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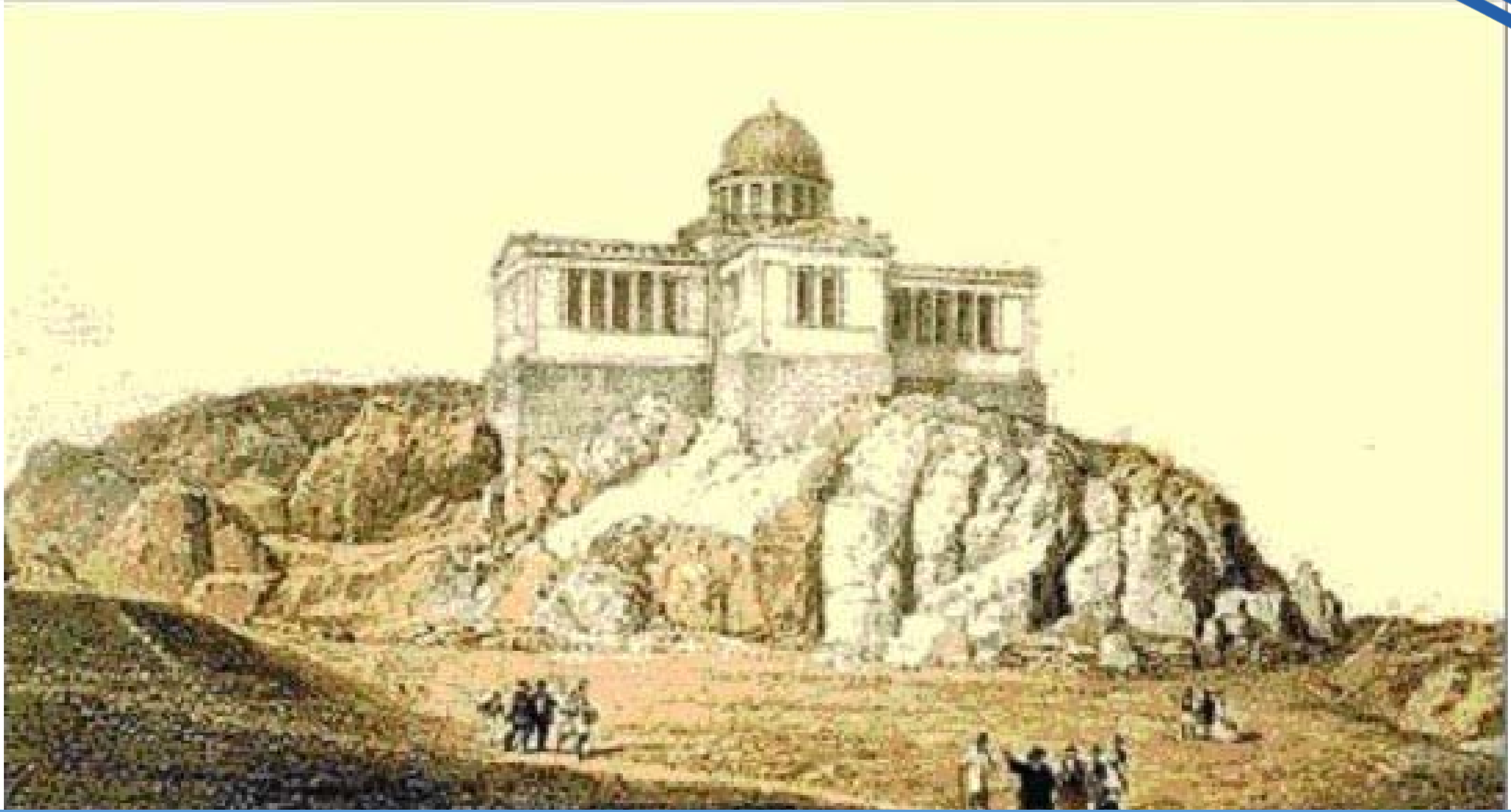
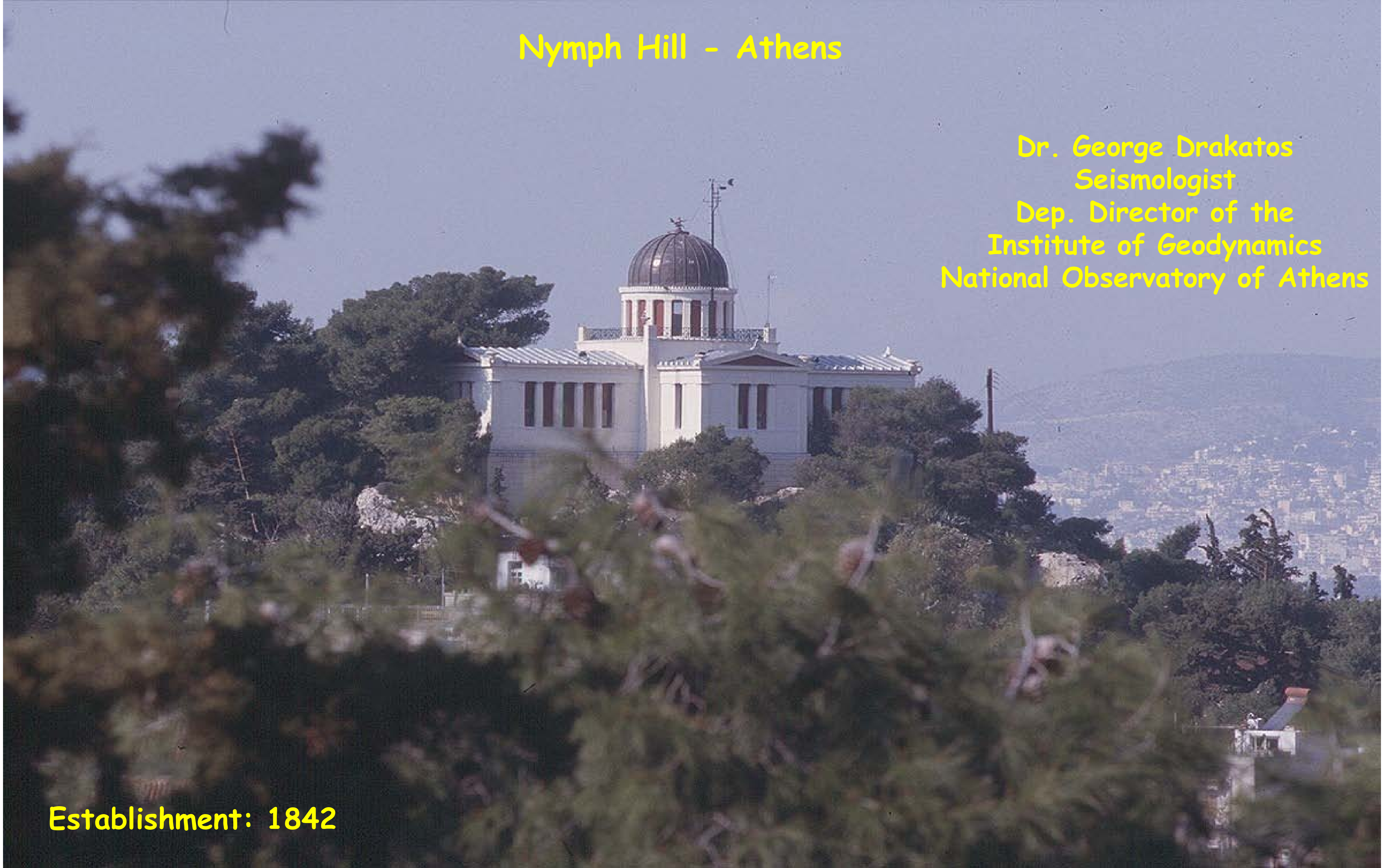


Crustal Deformation Monitoring using Satellite Techniques


Nymph Hill - Athens
Dr. George Drakatos
Seismologist
Dep. Director of the
Institute of Geodynamics
National Observatory of Athens
Establishment: 1842

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The original building of the Observatory was designed by renowned Danish architect Theophilus Hansen and was the first research Institution founded in Greece (1842) after its liberation from the Ottoman Empire.
The Nymph Hill, chosen for the construction of the NOA, has been known since antiquity.

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Ministry of Education, Research and Religious Affairs
General Secretariat for Research and Technology

INSTITUTE FOR ASTRONOMY, ASTROPHYSICS, SPACE APPLICATIONS & REMOTE SENSING
IAASARS
NATIONAL OBSERVATORY OF ATHENS

ΕΘΝΙΚΟΝ ΑΣΤΕΡΟΣΚΟΠΕΙΟΝ ΑΘΗΝΩΝ – NATIONAL OBSERVATORY ATHENS

INSTITUTE OF GEODYNAMICS
NATIONAL OBSERVATORY OF ATHENS

IERSD - NOA
INSTITUTE for ENVIRONMENTAL RESEARCH and SUSTAINABLE DEVELOPMENT
more than 170 years contribution to research and society

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European University Cyprus
CENTER FOR NATIONAL SECURITY AND DEFENSE RESEARCH – BULGARIAN ACADEMY OF SCIENCES
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AUA CENTER *for* RESPONSIBLE MINING
Funded by European Union Civil Protection

Geodetic Applications for Ground movement monitoring (1)

- ✓ **Geodesy has been gradually established as a tool for determining the spatial and temporal changes of structures and their environment. Movements in the range of a few millimeters to several centimeters per year can be detected by geodetic monitoring.**

- ✓ **The basic principle on which this kind of monitoring is based is the determination of the positions of the "vulnerable" points at a certain time t_o, called as a zero time measurement. These positions are measured at t_t in a subsequent seasons measurement. By comparing the different seasons, it is possible to determine the intensity, direction and speed of movements and distortion.**

Geodetic Applications for Ground movement monitoring (2)

- ✓ **When geodetic deformation is recorded, various reference stations are used to calculate the displacements of point objects.**

- ✓ **It is necessary to ensure that these stations are indeed stable. Otherwise, incorrect conclusions may be drawn. For the correct measurement of the displacements of the points - objects, the stability of the reference points must be verified and each unstable point is identified (Niemeier & Riedel, 2006).**

- ✓ **There are many geodetic methods that can be used to monitor territorial movements, depending on the characteristics of the purpose to be achieved.**

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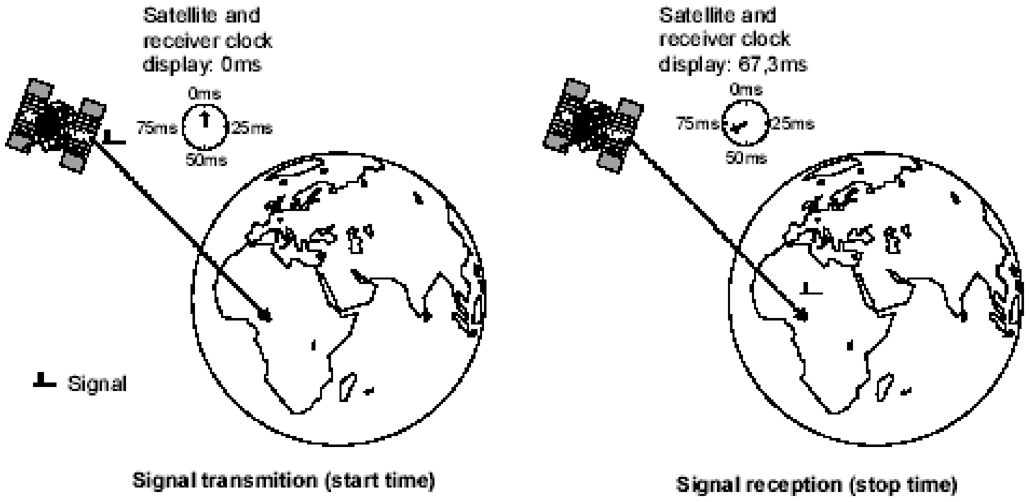
Positioning Principles

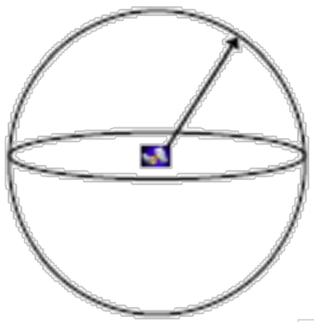
The calculation of the distance of the observation point from a satellite is based on the measurement of the travel time, that is the time required to reach the signal from the satellite to the receiver.

In practice, the signal travel time is calculated with high accuracy as follows:

At the same time as the signal emitted by the satellite, a similar signal is produced in the receiver. By comparing the signal received by the satellite receiver and the signal produced by the receiver, the signal travel time is finally determined.

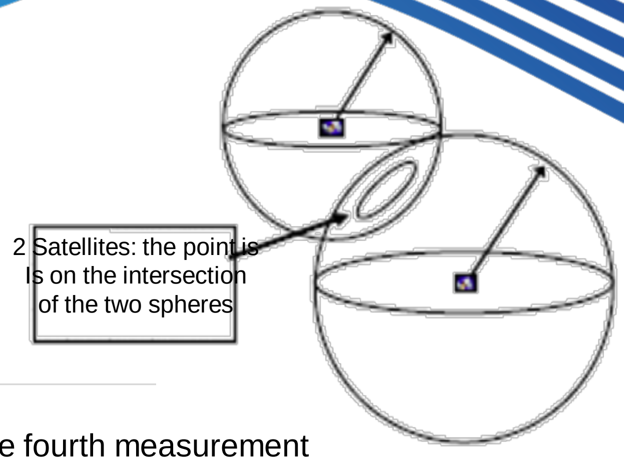


Single Point Positioning (1)

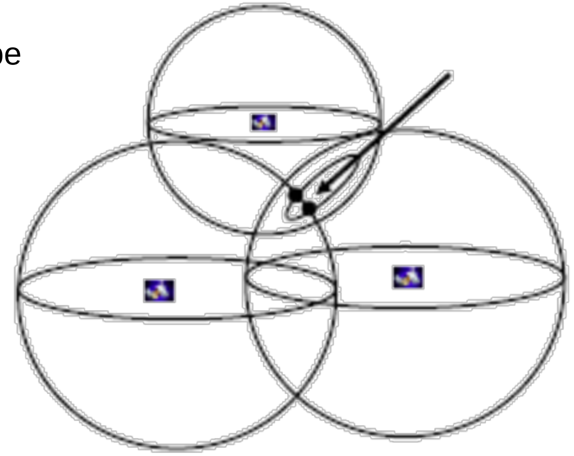


1 Satellite : the point could be on the sphere's surface

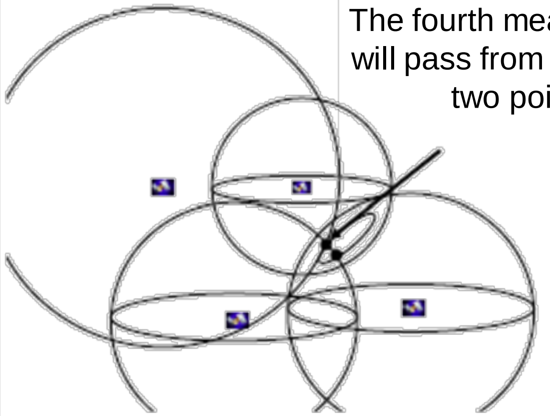
R=c · dt, dTr=0



The fourth measurement will pass from one of the two points



3 Satellites: there are two points on the circle circumference



4^{η} Satellite: One point on the circle circumference

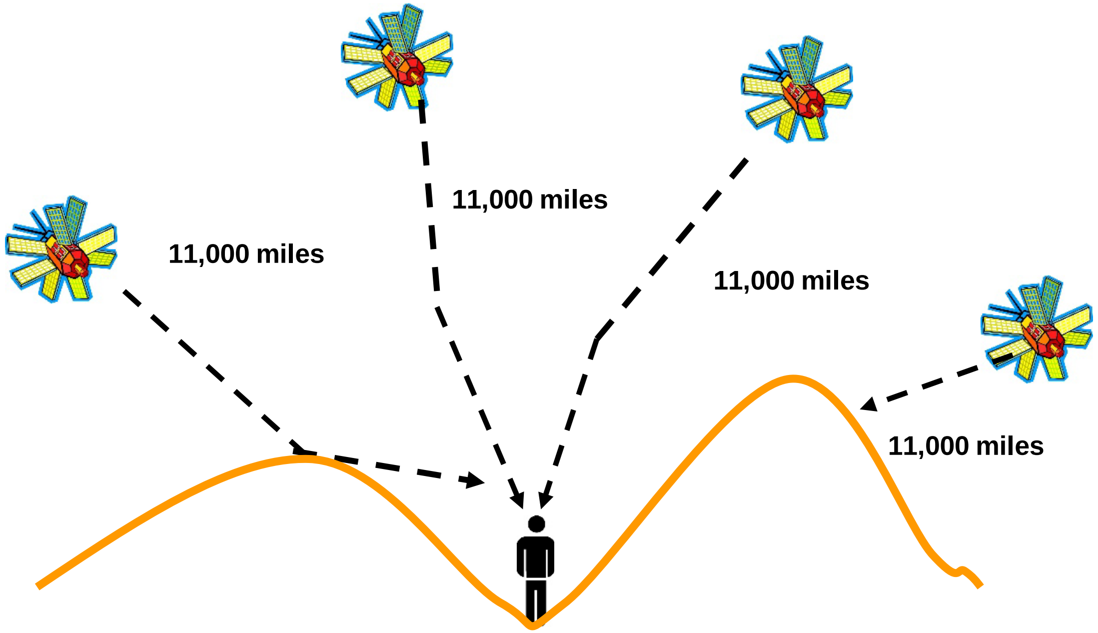
Single Point Positioning (2)

