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Crustal Deformation from GPS measurements at the Ionian Sea : Preliminary Results

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The Ionian Sea region comprises a plate boundary between Africa and Eurasia plates where relative plate motion is mainly tangential. This area is the most seismic part of Greece. Deformation patterns are complex because the horizontal motion of blocks across the Kefallinia transform fault is accompanied by shortening (in the north) and extension (central and south Ionian Sea). Since 2006 NOA has established a network of permanent GPS stations in order to understand the details of the deformation field, kinematics, strain tensor orientation and magnitude. Station velocities using at least two years of observations were calculated and compared to previous studies. Preliminary results on the strain tensor at the north and central Ionian Sea are presented.

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NOA, Institute of Geodynamics (2)

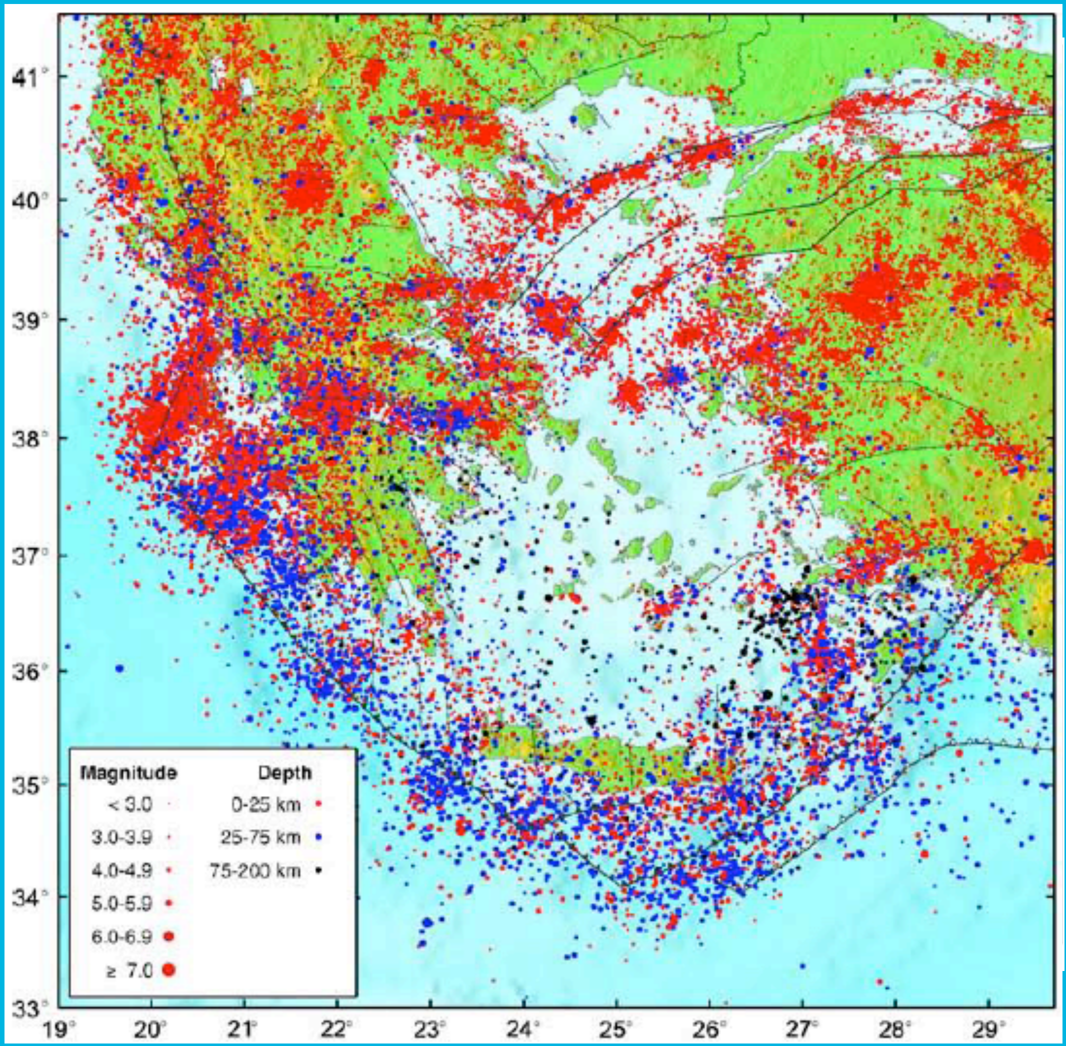
1. Tectonic Setting

Greece is located in the collision zone between the Nubian/Arabian and the Eurasian lithospheric plates .

Main Tectonic features:

- Hellenic Trenches
- Hellenic Arc (Seismic and Volcanic)
- North Aegean Trough
- Kefallinia Transform Fault (KTF)

Currently, KTF is the most seismically active region in Greece.



2. Permanent GPS networks in Greece

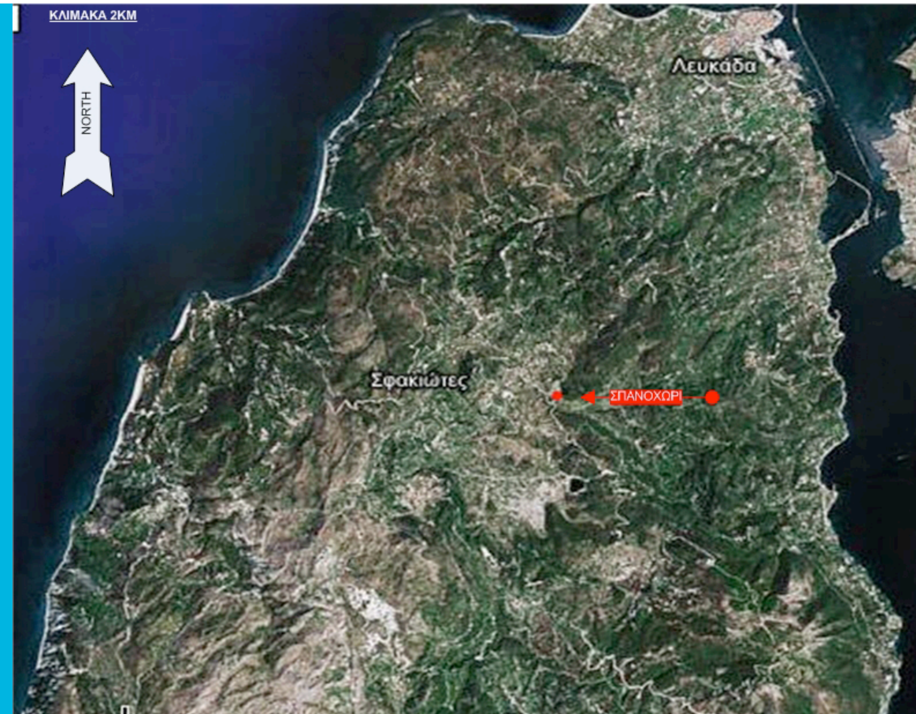
- CGPS EUREF
- CGPS National Observatory of Athens
- CGPS NOA - NTUA
- CGPS NTUA
- CGPS Oxford University - NTUA
- Hellas CGPS Network (ETH – NTUA)
- CGPS IPGP,France - NTUA

3. NOANET stations used in this study

Receivers Leica 1200 GRX Pro
Antennas Leica AX 1202
1-s observations

No	Code	Location	Start Date	No of days processed
1	KASI	Kassiopi – Kerkyra	30/3/2007	62
2	SPAN	Spanochori – Lefkada	21/5/2007	74
3	PONT	Ponti – Lefkada	14/2/2007	73
4	VLSM	Valsamata - Kefallinia	13/2/2006	117
5	RLSO	Riolos – Achaia	30/7/2006	121
6	NOA1	Pendeli- Attica	10/4/2006	100

