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Comparison of the frequency estimation of the DORIS/Jason2 oscillator thanks to the onboard DIODE and Time Transfer by Laser Link experiment

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Abstract

The main applications for DORIS are precise orbit determination, and precise Geodesy. Onboard Jason-2 for instance, the DORIS tracking component is the French contribution to the precise orbit determination capability, a key capability for altimetry product scientific result accuracy. T2L2 is a time transfer technique based on the propagation of light pulses for synchronization between two clocks. Hosting T2L2 on-board Jason-2 was to allow for very fine DORIS USO (Ultra-Stable Oscillator) frequency monitoring, and for this purpose T2L2 was connected to the DORIS USO. Thanks to the continuous tracking of T2L2/Jason-2 by the Laser Ranging network it is possible to monitor the USO for several days, weeks, and even much longer, and thus to also compare with the DIODE (the DORIS on-board orbit determination software) frequency bias estimates. The DORIS USO frequency biases estimate comparison between two independent systems, T2L2 and DIODE, can be of benefit to both, allowing the accuracies of both systems to be better understood, and for improvements to be made to both systems. Such comparison is the central topic of the present paper. T2L2 monitors the DORIS on-board USO frequency with an accuracy of much better than 10^{-12} which is the specification for the Doppler instrumentation.

The paper investigates the limits of the DORIS-DIODE frequency bias estimates using T2L2, showing that USO frequency compliance accuracy of 10^{-12} has been reached.

Keywords: DORIS; T2L2; Oscillator; On-board; Frequency determination; DIODE

1. Introduction

Beginning with SPOT2 and TOPEX in the nineties, the DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite) system has been continuously reinforced, improved and made more accurate. Its main purposes are Precise Orbit Determination, and accurate Geodesy (Laborde, 1987; Dorrer et al., 1991).

Due to the great success of DORIS (in addition to the Satellite Laser Ranging (SLR)) to provide altimetry missions with an accurate coverage of the orbit, the DORIS system (hardware and software, in space and at ground level) was involved in several altimetry missions, which includes Jason-2 (launched on June 20th, 2008). As an ascending Doppler system (one-way signal from the

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ground stations towards the satellite), the performance of DORIS is mainly based on the stability of the DORIS receiver Ultra Stable Oscillator (USO), which is of the order of a few parts in 10^{-13} over 1000 s; the USO plays the role of the on-board frequency and time reference. USO clocks are located both on-board and on the ground beacons.

In addition, for operational purposes, an embarked system named DIODE (Doris Immediate on-board Orbit Determination, an advanced function of the DORIS receiver), was developed by CNES (Jayles et al., 2002, 2004); it is based on both a Kalman filter and a reduced dynamical model, and provides in Near Real Time (NRT) the position and velocity of the spacecraft and, as a by-product, the on-board USO frequency bias estimate.

As a complement to the altimetry main mission, the presence of the T2L2 instrument (Time Transfer by Laser Link, Samain et al., 2008) on-board Jason-2 was decided mid-2005. T2L2 is currently only available on Jason-2 as a technology demonstrator with its own metrological and scientific goals (Exertier et al., 2013); it is based on the SLR technology and on the international laser tracking network (Pearlman et al., 2002). T2L2 was specified to realize ground-to-space time transfers with a time stability of about 1 ps over 1000 s and ground-to-ground time transfers in common view with an accuracy of 100 ps (Samain et al., 2008).

T2L2 is able to detect laser pulses, emitted at a wavelength of 532 nm (green) from approximately twenty SLR stations (Exertier et al., 2010). The space segment of T2L2 consists of two blocks, the one optics (for detection), the other electronics that enables one to time-tag each detected optical pulse. On-board Jason-2, the proper time reference system is provided by the DORIS USO (Samain et al., 2014). For ground SLR stations equipped with an ultra-stable clock (as a H-Maser) and with a picosecond-resolution timer, the time stability of the ground-to-space time transfer has been established at a few ps over around 60 s (Exertier et al., 2014). As a result, we computed from each Jason-2 passage over a SLR station (approximately 1000 s) a relative frequency bias every 60 s: its accuracy was estimated at a few parts in 10^{-13}. Thanks to the regular tracking of T2L2/Jason-2 provided by the SLR network, it has been possible to establish a time series of frequency biases of the DORIS USO over several days and weeks (and even much longer).

The interest of doing such a comparison between two independent techniques (DIODE and T2L2) used for the monitoring of the frequency bias of DORIS is twofold:

- The results of DIODE in terms of frequency bias estimation need to be compared to another independent system, what has never been made for a high precision level (around 10^{-12} which is the current specification for the Doppler instrumentation (Auriol and Tourain, 2010)). This means that twelve digits of the frequency value are correct. Since short-term noise is smoothed, this is valid over parts of the spectrum from a few minutes to several days.
- From the beginning, tests with T2L2 time transfer promised high accuracy for monitoring USO frequency stability. Over time, this accuracy was improved and turns out now to be better than the level of a few 10^{-13} over 1000 s. The second source of interest of the comparison is to show the strength and value of the T2L2 experiment.

Both DIODE and T2L2 systems have received benefit from this comparison, which is the central topic of the present paper.

For DORIS restitution, actually external comparisons for adjusted parameters are not always possible: positions and velocities may be compared with satellite ephemerides, pole coordinates may be compared with IERS values, but sometimes no external validation is possible (tropospheric bias for instance).

Here we have taken advantage of T2L2 presence on-board Jason-2: the paper investigates the current limits of the DORIS-DIODE frequency bias estimates using T2L2 estimates as a reference.

Section 2 presents the hardware and software equipment that were used to provide the two series of time biases to be compared. Section 3 presents the preliminary results, verifying Kourou, Toulouse and Grasse results during the chosen period. Section 4 presents the precise results of the comparison for a period of 10 days, in October 2013: analysis of T2L2 estimates, analysis of DIODE estimates and comparison between both. Finally we conclude in Section 5.

For this study, we use "on-ground DIODE" as an Orbit Determination program, because we had to reprocess the data several times with different tunings. Consequently, on-board products and especially frequency estimates downloaded in the telemetry are not considered here.

In order to have the very best results, we use the most advanced DIODE version (called DGXX-S v4_00) which is currently under validation, on-ground, and which will fly on-board Jason-3 and Sentinel-3. In this version, the models have been improved to the very "state-of-the-art", and take the best of the DORIS measurements accuracy.

2. Background for the comparison

This section presents the hardware and software equipment that were used to provide the two series of time biases to be compared. We also detail a few general aspects about DORIS frequency management and attitude manoeuvers, in order to enhance the clarity of the following analysis, presented in Sections 3 and 4.

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