IDS

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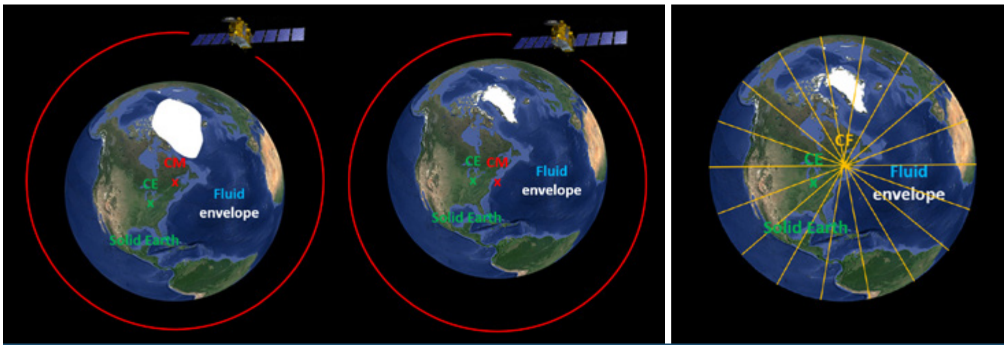
Newsletter of the International DORIS Service **September 2021**

A new method for monitoring the geocenter motion using DORIS observations

By **Alexandre Couhert** (CNES)

Major water and atmosphere mass transport occurring over large regions gives rise to a motion of the deformable terrestrial crust, that is its geometrical center-of-figure (CF), with respect to the center-of-mass (CM) of the Earth. This motion is strongest at the annual frequency where it mostly reflects non-tidal fluid mass redistribution on the Earth's surface. This heartbeat of the Earth is called the "geocenter motion".



MOTION OF THE CENTER-OF-MASS (CM) OF THE WHOLE EARTH (SOLID BODY AND FLUID ENVELOPE) WITH RESPECT TO THE CENTER-OF-MASS (CE) OF ITS SOLID PART [LEFT, CENTER] AND CENTER-OF-FIGURE (CF) [RIGHT].

Even though the expected **amplitude is smaller than the size of a cherry** (2-3 mm in the equatorial plane and up to 5 mm in the direction of the polar axis), it is now necessary to account for its perturbing effect on the modeling of ground station observations (tied to the crust), used to observe the natural orbital motion of the satellites. Satellites through application of the laws of motion, naturally orbit about the Earth's CM. Not accounting properly for the geocenter motion affects both satellite altimetry precise orbit determination and satellite-derived estimates of the change in regional mean sea level. Because of climate change, and the need to both measure the change in the ice-sheets and to understand their impact on sea level and global fluid mass redistribution, we must explore strategies to better observe and model these subtle variations in the Earth's geocenter.

Yet, space-geodetic observation of the geocenter motion is still in its infancy. Independent solutions derived using different techniques have systematic differences as large as the signal level. Estimating geocenter coordinates is one of the most demanding applications of high precision geodetic techniques due to the current precision of the geodetic data, and the nature and magnitude of different types of systematic error. DORIS observation of the geocenter motion is challenging because of the complex modeling of the non-gravitational forces of the DORIS satellites and the requirement to systematically estimate nuisance parameters such as Zenith Tropospheric Delays. Nevertheless, the DORIS tracking network, which is stable and uniquely well distributed geographically, can be leveraged to reduce network effects in DORIS-based geocenter time series.

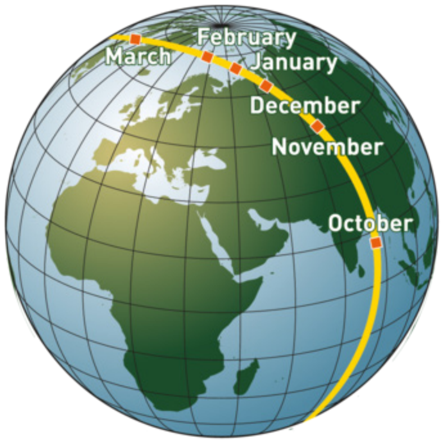
The outcomes of the work presented in Couhert et al. (2018)[1] provide insight into the dominant error sources which must be rigorously handled to measure such minute motions with DORIS observations from the Jason-2 altimeter satellite.

