#11 - DECEMBER 2024

# IDS NEWSLETTER

Newsletter of the International DORIS Service

DORIS/CRYOSAT2, ©ESA/CORVAJA STÉPHANE 2009

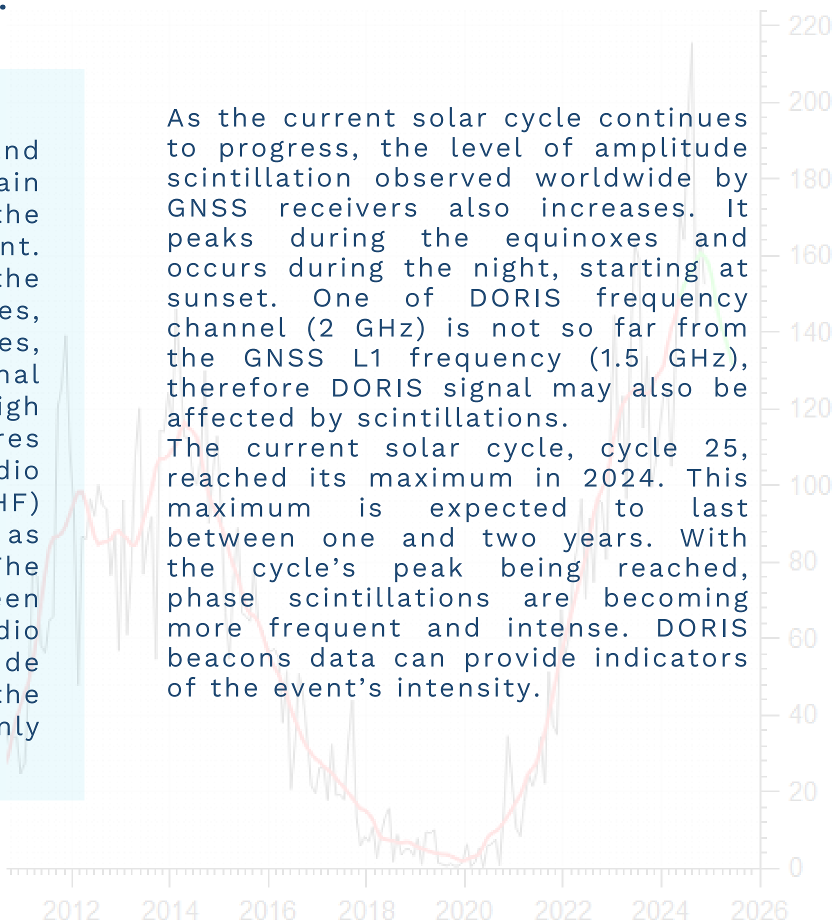
# Contribution of DORIS to Global **Ionospheric Scintillation** Mapping

By **Marie Cherrier and Philippe Yaya** (CLS)

**Ionospheric scintillations due to ionosphere irregularities may severely degrade GNSS data in equatorial and high latitudes regions. Networks of ground based GNSS receivers are used to derive maps of scintillation intensity, but it inevitably leads to sparse coverage. To improve the scintillation coverage, the DORIS system might be a solution.**

What are "**ionospheric scintillations**"?
In certain regions (at high latitudes and along the equatorial sector) and at certain local times (mainly after sunset), the ionosphere may become highly turbulent. These turbulences are due to the development of small-scale irregularities, principally plasma bubbles at low latitudes, and particles precipitation when a coronal mass ejection (CME) arrives at Earth at high latitudes. The presence of such structures can seriously affect the nature of radio waves, and thus alter High Frequency (HF) Communication and Navigation systems, as they propagate through the ionosphere. The term "ionospheric scintillation" has been used to describe this effect on the radio signals. They are of two types: amplitude scintillations (mainly observed at the equator), and phase scintillations (mainly observed at high latitudes).

