

Enhancement of the EUREF reference frame solution thanks to the EPN-Repro3

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Outline

- Methodology and results: Reference Frame Product based on EPN-repro 3
- Quality assessment:
 - Comparison with global reference frame realizations
 - Station Classification and Tool
- Where to find the EPN-repro3 based reference frame product?

Methodology and Results

Reference Frame Product based on EPN-repro 3

EUREF Reference Frame Solution based on EPN-repro 3

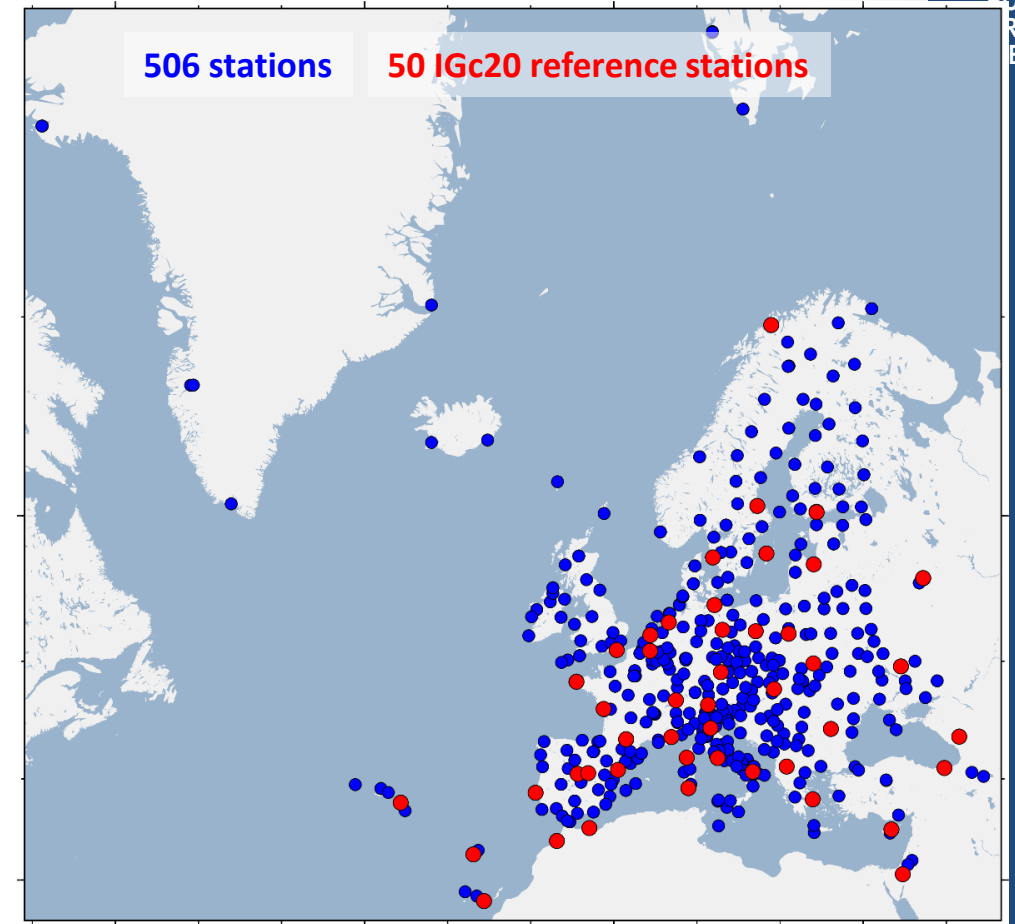
Input solutions: EPN-repro3 and operational EPN daily solutions between 1996-01-01 and 2025-09-28

From	To	Type	Antenna Calibration	Aligned to
0834 – 1 1996-01-01	2237 – 6 2022-11-26	EPN-repro3	epn_20.atx (igs20.atx)	IGS20
2238 – 0 2022-11-27	2385 – 6 2025-09-28	operational	epn_20.atx (igs20.atx)	IGS20/IGb20/IGc20

Völksen, C. et al. (2026). EPN-Repro3: Improved Maintenance of Regional Reference Frames Through Standardized and Complete Reprocessing of all Available GNSS Data (1996-Present). In: International Association of Geodesy Symposia. Springer, Berlin, Heidelberg.
https://doi.org/10.1007/1345_2026_371

What is new in EPN-repro3 compared to EPN-repro2 based solution?

- Additional historical data
- Same strategy between EPN-repro3 and operational
⇒ homogeneous time series
- Usage of type mean antenna calibrations instead of individual + type mean antenna calibrations
⇒ better consistency with IGS solution

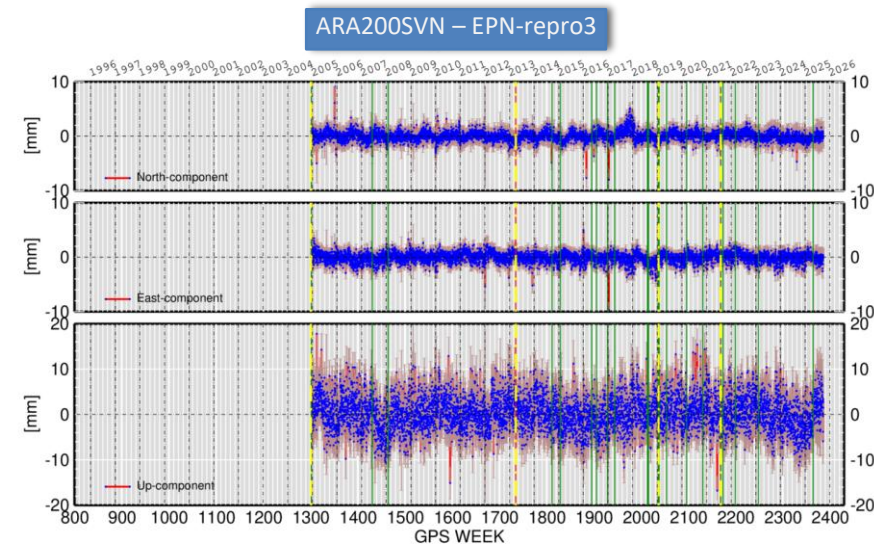
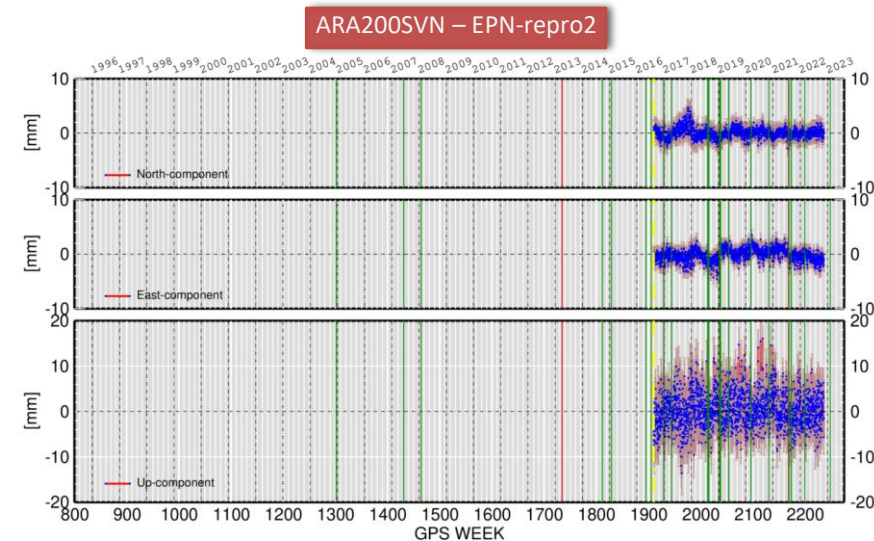
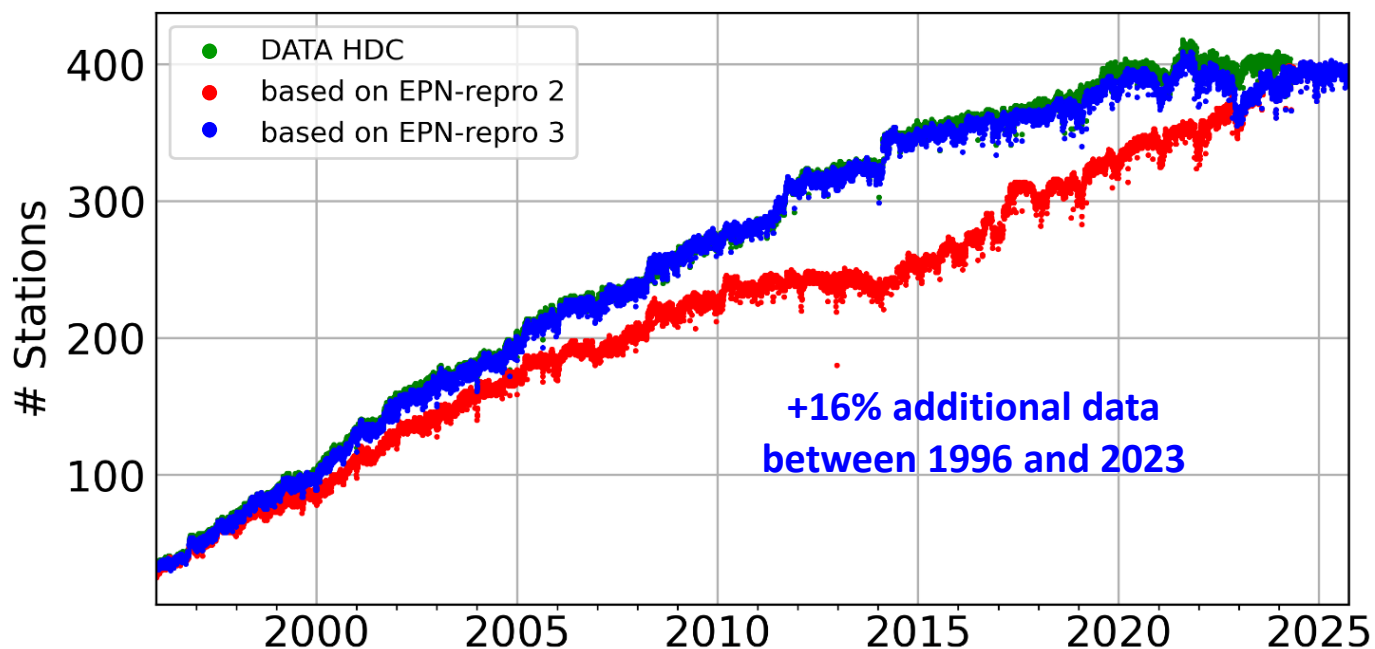


