The DORIS contribution to ITRF2020

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DORIS data span

The DORIS data used for the IDS contribution to ITRF2020 are listed in Table 1. The data used in the combination started in January 1993, mainly because the DORIS station network was not completely implemented until the launch of TOPEX/Poseidon (August 1992), and because a second satellite (SPOT-2) was necessary to strengthen the quality of the geodetic solutions. Data from three generations of DORIS instrument were processed. The first generation (1G) receiver could track only one DORIS beacon at a time. The main improvements in the following generation of instruments included miniaturization of the receiver, and of interest for geodesy the number of ground beacons that could be tracked: The SPOT2, SPOT3 and SPOT4 DORIS receivers also could only track one beacon at a time; The second-generation DORIS receivers on JASON-1, SPOT5 and Envisat, could track two beacons; The Jason-2/3, Cryosat-2, HY-2A, Saral and Sentinel-3A/B third-generation (DGXX) DORIS receiver can track up to seven beacons (*Auriol and Tourain, 2010*).

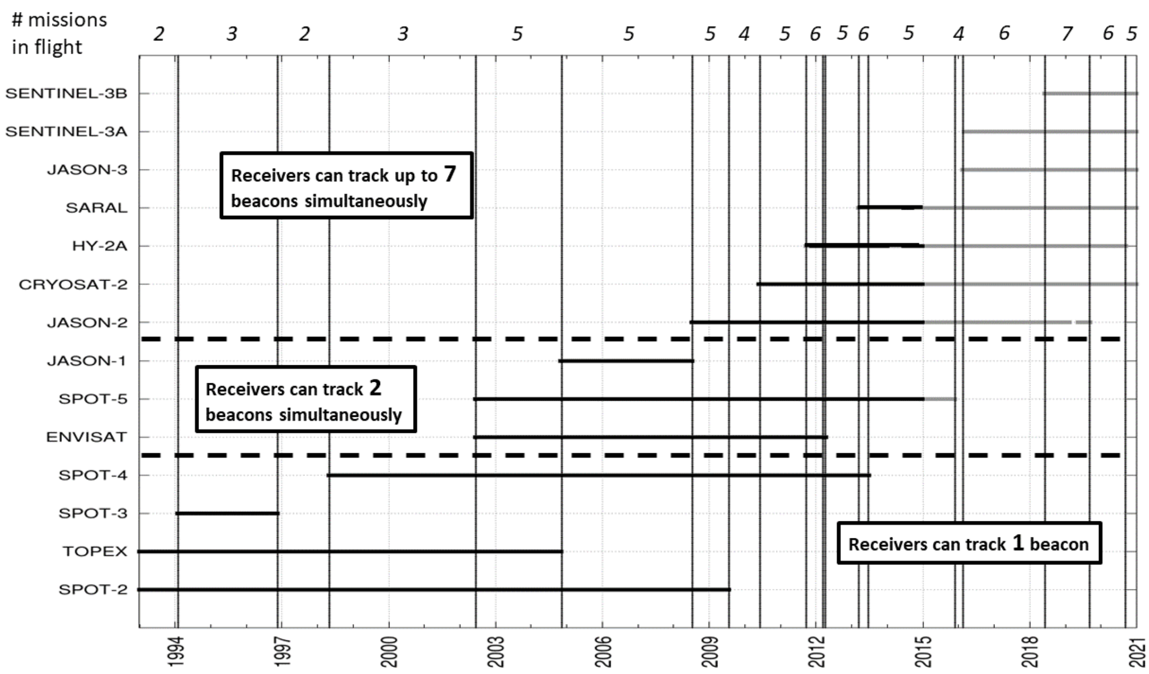

Figure 1 - Time evolution of the DORIS constellation for ITRF2020 (black = ITRF2014 constellation – gray + black = ITRF2020 constellation). Vertical lines correspond to starting and ending dates of the DORIS missions. Dashed lines divide DORIS receiver generations. From Moreaux et al., 2022.

