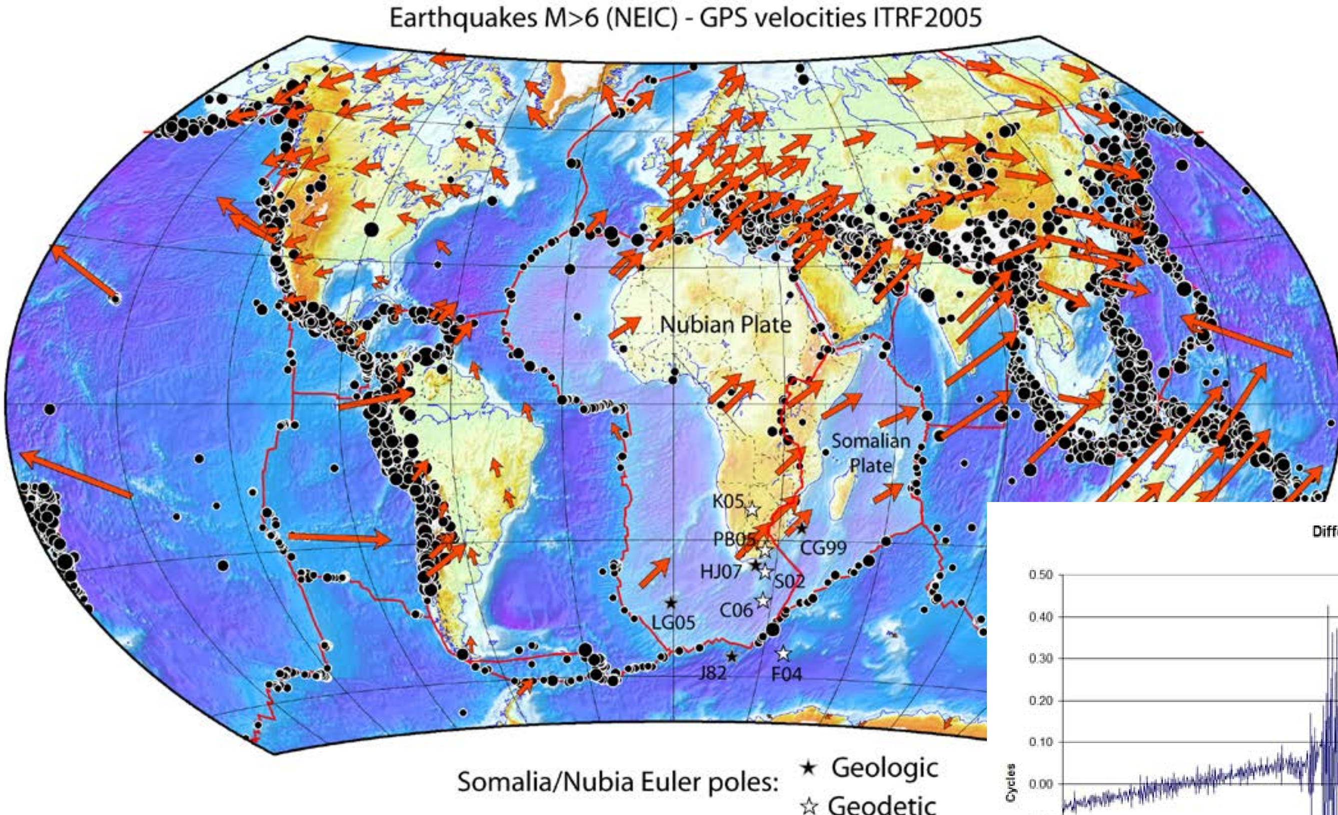




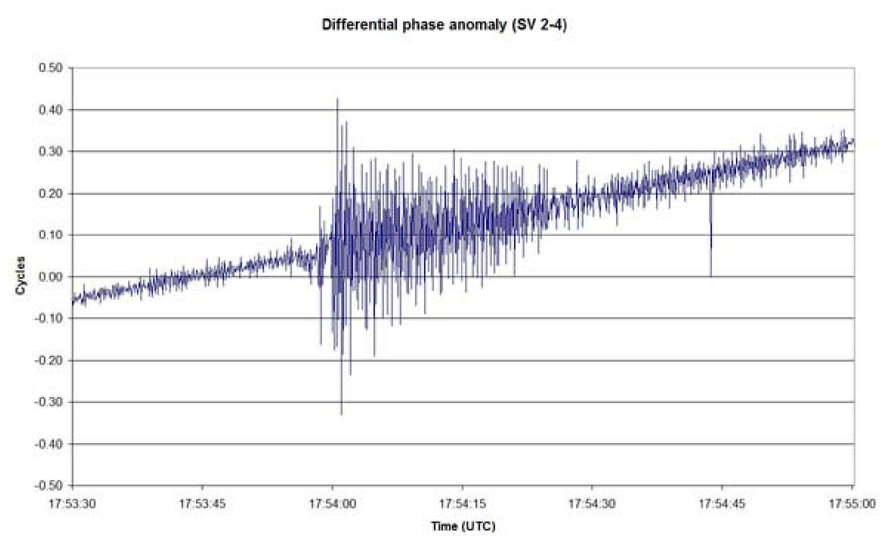
Velocities gradients measured by GPS in the Cascades (USA) (Miller et al., 2002)

