IDS

8

Newsletter of the International DORIS Service

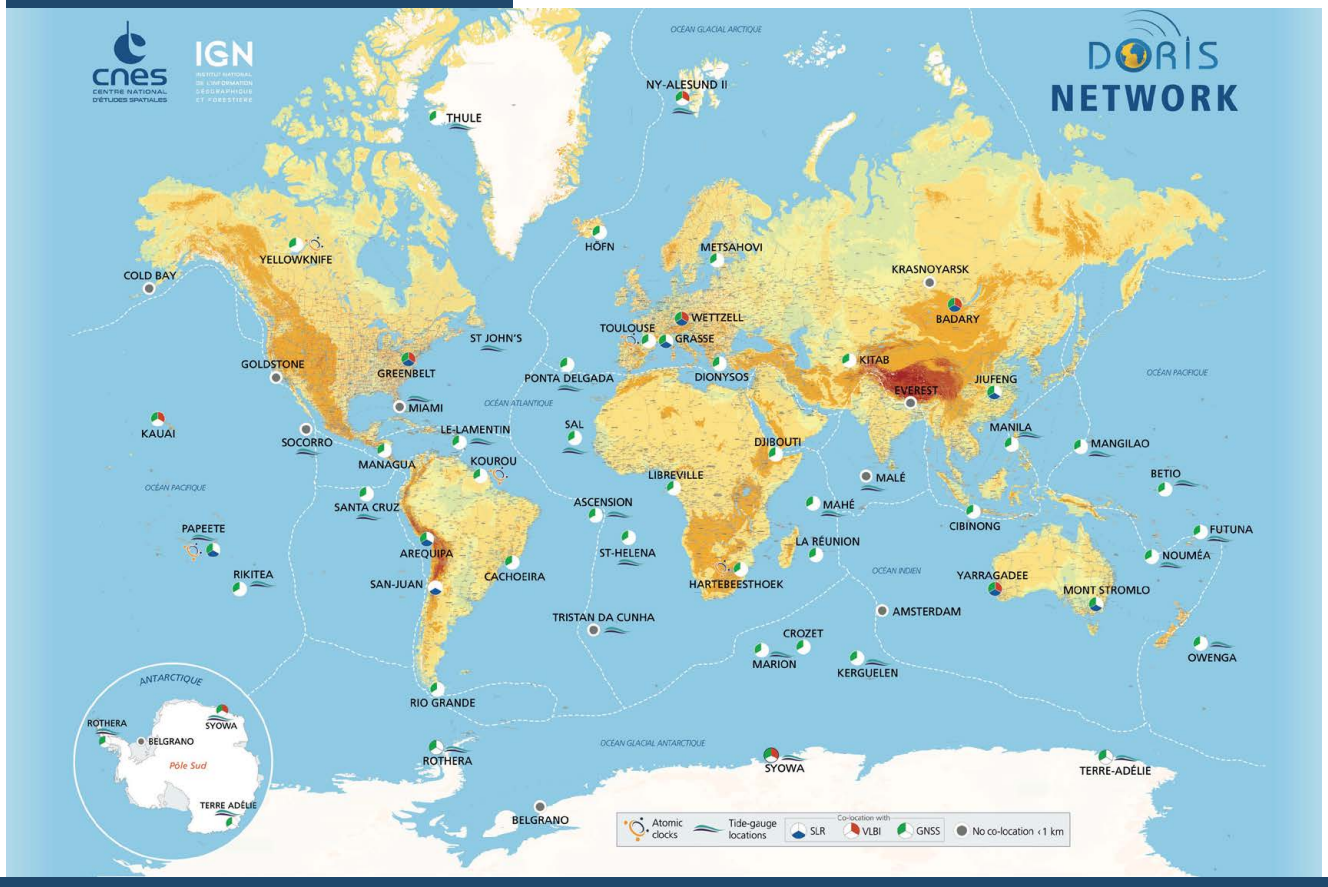
December 2020

2020 celebrates 30 years of the DORIS system

30 years of continuous operations at the heart of altimetry mission performance for oceanography and geodetic applications.

