DORIS and the International DORIS Service: Current Status and Planned Evolution

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SUMMARY

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system is one of the four techniques that contributes to the International Terrestrial Reference Frame (ITRF). The technique was developed to support orbit determination on LEO satellites, most notably the suite of ocean radar altimeter satellites. The DORIS system consists of a global well-distributed set of ground beacons emitting on two frequencies (2 GHz and 401 MHz) and an evolving suite of satellites that carry different generations of satellite receivers. In this paper, we summarize the evolution and status of the ground network, the satellite constellation; we provide an overview of the DORIS system performance and how it has changed with time; we summarize the products currently available, and we provide a perspective on possible future evolutions of the DORIS system.

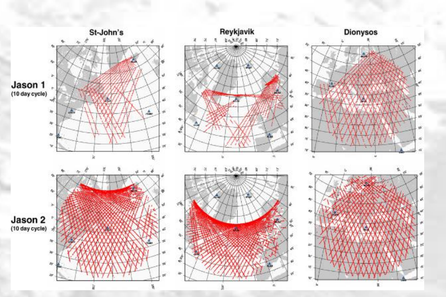
Status of the DORIS Constellation

Current DORIS Satellites On-Orbit

Satellite	Sponsors	Alt. (km)	Inc. (°)	Dates	SLR,,GNSS
Sentinel-3B	ESA/Copernicus	814	98.65	4/25/18 – 2025+	S, G
Sentinel-3A	ESA/Copernicus	814	98.65	02/2016 – 2023+	S, G
Jason-3	NASA/CNES/NOAA/EUMETSAT	1336	66.0	1/17/16–2021+	S, G
SARAL	CNES/ISRO	800	98.5	03/2013 – 2018+	S
HY-2A	CNSA/NSOAS	960	99.0	11/2011 – 2018+	S, (G)
Cryosat2	ESA	717	92.0	06/2010 – 2019	S
Jason-2	NASA/CNES/NOAA/EUMETSAT	1336	66.0	07/2008 – 2019 +	S, G

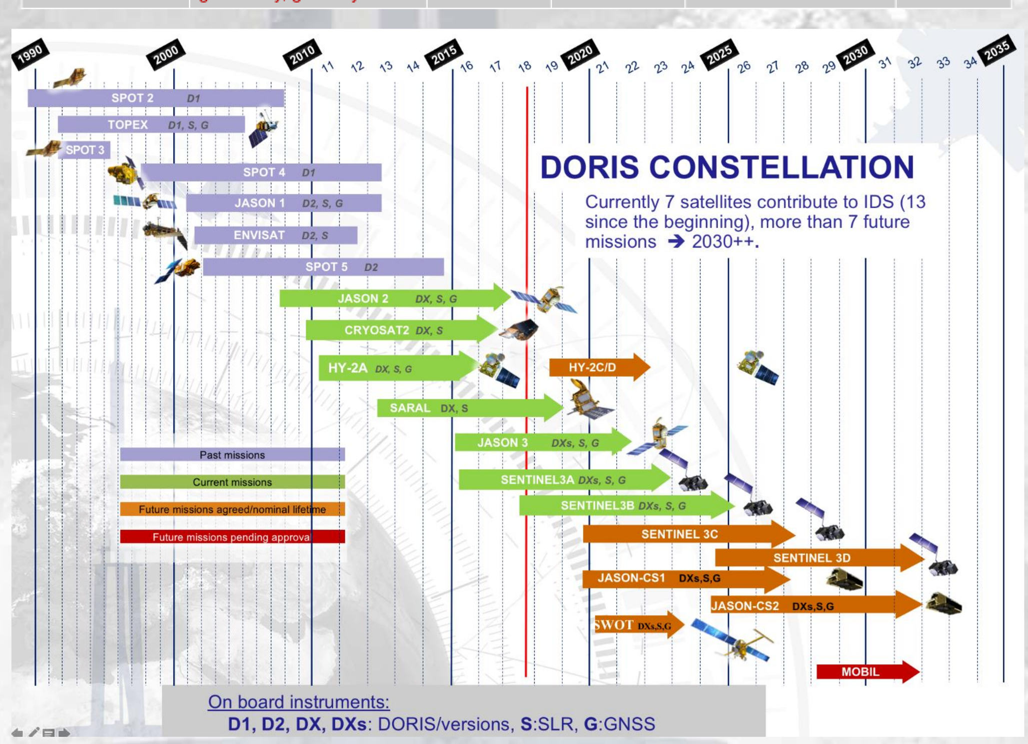
Jason-2, Jason-3 | Cryosat-2 | HY-2A | SARAL | Sentinel-3A,3B