Showing the (previously unknown) existence of “silent” earthquakes

There are coordinates transients

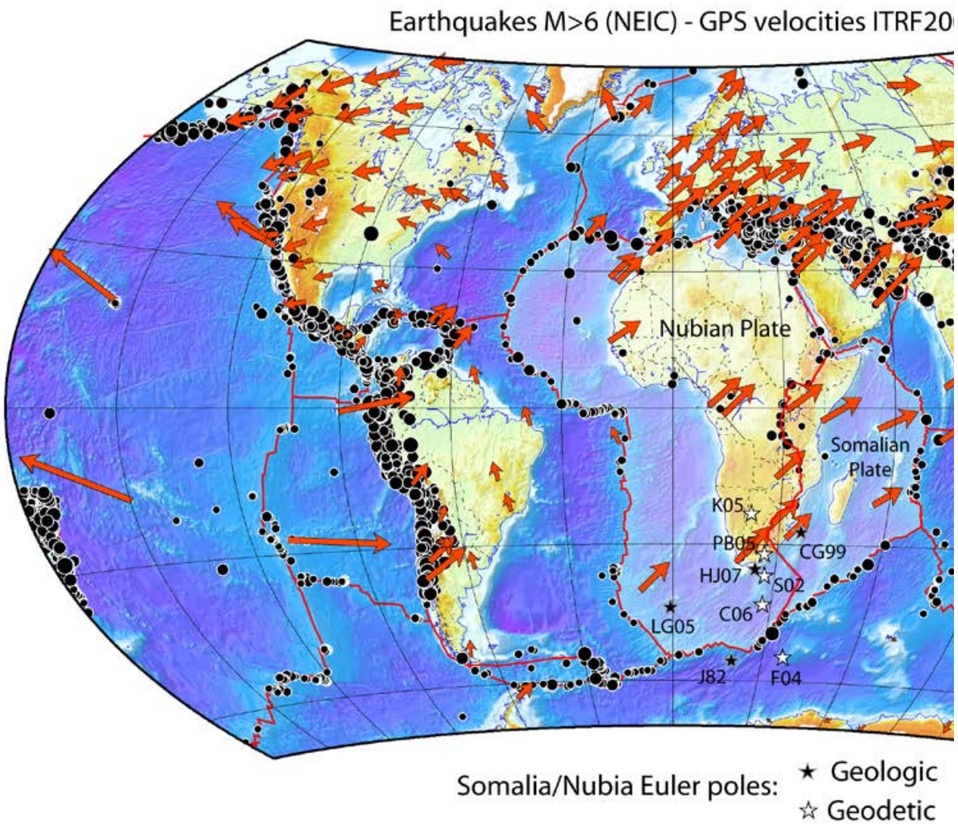


During earthquakes

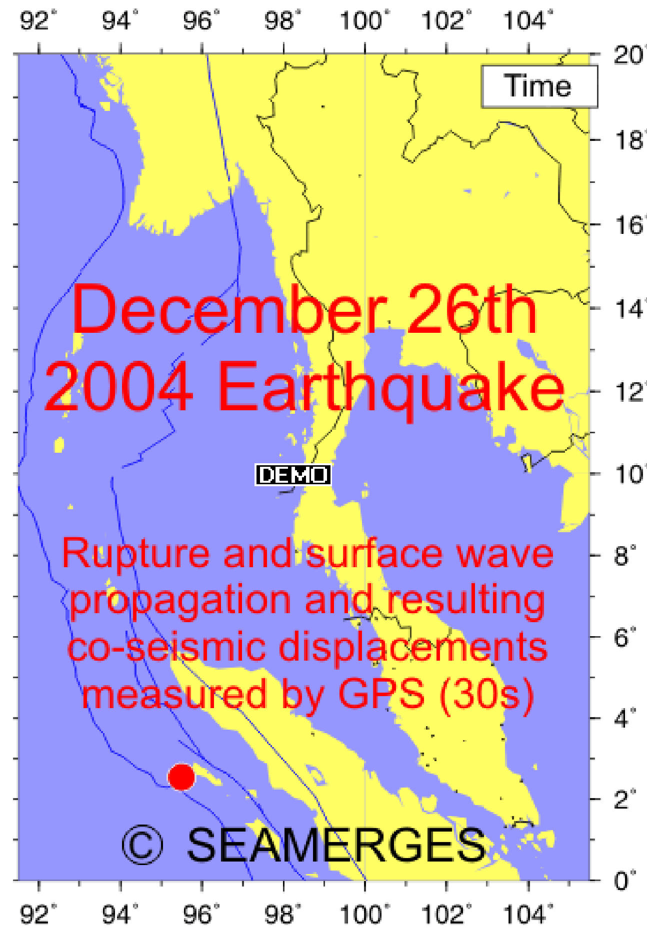


Aysen earthquake, Chile (M=6.2), 21 April 2007, C. Vigny, ENS

There are coordinates transients



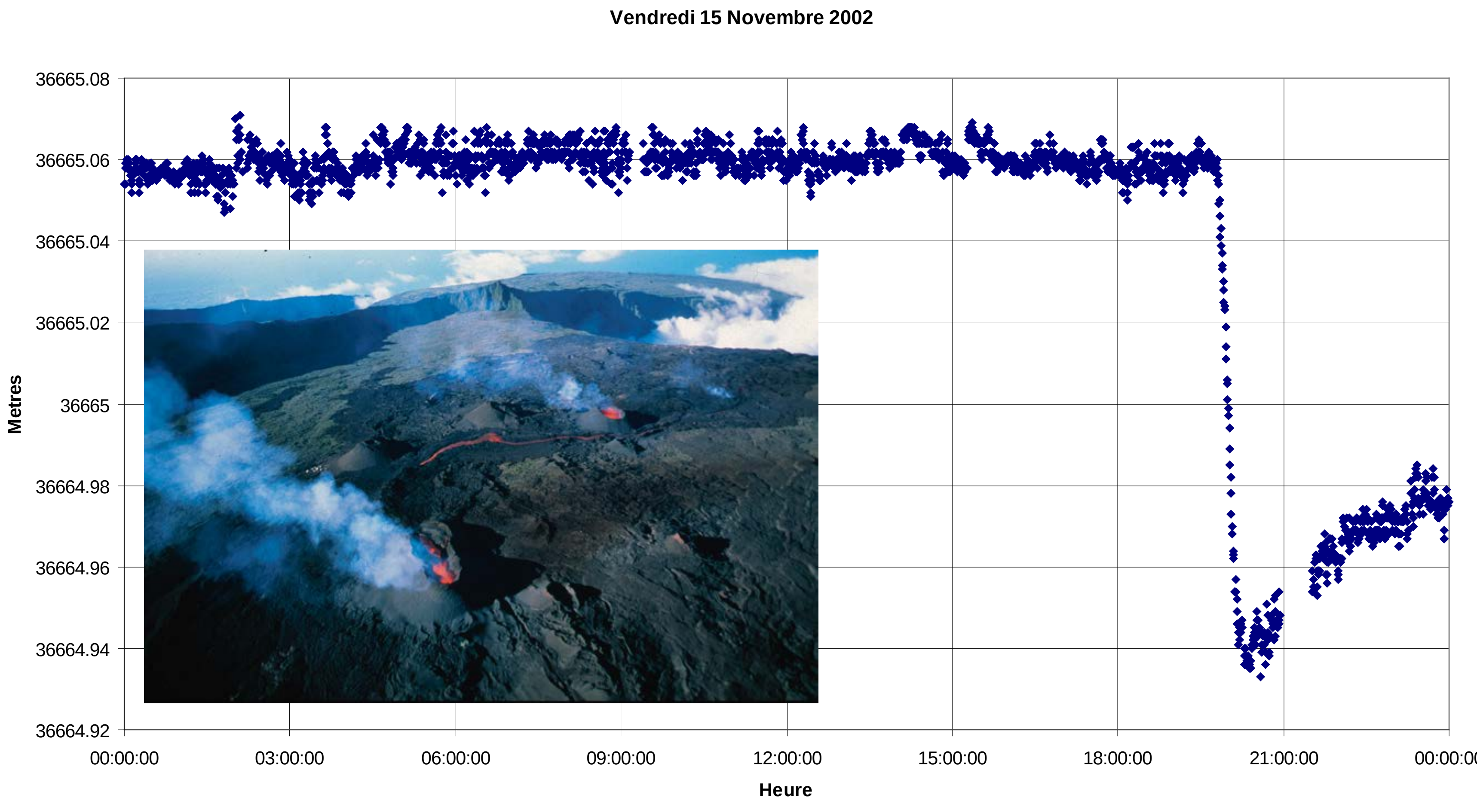
During earthquakes



http://www.deos.tudelft.nl/seamerges

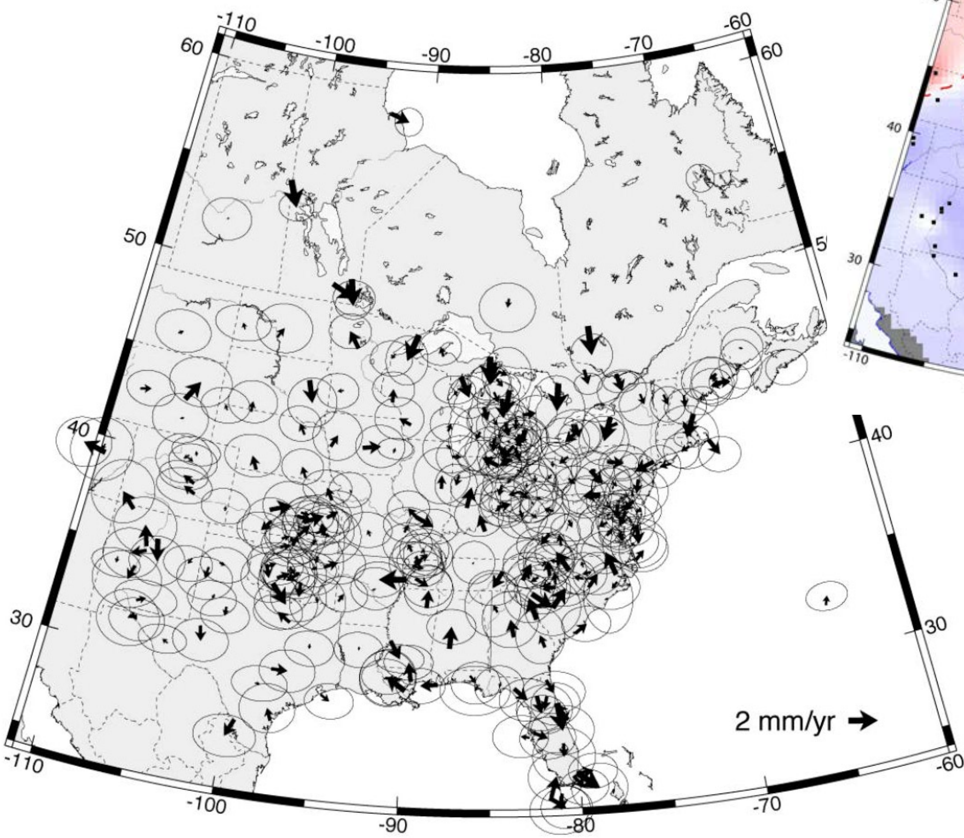
GPS displacements during the Sumatra earthquake (2004)

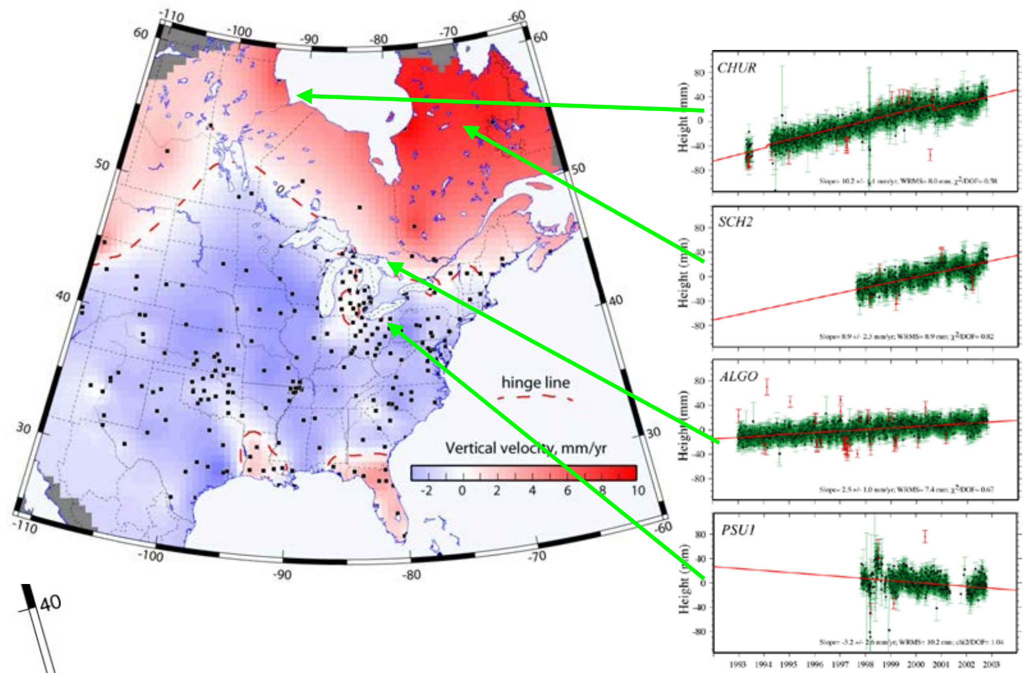
Transient GPS displacement during the start of a volcanic eruption



Deformation associated with a dyke injection at Piton de la Fournaise volcano (France)

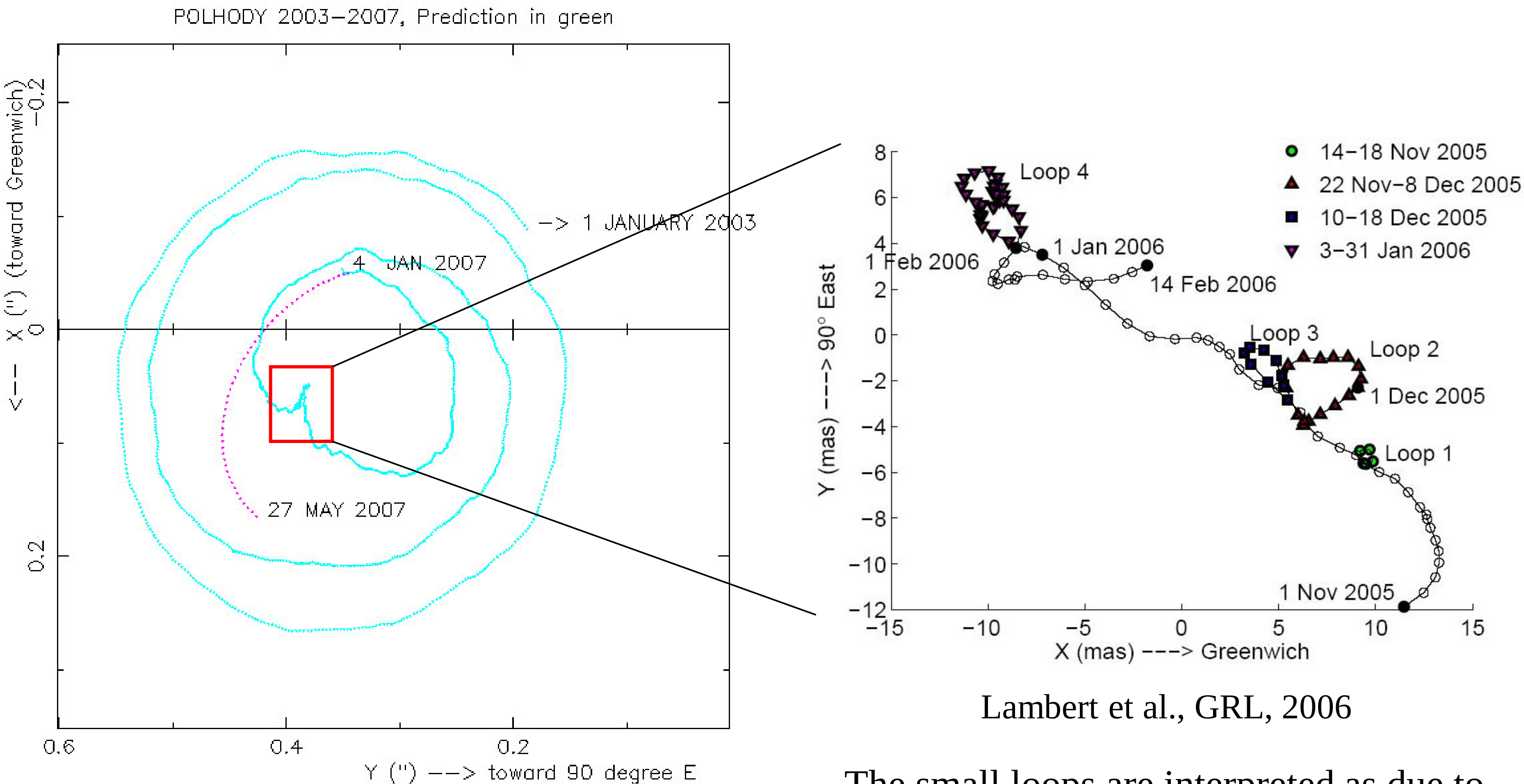
Post-glacial rebound





Deformation of the North American Plate Interior from a Decade of Continuous GPS Measurements E. Calais et al., JGR, 111, 2006

Variations of the Earth rotation



IERS – Solution C04

Lambert et al., GRL, 2006

The small loops are interpreted as due to the motion of large atmospheric masses (meteorological effect)

