The International DORIS Service: After 20 Years Looking to the Future

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Session: G52A – Geodetic Standards for Improved Accurate and Consistent Earth Observation Products from GGOS

AGU24

Washington, D.C. | 9–13 December 2024

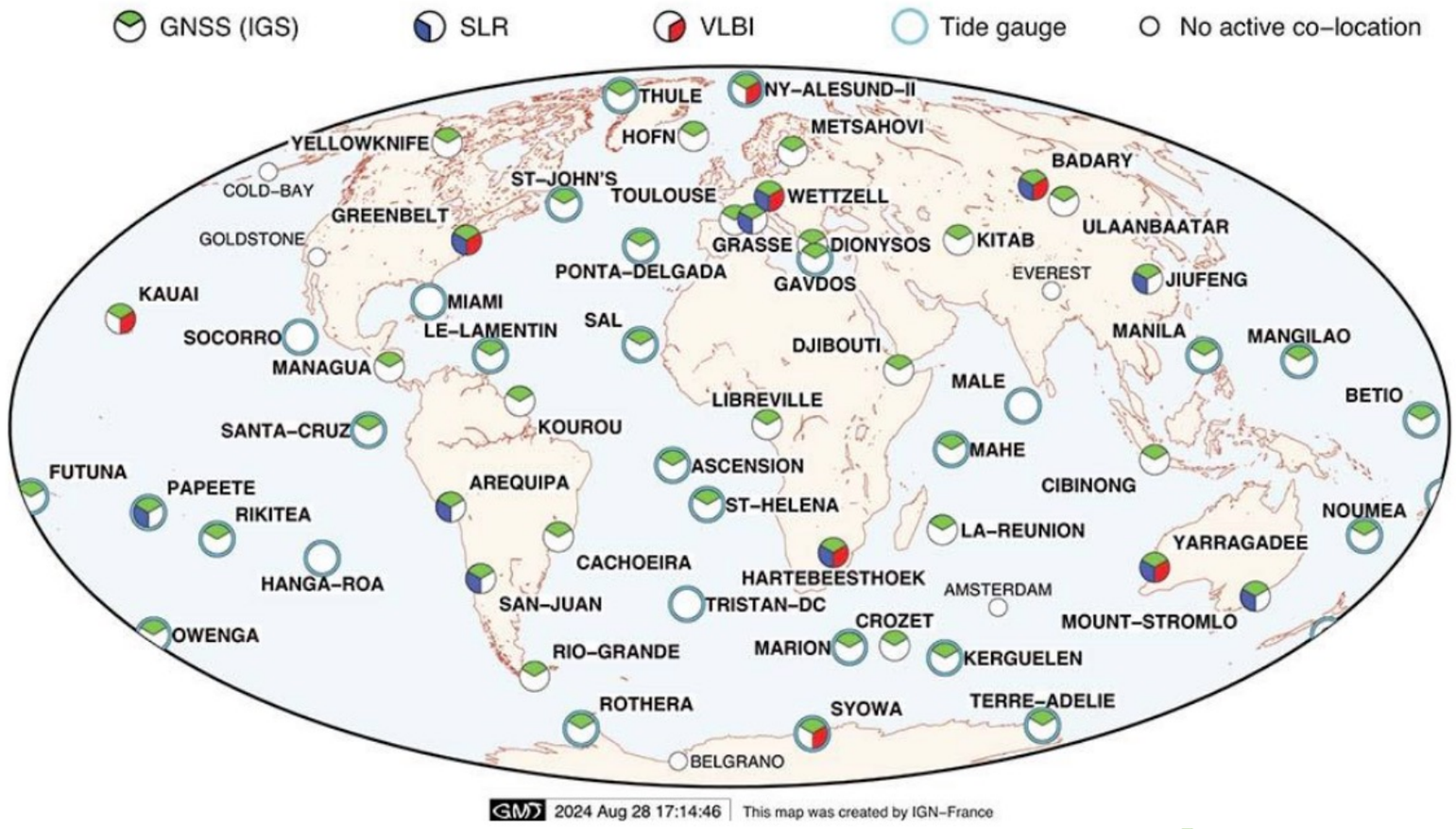
What is the IDS?

- **International Doris Service (IDS):** Accepted as an IAG Service in 2003
- Objectives of the IDS:

Support geodetic and geophysical research activities using DORIS data and derived products.

- **Routine Products:**
  - → **Precise Orbits** (Near Real Time, and longer latency for DORIS satellites).
  - → **Station Coordinates & Velocities** (for IDS stations).
  - → **Earth Orientation Parameters (EOPs)**.
  - → **DORIS Contributions to the ITRF.**
- **Other Products:**
  - → **Geocenter.**
  - → **Time biases for SLR stations (*from Jason-2/T2L2*).**
- **Under Development:**
  - → **Contribution to NRT & Final Global Ionosphere products.**

The DORIS Network: Currently 61 stations



NEW IN 2024!

Ulaan Baatar, Mongolia.
Commissioned: Sept. 5, 2024.

Planned for 2025!

