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Quality of multi-GNSS precise point positioning using stochastic modeling of the clock parameter

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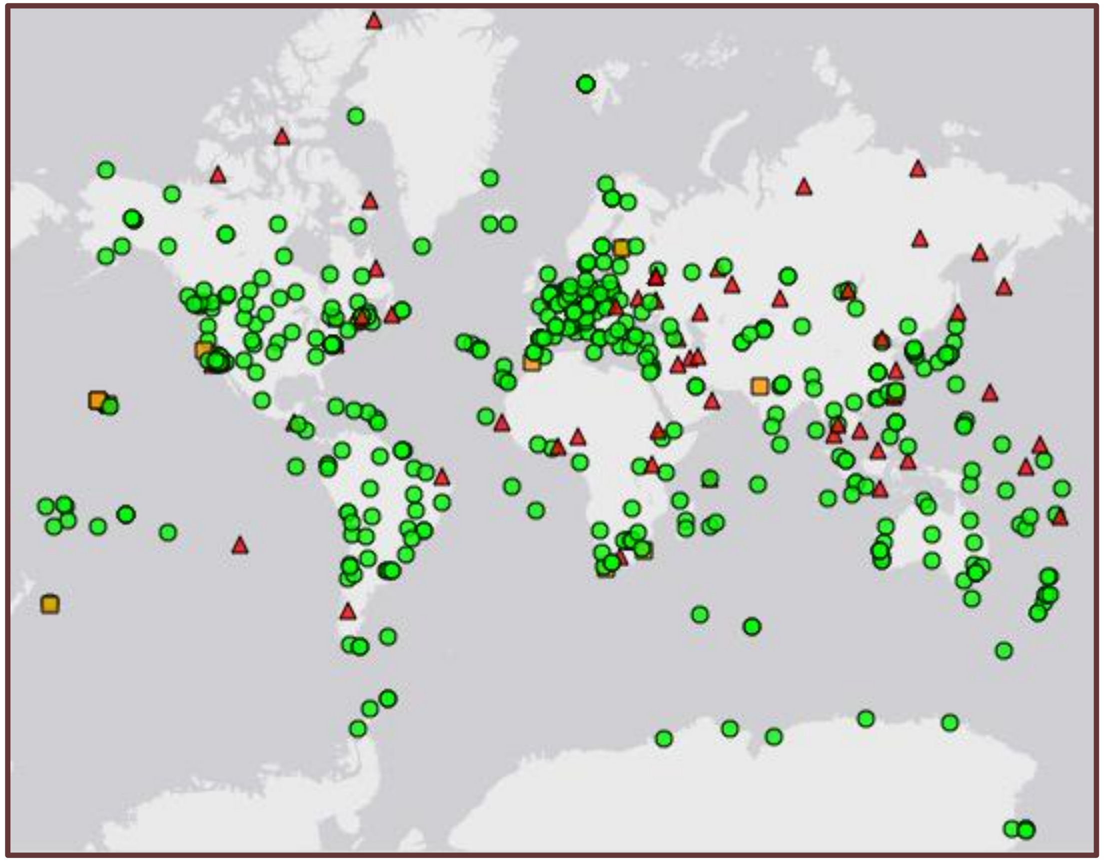
IGS Network / Types of clocks

- Not all stations track multi-GNSS:
  - GPS (**G**)
  - GLONASS (**R**)
  - Galileo (**E**)
  - BeiDou (**C**)

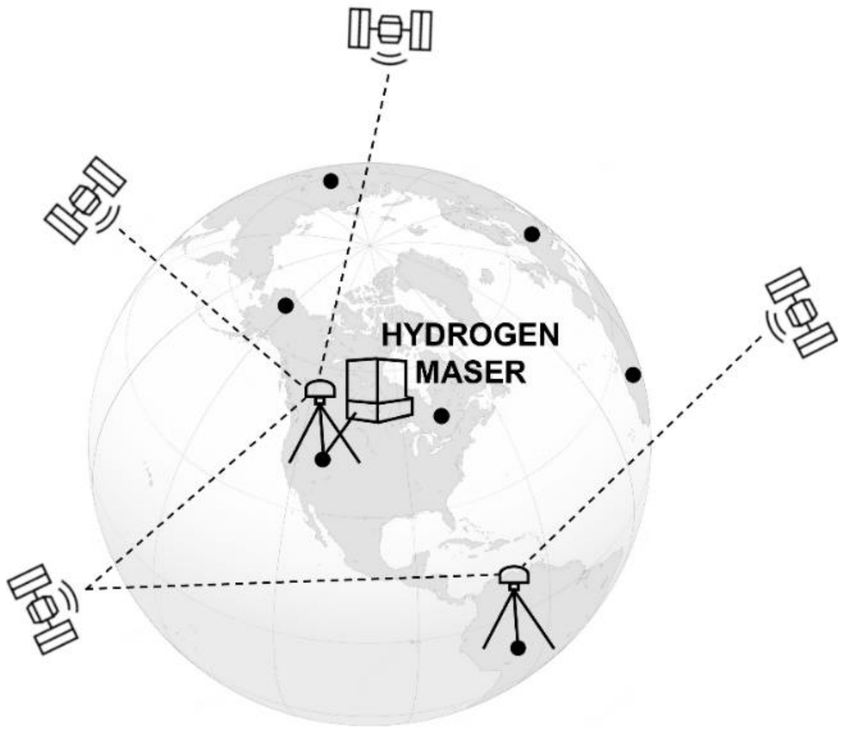
- Different types of clocks:
  - Internal crystal oscillator (**XO**)
  - Atomic clocks:
    - Rubidium (**Rb**)
    - Cesium (**Cs**)
    - Hydrogen Maser (**HM**)



