COSPAR02-A-02654

THE CURRENT EVOLUTIONS OF THE DORIS SYSTEM

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ABSTRACT

DORIS was developed for precise orbit determination and precise positioning on Earth. Three new satellites fitted out with dual-channel second-generation receivers have been recently launched. Jason-1, ENVISAT and SPOT-5 acquired a real autonomy thanks to DIODE real time on-board orbit determination software. Today the DORIS system has built up a global network of 55 stations. In order to reach new accuracy goals for Jason-1 and ENVISAT, it was decided to improve the long-term stability of the antennas when necessary. Third-generation beacons deployed from the end of 2001 offer new features and greater reliability. The satellites relay acquired and stored data at regular intervals to SSALTO, the new DORIS mission control center. DORIS data from the different satellites are currently available in the two Data Centers and used by the International DORIS Service Analysis groups.

DORIS SYSTEM AND MISSIONS

The DORIS system (Doppler Orbitography and Radiopositioning Integrated by Satellite) was designed and developed by CNES, the French space agency, in partnership with the space geodesy research institute GRGS and France’s mapping and survey agency IGN, to determine the position of satellites on orbit and to locate ground stations with extreme accuracy.

Since embarking on its initial proof-of-concept mission on SPOT-2 in 1990 and on its first operational mission on TOPEX/POSEIDON in 1992 the DORIS system has taken every new challenge in its stride.

SPACE SEGMENT

On-board instruments

Second generation DORIS receivers have a dual channel capability, allowing multiple stations positioning in the same area, an improved accuracy, phase measurements and a real autonomy thanks to DIODE navigator.

Real time on-board orbit determination accuracy is improved (see DIODE section). Through instrument and DIODE self-initialization, these receivers go from turn-on to routine mode without any ground commands. Based on DIODE directives for beacons signal acquisition, i.e. self-programming, the autonomous mode does not require daily upload any longer. Master beacons permanently broadcast “system uploads” allowing automatic update of the on-board network description.

Radiation hardened electronic components also increase instrument operational robustness.

Satellites

First generation receivers equipped four satellites: SPOT-2 (launched in 1990), TOPEX/POSEIDON (launched in 1992), SPOT-3 (1993-1996) and SPOT-4 (launched in 1998).

Three satellites carrying second generation DORIS receivers have been recently launched:

- Jason-1 was launched December 7,2001, the DORIS receiver was switched on December 8 and automatically started. The orbit accuracy is already on the TOPEX/POSEIDON level and should reach the aimed at radial centimeter level.

- ENVISAT was launched March 1, 2002
- SPOT-5 was launched May 4, 2002

New satellites will be launched in the future, such as CRYOSAT (ESA), Jason-2 or Pleïade (SPOT follow-on).

DIODE NAVIGATOR

General Features

The core of the routine part of DIODE is a Kalman filter. It uses a numerical integration with a Runge-Kutta algorithm to propagate the state vector every ten seconds and it processes the measurements provided by the DORIS receiver to correct its state vector.

All the DORIS measurements performed on orbiting satellites are stored on-board and transmitted each day to the DORIS ground segment. We have used this large amount of data, several years of continuous Doppler measurements on SPOT-2, SPOT-3, TOPEX and SPOT-4, to improve each version of DIODE.

First Generation

The first version of DIODE was switched on, on-board of SPOT-4, on March 26th, 1998, and has now been operated for four years and a half. Detailed analysis of the on-orbit results can be found in Jayles (1999) and Costes and Jayles (1999). The observed accuracy is around 5 meters RMS in 3D, from the beginning until now, while the availability is around 99,5 %.

DIODE first generation has been the first on-board orbit determination system, to provide long time results. Its main goal is achieved: on-board orbit determination is today flight-demonstrated: today, an on-board determination function has proved to be reliable enough, to be used in a reinforced way by the system (especially by the AOCS). Costes and Jayles (1999) give the detail of different benefits of such a function.

