# Quality assessment of GNSS reference stations: Criteria and Thresholds

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# Context

- Express reliably GNSS position or position/velocity solutions in a given reference frame (e.g. ITRF2014, IGS14, ETRF2014…)

  $\Rightarrow$ the identification and the usage of 'stable' and 'reliable' reference stations

- The EUREF Permanent Network has been set up to maintain and give access to the European reference Frame ETRS89

  $\Rightarrow$ EUREF computes and publish the 'EPN multi-year solution' in the latest ITRS/ETRS89 realizations.

  However, not all EPN stations are by definition suitable of reference stations.

- To help the identification of the best EPN reference stations, a new station classification was developed.

- A web tool is in development to help the user to choose reliable reference stations

# EPN multi-year position and velocity solution

- Multi-year position & velocity solution
  - using **CATREF** [Altamimi et al. 2007]
  - expressed in **IGS14**

- EPN **daily** SINEXs: 1996-now
  - **EPN-repro2** solutions (1996-2013)
  - Operational solutions (2014-now)

- Solution is **updated each 15 weeks**:
  - Official Positions & Velocities
        in IGS14, ETRF2000 and ETRF2014
  - List of position & velocity discontinuities
  - List of daily outliers
  - Cleaned position time series
  - Former Station Classification (Class A&B)
  - Revised Station Classification
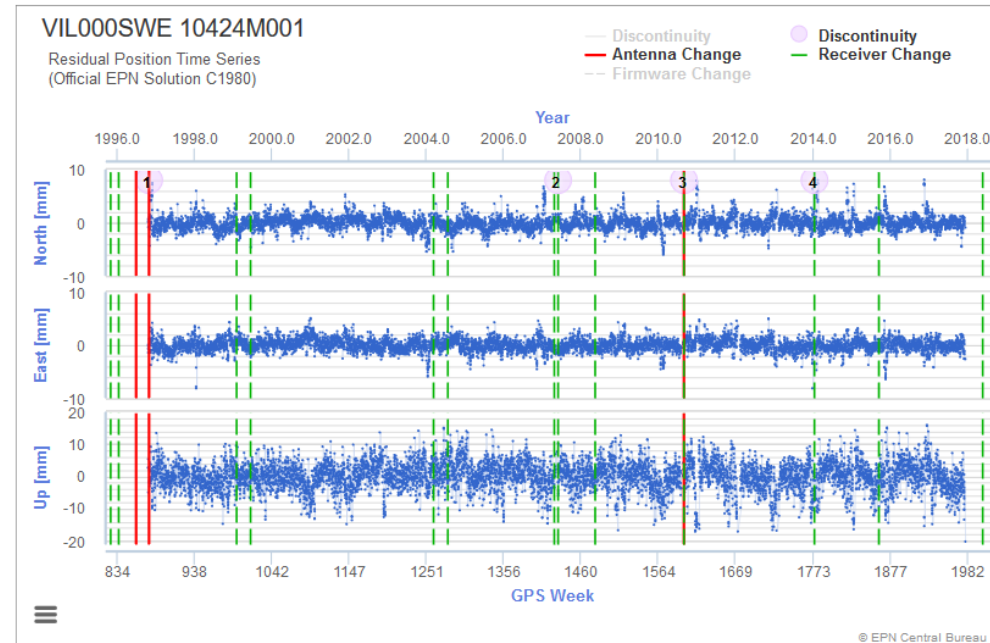- Rapid time series (updated on a daily basis)



http://epncb.oma.be/_productsservices/timeseries

http://epncb.oma.be/_productsservices/coordinates

# EPN multi-year solution: Former Station Classification

**Class A**
**Suitable as reference station**
**for ETRS89 densifications**
Positions at the 1 cm precision at all epochs
and velocities at the 1 mm/yr precision
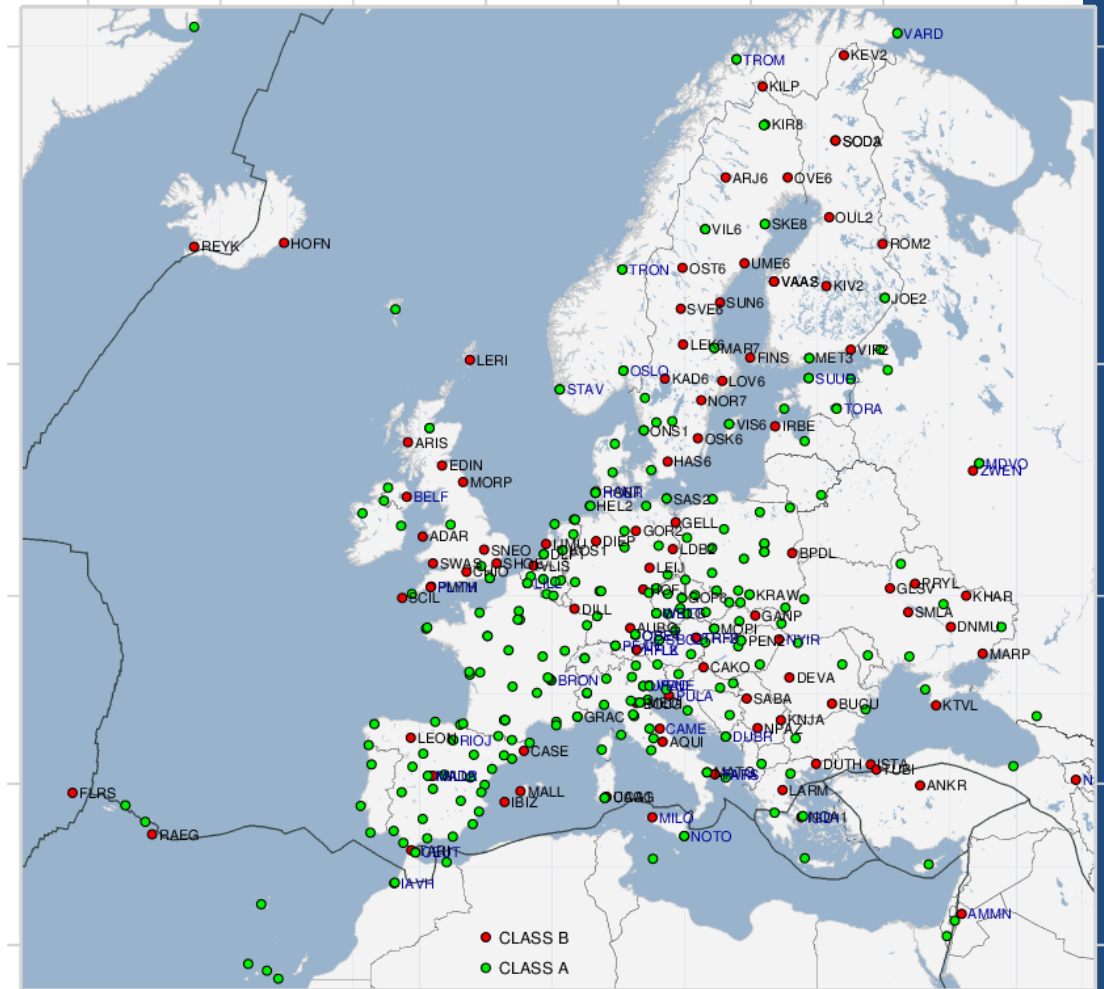Positions & Velocities are published

**Class B**
**Not suitable as reference station**
**for ETRS89 densifications**
Positions have a 1 cm precision
at the epoch of minimal variance
Positions at epoch of minimal variance are published
Velocities are not published
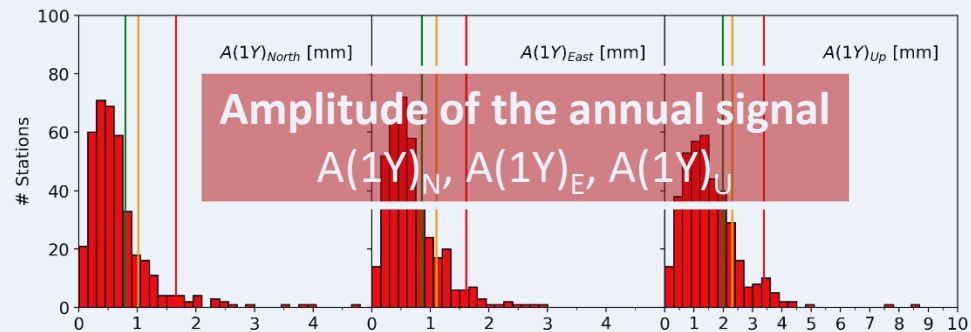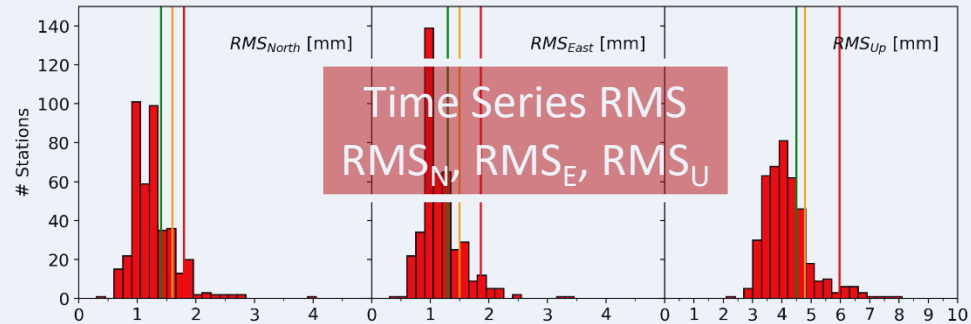
# New classification