Source: https://igs.org/network/

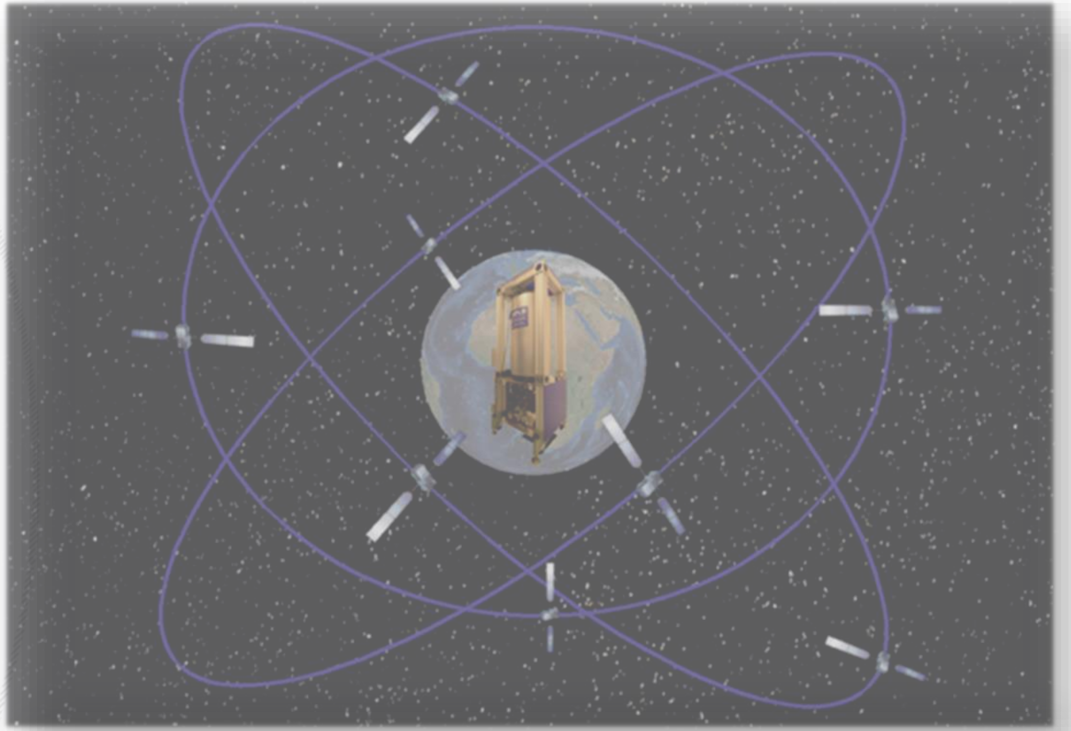
Station IGS selection / Methodology

- Different continents
- Systems: G, R, E, C
- Different receivers and antennas
- Clocks: XO, Rb, Cs, HM
- Final MGEX CODE products
- Measurement technique: Precise point positioning (PPP)
- Type of solutions: Monthly kinematic solutions (in continuous processing)
- Calculation interval: 30s