Katherine, Australia
- collocation, GNSS, VLBI.

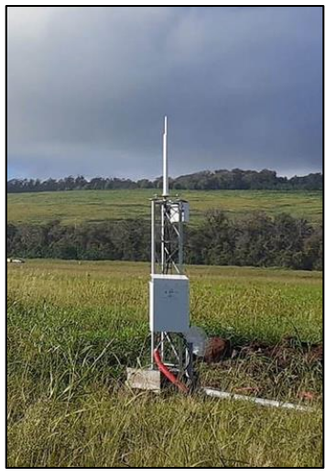
Kanpur, India
- eventual 4-technique site.
- IITK (GNSS) already installed.

- **The IDS strives to encourage DORIS colocations with other techniques.**
- **51 stations collocated with other IERS techniques; 29 collocated with tide gauges.**
- **Densification to about 70 stations is currently underway.**

The DORIS Network: Evolution Underway

4th Generation Beacon

- Better electronics, More robustness.
- 50 m between antenna & beacon.
- Deployment started in 2019.



67% of DORIS network now equipped with B4G.

HROC, Easter Island
Commissioned: Apr. 2023.

Starec Antenna C

- 2 GHz phase center defined to $\pm 2\ mm$.
- Deployment started in 2014.

49% of DORIS network now equipped with Starec C.

STKC, St. Johns,
Started: May 2019.

Connection to Atomic Clocks:

In addition to master beacons, a sub-network of beacons will be connected to atomic clocks:

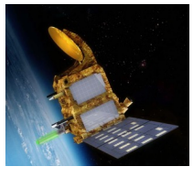
- <u>Current (4)</u>:
Yellowknife, Wettzell, Ny-Ålesund, Grasse.

- <u>Near future (2)</u>:
Greenbelt, Kauai

The DORIS Satellite Constellation

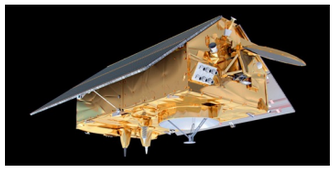
- **Presently Nine DORIS satellites on-orbit, all with the DGXX receivers (*able to track up to 7 DORIS beacons at one time*).**

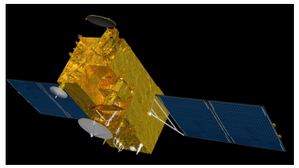

Cryosat-2 (2010)


Saral (2013)


Jason-3 (2016)


Sentinel-3A (2016)
Sentinel-3B, (2018)

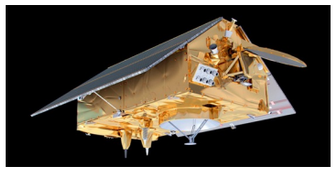

Sentinel-6A (2020)

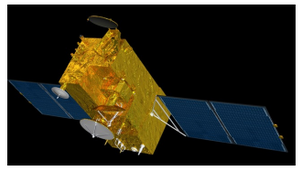

HY-2C (2020),
HY-2D (2021)


SWOT (2023)

- **Five satellites to join DORIS constellation in the near-future.**

Genesis (2028)


Sentinel-6B (2025)
Sentinel-6C (2030)


HY2-G, HY-2H

Sentinel-3NGT
2 satellites, launch ~2032 TBC.

- **3 Generations of DORIS instruments (1993-2024).**
(1) D1G, (2) D2G,
(3) DGXX/DGXX-S

- **Four altitudes:**
1336 km, ~950-960 km, ~800 km; ~700 km.

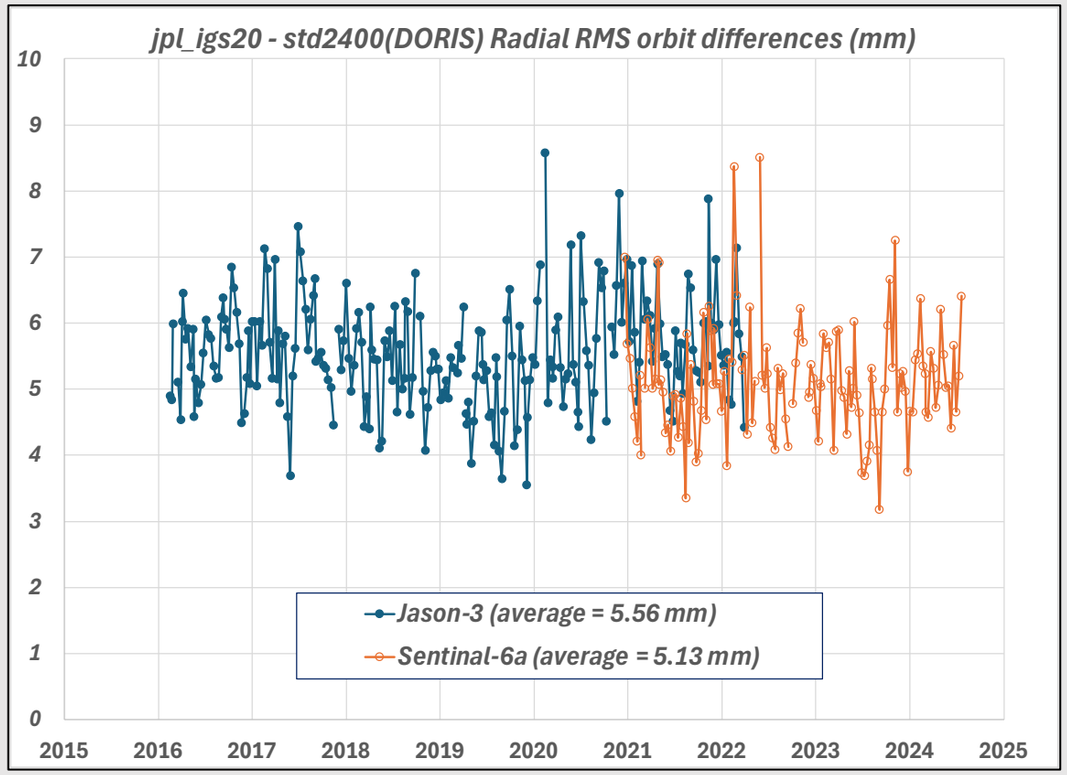
- **Four orbit planes:**
66, 78, 92, 98 degrees.

