Enhancing Multi-GNSS clock combination for Precise Point Positioning

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KONFERENCE DRUŽICOVÉ METODY V TEORII A PRAXI (GNSS 2025)

Introduction

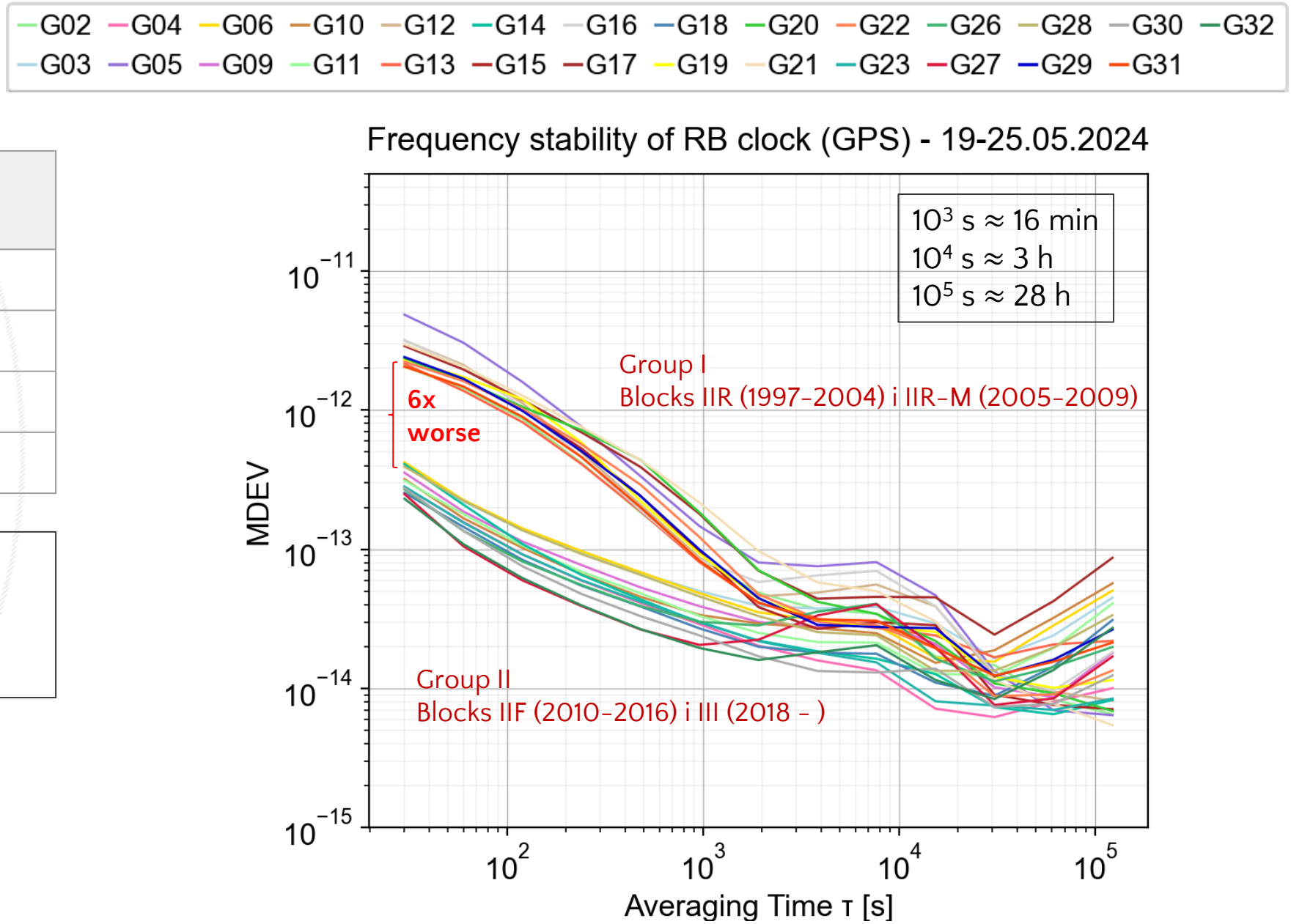
- Highly accurate and stable satellite orbit and **clock products** are crucial in precise positioning, navigation and time synchronisation in Global Navigation Satellite Systems (GNSS).
- **International GNSS Service (IGS)** provides clock products in the form of time offsets in reference to selected ground stations clocks.
- They are delivered individually by different **Analysis Centers (AC)**.