Second Generation and Second Generation Miniaturized

Main Features

The ENVISAT version (second generation) is similar to Jason-1 and SPOT-5 versions (miniaturized), and has been operating on-board of ENVISAT since March 2002. The accuracy on ENVISAT is around 1.0 meter RMS (3D), and 50 centimeters RMS on the radial component.

DIODE last validated version is used on-board of Jason-1, and is also flying on-board of SPOT-5.

Many enhancements have been integrated, and accuracy has been once again improved (pole coordinates adjustment, Hill accelerations, drag adjustment…). The algorithms of DIODE/Jason-1 are precisely described in Rozo and Jayles (2001). This version has reached ground qualification in mid-2000.

The real-time orbit is used on ground to produce Operational Science Data Records, which will be generated and distributed within 3 hours to operational oceanography centers throughout the world.

Real In-Flight Results

Figure 1 shows the results obtained on three months of Jason-1 real measurements: DIODE estimations are compared with the ZOOM precise orbit ephemeris (P.O.E.), which have an accuracy better than 3 centimeters on the radial component. The differences are shown in the orbital frame, in meters.

The radial RMS oscillates between 8 and 25 centimeters. The accuracy specified by altimetric users is 30 cm RMS on the radial component, and 1 meter RMS in 3-D.

Time determination is also elaborated as a correspondence between on-board time and ground TAI time, and provided to the platform. Figure 2 shows the results of a comparison between DORIS/DIODE TAI time-tagging of PPS events and the GPS PPS reference TAI time.

On this graph, 30 passes over the Master-Beacons have lead to periods of synchronization adjustment. The rest of the time, a prediction is elaborated, using the on-board estimation of the USO frequency.

The agreement is 1.4 microseconds (rms): as this time determination is provided to the carrier satellite, the DORIS receiver may be used as an on-board clock, providing a few microseconds time determination to the spacecraft.

All the lessons learned with the first generation have been integrated in this version: on Jason-1, since February 2002, the observed availability is 100 %.