CATREF Software [Altamimi et al. 2007]
Position and velocity discontinuities
compared with quality checks to explain unknown discontinuities
harmonized with IGS discontinuity list when possible
Aligned in origin, scale and orientation wrt IGc20 using 50 reference stations

Improvement of station history

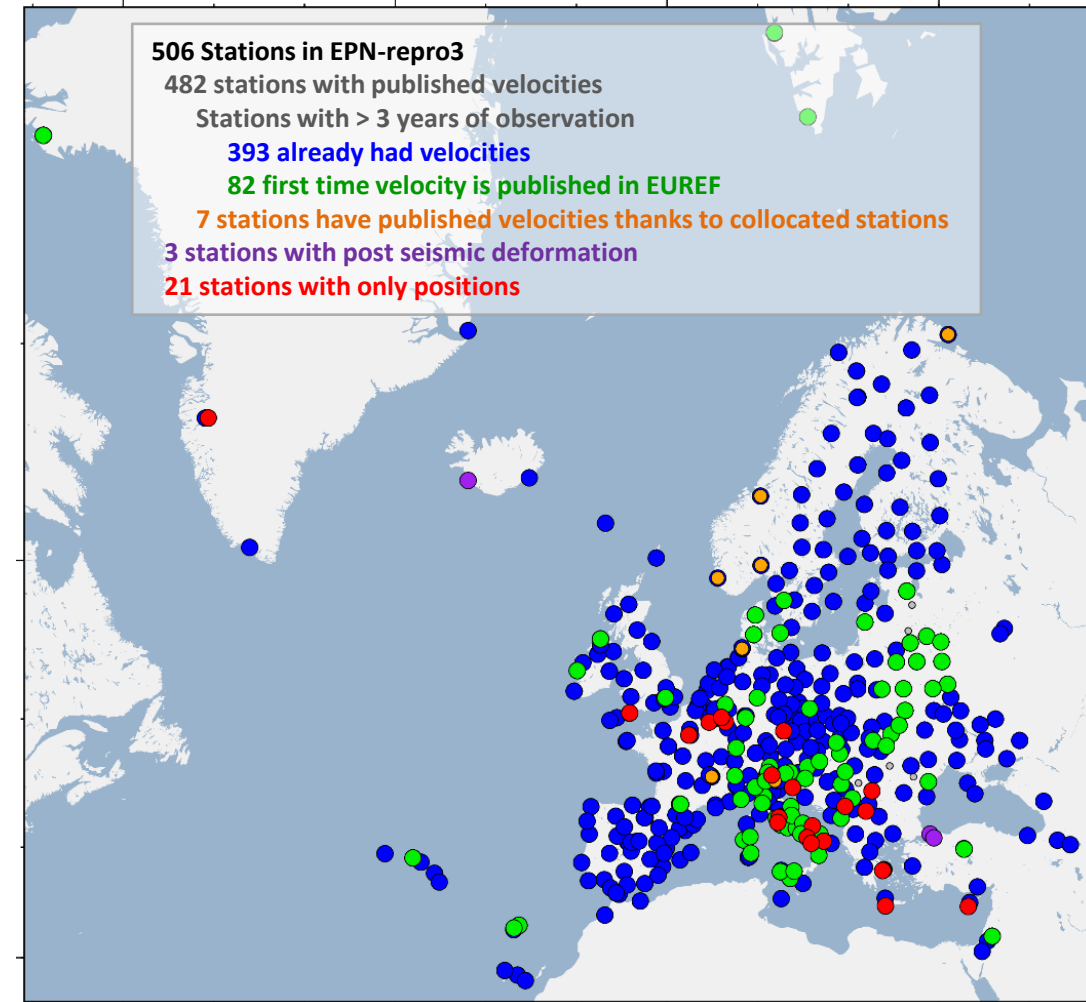
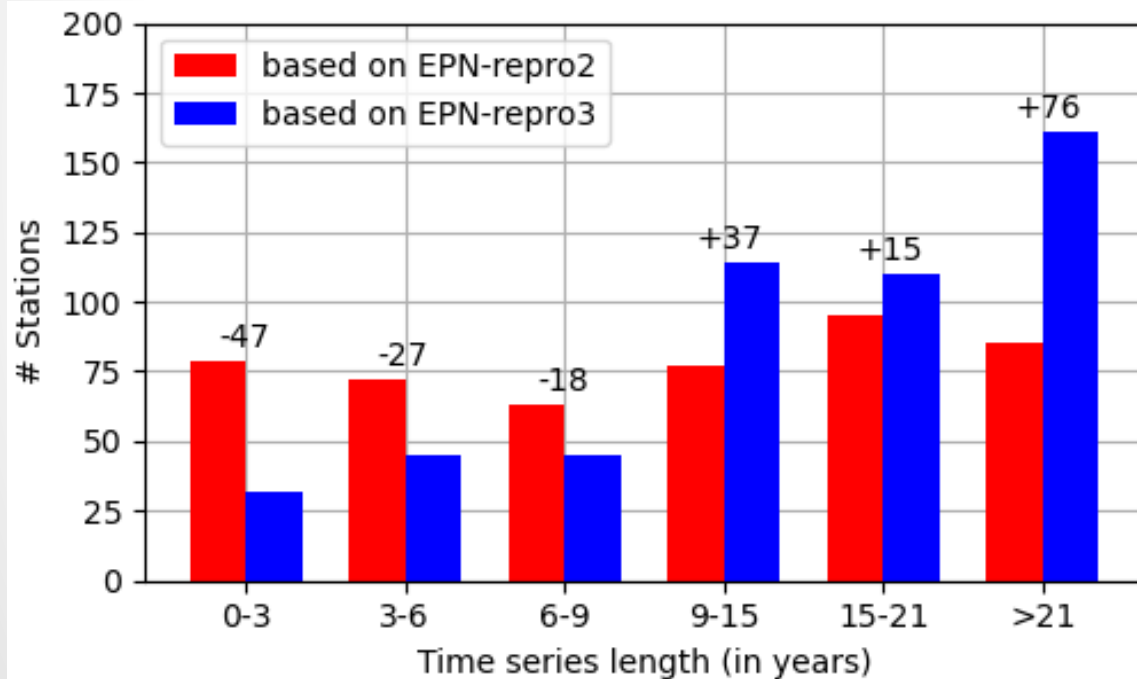
ACs used the data from the Historical Data Center (HDC)
managed by EPN CB

EPN CB looked for and collected all the historical data of
EPN stations from before their inclusion in the EPN



