Newsletter of the International DORIS Service April 2023

DORIS is on **SWOT**

A new satellite recently joined the constellation of DORIS satellites. It is SWOT, launched on 16 December 2022. There are now nine active DORIS instruments. Never before have so many DORIS instruments been in operation simultaneously.

SWOT (Surface Water Ocean Topography) is a joint project developed by NASA and Centre National d'Etudes Spatiales (CNES) with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency. Thanks to its new technical concept, a wide-swath interferometric altimeter named KaRin for Ka-band Radar Interferometer, the SWOT mission is the first satellite to address both ocean and hydrology objectives. It constitutes a major system design change for space altimetry.

SWOT includes the 18th DORIS receiver contributing to IDS and provides the DORIS constellation with a 4th orbit plane (78°). The instrument, a type DGXX-S receiver as on Jason-3, Sentinel-3A and Sentinel-3B, includes the DIODE navigation software (DORIS Immediate On-Board Determination) which processes the DORIS measurement to produce an estimation of the satellite orbit in real-time with a precision of a few centimeters.

On SWOT, the estimated orbit is used to drive the open loop tracking mechanism of the nadir altimeter Poseïdon-3C supplied by CNES, and for the first time, DIODE also provides a 20-second prediction of the satellite position to KaRIn, thus enabling better altimeter data acquisition in areas like coastal zones, inland waters and ice.

SWOT (© CNES / MIRA PRODUCTIONS)

DORIS was switched on on 11 January 2023 and very quickly the analysis of DIODE's calculations showed excellent performance for orbit determination and time tagging. Once again, the instrument has proven its autonomy and reliability.

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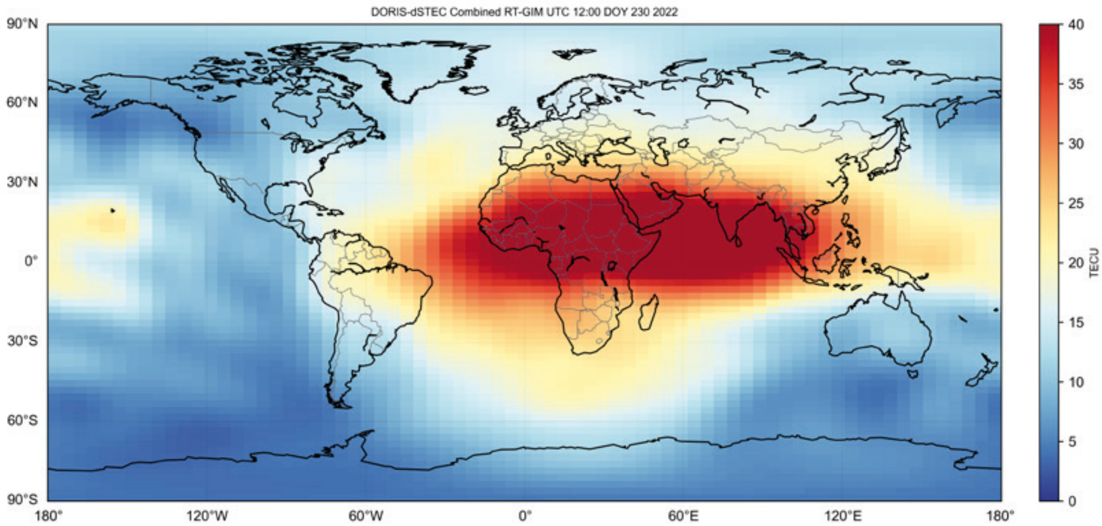
USING **NEAR-REAL-TIME DORIS DATA** FOR VALIDATING REAL-TIME GNSS IONOSPHERIC MAPS

By **Denise Dettmering** (DGFI-TUM) **and Ningbo Wang** (AIR-CAS)

Although primarily developed for precise orbit calculation, **the high-quality dual-frequency phase measurements of the DORIS system also provide valuable information for modelling the Earth's ionosphere.** For some time now, DORIS data from the Jason-3 satellite has also been available in near real time (NRT) with a delay of a few hours. These data are perfectly suited for an independent validation of Real-Time Global Ionospheric Maps (RT-GIM) derived from GNSS measurements with a latency of a few seconds.



DISTRIBUTION OF VERTICAL TOTAL ELECTRON CONTENT ON 18 AUGUST 2022 AT 12:00 UTC, FROM COMBINATION OF VARIOUS RT-GIMS WEIGHTED BY DORIS DSTEC

The ionosphere is the part of the Earth's atmosphere between about 80 and 1000 km altitude. In this region, the solar radiation stimulates ionization processes for the production of ions and electrons from different (neutral) chemical elements, e.g. oxygen, hydrogen and nitrogen.
The free electrons affect the propagation of radio signals used for geodetic measurement systems. Also the signals of the DORIS system are delayed and diffracted, depending on their respective frequency. The signal delay can be easily converted to Total Electron Content (TEC) along the propagation path (STEC) using the frequency of the signal.
It is usually expressed in TEC units (TECU), where 1 TECU corresponds to 10^{16} electrons per m^2.