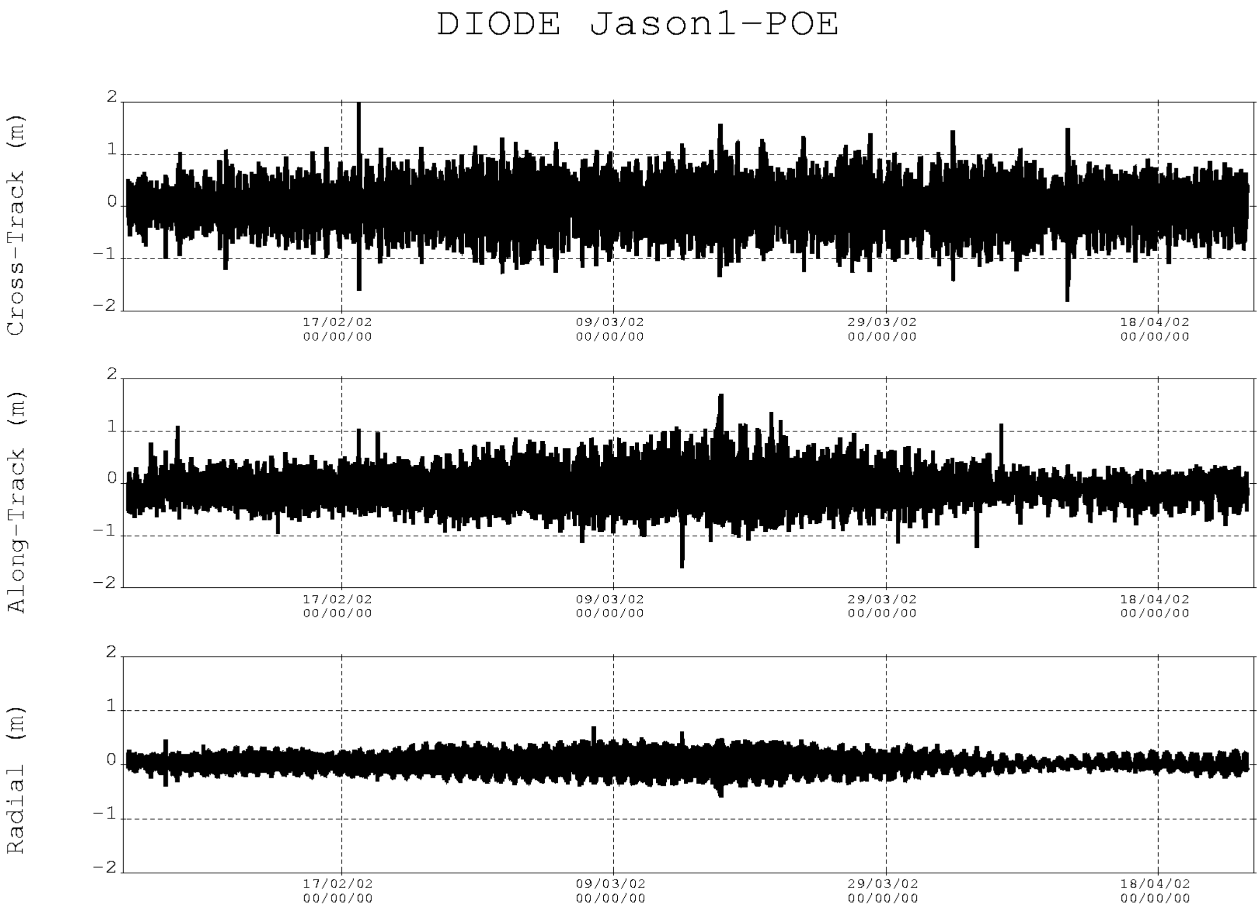

Fig.1. DIODE/Jason-1 positions accuracy

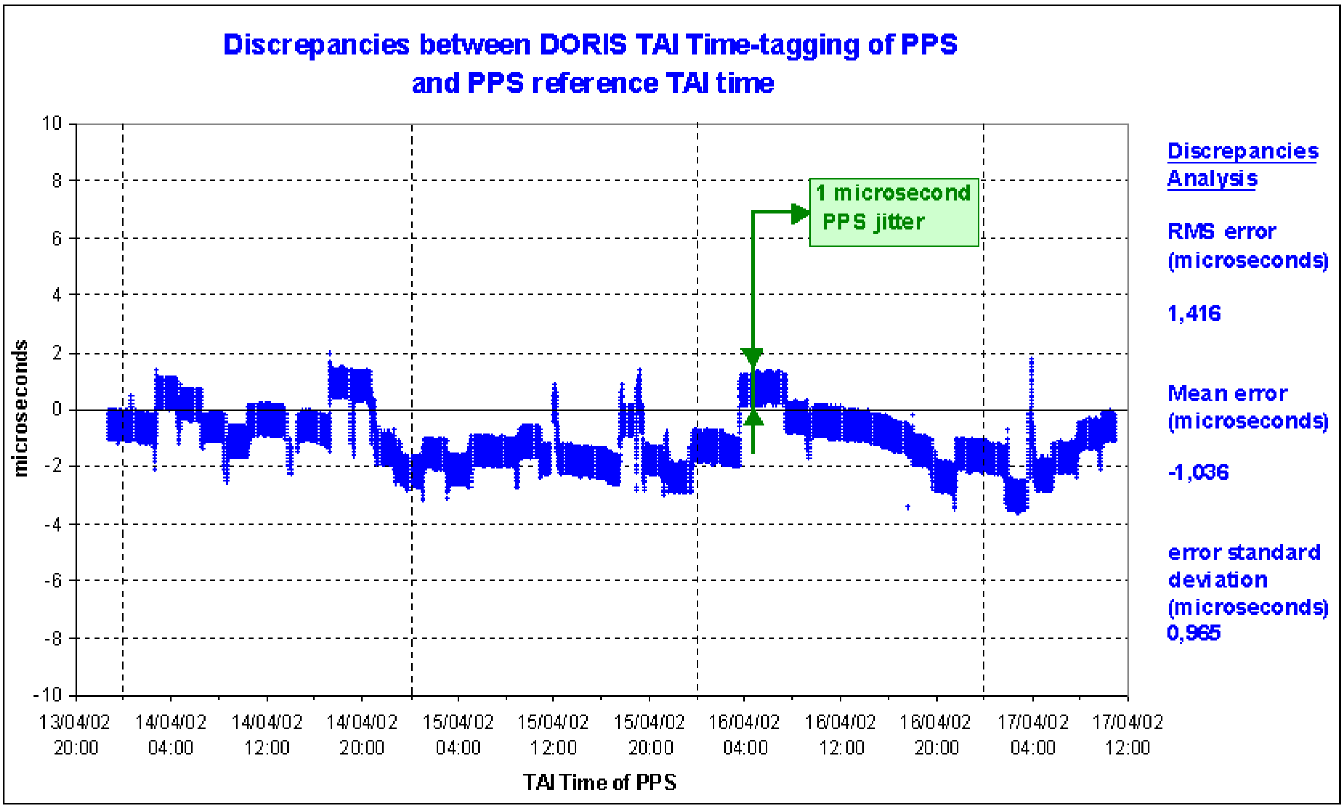

Fig.2. DIODE/Jason-1 time determination accuracy

Future Improvements: The 2GXX Generation

Orbitographic conception

This next-to-come version is currently under development. CRYOSAT should be the first satellite to fly with this version on-board. The first improvement is the selection of a Sparc ERC 32 microcomputer providing a better numerical accuracy. We have added new improvements: Doppler quality rating, Failure Detection and Incident Recovery strategy, integration of a new dedicated version of Grim5 60x60, elaborated by the G.R.G.S. and G.F.Z., … Moreover, all the lessons learned from Jason-1, SPOT-5 and ENVISAT experiments are being integrated.

Results on real TOPEX measurements

As we have always done, this preliminary version has been put in daily operation, on-ground, fed by TOPEX measurements. Figure 3 and Table 1 show the results of a three-day comparison with the Precise Orbit Ephemeris and Table 1 the corresponding statistics.