Improvement of station history

Time series length in years

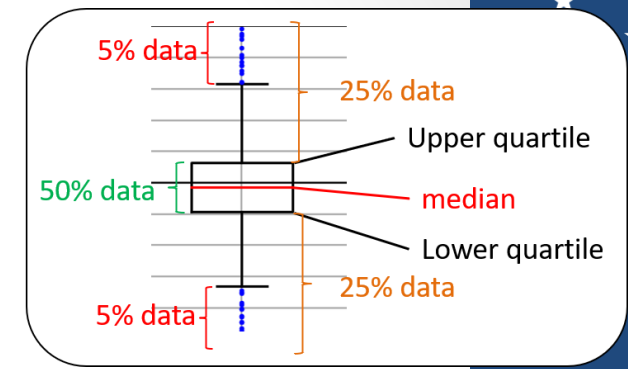
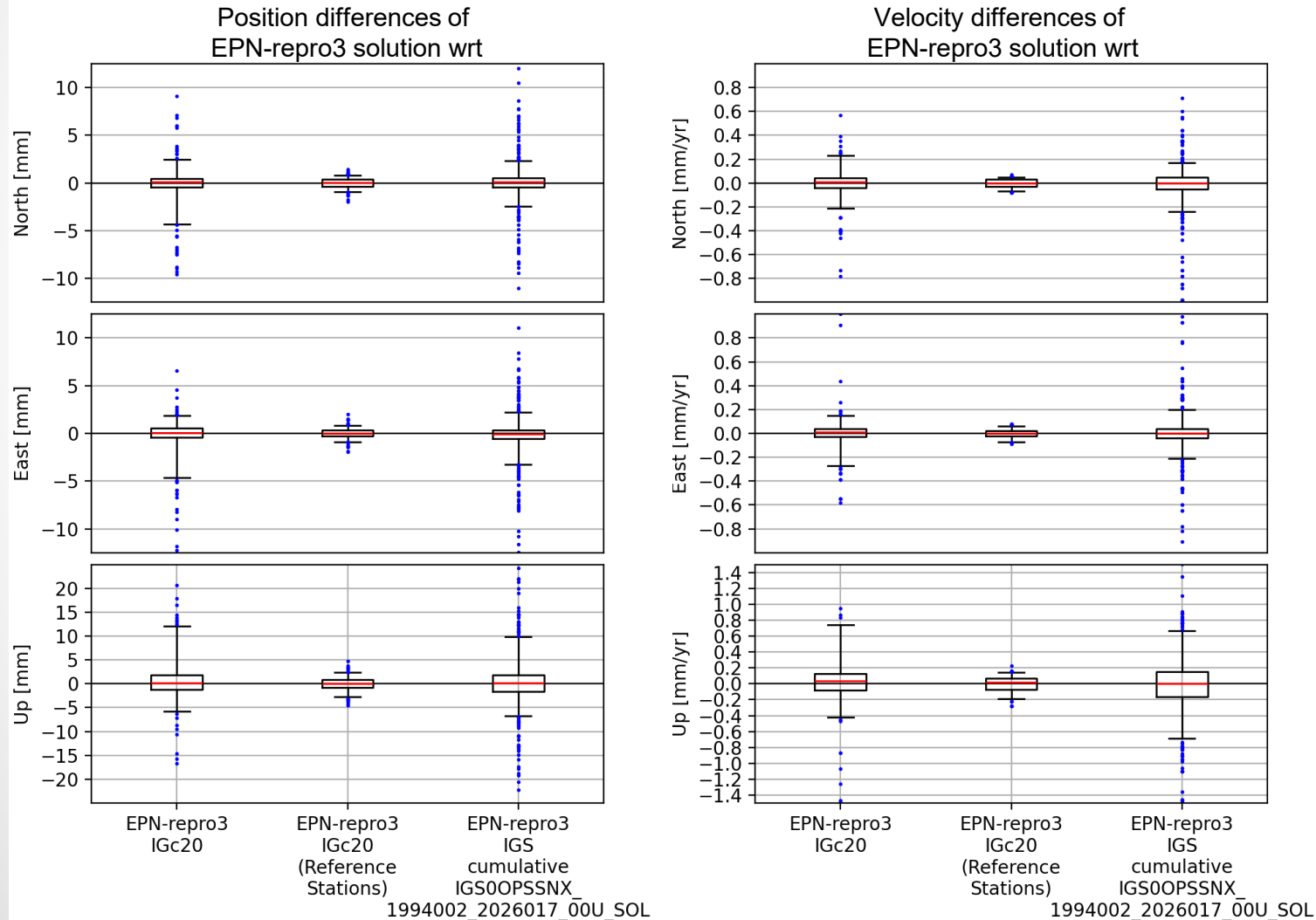


- More reliable velocity estimates
- 393 + 82 stations with velocity published (> 3yr)

Quality Assessment

Part 1: Comparison with Global Reference Frames

Agreement of EPN-repro3 and the global solutions



- No bias or systematic effect between the EPN-repro3 solution and the IGc20 or the IGS cumulative solution
- 85% of estimates have differences below
 - 5mm on horizontal and 1cm on vertical positions
 - 0.5mm/yr on horizontal and 1mm/yr on the vertical velocities

Quality Assessment

Part 2: Station Classification

Station classification and Web tool

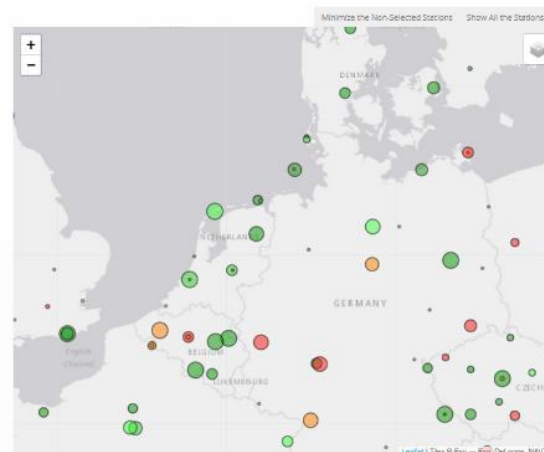
Web Tool and classification to help the selection of reference stations to align ETRS89 densifications campaigns to the EUREF Reference Frame solution

Comment on the selection of reference stations

- Include reference stations in the processing:
 - well distributed in and around the densification campaign
 - as many as possible
- Evaluate the position (and velocity) agreement between the densification solution and reference solution
- Reject stations with position/velocity disagreement

Goal of the tool and classification

- Identify the **most** reliable stations in the area of interest
 - provide necessary information of stations with weaknesses
- Be careful when you use them:
- check that they show a good agreement
 - make sure that you have backup stations in the same area



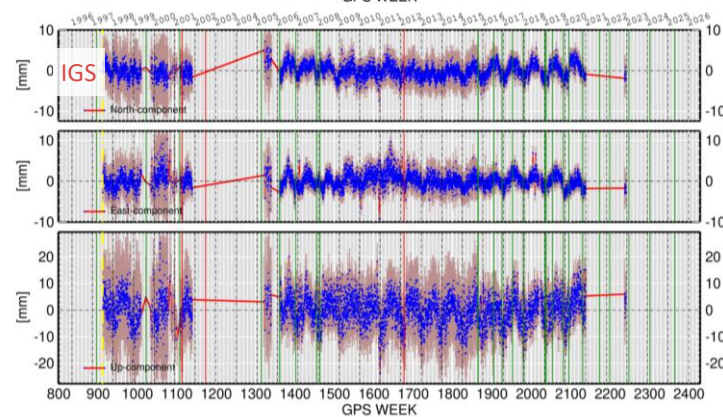
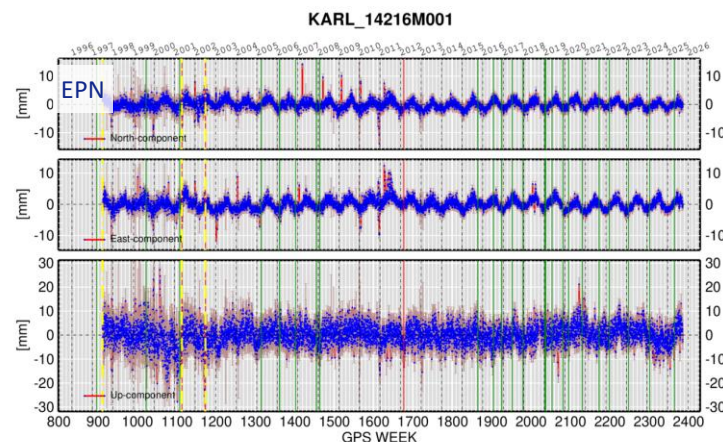
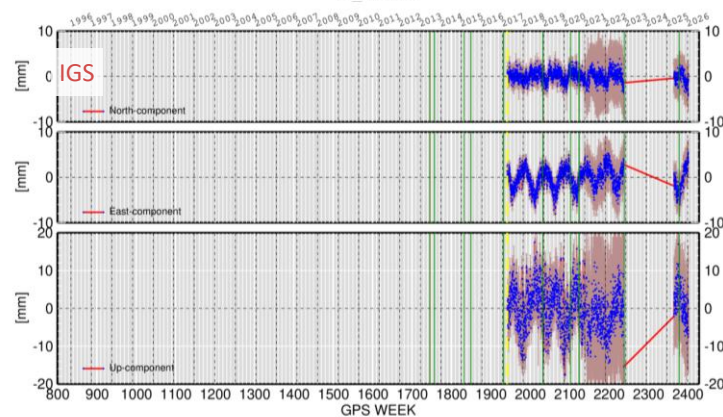
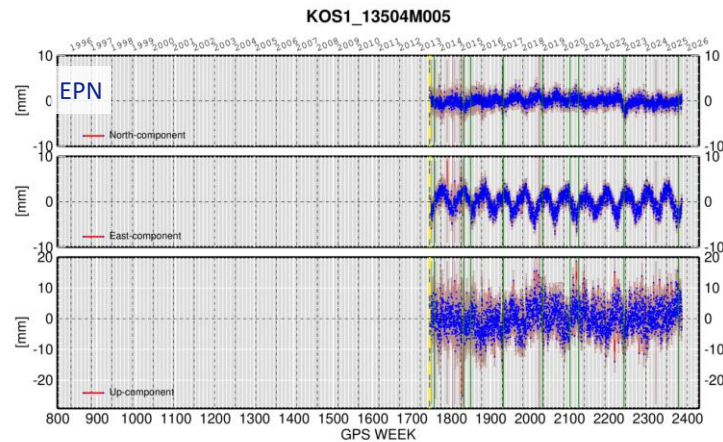
Station classification based on 5 criteria:

- Time Series
 - amplitude of the annual signals on North, East and Up components
 - root mean square of the residual position time series after removing the annual and semi-annual signals
- Velocity Estimation
 - realistic velocity error estimates from Hector software [Bos et. al. 2013] (linear trend, annual, semi-annual signals assuming temporal correlated noise (power-law + white noise))
 - differences between CATREF and Hector velocity estimations
- Velocity Variability



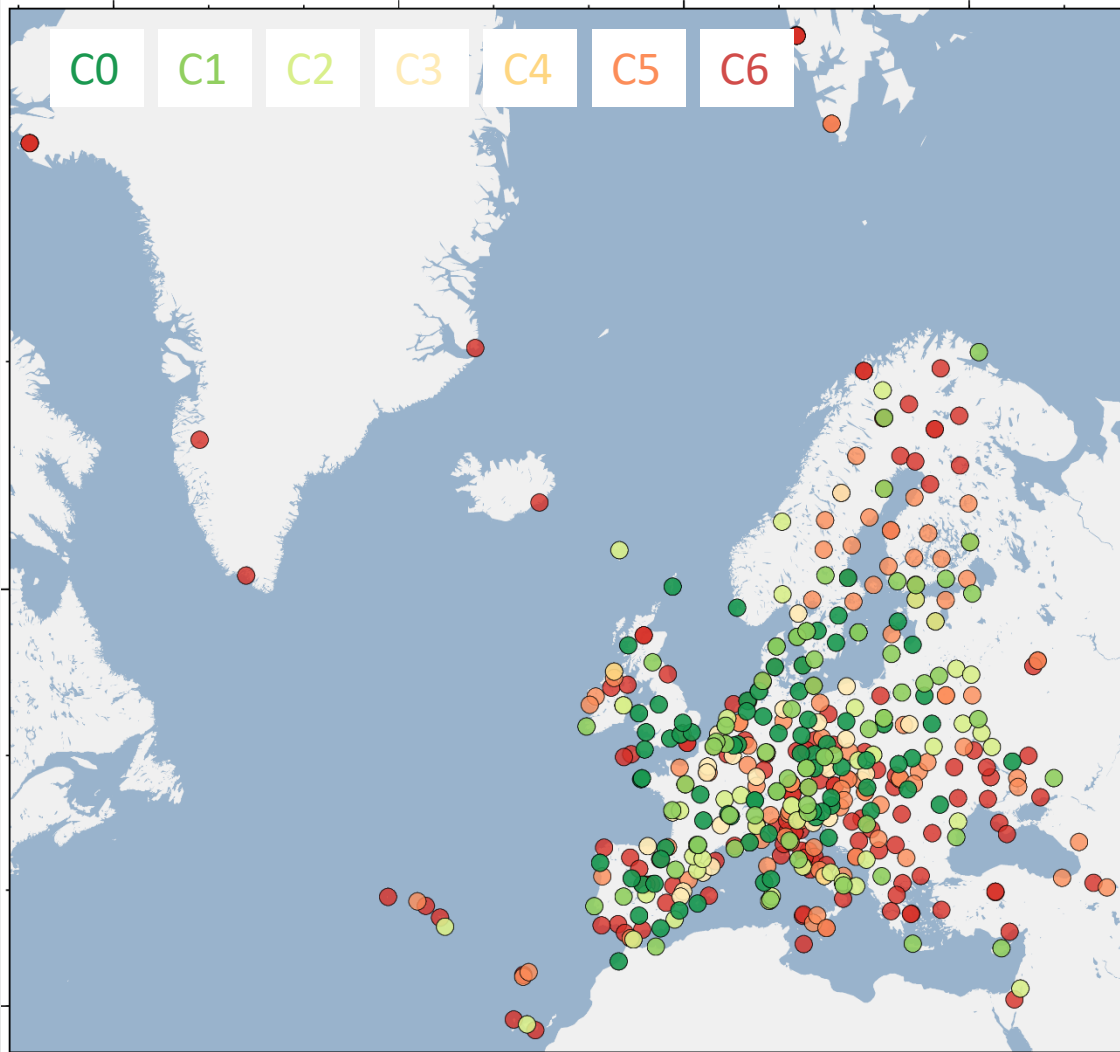
Remarks on the station classification and the web tool

- Sensitive to how the outliers are handled, discontinuities used
- Only valid for EPN solution
- Not suitable to select stations from other solutions (for example ITRF2020, IGc20...)

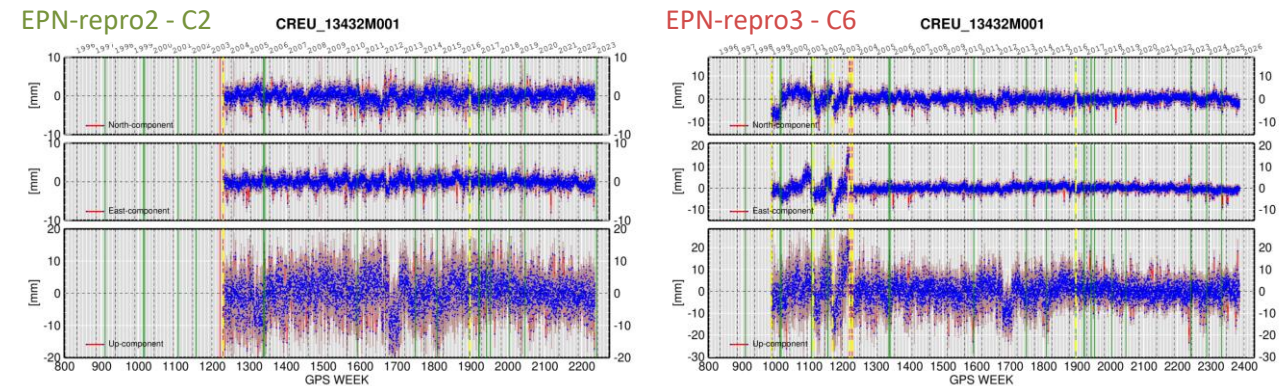


Don't use the EPN station classification to select stations from other solutions

Revision of Station Classification



- Very nice to identify the most stable stations
- Too many stations in classes “not-recommended” especially at the border of the network due to velocity changes or bad periods
- Due to additional data in EPN-repro3, station class was degraded for some stations