- Why changing ?
  - Class A & B are not flexible enough
    - Class A are not necessarily perfect
    - No velocity published for Class B stations is too drastic
    - Ability of a station to be used as reference station depend on the application (EPN-like multi-year solutions, short multi-year solutions (4-5 years), position solutions)
  - Current definitions seems simple, but hard to apply. In practice, it depends on the subjective choice of the EUREF reference frame coordinator
  - Need objective criteria and more flexibility
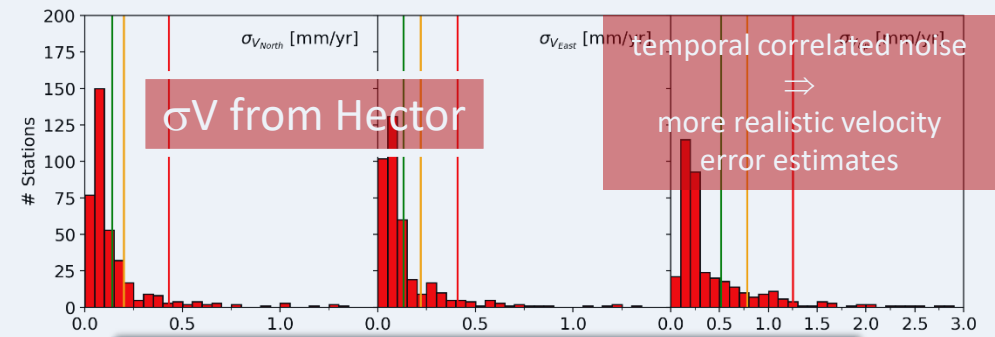
$\Rightarrow$ New Station Classification:
  - Several station classes based on the station performances
  - Several criteria have been selected in order to quantify the quality of a reference station
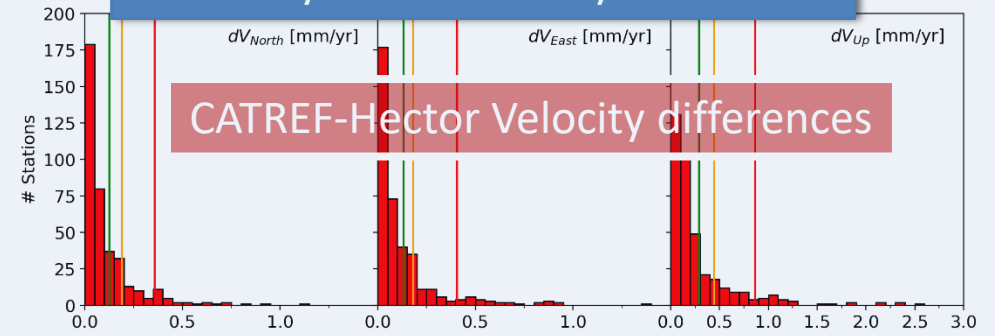  - Thresholds defined with 6 different classes for the EPN stations

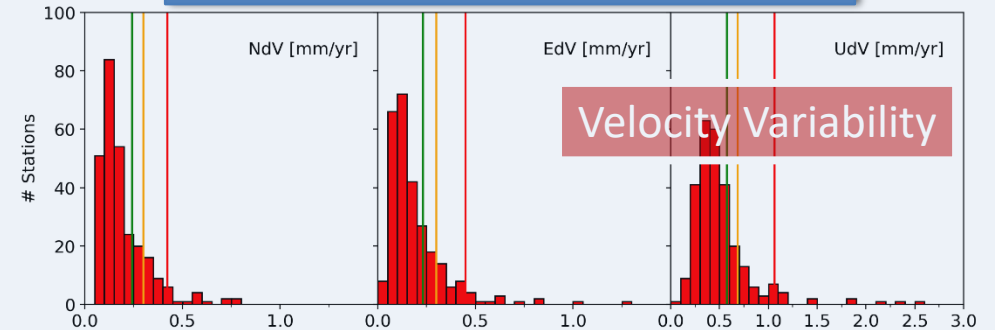# Criteria used

**Position Time Series Scattering & Signals**

Time Series RMS
$RMS_N$, $RMS_E$, $RMS_U$

**Amplitude of the annual signal**
$A(1Y)_N$, $A(1Y)_E$, $A(1Y)_U$

σV from Hector

temporal correlated noise
⇒
more realistic velocity error estimates

**Reliability of the Velocity Estimation**

CATREF-Hector Velocity differences

**Stability of the Station Over Time**

Velocity Variability

# Criteria used



Position Time Series Scattering & Signals

Time Series RMS $RMS_N$, $RMS_E$, $RMS_U$

Amplitude of the annual signal $A(1Y)_N$, $A(1Y)_E$, $A(1Y)_U$

$\sigma V$ from Hector

temporal correlated noise $\Rightarrow$ more realistic velocity error estimates

Reliability of the Velocity Estimation

CATREF-Hector Velocity differences

Stability of the Station Over Time

Velocity Variability

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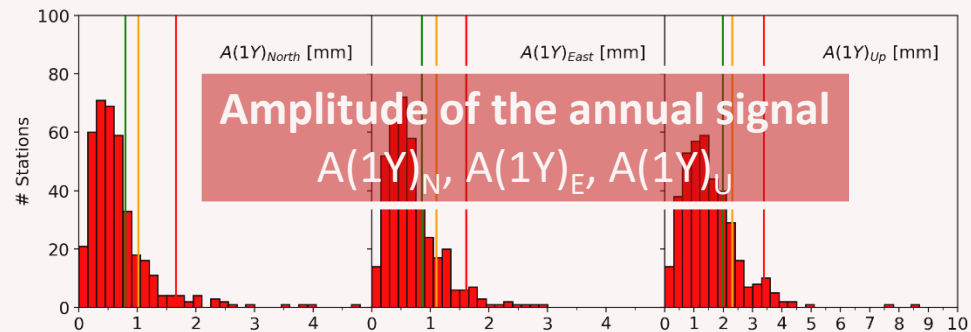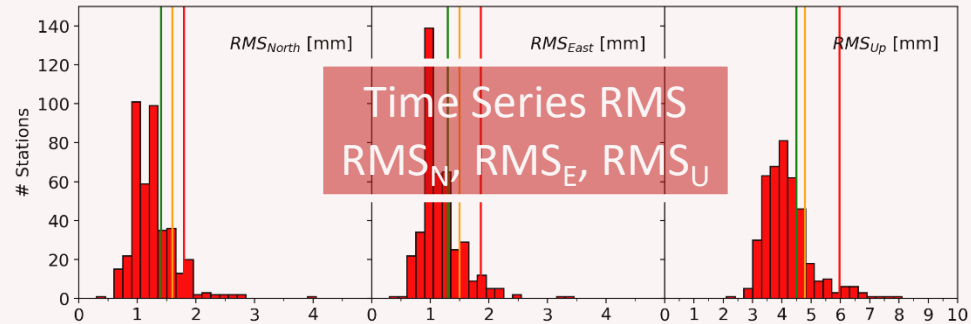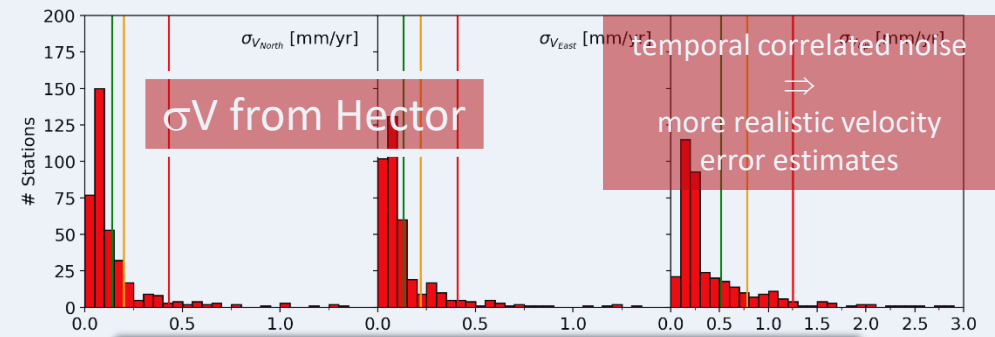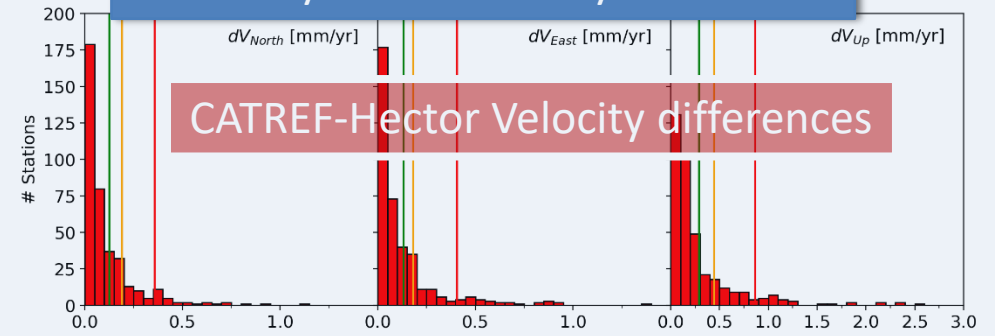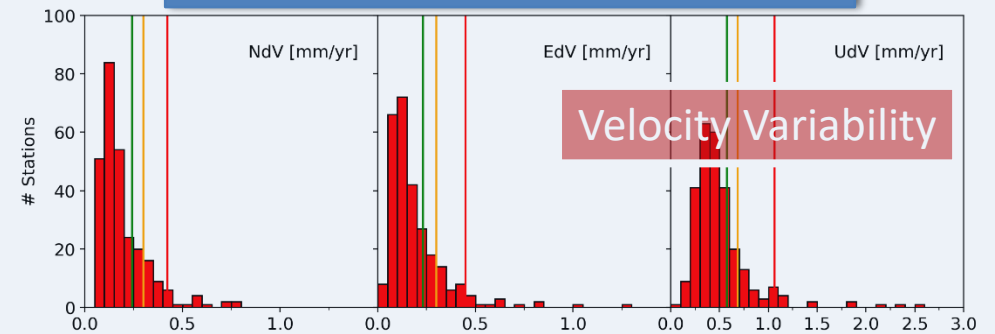
# Position Time Series, Scattering & Signals