https://www.esa.int/Applications/Navigation/Galileo_clock_anomalies_under_investigation

Introduction

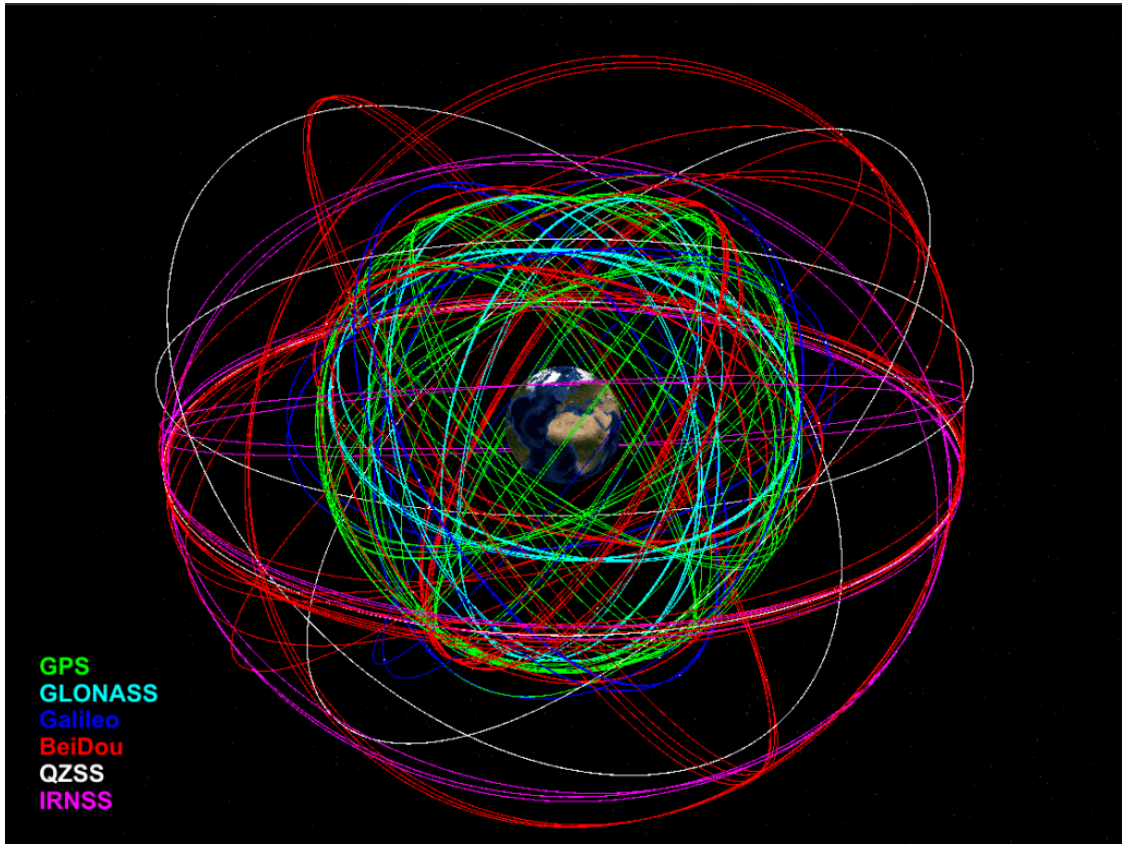
Navigation system	Clock type
GPS	RB, CS
Galileo	RB, PHM
GLONASS	CS
BeiDou	RB, PHM

RB – Rubidium
CS – Cesium
PHM – Passive Hydrogen Maser
MDEV – Modified Allan Deviation



Motivation

- There is still lack of unified, **combined multi-GNSS clock products** that includes GPS, GLONASS, Galileo, and BeiDou.
- The purpose of our research is to develop the **multi-GNSS clock product combination** for user applications.
- It would increase the **reliability** and **consistency** of multi-GNSS positioning and timing.



https://ggos.org/item/gnss-orbits-clocks/

Methodology

- The combination of orbit and clock products is conducted by the **Satellite Precise Orbit and Clock Combination (SPOCC)** software tool developed at GFZ Potsdam.
- Combined products are weighted average of the individual **AC solutions** with weights iteratively determined based on **least-squares variance component estimation (VCE)**.

