

Reprocessing 27 Years of GNSS Data: The EPN-Repro3 Campaign and Its Challenges

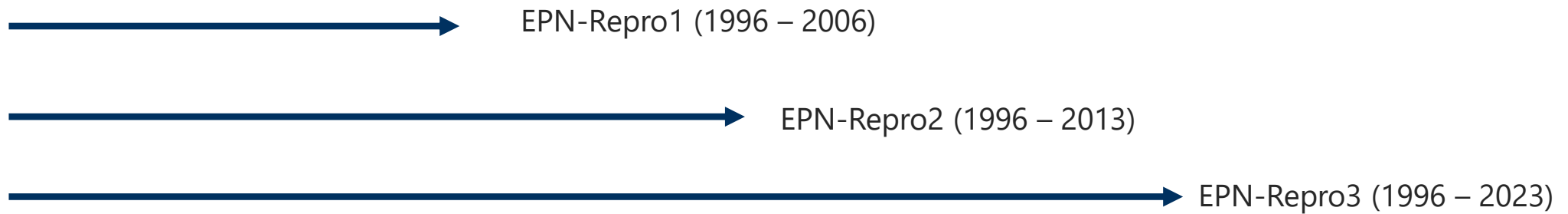
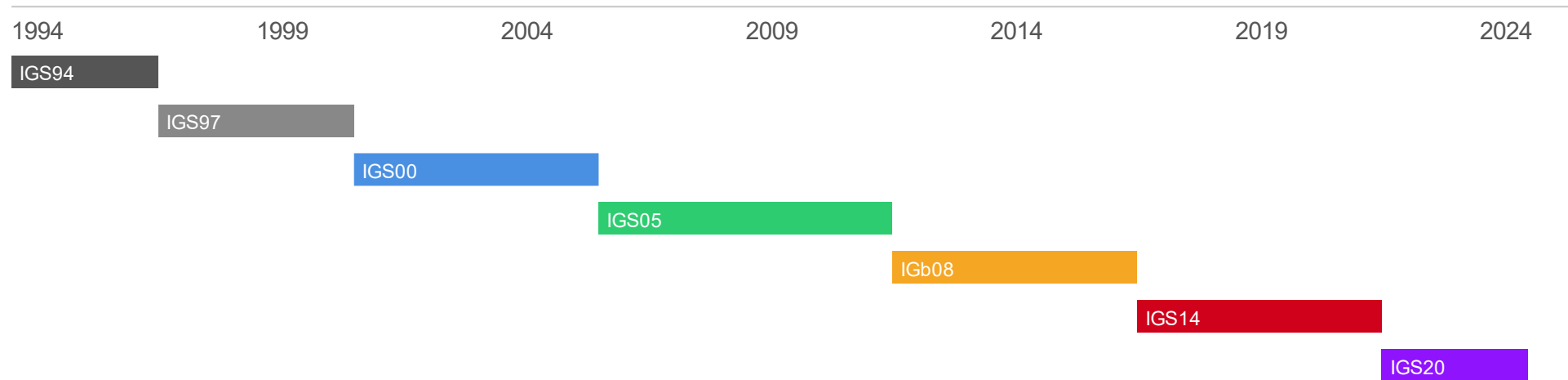
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Context of the GNSS reprocessing campaigns

- **Inclusion of multi-GNSS and multi-frequency data:** New satellite systems (e.g., Galileo, GLONASS) and additional frequencies require reprocessing to fully integrate them with GPS data
- **Improved models and standards:** Updated models for satellite orbits, clocks, antenna calibrations, and Earth rotation parameters improve the accuracy of the results
- **Consistency over time:** Reprocessing ensures that the entire GNSS dataset (from the beginning to present) is consistent and homogeneous, which is essential for long-term studies
- **Alignment with the latest reference frames:** Reprocessing allows the data to be aligned with the most recent realizations of the International Terrestrial Reference Frame (ITRF), improving spatial accuracy and compatibility with other geodetic products.
- **Support for scientific research:** High-precision data is crucial for geophysical applications such as tectonic plate motion, sea level change, and atmospheric studies.