Genesis orbit will be at ~6000 km altitude; The observation geometry very different from LEO missions.

Evaluation of DORIS-only orbits (2)

Jason-3 & Sentinel-6A Radial Orbit Differences:

(DORIS-only vs. GPS-only 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 & Sentinel-6A are 5-7 mm.

Here we compare GSFC **DORIS-only-orbits** with the independent JPL/**GPS-red-dyn.** orbits (2016-2024), to assess orbit consistency.

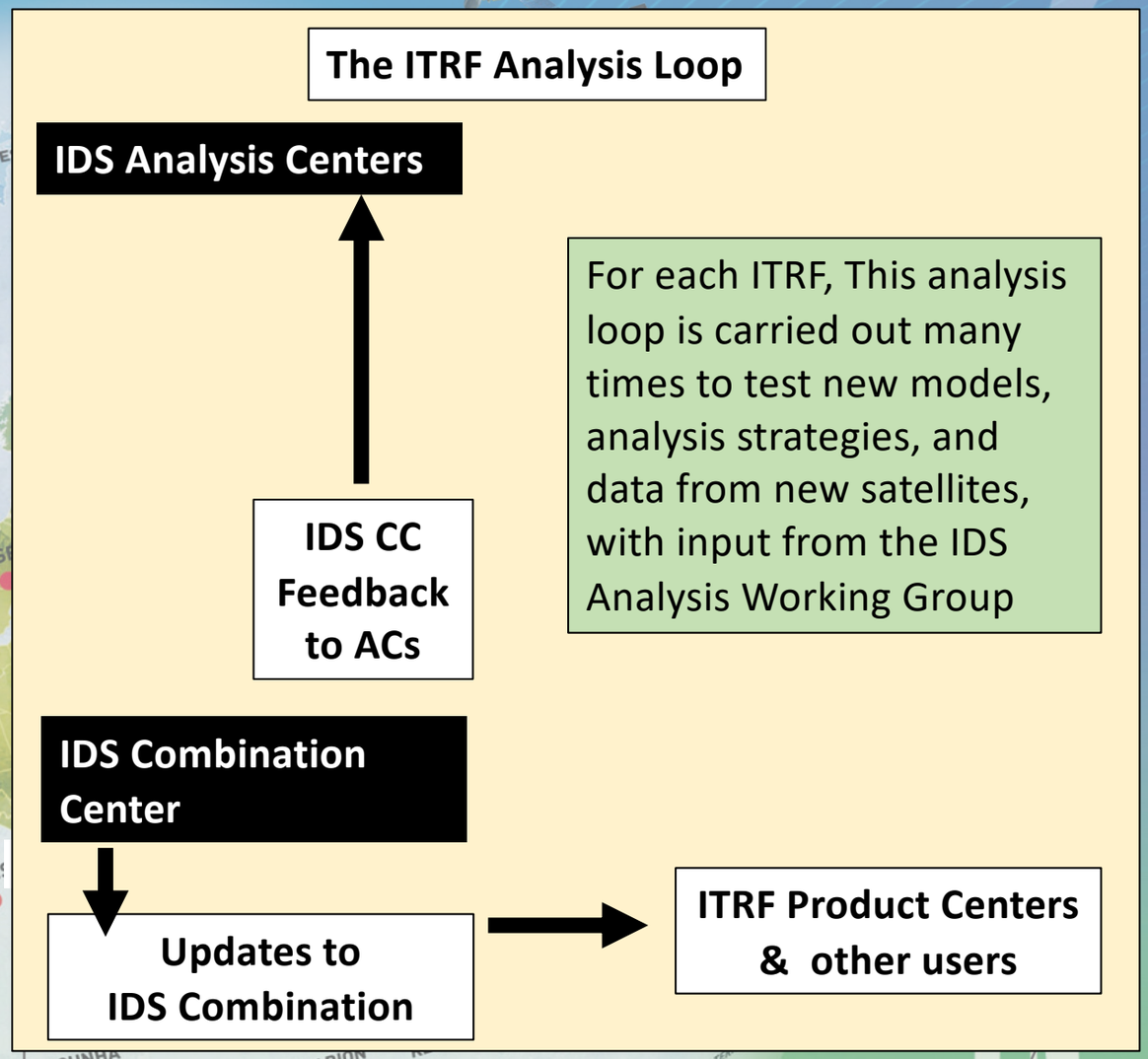
Computed with DPOD2020.V1.5 & IGS20-based GNSS orbits.