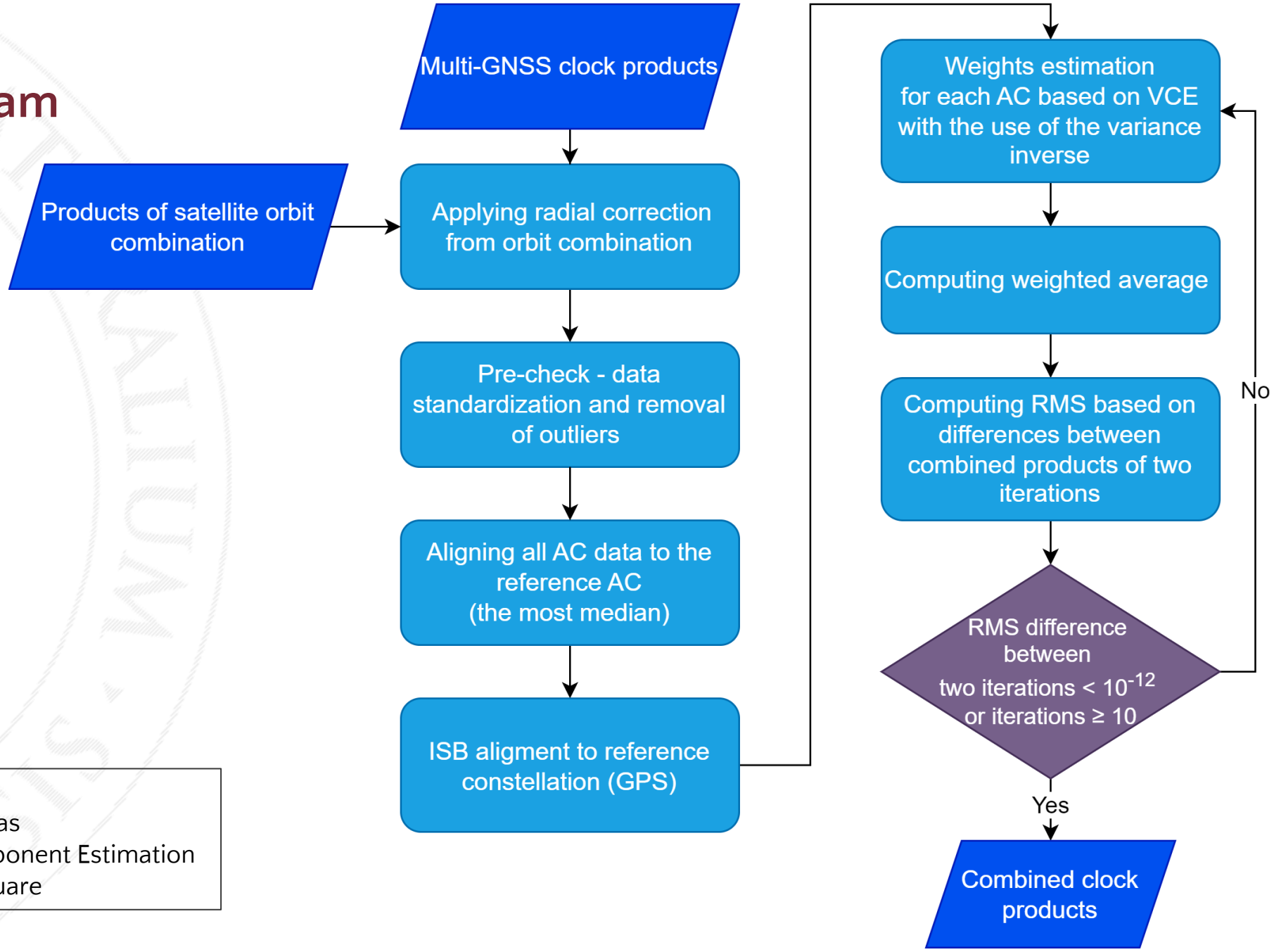
GFZ Helmholtz Centre for Geosciences

python™

spyder

Link to **SPOCC** page with references:
https://gnss.gfz.de/services/spocc

SPOCC Block Diagram

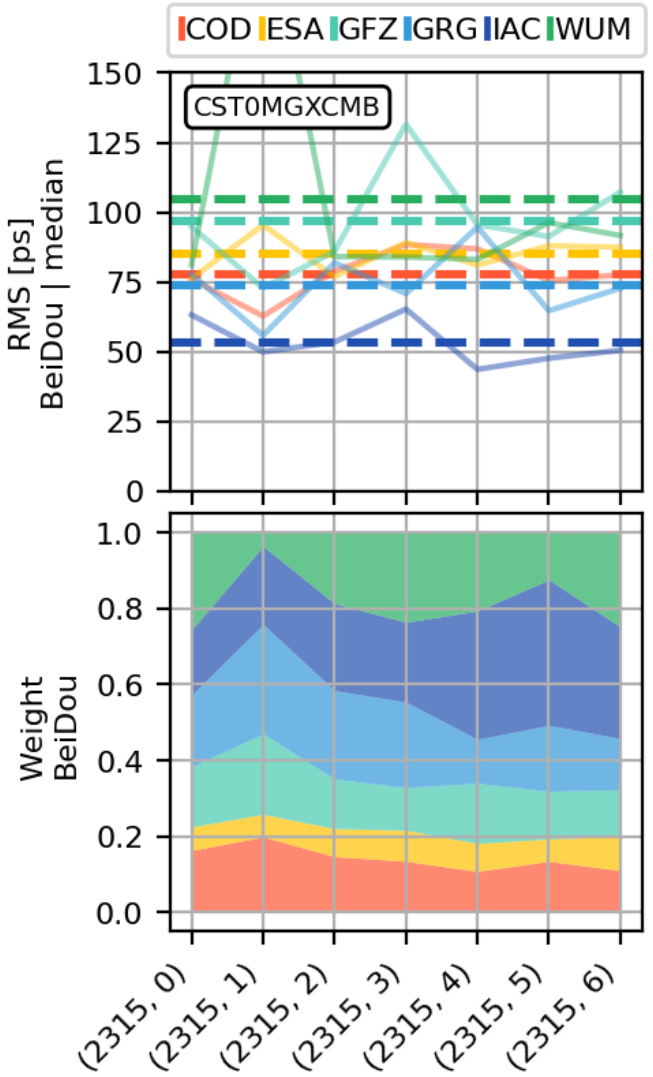


AC – Analysis Center
ISB – Inter-System Bias
VCE – Variance Component Estimation
RMS - Root Mean Square