The IDS recommended that Jason-1 be added in order to ensure that data from satellites at two different inclinations were incorporated into the solutions from November 2004 to July 2008, i.e. between the end of the TOPEX/Poseidon and through the start of the Jason-2 mission. The addition of data from the alternate inclination (66°) compared to the near-polar orbits of the other DORIS satellites improved the ground station observation geometry. The Jason-1 ultra-stable oscillator (USO) has been shown to exhibit high sensitivity to passage through the South Atlantic Anomaly (SAA). Thus, the analysis centers were required to use Jason-1 SAA-corrected data obtained from the model of *Lemoine and Capdeville* (*2006*). In addition, as for ITRF2014, due to the sensitivity of the SPOT-5 USO to the SAA demonstrated by *Štěpánek et al*. (2014), the IDS asked all the AC's to use the SPOT-5 SAA-corrected data from the model of *Capdeville et al. (2016)* starting on 2005/12/27 (2005:261 – SPOT-5 cycle 138). Once *Willis et al. (2016)* revealed a possible sensitivity of the Jason-2 USO to the SAA, the IDS initiated several studies which confirmed that Jason-2 was also impacted by the SAA. Then, due to the lack of a Jason-2 data correction model at the start of the ITRF2020 reprocessing, the IDS suggested to locally solve (reduce) for the SAA stations using the Jason-2 normal equations or solutions so that the SAA-perturbed stations in the Jason-2 normal equations would not impact the multi-satellite solutions. The same strategy was also recommended for the Sentinel-3A/B missions after *Jalabert and Mercier (2018)* and *Štěpánek et al. (2020)* showed the sensitivity of these missions to the SAA.

AC contributions

Four IDS ACs contributed to the ITRF2020 DORIS combination. Among the standards for the analysis of the DORIS data and the satellite orbit dynamics model, all AC's used time-variable gravity models and applied DORIS ground beacon phase center variation corrections. For ITRF2020, the IDS AC's made a special effort was made to improve the non-conservative force modelling for the Jason-1, Jason-2 & Jason-3 satellites by using both spacecraft body and solar array quaternions to model the satellites' orientation for the force model & the measurement model in the different orbit determination software. In addition, "Cr" (solar radiation reflectivity coefficient) was adjusted per arc to further mitigate solar-radiation-pressure (SRP) induced errors. Compared to ITRF2014, the AC's updated the background ocean tide models (for dynamical modeling and ocean loading corrections) from FES2004, FES2012, GOT4.8 to EOT11a, FES2014 & GOT4.10c. For ITRF2020, all the AC's adopted the GRACE-FO RL06 AOD1B ocean-atmosphere dealiasing model to account for the short period atmosphere and ocean mass variations (*Dobslaw et al., 2017*). In addition, compared to ITRF2014, all the IDS ACs adopted more recent GRACE+GOCE-derived static and time-variable gravity models. As with ITRF2014, the IDS AC's employed a range of elevation cutoff angles for DORIS data (7-12°). For ITRF2020, all the IDS AC's employed a function to down-weight the DORIS data vs. elevation, since this was demonstrated to stabilize the derived scale. We also note that, compared to the ITRF2014 processing, a new Alcatel phase center variation model was used for the contribution to the ITRF2020. All SINEX deliveries were compliant with IERS call for participation to ITRF2020.

AC	AC solutions	Software	Sol. Id.	Type	Data span	EOPs
European Space Operations Center	**ESA**	NAPEOS	**wd12/13**	NEQ	1993.0-2021.0	Motion+rate +LOD
Geodetic Observatory Pecny	**GOP**	BERNESE	**wd67**	var-cov	1993.0-2021.0	Motion+rate
CNES/CLS	**GRG**	GINS/DYNAMO	**wd43**	var-cov	1993.0-2021.0	Motion
NASA Goddard Space Flight Center	**GSC**	GEODYN	**wd51**	NEQ	1993.0-2021.0	Motion

Table 1 - IDS Analysis Center submission summary using Normal Equations (NEQ) or variance–covariance output (COV).

