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## Impact of Regional Reference Frame Definition on Geodynamic Interpretations

J. Legrand, N. Bergeot, C. Bruyninx, G. Wöppelmann, M.-N. Bouin, Z.  
Altamimi

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# Impact of Regional Reference Frame Definition on Geodynamic Interpretations

J. Legrand<sup>(1)</sup>, N. Bergeot<sup>(1)</sup>, C. Bruyninx<sup>(1)</sup>, G. Wöppelmann<sup>(2)</sup>, M.-N. Bouin<sup>(3)</sup>, Z. Altamimi<sup>(4)</sup>

(1) Royal Observatory of Belgium, Avenue Circulaire 3, B-1180 Brussels, Belgium;

(2) UMR LIENSS, Université de La Rochelle-CNRS, 2 rue Olympe de Gouges, 17000 La Rochelle, France;

(3) CNRM / Centre de Météo Marine, 13 rue du Chatellier, 29604 Brest, France;

(4) LAREG/IGN, 6-8 Avenue Blaise Pascal, 77455 Marne-la-Vallée, France

Corresponding author: J. Legrand, [J.Legrand@oma.be](mailto:J.Legrand@oma.be), Fax: +32-2-3749822

## 1 Abstract

2 Ten years (1997-2006) of weekly GNSS solutions of 205 globally distributed  
3 stations have been used to investigate the impact of the reference frame definition on  
4 the estimated station velocities. For that purpose, weekly regional solutions  
5 (covering the European region) and global solutions have been respectively stacked  
6 to obtain regional and global velocity fields. In both cases, the estimated long-term  
7 solutions (station positions and velocities) were tied to the ITRF2005 under minimal  
8 constraints using a selected set of reference stations. Several sets of global and  
9 regional reference stations were tested to evaluate first the impact of the reference  
10 frame definition on the global and regional velocity fields and later the impact on the  
11 derived geodynamic interpretations.

12 Results confirm that the regional velocity fields show systematic effects with respect  
13 to the global velocity field with differences reaching up to 1.3 mm/yr in the  
14 horizontal and 2.9 mm/yr in the vertical depending on the geographical extent of the  
15 network and the chosen set of regional reference stations.

16 In addition, the estimations of the Euler pole for Western Europe differ significantly  
17 when considering a global or a regional strategy. After removing the rigid block  
18 rotation, the residual velocity fields show differences which can reach up to 0.8  
19 mm/yr in horizontal component.

20 In Northern Europe, the vertical ground motion is dominated by the Glacial Isostatic  
21 Adjustment (GIA). A proper modeling of this effect requires sub-mm/yr precision  
22 for the vertical velocities for latitudes below  $56^\circ$ . We demonstrate that a profile of  
23 vertical velocities shows significant discrepancies according to the reference frame  
24 definition strategy. In the case of regional solutions, the vertical modeling does not  
25 predict any subsidence around  $52^\circ$  as predicted by the global solution and previous  
26 studies.

27 In summary, we evidence the limitation of regional networks to reconstruct absolute  
28 velocity fields and conclude that when geodynamics require the highest precisions  
29 for the GNSS-based velocities, a global reference frame definition is more reliable.

30

31 Keywords: Geodesy; Reference Frame; Methodology; GNSS; Velocity Field;  
32 Geodynamic.

33

## 34 **1. Introduction**

35 GNSS (Global Navigation Satellite Systems) is often used to produce 3D velocity  
36 fields aiming at geodynamic interpretations. Due to the expected small intra-plate  
37 deformations in most European regions, the accuracy of the estimated surface  
38 displacements must be at the sub mm/yr level in the horizontal and vertical  
39 components.

40 The IGS (International GNSS Service) started its first reprocessing campaign in Feb.  
41 2008 (Steinberger et al., 2008) and is presently reprocessing its global GNSS  
42 network data to deliver a set of consistent high quality GNSS products (e.g. orbits,  
43 clocks and earth rotation parameters) which will be used by regional GNSS  
44 densification networks during their reprocessing. Today, with the improving  
45 computing facilities and GNSS data analysis, it has become less demanding to  
46 perform a global analysis and regional networks may consider this approach. Within  
47 that context, we compared the regional approach to the global approach where  
48 global stations located on other continents were added to a regional GNSS network  
49 processing.

