Generation of a time scale at ESOC

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Abstract

Based on the identified need to generate an operational UTC time scale at the European Space Operations Centre (ESOC), an activity for generating a time scale using the three already available Active Hydrogen Masers (AHM) was started in April 2013. In the meantime, the system is fully developed and reached an operational state which would enable ESOC to contribute with its generated time scale to the UTC realisation by the Bureau International des Poids et Mesures (BIPM) in Paris.

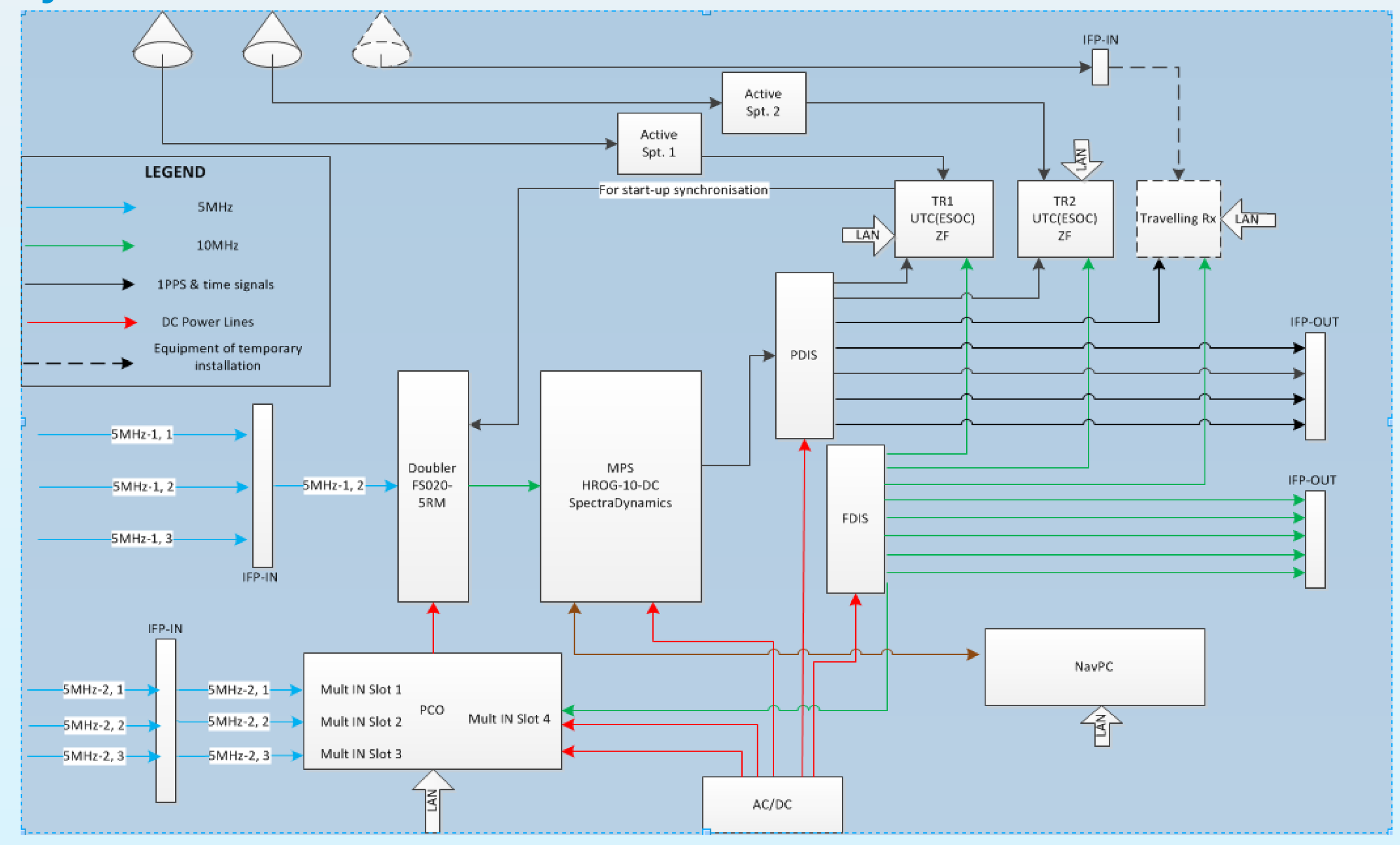
The monitoring is based on GPS Precise Point Positioning (PPP) results by comparing the ESOC time scale to existing UTC time scales, mainly UTC(PTB) and UTC(ESTC). Using the ESA internal rapid orbit and clock products, the PPP-based time transfer results are obtained with ESA's state-of-the-art GNSS data processing software Navigation Package for Earth Orbiting Satellites (NAPEOS). Since October 2015, the generated time scale has been kept within ±10ns with respect to both UTC(PTB) as well as UTC(ESTC), whereas BIPM requires an agreement to UTC within ±100ns [1].