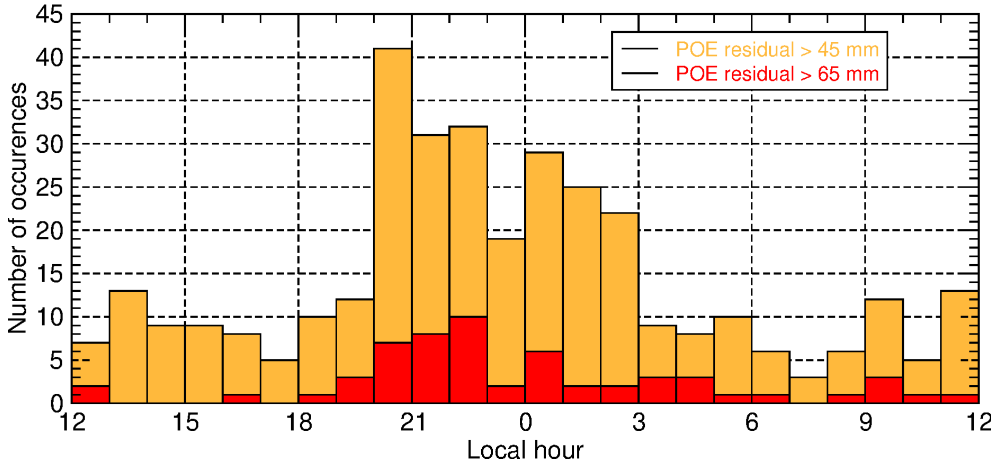
As the current solar cycle continues to progress, the level of amplitude scintillation observed worldwide by GNSS receivers also increases. It peaks during the equinoxes and occurs during the night, starting at sunset. One of DORIS frequency channel (2 GHz) is not so far from the GNSS L1 frequency (1.5 GHz), therefore DORIS signal may also be affected by scintillations.
The current solar cycle, cycle 25, reached its maximum in 2024. This maximum is expected to last between one and two years. With the cycle's peak being reached, phase scintillations are becoming more frequent and intense. DORIS beacons data can provide indicators of the event's intensity.




*This research work was presented at the IDS Workshop 2024: 10.24400/312072/i03-2024.3925.*

First indicator: **satellite orbit residuals**

Through the outputs from the Precise Orbit Determination (POD), a correlation is seen between high POD residuals values with the scintillation level. POD residuals become higher with the solar cycle, during equinoxes and after sunset.




DERIVED STATISTICS OF THE OCCURRENCE OF HIGH VALUES OF ORBIT RESIDUALS VS LOCAL HOUR

Second indicator: **data losses**

During a phase scintillation event at the equator, beacons located in the zone of maximum scintillation show data losses. For example, during the event of February 17th, 2024, beacons located in the zone of maximum scintillation are showing some data losses. The same behavior has been observed for beacons located at higher latitudes.

The least-square residuals of the orbit fitting on the DORIS data recorded during the same scintillation event show the degradation on the phase signal.

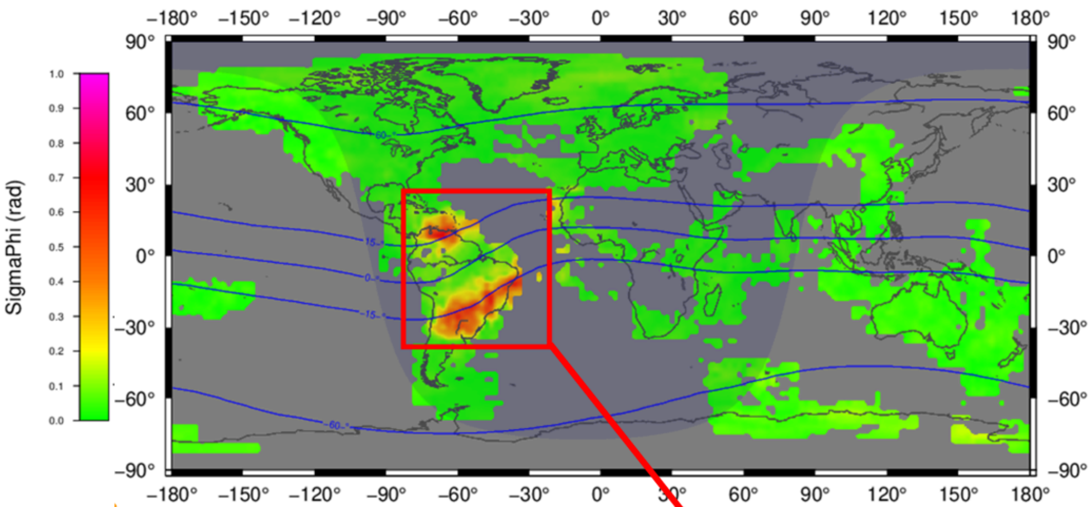
Higher residuals are recorded during the scintillations' peak, and thus eliminated when measurements are made by DORIS satellites with beacons located in the zone of maximum scintillation.

Furthermore, for these satellites, a complete data loss is observed during a few minutes when the scintillations peak is reached, and the residuals have a larger dispersion, in comparison with their passe during subsequent cycles (without scintillation).

Third indicator: **power signal attenuation**

Scintillation events occurring at Equatorial latitudes may have a slight impact on the power signal attenuation. Indeed, for such events, a slight increase in dispersion and a slight decrease in event average are observed when analyzing the power signal attenuation. These observations are less visible during high-latitude events (Northern or Southern latitudes).