50 Historically, two major methods were used to express a GNSS position and velocity  
51 solution in a given realization of the ITRF (International Terrestrial Reference  
52 Frame): (1) by constraining the positions and the velocities of a selected ITRF  
53 subset of stations to ITRF values, (2) by aligning the solution to the ITRF using a  
54 14-parameter Helmert similarity transformation under the minimal constraints  
55 approach for a selected set of stations. According to Altamimi (2003), the advantage  
56 of the first method is that the solution is well expressed in the ITRF frame, while its  
57 disadvantage is that the selected stations will have their coordinates entirely  
58 determined by the ITRF selected values. In comparison, the second method has the  
59 advantage of preserving the intrinsic characteristics of the solution and avoiding any  
60 internal distortion of the original network geometry.

61

62 In this paper, we concentrate on the second method and study specifically the  
63 alignment of the solutions (regional or global) to the ITRF2005 (Altamimi et al.,  
64 2007a) using a 14-parameter similarity transformation under the minimal constraints  
65 approach.

66 In Legrand and Bruyninx (in press), global and regional solutions for station  
67 positions have already been compared and it was demonstrated that positions  
68 obtained through global solutions are less sensitive to the reference frame definition  
69 compared to regional solutions. Wöppelmann et al. (2008) investigated the influence  
70 of using different sets of reference stations to express a global solution in a given  
71 frame and concluded that the best results were obtained using a large global  
72 distribution of reference stations mitigating the individual problems at each of the  
73 reference stations.

74 In this study, we investigate the impact of the size of the GNSS network and the  
75 choice of the reference stations on the estimated velocities and the derived  
76 geodynamic interpretations. For that purpose, we elaborated several long-term  
77 solutions by varying the geographical extension of the network and the reference  
78 stations used in the alignment to the same reference frame.

79 Geodynamic interpretations are often based on GNSS velocities fields stemming  
80 from a regional network processing. However, to detect sub-mm/yr motion it is  
81 fundamental to pay attention to the GNSS data processing strategy and particularly  
82 the reference frame definition. To address that problem, we focused on the Western  
83 part of Europe where geodynamics require sub-mm/yr precision for both horizontal  
84 and vertical velocities. We used the velocity solutions from our global and regional

85 networks to compare the results of different commonly-used geodynamic modeling  
86 strategies, such as the estimation of Euler rotation poles, residuals from rigid block  
87 motion and vertical velocity profiles.

## 88 **2. Data Set and Methodology**

89 The computation of a velocity field from GNSS data consists of several steps.

### 90 *2.1 Weekly Coordinate Solutions*

91 In a first step, weekly positions of continuous observing GNSS stations are  
92 estimated. Ten years (1997-2006) of weekly GNSS solutions produced by ULR  
93 (Université de la Rochelle) as its contribution to TIGA (Tide Gauge Benchmark  
94 Monitoring Project of the IGS) have been used throughout this paper. The ULR  
95 solutions are in the SINEX format, and provide station coordinates together with  
96 their covariance information for 225 globally distributed continuous GNSS stations  
97 (Figure 1) from which 205 stations have more than 3.5 years of data. The same  
98 parameterization and observation modeling were used over the whole 10-year  
99 period, estimating station coordinates, satellite orbits, earth orientation parameters,  
100 and zenith tropospheric delay parameters every 2 hours. IGS absolute phase centre  
101 corrections for both the tracking and transmitting antennas were applied (see  
102 Wöppelmann et al. 2009 for further details on the GNSS reprocessing). Each weekly  
103 solution was aligned to the ITRF2005 using minimum constraints with seven  
104 transformation parameters (translations, rotations and scale) with the CATREF  
105 software package (Altamimi et al., 2007b).

106 **FIGURE 1**

107 To study the differences between global and regional solutions, regional weekly  
108 solutions have been created from the ULR global weekly solutions by extracting 60  
109 GNSS stations located in Europe, all included in the EUREF Permanent Network  
110 (EPN) (Bruyninx, 2004).