The DORIS system uses two different carrier frequencies that are influenced differently by the free electrons of the ionosphere during their journey through the Earth's atmosphere. By combining both signals, conclusions can be drawn about the distribution of the free electrons, just as has been done with GNSS signals for some time and on an operational basis *(Dettmering et al., 2014).* The data processing is very similar to GNSS processing, but due to the frequency ratio used, the sensitivity of DORIS is even greater than that of GNSS.

Historically, most DORIS data is only available with a delay of several days, so that it is only available for post-processing applications. Recently, however, the first near real-time (NRT) DORIS data with a latency of a few hours have become available. Only data from one satellite mission (Jason-3) is available so far, but the addition of further satellites is already being planned.

References

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[3] Liu A., Wang N., Dettmering D., Li Z., Schmidt M., Liang W., Yuan H. (2023). Using DORIS Data for Validating Real-Time GNSS Ionosphere Maps. Advances in Space. Research. DOI: 10.1016/j.asr.2023.01.050

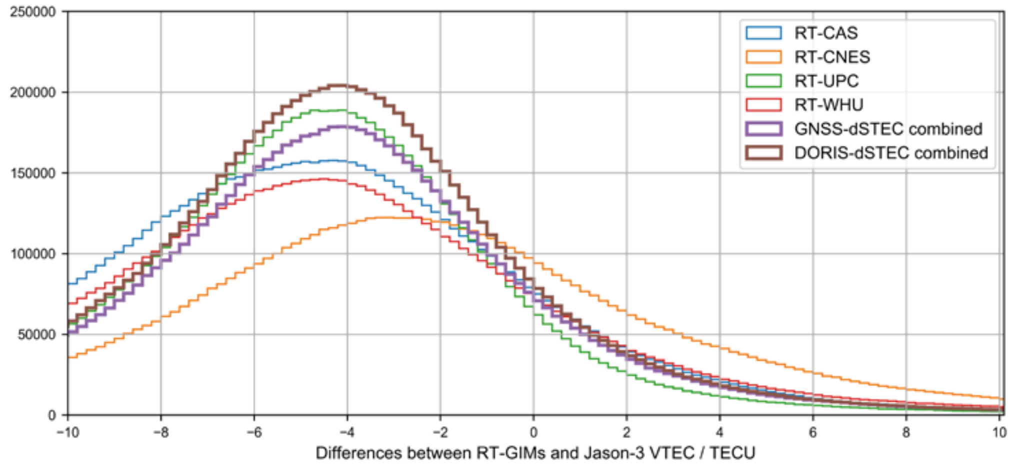
[4] Wang, N., Liu, A., Dettmering, D., Li, Z., Schmidt, M. (2022). Using Near-Real-Time DORIS data for validating real-time GNSS ionospheric maps. Presented at the IDS Workshop 2022. DOI: 10.24400/312072/i03-2022.3612

Since the data from one mission are too few to have a direct influence on ionosphere modelling, there are no NRT ionosphere models with DORIS data yet. However, the data can already be used to validate existing GNSS-based ionosphere models.

For this purpose, relative changes in the slant total electron content (dSTEC) derived from two-frequency measurements along the link between the ground station and the satellite, are calculated for individual overflights of the satellite, always related to the highest elevation of the arc. This method has been used for GNSS observations for a long time *(Hernández-Pajares et al. 2017). Liu et al (2023)* uses this method to validate real-time (RT) GNSS ionospheric models from different IGS analysis centres (namely from CAS, CNES, UPC, WHU; see Liu et al (2023) for more explanations) and finds that this works as well with DORIS data as with GNSS data and is completely independent of the model input data.

In addition to providing an indication of the accuracy of individual RT ionospheric models, the NRT DORIS data can also be used to weight the models of individual data centres for combination. *Wang et al (2022)* presents first results of such a weighting and shows through a validation with independent altimeter data from the Jason-3 mission that the new combination achieves a better performance than the combination based on classical methods.

It is planned to make NRT DORIS data available for additional satellite missions (Sentinel-3A, Sentinel-3B, Sentinel-6A) and possibly also to further reduce the latency times. This would then result in numerous further applications for ionospheric modelling.