Contributions to the ITRF

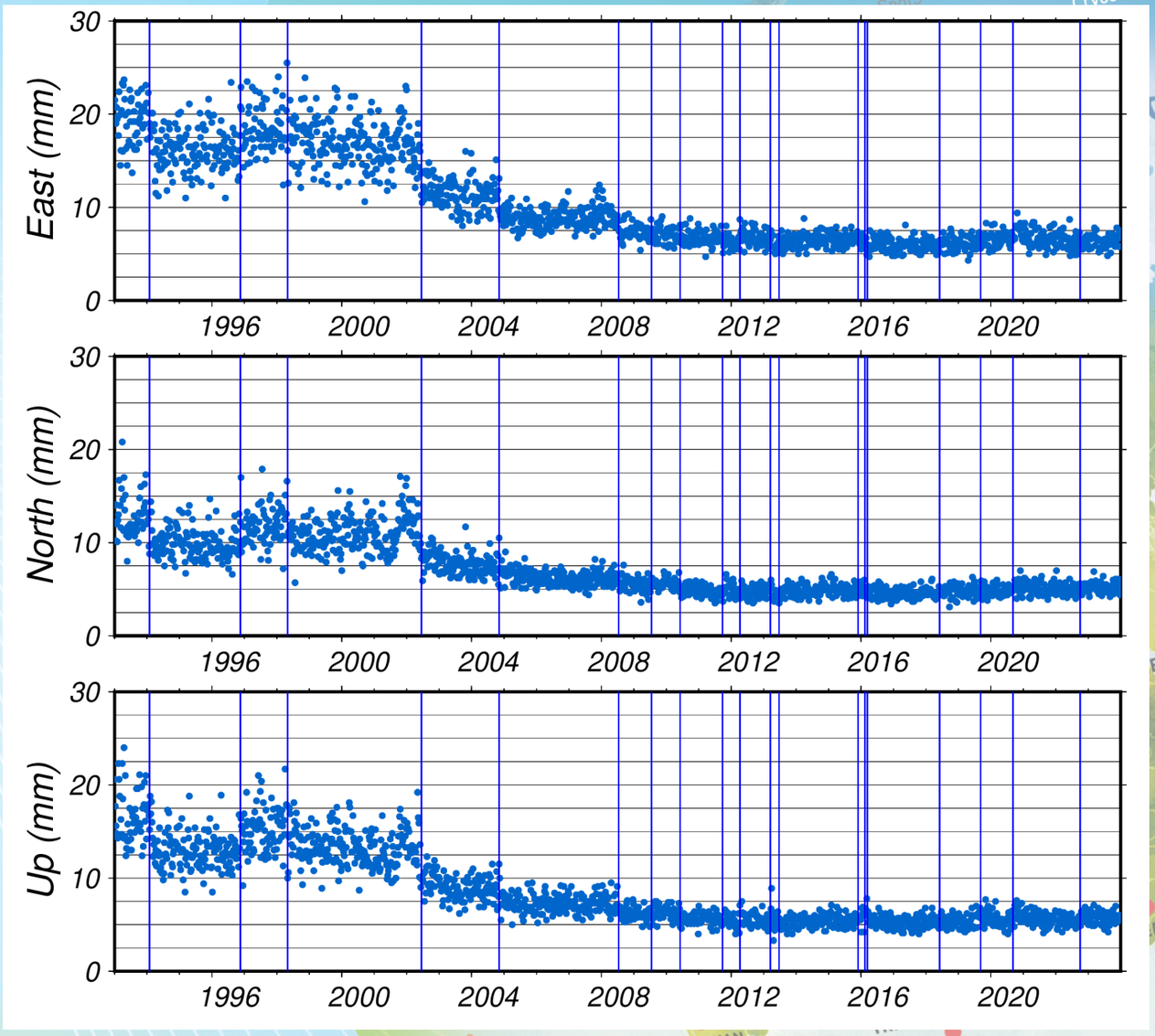
- **Six IDS Groups** participated in the most recent IDS Contribution to the ITRF (ITRF2020-extension):
  ESA, GFZ, GOP, GRGS, GSFC, IGN.

- **Other DORIS ACs and Associate ACs:**
  INA; CNES, DGFI-TUM, TU-Delft.

