Science applications of DORIS

DORIS DAYS 2025

November, 3 and 5

Jean-Michel Lemoine (CNES)

November 3

Session 1 – Presentation 3

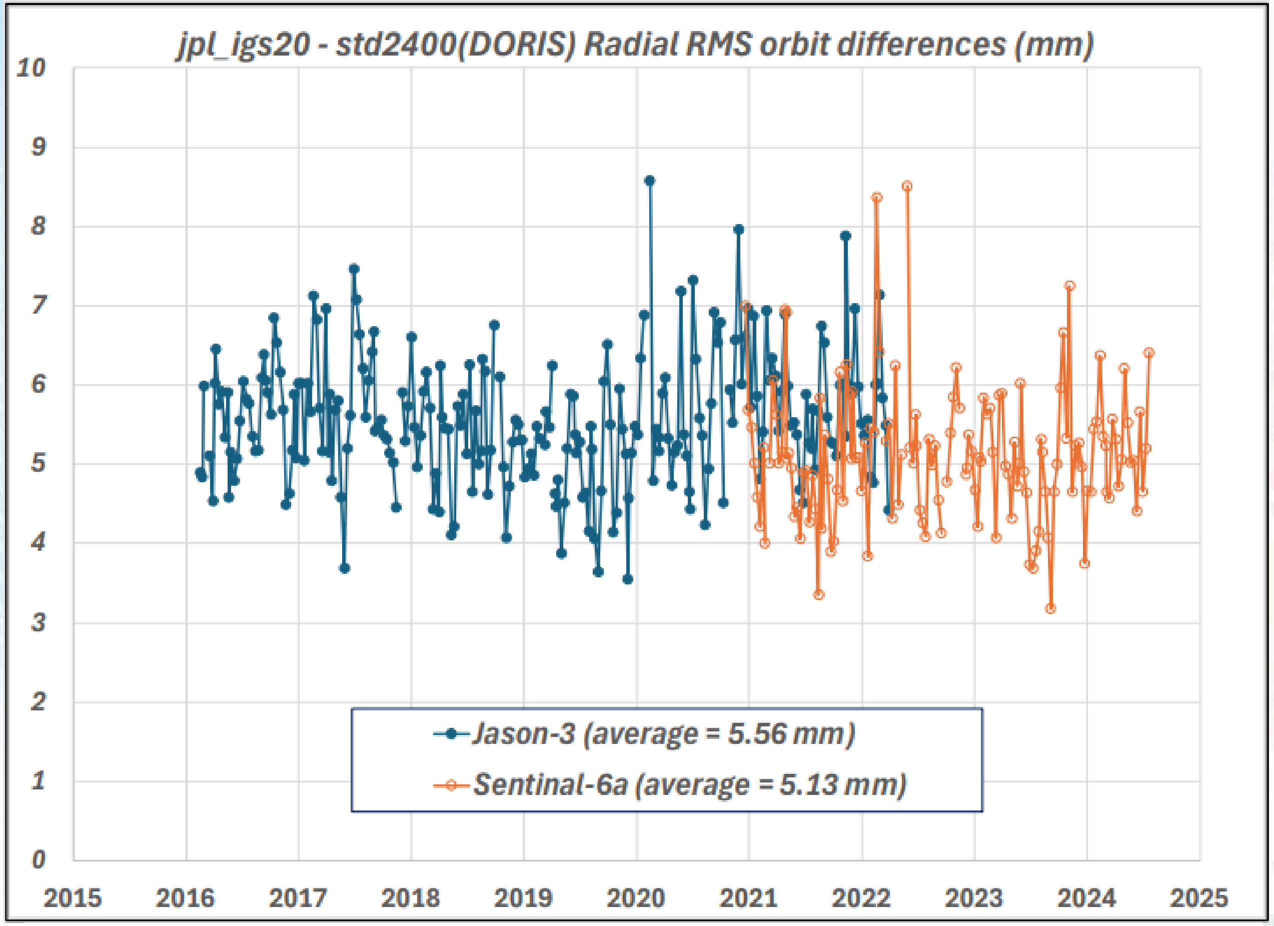
IDS

Summary

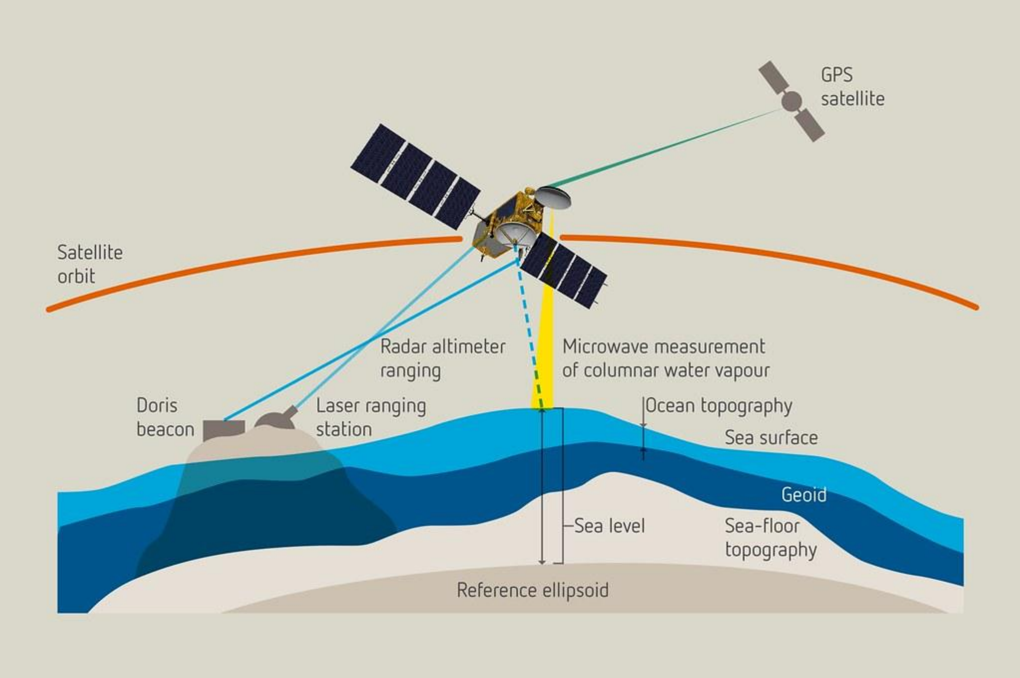
- Precise Orbit Determination (POD)
- Station positioning and plate tectonics
- International Terrestrial Reference Frame (ITRF)
- Gravity field modeling
- Troposphere
- Ionosphere

Precise Orbit Determination (POD) for satellite altimetry

Radial orbit differences between DORIS-only and GPS-only orbits of Jason-3 et Sentinel-6A (RMS / 10-day cycle)



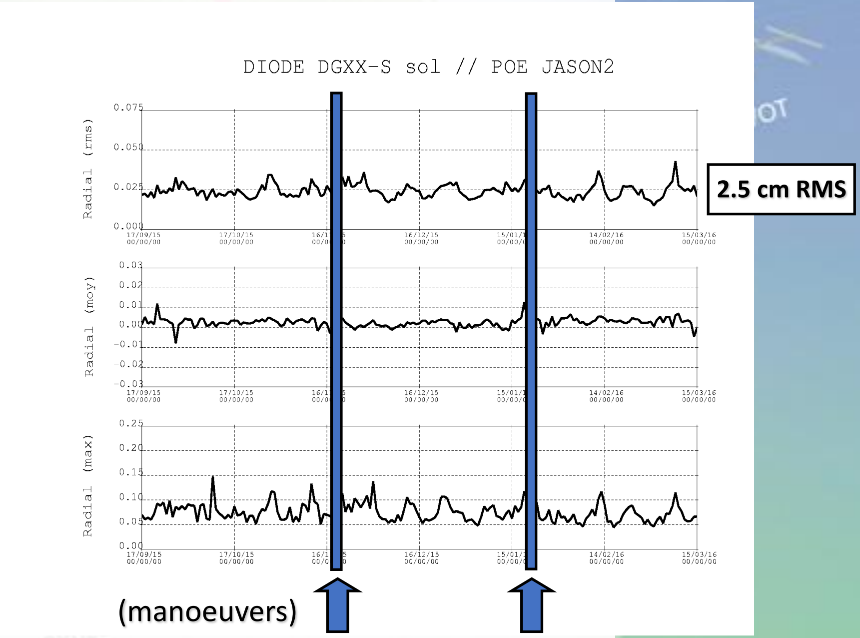
From Lemoine et al. « The International DORIS Service: After 20 Years Looking to the Future», AGU 2024



The radial orbit accuracy of DORIS is 5 to 7 mm for Jason-3 et Sentinel-6A.