HISTOGRAM OF DIFFERENCES BETWEEN RT-GIM DERIVED VTECS AND JASON-3 ALTIMETER VERTICAL TEC OBSERVABLES DURING JANUARY TO SEPTEMBER 2022

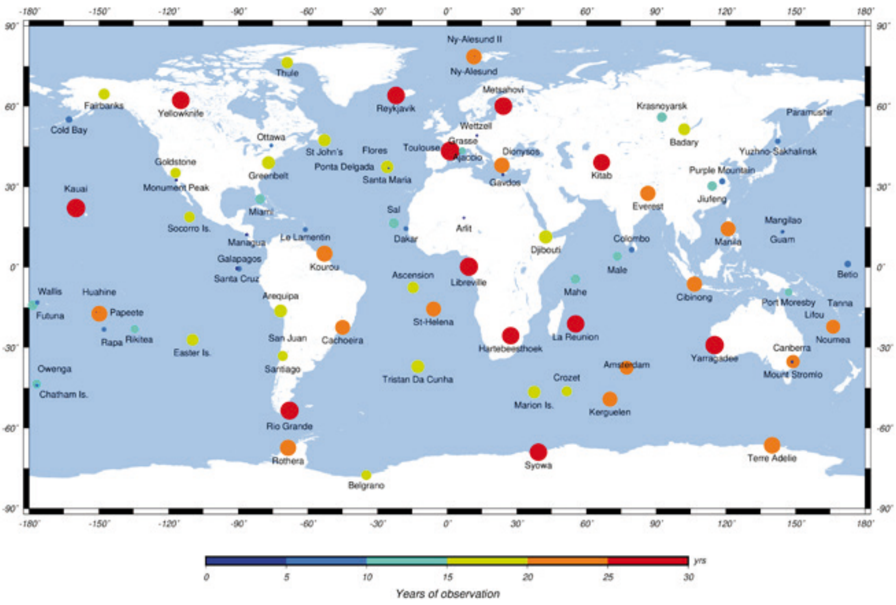
IDS CONTRIBUTION TO **THE 2020 REALIZATION** OF THE INTERNATIONAL TERRESTRIAL REFERENCE FRAME

By **Guilhem Moreaux** (CLS, IDS Combination Center)

In July 2021, the IDS delivered to the International Earth Rotation and Reference Systems Service (IERS) the DORIS contribution for the computation of the 2020 realization of the International Terrestrial Reference Frame (ITRF). Each realization of the ITRF provides a set of accurate coordinates and velocities of several thousand reference points located on the Earth's surface. In this way, the ITRF supports a variety of applications, such as land surveying, floodplain mapping, navigation. Furthermore, the ITRF can be used to study long-term Earth system processes, tectonic deformation, and indicators of global climate change, including sea-level rise and ice sheet melting. As one of the four space geodetic techniques (DORIS, GNSS, Laser and VLBI - Very Long Baseline Interferometry), DORIS contributes to the realization of the ITRF by delivering weekly estimations of the DORIS station positions and daily Earth rotation parameters. In addition to contributing to the geophysical application of the ITRF, the participation of the IDS to the ITRF realization allows the DORIS users to be referenced in the International Terrestrial Frame and so, to be easily connected and/or combined with other techniques. The availability of DORIS coordinates allows the computation of precise orbits of altimeter satellites for science products and for use of near-real-time data. In addition, the availability of DORIS coordinates in the ITRF allows these precise orbits to be computed consistently across three decades for the derivation of important climate indices, such as the Global Change in Mean Sea Level (e.g. https://www.aviso.altimetry.fr/msl).

For the 2020 realization of the ITRF (ITRF2020), the IDS produced 1456 weekly files including positions of 201 DORIS stations at 88 sites from 1993.0 to 2021.0. That new IDS series, ids 16, is the combination of the weekly DORIS solutions from the four operational IDS Analysis Centers: ESA (ESA/ESOC, Germany), GOP (Geodetic Observatory Pecný, Czech Republic), GRG (CNES/CLS, France) and GSC (NASA/GSFC, USA). The esa 13, gop 67, grg 43 and gsc 52 series were computed with four independent software packages following the IDS ITRF2020 standards and using the observations from fourteen DORIS satellites (CryoSat-2, Envisat, HY-2A, Jason-1, 2 and 3, Saral/Altika, Sentinel-3A and 3B, SPOT-2, 3, 4 and 5, TOPEX-Poseidon).