Three proprietary software tools have been developed in LabView for processing the measurements of a Phase Comparator (PCO):

- The real-time monitoring tool can display ADEV/OADEV as well as three-corner-hat at chosen intervals
- The post-processing tool adds the display of DVAR 3D-plots
- The clock files tool generates the daily and monthly files for the UTCr and the UTC respectively

System

Figure 1: Block diagram of ESOC's main system hardware



Calibration

The relative calibration of ESOC's GNSS time transfer equipment was carried out at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany in May 2015. PTB has been selected as one of the Group 1 laboratories in EURAMET in the scheme of GNSS calibrations that is applicable for laboratories and institutes collaborating with BIPM in the UTC realisation process. Within this procedure, also known as "golden system calibration", the ESOC equipment was calibrated against PTB's permanently installed reference station PT02 by connecting ESOC's geodetic timing receiver, to UTC(PTB). Therefore, both the ESOC receiver and PT02 were operated in a common-clock installation in accordance with the appropriate BIPM guidelines. RINEX as well as CGGTTS data were gathered for the time period 01/05/2015-04/05/2015 (MJD 57143 to 57146) and the calibration transferred to the ESOC GNSS chain accordingly.

In the meantime, the calibrated ESOC chain served itself as starting point for additional ESA internal calibrations which led especially to a further extension of ESOC's monitoring capabilities.

Steering Process

ESOC's steering algorithm aims to establish and maintain a tight connection to UTC for the generated time scale. Its state estimation is performed using a Kalman Filter. The steering value computation takes into account both the time offset to UTC as well as the frequency offset to a selected reference time scale characterised by a close as possible connection to UTC. Within a fully automated process, the steering is then applied by introducing frequency offsets into the frequency signal of the selected AHM using a high resolution microphase stepper (MPS) on a regular time interval.

Due to the given AHM short-term stability and the applied steering, for the last months the ESOC time scale has been kept in close connection to one of the most stable UTC realisation, UTC(PTB), existing globally, as it is shown in **Figure 2**.