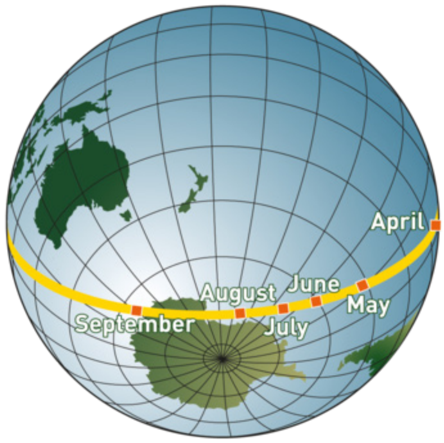
- **Sun-synchronous satellites should be disregarded** because errors in the modelling of Solar Radiation Pressure (SRP) can alias directly into the annual sinusoidal Z geocenter coordinate. Instead, data from Jason-like satellites should be used, since any potential errors in SRP modelling will have a distinct period of 118-days, independent of the geocenter signal one wants to estimate. SRP modelling error on the Jason-type satellites can be identified and mitigated, without compromising the Z geocenter estimate.

- **Vertical site displacement should be estimated** (with the inclusion of low-elevation DORIS data). It is a sensible way to take into account the various error sources reducing the quality of station height estimates to better sense the motion of CF with respect to CM.

- **State-of-the-art gravity and troposphere models should be used.**

Thus, the Jason-2/3 satellites are appealing for geodetic DORIS-based geocenter motion determination and should allow a better realization for CF. The more recent Sentinel-6 Michael Freilich and HY-2C/D missions, or the upcoming launches of future DORIS satellites such as SWOT, should also permit to derive the same type of geocenter solutions, provided the solar radiation pressure perturbations can be properly modelled.

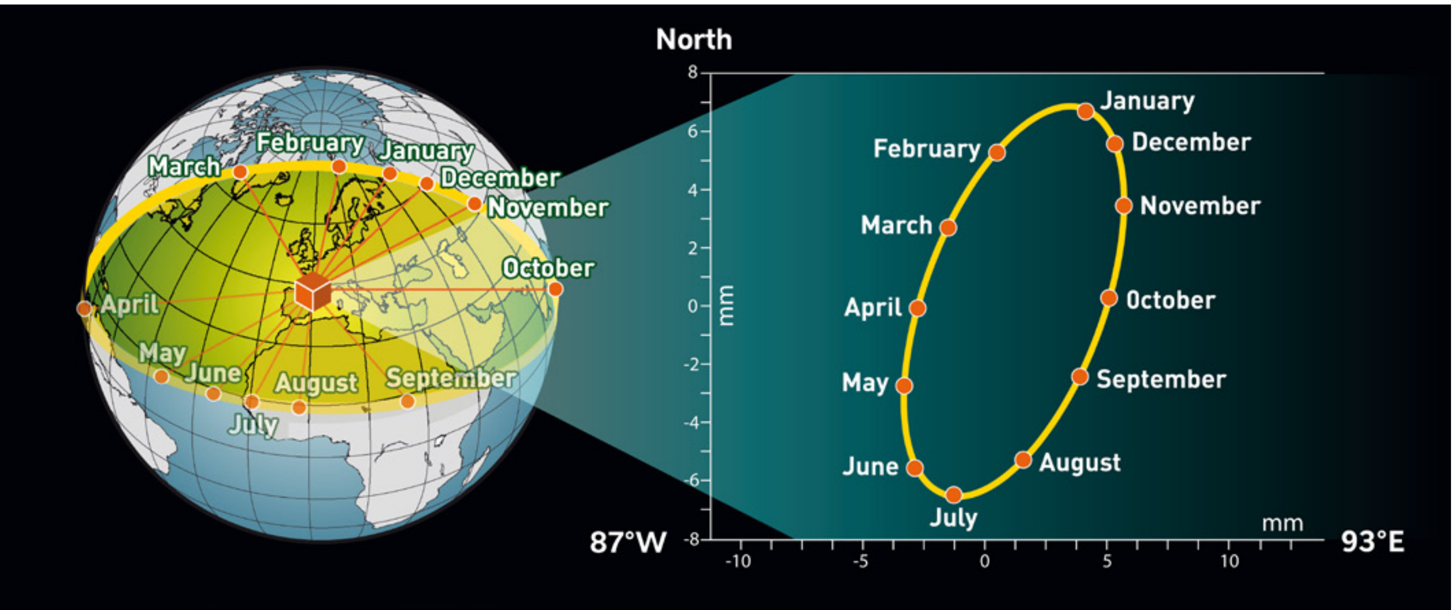




ANNUAL GEOCENTER MOTION PROJECTED ON THE EARTH'S SURFACE ON A MONTHLY BASIS. THE DISPLACEMENT OF THE GEOMETRICAL CENTER OF THE EARTH'S SURFACE WITH RESPECT TO ITS CENTER OF MASS IS MAINLY SEASONAL (COURTESY CNES).