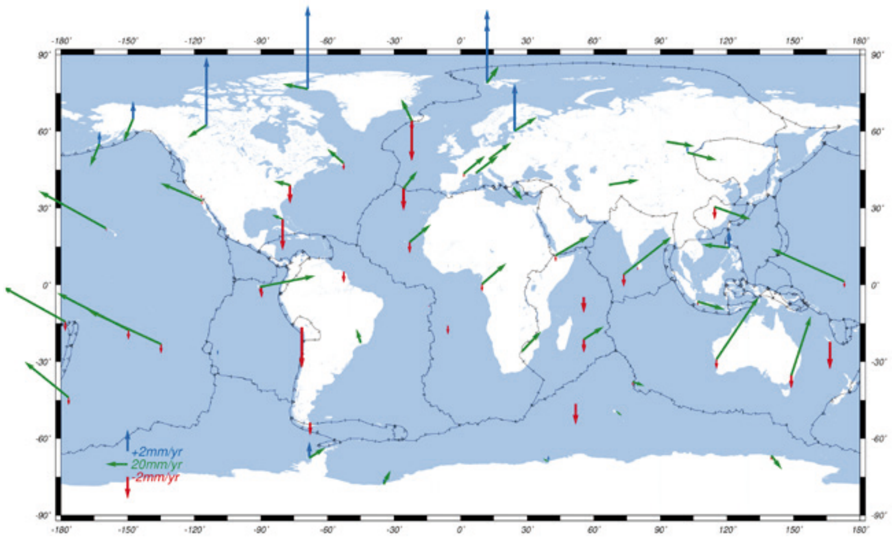
Thanks to the joint efforts of the host agencies for the DORIS stations as well as the IGN and CNES, 26 of the 88 sites have position estimations for more than 20 years, i.e. have been almost continuously operational since the beginning of the DORIS system. The five sites with the longest coordinate time series include Toulouse (France), Kauai (Hawaii, U.S.A.), Yarragadee (Australia), Libreville (Gabon), and Rio Grande (Argentina). In addition to its very good north-south distribution and to its global coverage, the DORIS network can be seen as very stable with 49 of the 88 sites free of any discontinuity in their coordinate time series. Overall, 86 discontinuities (sudden shift in position and/or velocity) were detected in the DORIS contribution to ITRF2020, and half of these discontinuities were due to earthquakes.



TIME SPAN OF THE 88 DORIS SITES INCLUDED IN DORIS CONTRIBUTION TO THE ITRF2020

By stacking the weekly coordinates of the DORIS stations from 1993.0 to 2021.0, the IGN IERS Combination Center estimated the mean positions and velocities of the DORIS stations. The velocities were modeled by linear motion. They are mainly dominated by their horizontal component with a magnitude of few cm/yr, which has been shown to be dictated by plate tectonics. In ITRF2020, like for the previous realization ITRF2014, the motion of DORIS stations that are affected by major earthquakes (Arequipa, Fairbanks, Goldstone, Managua, Reykjavik, San Juan, Santiago and Yuzhno-Sakhalinsk) are modeled by logarithmic and exponential functions for a better approximation of the coordinate time series.

The vertical displacements of the stations have smaller velocities than the horizontal displacements. However, large station vertical velocities can be seen over Canada and Fennoscandia, which are most probably due to Glacial Isostatic Adjustment (GIA). Relatively large vertical velocities may also be observed for stations located in presently glaciated areas, in particular Greenland, Antarctica, Alaska, Iceland, Svalbard, etc. While GIA in Canada and Fennoscandia is the result of ice sheets retreat since the last glacial maximum (~20-30 kyr BP), the ground vertical velocities observed over current glaciated areas are most probably induced by Recent Ice Melting (RIM). Both phenomena induce deformation of the solid Earth, sea level variations, gravity time variations, geocenter motions, and rotation variations. Moreover, other sources of long-term vertical motions may be locally possible, e.g. co/post-seismic deformation, hydrology, anthropogenic effects (such as groundwater pumping), etc.



HORIZONTAL AND VERTICAL DORIS ITRF2020 VELOCITIES WITH FORMAL ERROR LESS THAN 1 MM/YR

HÖFN, NEW DORIS SITE IN ICELAND

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

Iceland is an essential location for the even distribution of the DORIS network. Located at the edge of the Artic Circle and at the intersection of the North Atlantic and Artic Oceans, this island location allows DORIS to have a good coverage over the Nordic Region, in the middle of the surrounding DORIS stations of Ny-Alesund II (Svalbard), Metsähovi (Finland), Toulouse (France), Ponta-Delgada (Azores, Portugal), St-John's (Newfoundland, Canada) and Thule (Greenland).

DORIS in Iceland

A DORIS ground station (REYA) was installed in Reykjavik at the very beginning of the DORIS system in 1990, on the roof terrace of the Valhúsaskóli middle school building, thanks to the collaboration of the National Land Survey of Iceland: Landmælingar Íslands (LMI). In 1998, the Alcatel antenna was replaced by a Starec antenna (REYB) for better positioning results. In 2004, we moved the station to another site of the public transport administration (Vegagerðin) in order to avoid interference problems with new equipment from the Icelandic Telecom Agency installed nearby.

> **Höfn was the best option for the DORIS station relocation**

Unfortunately, by about ten years later, the rapidly changing urban environment around the antenna (REZB) led once again to considering moving the station. The presence of corrugated iron roofs that are very bad for the signal propagation and the erection of new buildings obstructing the visibility of the antenna significantly reduced the performance of the station. The announcement of the demolition of the building where it was located made the relocation of the station a priority in 2018.