Terrestrial Reference Frames in the course of time

IGS Reference Frames (1994–2025)

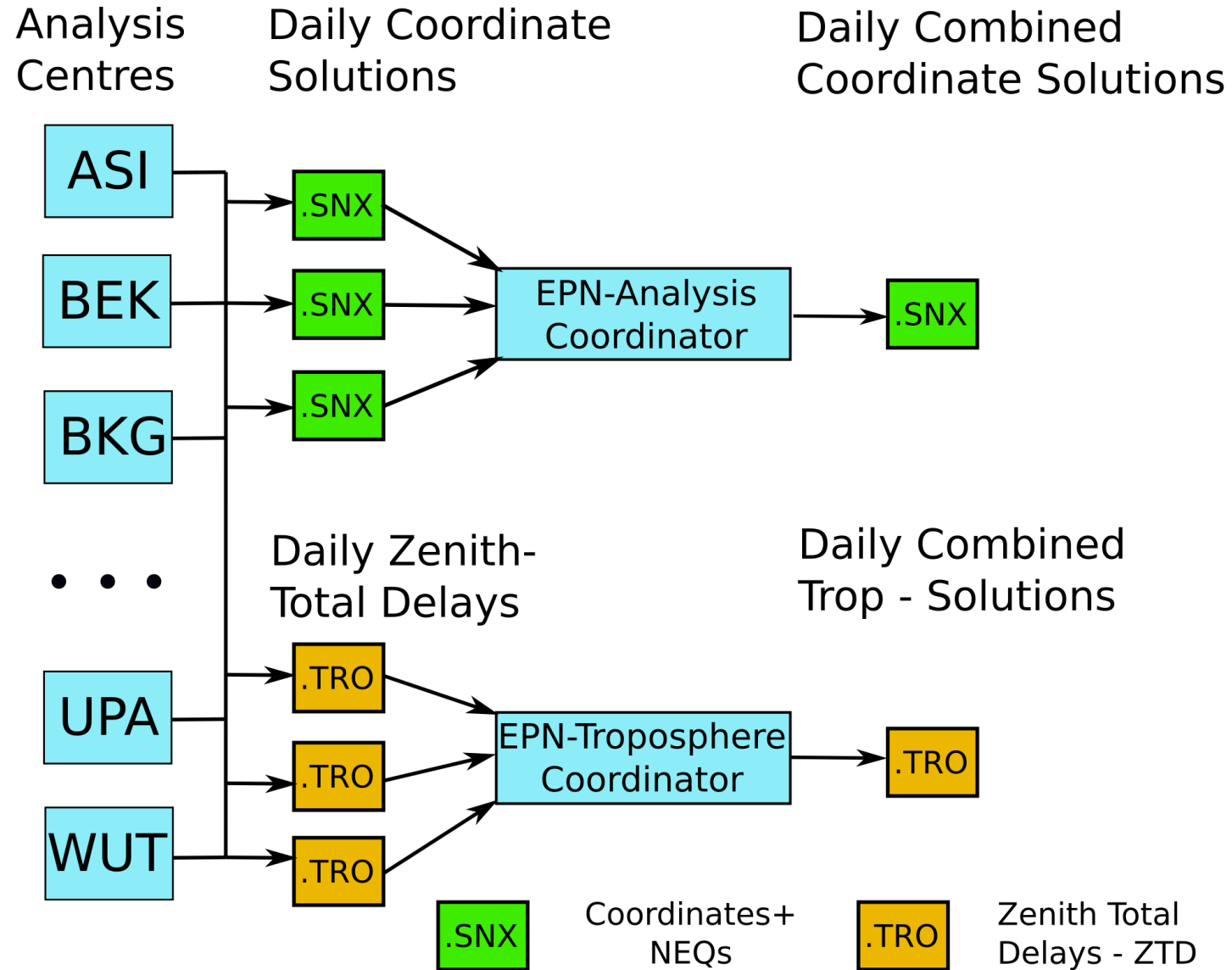


Past EPN Reprocessing Campaigns

- EPN-Repro1:
 - Reference Frame: **IGS05**; Antenna calibration: **epn_05.atx (individual)**
 - Solutions based on subnetworks (distributed processing) were provided (GPS week 834 - 1408)
 - Bernese: 14 subnetworks / GAMIT: 1 / GIPSY: 1 finalized in 2012
 - Reprocessed and operational solutions matched very well during transition (week1408)
- EPN-Repro2:
 - Reference Frame: **IGb08**; Antenna calibration: **epn_08.atx (individual)**
 - 5 solutions provided, (**3 Full-EPN** solutions based on GAMIT, GIPSY and Bernese, plus 2 subnetworks based on Bernese) (GPS week 834 – 1824)
 - But, inconsistencies in the transition of the reprocessed solutions (-1824) to the operational solutions (after 1824) finalized in 2016