All current and future DORIS satellites carry a DGXX-class receiver, which can track up-to seven DORIS stations at one time, greatly increasing the available data, as shown in the ground tracks for several DORIS stations that tracked Jason-1 (**with a 2-channel receiver**) and Jason-2 (*Auriol and Tourain, Adv. Space Res., 2010, doi: 10.1016/j.asr.2010.05.015*).



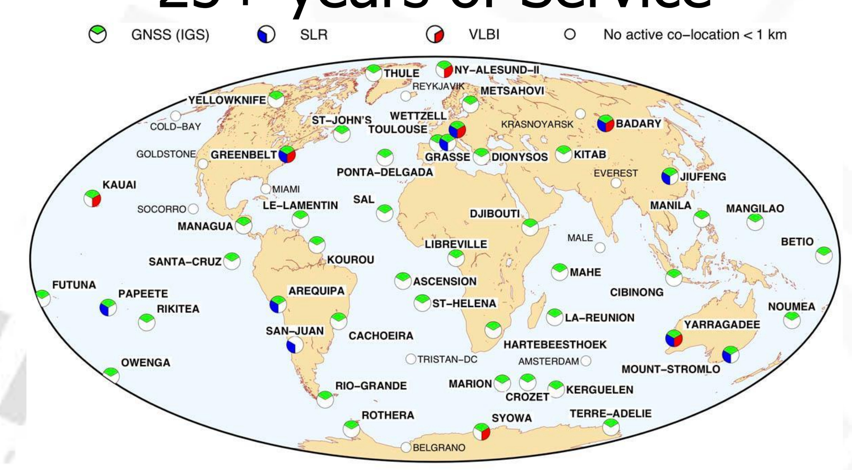
Future DORIS Satellites (≥ 2019)

Satellite	Sponsors	Alt. (km)	Inc. (°)	Dates	SLR,GNSS
Sentinel-3C, 3D	ESA/Copernicus	814	98.65	2020, 2025 + 5 yrs	S, G
HY-2C, 2D	CNSA/NSOAS	960	66	2019, 2020 + 3 yrs	S, (G)
Jason-CS1+ CSB	ESA/Copernicus/EUMETSAT/ NOAA/NASA/CNES	1336	66.0	2020, 2025 + 7 yrs	S, G
SWOT	NASA/CNES	970	78	After 2021 + 3 yrs	S, G
MOBIL	Proposal to ESA, gravimetry, geodesy	LEO-HEO	TBD	After 2028	S,G, + VLBI