VISIBILITY CIRCLE OF HOFC

Reconnaissance for relocation

When looking for a new site to host the DORIS station, the performance objectives remained a priority, but co-location with a GNSS station and/or with a tide gauge was also an essential criterion given the scientific interest that it could bring in the unique geophysical context of Iceland.

With the help of the LMI, several sites were considered for the relocation of the DORIS station with the following criteria: (1) reliable power supply, (2) clear view of the sky, (3) suitable RF environment, (4) stability of the antenna monument, and (5) co-location with a permanent GNSS station and/or tide gauge.

The site reconnaissance was organized in June 2019 in order to determine the best option according to the DORIS system requirements. Five sites were evaluated: three sites in Reykjavik close to the IGS station (REYK) or the tide gauge of Reykjavik (GLOSS n°229), a site in Reykhólar close to the GNSS station (RHOL), and a site in Höfn close to the IGS station (HOFN).

After the site visit and evaluation, it was found that Höfn was the best option for the DORIS station relocation, offering excellent hosting conditions and environment.

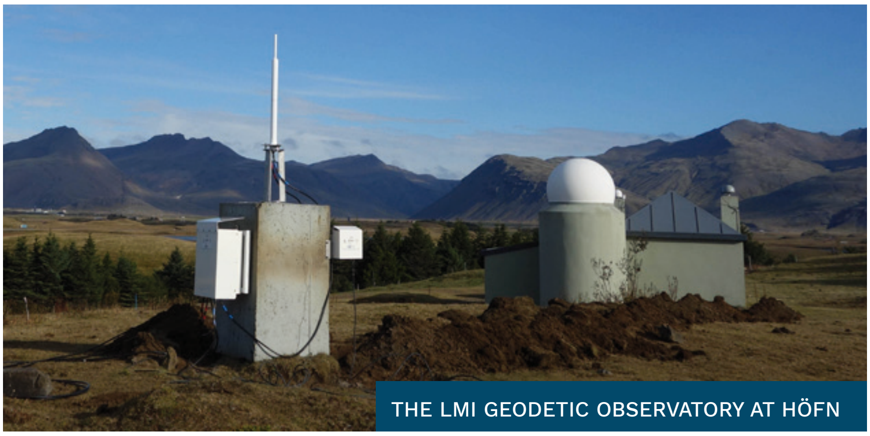
The geodetic observatory of the LMI in Höfn

The LMI operates a geodetic observatory that is located in Höfn, about 330 km east from Reykjavik. The observatory is based on the top of a small hill, 500 m north of the entrance to the village of Höfn. The site hosts two GNSS stations, one of which is part of the IGS network (acronym: HOFN) that was commissioned in 1997.

The long time series of position of this GNSS station provided us with essential information about the crustal deformation and the relative stability of this area following the recent events in Iceland: earthquake in 2008, volcano eruption in 2014/2015. Even if Höfn is close to the interplate volcanic belt of Öræfajökull, this location is not affected by local deformation as so many places in Iceland.

> **The observatory is a perfect site for geodesy instruments**

In addition, the observatory is a perfect site for geodesy instruments, offering an open view of the sky in a rural environment, accessible bedrock for the building of stable antenna monuments, and a reliable power supply.