GNSS-WARP
Wroclaw **A**lgorithms
for **R**eal-time **P**ositioning

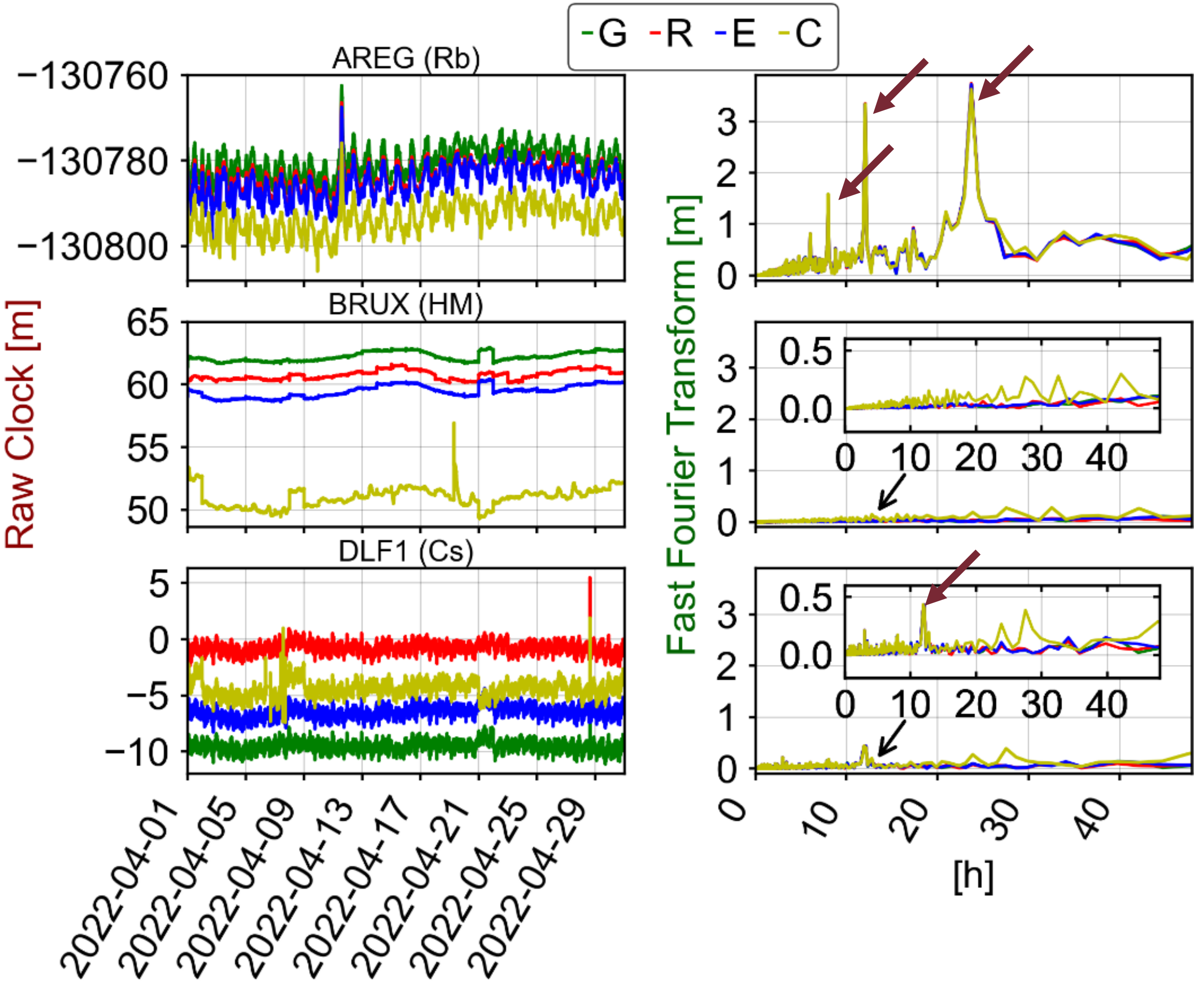
Python



STABILITY OF CLOCK PARAMETER

Raw / Fast Fourier Transform (FFT) - clock parameters

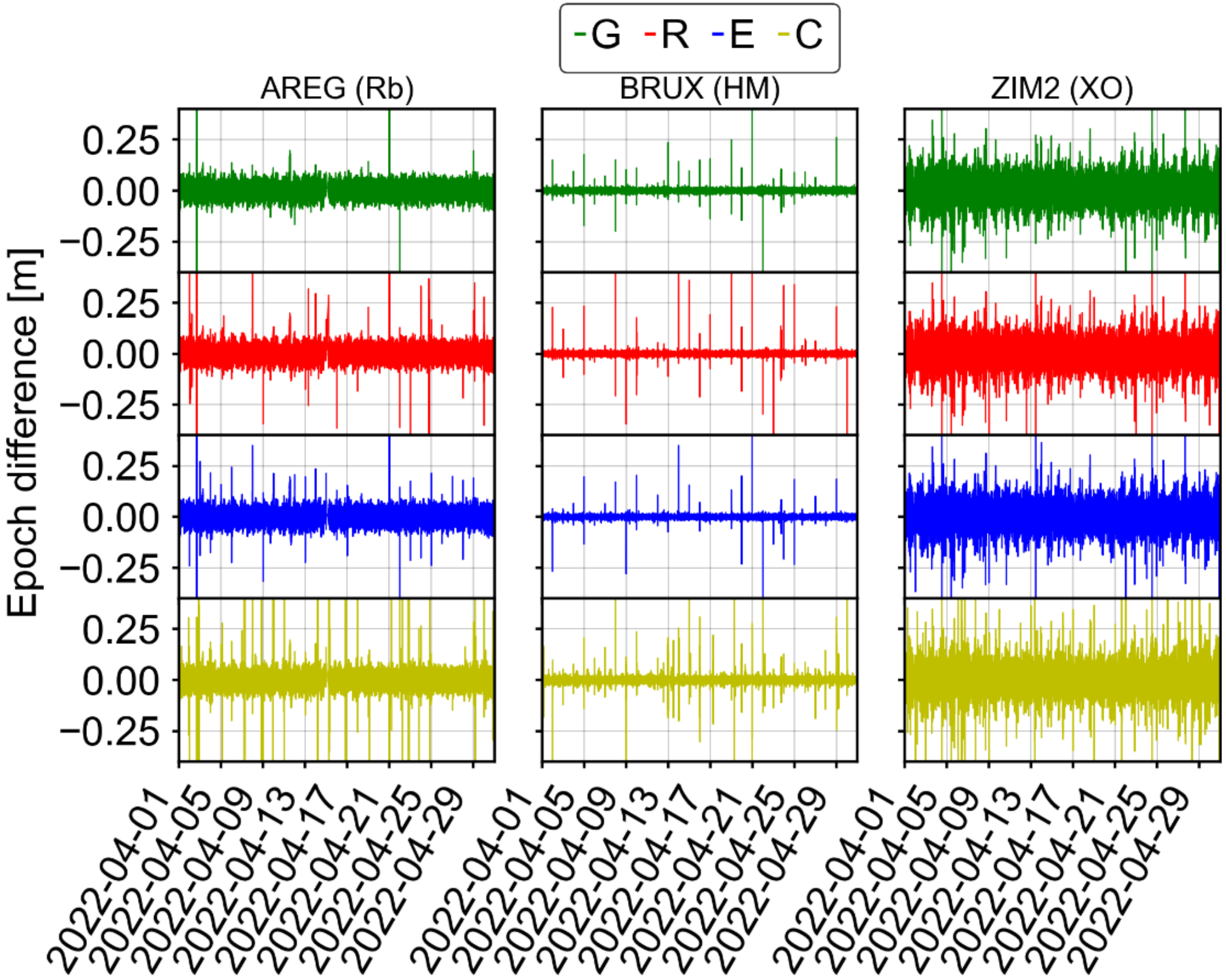
- Clock stability characteristics depends on the type of the clock
- Least noise results on BRUX station with HM clock
- The stability of the C system is lower than for other systems (see BRUX)
- Less stable clocks clearly indicate 24h, 12h, and 8h signals based on the FFT analysis
- Results for the system C show more characteristic signals
- Similar values achieved by all systems for less stable clocks (AREG) and similar results for G, R, and E for more stable stations (BRUX, DLF1)



