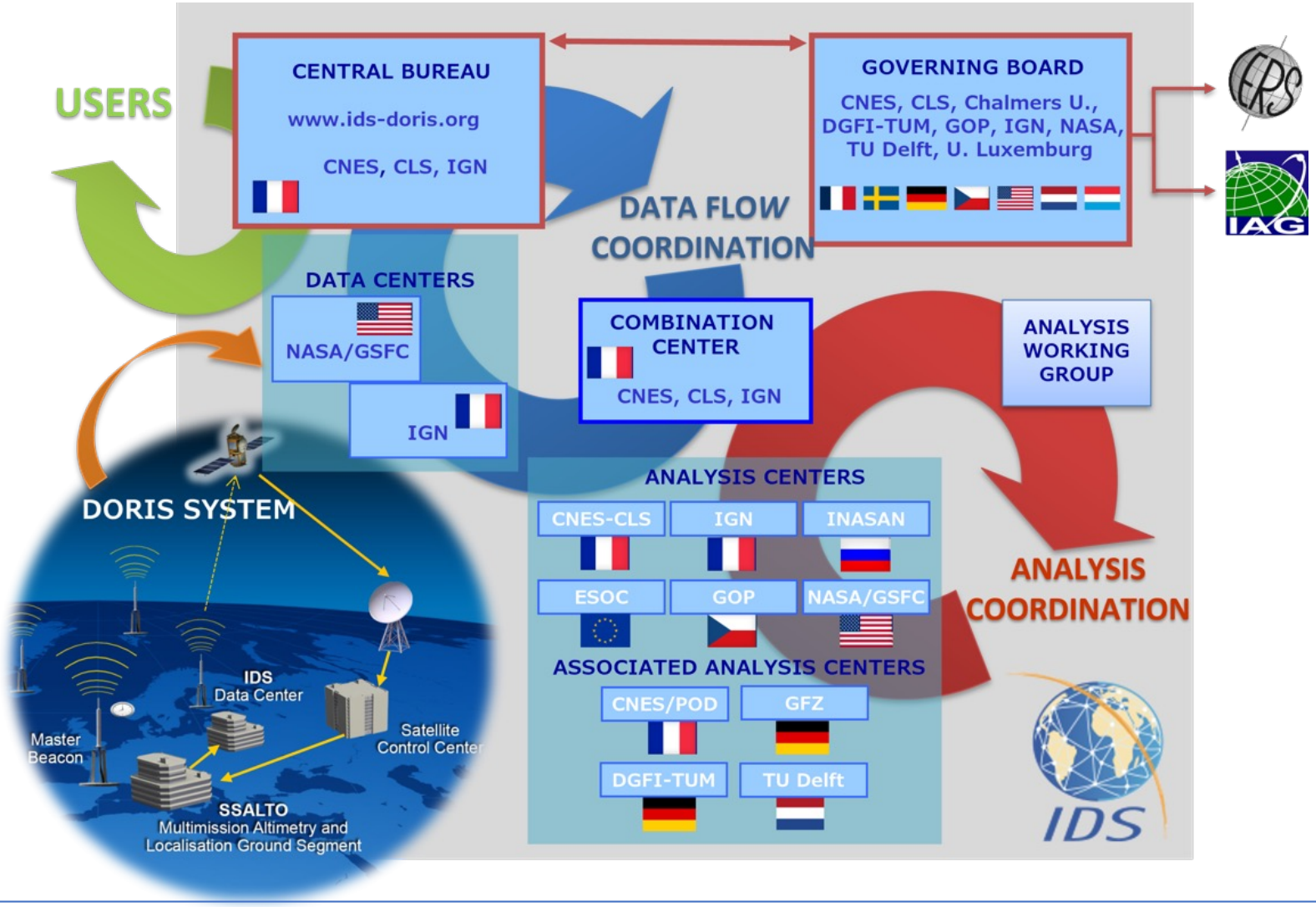
International DORIS Service (IDS): The IDS at 20 and the IVS at 25; Together on a long journey

