DORIS SYSTEM DEFINITION
(VERSION 1.2)

ABBREVIATIONS

SIGLE	DEFINITIONS
AOCS	Attitude and Orbit Control System
DIODE	Doris Immediate on-board Orbit Determination (Détermination Immédiate d'Orbite par DORIS Embarqué) : advanced function of the DORIS receiver, that computes the position and the velocity of the satellite : a *real time on-board orbit determination* software
DORIS	Doppler Orbitography and Radio Positioning Integrated by Satellite
GECO	Operations Coordination Board
IDS	International Doris Service
IERS	International Earth Rotation and Reference Systems Service
ITRF	International Terrestrial Reference Frame
POD	Precise Orbit Determination
RINEX	Receiver Independent Exchange Format
SALP	Service d'Altimetrie et de Localisation Précise is the project devoted to DORIS system operation and to altimetry missions control and processing.
SLR	Satellite Laser Ranging
SSALTO	Multi-Mission Ground Segment for Altimetry precise positionning and Orbitography, (CNES)
TAI	International Atomic Time
TC	Telecommands
TM	Telemetry
USO	Ultra-Stable Oscillator
VLBI	Very Long Baseline Interferometry

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1 SUBJECT

The DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) system has been developed jointly by CNES, IGN (Institut National de l'information Géographique et Forestière), and GRGS (Groupe de Recherche de Géodésie Spatiale) in the frame of the TOPEX/Poséidon altimetric project. A first demonstration occurred in 1990 with SPOT2, hosting a DORIS receiver developed by Thalès Systèmes Aéroportés (TSA). Processing of those measurements has allowed very precise orbit determination and station positioning.

First developed as a contribution to scientific missions, DORIS has been evolving over the last 20 years to become a very efficient system with a high level of integrity. Successful flights on-board different satellites have occurred: SPOT2, TOPEX, then SPOT3, SPOT4, Jason-1, ENVISAT, SPOT5, Jason-2, CryoSat-2 and HY-2 have led to a deep mutation of the DORIS system.

The main evolution was the implementation of a Real-Time Precise Orbit Determination capacity called DIODE. This capacity is embedded in the DORIS receivers since SPOT4.

This document aims at describing the DORIS missions, then the DORIS system in details, with its external and internal connections.

In this purpose, each function of the system is described using the HOOD method (Hierarchical Object Oriented Design). In the description sentences, subjects will give subsystems, verbs will indicate actions and object complements will suggest data fluxes. This technique is well suited for software design, but it is also very useful in system description.

2 SCOPE

This document applies to the DORIS system from the DGXX generation (Jason-2, Cryosat2, Pléïades…). Former DORIS generation (SPOT, TOPEX, …) are only mentioned as historical references.

3 DORIS MISSIONS AND REQUIREMENTS :

3.1 DORIS MISSIONS :

Two domains can be distinguished : off-line ground use of DORIS, and on-board real-time :

DORIS off-line purposes are Precise Orbit Determination, and Precise Geodesy.

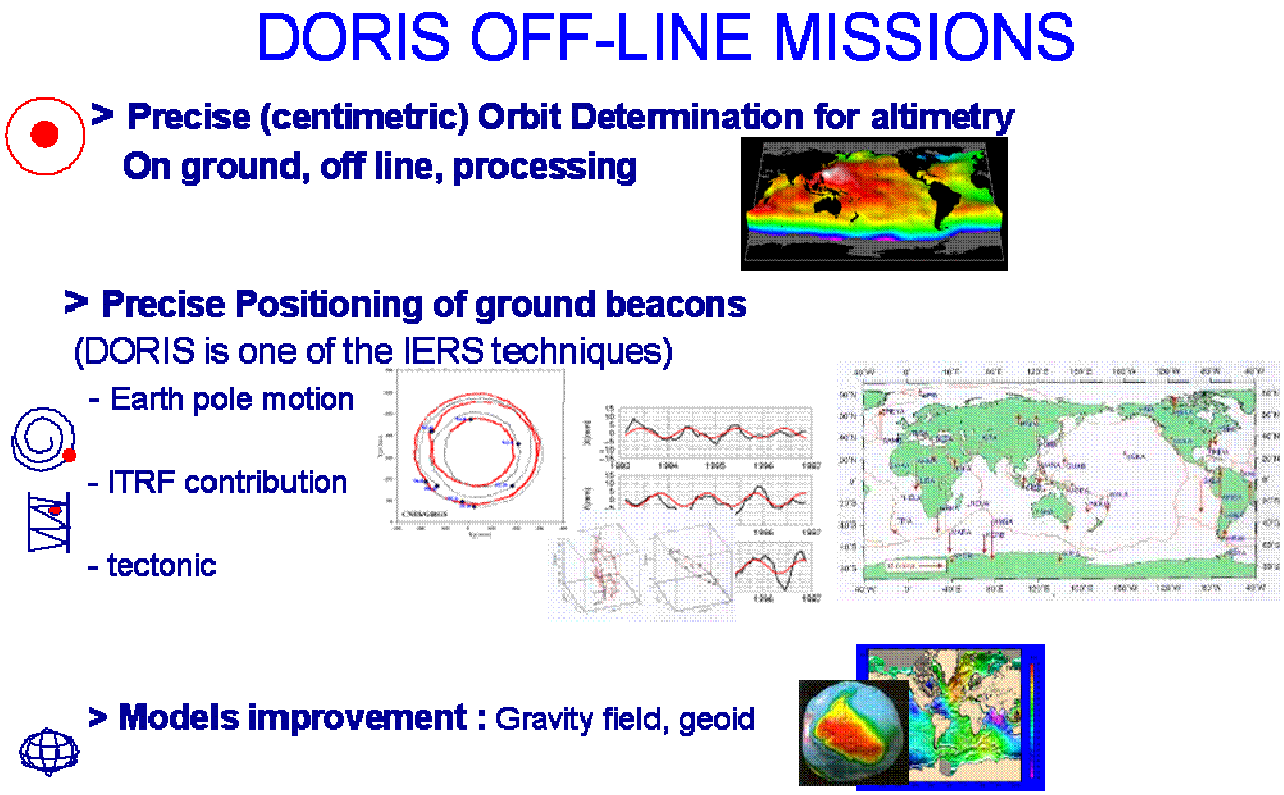

Fig.1 – DORIS off-line missions

DORIS real-time missions are :

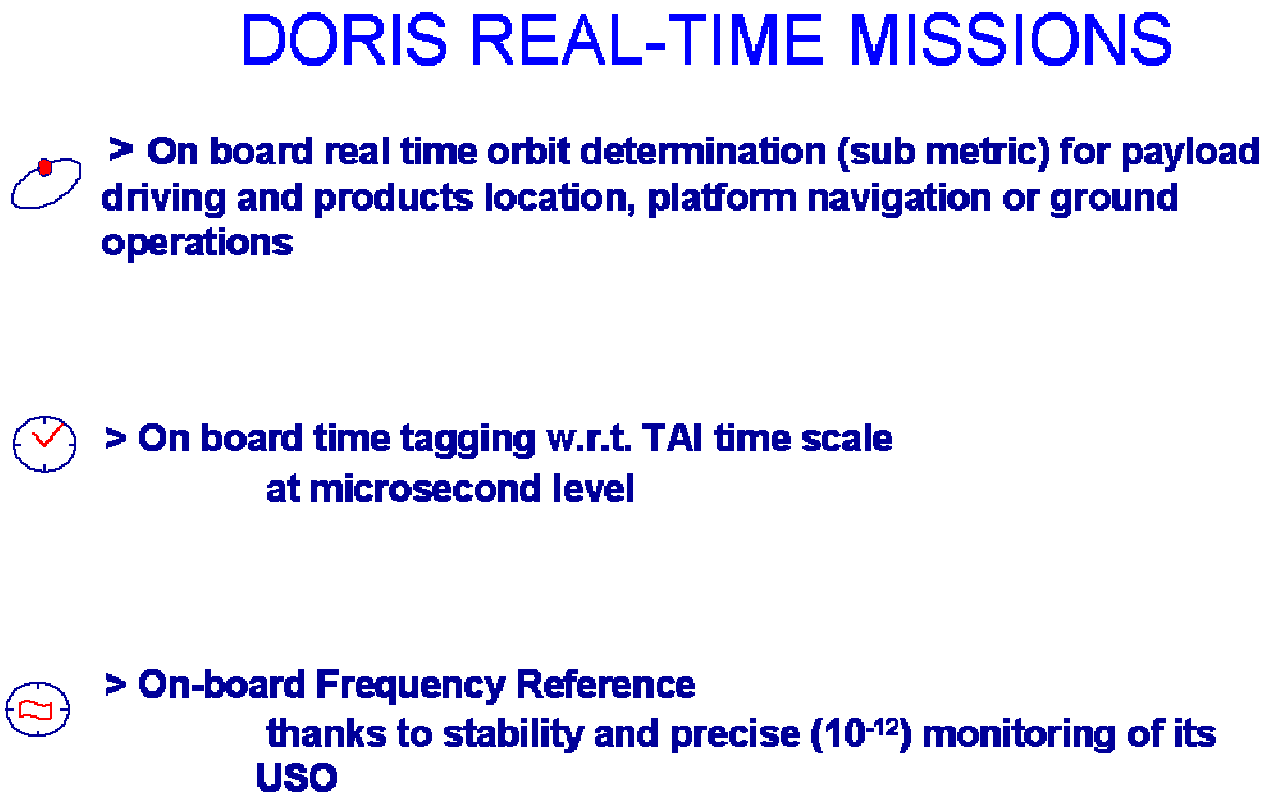

Fig.2 – DORIS real-time missions

3.2 DORIS MISSIONS / REQUIREMENTS :

Here below are given the requirements for each type of satellite mission.