Each GPS satellite has 4 individual clocks. Each one costs ~ $ 100,000 and has an accuracy of one billionth of a second (1 nsec)

PDOP Positional Dilution of Precision

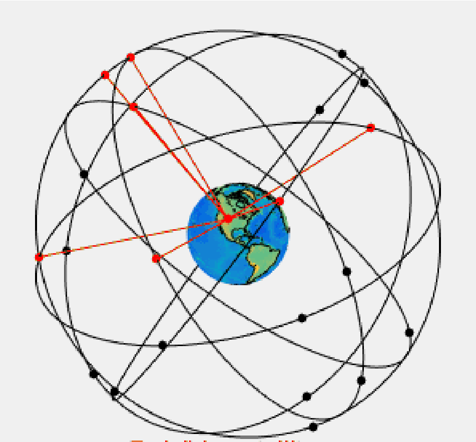
Reflection, refraction etc. increase the positional dilution of precision “PDOP”

- ***PDOP < 4 very good***
- ***4 < PDOP < 8 good***
- ***PDOP > 8 poor***



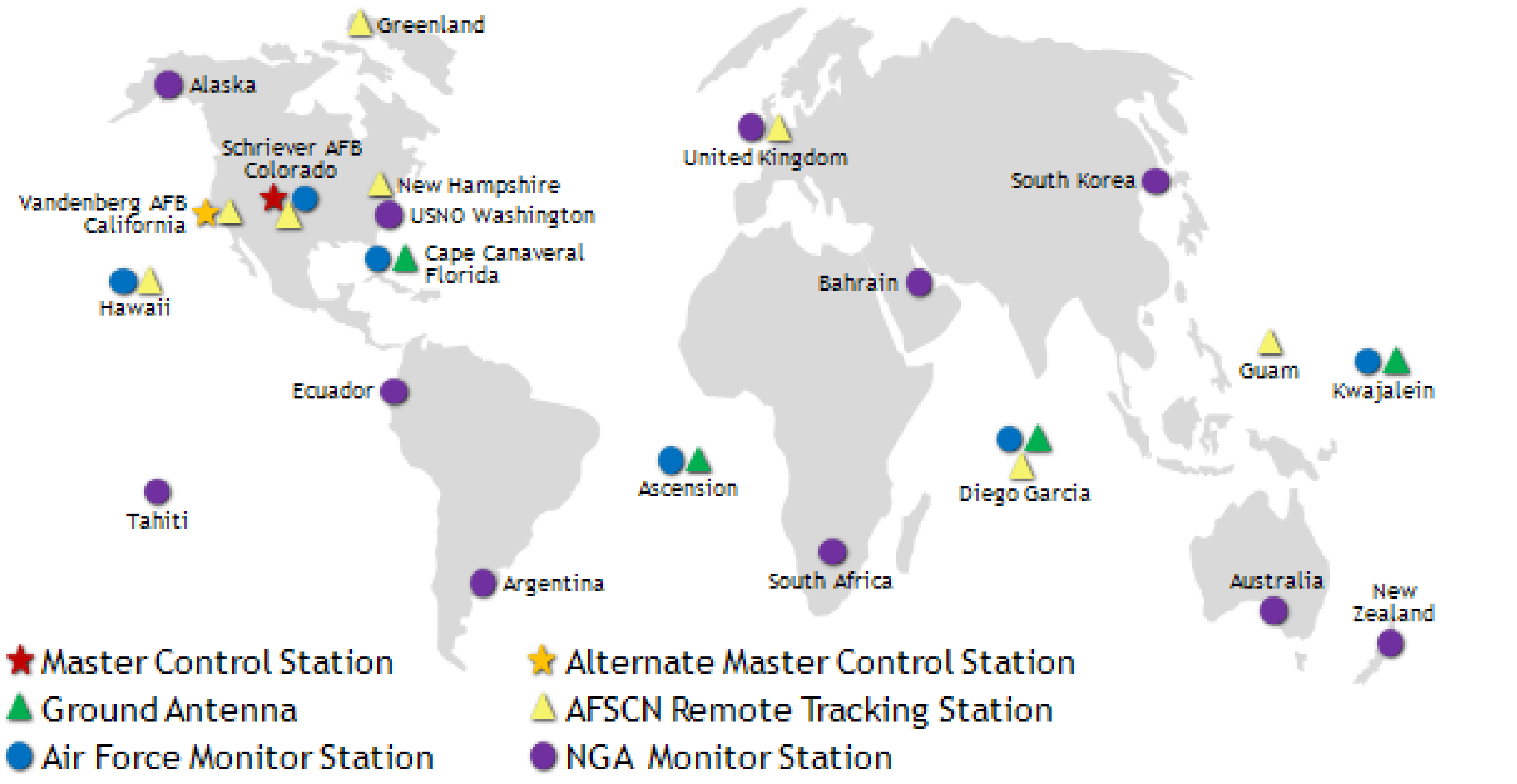
Global Positioning System

- ~30 satellites
- 20,600km radius of rotation
- 2 rotations/ day
- Six (6) orbital levels:
  - Angle 55 from equator
  - ~5 satellites per orbit
- At least six (6) satellites are visible every moment from the earth's surface



7 visible satellites

System GPS – Ground



Built-in GPS receivers

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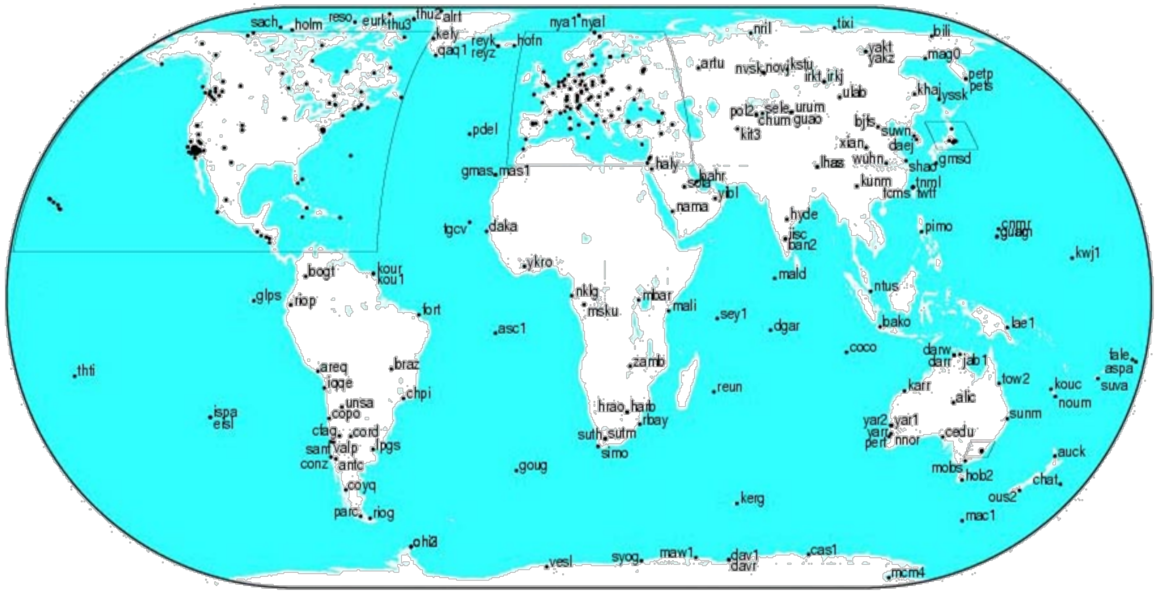
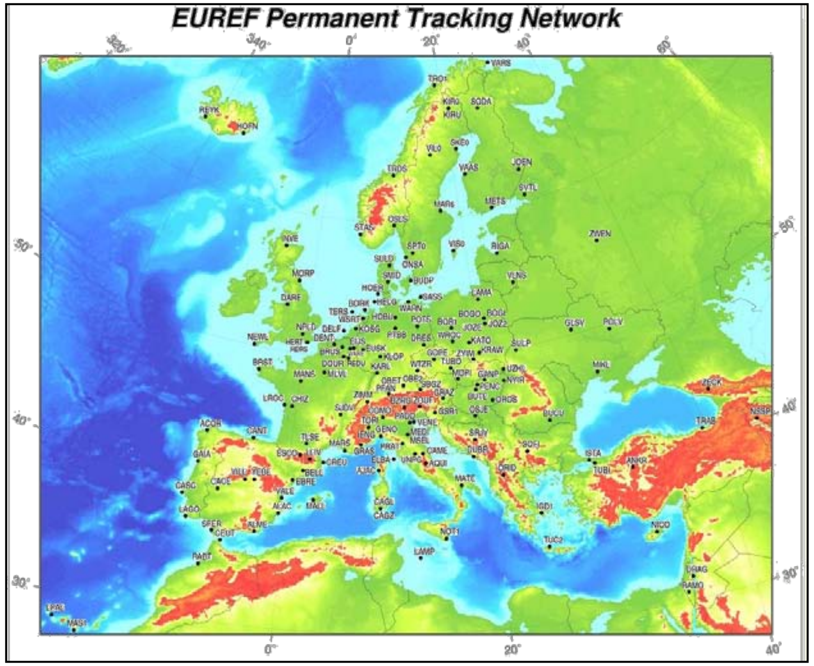
Global GPS permanent stations





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Global Geodynamics

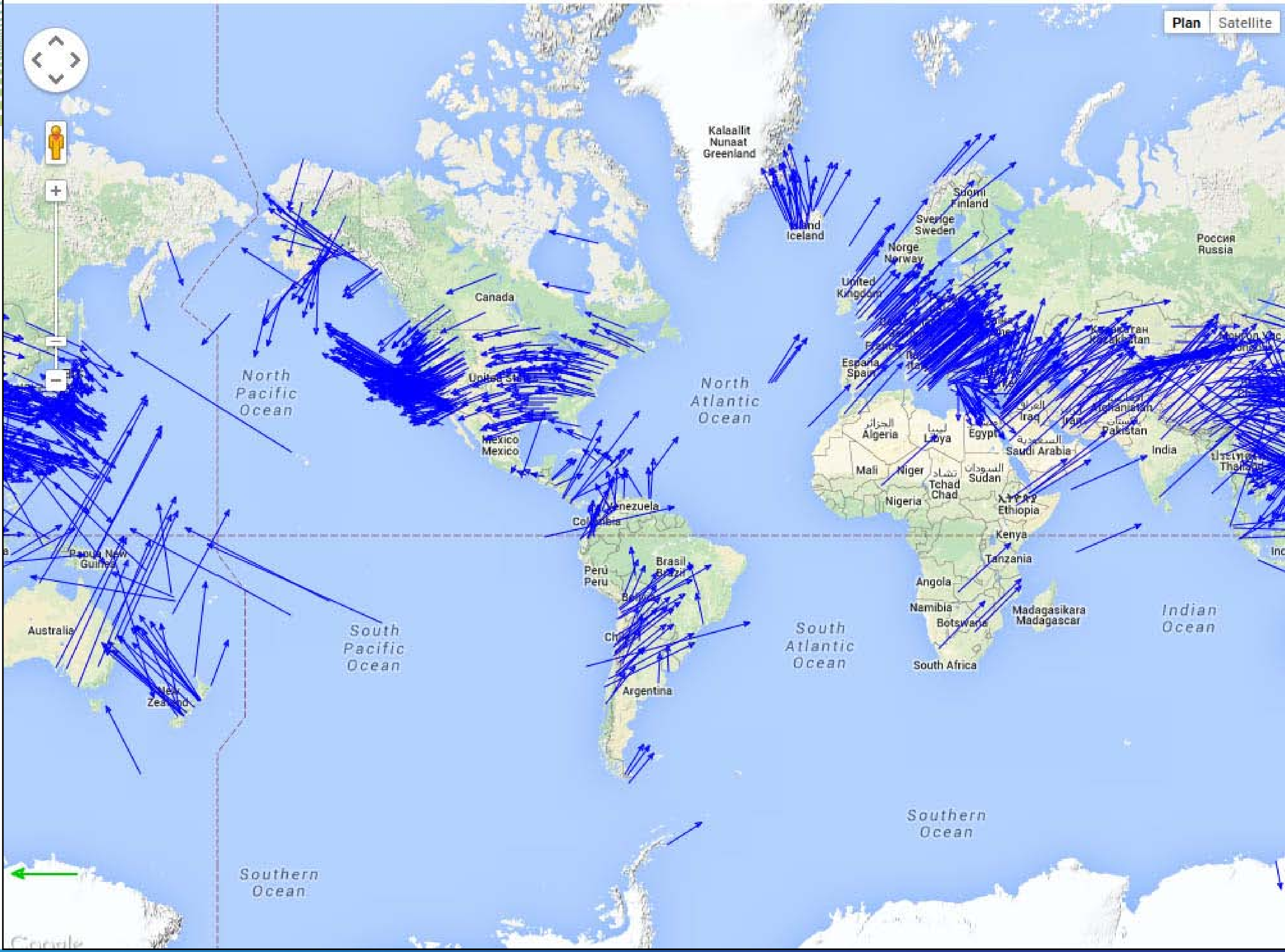

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Plate Tectonics

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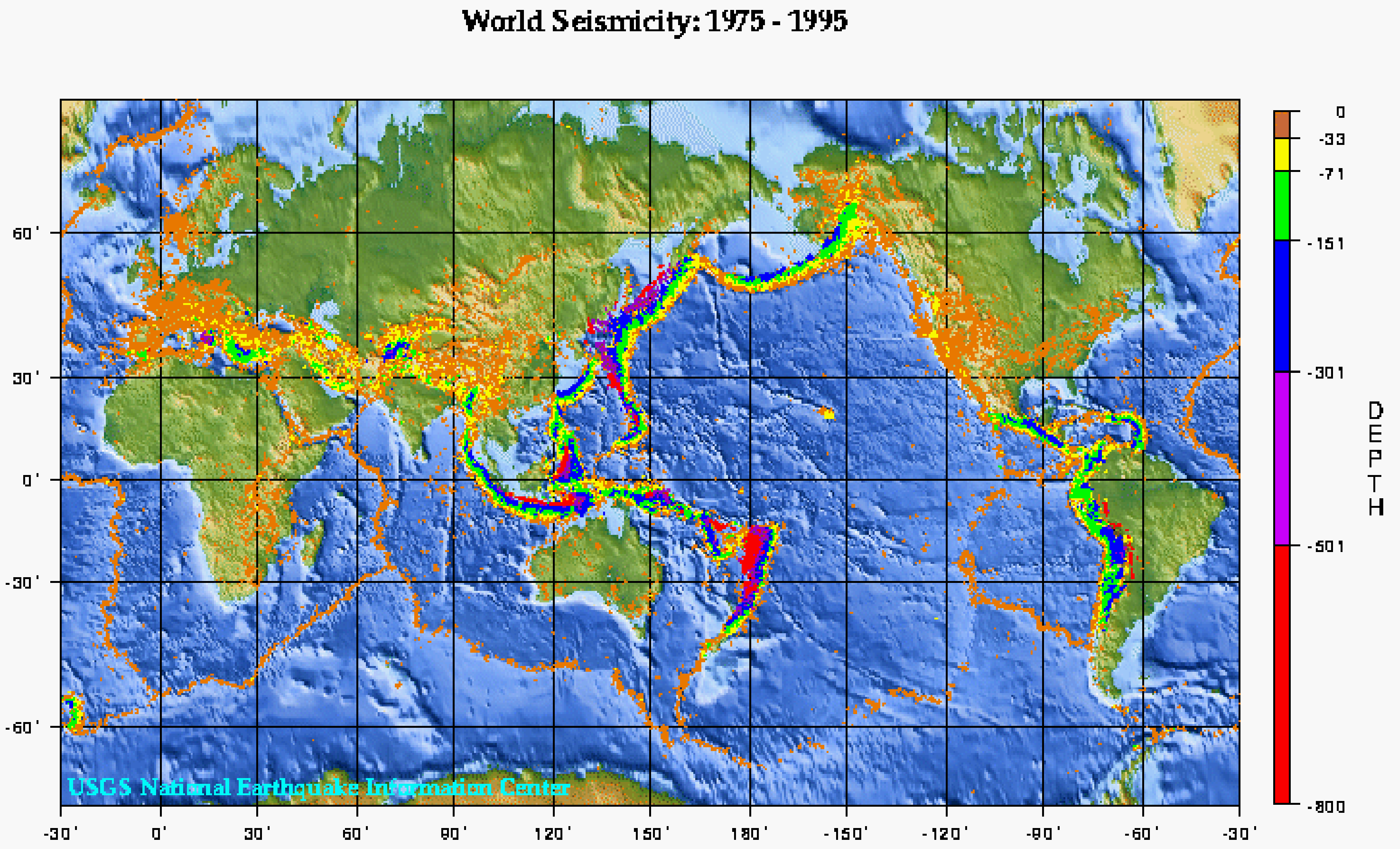
World Seismicity Maps