- RMS over the full time span of the residual position time series



- Amplitude of the annual signal

# Criteria used



Position Time Series Scattering & Signals

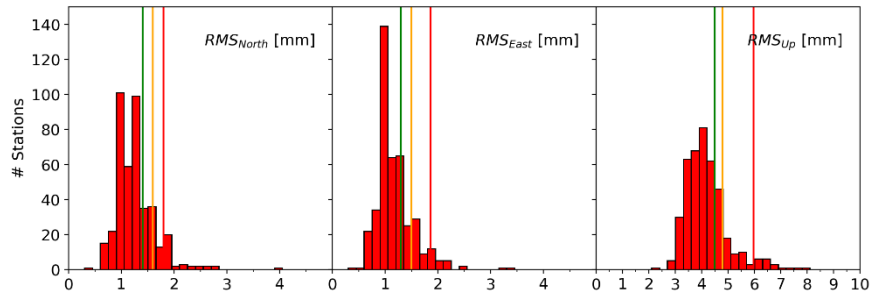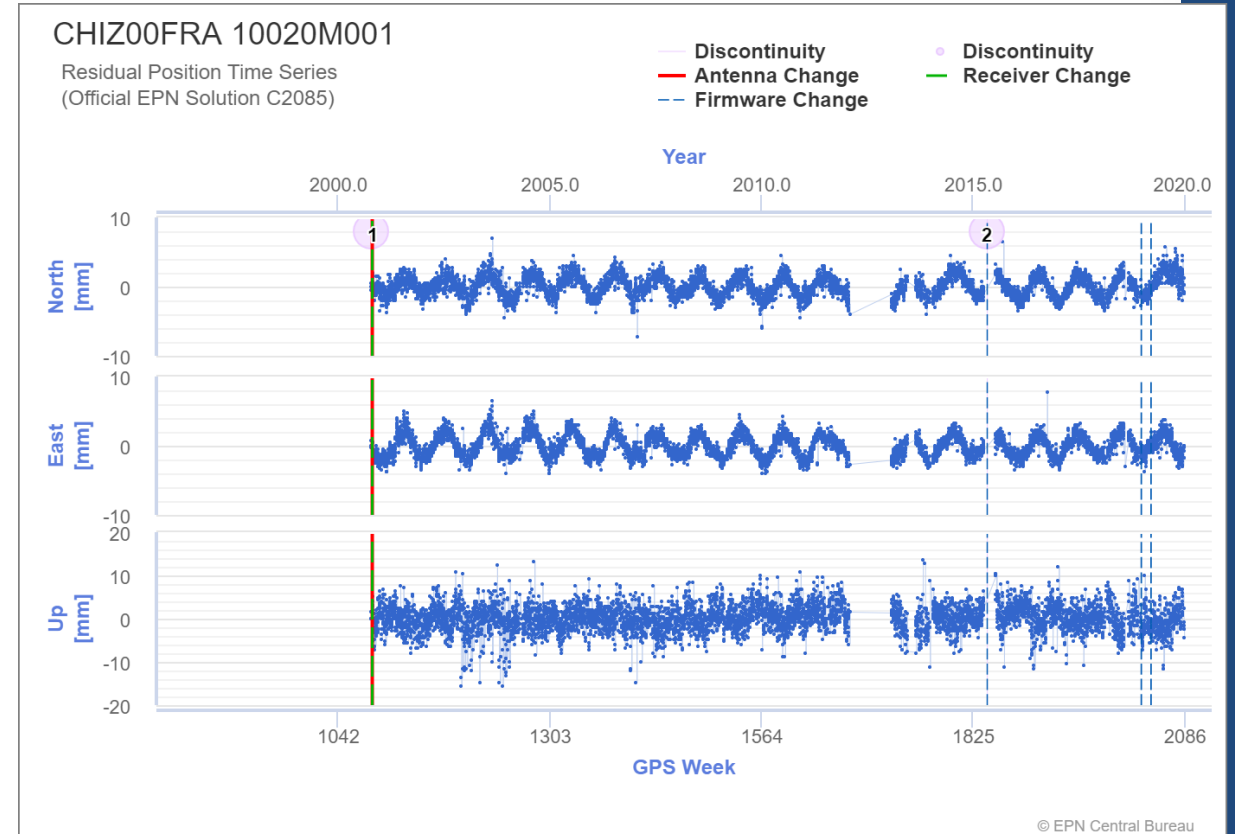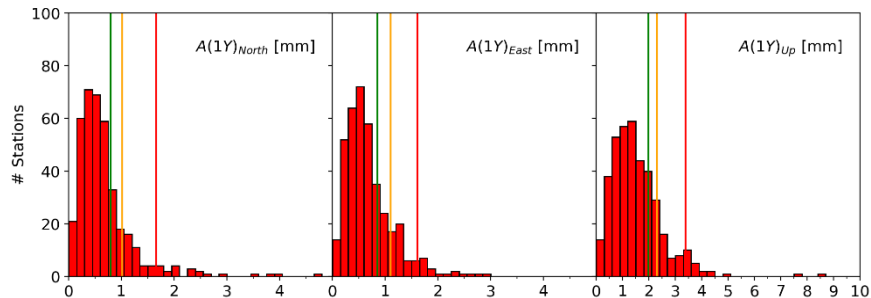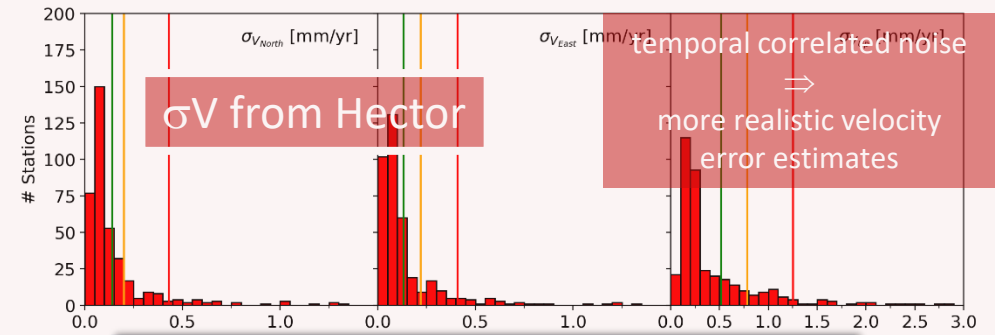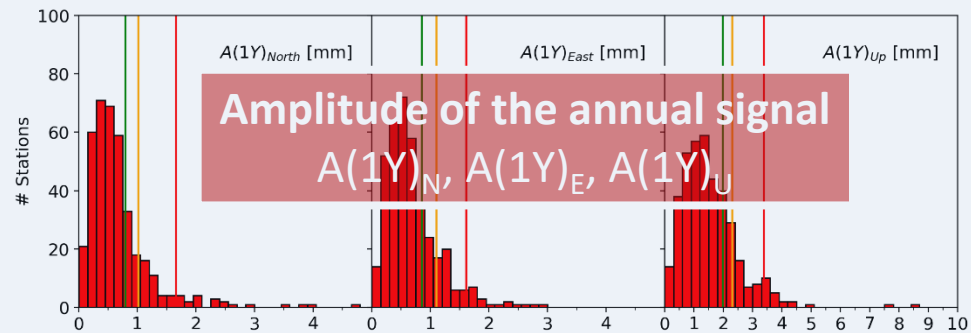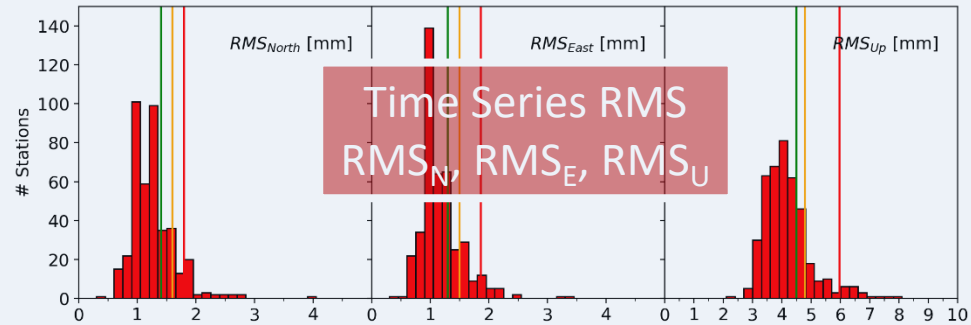Time Series RMS
$RMS_N$, $RMS_E$, $RMS_U$