Analysis Centers taking part in combination

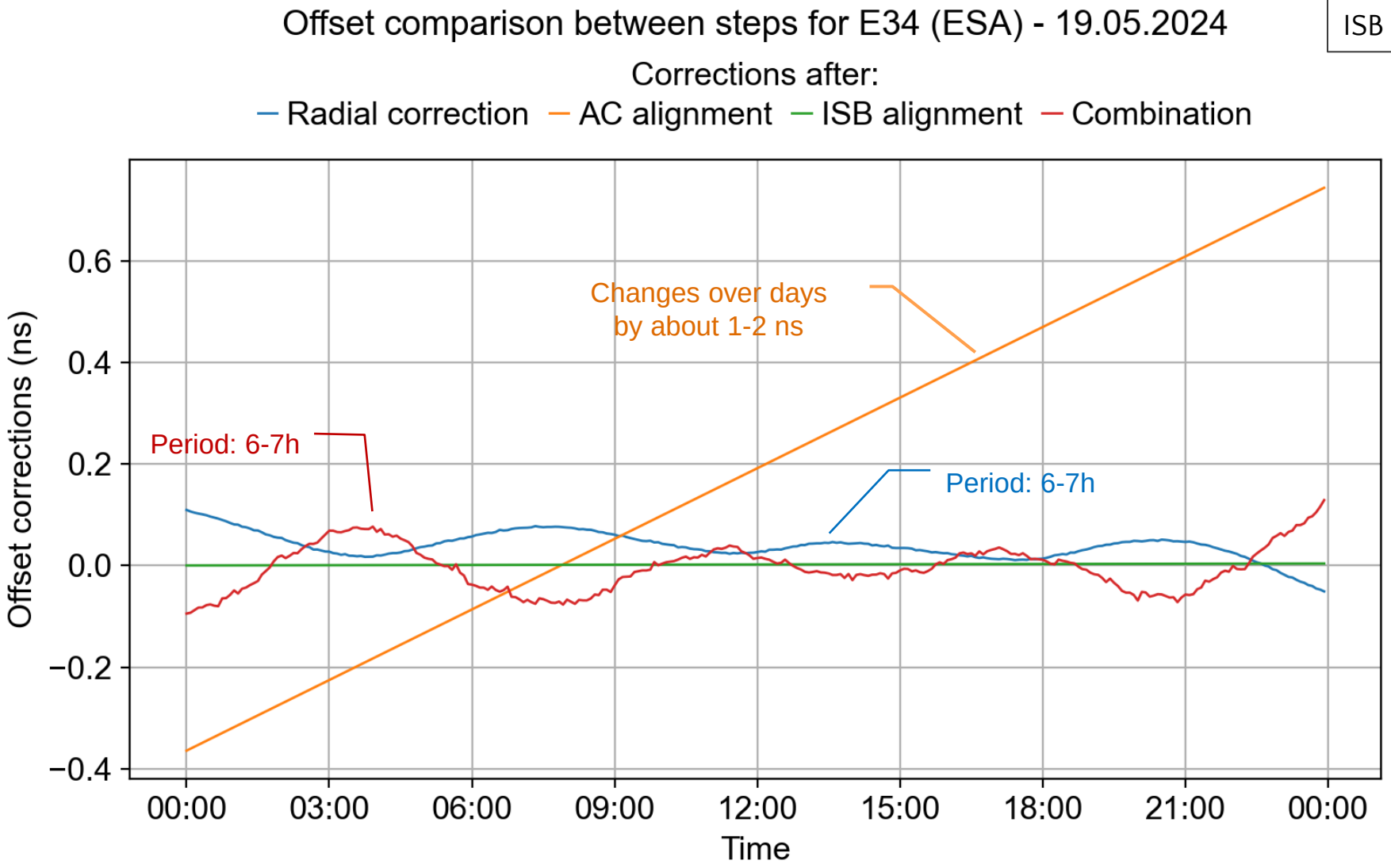
- COD: Center for Orbit Determination in Europe
- ESA: European Space Agency Final
- GFZ: GeoForschungsZentrum Potsdam
- GRG: Centre National d'Etudes Spatiales (CNES/CLS)
- IGS: International GNSS Service
