# THE EFFECT OF GNSS STATION DENSITY ON VELOCİTY ESTIMATION AND RELATIONSHIP OF ITRF2014, ETRF2014, ANGULAR AND LOCAL VELOCITY VALUES

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*Session 5: Applications: Earth Sciences, Geoinformation*

# WHAT WE DO IN THIS STUDY?

We formed two networks (Network#1, Network#2) covering IGS (International GNSS Service) stations across the European continent to examine the effect of increasing the number of stations in the analyses on velocity estimation.

Network #1 has 12 stations, whereas Network #2 has 41 stations with these stations.

CRAO (Ukraine), MADR (Spain), MATE (Italy), MEDI (Italy), METS (Finland), NOT1 (Italy), ONS1 (Sweden), SVTL (Russian Federation), TIT2 (Germany), WTZR (Germany), YEBE (Spain), ZECK (Russian Federation) IGS stations are common in Networks 1 and 2.

The velocities of these stations were compared based on network density.

# THE WORK FLOW

As input data, three years of observations at IGS stations and measurements from the GNSS campaigns of 2017, 2018, and 2019 were used.

The Bernese 5.2 GNSS Software was used to calculate the coordinates of the geodetic points in the ITRF2014 reference frame. ETRF2014 velocity values were calculated using ITRF2014 velocity values obtained from Bernese 5.2 GNSS Software analyses.

ETRF velocities are the velocities obtained from analyses performed at stations across Europe, minus crustal movements.

The velocities, known as angular velocity and local velocity (velocities by to the earth's surface), were then calculated.

These velocities were determined by calculating for comparing Bernese 5.2. GNSS Software velocities with coding velocities.

# ITRF2014 VELOCITY VALUES CALCULATION

| Parameters for Analysis | Analysis Methods |
|---|---|
| Input data (Observation, ionosphere files) | Daily Log files (ionosphere data at 1-hour intervals) |
| Network Structure | Maximum according to common observation (Obs-Max)* |
| Orbit | IGS precision orbit (orbit data at 15-minute intervals) |
| Ocean Correction | FES2004 Ocean Correction Model (BLQ file) |
| Ionosphere | Higher-Order Correction |
| Signal Uncertainties | Code-based wide-band (WL) uncertainty resolution (<6000 km)<br>Code-based narrow-lane (NL) uncertainty resolution (<6000 km)<br>(MW/L3 Melbourne/Wübenna Linear Combination used. <2000km)<br>Phase-based wide-band (L5) uncertainty resolution (<2000 km)<br>Phase-based narrow-lane (L3) uncertainty resolution (<200 km)<br>Quasi-ionosphere independent (QIF) strategy (<2000 km) |
| Prior Model | Saastamonian Model (highly sensitive hydrostatic model) |
| Projection function | GMF |

▪ The free RINEX data of IGS stations were evaluated in Bernese GNSS Software 5.2 for the date range 1/January/2017 – 31/December/2019. To evaluate the data, IGS station observations, orbital files, ionospheric correction values, an ocean correction file, URL 1 and URL 2 were uploaded using Bernese GNSS Software. Table 1 shows the parameters that were used in the evaluation.

▪ Table 1 shows the parameters and models used in Bernese software to balance the created network solutions.

The combination of IGS and EPN (European Permanent Network) coordinates was chosen as the preliminary coordinate in daily network solution.

Using piecewise linear functions, the troposphere data were estimated at one-hour intervals.

Before estimating parameters, the Global Mapping Function, GMF tropospheric projection function was chosen.

The analysis also took into account the ocean loading effect, satellite orbit information, and ionospheric correction values.

For ocean loading, FES2004 is preferred, and BLQ is selected as the output file. Other Bernese files with ATL, CRD, VEL, PLD, BLQ, and STA extensions have been arranged and uploaded to the appropriate folders.

- ITRF2014 velocity values were calculated using the normal equation systems obtained for the analyzed days and the ADDNEQ2 program in Bernese GNSS Software.

- The time series derived from these results were compared to the time series derived from EUREF results (URL 4).

- Some jumps were also observed in the EUREF Permanent Network (EPN) analyses (European Reference Network).

- EPN data is used for a wide range of scientific applications, including monitoring ground deformations, sea level, space weather, and numerical weather forecasting, in addition to its critical role in maintaining ETRS89.

- To estimate velocity at fixed GNSS stations, data must be analyzed for at least three years.