Amplitude of the annual signal
$A(1Y)_N$, $A(1Y)_E$, $A(1Y)_U$

$\sigma V$ from Hector

temporal correlated noise
$\Rightarrow$
more realistic velocity error estimates

Reliability of the Velocity Estimation

CATREF-Hector Velocity differences

Stability of the Station Over Time

Velocity Variability

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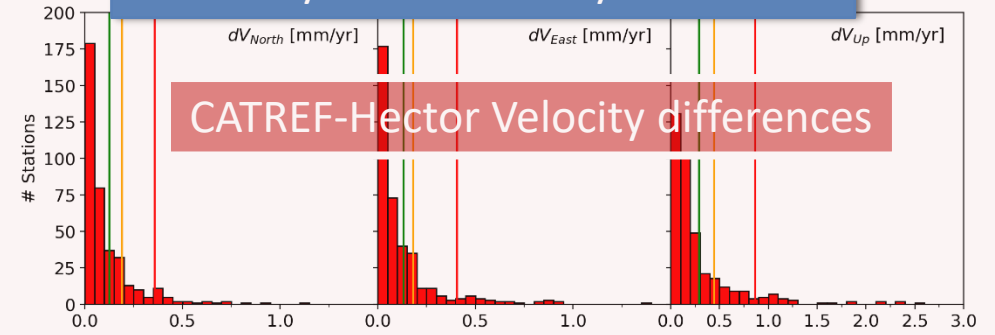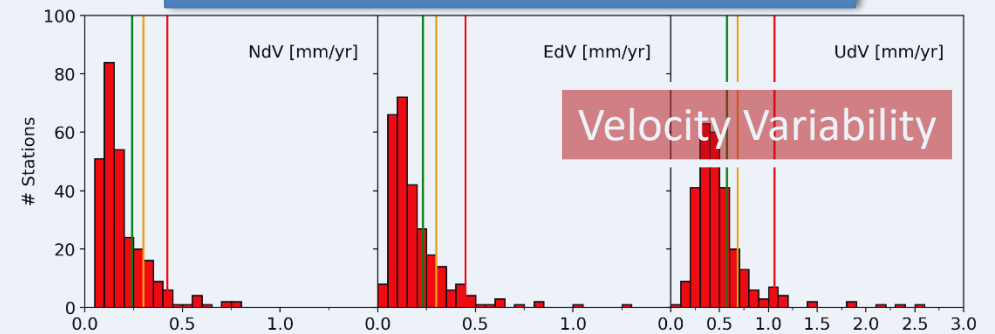
# Reliability of the Velocity Estimation

- CATREF software (Altamimi et al., 2007) based on least squares
  ⇒ velocity error estimates are too optimistic

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

  ⇒ more realistic error estimates from Hector ($\sigma_{VN}$, $\sigma_{VE}$, $\sigma_{VU}$)

- Velocity differences between CATREF and Hector estimations ($dV_N$, $dV_E$, $dV_U$) allow to assess the reliability of the velocity estimation

Histograms of the velocity errors from Hector



σV from Hector

Histograms of the velocity differences between CATREF and Hector
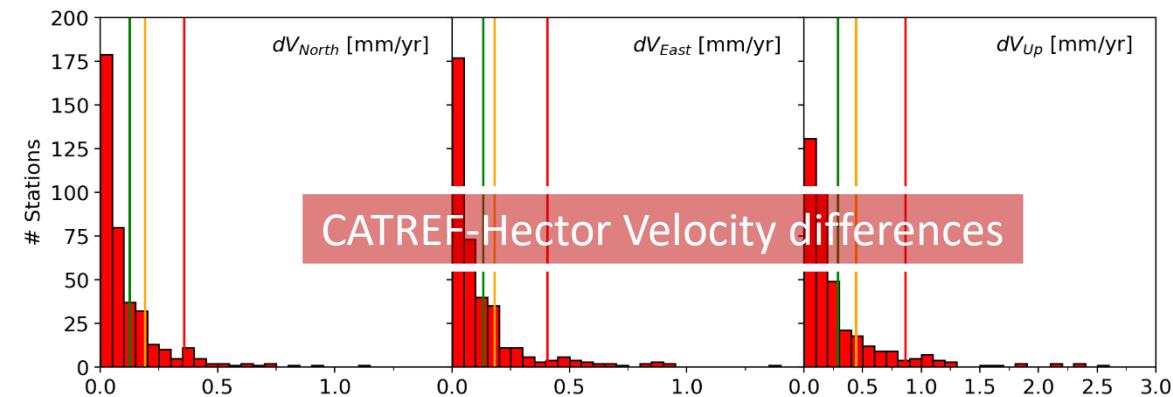


CATREF-Hector Velocity differences
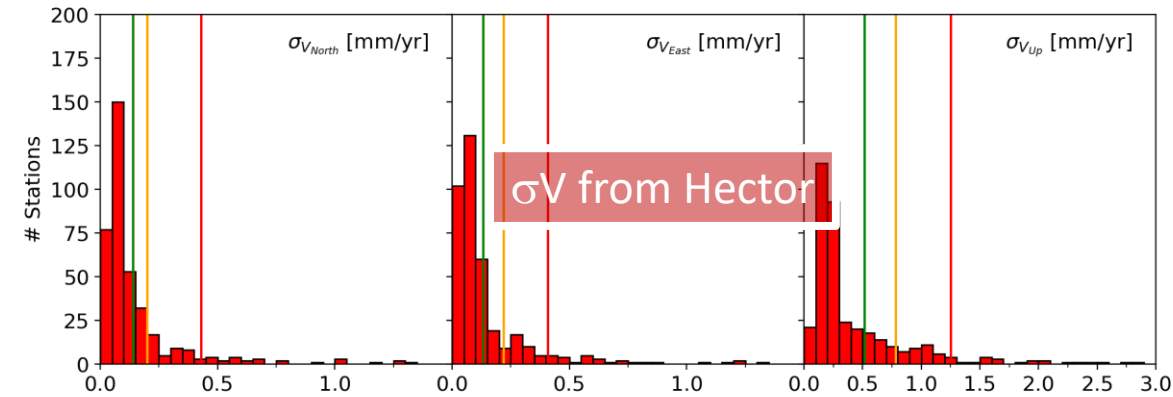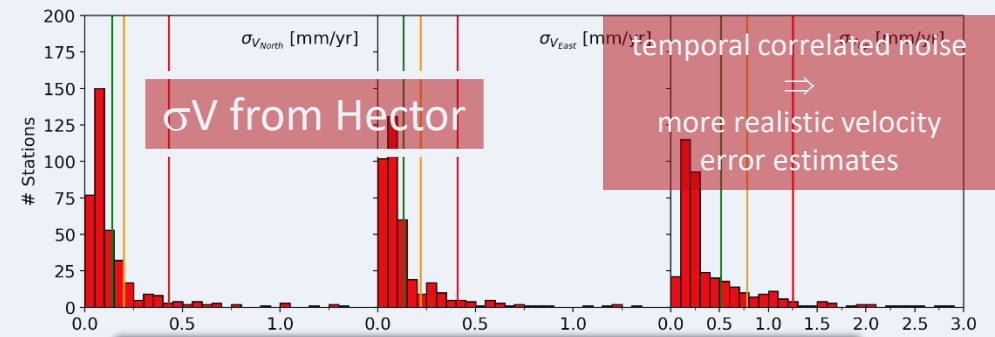
# Criteria used

**Position Time Series Scattering & Signals**

Time Series RMS
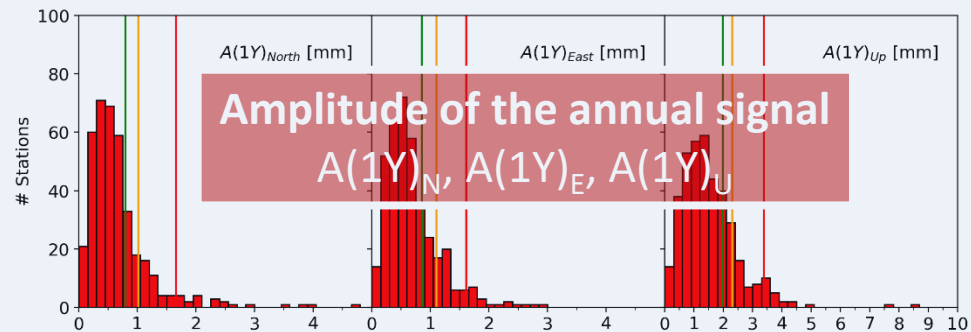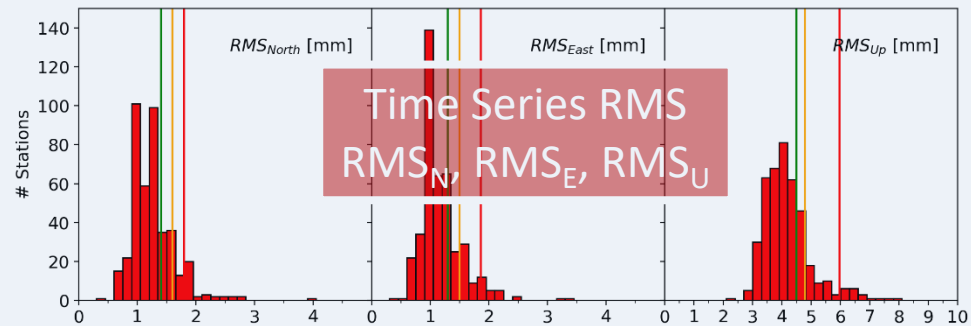$RMS_N$, $RMS_E$, $RMS_U$

$RMS_{North}$ [mm]  $RMS_{East}$ [mm]  $RMS_{Up}$ [mm]

**Amplitude of the annual signal**
$A(1Y)_N$, $A(1Y)_E$, $A(1Y)_U$

$A(1Y)_{North}$ [mm]  $A(1Y)_{East}$ [mm]  $A(1Y)_{Up}$ [mm]

σV from Hector

temporal correlated noise
⇒
more realistic velocity error estimates

$\sigma_{V_{North}}$ [mm/yr]  $\sigma_{V_{East}}$ [mm/yr]  $\sigma_{V_{Up}}$ [mm/yr]

**Reliability of the Velocity Estimation**

CATREF-Hector Velocity differences

$dV_{North}$ [mm/yr]  $dV_{East}$ [mm/yr]  $dV_{Up}$ [mm/yr]

**Stability of the Station Over Time**

Velocity Variability

NdV [mm/yr]  EdV [mm/yr]  UdV [mm/yr]