Sounding the plume of Miyake-jima volcano (Japan) using GPS

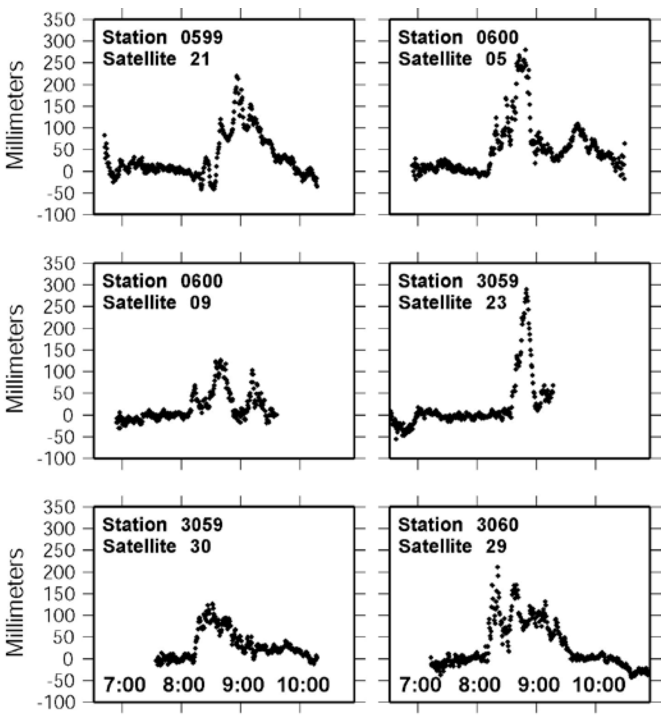


Figure 4

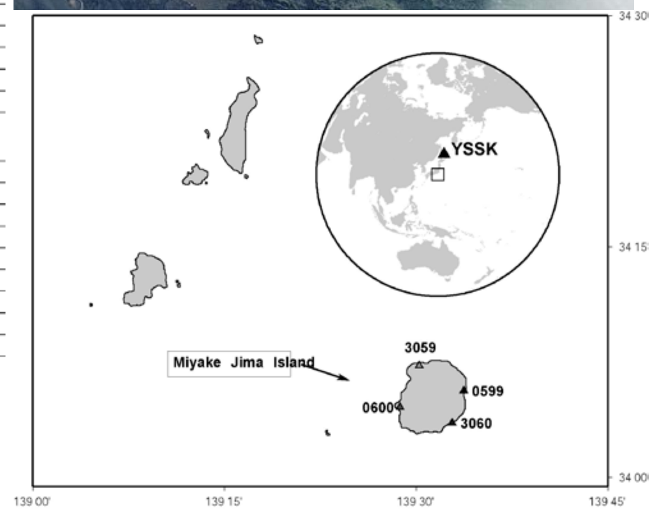


Figure 1

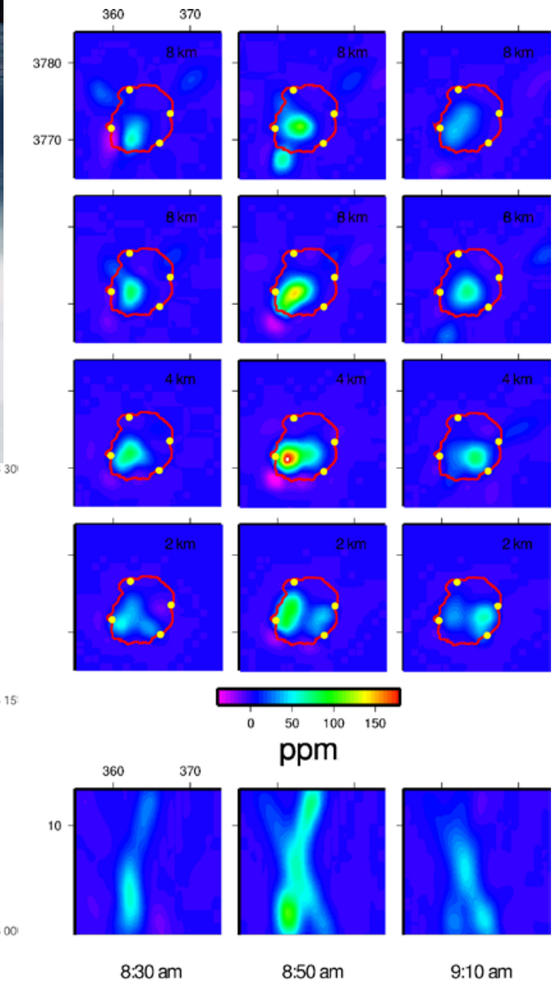
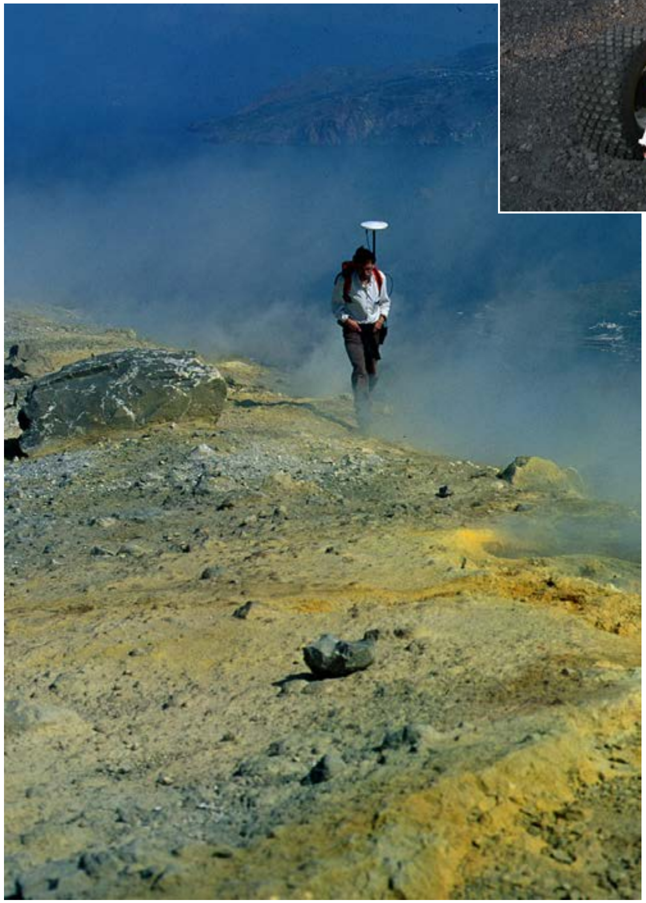
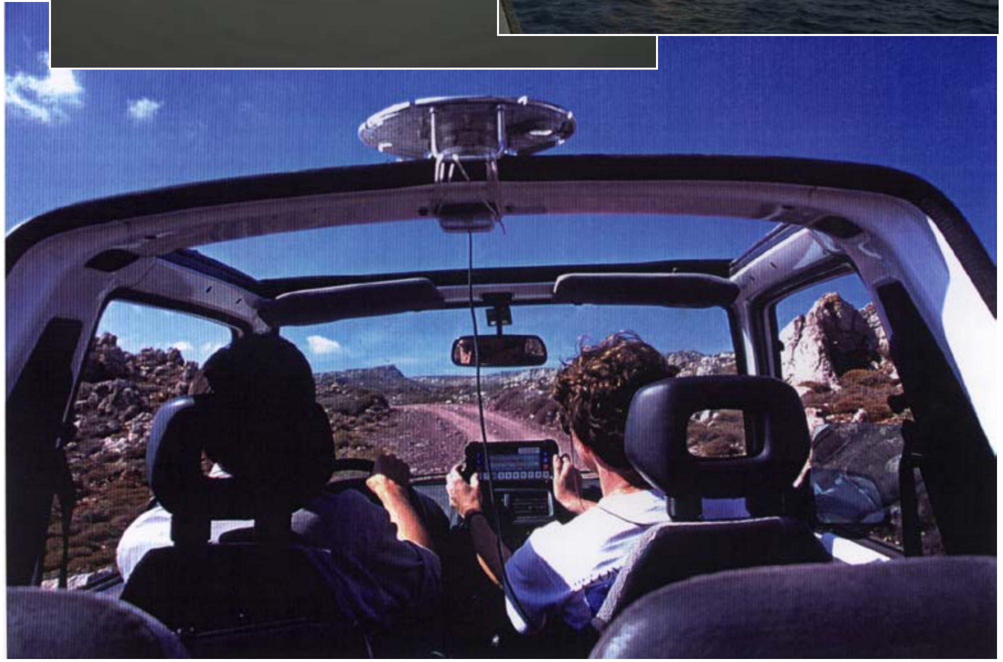


Figure 5

Kinematic GPS

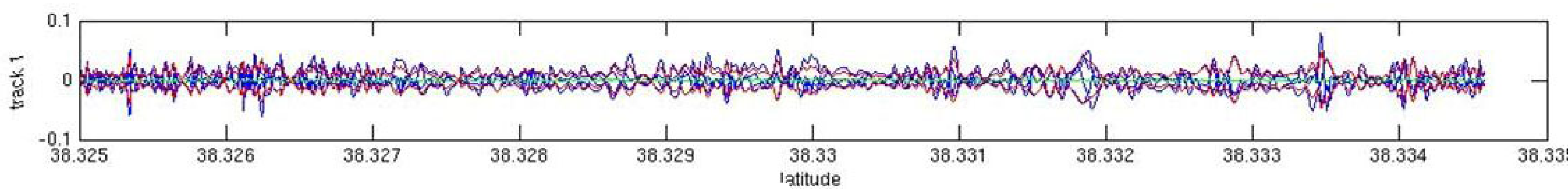




Need to define a reference surface and an average antenna height with respect to it