## 111 *2.2 Cumulative Position and Velocity Solution*

112 In a second step, the weekly positions (and their covariance information) were  
113 combined to estimate site positions and velocities expressed in a chosen reference  
114 frame. Global and regional velocity fields were obtained by stacking both sets of  
115 weekly solutions. The stacking was performed with CATREF and tied to the  
116 ITRF2005 under minimal constraints using 14 transformations parameters  
117 (translations, rotations, scale and their rates) using a selection of ITRF2005  
118 reference stations.

119 The quality of the alignment of the long-term solution on ITRF2005 depends on the  
120 selected set of reference stations; these stations should be of high quality. Their  
121 selection is based on the following criteria:

- 122 – residuals of the similarity transformation between the solution and the  
123 ITRF2005:
  - 124 ○ positions: below 7 and 15 mm in horizontal and vertical components,  
125 respectively
  - 126 ○ velocities: below 1.5 and 3 mm/yr in horizontal and vertical  
127 components, respectively
- 128 – station observation history: at least 3 years in the ITRF, as well as in the  
129 ULR time series



130 – optimal distribution of the reference stations over the network.

131 In this study, we distinguish two reference frame definition strategies: (1) a first case  
132 considering a set of global well distributed reference stations; (2) a second case with  
133 regional distributed reference stations.

134

### 135 **3. Effect of Reference Frame Definition on Absolute Velocity Fields**

136 To evaluate the impact of the reference stations on the global and regional velocity  
137 fields, several sets of reference stations were tested when expressing the cumulative  
138 solution in the ITRF2005.

#### 139 *3.1 Stability of the Networks*

140 The impact of outliers (residuals of the similarity transformation between ITRF2005  
141 and the solution exceeding the criteria presented above) in the reference stations and  
142 of reducing the number of reference stations (all of them responding to the above  
143 mentioned site selection criteria) was tested for the two networks. We observed that  
144 the velocities obtained by using different sets of the global reference stations differ  
145 below 0.2 mm/yr indicating that in general they behave in a stable way. However,  
146 the velocity fields obtained with the regional network were much more sensitive to  
147 the set of reference stations used (outliers and geometry) compared to the global  
148 network (see section 3.3).

149 In the regional network, it was evidenced that the border stations are crucial for a  
150 proper datum definition, they could considerably impact the coordinates and  
151 velocities of the whole network. Moreover, the estimated coordinates and velocities  
152 of the border stations were extremely sensitive to the reference frame definition

153 resulting in unstable estimates dependent on the chosen set of reference stations.  
154 This means that in general, even if they are mandatory for the reference frame  
155 definition, the coordinates and velocities obtained for the border stations should be  
156 treated with care, or even not used at all in the geodynamic interpretation.

### 157 *3.2 Regional and Global Sets of Reference Stations*

158 Finally, for the global network, 83 geographically well-distributed IGS05 stations  
159 (Ferland, 2006), following the criteria defined in section 2.2, were selected as  
160 reference stations to express the solution used throughout this paper in ITRF2005  
161 and obtain the  $V_{\text{GLOB}}$  velocity field. The IGS05 consists of 132 IGS stations based  
162 on station performance, track record, monumentation, co-location and geographical  
163 distribution selected by the IGS Reference Frame Working Group for the IGS  
164 realization of the International Terrestrial Reference Frame.

165 For the regional network, we selected two sets of reference stations (Figure 2), both  
166 following the criteria defined in section 2.2 and having a large probability of being  
167 used by users in Europe:

- 168 – Selection A: 23 reference stations consisting of all EPN ITRF2005 stations  
169 also part of the IGS05
- 170 – Selection B: 14 stations, subset of selection A with stations located only on  
171 the European continent

172 The two associated regional velocity fields are  $V_{\text{REGA}}$  (selection A) and  $V_{\text{REGB}}$   
173 (selection B).

174 **FIGURE 2**

175 *3.3 Comparison of the Velocity Fields*

176 Figures 3 shows the comparison of the horizontal and vertical velocity fields derived  
177 from the global ( $V_{\text{GLOB}}$ ) solution with the two regional solutions ( $V_{\text{REGA}}$  and  $V_{\text{REGB}}$ )  
178 and shows that both regional velocity fields present systematic effects with respect  
179 to the global velocity field. As shown in Table 1, the velocity differences are  
180 significant with respect to the error ellipses and can reach up to 1.3 mm/yr in the  
181 horizontal and 2.9 mm/yr in the vertical components. In zones where the aim is to  
182 measure (sub)-mm/yr deformations, such an effect cannot be neglected.