Real time on-board orbit determination: DIODE

- DIODE is a *real time on-board orbit determination* software; it computes the position and the velocity of the satellite using a Kalman filter algorithm
- Initiated by CNES in 1991, after a conclusive feasibility study from 1988 to 1990. Developed by CNES, with technical support of AKKA-COFRAMI.
- First version on-board SPOT4 (March 1998) : demonstration experiment
- Then DIODE was fully integrated in the DORIS on-board software. Enhanced versions were flown with ENVISAT, Jason-1 and SPOT5, then on every DORIS mission …
    - allowing advanced automation of the receivers
    - excellent availability (more than 99.7%).
    - positions and velocities produced with an accuracy better than 1 m RMS in 3D (2-3 cm RMS in radial !)



Station positioning

DORIS has a global network of **61 permanent stations**.

- The network of ground stations is evenly distributed around the world
- Ground stations transmitting continuously the DORIS signal (RF system → all weather system)
- Very good stability of this network through time + long time series (30 years) + uniform distribution → quality of the DORIS Reference Frame

Future stations:

Kanpur (India)

Potentially a 4-techniques site.

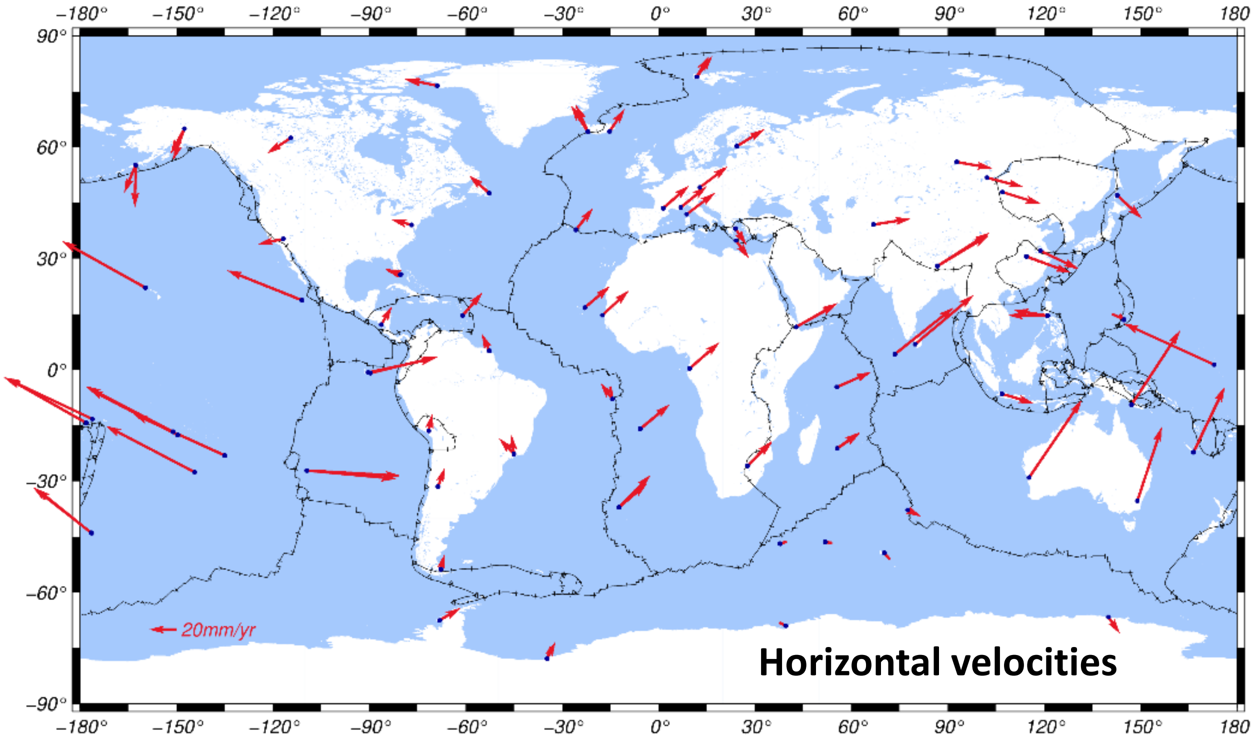
Collaboration between IDS and IIT Kanpur for the establishment of a DORIS Analysis Center.

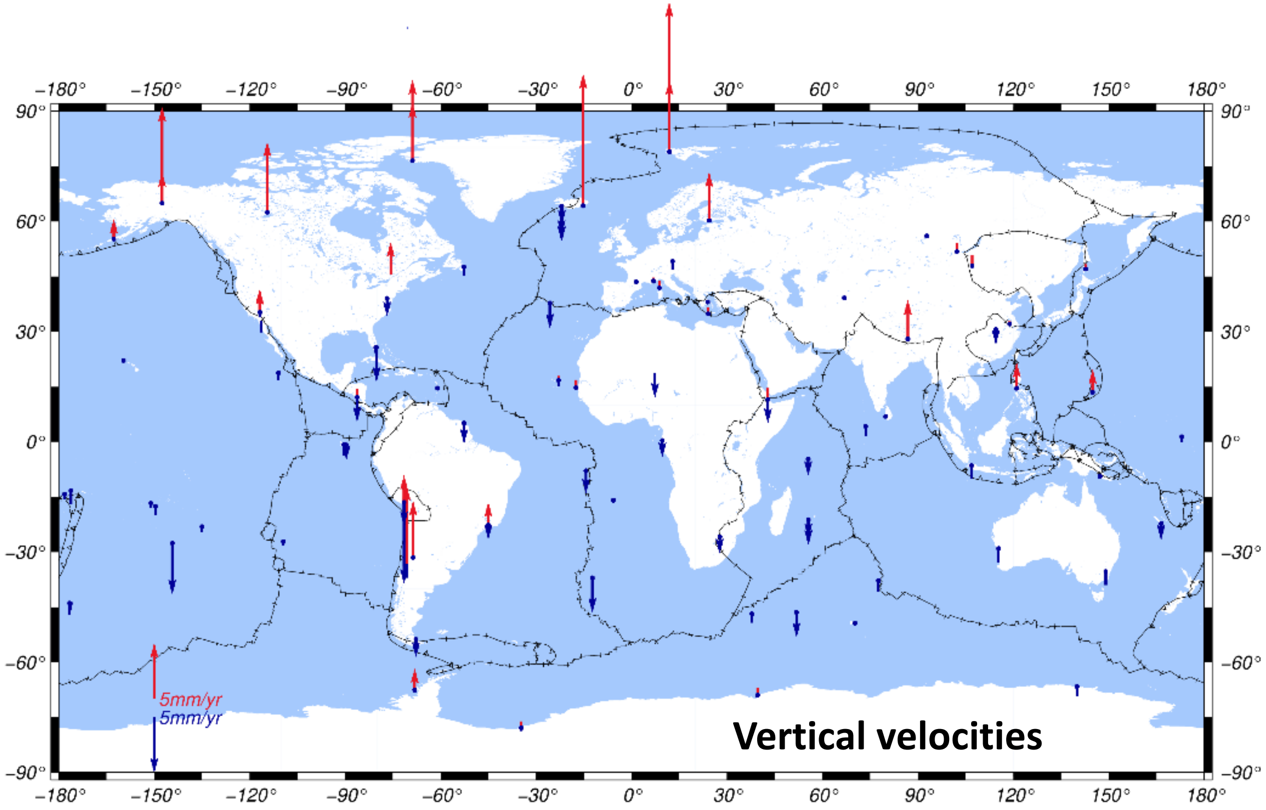
Katherine (Australia)

Colocation with GNSS and VLBI

- 51 colocations with other IERS techniques, 29 colocations with tide gauges.
- Deployment of the 4G beacons is underway.
- Network densification to approximately 70 stations is in progress.

