

The ESA Navigation Facility at the European Space Operations Centre

Independent Services and Reference Products for Precise Navigation and Timing

W. Enderle, F. Gini, E. Schoenemann, R. Zandbergen, F. Zimmermann

POSNAV 2022 – November 3-4, Berlin

- Introduction
- International Activities/Collaboration
- Products & Services
- Summary and Conclusion

Europe's centre of excellence for satellite operations,
located in Darmstadt, Germany

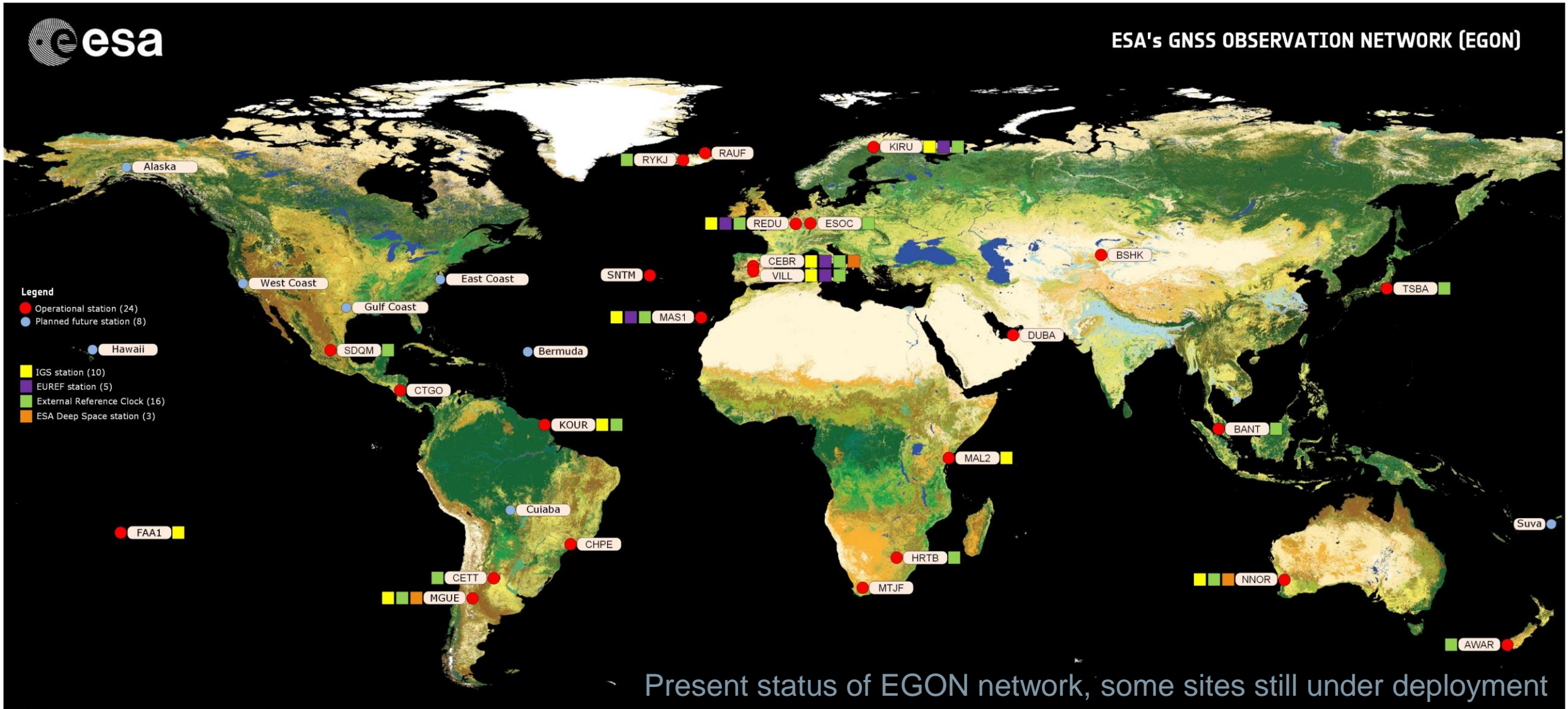
- Satellite Operations
- Ground Systems Engineering
 - Flight Dynamics/Mission Analysis
 - Precise Navigation
 - Ground System Infrastructure, e.g. Antennas
 - Mission Control/Data Systems and Simulators
- Space Safety Programme
 - Space-Debris Monitoring and Avoidance
Manoeuvres