DORIS was first carried on the SPOT-2 satellite, which recorded the first DORIS measurements on 3 February 1990. Since then, the system has operated continuously on 18 satellites, including the space imaging satellites SPOT-2/3/4/5, Pleiades1A-1B, altimetry missions for ocean observations such as TOPEX-Poseidon, ENVISAT, Jason-1/2/3, HY-2A, Saral/AltiKa, Sentinel3-A/B, and also for hydrological monitoring and ice measurements with Envisat, Cryosat-2, Saral/AltiKa and Sentinel3-A/B. On the latest missions such as Sentinel-3A/3B, the DORIS system can achieve radial orbit accuracies of 8-10 mm RMS (Root mean square). The DORIS data are used for both real-time orbit determination onboard the satellite, and precise orbits developed with a latency of two days to a few weeks for use with altimeter data provided by these different missions.

MOST OF THE DORIS STATIONS ARE CO-LOCATED WITH OTHER SPACE GEODETIC TECHNIQUES AND TIDE-GAUGES



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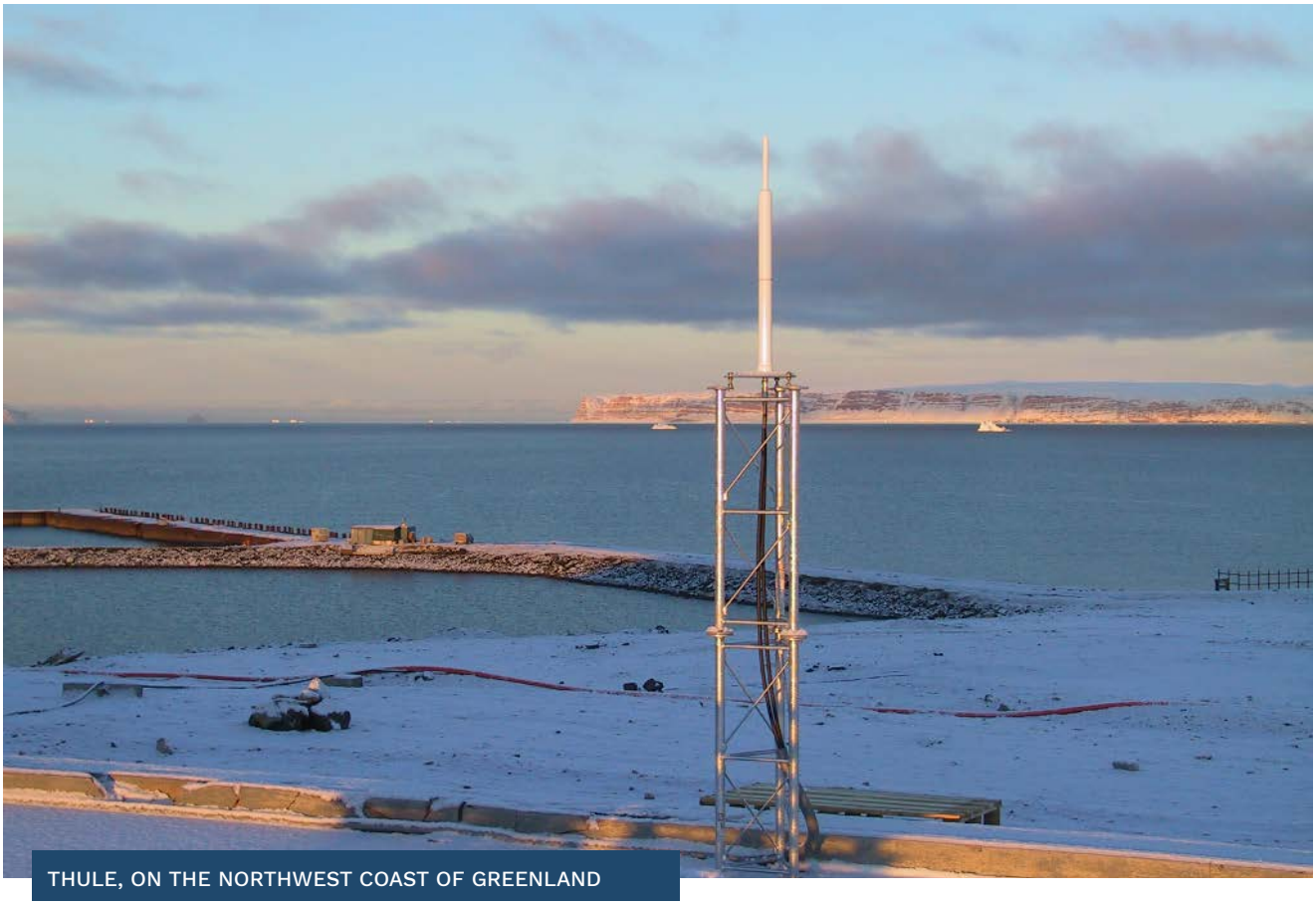