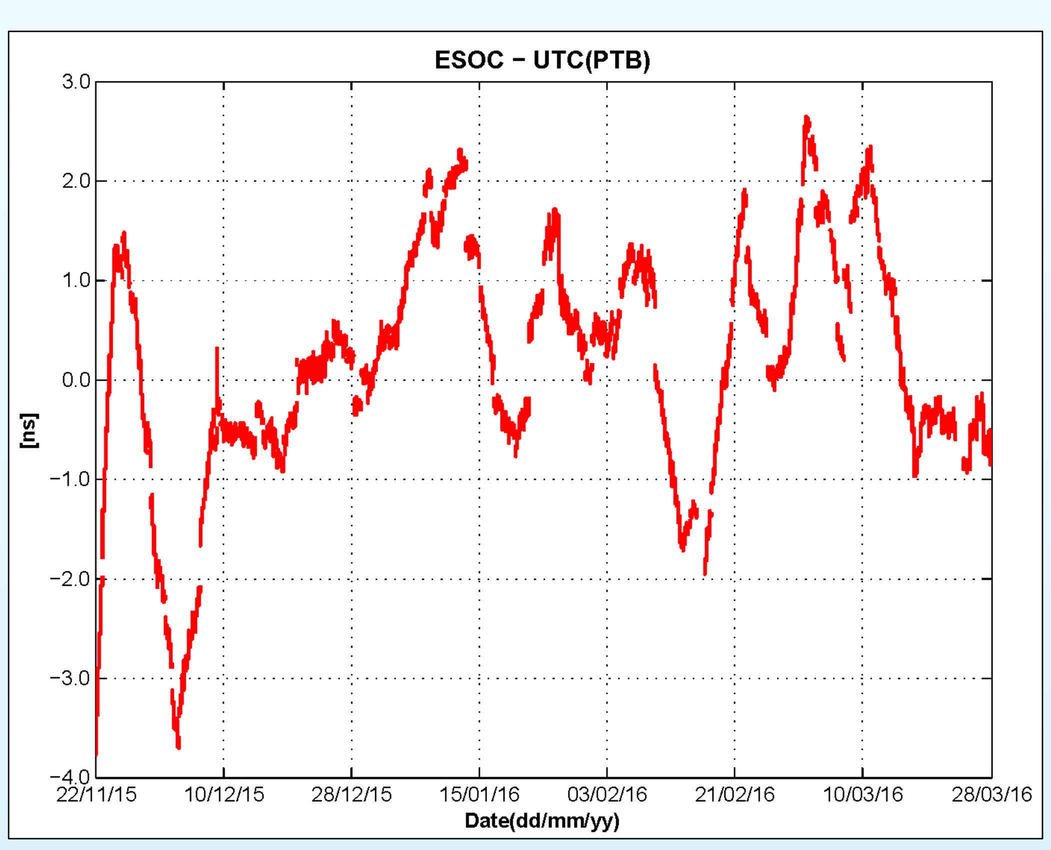


Figure 2: ESOC time scale performance with regard to UTC(PTB) for last 4 months

Performance Monitoring

Comparison among clocks: There is a Phase Comparator (PCO) integrated in the system in order to monitor continuously the phase of the three available AHM against the steered time reference. Three proprietary software tools have been developed for the real-time monitoring (**Figure 5**), the post-processing (**Figure 6**) and the generation of the clock files (**Figure 7**) for future contribution to BIPM's Circular T, with capability to calculate the accumulated phase offset from the raw phase data of the PCO channels. This last software generates both UTC and UTCr clock files.

Comparison to external references: In order to maintain a continuous performance evaluation to external references, the generated time scale is compared by processing GPS PPP links to selected UTC(k) realisations on an automated, daily basis. For this purpose, ESOC is exploiting the PPP processing capabilities of its state-of-the-art NAPEOS software (shown in **Figure 3**) and makes use of its internal-generated ESA rapid orbit and clock products, characterised by a considerably shorter latency for the previous observation day as well as a longer data coverage (24h) than the official IGS rapid products. As one of the most active IGS Analysis Centers (AC), ESA is providing some of the best rapid products available (see **Figure 4**). This way, the PPP processing results in an estimation of the local station clock offsets with regard to the ESA rapid time scale. The consideration of the corresponding delay budget of each timing laboratory enables the time link computation between the ESOC time scale and local UTC realisations.