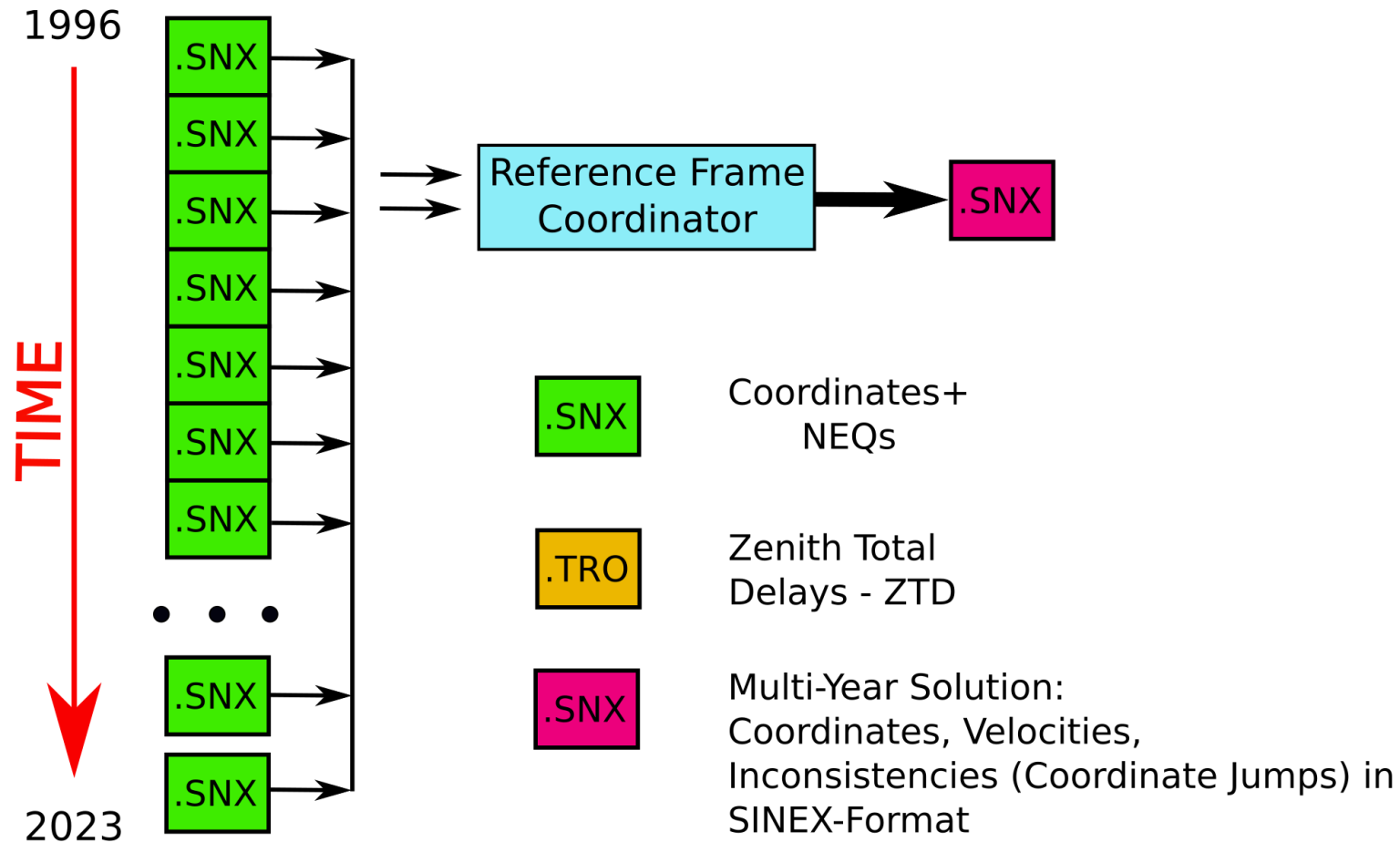
EPN-Repro3

- The global AC of the IGS have conducted their 3rd reprocessing campaign to provide consistent products that have been the input data for the computation of the ITRF2020
- Based on this new reference frame the EPN ACs have switched in GPS week 2238 (27. Nov 2022) to the new reference frame IGS20 for the operational computation of the EPN
- Consequently, previous operational products no longer match the actual analysis
- In order to obtain consistent products for the period from 1996 to the current generated products, a repeated processing of the old data is necessary
- This lead to the decision that the old data must now be re-analyzed in another reprocessing campaign, EPN-Repro3
 - No contribution with GIPSY-X (only contribution based on BERNESE, GAMIT and EPOS.P8 [GFZ])



Daily Combined Coordinate Solutions

Multi-Year Solution with Coordinate and Velocities



12 Participating Analysis Centres (ACs)

LAC	#Sites	New Sites in EPN-Repro3
BEK	131	LAMP00ITA
BKG	153	GRAC00FRA, IZMI00TUR, RVNE00UKR
GFZ	114	114 new sites
IGE	97	DOUR00BEL, FRNE00ITA, HERS00GBR, SART00ITA, ZIM200CHE
IGN	62	
MUT	159	DNMU00UKR, GWWL00POL, ISRN00ITA, KLNK00BLR, MOGI00BLR, SMLA00UKR, SWKI00POL, VITR00BLR
NKG	104	
ROB	113	GRAS00FRA, WTZR00DEU, ZIMM00CHE
