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ACES MWL DATA ANALYSIS PREPARATION STATUS

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We present the current state of development of the ACES Microwave link data analysis software at Syrte.

1 Introduction

The ACES-PHARAO mission is an ESA space mission aiming at realizing a time scale of high stability and accuracy on board the International Space Station (ISS), and perform time and frequency transfer between the payload and ground stations during the flight. A description of its setup and main objectives may be found in reference ¹. The SYRTE laboratory has been heavily involved in the design and development of the PHARAO cold atom clock (Laurent *et al.*, 2014) ² as well as the data analysis software that will generate the mission's scientific products. This paper focusses on the current status of the data analysis.

2 The ACES experiment setup

In order to compare their local timescales to the ACES timescale, several metrology institutes will host a ACES Ground Terminal (GT), which will enable them to perform a two-way time transfer through microwave signals. ISS visibility will only last 300 to 500 seconds for a given station, with common-view configurations being possible if two GTs are close enough. Collected data on ground and in space is centralized at CADMOS (see fig. 1).

The MWL core data consists in 3 series of one-way time comparisons for each pass : 13.475 GHz uplink, 14.7 GHz Ku-band downlink, 2.24 GHz downlink. Combining the first two signals allows to perform a two-way time transfer, while combining the last two signals allows to determine the delay due to the ionosphere traversal ³.

Time transfer data is determined either by determining the phase of the incoming carrier (dubbed "carrier" data), or by matching an encoded pattern at 100Mchips rate (dubbed "code" data). Code data is unambiguous, but coarse (20 ps resolution). Carrier data can theoretically achieve 1ps resolution, but suffers from phase ambiguity (any measurement will only be able to give a modulo- 2π phase). Combining both measurements correctly is key to optimal performance of the MWL.

Auxiliary data needed for data processing will also be contributed to the archive : instrumental calibrations, ISS orbitography, ground station positions and atmospheric parameters, etc.

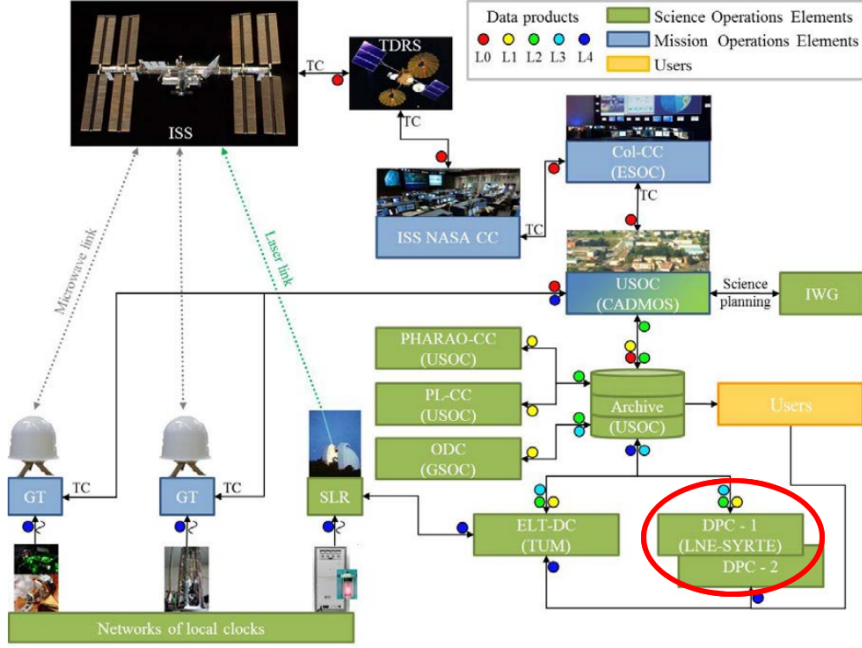


Figure 1 – Data processing flowchart for ACES-PHARAO data. L0 to L4 data levels correspond to various levels of processing from raw data to scientifically usable measurements. The red ellipse indicates the situation of LNE-SYRTE data processing center, at the interface between partially processed data in the archive, and users.