Station positioning: horizontal and vertical velocities



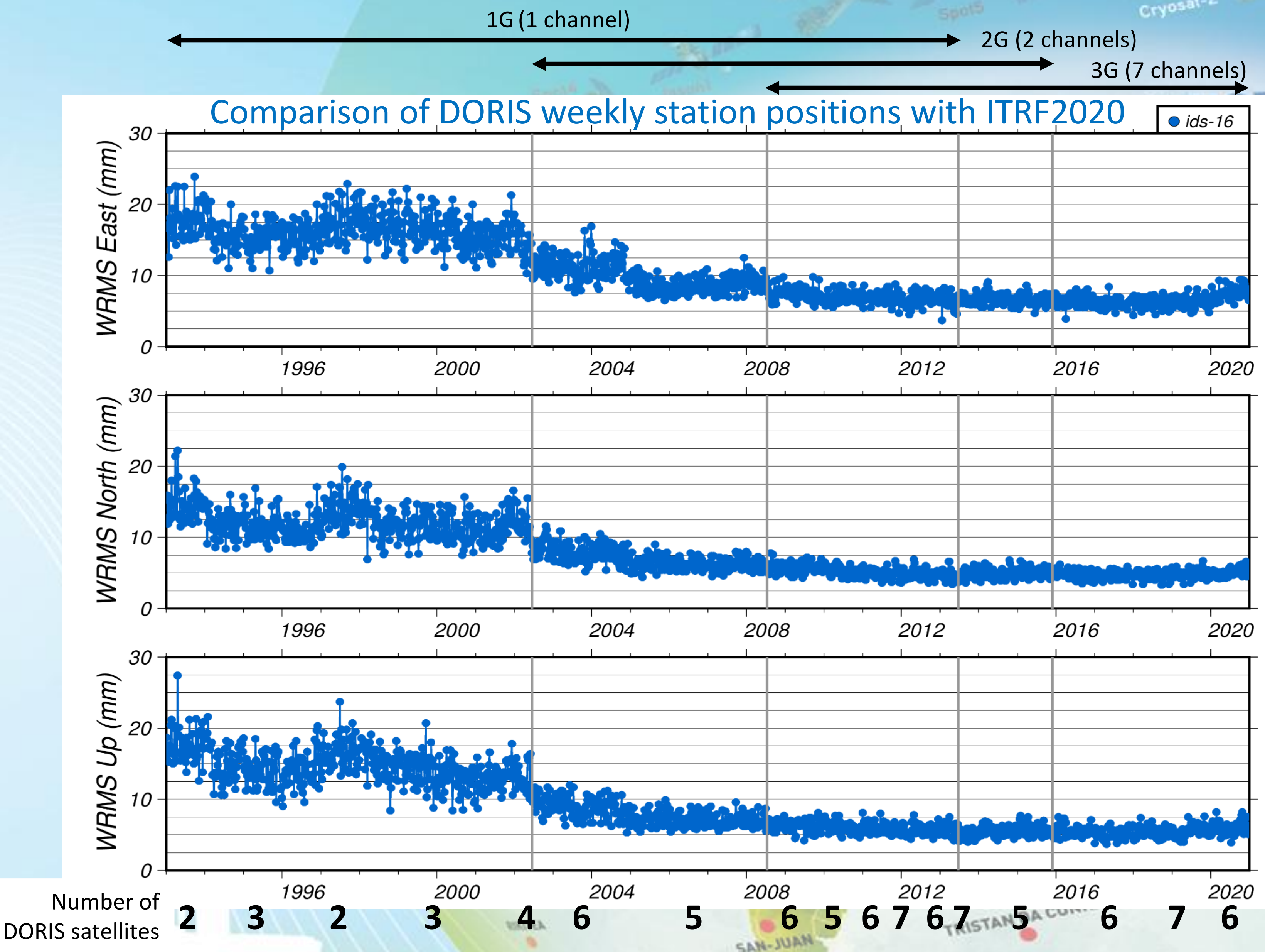


Source: IDS Combination Center

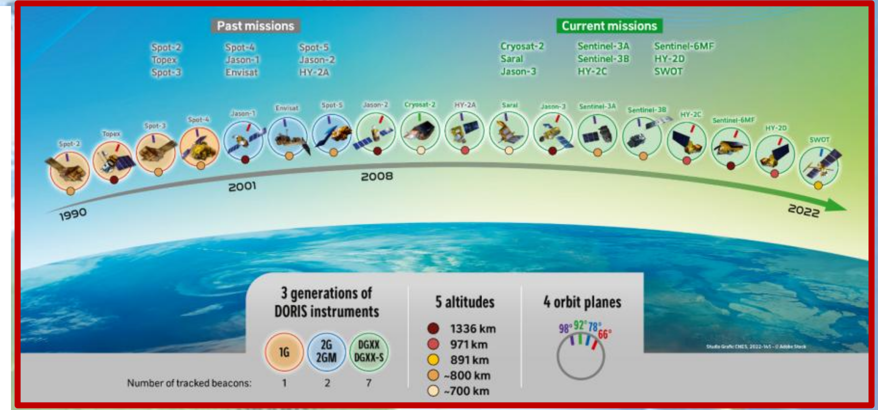
DPDO2020 solution version 4.0

DPOD = DORIS spatio-temporal extension of the current ITRF solution.

Station positioning: positioning accuracy



Today: **9 satellites,** all in DORIS/DGXX-S

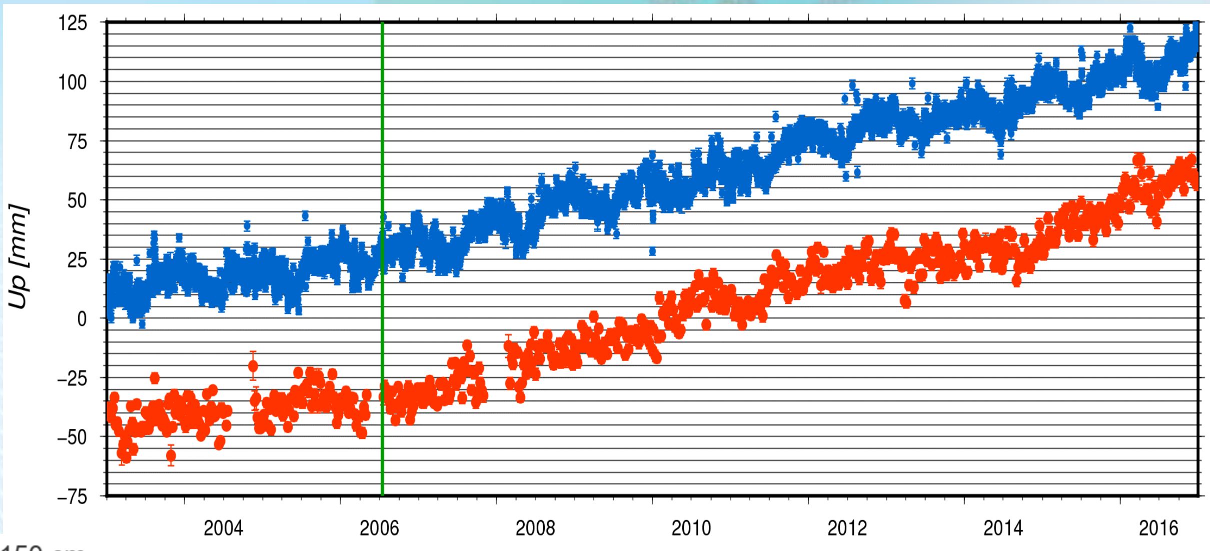


The improvement in results is correlated with the increase in the number of satellites and the deployment of the latest generation of DORIS receivers.

