The International DORIS Service after 20 years: Achievements and a look to the Future

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3) Geodetic Observatory Pecny, Ondrejov, CZECH REPUBLIC.
4) ESA/European Space Operations Centre, Darmstadt, GERMANY.
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6) Institut National de l'Information Géographique et Forestière, Saint Mandé, FRANCE.
7) Faculty of Aerospace Engineering, TU Delft, Delft, The NETHERLANDS.
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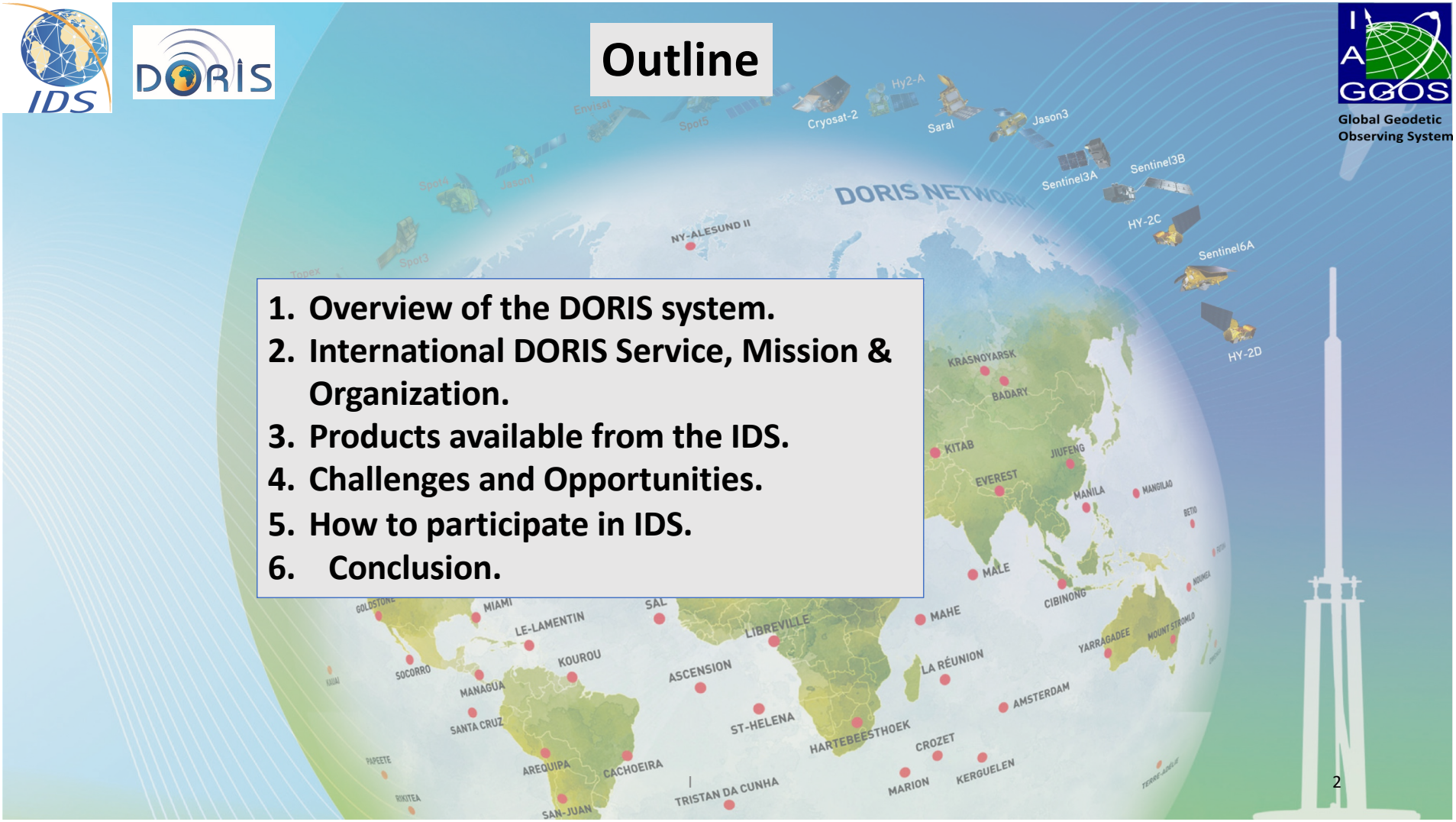
Session: G06 – Monitoring and Understanding the Dynamic Earth with Geodetic Observations, July 18, 2023

Global Geodetic Observing System

IUGG BERLIN 2023
THE 28TH GENERAL ASSEMBLY

Outline

1. Overview of the DORIS system.
2. International DORIS Service, Mission & Organization.
3. Products available from the IDS.
4. Challenges and Opportunities.
5. How to participate in IDS.
6. Conclusion.



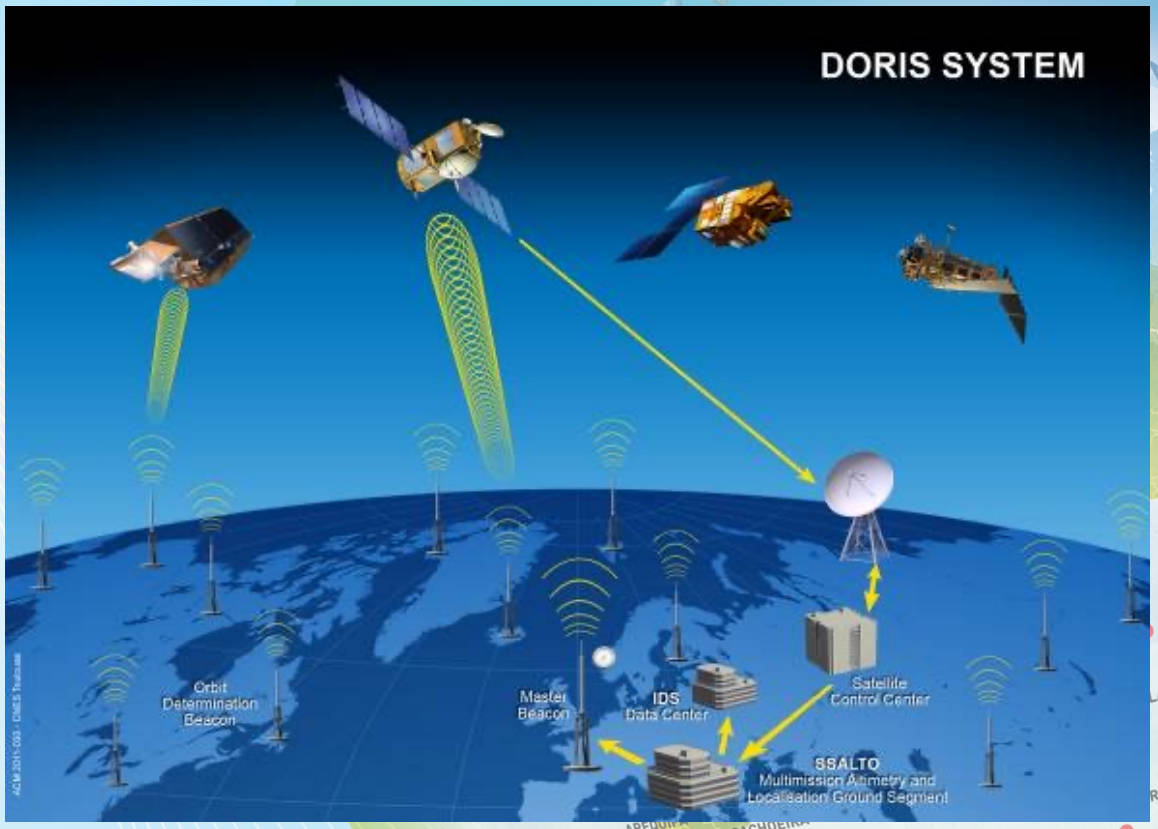
What is DORIS?

