4.2.3. STUDY OF THE EFFECTS OF PROCESSING STRATEGY VARIATIONS ON GPS POSITION ESTIMATES

Medžida Mulić, Asim Bilajbegović, Yuksel Altiner

4.2.3.1. Introduction

In the year 2000 the National Offices for Surveying and Mapping in Bosnia and Herzegovina set up a GPS network comprised of about 30 stations for the purpose of realizing the ETRS89. The average distance between the stations is about 50 km. Maintenance and monitoring of the station coordinates within this network will be ensured by the National DGPS service still to be established, which will also serve to meet the demands of cadastral surveying and positioning. For the determination of precise station coordinates in the new GPS network a GPS campaign was carried out in the period 17. 09. to 22. 09. 2000 (GPS week 1080) using identical instrument Trimble, each station having been observed twice over 24 hours. Precise orbit data entered into the evaluation of the observation data are described in an application of the International Terrestrial Reference Frame (ITRF), thus determining the ITRF realization of the estimated coordinates as well as the pertinent epoch.

4.2.3.2. EUREF criteria

From the GPS week 1130 (beginning: 02 September 2001) the strategy of data evaluation was with the EUREF weekly solutions supplemented as follows:

Reduction of the elevation mask for the observations from 15° to 10°.

1. **Elevation-dependent weighting of the observations according to cos2z, (z=zenith distance).**
2. **Change-over from the method by Saastamoinen to the Dry-Niell mapping function.**
3. **Determination of the values of the troposphere parameters per hour (with our data evaluations of the campaigns carried out in 1998 and 2000 every two hours).**
4. **Consideration of the correction values of the oceanic load effects on the stations, (*www.epncb.oma.be*).**

4.2.3.3. Evaluation of the data

Together with the data obtained on about 30 stations located in Bosnia and Herzegovina also the data of 11 selected ITRF/IGS stations (BOR1, BRUS, GRAZ, KOSG, MATE, MEDI, PENC, POTS, SOFI, WTZR, and ZIMM) were included for the determination of the geodetic datum. For the purpose of establishing links to the national networks of neighbouring countries the coordinates of some permanent stations of the EUREF network, Croatia (DUBR and OSJE), Italy (UNPG and CAME), Macedonia (ORID), and Romania (BUCU) were also estimated (Fig. 4.2.3.1.).

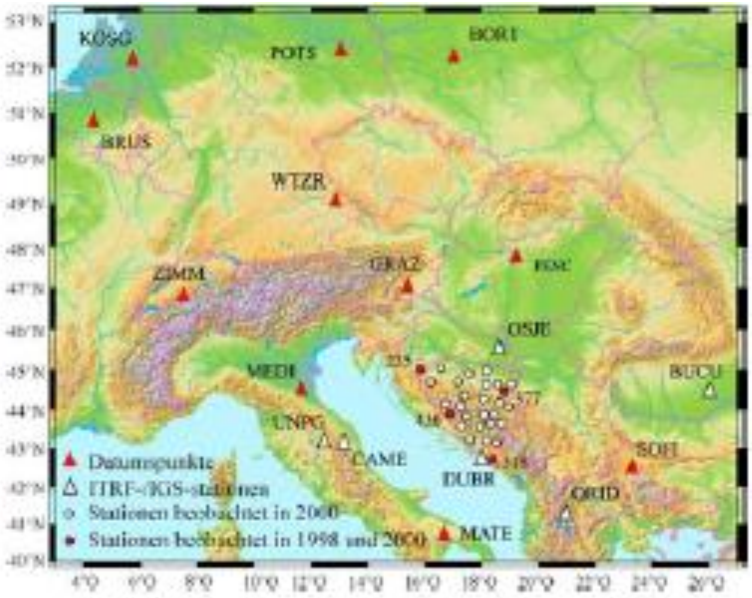

Fig. 4.2.3.1. Location of the stations introduced into the coordinate estimation

The evaluation was performed using the Bernese software (Hugentobler et al., 2001) and applying the EUREF criteria including the relative elevation-dependent calibration values of the antennas (Wübenna et al., 1997, Bilajbegovic 1999, Mader, 1999, Schmid, Rothacher, 2003, Altiner, 2005). The elevation mask of the observations is 10°. Besides the IGS orbit data as given in the ITRF97 for the GPS week 1080 the correction values of the oceanic load effects for the ITRF/IGS stations were also applied. The ambiguities were estimated according to the Quasi Ionosphere Free Solution, (QIF) method of the Bernese software. The final coordinates of the stations were computed with a high weighting of the coordinates of the datum points (0.1 mm a priori standard deviation) in a ionosphere-free solution by the combination of the daily solutions in the ITRF97 (epoch 2001.71), the relevant values of the troposphere parameters were estimated every two hours (solution I) after the method of Saastamoinen (Saastamoinen, 1972). For checking the quality of the heights the data were repeated after the introduction of the Niell`s dray mapping function, (Niell, 1996) as well as by an elevation-dependent weighting of the observations $\cos^2 z$ (solution II).