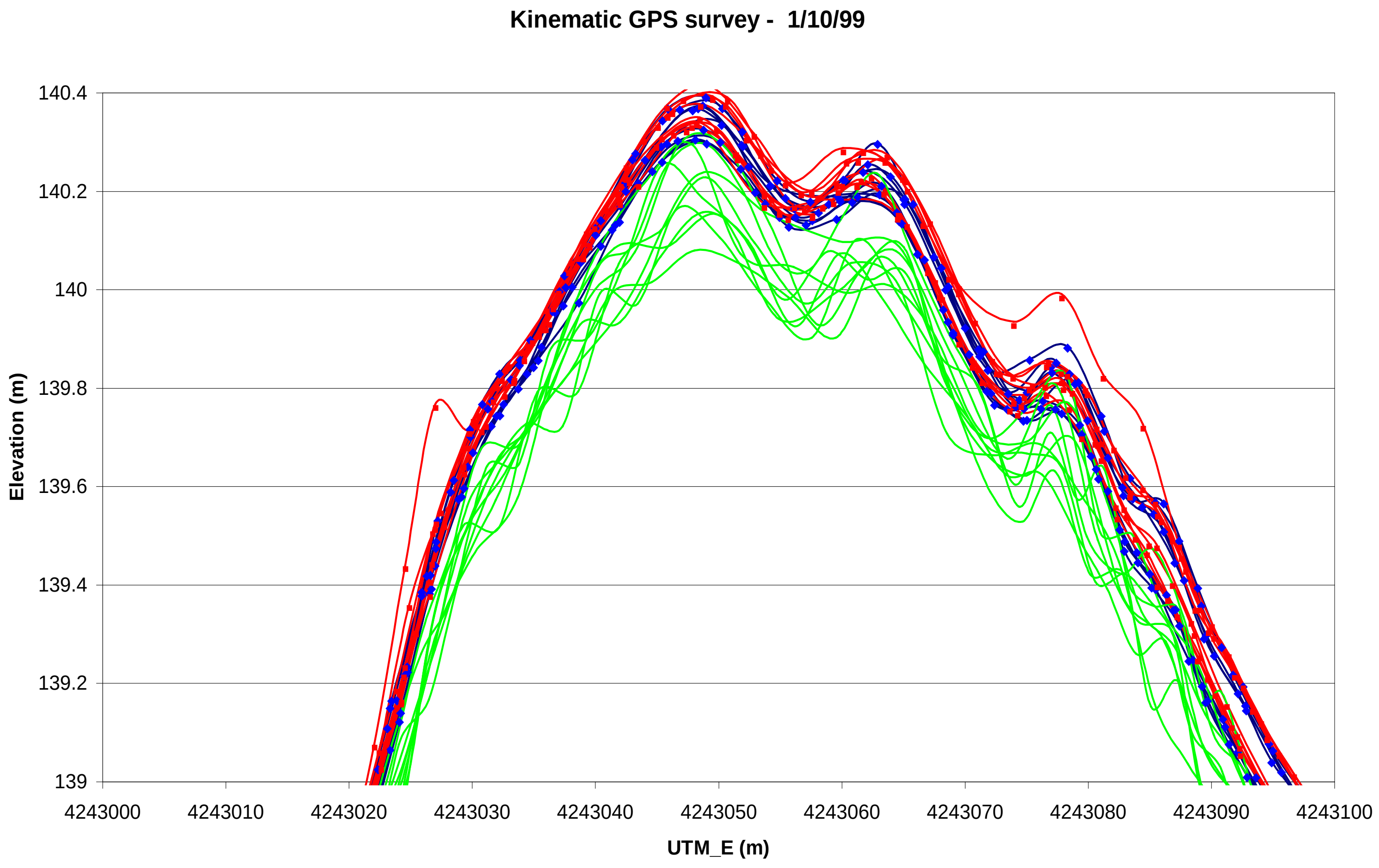
« Road » kinematic

0.2 m

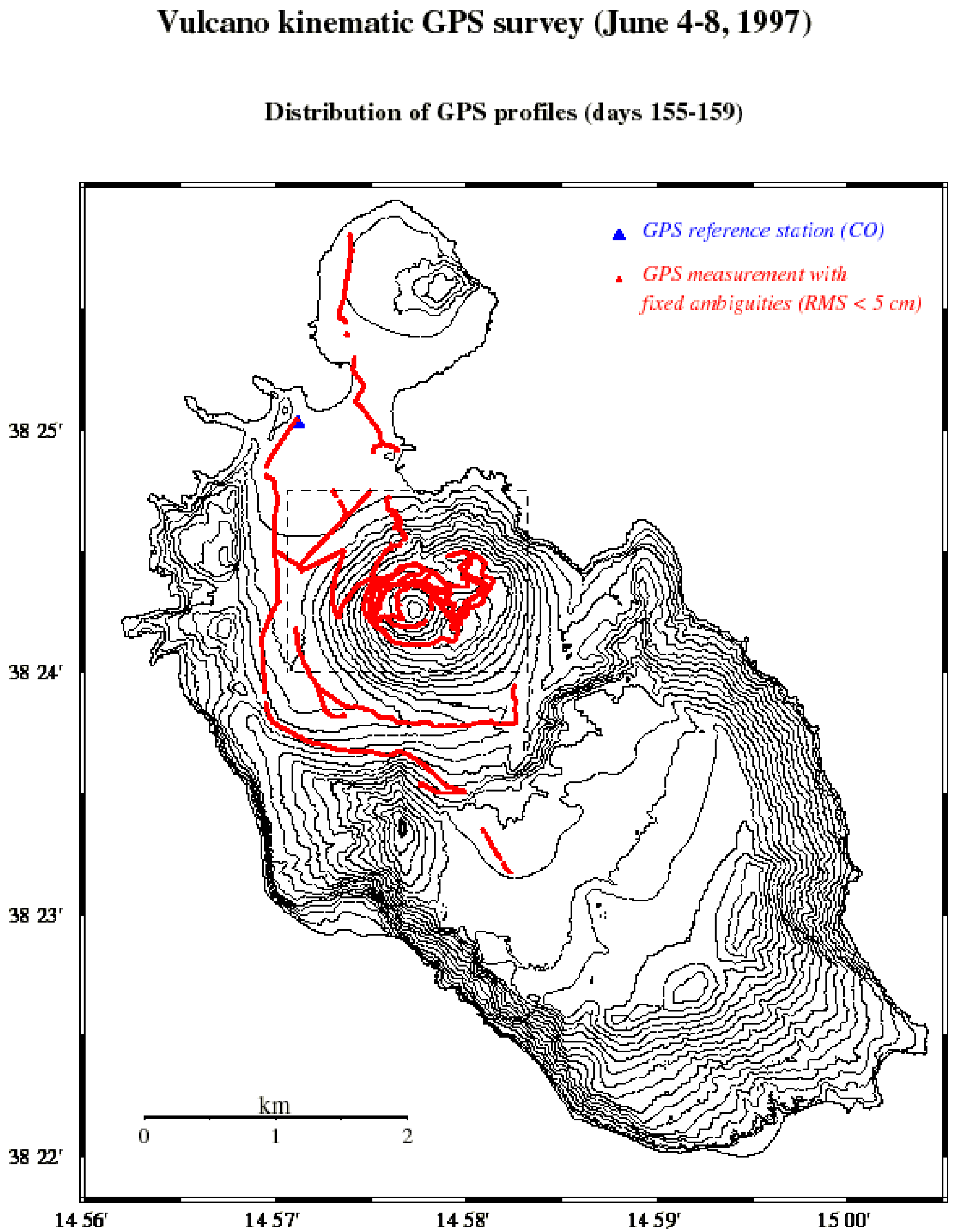


Repeatibility

Kinematic GPS - Simulated displacement + noise 10cm r.m.s.

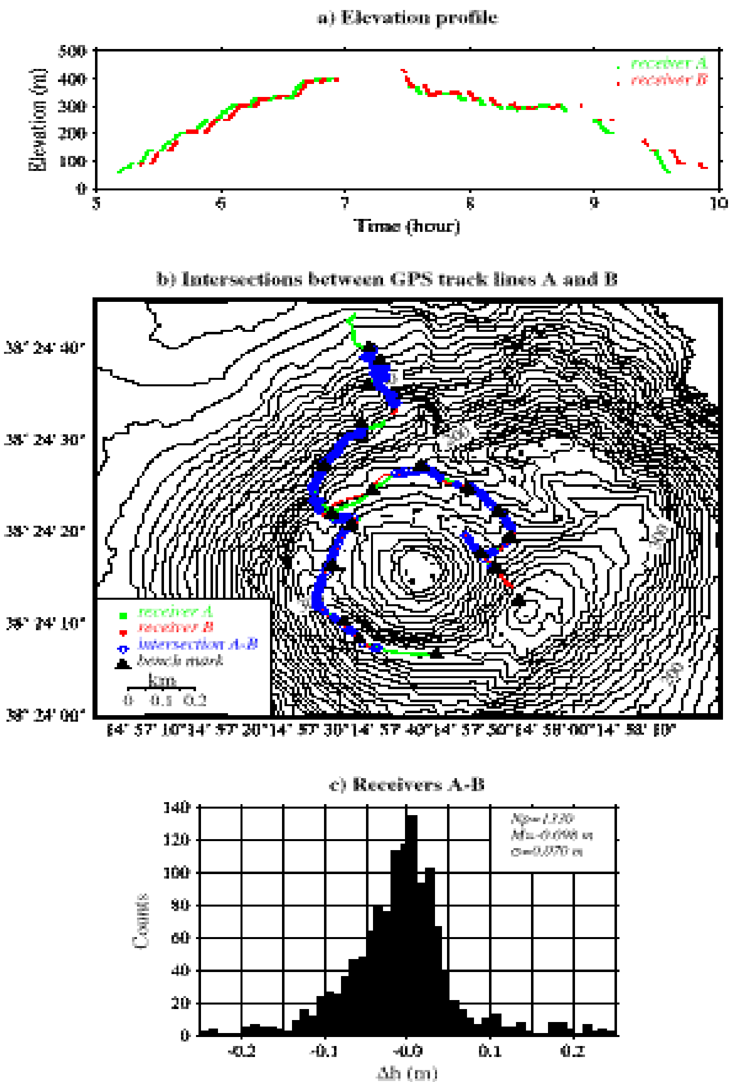


Topography measurements

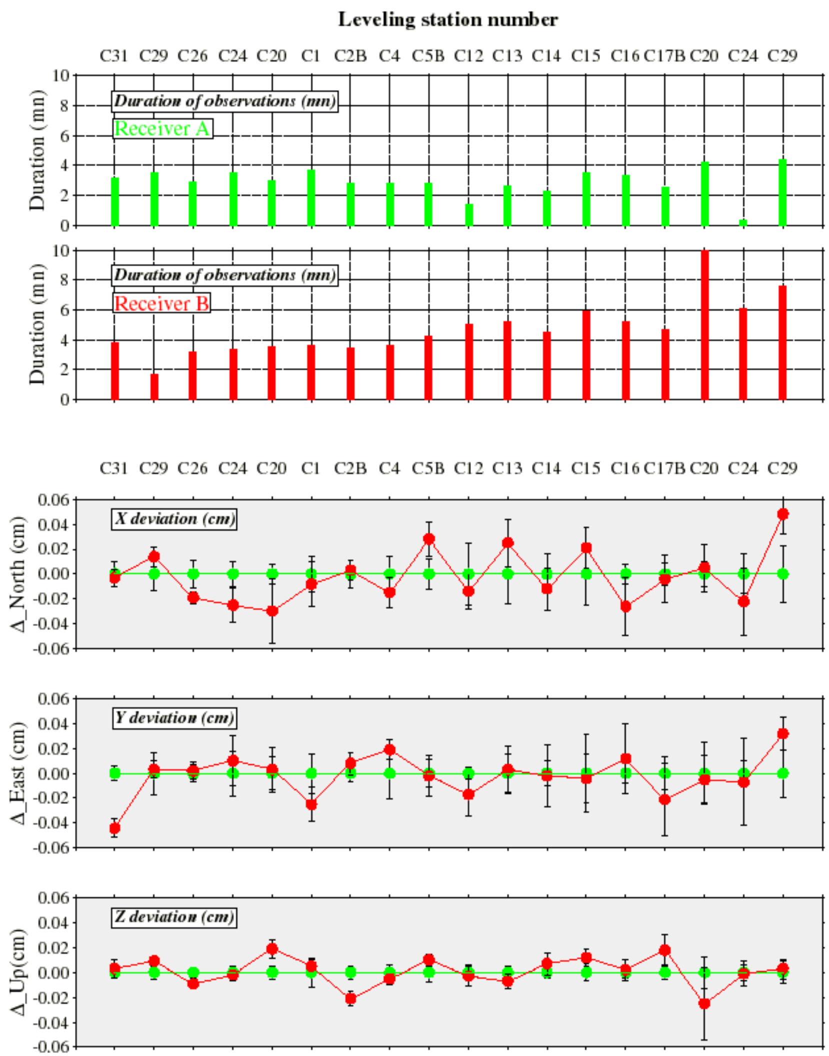


Assessment of the repeatability and accuracy

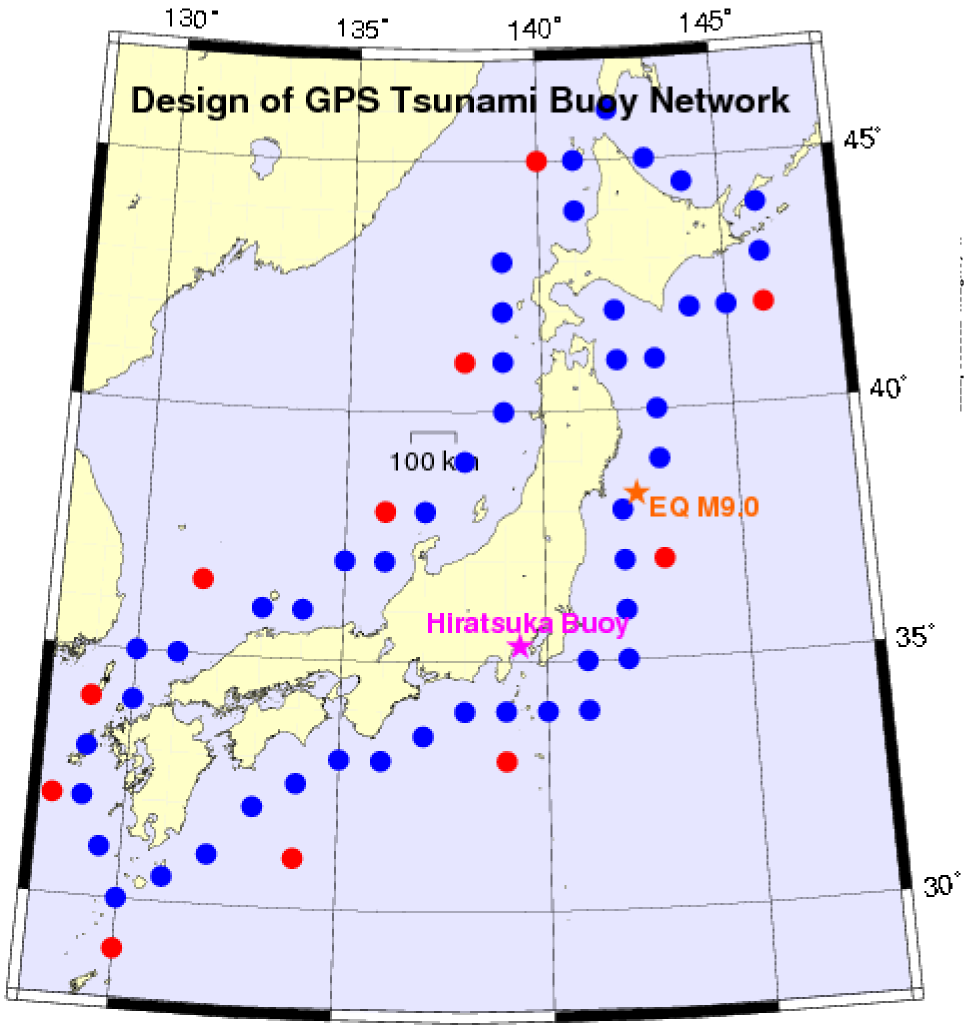
COE analysis of kinematic measurements (day 158)



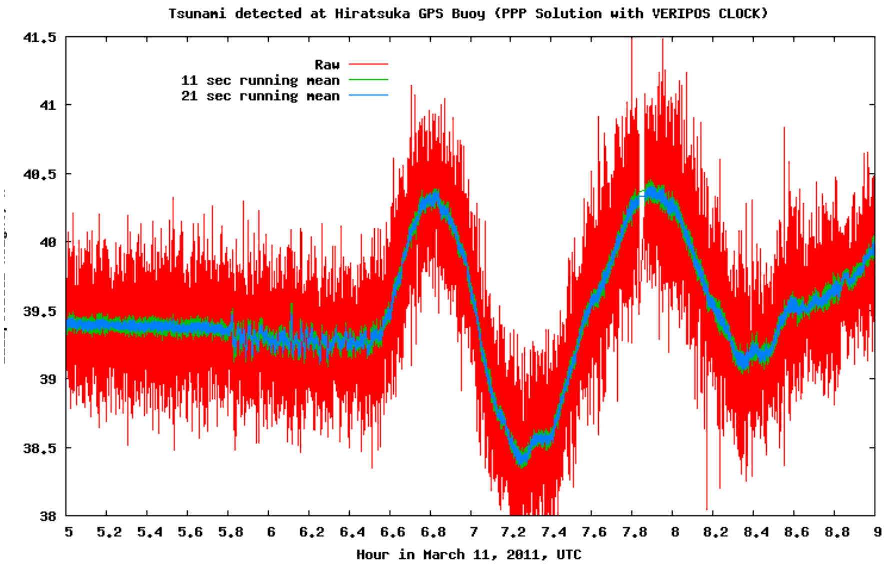
Intercomparison of kinematic measurements (day 158)