DORIS is one of the four techniques of Space Geodesy, along with SLR, VLBI & GNSS.

DORIS stands for

- **D**oppler **O**rbitography and **R**adiopositioning **I**ntegrated by **S**atellite
- **D**étermination d' **O**rbite et **R**adiopositionnement **I**ntégrés par **S**atellite
- **D**eterminación de **Ó**rbita y **R**adioposicionamiento **I**ntegrados por **S**atélite
- **D**eterminação de **Ó**rbita e **R**adioposição **I**ntegrado por **S**atélite

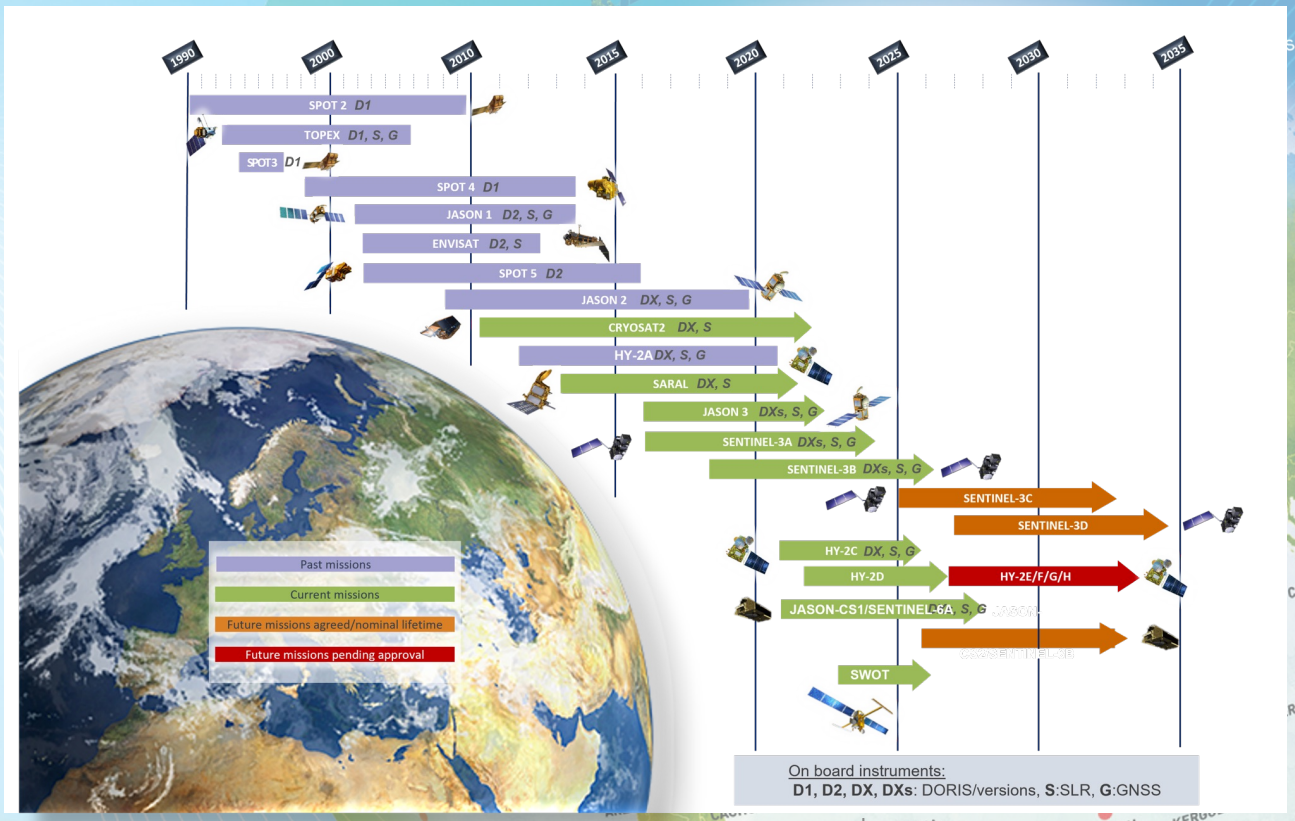
DORIS in a few words



- . Designed in the early 1980's for precise orbit determination of ocean altimetry missions.
- An uplink system based on Doppler shifts measurements of dual-frequency RF signals transmitted by a worldwide network of beacons.
- Centralized control center for receipt of data and system operations.
- Maintained by CNES & IGN (*France*).