- **Accuracy criteria**

Taking the EUREF criteria as basis the repeatability of the daily solutions, as compared with the combined solution, amount for both solutions (solution I and solution II) to about 3 mm for the horizontal components and to about 4 to 10 mm for the vertical components (Figs. 4.2.3.2. and 4.2.3.3.). The standard deviations of the estimated station coordinates amount to about 3 to 5 mm for the horizontal components and to 8 to 10 mm for the vertical components.

- **Coordinate transformation**

For the transformation of the estimated station coordinates from the ITRF97 into the ETRS89 the following formula was applied (Boucher, Altamimi, 2001):

(1) $$X_{i.E}(t_c) = X_{i.I}(t_c) + T_i + R_{ij} X_{j.I}(t_c)(t_c - 1989.0) \quad ,$$

with $i, j = 1, 2, 3$ **and**

(2)
$$R_{ij} = \begin{bmatrix} 0 & -R_3 & R_2 \\ R_3 & 0 & -R_1 \\ -R_2 & R_1 & 0 \end{bmatrix},$$

$X_{i.E}(t_c)$ **and** $X_{i.I}(t_c)$ **describing the coordinates in the ETRS89 or in the ITRFyy for the realization epoch of the observations** (t_c)**.** T_i **and** R_{ij} **indicate the translation and rotation parameters, respectively, between the ITRFyy and the ETRS89, (Boucher, Altamimi, 2001). After the transformation the coordinates of the stations are described in the ETRS89 with reference to the epoch 2000.71 (GPS week 1080, 17 to 23 September 2000).**

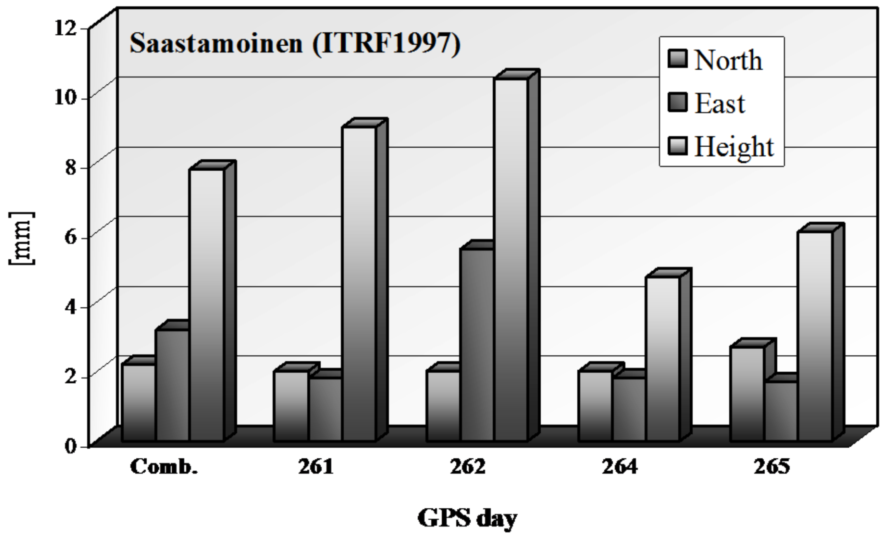

Fig. 4.2.3.2. Repeatability of the coordinates of the daily solutions in the ITRF97, computed by means of the method of Saastaminiaen