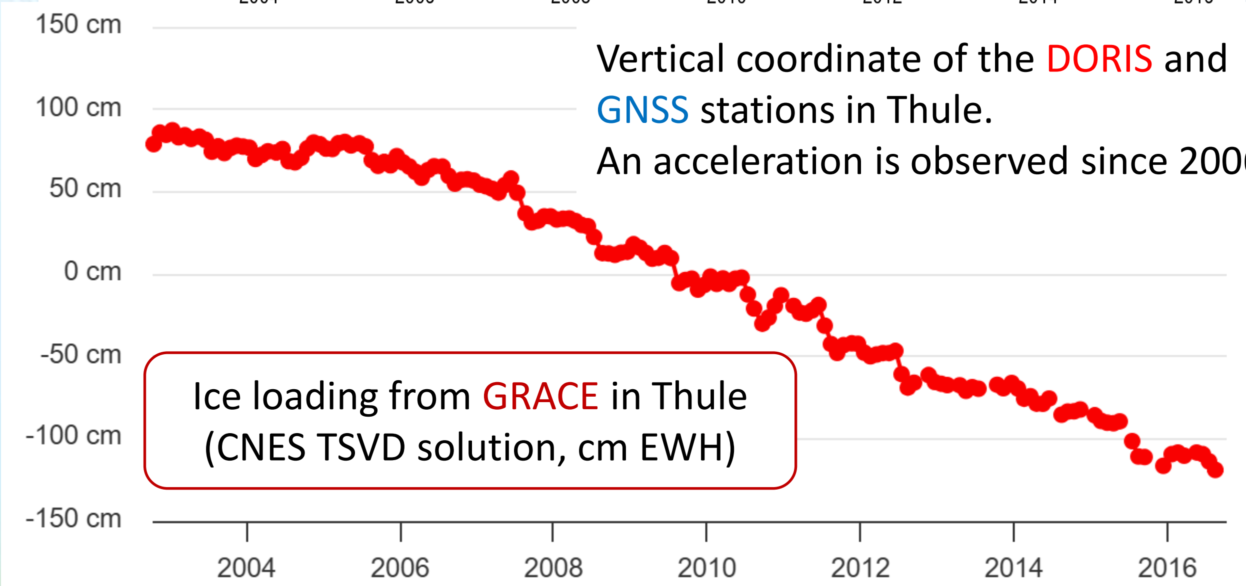
3D WRMS < 7.5 mm since mid-2008

Source: IDS Combination Center

Station positioning example: Thule
(Impact of glacial melt in Greenland)



Vertical coordinate of the DORIS and GNSS stations in Thule.
An acceleration is observed since 2006.

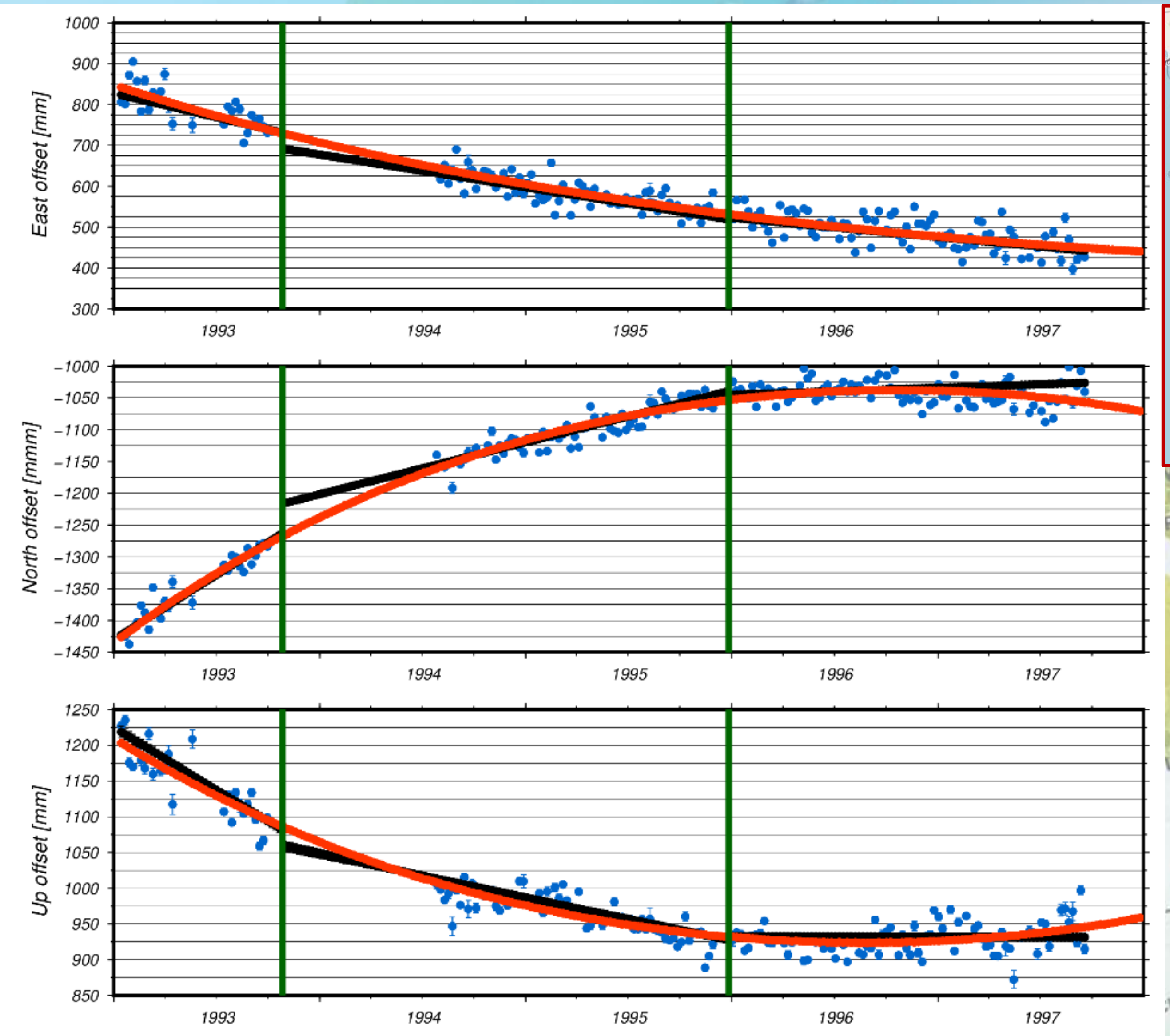


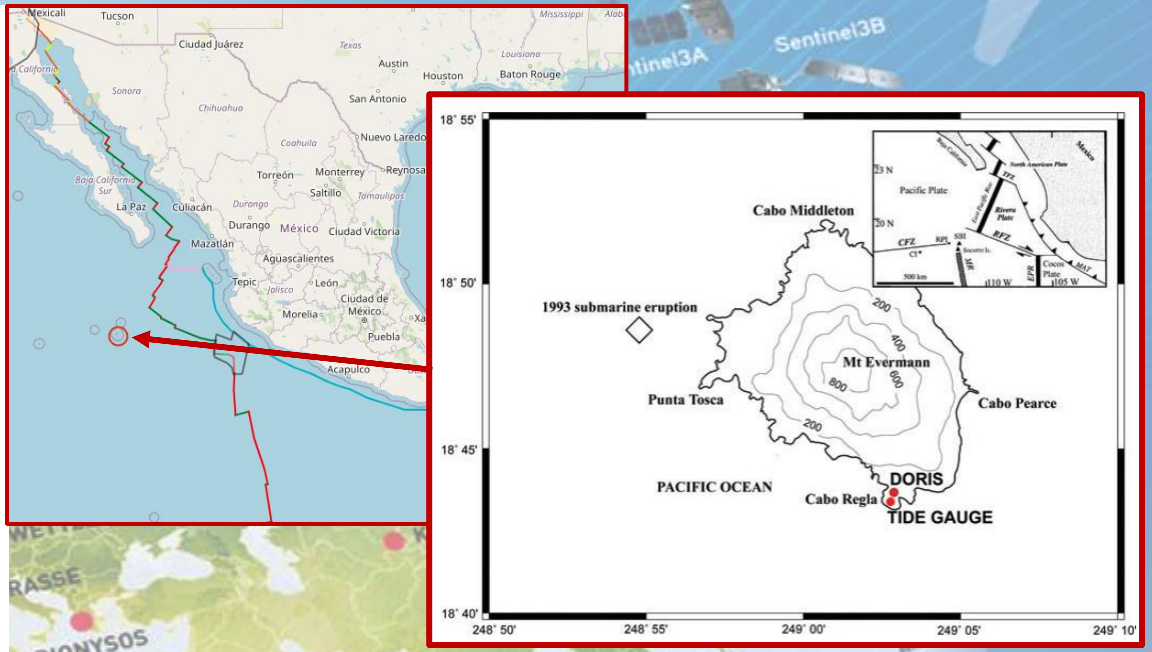
Ice loading from GRACE in Thule
(CNES TSVD solution, cm EWH)