WHY DO SUCH SMALL CHANGES MATTER?

After all, we all rely on millimeters. Two recent papers, Meyssignac et al. (2019)[(2)] and Blazquez (2020[(3)], highlighted that the highest uncertainty in understanding the variations of the global Earth energy-water cycle at regional and global scales is the uncertainty in the geocenter correction combined with the Glacial Isostatic Adjustment. These results further underscore the need to improve our understanding and modeling of the geocenter motion, **so we can better assess the current status of climate change and its future evolution.**



ANNUAL GEOCENTER MOTION AT ITS "REAL" SCALE, I.E A FEW MILIMETERS: IT DRAWS AN ELLIPSE IN THE PLANE 93°E (COURTESY CNES).

Alexandre Couhert's PhD work was awarded in 2021 the Special PhD Award from the Toulouse Academy of Sciences.

References

(1) Couhert, A., Mercier, F., Moyard, J., Biancale, R. (2018). Systematic error mitigation in DORIS-derived geocenter motion. Journal of Geophysical Research: Solid Earth, 123, 10,142– 10,161. DOI: 10.1029/2018JB015453

(2) Meyssignac B et al. (2019) Measuring Global Ocean Heat Content to Estimate the Earth Energy Imbalance. Front. Mar. Sci. 6:432. DOI: 10.3389/fmars.2019.00432

(3) Alejandro Blazquez. Satellite characterization of water mass exchange between ocean and continents at interannual to decadal timescales. Hydrology. Université Paul Sabatier - Toulouse III, 2020. English. NNT : 2020TOU30074. tel-03048246v1

DOPPLER CROSSINGS ON-BOARD **DORIS** RECEIVER CARRIER SATELLITES

By **Christian Jayles** (CNES), **Jean-Pierre Chauveau** (CLS), **Philippe Yaya** (CLS)

WHAT IS A "DOPPLER CROSSING"?

This event, also named frequency conflict, occurs **when the signals transmitted by two different beacons are received at the on-board antenna with apparently close values of frequencies** - equivalently expressed in terms of frequency, or in terms of radial velocity (Vrad) - with similar Radio-Frequency power levels.

This is a tricky situation for the DORIS on-board receiver. Its phase loops might be perturbed during a pass, when trying to follow a signal which is not coming from the programmed beacon.

Current DORIS receivers are able to track no more than 7 beacons simultaneously. But for Jason satellites (altitude = 1300 km) and higher, there may be too many beacon signals sensed together at the antenna, especially on the dense parts of the DORIS beacon network (e.g., in Europe). Too many beacons should be avoided, as this leads to Radio-Frequency perturbations between the beacons (i.e. jamming).

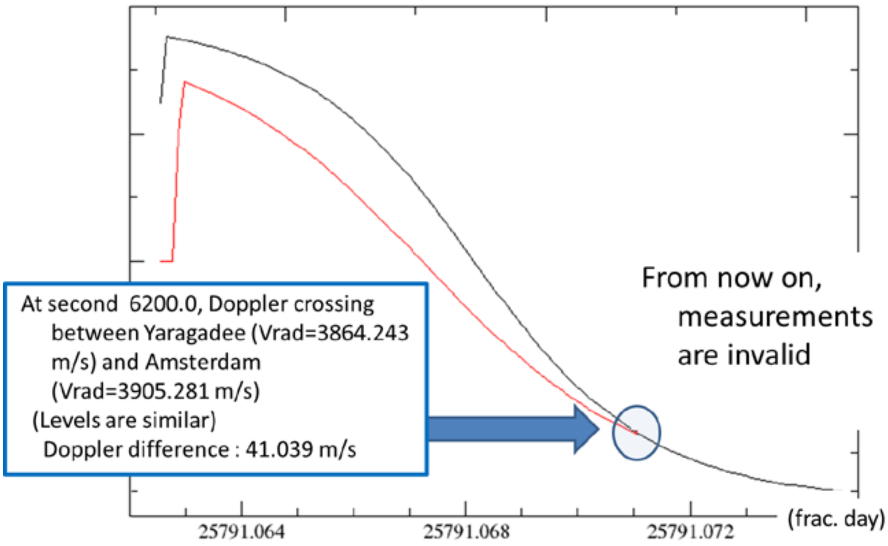
Doppler crossings must be analyzed, in order to check the receiver behavior and robustness in those situations, and also in order to manage the frequencies of our beacons. **Slightly shifting beacon frequencies make it possible to reduce the number of Doppler crossings.**