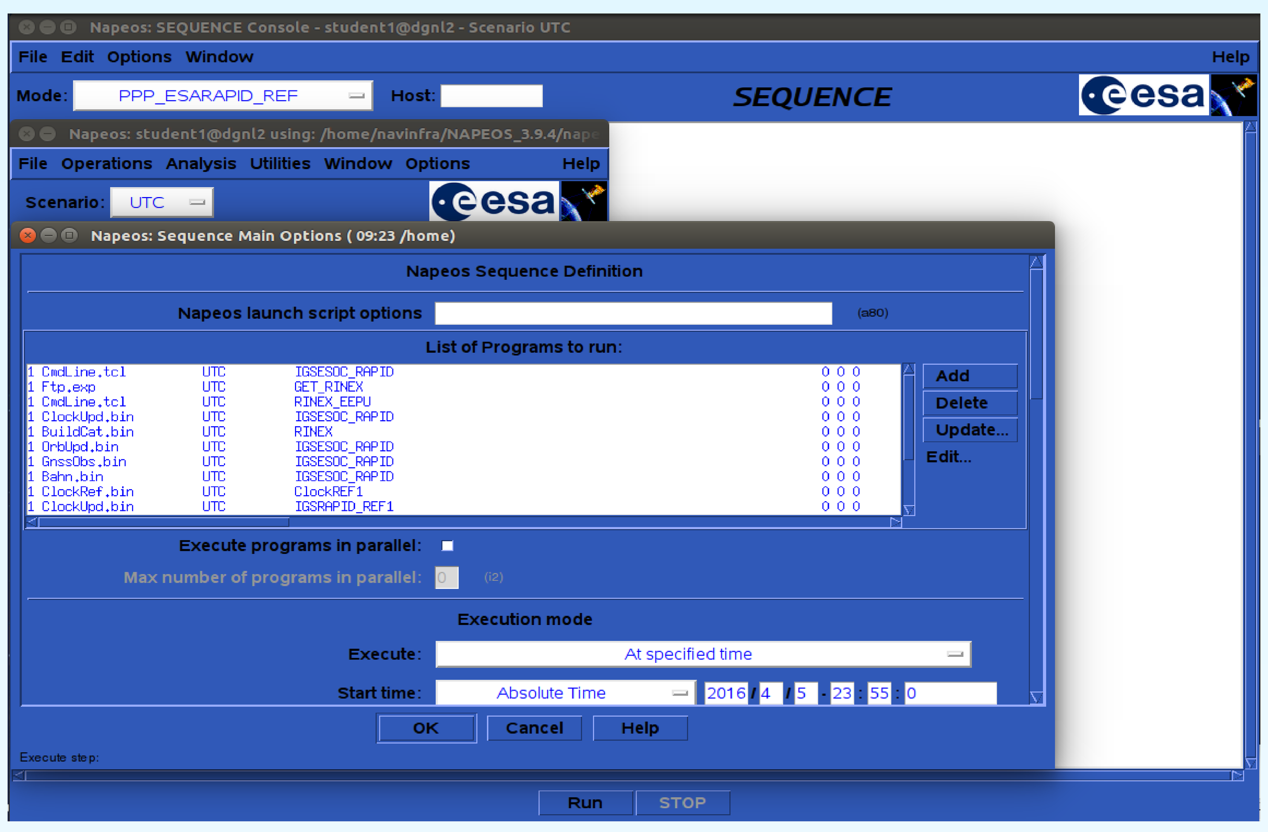


Figure 3: NAPEOS Sequence for routine GPS PPP link processing