Differentiation of adjacent clock epochs - short-term stability

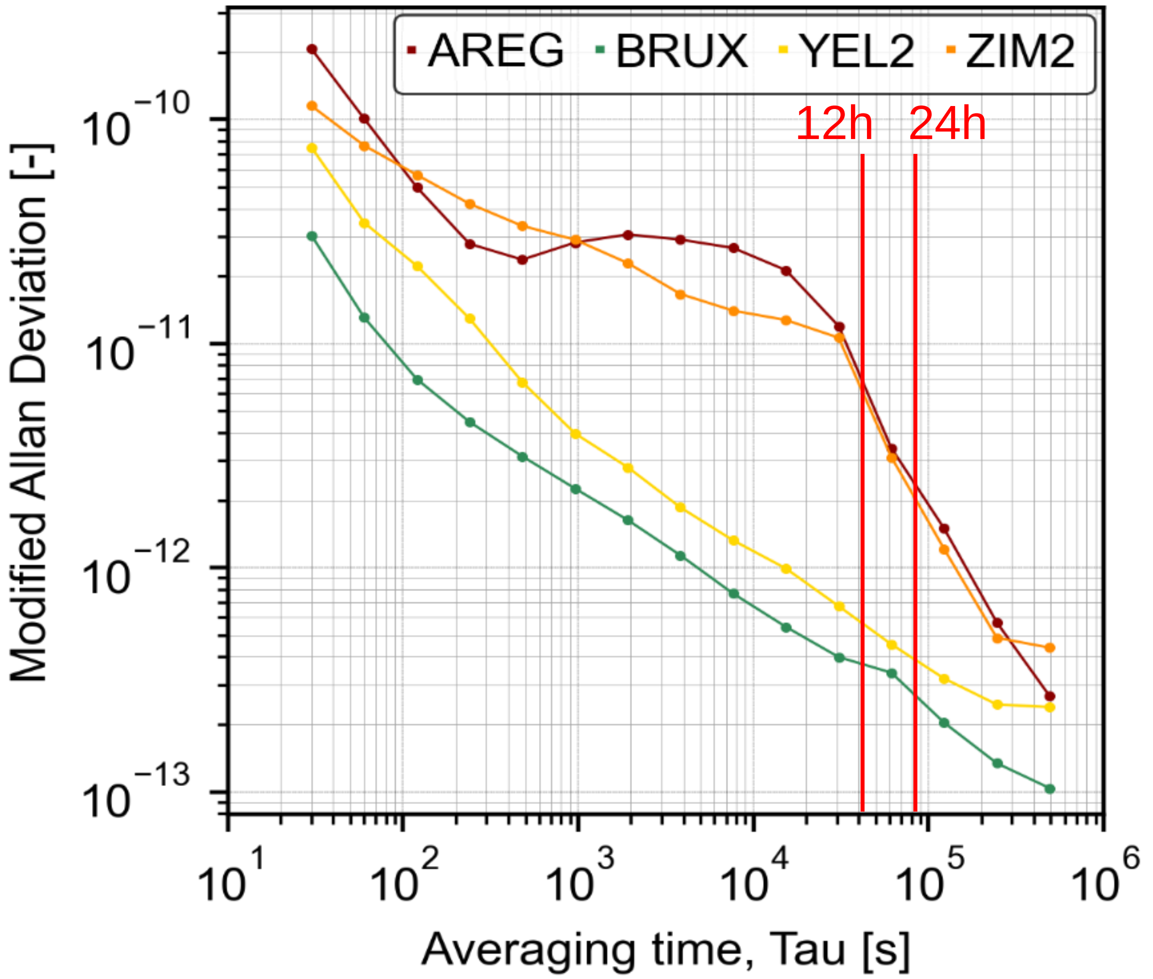
STD [m]	G	R	E	C
AREG	0.031	0.031	0.030	0.049
BRUX	0.008	0.009	0.008	0.028
ZIM2	0.040	0.040	0.040	0.059