- The velocity estimates estimated from coordinate estimations collected at IGS stations in each network for the period of January 2017 to December 2019 were compared to the ITRF2014 and ETRF2014 velocities as part of the study.

# IN NETWORKS CREATED: COORDINATE ESTIMATION WITH DAILY DATA ANALYSIS FROM JANUARY 2017 TO DECEMBER 2019.

# ETRF2014 VELOCITY VALUES CALCULATION

Following EUREF Decision 1, the European Terrestrial Reference System 89 (ETRS1989) was adopted in 1990 in Firenze, Italy.

ETRF velocities are the velocities acquired from analyses conducted at locations around Europe, minus crustal motions.

By using the similarity transformation provided in EUREF Technical Note 1, ETRS89 links to ITRS (URL 5).

The formulas were used to convert ITRF2014 velocity values acquired from Bernese GNSS Software analyses to ETRS2014 velocity values.

$$\dot{X}_E = \dot{X}_I + R * X_I \qquad \dot{X}_E = ETRS2014 \; velocities \;,$$

$$\dot{X}_I = ITRF2014 \; velocities \;, \; X_I = ITRF \; coordinates \;,$$

$R = Matrix \; with \; rotation \; angles \; (mas)$ (EUREF Technical Note 1 (Link 5) provides the value.)

# LOCAL VELOCITY VALUES CALCULATION

By developing code in the MATLAB R2019a software, geodetic orthogonal coordinates of X, Y, and Z were converted to geodetic curve coordinates.

Then, within the scope of the analysis, the velocities of the network stations were estimated as

$$\dot{X}_{(n,e,u)} = R * \dot{X}_{(x,y,z)}$$

$$R = \begin{vmatrix} -\sin\tau & \cos\tau & 0 \\ -\sin\varphi * \cos\tau & -\sin\varphi * \sin\tau & \cos\varphi \\ \cos\varphi * \cos\tau & \cos\varphi * \sin\tau & \sin\varphi \end{vmatrix}$$

Here $\dot{X}$ represents the velocities, and R is a transformation matrix containing the rotation angles calculated separately for each station.

The network stations' local velocities are reported in Graphics.

# ANGULAR VELOCITY VALUES CALCULATION

The study's scope included velocity calculations with coordinate estimations generated during a three-year period using the equation.

$$V_{(Model)} = \Omega * C$$

$C = \begin{bmatrix} X & Y & Z \end{bmatrix}$, C is a coordinate matrix.  $\Omega = \begin{bmatrix} 0 & -\omega_3 & \omega_2 \\ \omega_3 & 0 & -\omega_1 \\ -\omega_2 & \omega_1 & 0 \end{bmatrix}$, $\Omega$ is a matrix of transformations.

The velocity values used in the following formulas are ITRF2014 velocities derived via Bernese GNSS software analysis, and the formulas explain how the values are calculated.