Global Geodetic Observing System

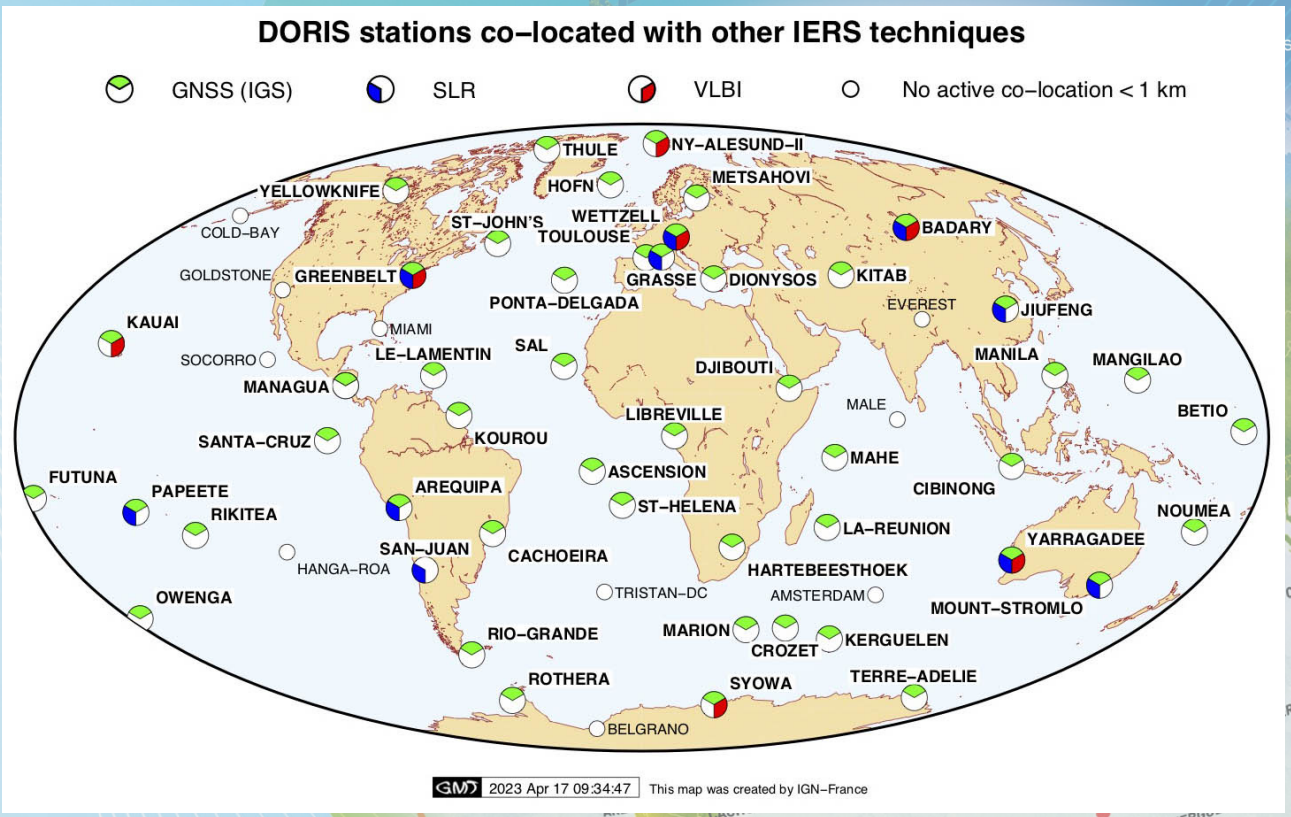
The DORIS Constellation



- 3 Generations of DORIS instruments: D1G, D2G, D3G.
- Four altitudes: 1336 km, ~970 km, ~800 km; ~700 km.
- Three orbit planes: 66°, 92°, 98°.

Presently Nine DORIS satellites on orbit!

The DORIS Network



- **half of current network sites > 27 years old. 20 sites in continuous operation since 1990.**
- **A densification to about 70 stations is currently underway.**
- **48/59 stations collocated with another IERS technique.**
- **The IDS strives to encourage DORIS colocations with other techniques.**

What is the IDS?

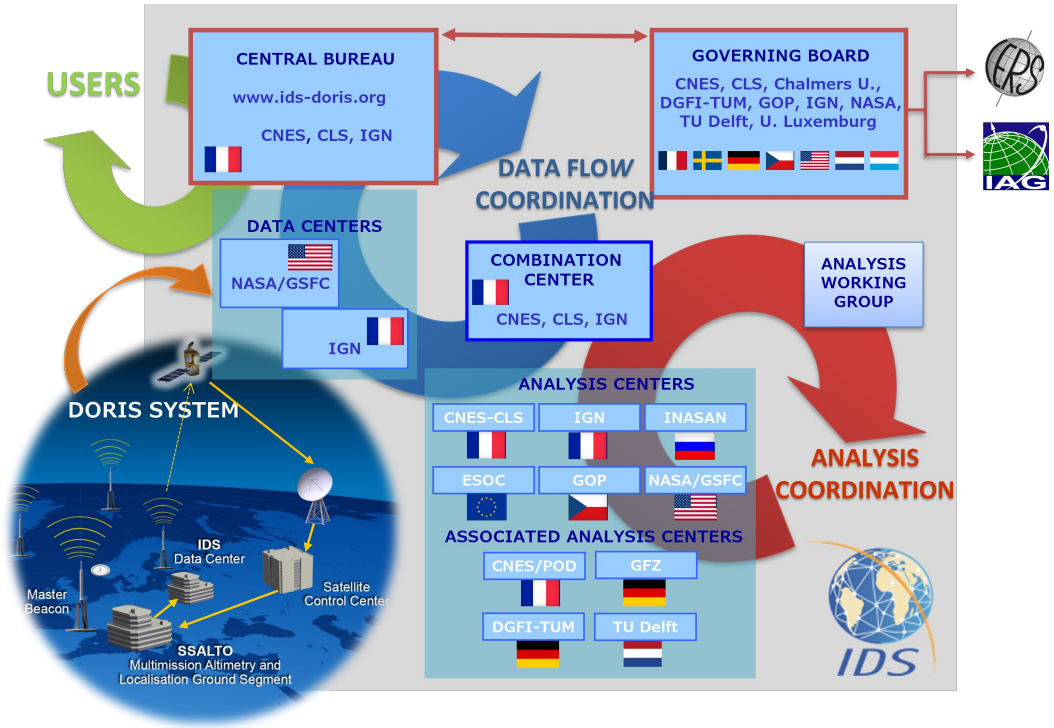
- IUGG 1999, Birmingham, UK. IDS Pilot project accepted.
- IUGG 2003, Sapporo, Japan.
  → International Doris Service (IDS) Accepted as an IAG Service.
- IDS Mission (from Terms of Reference):

• Support geodetic and geophysical research activities using DORIS data and derived products.
• Collects, archive and distribute DORIS data of sufficient accuracy to satisfy the objectives of a wide range of applications including:

→ High accuracy ephemerides of DORIS satellites.
→ Coordinates and velocities of the IDS tracking station.
→ Earth orientation parameters (EOPs).
→ Coordinates and scale of the terrestrial reference frame.

- **IDS submits DORIS solutions to the IERS and participates in GGOS.**

IDS Organization



+ IDS WG on Near Real Time DORIS Data. Chair: Denise Dettmering (DGFi/TUM).
Objective: delivery of NRT DORIS data for use in ionospheric models.