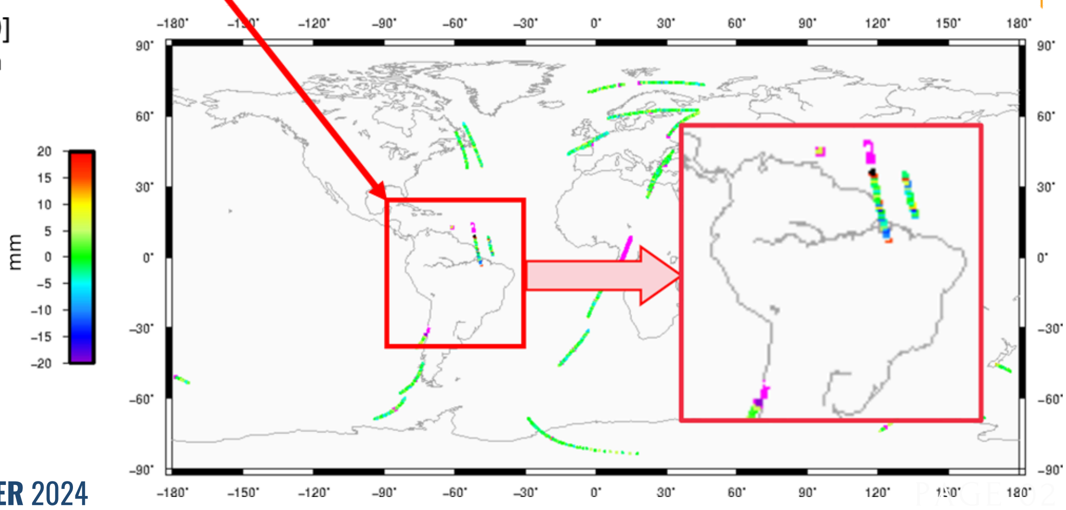
The objective now is to attempt to define scintillation proxies in light of all these observations made from the various DORIS data.




LEFT: PHASE SCINTILLATION MAP BASED ON A GNSS NETWORK
BOTTOM: RESIDUALS MAP OF DORIS SATELLITES PASSES (RESIDUALS REMOVED IN PINK)

17/02/2024 [00:45 – 01:00]
**Phase Scintillation**

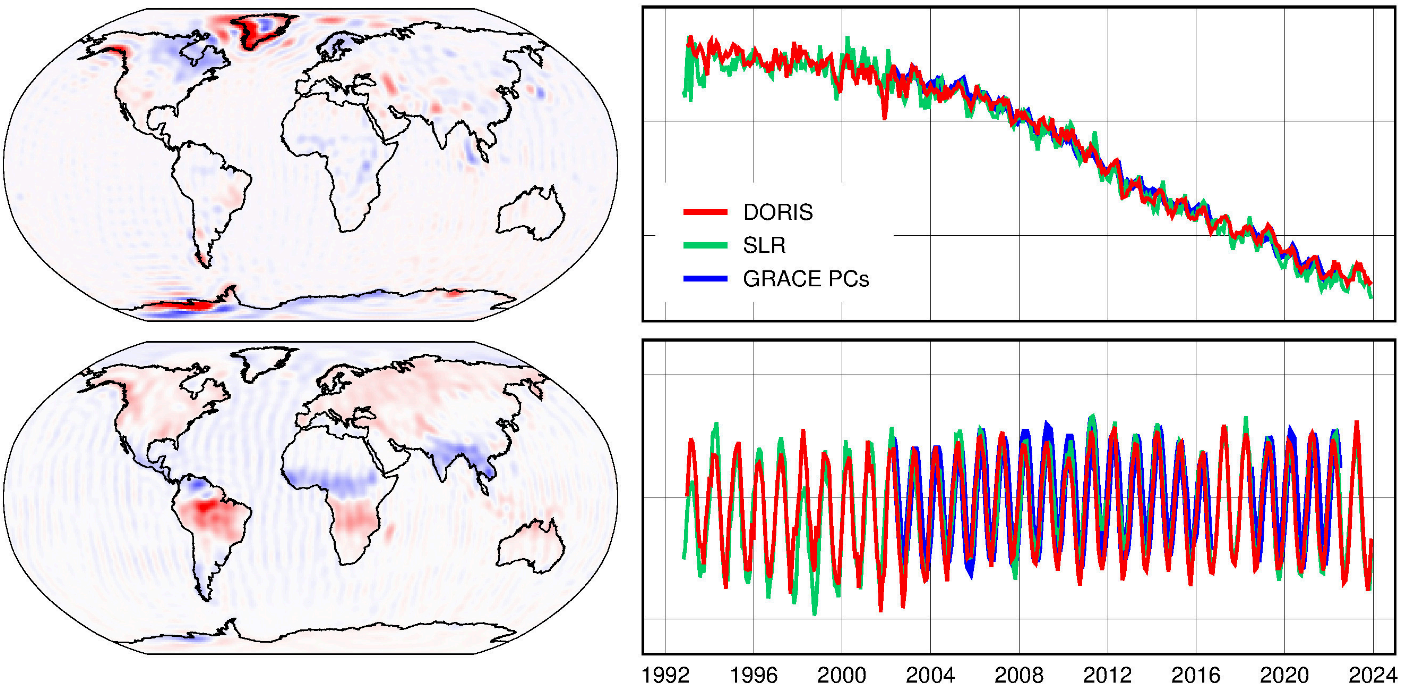
17/02/2024 [00:30 – 01:30]
**Orbit residuals**



