DORIS DAYS 2021

November 16,17 and 18

DORIS system technical overview

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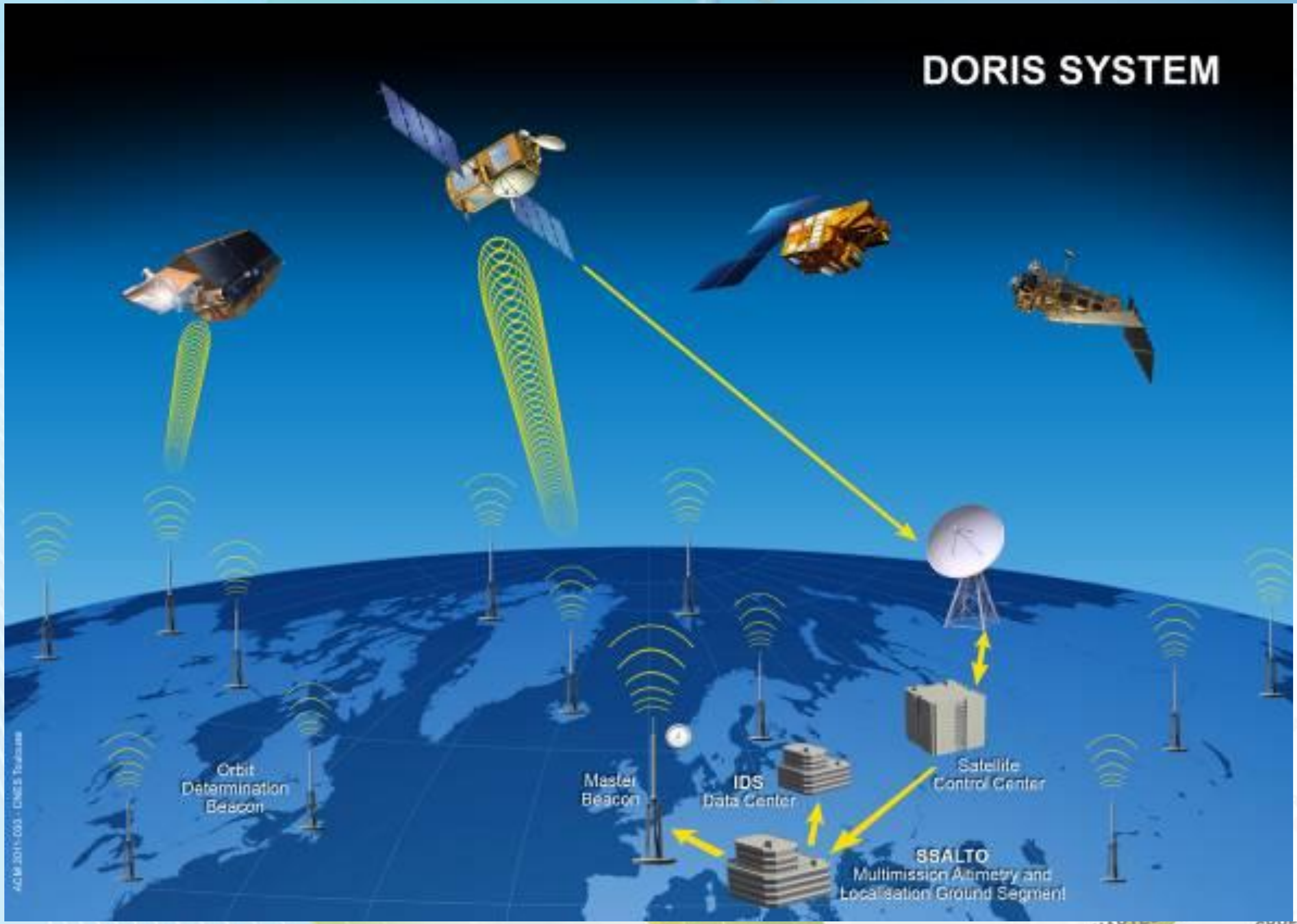
November 16

Session 1 – Presentation 2

DORIS System : Overall Concept



> Designed in early eighties for precise orbit determination of ocean altimetry missions