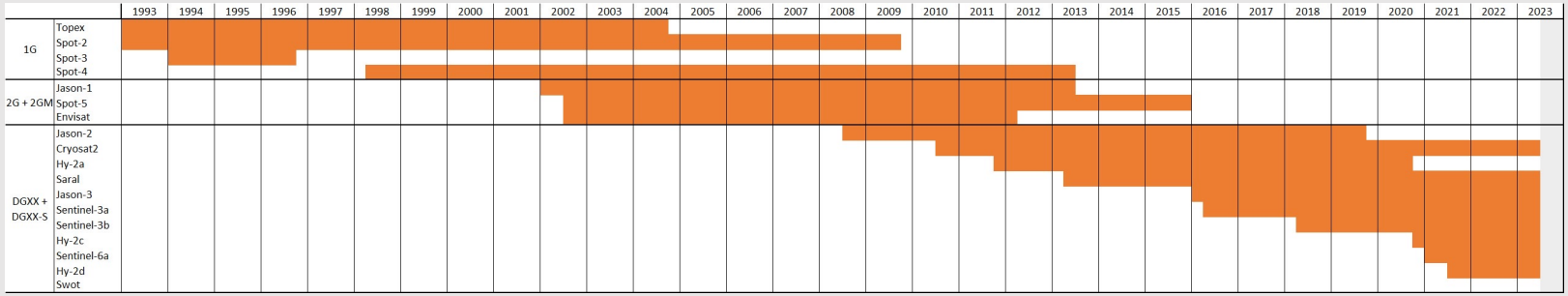
Current IDS Analysis Components

Analysis Centers	Software	Contact	ITRF contributions	Comments
ESA. (ESOC)	NAPEOS	M. Otten	ITRF2008, 2014, 2020	**Operational AC**
GOP (Geodetic Observatory Pecný)	Bernese	P. Štěpánek	ITRF2008, 2014, 2020	**Operational AC**
GRG. (CNES/CLS)	GINS/DYNAMO	H. Capdeville J.M. Lemoine	ITRF2005, 2008, 2014, 2020	**Operational AC**
GSC. (NASA GSFC)	GEODYN	F. Lemoine	ITRF2008, 2014, 2020	**Operational AC**
IGN.	GipsyX	A Pollet/ S. Nahmani	ITRF2005, 2008, 2014.	Previously led by P. Willis. Transition to GipsyX
INA. (INASAN)	Gipsy/Oasis	S. Kuzin	ITRF2008, 2014	New POD software being tested.

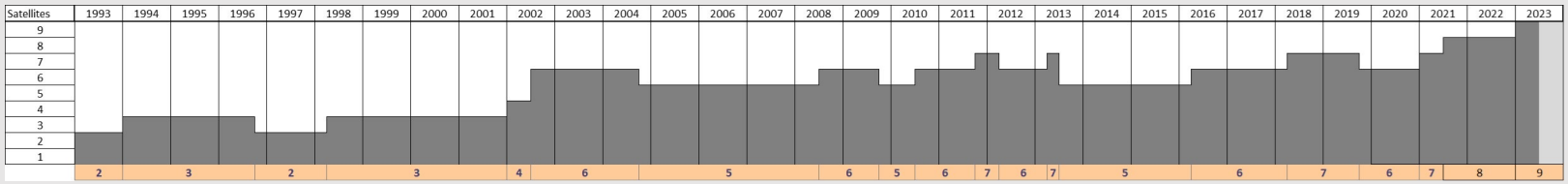
Associated Analysis Centers:
CNES/POD (*A. Couhert*); **DGFI/TUM** (*M. Bloßfeld*); **GFZ★** (*P. Schreiner*) ; **TU Delft** (*E.J.O. Schrama*).
Combination Center: G. Moreaux (CLS) with the support of Z. Altamimi (IGN) for CATREF software and strategy.
Analysis Coordinator: P. Štěpánek (GOP).
★**GFZ**: evaluation under way to become operational AC and contribute to ITRF2020 extension.

Available IDS Data

Data available at IDS Data Centers *(1993.01.01 - 2023.07.01)*



Number of satellites of the DORIS constellation *(1993.01.01 - 2023.07.01)*



Products Delivered by DORIS & IDS

- **Precise orbits**

(Real Time; Near Real Time (NRT); Longer latency).

→ "**Orbitography**" in the DORIS name means "**Orbit Determination**".

- **Station coordinates and Earth Orientation Parameters (EOP).**

→ This includes weekly solutions by analysis center, a combination produced by the IDS Combination Center, and IDS Contributions to the ITRF.

- **DORIS Terrestrial Reference Frame for Precise Orbit Determination (DPOD).**

→ Cumulative solution done ~2x/year with additional information. Latest is DPOD2020.
Dynamic reference frame for DORIS POD.

- **Geocenter**

→ A derived product (estimate of CoF w.r.t. CoM).

Precise Orbits from DORIS Data (1)

- **Real Time:** DIODE (”*DORIS Immediate Orbit Determination*”).

→ DIODE processes measurements in real-time to obtain on-board estimates of the orbital state vector.

→ Satellites: SPOT-4, Jason-1, ENVISAT, SPOT-5, Jason-2, Cryosat-2, SARAL/AltiKa, Jason-3, Sentinels-3A+3B, & Sentinel-6A.

→ The orbit is used by the s/c for payload management (*change altimeter tracking modes by location*), and is distributed on NRT altimeter data records.

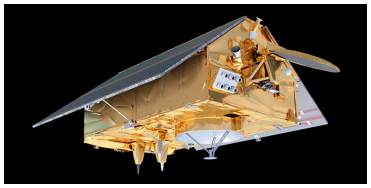
Only recently available as a separate product (sp3 files) to support work of IDS NRT Working Group (***probatory period with Jason-3***): IGN Data Center (ftp://doris.ign.fr/pub/doris/products/orbits/ssa/ja3/NRT)

→ At the request of the IDS, NRT orbits for other satellites (e.g. **Sentinel 3A, 3B & Sentinel-6A**) will be available later in 2023.

Contact **Dr. Denise Dettmering (DGFI/TUM)**, chair of IDS NRT WG for more information on how to use these data, & WG activities.

For general information on DIODE, contact the CNES DORIS project manager: **Cécile Manfredi @ CNES**.

Jason-3



Sentinel-6A

Precise Orbits from DORIS Data (2)

• **Longer Latency**: **For Geophysical Data Records of altimeter satellites, or from routine processing for the ITRF.**

→ Orbits are in the standard sp3 format.

→ Orbits delivered now by CNES AAC (with a few weeks latency),

and by the GRG AC (quarterly with routine SINEX deliveries):

→ GRG AC: Orbits are DORIS-only or DORIS+SLR, depending on the satellite.