COUNTING OUT DOPPLER CROSSINGS

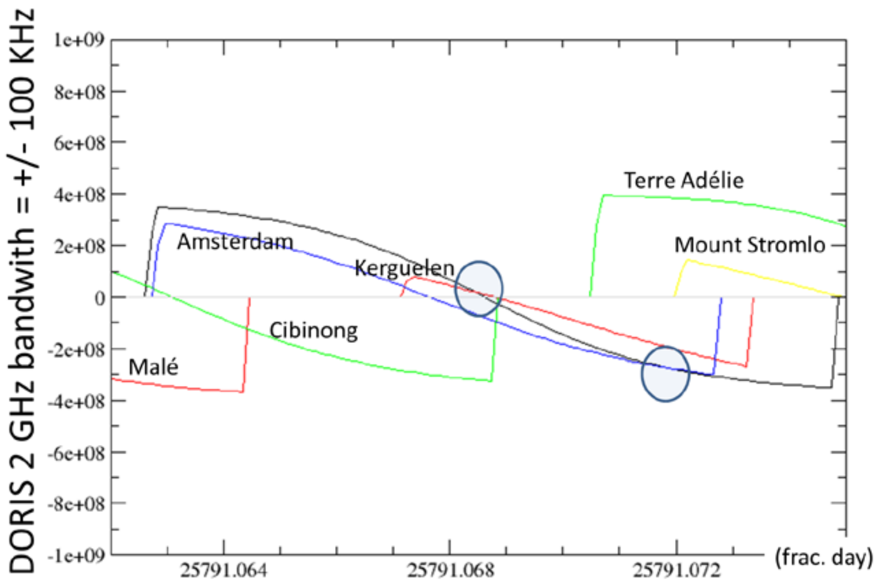
• At a station level

Now let us visualize the effect of a beacon frequency shift, here for our Yaragadee pass.

The figure opposite was done without frequency shift. Yaragadee signal conflicts two times (once with Kerguelen in red, then with Amsterdam in blue at the end of the pass).



A DOPPLER CROSSING BETWEEN THE BEACONS AT YARAGADEE (BLACK) AND AMSTERDAM (RED)

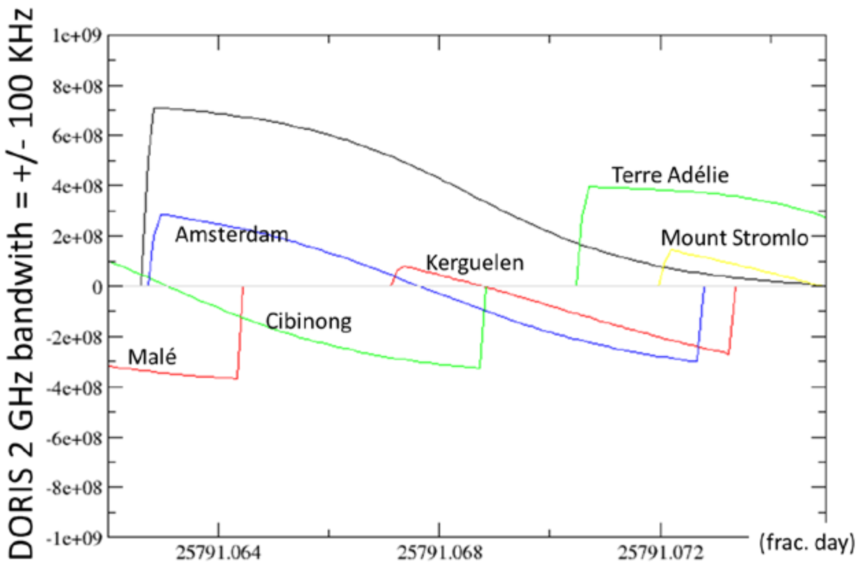


DOPPLER CROSSINGS OVER YARAGADEE (IN BLACK), NO SHIFT (K=0)

The figure opposite is done with Yaragadee frequency shifted. On this descending pass we have suppressed every crossing by using a K=50 frequency shift. Of course, it is necessary to check also other passes, including ascending passes.
Indeed, this optimization must be done on a single Jason cycle (about 9.91 days).

• At the network level

For the Jason-3 orbit, with the current network configuration (almost every beacon emitting at central frequency), for 58 stations, during three days and using classical thresholds (50 m/s for Doppler, 3dB for level), 282 crossings are found, i.e. around 90 crossings/day. For the CryoSat-2 orbit (altitude = 717km), with the same configuration and the same thresholds, 68 Doppler crossings are found (around 20/day).

