Hellenic Terrestrial Reference System 2007 (HTRS07):
A regional realization of ETRS89 over Greece in support of HEPOS
Contents

1. HEPOS
2. EUREF stations in Greece
3. “Geophysical conditions” – Station velocities
4. HTRS07: System – Frame – Epoch
5. HEPOS network adjustment
6. Development of transformation model
   HTRS07 ↔ HGRS87
7. Software developed
8. Future work
HEPOS

- HEllenic Positioning System.
- Developed by KTIMATOLOGIO S.A.
- Consists of 98 GPS CORS distributed all over mainland Greece and (most of) the islands.
- 55 km average interstation distance in mainland Greece.
- Supports Real-Time network-based techniques (VRS, FKP, MAC) & Post Processing.
- Has already been used for EU co-funded VLS orthophotomap projects (since 25/2/2008).
  - [http://www.hepos.gr](http://www.hepos.gr)

EUREF 2009 / Florence

HTRS07 in support of HEPOS
98 Stations of HEPOS

- 87 supporting network operations
- 11 supporting single-base

EUREF 2009 / Florence

HTRS07 in support of HEPOS
4 EUREF stations currently in Greece

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Greek EPN stations
(operational during HEPOS development)

TUC2

AUT1

NOA1

2004 / week 1294

2005 / week 1320

2006 / week 1379

EUREF 2009 / Florence

HTRS07 in support of HEPOS
ITRF2005 and Plate motion:
Horizontal Site velocities with $\sigma < 3\text{mm/y}$


NOTE: Greece moves SW (up to 3cm/y) relative to the Eurasia plate (!!)

F Symposium, London, June 2007
ETRF2005 Horizontal Velocities
(from Altamimi. EUREF 2006)

Velocities in SE Europe are TWO ORDERS of magnitude higher than in central Europe!
2005.0-2008.8 : Horizontal trajectories (ETRF2005)
(Based on official EPN coordinate values)

2D velocities

ETRF2005
AUT1: 1.03 cm/yr
NOA1: 2.80 cm/yr
TUC2: 3.00 cm/yr

ITRF2005
AUT1: 2.50 cm/yr
NOA1: 1.33 cm/yr
TUC2: 1.36 cm/yr

EUREF 2009 / Florence
HTRS07 in support of HEPOS
Fixed EUREF/EPN station for HEPOS network adjustment: AUT1

When we started (2007):

<table>
<thead>
<tr>
<th>Frame</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITRF05/2000.0</td>
<td>4466283.488 ± 0.003</td>
<td>1896166.775 ± 0.002</td>
<td>4126096.773 ± 0.003</td>
</tr>
<tr>
<td>ETRF05/2000.0</td>
<td>4466283.737 ± 0.003</td>
<td>1896166.625 ± 0.002</td>
<td>4126096.618 ± 0.003</td>
</tr>
</tbody>
</table>

AUT1 was decided to be kept fixed to:

<table>
<thead>
<tr>
<th>Frame</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETRF05/2007.5</td>
<td>4466283.7738</td>
<td>1896166.6498</td>
<td>4126096.5588</td>
</tr>
</tbody>
</table>

If we had used ETRF2000, instead of ETRF2005:

<table>
<thead>
<tr>
<th>Frame</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETRF00/2000.0</td>
<td>4466283.731 ± 0.012</td>
<td>1896166.624 ± 0.006</td>
<td>4126096.617 ± 0.011</td>
</tr>
</tbody>
</table>

Using EUREF velocities…

<table>
<thead>
<tr>
<th>Frame</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETRF00/2007.5</td>
<td>4466283.7617</td>
<td>1896166.6345</td>
<td>4126096.5450</td>
</tr>
</tbody>
</table>

Hence, HEPOS/HTRS07 is 1-2 cm off with respect to ETRF00

EUREF 2009 / Florence

HTRS07 in support of HEPOS
HTRS07 : Ref System for HEPOS

HEPOS reference system: ETRS89

in the frame: ETRF2005 (epoch: 2007.5)

The selected epoch indicates the mid-time of all GPS measurements collected during the HEPOS development project.