Frank G. Lemoine (1), Jérôme Saunier (2), Guilhem Moreaux (3), Claude Boniface (4), Laurent Soudarin (3), Petr Štěpánek (5)

1) NASA Goddard Space Flight Center Greenbelt, Maryland, U.S.A.
2) Institut Géographique National, St-Mandé, FRANCE
3) Collect Localisation Satellites, Ramonville Saint-Agne, FRANCE
4) Centre National d'Etudes Spatiales, Toulouse, FRANCE
5) Geodetic Observatory Pecny, CZECH Republic

Organization of the IDS



- The IDS was "incorporated" as an IAG service in 2003, at IUGG in Sapporo, Japan: recently had its 20th anniversary.
- The IDS has an organization like the other services: **GB, Central Bureau, Analysis Centers, Data Centers, & WG.**

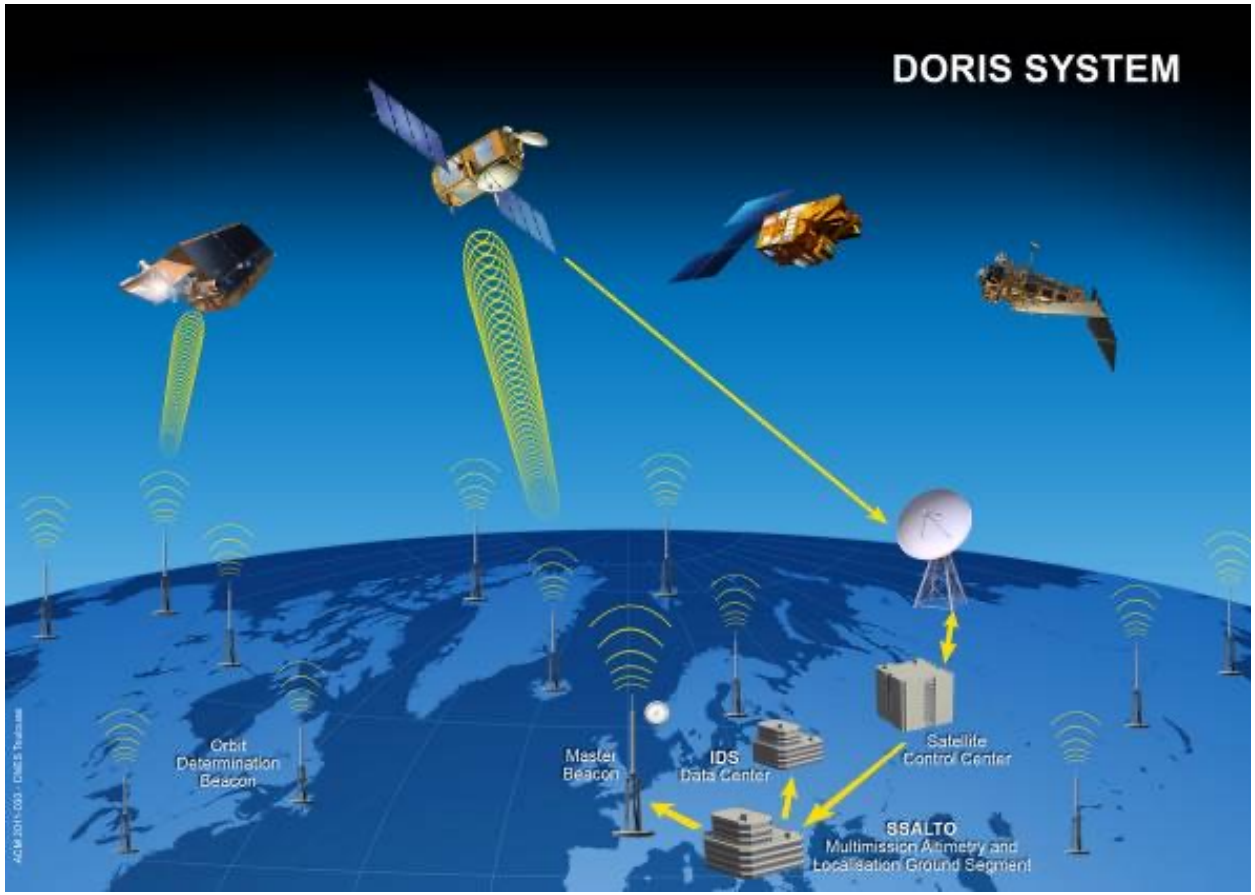
Current IDS Analysis Components

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). **Analysis Coordinator:** P. Štěpánek (GOP).