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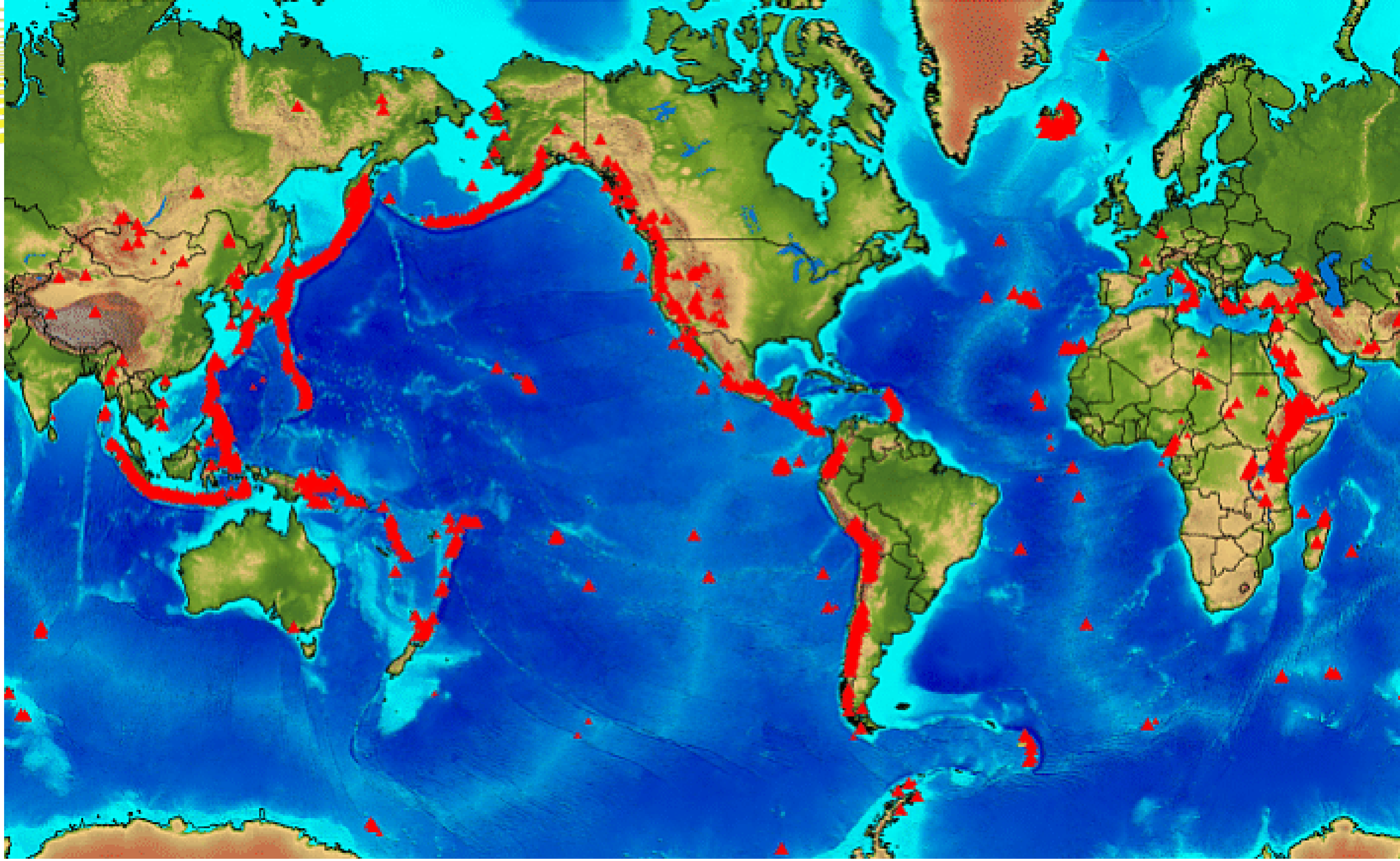
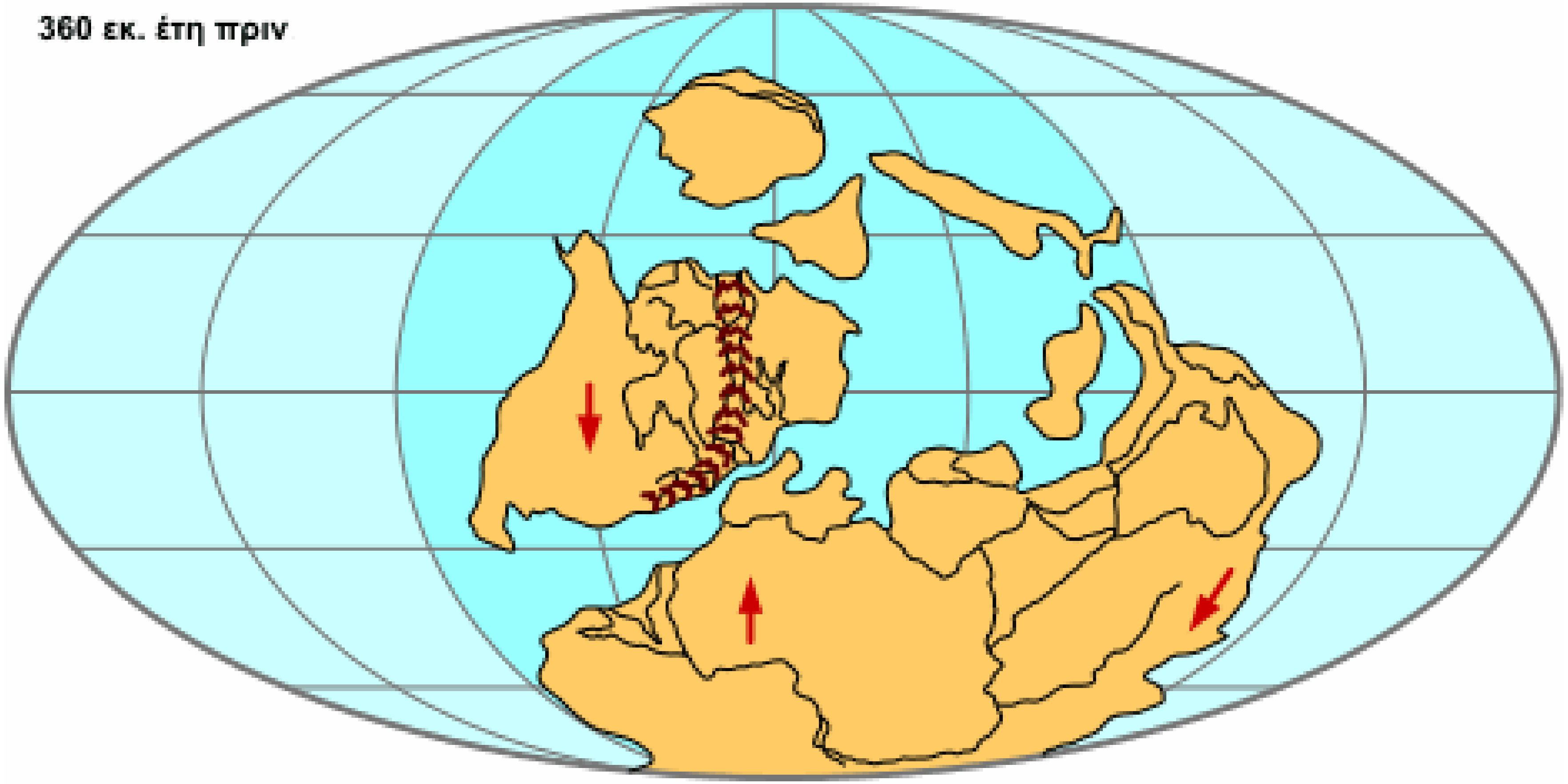
World Map of Volcanoes