⇒ Revision of the station classification

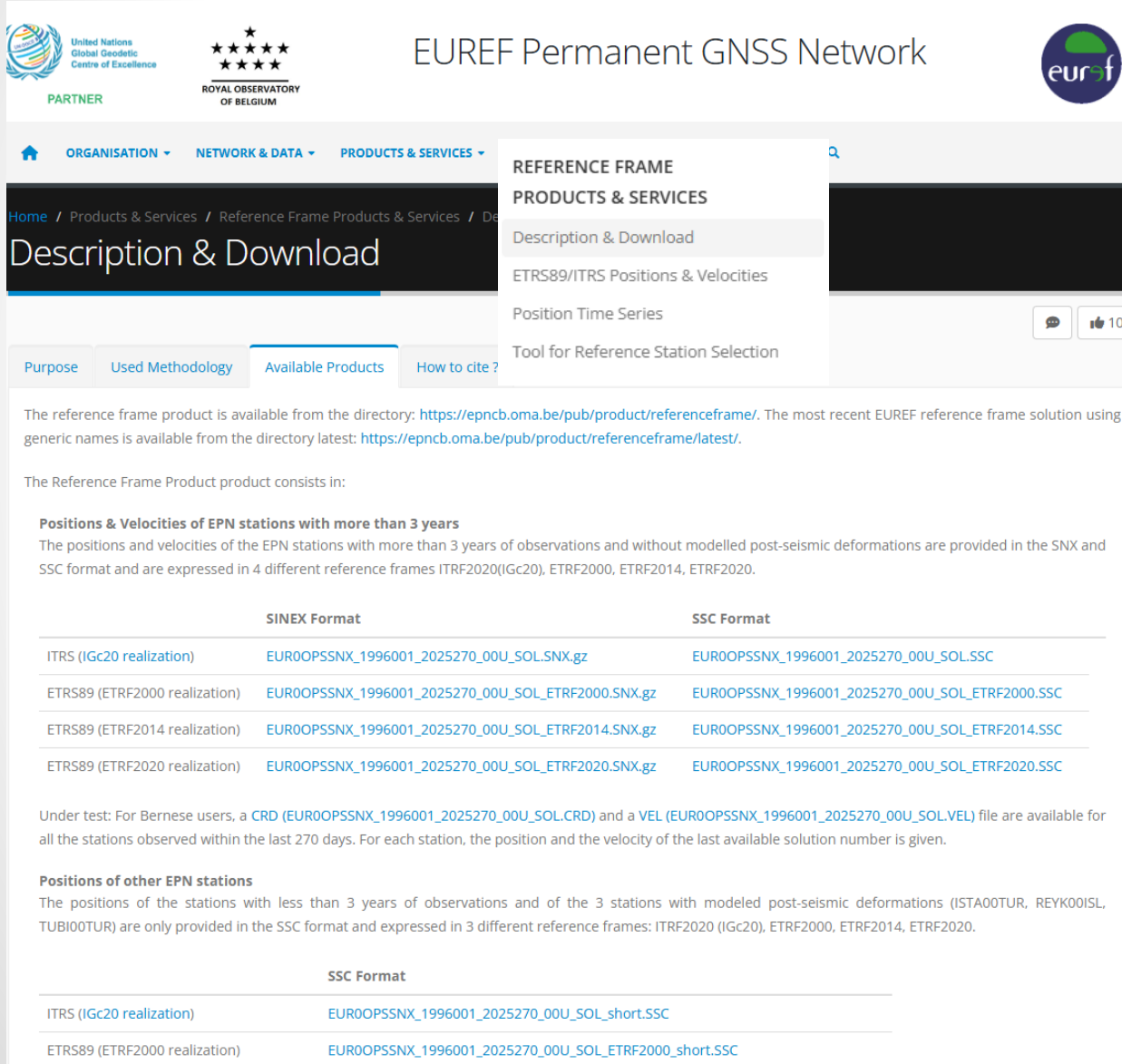
- Better handle stations with velocity changes
- Consider period of validity or exclusion
- Loosen the criteria in some area

Where to find
the EPN-repro3 based
reference frame product?

EPN-repro3 reference frame product:

What is available?

<https://epncb.oma.be>



The screenshot shows the EUREF Permanent GNSS Network website. The header includes logos for the United Nations Global Geodetic Centre of Excellence, the Royal Observatory of Belgium, and the EUREF logo. The main navigation bar has links for Organisation, Network & Data, and Products & Services. The 'Products & Services' dropdown menu is open, showing options for Reference Frame, Description & Download, ETRS89/ITRS Positions & Velocities, Position Time Series, and Tool for Reference Station Selection. The 'Description & Download' page is selected, showing a breadcrumb trail: Home / Products & Services / Reference Frame Products & Services / Description & Download. Below the breadcrumb, there are tabs for Purpose, Used Methodology, Available Products, and How to cite?. The 'Available Products' tab is active, displaying a table of reference frame products. The table has two columns: SINEX Format and SSC Format. The rows list products for ITRS (IGc20 realization), ETRS89 (ETRF2000 realization), ETRS89 (ETRF2014 realization), and ETRS89 (ETRF2020 realization). Below the table, there is a note about files available for Bernese users and a section for positions of other EPN stations.

EUREF Permanent GNSS Network

REFERENCE FRAME
PRODUCTS & SERVICES

Description & Download

ETRS89/ITRS Positions & Velocities

Position Time Series

Tool for Reference Station Selection

Home / Products & Services / Reference Frame Products & Services / Description & Download

Purpose Used Methodology Available Products How to cite?

The reference frame product is available from the directory: <https://epncb.oma.be/pub/product/referenceframe/>. The most recent EUREF reference frame solution using generic names is available from the directory latest: <https://epncb.oma.be/pub/product/referenceframe/latest/>.

The Reference Frame Product product consists in:

Positions & Velocities of EPN stations with more than 3 years

The positions and velocities of the EPN stations with more than 3 years of observations and without modelled post-seismic deformations are provided in the SNX and SSC format and are expressed in 4 different reference frames ITRF2020(IGc20), ETRF2000, ETRF2014, ETRF2020.

	SINEX Format	SSC Format
ITRS (IGc20 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL.SNX.gz	EUR0OPSSNX_1996001_2025270_00U_SOL.SSC
ETRS89 (ETRF2000 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000.SNX.gz	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000.SSC
ETRS89 (ETRF2014 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2014.SNX.gz	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2014.SSC
ETRS89 (ETRF2020 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2020.SNX.gz	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2020.SSC

Under test: For Bernese users, a **CRD** ([EUR0OPSSNX_1996001_2025270_00U_SOL.CRD](#)) and a **VEL** ([EUR0OPSSNX_1996001_2025270_00U_SOL.VEL](#)) file are available for all the stations observed within the last 270 days. For each station, the position and the velocity of the last available solution number is given.

Positions of other EPN stations

The positions of the stations with less than 3 years of observations and of the 3 stations with modeled post-seismic deformations (ISTA00TUR, REYK00ISL, TUBI00TUR) are only provided in the SSC format and expressed in 3 different reference frames: ITRF2020 (IGc20), ETRF2000, ETRF2014, ETRF2020.

	SSC Format
ITRS (IGc20 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL_short.SSC
ETRS89 (ETRF2000 realization)	EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000_short.SSC

Positions & Velocities in IGc20/ITRF2020, ETRF2000 and ETRF2020

By-products:

List of position & velocity **discontinuities**

List of daily **outliers**

Cleaned **position time series**

Station **classification** and a **tool** to identify the best reference stations

Rapid position time series updated daily

<https://epncb.oma.be/pub/product/referenceframe/>

```
├── archive
│   ├── C1355
│   ...
│   ├── C2235
│   │   ├── C2295_hybrid
│   │   └── C2355_hybrid
├── C2370
├── C2385
└── latest
```

Directories with generic names

Long naming conventions

<https://epncb.oma.be/pub/product/referenceframe/latest/>

EUR0OPSSNX_1996001_00U_SOL.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL.SNX.gz
EUR0OPSSNX_1996001_00U_SOL.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL.SSC
EUR0OPSSNX_1996001_00U_SOL_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_short.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000.SNX.gz
EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2000_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2000_short.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2020.SNX.gz
EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2020.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2020_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL_ETRF2020_short.SSC
EUR0OPSSNX_1996001_00U_SOL.CRD	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL.CRD
EUR0OPSSNX_1996001_00U_SOL.VEL	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_2025270_00U_SOL.VEL
EPN_discontinuities.snz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EPN_discontinuities.snz
EPN_outliers.lst	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EPN_outliers.lst

<https://epncb.oma.be/pub/station/coord/EPN/>

01_README.md	
02_README_repository_changes.md	
archive	
EUR0OPSSNX_1996001_00U_SOL.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL.SNX.gz
EUR0OPSSNX_1996001_00U_SOL.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL.SSC
EUR0OPSSNX_1996001_00U_SOL_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_short.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SNX.gz
EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2000.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2000_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2000_short.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SNX.gz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SNX.gz
EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2020.SSC
EUR0OPSSNX_1996001_00U_SOL_ETRF2020_short.SSC	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EUR0OPSSNX_1996001_00U_SOL_ETRF2020_short.SSC
EPN_discontinuities.snz	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EPN_discontinuities.snz
EPN_outliers.lst	-> https://epncb.oma.be/pub/product/referenceframe/C2385/EPN_outliers.lst

ITRF2020.CRD -> ITRF2020_2423.CRD
ITRF2020_2422.CRD
ITRF2020_2423.CRD
RTCM.CRD
Time_Series

List of files that will be removed from the directory https://epncb.oma.be/pub/station/coord/EPN/