Satellite images of north Lefkada showing the location of permanent station SPAN



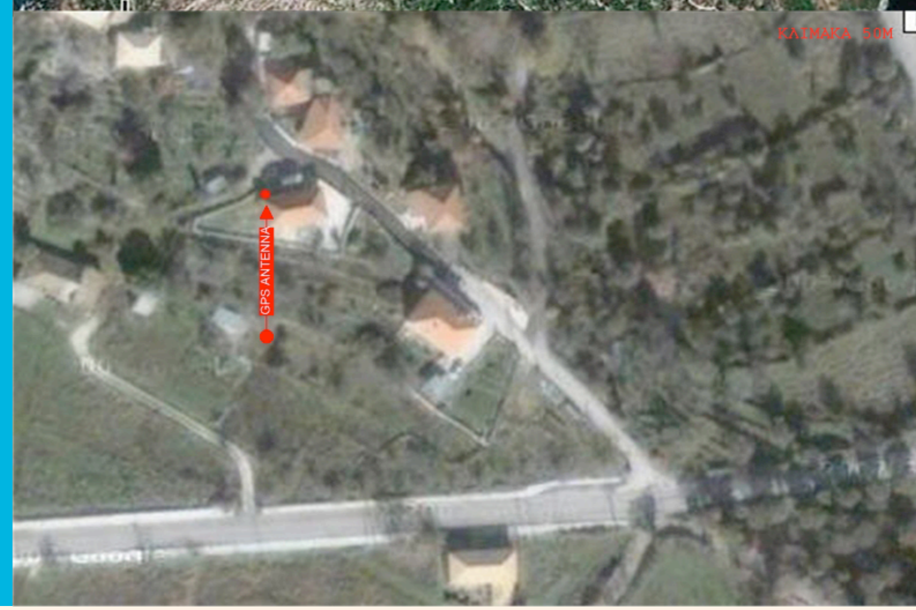
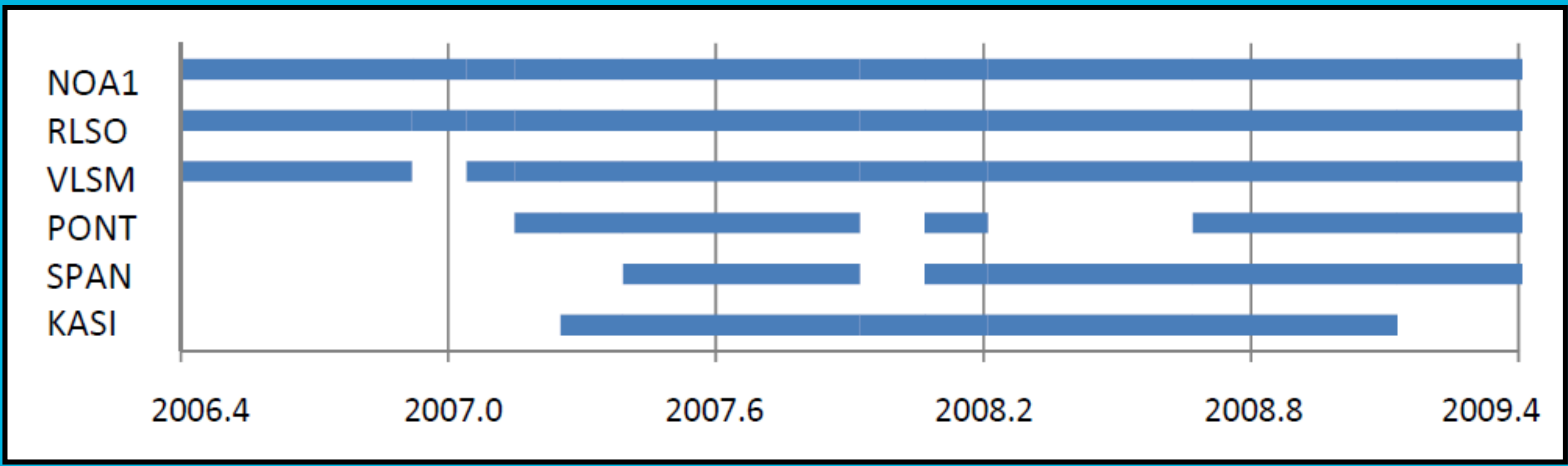


Diagram of 30-s Data availability

Data available from the Internet:

http://194.177.194.200/services/GPS/GPS_DATA/

Data gaps due to Ethernet card damage



4. Data Processing

Bernese software V. 4.2 was used following the standards below :

- Precise IGS (International Geodetic Service) orbits and corresponding pole
- IGS (International Geodetic Service) phase eccentricity file
- Automatic phase check
- QIF(Quasi Ionosphere Free) ambiguity resolution strategy (accepted baselines with resolved ambiguities more than 70%)
- Ionosphere model used for baselines longer than 400km
- Normal equations for each day (loose constraints)
- Combined solution using each day’s normal equation file

- Realization of the Reference Frame ITRF 2005
- 10 IGS stations were used
- Main criterion for station selection was network geometry

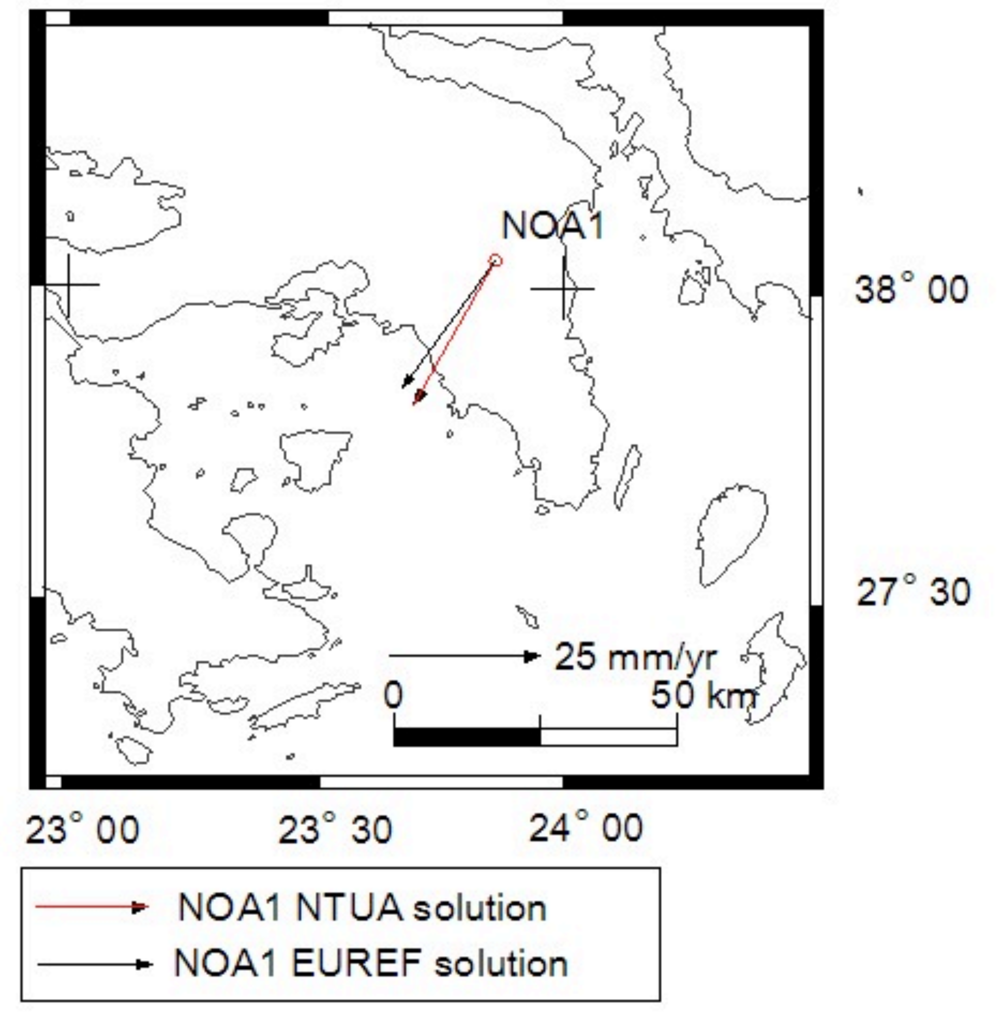
5. Results

Comparison to EUREF solution

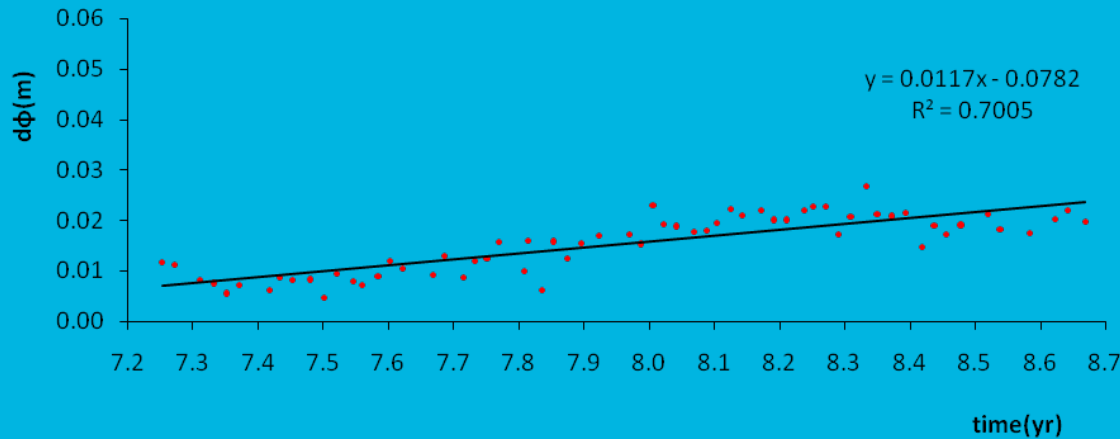
- Calculation of 100 days,
4 days per month
total of 27 months

