New results of the velocity field in Greece by an automatic process of a permanent GPS network

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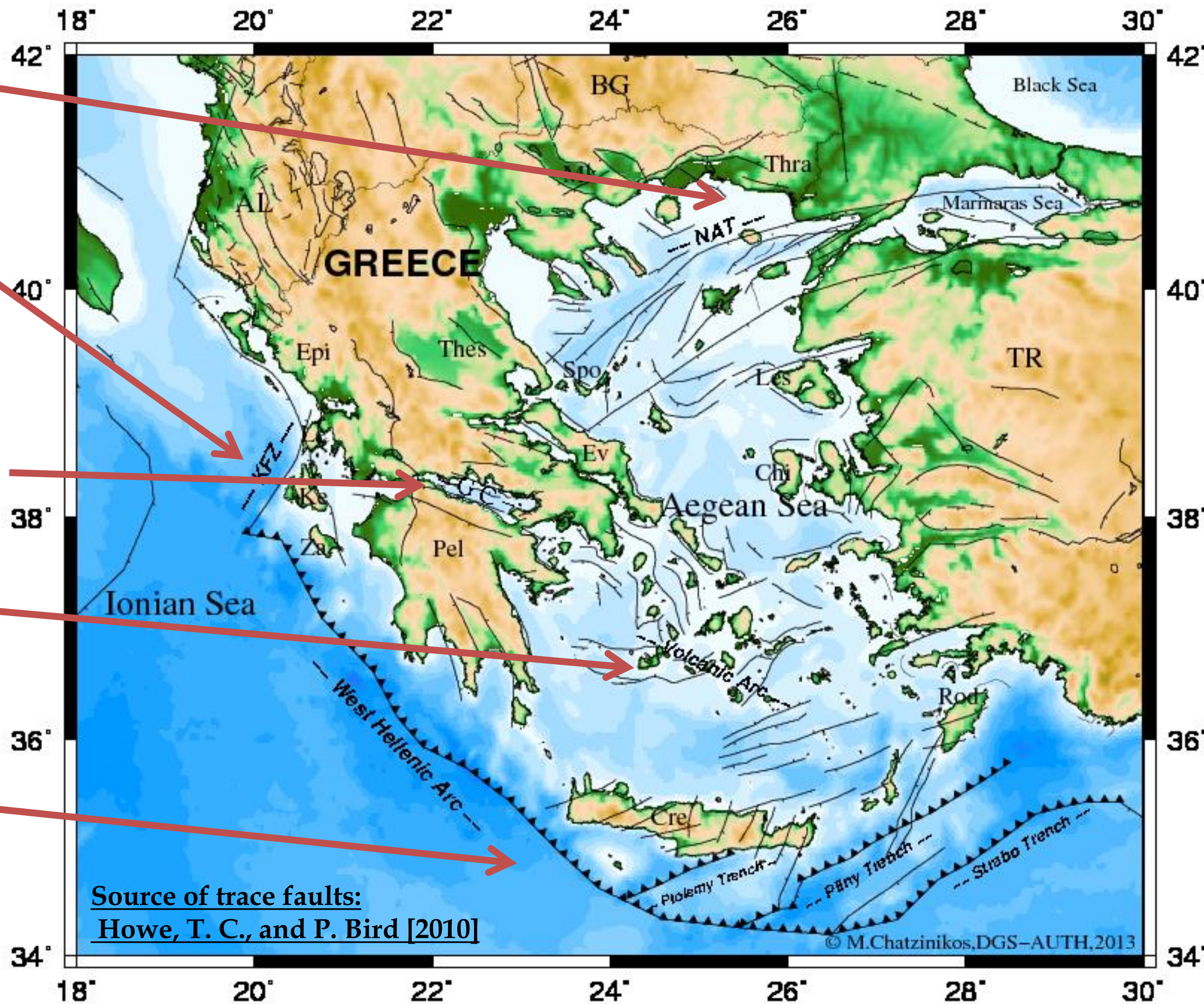
Outlines

1. Tectonic settings in Greece
2. CGPS data and GRNET
3. An automatic procedure for GPS data processing
4. Estimation of site velocities using different displacement models
5. A comparison of velocities between BERNESE v5.0 and H&D MOGS
6. Final results of the velocity field in Greece (IGS08, ETRF2000)
7. Summary

Tectonic Settings in Greece

- North Anatolian Fault
- Cephalonia Fault Zone
- Corinthian Gulf (complex fault zone)
- Volcanic Arc (Santorini – Nisyros - Methana Volcanoes)
- Hellenic Arc (Subduction of African beneath Aegean plate)

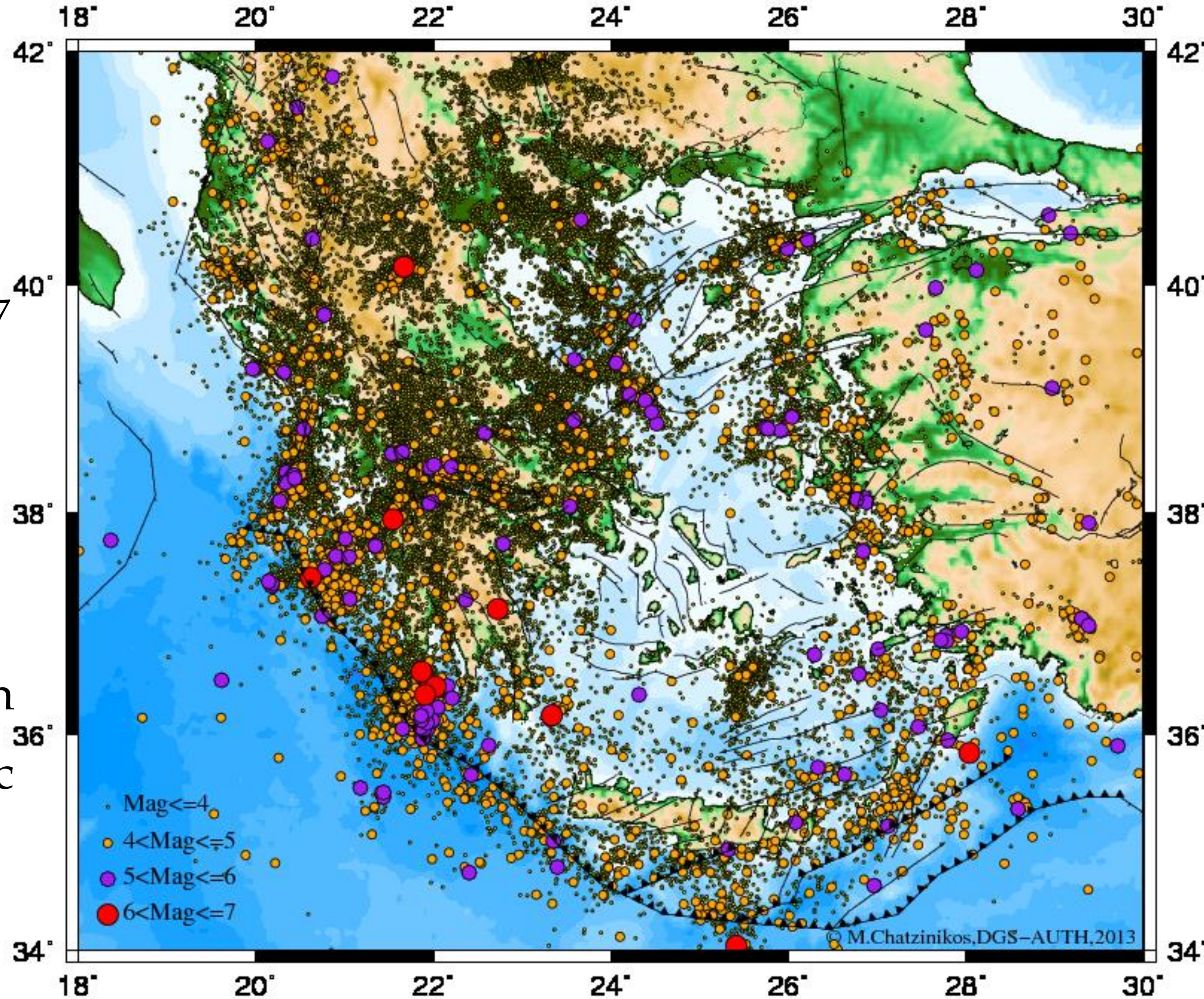


Earthquakes in Greece

- From 1995 until 2011
  - 53538 earthquakes Richter (scale)<7
  - 146 earthquakes 5<Richter (scale)<7

Source: http://geophysics.geo.auth.gr

- The most seismically active areas in Greece:
  - Ionian Islands
  - Northern Aegean
  - West Hellenic arc
  - Central Greece



GRNET & CGPS data

125 Permanent GPS/GNSS Stations:

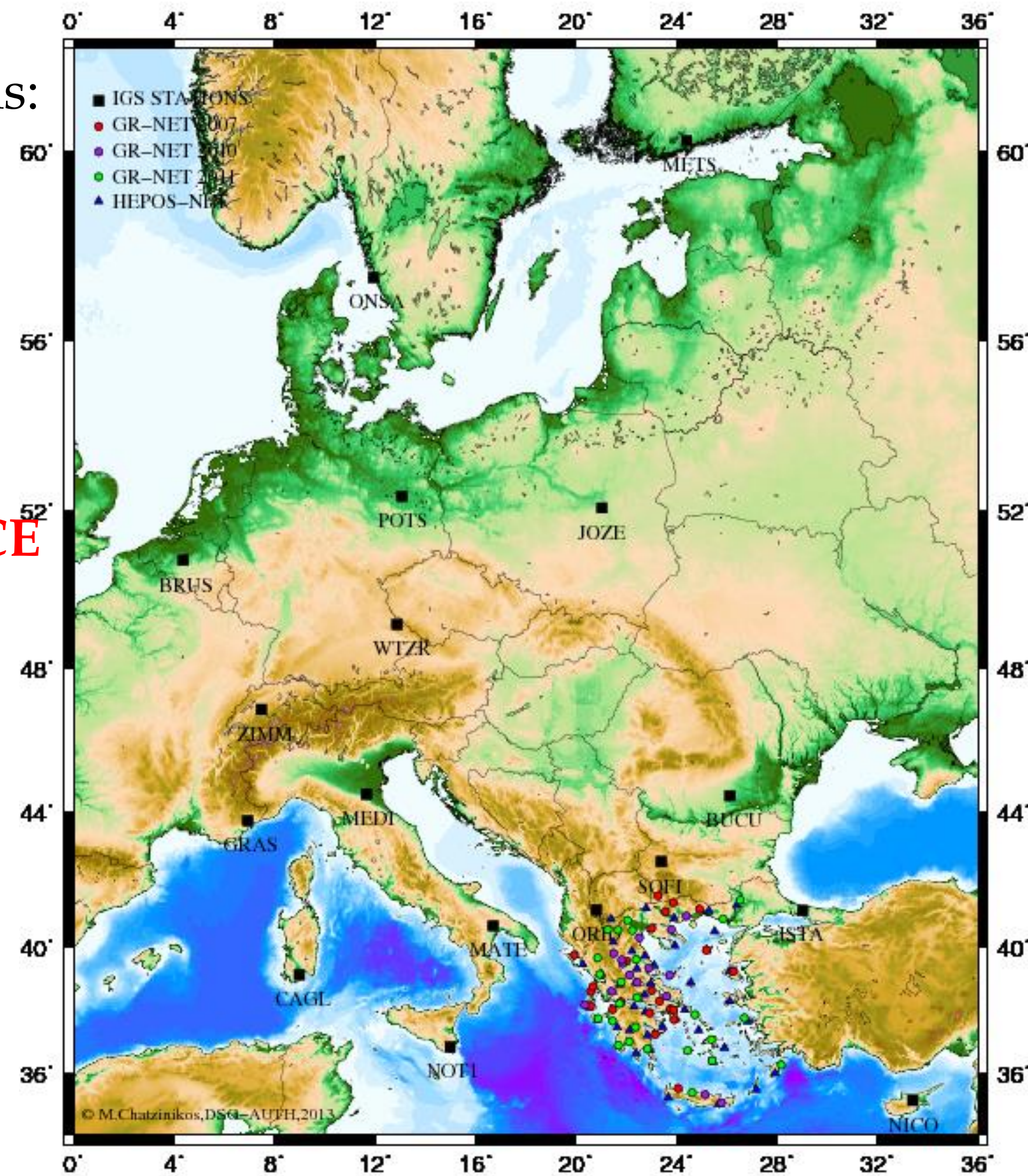
- 17 IGS/EPN Stations
- 108 stations at Greece
  - 6 EPN
  - 60 belongs to **LEICA SMARTNET-GREECE** (METRICA S.A)
  - 42 belongs to **HEPOS** (KTIMATOLOGIO S.A)