- **IDS Combination Center:**
  → G. Moreaux (CLS) with the support of Z. Altamimi (IGN) for CATREF software and strategy.
- **IDS Analysis Coordinator:**
  P. Štěpánek (GOP).



DORIS Positioning through time from DPOD2020



DORIS Position Residuals w.r.t **DPOD2020v3** for weekly solutions, computed by the IDS CC.

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

Positioning performance is determined by generation of DORIS receiver (*no. of satellites tracked*) & number of DORIS satellites whose data are used.

1993-2002: D1G.

→ Track 1 DORIS beacon at a time.

2002-2008: D1G+D2G.

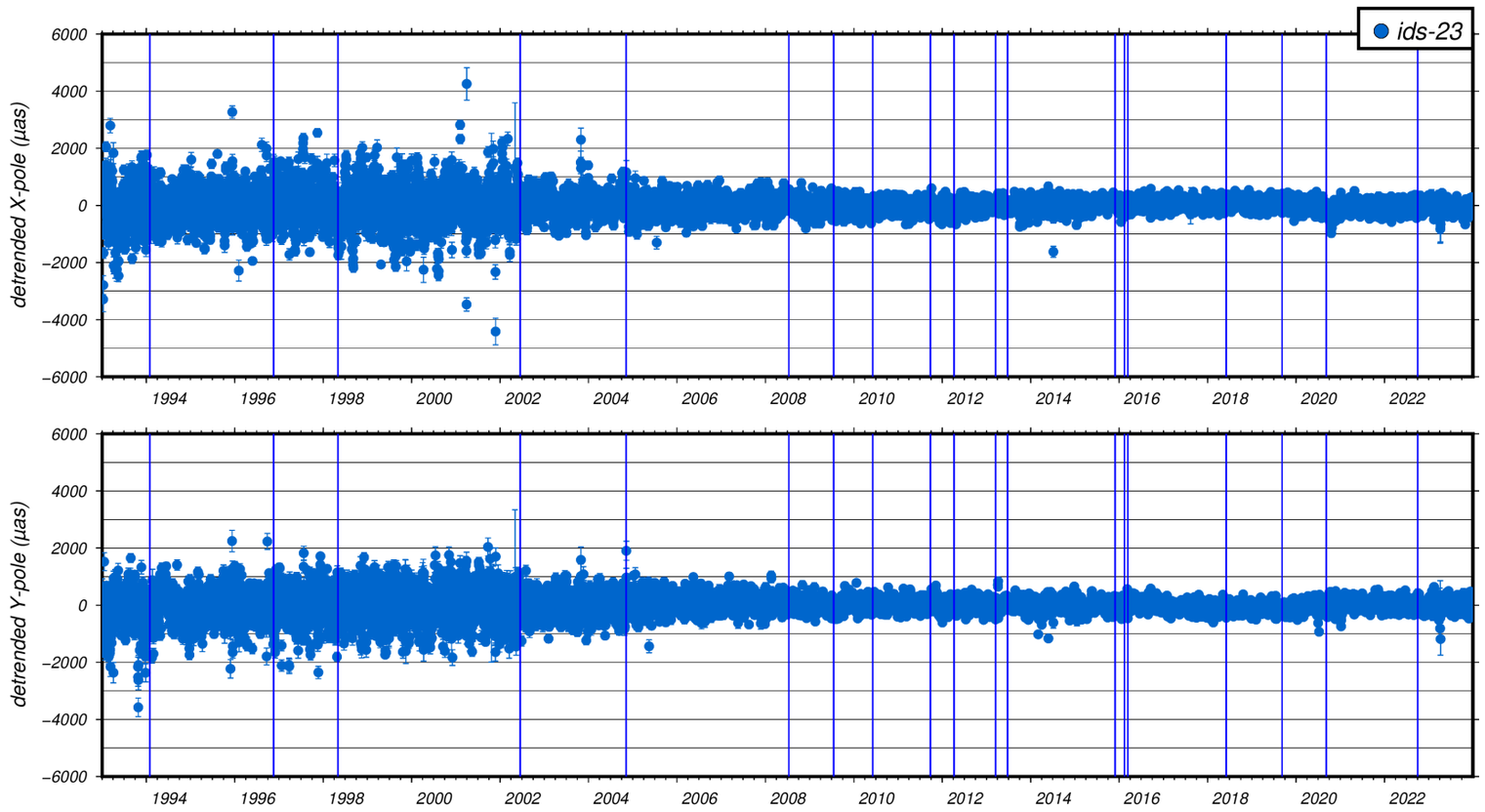
→Track 2 DORIS beacons at a time

≥ 2008: DGXX, DGXX-S era.

Track up to 7 DORIS beacons at one time.