# DORIS application for the **gravity field**

By **Anno Löcher** (University of Bonn)

**As follows necessarily from physics, the orbits of the DORIS satellites are influenced by the temporal variations of the gravity field. Getting from this a meaningful picture of these variations is a difficult task as gravity fields from DORIS have in general poor spatial resolution. By introducing prior knowledge from the GRACE mission, this task can be greatly simplified by focusing on the most significant variations represented by characteristic spatial patterns. As a result, DORIS can provide monthly maps of the gravity field with the full GRACE resolution.**




EMPIRICAL ORTHOGONAL FUNCTIONS #1 AND #2 FROM GRACE WITH ASSOCIATED PRINCIPAL COMPONENTS AND SCALING FACTORS ESTIMATED FROM SLR AND DORIS

Temporal changes in the gravity field let conclude on mass transports on or near the Earth's surface and are thus of highest interest for studies on terrestrial water storage, sea level or the state of ice sheets and glaciers, all of them indicators for a changing climate. This type of Earth observation is closely related to the mission GRACE (Gravity Recovery And Climate Experiment) launched in 2002 which made it possible to calculate monthly gravity fields with a spatial resolution of 300 km. The GRACE time series is continued meanwhile by GRACE Follow-On which is essentially a duplicate of GRACE. Plans for a third, improved generation of GRACE missions are already in the works.

To extend the GRACE time series further into the past, a number of efforts were made to obtain temporal gravity fields from other missions. An obvious choice for this was the spherical satellites observed by SLR since the early 1990s. However, due to the sparse and unequally distributed stations, SLR cannot resolve the gravity field better than up to a few thousand kilometers. For studying mass changes at some region of the Earth, such solutions cannot be a substitute for GRACE. Even in the largest areas, secular or seasonal signals can then be grossly misestimated.

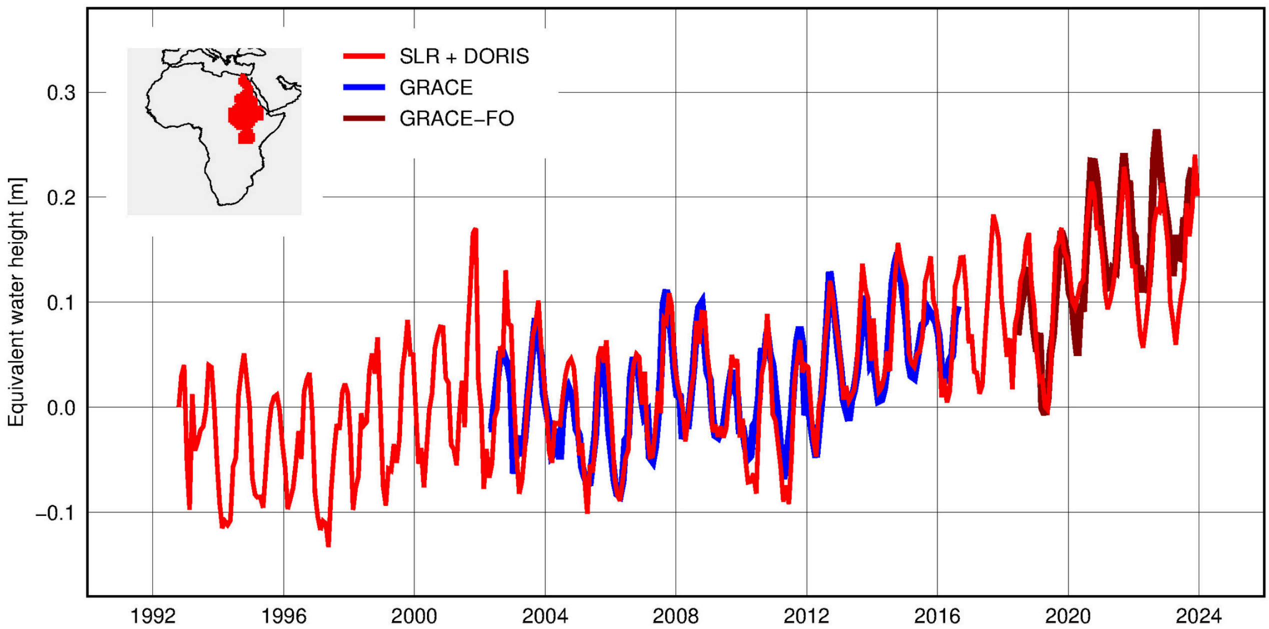
To avoid such mismatch, it proved expedient to recover from SLR specifically the most significant changes that are identified with the help of GRACE. To do so, the GRACE time series is subjected to a principal component analysis (PCA) which separates the series into its constituent signals, each represented by a spatial pattern, the empirical orthogonal function (EOF), and a time series of scaling factors, the principal components (PCs). The signals are returned by the PCA in the order of their significance. Hence, the leading ones can be attributed to known processes in the Earth system such as the loss of ice masses at high latitudes or the hydrological cycle.