- EUREF solution includes 425 daily solutions

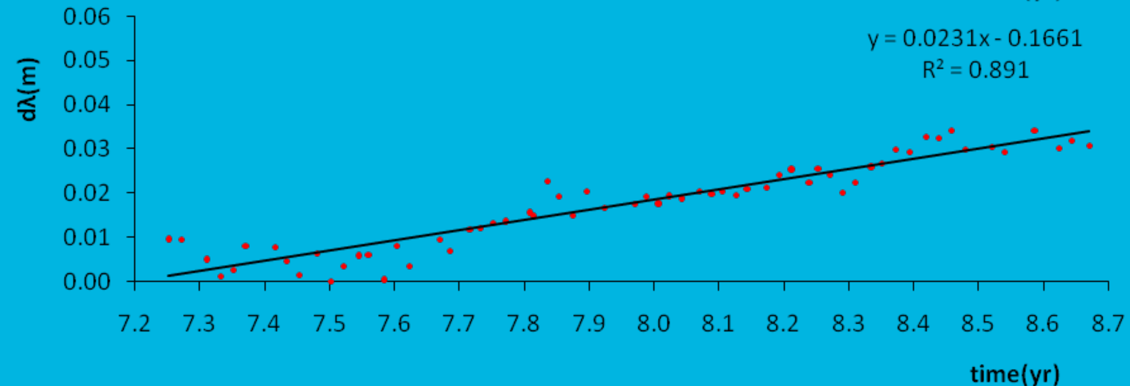
- For EUREF NOA station differences are:
Angular 5°
Linear 1.2 mm/yr