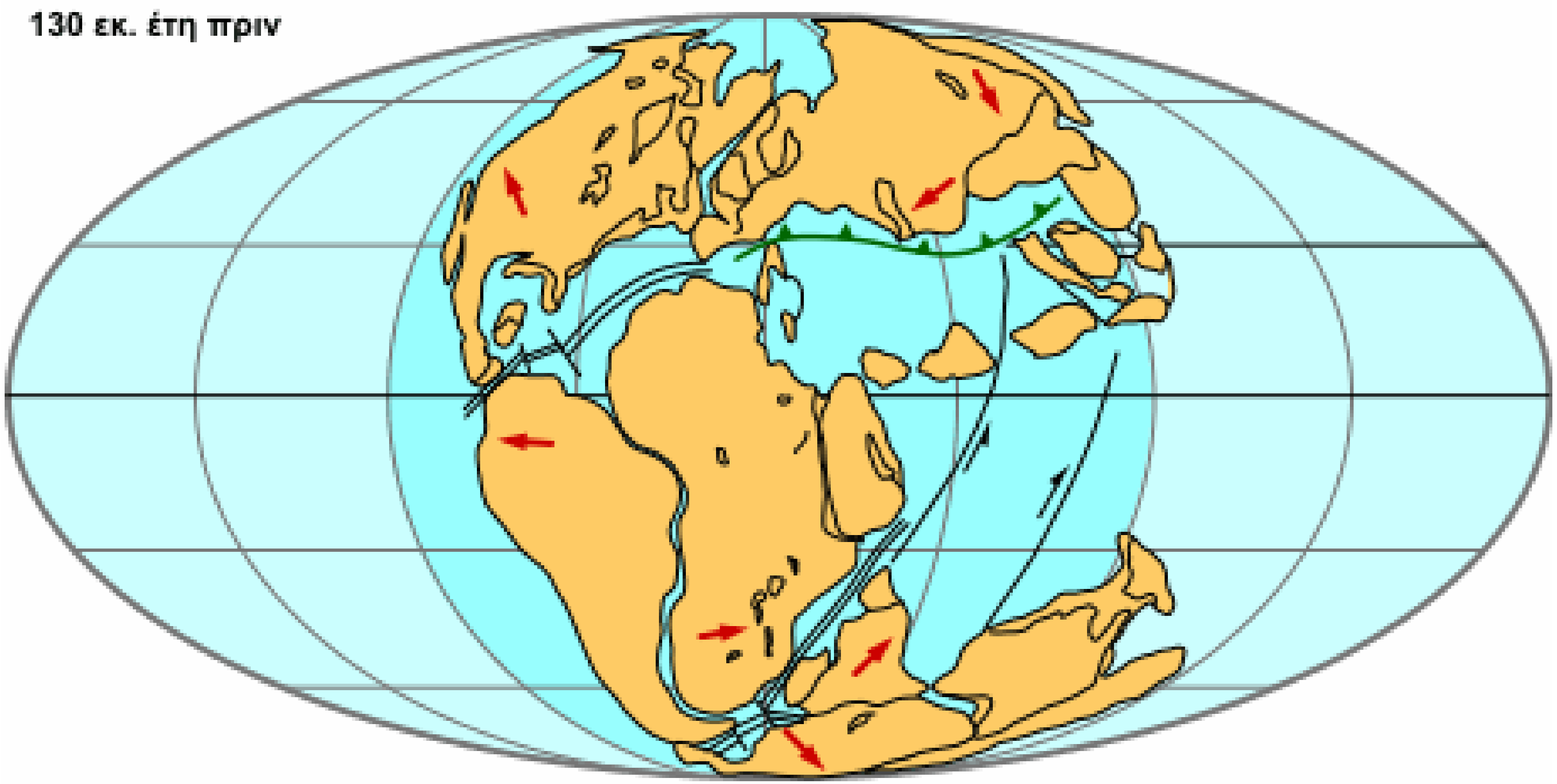
600 million years ago

360 million years ago

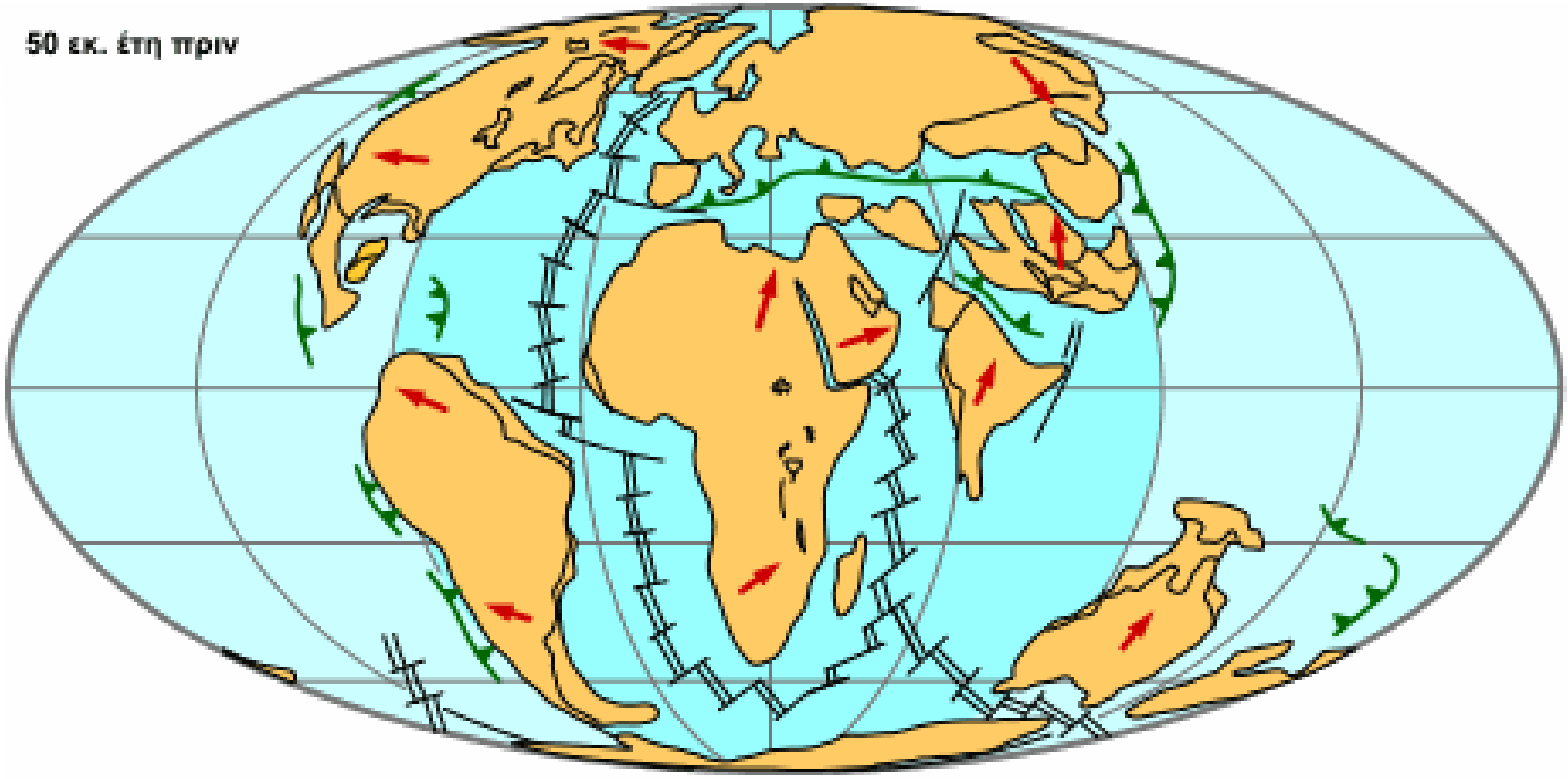


250 million years ago

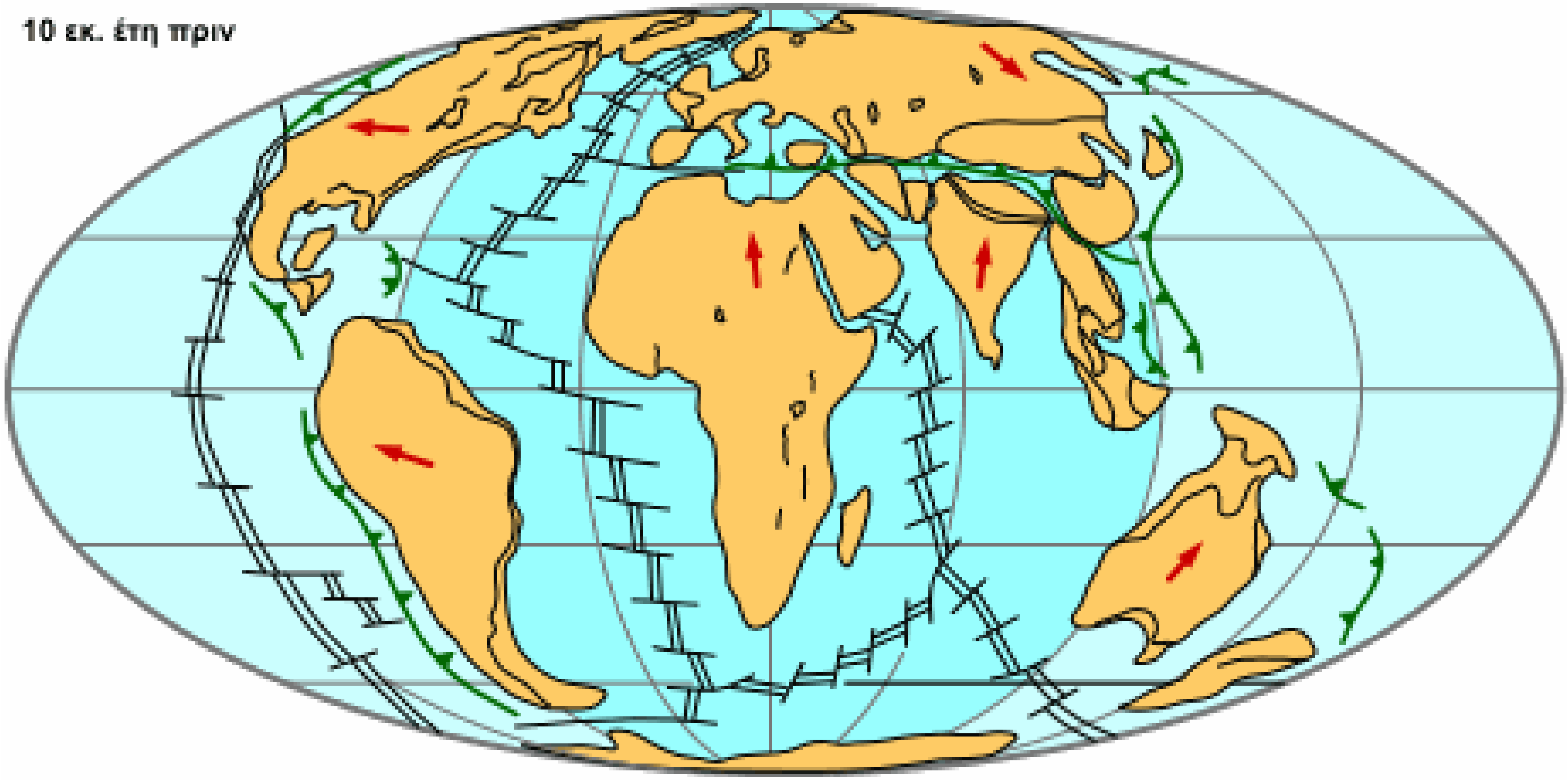
130 million years ago



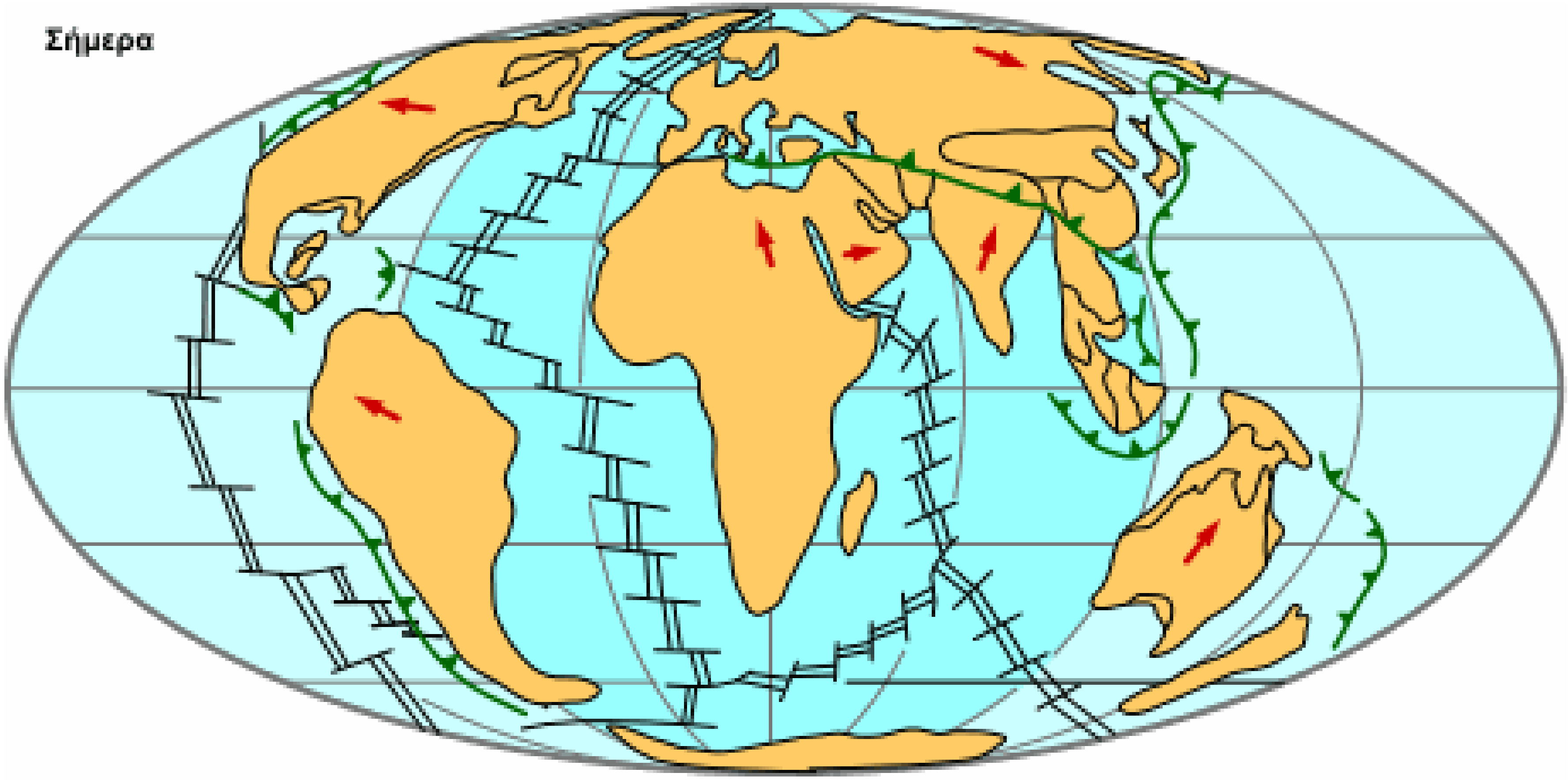
50 million years ago



10 million years ago



Today



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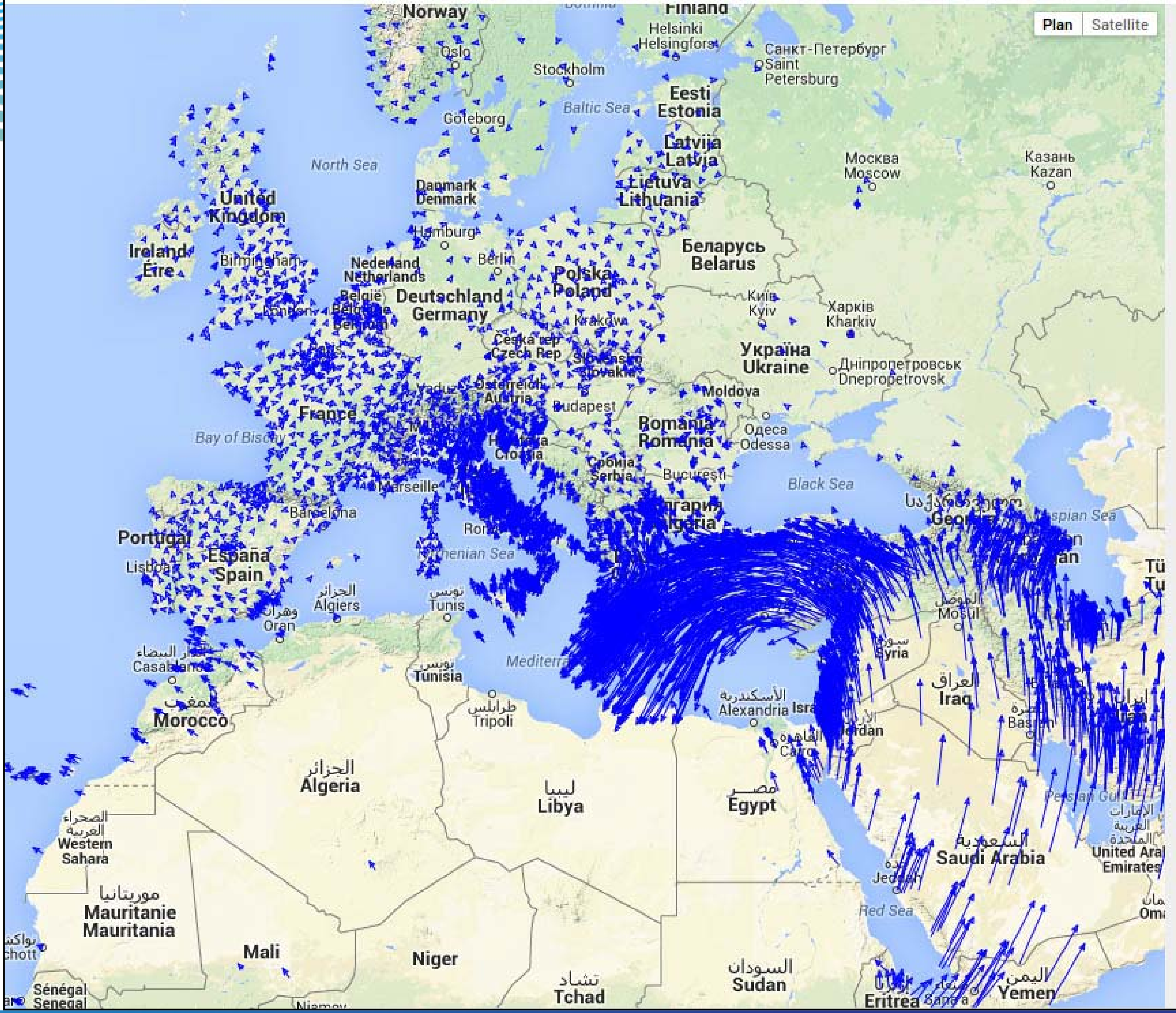
Geodynamics in Europe and Mediterranean Sea region



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Civil Protection

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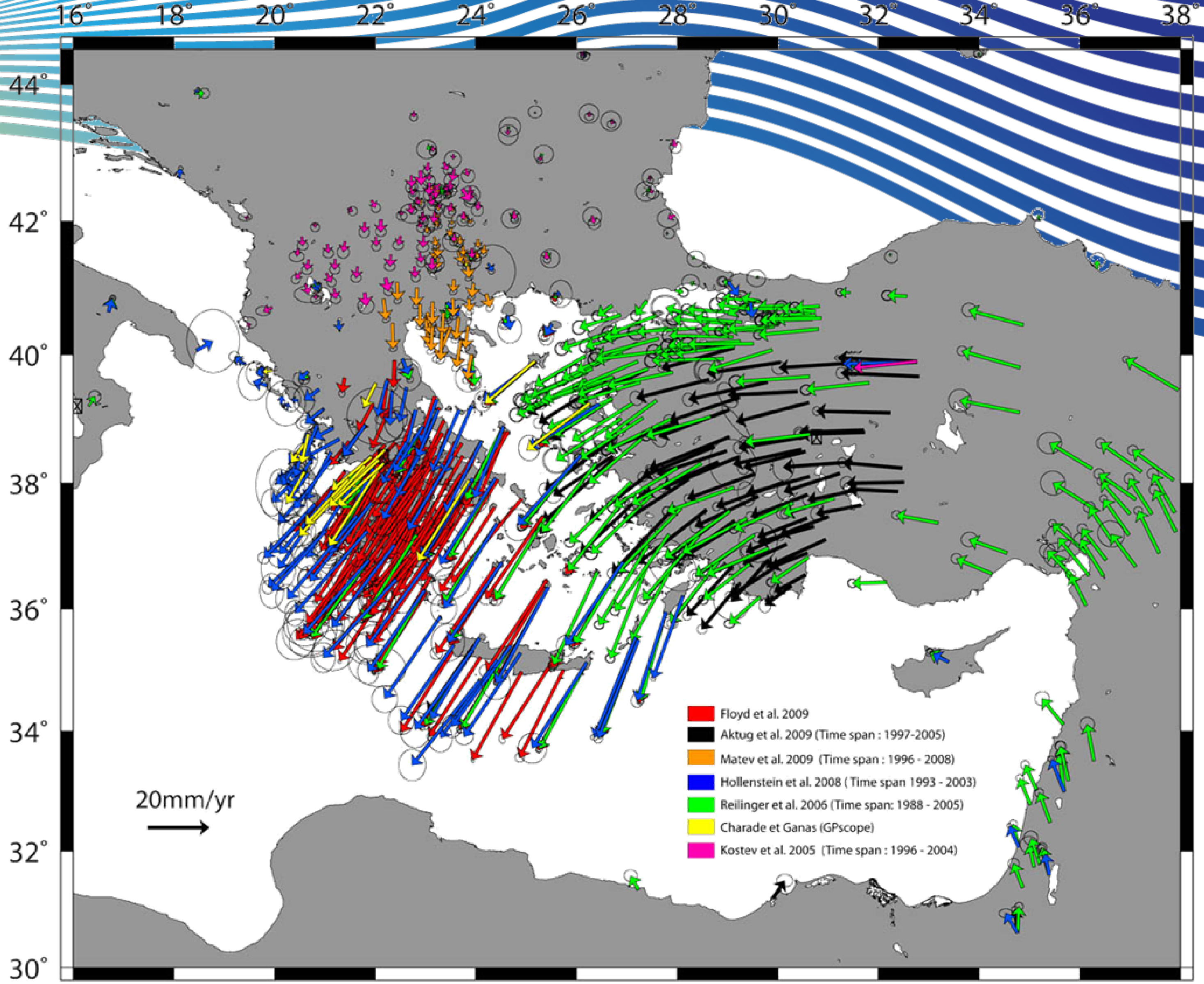
GPS velocity measurements in eastern Mediterranean sea region



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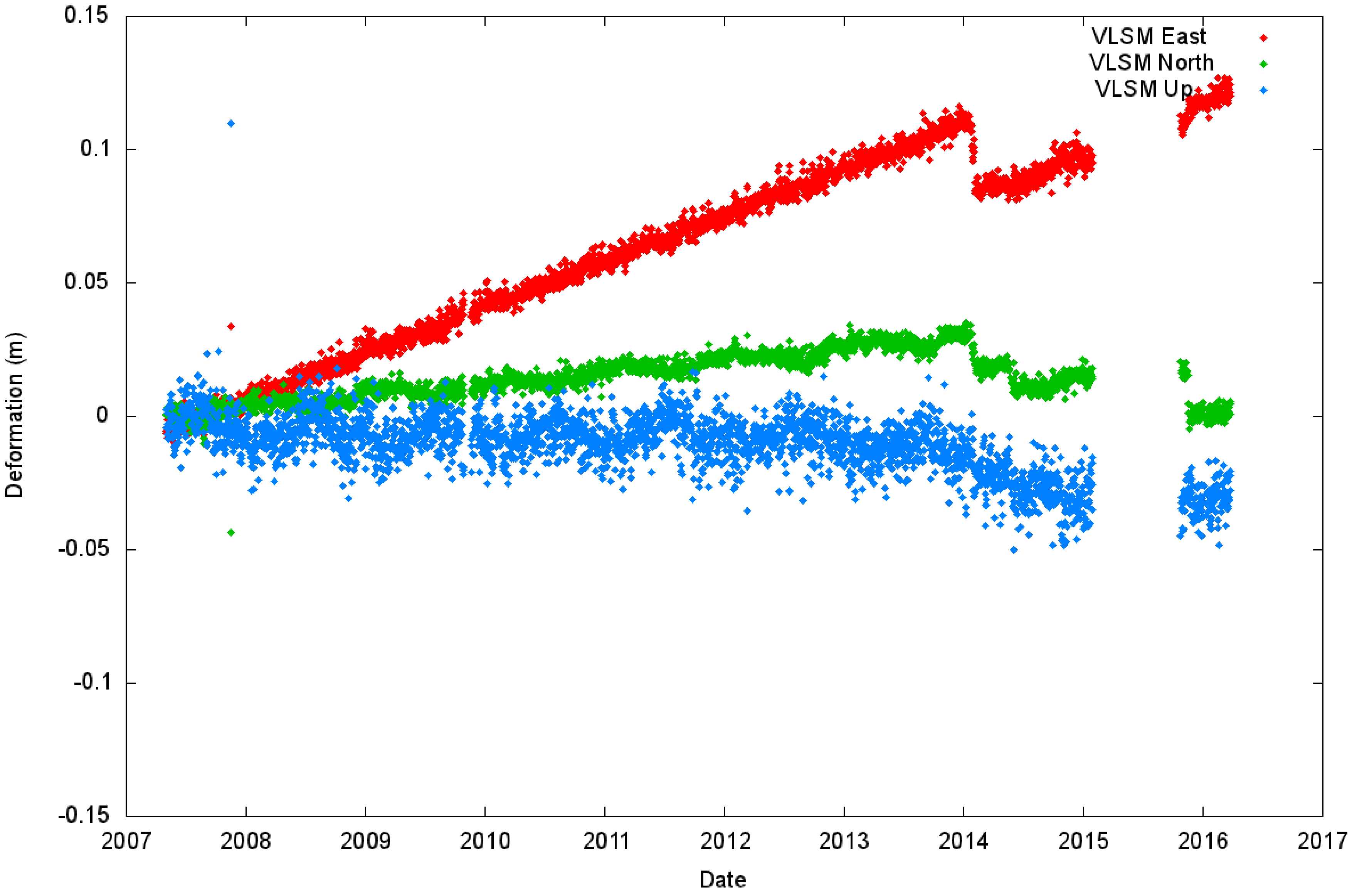
Kefallinia Earthquake: 2014, Mw=6.1, Mw=6.0 - VLSM