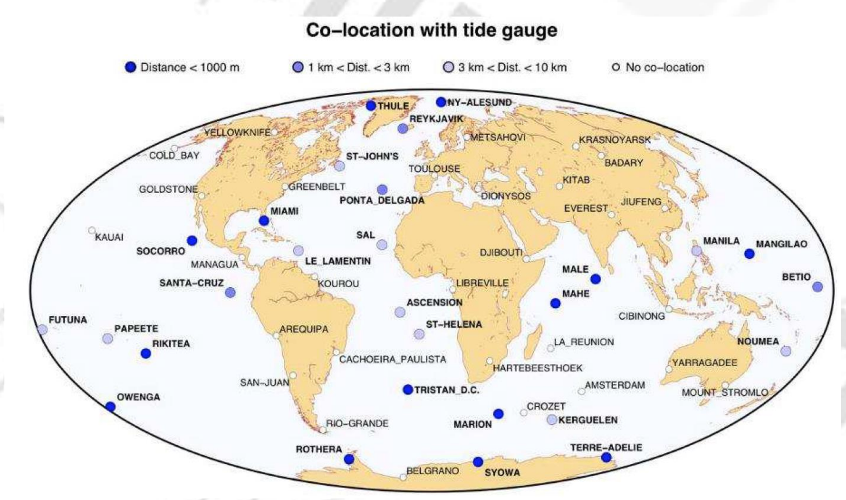


The DORIS network: Current Status

DORIS Tracking Network: 25+ years of Service

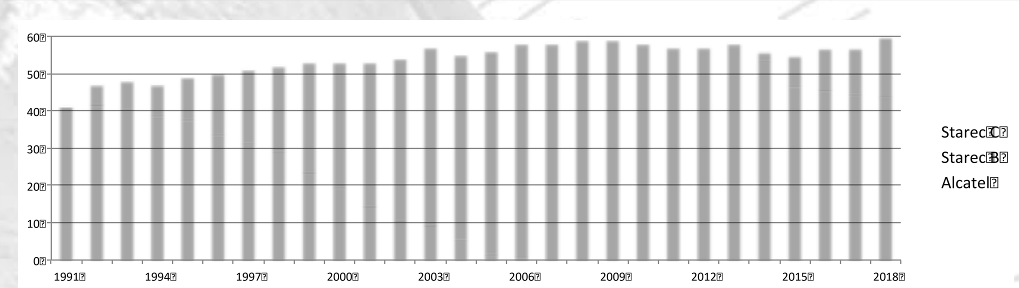


48 Colocations out of 59 DORIS Sites



DORIS Network Evolution

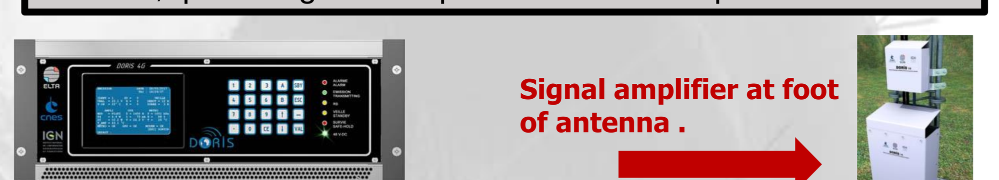
- Since the inception of the DORIS system, new antennae have been developed to improve DORIS measurement accuracy. From 1992 to 2006, the original Alcatel antenna were replaced with Starec "B" antenna (*Fagard, 2006*).
- Since 2014, a new Starec "C" antenna has been developed whose key feature is that the uncertainty of the vertical location of the 2GHz phase center is reduced from ~5 mm to 1 mm (*Saunier & Tourain, 2016*).



Today, about 25% of the network has Starec "C" antennae.

Development of 4th Generation Beacon

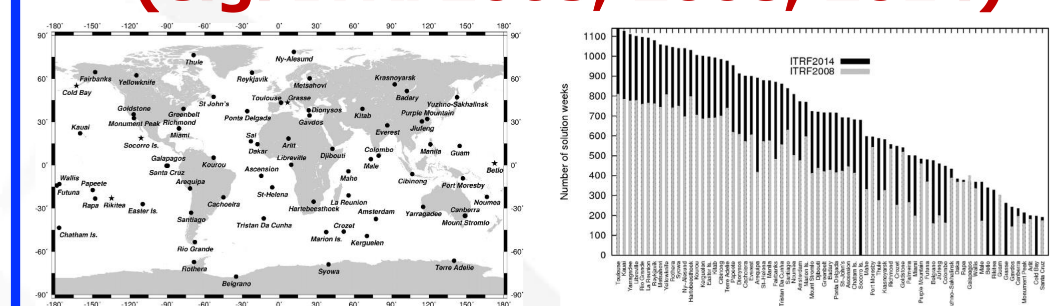
- The DORIS 4th generation beacon has been developed and will be deployed starting in 2019. The beacon has been manufactured with up-to-date electronics allowing reliable operation through 2033.
- A signal amplifier at the foot of the antenna will allow a larger distance (50 m instead of only 15 m) between beacon and antenna, providing better options for antenna placement..