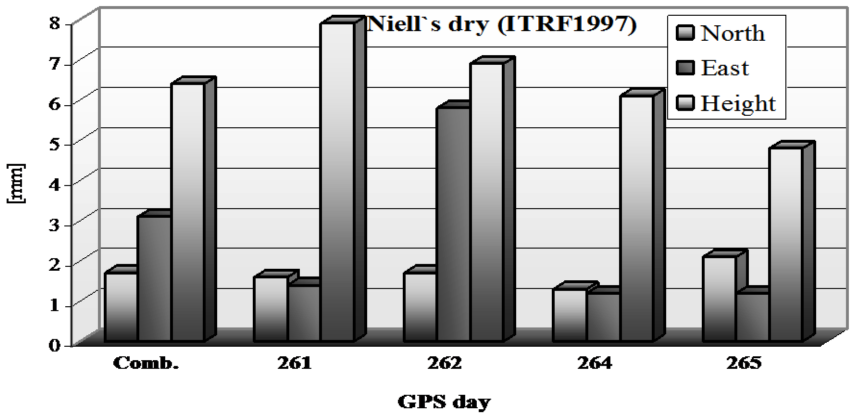

Fig. 4.2.3.3. Repeatability of the coordinates of the daily solutions in the ITRF97, computed by means of the method of Neil`s dry

- **Comparison in the ETRS89**

The coordinates of the solutions II and I were transformed into the ETRS89 and compared by means of the formulas (1) and (2) of the ITRF97 (epoch 2000.71). The results achieved by this comparison of coordinates are illustrated separately for horizontal components and vertical components in Figs. 4.2.3.5. and 4.2.3.6., respectively. With exception of station 268, the differences in elevation lie between 2 to 5 mm. Differences for heights are in the range of 1 to 15 mm (here the station PONI is an exception wit a height difference of 30 mm).

Four stations of new net in Bosnia and Herzegovina (235, 318, 377 and 436) were also co-observed (Altiner et al., 1999) within the frame of a EUREF campaign (Balkan98) carried out over the period 4 to 9 September 1998 (5 days/24hours a day). The evaluation of data has been carried out according the available data processing strategy before the supplement of EUREF criteria from the GS week 1080 onwards. The coordinates of the stations involved in the Balkans98 campaign were estimated with an a priori weighting of 0.1 mm for the coordinates of the selected ITRF/IGS stations (datum points: GRAZ, MATE, WTZR, and ZIMM) in the ITRF96, and subsequently transformed into the ETRS89. The results of the coordinate comparison in the ETRS89 obtained for these 4 stations have been listed in Table 4.2.3.2. (solution II (Niell-dry) of the "2000 campaign" minus solution of the Balkans98 campaign). A comparison with solution I (Saastamoinen) shows similar results. The coordinate differences for the horizontal components amount to clearly below 10 mm. Here, the station Livanjsko Polje (436) is an exception. In the course of an investigation following the observation campaign in the year 2000 it was detected that the observing station pillar of that station had become unstable. It is assumed that the coordinate difference of about 3cm for the North component and of about 2cm for the East component can be attributed to the instability of the station pillar.

- **Estimation in the ITRF2000**

The official coordinates of the ITRF2000 (epoch 1997.0) present a discontinuity of about 2 cm in a northerly direction as compared with the coordinates of the ITRF97 (epoch 1997.0) (*http://www.epncb.oma.be*). To examine the effect of this discontinuity/gap the orbit data and earth rotation parameters for the GPS week 1080 were transformed by means of known transformation parameters by Kouba (*ftp://macs.geod.nrcan.gc.ca/pub/requests*) from the ITRF97 into the ITRF2000 (transformation of the orbit data yields no accuracy improvement for the satellite coordinates). The data were re-evaluated with the new orbit data as given in the ITRF2000.

Thus, the solutions III and IV were created in accordance with the strategy applied for the solutions I and II (solution III: the values of the troposphere parameters are computed following the approach of Saastamoinen; solution IV: determination of the values of the troposphere by means of the Niell`s dry mapping function and through elevation-dependent weighting of the observations).

The repeatabilities of the daily solutions as compared with the combined solution present similar results as the solutions I and II and amount to about 3 mm for the horizontal components and to about 4 to 10 mm for the vertical components (Figs. 4.2.3.6. and 4.2.3.7.