3.2.1 ALTIMETRY ON HIGH ORBITS

(TOPEX, Jason)

- Ultimate Accuracy POD 1 centimeter RMS on the Radial component
- DIODE 5 centimeters RMS on the Radial component
- DIODE : Initialisation Delay = best effort

3.2.2 IMAGE MISSIONS

(Spot, Pléïades) :

- Real-Time on-board accuracy DIODE : 1 meter / 3 Directions
- Initialisation Delay : 20h maxi (Pléïades full performance)

3.2.3 CONTROL CENTRE ANCILLARY ORBIT

- Real-Time on-board accuracy DIODE 1 meter / 3 Directions
- Initialisation Delay : until Pléïades, no real requirement as this system was a redundant information for orbit control (Spot5, Jason-1/2). For Pléïades, initialisation delay : 20h maxi (Pléïades full performance).

3.2.4 ON BOARD AOCS ANCILLARY ORBIT

- Real-Time on-board accuracy DIODE 100 to 500m,
- Unavailability < 24 hours
- Initialisation Delay : 15h maxi (Pléïades coarse performance)

3.2.5 AOCS TIME REFERENCE

- Real-Time TAI datation better than 5 microseconds RMS.
- Unavailability < 24 hours
- Initialisation Delay : 15h maxi (Pléïades coarse performance)

3.2.6 GEODESY

- Elementary measurement accuracy shall be compliant with a better-than-1cm accuracy : Doppler < 0.3 mm/s, Phase < 3 mm

4 OVERVIEW AND FIRST LEVEL DESCRIPTION

4.1 OVERVIEW

The system is based on accurate measurements of the Doppler shifts on a radiofrequency signal emitted by ground stations and received on-board different satellites, carrying DORIS receivers. A ground segment monitors and processes the data. Scientific products are distributed by the International DORIS Service.

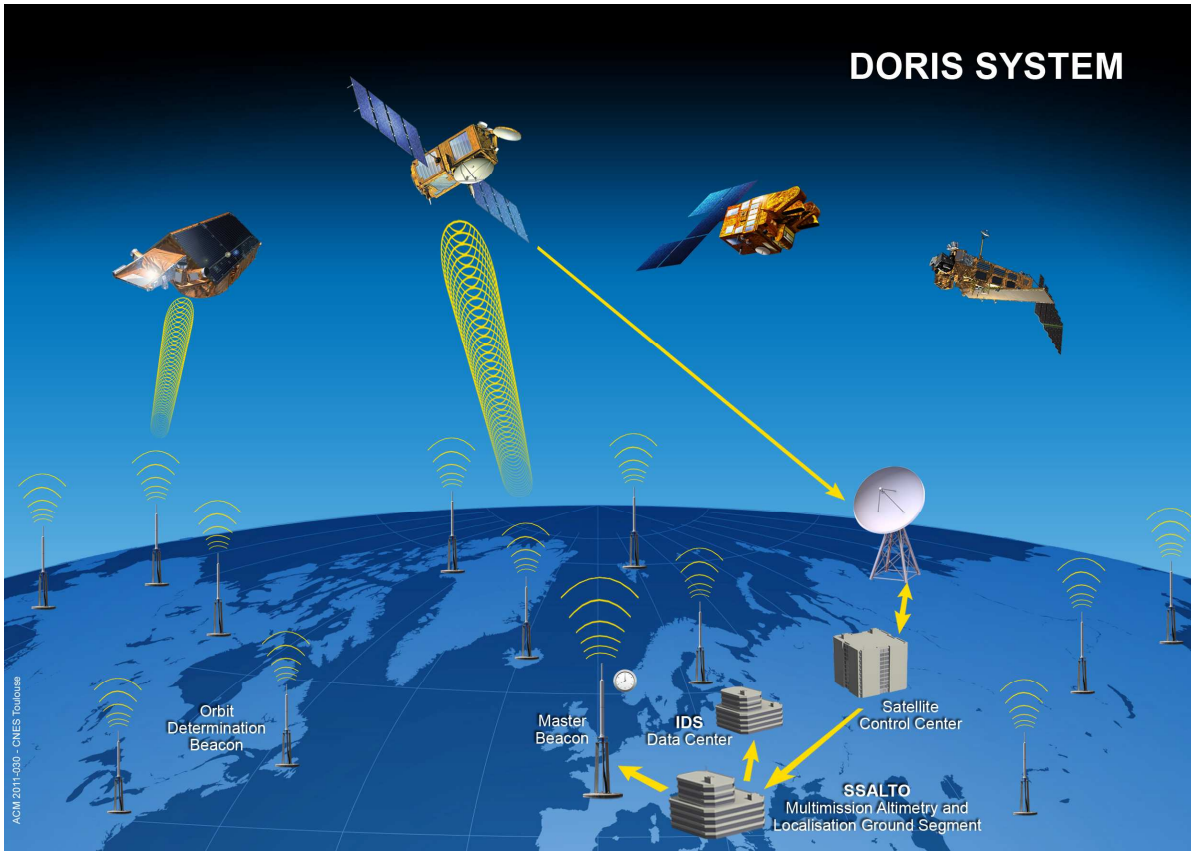

Fig.3 – The DORIS system : main features

Choosing an upway link, has allowed complete automation of the beacons and very simple communication of the overall system, since measurements and real-time products are performed, time-tagged and stored on-board. For each of the carrier satellites, a unique time scale is used to elaborate measurements: reference time is derived from the DORIS on-board Ultra-Stable Oscillator (USO). The behaviour of this on-board clock is monitored by on-board real-time restitution, and carefully checked by ground processings.

The number of carrier satellites is unlimited.

4.2 FUNCTIONAL DESCRIPTION

The DORIS system can be described as follow :