Compared to the IDS, the IVS has more Analysis Centers, but many (50%?) IVS ACs use the same software (SOLVE/nuSOLVE); In IDS, every AC has their own software and is responsible for their own POD software updates.

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*).

DORIS Satellite Constellation Status

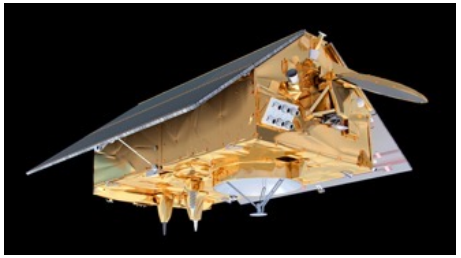
- **Nine satellites with DORIS receivers now on orbit.**

Cryosat-2, Saral, Jason-3, Sentinel-3A & 3B, HY-2C, HY-2D, Sentinel-6A, & SWOT. (*All are ocean radar altimeter satellites*).

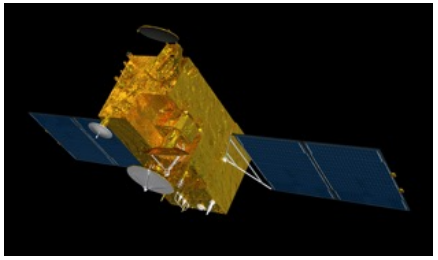
- **Five missions set to launch in the next five years will include DORIS receivers,** including Sentinel-6B (2025), Sentinel-6C (end 2024), Sentinel-3D (2028), HY-2E (2025) & Genesis (2028).

- **GENESIS Mission (2028).**

→ **After ESA Workshop (*February 29, 2024*), it is clear this will be a flagship mission for Geodesy where all the geodetic techniques will be working together to improve the TRF.**