GPS data time span:

- From 2007 until 2013

GPS continuous data per station:

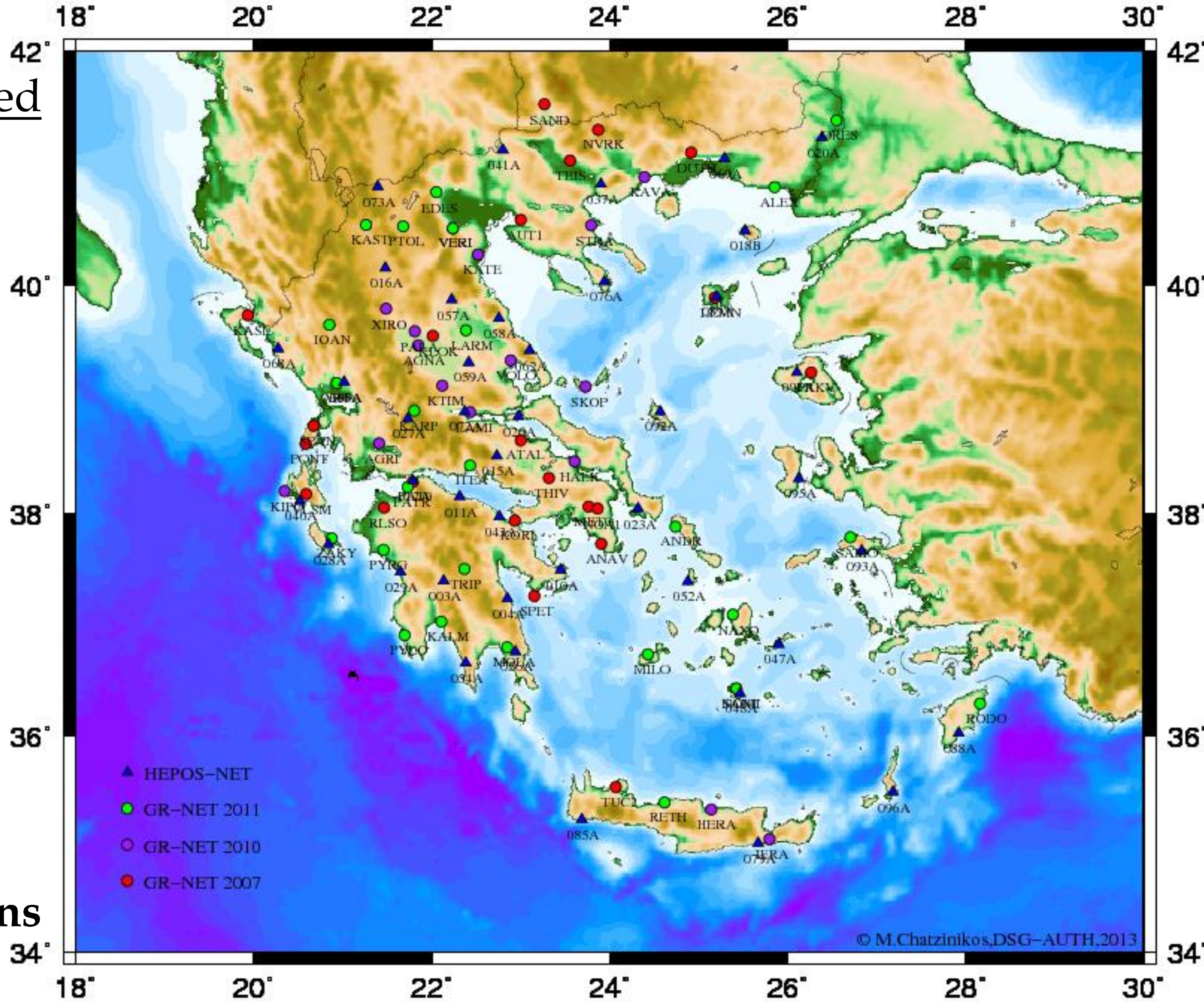
- From 2 to 6 years



GRNET sub-networks

<u>GRNET was divided in 4 sub-networks:</u>

- **GRNET 2007** (40 stations)
- **GRNET 2010** (27 stations)
- **GRNET 2011** (34 stations)
- **HEPOSNET** (49 stations)
- **7 to 9 joint stations** between sub-nets



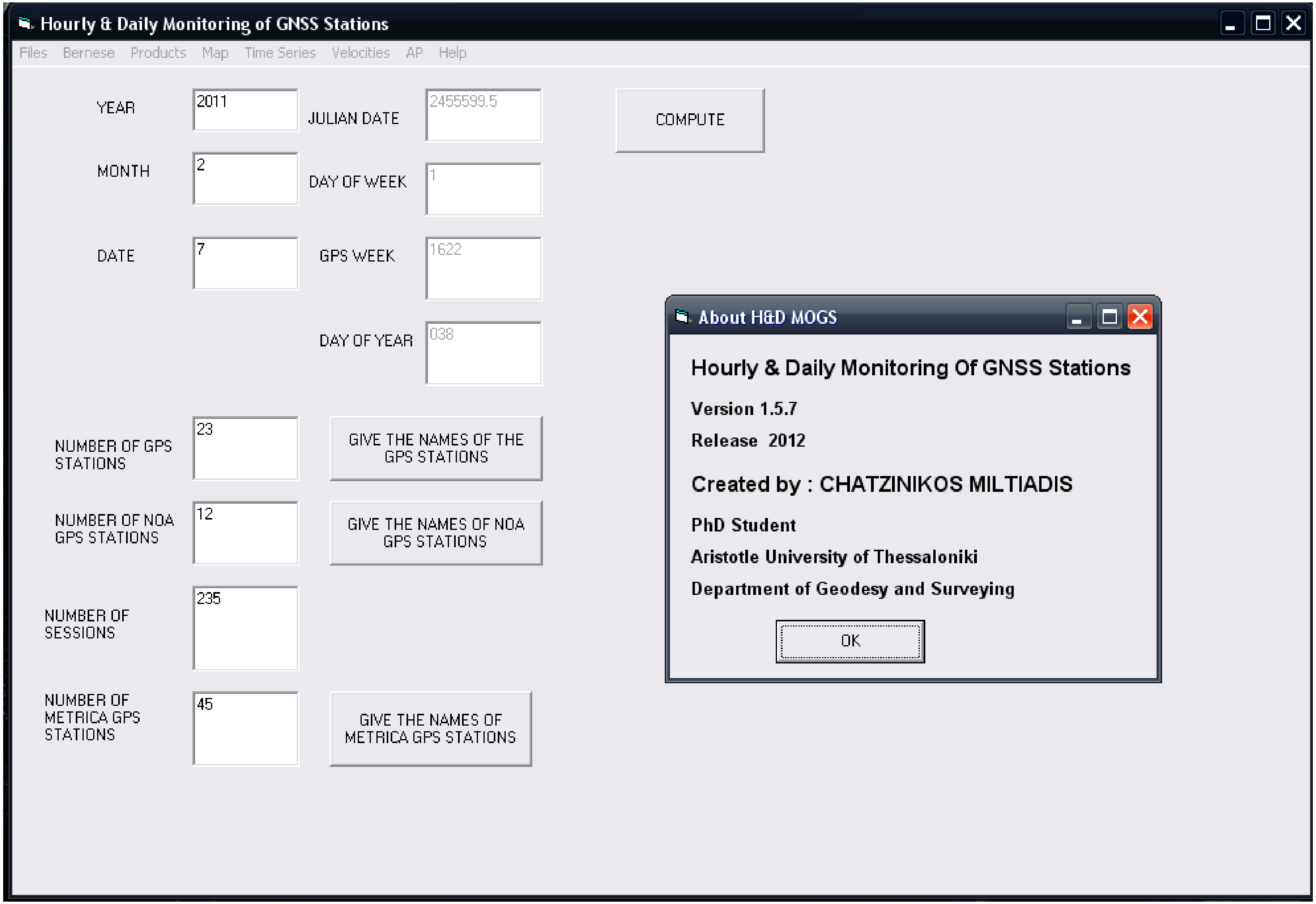
H&D MOGS software

Hourly and **D**aily **M**onitoring **O**f **G**NSS **S**tations:

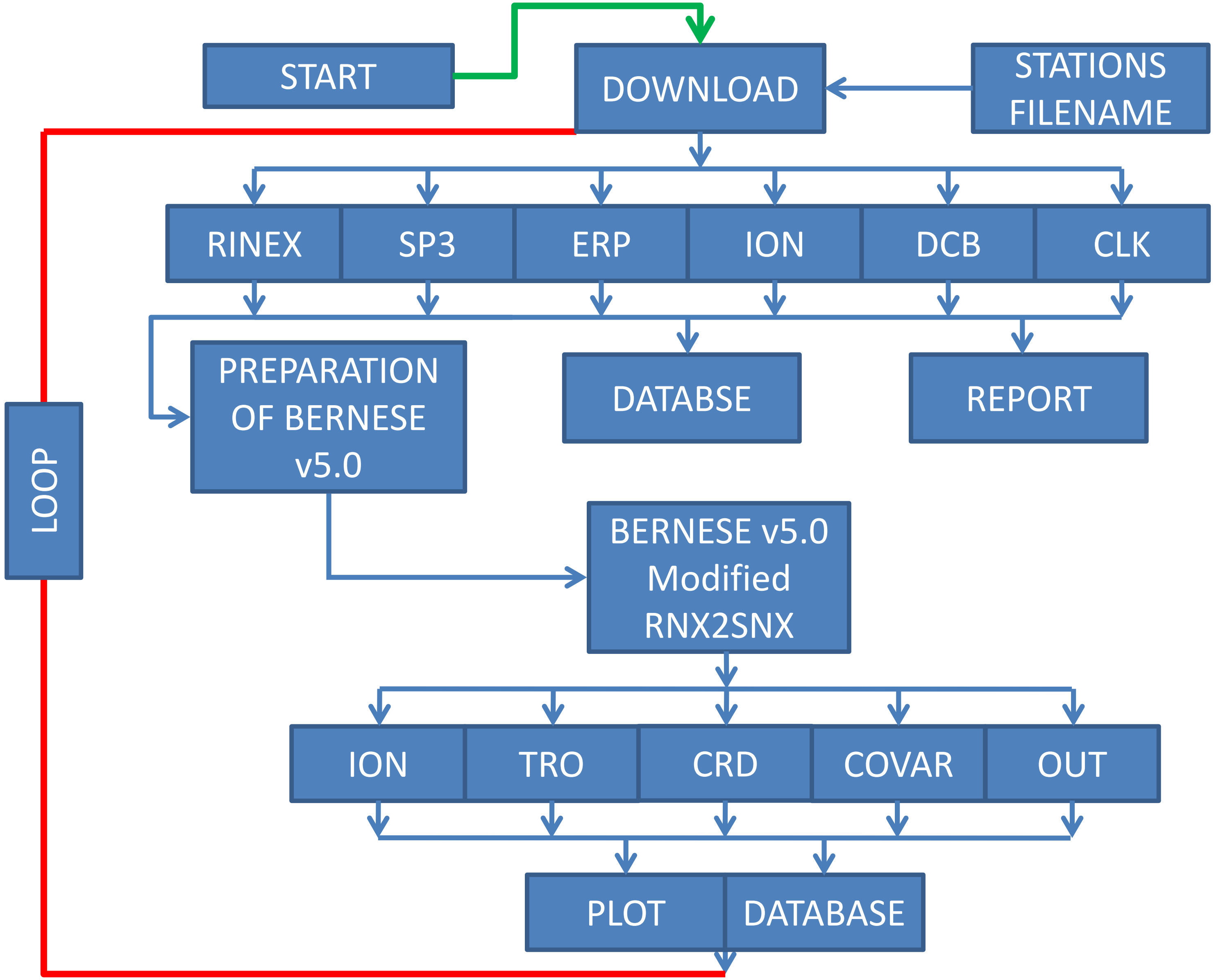
- created for **monitoring of GNSS station position by an automated procedure**
- written in Fortran with its interface in Visual Basic.