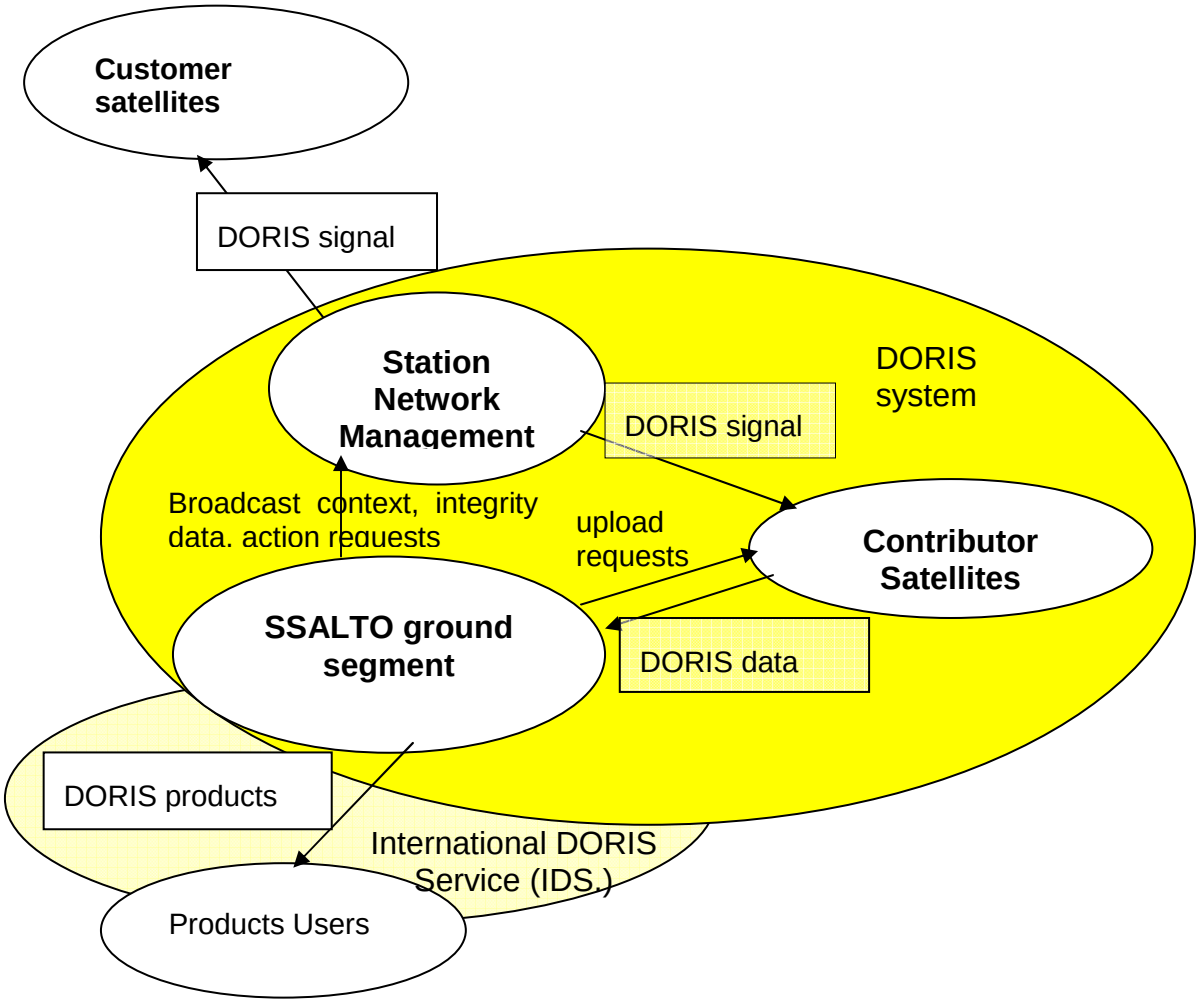

Fig.4 – The DORIS system : external and internal connections

The ***DORIS signal*** is emitted by the stations of the ***DORIS network*** and received on-board ***customer satellites*** and ***contributor satellites***, which are fitted with DORIS receivers. On-Board Real-Time products are useful to the satellite AOCS, other on-board passengers or the ground segment

DORIS data of the ***contributor satellites*** is sent to the DORIS monitoring and Ground Processing, known as ***SSALTO*** (Orbitography and Altimetry Multi-mission Center) .

SSALTO archives the ***DORIS data*** of each ***contributor satellite***, checks the different DORIS receivers performances and, checks the overall DORIS ***system integrity***, elaborates the ***Broadcasts uploads***, the ***DORIS products***, ***requests*** for the satellites or ***action requests and integrity data (if necessary)*** for beacons operation (OFF/ON, renew, …).

4.3 STATION NETWORK MANAGEMENT

The DORIS Station Network is managed jointly by CNES and IGN teams, and by Host Agencies of more than 30 stations.

This function is detailed in parag. 8.

4.4 CONTRIBUTOR PROJECTS OR SATELLITES

These are the projects whose satellites host a DORIS receiver and forward their data to SSALTO. They are detailed in parag. 9.

On-Board RealTime products are useful to the satellite AOCS, other on-board equipment or the ground segment.

4.5 CUSTOMER PROJECTS OR SATELLITES

These are the projects whose satellites, hosting a DORIS receiver, do not forward their data to SSALTO. This may be the case for instance if the orbit/attitude control strategy contains very frequent manoeuvres making the measurements incompatible with precise positioning (e.g. Pléïades).

These projects may take advantage of the on-board products (ITRF or J2000 bulletins, TAI time-tagging, geodetic quantities, …). But of course, no precise reprocessing is performed by SSALTO on their data : these project cannot take advantage of DORIS ground ultimate orbits. They do not either contribute to the determination of the DORIS Reference Frame.

They benefit from the DORIS system services : DORIS signal, signal integrity monitoring lessons learnt from these missions. They also contribute to the maintenance of the system and its influence.

4.6 SSALTO GROUND SEGMENT

SSALTO is in charge of DORIS monitoring and ground processing. It archives the DORIS data of each contributor satellite, checks the different DORIS receivers performances, checks the overall DORIS system integrity, and elaborates the Broadcasts uploads, the DORIS products, requests for the satellites or action requests for beacons operation (OFF/ON, renew, …).

This function is detailed in parag. 10.

4.7 IDS AND THE DORIS PRODUCTS

IDS Data Centers receive measurements from SSALTO, archive and distribute them. Measurements are then retrieved by the different IDS Analysis Centers, to elaborate high level scientific results or products.

They are detailed in parag. 6 and 7.

5 DATA EXCHANGED

5.1 BROADCAST CONTEXT, INTEGRITY TM, ACTION REQUESTS

A set of directives is elaborated every week during the GECO meetings. An overview of the operational network status by the different experts, leads to a list of requests : programmation of a new beacon, update Time beacons delays, investigate to find the reason of an event, …

These directive will be taken into account by the Station Network Teams.

5.2 THE DORIS SIGNAL

The DORIS signal is a radiofrequency signal, mainly composed of two links :

« standard » beacons emission, constituted of two carriers (with either one or both) modulated by the « Beacon Message », Two frequencies are used (2.03625 GHz for precise measurement of the Doppler effect, and 401.25 MHz for ionospheric effect compensation). The 1st and 2nd generation beacons only modulate the low frequency carrier, while the most recent beacons (from 3rd generation and later on) modulate both carriers. The « Beacon Message » gives specific information about the Beacon (identity, technological data, meteorological data, synchronization data).

« broadcasts » uploads are emitted by a few specific Beacons (the “Master” Beacons). Elaborated by the SSALTO Ground Segment, these uploads contain overall information about the Station Network, that will be useful for the on-board receivers :

- Precise coordinates of the DORIS antennas (at a certain epoch) are defined by the Station Network Teams, and communicated by DORISmail. Introduced in the DORIS Data Base, this information is used every week by SSALTO to compute the current value of the coordinates. This information is converted into the appropriate format and emitted by the Upload Beacons. On-board navigators use these values of the coordinates, to perform position and time-tagging determination (by processing Doppler and Synchronization measurements). At this level, a one centimeter accuracy is sufficient for the coordinates, since the Navigation function may neglect smaller errors. Accuracy of the coordinates is far more demanding for very precise ground products.

- Precise time ties for the Time Beacons : these are the beacons whose clock parameters are known with respect to International Atomic Time (TAI). Time Broadcasts are used by on-board navigators to determine accurate correspondance between on-board DORIS time, and ground TAI time (by processing Synchronization measurements). Time shift and drifts of the DORIS Time Beacons (slaved to atomic cloks) are periodically measured and monitored with the required accuracy, then forwarded into space through Broadcast Time Uploads. Similarly to the coordinates, a one-microsecond uncertainty will not provoke strong disturbance in the on-board orbit products and can be accepted.

- And also general Time correspondence information: Coordinated Universal Time (UTC) and Universal Time 1 (UT1) biases with respect to TAI.

Every week a new set of Broadcasts uploads is elaborated. Integrity of their transmission is guaranteed by using a detection/correction error code.

5.3 DORIS DATA

The TM/TC exchanges between DORIS instrument and the carrier satellite, the satellite ground segment and the DORIS ground segment make use of Source Packets called DORIS Packets.

The different DORIS packets are listed hereafter :

Anomaly Report (if relevant)	To report any malfunction or commanding and needing corrective actions from ground
Routine Report	To report current status and activity of the receiver and also information about the DORIS signal received from the beacons and processed by the On-Board Software
Datation	Containing time ties between on-board time and TAI time scale
Attitude (if relevant)	Copy of attitude data received from the satellite AOCS
J2000 Navigation	Inertial position and velocity of the satellite, well-adapted to AOCS use
Geodesical Navigation	Position of the satellite w.r.t. a specific terrestrial reference frame dedicated to drive other payload instrument
ITRF Navigation	Position and velocity of the satellite w.r.t. the current International Terrestrial Reference Frame. Well-adapted to remote sensing payload products accurate location.
Doppler	Contains elementary Doppler, range and pseudo-range instrument
Test Jamming (on request by TC)	Contains RF levels in DORIS bands
Test Dump (on request by TC)	Allows on-board software parametrization checking
Test others (on request by TC)	Test data for trouble shooting purpose

All these DORIS packets shall be transmitted as soon as possible to the DORIS monitoring and Ground processing segment by every contributor satellite.

5.4 UPLOAD ADVISES OR REQUESTS

A few requests can be asked to the contributor satellites : update a new version of the On-Board Flight Software, or upload a new tuning for one of the on-board parameters.

This kind of event is very uncommon.

5.5 DORIS PRODUCTS

5.5.1 DORIS PROCESSED MEASUREMENTS

The DORIS processed measurements are made available to the scientific community (associated with the precise Orbit products), via the IDS Data Centers at NASA/Crustal Dynamics Data Information System (CDDIS) and IGN/Laboratoire de Recherches en Géodésie (LAREG).

RINEX format is supported.

5.5.2 DORIS ORBITS

DORIS Precise Orbit Ephemeris (POEs) are especially useful to scientific projects, as a help in the science data processing of the satellite data. This has been the case of the CNES/Nasa projects TOPEX/Poséidon since 1992, Jason series and also of the ENVISAT and CRYOSAT ESA missions, for their altimetric measurements .

Rapid products are also elaborated with a few days delay for fast delivery to quick-look processing (Intermediate Geophysical Data Records (IGDR) Jason1 files).

Accuracy of DORIS orbits and DORIS time-tagging data allow the best benefit for altimetric measurements, and lead to better understanding of Earth phenomena like El Niño or the global rise of the sea level.