Sentinel-6A

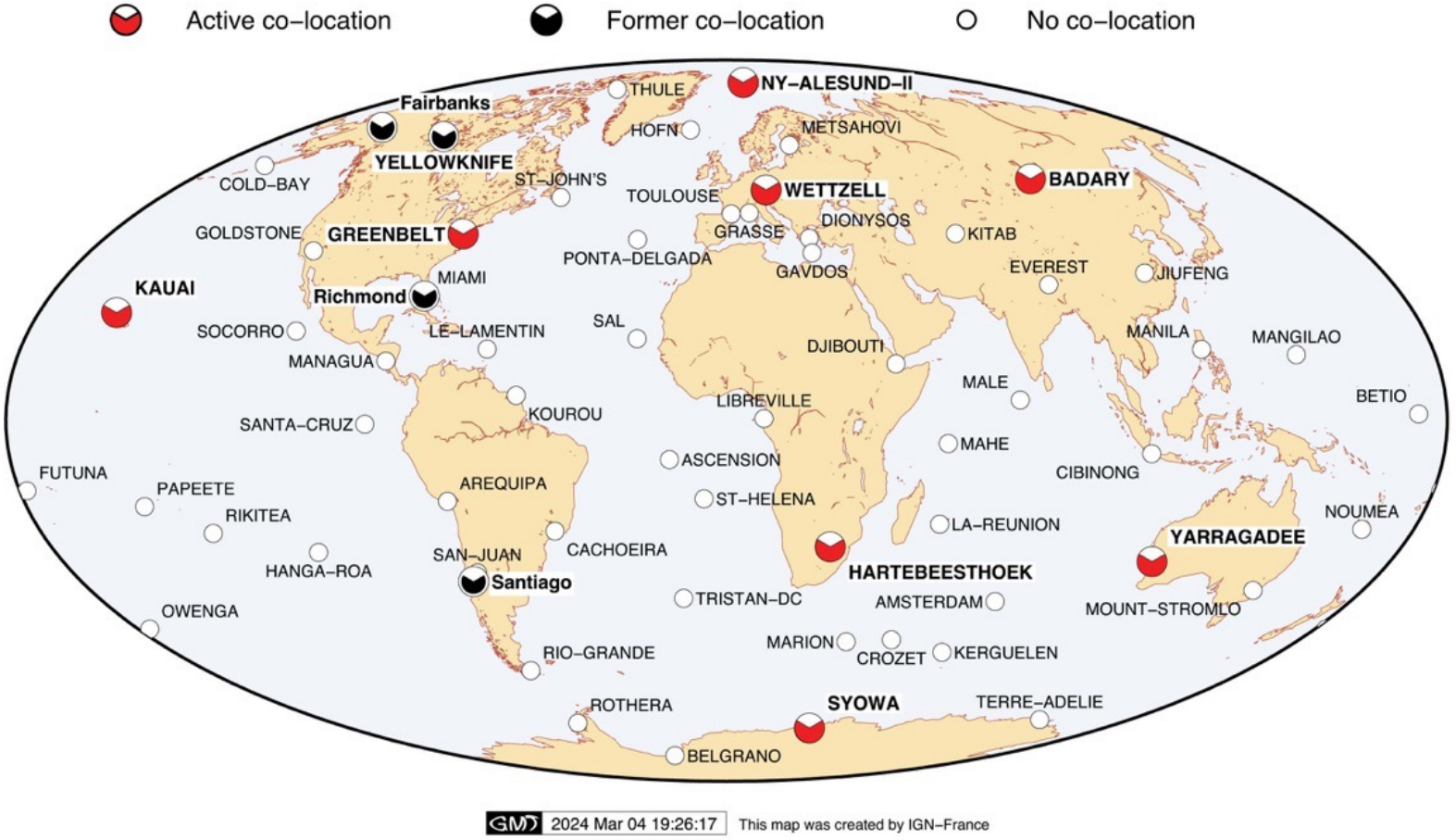


HY-2C

SWOT

DORIS satellites present challenges for modelling of nonconservative forces *(e.g. Sentinel-6A, need to model self-shadowing; HY-2C, complicated attitude law, and no quaternions available*); Also on SWOT, center-of-mass changes around orbit as the solar array rotates.

DORIS Ground Network



Current colocations w. VLBI: **Greenbelt (23 yrs), Hartebeesthoek, Kauai (30 yrs), Ny-Ålesund II (5 yrs), Syowa (27 years), Wettzell (7 yrs), Yarragadee (13 yrs); Badary**

Some previous colocations w. VLBI: **Fairbanks (10 yrs), Richmond (6 yrs), Santiago, Yellowknife (15 yrs);**

DORIS values H_2 maser connections to DORIS at IVS sites: This allows a direct reading of the DORIS satellite USO, and is important part of the real-time DORIS system, DIODE.

DORIS & VLBI Compatibility

Successive RF compatibility campaigns:

Greenbelt, MD USA (2014) / Wettzell, Germany (2015-2016) / Papenoo, French Polynesia (2017)

Requirements for installing DORIS and VLBI on the same site:

- Minimum distance between DORIS and VLBI antennas shall be 300 m.
- RF barrier (natural or artificial) between both antennas is highly recommended.
- Strive for having DORIS above VLBI because DORIS signal is lower at low elevation.
- RF compatibility tests in real conditions are in any case required (reflection/environment…)