Evolution of EOP Performance for DORIS from DPOD2020

IDS EOP Differences with IERS C04 series for DPDO2020v3



Std. Dev. Of Diffs. With IERS C04 computed by the IDS CC

1993 doy001-2002 doy167:
Xpole: 665 μas
Ypole: 593 μas

2008 doy195-2015 doy333
Xpole: 205 μas
Ypole: 191 μas

2015 doy333-2023 doy365
Xpole: 188 μas
Ypole: 181 μas

New IDS Working Groups

WG on Near Real Time (NRT) Ionospheric Applications

- **Use NRT DORIS data & orbits to contribute to ionospheric products.** (**NRT data available from 7-9 satellites < 3hrs latency**).
- **WG Approved by IDS GB October 2024.**
- Chair: Ningbo Wang (AIR/CAS);
  Co-Chair: Phillipe Yaya (CLS).
- Continuation of NRT WG led by Denise Dettmering (DGFI-TUM).
- Presently 15 members & growing.

Results of pilot project with Jason-3 NRT data described in this publication:

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.

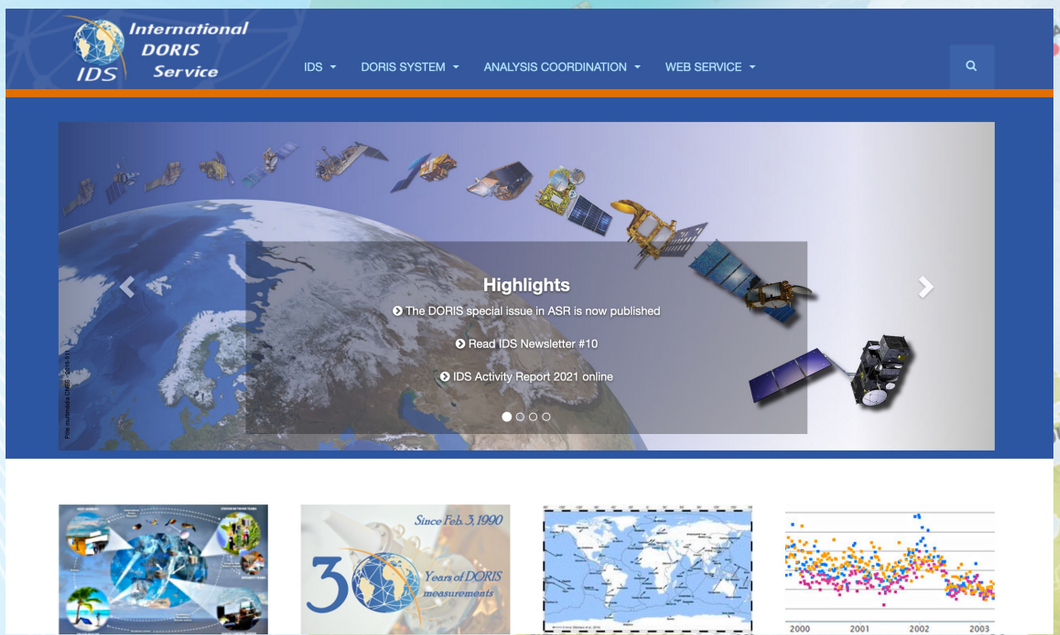
WG on Integrated Clock Strategies for DORIS

- DORIS clocks (USO's) on-orbit are subject to perturbations from radiation (esp. SAA) and other sources. A limiting error source in DORIS data analysis.
- **Use external information (models) and ties to GNSS clocks to improve DORIS USO modelling, on-orbit and on the ground: Sentinel-3A, 3B, Sentinel-6A, Sentinel-6B & eventually Genesis.**
- **Develop a routine improved clock product for use in DORIS processing.**
- **WG Approved by IDS GB June 2024.**
- Chair: Patrick Schreiner (GFZ);
- Presently 14 members.

Better DORIS USO modelling will improve DORIS contributions to the ITRF & will be important for the Genesis mission.

Where to go for more information?

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

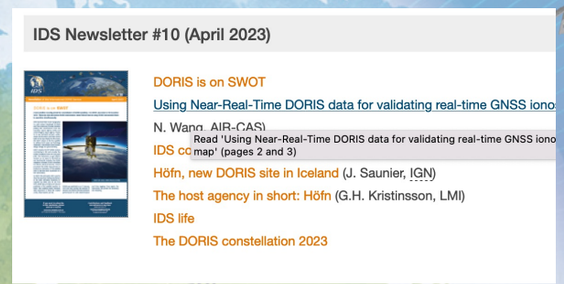


- IDS Bibliography, All meeting presentations,
- IDS Station site logs & station viewer.
- IDS Station Position Time series viewer.
- IDS Satellite information.

Etc.