- IAC: Information and Analysis Cente
- JAX: Japan Aerospace Exploration Agency
- JPL: Jet Propulsion Laboratory
- WUM: Wuhan University

Final AC weights for combination – BeiDou (19-25.05.2024)



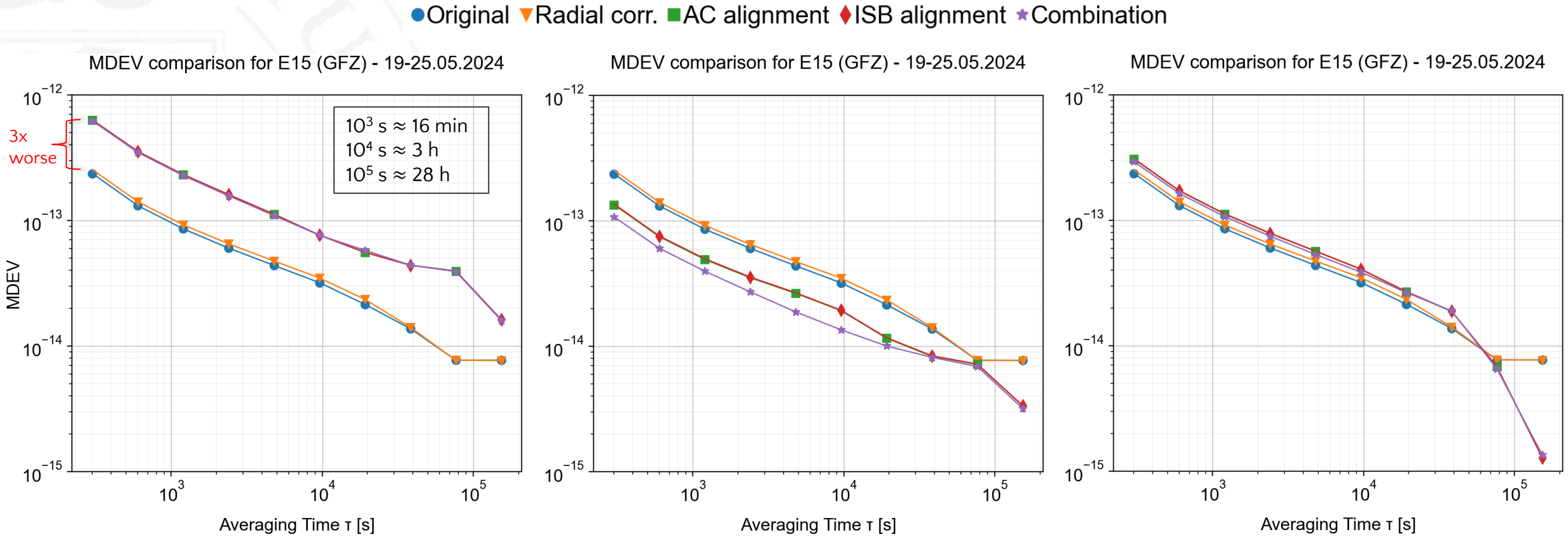
Clock correction comparison across combination steps