IQR [m]	G	R	E	C
AREG	0.036	0.036	0.036	0.037
BRUX	0.007	0.007	0.007	0.010
ZIM2	0.044	0.044	0.044	0.046

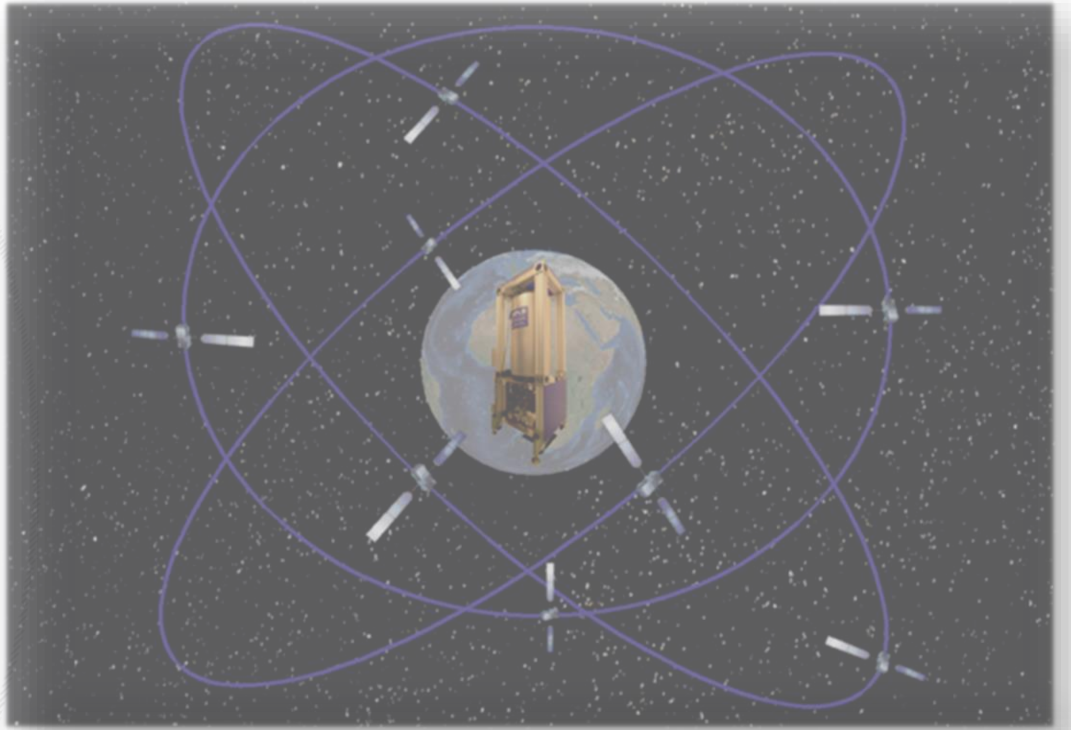


Modified Allan deviation (MDEV) - long-term stability for G system

- AREG (Rb), BRUX (HM), YEL2 (HM), and ZIM2 (XO)
- BRUX station clock achieves the highest stability
- More stable clocks contain mostly white noise
- Less stable clocks also contain other types of noise (such as flicker noise and random walk)