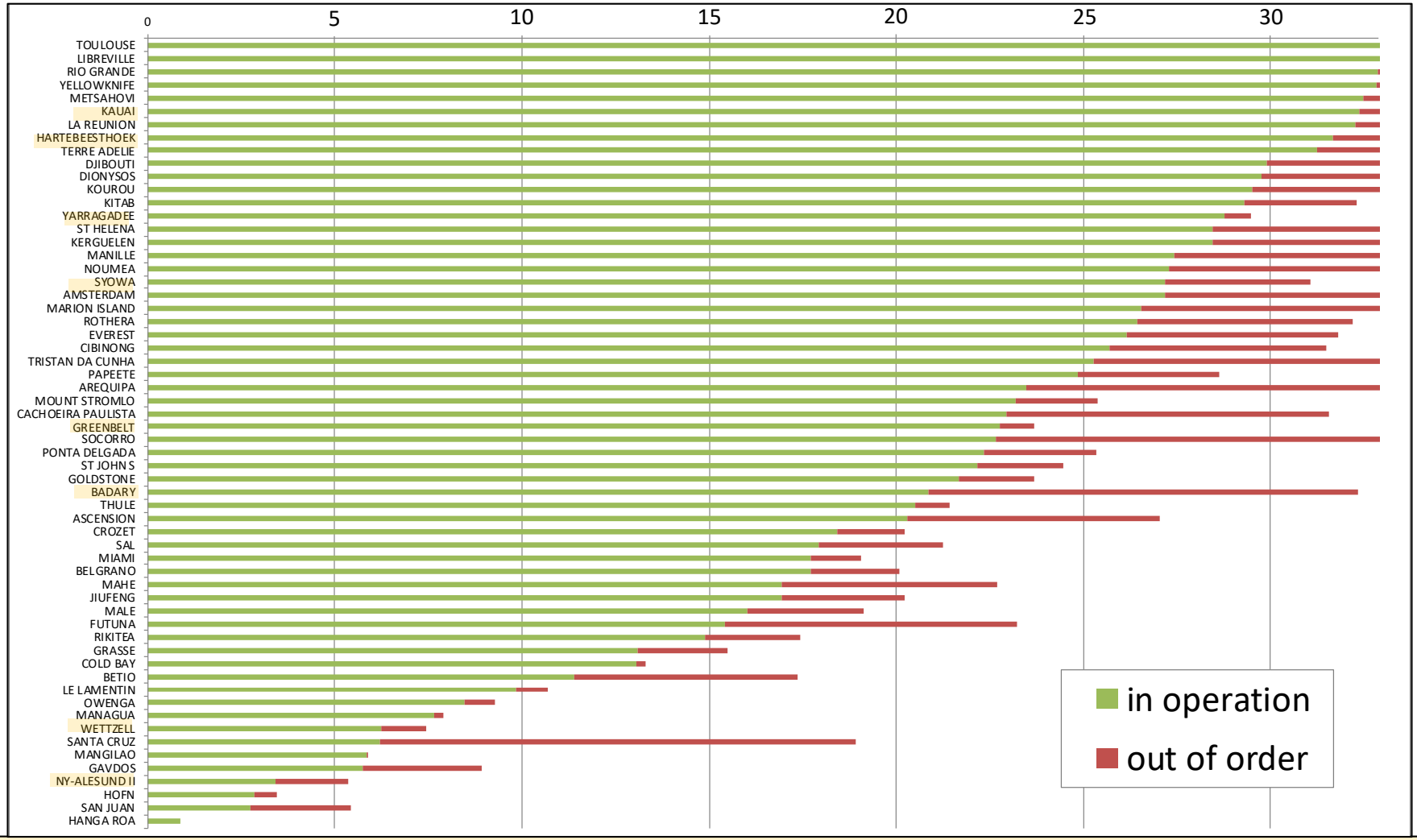
Guaranteed compatibility on all DORIS/VLBI sites: no interference

Ny-Ålesund II

Wettzell

Long time series at DORIS sites

Half of the current network stations has more than 22.5y data availability



Like many IVS stations, many DORIS stations have a long time history, because the CNES/IGN put a premium on having sites that are stable & reliable with good ground observing geometry.