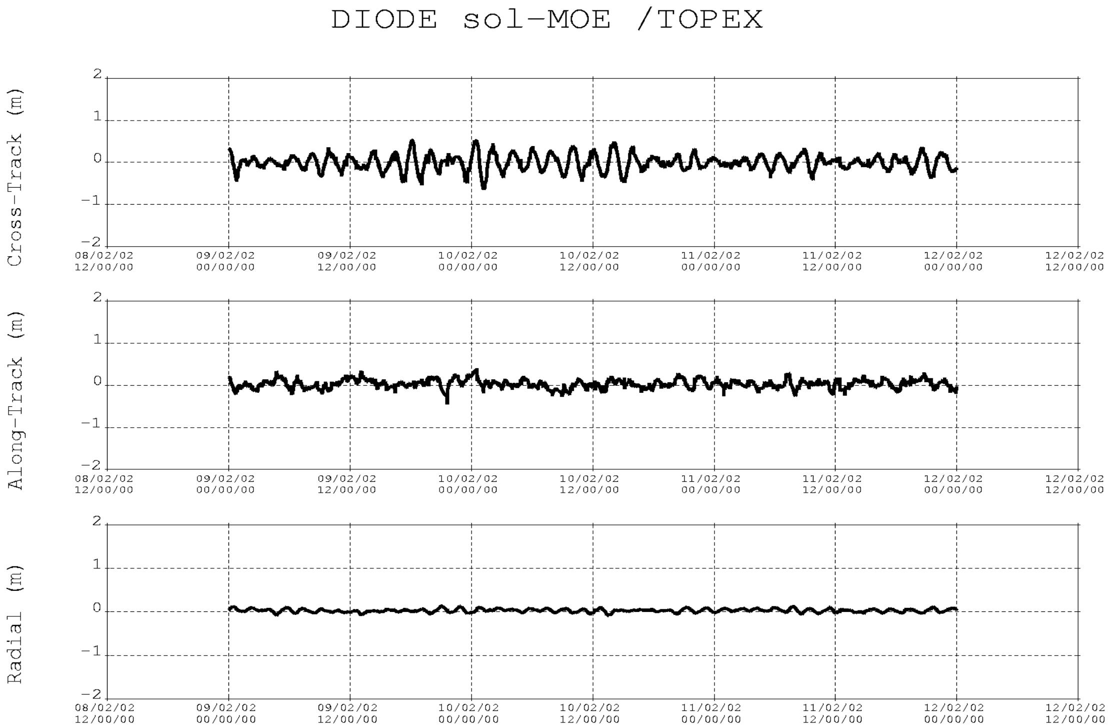

Fig.3. DIODE/CRYOSAT position accuracy with TOPEX measurements

Table 1. Statistics			
	Maximum	Mean	Standard Deviation
Radial (m)	0.136655	0.032940	0.037911
Along-track (m)	0.449248	0.034870	0.103829
Cross-track (m)	0.649905	-0.005054	0.184848
Distance (m)	0.658156	N.S.	0.220709

Notice the 3.8 cm standard deviation on the radial component, and the maximum value better than 14 cm (during three days). A 3.3 cms mean value can be observed, and we are investigating to find the reason for this bias.

NETWORK

Third generation beacon

CNES developed third generation beacons to improve DORIS system accuracy and capacity. The emitted frequencies can now be shifted with respect to nominal frequencies: +/- 50 kHz (2 GHz) and +/- 10 kHz (400 MHz). It will thus be easier to avoid jamming by nearby stations.

Beacon modulation is now transmitted on both 2 GHz and 400 MHz frequencies (only on 400 MHz frequency with previous beacons). This modulation is used to transmit beacon message and synchronization word. Current TAI date (with a LSB of 10 seconds) is broadcast and the observability of beacon operation status is improved. The beacon has an auto-initialization mode, can be remotely controlled and upgraded into a master beacon.

Such beacons have already been installed in Toulouse (master beacon), Tristan Da Cunha, Mahe, Cibinong, St Helena and Thule. Other upgrades are planned this year, such as in the French Southern Indian Ocean territories.

Monumentation

In order to reach new accuracy goals for Jason-1 and ENVISAT, it was decided to improve the long-term stability of the antennas when necessary.

This network renovation action started in 2000 with the stations of Cibinong, Djibouti, Hartebeesthoek and Metsahovi. Two new stations were installed in Greenbelt, replacing Ottawa (antenna on a concrete pillar instead of a high building) and in Futuna (antenna on an iron tube + concrete), replacing Wallis. Several new local ties with other geodetic techniques were realized and transmitted to the IERS Central Bureau. 11 stations were renovated in 2001: Rio Grande, Easter Island, Santiago, Amsterdam, Kerguelen, Kitab, Ponta Delgada, Yellowknife, Arequipa, Noumea and Chatham, and three, until now in 2002: Tristan da Cunha, Terre Adélie and Port Moresby. Several other renovations are under way. More than half of the stations (24 excellent, 4 good) meet the new stability requirement, to be compared to 1 out of 6 two years ago.

DORIS GROUND SEGMENT

SSALTO, the new DORIS and altimetry multi-mission Control Center is operational since December 2000. Thanks to its links with the Control Centers of the different satellites fitted out with a DORIS receiver, it is able to collect DORIS measurements, preprocess and send them to the DORIS Data Centers as well as ancillary data such as maneuvers, attitude, meteorological data.

SSALTO also produces preliminary and precise orbits, which will be sent to the Data Centers as soon as a format is adopted. The AVISO component will ensure archiving.

Since the end of 2001, SSALTO successfully withstood the workload increase owing to the three new missions in spite of very close launches.

INTERNATIONAL DORIS SERVICE

For the DORIS Pilot Experiment an international Call for Participation has been issued in September 1999. A Steering Committee has been set up.