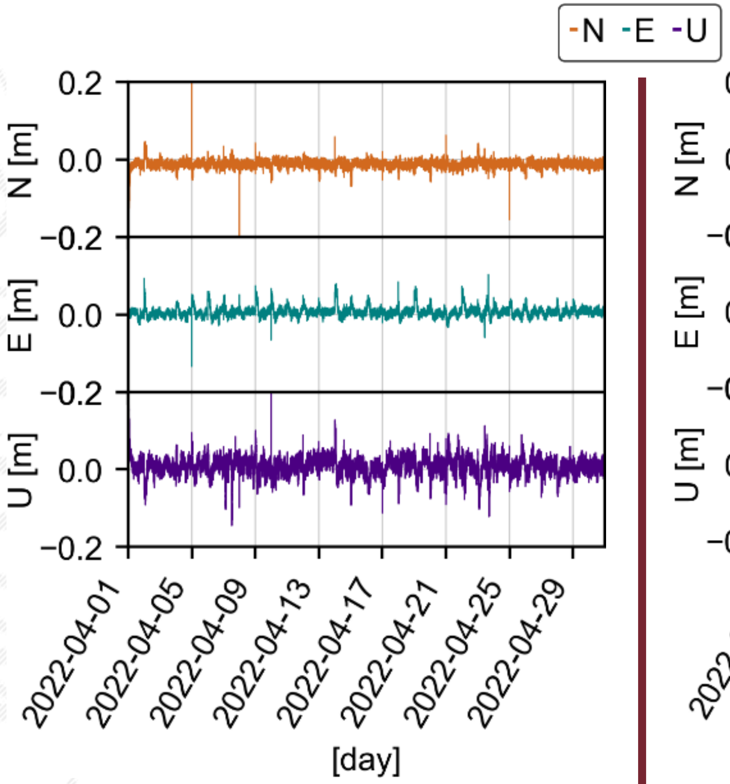
Period: 01.04.2022 – 30.04.2022



DETERMINATION OF THE CLOCK PARAMETERS

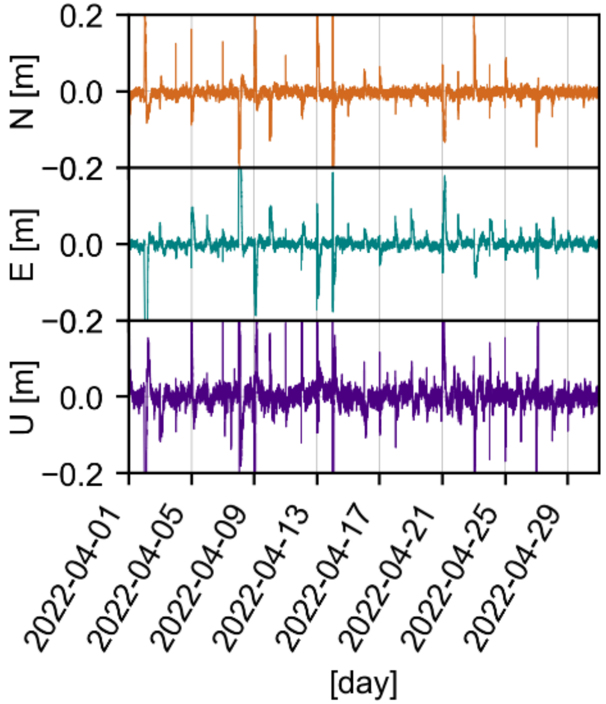
Determination of the clock parameters – PTBB (HM)

- **Independent clock parameters**
- For each measurement epoch, four clock parameters are calculated (G, E, R, C)



	N	E	U
STD [m]	0.013	0.014	0.032
IQR [m]	0.010	0.011	0.025

- **Clock parameter from G system with Inter-System Biases (ISB) to other systems (R, E, C)**
- One parameter is calculated for each epoch and the ISB for the other systems is determined once per day



	N	E	U
STD [m]	0.027	0.037	0.057
IQR [m]	0.011	0.012	0.026

Which solution is better?

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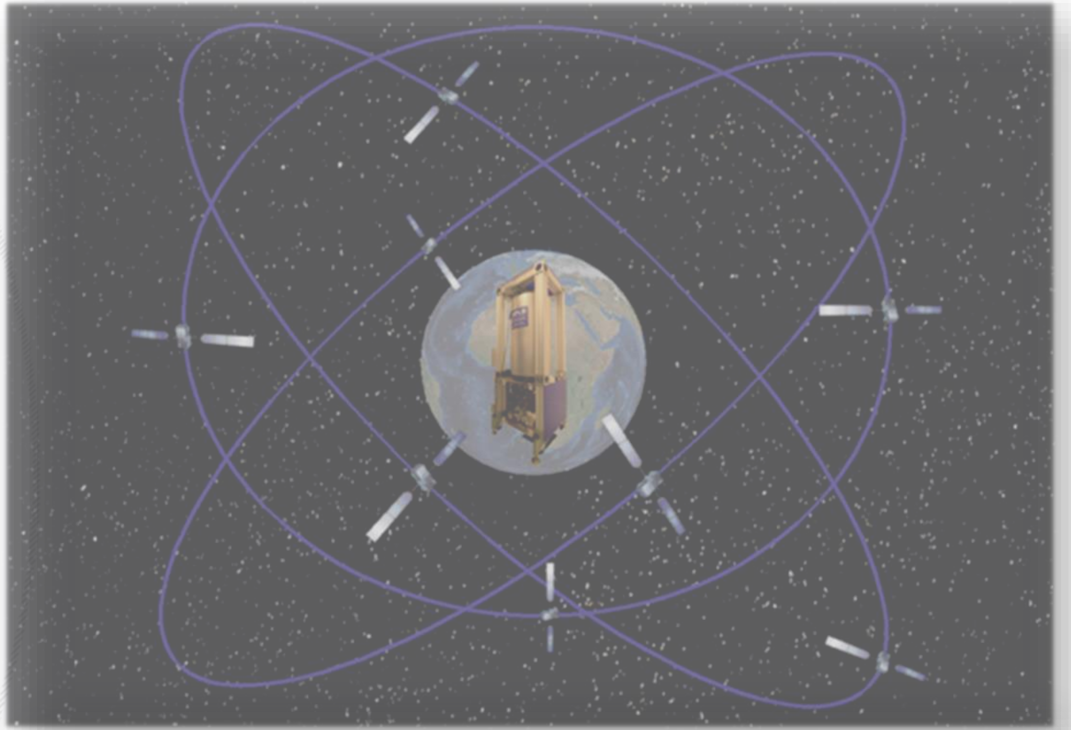