THULE, ON THE NORTHWEST COAST OF GREENLAND

The DORIS system (Doppler Orbitography and Radio positioning Integrated by Satellite) was designed and developed in the early 1980s by CNES (the French Space Agency), IGN (Institut Géographique National, the French Mapping and Survey Agency) and the GRGS (Groupe de Recherche de Géodésie Spatiale) to determine satellite positions with high accuracy for support altimetry missions dedicated to ocean monitoring.

This system is based on Doppler shift measurements of radio-frequency signals (400 MHz and 2 GHz) transmitted by a network of ground stations, used as reference points on the Earth's surface. There are about 60 DORIS stations uniformly distributed around the world, and these stations are hosted by 48 various international host agencies.

In addition to precise orbit determination, the DORIS system can also locate ground positions with the same intrinsic accuracy. The data are also used for determination of Earth Orientation Parameters (EOP), and can be used to determine the geocenter of the Earth. DORIS is one of the four space geodetic techniques that contribute to the International Terrestrial Reference Frame (ITRF).

Over the past 30 years, DORIS has enlarged the scope of its scientific applications:

1. DORIS has contributed to monitoring changes in mean sea level, both regionally and globally, using data from the TOPEX/Poseidon and Jason 1, 2, & 3 missions.

2. Through the precise orbits provided for the Envisat, CryoSat-2, Saral/AltiKa and Sentinel3-A/B missions, the DORIS system has participated in monitoring the change in height of the Antarctic ice sheet over 25 years.

3. DORIS contributes to the International Terrestrial Reference Frame (ITRF) realization and maintenance with increased performance each time,

4. The co-location of DORIS with tide gauges allows monitoring on the same site the vertical ground movements measured by the DORIS technique and the variations in sea level relative to the ground recorded by the tide gauge in order to deduce the absolute variations in sea level and compare them to the values obtained by satellite altimetry.

5. DORIS observes and analyses geophysical phenomena such as earthquakes or periodic inflation and deflation events of volcanoes, tectonic plate movements, local ground uplift or subsidence, etc.

The DORIS instruments (both on board the satellites and on the ground), as well as the DORIS

THE GREEK DORIS STATION OF DIONYSOS FACING THE AEGEAN SEA

DORIS STATION AT CROZET ISLANDS, FRENCH SOUTHERN AND ANTARCTIC LANDS

THE DORIS STATION OF FUTUNA IN THE PACIFIC OCEAN

monitoring and control system have undergone continual improvement over the years. The centralized CNES/IGN management has made it possible to control the development of the network and more easily achieve its objectives: the DORIS network is today the most homogeneous, stable and durable geodetic network in the world. Most of the DORIS stations are co-located with other space geodetic techniques (Satellite Laser Ranging, Very Long Baseline Interferometry and Global Navigation Satellite Systems) and tide-gauges, thus promoting technological inter-comparisons and scientific advances.

In 30 years, the position in orbit has been reduced from 13 cm to less than 1 cm. The DORIS-DIODE navigator on board the satellites calculates the satellite's trajectory in real time with a radial accuracy of 2 to 3 cm. The DORIS contribution to the ITRF has progressed in the same way with new possible applications.

Further progress is expected in the next decade with the 4th generation beacon and the 3rd generation antenna, whose deployments started in 2019. The 3rd generation antenna (the Starec “C” antennae) defines the 2 GHz phase center location with a precision of ± 2 mm. Studies are underway for the development of a future miniaturized on-board receiver coupling GNSS and DORIS signals.