183 **FIGURE 3**184 **TABLE 1**

185 At the start of the computations, the stations in each weekly regional solution have  
186 the same coordinates as in the corresponding weekly global solution. Then, during  
187 the stacking, station coordinates and velocities are estimated together with a  
188 similarity transformation between each weekly solution and the reference datum.  
189 Especially in regional networks, these transformations will absorb common mode  
190 signals and will slightly change the estimated velocities (effect  $N_1$ ). Finally, the  
191 stacked solution is tied to the ITRF2005 using minimal constraints applied upon  
192 different sets of reference stations. The minimal constraints method typically does  
193 not alter the network geometry. The choice of the reference stations used to express  
194 the long-term solution in ITRF2005 has an impact on the alignment and  
195 consequently also changes the estimated velocities (effect  $N_2$ ). In general, these two  
196 effects ( $N_1$  and  $N_2$ ) are known as the network effect. The effect  $N_2$ , which only

197 depends on the choice of the reference stations, is fully explained by a similarity  
198 transformation whose parameters are shown in Table 2. These transformation  
199 parameters have been estimated with all stations of the regional network; the  
200 correlations between the transformation parameters are the same for the two regional  
201 networks and are shown in Table 3. The translation rates are strongly correlated with  
202 the rotation rates (affecting only the horizontal velocities) and the scale (affecting  
203 only the vertical velocities). These transformation parameters explain more than  
204 90% of the velocity differences. The systematic effects observed in the horizontal  
205 velocities (see Figure 3, left) are explained by the rotation rates and the translation  
206 rates. For the vertical component, the bias (Regional A) and the tilt (Regional B)  
207 observed in Figure 3 (right) are explained by the scale rate together with the  
208 translation rates. The residuals obtained after the similarity transformations are  
209 caused by the effect  $N_1$ ; they are below 0.2 mm/yr in horizontal and 0.6 mm/yr in  
210 vertical (see Table 4) and are the same for the two regional networks. The effect  $N_1$   
211 is correlated with the size and the geometry of the whole network.

212 Summarized, the differences between the global and regional velocity fields are due  
213 to the combined effect of the size of the network and the selection of the reference  
214 stations and are called “network effect”.

215 **TABLE 2**

216 **TABLE 3**

217 **TABLE 4**

218 The disagreement between the velocity fields is amplified when the reference  
219 stations cover a smaller geographical area (selection B). This effect is probably  
220 increased by the fact that in selection A, some reference stations belong to the  
221 American, the African or the Arabian plates; while for selection B, all the reference  
222 stations are located on the European plate. Adding reference stations from outside  
223 the European continent allows reducing the difference between the regional and  
224 global velocity fields.

225

## 226 **4. Effect of the Reference Frame Definition on Geodynamic**

### 227 **Interpretations**

#### 228 *4.1 Impact on Euler Pole Rotation Estimation*

229 Euler Pole rotations are usually used to model the mean rigid block rotation of a  
230 tectonic entity (e.g. tectonic plate, tectonic block). Consequently, Euler pole rotation  
231 is also used to estimate the residuals from the rigid block motion hypothesis in order  
232 to detect strain accumulation areas and/or intra-plate deformations. To quantify the  
233 impact of the reference frame definition on the Euler pole rotation estimation, the  
234 mean rigid block rotation has been estimated individually for the Western part of  
235 Europe from each of the three solutions.

236 In each case, the same 40 stations were used satisfying the following criteria:

- 237 – continuously observed during at least 3 years;
- 238 – located on rigid parts of the European tectonic plate;

- 239 – formal error of the estimated horizontal velocity (as result of the stacking)  
240 below 1.5 mm/y;  
241 – post-fit velocity residual below 1.5 mm/yr, after the estimation of the rotation  
242 pole.