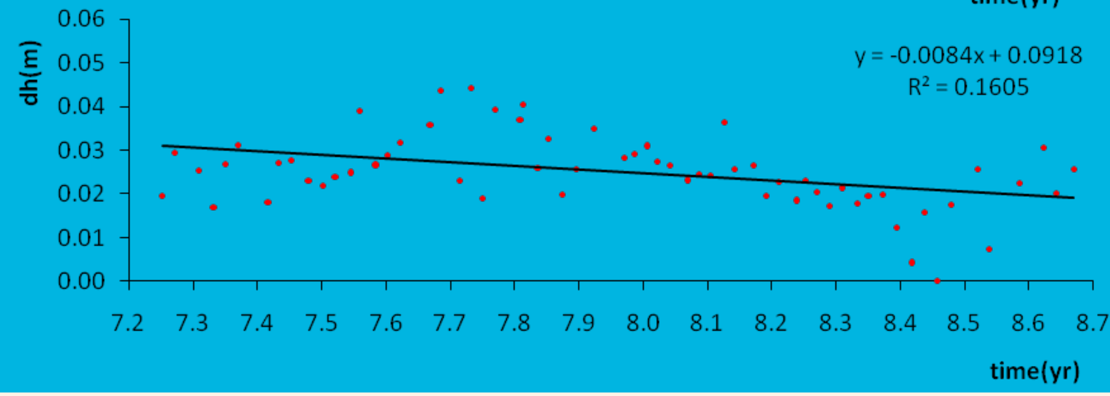
Tectonic Motion of KASI in ITRF 2005



Vn (mm/yr)	11.7
σVn (mm/yr)	±1.0

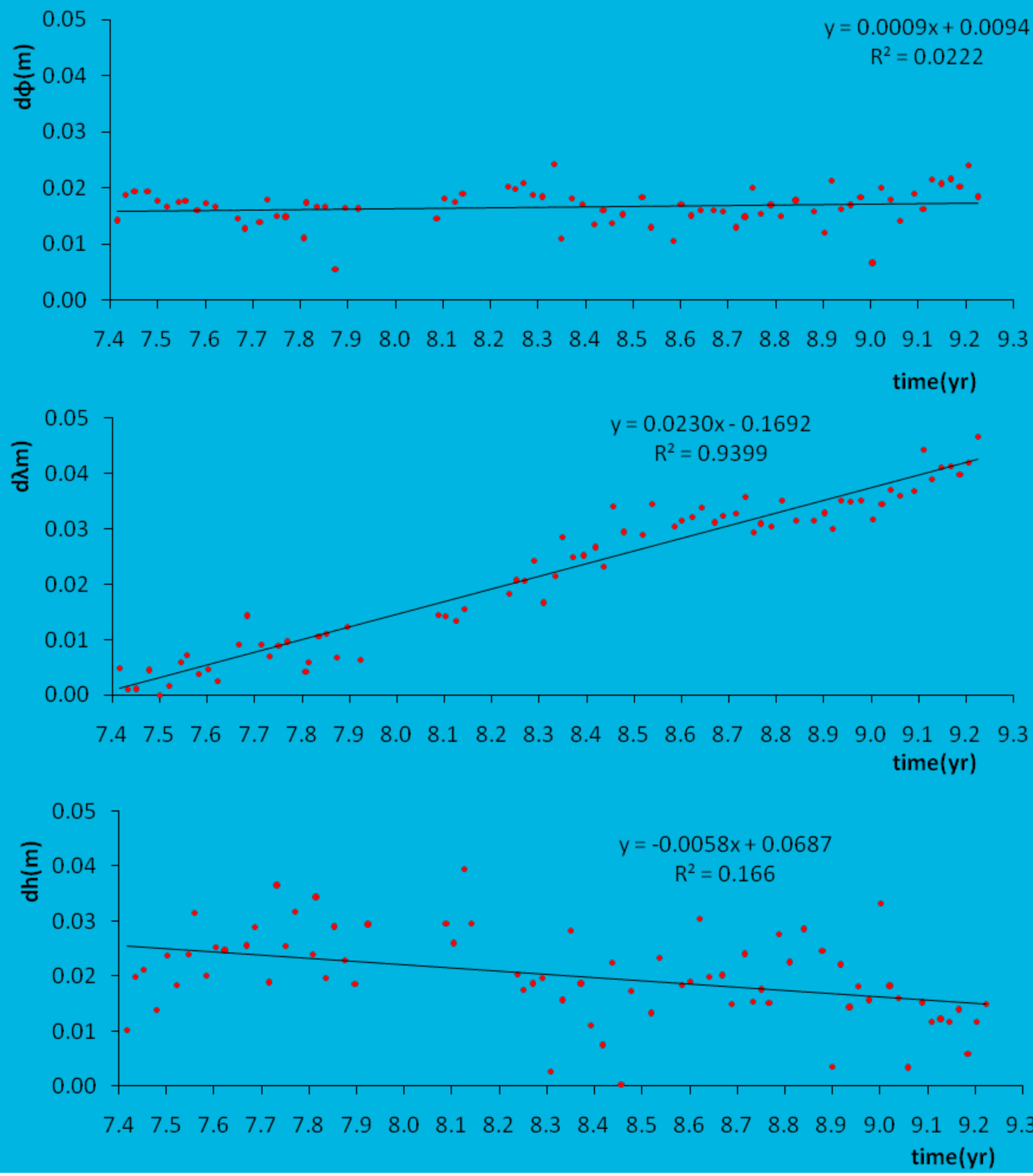


Ve (mm/yr)	23.1
σVe (mm/yr)	±1.0



Vu (mm/yr)	-8.4
σVu (mm/yr)	±2.5

Tectonic Motion of SPAN in ITRF 2005

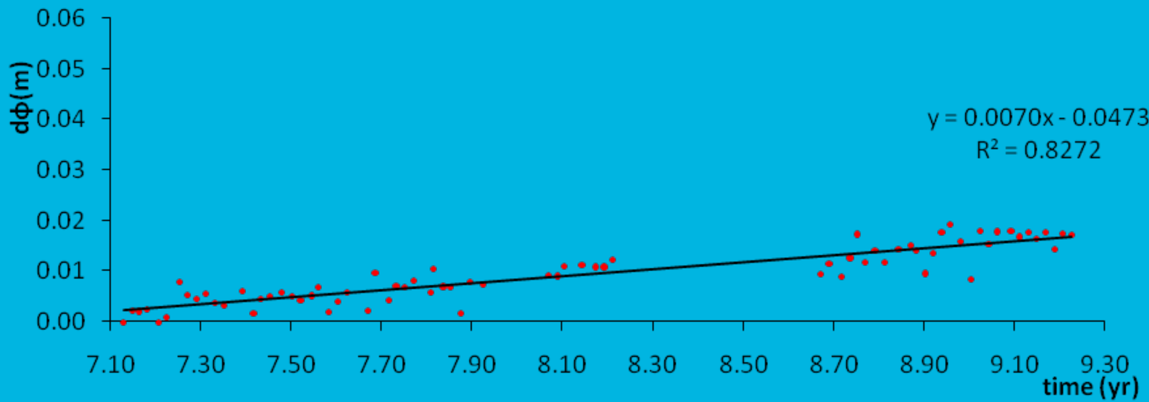


Vn (mm/yr)	0.9
σVn (mm/yr)	±0.7

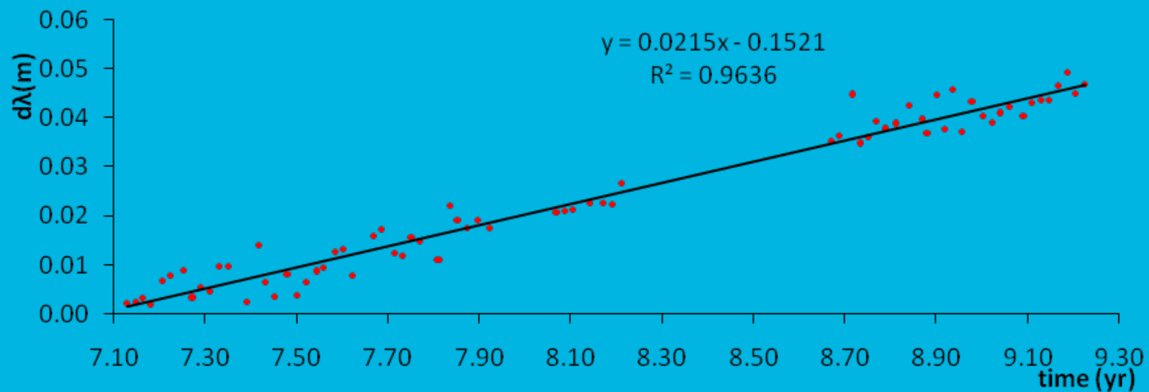
Ve (mm/yr)	23.0
σVe (mm/yr)	±0.7

Vu (mm/yr)	-5.8
σVu (mm/yr)	±2.2

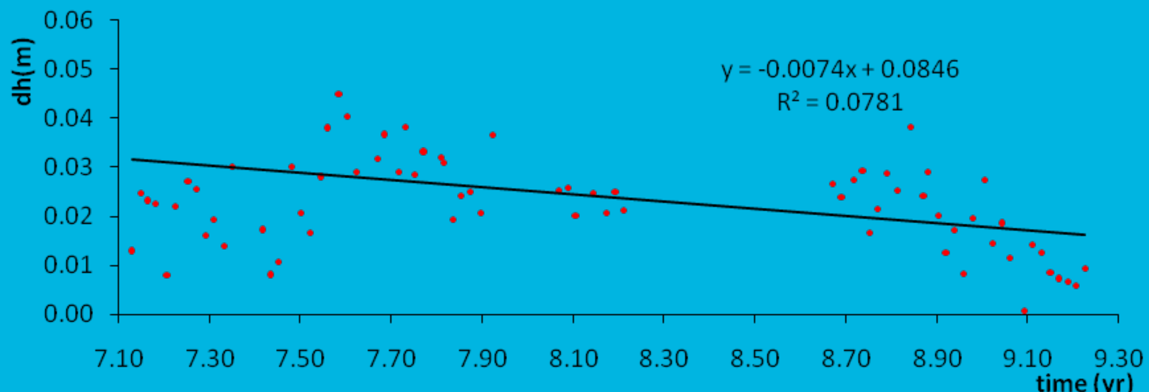
Tectonic Motion of PONT in ITRF 2005



Vn (mm/yr)	7.0
σVn (mm/yr)	±0.4

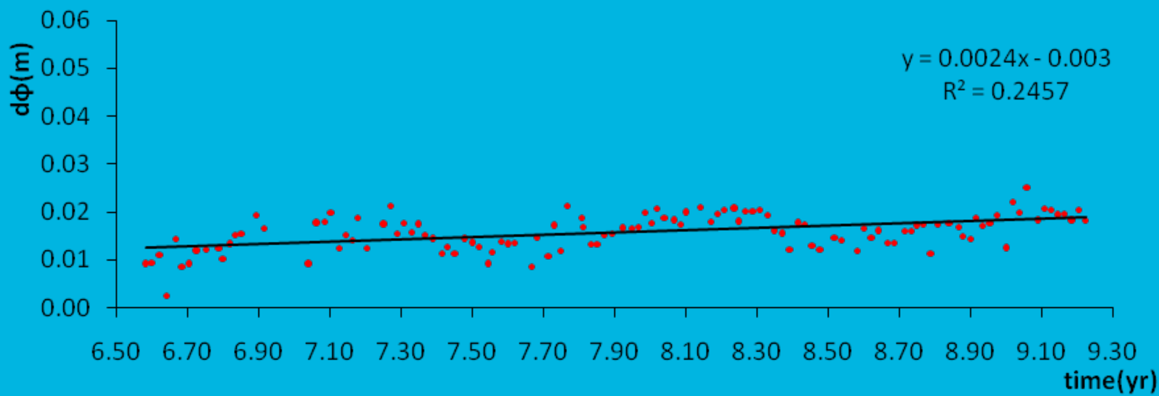


Ve (mm/yr)	21.5
σVe (mm/yr)	±0.5

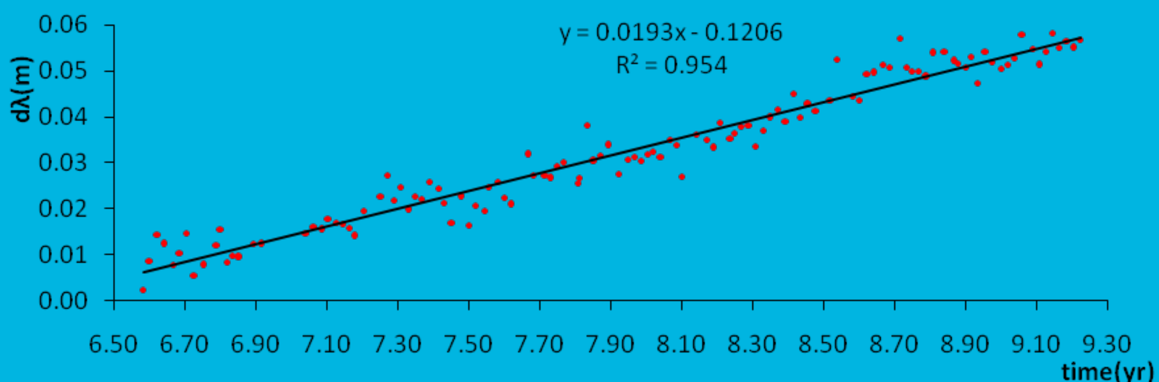


Vu (mm/yr)	-7.4
σVu (mm/yr)	±3.0

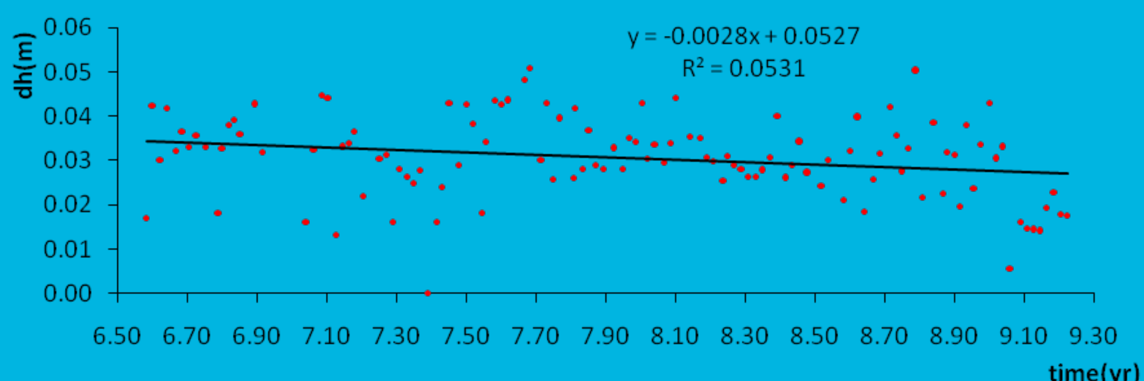
Tectonic Motion of VLSM in ITRF 2005



Vn (mm/yr)	2.4
σVn (mm/yr)	±0.4

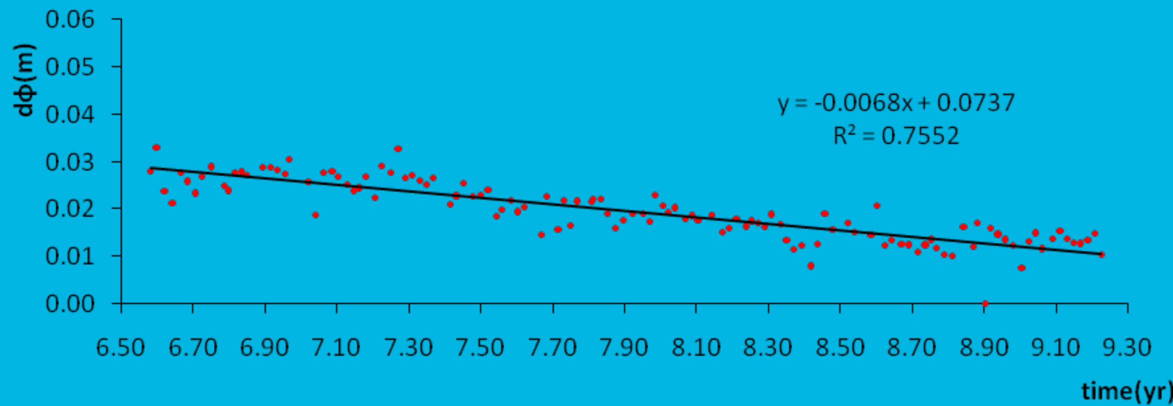


Ve (mm/yr)	19.3
σVe (mm/yr)	±0.4

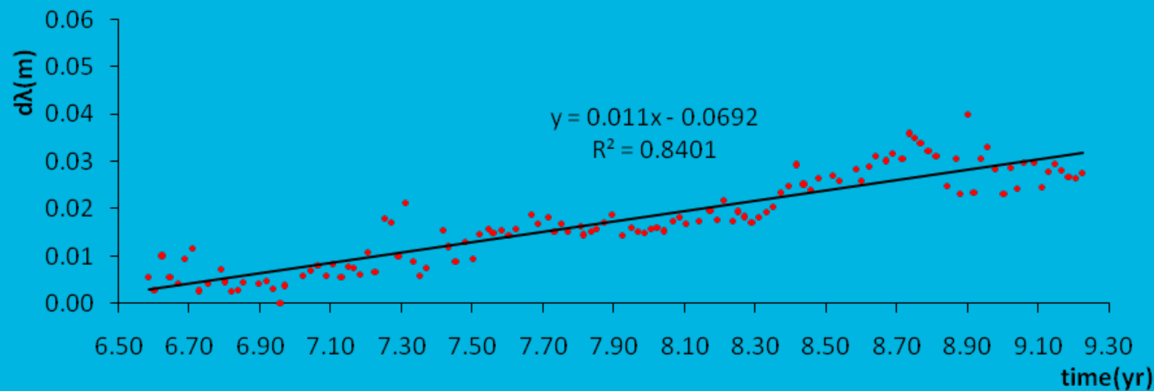


Vu (mm/yr)	-2.8
σVu (mm/yr)	±1.1

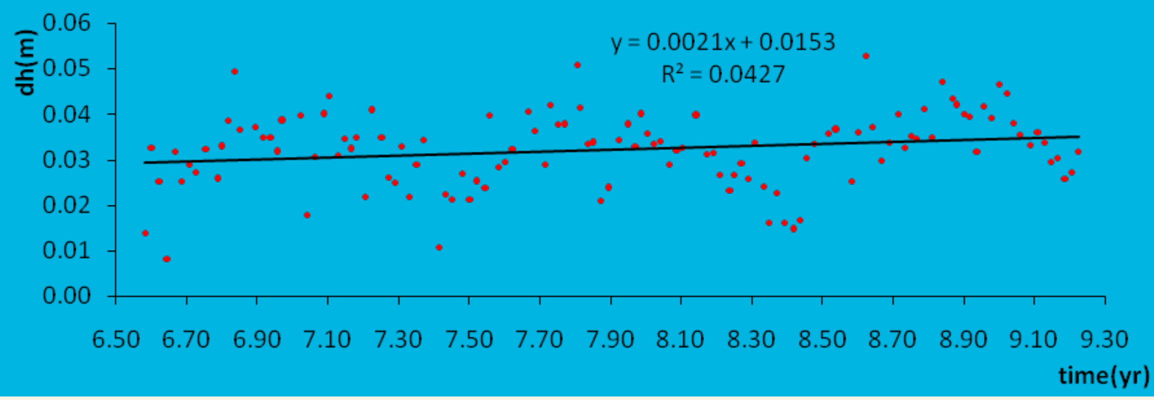
Tectonic Motion of RLSO in ITRF 2005



Vn (mm/yr)	-6.8
σVn (mm/yr)	±0.4



Ve (mm/yr)	11.0
σVe (mm/yr)	±0.4



Vu (mm/yr)	-2.1
σVu (mm/yr)	±0.9

VLSM	Vn (mm/yr)	σ (mm/yr)	Ve (mm/yr)	σ (mm/yr)	Vu (mm/yr)	σ (mm/yr)
1Y	6.4	± 2	18.3	± 1.8	-11.9	± 5.6
1.5Y	3.6	± 0.9	17.3	± 0.9	1.3	± 2.6
1.6Y	4.1	± 0.8	16.9	± 0.8	1.9	± 2.4
1.7Y	4.4	± 0.7	17.2	± 0.7	0.7	± 2.1
1.8Y	4	± 0.7	17.2	± 0.7	0.2	± 1.9
1.9Y	2.6	± 0.6	18.6	± 0.5	-1.7	± 1.5
2Y	2.3	± 0.5	18.8	± 0.5	-2	± 1.5
