Overview of the DORIS processing improvements for the next ITRF realization

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Context

Since the release of the 2020 realization of the International Terrestrial Reference Frame (ITRF2020), the Analysis Centers (ACs) of the International DORIS Service (IDS) have been engaged in several efforts to improve the processing of the DORIS observations obtained since the launch of the HY-2A mission mid-2011. These efforts include (i) improving the orbit and measurement modelling (atmospheric loading effects, satellite surface force modeling…) (ii) reviewing the mitigation strategies of the South Atlantic Anomaly (SAA) effects on the onboard DORIS Ultra Stable Oscillators (USO's) (iii) individually analyzing the DORIS satellite contributions to geocenter and scale, and (iv) assessing the impact of the latest DORIS satellites (Sentinel-6A, HY-2C, HY-2D and SWOT) on the IDS products.

Among the studies on the SAA mitigation strategies, in the scope of the IDS WG titled "Integrated Clock Correction Strategies for DORIS", the IDS community will take advantage of the connection of the GPS/GNSS and DORIS receivers to the same USO on Sentinel-3A/3B/6A to correct the DORIS phase measurements.

The objective of this study is to present the major DORIS processing evolutions and studies which may improve the quality of the DORIS scale, geocenter and station positions.

IDS Series & DORIS Missions

The following table contains some details about what we call in afterwards by ESA, GOP, GRG, GSC, IGN and IDS weekly series.

Analysis Center	Series	Time Period	Comments
ESA	ESA 13	1993.00-2021.00	ESA contribution to ITRF2020.
	ESA 16	2021.00-2025.50	ESA contribution to ITRF2020-u2024.
GOP	GOP 67	1993.00-2021.00	GOP contribution to ITRF2020.
	GOP 70	2021.00-2025.50	GOP contribution to ITRF2020-u2024.
GRG	GRG 43	1993.00-2011.75	GRG contribution to ITRF2020.
	GRG 52	2011.75-2021.60	New: SAA mitigation strategy for HY-2A.
	GRG 56	2021.60-2025.50	GRG contribution to ITRF2020-u2024.
GSC	GSC 52	1993.00-2011.85	
	GSC 53	2011.85-2021.00	New: SAA mitigation strategy for HY-2A.
	GSC 61	2021.00-2025.50	GSC contribution to ITRF2020-u2024.
IGN	IGN 22	2021.00-2025.50	IGN contribution to ITRF2020-u2024.
IDS	IDS 19	1993.00-2021.00	Extension of the IDS contribution to ITRF2020.
	IDS 26	2021.00-2025.50	New combined solution from ESA 16, GOP 70, GRG 56, GSC 61 and IGN 22.

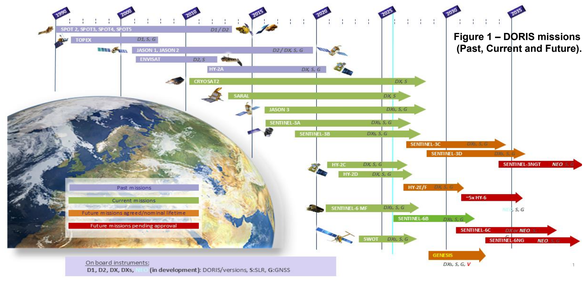

Figure 1 – DORIS missions (Past, Current and Future).

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Scale

From Figure 2 which displays the scales with respect to ITRF2020-u2023 from 1993.0 to 2025.0 of the ESA, GOP, GRG, GSC, IGN and IDS weekly solutions, we observe that the scale time series:

- Have a mean offset of about 8 to 12 mm.
- May be impacted by a few events (indicated by the vertical grey lines) related to the time evolution of the DORIS satellite constellation.
- Is quite stable since mid-2012 (lie in a range of ±2.50 mm, trend of about 0.11 mm/yr for IDS) .