SGO	64	BISK00CZE, BRTS00BLR, BSVZ00ITA, DGOR00MNE, DVCN00SVK, ENZA00ITA, KNJA00SRB, MNSK00BLR, MOP200SVK, MOPI00SVK, PFA300AUT, RIVO00ITA, VIRG00ITA, ZZON00HUN
SUT	81	AGRN00ITA, BME100HUN, BUTE00HUN, CFRM00CZE, CLIB00CZE, CPAR00CZE, CTAB00CZE, GALH00ITA, GOP600CZE, KATO00POL, KRA100POL, LINZ00AUT, PENC00HUN, SVLL00ITA, UBEN00ITA, VACO00CZE,
UPA	101	AGRN00ITA, ASIR00ITA, BIRG00ITA, BSVZ00ITA, GOPE00CZE, GRAZ00AUT, LIGN00ITA, MATG00ITA, MEDI00ITA, PENC00HUN, SART00ITA, SVLL00ITA, UBEN00ITA, UCAG00ITA, VIRG00ITA
WUT	153	BBYS00SVK, KUNZ00CZE, MARP00UKR, NOVPO0BLR, PINS00BLR, PSTV00BLR, SODA00FIN, TREU00ITA, TRMI00ITA

Antenna calibration used for EPN-Repro3

- EPN-Repro3 applied absolute antenna calibrations for multi-frequencies (GPS, GLONASS and Galileo)
- EUREF GB and the EPN ACs decided to rely **solely on type mean calibrations** for the operational analysis and EPN-Repro3
- Only observations shall be analysed where corrections for the PCV and PCO are available (no mixing of antenna calibration e.g. GPS for GLONASS)
- The multi-frequency calibration for the operational analysis are based on the file igs20_2247.atx with some additions (e.g. radome type BEVA and Topcon TPSCR.G5)
- This file has been frozen on May 11, 2023 as **epn_20_r3.atx** and remains unchanged for the entire analysis of EPN-Repro3 (maintained by MUT)

