The 3D time dependent transformation model on the NOANET CORS GNSS. A collaboration between Geodesy & Geodynamics

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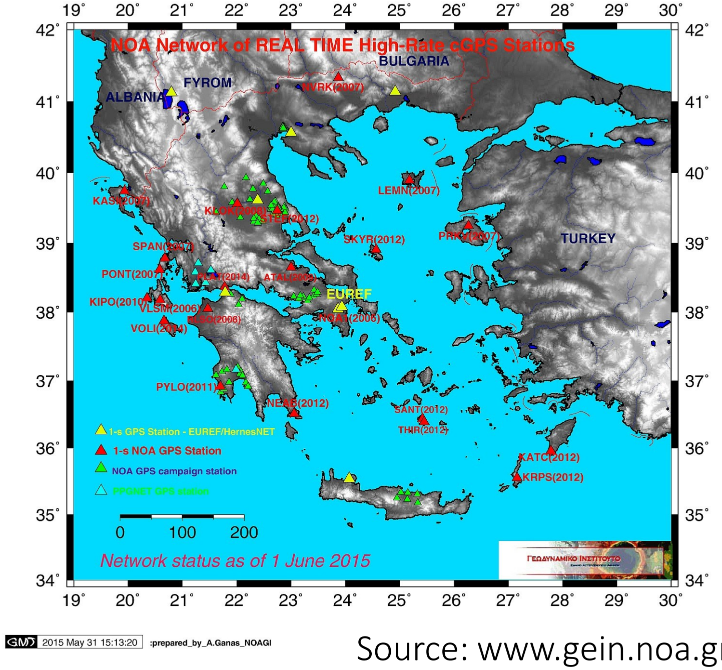
The NOANET

- The CORS network of the National Observatory of Athens (NOA)
- Initially established for monitoring crustal deformations of the Greek area in 2008 (Ganas et al. 2008; Chousianitis et al. 2013)
- 18 COR Stations nationwide (2018)
- Station NOA1 located in Attica is part of the EPN