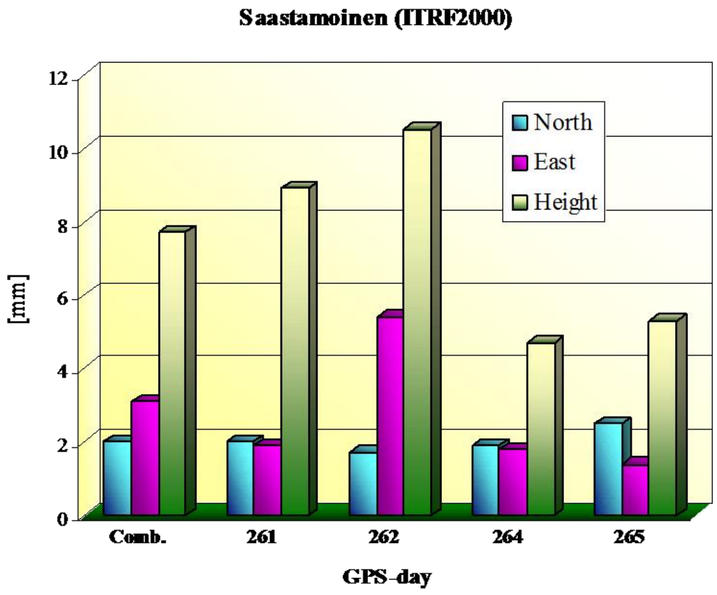

Fig. 4.2.3.5. Repeatability of the coordinates of the daily solutions in the ITRF2000 computed by means of method of Sastamonien

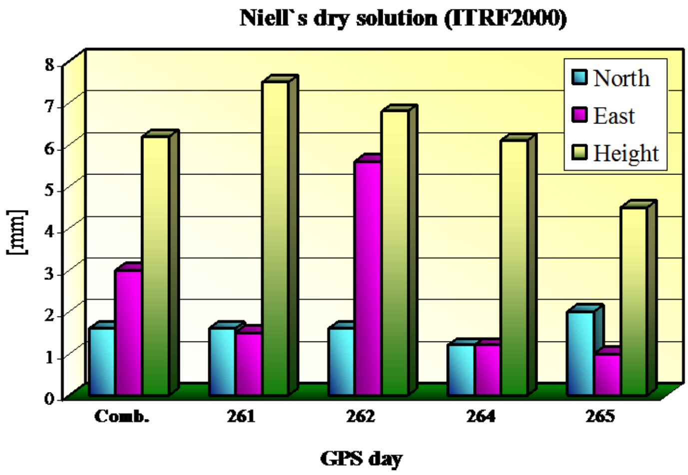

Fig. 4.2.3.6. Repeatability of the coordinates of the daily solutions in the ITRF2000 computed by means of method Neill`s dry

The discrepancy in northern direction between the solutions II and IV in the ITRF97 and ITRF2000 can be seen clearly in Fig. 4.2.3.8. Differences for heights are much smaller and are less than 5 mm for all stations. The standard deviation of estimated coordinates is in the range of about 3 to 5 mm for horizontal components and 8 to 10 mm for height, as in the solutions I and II. The estimated coordinates were transformed from the ITRF2000 into the ETRS89.

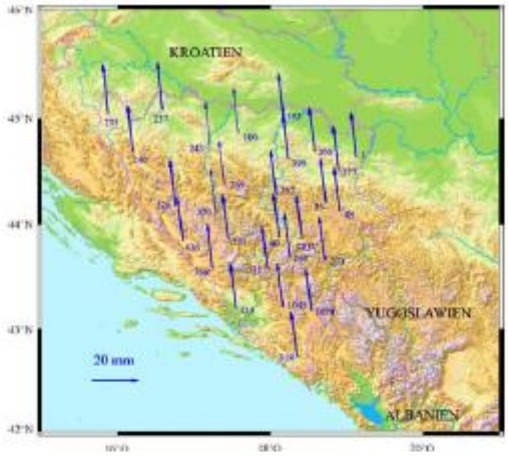

Fig. 4.2.3.8. Horizontal position differences between the solutions II and IV in the ITRF97 and ITRF2000 (solution IV minus solution II)

• Comparison in the ETRS89

Although the station coordinates present a discontinuity of 2 cm in northern direction as compared with the ITRF97, the corresponding coordinate differences in the ETRS89 are small (about 5 mm for the horizontal components and 10 mm for the vertical components).

The difference vectors (solution IV minus solution II) for the horizontal coordinates predominantly show in a westward direction (Fig. 4.2.3.9.).