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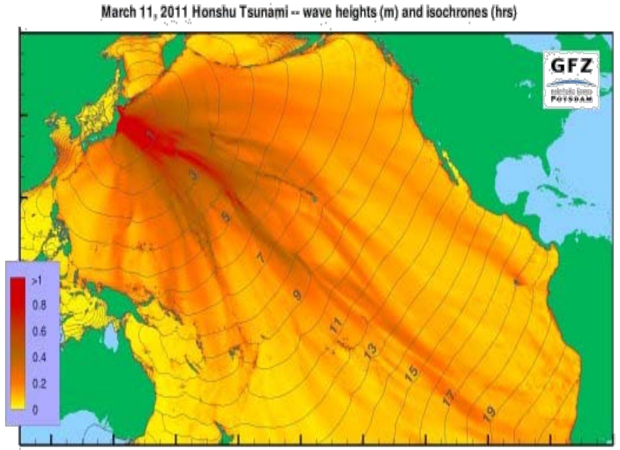
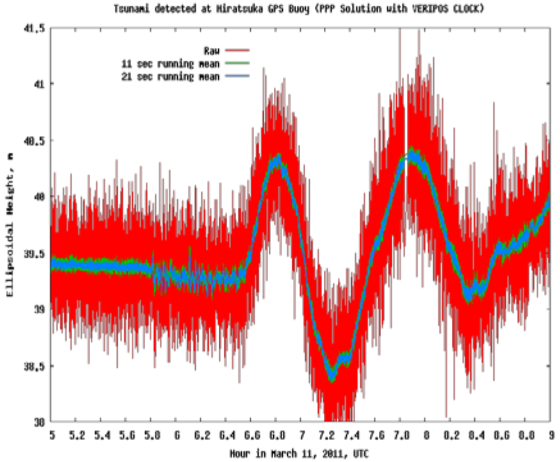
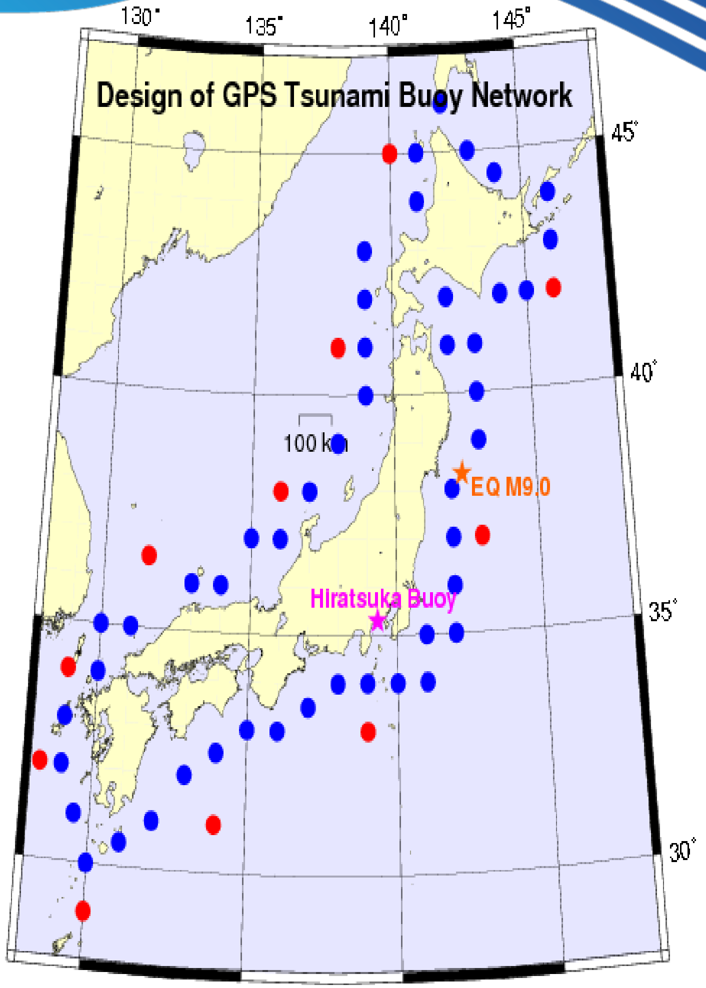
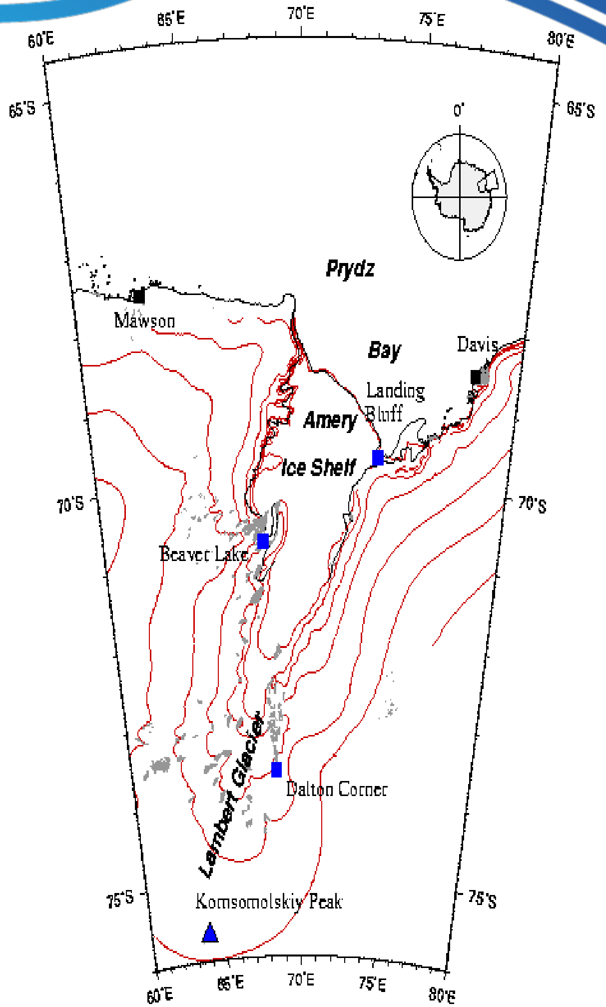
GPS for Tsunami monitoring







Glacier' movement monitoring



Glacier monitoring using GPS

(Australian National University – OMP Toulouse)

Glacier monitoring using GPS

Mont Blanc (Glaciologie Grenoble)

Global Navigation Satellite System Application to Landslide monitoring

- The GNSS technology measures the ground deformation with high accuracy.
- A base station far from the sliding area and a sufficient number of stations/or benchmarks at various points of the distortion/landslide (Rover Stations) are installed to perform the measurement.
- The results are the measurements of the individual stations (Rovers Stations) and the base station in solving through special software to derive data for deformation / landslide
- The main advantage of the method is that GNSS receivers are not required to be in visual contact with each other.
- This gives the advantage of taking measurements even in extreme weather conditions in real time or after processing.

Deployment of a new permanent station (cGPS)

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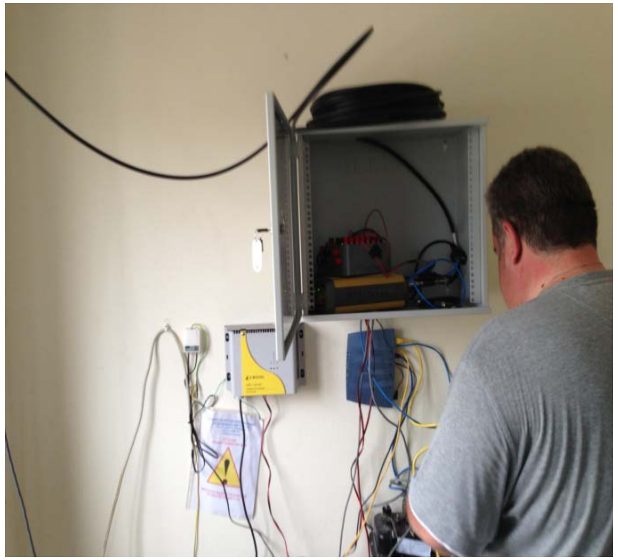
Preparation works for the cGPS deployment and station preparation of communication links etc.



GPS receiver's antenna

Installation and measurements of non permanent network

Installation of non permanent station

Measurement of non permanent network

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Measurement of non permanent network






Measurements at benchmarks

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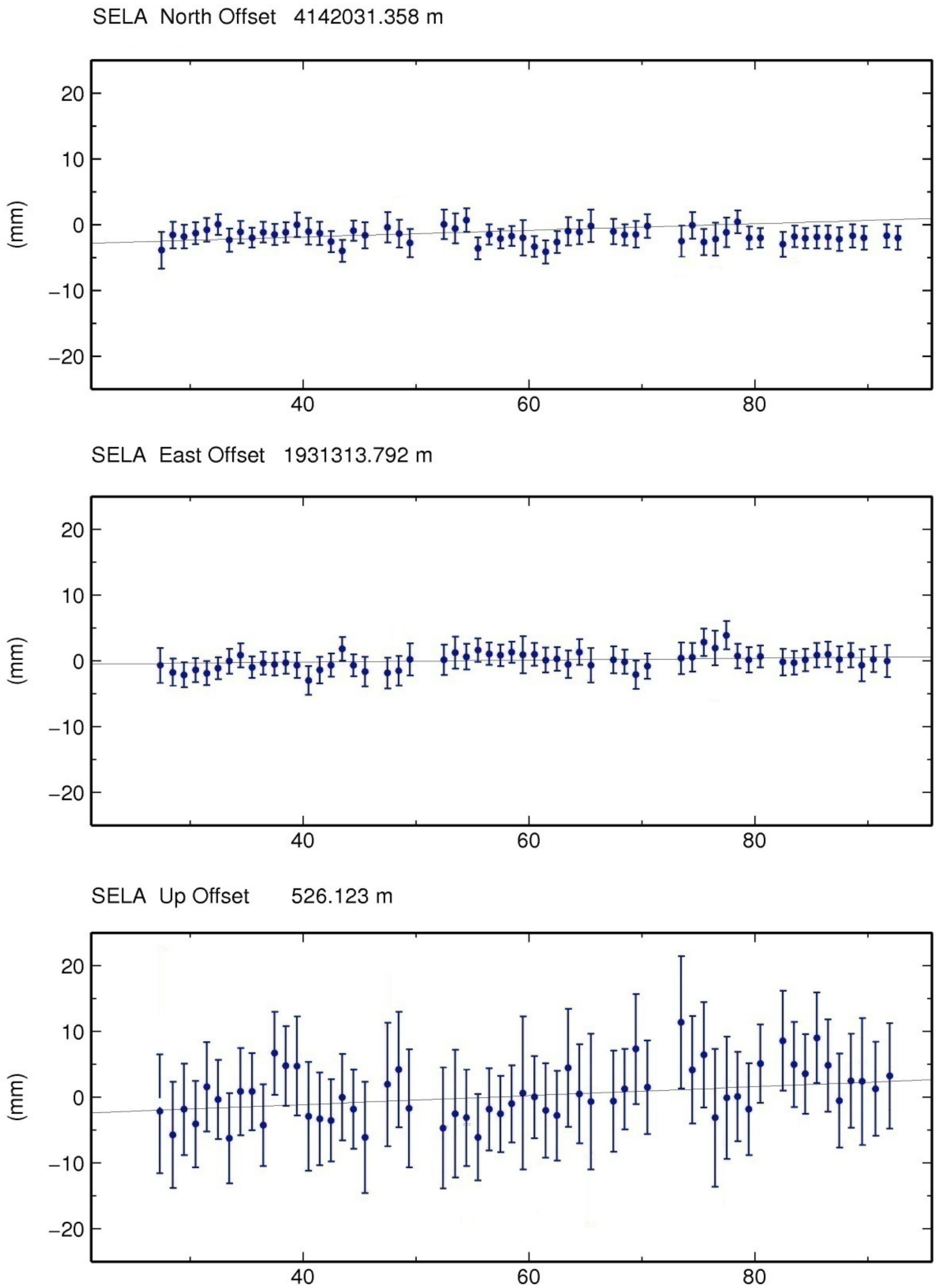
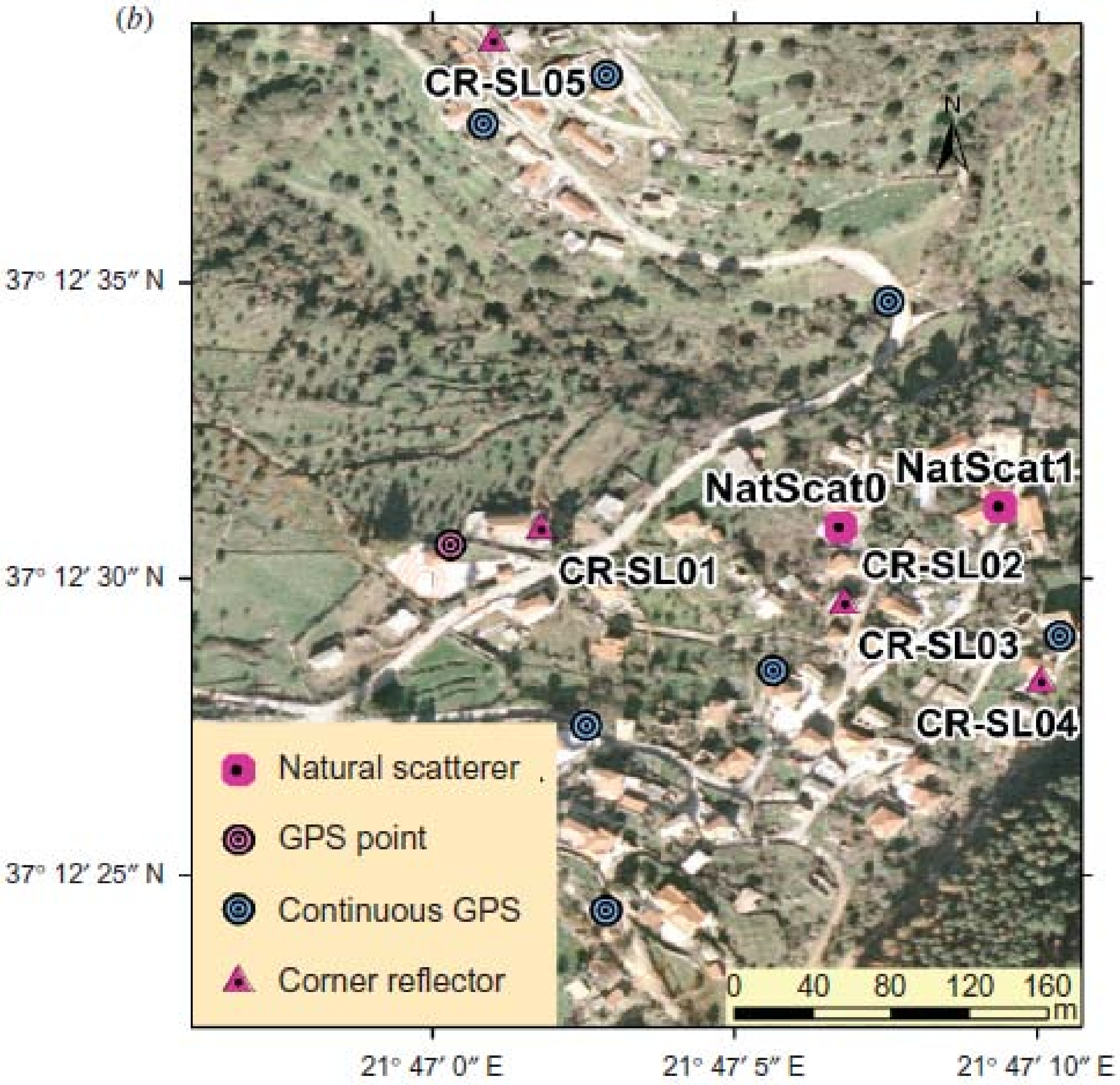
Deformation timeseries