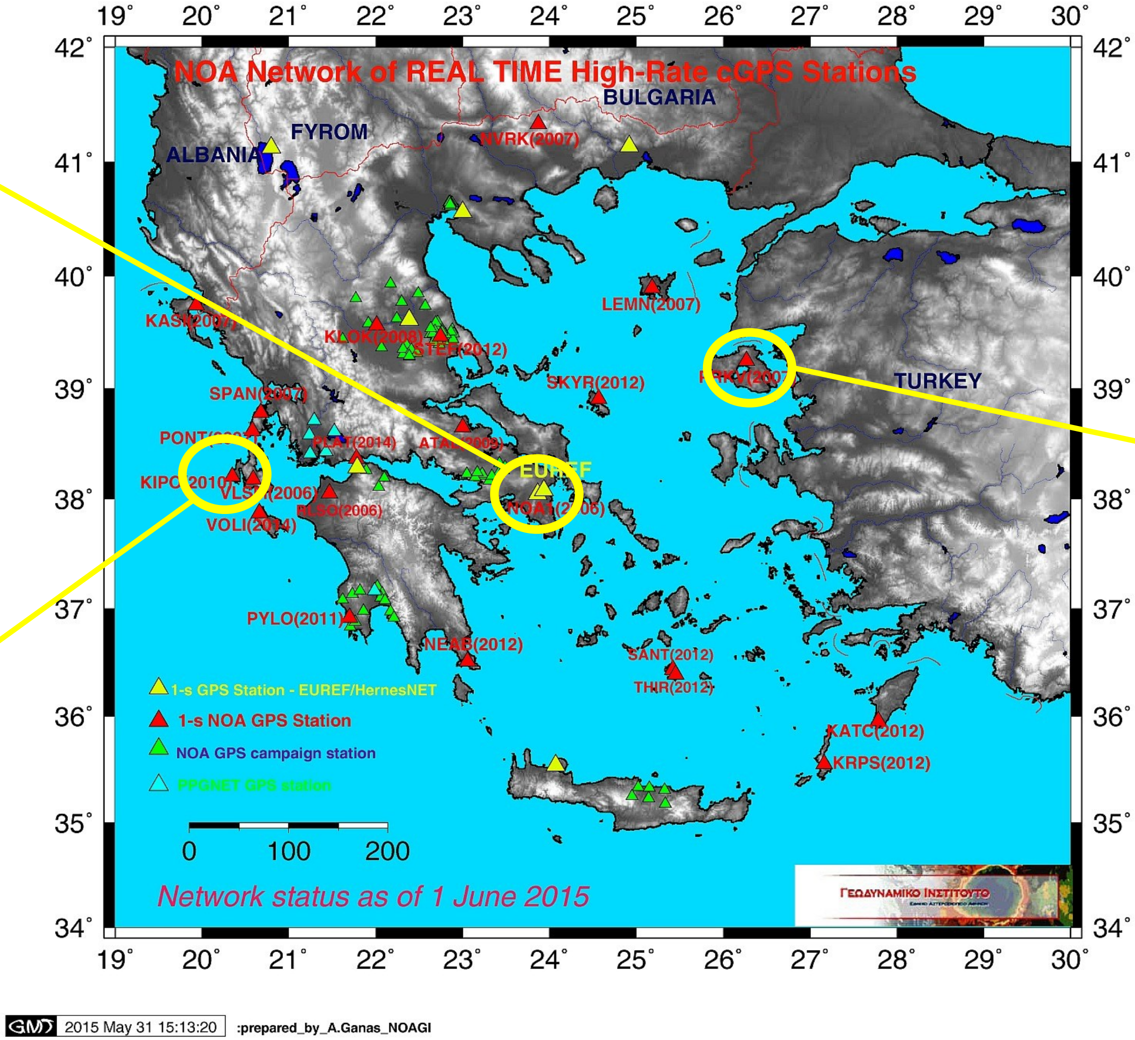
Source: www.gein.noa.gr

Source: www.epnbc.oma.be

The NOANET

NOA1 (Penteli, Attica)

KIPO (Kipouria, Cephalonia Island)



PKRV (Paraskevi, Lesvos Island)

Source: www.gein.noa.gr

The NOANET

- The Network's reference frame was realized by 18 IGS stations, using GAMIT software (Chousianitis et al. 2013)
- The NOA1 station (EPN) was not included in the frame realization
- Open Data policy
- 1-s & 30-s Data (1-s data available upon request)
- Official solution for 10/18 stations. Coordinates referred to ITRF05 (estimated for a certain epoch) and velocities to the Eurasian Plate

Station	X (m)	Y (m)	Z (m)	epoch (year)	V_E (mm/a)	V_N (mm/a)
ATAL	4591113.837	1948751.167	3962396.681	2010.081	12.06	-5.29
KASI	4616572.582	1674415.556	4056441.293	2009.664	19.49	14.10
KLOK	4564747.022	1845610.774	4040935.116	2009.710	20.74	5.78
LEMN	4434466.076	2084864.374	4069305.463	2009.809	6.56	-1.37
NOA1	4599643.319	2034827.976	3909890.749	2011.210	7.16	-11.94
PONT	4671272.658	1754437.059	3959389.395	2011.999	-3.46	-7.2
PRKV	4435581.306	2188830.489	4013585.908	2009.732	4.64	-0.14
RLSO	4679938.994	1840151.157	3910407.703	2010.391	8.86	-8.58
SPAN	4658312.235	1757780.670	3973702.588	2009.796	20.69	4.01
VLSM	4699991.611	1765547.717	3921162.215	2010.338	17.20	3.67

Source: www.gein.noa.gr accessed March 2018

The case study – Local RF

The core idea of this report is to describe an algorithm, transforming the official coordinates of NOANET (as published officially) to the local reference frame of Greece (HGRS87) using the time-dependent transformation (Altamimi, 2002)

Hellenic Geodetic
Reference System of 1987
HGRS87

1. A non geocentric reference frame which it mainly concentrates to the horizontal coordinates (the vertical information is quite problematic)
2. Classical datum
3. Established over 30 years ago
4. Official Cadastral System
5. Fully operational

Hellenic Terrestrial
Reference System of 2007
HTRS07

1. Official Reference System of HEPOS
2. Densification of ETRS89
3. Coordinates refer to ETRF05 (ep. 2007.50)
4. Official trasformation between HGRS87-HTS07 – horizontal component (Katsambalos et al. 2010)
5. Nationwide rms ±8.3cm

The case study – Methodology Flow

Topocentric velocities (v_e v_n v_u)