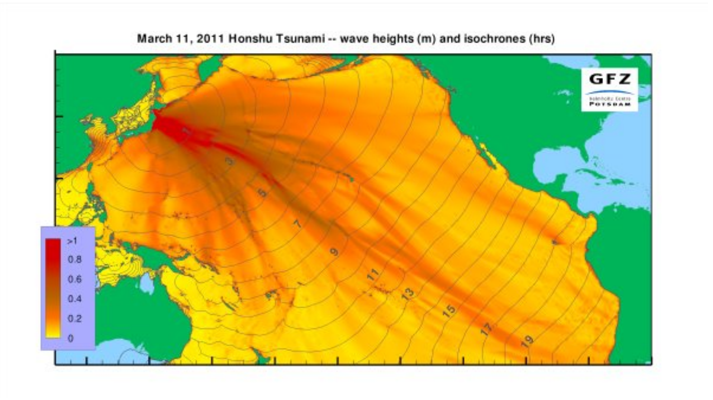
GPS on buoy



Design of GPS Tsunami Buoy Network
130°
135°
140°
145°
45°
40°
35°
30°
100 km
EQ M9.0
Hiratsuka Buoy

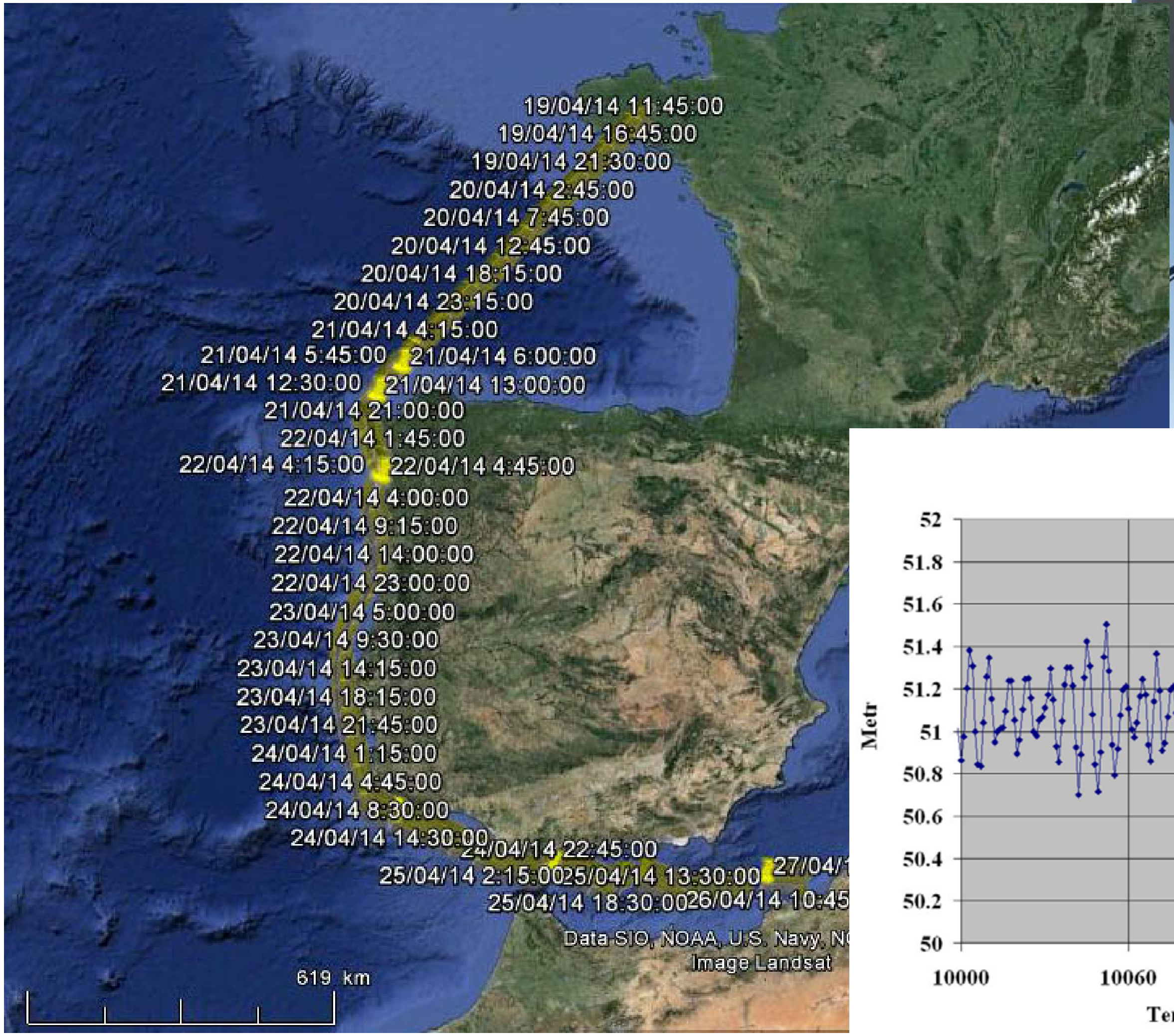


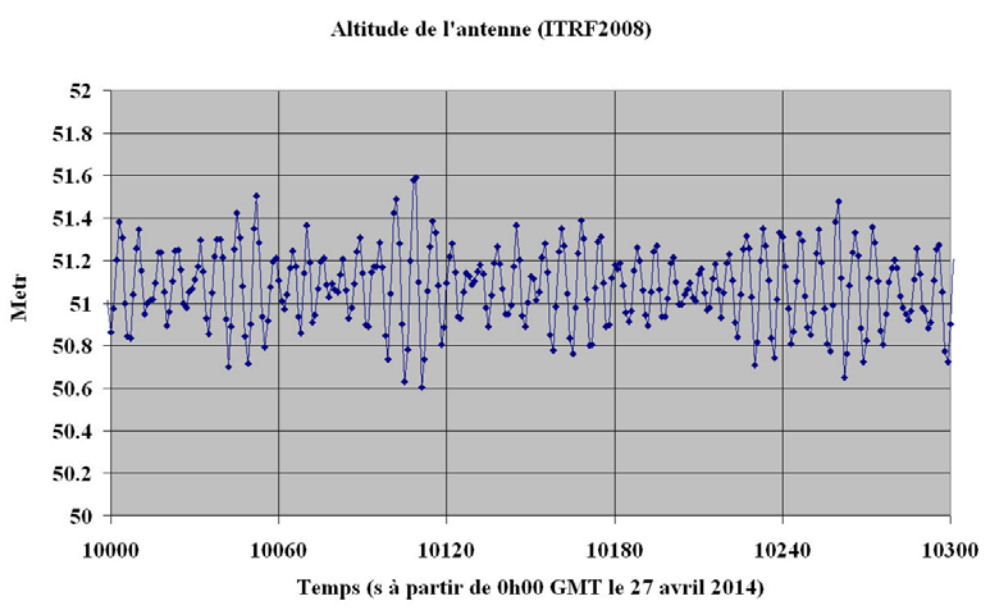
Tsunami detected at Hiratsuka GPS Buoy (PPP Solution with VERIPOS CLOCK)
Raw
11 sec running mean
21 sec running mean
41.5
41
40.5
40
39.5
39
38.5
38
5 5.2 5.4 5.6 5.8 6 6.2 6.4 6.6 6.8 7 7.2 7.4 7.6 7.8 8 8.2 8.4 8.6 8.8 9
Hour in March 11, 2011, UTC



March 11, 2011 Honshu Tsunami -- wave heights (m) and isochrones (hrs)
GFZ
>1
0.8
0.6
0.4
0.2
0

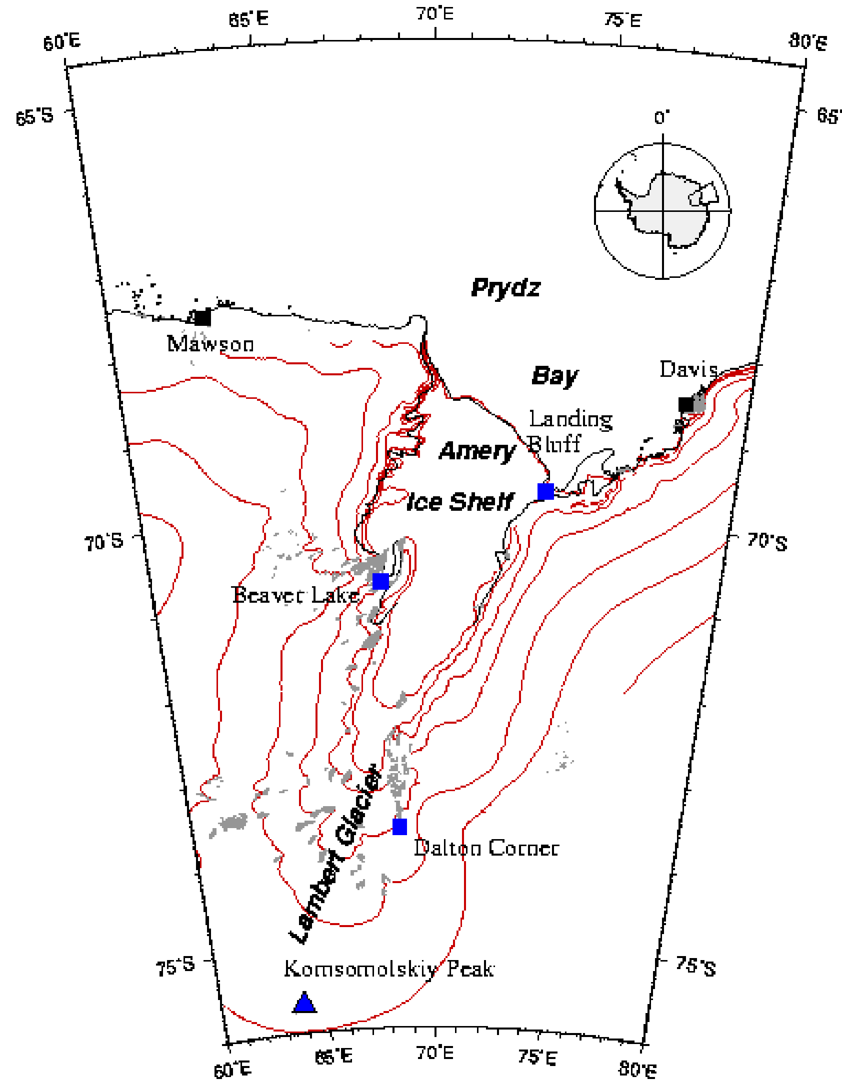
GPS on board of Tara





GPS measurements on glaciers

Monitoring of the Lambert glacier, Antarctic (Australian National University)



Monitoring of alpine glaciers (Glaciologie Grenoble)