4th generation beacon

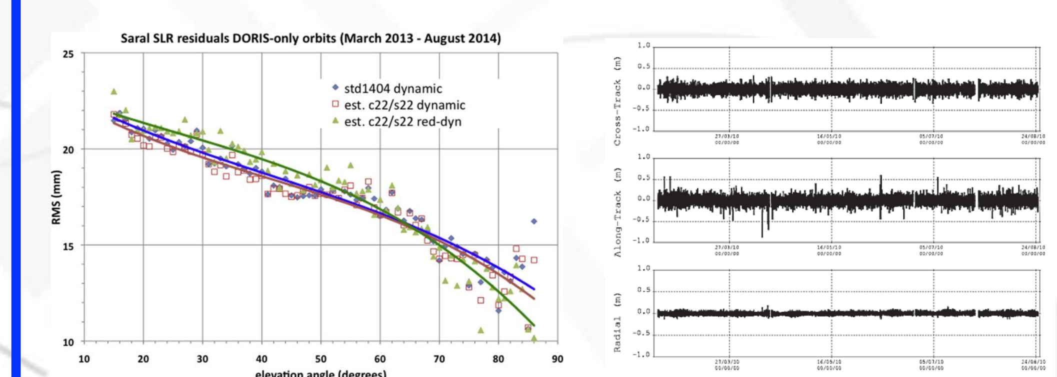
Key Scientific and Mission Contributions

Contribution to the ITRF (e.g. ITRF2005, 2008, 2014)



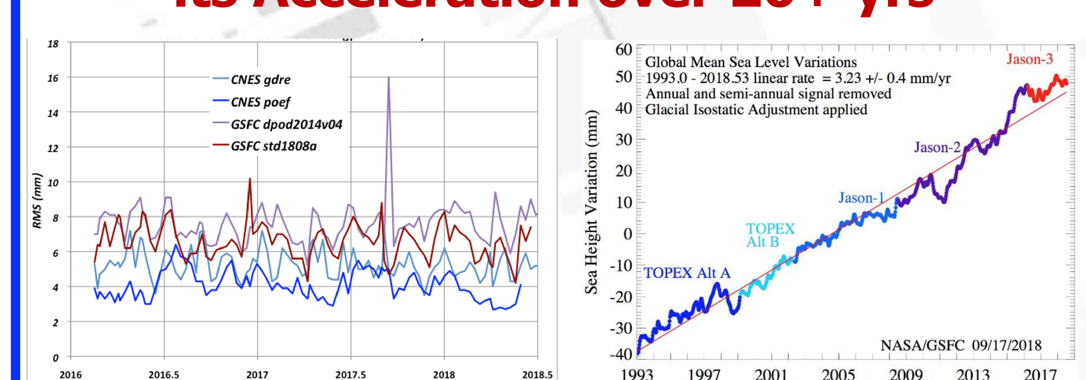
(**Left**) Geographical distribution of DORIS stations included in the IDS Contribution to ITRF2014, and (**Right**) No of weeks of site positions in ITRF2008 & ITRF2014. (*Moreaux et al., Adv. Space Res., 2016, doi:10.1016/j.asr.2015.12.021*).

Precise orbits for altimeter missions



(**Left**) Independent SLR fits on SARAL. The RMS radial orbit error for the SARAL DORIS-only orbits is about 13-14 mm. (*Zelensky et al., Adv Space Res., 2016, doi:10.1016/j.asr.2015.12.011*).
(**Right**): The Jason-2 DORIS real-time (DIODE) orbit differences with an a posteriori precise orbit (*over 150-days*) is 2.5 cm radial RMS, and ~9 cm in total position.
(*Jayles et al., Adv Space Res., 2016, doi:10.1016/j.asr.2015.08.033*).

DORIS+SLR data enable computation of the Global Mean Sea Level Rate & its Acceleration over 26+ yrs

