EPN Multi-year Position/Velocity Solution

Reference Frame Coordination Status Report

J. Legrand, C. Bruyninx
Royal Observatory of Belgium

Contact: Juliette.Legrand@oma.be
• Methodology: How the solution is done
• Released Products: what is available and where
• EPN vs IGS
• Station classification
Methodology
Input Solutions

EPN-repro2 DAILY SINEXs processed with epn_08.atx converted to epn_14.atx
Operational DAILY SINEXs processed with epn_08.atx converted to epn_14.atx
Operational DAILY SINEXs processed with epn_14.atx

Positions before GPS Week 1934 have been corrected in order to be consistent with epn_14.atx calibration model

Set of daily positions consistent with the epn_14.atx calibration model
Methodology

EPN daily SINEXs (1996-now)

\[ X(t_i) = X_0 + V_0(t_i - t_0) + \sum \Delta X_j(t_i) \]

Discontinuities velocity constraints

CATREF
[Altamimi et al.]

EPN multi-year positions and velocities at \( t_0 = 2010.0 \)

Outliers removed

Daily positions

Mean Position & velocity

Residuals

Positions at \( t_i \)

Positions at \( t_{i+1} \)

Positions at \( t_n \)
Methodology

**EPN daily SINEXs (1996-now)**

**discontinuities velocity constraints**

**EPN multi-year positions and velocities at \(t_0 = 2010.0\)**

\[
x(t_i) = X_0 + V_0(t_i - t_0) + \sum_j \Delta X_j(t_i)
\]

Outliers removed

Positions at \(t_i\)

Positions at \(t_{i+1}\)

Positions at \(t_n\)

CATREF [Altamimi et al.]

Daily positions

Mean Position & velocity

Residuals
Position Time Series in ETRF2014

Year

North [mm]

-10

0

10

East [mm]

10

0

-10

Up [mm]

20

0

-20

-40

GPS Week

834 938 1147 1251 1460 1564 1773 1982

(X₁, V₁) (X₂, V₂) (X₃, V₃) (X₄, V₄)
Constraints on Velocities

$V_2 = V_3 = V_4$

Position Time Series in ETRF2014

Post-seismic deformation of 5 ITRF2014 stations corrected using ITRF2014 model

ANKR00TUR, BUCU00ROU, ISTA00TUR, REYK00ISL, TUBI00TUR
Methodology

EPN daily SINEXs (1996-now)

\[ \theta_i, \theta_{i+1}, \theta_n \]

Transformation parameters (Translations, Rotations, Scale) between the daily SINEXs and the combined solution

discontinuities velocity constraints

EPN multi-year positions and velocities at \( t_0 = 2010.0 \)

\[ \theta_i, \theta_{i+1}, \theta_n \]

EPN multi-year solution is

aligned to the reference solution IGS14

with minimal constraints approach applied on

Translations, Rotations, Scale and their rates

using a selection of IGS14 stations

(where both solutions show a good agreement)

In practice, 44 IGS14 stations that agree better than:

- 3 mm for the horizontal and 6 mm for the vertical positions
- 0.25 mm/yr for the horizontal and 0.5 mm/yr for the vertical velocities
Available Products
The most accurate and up-to-date EPN station positions and velocities are derived from a multi-year combination of the EPN daily combined SINEX files. The multi-year solution is used for the realization of the regional densification of the TERS89. The multi-year combination comprises EPN daily SINEX files from GPweek 324 up to GPweek 1722 and routine daily EPN combined SINEX files from GPweek 1722 up to the most recent solutions. The multi-year solution is updated every 15 weeks in order to provide up-to-date coordinates and velocities.

Only Class A stations are suitable as reference stations for the densification of the TERS89. The associated files can be downloaded from the EPN Central Bureau; the most recent realization is available through the links:

- EPN_A.IGS14.SSC, table with station positions (at epoch 2010.0) and velocities
- EPN_A.IGS14.SN2X, solution in SINEX format

In the TERS89 (ETRF2000) realization:
- EPN_A.ETRF2000.SSC, table with station positions (at epoch 2010.0) and velocities
- EPN_A.ETRF2000.SN2X, solution in SINEX format

In the TERS89 (ETRF2014) realization:
- EPN_A.ETRF2014.SSC, table with station positions (at epoch 2010.0) and velocities
- EPN_A.ETRF2014.SN2X, solution in SINEX format

For Class B stations, EUREF provides only position estimates (EPN_B.IGS14.SSC, EPN_B.ETRF2000.SSC, EPN_B.ETRF2014.SSC) at the epoch of minimal variance. The velocity estimates of the Class B stations are not released because of their imprecision (caused by e.g. the short
duration of the observation arcs).