- software features:
  - **fully cooperated** with:
    - **BERNESE** GPS SOFTWARE v5.0 for data processing
    - MATLAB for plotting output files
    - GMT for creation of maps
  - **Analysis of stations position time series**
    - Estimation of discontinuities magnitude
    - Estimation of periodic signals
    - Identification of outliers
    - Estimation of stations velocities
  - runs in:
    - Manual mode
    - Automatic mode

H&D MOGS INTERFACE



Automation in GPS data processing



GPS data processing

Strategy of session solution for each one sub-network with BERNESE v.5.0:

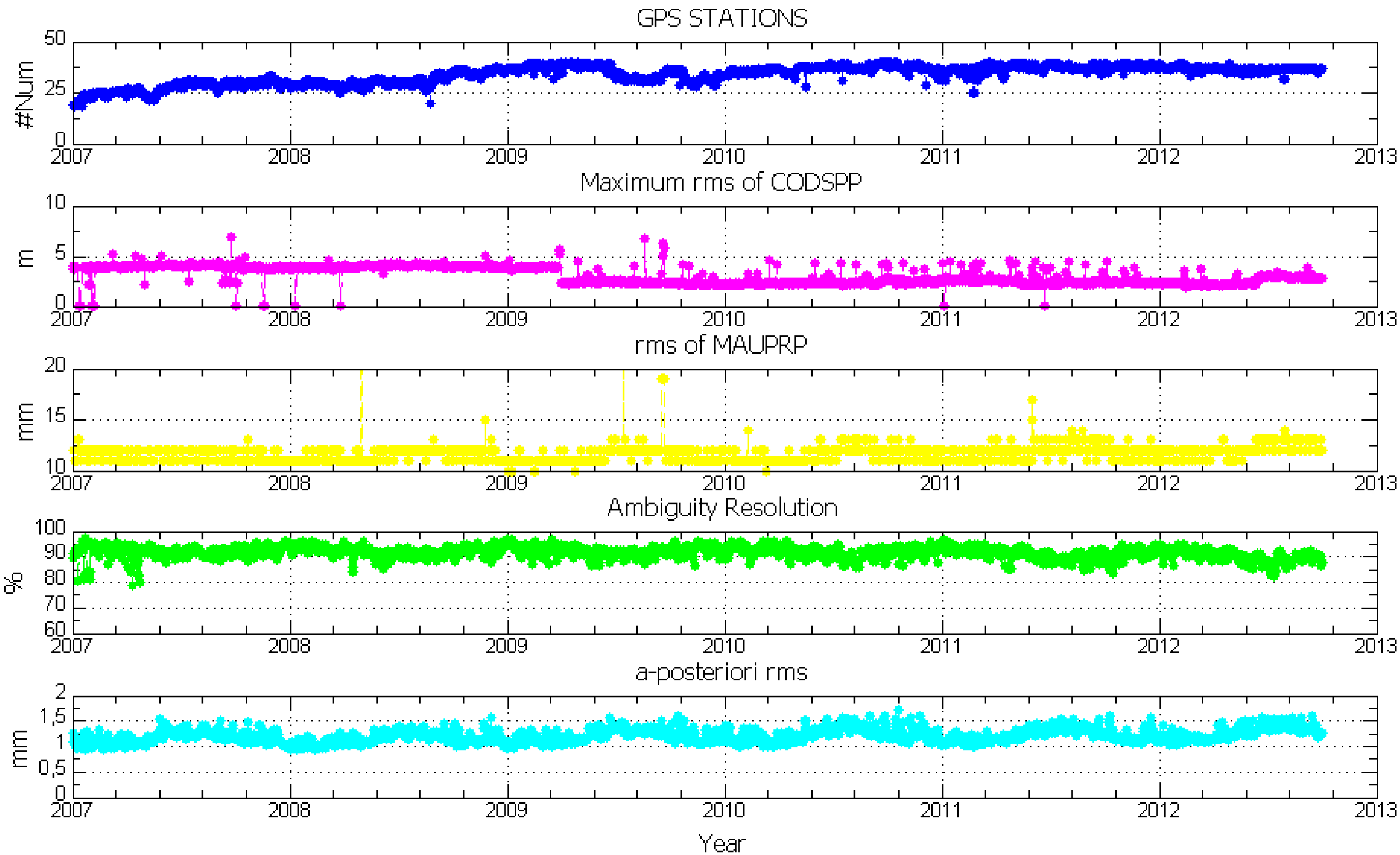
- **EUREF guidelines**
- Software: **Bernese v5.0** (modified script file RNX2SNX)
    - Ambiguities resolution methods: SIGMA<200 km and QIF>200km
    - 5^{o} elevation mask
    - Dry & Wet Niell mapping function
    - One tropospheric parameter every two hours
    - Absolute antenna PCO+PCV model: IGS05/IGS08
    - Minimum constraint solution: 7-17 IGS stations depending on the sub-net

Daily solutions:

- Stacking of the four sub-networks
- Minimum constraint solution: 17 IGS stations (IGS05/IGS08)

BERNESE Daily Solutions

Example: Quality parameters for each daily solution (sub-network GRNET 2007)



Estimation of Site Velocities

Strategy with H&D MOGS software

- Input data: daily **CRD** and **VAR-COVAR** files **from BERNESE**
- Transformation of geocentric coordinates and its uncertainties into topocentric
- Estimation of site velocities with the **linear model**

$$X(t) = X(t_0) + (t - t_0) \cdot V$$

- Estimation of site velocities with an **extended displacement model** (linear +annual signals + semi-annual signals + discontinuities)

$$X(t) = X(t_0) + (t - t_0) \cdot V_0 + \sum_{i=1}^{m_{\Delta X}} \left(\Delta X_i \cdot k_{\Delta X,i}(t)\right) + \sum_{i=1}^{m_s} \left([a_i \cdot \sin(\omega_i \cdot \Delta t) + b_i \cdot \cos(\omega_i \cdot \Delta t)] \cdot k_{s,i}(t)\right)$$

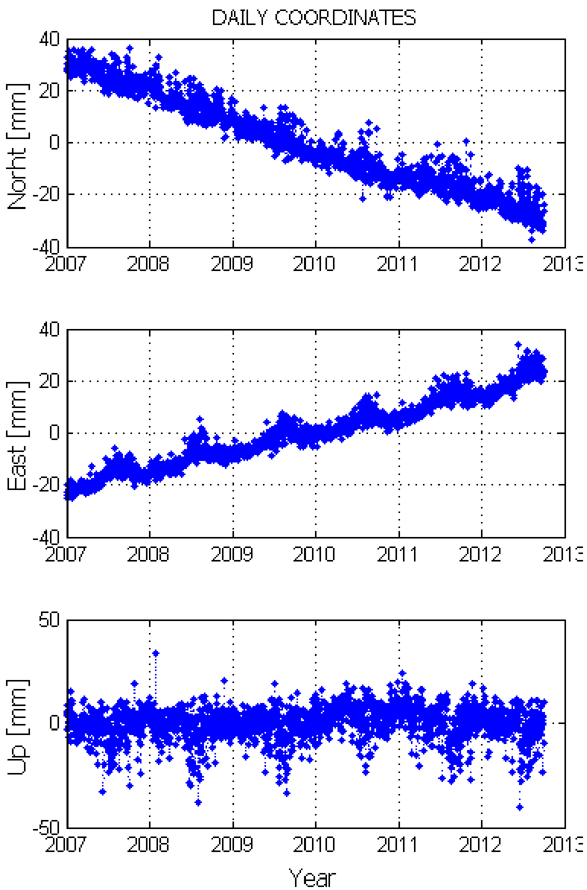
- Definition of possibly discontinuities in the **extended model**
- Parameter significant tests
- Data Snooping on residual time series

✓ The parameters are estimated by least square adjustment **separately for each station and coordinate component**.