[Moreaux et al., 2019] confirmed similar behavior in water height equivalences derived from GRACE mission data and correlated this increase in Thule station uplift to an accelerated mass loss of glaciers located along the coast.

DORIS can be useful for monitoring ice sheet melt and climate change.

Station positioning example: volcanological application
(deflation of Mt. Evermann volcano observed at Socorro)

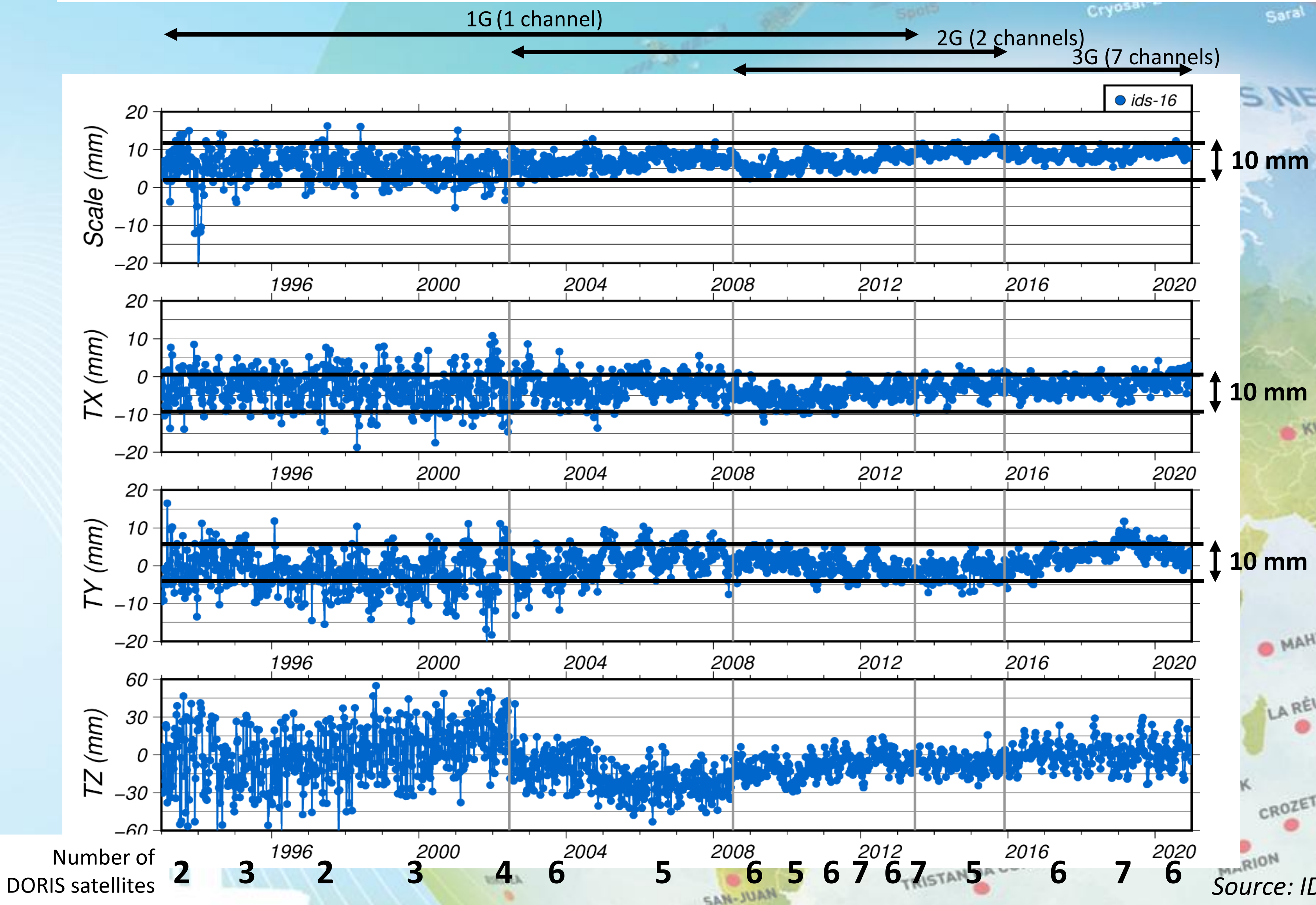




An underwater volcanic eruption between January 1993 and March 1994, 4 km west of the island, was the cause of the volcano's deflation [Briole et al., 2009]

DORIS can be used to monitor earthquakes and better model landslides.

Earth reference frame
(Scale and translations, comparison to ITRF2020)



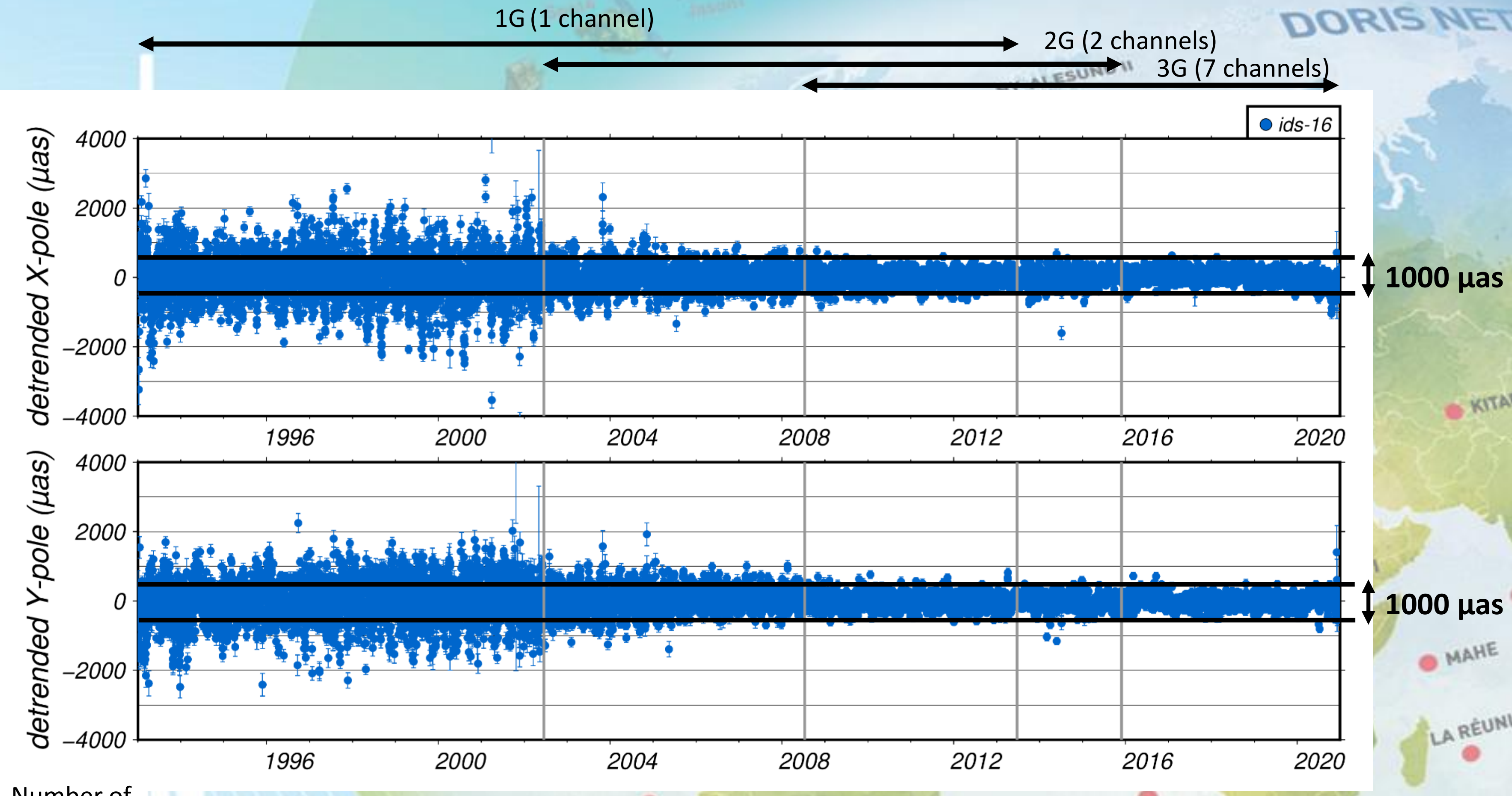
Scale, **Tx** and **Ty** have been within a range of 10 mm since mid-2002.