SINEX Preprocessing analysis

The software used for the IDS combination was the IGN/LAREG CATREF package (*Altamimi et al., 2002*). As a validation step and before the weekly combination, each SINEX series was pre-sprocessed with the following steps being applied:

(1) Verification of DORIS station identification (dome number, station acronym),
(2) Rejection of stations over the whole time period (never used),
(3) Rejection of stations over specific periods (partially used),
(4) Verification/update of position discontinuities (but the solution number is set to 1 for the weekly combination),
(5) Inversion of the free singular normal equations for ESA and GSC.
(6) Projection using minimal constraints and rejection of perturbing stations,
(7) Comparison with intrinsic cumulative position and velocity solution from 1993.0 to 2021.0.
(8) Analysis and rejection of high residual stations.

Loosely constrained network solutions were projected over their proper space using minimal constraints. Some partial or complete rejections of stations from the SINEX were made by using the results from the SSALTO DORIS ground processing segment or from other analysts. After this validation step, all the SINEX files of a series were expressed in the same DORIS reference system and spurious points were removed. A cumulative position/velocity DORIS solution was calculated including recent DORIS data and used as a datum in the projection.

Combination strategy

Several iterations were necessary to provide the best IDS combination of the AC solutions. The combination process started with the individual series of solution files as output from the preprocessing step, i.e. with minimum constrained solutions. To strengthen the quality of the combined weekly solutions, we only computed solutions for weeks where we had contributions from at least two ACs. In addition, each week, we only estimated positions of stations which had been estimated by at least two ACs.

Analysis of differences of EOPs of the individual series with respect to the IERS C04 series (*Bizouard and Gambis*, 2009) showed that ESA series gave both larger differences and standard deviations compared to the performance of the three other IDS contributors. Therefore, the ESA contribution was not included in the estimation of the combined pole. Table 3 of *Moreaux et al. (2022)* summarizes the contribution of each AC to the IDS 16 combined solution. For more information on the combination strategy, please refer to *Moreaux et al. (2022).*

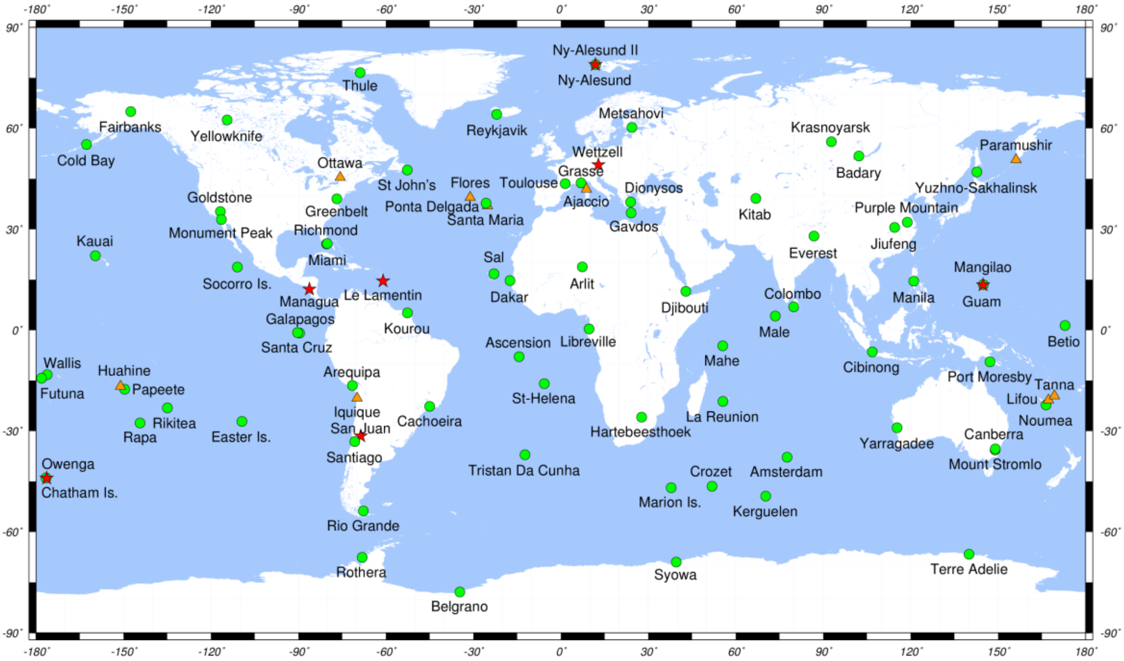

Figure 2 - Geographical distribution of the DORIS stations included in the IDS contribution to the ITRF2020 (red stars indicate new sites installed since 2015.0 and orange triangles old sites not included in the ITRF2014). From Moreaux et al., 2022.