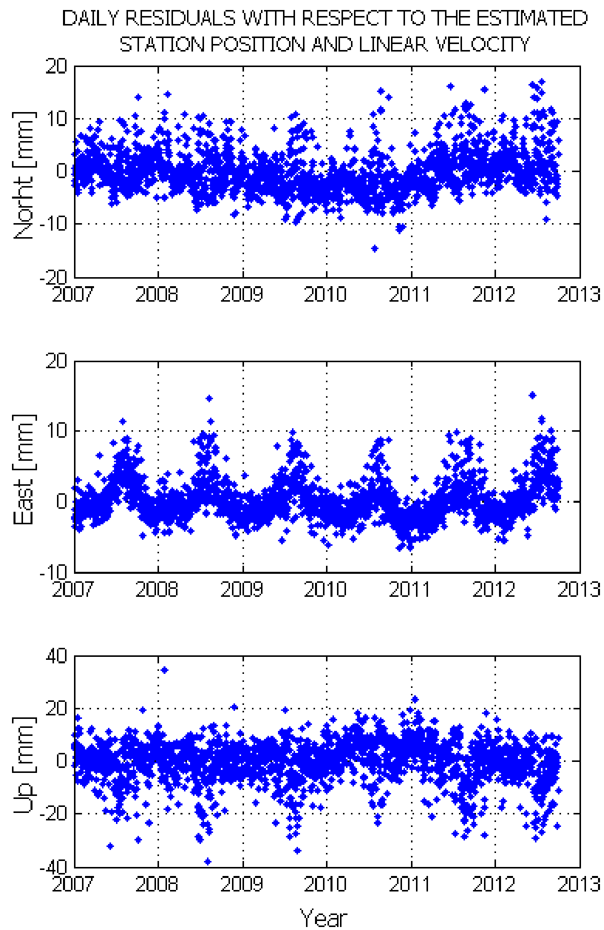
Time series analysis with H&D MOGS

Example: NOA1 station velocities

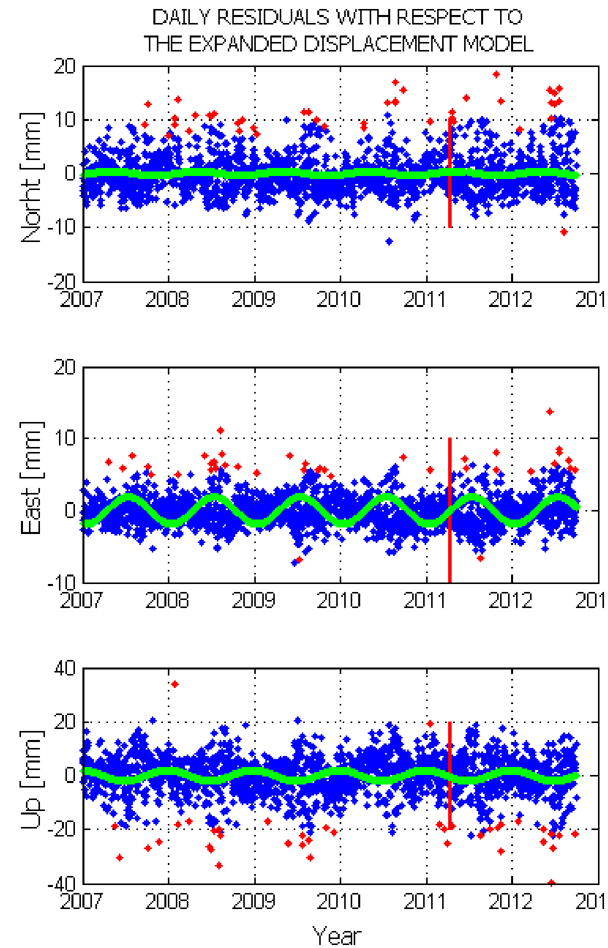
1) Input Data



2) Linear velocity model



3) Extended displacement model



Discontinuities in GRNET using the extended model

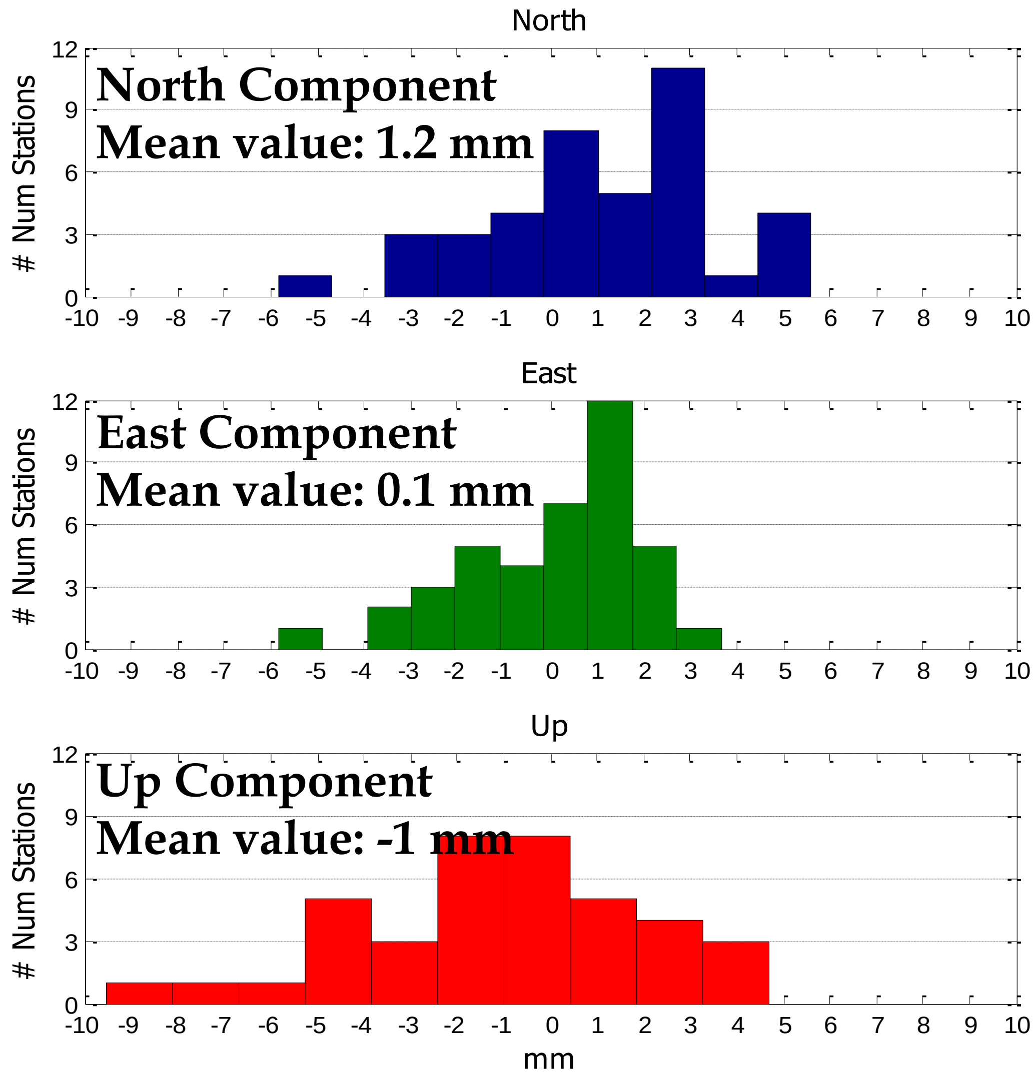
Testing 138 Predefined Discontinuities (significant test):

111 accepted:

- 94 due to switch from IGS05 to IGS08
- 16 due to stations equipment change
- 1 due to earthquake

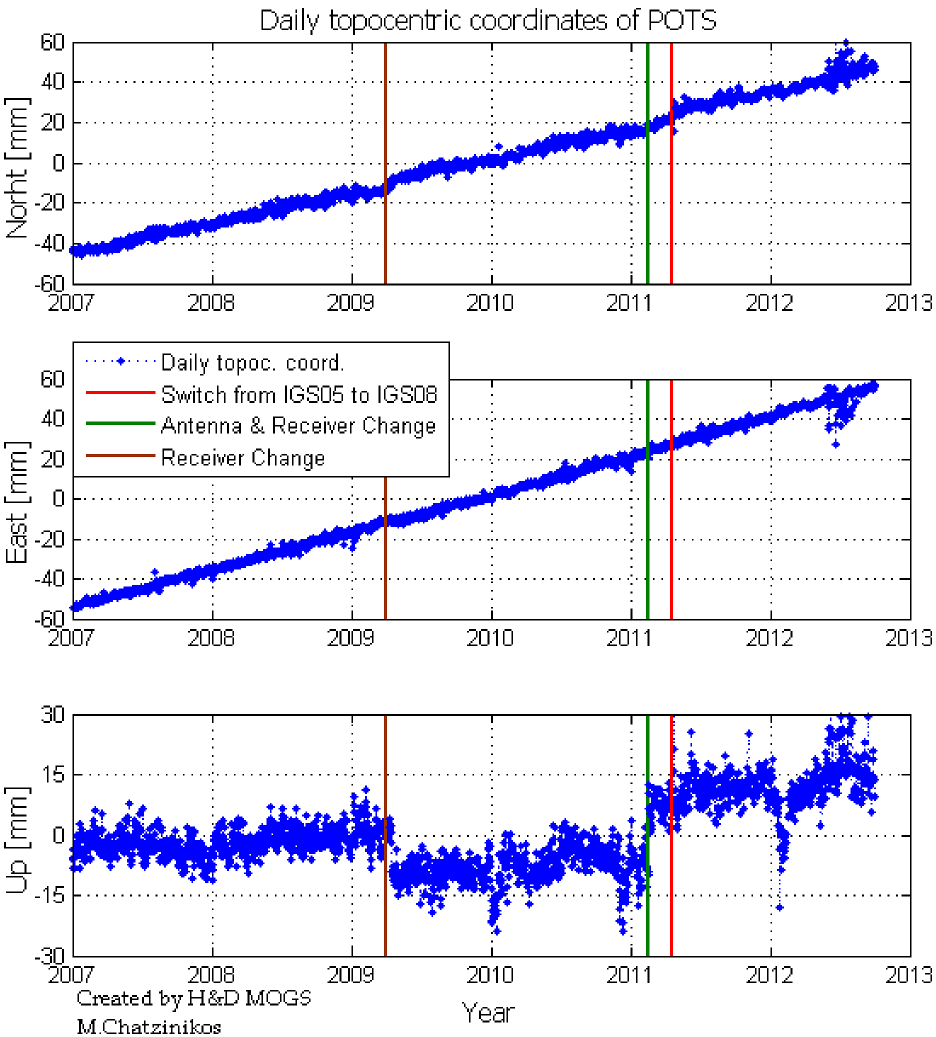
27 rejected

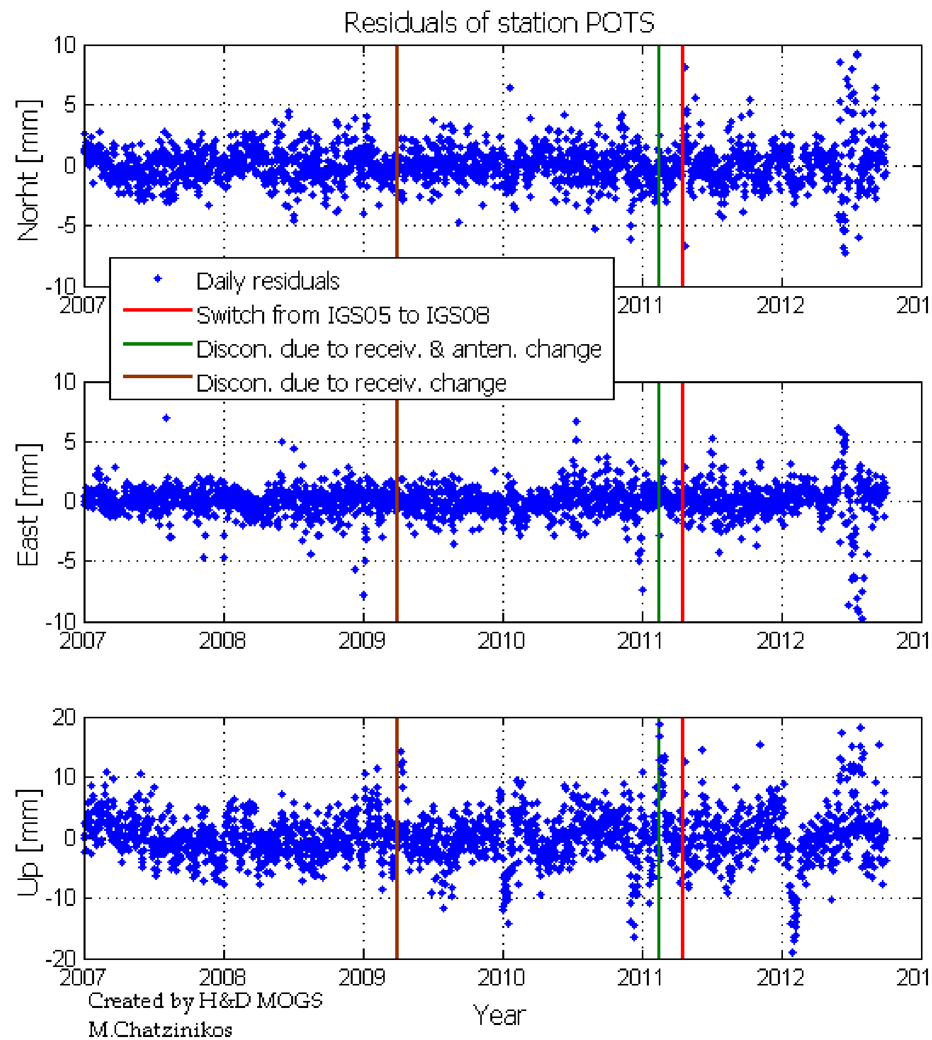
Histogram of discontinuities due to switch from IGS05 to IGS08



Discontinuities due to equipment change

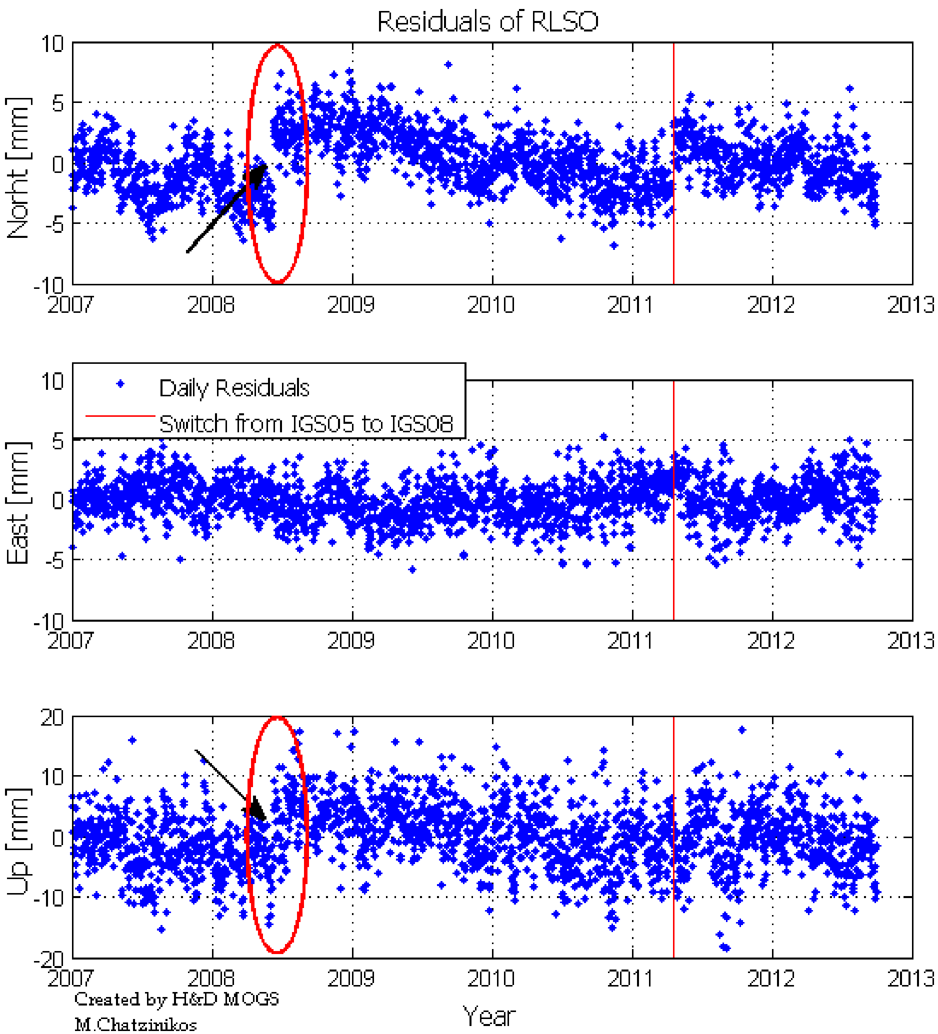
Example: discontinuities due to receiver and antenna change of station POTS