243 **TABLE 5**

244 The resulting rotation poles together with the Eurasian rotation pole published in  
245 ITRF2005 [Altamimi et al. 2007a] are given in Table 5. From this, it can be seen  
246 that the ITRF2005 rotation pole for Eurasia is closer to the rotation pole from  
247 Regional B than to the rotation poles from Regional A or Global. Indeed, the  
248 reference stations used to tie the Regional B solution to ITRF2005 are only located  
249 on the European plate and 12 of these 14 stations were used by [Altamimi et al.  
250 2007a] to estimate the Eurasian rotation pole. As a consequence, due to the principle  
251 of the minimal constraints, the Regional B velocities of the European stations are  
252 closer to the ITRF2005 values than the two other solutions and finally the rotation  
253 pole from Regional B is closer to the rotation pole from [Altamimi et al. 2007a] than  
254 the others. Nevertheless, this does not remove the fact that regional solutions behave  
255 in an unstable way: any other choice of reference stations could lead to a different  
256 rotation pole for Europe. This is confirmed by Table 5 which shows that the three  
257 resulting rotation poles estimated from  $V_{REGA}$ ,  $V_{REGB}$  and  $V_{GLOB}$  differ significantly.  
258 Consequently, the choice of the reference stations during the reference frame  
259 definition has a relevant impact on the estimated rotation pole.

260

#### 261 *4.2 Residuals from Rigid Block Motion Hypothesis in Western Europe*

262 To test the impact of the network effect on the detection of non-rigid deformation, in  
263 each case, the modeled rigid block rotation was removed from the horizontal  
264 velocities to obtain the residual velocity fields. The order of magnitude of the  
265 residuals is the same for  $V_{REGA}$ ,  $V_{REGB}$  and  $V_{GLOB}$ . Nevertheless, we observe  
266 systematic effects when comparing them (see Figure 4). The RMS of the differences  
267 between  $V_{GLOB}$  and  $V_{REGA}$  is about 0.1 mm/yr and the differences reach up to 0.5  
268 mm/yr. The RMS of the differences between  $V_{GLOB}$  and  $V_{REGB}$  is 0.2 mm/yr, but the  
269 maximal difference reaches 0.8 mm/yr. The velocity residuals of the two regional  
270 solutions are similar in the middle of the network, but the differences between the  
271 two sets of residuals are larger when getting closer to the edges of the regional  
272 networks.

273 The reference frame definition strategy therefore has a significant impact on the  
274 velocity estimation, and this has to be considered when sub-mm/year precision is  
275 required for a proper interpretation of the intraplate deformations.

#### 276 **FIGURE 4**

277

#### 278 *4.3 Impact on GIA Model Estimation*

279 In Northern Europe, the vertical motion is mainly due to the post-Glacial Isostatic  
280 Adjustment (GIA). According to previous studies the estimated vertical motion can  
281 reach 10 mm/yr in the Fennoscandian region (Nocquet et al., 2005). Additionally,  
282 the first order of the GIA effect on vertical velocities over Western Europe, is well

283 explained by a 4<sup>th</sup> order polynomial function (Milne et al., 2001) with uplift in  
284 Northern Europe and transitions zones between uplift and subsidence below 56° of  
285 latitude. However, the transition between the GIA-induced uplift and subsidence  
286 zone is not well constrained due to the small velocities that have to be measured in  
287 the Western central part of Europe for regions below 56° of latitude.

288 The three vertical velocity fields ( $V_{\text{GLOB}}$ ,  $V_{\text{REGA}}$  and  $V_{\text{REGB}}$ ) have been used to  
289 construct velocity profiles along the European region subject to post-glacial  
290 rebound. The stations used for the vertical velocity profiles range from 45° to 71° of  
291 latitude and -5° to 35° of longitude.

292 We estimated the parameters of a 4<sup>th</sup> order polynomial function from the vertical  
293 profiles of the global and two regional solutions to model the contribution of the  
294 GIA on the estimated velocities (Figure 5). As can be seen in Figure 5, the velocity  
295 of the station TRDS (Trondheim, Norway) is atypical. For that reason, the modeling  
296 was done with and without TRDS showing that TRDS influences dramatically the fit  
297 of the data and changes the 4<sup>th</sup> order function parameters.

298 Table 6 demonstrates that the models from  $V_{\text{REGA}}$  and  $V_{\text{REGB}}$  exhibit a constant bias  
299 with respect to the modeling from the global solution  $V_{\text{GLOB}}$  (up to 0.5 mm/yr). This  
300 is due to the impact of the reference frame definition on vertical velocities illustrated  
301 in Figures 3. The RMS of the difference between the model from  $V_{\text{REGA}}$  (resp.  
302  $V_{\text{REGB}}$ ) and the model from  $V_{\text{GLOB}}$  can reach 0.3 mm/yr (resp. 0.5 mm/yr).  
303 Consequently, when a velocity field is derived from a regional network, GNSS  
304 stations located far outside the studied region should also be integrated to minimize  
305 the effect of reference frame definition on the estimated site velocities.