IDS + IVS sites with > 30 yrs of DORIS data: Kauai, Hartebeesthoek

IDS + IVS sites with > 20 yrs of history: Badary, Greenbelt, Syowa

Products Delivered by DORIS & the IDS

Global Geodetic Observing System

- **Precise orbits for LEO scientific satellites:**

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

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

For Orbit Determination, DORIS complements SLR & GNSS.

- **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 contributes to the ITRF along with VLBI, SLR & GNSS.

- **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**.

IDS does dynamic updates of its own technique TRF, like the IVS, ILRS, & IGS.

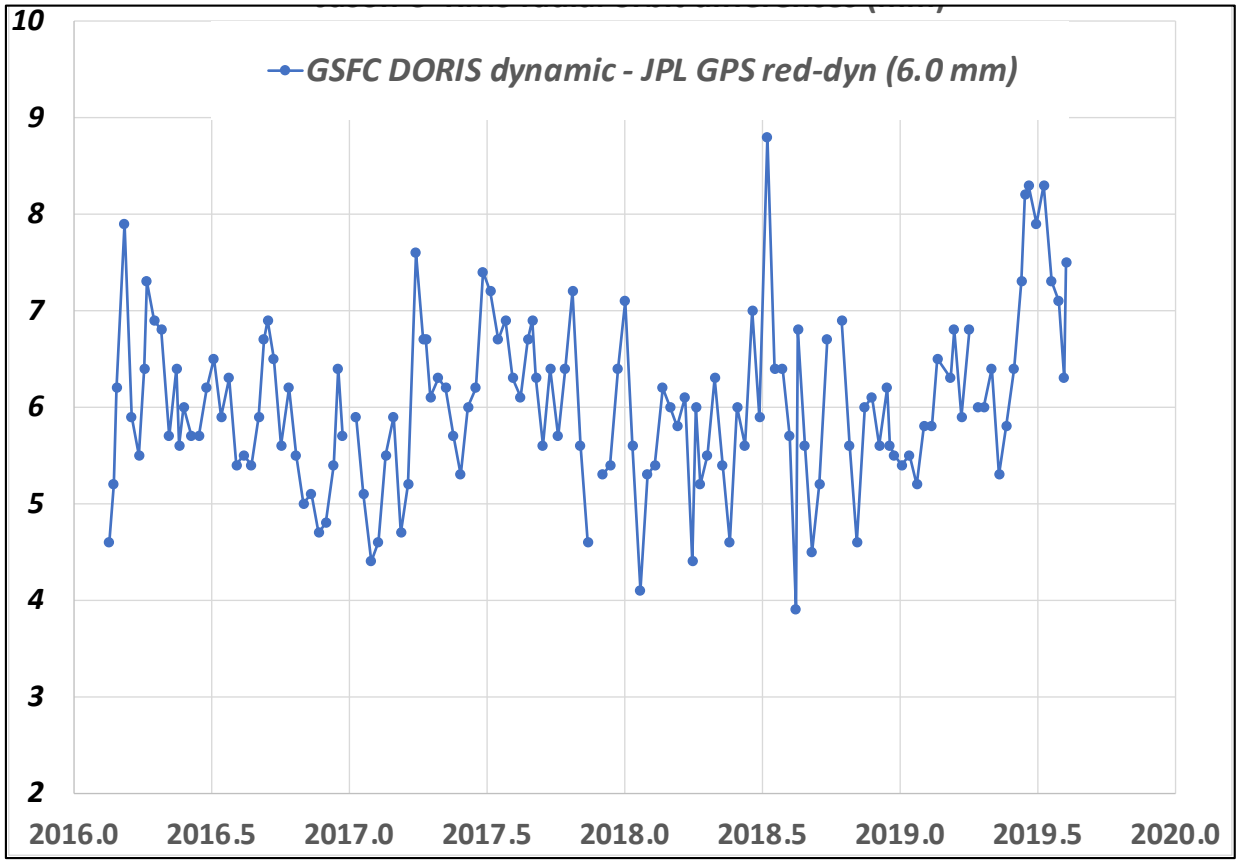
- **Geocenter**

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

DORIS current orbit quality

Jason-3 Radial Orbit Differences, mm:
(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.