THE LMI GEODETIC OBSERVATORY AT HÖFN

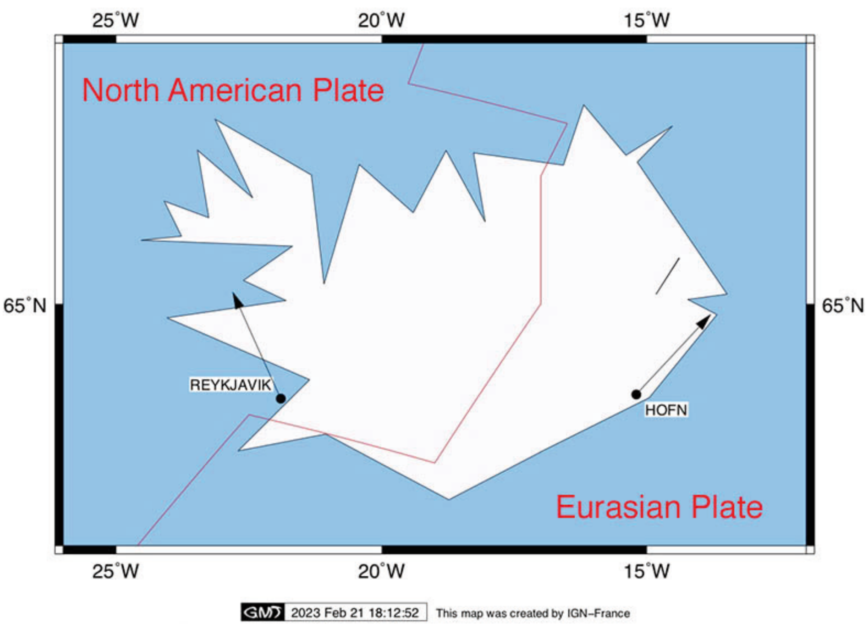
The DORIS station installation

During the site reconnaissance in June 2019, the best option for the DORIS station installation was defined according to the system requirements. Unfortunately, the outbreak of the Covid-19 pandemic in early 2020 stopped our project for a number of months. However, the improvement of the situation in Europe enabled us to complete the installation of the DORIS station at Höfn in September 2020.

This station is equipped with the 4th generation beacon with a signal amplifier at the foot of the antenna (see IDS Newsletter #9). The antenna is mounted on a 45 cm high, 3-foot stainless steel support installed on a 0.7 m square, 1.2 m high concrete pillar.

A high precision local tie survey was performed by IGN in order to determine tie vectors between DORIS and the two permanent GNSS stations, including also a geodetic mark that was used for VLBI campaigns. These tie vectors between co-located instruments are essential for the combination of the terrestrial reference frames provided by the four space geodetic techniques for the realization of the International Terrestrial Reference Frame (ITRF).

The addition of DORIS endows the LMI observatory with a certain role in the contribution to ITRF and probably reinforces the site sustainability.



VELOCITY COMPARISON REZB / HOFC (SOURCE: DPOD2020_1)

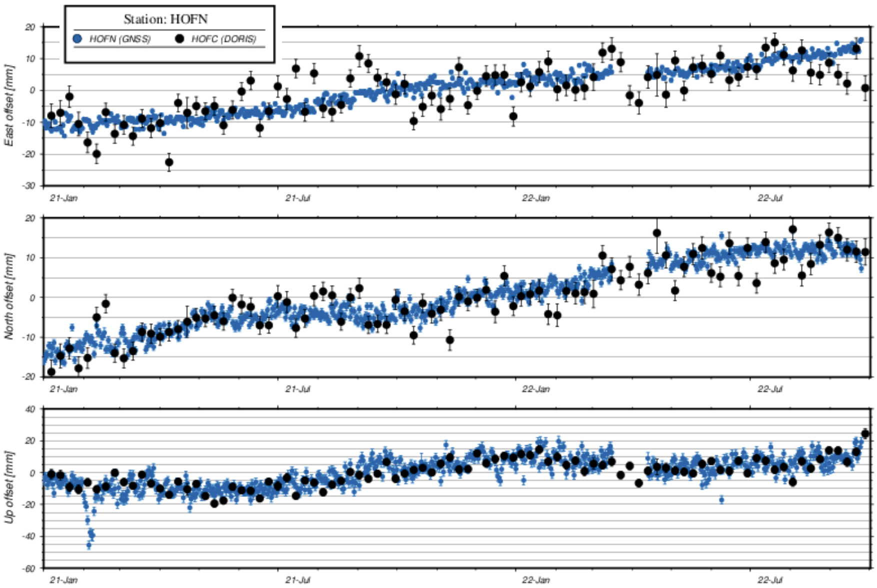
First results and performance

Straddling the plate boundary between the North American and the Eurasian plates, Iceland is an ideal field study of geodynamics. After 30 years operation on the west side of Iceland (North American plate), DORIS is now operating on the east part of Iceland (Eurasian plate). The position time series of DORIS in Iceland contributes with GNSS observations to the monitoring of the crustal deformation in Iceland. The plate separation over Iceland is about 1 to 2 cm a year. If we compare the velocity of the former DORIS station in Reykjavik with that of the current DORIS station on Höfn, we can see it moving in the opposite direction: HOFC is moving 13.8 mm/yr to the East, while REZB was moving 8.9 mm/yr to the West (source: DPOD2020_1).

Other interesting comparisons are now possible at Höfn thanks to the co-location of DORIS with GNSS. A good agreement between the position time series of the GNSS station HOFN and the DORIS station HOFC is observed. This co-location will allow to better monitor the crustal deformation at Höfn.

Regarding the contribution of the DORIS station to the Precise Orbit Determination (POD), first results confirmed the excellent antenna environment. The Doppler residuals in the orbit adjustment process are low compared to the other stations of the network: the mean of Precise Orbit Ephemeris (POE) RMS in 2021 for HOFC is about 5.8 mm (source: Philippe Yaya, CLS, CNES DORIS performance working group) that places the station in the 11th position in the network ranking. Comparatively, the DORIS station in Reykjavik was ranked between 40th and 50th during the last decade.