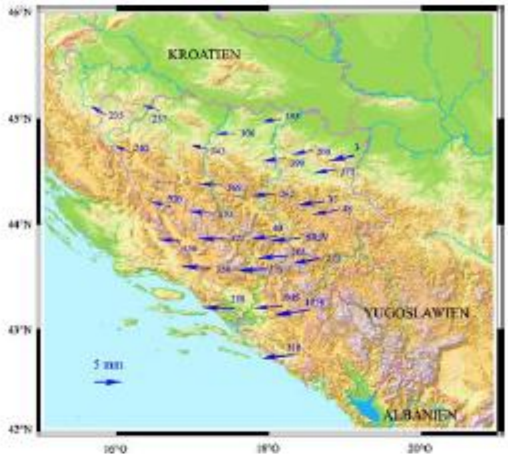

Fig. 4.2.3.9. Horizontal position differences between the solutions II and IV in the ETRS89,
(Solutions IV minus solutions II)

All height differences present a positive sign (Fig. 4.2.3.10.), which means that here a systematic becomes evident. This systematic difference, especially for height, is also supported by the results of the EUREF weekly solutions (Fig. 4.2.3.11.).

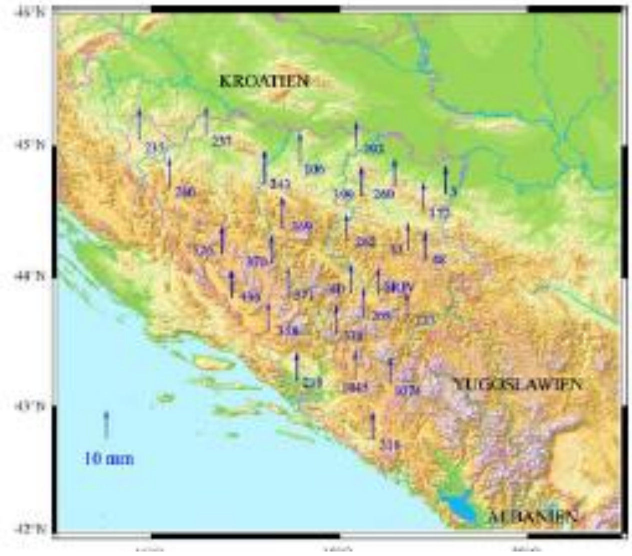

Fig. 4.2.3.10. Height differences between the solutions II and IV in the ETRS89, (solution IV minus solution II)

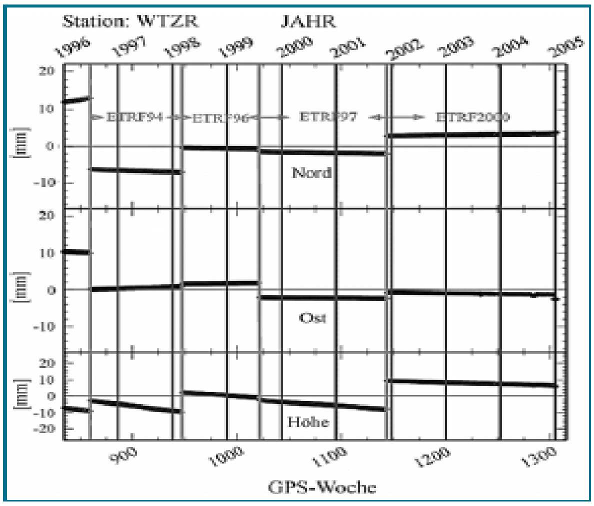

Fig. 4.2.3.11. Time series for ITRF/IGS station Wettzell (WTZR) in the ETRS89, which was defined as a geodetic datum point for EUREF weekly solution, indicates (switch time from ITRF97 into ITRF2000) for height differences of about 12 mm arise. Small differences for horizontal components are also clear to be recognised, as given in this paper, too. (*http://www.epncb.oma.be*)

4.2.3.4. Comparison with the Balkan98 GPS campaign

Comparison of the coordinates of identical stations situated in the ETRS89 (solutions I to IV) with the results of the Balkans98 campaign shows that the coordinate differences lie within the range of accuracy of the GPS method (up to 10 mm both for horizontal components and vertical components). It should be mentioned that with the GPS campaign performed in the year 1998 the stations were observed over a period of five days and for 24 hours each day, whereas the observations of the campaign performed at a later date comprised only two 24-hour observation days.

Table 4.2.3.1. Coordinate differences in the ETRS89 (transformed from ITRF97) between the identical points of the results Balkan98 and 2000 campaign (solutions I minus Balkan98).