6 DORIS ON-BOARD PRODUCTS

6.1 DORIS FREQUENCY MONITORING

For altimetric payloads, DORIS offers a monitored frequency which is known at a few 10-12 level.

6.2 NAVIGATION J2000 POSITION/VELOCITY

Available for AOCS and/or CCS.

6.3 NAVIGATION ITRF POSITION/VELOCITY

DORIS ITRF position/velocity estimations of the carrier satellite are also available in real-time, for instance in the Jason-1 Operational Sensor Data Records (OSDR) products. They are provided in the Jason-2 OGDR products, and made available for near-real time ocean monitoring. They are also planned in OGDR for Jason-3 and Jason-CS missions.

DORIS ITRF position/velocity estimations are also used on Spot5 or Pleïades for ground image localisation. They may be used by any on-board equipment, or after being inserted in the telemetry, for any component of the ground segment, for instance the Satellite Control Center (CCS).

6.4 NAVIGATION GEODETIC REPORT

For altimetric payloads, to which it DORIS-DIODE offers geodetic information that allow to take the best of the altimeter, especially for coastal sea survey or inland water measurement (lakes, rivers).

This may also be used by other on-board or ground components of the satellite system.

6.5 TAI TIME DETERMINATION

A 5 microseconds accuracy (typically 1 microsecond RMS) has been demonstrated on-board Jason-1 and Jason-2.

This time determination may be useful for on-board products time-tagging (e.g. CryoSat2 or Pléïades).

7 INTERNATIONAL DORIS SERVICE (IDS) AND DORIS GROUND PRODUCTS

7.1 IDS :

DORIS has been contributing to the determination of the International Terrestrial Reference Frame (ITRF) of the International Earth Rotation and Reference Systems Service (IERS) since 1994, and since then its accuracy has always been improved. This contribution naturally led to a DORIS pilot experiment in 1999, then to the official setting of the IDS, approved by International Association of Geodesy (IAG) and IERS in 2003.

In parallel, IAG and IERS have been reorganizing, and new scientific projects have started, expecting a DORIS contribution : the IAG Global Geodetic Observing System (GGOS), and the IERS Combination Pilot Project. IDS data centers receive measurements from SSALTO, archive and distribute them. Since DORIS is part of IERS, two user archives are in operation, one in Europe managed by IGN, the other one in the USA under NASA/CDDIS management.

The primary objective of the IDS is to provide a service to support, through DORIS data and products, geodetic and geophysical research activities.

The IDS collects, archives and distributes DORIS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentations.

From these data sets the IDS Analysis Centers, or other scientific groups elaborate high level scientific results or products, such as time series, ITRF solutions, ionospheric or tropospheric results, etc.

7.2 DORIS PROCESSED MEASUREMENT ARCHIVE :

Associated with the precise Orbit products, the DORIS processed measurements are made available to the scientific community via the IDS (NASA/Crustal Dynamics Data Information System (CDDIS), IGN/Laboratoire de Recherches en Géodésie (LAREG)).

The time-tagging measurements are only used to determine TAI date of the Doppler measurements : their accuracy (a few microseconds, equivalent to a few times 300m) make them of little interest for scientific users. Only the Doppler measurements, when properly time-tagged, are provided to IDS.

7.3 IDS SCIENCE PRODUCTS :

They are elaborated by the International DORIS Service Analysis Centers, and are delivered to the scientific community.

The Analysis Centers are committed to provide at least one of the following IDS products on a regular basis. Their expertise in DORIS data analysis is a key factor of the product accuracy.

Current IDS Analysis Centres are :See http://ids-doris.org/organization/analysis-centers.html

- CNES-CLS in France (software: Gins), they provide products at a regular rate (≈ every week)
- ESA-ESOC in Germany (NAPEOS), regular rate (≈ every month)
- IGN-JPL in France (Gipsy/Oasis), ≈ weekly rate
- INASAN , Russia (Gipsy/Oasis), ≈monthly rate
- Geoscience Australia (Geodyn), monthly rate

- Geodetic Observatory of Pecny, Czech Republic (Bernese), monthly rate
- GSFC/NASA, USA (Geodyn), monthly rate

7.3.1 LOCALISATION PRODUCTS (COORDINATES AND VELOCITIES OF THE DORIS STATIONS)

The solutions (weekly estimations of the network stations coordinates) produced by each Analysis Center are evaluated, combined and delivered to IERS on a regular basis for a contribution to ITRF.

7.3.2 GEOCENTER, SCALE OF THE TERRESTRIAL REFERENCE FRAME, EARTH ROTATION PARAMETERS

DORIS is also very interesting for geocenter determination, which is a recent scientific subject. DORIS offers the long-term stability of its network, and excellent geographic distribution..

About the scale, the DORIS combination provided for ITRF2008 was significantly improved (with respect to the previous submission to ITRF2004) it was in the same range of the scale determined by the SLR and VLBI (the references for the scale determination).

7.3.3 HIGH ACCURACY EPHEMERIDES OF DORIS SATELLITES

The IDS Analysis Centers provide also orbit ephemeris such as DORIS Orbit (POE) provided by SSALTO.

7.3.4 IONOSPHERIC INFORMATION

DORIS ionospheric data are not a real product yet, but there is a need in the scientific community, and the project is under study. New applications are being investigated. Comparisons with results derived from other techniques have already been made, showing good agreement .

7.3.5 TROPOSPHERIC INFORMATION

Comparisons have been made between DORIS and other systems tropospherical corrections, showing that DORIS produces a very interesting accuracy on this effect, and should be more widely used. Better than 5 millimeters consistency has been achieved on the vertical component, with respect to other techniques

7.3.6 OTHER PRODUCTS

Analysis of satellite antenna maps and determination of on-board USO frequencies for South Atlantic Anomaly (SAA) monitoring have given very accurate results . These studies may lead to future development of new DORIS products.

8 STATION NETWORK MANAGEMENT

8.1 FUNCTIONAL DESCRIPTION

The DORIS signal is emitted towards space by the DORIS stations Network (On-Site Beacons). It is a dense and global network whose setting and maintenance are controlled by the Station Network Teams, supervised by the “Groupe Mission DORIS”.

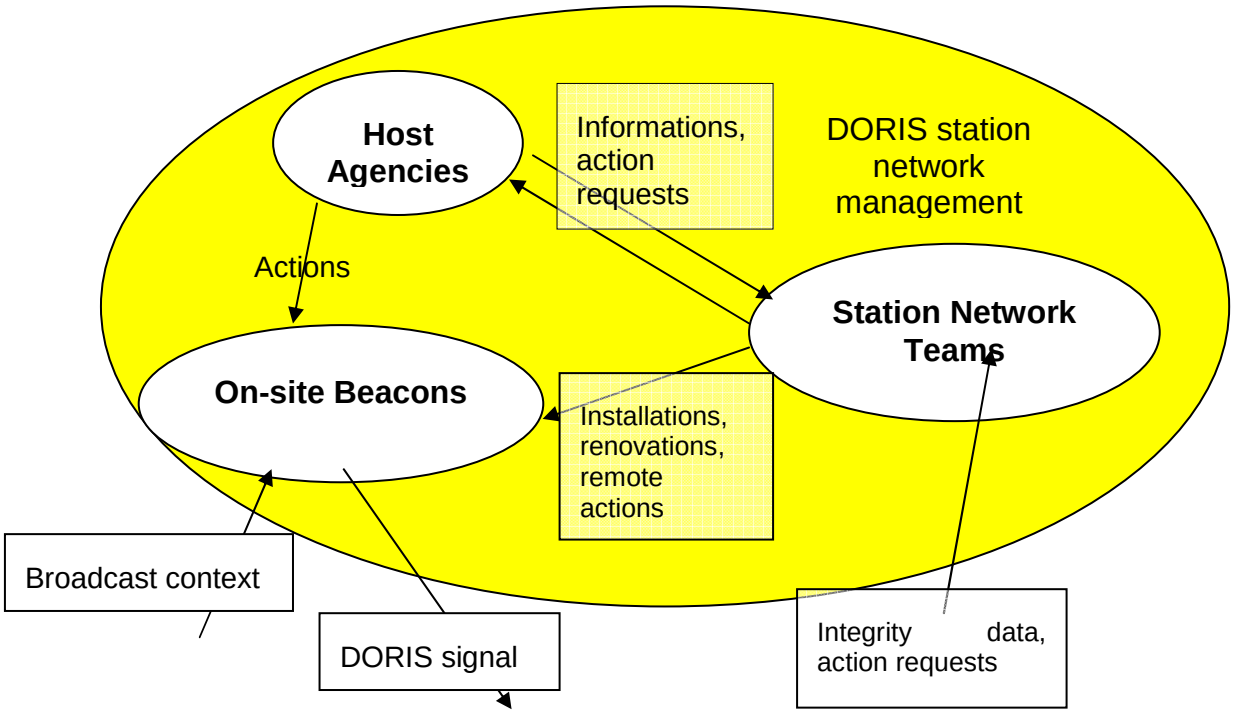

Fig.5 – The DORIS station network management

These teams take into account requests from Integrity Team (part of DORIS monitoring and ground processing) and speak with Host Agencies, aiming at the best availability possible (indicators). They organize actions on the beacons that are performed either directly by Station Network Teams, or asked to Host Agencies.