In addition, following the IDS retreat organized in 2018, the IDS has drawn up a strategic plan for the years to come. About twenty recommendations were presented to stakeholders during the DORIS steering committee (CNES/IGN) at the end of 2019. These recommendations focus on three main themes:

→ expand the DORIS community;
→ evolve the technology;
→ improve infrastructure and treatment of data.

Some recommendations are already being implemented; others are in preparation.

The DORIS system really has a bright future ahead of it and will contribute to the success of many future missions.

IDS AND **DORIS** MILESTONES

early 1980s
Decision of the realisation of the DORIS system, jointly by the French space agency (CNES, Centre National d'Etude Spatial), the French national mapping agency (IGN, previously for Institut Géographique National), and the French research group in the field of space geodesy (GRGS, Groupe de Recherche de Géodésie Spatiale)

1986
Start of the deployment of the DORIS ground network. 32 stations with ALCATEL antenna (type "A") installed before Spot-2

1990
Spot-2 (Cnes) embarkes the first DORIS instrument, 1st generation with 1-channel receiver (6–month trial experiment, in use for more than 19 years). Goal of the mission: Earth observation. Objective for DORIS: decimeter level orbit accuracy. **First DORIS measurement on February 3rd.**

1990
DORIS Day meeting (December 1990, Paris)

1992-1999
Densification of the network, expanded to 54 stations. Massive Alcatel antennas are progressively replaced by the light and narrow Starec model (type "B").

1992
Topex/Poseidon (Nasa/ Cnes) Goal: measure sea surface height. Objective reached by DORIS: 5-cm orbits quality in the radial component

1993
Spot-3 (Cnes)
Goal: Earth observation

1994
First DORIS contribution to the International Terrestrial Reference Frame (ITRF); 2 groups: IGN and LEGOS/GRGS)

1995
2nd generation of ground beacon

1998
Spot-4 (Cnes) with the first version of Diode software for real-time on-board orbit determination.
Goal: Earth observation

1999
DORIS Pilot Experiment to assess the need and feasibility of an International DORIS Service

2000-2009
Major renovation effort of the network. Objective: 1 cm over 10 years in terms of stability of the DORIS antenna reference point. Deployment of the 3rd generation ground beacons with the ability to emit on shifted frequency

2001
Jason-1 (Cnes/Nasa) with the first DORIS receiver of the 2nd generation with 2 channels. Goal: measure sea surface height

2002
Envisat (Esa). Goal: observe Earth's atmosphere and surface

2002
Spot-5 (Cnes).
Goal: Earth observation

2003
Official start of IDS as an IAG Service, on July 1st. Objective: to provide a service to support geodetic and geophysical research activities through DORIS data and derived products

2003
First IDS Governing Board meeting (November 2003, Arles, France)

2004
3rd Master Beacon at Hartebeesthoek (South Africa)

2005
DORIS Integrity Team set up to monitor permanently the DORIS signal transmitted in space, control its characteristics, investigate non nominal situations, take corrective actions if needed.

2005
Contribution to ITRF2005 (4 groups: IGN/JPL, LEGOS/ CLS, INASAN, NASA/GSFC)

2007
STPSat-1: Citris (Scintillation and Tomography receiver in space) developped by the NRL (Naval Research Laboratory) uses the transmissions of the DORIS beacons.

2008
Jason-2 (Cnes/Nasa/ Eumetsat/Noaa) with the first DORIS receiver of the 3rd generation (DGXX) with 7 channels. Goal: measure sea surface height

2008
First Analysis Working Group meeting

2009
Start of the Combination Centre

2009
Contribution to ITRF2008 (7 groups: IGN/JPL, CNES/ CLS, INASAN, NASA/GSFC, ESOC, GOP, Geosciences Australia)

2009
4th Master Beacon at Papeete

2010-today
Modernization of the network. The DORIS network achieves 90% coverage (for satellites orbiting at 800 km altitude) and provides a reliable service with a network availability maintained over 85% of operating stations since 2012 thanks to the joint effort of CNES, IGN and all agencies hosting the stations.