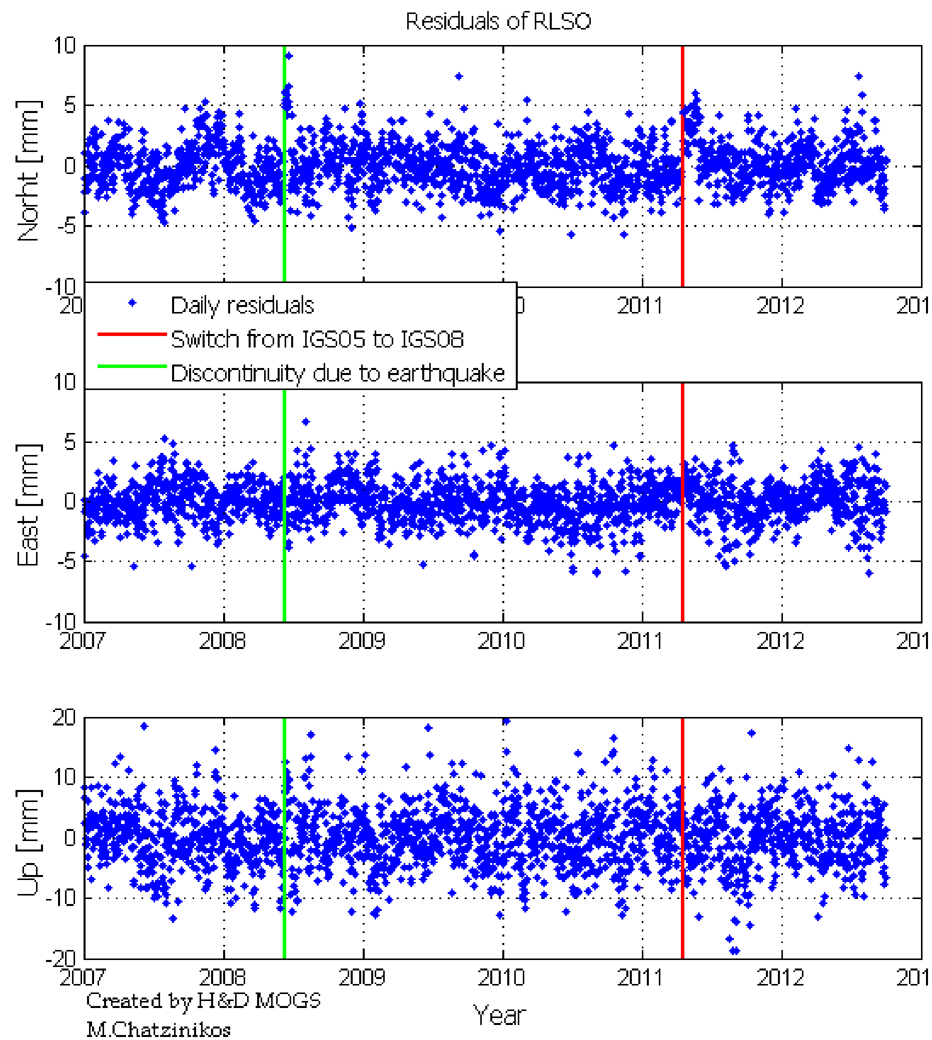




Discontinuities due to earthquake

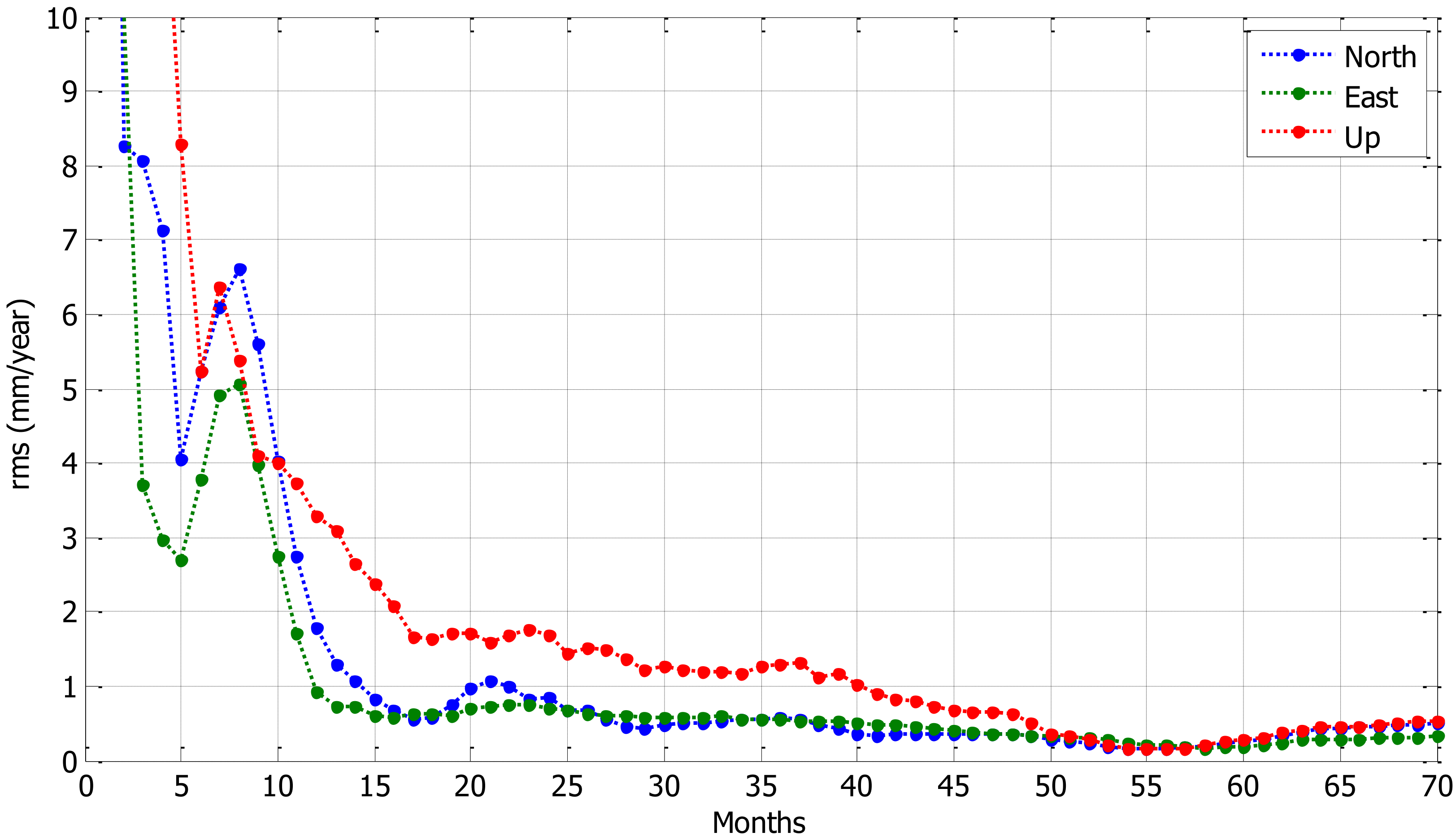
On June 2008 an earthquake (6.4 Rich.) occurred near station RLSO (Achaia)
Magnitude of discont.: North: 6±0.17 mm, East: -2±0.15 mm, Up: 8.9±0.43 mm





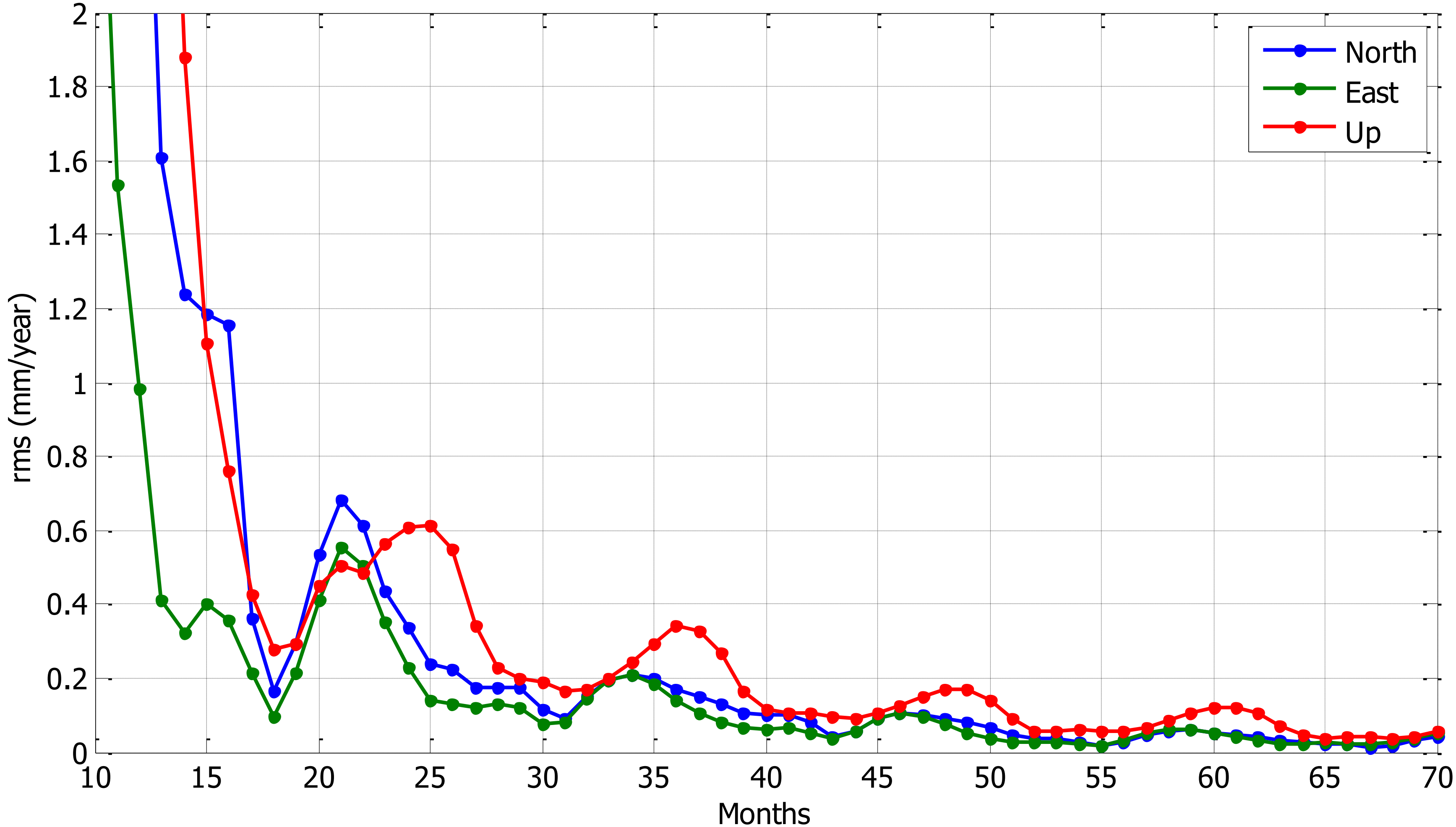
Linear velocity model versus time span

RMS differences between velocity estimations using the linear model for a time series of a given length and the final estimation of velocities using the extended model with the total time span (subnet GRNET 2007).