Following the launch of the Surface Water and Ocean Topography mission (SWOT) satellite altimeter in December 2022, the DORIS constellation has now 9 satellites. The ground station in Höfn contributes to the real time onboard orbit computation (integrated software to the DORIS instrument: DIODE) and also to the near-real-time maps of the ionosphere (see accompanying article in this Newsletter by Denise Dettmering and Ningbo Wang, IDS NRT data WG).



POSITION TIME SERIES OF DORIS AND GNSS STATIONS AT HÖFN (SOURCE: GUILHEM MOREAUX, IDS COMBINATION CENTER)

The relocation of the Icelandic DORIS station from the urban environment in Reykjavik to the geodetic observatory of LMI in Höfn allowed to significantly improve the performance of the station and strengthen its contribution to DORIS data and products. We deeply thank the LMI for its essential support in the realization of this project and long years of their collaboration with DORIS!

THE HOST AGENCY IN SHORT / **HÖFN**

By **Gunnar H. Kristinsson** (LMI, Director)

Landmælingar Íslands (LMI) is a government agency responsible for mapping and land surveying in Iceland, also called the National Land Survey of Iceland. LMI is a government agency responsible for mapping and land surveying in Iceland. LMI was established in 1956 and has since been an important organization in Iceland, providing reliable and accurate geospatial data and surveying networks. Current staff is 22.

LANDMÆLINGAR ÍSLANDS

LMI serves as the leading source for accurate and current geospatial data and services for both public and private sectors in Iceland. For decades, LMI has been providing various topographical and tourist maps of Iceland. However, since 2005, the agency has shifted its focus towards open digital data and geospatial services, reflecting the ever-changing technological landscape.LMI‘s focus on open digital data and geospatial services plays a critical role in the development of Iceland's Spatial Data Infrastructure (SDI). By providing easy and convenient access to geospatial data, the agency is promoting the sharing and use of this data across different sectors, which can lead to improved decision-making and innovation. The agency is responsible for the implementation of SDI in Iceland and is therefore involved in various SDI initiatives and collaborations at the national and international levels.

LMI participates in various international organizations, such as the Nordic Geodetic Commission and EuroGeographics, and acts as the National contact point for Copernicus and UN-GGIM.

As described in the name of the institution the LMI is also responsible for the geodetic networks in Iceland. Maintaining geodetic networks in Iceland is a challenge due to Iceland’s position on the Mid-Atlantic ridge. The Eurasian and the North American plates are drifting apart with velocity around 1cm/year in each direction. Earthquakes and eruption can cause a local deformation of several decimetres. Vertical deformations also occur due to melting of the glaciers (landuplift) and extraction of geothermal energy (land subsidence). LMI runs the IceCORS network of 33 CORS stations and a benchmark network ISNET of 150 points that are measured on a regular basis. The geophysical community in Iceland also operates over 100 more CORS stations. This serves as a basis for velocity modeling Iceland, but it is complemented with INSAR data from the Sentinel 1 satellites. The most important permanent station in the network is the IGS in the geodetic observatory of LMI in Höfn, where the DORIS station was set up in 2020.

IDS LIFE

20! Twenty years is the age the IDS will be in 2023.

The IDS was implemented in 2003 under the umbrella of the International Association of Geodesy (IAG) and since then it has guaranteed access to DORIS data and derived products for the user community thanks to a reinforced structure with two Data Centers, six Analysis Centers, four Associated Analysis Center, a Combination Center, and several partner groups. For some years now, the IDS has aimed to grow the community, extend the DORIS applications, and improve the technology, the infrastructure and the processing.

On 1 July 2023, the IDS will turn 20. To celebrate this anniversary, a special event will be organized in Berlin on the occasion of the general assembly of the International Union of Geodesy and Geophysics (IUGG; 11-20 July 2023, https://www.iugg2023berlin.org/)

IDS Workshop 2022: Abstracts, presentations and photos are online

The IDS Workshop 2022 was held in Venice, Italy, on October 31 and November, in conjunction with the 2022 Ocean Surface Topography Science Team meeting. About 50 people participated in the Workshop. The program was divided into four sessions, during which 24 contributions were presented. The PDF versions are available on the IDS website for viewing or downloading. DOIs were assigned to each of the abstracts of the workshop. Find the abstracts, presentations and pictures of the workshop at https://ids-doris.org/ids/reports-mails/meeting-presentations/ids-workshop-2022.html.