2010
3 cm orbit accuracy achieved in real time on board Jason-2

2010
Cryosat-2 (ESA); DORIS enters the Spacecraft Attitude & Orbit Control System. Goal: polar observation

2011
HY-2A (China Academy of Space Technology)
Goal: observe the ocean dynamics

2013
Saral/Altika (Isro/CNES)
Goal: observe the oceans

2014
Deployment of Starec ground antennae with consolidated manufacturing process (type "C")

2014-2015
Contribution to ITRF2014 (6 groups: IGN/JPL, CNES/ CLS, INASAN, NASA/GSFC, ESOC, GOP)

2016
Jason-3 (Cnes/Nasa/ Eumetsat/Noaa) with the 1st DGXX-S instrument. Goal: measure sea surface height

2016
Sentinel-3A (ESA - Copernicus program) Goal: deliver routine operational services to policy-makers and marine and land service users

2018
Sentinel-3B (ESA - Copernicus program) Goal: deliver routine operational services to policy-makers and marine and land service users

2018
First IDS retreat

2019
Start of the 4th generation ground beacon deployment

2020
30 years of DORIS measurements

2020
HY-2C (China Academy of Space Technology) Goal: observe the ocean dynamics

2020
Sentinel-6A/ Michael Freilich (ESA - Copernicus program) Goal: measure sea surface height

2020
Contribution to ITRF2020 in progress

satellites
network

2020, **TWO NEW MISSIONS** HAVE JOINED THE DORIS CONSTELLATION

HY-2-C WAS LAUNCHED ON 21 SEPTEMBER 2020 FROM THE CHINESE LAUNCH BASE OF TAIYUAN.

HY-2 (HaiYang means "ocean") belongs to a series of Chinese oceanographic satellites started in 2011 with HY-2A, HY-2B (2018), HY-2C (September 21, 2020) and HY-2D planned in 2021. All these satellites except model "B" carry a DORIS receiver onboard. The objective of HY-2 is to monitor ocean dynamics using microwave sensors to detect wind fields at the ocean surface, sea surface height and surface temperature. CNES provides the precise orbit and retrieves the altimetry measurements which then contribute to the multi-mission maps of AVISO+ and the Copernicus Marine Service. After the commissioning phase, CNES will also distribute, the raw DORIS data (DORIS RINEX format) and the precise orbits (SP3 format) to the IDS data centers.

© CNES Sentinel-6A

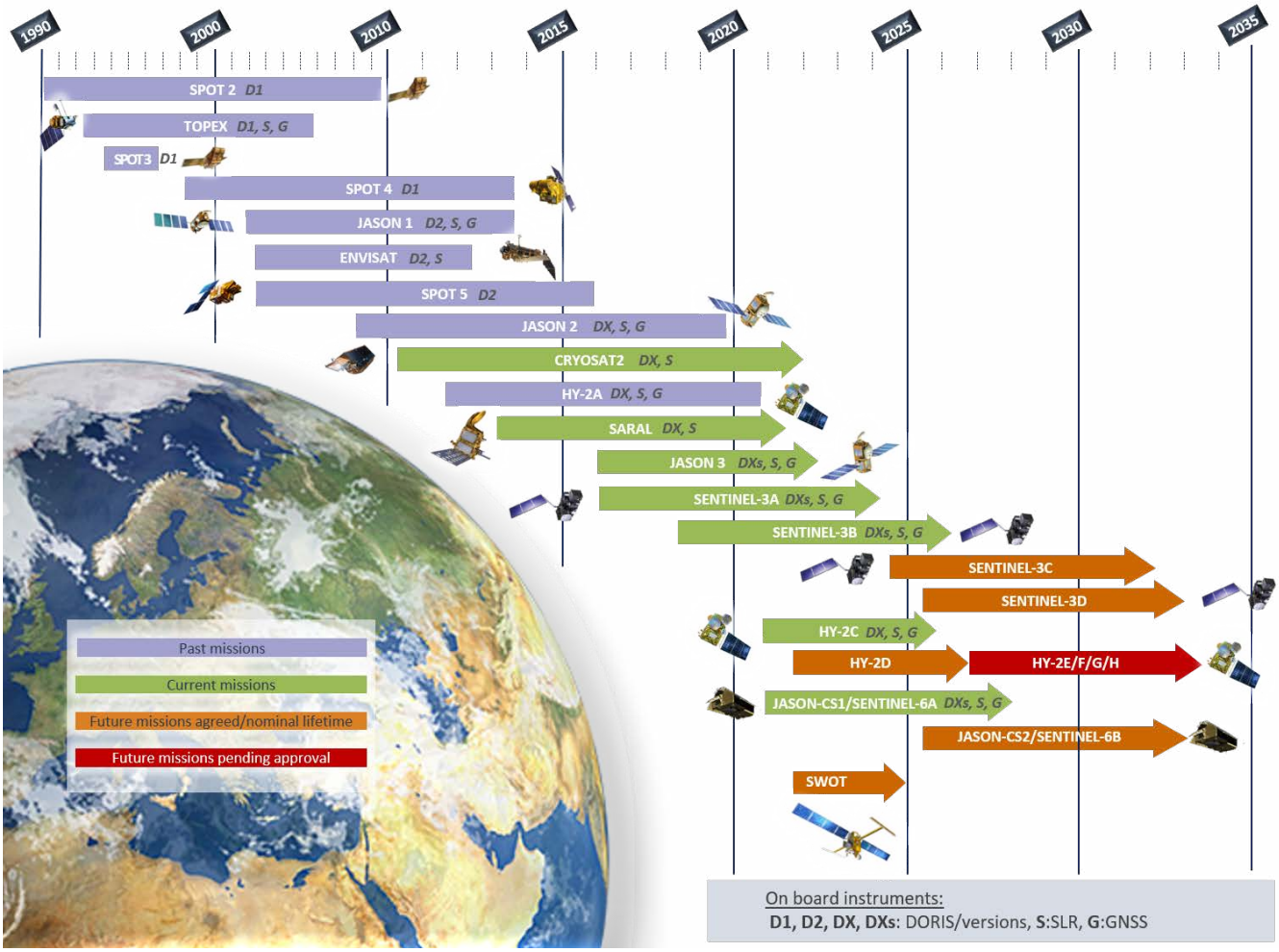
THE SENTINEL-6/JASON-CS IS A RESULT OF INTERNATIONAL COOPERATION BETWEEN ESA, EUMETSAT, THE EUROPEAN UNION, NOAA, CNES AND NASA.