The Station Network Teams also manage logistic supports : expedition time, standard exchange duration, possible on-site redundancy, spare capacity, spare procurement time, etc.

The Integrity Team declares during Groupe d’Exploitation et de Coordination des Opérations DORIS, Point Système SALP or Groupe Mission DORIS meetings whether the beacon is back to nominal operation or not.

DORIS products quality is strongly linked to the quality of network. The **network status** is controlled every week during the GECO meeting, and more frequently when a launch is coming up for a satellite hosting a DORIS receiver.

The network status depends on :

- the number of Orbitography Beacons in activity

- the number of Time Beacons
- the number of Master Beacons

It also depends on the logistics, i.e. the supply time from stock, the standard replacement time, the number of spare available on site, the stock size, the time needed to supply new equipement.

8.2 ON-SITE BEACONS

The stations network deployed for DORIS is global, dense and homogeneous, and thus unique among the different techniques that contribute to International Terrestrial Reference Frame (ITRF). The very good stability of this network through time (very few changes of antennas or sites), and its homogeneous geographical repartition (North/South) are essential for the quality of the DORIS Reference Frame. Improving the equipments clearly contributes to a better accuracy, as it can be seen for instance on the time series of several renewed stations.

Every station is fitted with:

- a dual-frequency 400 MHz and 2 GHz transmitter, including a USO,
- an omni-directional dual-frequency antenna,
- a battery pack, to provide autonomy versus power supply,
- a meteorogical package providing temperature, pressure and humidity measurements, used for tropospheric correction.

38 stations are co-localized with other precise positioning techniques (Very Long Base Interferometry (VLBI), Laser ranging (SLR), Global Positioning System (GPS), …), which allows systems intercalibration. Long-term life and stability are the great qualities of the DORIS Network, and several time series are extremely long (measurements started in 1990 with the first DORIS receiver flight on-board SPOT2).

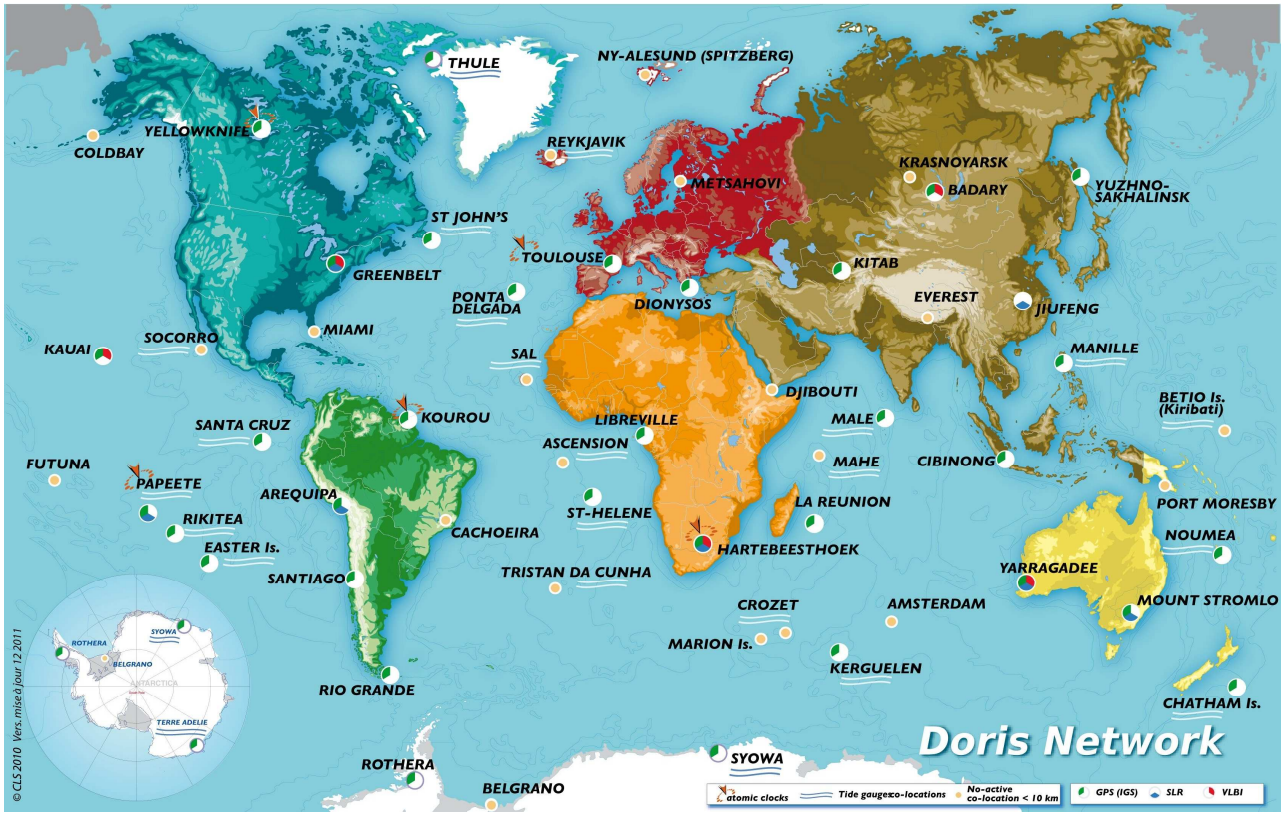

Fig. 6 – The DORIS network in 2011 (with co-locations)

The DORIS current coverage allows observation of the Jason orbits (presence of orbitographic measurements) over more than 95% of the time.

The DORIS Network is composed of **about 60 beacons** (on-site Beacons).

Among these, most are **Orbitography Beacons** (B.O.) which will be used as geographic references by orbit determination software, others are scientific I.D.S. beacons.

Among these Orbitography Beacons some also play the role of **Time Beacons** (B.T.). The Time-Beacon clocks are tied to atomic clocks, whose delays are precisely restituted and monitored with respect to TAI atomic time.

Among these BT, some are also Master Beacons (B.M., 4 today) : they also emit towards space the Broadcast uploads, see parag. 5.2.

8.3 HOST AGENCIES

Beacons are hosted by institutes (Host Agencies) of more than 30 different nations. In order to ensure thermal stability, laboratory environment is necessary. Although DORIS beacons are working automatically, and remote-controlled, human presence is strongly advised in order to face failure due to aging or caused by the environment (electric gap, weather, wild life) . Most host agencies are geodesic research labs.

The IGN negociates the tripartite agreement between the CNES, the IGN and the host agencies, including autorisation to transmit.

Host agencies are asked to take actions on the equipments, like switching them back on after a power failure, and to keep the Station Network Team informed of any activities on site, such as construction work, electrical maintenance or the installation of a new antenna nearby.

8.4 STATION NETWORK TEAMS

The CNES IGN convention defines two team :

The SIRS, Service d'Installation et de Rénovation des Stations, is the IGN responsibility. It performs all the geodesic related activities, i.e. setting up a location, moving a location or deciding upon a new location.

The SMOS, Service de Maintenance et d'Opération des Stations DORIS, is the CNES responsibility. Its purpose is to maintain the permanent orbitography station network in operating condition, following the GECO (Groupe d'Exploitation et de Coordination Opérationnelle) directives. With the help of the integrity team, the SMOS is in permanent contact with Host Agencies, makes sure that the equipments are working, and organises the equipments' maintenance…

The SMOS manages the current stock of beacon, antenna and other network equipments. Its is financed by SALP project.

A contract with the suppliers guaranties the maintenance of the hardware.

9 CONTRIBUTOR PROJECT

These are the projects whose satellites host a DORIS receiver and forward their data to SSALTO. These data and measurements are then processed to determine the satellite precise orbits, but also to monitor the DORIS system health and to contribute to the determination of the DORIS Reference Frame.