2.1 Two-way microwave link

The basic principle of such a link has been presented in Delva *et al.* (2012)³. In summary : sending a timestamp from clock *A* to clock *B* while sending a timestamp the other way, from clock *B* to clock *A*, allows (at the first order) to cancel the signal’s propagation time between the two clocks, thus allowing the calculation of the desynchronisation without precise knowledge of this time of flight. However, we remain sensitive to the variation of this value between the uplink and downlink measurement : ISS orbitography and ground station positioning allow us to model this effect to the required level.

As ISS positionnal uncertainty has been found to be a major source of error, we minimize its influence by interpolating signals so that uplink arrival time matches downlink departure time, thus making the “same” error on both trips, which cancels out well (Λ configuration³).

2.2 Software development

SYRTE has developed a data processing and analysis software, designed to extract scientific products from (nearly) raw ACES data. To test this software and experiment we also developed a simulation software that generates raw data in the format specified by ACES Ground Segment ICD, aiming at including all relevant effects in the calculation.

Care has been taken to separate as much as possible the development of both softwares : different developpers, different languages (Python + Numpy for the processing software, Matlab for the simulation), different approaches are used in order to avoid common interpretation mistakes.

3 Current status

Figure 2 is the output of the tool we have designed for validating our software during its coding : as much as possible, each effect is isolated during the process and compared to its theoretical value (i.e. the value we can calculate from simulation’s input parameters).