↓

Geocentric velocities (v_X v_Y v_Z)

w.r.t. the Eurasian Plate

$$\mathbf{v}_{XYZ} = \mathbf{R}^{-1}\mathbf{v}_{enu}$$

↓ through angular velocities

$$\mathbf{v}_i^{ITRF\,2008} = \mathbf{v}_i^{europe} - \mathbf{\Omega}^{ITRF\,2008}\mathbf{x}_i^{ITRF\,2008}$$

ITRF Geocentric velocities

↓ Time dependent transformation (Altamimi, 2002)

ITRF2005 to ETRF2005 (ep.2007.5)
(Boucher & Altamimi, 2007)

Coordinates and velocities w.r.t. HTRS07

↓ HEPOS Transformation Tool

HELLENIC CADASTRE S.A.
www.hepos.gr/downloads
(Katsabalos et al. 2010)

HGRS87 Coordinates

The case study – Methodology STEPS 1 & 2

$$\begin{bmatrix} v_X \\ v_Y \\ v_Z \end{bmatrix} = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\lambda \end{bmatrix}^{-1} \begin{bmatrix} v_e \\ v_n \\ v_u \end{bmatrix}$$

Topocentric velocities (v_e v_n v_u)

↓

Geocentric velocities (v_X v_Y v_Z)

(Topocentric and geocentric velocities: w.r.t. the Eurasian Plate)

↓ through angular velocities

ITRF Geocentric velocities

$$\begin{bmatrix} v_{X_i}^{ITRF2008} \\ v_{Y_i}^{ITRF2008} \\ v_{Z_i}^{ITRF2008} \end{bmatrix} = \begin{bmatrix} v_{X_i}^{europe} \\ v_{Y_i}^{europe} \\ v_{Z_i}^{europe} \end{bmatrix} - \begin{bmatrix} 0 & \omega_Z & -\omega_Y \\ -\omega_Z & 0 & \omega_X \\ \omega_Y & -\omega_X & 0 \end{bmatrix} \begin{bmatrix} X_i^{ITRF2008} \\ Y_i^{ITRF2008} \\ Z_i^{ITRF2008} \end{bmatrix}$$

$$\omega_X = -0.085 \pm 0.011\ mas/a$$
$$\omega_Y = -0.533 \pm 0.007\ mas/a$$
$$\omega_Z = 0.774 \pm 0.012\ mas/a$$

Transformation of ITRF coordinates and velocities to HTRS07 RF using the time dependant transformation parameters

ITRF Geocentric coordinates & velocities

↓ Time dependent transformation (Altamimi, 2002)

Coordinates and velocities w.r.t. HTRS07

A. Transformation of ITRF2008 coordinates & velocities to ITRF2005
B. ITRF2005 to ETRF2005 (ep. 2007.5). Last realization of ETRS89 is ETRF2000 . The transformation procedure should take into account ETRF2000

NOTE:

The 3D-translation vector was estimated by using the 3D coordinate difference between the ETRF2005 and ETRF2000. It should be considered in order to be consistent to the -*withdrawn*- ETRF2005 (the frame in which the HTRS07 is aligned)

The case study – Methodology STEP 4

Coordinates w.r.t. HTRS07

↓ HEPOS Transformation Tool

HGRS87 Coordinates

Transformation of HTRS07-derived coordinates to HGRS87 using the HEPOS TRANSFORMATION TOOL

A. 7-Parameter Helmert Transformation between HTRS07 & HGRS87
B. The Transformation residuals (referring to Transverse Mercator projection plane) are interpolated into a 2km x 2km grid pointwise

$$\begin{pmatrix} T_x \\ T_y \\ T_z \\ D \\ R_x \\ R_y \\ R_z \end{pmatrix}^{HTRS07 \rightarrow HGRS87} = \begin{pmatrix} 203.437m \\ -73.461m \\ -234.594m \\ -0.294\,ppm \\ -0.170 arc\sec \\ -0.060 arc\sec \\ -0.151 arc\sec \end{pmatrix}$$

$$\begin{pmatrix} E \\ N \end{pmatrix}_i^{HGRS87-official} = \begin{pmatrix} \bar{E} \\ \bar{N} \end{pmatrix}_i^{HGRS87} + \begin{pmatrix} \delta E \\ \delta N \end{pmatrix}_i^{grid}$$