The contributor satellites in 2011 are presented in the following figure :

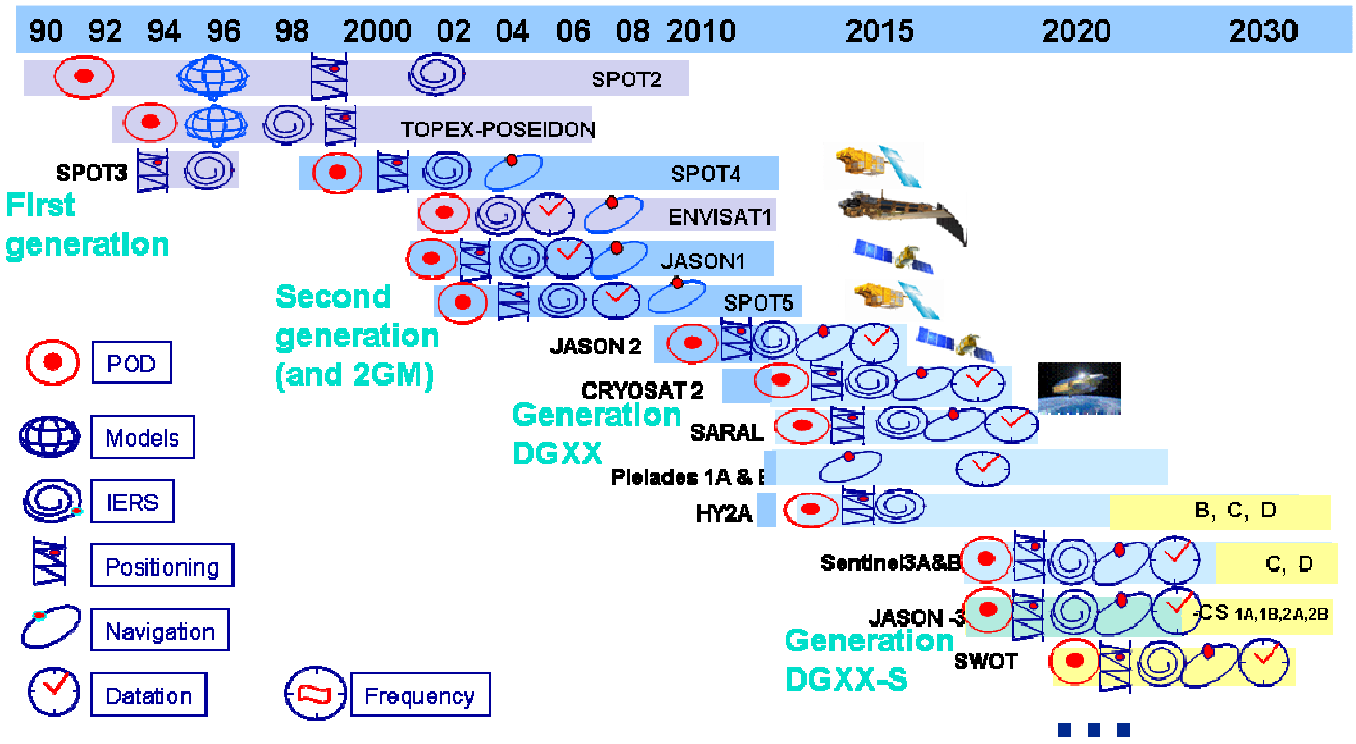

Fig. 7 – DORIS « Contributor » projects through time

9.1 FUNCTIONAL DESCRIPTION

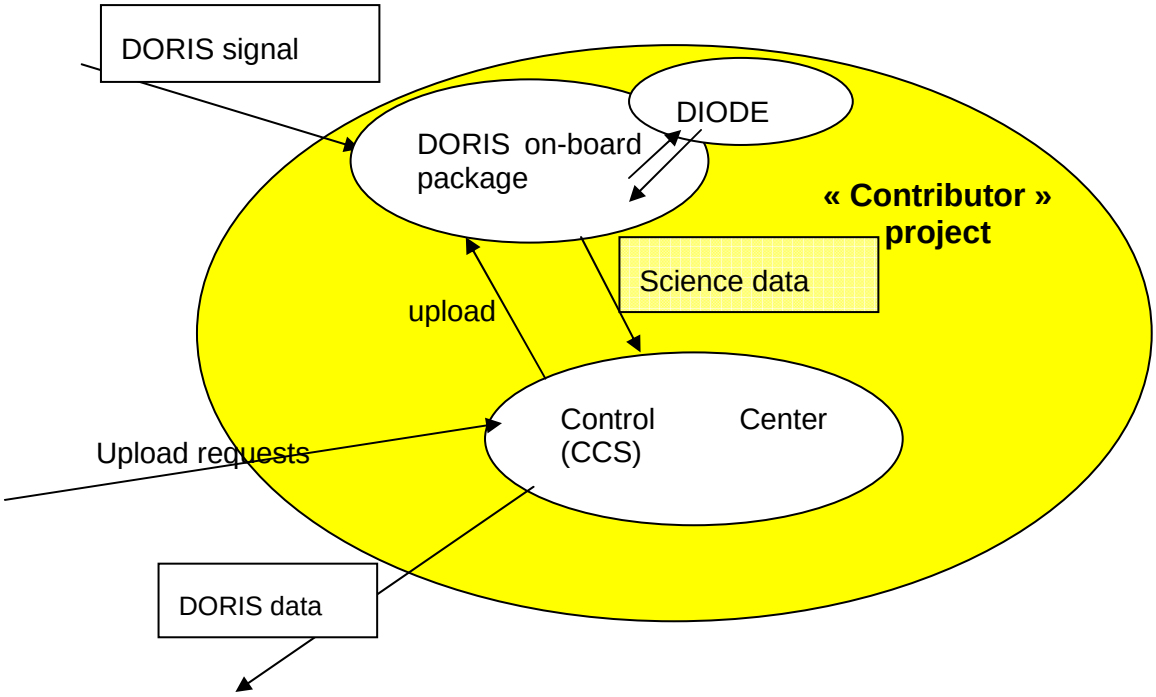

Fig. 8 – « Contributor » projects

The DORIS signal is tracked by the DORIS receiver on-board the satellite. The receiver elaborates on-board the DORIS measurements (Doppler, Phase and Pseudo-Range measurements). The DIODE Navigation function processes these measurements in real-time to produce Navigation data (Time-Tagging bulletins, ITRF and J2000 positions and velocities, geodetic bulletins, …).

Measurements and Navigation data are stored on-board the satellite as DORIS science data,then downloaded via the satellite telemetry towards the Satellite Control Center (CCS). The CCS gathers the DORIS data (science + HouseKeeping), checks them for its own purposes, then forwards them to the SSALTO multi-mission processing Center, together with ancillary data (manoeuver characteristics, attitude characteristics, …).

These data are then analysed by the DORIS Integrity Team, and forwaded to I.D.S. Analysing Centers.

This is how contributor satellites contribute to the DORIS health control. Although the system could work with only one contributor, four or more are necessary to guarantee observability and accuracy of the DORIS system (mainly accuracy and stability of the ground stations reference frame).

User projects are generally advised to integrate the DORIS Command/Control in their own Control Center,.

The satellite Control Center may also elaborate a few Commands or Uploads dedicated to the monitoring of the DORIS receiver if necessary : in particular, Manoeuver uploads will help the DIODE function to stay active during thrusts.

A manoeuvre without upload (or with wrong quantities), or an upload without manoeuvre may lead to DIODE divergence, and self re-initialisation, and no Navigation data (but DORIS measurements will keep on being available).

The CCS may also transmit to the satellite a few uploads on request or advise of SSALTO (tuning parameters of the on-board software for instance).

Accomodation of DORIS on each satellite may lead to specific parameter tuning, or particular designs.

9.2 NUMBER OF CONTRIBUTOR SATELLITES

Simulations performed during the studies for a DORIS dedicated micro-satellite have shown that 4 satellites are required to obtain a one-centimeter accuracy on monthly time series. More recently, several scientists have published through IDS 10 years of station coordinates time series. It can be seen here again, on these results obtained with real data, that the number of Contributor satellites has a strong impact on the achieved accuracy. In 2010 with five satellites, one centimeter is almost obtained on one-week localisations and thus on Reference Frame. The same sensitivity is observed on the pole coordinates determination.

The « DORIS constellation » as it is in 2011 (past, present and future) is well known. If the number of “Contributor” satellites allows today a precise determination of the DORIS Reference Frame, threads can be expected, since several satellites are today becoming old. On the other hand, current DORIS receivers of DGXX generation, giving more regular beacon observations, accurate location may be obtained with less instruments in flight. However more contributors will always give better accuracy.

9.3 DORIS ON-BOARD PACKAGE AND DIODE :

Measurements and on-board products elaborated by DORIS receivers are used for :

- ⇨ precise orbit determination or control (either on-board or on ground),
- ⇨ beacon positioning,
- ⇨ geophysical modelling (earth gravity field, atmosphere, ionosphere, …)
- ⇨ the DORIS system itself, in order to control its integrity.

The DORIS on-board package includes :

- ➪ a twin receiver performing Doppler measurements and receiving auxiliary data from the beacons, including two USOs (Ultra-Stable Oscillators),
- ➪ a dual-frequency omni-directional antenna.