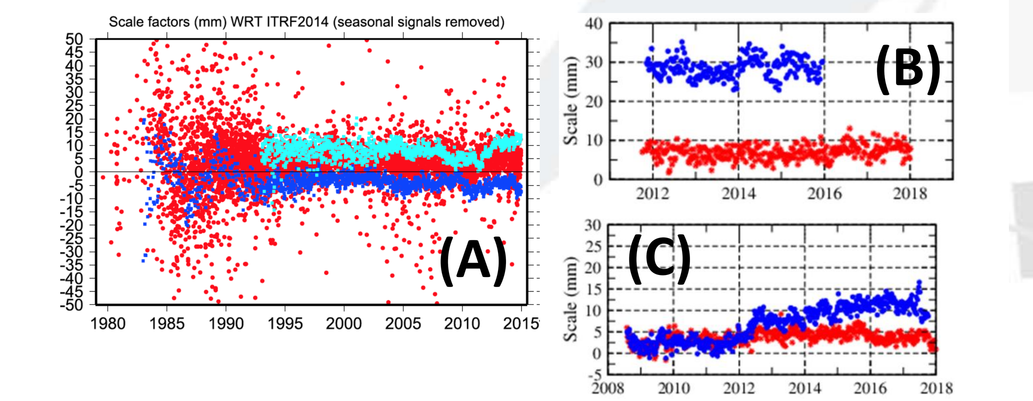


https://podaac.jpl.nasa.gov/Integrated_Multi-Mission_Ocean_AltimeterData

(Left): The inter-comparison of SLR/DORIS-derived orbits (NASA GSFC), and independent GPS-derived orbits (JPL & CNES/POE-F) allow us to validate the radial orbit accuracy for missions such as Jason-2/Jason-3. This helps to guarantee the stability of the derived orbits for computation of sea surface height, and especially for the determination of Mean Sea Level**. For Jason-2 and Jason-3 we are confidant from this analysis that the RMS radial orbit accuracy is 8-10 mm.**
(Right): Global Mean Sea Level Variation computed from multi-mission altimeter data as part of NASA's MEaSUREs program through the OSTST (Ocean Surface Topography Science Team), using SLR & DORIS data from 1993 to 2018 based on ITRF2014. Continuous, on-orbit, geodetic quality GPS data for the reference missions (TP, J1, J2, J3) were unavailable prior to the launch of Jason-1.

Preparations for the ITRF2020 Reprocessing

Resolution of 2012 Scale Anomaly



The DORIS scale w.r.t ITRF2014 after 2012 was characterized by an anomalous increase after 2012 (see Figure (A), from *Altamimi et al., 2016*, where the DORIS scale is light blue; SLR scale is dark blue, and VLBI scale is in red)). This anomaly was traced to modelling for the HY-2A satellite which started to contribute data after November 2011. The GRG DORIS analysis center showed that correcting the HY-2A CoM (Figure B), and ignoring the data preprocessing flags in the DORIS V2.2. format (Figure C) made the DORIS scale more homogeneous for the entire period from 2008 to 2018.

Mitigate the SAA effect on Jason-2 & Jason-3 DORIS data

Station	Solution 1 (in cm) North	Solution 1 (in cm) East	Solution 1 (in cm) Up	Solution 2 (in cm) North	Solution 2 (in cm) East	Solution 2 (in cm) Up
Cachoeira	0.9	-0.2	2.2	0.3	0.2	0.7
Arequipa	-0.5	1.1	2.3	0.0	0.3	0.4
Kourou	-0.4	0.1	0.2	-0.2	0.06	0.04
Ascension	0.1	-0.5	2.0	0.1	-0.1	0.5
Saint Helene	1.4	-0.4	1.6	0.5	-0.2	0.4
Le Lamentin	-0.1	-0.3	-1.1	0.0	-0.1	-0.2
Libreville	-1.0	-0.3	1.1	-0.02	-0.06	0.2
Yarragadee	*0.1*	*-0.1*	*0.06*	*0.1*	*-0.1*	*0.07*

Recent publications (**Belli etal., Adv. Space Res., 2016, doi:10.1016/j.asr.2015.11.025; Willis et al., 2016, doi:10.1016/j.asr.2016.09.015**) have shown that the Jason-2 DORIS UltraStable Oscillator (USO) is perturbed by its passage through the South Atlantic Anomaly (SAA), a region near South America where the Earth's magnetic field is weaker and radiation exposure is more intense. The pre-irradiation of the USO's did not completely mitigate the SAA effect. Thus, the derived positions of the stations in that area are perturbed. The ITRF2014 DORIS solution is affected through the Jason-2 data.