IDS Newsletter

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



Contacts for more information:

IDS Central Bureau:

Email: ids.central.bureau@ids-doris.org

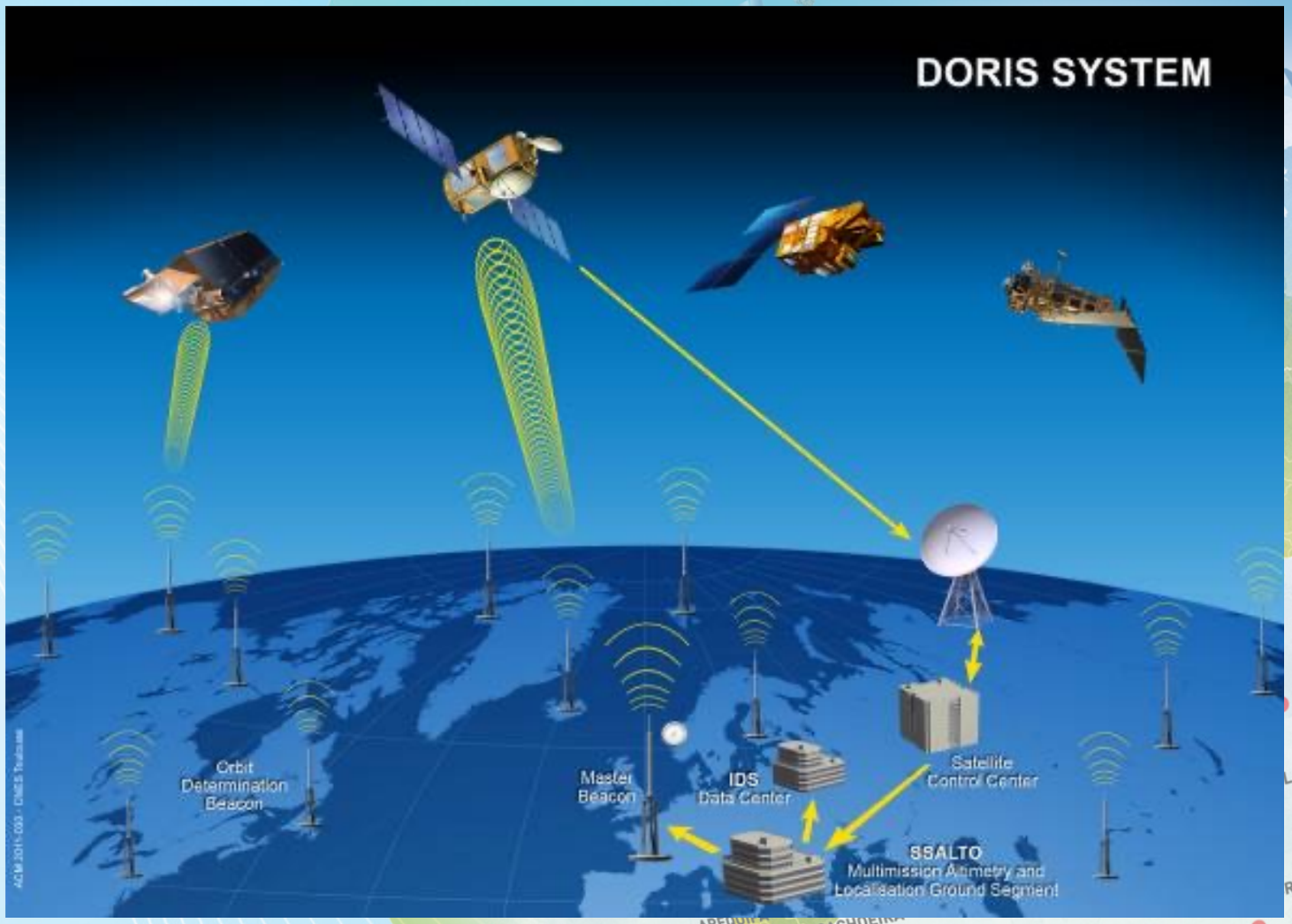
IDS Analysis Coordinator:

Email: ids.analysis.coordination@ids-doris.org


DORIS NETWORK
Jason2
Envisat
Spot5
Cryosat-2
Hy2-A
Saral
Jason3
Sentinel3A
Sentinel3B
HY-2C
Sentinel6A
HY-2D
Spot4
Jason1
Topex Poseidon
Spot3
Spot2
NY-ALESUND II
THULE
YELLOWKNIFE
ST JOHN'S
GREENBELT
GOLDSTONE
MIAMI
SOCORRO
LE-LAMENTIN
KOUROU
MANAGUA
SANTA CRUZ
AREQUIPA
CACHOEIRA
SAN-JUAN
PONTA DELGADA
SAL
TOULOUSE
GRASSE
DIONYSOS
DJIBOUTI
LIBREVILLE
ASCENSION
ST-HELENA
TRISTAN DA CUNHA
HARTEBEESTHOEK
MAHE
LA RÉUNION
MALE
AMSTERDAM
CROZET
MARION
KERGUELEN
EVEREST
JIUFENG
MANILA
MANGILAO
CIBINONG
BETIO
NOUMEA
YARRAGADEE
MOUNT STROMLO
KAUAI
PAPEETE
RIKITEA
TERRE-ADÉLIE

Backups

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*)

What is DORIS?