- ESA's centre of expertise for Precise Navigation is based at ESOC
- Contributes to ESA missions, third-party activities and EU space programmes (Galileo, EGNOS, Copernicus)
- Develops, maintains and operates its own infrastructure:
 - ESA Navigation Facility
 - ESA's GNSS Observation Network (EGON)
 - Software for Precise Orbit Determination (POD) and high accuracy GNSS data processing
- Precise Orbit and Clocks Determination for all GNSS Satellites and also POD for LEO satellites (ESA missions as well as Copernicus).
- Processing of Multi-GNSS data from EGON as well as from sensor stations of the International GNSS Service (IGS) in real-time and also non real-time



ESA's GNSS Observation Network EGON (1)



- GNSS ground receiver data is a required input for all Precise Navigation GNSS activities.
- The Navigation Support Office has been deploying receivers on a global scale in order to ensure access to high quality GNSS data under ESOC control
 - These are state-of-the-art multi-system geodetic receivers providing data in real time, used at ESOC both in real-time and non real-time applications.
 - Four global constellations supported (Galileo, GPS, GLONASS, Beidou)
 - Combined processing
 - Challenges: Data volume, Data compatibility and availability of GNSS Data
- In addition to the EGON GNSS data, also GNSS data from the IGS network is used within different activities

- ESOC is a founding member of the [International GNSS Service \(IGS\)](#) and one of the analysis centres producing typical GNSS batch and real-time processing products such as orbit and clock solutions, satellite biases and station coordinates.
- ESOC's products are among the most accurate Orbits and Clocks in IGS.
- Similar collaboration activities for the other space geodetic techniques:
 - Laser Ranging / [International Laser Ranging Services \(ILRS\)](#)
 - DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) / [International DORIS Service \(IDS\)](#)
 - VLBI (Very-Long-Baseline Interferometry) / [International VLBI Service \(IVS\)](#), currently at validation stage

International Terrestrial Reference Frame (ITRF)

- Computed every few years, under coordination by the Institut National de l'Information Géographique et Forestière (IGN), located in Paris, France
- Uses data from all four geodetic techniques/services (IGS, ILRS, IDS and IVS)
- ITRF-2020 has been published by IERS on 15 April 2022
- Main parameters defining the ITRF are the positions and velocities of the contributing stations and additional models and parameters, such as tectonic plate motion and Earth Pole Motion
- ESOC is participating actively in processing campaigns for the first three techniques and is well placed to conduct also the VLBI data processing.

International Earth Rotation and Reference Systems Service (IERS)

- Availability of highly accurate, up to date Earth Orientation Parameters (EOP)
 - Relevant for all space missions
 - Major importance for all positioning and navigation applications on Earth, sea, air and in space
-
- Deeply involved in the activities of the [International Committee on GNSS \(ICG\)](#), which is acting under the umbrella of the United Nations.
 - ESA staff is co-chairing the so-called Space Use Subgroup (SUSG), responsible for the definition of the GNSS Space Service Volume (SSV) and associated reference scenarios