Station	North (mm)	East (mm)	Height (mm)
0318 LEOT	9	-3	-18
0436 LIVNO	-34	-19	5
0235 KUDB	6	-5	-12
0377 STOL	-4	-1	6

Table 4.2.3.2. Coordinate differences in the ETRS89 (transformed from ITRF2000) between the identical points of the results Balkan98 and 2000 campaign (solutions III minus Balkan98).

Station	North (mm)	East (mm)	Height (mm)
0318 LEOT	8	-10	-8
0436 LIVNO	-33	-24	15
0235 KUDB	8	-7	-3
0377 STOL	-5	-3	3

4.2.3.5. Conclusions

The repeatability of the coordinates in the case of the daily solutions in the ITRF97 and the ITRF2000 for the models of Saastamoinen and Niell`s dry used for the determination of the troposphere delay provides indication that Sastamonien solution is the a little better for height components, (Figs. 4.2.3.2.-3. and 5-6).

Regarding the coordinate differences occurring in the ETRS89 no systematics in the horizontal components or in the vertical components can be detected for the solutions I and II (Figs. 4.2.3.5. and 4.2.3.6.). The height differences obtained between the two models vary from 5 to 30 mm, whereas the horizontal components differences in the case of the coordinates amount to 3 mm (station 268 excepted).

Comparison of the coordinates of identical stations situated in the ETRS89 (solutions I to IV) with the results of the Balkans98 campaign shows that the coordinate differences lie within the range of accuracy of the GPS method (up to 10 mm both for horizontal components and vertical components). It should be mentioned that with the GPS campaign performed in the year 1998 the stations were observed over a period of five days and for 24 hours each day, whereas the observations of the campaign performed at a later date comprised only two 24-hour observation days.

The use of different methods with the determination of the zenith delay (Niell`s dry mapping function or Saastamoinen: solution II minus solution I and solution IV minus solution III becomes evident in the height values (in this case up to 15 mm). Since the approach of Saastamoinen was basically developed for the satellites with an elevation of more than 10°, the method of Niell`s dry mapping function shall be given preference for elevations of below 10° (Niell, 1996).

Given that presently the ITFR2000 is considered to be the most precise time frame, and that as an up-to-date realization a better consistency can be expected with respect to the future realization ITRF2005 the solution IV based on the EUREF criteria, and the

coordinates of which were transformed from the ITRF2000 into the ETRS89, is to be recommended for the fixing the official coordinates in Bosnia and Herzegovina. Thus, an accuracy of 10 mm is secured both for the horizontal and heights components of the coordinates. This solution may also constitute a basis for a more precise determination of the phase ambiguity as well as of the surface correction values with regard to the DGPS service still to be elaborated (Ihde et al., 2005, Altiner, 2005).

4.2.3.6. References

Altiner, Y., Seeger, H., Schlüter, W., 1999. Results of the Balkan'98 GPS Campaign in Albania, Bosnia and Herzegovina, and Yugoslavia, Veröffentlichung der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, Nr. 60, 106-113, München.

Altiner, Y., 2005. Diagnoseausgleichung SAPOS. Integration von SAPOS®-Stationen in Internationale Netze, ZfV, 4/2005, 209-217.

Black, H. D., 1978. An Easily Implemented Algorithm for Tropospheric Range Correction, J. Geophys. Res., 38(B4), 1825-1828.

Black, H. D., Eisner, A., 1984. Correcting Satellite Doppler Data for Tropospheric Effects, J. Geophys. Res., 89(D2), 2616-2626.

Boucher, C., Altamimi, Z., 2001. Specifications for reference frame fixing in the analysis of a EUREF GPS campaign, (http://lareg.ensg.ign.fr/EUREF/).

DeMets, C., R. G. Gordon, D. F. Argus, and Stein, S., 1994. Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions: Geophysical Research Letters, v. 21, 2191-2194.

Marini, J. W., 1972. Correction of satellite tracking data for an arbitrary tropospheric profile, Radio Science, 7, 223-231.

Mulic, M., Bilajbegovic, A., Altiner, Y., 2006. Untersuchung der Einflussfaktoren bei der Koordinatenbestimmung nach EUREF-Kriterien, AVN, 2/2006, 49-54.

Niell, A. E., 1996. Global mapping functions for the atmosphere delay at radio wavelengths. J. Geophys. Res., 11(B2), 3227-3245.

Saastamoinen, J., 1972. Contribution to the theory of Atmospheric Refraction, Bull. Géod., 105, S. 279-298, 106, S. 383-397, 107, 13-34.