2.5Y	2.1	± 0.4	19.6	± 0.4	-1.7	± 1.2

RLSO	Vn (mm/yr)	σ (mm/yr)	Ve (mm/yr)	σ (mm/yr)	Vu (mm/yr)	σ (mm/yr)
1Y	-2.1	± 1.7	9.1	± 2.2	-1.5	± 5.1
1.5Y	-6.7	± 0.8	9.8	± 0.9	3.2	± 2.2
1.6Y	-6.9	± 0.7	9.6	± 0.8	3.1	± 1.9
1.7Y	-7	± 0.6	9.4	± 0.7	1.4	± 1.8
1.8Y	-7.3	± 0.6	9.6	± 0.6	-0.4	± 1.7
1.9Y	-7.7	± 0.5	11.9	± 0.6	-2.7	±1.4
2Y	-7.6	± 0.5	12	± 0.6	-2.3	± 1.4
2.5Y	-7.3	± 0.4	12	± 0.5	1.8	± 1.1

Dependence of station velocities on observation duration

Velocities start to stabilize after 2 years in the horizontal components

More time is needed for the vertical component

VLSM	4 dpm	σ (mm/yr)	3 dpm	σ (mm/yr)	2 dpm	σ (mm/yr)	1 dpm	σ (mm/yr)
Vn(mm/yr)	2.4	±0.4	2.1	±0.5	2.1	±0.6	2	±0.9
Ve(mm/yr)	19.3	±0.4	19.4	±0.5	18.6	±0.6	17.8	±0.7
Vu(mm/yr)	-2.8	±1.1	-2	±1.4	-3.2	±1.6	-3.9	±2.5

RLSO	4 dpm	σ (mm/yr)	3 dpm	σ (mm/yr)	2 dpm	σ (mm/yr)	1 dpm	σ (mm/yr)
Vn(mm/yr)	-6.8	±0.4	-7	±0.4	-6.4	±0.5	-6.3	±0.7
Ve(mm/yr)	11	±0.4	11	±0.5	10.6	±0.6	9.9	±0.9
Vu(mm/yr)	2.1	±0.9	2	±1.1	2.9	±1.4	2.5	±2.1

SPAN	4 dpm	σ (mm/yr)	3 dpm	σ (mm/yr)	2 dpm	σ (mm/yr)	1 dpm	σ (mm/yr)
Vn(mm/yr)	0.9	±0.7	1	±0.8	1.5	±1	1.4	±1.3
Ve(mm/yr)	23	±0.7	23.2	±0.8	23.8	±0.7	23.8	±1.1
Vu(mm/yr)	-5.8	±1.5	-5.7	±1.8	-6.4	±1.8	-6.7	±2.2

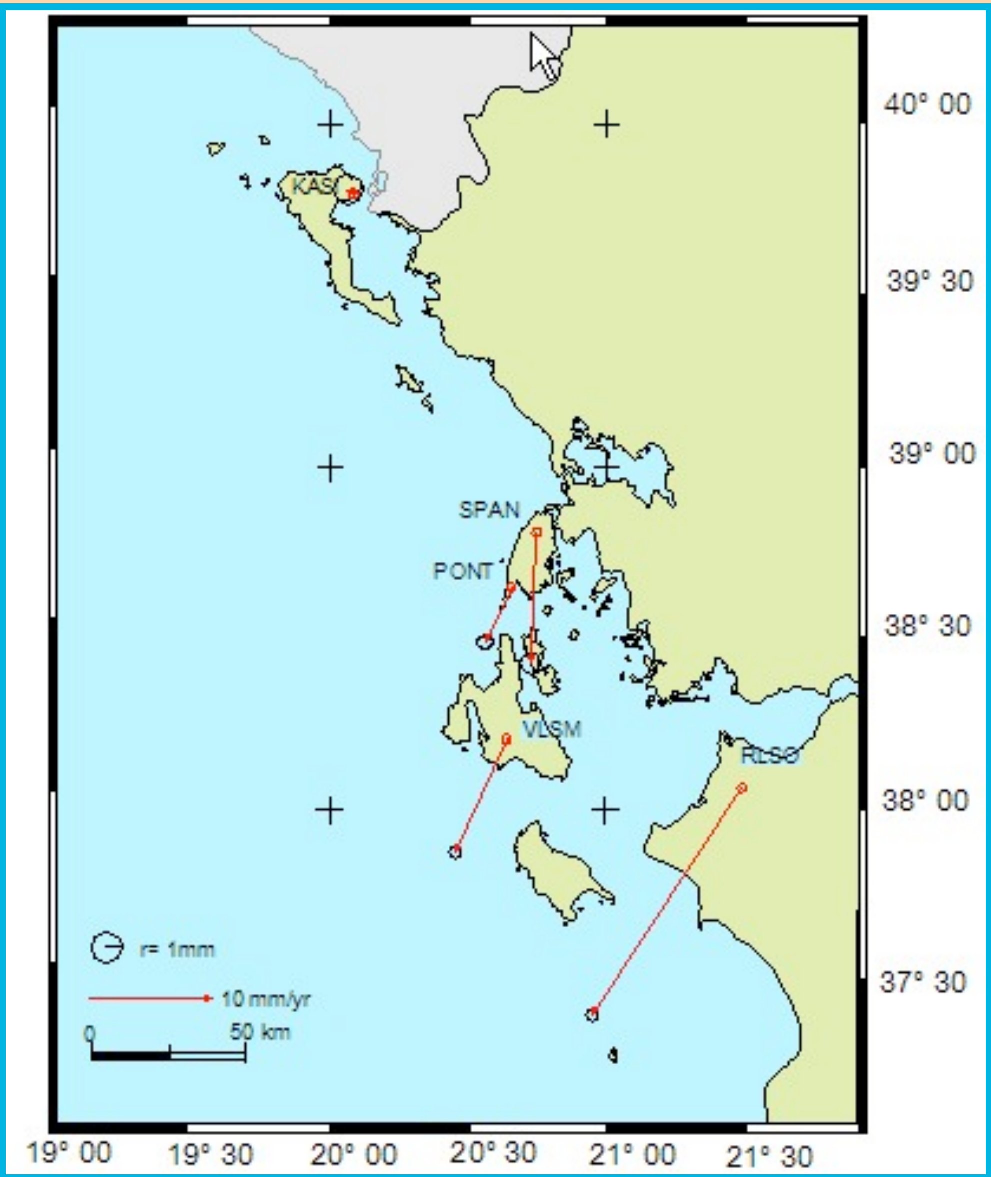
KASI	4 dpm	σ (mm/yr)	3 dpm	σ (mm/yr)	2 dpm	σ (mm/yr)	1 dpm	σ (mm/yr)
Vn(mm/yr)	11.7	±1	12.6	±1.2	12.8	±1.4	11.5	±1.7
Ve(mm/yr)	23.1	±1	22.9	±1.4	23.3	±1.8	26.8	±2.2
Vu(mm/yr)	-8.4	±2.5	-0.4	±6.7	5.3	±9.8	-5.4	±6.5