Precise Navigation Products

- High-accuracy GNSS orbits and clocks (batch processing and also real time)
- Precise Orbit Determination of satellites ranging from Low Earth Orbit (LEO) via High Eccentric Orbit (HEO) to Lunar Orbit
- Challenging requirements on accuracy, timeliness and availability
- Separate processing chain set up to provide fully automated operational POD solutions for all satellites in GNSS and/or other orbital regimes.
- Based on EGON data combined with a selection of IGS sites ensuring uniform satellite coverage
- MGNSS (for Multi-GNSS) Orbits and Clocks, made available to the community free of charge by the Navigation Support Office at

http://navigation-office.esa.int/GNSS_based_products.html

GNSS based products

- GNSS metadata
- GOCE reentry orbits

SLR based products

DORIS based products

Combined (multi-technique) products

The Navigation Support Office records GNSS station data and generates GNSS products for all constellations (GPS, Galileo, Glonass, Beidou, QZSS) on an operational basis. All products are characterized by high precision, availability and reliability. In the following the RINEX codes are used to identify the systems: Galileo (E), GPS (G), Glonass (R), Beidou (C), QZSS (J).

This page gives an overview on our published data and products. More information concerning their generation can be found in our Analysis Strategy Summaries for IGS and ESOC MGNS .

STANDARD PRODUCTS AND DATA

Our latest published products are freely available on our web page (<http://navigation-office.esa.int/products/gnss-products/>) and can be retrieved via file browser or http download methods (e.g. wget or curl) .

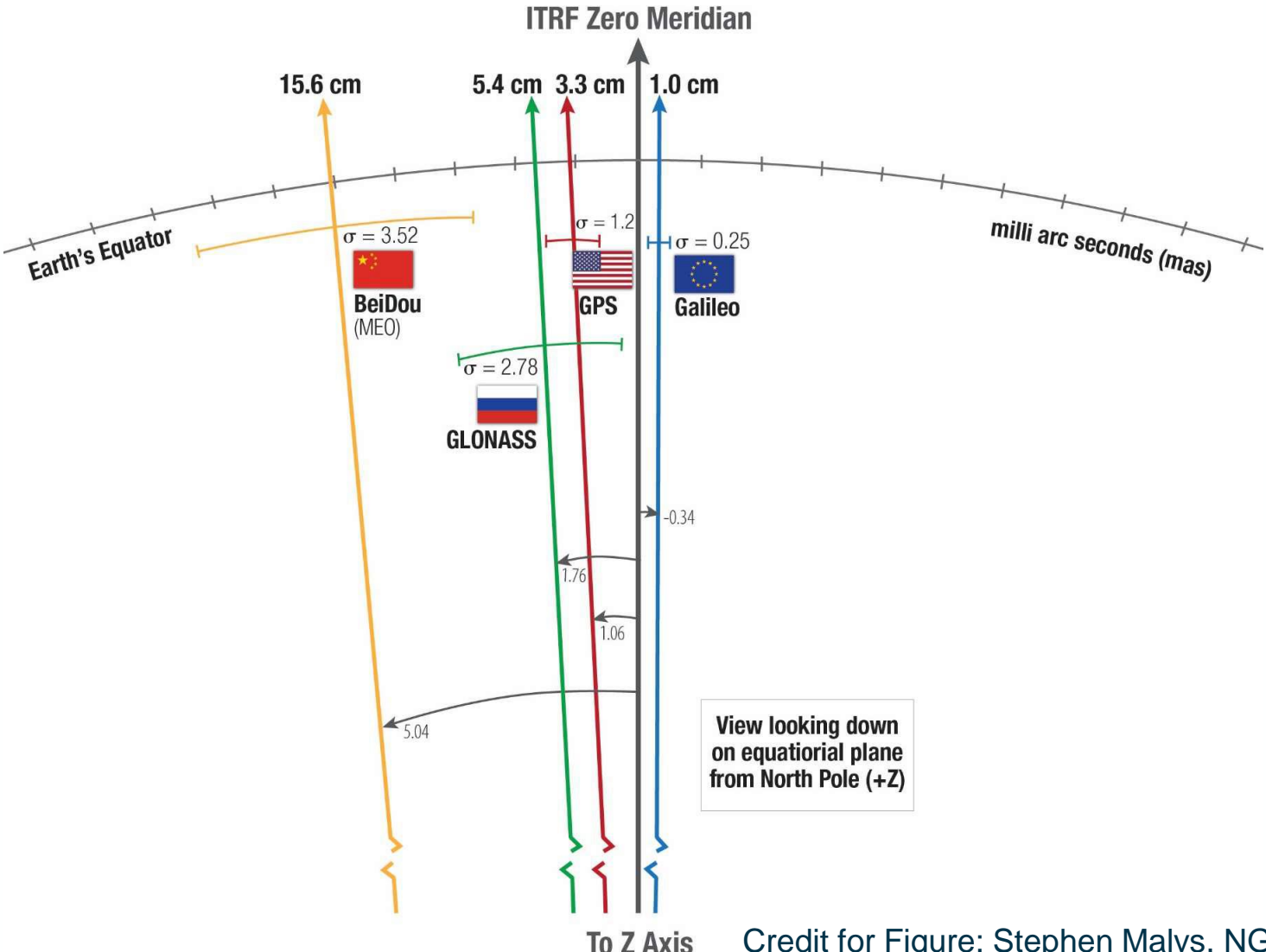
GNSS station data (RINEX) and historical products can be found on ESA's GNSS Science Archive and Service Centre (GSSC).