STOCHASTIC MODELING OF THE CLOCK PARAMETER

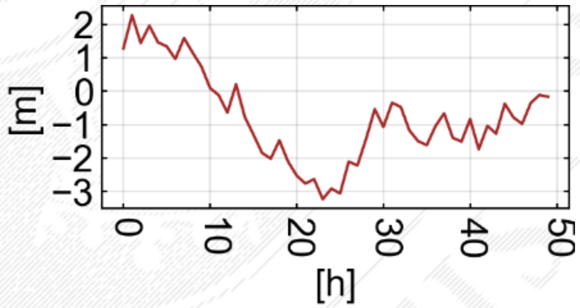
Stochastic modeling of the clock parameter

stochastic modeling = random walk (RandWlk) + reset of receiver clock parameter at the boundary of the day

$$\mathbf{RandWlk} = \frac{\mathbf{values}}{\sqrt{\mathbf{t}}}$$

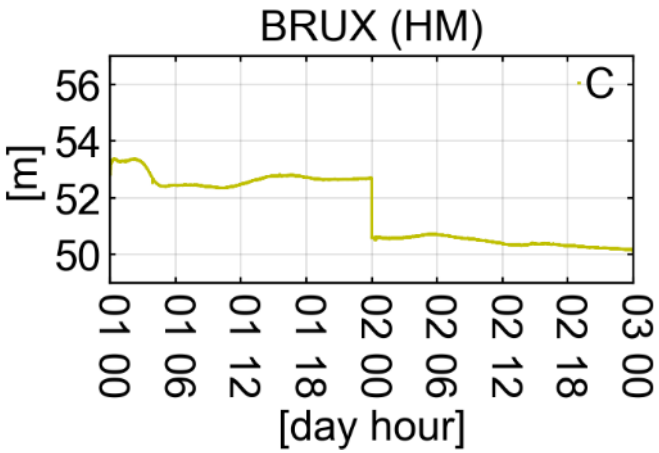
- **t** – interval between observations, files RINEX (30s)
- **values** – estimated value

Values [mm]:
10 - 250



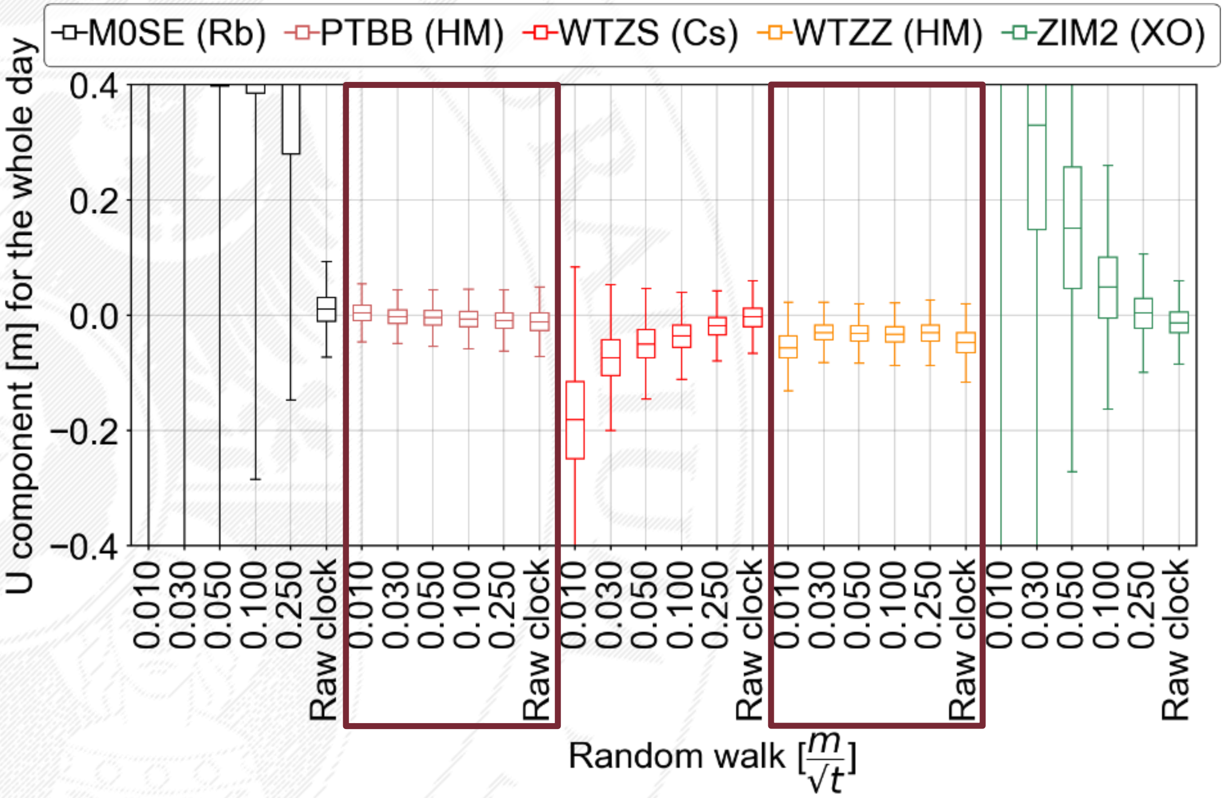
Random walk is the process of determining the probable position of a point subject to random motion.