→ CNES AAC: Orbits are DORIS-only or DORIS+GPS, depending on the satellite. Also current orbits for CNES AAC use the "POE-F" set of standards:

For more information contact:
(1) Alexandre Couhert @ CNES (CNES AAC)
(2) Hugues Capdeville @ CLS (GRG AC)

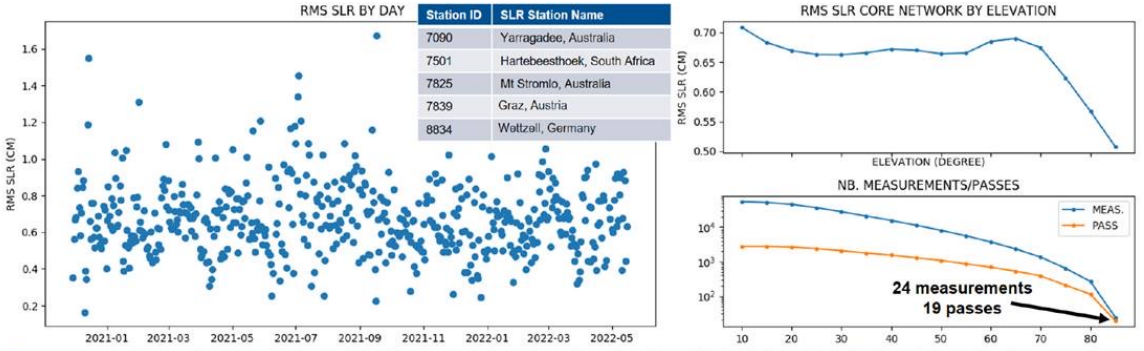
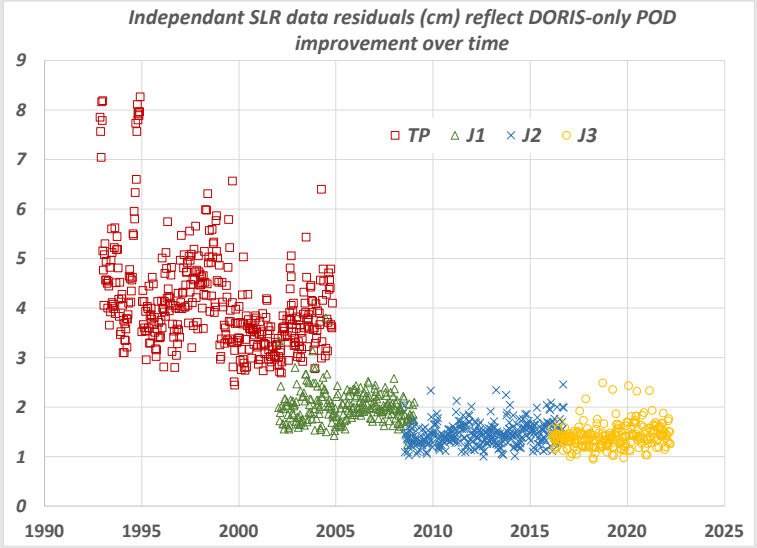


FIGURE : RMS of SLR CN residuals (mm) for the Sentinel-6 MF CNES POE-F orbit solution vs. time (left) & elevation angle (right). (figure provided by Alexandre Couhert, CNES)

Evaluation of DORIS-only orbits (1)

Independent Satellite Laser Ranging data Illuminates Improvement In DORIS-only POD performance over time

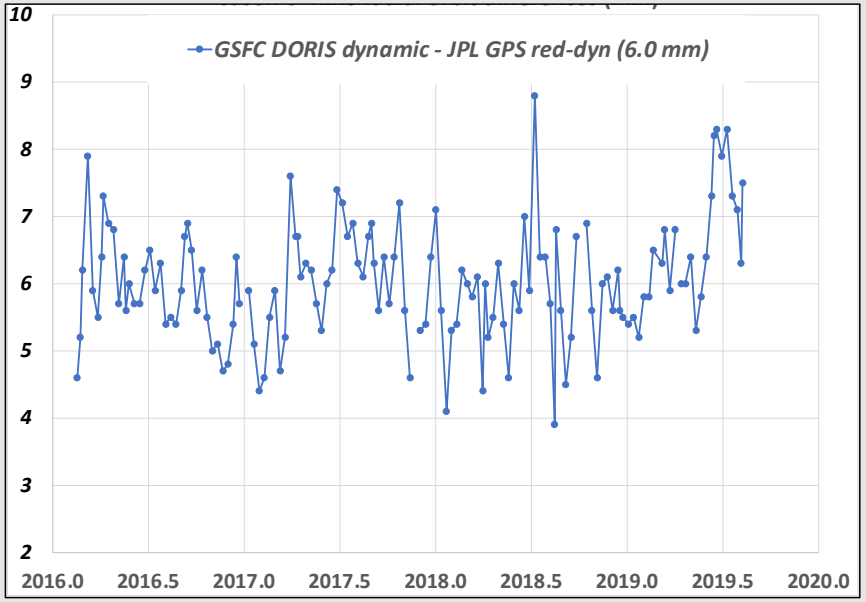


The SLR data illuminate improvements in the DORIS system:
~ June 2002: **Expansion of DORIS satellite constellation, & Availability of two-channel DORIS receivers.**
Summer 2008: **Launch of first satellite with an seven-channel DORIS Receiver (Jason-2)**
(Figure from Nikita Zelensky, Univ. Maryland/ESSIC).

Evaluation of DORIS-only orbits (2)

Jason-3 Orbit Differences: (DORIS-only vs. GPS reduced-dynamic)

(*RMS radial orbit differences per altimeter data cycle, per ~10 days*)



(Figure from Nikita Zelensky, Univ. Maryland/ESSIC).

DORIS radial orbit accuracy for Jason-3 is 6-8 mm.

Here we compare a GSFC **DORIS-only-orbit** with the independent JPL/**GPS-red-dyn** orbits (2016-2019), to assess orbit consistency.

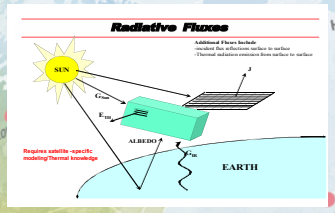
Computed with DPOD2014.

IDS Modelling Improvements Implemented for ITRF2020

(Examples: not a complete list)

• Better modeling of the static & time-variable gravity field using latest gravity solutions that include data from GRACE, GRACE FO, GOCE & other satellites.

Jason-2



• Better modelling of non-conservative forces on Jason 1,2,3 satellites (solar array quaternions, and adjust Cr/arc). → reduce 117-day signals in DORIS products.