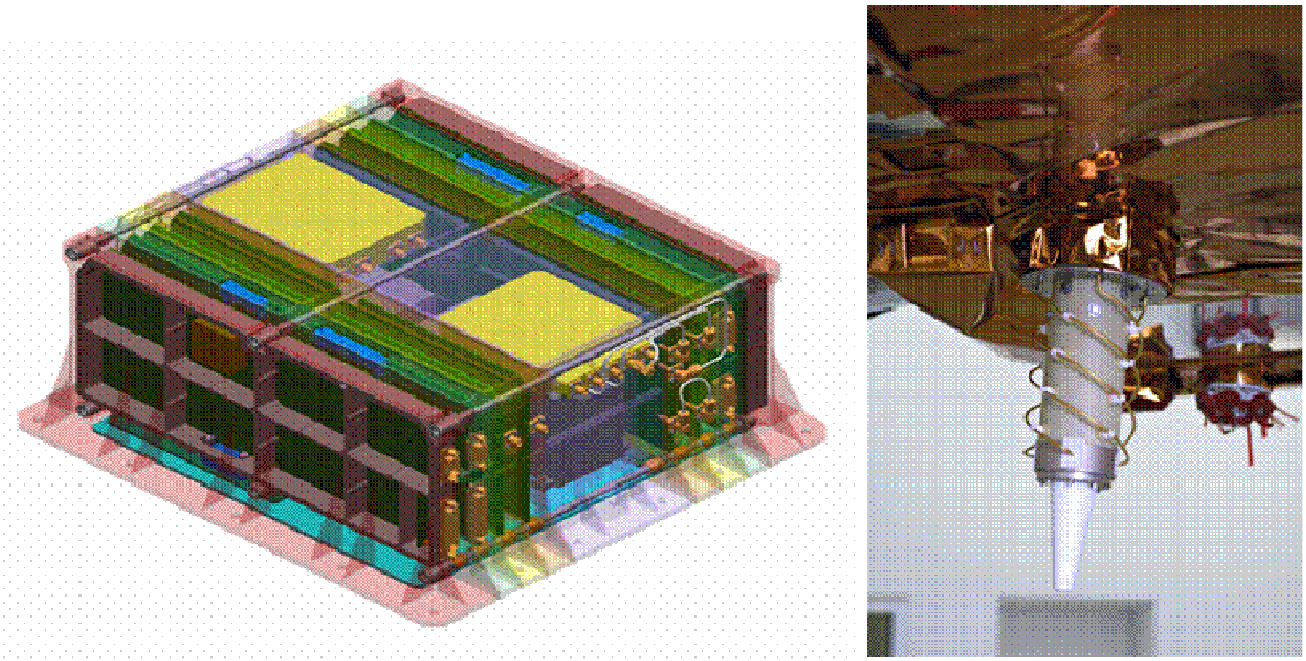

Fig. 9 : The on-board package

9.3.1 RECEIVER FUNCTIONAL DESCRIPTION

Each receiver has been designed to elaborate precise Doppler or Phase measurements (better than 0.3 mm/s over 10 seconds), and time-tagging measurements (a few microseconds).

Note that **0.3 mm/s over 10 seconds** in velocity, is equivalent to :

- 3 mm in range measurement,
- 10^{-12} in relative frequency,
- 2 mHz in frequency measurement on the 2 GHz channel,

- 7 °in phase measurement on the 2 GHz channel.

Also, a few microseconds in time-tagging is equivalent to :

- 1 km in pseudo-range measurement,
- 7 mm on the Along-Track position.

Dedicated to accuracy applications, dual-frequency receivers allow ionospheric correction of the measurements.

Current receivers (DGXX and DGXX-S) implement 7 channels (UT) in order to allow seven beacons to be tracked simultaneously. They also perform very accurate and complete phase, delta-phase Doppler and pseudo-range measurements.

Since the first mission, DORIS receivers have evolved, leading to different generations of the on-board instrumentation. The weights by Unité de Traitement (UT = dual-frequency channel), noted wbut, are calculated for one dual-frequency channel without USO, without external antenna switch (when relevant) and without redundancy:

1rst generation **(wbut = 18 kg)** SPOT2, SPOT3, TOPEX-Poseidon (*), SPOT4 1 channel	**2nd generation** **(wbut = 5.5 kg)** ENVISAT (*) 2 channels	**2nd generation miniaturised** **(wbut = 3 kg)** Jason-1 (*), SPOT5 2 channels
Intermediate DGXX **(wbut = 3 kg)** CryoSat-1(*) 2 channelS	**Full DGXX and DGXX-S generation** **(wbut = 1.15 kg)** Jason-2, Pléïades, AltiKa, CryoSat-2, HY-2A, Jason-3, Sentinel-3 2 x 7 channelS twinned (redundant) in one box including USOS and automated antenna switching	

(*) redunded by twinning USO and receiver boxes, and adding an antenna switch box.

Table 1 : DORIS receivers evolution

9.3.2 RECEIVER SOFTWARE

Software versions can be securely uploaded in-flight without mission interruption (use of two banks of redundant EEPROM), for instance in order to improve performances or robustness. The software is constituted of Gestion MVR and DIODE navigation function.

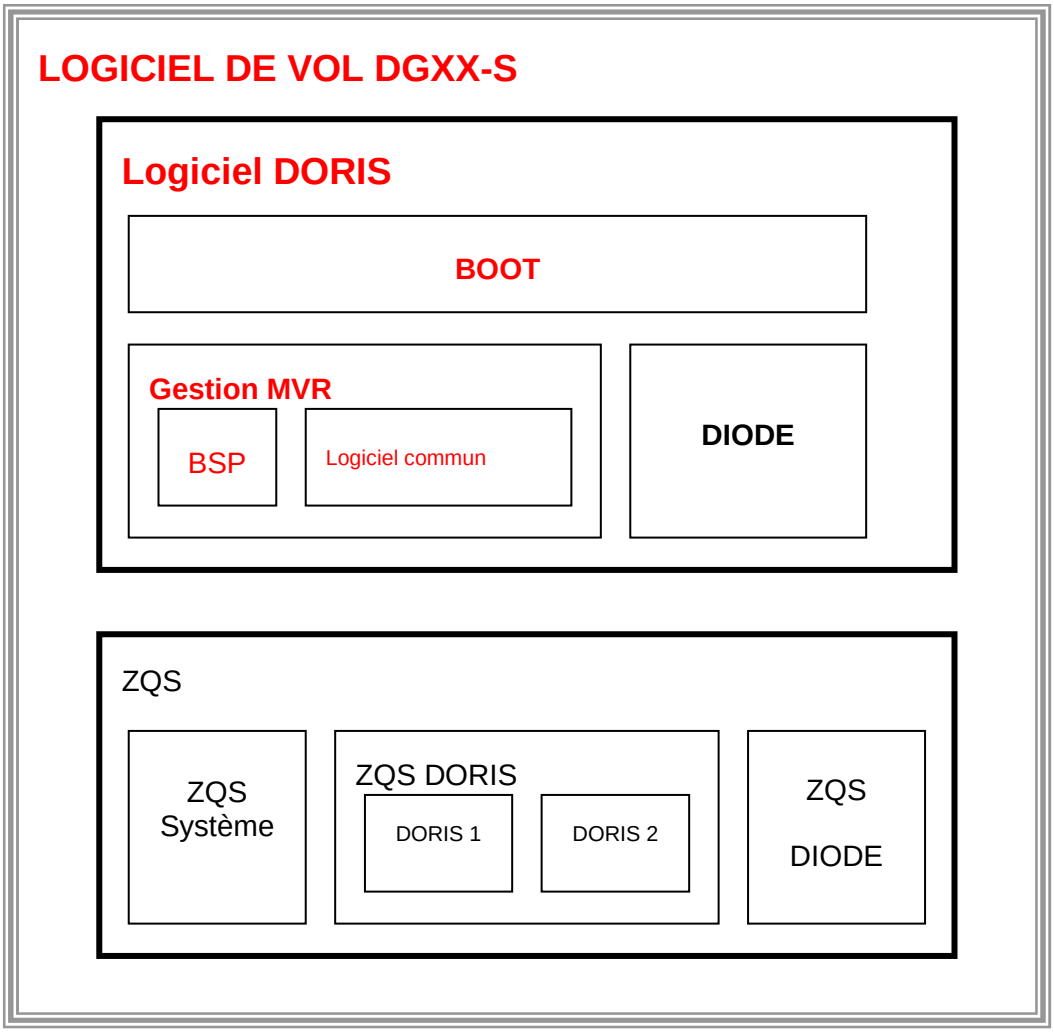

Fig. 10 : The on-board software

The “Logiciel DORIS” software is generic for all missions, while the instantiation for each mission is done by the parameters located in the Quasi-Static Zones (ZQS).

Initialisation (or re-initialisation) is done step by step during a rather complex process :

- Either DIODE alone (if only DIODE has diverged),
- Or GESTION_MVR first, then DIODE, if DORIS has been turned OFF (some SAFEHOLD strategies contain a DORIS OFF command) or restarted (case of multiple memory errors). In this case it is necessary to re-synchronise hardware and it is a little longer … up to 13 hours, depending on the orbit and the Master or Time Beacons in visibility

9.3.3 DIODE NAVIGATION FUNCTION

DIODE stands for Doris Immediate on-board Orbit Determination. It is an advanced function of the DORIS receiver, that computes the position and the velocity of the satellite : a *real time on-board orbit determination* software.

DIODE was initiated by CNES in 1991, after a conclusive feasibility study from 1988 to 1990. The orbit determination software has been realised by CNES, with a technical support of the COFRAMI-AKKA company.

The first issue of DIODE has already been flying on-board SPOT4 since March 1998, on an electronic card realised by Dassault Electronique and added as a passenger in the DORIS receiver. After that demonstration experiment, DIODE has been fully integrated in the DORIS on-board software, becoming a permanent feature .