Linear velocity model versus extended displacement model

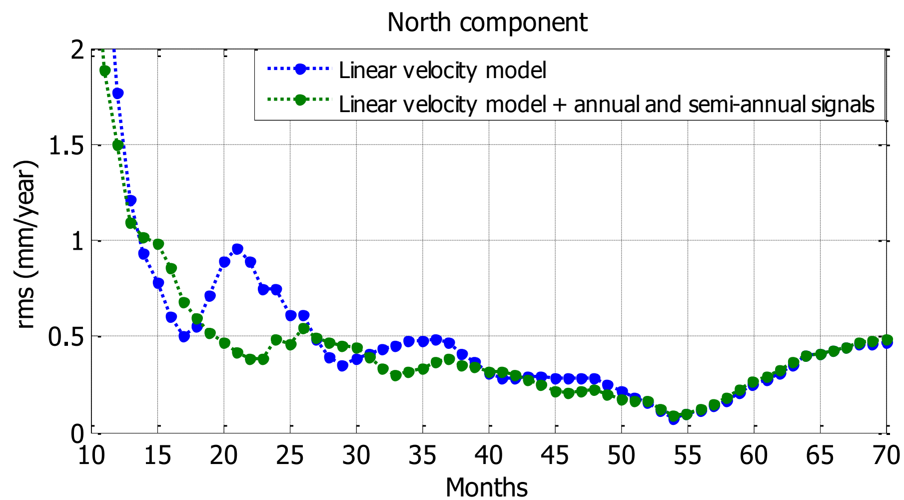
RMS differences between velocity estimations using the linear and the extended model for a time series of a given length (subnet GRNET 2007).

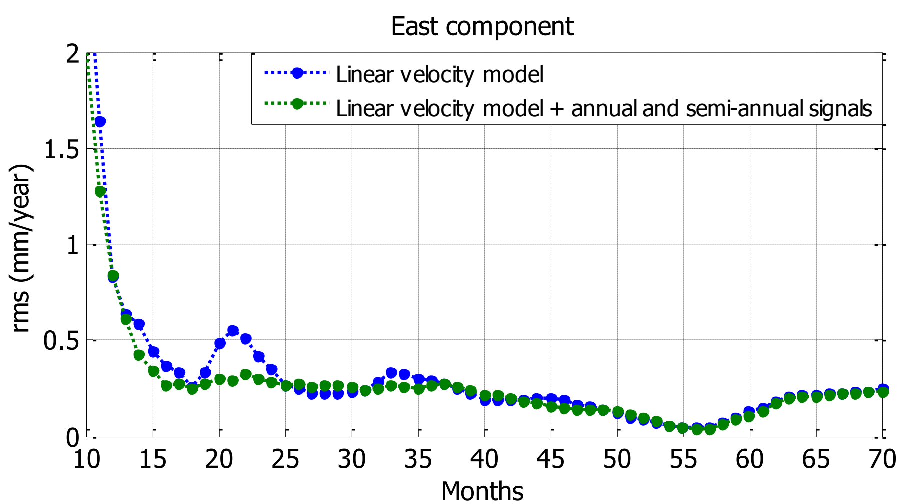


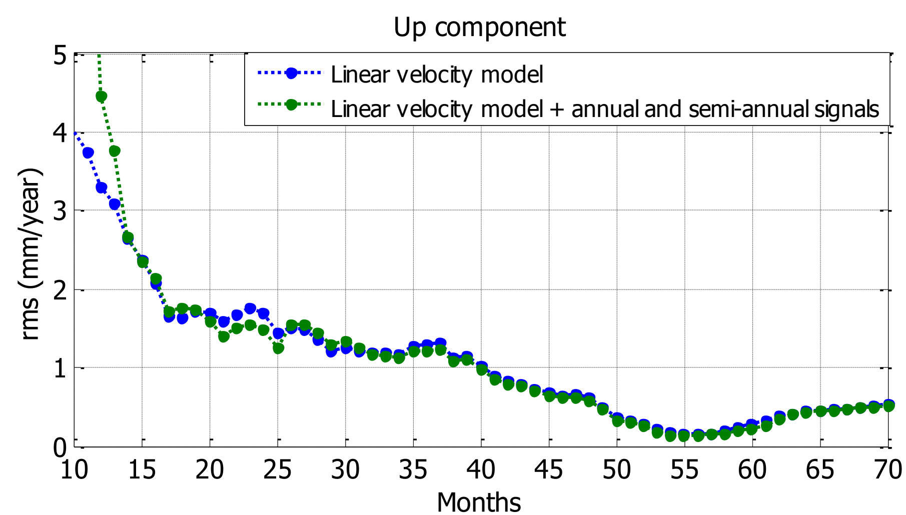
Linear and extended displacement model versus time span

RMS differences of velocities between linear and extended model relative to the final estimation (subnet GRNET 2007)

- The extended model shows smaller rms than the linear model for the periods of 18-25 and 32-38 months.
- The rms differences between the two models depend on the amplitude of annual and semi-annual signals.
- After 50 months rms is almost the same for the two models.





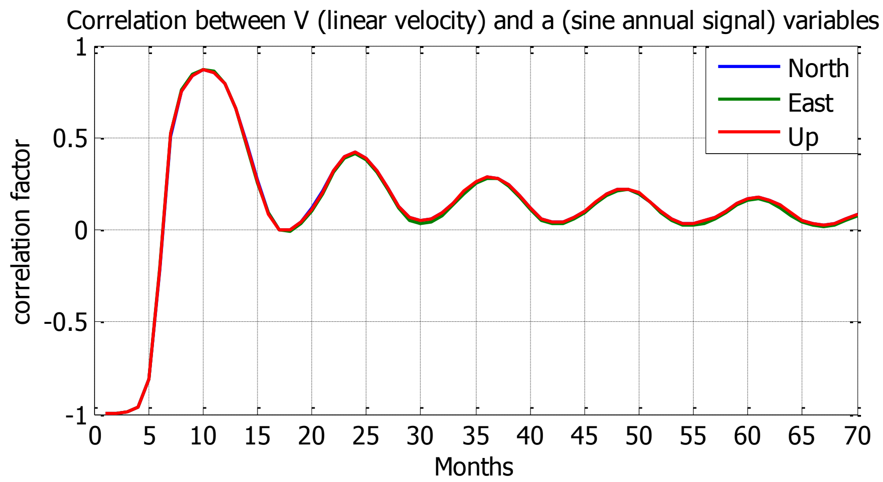


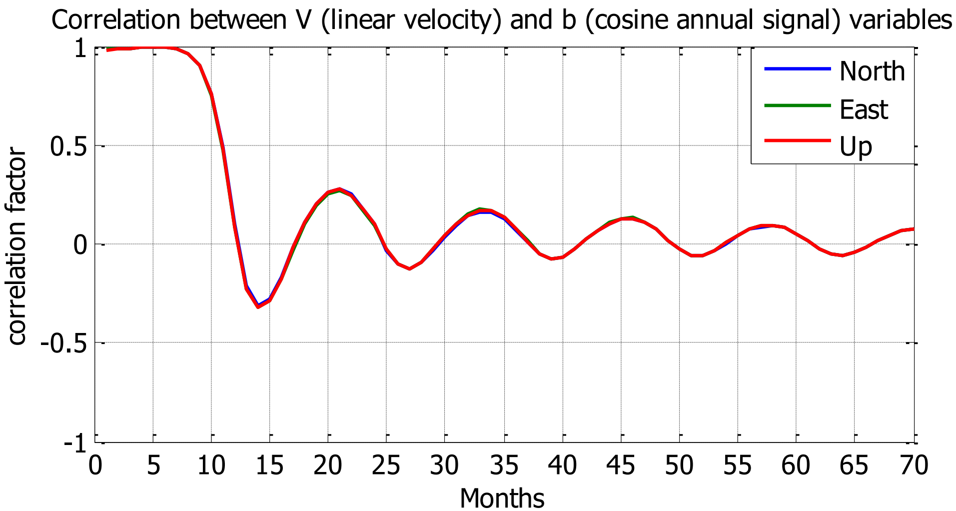
Correlation between velocity and annual signals

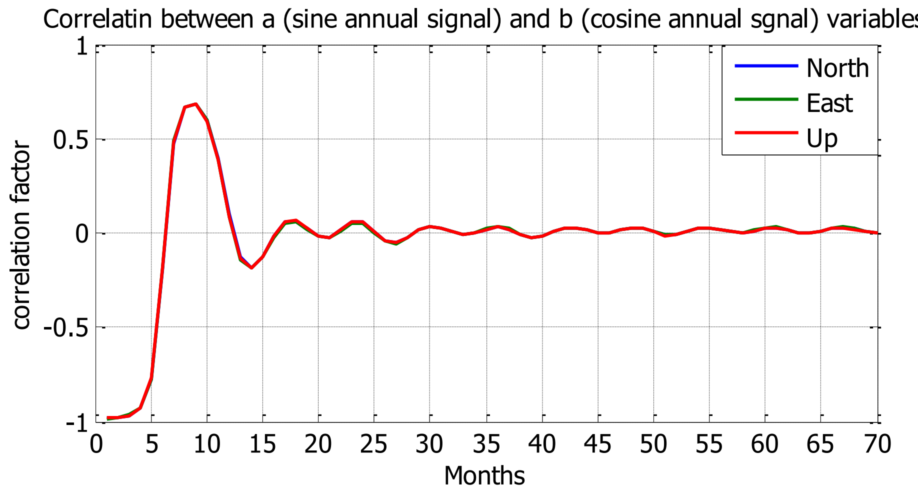
• The correlation between velocity and annual sine – cosine amplitudes is reduced to 30-40% after 18 months and 20% after 30 months.

• The correlation between velocity and annual amplitudes still exists after 60 months (10-20%).

• The correlation between annual sine and cosine amplitudes is almost vanished after 15 months.