(b)
CR-SL05
NatScat0
NatScat1
CR-SL01
CR-SL02
CR-SL03
CR-SL04
N
37° 12′ 35″ N
37° 12′ 30″ N
37° 12′ 25″ N
21° 47′ 0″ E
21° 47′ 5″ E
21° 47′ 10″ E
Natural scatterer
GPS point
Continuous GPS
Corner reflector
0 40 80 120 160
m

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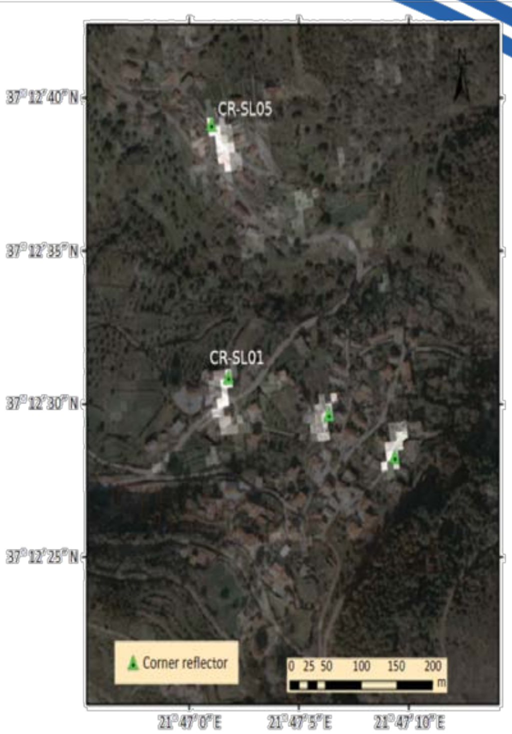
Installation and exploitation of Corner Reflectors



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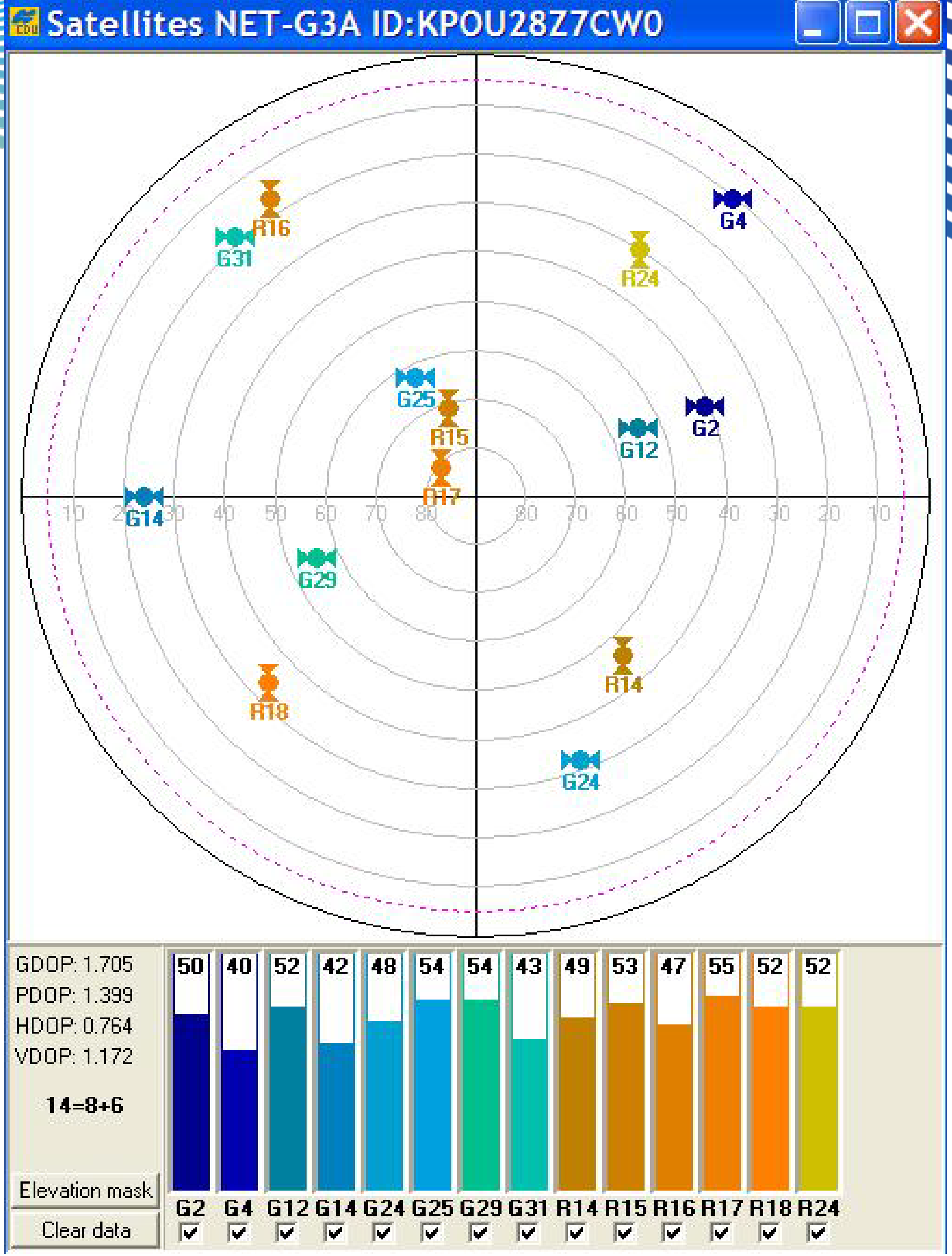
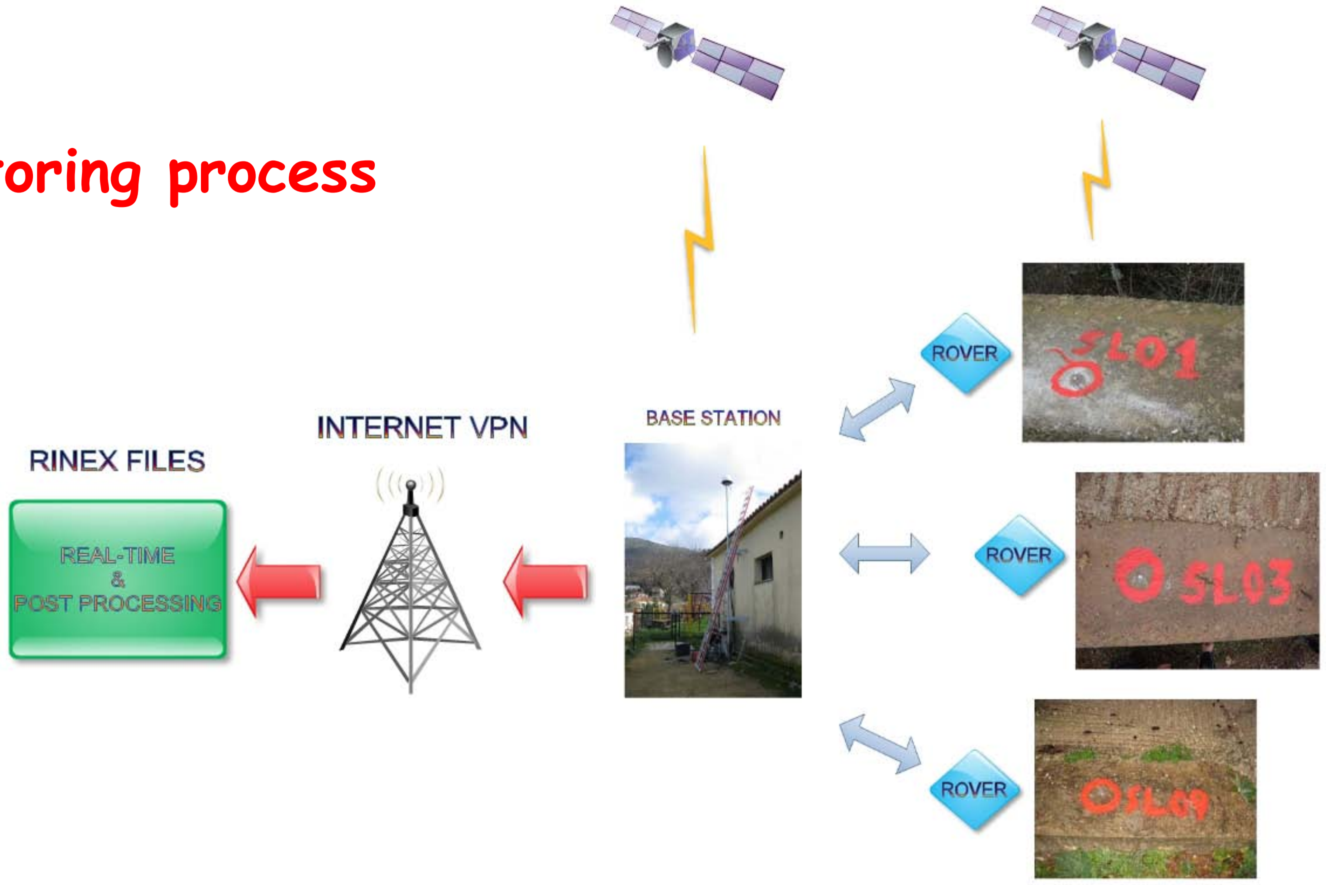
GPS Data Downloading

Data downloading from 14 Satellites (8 GPS and 6 GLONASS)



GPS sensors monitoring process



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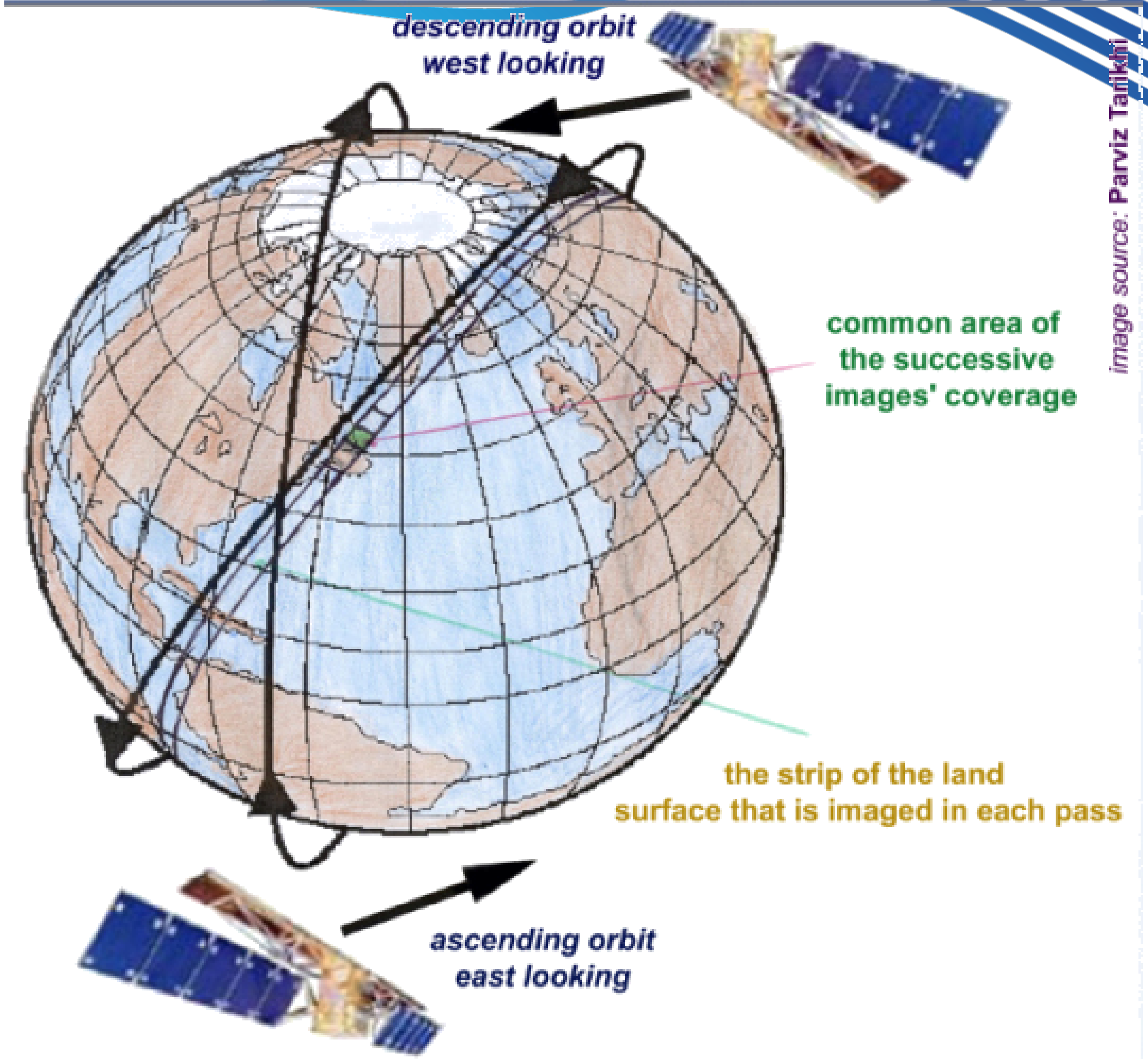
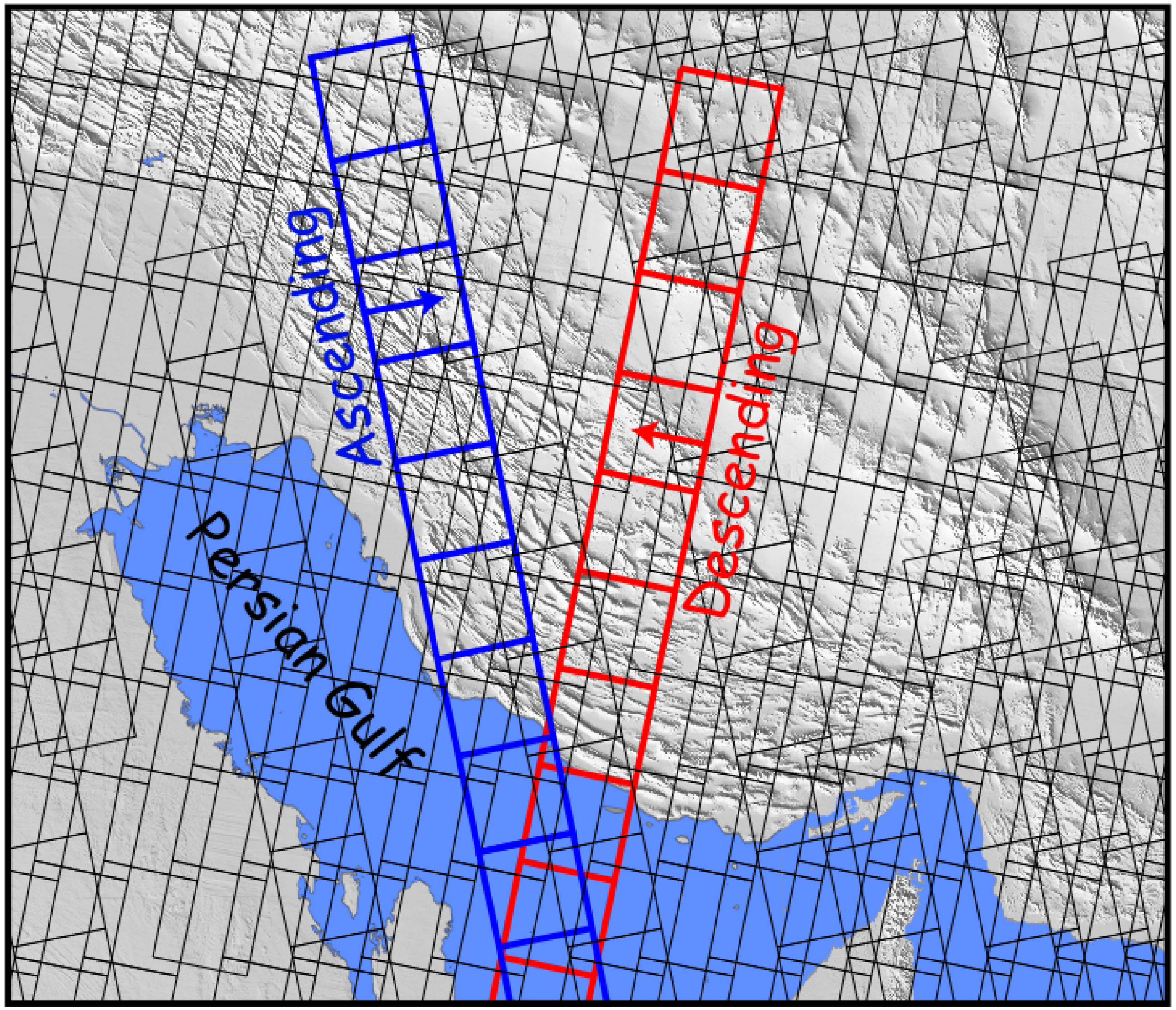
Synthesis Aperture Radar