The ITRF Analysis Loop

IDS Analysis Centers

Test SINEX solutions

IDS CC Feedback to ACs

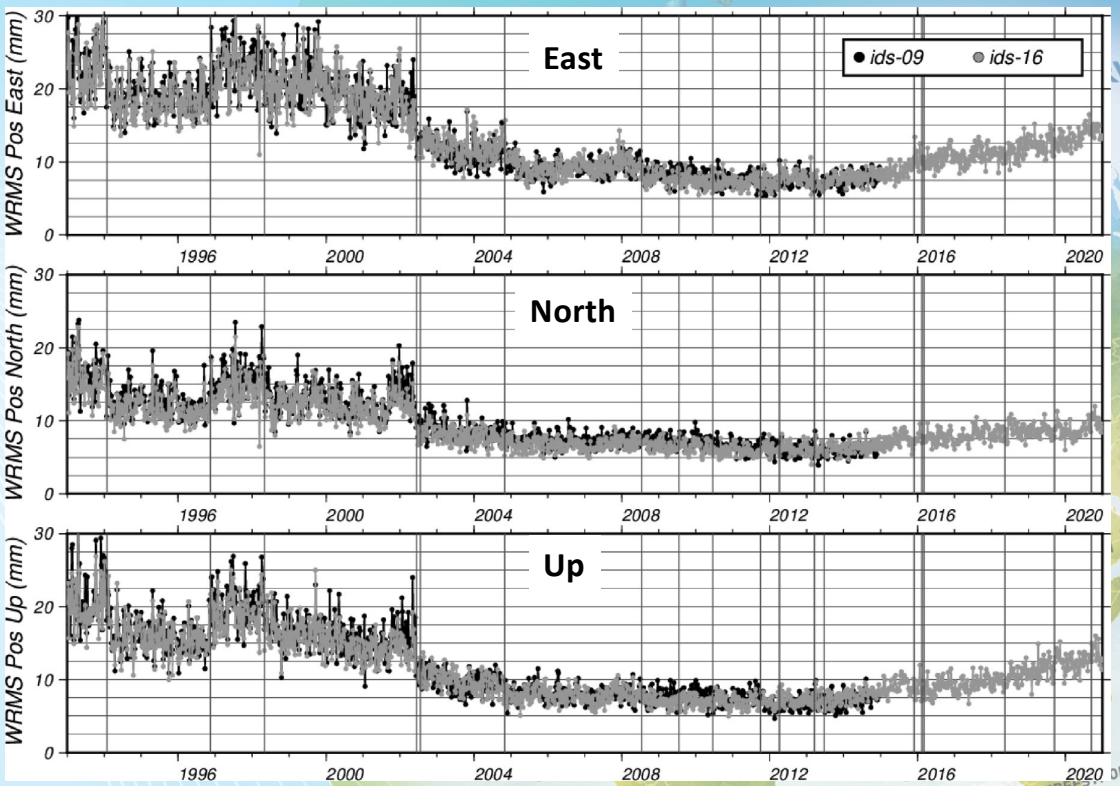
IDS Combination Center

Updates to IDS Combination

ITRF Product Centers & other users

For each ITRF, This analysis loop is carried out many times to test new models, analysis strategies, and data from new satellites, with input from the IDS Analysis Working Group

DORIS Positioning through time from ITRF2020



DORIS Position Residuals w.r.t ITRF2020 **for ITRF2020 (grey)** and **ITRF2014 (black)** weekly solutions.

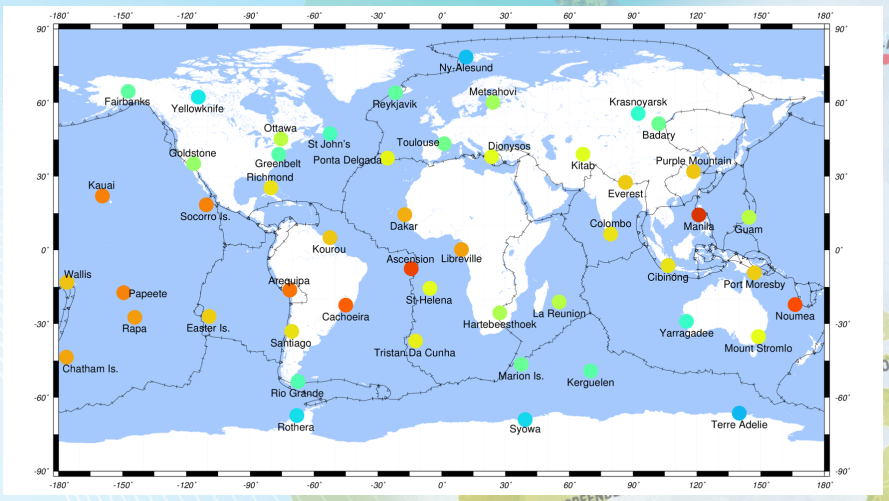
The vertical lines correspond to changes in the number of satellites in the DORIS satellite constellation.

Moreaux et al. (2022).
Adv. Space Res.,72(1), 65-91
doi:10.1016/j.asr.2022.07.012.

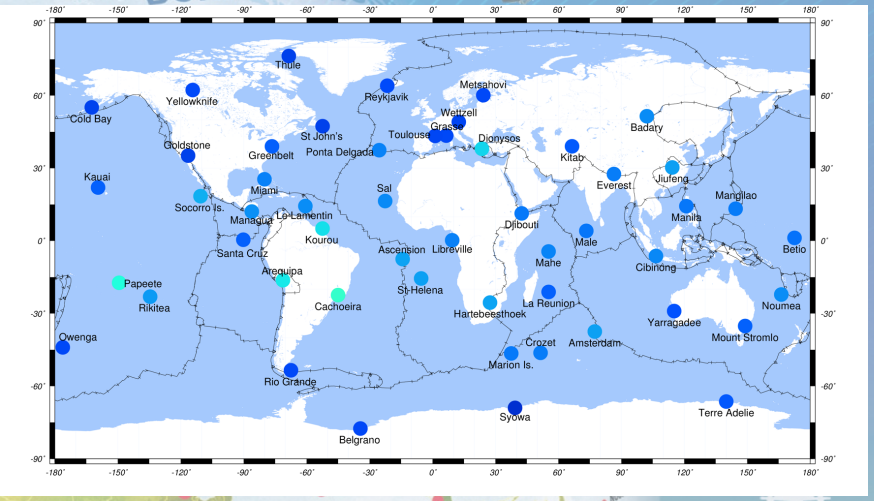
DORIS Positioning from the IDS Contribution to ITRF2020