- Velocity analysis with respect to the number of days per month (dpm) analyzed

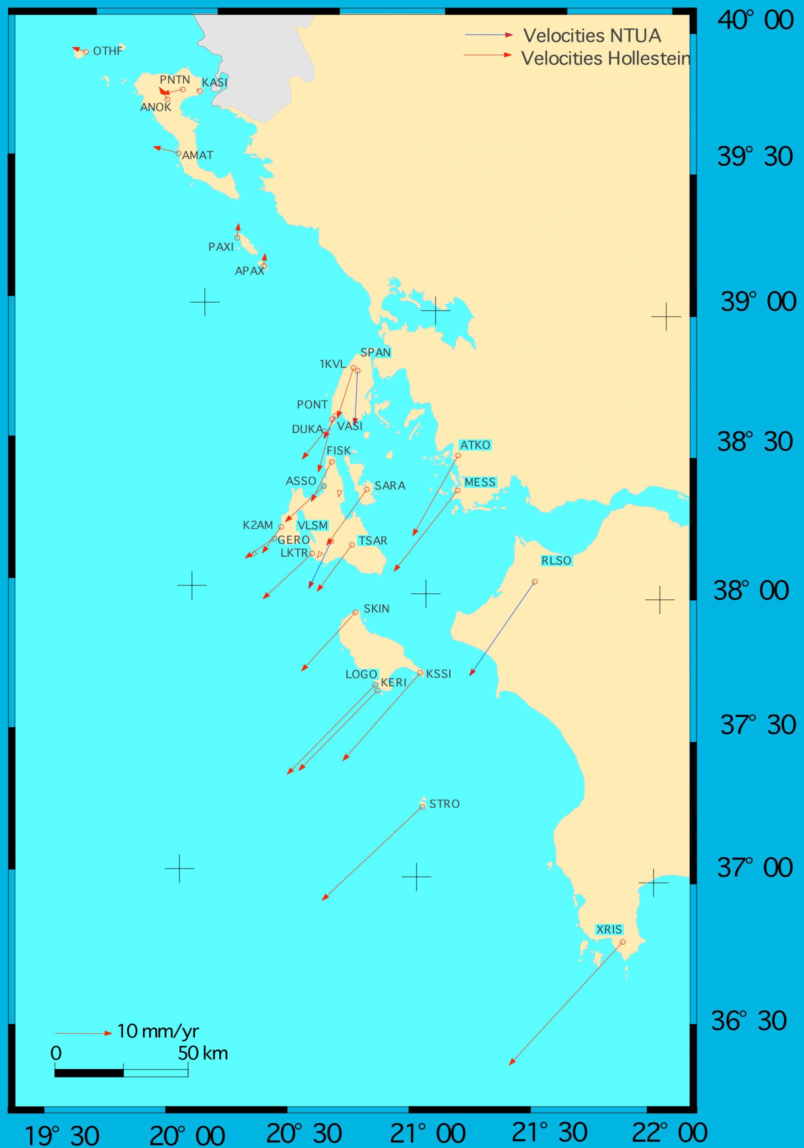
- The temporal density of calculations does not affect significantly the velocities

Station Velocities with respect to a fixed Europe

Velocities with respect to a fixed Europe (mm/yr)				
CODE	**Vn**	**σ**	**Ve**	**σ**
KASI	0.3	±1.0	-0.5	±1.0
PONT	-4.4	±0.4	-2.1	±0.5
RLSO	-18.2	±0.4	-12.6	±0.5
SPAN	-10.6	±0.7	-0. 6	±0.7
VLSM	-9.0	±0.4	-4.3	±0.4



Comparison with the research work of Hollenstein et al. (2008)



<u>Hollenstein et al. data analysis</u>

- 76 stations, 18 campaigns carried out between 1993 and 2003
- 22 stations, continuous data between 1995 and 2003
- 54 European IGS and EUREF sites
- Processed using the Bernese GPS Software version 4.2
- 15 European IGS stations used for the realization of ITRF2000
- Velocity of Eurasia calculated from 54 IGS and EUREF sites

<u>We used for the comparison</u>

- 10 permanent stations
- 14 campaign sites

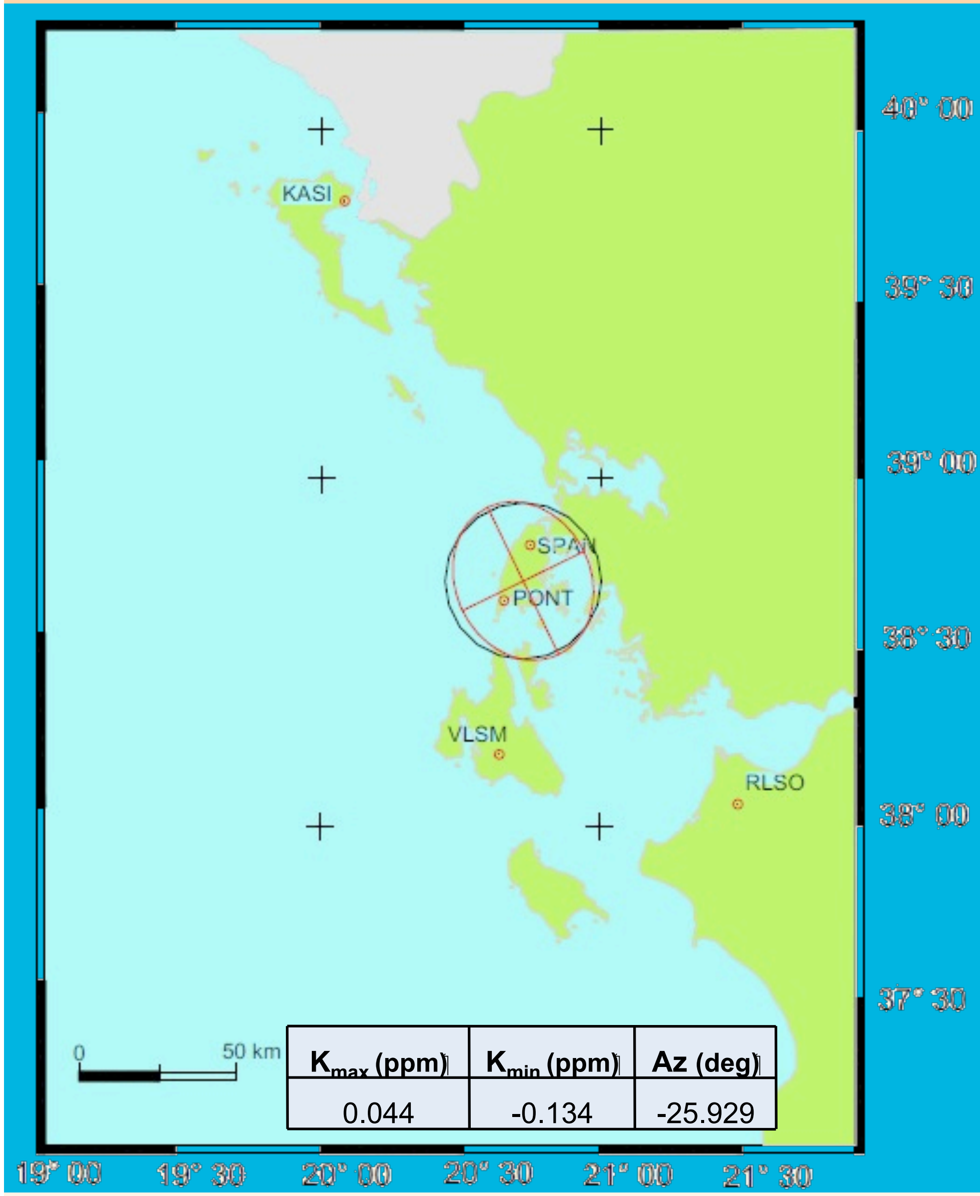
Calculation of Strain Tensor Parameters

Assumptions:

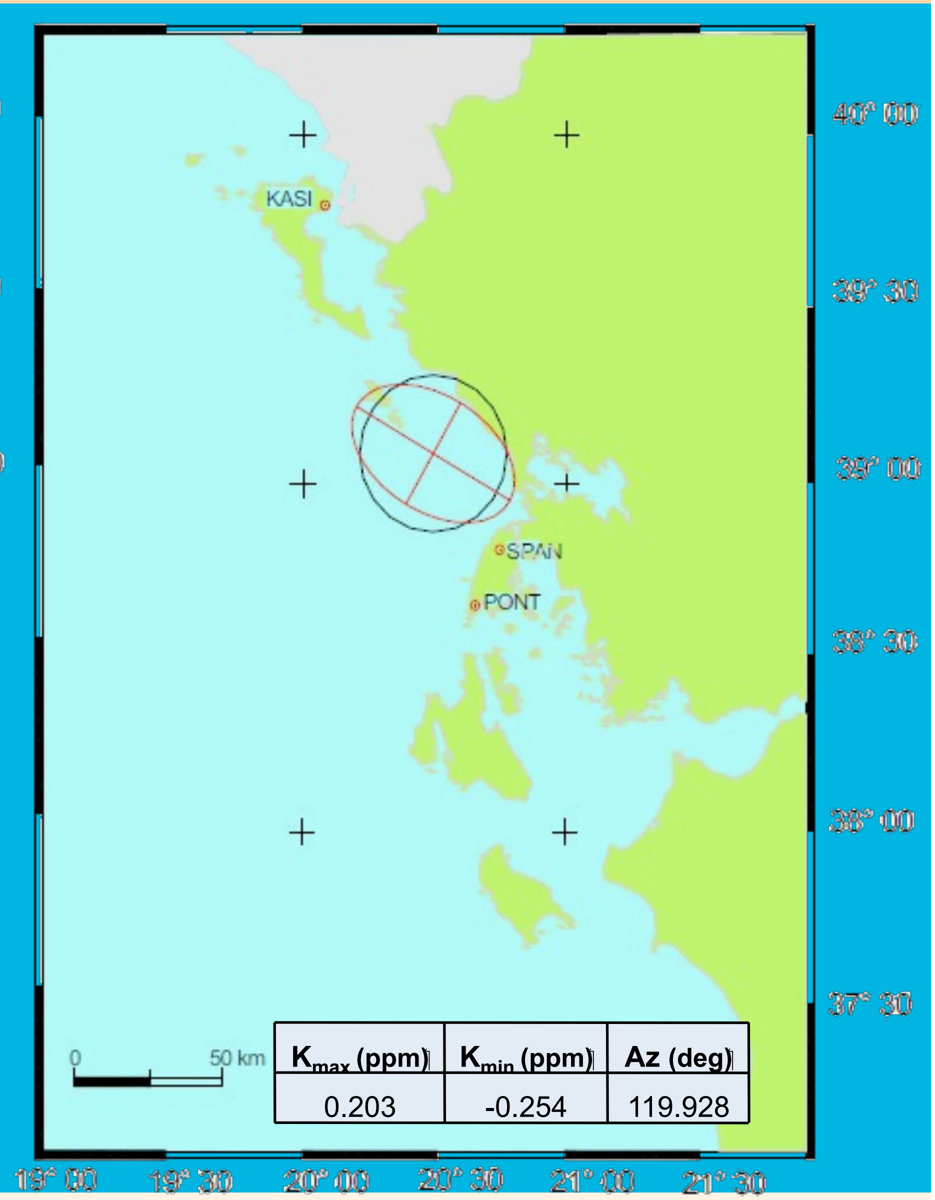
- 2-dimensional deformation of earth's crust in time
- Crust is considered a thin deformable shell on a spherical earth
- Mapping distortions are ignored for regions with radius of less than 5°
- Time (earthquakes) or space (faults) discontinuities are not included in the calculation

Strain tensor (all points – north Ionian Sea)

Period of Observations : 2006.5-2009.3

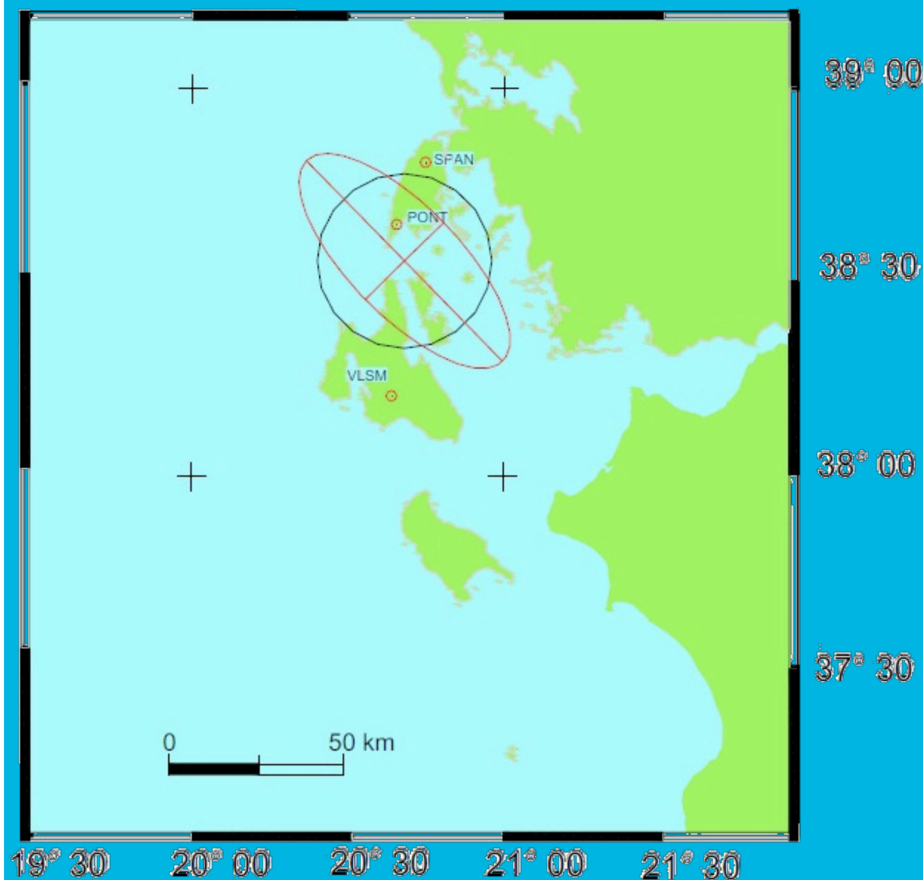


K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.044	-0.134	-25.929

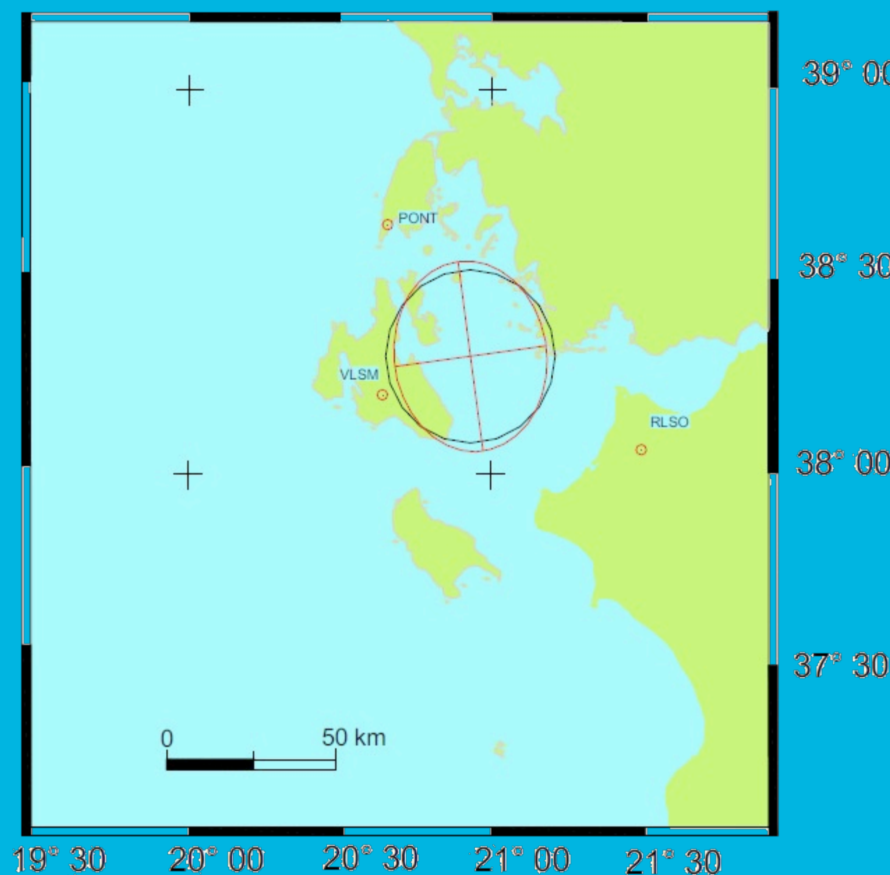


K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.203	-0.254	119.928

Strain Tensor in the central Ionian Sea (Lefkada – Kefallinia islands and Peloponnese) Period of Observations : 2006.5-2009.3