HTRS07 is a realization of ETRS89 and it is in accordance to the INSPIRE Directive (15/5/2007).
TM07 : Projection for HTRS07

Transverse Mercator (one zone for all Greece)

- Central Meridian: \( \lambda_0 = 24^\circ \) East
- Scale along CM: \( k_0 = 0.9996 \)
- Latitude of origin: \( \phi_0 = 0^\circ \)
- False Easting: \( X_0 = 500 \, 000.00 \) meters
- False Northing: \( Y_0 = -2 \, 000 \, 000.00 \) meters

For Kastelorizo ONLY:

- Central Meridian: \( \lambda_0 = 30^\circ \) East
- Scale along CM: \( k_0 = 1.0000 \)
- Latitude of origin: \( \phi_0 = 0^\circ \)
- False Easting: \( X_0 = 500 \, 000.00 \) μέτρα
- False Northing: \( Y_0 = -2 \, 000 \, 000.00 \) μέτρα

Reference Ellipsoid: GRS80

EUREF 2009 / Florence  
HTRS07 in support of HEPOS
HEPOS 98-stations adjustment

Two weeks (1448 & 1449) of observations

Bernese 4.2
Solution in ITRF2005/2007.79
Memo has NOT been used
Translation to ETRF2005/2007.5
DX=0.3839m, DY=-0.2912m, DZ=-0.2361m

- Preprocessing : Triple Differences
- Cutoff angle : 3 degrees
- Data sampling : 30 seconds preprocessing / 180 seconds final
- Processing : Ionosphere-free double differences
- Antenna calibrations : IGS05 model absolute values
- Troposphere : Dry-Neill
- Ionosphere : Regional model computation
- **Datum definition** : Twelve EUREF stations including AUT1, NOA1, TUC2 and GLSV, JOZE, MATE, NICO, NOT1, TRAB, WTZR, WTZR, RAMO
- Orbits : IGS final orbits and ERP parameters
- Planetary Ephemeris : DE200
- Ocean loading : Onsala FES2005 model
- Tidal model : Solid earth IERS 1996 conventions

- **rms accuracies** : σE=2mm, sN=2mm, σH=5mm

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Two days (292,293) of 2007
Precise Orbits
5050 baselines

15 mm rms difference wrt IGN

EUREF 2009 / Florence
HTRS07 in support of HEPOS
Datum Transformation:
HTRS07 ↔ HGRS87

- **HGRS87** is (still) the official (non-geocentric) reference system for the Hellenic Cadastre.

- **24000** pillars in Greece, maintained by the Hellenic Geographic Military Service (HEGS).

- Available data: E, N or \( \phi, \lambda \) and \( H \) (mostly from trigonometric leveling)

- **2470 pillars** (10% of Greek triangulation network) re-measured to obtain ITRF/ETRF coordinates.

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Point distribution around Thessaloniki.
Apprx 8 points / 1:50,000 sheet

EUREF 2009 / Florence
HTRS07 in support of HEPOS
Software : ITRFyy <> ETRFxx (Boucher-Altamimi MEMO)

EUREF 2009 / Florence

HTRS07 in support of HEPOS
All 2470 pillars positioned in three reference frames

- 6H-24H obs & precise orbits / Min constraints
- Solution in ITRF2000/2007.236
- Always check at NOA1 & TUC2
- Transformation to ETRF2000/2007.236 using B/A Memo

$$X_{yy}(t_c) = X_{yy}(t_c) + T_{yy} + \begin{pmatrix} 0 & -\dot{R}_{3yy} & \dot{R}_{2yy} \\ \dot{R}_{3yy} & 0 & -\dot{R}_{1yy} \\ -\dot{R}_{2yy} & \dot{R}_{1yy} & 0 \end{pmatrix} \times X_{yy}(t_c) \cdot (t_c - 1989.0)$$

- Translation to ETRF2005/2007.5 using offset at AUT1
  +0.020, +0.016, +0.004 m

EUREF 2009 / Florence  
HTRS07 in support of HEPOS
2470 pillars occupied to estimate and validate HTRS07 – HGRS87 parameters

<table>
<thead>
<tr>
<th>order</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>14</td>
</tr>
<tr>
<td>II</td>
<td>39</td>
</tr>
<tr>
<td>III</td>
<td>328</td>
</tr>
<tr>
<td>IV</td>
<td>2085</td>
</tr>
</tbody>
</table>
Transformation & Validation points