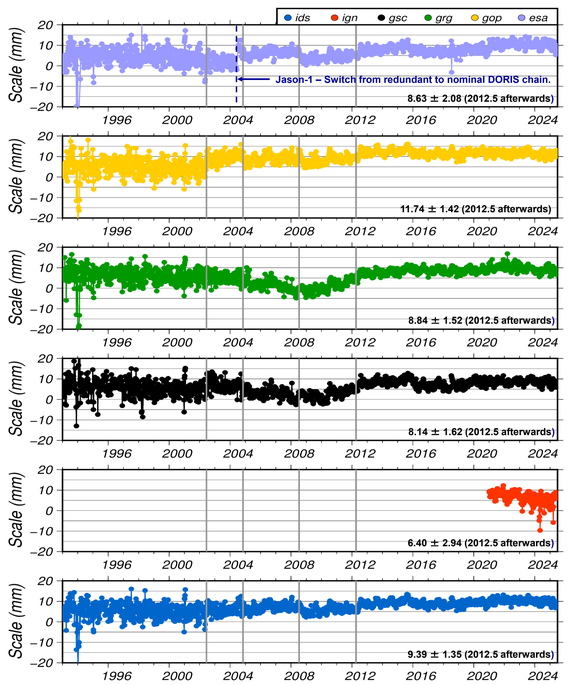


Figure 2 – Scales with respect to ITRF2020-u2023 of the ESA, GOP, GRG, GSC, IGN and IDS series. Vertical bars indicate the dates of, respectively, the end of the inclusion of Jason-1 (late 2004), the start of Jason-2 (mid -2008), the end of Envisat (early 2012) and the end of SPOT-5 (late 2015).

To improve the overall stability and to reduce the mean offset of the scale, the IDS ACs may:

- Mitigate the impact of the SAA on some DORIS Ultra Stable Oscillators (USO) by, when GNSS and DORIS receivers use the same USO (ex: Sentinel-3A, Sentinel-3B, Sentinel-6A, Sentinel-6B), estimating the behavior of the USO using GPS measurements.
- Take advantage of mission tandem phases.

  (ex: Jason-2/3, Sentinel-3A/3B, Sentinel-6A/6B).
- Review the contribution of each DORIS mission to their multi-satellite solutions.
- Choose a mission as a scale reference and align all the others to it.

Geocenter

Because i) the DORIS satellites are at low altitudes (800-1.400 km) and ii) almost all the DORIS satellites are unique, precisely modeling the nonconservative forces acting on these satellites is very challenging and has a direct impact on the quality of the z-component of the DORIS geocenter.

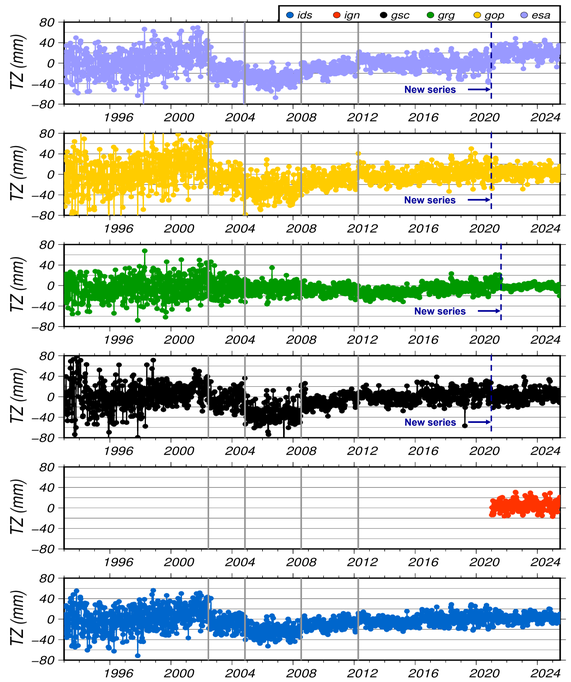
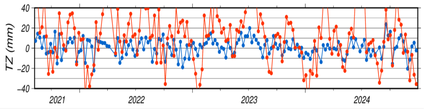


Figure 3 – Z-translation with respect to ITRF2020-u2023 of the ESA, GOP, GRG, GSC, IGN and IDS series. Vertical bars indicate the dates of, respectively, the end of the inclusion of Jason-1 (late 2004), the start of Jason-2 (mid -2008), the end of Envisat (early 2012) and the end of SPOT-5 (late 2015).