The August 12, 2014 experiment

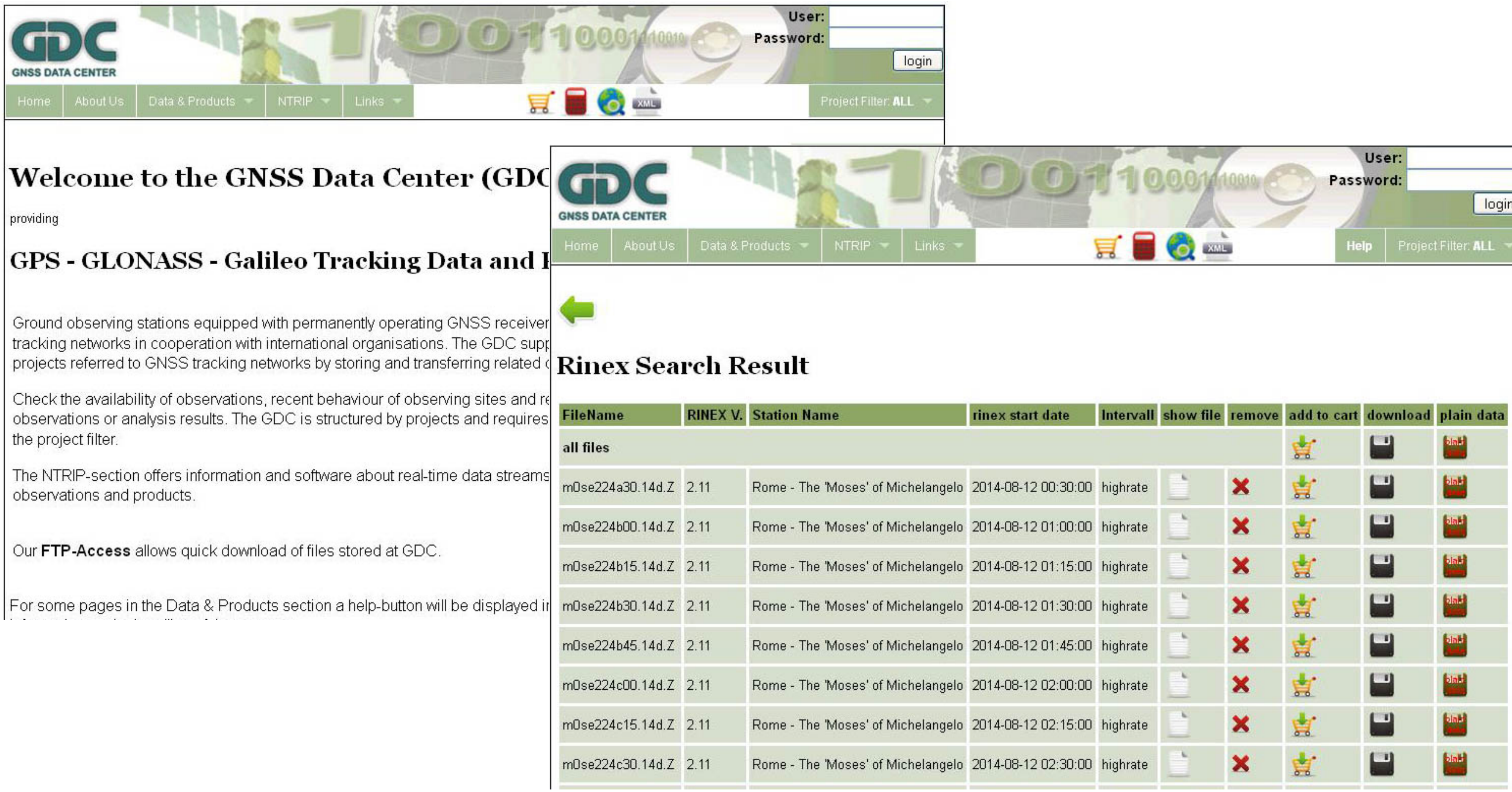
Differential positioning with respect to the GPS station M0SE located in Roma

MOSE is one of the stations of the EUREF network

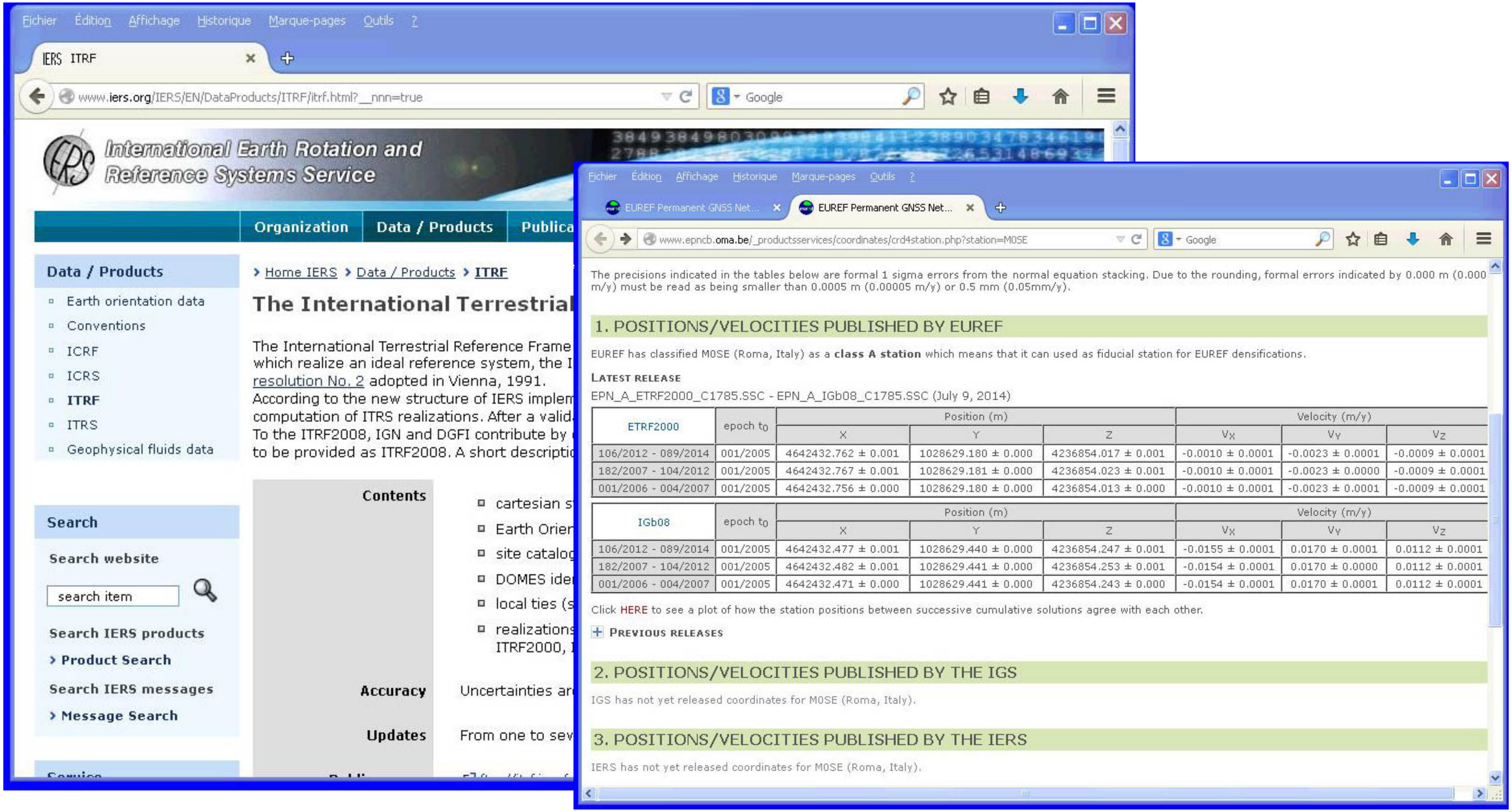
(http://www.epncb.oma.be)

Data available through the EUREF web site (30s) or the GDC web site (1s)

(http://igs.bkg.bund.de/)