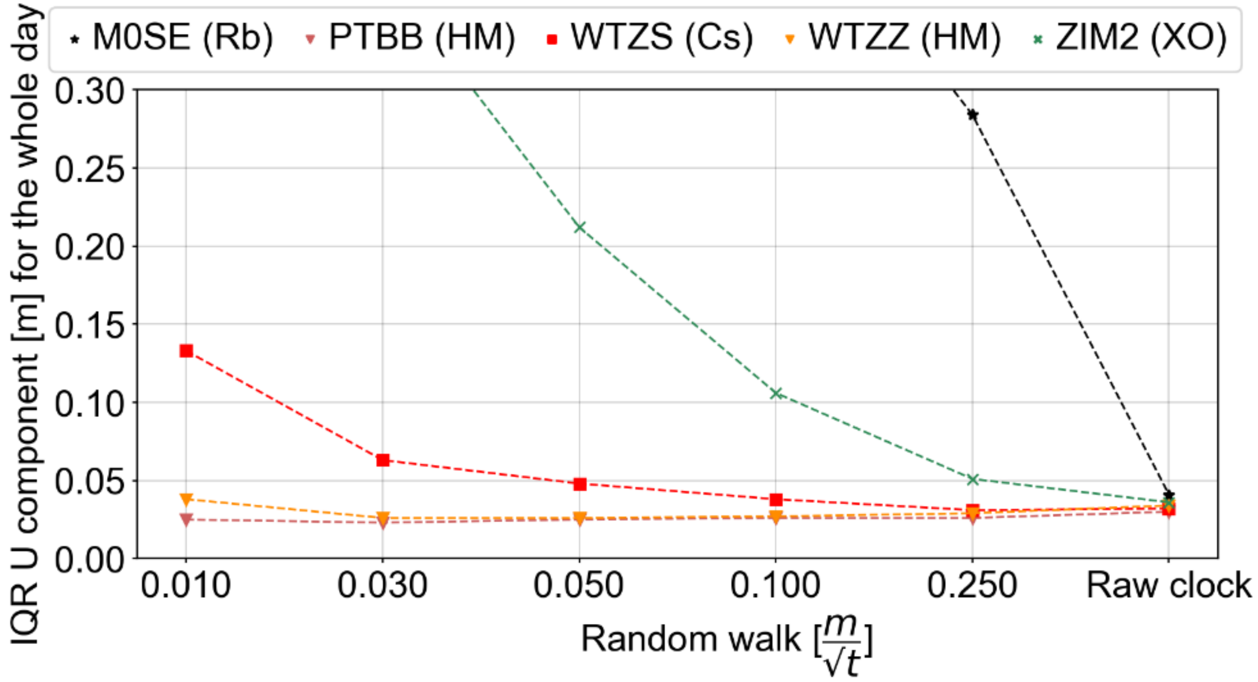
The **clock** components for each system are **reseted** at the **boundary of the day**. This is done by increasing the values at the corresponding epochs on the diagonal elements in the covariance matrix.



Stochastic modeling of the clock parameter

Period: 01.05.2021 – 31.05.2021





kinematic solution, multi-GNSS (G,R,E,C)

	M0SE	PTBB	WTZS	WTZZ	ZIM2
Best solution	Raw clock	$\frac{0.030\,m}{\sqrt{30\,s}}$	Raw clock	$\frac{0.030\,m}{\sqrt{30\,s}}$	Raw clock
IQR [m]	0.041	0.023	0.032	0.026	0.036

Stochastic modeling superimposed on the clock parameter is effective for the most stable clocks (HM).

Conclusion

- Analysis of the stability of the GNSS clocks allows for deriving stochastic parameters for clock modeling – there are large differences between HM, Cs, Rb, and XO clocks
- The clock parameters can be determined independently for each system or for one system along with the inter-system biases (ISB) for the other systems
- Stochastic modeling superimposed on the clock parameter is effective for the most stable clocks (HM) improving the stability of the solution

In the future

- Further analysis of the determination of the clock parameters independently for each system and for one system together with the ISB for the other systems
- Further study of determining stochastic modeling for the clock parameters to optimize station coordinate repeatability

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Thank you for your attention!

Further reading:

- Mikoś, M., Kazmierski, K., & Sośnica, K. (2023). Characteristics of the IGS receiver clock performance from multi-GNSS PPP solutions. GPS Solutions, 27(1), 1-13. DOI: https://doi.org/10.1007/s10291-023-01394-9

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