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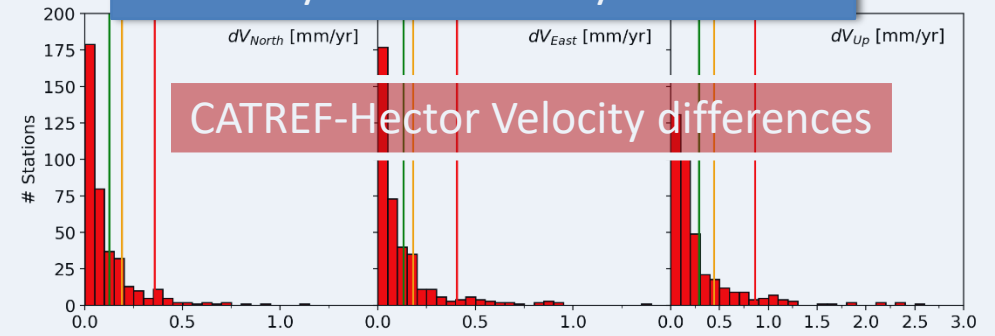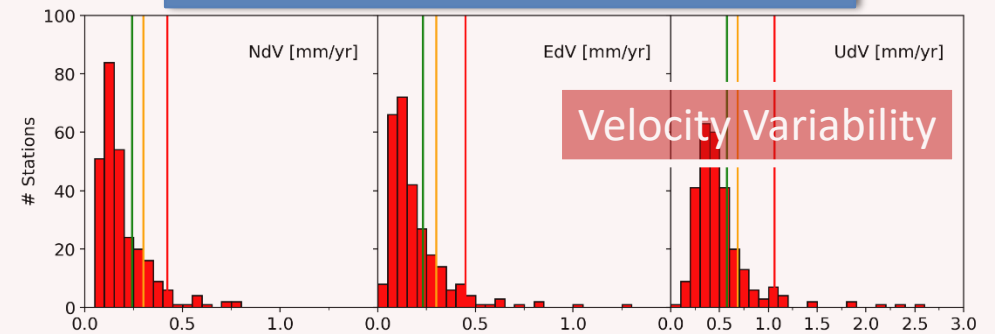
# Velocity Variability (1)

Input time series: position time series
with jumps and trends

Differences between the velocities based
on 4 years of data and the velocity based
on full data set of the station



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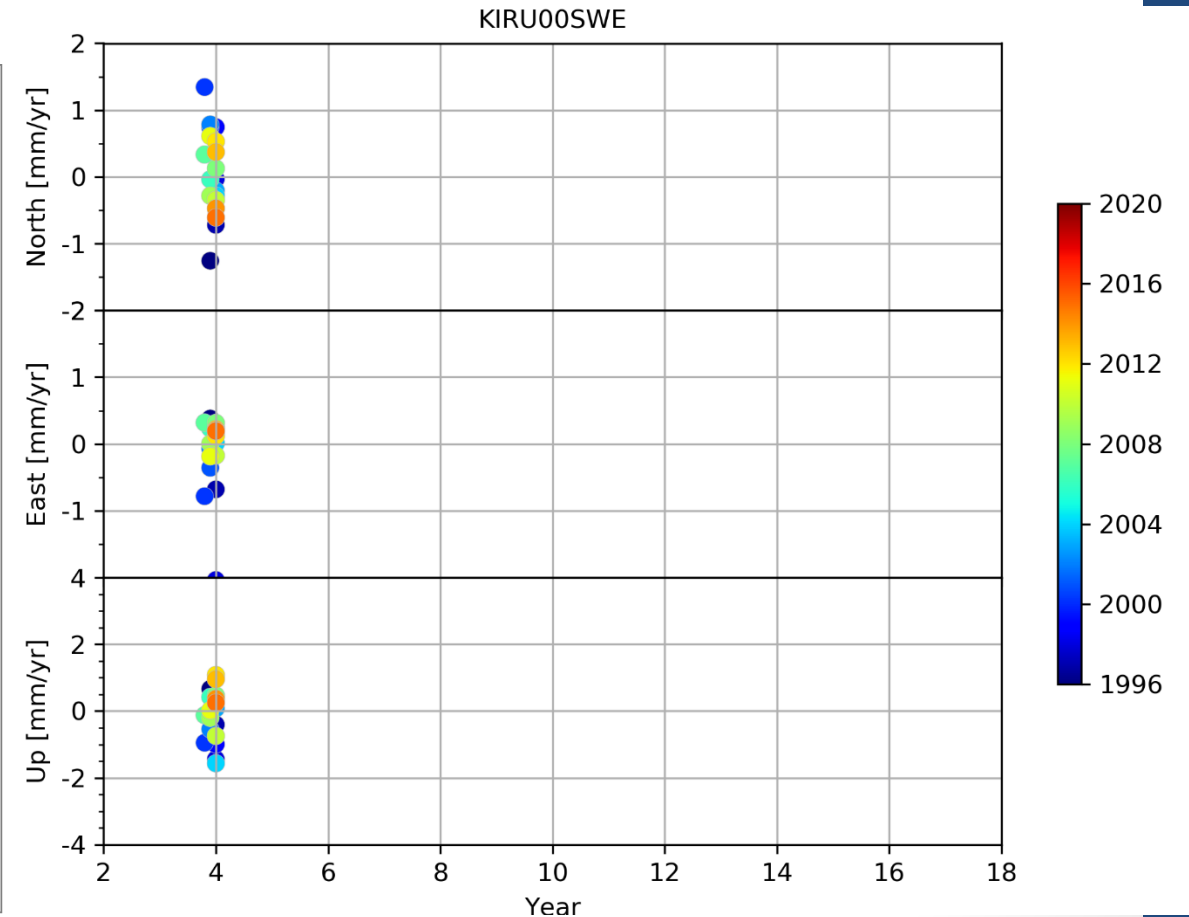
# Velocity Variability (2)

Differences between the velocities based on 8 years of data and the velocity based on full data set of the station