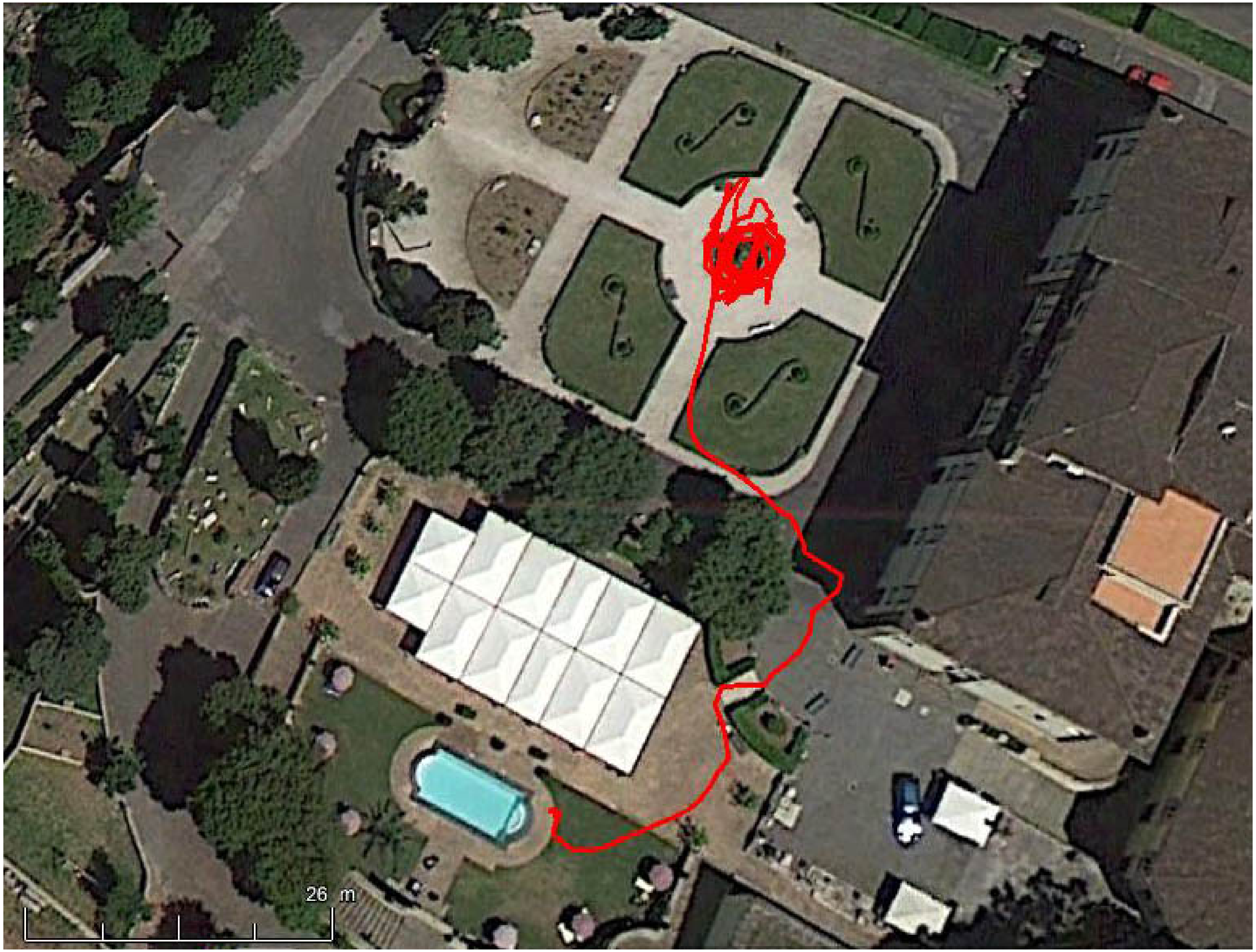


Coordinates of M0SE

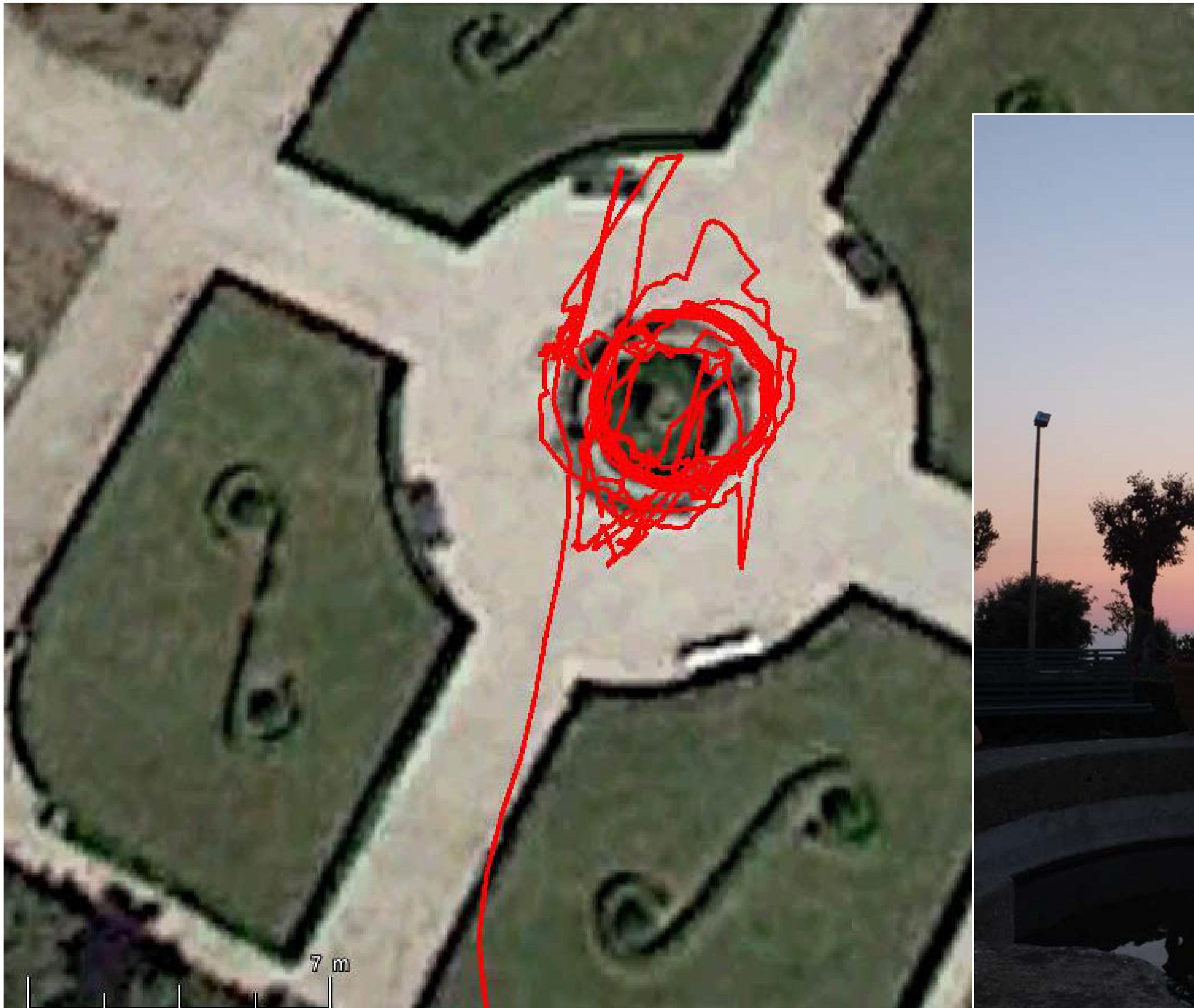


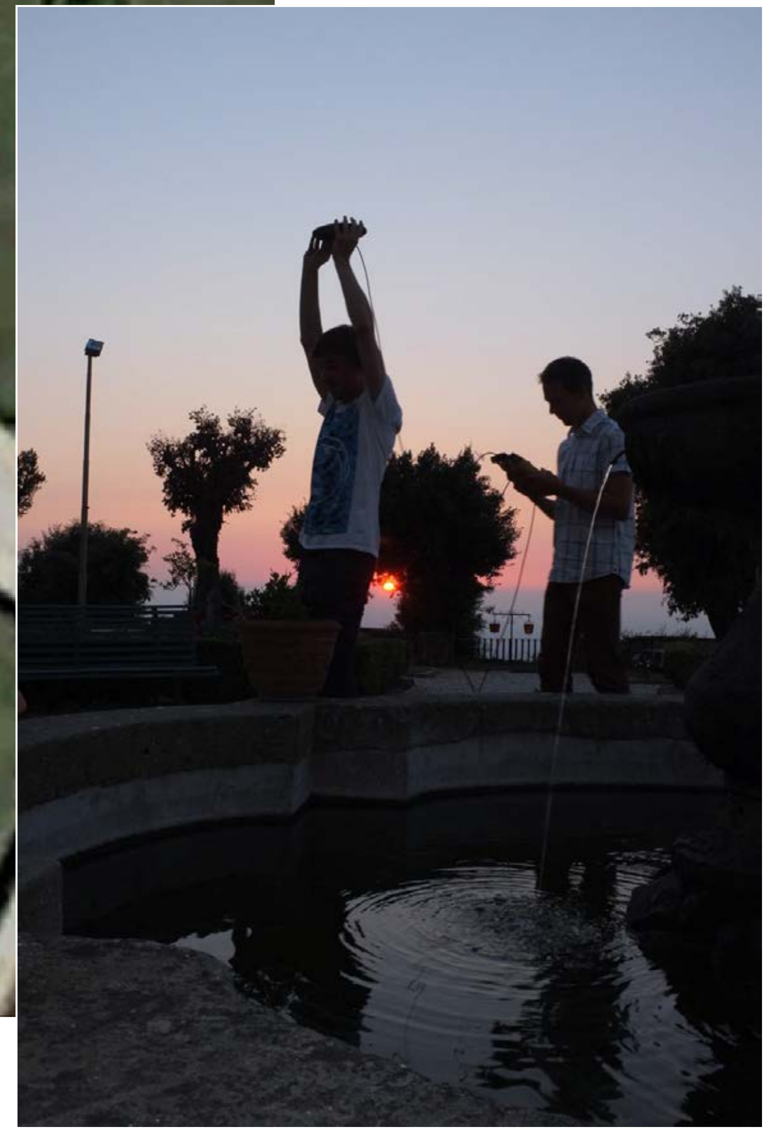
We use the ITRF2008 coordinates (http://itrf.ign.fr/ITRF_solutions/2008/) at the reference epoch (2005.0)

The entire 2 hours measurements

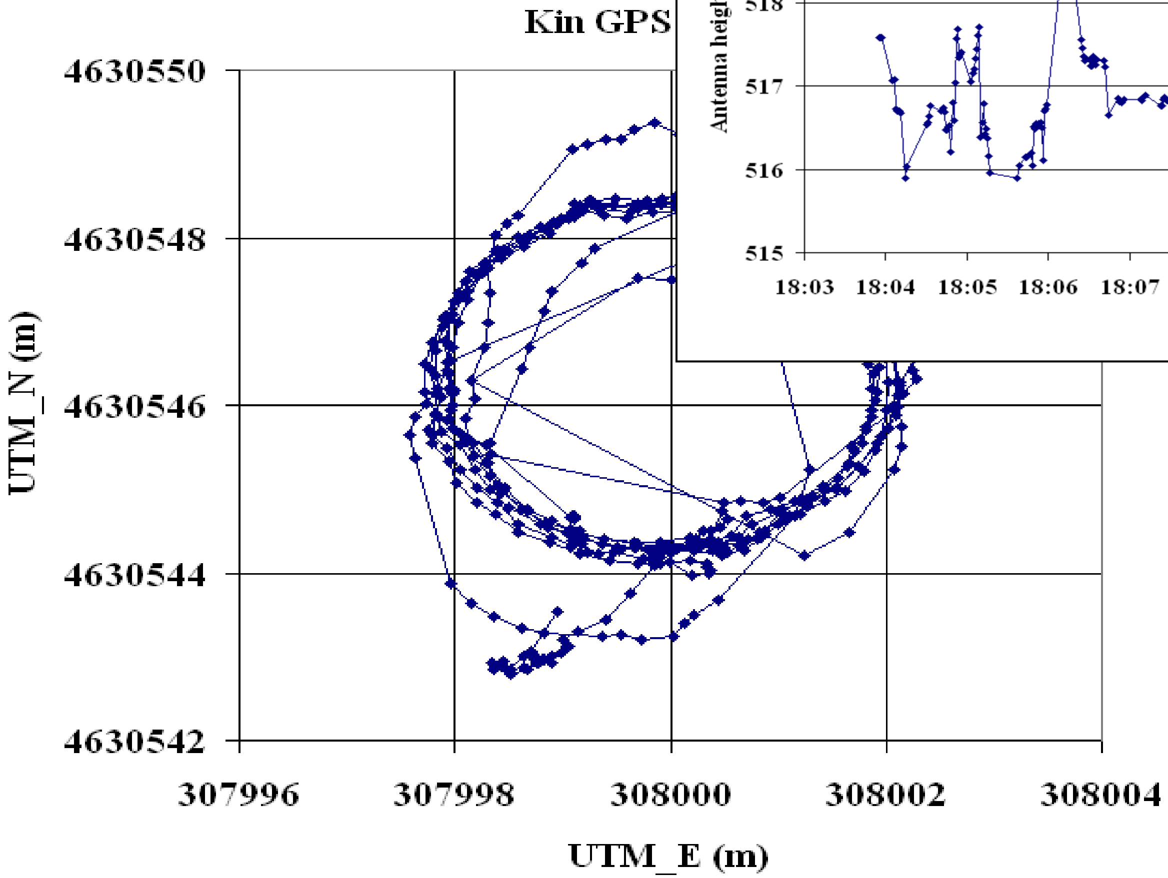


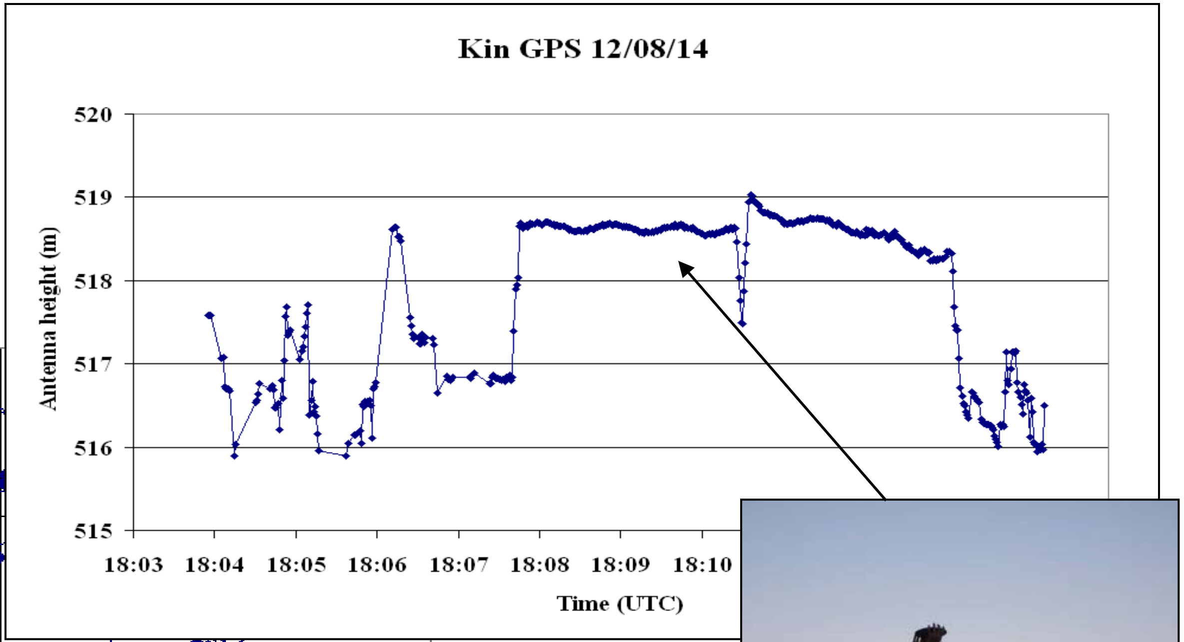
Positioning the fountain



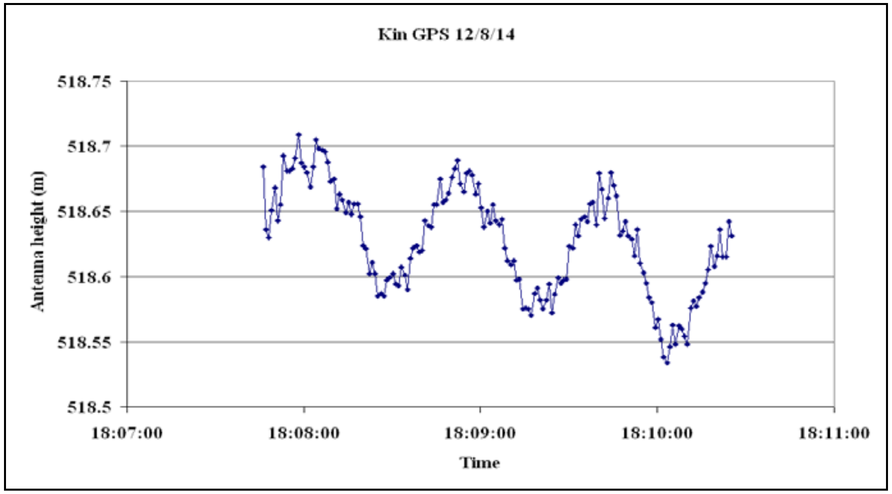


The whole 12mn observations (~10 loops)