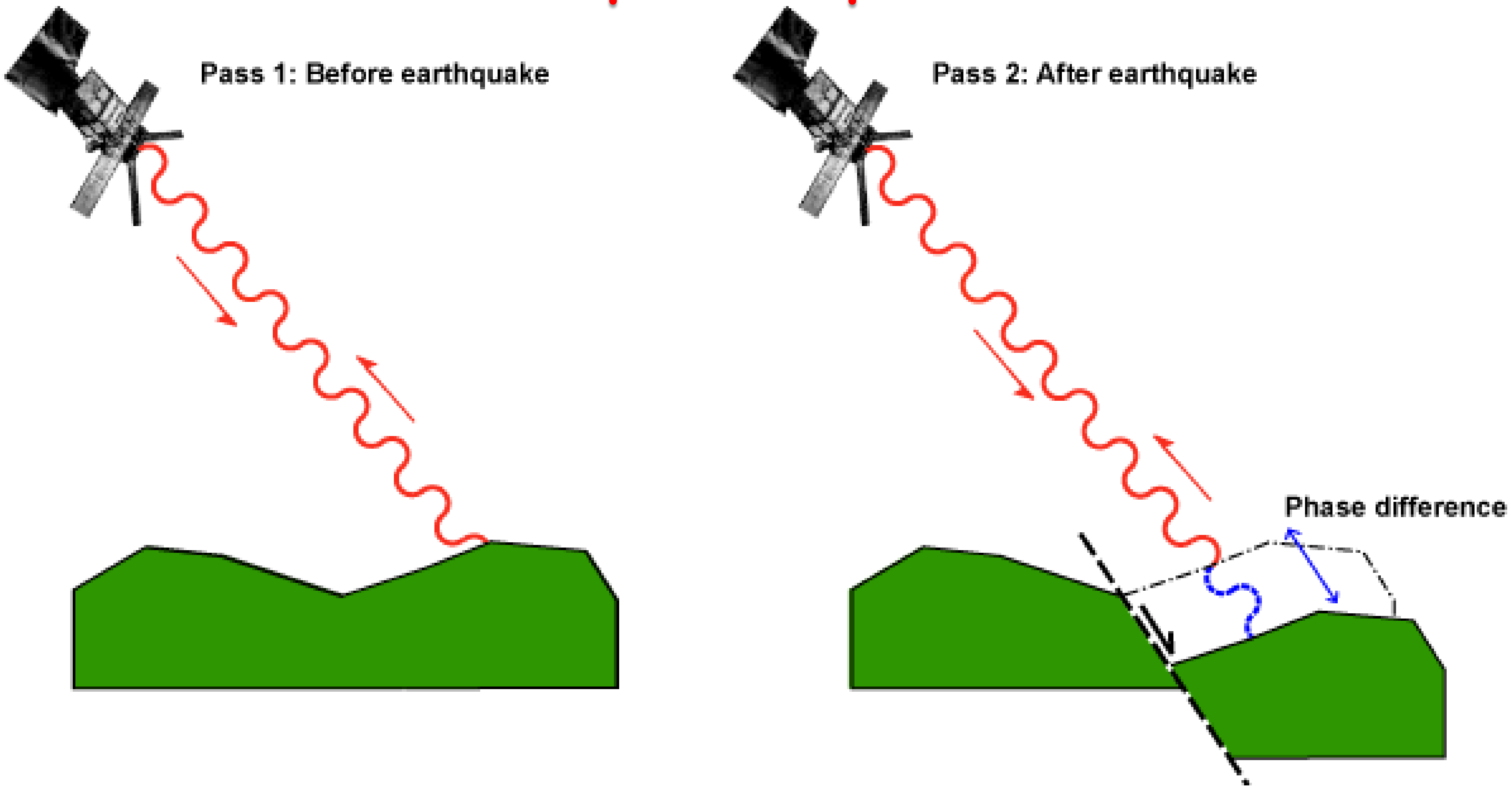
Dr. Panayiotis Elias



Ascending and Descending Orbits

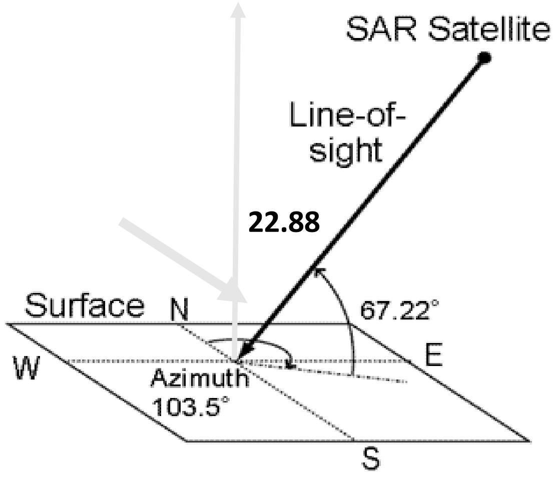


Principles of operation



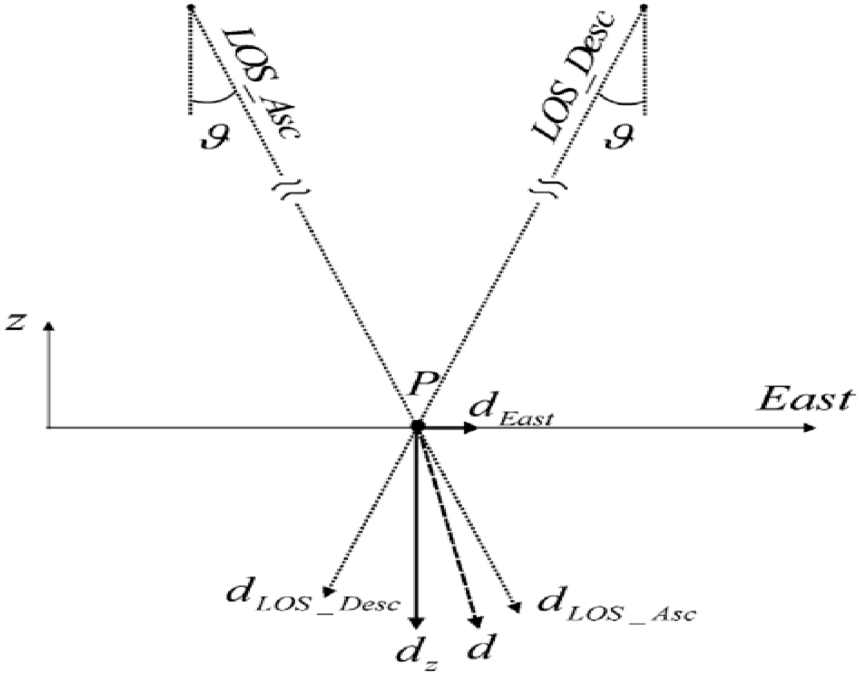
Geometry of the measurements

Line of sight



Sensitivity of the measurements in 3D
(για ASAR/ENVISAT)

$$\vec{\boldsymbol{U}} = \begin{bmatrix} U_{east} \\ U_{north} \\ U_{up} \end{bmatrix} \sim \begin{bmatrix} \pm 0.38 \\ 0.09 \\ 0.92 \end{bmatrix}$$

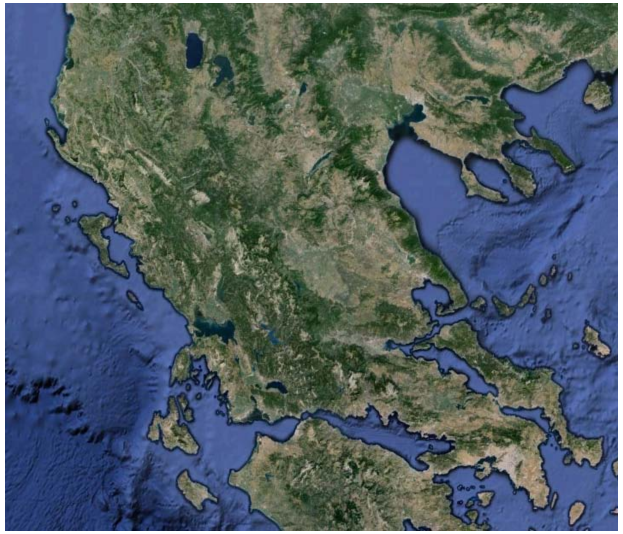


Looking from south...

Applications to …

- Natural Hazards (Seismic Faults-Earthquakes, Landslides, subsidence-uplift)
- Civil engineering (Roads, Railways, Bridges, Dams, Tunneling, Cities)
- Mining (Open pit Mines, undergroung Mines)
- Oil and Gas (Oil reservoirs, Undergroung Gas Storage, Pipelines, Carbon Capture and storage.)

Tracking – Quantification of Road Network Failure



- TERRASAR-X 19 passes from Aug ’12 to Sep ’13
- Software: SARSCAPE
- Methodology: SBAS

Cooperation Dr. Elias P. and INFOREST, Mrs. M. Chanioti

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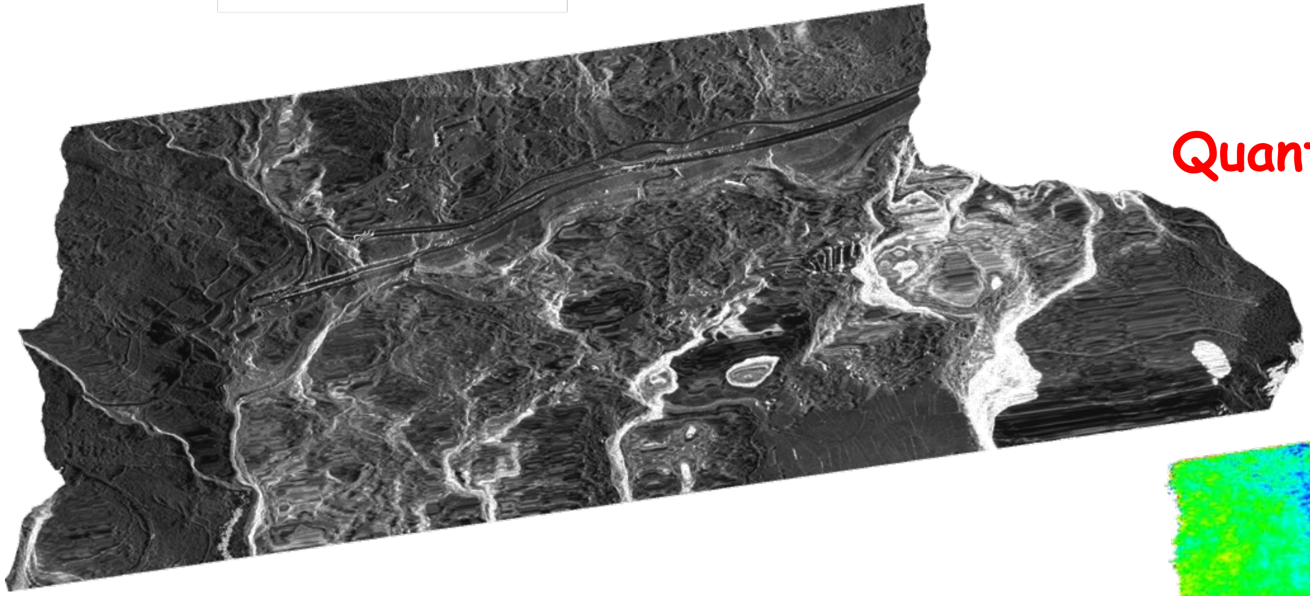
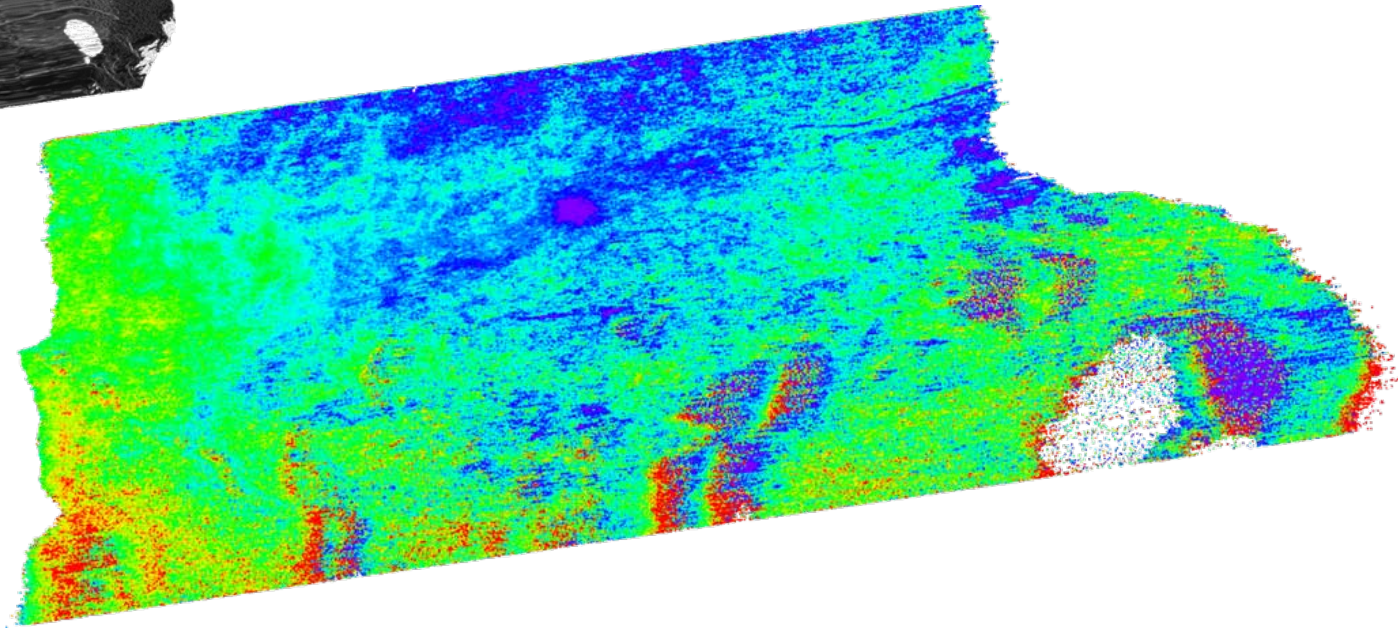
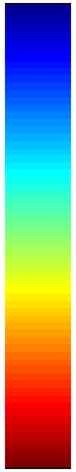
Tracking – Quantification of Road Network Failure (2)