Katsambalos et al. 2010

The case study – Data and results

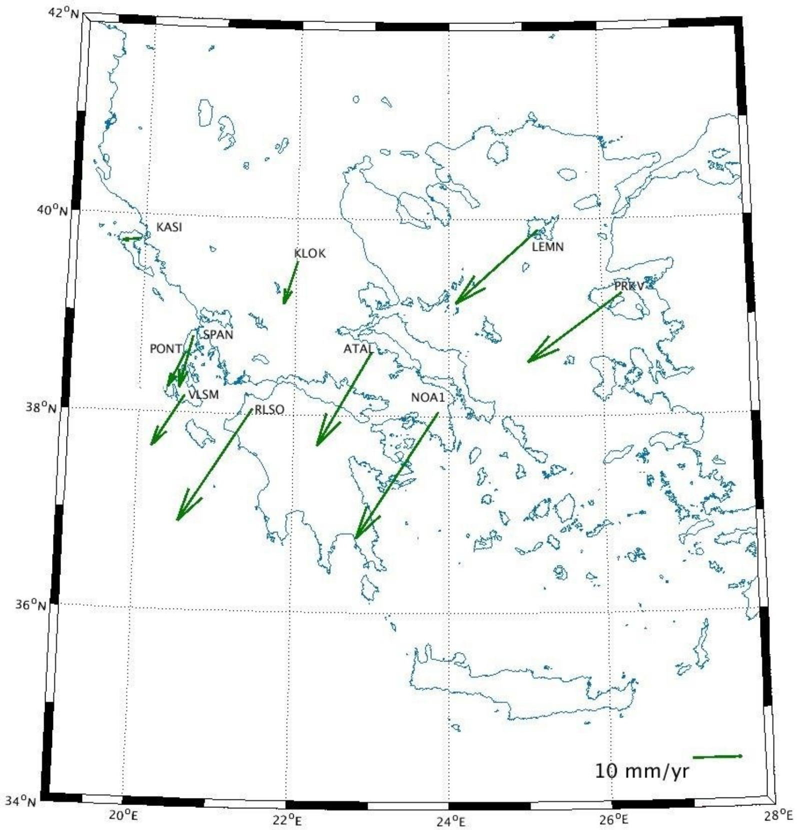
Station	X (m)	Y (m)	Z (m)	epoch (year)	V_E (mm/a)	V_N (mm/a)
ATAL	4591113.837	1948751.167	3962396.681	2010.081	12.06	-5.29
KASI	4616572.582	1674415.556	4056441.293	2009.664	19.49	14.10
KLOK	4564747.022	1845610.774	4040935.116	2009.710	20.74	5.78
LEMN	4434466.076	2084864.374	4069305.463	2009.809	6.56	-1.37
NOA1	4599643.319	2034827.976	3909890.749	2011.210	7.16	-11.94
PONT	4671272.658	1754437.059	3959389.395	2011.999	-3.46	-7.2
PRKV	4435581.306	2188830.489	4013585.908	2009.732	4.64	-0.14
RLSO	4679938.994	1840151.157	3910407.703	2010.391	8.86	-8.58
SPAN	4658312.235	1757780.670	3973702.588	2009.796	20.69	4.01
VLSM	4699991.611	1765547.717	3921162.215	2010.338	17.20	3.67

Initial coordinates and velocities of 10/18 NOANET stations (source: Chousianitis et al. 2013, accessed at www.gein.noa.gr/gps.html)

Station	X (m)	Y (m)	Z (m)	V_X (mm/a)	V_Y (mm/a)	V_Z (mm/a)	V_N (mm/a)	V_E (mm/a)
ATAL	4591114.237	1948750.860	3962396.417	16.08	-5.63	-15.35	-19.15	-10.99
KASI	4616572.975	1674415.270	4056441.067	0.95	-3.79	-0.90	-0.50	-3.69
KLOK	4564747.434	1845610.460	4040934.865	5.44	-1.44	-6.31	-8.76	-2.71
LEMN	4434466.472	2084864.073	4069305.219	15.26	-10.58	-10.89	-14.88	-16.95
NOA1	4599643.719	2034827.662	3909890.539	20.34	-9.79	-20.53	-25.73	-16.77
PONT	4671273.048	1754436.757	3959389.129	5.19	-2.09	-6.66	-7.20	-3.46
PRKV	4435581.697	2188830.187	4013585.668	15.84	-13.46	-11.30	-13.79	-19.41
RLSO	4679939.379	1840150.841	3910407.471	17.11	-6.93	-17.30	-23.08	-14.62
SPAN	4658312.590	1757780.315	3973702.339	6.29	-1.53	-9.16	-10.57	-2.56
VLSM	4699992.015	1765547.414	3921161.949	7.24	-4.50	-7.84	-10.48	-6.42