Global Geodetic Observing System

Year 2000



Year 2020

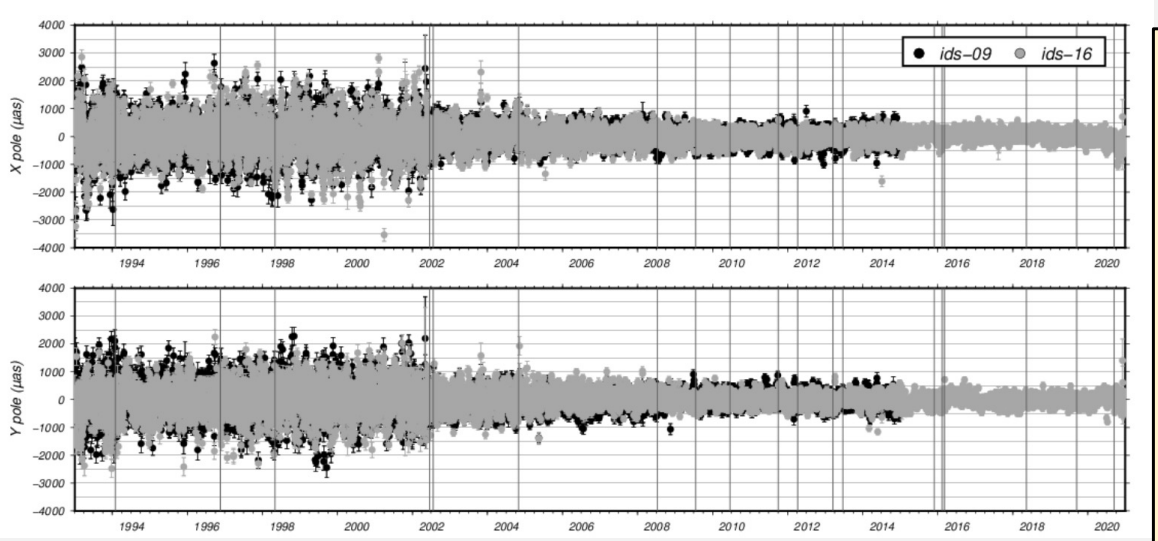


Year 2000: Three satellites: 1-channel DORIS receivers

Year 2020: Six satellites: 7-channel DORIS receivers

Evolution of EOP Performance for DORIS from ITRF2020

IDS EOP Differences with IERS C04 series for ITRF2014 (ids09) and ITRF2020 (ids16)



Std. Dev. Of Diffs. With IERS C04 (ids16)

1993-2002:
Xpole: 664 μas
Ypole: 587μas

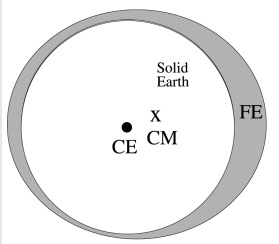
2002-2008
Xpole: 331 μas
Ypole: 321 μas

2015-2021
Xpole: 192 μas
Ypole: 171 μas

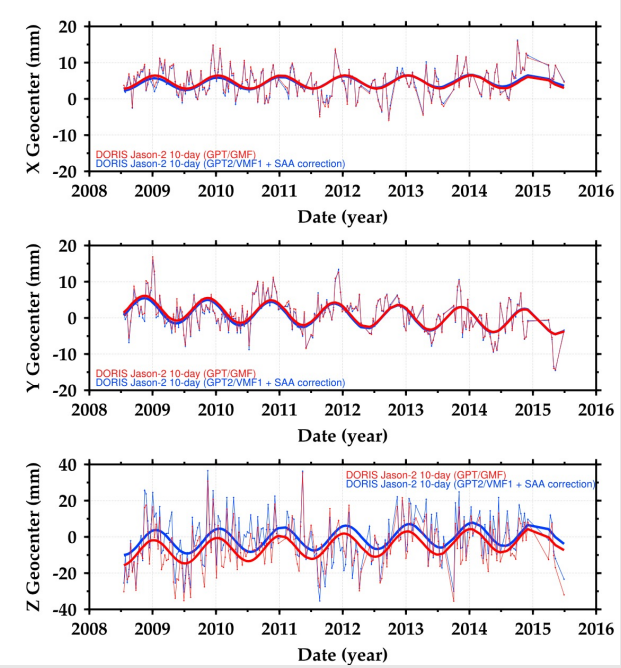
Moreaux et al. (2022), *Adv. Space Res.*, doi: 10.1016/j.asr.2022.07.012.

Geocenter

Concept of Geocenter



From Couhert et al. (2018)
10-day estimates from Jason-2 DORIS-only



Two types of solutions from DORIS:

1. Derived by stacking of AC or IDS combination solutions w.r.t a reference datum.

2. Couhert et al. (2018) ("Systematic error mitigation in DORIS-derived geocenter motion". *JGR, 123*, 10,142–10,161. doi:10.1029/2018JB015453) showed that DORIS data from Jason-2 only (***excluding the polar-orbiting satellites***), can be used to derive solutions for geocenter. For determination of the annual signal, the solutions are competitive with those from SLR data to the LAGEOS satellites.

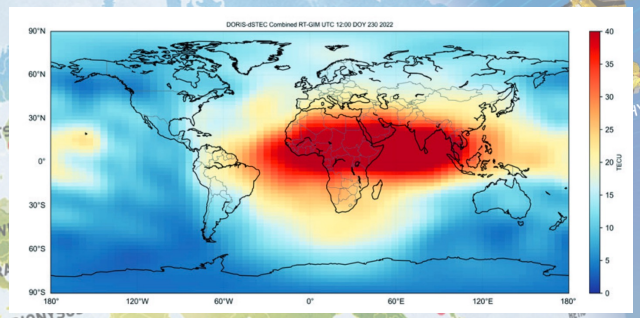
IDS WG on Near Real Time Data

- WG established 2017.
- Chair. Denise Dettmering, DGFI/TUM.

The main topics addressed by the WG are:

- Development of a DORIS ionospheric product (STEC/VTEC or dSTEC/dVTEC),
- Using DORIS data for global real-time ionospheric modeling,
- Using DORIS data to validate the performance of global ionospheric TEC models,
- Improving ionospheric modelling with focus on the combination of different space-based observation datasets,
- Networking with other IAG working groups: GGOS JWG 3 & IAG JWG 4.3.1.

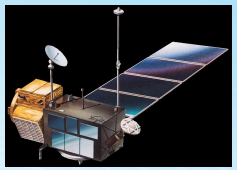
NRT Data (*along with NRT DORIS orbits*) are perfectly suited for an independent validation of Real-Time Global Ionospheric Maps (RT-GIM).



Distribution of vertical Total Electron Content on 18 Aug. 2022/12:00 UTC, from a combination of various RT-GIMS weighted by DORIS STEC.

Liu A., Wang N., Dettmering D., et al. (2023). "Using DORIS Data for Validating Real-Time GNSS Ionosphere Maps". *Adv Space Res.*, doi: 10.1016/j.asr.2023.01.050

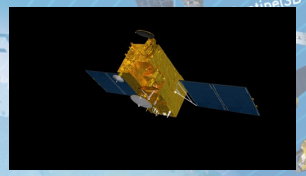
IDS Challenges & Opportunities:
DORIS Satellites


TOPEX


SPOT-5


CryoSAT-2


Sentinel-3A, 3B


HY-2D


SWOT

Challenges

- **Every satellite is unique,** and requires special & careful treatment, for measurement and force modelling.
- Complex shape of satellites complicates surface force modelling.
- **Ancillary information (e.g. body quaternions & solar array angles) not always available**, especially for the earlier missions.
- New satellites generally require implementation of a new attitude law in the POD software.

⇒ extra work for an AC with their own POD software.