- **DORIS is one of the four techniques of Space Geodesy, along with SLR, VLBI & GNSS.**
- **Has contributed to the ITRF, and to POD for LEO satellites since 1990.**

DORIS stands for

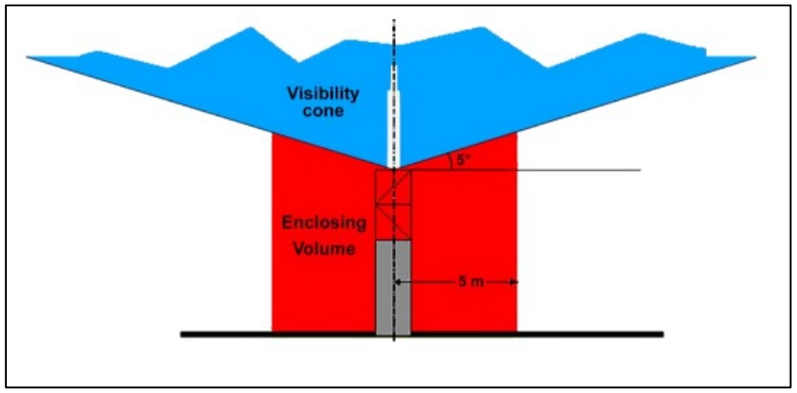
- **D**oppler **O**rbitography and **R**adiopositioning **I**ntegrated by **S**atellite
- **D**étermination d' **O**rbite et **R**adiopositionnement **I**ntégrés par **S**atellite
- **D**eterminación de **Ó**rbita y **R**adioposicionamiento **I**ntegrados por **S**atélite
- **D**eterminação de **Ó**rbita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

The DORIS Network: Requirements

The network is managed to rigorous geodetic and operational standards.

SYSTEM REQUIREMENTS

- Clear sky view above 5° elevation
- No metal object (likely to cause multipath) in a 5m radius around the antenna
- No interferences with receiving / transmitting devices in the vicinity



GEODETIC REQUIREMENTS

➢ **Minimize velocities uncertainty and noise in the position data**

- Monuments must be firmly coupled with the substrate
- Properly size monument foundations according to soil structure
- Minimizing thermal or elastic distortion due to weather conditions
- Stability assessment: field measurements during maintenance operations

THREE STANDARD MONUMENTS

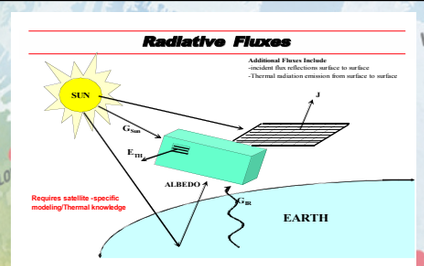
Specifications applied to all new constructions since 2010

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

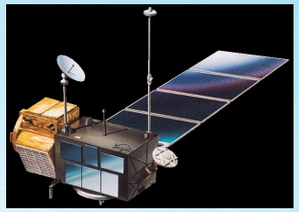
IDS Combination Center

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

IDS Challenges & Opportunities:
DORIS Satellites

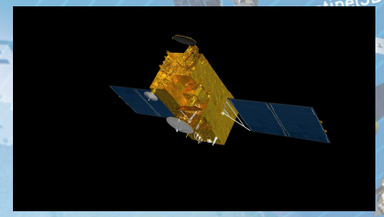


TOPEX

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!!**

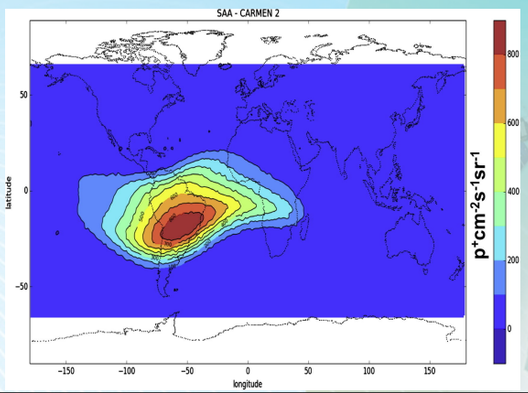
Opportunities

- All current satellites have multiple tracking systems (SLR & GNSS).
- We can usually work with other POD experts (e.g. CPOD) to aid in modelling & analysis.
- Design metrology has improved with time (better know parameters such as tracking points, center-of-mass).
- Most (not all) of current missions provide quaternion information.
- POD techniques & background models have improved with time (red-dynamics, ITRF model, GRACE/GOCE, VMF …).

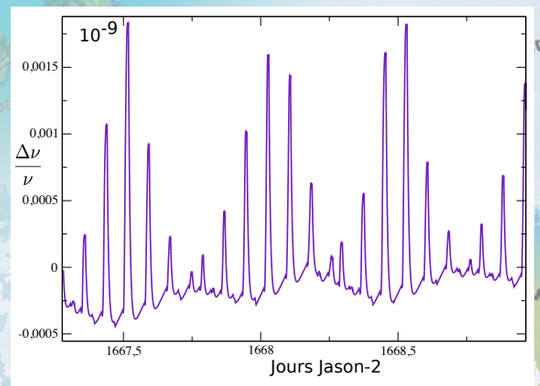
- **We now have nine active DORIS Satellites!!**

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.

WHOM to contact?
- IDS Analysis Coordinator (Petr Štěpánek, GOP).
- IDS Central Bureau.

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?

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.