http://epncb.oma.be/ftp/station/general/epn_20_r3.atx

Recommendations for EPN-Repro3

- Analysis Centres (ACs) might use any reprocessed IGS-Repro3 product, which is most suitable for their software
- Combined IGS product are also possible when available
- The EPNCB historical database is **mandatory** for access of GNSS data
 - the database has been reviewed and updated
- The GNSS analysis software shall fulfil the requirements used in IGS Repro3
 - Bernese 5.4 was made available
- All previously active EPN stations should be included in the analysis, even the stations that are inactive today

Meta-data:

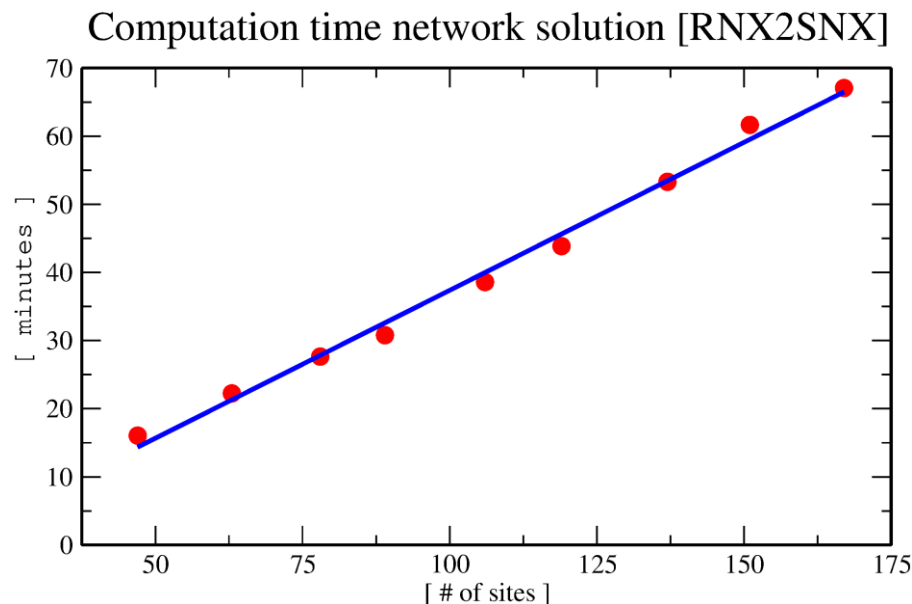
- Meta-data with the relevant information are available from **EUREF54_R3.STA** (*Bernese Station Information File* with status May 11, 2023)

http://epncb.oma.be/ftp/station/general/EUREF54_R3.STA

Standards for the Analysis of EPN-Repro3

Reference frame	IGS20
GNSS observations to be used	GPS, GLONASS, Galileo
Orbits and ERPs for EPN-Repro3	Reprocessed products with GPS, GLONASS, and Galileo (e.g. COD, GFZ, ESA,...)
Ocean tide loading model	FES2014b
Product filenames	Long filenames according to new IGS convention
Tropospheric mapping function	Vienna mapping function VMF3 required
Format of the troposphere products	Troposphere SINEX 2.0
Atmospheric tidal loading (ATL)	Atmospheric tidal loading will not be applied for the coming analysis of EPN operational and reprocessed products. The insufficient accuracy of the existing models is not enough to get a significant gain. Existing correction models still differ too much even among themselves

Computer Resources



Computed with:

Software: Bernese 54 (gfortran)

CPU: Intel ® Core i7-8700 / 6 cores

6 Clusters formed

OS: Ubuntu 22.04

GNSS-Analysis requires 25 seconds per site in a single network analysis (GPS/GLONASS/Galileo)

Parallel processing of several days recommended

- EPN-Repro3 spans a period of almost 27 years (9828 days)
- Of all the reprocessing campaigns carried out so far, EPN-Repro3 presents the greatest challenge in terms of effort