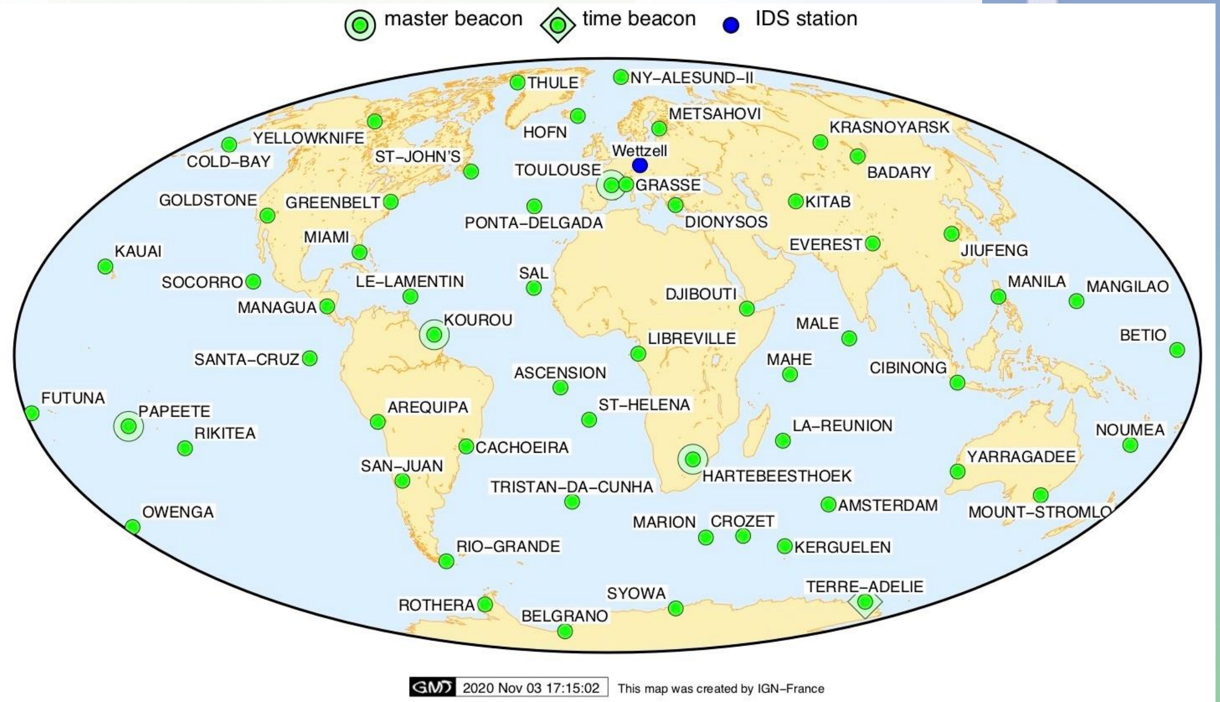
> Based on Doppler shifts measurements of RF signals transmitted by a worldwide network of beacons

> There is no limitation to the number of satellites carrying DORIS receivers

DORIS operating principle and network

- The Doris system was designed by CNES, the French space agency, in partnership with France's mapping and surveying agency IGN and the space geodesy research institute GRGS
- CNES is mainly in charge of the beacon and antenna design (ground and space), its evolution, and the daily monitoring of the DORIS system
- IGN is mainly in charge of the network deployment and maintenance, and of the data dissemination

- The network of ground stations has nearly 60 stations, evenly distributed around the world
- Ground beacons : orbitography (~55), master (4), time (1)
- Very good stability of this network through time + long time series (30 years) + uniform distribution → quality of the DORIS Reference Frame
- Ground stations transmitting continuously the DORIS signal (RF system → all weather system)