Enhanced versions of DIODE are flying with ENVISAT, Jason-1 and SPOT5, allowing advanced automation of the receivers and time-tagging functions with very convincing results. Position-velocities are produced with a pretty good accuracy (less than 1 m RMS in 3D), and an excellent availability (almost 100%). For instance, following an error in the platform GPS receiver results, Jason1 orbit control (manoeuver predictions) is currently done using the DORIS-DIODE on-board position/velocities bulletins.

For the CryoSat2 mission, DORIS-DIODE has offered a new product : J2000 on-board bulletins to be used by the Attitude and Orbit Control System (AOCS). The same capacity is used on-board Pléïades-HR. These on-board real-time products are also nominally used by the ground segments for operations.

9.4 SATELLITE CONTROL CENTER (CCS) :

9.4.1 FUNCTIONAL DESCRIPTION

User projects are generally advised to integrate the DORIS Command/Control in their own Control Center.

DORIS on-board products are then available for operations.

9.4.2 DORIS COMMAND/CONTROL

The DORIS Command/Control activity is reduced to almost nothing :

- A few satellites events have to lead to an upload, for instance in case of orbit manoeuvre. The CCS has the best information and is the best place to lead this activity.
- The CCS gathers DORIS telemetry and may use them to monitor/control the satellite orbit, or to check the DORIS receiver health.
- All the DORIS packets shall be transmitted to the DORIS monitoring and Ground processing segment, with frequency/delay compliant with mission requirements (for instance : Jason-2 OGDR shall be available within 3 hours).

9.4.3 USE OF DORIS ON-BOARD PRODUCTS

The DORIS-DIODE orbits may be used for Orbit Control activities (station keeping manoeuvre design). This is done for Spot5, Jason-2, Pléïades.

10 SSALTO GROUND SEGMENT :

SSALTO (Orbitography and Altimetry Multi-Mission Center) is a facility devoted to DORIS system and to altimetry missions control and processing.

In this document, only SSALTO activities related to DORIS are mentioned (for instance, nothing is presented about POSEIDON monitoring).

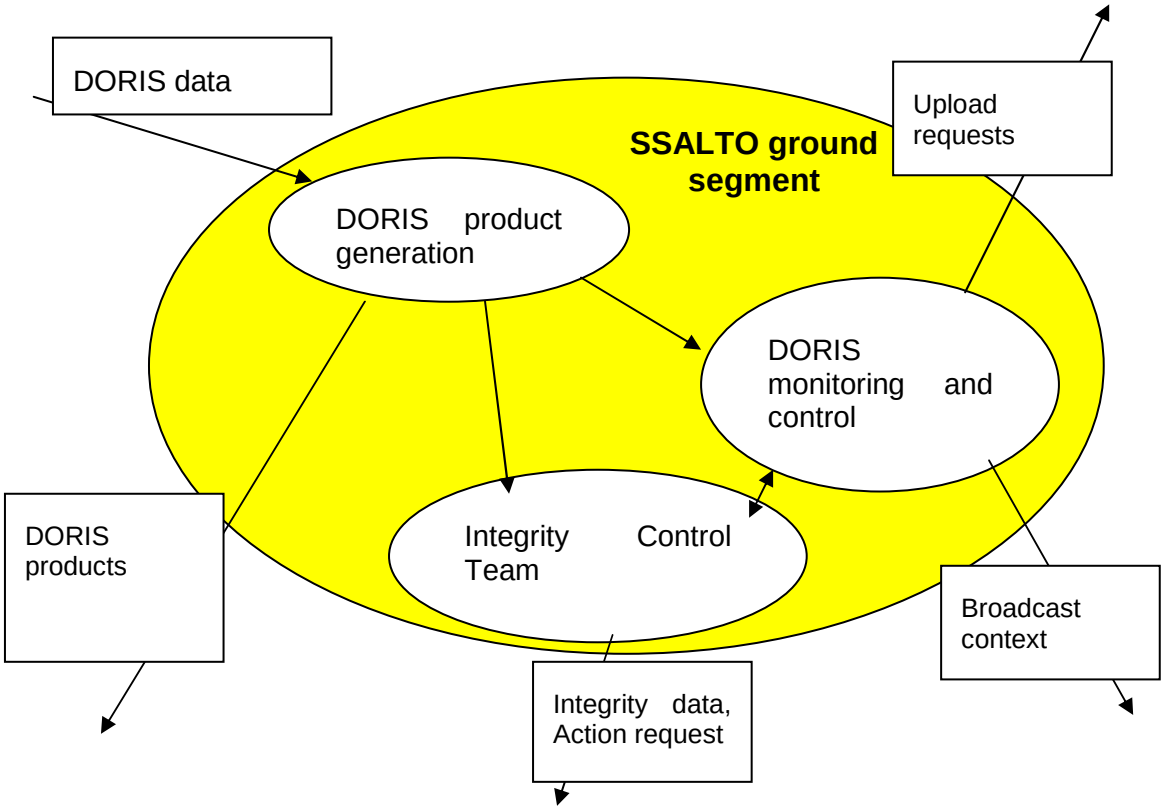

Fig. 11 – DORIS monitoring and ground processing

SSALTO archives the data of each contributor satellite, checks the different DORIS receivers performances and the overall DORIS system health and integrity.

SSALTO also elaborates the Broadcast uploads, the DORIS products, requests for the satellites, or action requests for beacons operation .

10.1 FUNCTIONAL DESCRIPTION

SSALTO is located in CNES, Toulouse, France, and is in charge of :

- DORIS product generation,
- DORIS monitoring and Control,
- DORIS Intregrity Control Team,
- Technological archive and delivery of altimetry products, through two websites (http://www.aviso.oceanobs.com) et (http://ids-doris.org/)

10.2 DORIS PRODUCT GENERATION

SSALTO elaborates the DORIS products, that are then forwarded to users, together with altimetry products, and in the frame of the International DORIS Service (I.D.S.).

- Science Telemetry acquisition and pre-processing
- Precise Orbit Determination (using other contributing techniques) and station precise positioning
- Elaboration of altimetry ground products taking the best of DORIS data to provide the DORIS ultimate accuracy

10.3 DORIS MONITORING

SSALTO also elaborates uploads : the Broadcasts, giving information to the in-flight receivers about the current status of the network. These information will be emitted towards space by several specific beacons.

- Performance monitoring of DORIS Contributors receivers
- Performance monitoring of DORIS/DIODE on-board products (which are also available in the Satellite Control Centers)
- Station network monitoring and control of the DORIS signal integrity

SSALTO may also elaborate requests for the contributors satellites (advises for software tunings, new version of an on-board software).

10.4 DORIS INTEGRITY CONTROL TEAM

Checks and processing are permanently performed to verify that the DORIS signal is compliant with its specifications, both in terms of accuracy and in terms of availabilty.

A DORIS Integrity Toolkit has been designed by CNES in order to organize and extend this activity.

DORIS integrity is permanently followed by a survey team. The operations are coordinated in the Groupe d'Exploitation et de Coordination des Opérations DORIS (GECO) meetings, held on a weekly basis.

The DORIS data elaborated on-board the contributor satellites are sent to SSALTO, then archived daily in the DORIS Data Base which is checked by the CNES SSALTO exploitation (operated by CLS) and the Station Network Teams, with a technical support of the CNES system engineers.

Detailed checks are made on :

- Beacon Message,
- Signal power level received on-board the "contributor" satellites,
- DORIS measurement processing,
- Broadcast Uploads,
- Station Coordinate Broadcasts,
- Time Broadcasts,
- Time Scales information,
- DIODE quality index monitoring,
- USOs frequency,
- Software reports,
- Time-tagging function monitoring,
- DORIS robustness (each fact is recorded in order to improve system, receiver or navigation algorithms).

SSALTO may also elaborate action requests for beacons operation (OFF/ON, renew, …).

11 DORIS SYSTEM STATUS :

Each subsystem has specifical modes that can impact the global DORIS system status.

In order to analyse globally the system modes, it should be necessary to examine each component and its availability.

In practice, two different global modes can be distinguished :

ROUTINE : every DORIS on-orbit receiver is in routine mode

INITIALISATION OF A RECEIVER : one of the on-orbit DORIS receivers is in an initialisation/convergence process (or, has been set OFF temporarily). From 2008 to 2012, this occurred once on-board Jason-2 (upload of a new version of the On-Board Software), and twice on-board CryoSat-2 (YellowKnife anomaly, satellite SAFEHOLD).

For instance, the routine phase can be summarized as follows :

PHASE	MISSION	BO	BT	BM	Time constraints
ROUTINE	Altimetry on high orbits	45 (*)	1 pass/day	1 pass/week	none
	Image missions	14 (*)	Id 1 pass/day	Id 1 pass/week	none
	Control Centre Ancillary Orbit	14 (*)	Id	Id	none
	On-board AOCS Ancillary Orbit	3 (*)	Id	Id	none

(*) = permanently

Table 2 : System Requirements w.r.t. Beacon Network in Routine Phase

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