$$V = \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = A * \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & Z & -Y \\ -Z & 0 & X \\ Y & -X & 0 \end{bmatrix} \quad , \quad \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} = (A^T A)^{-1} (A^T V)$$
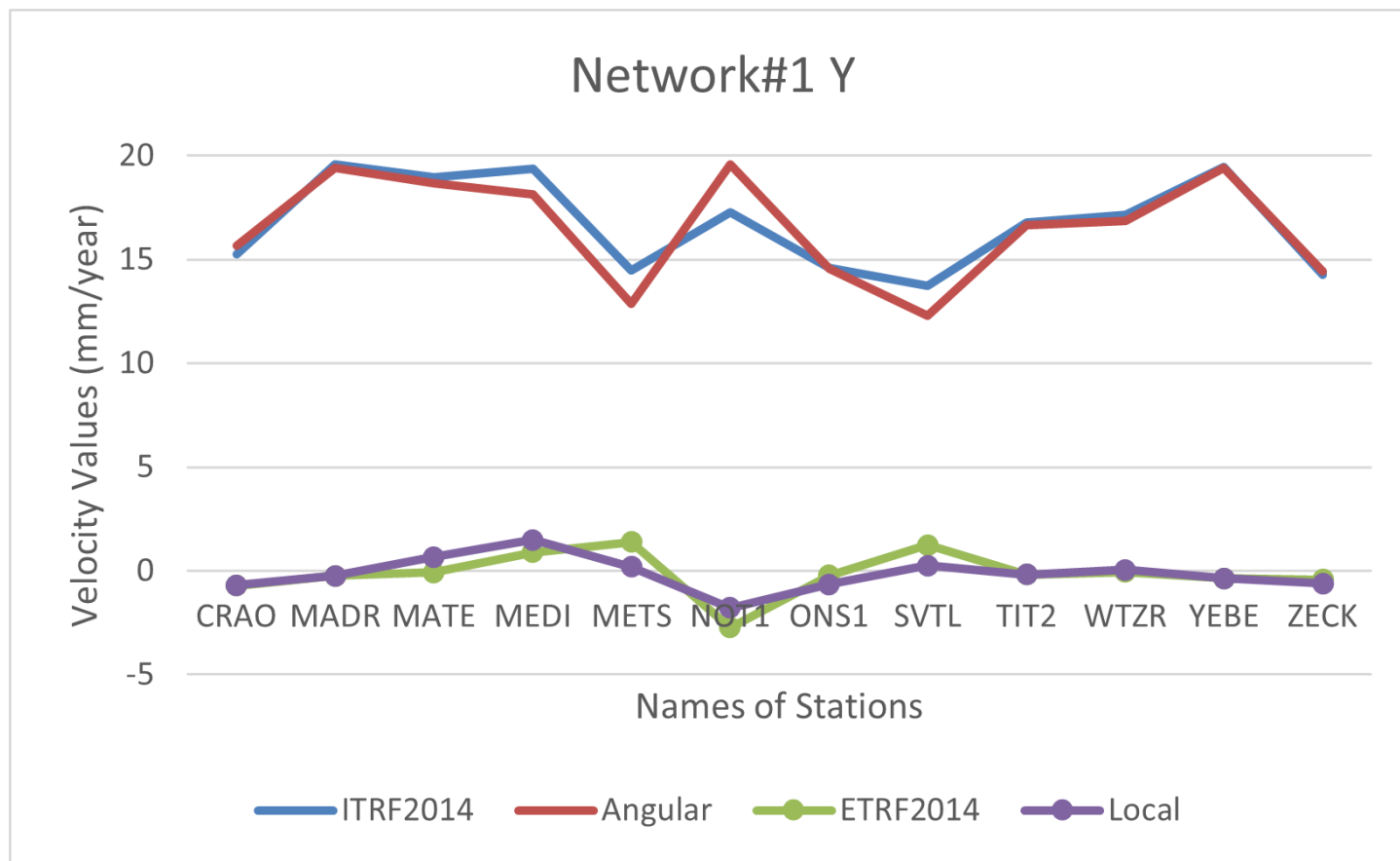
In addition, coordinate values from the ITRF2014 were employed in this calculation (Ammon 2001, Herring 2010).These velocities, which we determined using the preceding procedures, are referred to as model velocities.