Tz is sensitive to solar pressure and to the modeling errors of atmospheric drag.

Source: IDS Combination Center

Earth Orientations Parameters (EOP)

Difference between the DORIS EOP series for ITRF2020 and the IERS C04 series



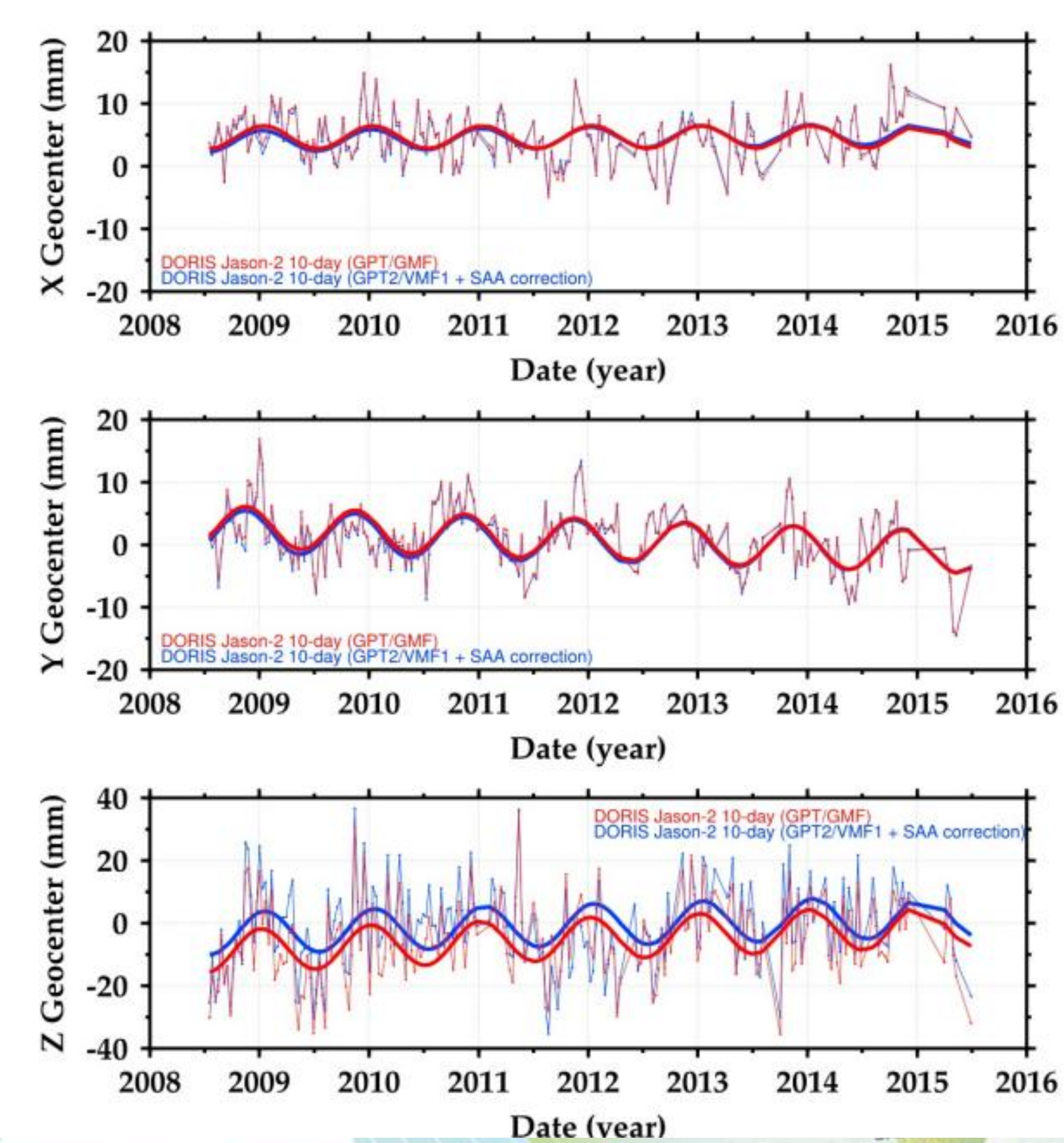
Number of DORIS satellites 2 3 2 3 4 6 5 6 5 6 7 6 7 5 6 7 6

Source: IDS Combination Center

Results are improved when more satellites are available and with the latest generation of DORIS receivers.

RMS have been around 200 µas since the end of 2015.

Geocenter displacement



[Couhert et al., 2018] showed that DORIS data from Jason-type orbits (**excluding polar-orbiting satellites**) can be used to derive solutions for the geocenter.

DORIS solutions can be used to determine the annual geocenter signal with a quality comparable to that of SLR solutions from LAGEOS satellites.

Fig. from Couhert et al., 2018 « Systematic Error Mitigation in DORIS-Derived Geocenter Motion »

DORIS is one of the four geodetic techniques

	GNSS	SLR	VLBI	DORIS
Network density / homogeneity	🙂	☹	☹	🙂
Equipment/Teams stability	☹			
Short term accuracy	🙂	🙂	🙂	☹
Long term series	☹			🙂
Calibration / Biases / ref. point	☹ Some missing	☹ Time scale Ref. point	☹ Time scale Ref. point	🙂