IDS Governing Board: results of the elections 2022

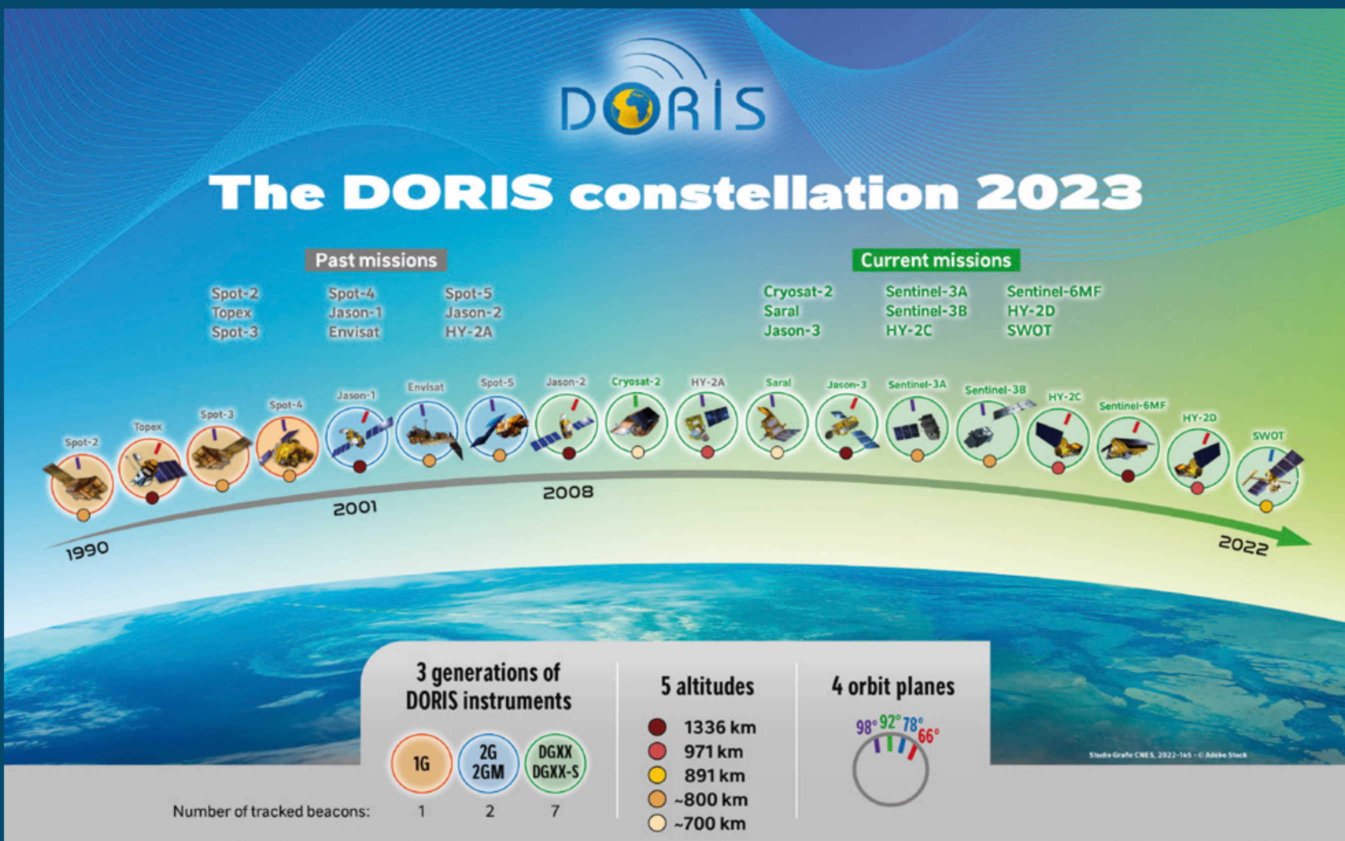
At the end of 2022, the IDS held elections to renew two seats on the Governing Board. Petr Stepanek (GOP) was elected as the new analysis Coordinator. He was part of the previous Analysis Coordination team with Hugues Capdeville. He will therefore continue this task for the next 4 years. Laura Sanchez (DGFI-TUM) succeeds Claudio Abbondanza in one of the positions of Member-at-large. She joins the GB up to 2026. Big thanks to Hugues and Claudio, and sincere congratulations to Petr and Laura.

Change of CNES/IDS project manager

Pascale Ferrage changes of activity and is replaced by Arnaud Selle as CNES/IDS project manager and representative of the DORIS system within the IDS. Warm and friendly welcome to Arnaud! Many thanks to Pascale for 13 years of involvement in the organization and animation of the IDS, the dissemination of CNES data to the IDS, the communication actions, ...

DPOD2020 available

The first version of the DORIS extension of ITRF2020 for Precise Orbit Determination (DPOD2020) has been available at the CDDIS and IGN IDS data centers since January 2023. The DPOD2020 realizations are deduced from DORIS position and velocity cumulative solutions aligned to the ITRF2020 based on the latest IDS weekly combined solution. The DPOD2020 solution will be updated two times a year and provided in both SINEX and text formats. Note that until the IDS officially moves to the ITRF2020, the IDS Combination Center will continue to update the DPOD2014, aligned to the ITRF2014.



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