TYPE	ID	CONST.	PUBLISH DELAY	PRODUCTS	CONTENT TYPE	FORMAT	INTERVAL	PERIOD	COMMENT
ESOC MGNS FINALS NOTE: MGNS IS FOCUSED ON CONSISTENCY OVER TIME, THEREFORE ABOUT ONCE A YEAR ALL DATA IS	ESA0MGNFIN	EGRCJ	12 - 5 days	Ephemeris	SP3	.SP3	300 s	24 h	Published every Thursday
				Clocks	CLK	.CLK	30 s	24 h	
				Inter-System Bias	ISB	BIA	24 h	24 h	
				Earth Rotation Parameter	ERP	.ERP	24 h	24 h	
				Summary file	SUM	SUM		168 h	
				SLR	SLR	.SUM		168 h	

Galileo Terrestrial Reference Frame (GTRF)

- Dedicated reference frame, computed based on Galileo infrastructure
- Requirement that GTRF remains aligned with ITRF within 3 cm at two sigma (95.4%)
- Scientific consortium was selected, which consists of European experts in GNSS data processing and reference frame calculation:
 - Astronomical Institute of the University of Bern, Switzerland (AIUB)
 - Bundesamt für Kartografie und Geodäsie, Frankfurt, Germany (BKG)
 - European Space Operations Centre, Darmstadt, Germany (ESOC) – coordinating role
 - Deutsches GeoForschungsZentrum, Potsdam, Germany (GFZ)
 - Institut National de l'Information Géographique et Forestière, France (IGN)
- Basis for the reference frame creation is the generation of independent orbit and clock solutions, station coordinates and other relevant parameters.

Comparison of Reference Frames for the four GNSS



Credit for Figure: Stephen Malys, NGA, 2019

Earth Orientation Parameters (EOP)

- EOP data provides the link between the coordinate systems on Earth and in space.
- Represent a critical input for Precise Orbit Determination
- Presently only available on US infrastructure
- To provide more redundancy, ESOC is preparing for the generation of an independent product.
- The data production process consists of the following steps:
 - Step 1: Observation and analysis of historical data, making use of all available geodetic techniques
 - Step 2: Prediction by specially tailored extrapolation
 - Step 3: Evaluation of the results
- Presently at an experimental stage
- Experimental EOP results are compared with the actual EOP data post-facto, showing high quality

Coordinated Universal Time (UTC)

- The Navigation Support Office operates a Timing Facility at ESOC.
- Local timescale generation based on two active hydrogen masers operated in a thermally stable environment
- Steering performed via two independent phase and frequency offset generators and redundant processing on two parallel servers
- Remote operations and performance monitoring with high availability thanks to full system redundancy
- Second independent timescale generated at ESA/ESTEC
- Time Offset continuously monitored using a redundant calibrated multi-GNSS link
- In 2021, the UTC system at ESOC was officially declared operational.
- Operational use for mission operations, deep space stations and as time reference for services