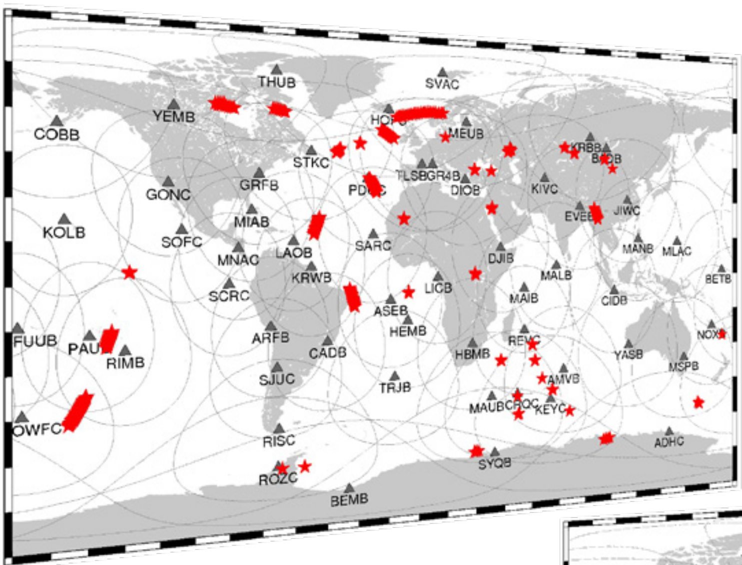


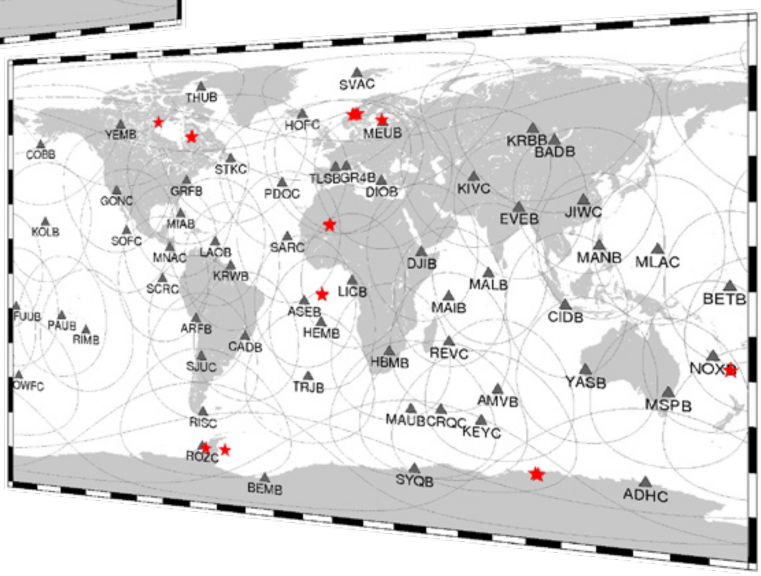
NO MORE DOPPLER CROSSINGS OVER YARAGADEE (IN BLACK), FREQUENCY SHIFTED (K=50)

The higher the satellite, the greater the number of visible beacons and the higher the number of Doppler collisions are likely to be.
By using a « shift optimization tool », it is possible to reduce the number of crossings. For this Jason-3 orbit, with only 13 bea-cons shifted, the crossings come down from 282 to 28 only. This new configuration does not really modify CryoSat-2 crossings: 67 instead of 68.

CONCLUSIONS

The strategy of frequency shifting experimented here, **allows significant reduction of the Doppler crossings** on the Jason orbit. This will improve the quality of DORIS measurement and reduce internal jamming between DORIS stations.
Another very important lesson learned is “avoid too many beacons in same regions”, as it leads to Radio-Frequency perturbations between the beacons (jamming). Looking for a homogeneous network configuration and filling geographic gaps is a much better way to complete the DORIS network.





DOPPLER CROSSINGS FOR A JASON-3 ORBIT, USUAL "CENTRAL FREQUENCY NETWORK" STRATEGY [ABOVE] AND DOPPLER CROSSINGS FOR A JASON-3 ORBIT, “SHIFT OPTIMIZATION” STRATEGY [RIGHT] (VISIBILITY CIRCLES = 10°)