Mathematically, the PCA provides another linear representation of the GRACE fields with much fewer elements than the usual one by spherical harmonics. SLR or any other technique can take advantage of this by using the EOFs as base functions for the gravity field and estimating the PCs from observations. A monthly solution can thus be determined by very few parameters. It has formally, nevertheless, the full GRACE resolution which is inherited via the EOFs.

**DORIS data contained a strong and usable gravity signal from the beginning**

As hoped, this approach allowed SLR to capture the mass variations in many regions with high accuracy [1]. To put this result on a broader basis, the approach has been applied now to DORIS whose record of observations covers the same long period [2] [3]. For this purpose, the ten DORIS satellites with altitudes below 1000 km and launch dates prior to 2020 were selected. As an unexpected outcome, it was found that the most dominant mass changes can be well recovered from each of these satellites alone, albeit with some noise. This even applies to the early Spot satellites which shows that the DORIS data contained a strong and usable gravity signal from the beginning.

By combining the ten satellites, the results from DORIS come close to those from SLR, although a validation with the GRACE time series indicates a slightly larger error. In the end, DORIS turns out as a good complement for SLR, as the combination of both leads to a significantly improved solution. As measured again by the comparison with GRACE, the addition of DORIS reduces the error on average by 9 percent, locally by up to 30 percent. The EOF approach has been refined for SLR by co-estimating low-resolution fields using spherical harmonics and used in this form for a time series published in the ICGEM database (IGG-SLR-HYBRID). An update of this solution, now based on SLR and DORIS, will be made available in near future.




MASS VARIATIONS IN THE NILE BASIN FROM A COMBINED SLR/DORIS SOLUTION COMPARED TO GRACE AND GRACE FOLLOW-ON

***References***

*[1] Löcher, A., Kusche, J. (2021). A hybrid approach for recovering high-resolution temporal gravity fields from satellite laser ranging. Journal of Geodesy, 95(1). DOI: 10.1007/s00190-020-01460-x.*

*[2] Löcher, A., Kusche, J. (2022). A 30-year record of the time-variable gravity field from DORIS and SLR using a tailored parametrization via GRACE EOFs. Presented at the IDS Workshop, Venice, Italy, 31 October - 2 November 2022. DOI: 10.24400/312072/i03-2022.3650.*

*[3] Löcher, A., Kusche, J. (2023). Monthly gravity fields from SLR and DORIS using tailored base functions: final improvements. Presented at the DORIS Analysis Working Group Meeting, Saint-Mandé, France, 28-29 November 2023 https://ids-doris.org/images/documents/report/AWG202311/IDSAWG202311-Löcher-MonthlyGravityFields.pdf*

# DORIS back in **Rapa Nui**

By **Jérôme Saunier** (IGN, IDS Network representative)

**Rapui Nui is the Polynesian name of Easter Island. This island was settled by a group of Polynesians at the end of the first millennium, who left their mark on this mysterious island forever. Moai, these monumental statues, still fascinate. It was on Easter Day 1722 that the Dutch explorer Jakob Rogeveen discovered this isolated island and gave it its name to reveal it to the world. Easter Island was annexed by Chile in 1888.**

## First DORIS occupation

Located nearly 4000 km from the mainland, in the middle of the ocean, Easter Island is a prime location for the DORIS network to cover the South Pacific. This strategic location was immediately identified for the installation of a station before the start of the DORIS system in 1990. The Space Research Center in Chile, established on the basis of a partnership between NASA and the University of Chile, led to the installation of two DORIS stations in Chile: one at Peldehue (north of Santiago) and the other on Easter Island. This first DORIS occupation on Easter Island lasted over 25 years.

To build up a sufficiently dense network of stations for the launch of the DORIS system in 1990, stations deployment began as early as 1986. The station in Easter Island was installed at the end of 1988, equipped with DORIS beacon 1.0 and Alcatel antenna monumented on a 4-meter tower that was guyed with cables.

The station was co-located for a few years with mobile SLR station (CDP 7097) and IGS station (acronym EISL). As part of the DORIS network renovation program started in 2000, the DORIS antenna was upgraded and relocated in early 2001 by around ten meters to a 2-m high very rigid tower to improve stability.