Central bureau

CNES, CLS and IGN perform the operational tasks of the Central Bureau. A specific Web site has been created presenting the Pilot Experiment organization, the proposals, the members of the different groups, the DORIS Mails, the Site logs, a lot of new information on the DORIS system and also links to all DORIS groups Web sites: http://ids.cls.fr

IDS workshop

An IDS Workshop was held in Biarritz on June 13 and 14, 2002. About 90 people, representing various contributors and users of the DORIS system attended it: the host agencies (stations), the Data and Analysis Centers and the project partners. (See http://ids.cls.fr/html/report/ids_workshop_2002/programme.html: program and presentations)

Data Centers

Two Data Centers (NASA/CDDIS and IGN/LAREG) archive and distribute DORIS measurements and ancillary data. They will also archive and distribute products as soon as they are available, with the help of Carey Noll (Data Flow coordinator): data are currently available for 5 satellites for more than 12 years: SPOT-2, TOPEX/POSEIDON, SPOT-3, SPOT-4, Jason-1 and SPOT-5. Data from the recently launched ENVISAT will be available soon.

Analysis Campaign

There are eleven candidate Analysis Centers willing to process DORIS measurements.

The IDS Central Bureau initiated in November 2001 an Analysis Campaign that originally focused only on sets of station coordinates derived from the June 2001 observations of the Spot2, Spot4 and Topex/Poseidon.

Responses were received from six Analysis Centers, while three other expressed interest to participate at a later time. The content of the responses was larger than expected, in several ways: the data span covers several years, as compared to the single month requested, and the products span not only sets of stations coordinates, but also times series of the Earth's orientation parameters and of the geocenter location and orbits.

Martine Feissel joined the Steering Committee in January 2002 as Analysis Coordinator. Starting in March 2002, the newly designated Analysis Coordinator joined her efforts with those of the IDS Central Bureau to adapt the comparison capabilities to the results provided. The objectives of the campaign now apply to a larger set of results: station coordinates (global solutions or time series weekly, monthly), satellite orbits, geocenter location time series and Earth orientation (EOP) time series.

The objectives remain as listed above, with one addition, to check the consistency of the estimated time varying parameters (Geocenter, EOP) and the estimated reference frames (sets of station coordinates, ephemerides). The results of the campaign were discussed at the 2002 IDS Workshop.

The Stations Selection Group

The Stations Selection Group chaired by Frank Lemoine includes scientists involved in various applications such as geodesy, geophysics, altimeter calibration, tide gauges, ITRF collocation and a representative of the DORIS Stations Installation and Maintenance Service (IGN/SIMB).

The group defined site criteria taking DORIS site constraints into account and prepared a Station Response Form, which was sent to candidate sites.

During the 12th December 2001 to 5th February 2002 period, Geoscience Australia (formerly Australian Surveying and Land Information Group, AUSLIG) deployed a Doris beacon on the Sorsdal Glacier, which is located in the vicinity of the Davis Station (68°S-78°E), Australian Antarctic Territory. It is the first site selected for the IDS Doris Pilot Experiment.

A third generation beacon was installed in February 2002 in Ajaccio, an altimeter calibration site in Corsica. New proposals have been selected in 2002. Burnie (Australia) supports long-standing altimeter calibration site in Bass Strait, TIGO will provide a long-term tie in the Southern Hemisphere between four geodetic techniques (SLR, DORIS, GPS, VLBI) and Gavdos (Crete): for altimeter calibration.

CONCLUSION

With DIODE, on-board orbit determination is today a reality and has been in-flight demonstrated: this concept enters now an operational phase, and its main ideas and principles are validated. Many satellite conceptors now integrate a « navigation » function in new platform designs. The modular conception of SSALTO allows new instruments to be easily integrated or to deliver a DORIS instrument control center for a “DORIS user” project.

From now on, constellations, automated Earth observation systems, and satellite designers in general, should be confident that on-board orbit computation has become an operational facility, with a pretty good accuracy and a convincing reliability. CRYOSAT, Jason-2 and Pléiades will be our next users. We are sure that, for those flights, DORIS and DIODE will improve their performance again.

The IDS workshop held in June in Biarritz gathered the whole DORIS community from people involved in stations to analysis centers. We are on the way to establish a new International Service.

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Manuscript received: 10 November 2002, revised 19 March 2003, accepted: 14 March 2003