MAJOR RENOVATION AT **RÉUNION** ISLAND

By **Jérôme Saunier (IGN)**

PITON DE LA FOURNAISE (2632 M) FROM THE FORMICA LEO CONE

As a system developed and maintained in France by the CNES (French Space Agency) and the IGN (Institut Géographique National), DORIS has deployed its network to numerous French overseas territories: Guyana, West Indies, Polynesia, New Caledonia, Wallis and Futuna Islands, French Southern and Antarctic Lands (TAAF) and Réunion Island. There are now 11 DORIS stations located in French overseas territories. With two additional stations in mainland France (Toulouse and Grasse), **over 20% of the network stations are based on French territories.** This greatly eases the maintenance, in particular equipment shipment and all required administrative authorizations. About 10000 km south from Paris, Réunion is part of the Mascarene islands in the western Indian Ocean, east of Madagascar, Southern Africa. This French overseas department is a volcanic island dominated by the dormant shield volcano "Piton des Neiges" (3069 m). But after the shield-building stage (about 350,000 years ago), the focus of activity migrated in the eastern part of the island to the "Piton de la Fournaise" (2632 m) that is still intensively active today. This mountainous island has been carved by the intense erosion in the tropical climate and has stunning landscapes.

In order to monitor the volcano activity, an observatory was established in 1979 close to the "Piton de la Fournaise" and is managed by the "Institut Physique du Globe de Paris" (see insert about the Observatory on page 7). The DORIS station has been hosted at the volcano observatory since 1987. Located in the heart of the island at an altitude of 1560 m, the observatory offers easy access to the volcano (15 km), good facilities and reliable connection to networks.

This station was part of the 32 operational stations at the start of the DORIS system in early 1990. Therefore, the station could have known many evolutions. But, actually, due to its very good working order, the station knew only two changes in 30 years! The first generation antenna Alcatel gave way to a Starec antenna in 1998 and the third generation beacon replaced the first one in 2003.

Indeed, the station is ranked in the top five of the DORIS network regarding the data availability. From 1993 (when records began) to February 2020, the station - with the successive acronyms REUA and REUB – has provided 1356 weeks (out of 1410) of observation data. This corresponds to an outstanding availability rate for the station of 96%!

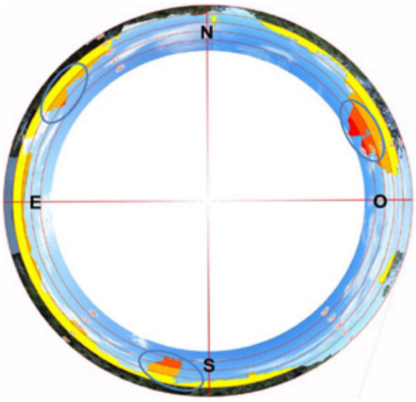
That is the reason why we carried out a very few maintenance operations. According to space segment principle, we do not touch what does work! So, we thought it might be time to perform a major renovation at La Réunion.

The station renovation was performed in February 2020, just before the Covid-19 lockdown in France. **The objectives were threefold: (1) to change the whole existing equipment; (2) to replace the antenna monument that no longer met current standards; (3) to move the antenna to improve its environment.**

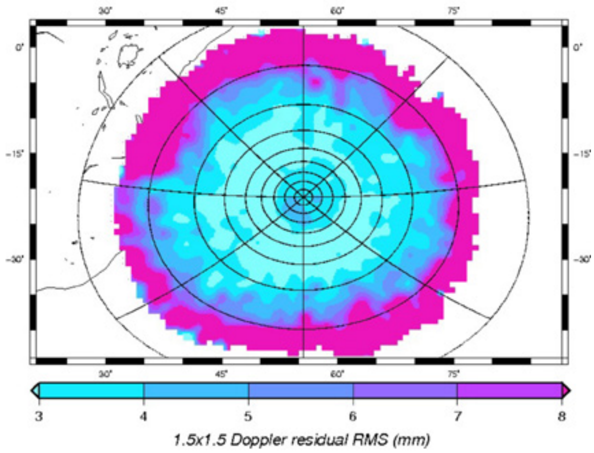
First, the station has been completely replaced and its **equipment modernized with a type C antenna and a 4th generation beacon** (see insert on page 7) to take advantage of the latest DORIS technologies.

Then, **the antenna monument was brought up to current standards.** In the 2000s, a full renovation of the DORIS stations was initiated with a view to improve the stability of the monumentation that is essential for precise positioning applications to minimize velocity uncertainties and noise in the position data. But the DORIS station at La Réunion escaped this operation. High-guyed towers were removed from the network one after the other, except at La Réunion. This type of monument is not stable over time: the guy ropes can loosen, even worse break. That is exactly what happened: before disassembling, we found that one of the three guy ropes broke. The antenna was tilted, and the site survey showed that the position of the antenna reference point shifted by over 2 cm in the horizontal plane from its original position. By analyzing the position time series or the residuals of cumulative solution of REUB, we can deduce that the guy rope probably broke around March 2019.