Files	New Location
classB_noisy.lst_not_maintained	Generic file not maintained since solution C2160 (July 2021). The file can be found in repositories CWWW (solutions C1995 to C2160) in https://epncb.oma.be/pub/product/referenceframe/archive/C2160/classB_noisy.lst
classB_short.lst_not_maintained	Generic file not maintained since solution C2160 (July 2021). The file can be found in repositories CWWW (solutions C1995 to C2160) in https://epncb.oma.be/pub/product/referenceframe/archive/C2160/classB_short.lst
EPN_A_ETRF2000_C2160_ext.SSC	https://epncb.oma.be/pub/product/referenceframe/archive/C2160/EPN_A_ETRF2000_C2160_ext.SSC
EPN_A_ETRF2000_C2160.SNX.Z	https://epncb.oma.be/pub/product/referenceframe/archive/C2160/EPN_A_ETRF2000_C2160.SNX.Z
EPN_A_ETRF2000_C2160.SSC	https://epncb.oma.be/pub/product/referenceframe/archive/C2160/EPN_A_ETRF2000_C2160.SSC
EPN_A_ETRF2000.SNX.Z	Generic file not maintained since solution C2160 (July 2021). The file EPN_A_ETRF2000_CWWW.SNX.Z can be found in repositories CWWW (solutions C1995 to C2160) in https://epncb.oma.be/pub/product/referenceframe/archive/C2160/EPN_A_ETRF2000_CWWW.SNX.Z
EPN_A_ETRF2000.SSC	Generic file not maintained since solution C2160 (July 2021). The file EPN_A_ETRF2000_CWWW.SSC can be found in repositories CWWW (solutions C1995 to C2160) in https://epncb.oma.be/pub/product/referenceframe/archive/C2160/EPN_A_ETRF2000_CWWW.SSC

Files not maintained will be removed from the directory

<https://epncb.oma.be/pub/station/coord/EPN/>

Check the readme files to identify if you are using files that will be removed from this directory.

a priori coordinates for EPN stations

ITRF2020.CRD in ITRF2020

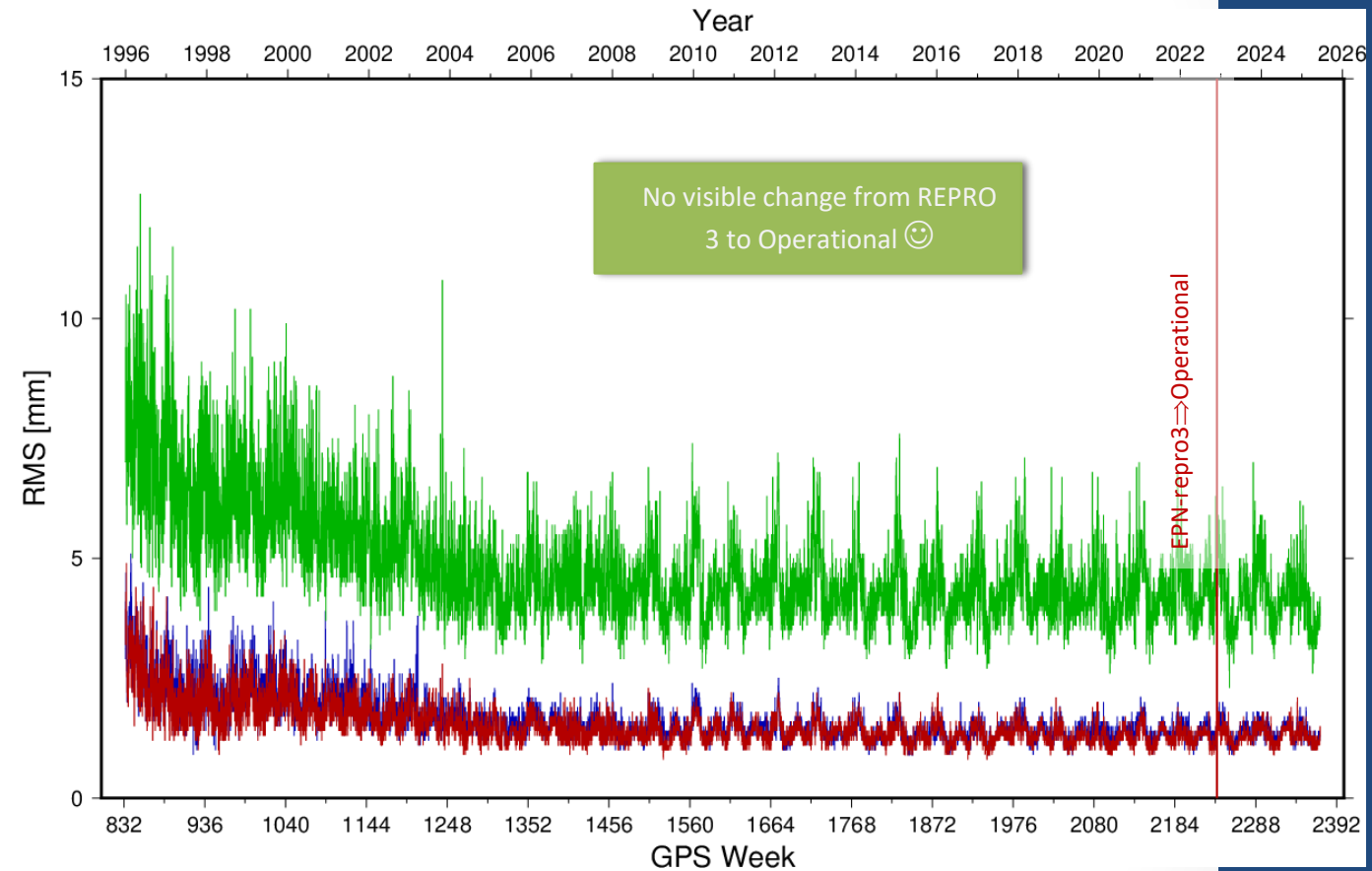
RTCM.CRD in ETRF2000

Conclusions

- EUREF Reference Frame Product based on EPN-repro3
 - More data and longer time series than the EPN-repro2 product
 - Successful switch from EPN-repro 3 to operational
 - Good agreement with IGc20 and latest IGS cumulative solution
 - Current status:
 - C2370 has been released in February 2026
 - C2385 in March 2026
 - C2400 will be published soon
- Make sure you are using the new names in the directories <https://epncb.oma.be/pub/station/coord/EPN/> and <https://epncb.oma.be/pub/product/referenceframe/>
- Station Classification is under revision

Internal consistency of EPN-Repro3

- Switch from EPN-repro3 to operational:
 - No change in the WRMS time series
 - No discontinuities added to account for a position change
- Huge improvement with respect to EPN-Repro2 where almost 40 stations (7 of them IGS14 stations) were impacted by the switch from EPN-repro2 to operational



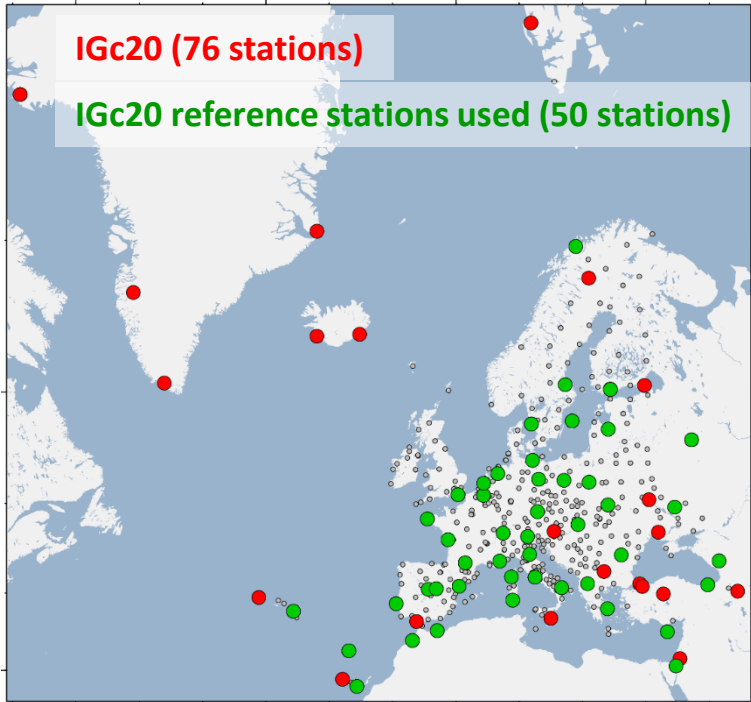
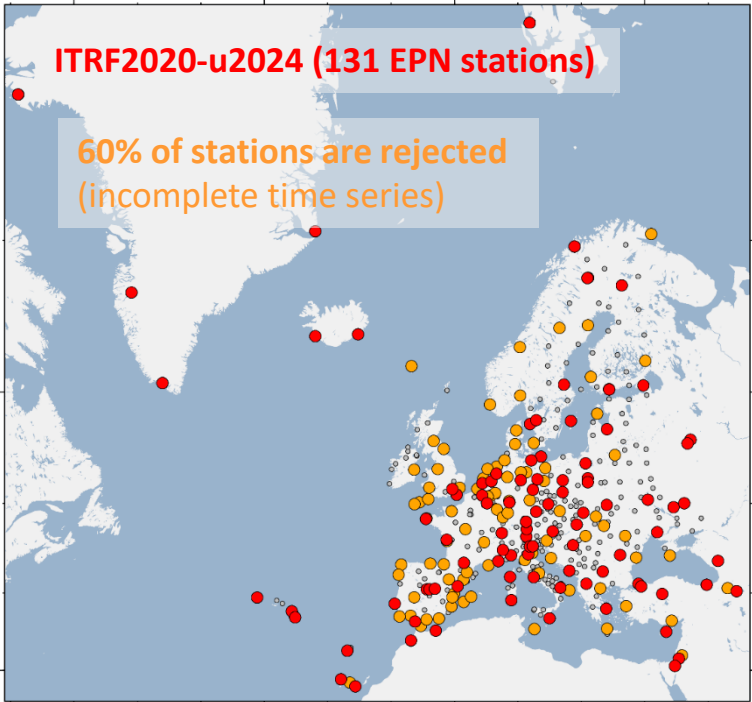
Comparison with the several Global Reference Frames