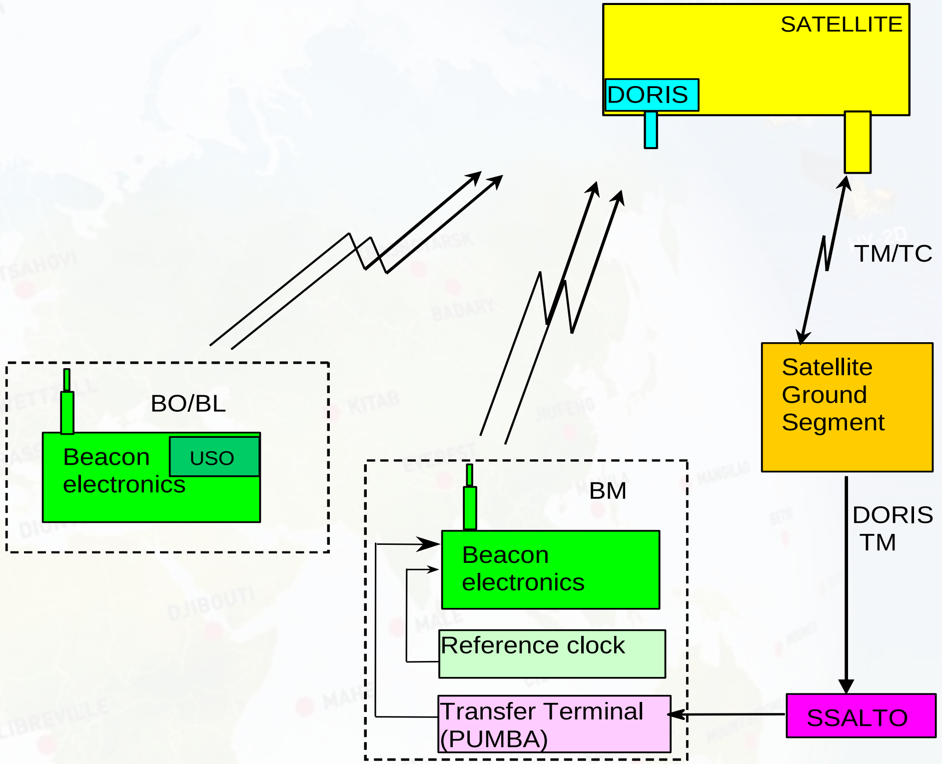


The DORIS signal

« standard » beacons emission :

- Two frequencies (2.03625 GHz and 401.25 MHz for ionospheric effect compensation).
- « Beacon Message » : beacon identity, technological data, meteorological data, synchronization data.

=> free signal (nothing confidential)



« broadcasts » uploads emitted by "Master" Beacons.

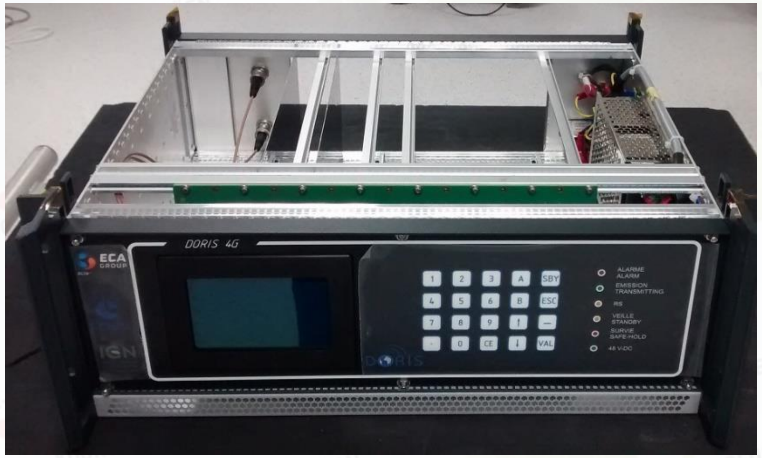
- Elaborated by the SSALTO Ground Segment, contain
  - Precise coordinates of the DORIS antennas.
  - Precise time ties for the Time Beacons.
- Every week a new set of Broadcasts uploads is elaborated.

Ground beacons and antennas

- Ground stations are made up of
  - a transmission and control unit generating two modulated signals (= the beacon)
  - an antenna transmitting the beacon generated signals

- The DORIS beacon contains an Ultra Stable Oscillator (USO), a power pack with a charger, a battery to provide power supply autonomy and a remote control system (IRIDIUM)

- The outside elements include:
  - an omni-directional dual-frequency antenna
  - sometimes a meteorogical package providing temperature, pressure and humidity measurements, used for tropospheric correction.