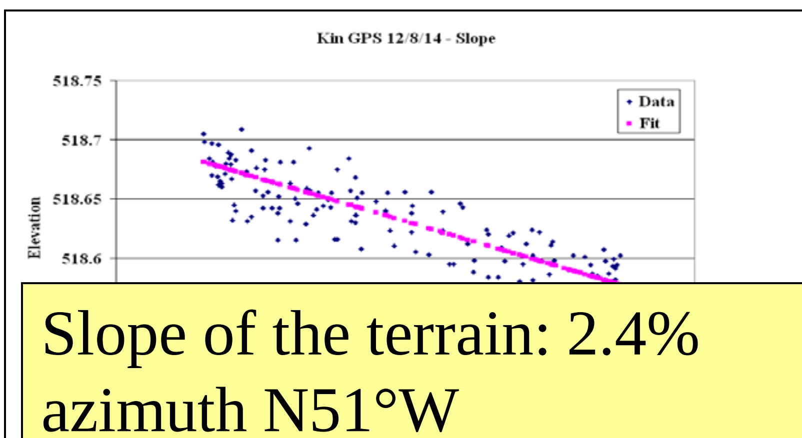




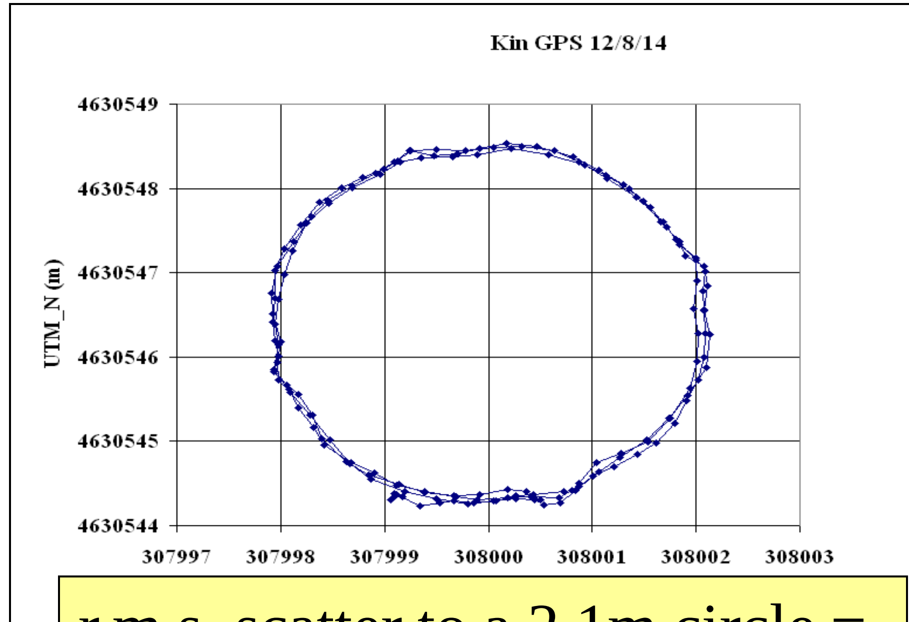
A zoom into the 3 best minutes (3 loops)



Antenna height decreases with time (operator?)

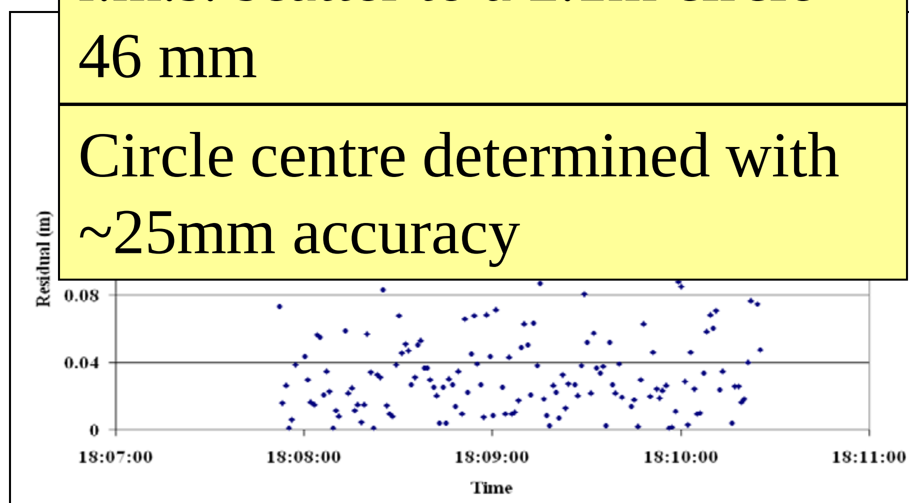


Slope of the terrain: 2.4% azimuth N51°W

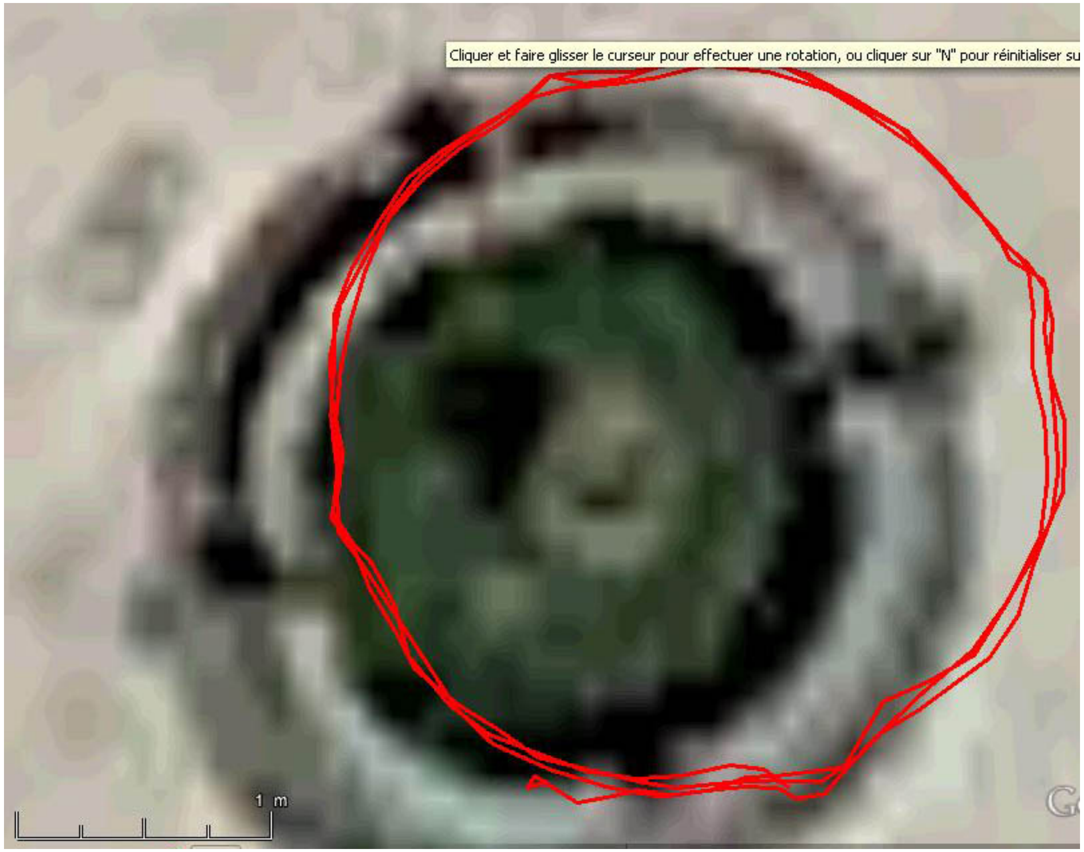


r.m.s. scatter to a 2.1m circle = 46 mm

Circle centre determined with ~25mm accuracy

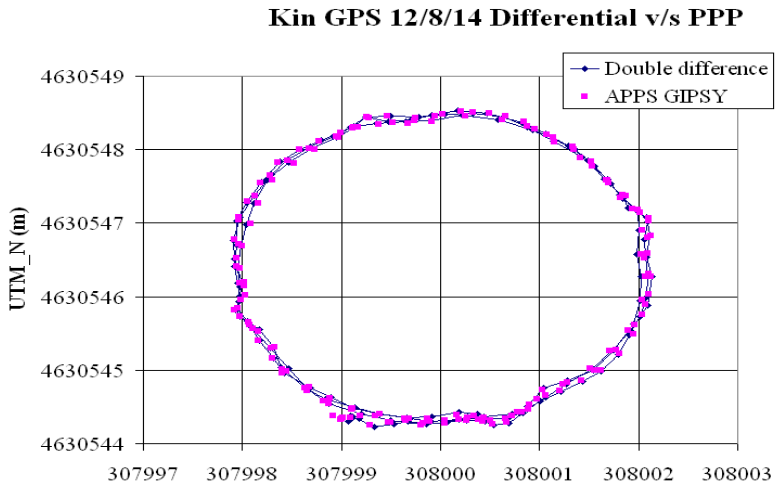


UTM_33 coordinates of centre of the fountain

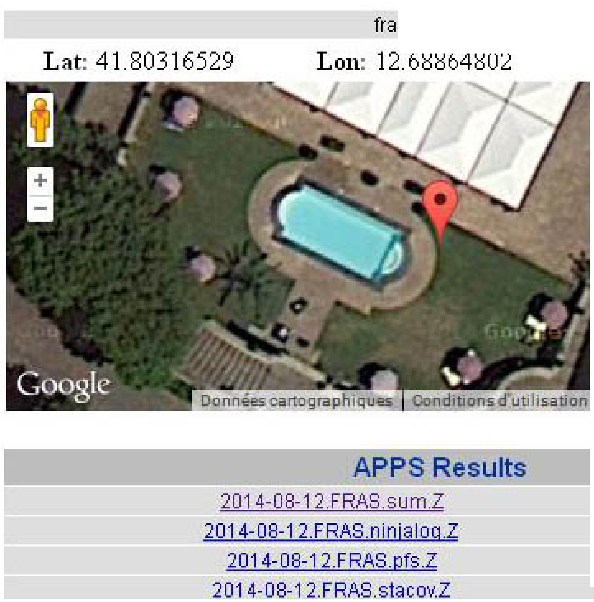


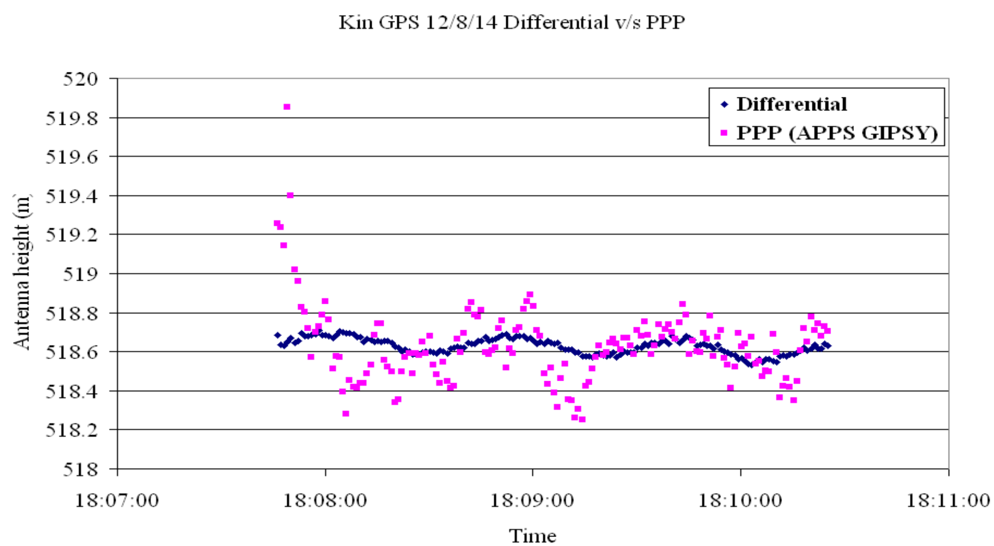
- East: 307999.990 ± 0.025 m
- North: 4630546.390 ± 0.025 m

Comparison with PPP (single point positioning) (GIPSY *apps.gdgps.net/*)

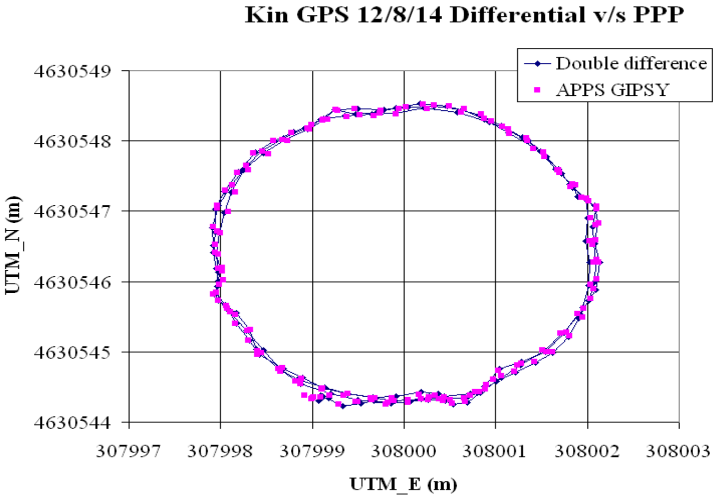


Horizontal fit: 26mm r.m.s.





Comparison with PPP (single point positioning) (GIPSY *apps.gdgps.net/*)



Horizontal fit: 26mm r.m.s.