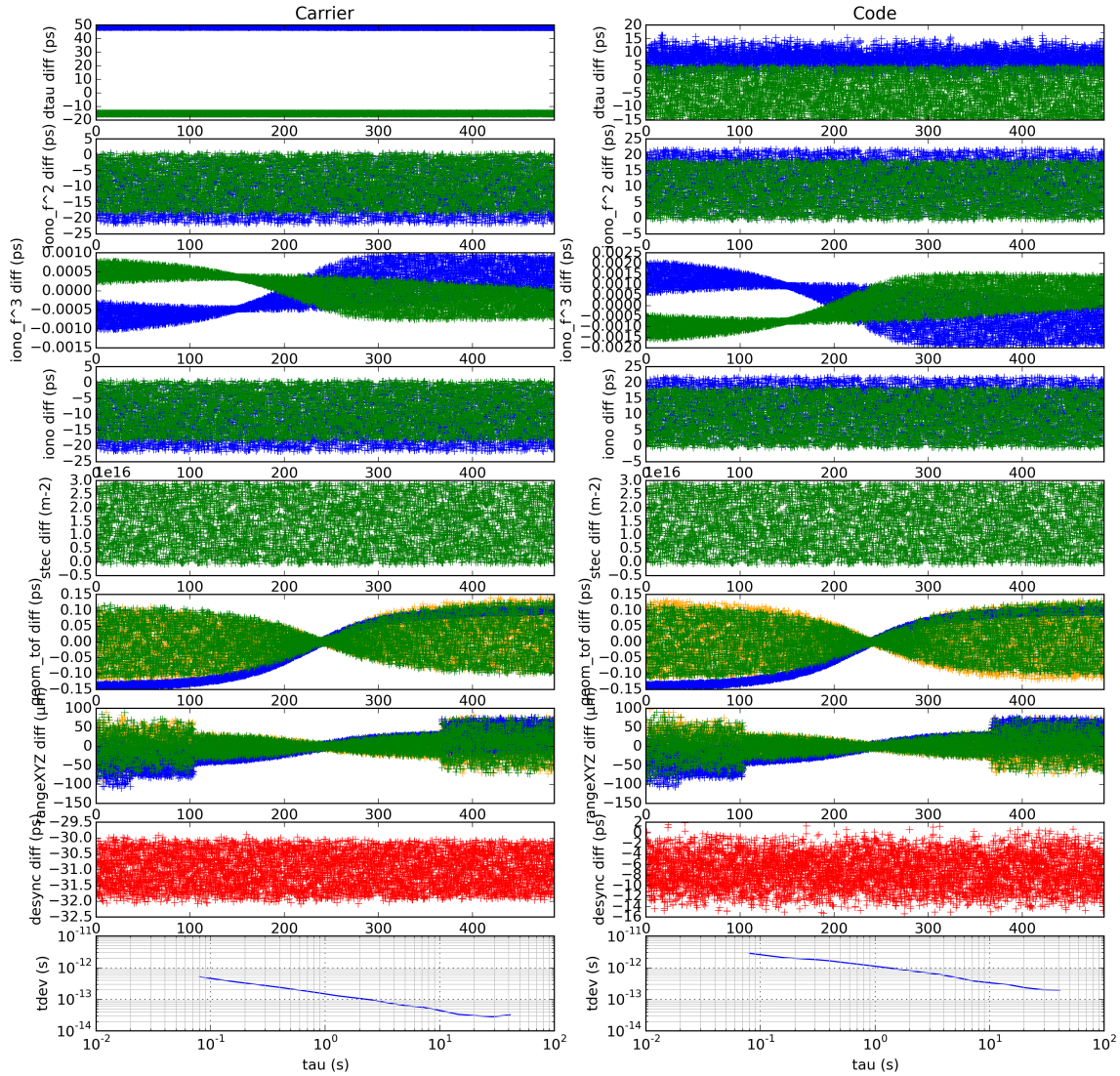


Figure 2 – Typical output from a comparison between the input data (i.e. theoretical values calculated by the simulation), and intermediate/final results calculated by the processing software. In this example, the simulated data includes a keplerian orbit for the ISS, earth rotation, atmospheric delays with variable parameters (troposphere + ionosphere), initial desynchronisation between the clock equal to 0.1 ms, frequency drifts due to velocity and gravitational potential for ground and space. Each point is the difference between the expected data at this date (known from the simulation’s scenario), and the data actually calculated by the processing software for the same coordinate time. Ideally we should therefore get values close to zero + noise. Blue points refer to uplink (f1) signals, green points refer to downlink (f2) signals, and red points refer to desynchronisation (which combines both signals). Left column contains result for carrier-phase data, and right column for code-phase data. Sampling period is 80 ms. See text for a description of the lines.

Preprocessing (1st line of fig 2) This module transforms raw data into pseudo-ranges, which is the expected input for our algorithms (see Delva *et al.* 2012³).

The 20 ps spread on code data is expected : it is a direct consequence of the 10 ns resolution of the raw data. Carrier data is affected by an offset of a few 10 ps, which we are currently investigating.

Tropospheric delays (2nd line of fig 2) Tropospheric delay is a (mainly) non-dispersive effect that can reach several hundred nanosecond on each signal. Two-way measurement cancel

it to a large extent, but we want to evaluate it as well as possible at higher orders. Some dispersive, second order effects have been studied by Hobiger, Piester and Baron (2013)⁴ and will be implemented in the future.

Ionospheric delays (3rd, 4th and 5th lines of fig 2) These are due to the dispersive nature of the ionosphere, and therefore affect differently frequencies f_1 and f_2 . We separated those in 2 terms, one that is proportional to $1/f^2$, the other that is proportional to $1/f^3$. Slight differences may be seen in the latter case : these have been identified as results of the difference between the model used for Earth's magnetic field in the simulation and in the processing software, and remain largely below detection threshold. STEC (Slanted Total Electron Content) is an intermediate result of this calculation and will be issued as a by-product.

Geometrical time of flight and range (6th and 7th lines of fig 2) Geometrical time of flight is the "classical, atmosphere-free" coordinate time interval between emission and reception of a given signal : As both stations move with respect to a geocentric non-rotating reference frame (GCRF), this calculation needs iterations or Taylor series developments to converge.

Range is the instantaneous distance between the two stations at a given coordinate time. This is calculated from the ISS orbitography files and the ground station coordinates, after conversion to GCRF.

Desynchronisation and associated time deviation (8th and 9th lines of fig 2) This is the end result of the processing : residual spreads are consistent with those of the pseudo ranges (first line), which is expected. The offset for carrier-phase data is the mean between the offsets on pseudo-ranges, it is a direct consequence of the offsets on pseudo-ranges which should disappear once those are removed.

Apart from this offset, no visible effects are noticed throughout the pass, showing that all other effects were correctly removed.

4 Conclusion

Our analysis software now implements the core functionalities that will be needed to perform ACES data analysis. Although some important points still need to be elucidated, we are confident that this software will be operational on schedule, with an ACES launch foreseen in early 2017.

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