DORIS ground beacon electronics

Nouméa antenna, and the local team in New Caledonia

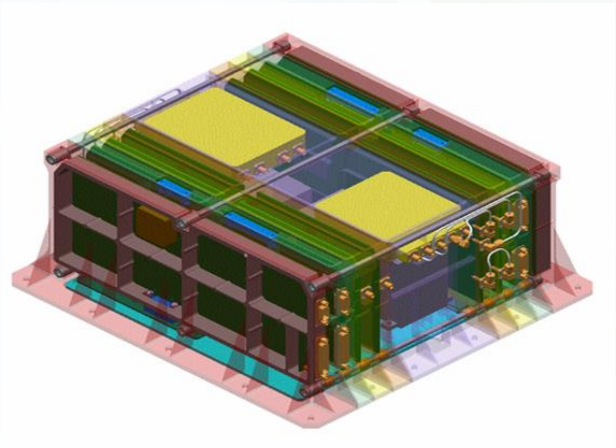
Satellite receivers and antennas

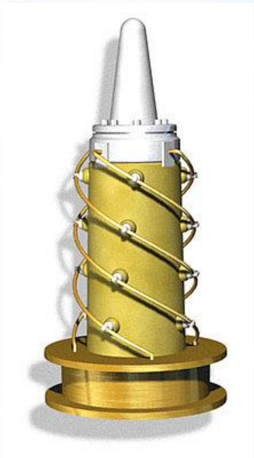
- Current DORIS dual frequency Instrument (DGXX, then DGXX-S)

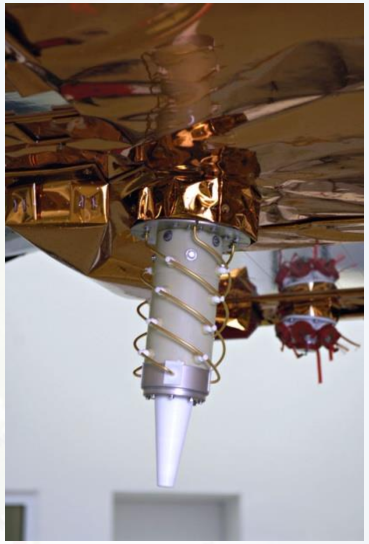
- Cold redundancy of Receivers and USOs
- 10 MHz distribution for other users with X-isolation
- Automatic RF antenna switching on active receiver
- Weight = 18 kg
- 390 x 370 x 165 (mm)
- 23 W typical

- DIODE = on-board orbit determination software based on a Kalman filter (18000 lines)

Doris onboard receiver







Doris receiving antenna (length 42 cm)

Provider = Thalès-DMS

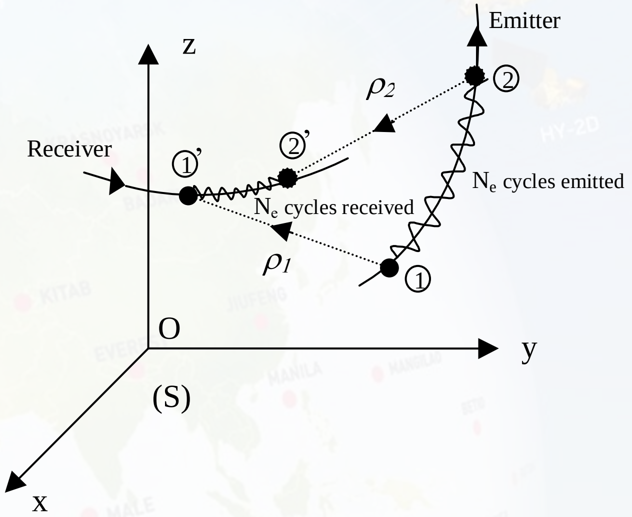
Switch ON and let it work :

- Operations reduced to almost nothing,
- Excellent availability, e.g. J2: no failure during lifetime (>11 years)

The DORIS phase measurement

- Between events ❶ and ❷, N_e cycles are emitted by the DORIS beacon at frequency f_e
- This radio electric signal travels through space and reaches the receiver at events ❶' and ❷'
- During the time separating events ❶' and ❷' on-board the satellite, the DORIS receiver has generated N_r cycles with its proper oscillator at frequency f_r
- The DORIS receiver then accurately measures the phase difference between the received and generated signals, every x (3 or 7) seconds
- This measurement can be used as an ambiguous phase measurement or, by differentiation, as a Doppler count N_{DOP}
- In that case, the simplified velocity observation equation is:

$$V_{E\_R} = \frac{c}{f_e}\left(f_e - f_r - \frac{N_{Dop}}{\Delta t} \right)$$



Measurement corrections

- **Ionospheric correction**: the first order correction is obtained thanks to the dual frequencies f_2 and f_{400}:

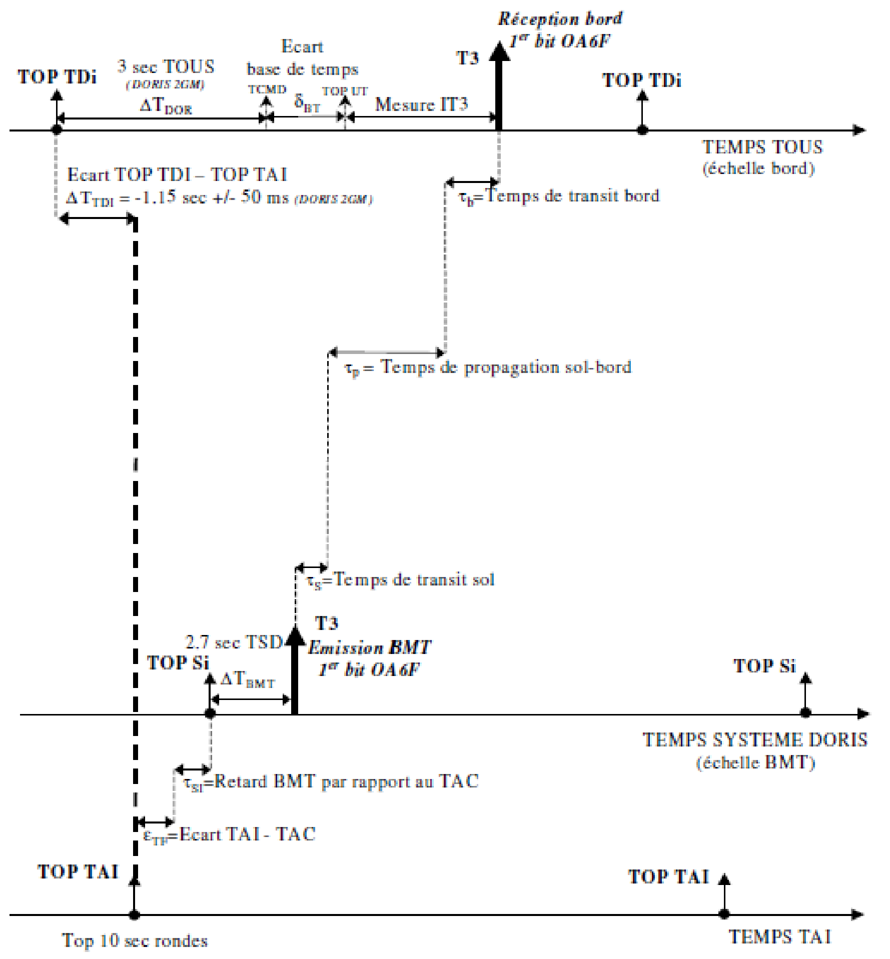
$$L_{iono-free-2GHz} = L_{2GHz} + \frac{L_{2GHz} - \sqrt{\gamma} L_{400MHz}}{\gamma - 1}$$