SENTINEL-6A MICHAEL FREILICH (COPERNICUS- ESA/ EUMETSAT/CNES/NOAA/ NASA), THE FIRST OF A TWO-SATELLITE SENTINEL-6 SERIES, WAS LAUNCHED BY A FALCON-9 ROCKET FROM VANDENBERG AIR FORCE BASE, CALIFORNIA, ON 21 NOVEMBER 2020.

Also known as Jason Continuity of Service (Jason-CS), the Sentinel-6 satellites will replace the Jason-3 satellite, thus ensuring the continuity of sea level measurements and operational oceanographic services on the Topex and Jason reference orbit beyond 2030.

The Sentinel-6 mission is part of the European Copernicus program and the MyOcean operational oceanography project supported by the European Commission. This mission is a cooperation between ESA, the European Commission and EUMETSAT. The United States is also a key partner in the mission, with NASA and NOAA playing a role in the launch, US-side operations and the provision of a radiometer, GNSS-RO receiver and Laser Retroreflector.
CNES, another key partner of the mission, is in charge of providing the precise orbit of the satellite (via its DORIS instrument and ground station network, and the GNSS-POD receiver), as well as the sea surface height and wave height products that will be used by the Copernicus Marine Service. CNES is also responsible for the expertise and evaluation of the performance of the instruments and the mission. Sentinel-6 uses a new satellite bus based on CryoSat, with a capability to minimize the accumulation of orbital debris (the de-orbiting of the satellite within 25 years is now required by law). The Poseidon-4 altimeter will operate in the so-called 'interleaved mode' that provides simultaneously pulse-limited waveforms (computed on-board and in line with previous reference missions) and Full Rate RAW waveforms that allow SAR processing on-ground.

2020, **TWO NEW MISSIONS** HAVE JOINED THE DORIS CONSTELLATION



Today there are seven DORIS satellites that contribute to IDS: CryoSat-2, SARAL/Altika, Jason-3, Sentinel-3A, Sentinel-3B, HY-2C, Sentinel-6A/Mike Freilich.