	Reference epoch	Begin Date	End Date	Nb EPN stations
EPN-repro3	2020.0	1996-01-01	2025-09-28	506
IGc20	2020.0	1994-01-02	2025-03-16	76 (50 stations used as reference station)
ITRF2020-u2024	2020.0	1994-01-02	2025-03-16	total: 213 stations (131 + 82 excluded due to gap or shorter history in IGS/ITRF solutions)
IGS00PSSNX_1994002_2026017_00U_SOL	2020.0	1994-01-02	2026-01-18	225 (135 + 90 excluded due to gap or shorter history in IGS/ITRF solutions)

131 stations

60% of stations are rejected
(incomplete time series)

135 stations



Comparison of position time series

EPN-repro3 vs IGS cumulative solution



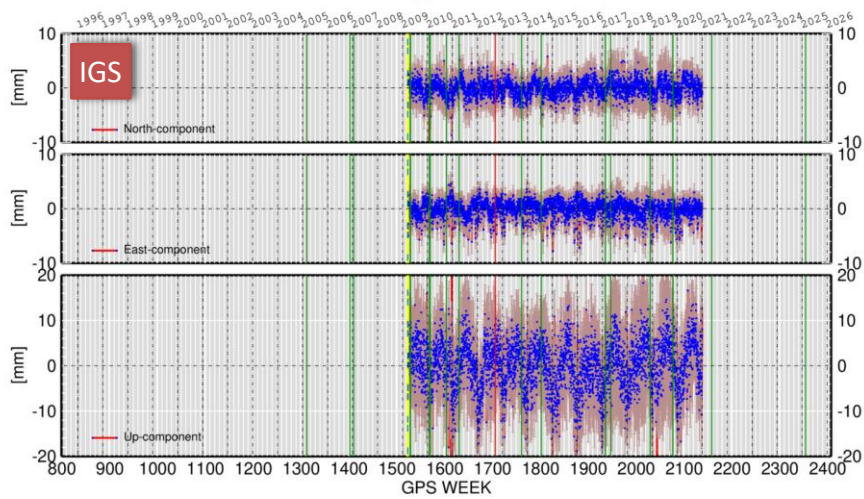
60+ stations don't have complete time series
⇒ should be used as reference stations with care

Situation is much better for the IGS stations (stations having a sitelog in IGS)

Very good data availability and complete history for the IGc20 stations

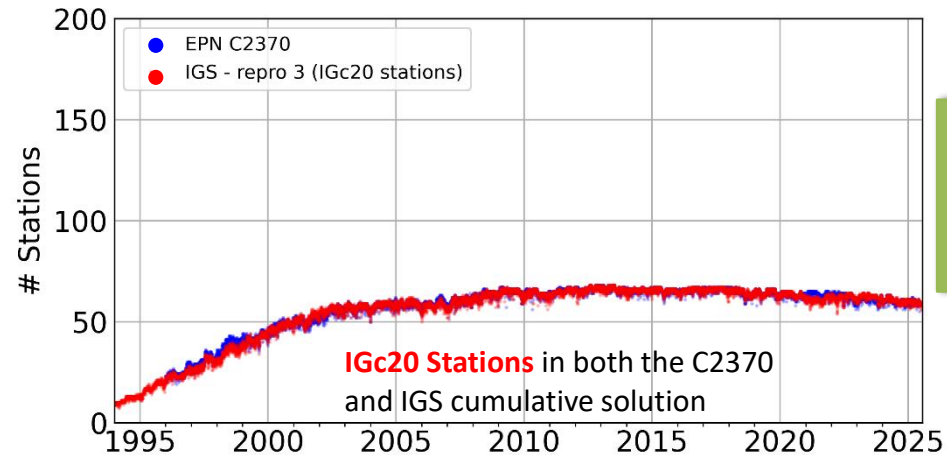
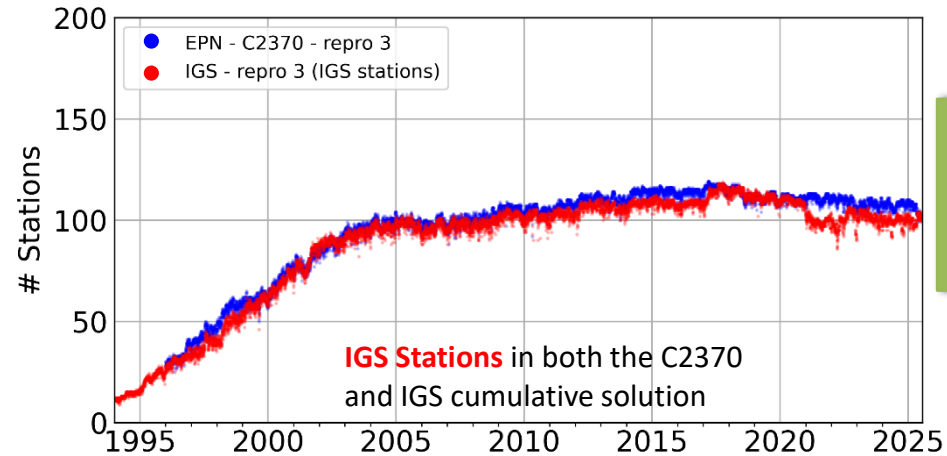
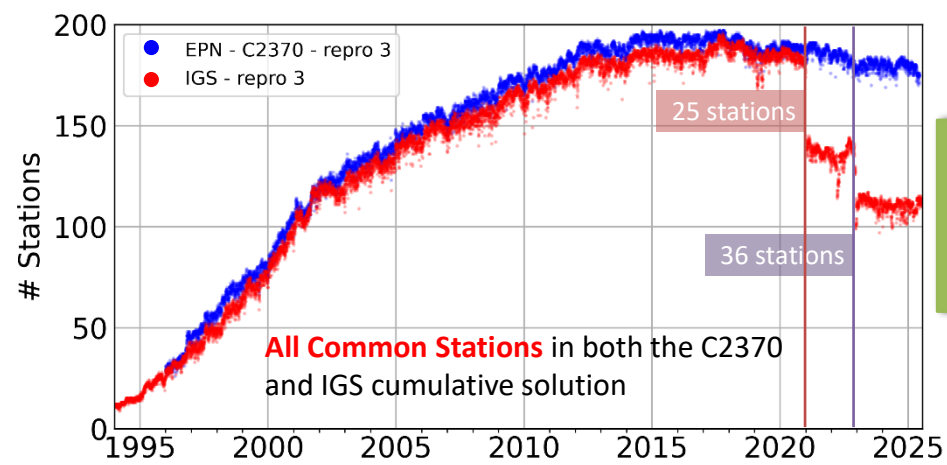
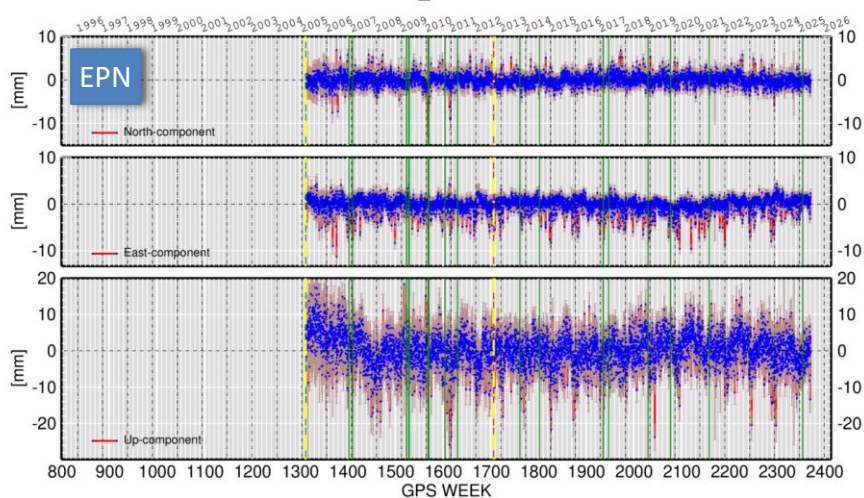
IGS Residual position time series from <ftp://igs-rf.ign.fr/pub/stacking-res/>