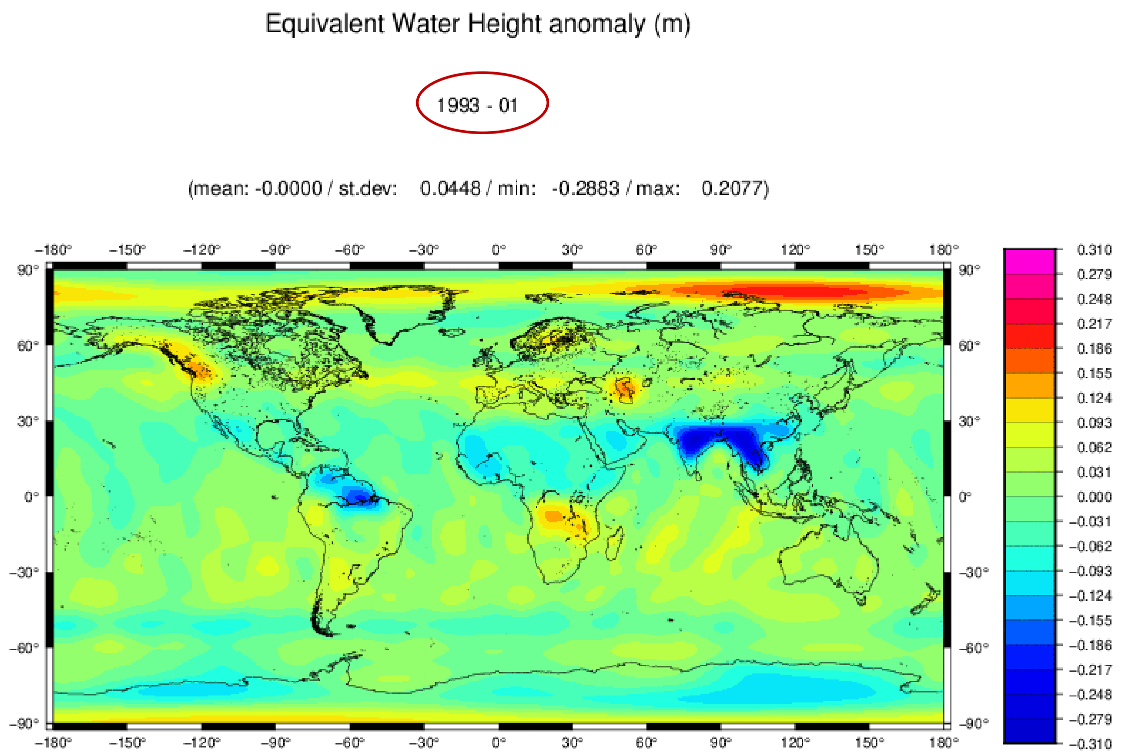
“ At centimetre level or less, no technique can give alone the true position. Permanent intercomparisons between different techniques are essential to track down the truth in the midst of biases and noise “ **R. Zaharia**

<u>The best technique for :</u>				
Earth pole motion	🙂			
ITRF (centre) / scale		🙂		
Universal Time			🙂	
Long term phenomena				🙂

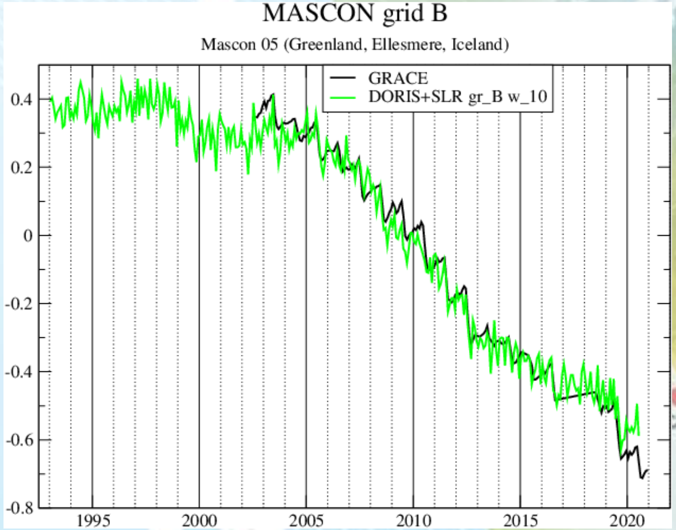
Gravity field

Using SLR and DORIS data, and leveraging lessons from GRACE, it was possible to obtain solutions of the Time-Variable Gravity field (TVG) prior to 2002.

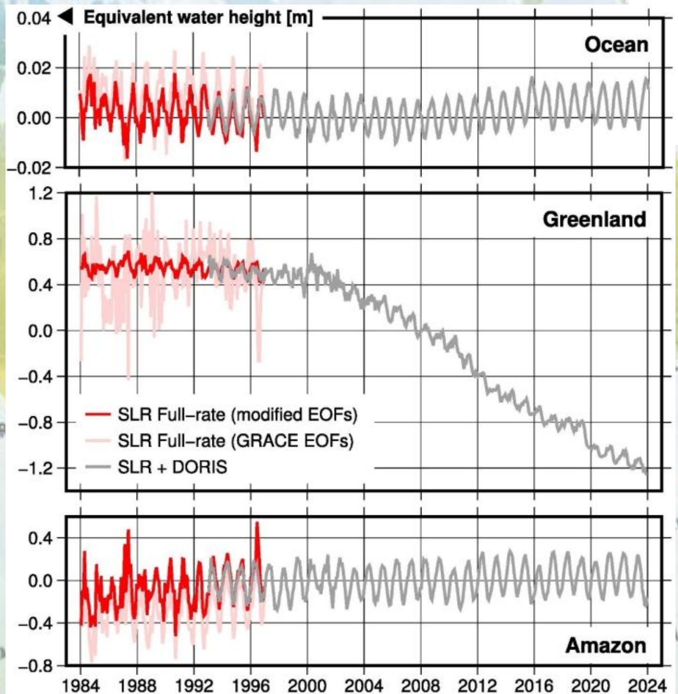
Two different techniques were used: “super-mascons” (Lemoine, GET, Toulouse) or EOFs (Löcher, University of Bonn).



From GET/OMP, Toulouse



Greenland ice mass from Lemoine (“super-mascons”)



From Löcher, Anno; Kusche, Jürgen; Nie, Yufeng (2025): A 40-year record of the Earth’s time-variable gravity field from SLR and DORIS. Advances in Space Research. 10.1016/j.asr.2025.05.089

Troposphere

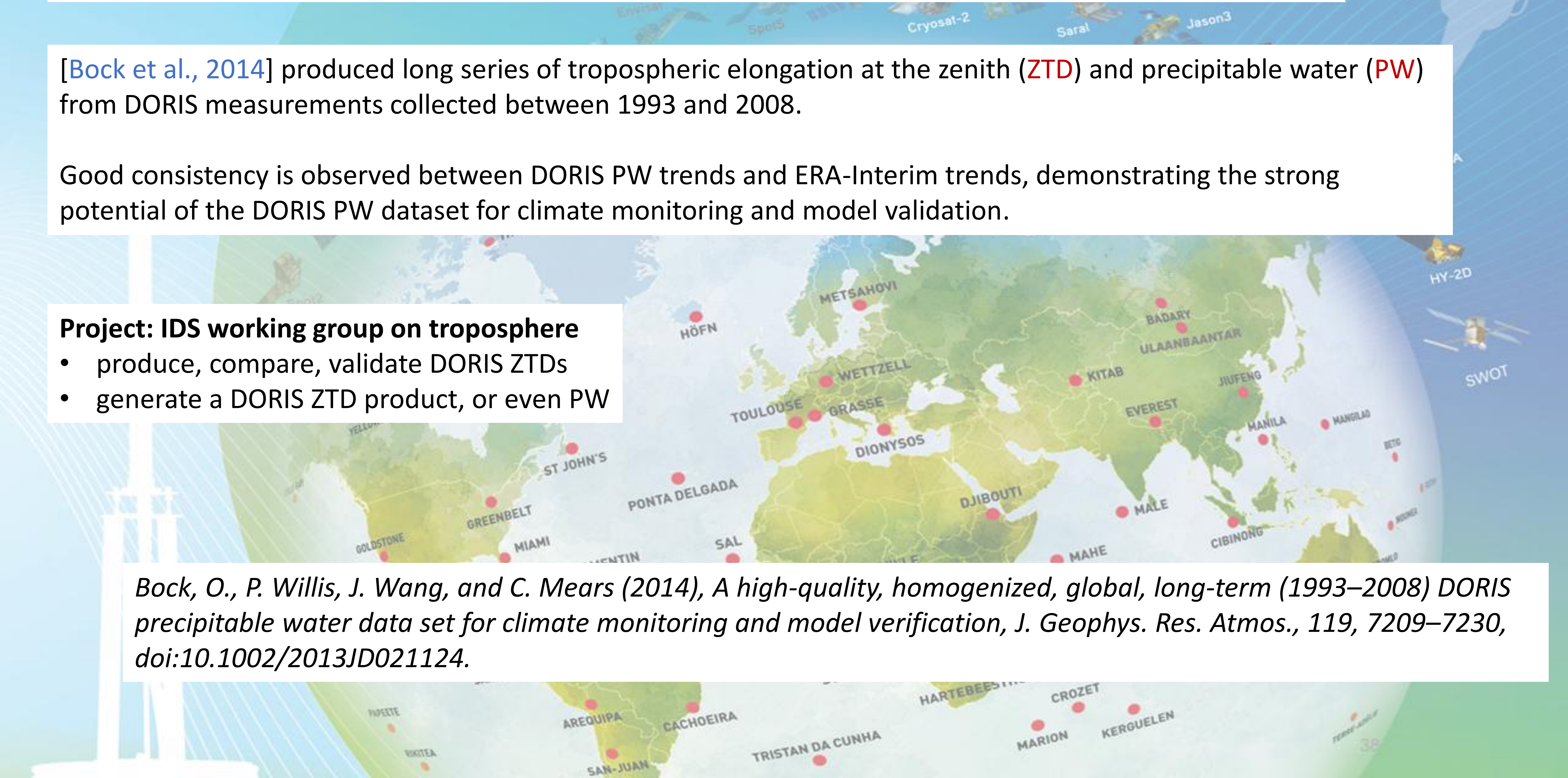
[Bock et al., 2014] produced long series of tropospheric elongation at the zenith (ZTD) and precipitable water (PW) from DORIS measurements collected between 1993 and 2008.