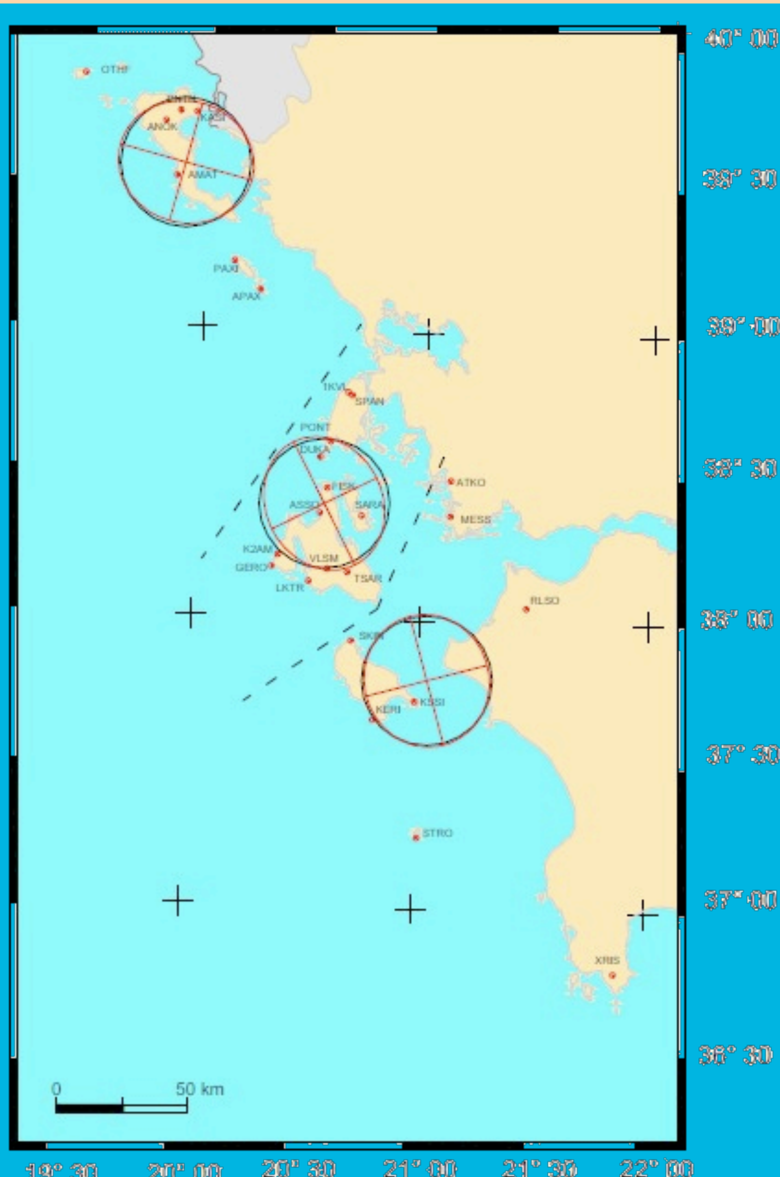


K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.607	-0.370	-44.371



K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.104	-0.099	-7.664

Strain Tensor using data from Hollenstein et al., 2008
Period of Observations : 1993-2003

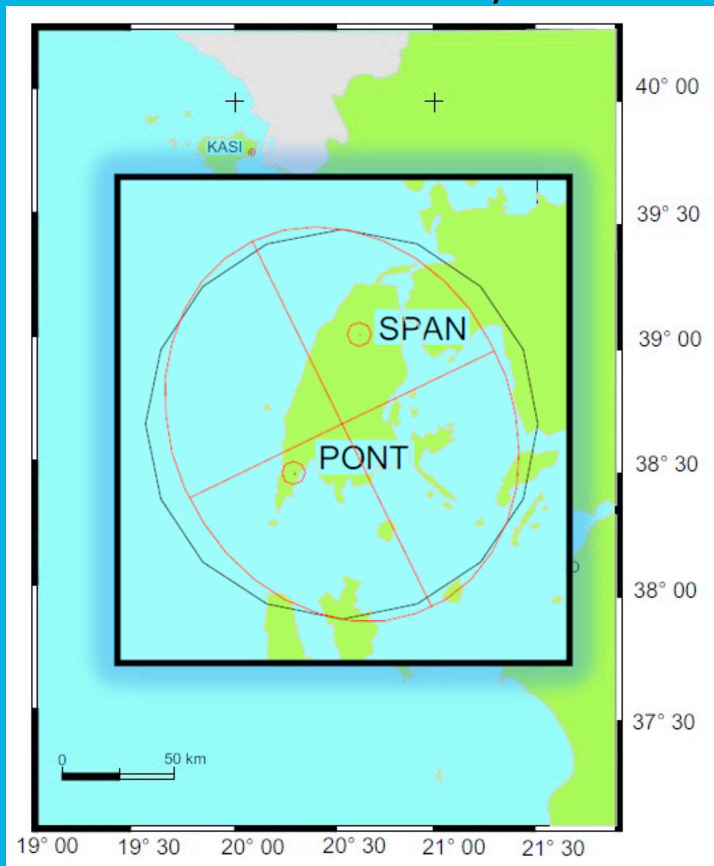


- North of KTF (North)
- Lefkada – Kefallinia islands (Central)
- Zakynthos –Peloponnese (South)

region	K_{max} (ppm)	K_{min} (ppm)	Az (deg)
North	0.045	-0.058	105.726
Central	0.062	-0.105	-26.079
South	0.029	-0.040	-14.447

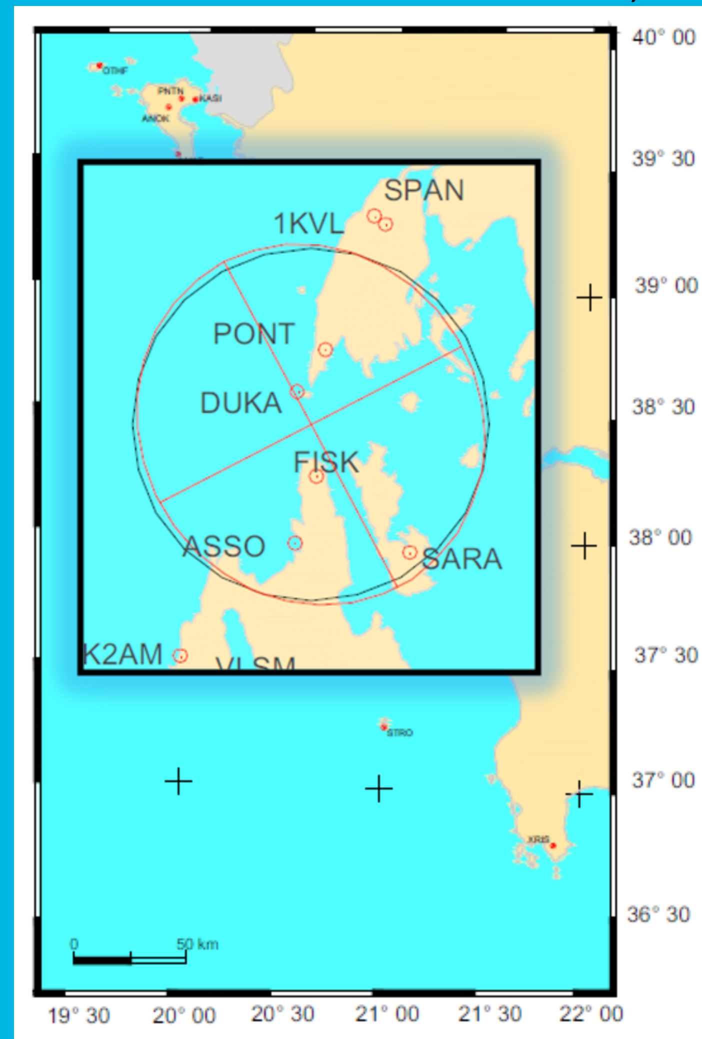
Comparison of Strain Tensors

From this study



K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.044	-0.134	-25.929

From the work of Hollenstein et al., 2008



K_{max} (ppm)	K_{min} (ppm)	Az (deg)
0.044	-0.045	-27.787

Conclusions

1. In velocity estimation it is more important to take into account the duration of observations than the temporal density of them.

2. To obtain reliable preliminary velocity estimation it is necessary to collect at least 2 years of observations with one solution per month.

3. The station velocities in the central Ionian sea vary between 5-20 mm/yr with respect to a fixed Europe. Motion is to the SSW.

4. The differences in velocities compared with Hollenstein et al., 2008, may be due to the realization of the reference system and the use of a different model for the velocity of Eurasia.

Conclusions

5. Strain tensor analysis shows that overall, the Ionian Sea region is extending in the NW-SE direction, as is also found by Hollenstein et al., 2008*

6. However, different strain patterns are obtained for north and for central Ionian sea. The north Ionian is under NE-SW compression. The central Ionian is under NNW-SSE extension.

7. The north part of Lefkada seems to move faster than the south part.

*Hollenstein Ch., Muller M.D., Geiger A., Kahle H.-G, 2008, Crustal motion and deformation in Greece from decade of GPS measurements, 1993-2003, *Tectonophysics 449, 17-40*.

Thank you

for your attention