Between 2002 and 2012, the beacon was replaced several times due to breakdowns, each time interrupting service for a few months.

## The three successive DORIS antennas in Easter Island

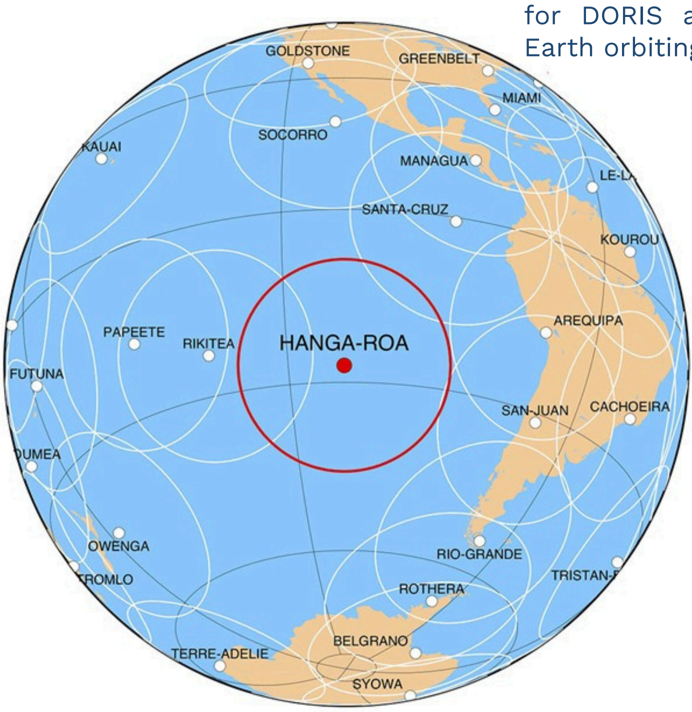
EASA - Alcatel (1990)

EASB – Starec B (2001)

HROC – Starec C (2023)

## Relocation project

Following the closure of the Space Research Center in Easter Island in 2008, and the degradation of the environment that impacted significantly the station performance, the relocation of the station was planned. A reconnaissance mission in 2014 considered two possibles sites. The first option studied was the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) seismic and radionuclide station located in the middle of the island. This site had all the assets needed to host the DORIS station: wide-open sky, well-maintained and secured site and co-location with the IGS station “ISPA”. Unfortunately, after 3 years of negotiations with the many organizations involved - CTBTO, CCHEN (Comisión Chilena de Energía Nuclear), SSC-Chile (Swedish Space Corporation)-, we realized that we had been on the wrong track. In the meantime, the DORIS station was shut down for good and dismantled in August 2015. Our efforts were then redirected to the second site under consideration: the meteorological station near Mataveri airport, in Hanga Roa. After some discussions with the DMC (Dirección de Meteorológica de Chile), the project really took off in 2019 after we got back in touch with the University of Chile (UdC), our long-standing partner in Chile.




Pr. Jaime Campos, director of the Seismic Risk Program (PRS), from the Facultad de Ciencias Físicas y Matemáticas (FCFM) of the UdC, welcomed the project with enthusiasm!

## Collaboration with Facultad de Ciencias Físicas y Matemáticas de la Universidad de Chile

It was important for the FCFM of the UdC to establish a concrete scientific collaboration with its DORIS partners - CNES and IGN - through a signed agreement. IDS has thus proposed itself as a privileged interlocutor to promote research activities around DORIS data and products in areas of interest to the FCFM: geodesy and geophysics, monitoring deformations of the solid Earth, monitoring of hydrosphere movements, determination of the International Terrestrial Reference Frame (ITRF). The tripartite agreement was signed in March 2022. The UdC participated for the first time in the IDS Workshop in Venice in November 2022.

## The DORIS station installation

The two years of the Covid-19 global health crisis naturally delayed the project. But less than a year after signing the agreement, we were ready to install the station. The DMC site adjacent to the airport runway offers a clear view of the sky, which is the most important requirement for DORIS antennas tracking low-Earth orbiting satellites.

The antenna is installed on a 2 meter-high very rigid tower set on a concrete base deeply anchored in the ground to ensure stability. The antenna visibility is excellent: no obstruction above 5° elevation, expect some trees in north-northwest direction. The station was commissioned on April 13th, 2023.

## First results and performance

After a year of operation and contribution to precise orbit determination (POD) of the DORIS-equipped satellites, the station's performance has been evaluated. In terms of geographical coverage, it is clear that this station located in the middle of the South Pacific, 2600km from Rikitea or 4000km from San Juan, makes a major contribution to POD. A detailed analysis from Philippe Yaya (CLS) for the DORIS Performance Group shows that POE (Precise Orbit ephemeris) RMS are good (mean of 7 mm), allowing the station to shift from the end to the middle of the network ranking. However, a seasonal effect was observed. POE RMS correlated with mean temperature (higher RMS when higher temperature) and the increase of RMS affects low elevation measurements. This might be a possible seasonal tropospheric effect.