- **We now have nine active DORIS satellites!!**

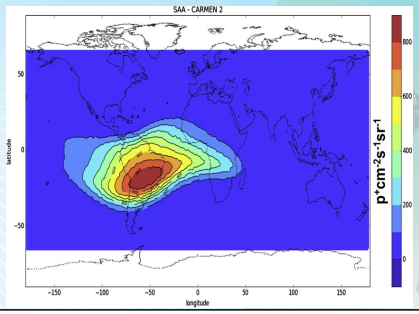
Opportunities

- All current satellites have multiple tracking systems (**SLR & GNSS**).
- We can usually work with other POD experts (e.g. CPOD, OSTST) to aid in modelling & analysis.
- **Design metrology has improved with time** (better know parameters such as tracking points, center-of-mass).
- Most of current missions provide quaternion information.
- POD techniques & background models have improved with time (red-dynamics, ITRF model, GRACE/GOCE, VMF …).

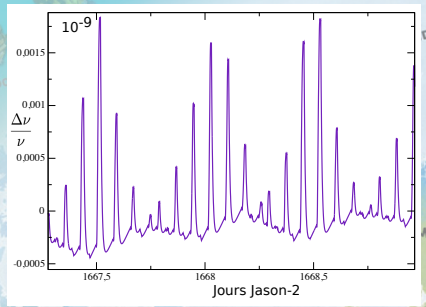
- **We now have nine active DORIS Satellites!!**

IDS Challenges & Opportunities: DORIS Data & South Atlantic Anomaly

Challenge



High Energy proton flux
On Jason-1, from Carmen-2
(from H. Capdeville & J-M. Lemoine)



Jason-2 DORIS USO Frequency Variations over 1.5 days from the T2L2 experiment.
(Belli et al., 2015)

- First identified on Jason-1, but then later found on other DORIS satellites (Jason-2, Jason-3).
- Radiation Effect can be more severe on higher (1336 km) satellites, but there is a dependence on whether the USO was annealed & behavior of actual USO crystal in space environment.

Opportunities

- Using external data IDS has developed a model to mitigate this effect on SPOT-5 (Capdeville et al., 2016).
- Belli et al. (2015, 2021), developed corrected data for Jason-2 based on the Jason-2 T2L2 experiment. Data not used in ITRF2020.
- On Sentinel-3A, 3B the GNSS and DORIS clocks were connected, allowing a direct way to model the DORIS USO. Jalabert & Mercier (2018) and Štěpánek et al. (2020) showed the GNSS clock connection could improve DORIS USO modelling for these satellites. Sentinel-6A also has this DORIS-GNSS clock connection.
- More ground stations are becoming connected to atomic clocks (H_2 masers). (allows through POD a snapshot of DORIS Satellite USO behavior).

How to become involved in the IDS community?

Become an IDS Analysis Center (AC) or an IDS Associate Analysis Center (AAC)

AC:
Provides at least one product on a regular basis.

AAC:
Provides specialized or derived products, not necessarily at regular intervals.

HOW?
By mutual agreement with the IDS.
(*by recommendation of IDS Analysis Coordinator & IDS CC & approval of IDS GB*).

WHOM to contact?
- IDS Analysis Coordinator (*Petr Štěpánek, GOP*).
- IDS Central Bureau (*Laurent Soudarin, CLS, CB*

Join or propose an IDS Working Group

IDS WG on Near Real Time Data
Chair: Denise Dettmering (DGFI/TUM).

Proposed WG on the geocenter.
Contact: Alexandre Couhert (CNES) & Petr Štěpánek (GOP).

WG on the SAA? *Contact J-M Lemoine (CNES) if interested.*

How to become involved in the IDS community?

Work on a research topic with IDS collaborators

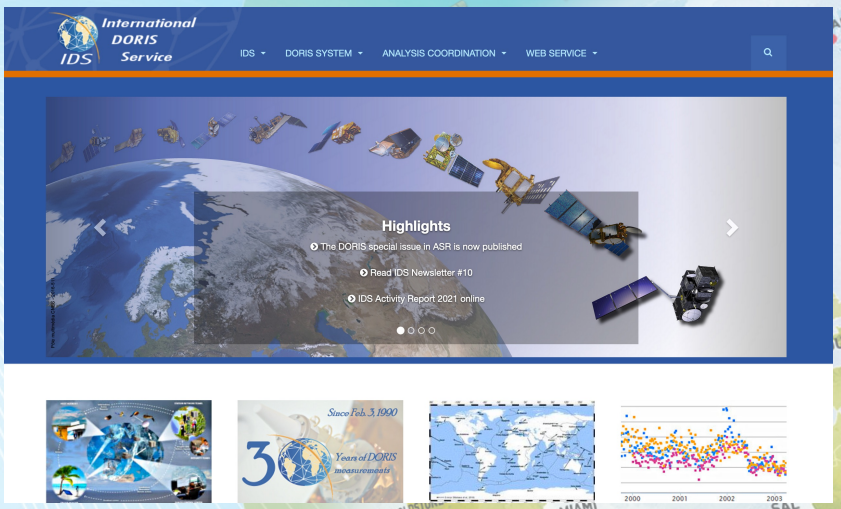
- How to better *model radiation impact on USOs.* (contact J-M Lemoine CNES).
- How to infuse *new technology* into DORIS system.
- *Improve Non-conservative modeling* for DORIS satellites.
- Systematic test of improved modeling for ground oscillators using *connected GNSS receivers.*
- How to leverage the long time series of data at DORIS sites for long-term *monitoring of climate* through development of a troposphere product. (*suggested by Pascal Willis & also Paul Poli (SHOM) in 2018 at IDS Retreat*).
- Processing *phase data* in DORIS RINEX files (*see Mercier et al., 2010, Adv. Space Res.*)

Attend an IDS meeting

- **IDS Analysis Working Group meetings usually meet twice per year.**
  → Next meeting is Nov. 28-29, 2023, Saint-Mandé, France, hosted by IGN.
  Contact: IDS Analysis Coordinator (Petr Štěpánek, GOP)
- **IDS Workshop. (**Bi-annual meeting: next meeting associated with OSTST in 2024).
- **Join a DORIS-Days training seminar.** "How to process DORIS data with GINS." Early 2024.

Where to go for more information?

Visit the IDS website: *https://ids-doris.org/*

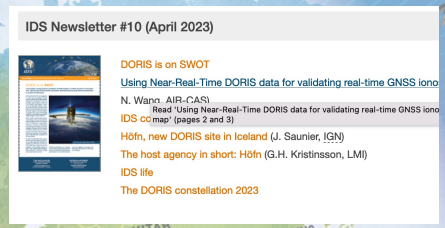


- IDS Bibliography, All meeting presentations,
- IDS Station site logs & station viewer.
- IDS Station Position Time series viewer.
- IDS Satellite information.

Etc.

IDS Newsletter

https://ids-doris.org/documents/newsletters/



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