In the future, many news missions are scheduled with the following launches to come:

- **HY-2D** (CNSA/NSOAS) with DORIS DGXX-S + LRA + GPS is planned for May 2021, and HY2 E-F-G-H are waiting for approval.
- **SWOT** (Surface Water Ocean Topography) is planned for the end of 2021 (DGXX-S + GPS + LRA). Further information on Swot website or on Aviso website.
- **Sentinel-3C** (Copernicus- ESA/ EUMETSAT/CNES) is planned for 2024 (DORIS DGXX-S with mini USO + LRA + GPS) (nominal lifetime of 7 years). Then Sentinel-3D is planned for 2025. Further information is available on the ESA website
- **Sentinel-6B/Jason-CS2** is planned in 2025

More information on the International DORIS Service website (https://ids-doris.org)

IDS LIFE

HY-2A satellite decommissioned

With the end of the mission, the last DORIS data were delivered in September 2020. HY-2A has been part of the DORIS constellation since its launch (2011-08-15). The satellite carried a DGXX receiver, and provided nine years of data from its orbit at an altitude of 963 km and at an inclination of 99.4 deg.

DORIS network projects continue notwithstanding Covid-19

Notwithstanding the difficulties in maintaining the stations during the global Covid-19 pandemic, the ground network showed good operating results thanks to the 4th generation beacon deployment started last year to firstly replace old equipment with signs of weakness. Most of the development projects are at a standstill but, fortunately, some advances were made in Europe this summer: new DORIS site in Höfn, Iceland in place of Reykjavik (commissioned September 24th); reconnaissance in Crete, Greece for an additional station. We thank all the host agencies for their ongoing efforts to keep the DORIS station operating!

Access to DORIS data and products

The NASA CDDIS Data Center stopped providing anonymous ftp services as of 1 November 2020. All users are now requested to use https, and an NASA Earthdata login as a method of access to the CDDIS archive. Instructions and example links are available here: **https://cddis.nasa.gov/Data_and_Derived_Products/CDDIS_Archive_Access.html**
Unencrypted anonymous ftp services are still available at IGN Data Center for the time being: **ftp://doris.ign.fr/**

Coming soon: Near-real-time DORIS data and DIODE orbits

The near-real-time (NRT) distribution of DORIS/RINEX data and DIODE orbits from Jason-3 satellite will be available in the near future. These NRT products will be delivered initially to the IGN Data Center; a test and evaluation period will follow before the availability of NRT products is extended to other missions. Interested persons should contact Pascale Ferrage (CNES) or Denise Dettmering (DGFI/TUM) for more information.

IGN DORIS Analysis Center

Arnaud Pollet and Samuel Nahmani will lead the IGN/DORIS Analysis Center activities following the retirement of Pascal Willis.

DORIS Meetings planned for 2021:

- **February.** (Virtual) Meeting of Analysis Centers and Associate Analysis Centers. Subject: update on ITRF2020.
- **Late March to early April 2021.** (Virtual) Analysis Working Group meeting.
- **Late May, early June 2021.** (Virtual) IDS School on DORIS data and products (postponed from May 2020).
- **October 18-20,** Venice, Italy. IDS Workshop associated with Ocean Surface Topography Science Team (OSTST) meeting: **https://ostst-altimetry-2021.com/**

Some noteworthy DORIS-related publications in 2020

1. Bertiger, W., Bar-Sever, Y., Dorsey, A., et al. (2020). "GipsyX/RTGx, a new tool set for space geodetic operations and research", *Adv. Space Res.*, 66(3), 469-489, doi:10.1016/j.asr.2020.04.015.

2. Zhou, C.C., Zhong, S.M., and Peng, B.B., et al. (2020). "Real-time orbit determination of Low Earth orbit satellite based on RINEX/DORIS 3.0 phase data and spaceborne GPS data", *Adv. Space Res., 66(7),* 1700-1712, doi:10.1016/j.asr.2020.06.027.

3. Hernandez-Pajeres, M., Lyu, H.X., Garcia-Fernandez, M. and R. Orus-Perez (2020). "A new way of improving global ionospheric maps by ionospheric tomography: consistent combination of multi-GNSS and multi-space geodetic dual-frequency measurements gathered from vessel-, LEO- and ground-based receivers", *J. Geodesy, 94(8),* 73, doi:10.1007/s00190-020-01397-1

4. Stepanek, P., Bingbing, D., Filler, V. and U. Hugentobler, (2020). "Inclusion of GPS clock estimates for satellites Sentinel-3A/3B in DORIS geodetic solutions", *J. Geodesy, 94:116,* doi:10.1007/s00190-020-01428-x.