DORIS relies on IVS determination of UT1 for Precise Orbit Determination (POD)

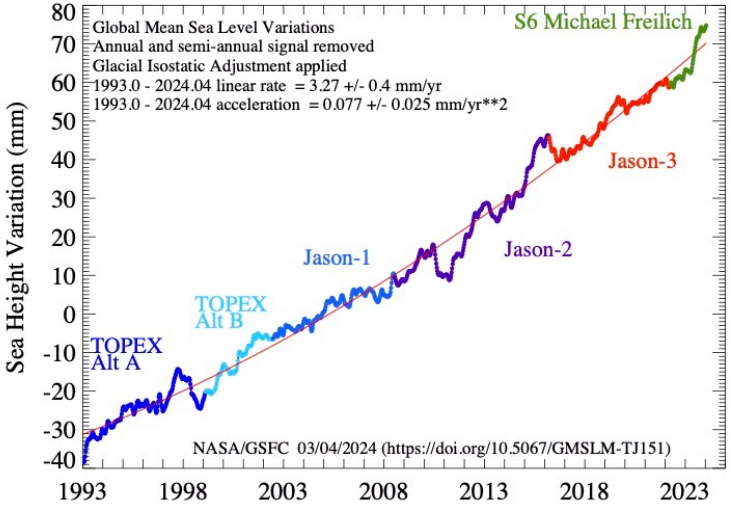
(part of IDS Answer to Questions raised by the IVS before its retreat in June 2023)

- The IDS needs accurate values of UT1-UTC to support precise orbit determination and verification of orbit accuracy through intertechnique comparisons (SLR & GNSS) …..
- The most important time scale for the results is a few weeks – so the results are available to deliver precise orbits for products that are used for climate-related analyses (e.g. to monitor change in Global mean Sea Level).

Sentinel-6A Radial Orbit Accuracy Requirements:
< 3 hrs; < 3 cm; < 36 hrs: 1.5 cm; 30-60 days: < 10 mm.
(*Donlon et al., 2021, doi: 10.1016/j.rse.2021.112395***).**

- However, there is a real-time component, since DIODE delivers real-time DORIS orbits.
- We also rely on the IVS/VLBI determinations of the nutation corrections to the IAU2000 nutation model, since DORIS has no means to determine these parameters.

(some) Inputs for Global Mean Sea Level Determination



https://doi.org/10.5067/GMSLM-TJ151

- Accurate Long-Term TRF, with a stable determination of scale & origin: Contributors: SLR, DORIS, GNSS, VLBI.

- Precise orbit determination for Altimeter Satellites
Contributors: SLR, DORIS, GNSS, **but VLBI provides both UT1 and the Nutation Corrections needed for POD.**

- Modelling of time-variable from GRACE-FO & the SLR geodetic satellite constellation:
→Uses SLR data to the geodetic satellite constellation (**Lageos-1, Lageos-2, Starlette, Stella, Ajisai, Lares, Larets**) to determine C_{20} & C_{30}. **but POD for these satellites relies on UT1 determination by VLBI.**

- Global atmosphere models (ECMWF) & ocean models, for computation of gravity contribution ("dealiasing") of atmosphere & oceans, and for refraction corrections (VMF1, 3);

  As radio techniques, DORIS & VLBI are users of these products. VMF1 & VMF3 are also used to process DORIS data, however VMF1 & VMF3 were developed by members of the IVS community.

- Network of tide gauge stations for altimeter validation, with accurate determination of **vertical velocities in a stable TRF.**
Contributors: GNSS & DORIS for the vertical velocities; All geodetic techniques for providing the stable TRF.

Happy 25th Anniversary to the IVS

2023: 20th anniversary of the IDS

2024: 25th anniversary of the IVS

IDS Analysis Working Group Meeting, Saint-Mandé, France; Nov 28-29, 2023

The IDS sends its greetings to the IVS on the occasion of its 25th anniversary as an IAG geodetic service, and wishes you many more years of collecting and analyzing VLBI data.