Finally, this major renovation aimed at improving the station performance in **seeking a better environment for the antenna:** having a clear view of the sky and preventing multipath signal propagation due to reflections on near objects. The antenna was too close to the building and the helicopter-landing platform. **The station was moved 70 m south to the back of the lot of the observatory,** offering a clear horizon with a view over the sea in the southwest direction. A C-type antenna was erected on a 2 m high rigid metal tower on concrete block deeply anchored to the ground leading to a new acronym for the station: REUC. The beacon (transmission unit) is housed in a new building with air-conditioning. The entire installation meets the current system requirements.



SPHERICAL 360° PANORAMIC VIEW SHOWING THE BLOCKED AREAS FROM REUC



POE RMS MAPPING (SARAL)

First results were presented at the end of 2020 (about 9 months following the commissioning) during the quarterly CNES/IGN meeting of the DORIS performance working group. This evaluation conducted by Philippe Yaya (CLS) concluded that the mean of residuals of the least-square precise orbit adjustment for REUC (POE RMS) seems more stable and lower than for REUB, jumping 12 places in the "network stations POE ranking". This outcome is linked to the improvement of the antenna visibility. The relationship between the panoramic view of the sky and the POE RMS mapping was clearly demonstrated: residuals are higher in the directions of three trees. On the occasion of a maintenance visit in July 2021, we asked the host agency to prune away the top of these trees to get a better view of the sky. In this way we hope to improve again the station performance.

Another strength of this site is the **colocation with the GNSS station "REUN",** installed and managed by IGN since 1998 and part of the IGS network. The recent site survey performed by IGN during the DORIS station renovation provided new tie vectors in order to contribute to the next realization of the International Terrestrial Reference Frame (ITRF2020).

Finally, this site is essential for the coverage of the Indian Ocean that represents 20% of the Earth's surface. It certainly contributes to altimetry but also to geodesy and geophysics thanks to the long-term observation data from its co-located DORIS and GNSS stations.

Following this renovation, the DORIS station at La Réunion has improved in several respects: it has a very stable antenna monument, a quiet and open antenna environment and up-to-date equipment, augurin g for a promising future. Installed on the island for nearly 35 years, DORIS is now part of the "Bourbon Island" landscape. One may wonder why Doris is so popular, seeing everywhere written in Creole on the walls: "la Dodo lé la!"*. Doris, what a funny bird!

** Bourbon also known as 'Dodo' (the local extinct flightless bird) is an extremely popular beer on La Réunion: https://fr.wikipedia.org/wiki/Bourbon_(bière)*

THE DORIS ANTENNA « REVC » WITH UNOBSTRUCTED VIEW OVER THE SEA

THE HOST AGENCY **IN SHORT**

LA RÉUNION

By **Philippe Kowalski**
Observatoire Volcanologique du Piton de la Fournaise
from the Institut Physique du Globe (IPGP), France

The Observatoire Volcanologique du Piton de la Fournaise (OVPF) is one of the French overseas volcano observatories managed by the Institut de Physique du Globe de Paris (IPGP). It has been in charge of the Piton de la Fournaise volcano monitoring since its founding in 1979.

OVPF was created after the April 1977 eruption during which lava flows reached an inhabited area (Piton Sainte-Rose village) for the first time since people had settled on the island.

From this time, the volcano observatory is located in Bourg Murat (15 km northwest of the Piton de la Fournaise summit) and provides monitoring and reporting duties to all relevant stakeholders, as well as conducting volcano-logical research and know-ledge transfer to population.

To achieve these goals, OVPF maintains geophysical and geochemical sensor real-time networks spread over the volcano and around the entire island. The main methods used are seismology, geodesy (GNSS, tiltmeters and extensometers), geochemistry (CO_2, SO_2 in the air and in the soil).

Since the 1980's, the observatory has hosted some external stations: GNSS (from IGN), DORIS (from IGN and CNES), SVOM (from CNES). DORIS was the first agreement made with an external institution.

After the discovery in Mayotte in 2019 of a new submarine volcano, the OVPF participated in the establishment of a new multi-parameters monitoring network (REVOSIMA, Réseau de surveillance volcanologique et sismologique de Mayotte). In 2020, OVPF was officially placed in charge of the operational monitoring, for which the IGN, along with various other French institutes, contribute their geodesy expertise.

To carry out their responsibilities, the OVPF staff has progressively increased (from 1980 to today) to up to 17 persons including mostly engineers and researchers.