The final IDS 16 combination included solutions for 201 DORIS stations on 87 different sites with 48 sites located in the northern hemisphere and 39 in the southern hemisphere (see Figure 2). For reference, the IDS network for ITRF2008 included 160 stations located at 71 sites. The sixteen new sites include both old sites with less than 2.5 years of observations which were rejected at the early stage of the IDS processing for the ITRF2014 (Ajaccio, Flores, Huanine, Iquique, Le Lamentin, Lifou, Ottawa, Owenga, Paramushir, Santa-Maria, Tana) and totally new sites, i.e. installed since 2015: Managua, Mangilao, Ny-Ålesund II, San Juan and Wettzell.

TRF parameters

The intrinsic TRF parameters of IDS 16 series are compared in Figure 3 to ITRF2014 for an external validation. From that figure we can observe that TX and TY remain most of the time within 20 mm while TZ presents higher variations (between -50 to +50 mm). We also see that the standard deviation of all the IDS 16 X- and Y-translations is lower than the IDS 09 (IDS contribution to the ITRF2014) ones thanks to the reduction of the amplitude of the annual and 118-day (draconitic period for the Jason satellites) signals by a factor of two. These reductions are the consequence of a better modelling of the non-conservative forces on the Jason satellites. The Z-translations of both IDS 09 and IDS 16 show similar performance and look highly correlated with the Sunspot number. Nevertheless, we observe a slight degradation of the IDS 16 TZ standard deviation after adding Jason-3 (early 2016) due to higher variations of that parameter for that mission.

Analysis of the IDS 16 scale with respect to the ITRF2014 showed a slope from 1993.0 to mid-2002. That pattern is explained in *Moreaux et al. (2022)* by the use of different Alcatel PCVs between ITRF2014 and the IDS ITRF2020 processing as well as by the gradual replacement over time of the Alcatel by Starec ground antennas. Compared to the IDS 09 scale parameter, the IDS 16 one does not show any more an increase in late 2011 thanks to the use of the correction of the Center-Of-Mass Center-Of-Phase vector for that mission and to more stable scales for the Cryosat-2 and Jason-2 single satellite solutions. Then, if we restrict scale values from mid-2002 to 2021.0, the scale slope of IDS 16 with respect to the ITRF2014 is about 0.062 mm/yr.