Two strategies can be applied to mitigate this phenomenon: (I) First adjust a frequency polynomial per pass for a DORIS station in the SAA region; Second, Locally adjust the SAA stations on the Jason-2 and Jason-3 normal equations to disallow their contribution to the combination; (II) Apply a better USO-model for Jason-2 derived from Jason-2 T2L2 data. Approach (II) is under investigation at NASA GSFC. Approach (I) is tested in the Table above by the GRG DORIS analysis Center and is shown to reduce the perturbations in position to the SAA stations.

New candidate static & Time-variable gravity model

- Using 14 years of GRACE data (2002.5-2016.5), 3 years of GOCE data, and 33 years of SLR data (1985-2018), a new gravity model has been developed by Jean-Michel Lemoine et al. (**IDS Workshop 2018**): EIGEN-GRGS.RL04.MEAN-FIELD.
- The model consists of static terms to L=300, time-variable components to 90x90, modeled as a bias, semiannual and annual term per year.
- The degree two terms for the pre-GRACE period using SLR data.

More information is available at:
https://ids.doris.org /images/documents/report/ids_workshop_2018/IDS18_s3_LemoineJM_NewtimeVariableGravityFieldModelForPOD.pdf

Current Activities & New Results

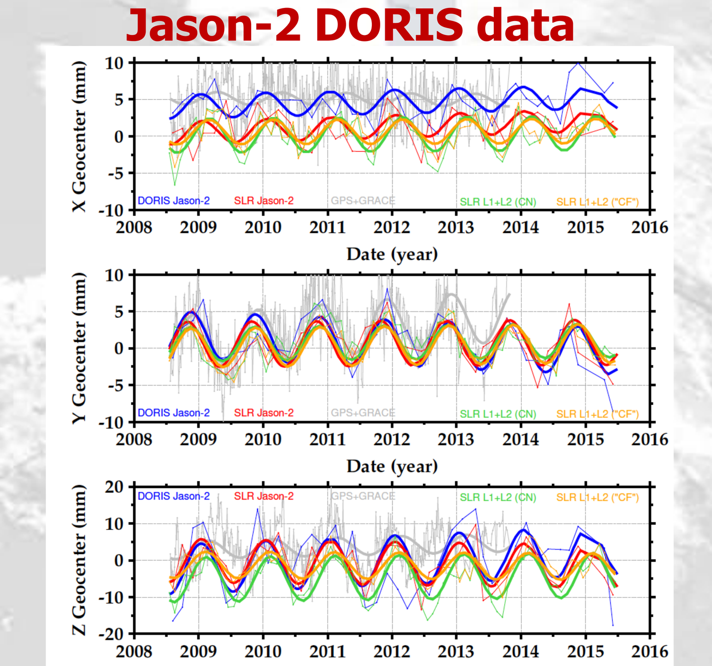
Working Group on NRT Data

The general objective of this working group is a thorough assessment on applications, benefits, requirements and prospects of DORIS data with improved data latency. Currently, data is available as daily RINEX files with a latency of about one day. Thus, DORIS real-time and near real-time (NRT) applications of any kind are currently only possible on board of the satellite..

DORIS NRT data sets would be useful for different applications, one of them is the modelling of the Earth's ionosphere. Using DORIS in combination with GNSS (and additional techniques) helps to improve the accuracy and reliability of ionospheric maps, especially in ocean regions with poor GNSS coverage. This has been proved for post-processing applications but will probably also hold for NRT.

For more information contact the NRT Working Group Chair: Denise.Dettmering@tum.de

Geocenter Derived from Jason-2 DORIS data



(**Above**) Figure 3 from **Couhert et al. (2018, "Systematic error mitigation in DORIS-derived geocenter motion", JGR-Solid-Earth, doi:10.1029/2018JB015453).**
The paper explains how the DORIS data can be processed to produce a geocenter time series comparable to that derived from LAGEOS1+2. This points to the possibility to derive a new IDS product for users using the non-polar orbiting satellites (e.g. Jason-2, Jason-3, HY-2C, SWOT).
The IDS GB is considering to establish a Pilot Project and Working Group to further explore the development of this potential new product.

For more information about DORIS & the International DORIS Service,

(1) Go to the URL https://ids-doris.org
(2) Contact the IDS Central Bureau:
Email: ids.central.bureau@ids-doris.org
(3) Contact the IDS Analysis Coordinators:
Email: ids.analysis.coordination@ids-doris.org