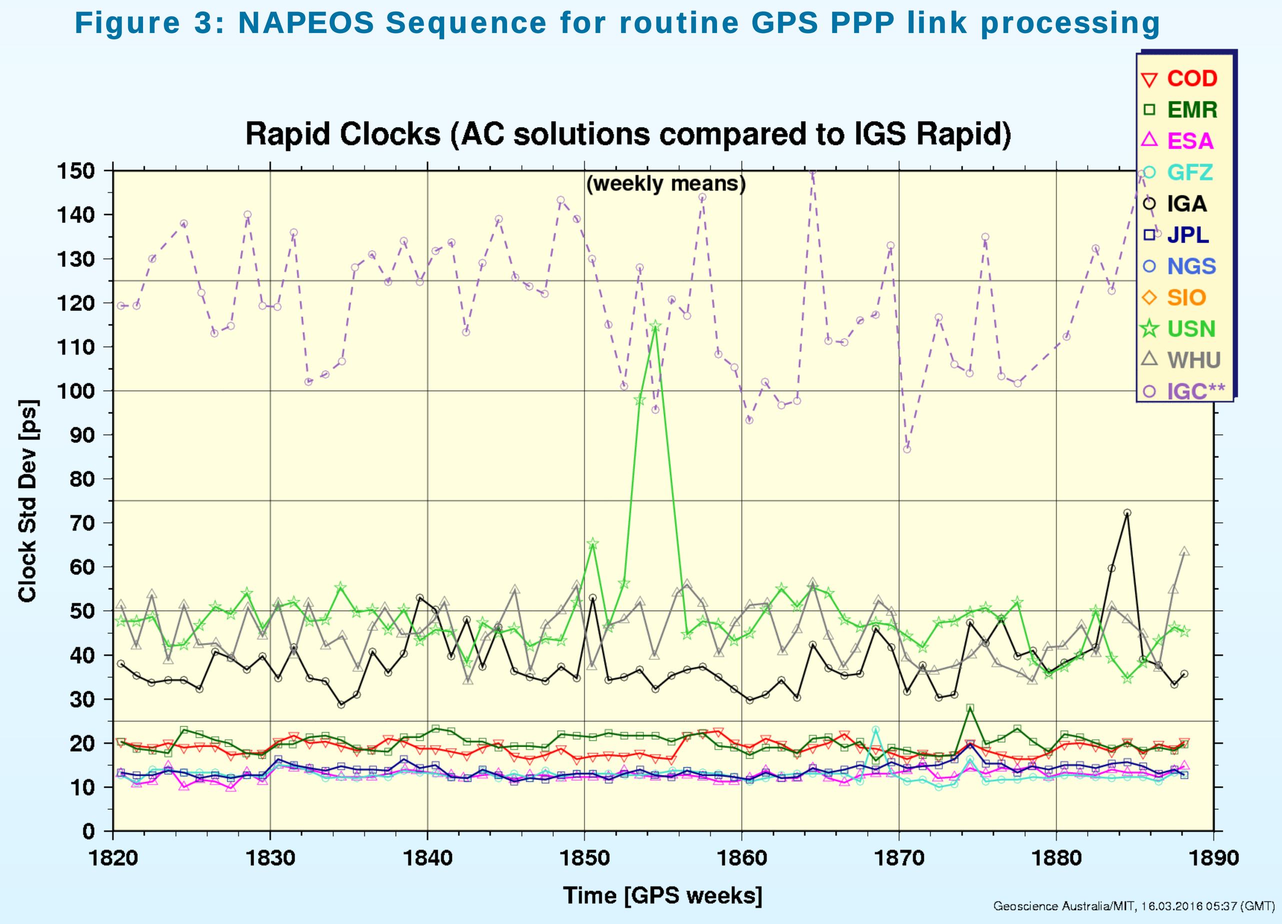


Figure 4: Verification of ESA's rapid clock products performance by IGS AC Coordinator (ACC)