Computation @ BEK

- **Existing IT System:** old, frequent failures and insufficient performance
- **Cost Considerations:** high investment required for new hardware
- **Smart Solution:** Virtual Machines (VMs) provided by the BADW's Leibniz Supercomputing Centre
 - reasonable costs at 1000 € per year for one VM
- **Efficient Resource Use:** *one week of computer time* needed for the analysis of *one year of data* (processing of three days in parallel)
 - considerable time had to be spent checking the results (typical problem: stations were missing due to an error during setup)
- **Scalable Setup:** VMs can be decommissioned after processing is complete

Workflow of the Analysis Centres

- The ACs compute their products, checks them, and make them available via the data centers at BEV and BKG,
- Upload reported to the coordinators Tomasz, Rosa and me
- Tomasz, as the analysis coordinator, checks the available solutions **of each AC** for outliers and the metadata. He reports errors to the ACs
- AC reprocess parts of their solutions to remove reported outliers, correct metadata, and provide final cleaned solutions
- Each AC should also use the information provided by Tomasz to recompute their weekly coordinate solutions
 - ACs estimate daily tropospheric products based on the weekly coordinate solutions

Status EPN-Repro3, June 18, 2025

AC	Analysis Centres	Sites	Daily SNX [yyyy, doy]	
BEK	Erdmessung und Glaziologie, BAAdW (D)	131	1996, 001	2022, 330
BKG	Bundesamt für Kartographie und Geodäsie (D)	153	1996, 009	2022, 330
GFZ	Geoforschungszentrum Potsdam (D)	114	1995, 365	2022, 330
IGE	Instituto Geográfico Nacional de España (ESP)	97	1996, 001	2022, 337
IGN	Institut national de l'information géographique et forestière (F)	62	1996, 001	2022, 337
MUT	Military University of Technology (PI)	159	1996, 001	2022, 330
NKG	Nordic Geodetic Commission, Landmåteriet (S)	104	1996, 001	2022, 330
ROB	Royal Observatory of Belgium (B)	113	1996, 001	2022, 330
SGO	Lechner Nonprofit Ltd. Satellite Geodetic Observatory (HUN)	64	1996, 001	2022, 330
SUT	Slovak University of Technology (SLO)	81	1995, 365	2022, 337
UPA	University of Padua (I)	101	1996, 001	2022, 330
WUT	Warsaw University of Technology (PI)	153	1996, 001	2022, 337

Upcoming and workflow in progress

- The **Analysis Coordinator** computes for each day a combinations of all 12 ACs (Tomasz) as input for the multi year solution
- The **Reference Frame Coordinator** (Juliette) will computes a new multiyear solution based on the combined products provided by Tomasz
 - Refined coordinated solution for the ETRS based on reprocessed solutions (EPN-Repro3) and operational solutions after week 2230 (ITRF2020)
- The **Troposphere Coordinator** (Rosa) combines the reprocessed daily troposphere solutions and verifies them

Summary

- Initial Discussion began in July 2021 with all the EPN-Analysis Centres
- Delays:
 - Discussion on the standards and analysis strategies
 - Update of the GNSS software for the analysis
 - Extensive data processing (27 years of data from 400 stations,).
 - Computer resources were partly limited updated computer resources
- Daily solutions of each participating AC **are now available** at the data centres
- Current Tasks:
 - Daily solutions combination managed by the Analysis Coordinator
 - Multi-Year calculation handled by the Reference Frame Coordinator
 - Combination of tropospheric parameters across 27 years
- Status: Near completion, but the process took longer than anticipated

IAG Scientific Assembly 2025 to take place in Rimini, Italy, September 1-5

EPN-Repro3: Improved Maintenance of Regional Reference Frames Through Standardized and Complete Reprocessing of all Available GNSS Data (1996-Present)

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Session: G01-3, Regional Reference Frames: Status, Challenges and Applications

The presentation allows us to publish our research in the IAG symposia series. We have already indicated that we intend to publish our results in this series. The IAG symposia series is published Open Access and is free of charge for the authors.

**Thank you all for your effort, your time, and
your *patience***



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