with $\gamma = \left(f_{2GHz} / f_{400MHz} \right)^2$

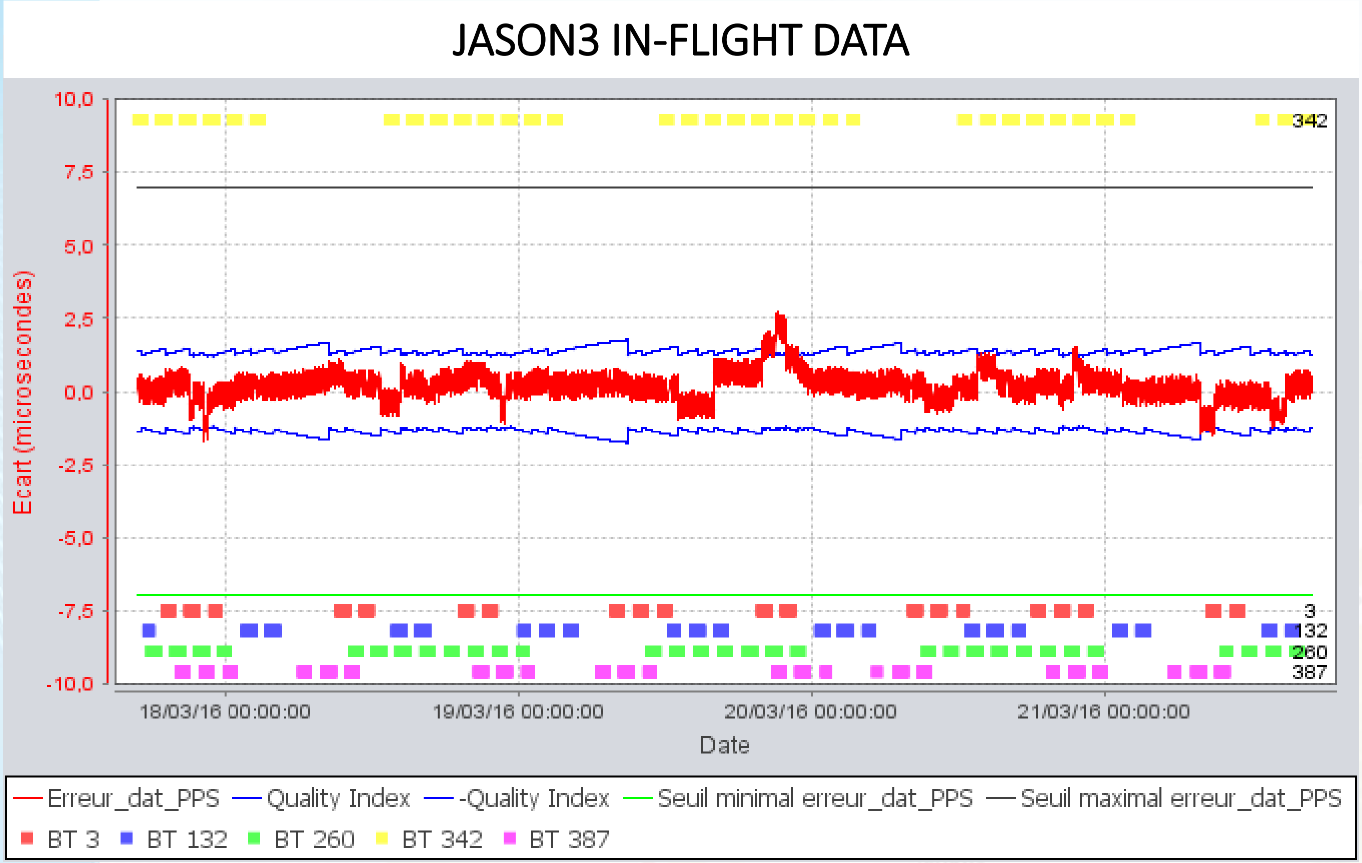
- **Tropospheric correction**: the dry and wet parts are computed either from meteorological data collected at the station, or from models (e.g. VMF-1). In any case, an additional tropospheric zenithal bias has to be adjusted at each pass (at least)
- **Frequency offsets** of the beacon and receiver oscillator: an empirical frequency bias has to be adjusted at each pass
- **Relativity**: the effect of relativity on the beacon and receiver clock oscillators has to be taken into account, as well the elongation of the travel time of the RF signal

On-board time tagging

- Each ground beacon emits, every 10 s, a synchronisation bit “IT3”, which is received on-board and compared with the receiver time scale
- The bits received from the Time Beacons are then used to compute the on-board time scale offset
- Individual accuracy : 7 microseconds on 400 MHz channel
- Accuracy after post-processing: 1 -2 microseconds