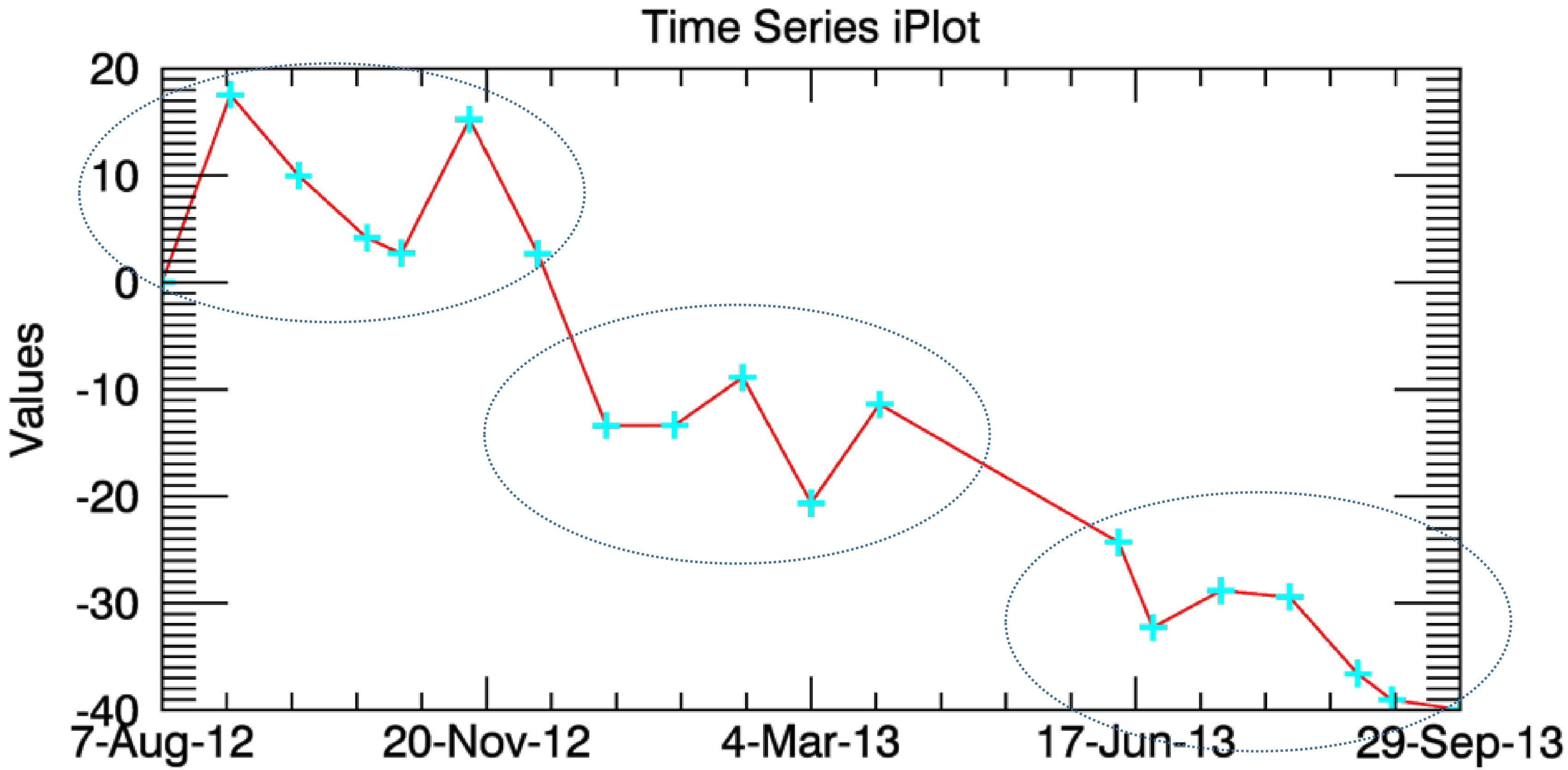
Tracking – Quantification of Road Network Failure (3)

mm / year



Deformation rate (mm / year) to the direction of maximum slope

Tracking –
Quantification of Road Network Failure (4)



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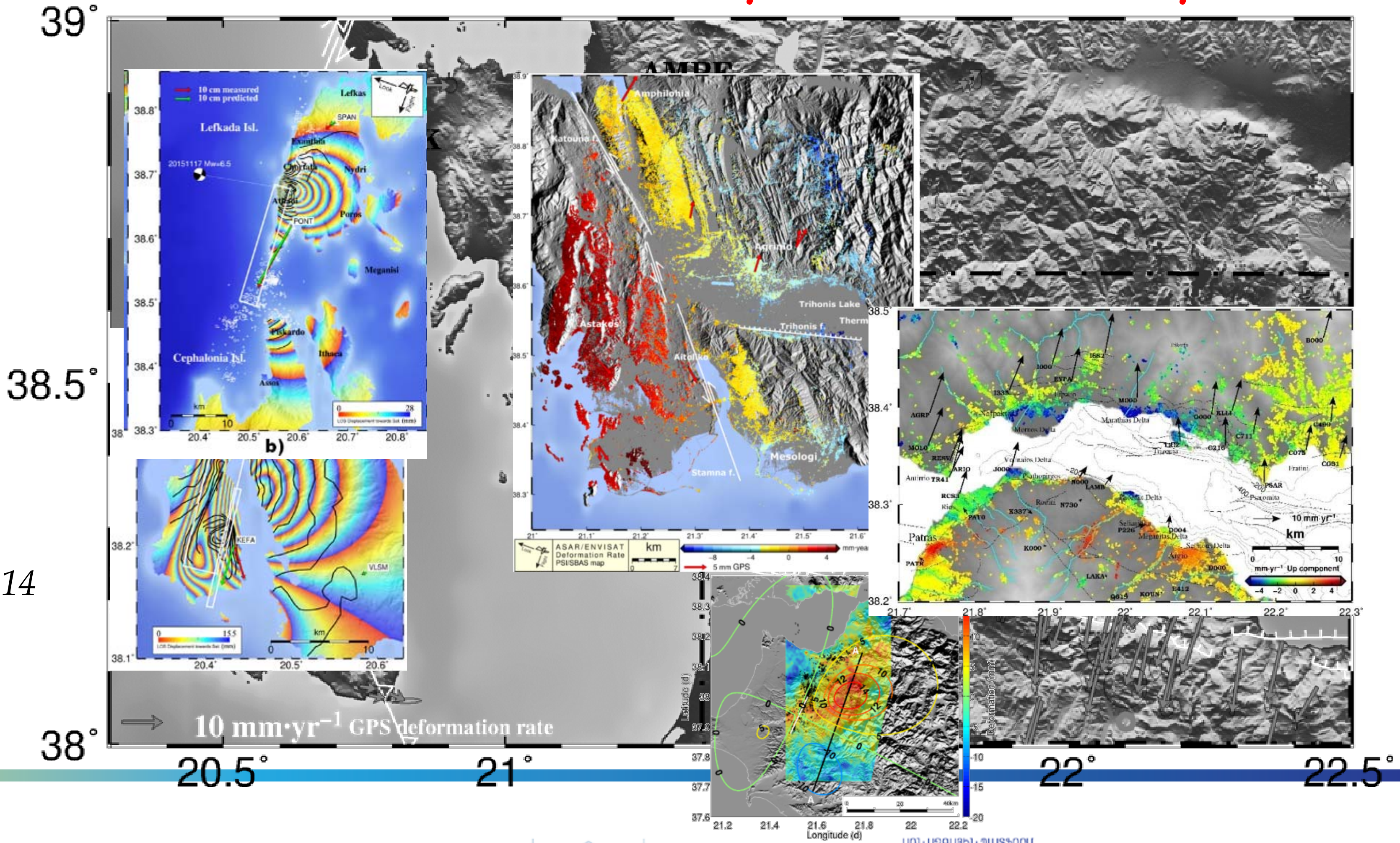
Corinth Rift Laboratory και Interferometry

Serpetsidaki et al., 2014

Briole et at., 2016



Ganas et at., 2016

Elias et al., 2016, 2017

Ilieva et al., 2016

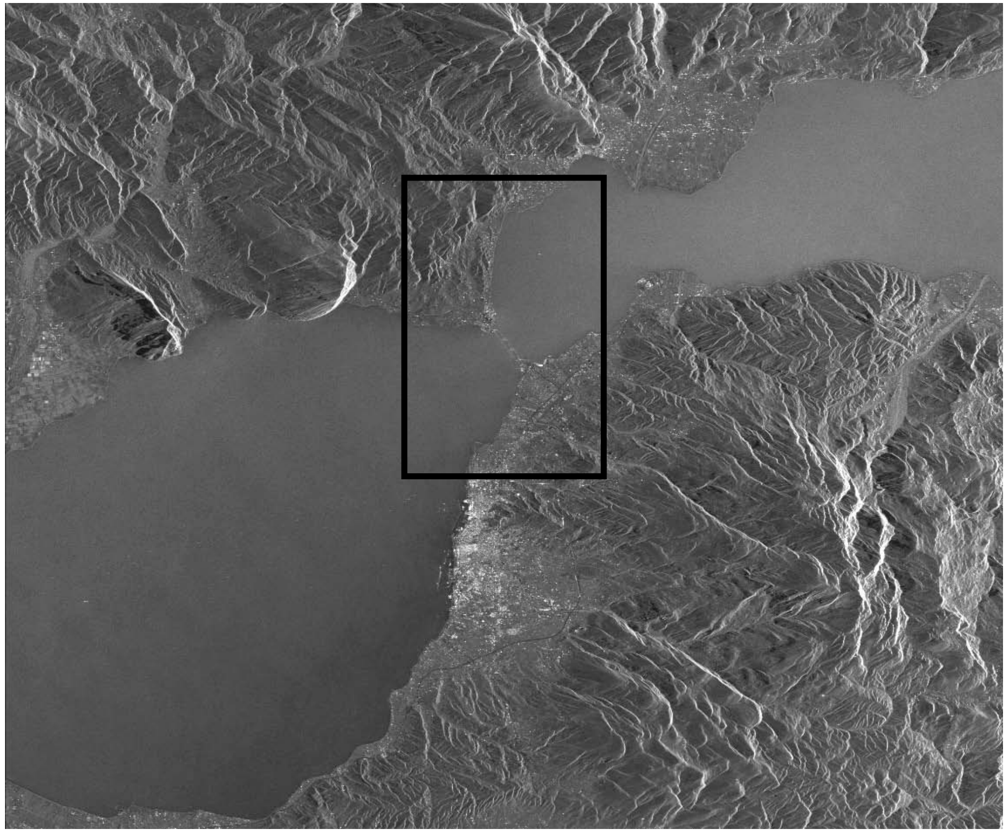
Rio – Antirio Bridge

The Rio – Antirio Bridge is the longest multi-span cable stayed bridge of the World with its 2,252 meters deck.

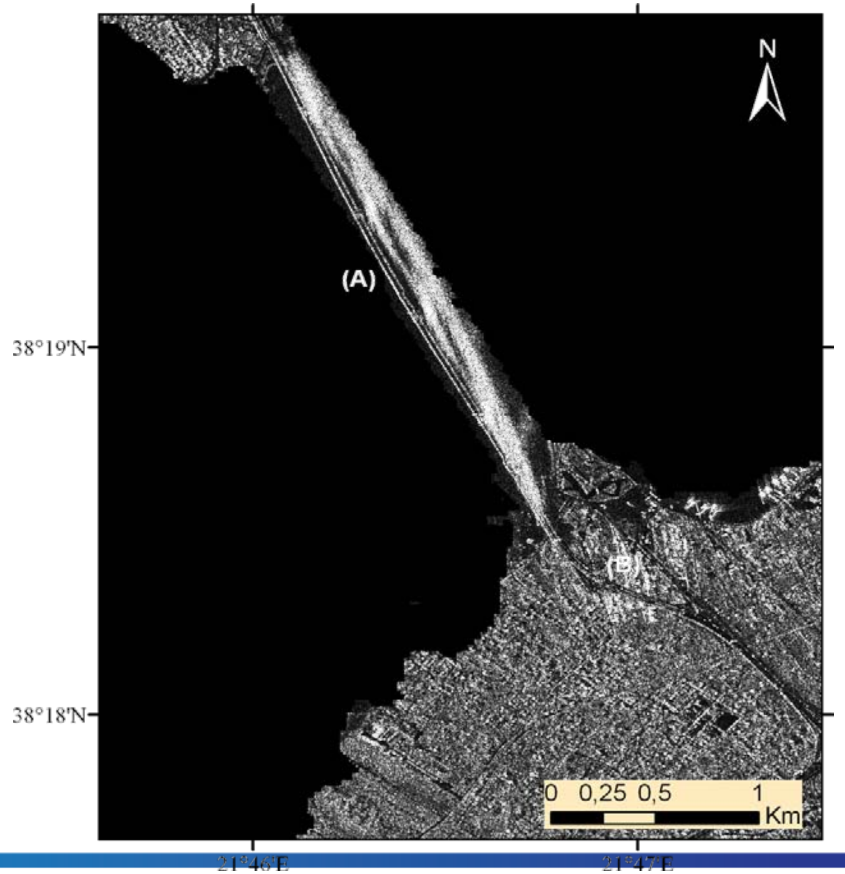
Its foundations lay on a seabed that reaches 65 meters of depth. This is a world record for a bridge as well as their diameter of 90 meters making of them the world's largest bridge foundations.

Rio – Antirio Bridge

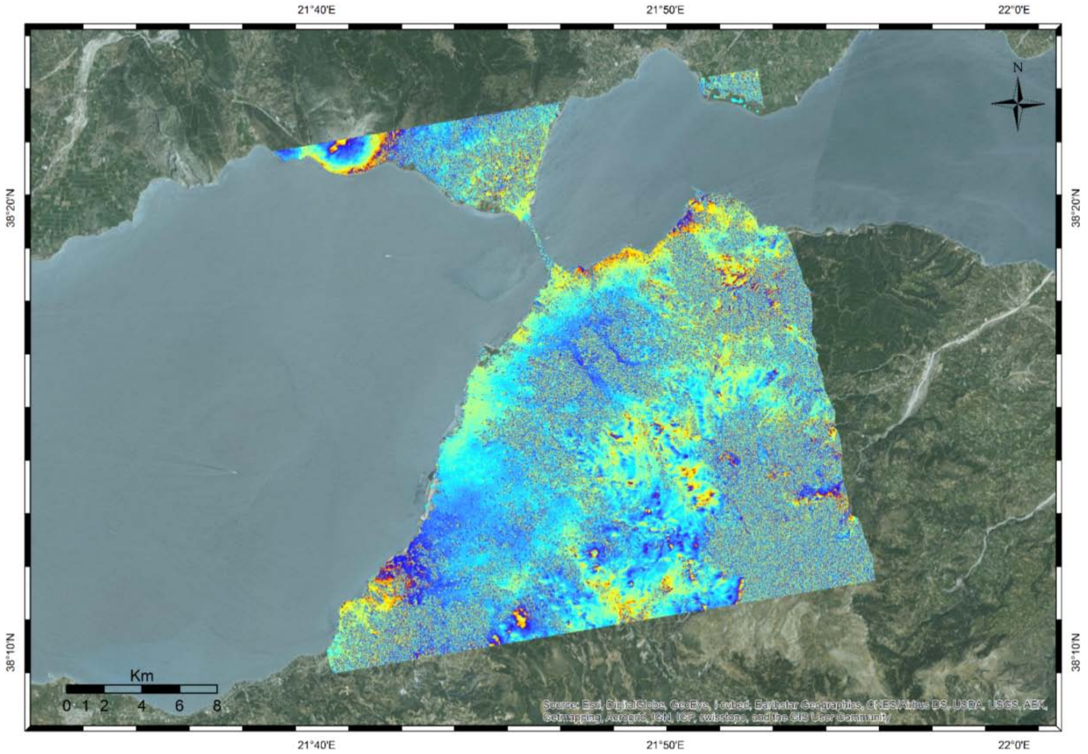
Amplitude image of bridge area

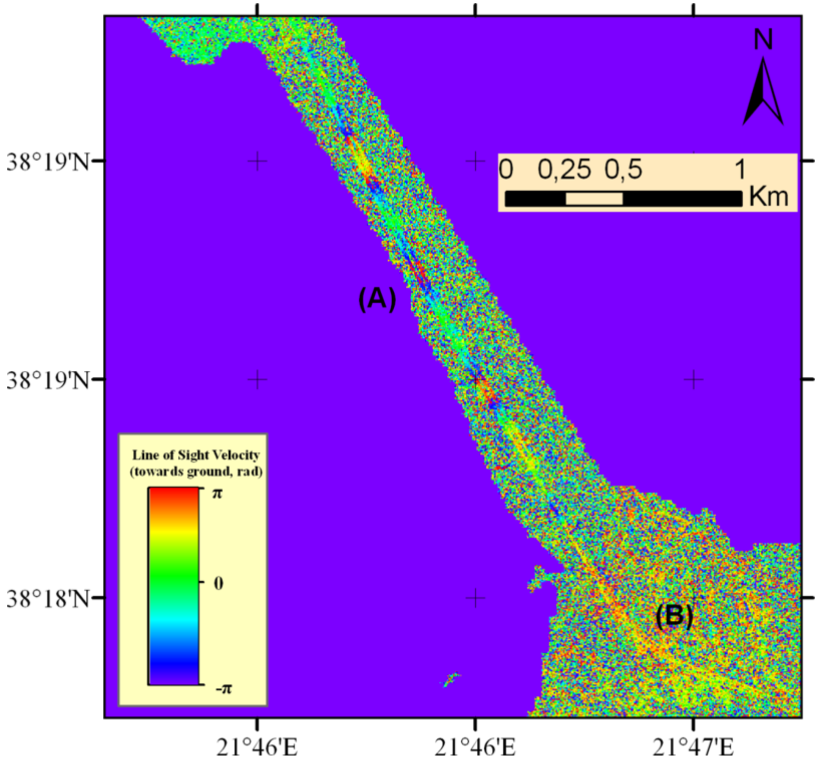


Radarsat-2, Ascending, Spotlight_ U16



Rio – Antirio Bridge





Interferometric pair of RS2 processing

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Thank you

Dr. George Drakatos
Dep. Director of IG/NOA