Input time series: position time series with jumps and trends
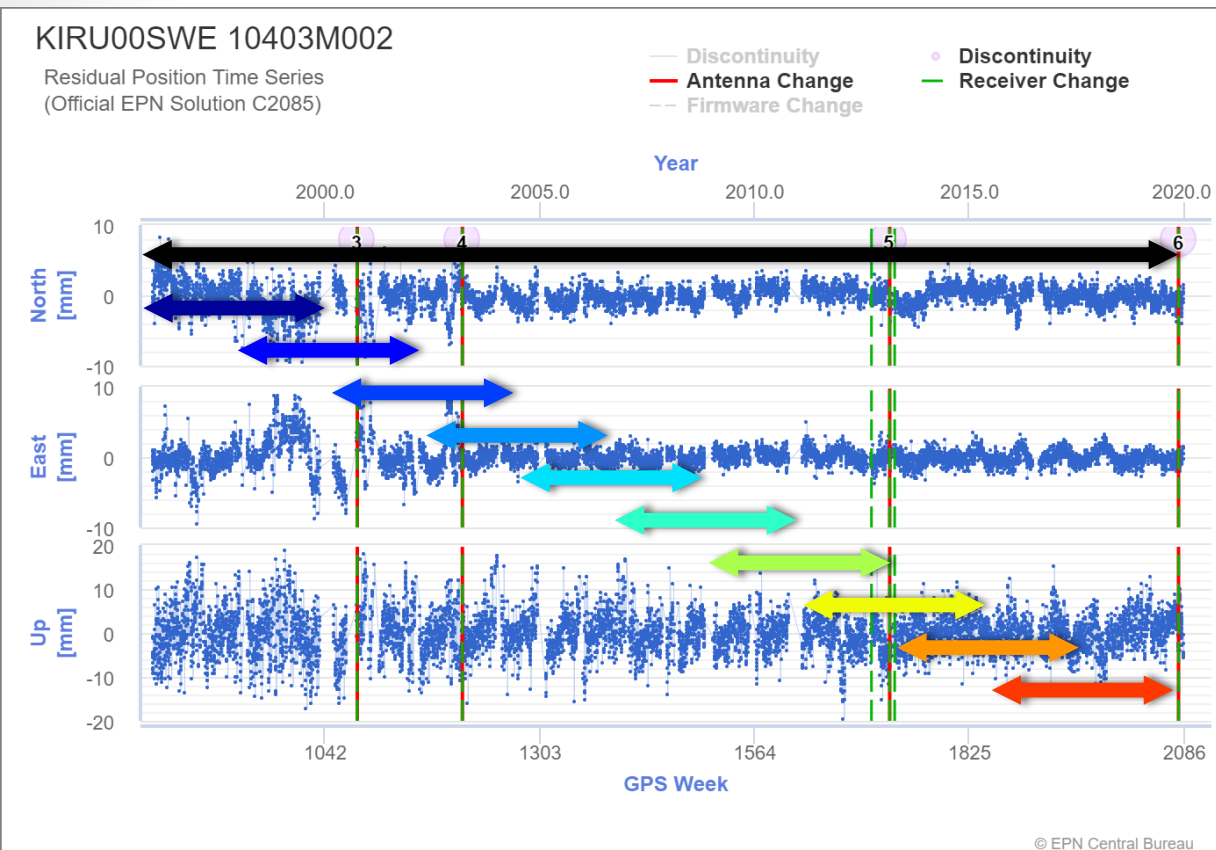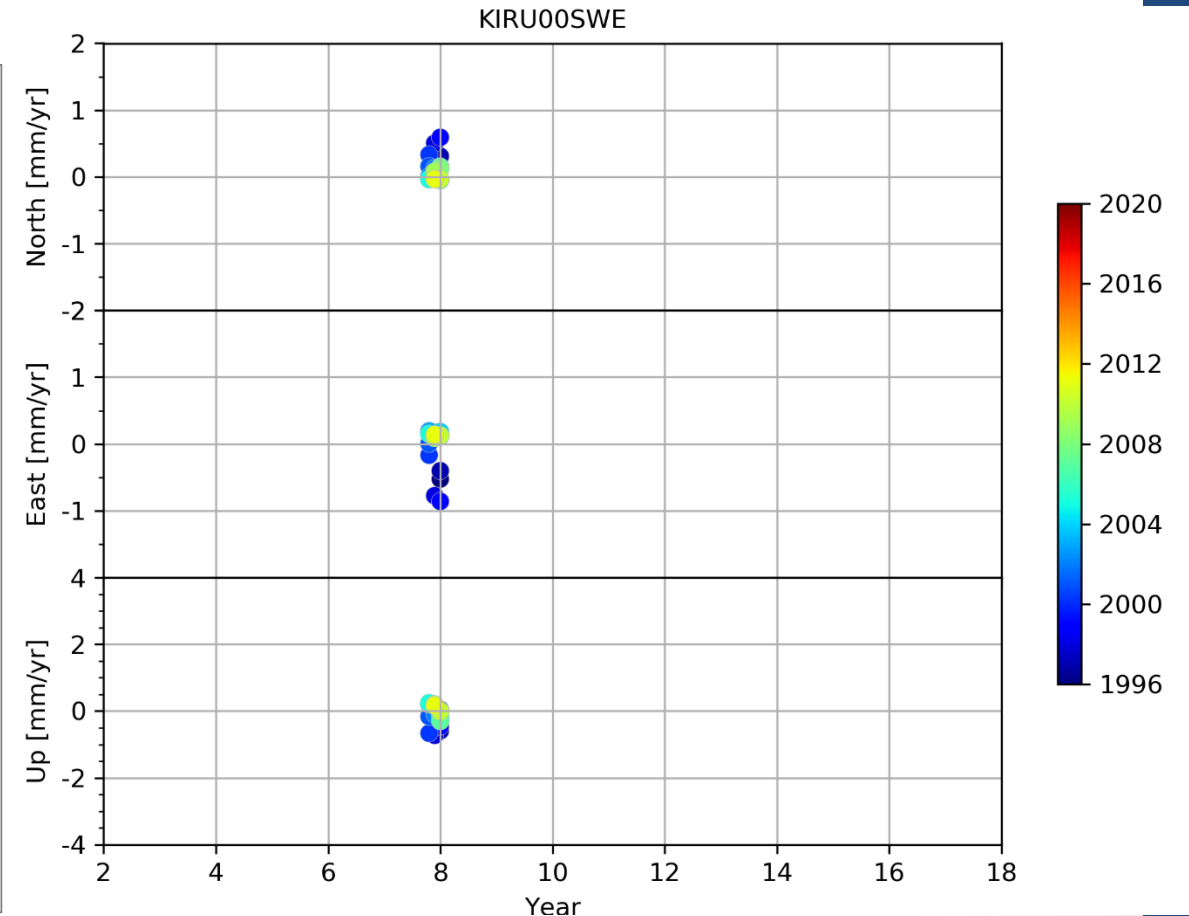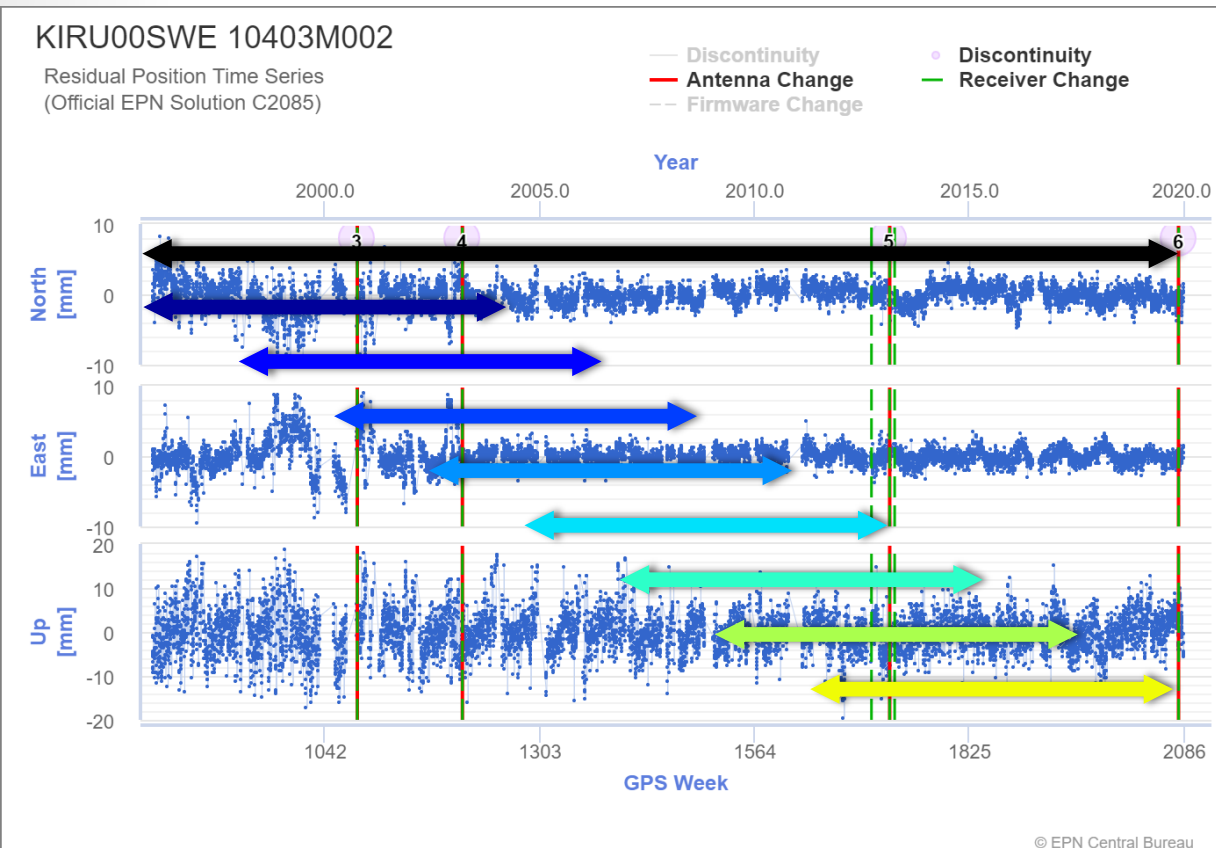
# Velocity Variability (3)
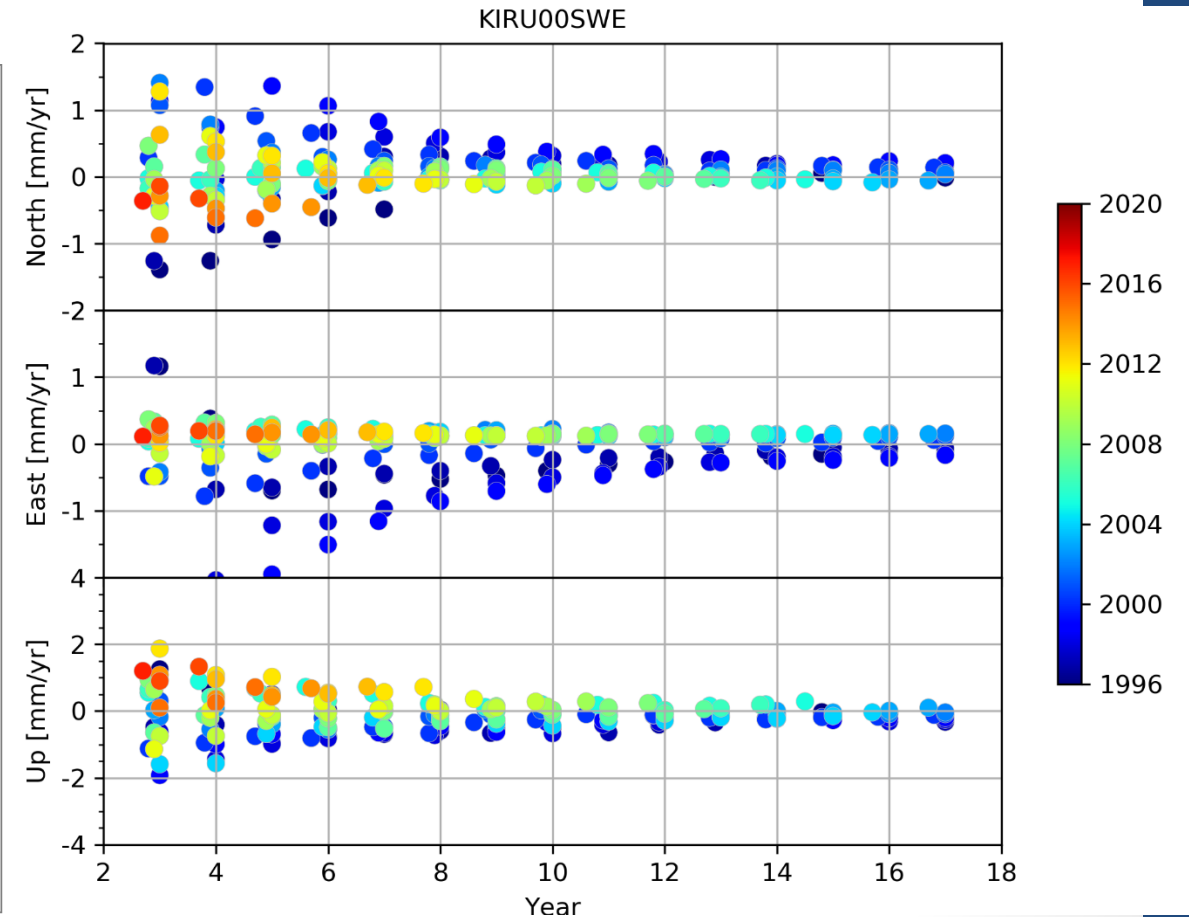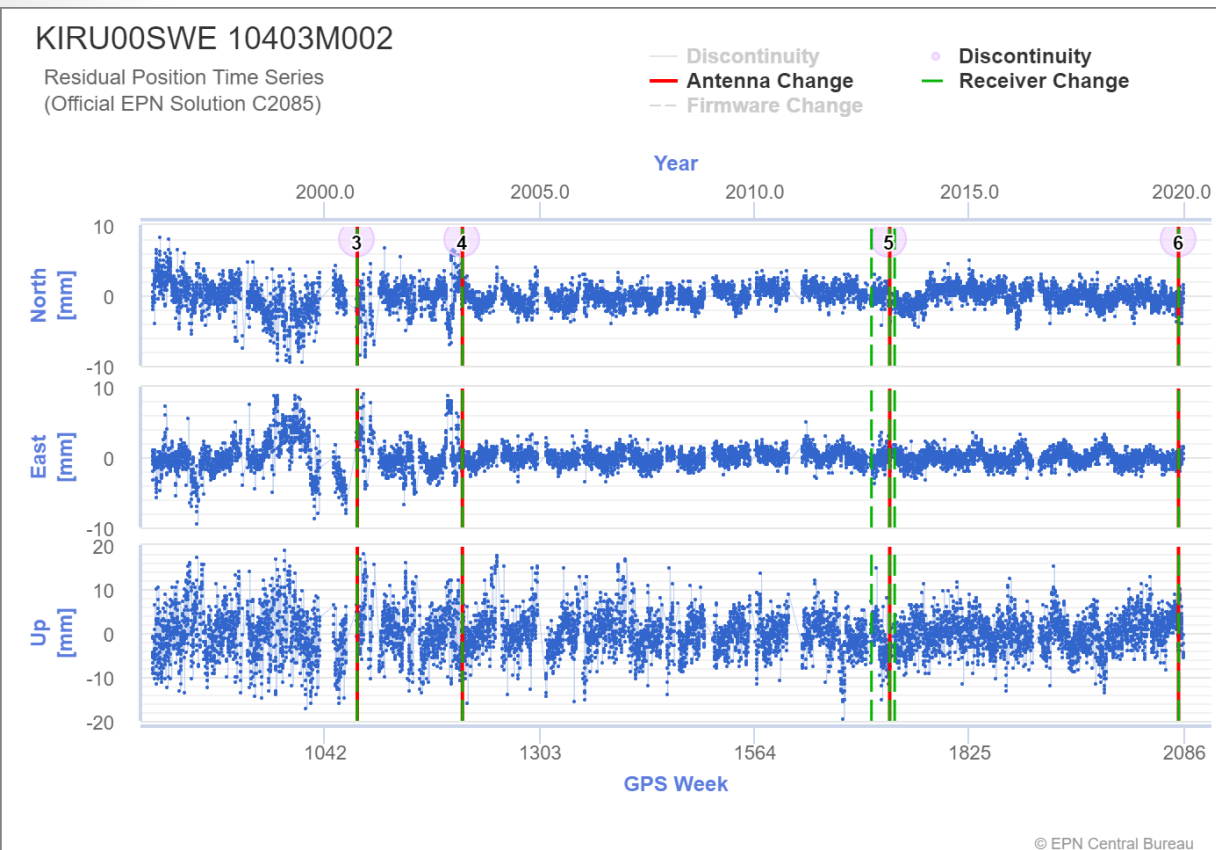
Input time series: position time series
with jumps and trends