5. Beutler, G., Villager, A., Dach, R., Verdun, A., and A. Jäggi (2020). "Long polar motion series: Facts and insights", *Adv. Space Res., 66(11),* 2487-2515, doi: 10.1016/j.asr.2020.08.033.

A full list of articles related to DORIS published since 1985 is available on the IDS website at https://ids-doris.org/ids/reports-mails/doris-bibliography/peer-reviewed-journals.html

PASCAL WILLIS RETIRES

After a long and active career promoting analysis and use of DORIS data in geodesy, Dr. Pascal Willis retired from the Institut Géographique National (IGN) in April 2020. Pascal and his wife, Michèle have retired to their new domicile, near La Rochelle, France. Pascal remains active as Editor-in-Chief of the journal, Advances in Space Research. In this capacity, people in the DORIS community can continue to take advantage of his advice and suggestions regarding the research they would like to publish.

Pascal received degrees as engineer from the École Polytechnique (1983) and the École Nationale des Sciences Géographiques (1986). In 1989, he received his Ph.D from the Paris Observatory with a thesis focused on "The Static and Kinematic Applications of GPS for Geodesy". He received his "Habilitation à Diriger des Recherches (HDR)" in 2003 from the Université Pierre et Marie Curie (Paris VI)[1]. His initial professional work was with GPS, but he became more focused on the analysis of DORIS data starting with the TOPEX/Poseidon mission. His work concentrated on how to apply methodological improvements to the analysis of DORIS data and the development of better DORIS-derived geophysical products. He worked to improve precise orbit determination with DORIS data throughout his career. Pascal directed an analysis center for DORIS at the IGN that regularly submitted geophysical products and contributed to ITRF realizations. He worked to interpret the time series of coordinates for science and geophysics. He also worked to promote new products from DORIS data, collaborating with researchers to promote DORIS as a tool for to use troposphere delays for climate studies. As part of his research activities he co-directed or directed the Ph.D work of Jean-François Crétaux (Ph.D, 1993), Laurent Morel (Ph.D, 2001), Stéphane Durand (Ph.D, 2003) and Marie-Line Gobinddass (Ph.D, 2010).

A career devoted to geodesy

Pascal Willis forged a tight collaboration with the Jet Propulsion Laboratory (JPL) from the early days of the TOPEX/Poseidon mission. He used the JPL GIPSY/OASIS II software to process DORIS data, working closely with JPL to maintain and continually improve this capability. He worked at JPL as a visiting scientist from 2001-2006, and in recent years collaborated with Dr. William Bertiger and other scientists at JPL to validate the processing of DORIS/RINEX data in the new JPL GipsyX software.

Pascal Willis was one of the co-founders of the International DORIS Service (IDS) in 2003, and served on the Governing Board as Analysis Centers' Representative. In this capacity, he was elected and served as Chairperson from 2009 to 2016. Throughout his career, Pascal worked tirelessly to promote and improve the contribution of DORIS as one of the four techniques of space geodesy.

Pascal's non-DORIS professional contributions also included being an early advocate of the scientific contributions of other GNSS constellations (GLONASS & Galileo). He led the IGEX-98 campaign for GLONASS as part of his responsibilities being a member, at the time, of the Governing Board of the (then) International GPS Service (IGS). As a guest editor for GLONASS and Galileo special issues in the Journal of Geodesy (2000-2001) and Advances in Space Research (2009-2010) he helped to elevate the contributions of these navigation systems in the scientific community. Since 1995 Pascal has served continuously as an Associate Editor or Guest Editor for different scientific journals and International Association Geodesy (IAG) proceedings volumes. Many readers will be familiar with this pointed and detailed reviews of their papers, always aimed to improving the quality of science communication.

We will miss Pascal as a regular participant in the IDS. We congratulate Pascal on his retirement and wish both him and his wife Michèle enjoyable and exciting explorations in the coming years.

1. In some countries (such as France) a "Habilitation" is required to conduct university teaching, direct research or become a university professor.

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