There are a few difficult sites in the DORIS network that require a lot of work but are well worth the effort. Hanga Roa in Easter Island is one of these sites. It took 9 years of hard work to bring this relocation project to fruition. After an 8-year absence, DORIS is back to operation in Easter Island, an essential location!
There are now plans to add a permanent GNSS station to the site, as part of the REGINA infrastructure (https://regina.cnes.fr/) and as part of the IGS network.
Our warmest thanks go to the PRS team for their real motivation in this collaborative project, for which we expect fruitful results.

**¡Viva DORIS en la Isla de Pascua!**

# The host agency in short / **HANGA-ROA**

By **Edgardo Santibáñez**
Researcher at Seismic Risk Program (PRS) of the University of Chile
https://prs.uchile.cl/

**The Seismic Risk Program (PRS) of the University of Chile**

After the impact of the 2010 Maule earthquake, the **Faculty of Physical and Mathematical Sciences (FCFM)** of the University of Chile, promoted the creation of four new centers and programs: the National Seismological Center (CSN), the Seismic Risk Program (PRS), the Center for Climate and Resilience Research (CR)2 and the Applied Geophysics Nucleus (NGA). The Seismic Risk Program, PRS of the University of Chile, is oriented to technology and knowledge transfer, from academia to society, through research, development and innovation (R&D+i) around our seismological reality. This program is framed within the Activities of National Interest (AIN) carried out by the University of Chile. The PRS is a virtuous link between the Seismologists of the Department of Geophysics of the FCFM (DGF) and the National Seismological Center, in all those areas and/or subjects in which their interests and/or research converge, ensuring the transfer of knowledge and technologies that contribute to the management of socio-natural risks in our country through products whose impact is in the field of public policies and decision makers.

## Our interest in DORIS

The installation and commissioning of the DORIS station on Easter Island in April 2023, constituted the culmination of a process that began in early 2019. On the part of the University of Chile, the coordination was in charge of the PRS housed in the DGF. For the research areas of the PRS, it is of great interest to incorporate new satellite technologies for the monitoring and study of the deformation of the earth's surface by means of the time series of DORIS positions, together with GNSS observations, as well as for the study of ionospheric disturbance signals before, during, and after earthquakes and tsunamis, and orbitography with data from the DORIS satellite constellation.

The participation of the Dirección General de Aeronática Civil (DGAC)* and the Dirección Meterorológica de Chile (DMC)** has also been key in this process. They provided a site and a space in a building for the installation of the DORIS station at the Mataveri airport in Easter Island, facilitated the logistics for the equipment and the antenna, and welcomed and provided support to the installation specialist technician. Currently, they have personnel who act as counterparts of CNES and IGN in the follow-up of the operation. For the DMC, the contribution of DORIS to climate change studies and the measurement of sea level variations for the study of the El Niño and La Niña phenomena that periodically impact our territory is of great interest.

For Chile, participating in DORIS is to expand the capacity to observe the Earth System from the Southern Hemisphere and is not only of scientific interest, but also of public interest, because of the contribution that research based on its data can make to disaster risk management and thus to the reduction of the economic and social impacts of geo-hazards.

The location of the DORIS station on Easter Island, in the middle of the Pacific Ocean, could have an almost poetic or archetypal connotation. For the Rapa Nui (Easter Islanders), in the native language, the island is known as Te Pito o Te Henua, which means “The navel of the world”, and Mata Ki Te Rangi, which is equivalent to “Eyes that look at the sky”. With DORIS, we can accurately determine the coordinates of the “navel of the world” and also “look at the sky” and accurately measure the orbit of satellites.

** The General Directorate of Civil Aeronautics (DGAC) is a Public Service under the Command-in-Chief of the Chilean Air Force, created in 1930. Its main function is the management and administration of public aerodromes and services aimed at aiding and protecting air navigation.*

*** The Meteorological Directorate of Chile (DMC) is the agency responsible for the meteorological work in the country, whose function is to provide the basic and processed meteorological information required by aeronautics, and to provide meteorological and climatological services to the different socioeconomic activities required by the country for its development. It also conducts meteorological research, in coordination with national and international organizations, and manages the National Meteorological Data Bank.*

# **IDS** LIFE

## IDS Governing Board elections

The IDS is running elections to renew three seats on the Governing Board:

- **Analysis Centers' representative**, occupied by Frank Lemoine (NASA/GSFC, USA),
- **Data Centers' representative**, occupied by Patrick Michael (NASA/GSFC, USA) (substitute Taylor Yates),
- **at-large member**, occupied by Karine Le Bail (Chalmers University of Technology, Sweden).

Results will be announced early January 2025.