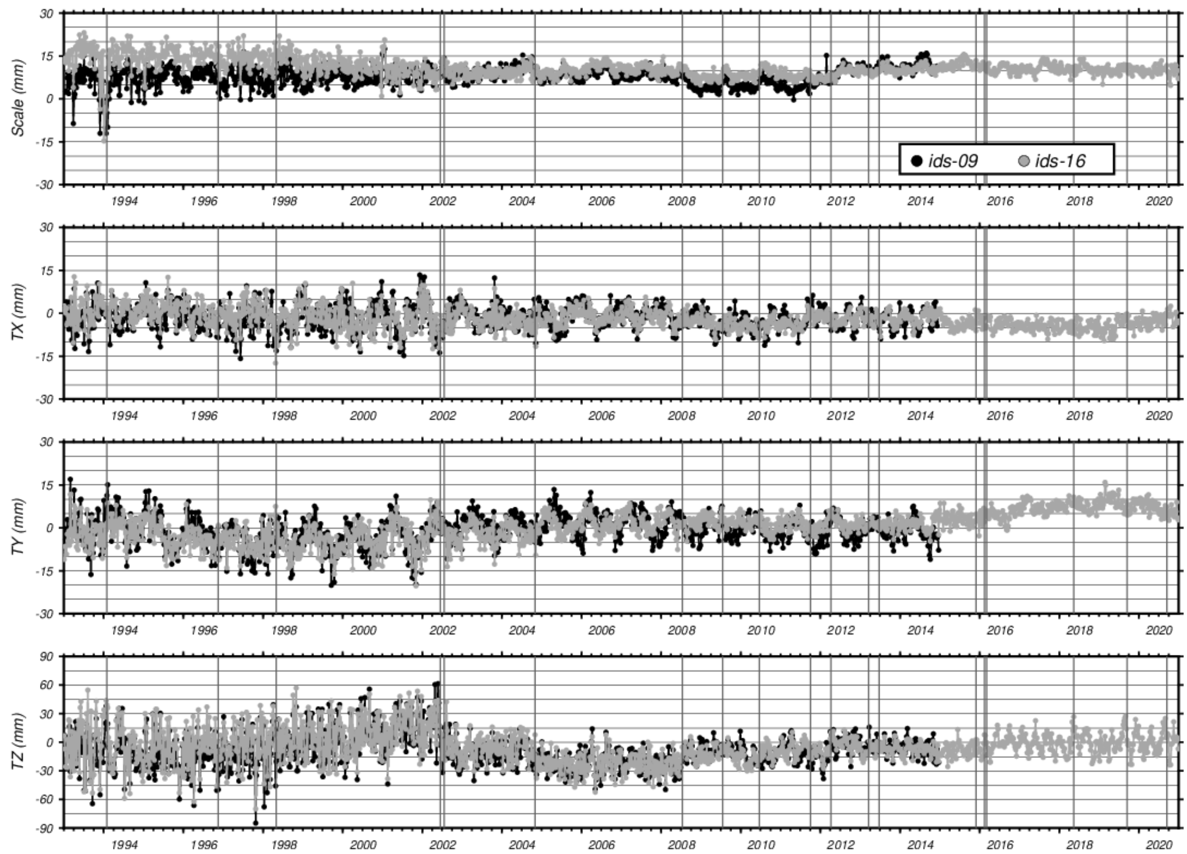

Figure 3 – IDS 09 (ITRF2014) and IDS 03 (ITRF2008) translation and scale parameters with respect to ITRF2008. Vertical lines correspond to DORIS satellite constellation changes and top numbers to satellites number. From Moreaux et al., 2022.

Residuals

From Figure 4, the North component is always the best determined, while the East is the worst one and whereas the Vertical is intermediate. This can be fully explained by the conjunction of two features of the DORIS technique: i) the Doppler technique provides observations that lack information in the direction perpendicular to the satellite track and, ii) except for TOPEX/Poseidon, Jason-1 and Jason-2, all the DORIS satellites have a near-polar orbit. In addition, we can see that the WRMS time series can be divided in three time periods: before mid-2002 (including of the first satellite with onboard the second generation of DORIS receiver), between mid-2002 and mid-2008 (including of the first satellite with onboard the third generation of DORIS receiver) and after mid-2008. This time decomposition emphasizes the impact of having more and more stations simultaneously received onboard allowing more observations by station. We can also notice that having since late 2015 a full constellation with onboard the third generation of DORIS receivers has only a very slight (but still) positive impact on the performance. In overall, the WRMS of the East/North/Up position residuals are below 6-7 mm since mid-2008.