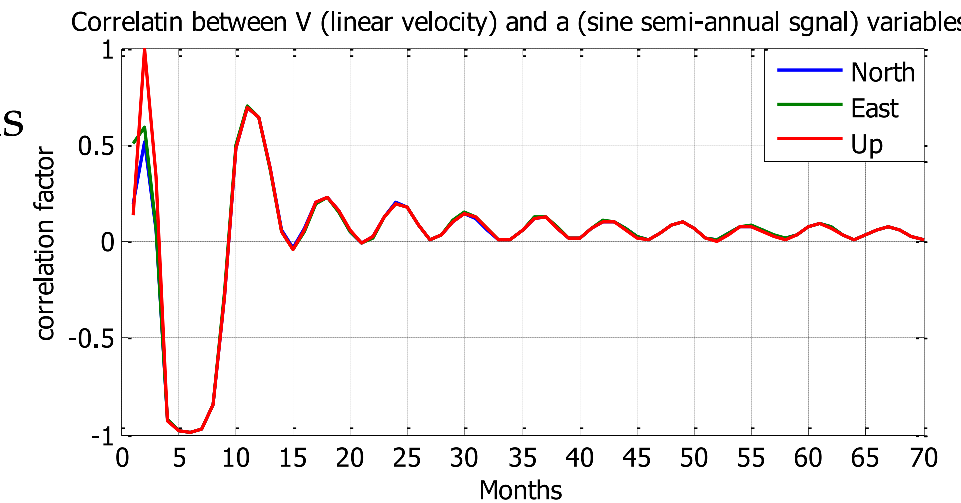


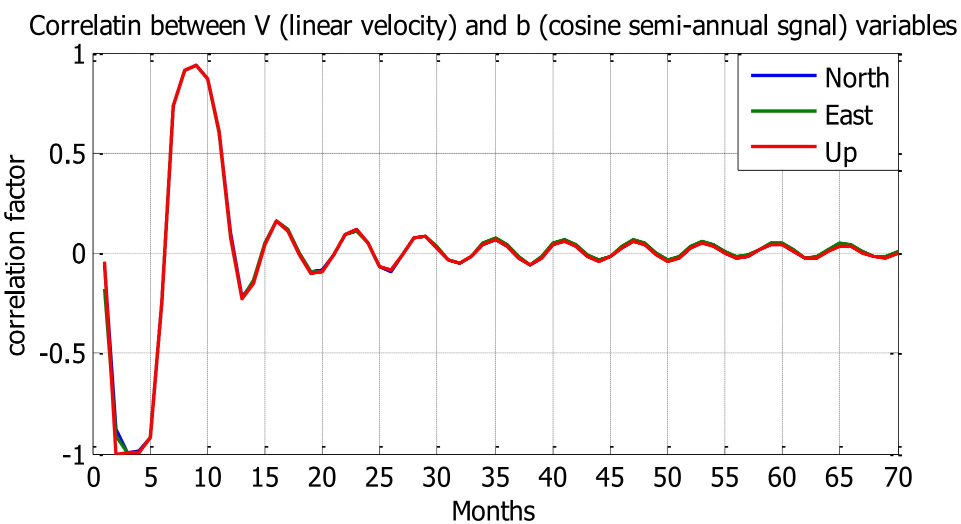


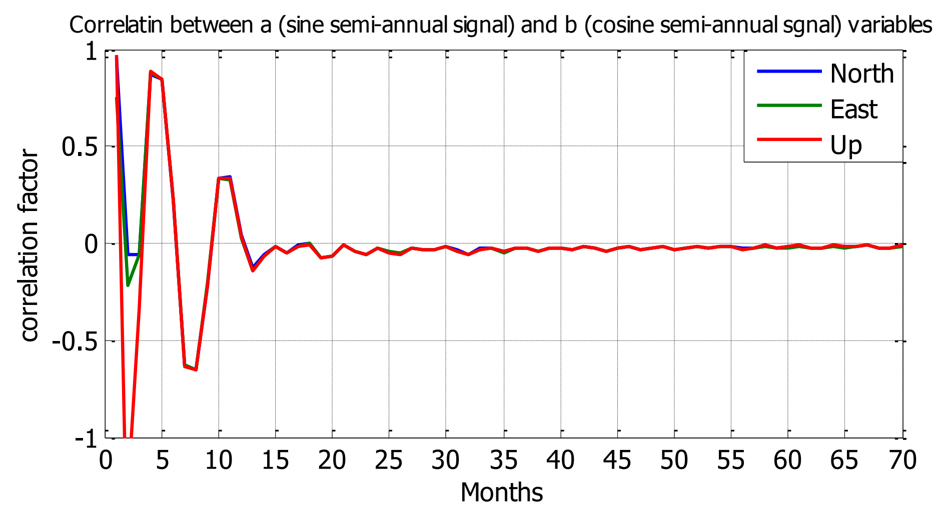
Correlation between velocity and semi-annual signals

- The correlation between velocity and semi-annual sine – cosine amplitudes is reduced to 20% after 15 months.

- The correlation between semi-annual sine and cosine amplitudes is almost vanished after 15 months.



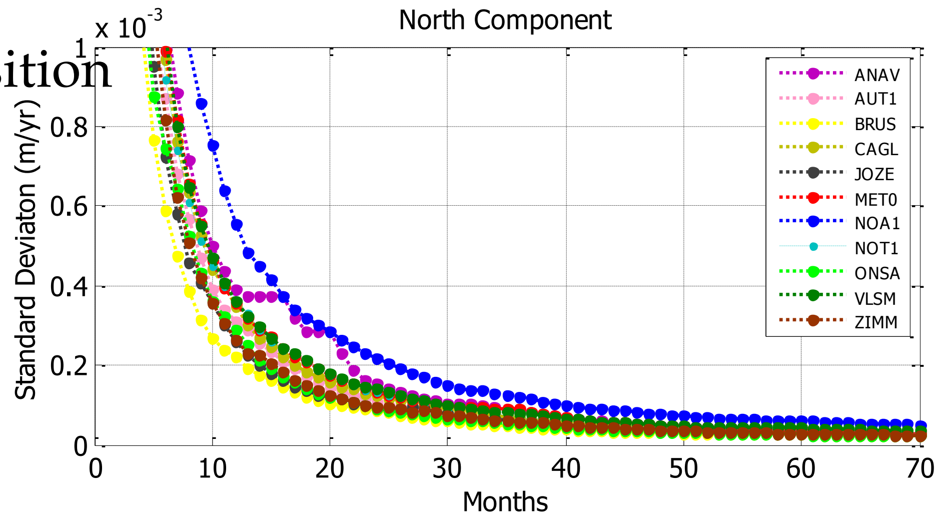


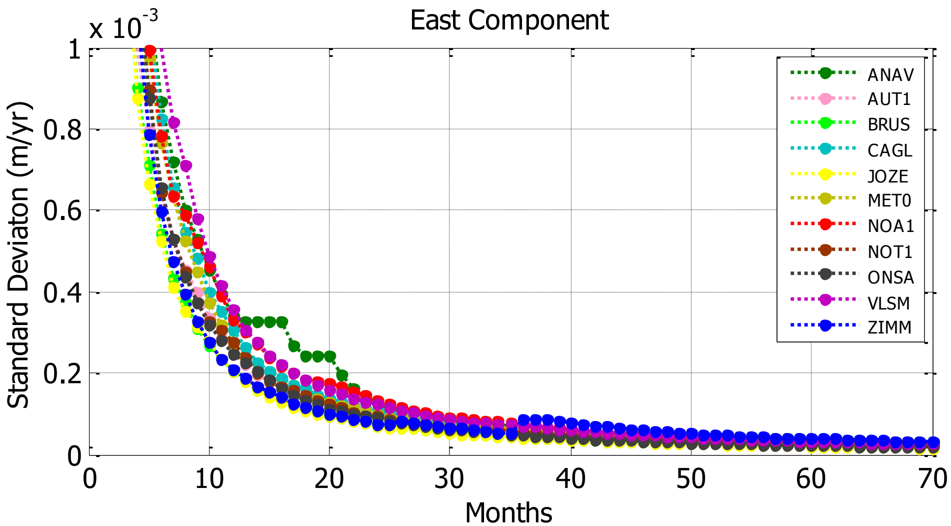


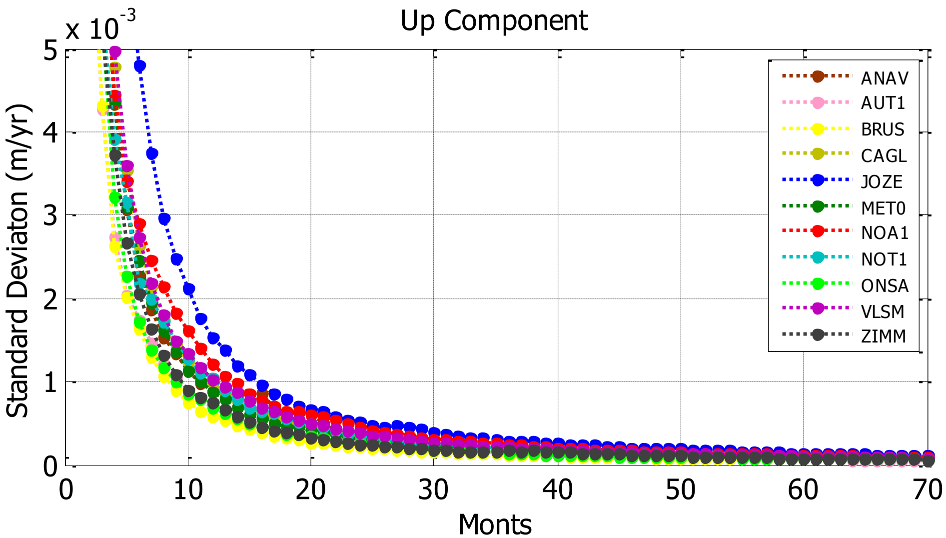
Standard Deviation of velocity estimation

Depends on:

- The repeatability rms of the station position
- The mathematical model
- The observation time span
- The coordinates component

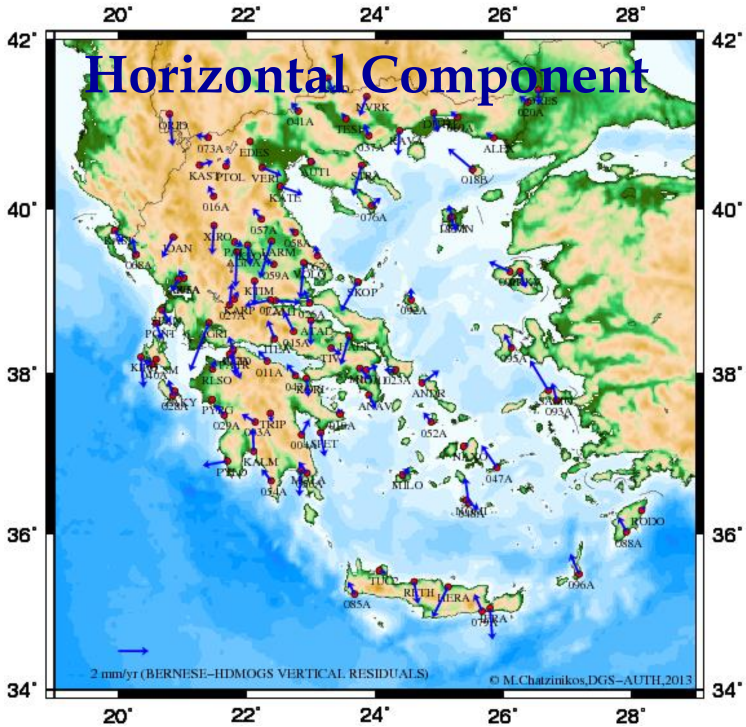


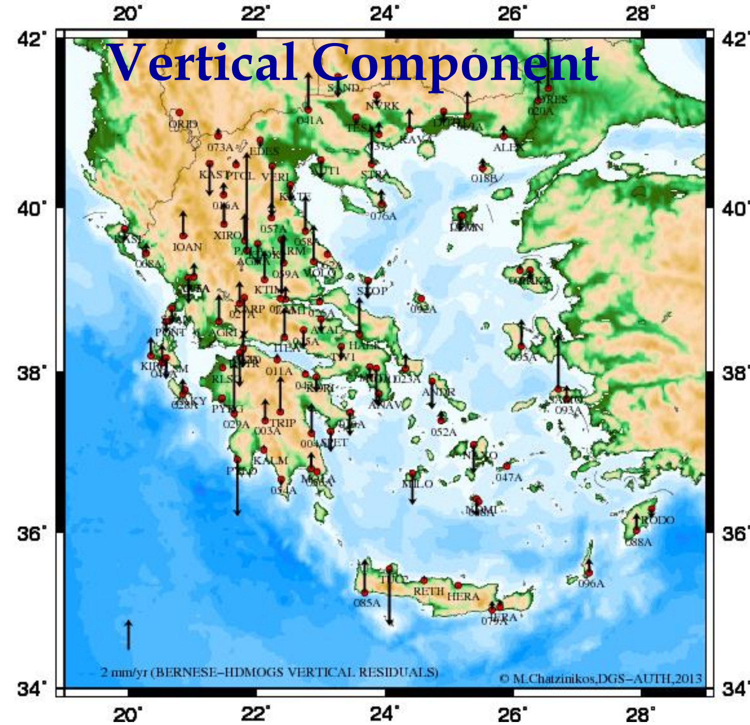




Comparing Velocities between H&D MOGS and BERNESE v5.0

The differences of the velocity estimation (IGS08) between BERNESE v5.0 and H&D MOGS (extended model)