306 In agreement with the GIA models, subsidence is predicted (maximum subsidence  
307 of 0.2 mm/yr at 51.7° latitude) by the global solution, while the regional solutions do  
308 not show subsidence at all, but a minimum uplift of 0.3 mm/yr at that latitude.  
309 Consequently, to detect mm and sub-mm/yr vertical velocities from GNSS data  
310 modeling, the regional approach is not appropriate. In our case, the transition  
311 between subsidence and uplift in northern Europe is important for example to  
312 investigate long-term sea level rise in the northern part of Belgium.

313 **FIGURE 5**

314 **TABLE 6**

315

## 316 **5. Conclusion**

317 In order to express a GNSS solution in the ITRF, it is possible to constrain the  
318 positions and velocities of some sites to their ITRF values or to align the solution to  
319 the ITRF using a 14-parameter similarity transformation under minimal constraints.  
320 In this study, we focused on the minimal constraints approach to express our GNSS  
321 solutions in ITRF2005 and we investigated the influence of the reference frame  
322 definition - in terms of reference station selection and network extension - on the  
323 estimated velocity field.

324 It was shown that based on identical sets of weekly positions as the basis, different  
325 velocity vectors (up to 1.3 mm/yr in the horizontal and 3 mm/yr in the vertical) can  
326 be estimated depending on geographical extent of the network (regional versus  
327 global). The obtained velocity differences are due to a network effect which depends

328 on the selection of the reference stations. The disagreement between the global and  
329 regional velocity fields is amplified when the reference stations cover a smaller  
330 geographical area. In the regional network, the border stations have the most  
331 unstable velocity estimates.

332 The Euler rotation poles estimated from the regional networks differ significantly  
333 from the rotation pole estimated from the global solution. After removing the rigid  
334 block rotation, the residual velocity fields show differences up to 0.9 mm/y. We also  
335 proved that, in contrary to the global solution and the GIA models, none of the  
336 regional solutions could predict subsidence around 52° latitude.

337 In conclusion, when expressing a GNSS solution in the ITRF2005 using minimal  
338 constraints, the network effect due to the size of the GNSS network and the choice  
339 of the reference stations has a significant influence on the estimated velocity field  
340 and consequently might cause wrong geodynamical interpretations. Consequently,  
341 when sub-mm/year precision is required for a proper interpretation of intraplate  
342 deformations or vertical velocities, a global approach should be considered.

343

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## 390 **Figures**

391 Fig. 1. Global (black triangles) and regional (white triangles) networks used in this  
392 study. The dashed area corresponds to Figure 2.

393 Fig. 2. Stations used for the reference frame alignment of regional solutions.

394 Selection A: stations are indicated with black and white triangles; selection B:  
395 stations are indicated with white triangles.

396 Fig. 3. Difference between global and regional velocity fields (mm/yr). Left:  
397 horizontal differences, Right: vertical differences. Top: VREGA - VGLO, bottom:  
398 VREGB - VGLO. Error ellipses are at the 99% confidence level.

399 Fig. 4. Differences between residuals from rigid block motion of the global solution  
400 with the regional selection A (top) and regional selection B (bottom). Error ellipses  
401 are at the 99% confidence level.

402 Fig. 5. Vertical profiles and best fit 4th order polynomial function for: a): global  
403 solution; b) regional solution, selection A; c) regional solution, selection B. The  
404 lines are the best fits from GNSS data with (thin) and without (bold) TRDS. The  
405 best fit from the global solution is repeated in b) and c) (dashed lines). Error bars at  
406 the 99% confidence level.