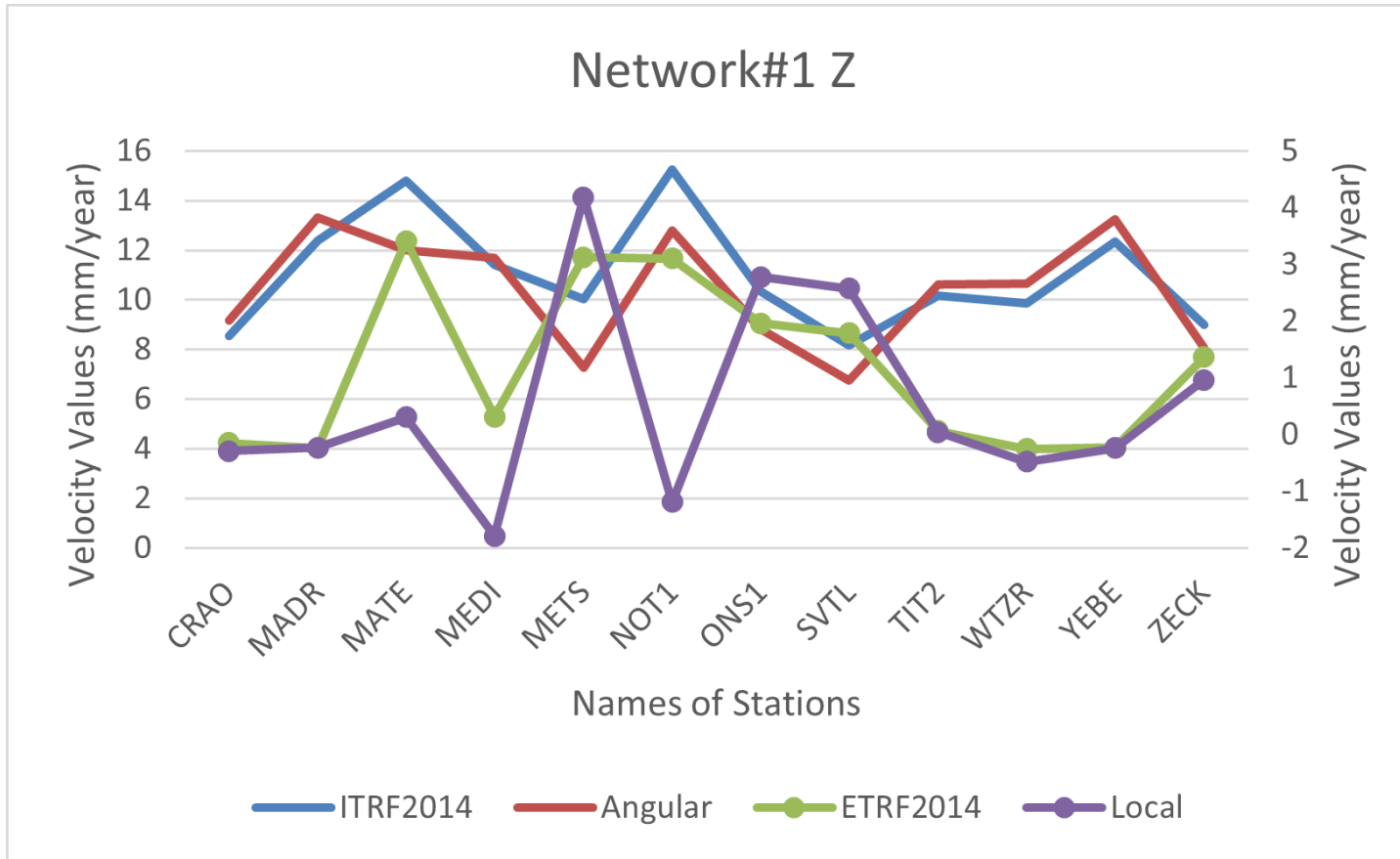
ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The X Direction Of IGS Stations In The Network#1 Are Graphically Displayed.
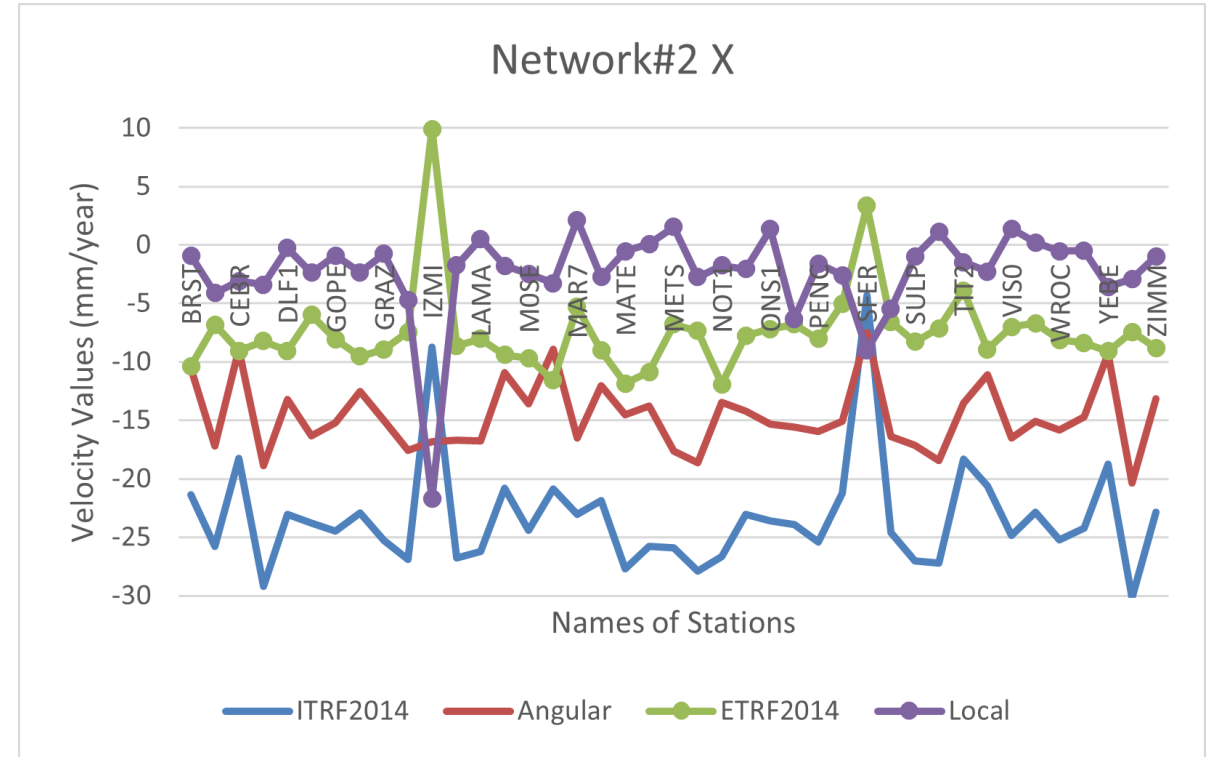
ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The Y Direction Of IGS Stations In The Network#1 Are Graphically Displayed.
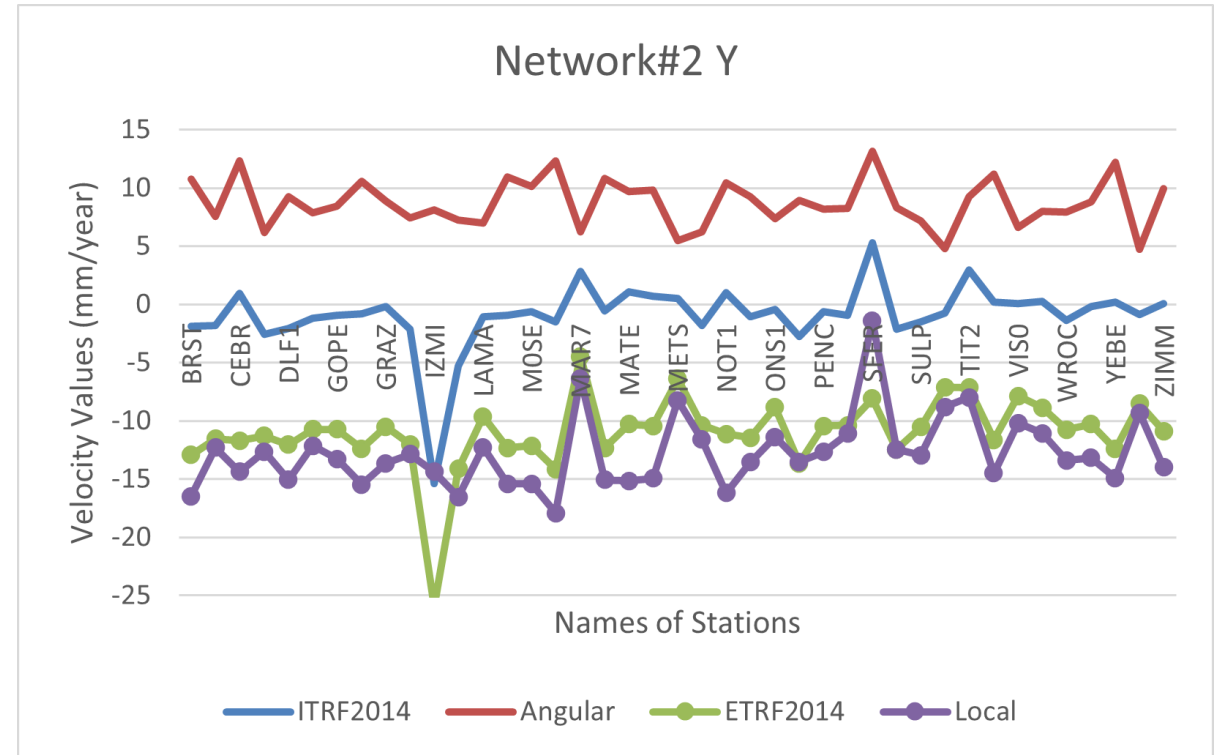
Network#1 Z

ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The Z Direction Of IGS Stations In The Network#1 Are Graphically Displayed.
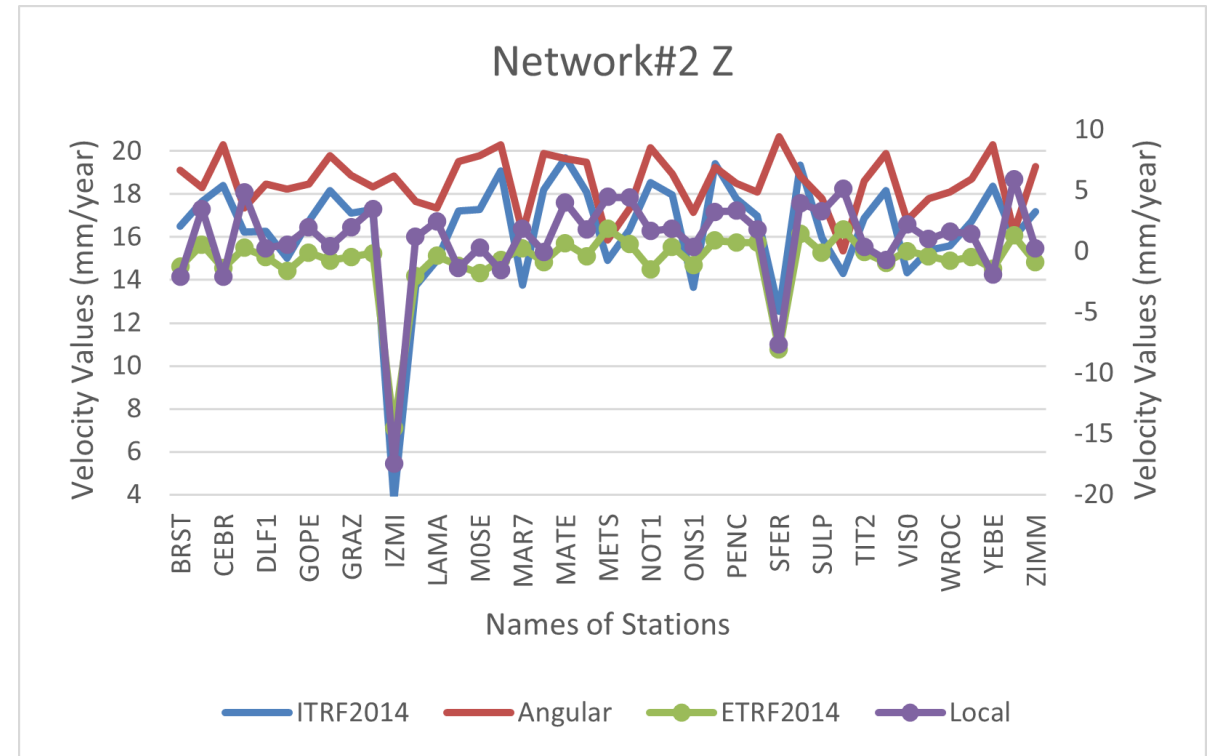
ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The X Direction Of IGS Stations In The Network#2 Are Graphically Displayed.

ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The Y Direction Of IGS Stations In The Network#2 Are Graphically Displayed.

ITRF2014 Velocities, ETRF2014 Velocities, Local Velocities, And Calculated Angular Velocities In The Z Direction Of IGS Stations In The Network#2 Are Graphically Displayed.

Calculated angular velocities are expected to match ITRF2014 velocities, while calculated local velocities will match ETRF2014 velocities.

Despite the fact that this harmony has been achieved in other stations (mm), it was not observed at the IZMI IGS station in Network#2.

We can interpret this situation as ITRF2014 rates being higher as a result of the analysis performed in the Bernese software due to the IZMI IGS station's discrete and incomplete data.

Charles J. Ammon, Computing Local Plate Velocities, Using MATLAB Notes, Department of Geosciences, Penn State University, August 2001

Dach R., Lutz S., Walser P., Fridez P., 2015, Bernese GNSS Software Version 5.2. http://www.bernese.unibe.ch/

Tom Herring, Treatise on Geophysics, Volume 3: Geodesy, Elsevier, 2010, ISBN 0444535799, 9780444535795

URL 1: ftp://cddis.nasa.gov/ , (Ekim 2019)

URL 2: http://ftp.aiub.unibe.ch/ , (Ekim 2019)

URL 3: http://www.epncb.eu/_productsservices/coordinates/

URL 4: http://www.epncb.eu/_productsservices/timeseries/index.php?station=BRST00FRA

URL 5: http://etrs89.ensg.ign.fr/pub/EUREF-TN-1.pdf , EUREF Technical Note 1: Relationship and Transformation between the International and the European Terrestrial Reference Systems Zuheir Altamimi Institut National de l'Information Géographique et Forestière (IGN), France

URL 6: http://www.epncb.eu/_productsservices/coord_trans/