DORIS/Diode Time-tagging accuracy



Accuracy : 1 - 2 microseconds

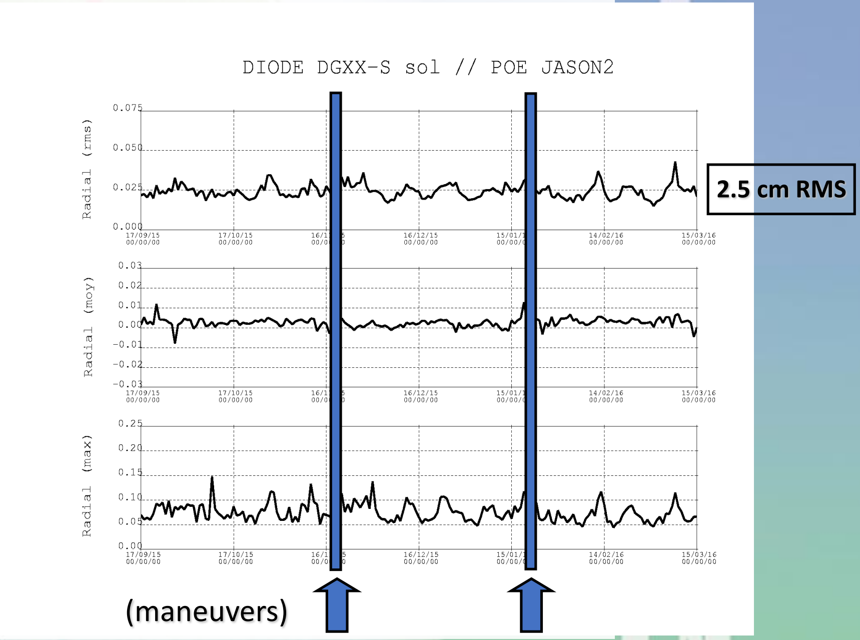
(which is equivalent to 7 – 14 mm Along-Track & 1 – 2 millimetres Radial)

Time Beacons :

- Toulouse (France)
- Kourou (French Guyana)
- Hartebeesthoek (South Africa)
- Papeete (French Polynesia)
- (Yellowknife, Canada)
- Terre Adélie (Antarctica)

Real time on-board orbit determination: DIODE

- DIODE is a *real time on-board orbit determination* software; it computes the position and the velocity of the satellite using a Kalman filter algorithm
- Initiated by CNES in 1991, after a conclusive feasibility study from 1988 to 1990. Developed by CNES, with technical support of AKKA-COFRAMI.
- First version on-board SPOT4 (March 1998) : demonstration experiment
- Then DIODE was fully integrated in the DORIS on-board software. Enhanced versions were flown with ENVISAT, Jason-1 and SPOT5, then on every DORIS mission …
    - allowing advanced automation of the receivers
    - excellent availability (more than 99.7%).
    - positions and velocities produced with an accuracy better than 1 m RMS in 3D (2-3 cm RMS in radial !)



DORIS is one of the four geodetic techniques

	GNSS	SLR	VLBI	DORIS
Network density / homogeneity	🙂	☹️	☹️	🙂
Equipment/Teams stability	☹️			
Short term accuracy	🙂	🙂	🙂	☹️
Long term series	☹️			🙂
Calibration / Biases / ref. point	😐 Some missing	☹️ Time scale Ref. point	☹️ Time scale Ref. point	🙂

“ At centimetre level or less, no technique can give alone the true position. Permanent intercomparisons between different techniques are essential to track down the truth in the midst of biases and noise “ **R. Zaharia**

<u>The best technique for :</u>	GNSS	SLR	VLBI	DORIS
Earth pole motion	🙂			
ITRF (centre) / scale		🙂		
Universal Time			🙂	
Long term phenomena				🙂

Some reference papers

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- Belli, A.; Zelensky, N.P.; Lemoine, F.G.; Chinn, D.S., 2021. Impact of Jason-2/T2L2 Ultra-Stable-Oscillator Frequency Model on DORIS stations coordinates and Earth Orientation Parameters, ADVANCES IN SPACE RESEARCH, 67(3):930-944, DOI : 10.1016/j.asr.2020.11.034 OPEN ACCESS

… and many more at

https://ids-doris.org/ids/reports-mails/doris-bibliography/peer-reviewed-journals.html

Key points

- DORIS is a dual-frequency up-link radio-electric satellite and station positioning device
- It has been working continuously since 1990, with regular upgrades to beacons, antennas and on-board receivers
- It is one of the four geodetic techniques participating in the definition of the Terrestrial Reference Frame
- Its main strength lies in its dense, stable and homogeneous network, which allows the study of long-term effects