AC – Analysis Center
ISB – Inter-System Bias



MDEV plots of clock offsets across combinations steps

AC – Analysis Center
ISB – Inter-System Bias
MDEV – Modified Allan Deviation



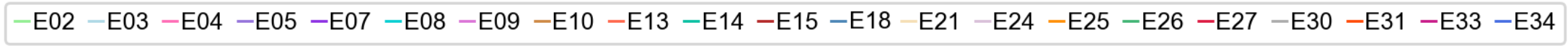
Clock product combination with the reference AC selected **as the most median** of all ACs

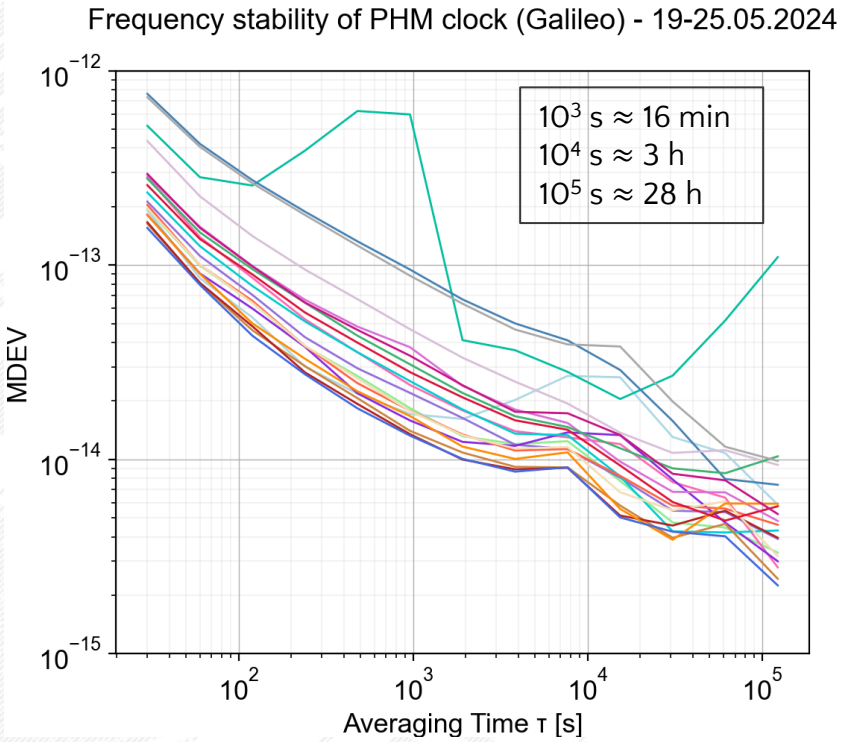
Clock product combination with the **CODE** as the reference AC