For the transformation 2199
For validation 231

EUREF 2009 / Florence
HTRS07 in support of HEPOS
Helmert-type 3D similarity transformation model (7 parameters)

\[
\begin{bmatrix}
X' \\
Y' \\
Z'
\end{bmatrix}
= \begin{bmatrix}
t_x \\
t_y \\
t_z
\end{bmatrix} + \begin{bmatrix}
(1 + \delta s) & \varepsilon_z & -\varepsilon_y \\
-\varepsilon_z & (1 + \delta s) & \varepsilon_x \\
\varepsilon_y & -\varepsilon_x & (1 + \delta s)
\end{bmatrix}
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]
## Estimated Parameters (HTRS07 to HGRS87)

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>tx</td>
<td>203.437 m</td>
<td>± 0.265 m</td>
</tr>
<tr>
<td>ty</td>
<td>-73.461 m</td>
<td>± 0.285 m</td>
</tr>
<tr>
<td>tz</td>
<td>-243.594 m</td>
<td>± 0.244 m</td>
</tr>
<tr>
<td>εx</td>
<td>-0″.170</td>
<td>± 0″.007</td>
</tr>
<tr>
<td>εy</td>
<td>-0″.060</td>
<td>± 0″.009</td>
</tr>
<tr>
<td>εz</td>
<td>-0″.151</td>
<td>± 0″.009</td>
</tr>
<tr>
<td>scale</td>
<td>-0.294 ppm</td>
<td>± 0.031 ppm</td>
</tr>
</tbody>
</table>

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Horizontal residuals at transformation & validation points

<table>
<thead>
<tr>
<th>points</th>
<th>max</th>
<th>min</th>
<th>mean</th>
<th>σ</th>
<th>rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>2199</td>
<td>2.342</td>
<td>0.010</td>
<td>0.550</td>
<td>0.301</td>
<td>0.627</td>
</tr>
<tr>
<td>231</td>
<td>2.585</td>
<td>0.019</td>
<td>0.584</td>
<td>0.350</td>
<td>0.680</td>
</tr>
</tbody>
</table>

EUREF 2009 / Florence  
HTRS07 in support of HEPOS
Regional horizontal residuals

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Corrections on a 2x2 km Grid
(computed using biharmonic spline interpolation)

\[ \delta E'_{i} \quad \delta E_{n,m} \quad \delta N'_{i} \quad \delta N_{n,m} \]

<table>
<thead>
<tr>
<th>points</th>
<th>max</th>
<th>min</th>
<th>mean</th>
<th>(\sigma)</th>
<th>rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>2199</td>
<td>0.049</td>
<td>0.000</td>
<td>0.007</td>
<td>0.004</td>
<td>0.008</td>
</tr>
<tr>
<td>231</td>
<td>0.244</td>
<td>0.006</td>
<td>0.068</td>
<td>0.047</td>
<td>0.082</td>
</tr>
</tbody>
</table>

EUREF 2009 / Florence
HTRS07 in support of HEPOS
Software for the transformation: HTRS07 <-> HGRS87

- 7-parameter model + gridded corrections on a 2kmx2km grid
- Four versions, available from www.hepos.gr
- 8 cm rms transformation accuracy everywhere in Greece

EUREF 2009 / Florence

HTRS07 in support of HEPOS
Future Work

- Apply TWG recommendation for ETRF2000 (?)
- Official change from HGRS87 to HTRS07
- A reliable geodetically computed velocity field model for the tectonic motions in Greece (estimated up to 3 cm/year). The contribution of the 98 HEPOS stations. Repeated (yearly?) adjustment of the network.
- Define a new national **vertical** reference system, in support of HEPOS.
- Compilation of a new geoidal model ?
- Use the new EGM08 model for the conversion h=H+N.
Thank you

Prof. K. Katsampilos, AUTh
kvek@topo.auth.gr

Assoc Prof. Ch. Kotsakis, AUTh
kotsaki@topo.auth.gr

Asst Prof. M. Gianniou, KTIMATOLOGIO SA
mgianniu@ktimatologio.gr

EUREF 2009 / Florence

HTRS07 in support of HEPOS