From Figure 3, we can observe a clear reduction of the scattering of the z-translations with the introduction of the new series in 2021, mainly due to the use of the Sentinel-6A macromodel from Conrad et al. (2022).
The reduction of the scattering is more pronounced for GRG as the consequence of the estimation of daily normal (i.e. cross-track) constant acceleration biases for Jason-3 (see Figure 4).

Figure 4 – Z-translation with respect to ITRF2020-u2023 of the Jason-3 GRG solutions: with and without daily normal constant accelerations



The quality of the DORIS geocenter may benefit from:

- Analyzing mission tandem phases.
- Reviewing the contribution of each DORIS mission.
- New satellite macromodels and improved attitude modeling.
- Revisiting the estimation of solar radiation pressure coefficients during higher solar activity.
- Estimating daily normal constant accelerations.

Station Positions

Looking at the East, North and Up weekly Weighted RMS (WRMS) of the station position residuals of the latest IDS series with respect to ITRF2020-u2023 (cf. Figure 5), we observe that the residuals can be divided in four time periods:

1) until early-2002 (inclusion of the first satellite flying the second generation of DORIS receiver – two beacons simultaneously received),
2) from mild-2002 to mid-2008 (inclusion of the first satellite with the third generation of DORIS receiver – seven beacons simultaneously received),
3) from mid-2008 to 2021.0,
4) and 2021.0 afterwards.

This time decomposition emphasizes the effect of having more and more stations simultaneously observed by the DORIS satellites, allowing more observations for each individual station. The discontinuity in 2021.0 and relative reduction in the WRMS show the benefits of adding more satellites (Sentinel-6A, HY-2C, HY-2D) in the new series as well as having one more IDS AC (IGN) contributing to the IDS weekly combined solutions.

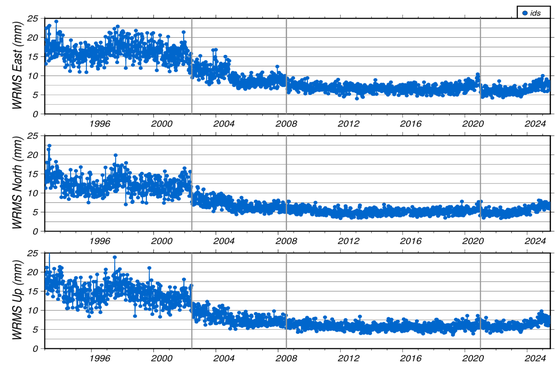


Figure 5 – Weighted RMS of the station position residuals with respect to ITRF2020-u2023 of the IDS series. Vertical bars indicate the dates of, respectively, the dates of the inclusion of the first satellite flying the second generation of DORIS receiver (early 2002, Envisat), of the inclusion of the first satellite with the third generation of DORIS receiver (mid-2008, Jason-2) and the start of the new IDS ACs & CC series (2021.0).

Thus, the inclusion of SWOT, Sentinel-6B, HY-2E, HY-2F missions in the IDS AC series and the arrival of a new IDS AC (GFZ) may improve the quality of the DORIS station positioning.

The positioning of the DORIS stations located in the SAA region (Arequipa, Ascension, Cachoeira-Paulista, Hartebeesthoek, Kourou, Le Lamentin, Libreville, San Juan, Saint Helena, Tristan Da Cunha – see Figure 6) should also benefit from the new SAA mitigation strategy for the missions with GNSS and DORIS receivers using the same USO.

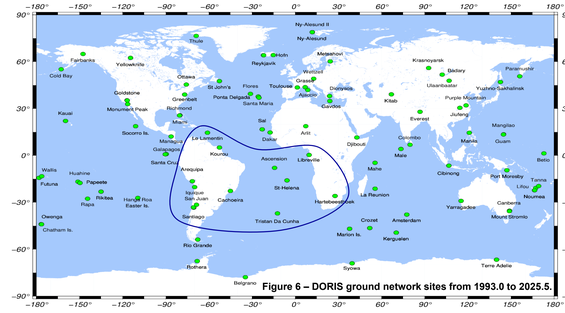


Figure 6 – DORIS ground network sites from 1993.0 to 2025.5.