## Tables

	Horizontal (mm/yr)			Vertical (mm/yr)		
	Mean $\pm$ RMS	Max	Mean of $1\sigma$ Error Ellipses	Mean $\pm$ RMS	Max	Mean of $1\sigma$ Error Ellipses
$\mathbf{V}_{\text{REGA}} - \mathbf{V}_{\text{GLO}}$	0.3 $\pm$ 0.4	0.9	0.03	0.3 $\pm$ 0.5	1.2	0.04
$\mathbf{V}_{\text{REGB}} - \mathbf{V}_{\text{GLO}}$	0.6 $\pm$ 0.7	1.3	0.03	0.1 $\pm$ 1.0	2.9	0.04

Table 1. Statistics of the differences between the global and regional velocity fields.

Transformation parameters between	$\dot{T}_X$ (cm/yr)	$\dot{T}_Y$ (cm/yr)	$\dot{T}_Z$ (cm/yr)	$\dot{S}$ ( $10^{-9}$ /yr)	$\dot{R}_X$ (mas/yr)	$\dot{R}_Y$ (mas/yr)	$\dot{R}_Z$ (mas/yr)
$\mathbf{V}_{\text{GLOB}}$ and $\mathbf{V}_{\text{REGA}}$	-0.099	-0.162	0.004	0.057	-0.058	0.023	0.028
$\pm$	0.025	0.033	0.024	0.034	0.010	0.009	0.008
$\mathbf{V}_{\text{GLOB}}$ and $\mathbf{V}_{\text{REGB}}$	-0.153	-0.483	0.093	0.059	-0.169	0.046	0.061
$\pm$	0.025	0.033	0.024	0.034	0.010	0.009	0.008

Table 2. Translation, scale and rotation rates between the global and regional velocity fields.

	$\dot{T}_X$	$\dot{T}_Y$	$\dot{T}_Z$	$\dot{S}$	$\dot{R}_X$	$\dot{R}_Y$
$\dot{T}_Y$	-0.088					
$\dot{T}_Z$	-0.216	0.018				
$\dot{S}$	-0.511	-0.034	-0.682			
$\dot{R}_X$	-0.092	0.884	-0.008	0.000		
$\dot{R}_Y$	-0.826	0.080	0.685	0.000	0.086	
$\dot{R}_Z$	0.088	-0.740	-0.002	0.000	-0.388	-0.041

Table 3. Correlations between the translation, scale and rotation rates estimated in Table 2. The correlations larger than 0.5 are shown in grey.

	<b>Horizontal (mm/yr)</b>		<b>Vertical (mm/yr)</b>	
	<i>Mean ±RMS</i>	<i>Max</i>	<i>Mean ±RMS</i>	<i>Max</i>
$V_{REGA} - V_{GLO}$	0.0 ± 0.06	0.2	0.0 ± 0.14	0.6
$V_{REGB} - V_{GLO}$	0.0 ± 0.06	0.2	0.0 ± 0.14	0.6

Table 4. Statistics of the velocity residuals after the estimation of the translation, scale and rotation rates shown in Table 2.

<i>Pole estimation strategy</i>	<i>Longitude (°)</i>	<i>Latitude(°)</i>	<i>W (°/Ma)</i>
<b>Global solution</b>	-102.02 +/- 0.82	53.02 +/- 0.56	0.252 +/- 0.002
<b>Regional solution A</b>	-100.51 +/- 0.91	53.35 +/- 0.59	0.251 +/- 0.002
<b>Regional solution B</b>	-97.77 +/- 1.00	55.15 +/- 0.58	0.256 +/- 0.002
<b>ITRF2005</b> <b>[Altamimi et al. 2007a]</b>	-95.98 +/- 0.97	56.33 +/- 0.55	0.261 +/- 0.003

Table 5. The rotation poles estimated from  $V_{REGA}$ ,  $V_{REGB}$  and  $V_{GLOB}$  solutions and comparison with the Eurasian rotation pole from ITRF2005 published in [Altamimi et al. 2007a].

	$V_{REGA} - V_{GLO}$ (mm/yr)		$V_{REGB} - V_{GLO}$ (mm/yr)	
	<i>With TRDS</i>	<i>Without TRDS</i>	<i>With TRDS</i>	<i>Without TRDS</i>
<b><i>Mean bias</i></b>	0.3	0.2	0.5	0.5
<b><i>RMS</i></b>	0.3	0.3	0.4	0.4

Table 6. Mean biases and RMS between modeled functions from  $V_{REGA}$  or  $V_{REGB}$  solutions and global solution

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Figure 1