Good consistency is observed between DORIS PW trends and ERA-Interim trends, demonstrating the strong potential of the DORIS PW dataset for climate monitoring and model validation.

Project: IDS working group on troposphere

- produce, compare, validate DORIS ZTDs
- generate a DORIS ZTD product, or even PW

Bock, O., P. Willis, J. Wang, and C. Mears (2014), A high-quality, homogenized, global, long-term (1993–2008) DORIS precipitable water data set for climate monitoring and model verification, J. Geophys. Res. Atmos., 119, 7209–7230, doi:10.1002/2013JD021124.



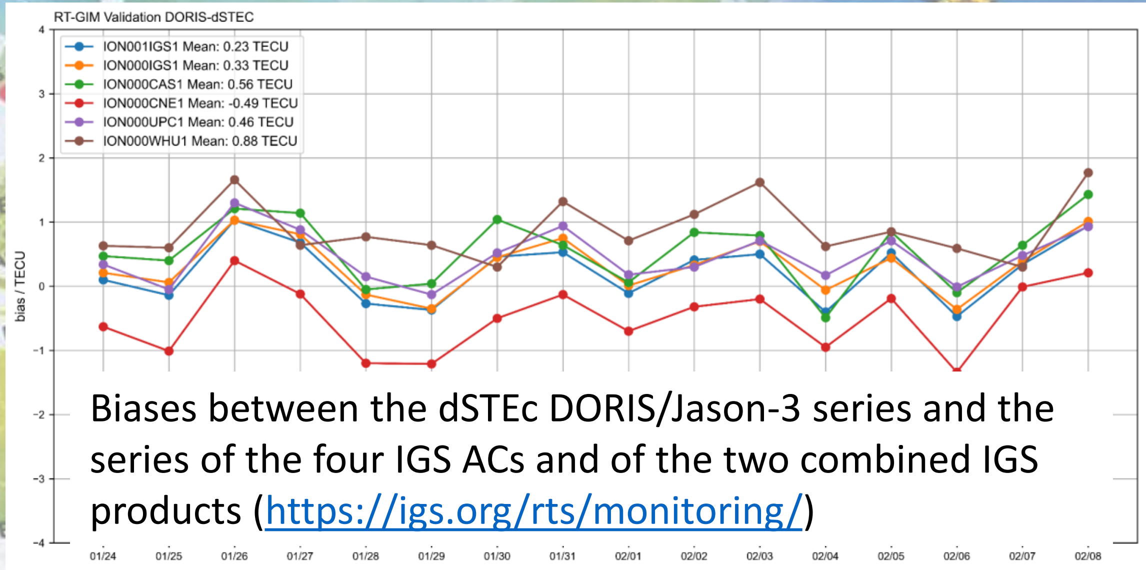
Ionosphere

Assets of DORIS:

- The ratio between the two DORIS frequencies (2036.25 MHz and 401.25 MHz) is approximately 5, compared to a maximum of 1.34 for GPS signals, resulting in a 14-fold more precise measurement of the ionospheric delay by DORIS.
- Data is in RINEX/DORIS 3.0 format, similar to the RINEX/GNSS format.
- RINEX/DORIS data is available to the public in less than 3 hours.

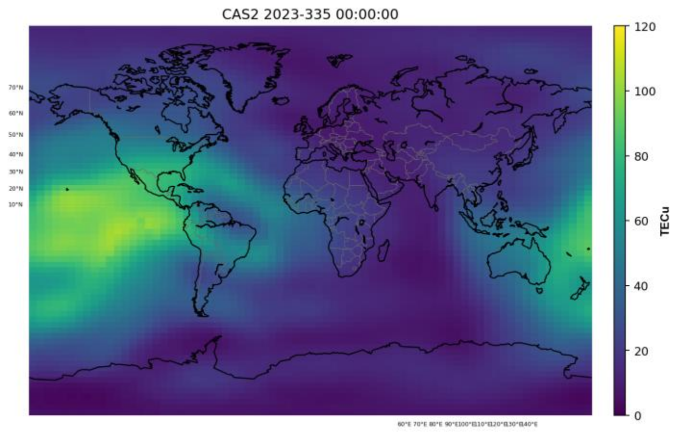
Use of NRT DORIS data for independent and external validation of existing GNSS-based ionospheric models

Since August 2025, NRT DORIS data from Jason-3 has been routinely used by the IGS real-time service to check the accuracy of various RT-GIM products with a delay of approximately 24 hours.



Biases between the dSTEc DORIS/Jason-3 series and the series of the four IGS ACs and of the two combined IGS products (https://igs.org/rts/monitoring/)

Construction of combined GIM maps with DORIS



IDS Working Group « NRT ionospheric application »
Chair: Ningbo Wang (AIR/CAS)

List of variables that DORIS can observe

https://ids-doris.org/user-corner/applications.html

POD

- Precise orbits for altimeter missions contributing to determination of the Mean Sea Level [Rudenko et al., 2019]

Positioning

- Tectonic plate parameters [Kraszewska et al., 2018]
- Horizontal and vertical velocities of the stations [Moreaux et al., 2016]
- Glacial Isostatic Adjustment [King et al., 2010]
- Long-time series of station positions, records of events affecting the DORIS stations such as:
  - Earthquakes (eg Gorkha Earthquake recorded at Everest's station) [Moreaux et al., 2019],
  - present day ice melt of nearby glaciers (eg uplift acceleration in Thule, Greenland) [Moreaux et al., 2019],
  - volcanic activity (eg deflation of the Mt. Evermannn volcano observed at Socorro) [Briole et al., 2009],
  - subsidences (eg slow subsidence of the Tahiti island) [Fadil et al. 2011], …

Reference system

- Contribution to the realization of the ITRF [Moreaux et al., 2016]
- Geocenter motion [Couhert et al., 2018] and Scale of the Terrestrial Reference Frame [Štěpánek and Filler, 2018]
- Earth Pole coordinates and estimation of LOD [Štěpánek et al., 2018]

Terrestrial environment

- Contour of the South Atlantic Anomaly [Capdeville et al., 2016]
- Vertical Total Electron Content of the Earth's ionosphere [Dettmering et al., 2014]
- Detection of scintillations (eg CITRIS project) [Siefring et al., 2011]
- Thermosphere perturbations during severe geomagnetic conditions [Willis et al., 2005]
- Long time-series of tropospheric delays and precipitable water [Bock et al., 2014]

Gravity field

- Gravity field time series [Löcher et al., 2025]

Key points

- DORIS is one of the four geodetic techniques participating in the realization of the Terrestrial Reference Frame
- It has been working continuously since 1990, with regular upgrades to beacons, antennas and on-board receivers
- Its main strength lies in its dense, stable and homogeneous network, which allows the study of long-term effects
- Apart from POD, station positioning and TRF, it can provide scientific insights in
    - Gravity field
    - Troposphere
    - Ionosphere