Differences between the velocities based
on various time windows (3 to 17 years)
and the velocity based on full data set of
the station

# Velocity Variability (4)

**Velocity Variability (NdV, EdV, UdV):**
RMS of the agreement between the station velocities obtained from the moving time windows (> 4 years) and the velocity obtained using the full time series.

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(top)      Detrended position time series (with jumps)
(middle)  Velocity variability plots
(bottom) Value of the velocity variability
                 for 5 stations (ONSA00SWE, VIGO00ESP, TERS00NLD, MORP00GBR, MEDI00ITA)
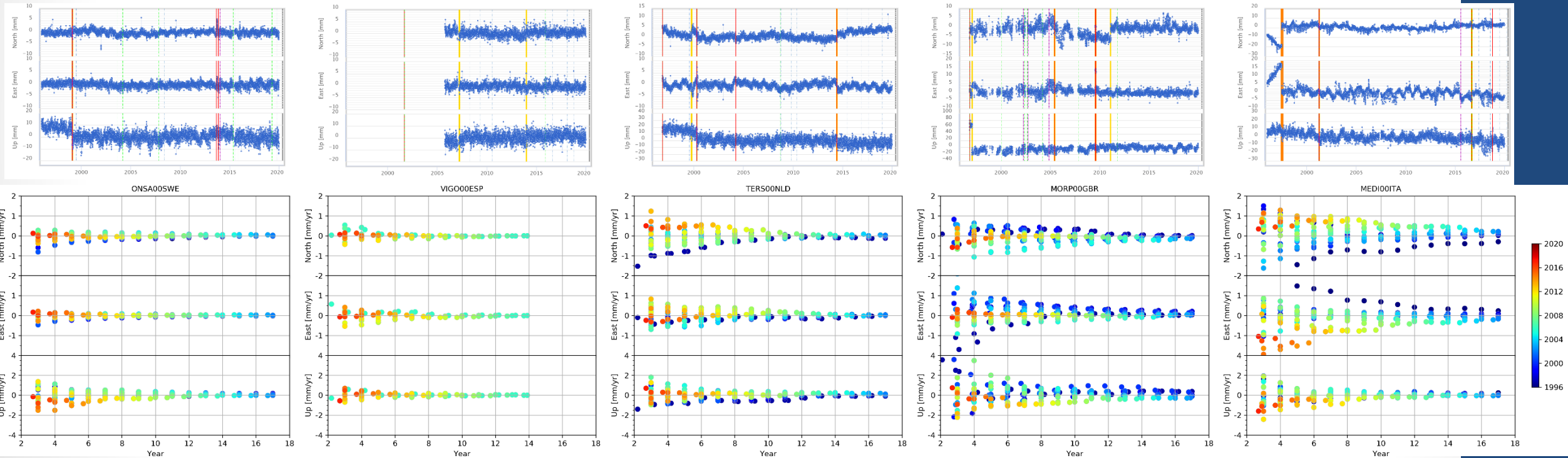


| [mm/yr] | ONSA00SWE | VIGO00ESP | TERS00NLD | MORP00GBR | MEDI00ITA |
|---|---|---|---|---|---|
| NdV | 0.12 | 0.09 | 0.24 | 0.27 | 0.50 |
| EdV | 0.07 | 0.12 | 0.19 | 0.29 | 0.45 |
| UdV | 0.29 | 0.15 | 0.33 | 0.61 | 0.34 |

# Selection Criteria Plots:

Black circles: values for each of the criteria for the stations ONSA00SWE, TERS00NLD, MORP00GBR, MEDI00ITA

Bars: the green, orange and red colours highlights the percentiles 25, 50, 75, 85, 95 for the EPN stations.

# The Thresholds



Percentile 75  Percentile 85  Percentile 95

$A(1Y)_{North}$ [mm]