AMSTERDAM ISLAND
(© IGN/CNES)

THE 4TH GENERATION OF **DORIS** BEACON

This 4th generation beacon project was launched in 2013 to meet two essential needs: ensure the sustainability of production (with up-to-date electronic components allowing reliable operation through 2033) and to improve the antennas environment by increasing the beacon-antenna distance (which was limited by the cable length of 15 m). The technical solution lay in adding a signal amplifier at the foot of the antenna to restore the signal to its nominal power after the signal losses during the long cable transfer. For the 4th generation beacons, the antenna cables were extended from 15 to 50 m, providing better options for antenna placement in an open environment, a major criterion for obtaining good observations. Additional architecture improvements were made, as reducing in the size the power unit, adding remote control system, etc. The deployment of the 4th generation beacons began in June 2019 at St-John's on the island of Newfoundland, off the Atlantic coast of Canada and marks the beginning of a new era in the evolution of the DORIS network.

IDS LIFE

DORIS days 2021

The IDS is organizing online “DORIS Days" on November 16, 17 and 18, 2021. This event is an introductory course to give non-practitioners in DORIS the opportunity to broaden their knowledge of the DORIS technique as well as to provide information on IDS products. Several sessions will be given online. Information related to this event and registration form are available on the page: **https://ids-doris.org/ids/reports-mails/meeting-presentations/doris-day-2021.html**

Announcement of a DORIS Special Issue

Papers are invited for a special topical issue of Advances in Space Research (ASR) on New Results from DORIS for Science and Society. The deadline for submissions is 31 January 2022. Dr. Ir. Ernst Schrama and Dr. Ing. Denise Dettmering are the Guest Editors for this special issue. Details on the topics included for this issue are available at the following COSPAR web site : **https://cosparhq.cnes.fr/assets/uploads/2021/05/DORIS-announcement.pdf**

IDS Workshop 2022

The next IDS Workshop will be held at the Palazzo del Cinema in Venice, Italy, from 21 to 23 March, 2022, in con-junction with OSTST 2022. This is a meeting for all those who analyze DORIS data, use products derived from DORIS data, or who are involved with the DORIS network. The meeting will highlight current developments and the sta-tus of scientific results that use DORIS data, and will provide a platform for discussion and coordination for future activities. In parallel to the oral and posters sessions, all the presentations will also be available in a web forum. This will also allow people who are not able to attend in person the meeting to show and discuss their results. All logistical information and key dates are available at: **https://ostst-altimetry-2022.com**

IDS Governing Board

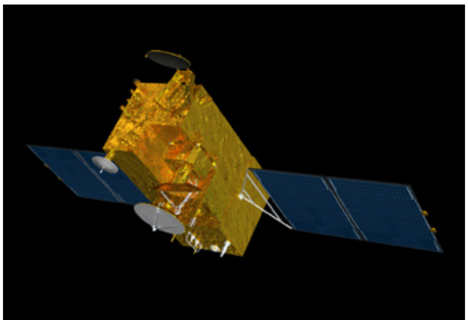
In early 2021, IDS held elections to renew three seats on the Governing Board (GB) for the 4-year term 2021-2024. The members elected by the IDS Associates are the following :

- **Analysis Centers’ Representative:** Frank Lemoine (NASA – Goddard Space Flight Center, USA)
- **Data Centers’ Representative:** Patrick Michael (NASA – Goddard Space Flight Center, USA)
- **Member-at-large:** Karine Le Bail (Chalmers University of Technology, Sweden)

In addition, Tonie van Dam (IERS Directing Board Chair) was appointed by IERS as its representative within the IDS GB. Denise Dettmering remains an ex officio member of the IDS GB, in the role of Chair of the IDS Working Group on Near Real Time Data. The members of the new Governing Board elected Frank Lemoine chairman for 2021-2024.
The IDS GB sincerely thanks Brian for serving as the IERS representative from 2013 to 2020, and is very pleased to welcome Karine and Tonie.

HY-2D, A NEW **DORIS** CARRIER SATELLITE

The 4th satellite of the series of Chinese oceanographic satellites HY-2 (HaiYang means "ocean") has been launched on May 19, 2021 from the Jiuquan Satellite Launch Center, PRC. HY-2D has the same orbit (inclination 66°, altitude 971 km) as HY-2C, launched in September 2020, while HY-2A (August 2011-September 2020) and HY-2B (October 2018-now) have sun-synchronous orbits at 963 km. With the exception of HY-2B, these satellites are equipped with the DGXXX receiver. The next satellites in the series to be launched in the coming years should also carry DORIS.



HY-2D (©NSOAS)

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