## IDS Activity report 2023

The report is out and available through the DOI 10.24400/312072/i02-2024.002

The IDS would like to thank all the authors and co-authors for their valuable contributions.

## Change of CNES/IDS project manager

**Cécile Manfredi** is the new CNES/IDS project manager and representative of the DORIS system within the IDS. Welcome Cécile!

## NRT DORIS data and orbit available

Since July 2024, DORIS data have been provided to IDS in Near-Real time i.e. with a **latency of 3 hours or less** after their acquisition by the DGXX receivers of Cryosat-2, Jason-3, HY-2C, HY-2D, Saral, Sentinel-3A, Sentinel-3B, Sentinel-6A and Swot. They are primarily intended for use by the WG "NRT ionospheric applications", whose aim is to promote the usage of NRT DORIS data for ionospheric applications, e.g. diagnosing scintillations. But anyone interested in this data can contact the IDS Central Bureau to obtain access.

## Two new Working Groups

The IDS Governing Board has set up two new working groups (WG) in 2024.

The "**Integrated Clock Correction Strategies for DORIS**" WG is led by Patrick Schreiner (GFZ, Germany) and aims to address the behavior of DORIS clocks, exploiting DORIS clock co-locations in space and on ground. The goal is to derive methods to better model the behavior of DORIS USO and reduce a source of systematic error in the DORIS technique.

The "**NRT ionospheric applications**" WG, led by Ningbo Wang (AIR/CAS, China), is the continuation of the "NRT data". Its aim is to advance the use of Near-Real Time (NRT) DORIS data for ionospheric research applications.

More information at https://ids-doris.org/ids/organization/working-groups.html.

## DPOD includes now post seismic deformation and seasonal corrections

The so-called DPOD product is a set of coordinates and velocities of all the DORIS tracking stations for Precise Orbit Determination (POD) applications. It can be seen as a DORIS extension of the current ITRF realization. It is realized by the IDS Combination Center (CC) and updated several times a year to take into account events affecting the network beyond the period covered by the ITRF realization such as new stations in the network or discontinuities in time series due for instance to earthquakes. The **DPOD2020** is aligned to the ITRF2020. Its version 2.0 issued in February 2024 brings something new, by providing annual and semi-annual station position corrections as well as post-seismic deformation corrections. A new feature to discover on the dedicated page: https://ids-doris.org/analysis-coordination/combination/dpod.html

# **DORIS** NEWS

## DORIS will be on Genesis

The GENESIS project, managed by ESA Navigation Directorate, is a mission aiming to significantly improve the International Terrestrial Reference Frame (ITRF) by carrying on the same platform, for the first time, the four space-based geodetic techniques (DORIS, GNSS, SLR, VLBI) that contribute to its realization. The mission is designed to fly in a medium-altitude circular orbit at 6,000 km. The launch is scheduled for 2028. **The DORIS instrument for the Genesis mission was accepted by ESA on October 3, 2024**. A DGXX-S model suited to this mission will be supplied by CNES. IDS fully supports this project and together with CNES experts, is involved in the Genesis Science Exploitation Team.

## DORIS NEO

The DORIS tracking system has been undergoing continuous improvement since the early 2000s. While the first generation of receivers (1G), embarked on Topex/Poseidon, Spot-2, Spot-3 and Spot-4, had a single channel, able to receive signals from only one beacon at a time, a second generation with two channels equipped Envisat (2G) and, in its miniaturized version (2GM), Jason-1 and Spot-5. Since Jason-2, launched in 2008, the DORIS-equipped satellites embark a 3rd generation instrument, DGXX and DGXX-S versions. With seven channels and the ability to track up to seven beacons simultaneously, the DORIS DGXX instrument has considerably increased the number of measurements, particularly at lower elevation.

Today the 4th generation, named **DORIS NEO**, is under development. It will have the same functionality and performance as the DGXX, but It will use a Software Design Radio (SDR) architecture and offer enhanced modularity. The first model will be available in 2028.

## News from the Network

2023 and 2024 were very busy years for the DORIS network's field operations. Three new sites were added, bringing the total number of stations to 61, a record in the network's history. These are:

**Hanga Roa** on Easter Island, which was eagerly awaited for the coverage of the South Pacific (see article by Jérôme Saunier in this issue);

**Gavdos**, off the coast of Crete in Greece at the new ESA Permanent Facility for altimetry calibration that is located under a triple crossover of Sentinel 3 and Sentinel 6;

**Ulaanbaatar** in Mongolia at the Ulaanbaatar Astronomical Observatory, making a major contribution to DORIS network's coverage in this region.

Finally, one of the major network operations during this period is the complete **renovation of the "Everest" station** at the Pyramid Observatory Laboratory with new equipment, a new location and a new monument for the antenna. This mission was a real adventure, and we'll tell you all about it in a future Newsletter.

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