BADH_14288M001



ftp://igs-rf.ign.fr/pub/stacking-res/BADH_igs_IGS.res

BADH_14288M001



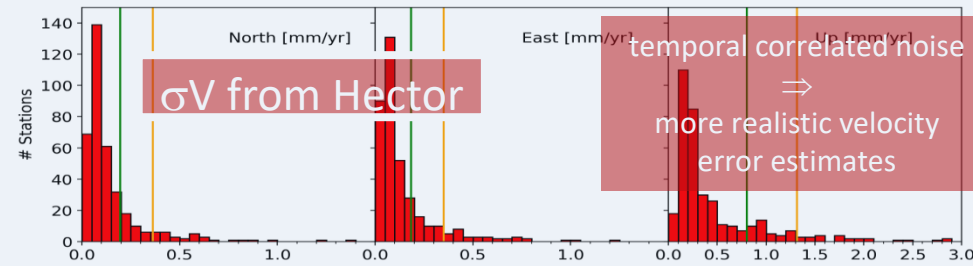
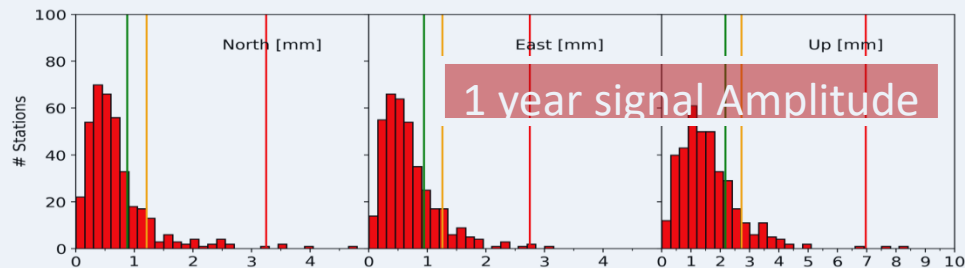
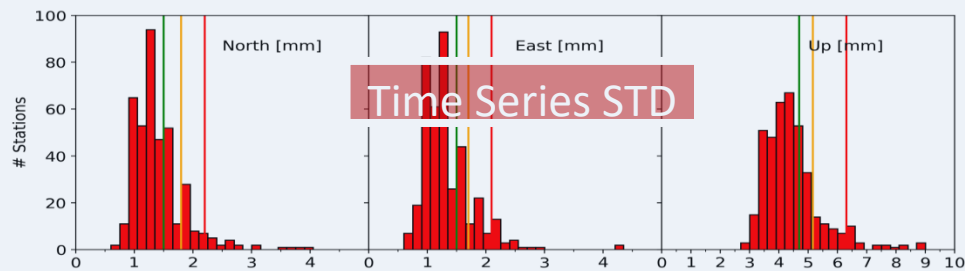
EUREF Reference Frame Product

- EUREF Reference Frame solution is **updated each 15 weeks**
- Processing steps
 - Multi-year position & velocity solution using **CATREF** [Altamimi et al. 2007] expressed in **IGc20** based on the EPN daily combined SINEXs
 - Visual inspection of residual position time series
 - **Outlier rejection**
 - Introduction of the new **position discontinuities**
 - Introduction of the new **velocity changes**
 - **Quality Checks** (daily values and monthly skyplots)
 - Comparison with other time series (IGS, NGL, local network,...)
 - Contact station manager
 - velocity constraints on collocated stations
 - Comparison with other products
 - Comparison with IGc20 and IGS cumulative $\Rightarrow$ Harmonization with IGS discontinuities
 - Comparison with the **previous** EPN reference frame solution $\Rightarrow$ understand the reason of large differences
 - **Station Classification**
 - **Velocity estimation** with **Hector** software [Bos et. al. 2013] (linear trend, annual, semi-annual signals assuming temporal correlated noise (power-law + white noise))
 - Each 2 releases, re-run of the **velocity variability** estimation ($\sim 100\,000$ velocity estimations)
 - Define **thresholds** and apply them to define **classes**
 - when station class change $\Rightarrow$ understand the **reason of the change**

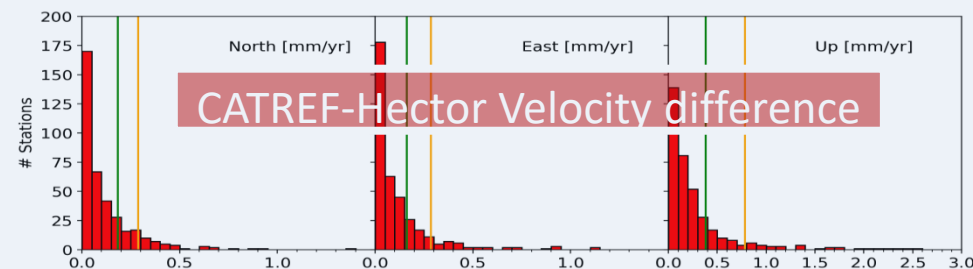
Station Classification (1/2)

6 categories based on the performance of the station on 5 criteria

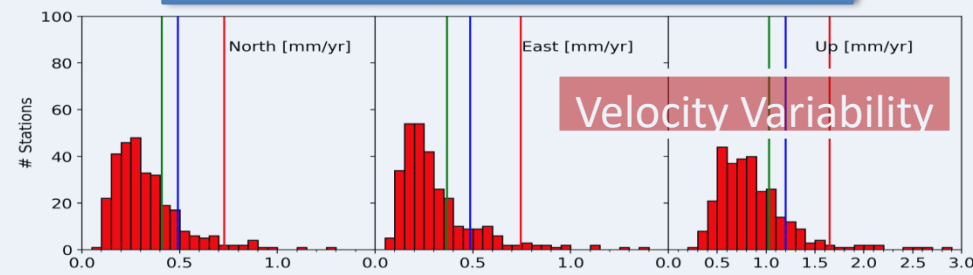
Position Time Series Scattering & Signals



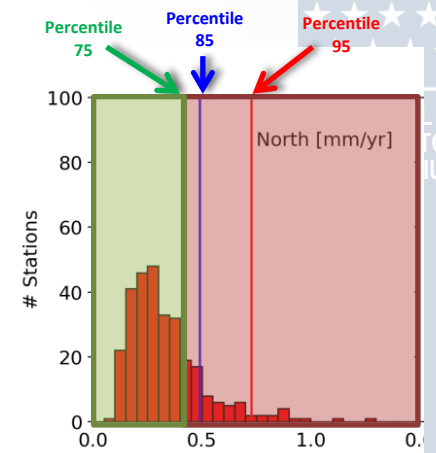
Reliability of the Velocity Estimation



Stability of the Station Over Time



Station Classification (2/2)



Value < Percentile 75

- Keep the 75% **best stations** for the considered criteria
- Reject the 25 % **worst stations** for the considered criteria

		Criteria					Comment
Name	Number	Velocity variability	Timeseries RMS	Amplitude 1Y signal	DV _{Catref-Hector}	σ _{Hector}	
C0	84	< Percentile 75	< Percentile 75				Most Stable Stations
C1	62	< Percentile 75	< Percentile 85				
C2	46	< Percentile 75	No threshold		< Percentile 85		Stable but Noisy or with Seasonal Signals
C3	29	< Percentile 85	< Percentile 85				Less Stable
C4	2	Not Available - Short time series	< Percentile 85				
C5	101	< Percentile 85	No criteria > Percentile 95				Even Less Stable
C6	153	velocity variability > Percentile 85 and/or 1 or more other criteria > Percentile 95 or Short time series with 1 or more criteria > Percentile 85					Less Reliable
Short	30	< 3yr - not applicable					No velocity published