3D coordinates (ETRF2005, ep. 2007.5) and velocities (wrt Eurasian Plate)

The case study – Data and results



Velocities of the 10/18 Stations of NOANET (table 2)

Station	E (m)	N (m)	H (m)
ATAL	412779.769	4278464.729	98.040
KASI	151572.121	4407223.086	77.105
KIPO	180078.656	4234377.289	103.831
KLOK	210892.886	4297476.543	425.000
LEMN	600775.539	4416729.834	66.835
NOA1	487920.522	4210758.282	499.102
NVRK	488949.900	4575750.106	586.093
PONT	201019.238	4230648.362	411.372
PRKV	695311.893	4346200.967	130.033
RLSO	329279.223	4381044.505	103.21
SPAN	294541.801	4087544.098	16.564
VLSM	277411.696	4214756.881	107.952

Projection coordinates (TM) wrt HGRS87 and Orthometric Height, derived from aspecific geoid model for Greece.

Final Remarks - Conclusion

- The accuracy of the transformation between HTRS07 & HGRS87 is ±8.3cm (residuals rms nationwide – official vs estimated)
- The orthometric heights presented, are not assessed and validated.
- See also: Ampatzidis et al. (2017) in Bulletin Of Geological Society of Greece, Vol 51, 113-127

BENEFITS OF THE PROPOSED PROCEDURE

Transforms the NOANET to HGRS87.

We can assess the behaviour of a classical datum with modern TRFs thanks to the Time - Dependent transformation and the velocities of NOANET

Tackles similar geodetic problems in areas with intense geodynamic behavior.

Provides useful information for daily end users.

End users can validate their work on HGRS87 (which is outdated but operational) due to seismic activity

The NOANET can be used in the establishment of a new modern RF

Either as part of greater CORS GNSS network, or as an external validation source.

References

Altamimi, Z., L. Métivier, and X. Collilieux, 2012. ITRF2008 plate motion model, J. Geophys. Res.,117, B07402, doi:10.1029/2011JB008930.
Altamimi, Z., X. Collilieux, and L. Metivier, 2011. ITRF2008: an improved solution of the International Terrestrial Reference Frame, Journal of Geodesy, doi:10.1007/s00190-011 0444-4.
Altamimi, Z., P. Sillard, and C. Boucher, 2002. ITRF2000. A new release of the International Terrestrial Reference Frame for Earth science applications. Journal Geophys. Res., vol. 107, No B10, 2214, pp. 19 DOI:10.1029/2001JB000561.
Ampatzidis, D., Kalamakis, N., Katsambalos, K., 2017. Expressing the NOANET GNSS network to the Hellenic Geodetic Reference System of 1987 (HGRS1987): A synergy Between Geodesy and Geodynamics. Bulletin of the Geological Society of Greece, vol51, p.113-127.
Chousianitis K., Ganas A., Papanikolaou M., Argyrakis P., Drakatos G. and Makropoulos K., 2013b. Time series analysis of the NOANET CGPS stations. Bulletin of the Geological Society of Greece, vol. XLVII, No. 2, pp. 508-517.
Ganas, A., G. Drakatos, S. Rontogianni, C. Tsimi, P. Petrou, M. Papanikolaou, P. Argyrakis, K. Boukouras, N. Melis and G. Stavrakakis, 2008. NOANET: The new permanent GPS Network for Geodynamics in Greece. Geophysical Research abstracts, Vol. 10, EGU2008-A-04380.
Gubler E., Poder K., Hornik H. (Eds), 1992. Report on the Symposium of the IAG Subcommission for the European Reference Frame (EUREF). Florence 28 - 31 May 1990: Report.
Katsambalos, K., Kotsakis, C. and Gianniou, M., 2010. Hellenic terrestrial reference system 2007 (HTRS07): a regional realization of ETRS89 over Greece in support of HEPOS. Bulletin of Geodesy and Geomatics, LXIX (2–3), pp. 151–64.
Soler, T. and Snay, R., 2004. Transforming Positions and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983. Journal of Surveying
Engineering, Vol. 130, No. 2.

DISCLAIMER: *The initial coordinates and velocities for NOANET used in this report are the officially released and the authors used them as published, without any further validation or processing*

Thank you for your attention

Questions - Discussion