Description and additional information about the EPN multi-year solution:
- An updated version of the description is currently under preparation. A preliminary version of the current solution has been presented at the EUREF WC Workshop held in Brussels, the October 12-14, 2017 (Presentation). Description for the previous solution is available here:
- Map of the multi-year EPN positions and velocities.
- EPN station discontinuities: be careful for some stations (due to different periods of observations) the harmonization with the IGS/ETRF discontinuity table was not possible.
- List of rejected outliers: Format has changed in order to take into account daily files.
- Residual position time series.
- Miscellaneous plots:
  - Helmert transformation parameters between the multi-year and the weekly Input SINEX solutions.
  - Weighted weekly rms of the Input SINEX solutions.
  - Length of the observation series used in the combination.

Updated and published online each 15 weeks
- Last update C1980 (March 2018)

- Official Multi-year Positions & Velocities (SINEX & SSC files)
  - in IGS14, ETRF2000 and ETRF2014
  - Station Classification (Class A&B)
- List of position & velocity discontinuities
- List of daily outliers
- Cleaned time series
- Several Plots
EPN Network

Period of observation in years
(381 stations in the combined solution)

Histogram of the number of years of observation in the EPN
Daily Weighted RMS: comparison wrt C1934

**Last IGb08 solution: C1934**
EPN-repro1 / Weekly solutions

**Last IGS14 solution: C1980**
EPN-repro2 / Daily solutions
EPN velocity field in ETRF2014

ETRF2014 horizontal velocity field derived from the latest EPN cumulative solution. In the ETRF2014, the horizontal velocities are expressed with respect to the Eurasian plate. The Eurasian plate rotation model from ITRF2014 (Altamimi et al., 2017) has been used. The green dots on the map indicate the youngest sites (less than 3 years of observations), which have unrealistic velocities.

ETRF2014 vertical velocity solution derived from the latest EPN cumulative solution. The uplift is indicated red, subsidence with blue arrows. The green dots on the map indicate the youngest sites (less than 3 years of observations), which have unrealistic velocities.
Position Time Series

MULTI-YEAR EPN SOLUTION

EPN station position time series:
WSRT00NL (Westerbork, Netherlands) [Class A]

OFFICIAL SOLUTIONS INCLUDED UP TO 16-12-2017 (GPS WK 1979) (READ MORE)

WSRT00NLD 13506M005
Position Time Series in IGS14
(Official EPN Solution C1980)

a link to download Residual Position Time Series data for solution C1979 are available here
Official Position Time Series in ETRF2014

Useful to check:
⇒ the size of the position discontinuities
⇒ if the station has a residual movement wrt to ETRF2014
Position Time Series

MULTI-YEAR EPN SOLUTION

Other residual position time series: ITRF2014, IGS14, Nevada Geodetic Laboratory

Residual Position Time Series

Official Station Velocities published by EUREF:

<table>
<thead>
<tr>
<th>Frame</th>
<th>$V_{\text{North}}$ (mm/yr)</th>
<th>$V_{\text{East}}$ (mm/yr)</th>
<th>$V_{\text{Up}}$ (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGS14</td>
<td>16.5 ± 0.00</td>
<td>17.7 ± 0.00</td>
<td>-0.5 ± 0.01</td>
</tr>
<tr>
<td>ETRF2014</td>
<td>0.5 ± 0.00</td>
<td>0.3 ± 0.00</td>
<td>-0.6 ± 0.01</td>
</tr>
</tbody>
</table>

Download Residual Position Time Series data
Extended Time Series

- Cleaned operational daily combined solutions
- Raw operational daily combined solutions
- Updated on a daily basis

No cleaning, no discontinuities introduced
Extended Time Series

Useful to check:
- if the station behave correctly since the last update
- if the station is affected by a position change
- if the last EPN solution is still representative of today station position