# Stations

75% best stations

25% worst stations

15% worst stations
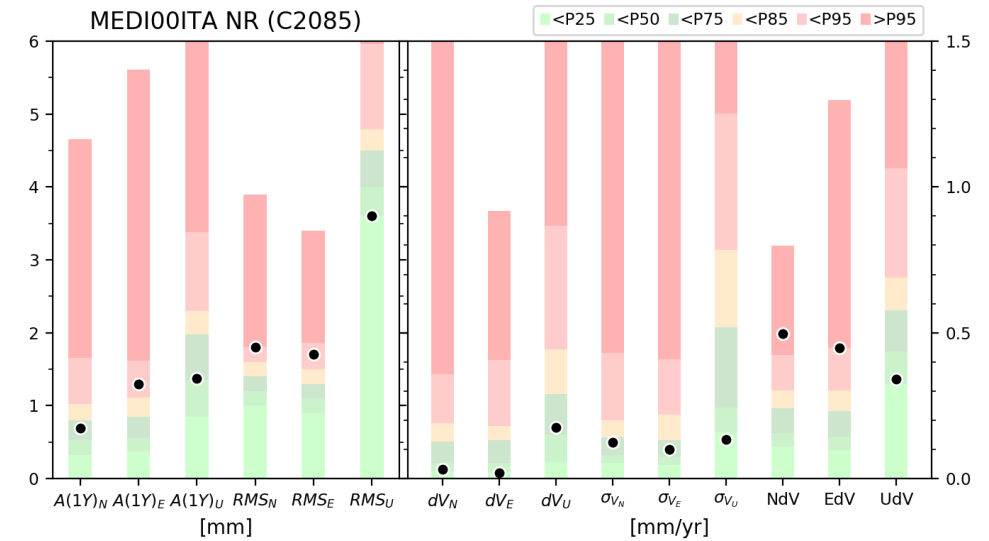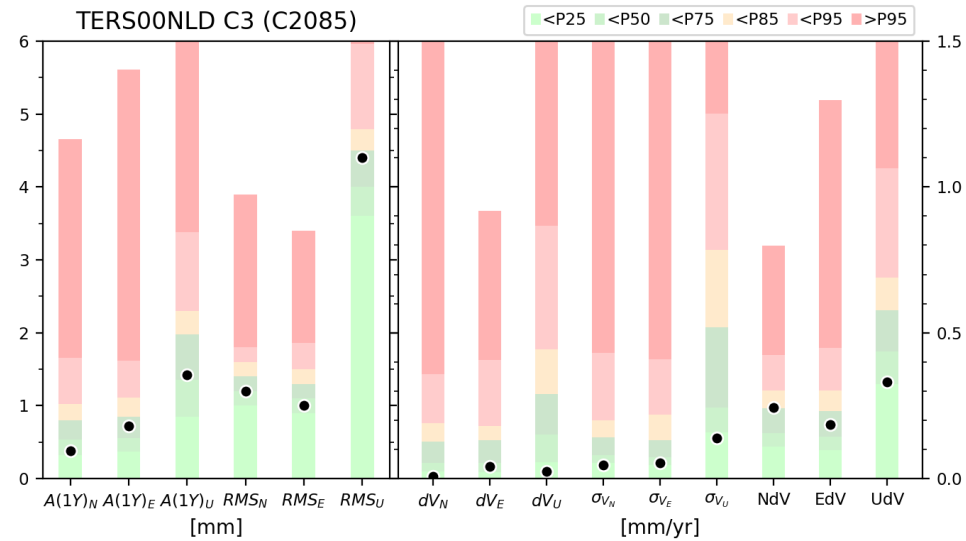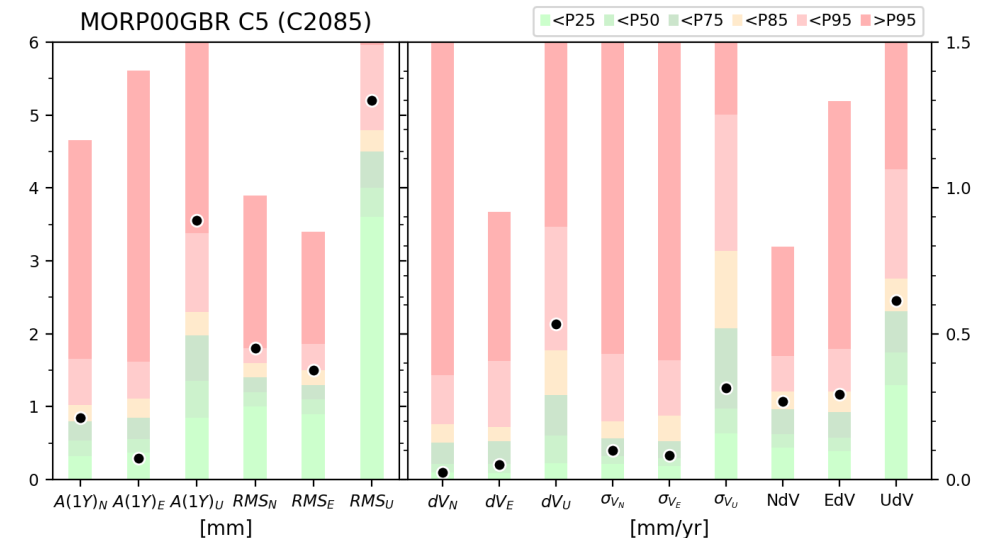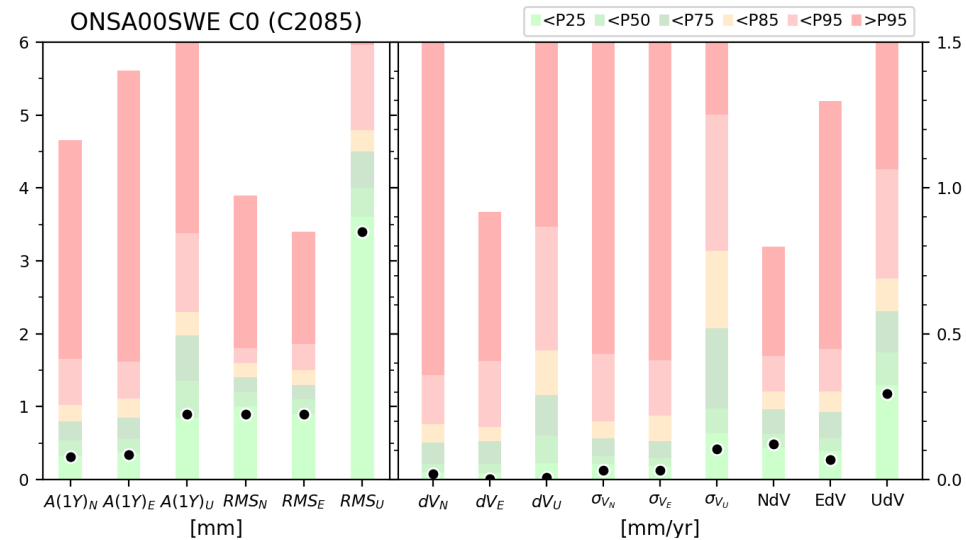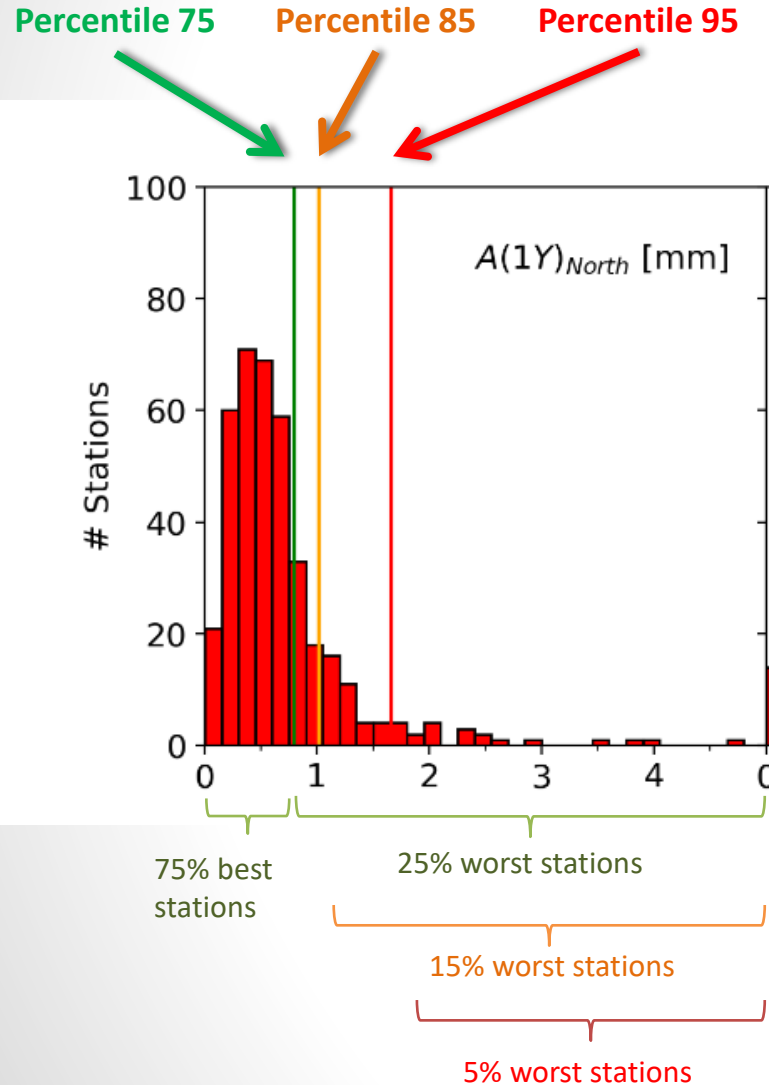
5% worst stations

- Goal: find the reliable reference stations
- Idea: reject the station that have the worst performances for each criterion

- The thresholds are based on 3 different percentiles: percentile 75, 85 and 95.

- Thresholds are relaxed step by step in order to define the different classes

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# The Station Classes

- Seven classes have been defined by relaxing the thresholds step by step.

| Name | Number | Velocity variability | Timeseries RMS | Amplitude 1Y signal | DV_Catref-Hector | σ_Hector | Comment |
|---|---|---|---|---|---|---|---|
| C0 | 55 | < Percentile 75 | < Percentile 75 | | | | Most Stable Stations |
| C1 | 28 | < Percentile 75 | < Percentile 85 | | | | |
| C2 | 51 | < Percentile 75 | No threshold | | < Percentile 85 | | Stable but Noisy or with Seasonal Signals |
| C3 | 16 | < Percentile 85 | < Percentile 85 | | | | Less Stable |
| C4 | 8 | Not Available - Short time series | < Percentile 85 | | | | |
| C5 | 66 | < Percentile 85 | No criteria > Percentile 95 | | | | Even Less Stable |
| C6 | 115 | 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 | 76 | < 3yr - not applicable | | | | | No velocity published |

More information:
http://epncb.oma.be/_productsservices/ReferenceFrame/Station_Classification.php

under evaluation within EUREF

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# Web Tool for Selecting Reference Stations

http://epncb.oma.be/_productsservices/ReferenceFrame/

- The goal of the tool is to help the user to choose the EPN reference stations to process together with their network $\Rightarrow$ BEFORE the GNSS processing
- Input:
  - Begin and end dates of the solution $\Rightarrow$ define the time span of the stations
  - Optional: pre-selected list of reference stations
- Output:
  - Interactive map with 3 station categories:
    - recommended, usable and not recommended
      $\Leftarrow$ depending on station time span and station class
  - Additional information and plot
  - Possibility to select and de-select reference station
  - Export of list of long markername, table, Bernese FIX file and CATREF xvret.dat file

under evaluation within EUREF

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# Conclusions

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- Both the classification and the tool are under evaluation within EUREF

- A demo version is available online    http://epncb.oma.be/_productsservices/ReferenceFrame/

- The tool helps the selection of optimal reference stations by providing a restricted list of reference stations and by giving access to additional information (number of position or velocity discontinuities, post-seismic deformation,...) and plots (detrended position time series, selection criteria values, velocity variability) for the stations

- Future improvements:
  - Take into account the geometry of the network
  - Improve usage of the information concerning the period of observation

Questions/Comments: Juliette.Legrand@oma.be