Clock product combination with the **ESA** as the reference AC

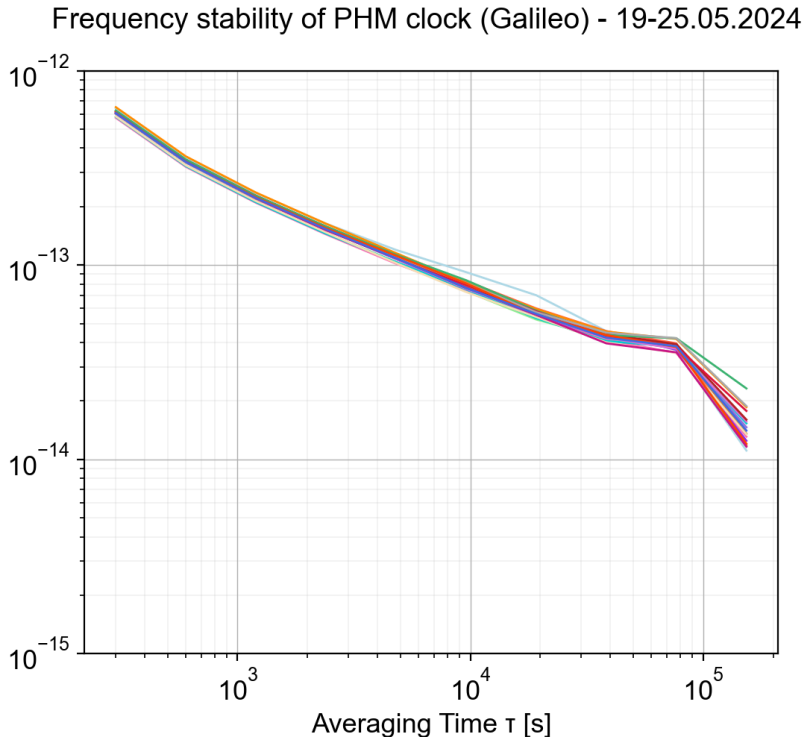
MDEV plots after clock combination for Galileo

AC – Analysis Center
MDEV – Modified Allan Deviation
PHM – Passive Hydrogen Maser

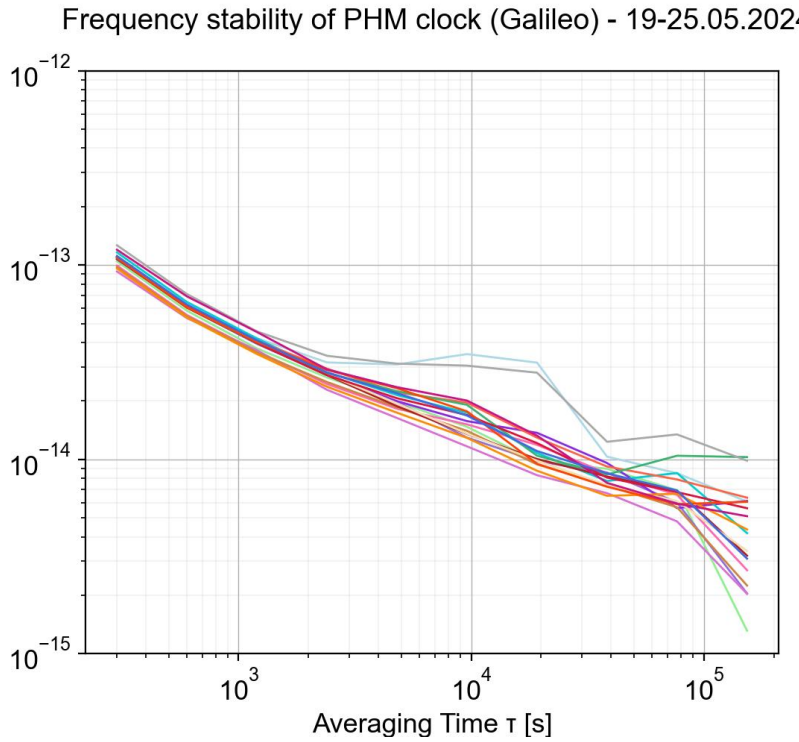




Clocks **before combination** from the ESA Analysis Center (AC)



Clocks combination with the **most median AC** as the reference AC



Clock product combination with the **CODE** as the reference AC

Conclusions & further steps

IGS products still do not include multi-GNSS orbits and clocks. The clock combination can increase **consistency** among satellite products and improve their **stability and completeness**.

The largest corrections come from **Analysis Center alignment**, therefore the choice of reference AC is **crucial**.

The **CODE** Analysis Center as reference AC significantly improves clock stability in combinations (instead of selecting AC with median clock value).

Future research will include **various weighting strategies** for the clock combination and their impact on **Precise Point Positioning (PPP)**.

Thank you for your attention!

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Link to **SPOCC** page with references:
https://gnss.gfz.de/services/spocc