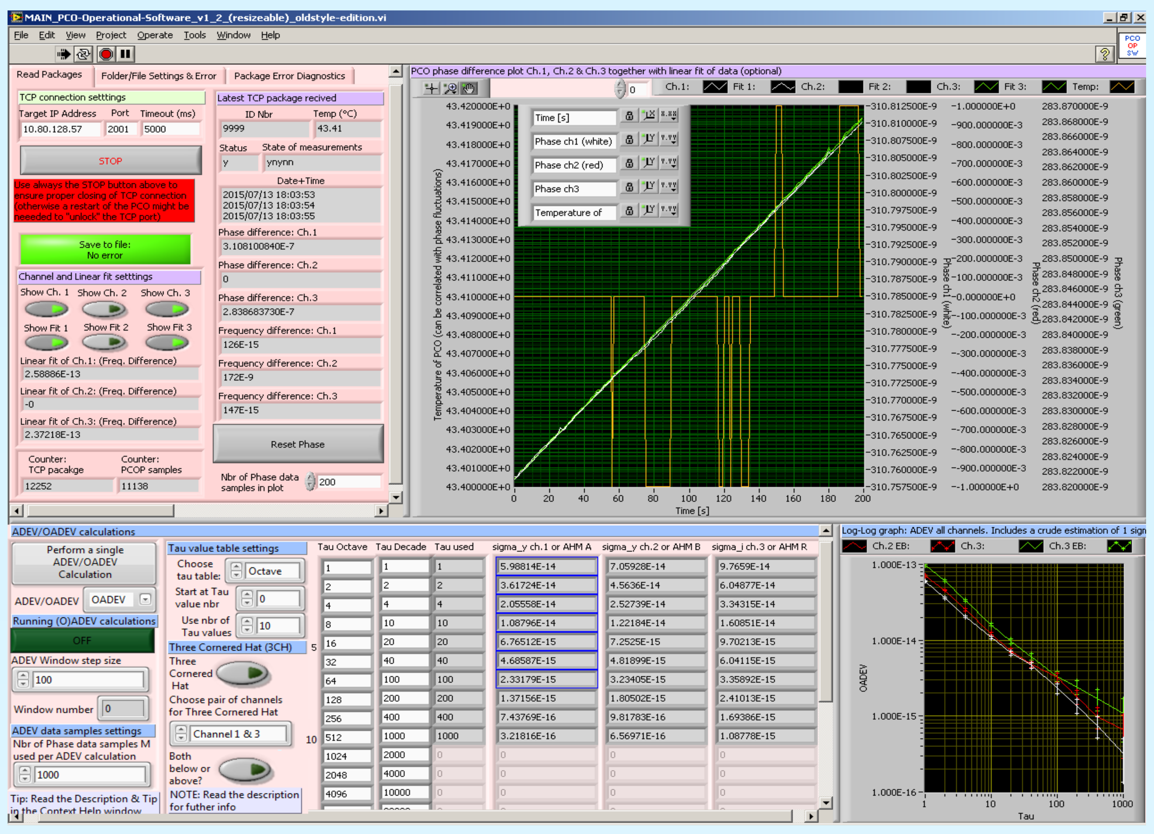


Figure 5: Real-time software for stability monitoring

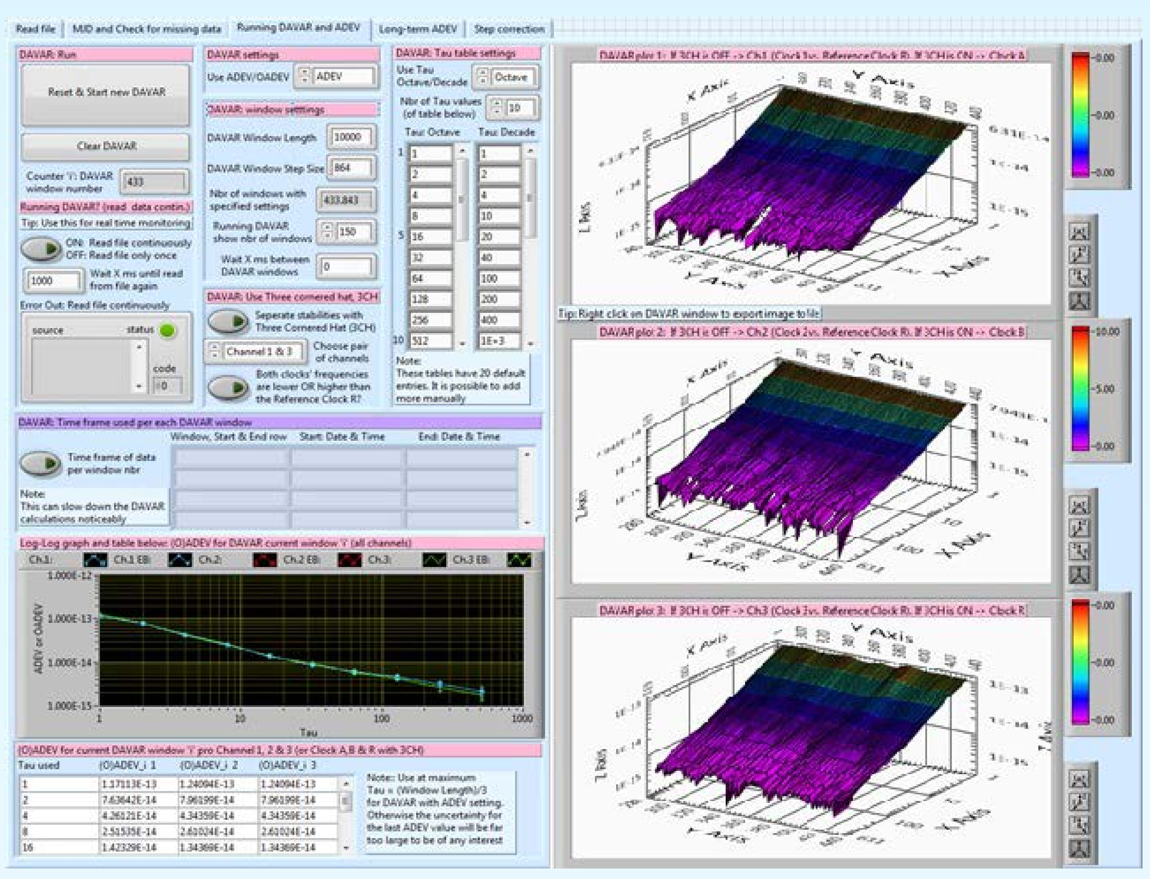


Figure 6: Post-processing software for stability monitoring

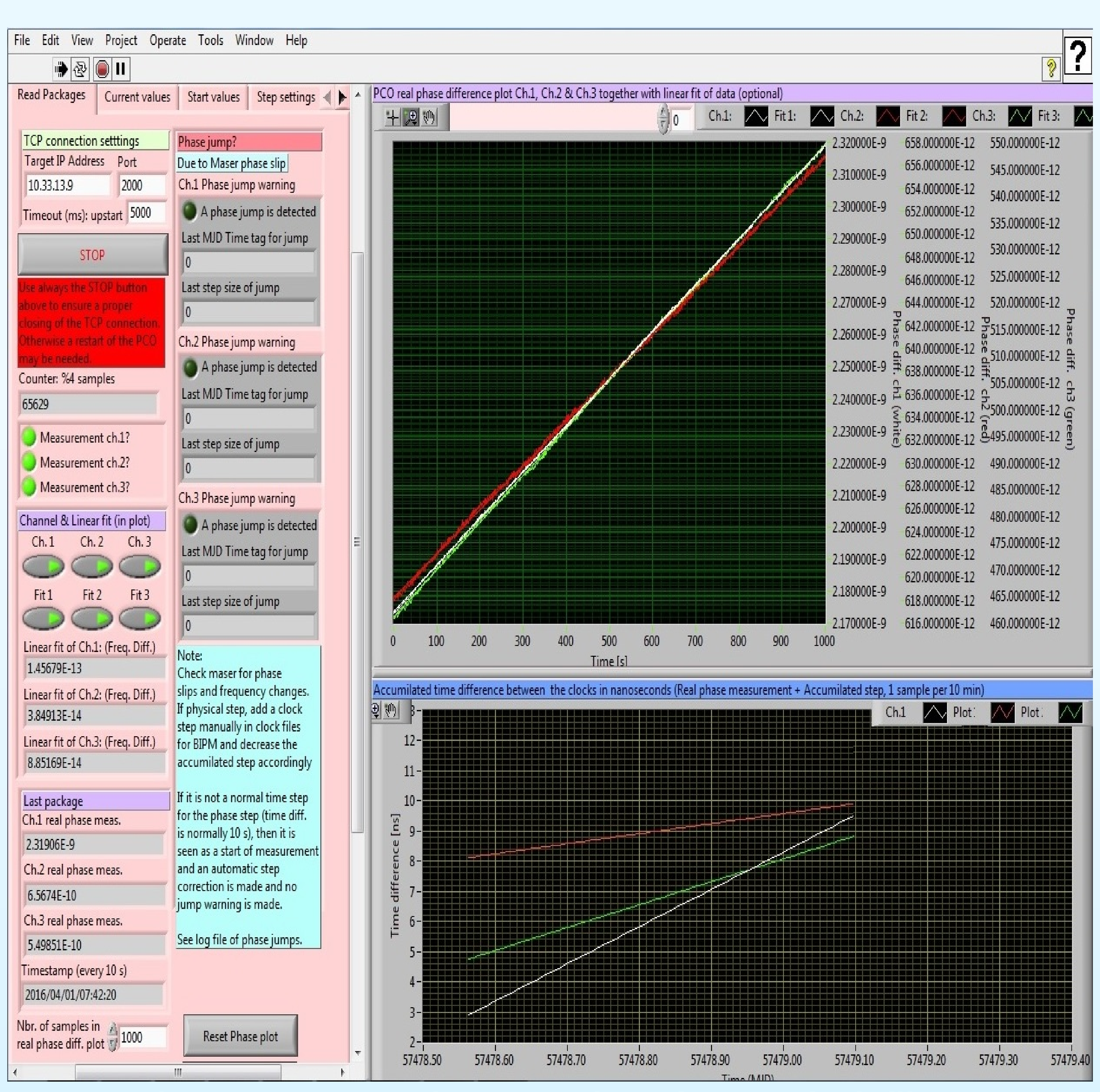


Figure 7: Automatic generation of BIPM clock files

Operational Needs, Benefits and Applications

- Operational UTC time scale generation capability enables full control over ESOC's entire precise orbit and clock product generation chain
- Benefits for several existing ESA Precise Orbit Determination (POD) operations, especially for Earth observation satellites, Galileo and EGNOS
- Risk mitigation in the context of 3rd party contracts with high availability requirements for GNSS product supply
- Extension of ESOC's existing product range as well as opening-up of future product opportunities
- Application as centralised time & calibration reference for ESA's Deep Space Stations (DSS) in New Norcia (Australia), Cebreros (Spain) and Malargüe (Argentina)

Evolution

For the future, it is planned to enhance the time scale generation system with additional clocks (e.g. Cs clocks), to add redundancy to the steering and the post-processing of the data, as well as to put additional monitoring equipment for the phase and time offsets.

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References: [1] - Consultative Committee for the Definition of the Second (CCDS), Recommendation S5, 1993

European Space Agency