Timing Facility at ESOC



LAB (GSRF)



UTC products

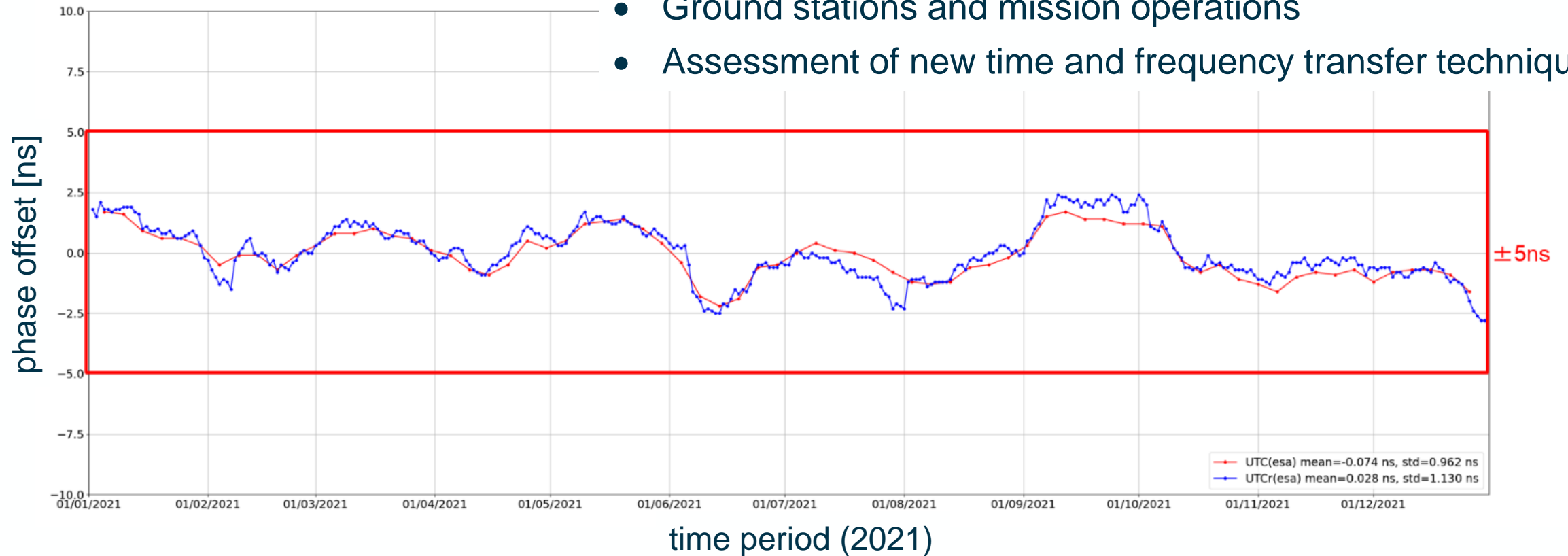


Maser Room



Redundant calibrated multi-GNSS link at ESOC

- Distribution to local users and services
- Characterization of on-board equipment and clocks
- Monitoring of multi-GNSS time dissemination
- Ground stations and mission operations
- Assessment of new time and frequency transfer techniques



- Users and providers of GNSS data for systems and applications require data of high accuracy, availability and reliability.
- The Navigation Support Office at ESOC provides Precise Orbits and Clocks for GNSS and also satellites in other orbital regimes.
- The Navigation Support Office has demonstrated operational products & service availability of >99.5%.
- The Navigation Support Office generates the geodetic reference for the ESA missions, is deeply involved in the generation of the International Terrestrial Reference Frame and also the Geodetic Reference Frame for Galileo.
- Access to a stable and accurate time reference is key for space missions, where ESA's contribution to UTC is an important asset.
- The Navigation Support Office provides high accuracy GNSS Orbits and Clocks data for free to the public community.
- The Navigation Support Office provides independent Earth Orientation Parameter data to Europe.