Discontinuity introduced for C1995
EPN vs IGS
IGS Multi-year Solutions

IGS14 solution
- 60 EPN stations
- Period 002/1994 - 056/2015

Each week, IGS also publishes an IGS multi-year solution IGSYYPWW (e.g. IGS18P14.snx for GPS week 1995)
- 194 EPN stations
- Period 002/1994 – 097/2018
- Discontinuity list
EPN Stations in the IGS solution

194 EPN stations in IGS18P14

55 EPN stations not usable in the IGS solution
Royalties by Belgium

Position differences at mean epoch of EPN position estimates

\[ |X_n| < 0.6 \text{ mm for } 90\% \text{ of the 448 position estimates} \]

\[ |X_e| < 1.0 \text{ mm for } 90\% \text{ of the 448 position estimates} \]

\[ |X_u| < 3.1 \text{ mm for } 90\% \text{ of the 448 position estimates} \]

Velocity differences for the station with more than 3.5 years of data

\[ |V_n| < 0.3 \text{ mm/yr for } 90\% \text{ of the 188 velocity estimates} \]

\[ |V_e| < 0.3 \text{ mm/yr for } 90\% \text{ of the 188 velocity estimates} \]

\[ |V_u| < 0.9 \text{ mm/yr for } 90\% \text{ of the 188 velocity estimates} \]
Conclusion: EPN vs IGS

• Agreement with IGS14 and IGS18P14 is good
  • 55 stations are not usable in IGS18P14
  • In general, the time series are more complete in EPN than in IGS solution

• The possibility of using weekly updates of the IGS14 solution is under investigation in order to increase the number of reference stations

• The discontinuity list has been harmonised with IGS (beginning of 2018) but there are disagreements for 15 of the 139 useable stations
Station Classification
Class A and B

EPN stations are categorized taking into account the station quality and the length of the available observation time span:

- **Class A**: station positions have a 1 cm accuracy at all epochs of the time span of the used observations
- **Class B**: station positions have a 1 cm accuracy at the epoch of minimal variance. Stations are in Class B because of a short time frame of SINEX availability or a higher noise level (including the seasonal variability) of the position time series.

- EPN solution in IGS14
  - New estimates in a different frame
    - comparison with previous solution was not relevant
  - Need for positions and velocities for former EPN stations
Velocities: realistic error estimates

- Good position estimates require reliable velocities

- Velocities error estimates coming from CATREF are too optimistic

⇒ derive more realistic error estimates on velocities

- Position + Velocities + Residuals from CATREF are used to reconstruct well referenced Position Time Series

- Hector developed by [Bos et. al. 2013] used to estimate:
  - linear trend
  - annual, semi-annual signals
  - assuming temporal correlated noise (power-law + white noise)
Comparison CATREF vs HECTOR

- To determine stations classes
  - Use more realistic error estimates from Hector to assess the quality of the station
  - Use a 2\textsuperscript{nd} estimate of the velocity from Hector to compare with CATREF estimate in order to assess the reliability of the velocity estimation

- Remaining Issues:
  - stations with long history and instabilities are not detected
  - Qualitative criteria still needed

Histograms of the velocity differences between CATREF and Hector

Histograms of the velocity errors from Hector
Future: Revision of station classes

• Class A & B are not flexible enough
  • Class A are not necessarily perfect
  • Class B are not always bad all the time

• Future
  • Define a core network with the best performances
  • Several classes with different criteria for the remaining stations
    • Criteria for best selection of station are depending on the usage:
      • long term position and velocity solution
      • 5-year position and velocity solution
      • position solution
Future: Revision of station classes

• Online tool to discover suitable EPN reference stations:
  • Stable between T1 and T2 date
  • No position offsets larger than X between T1 and T2 date
  • Suitable to align solution with N years of observations
  • No position differences > X in the extended time series since the last solution
  • ...

Need your feedback in order to better answer your needs!

Are you using the EPN multi year product?
How? Do you have complaints about it?
What else do you need?

...
SFER00ESP 13402M004
Residual Position Time Series
(Extended EPN Solution C1980U)
Please have a look at your time series from time to time!

Let me know (juliette.legrand@oma.be or epncb@oma.be)
if you know the reason of the problem
It will help me to handle it correctly.

All information about the stations are welcome!
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