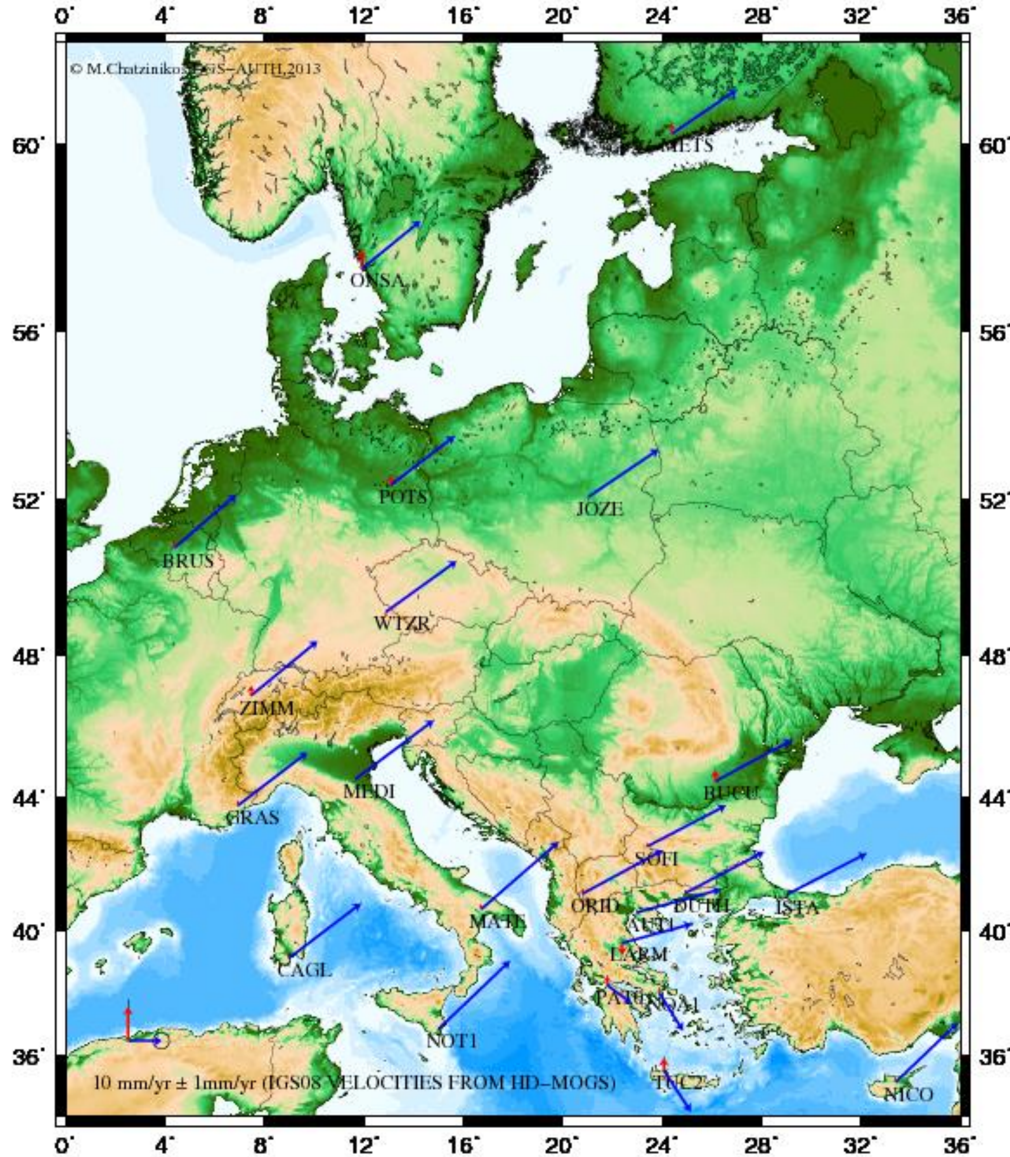
	North (mm/yr)	East (mm/yr)
RMS differences:	1.1	0.6
Differences:	(0-3.2)	(0-1.7)

	Up (mm/yr)
RMS differences:	1.8
Differences:	(0.1-6.6)

Time span < 4 years: significant differ., > 4 years negligible differ. (< 0.6 mm/yr) due to the inclusion of periodic terms and discontinuities in H&D MOGS

Final results: IGS08 EPN Site Velocities

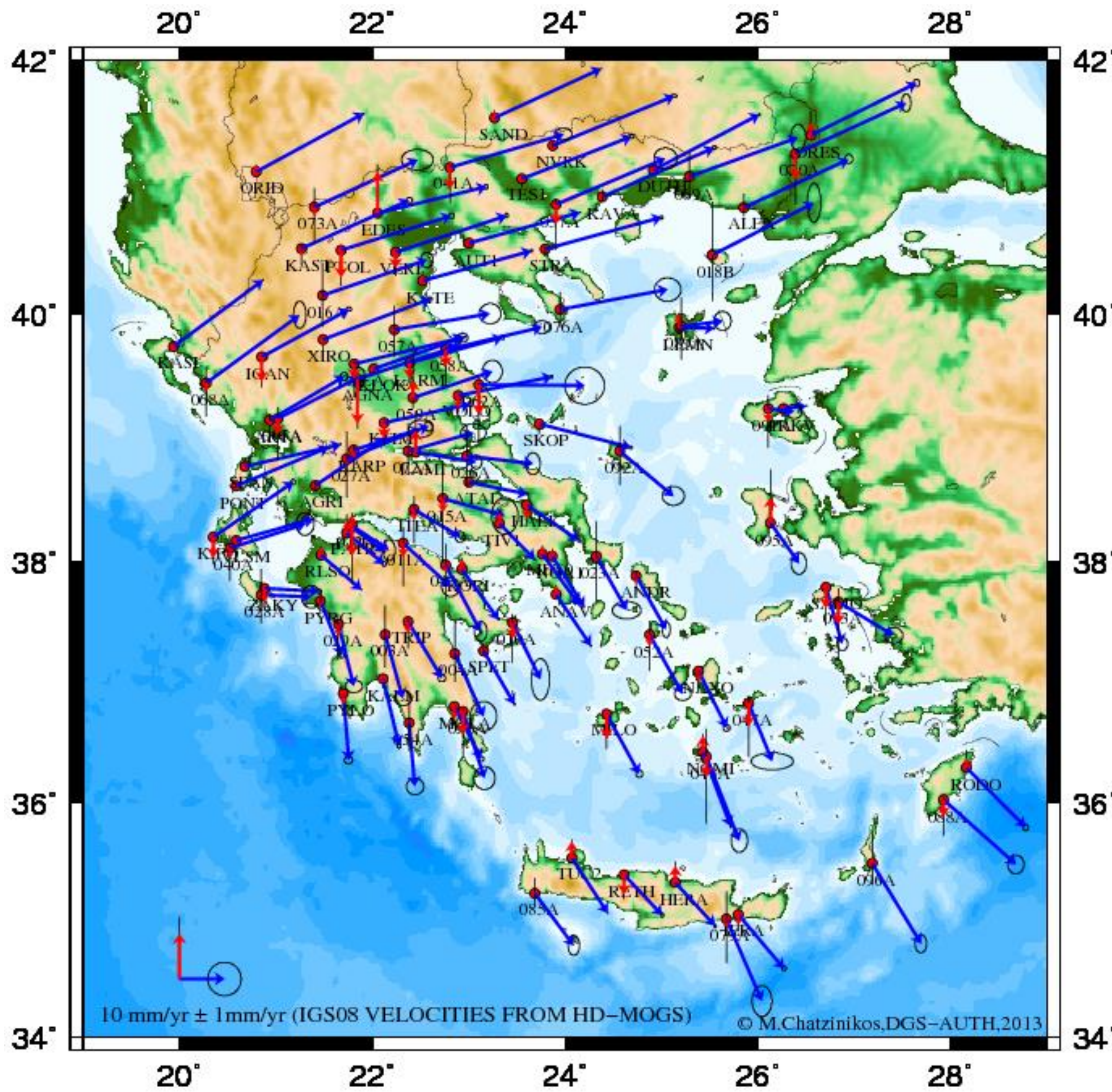
IGS08 velocities of EPN stations by H&D MOGS using the extended displacement model



Final results: IGS08 Site Velocities in Greece

IGS08 velocities of Greek stations by H&D MOGS using the extended displacement model

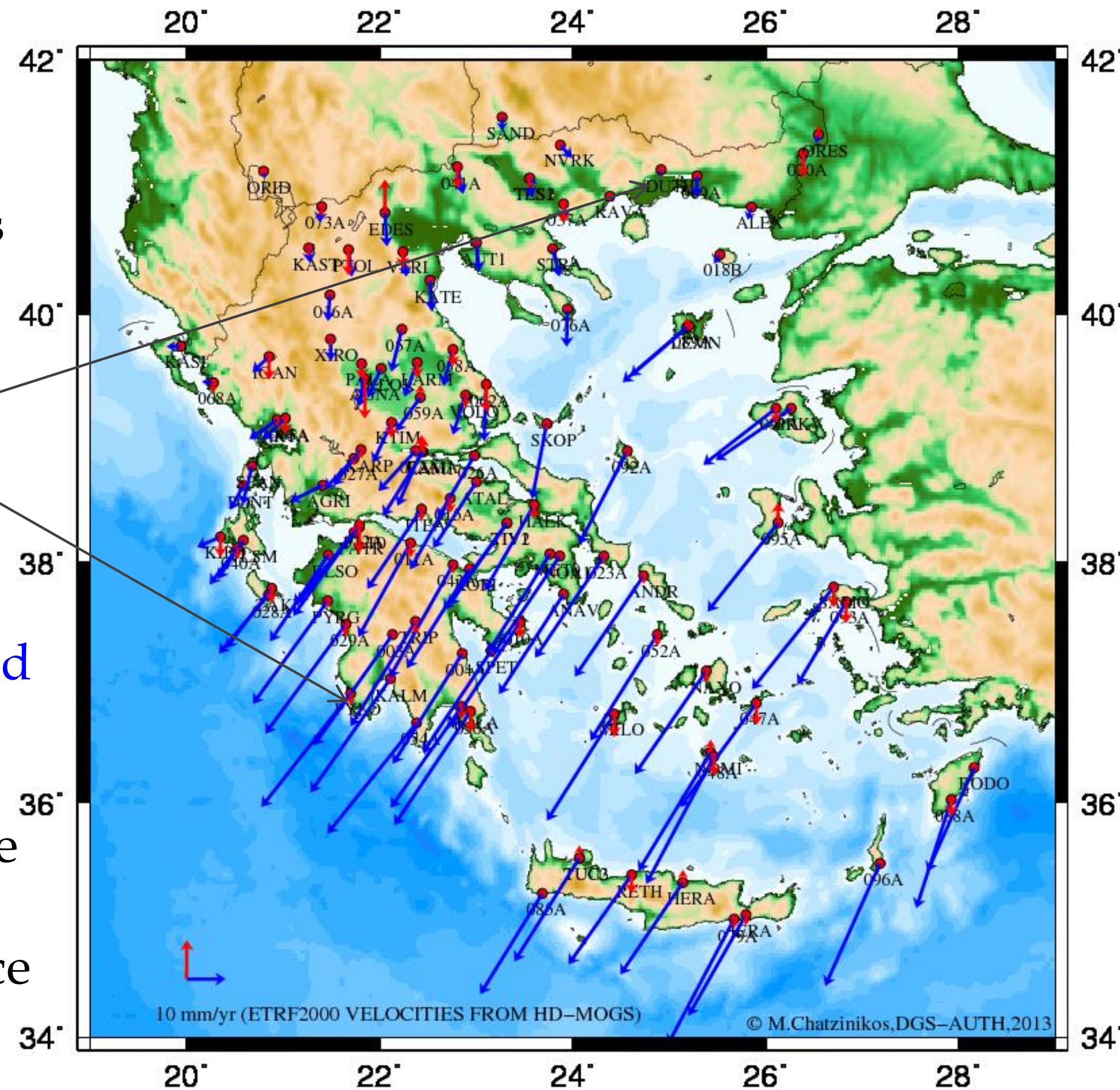
- Crust in Central and Northern Greece is moving eastern and northeastern
- Crust in Southern Greece is moving southeastern.



Velocities in ETRF2000
Stability of ETRS89 in Greece

ETRF2000 velocities in Greece

- Inhomogeneous velocities
  - Horizontal velocities from 1.7 mm/yr (DUTH) to 37.4 mm/yr (PYLO)
  - Unstable reference frame for Greece (?)
- Application of the estimated velocity model in Greece: transformation of SMARTNET-GREECE in the reference epoch (2007.5) of Hellenic Terrestrial Reference System 2007 (realization of ETRS89 in Greece)



Summary

1. A new estimation of the velocity field in Greece has been derived using continuous GPS data and a rigorous process via an automatic procedure.

2. The velocity field estimation confirms the tectonic behavior of Greece.

3. The used extended displacement model produced more accurate results than the linear model for a time period of 2 to 4 years.

4. Comparing velocity estimations by H&D MOGS and BERNESE v.5.0 shows rms differences smaller than 1 mm/yr.

5. Velocities have been estimated in IGS08 and ETRF2000.

6. A permanent GNSS network in Greece has to take into account the velocity field in order to be stable in the reference epoch of HTRS07. This demand has been successfully applied to SMARTNET-GREECE.

Thank you for your attention!

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