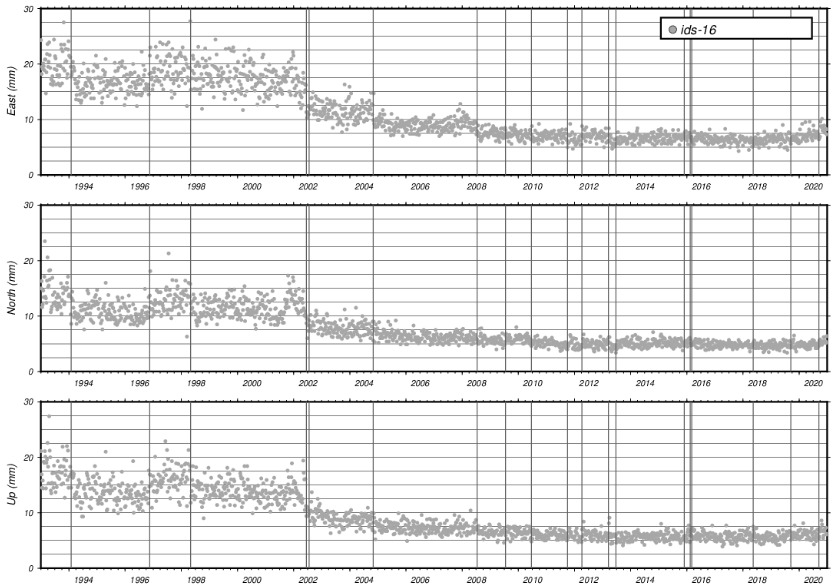

Figure 4 - IDS 16 weekly solutions WRMS of the station residuals wrt IDS 16 cumulative position and velocity solution. Vertical lines correspond to DORIS satellite constellation changes. From Moreaux et al., 2022.

Polar Motion

Figure 5 displays the difference of the IDS X and Y pole components with the IERS C04 pole series. As with the station positions residuals, the precision of the EOP significantly improves when the DORIS constellation has more than three satellites, i.e. after April 2002. Moreover, we also observe benefits of the satellite missions that include DGXX receivers, beginning with Jason-2 (July 2008) with a clear reduction of the standard deviations. From that figure, we also observe similar performance in the two pole components thanks to the relatively homogeneous distribution of the DORIS tracking network. Comparisons of IDS 16 and IDS 09 polar motion solutions show a substantial improvement of IDS 09 differences wrt the IERS C04 series even if the new series was obtained with fewer contributors.

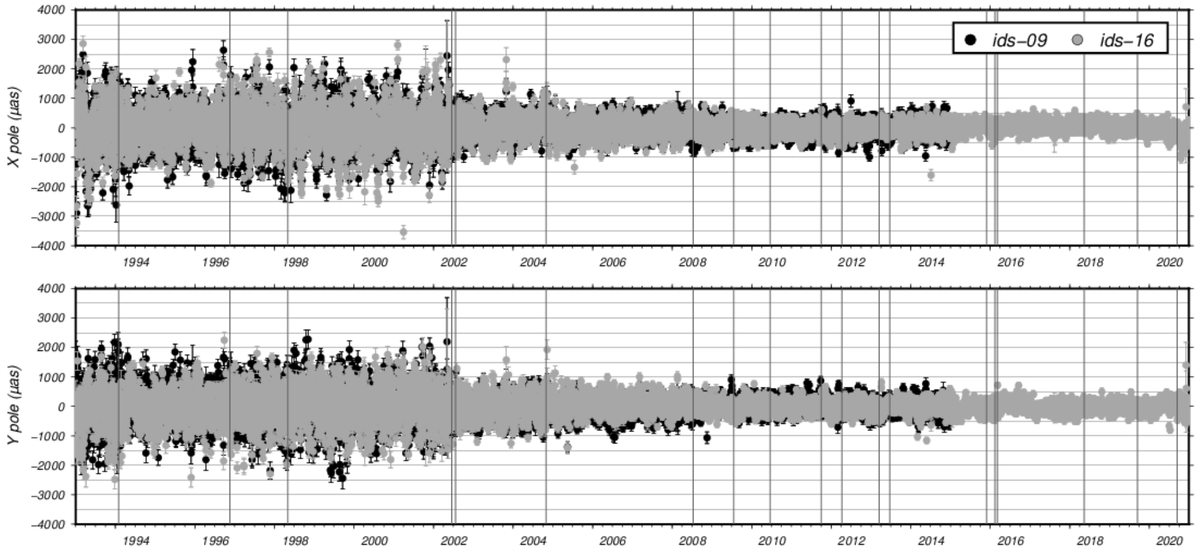

Figure 5 - IDS 16 (gray – IDS contribution to ITRF2020) and IDS 09 (black – IDS contribution to ITRF2014) polar motion compared to IERS C04 series. Vertical lines correspond to DORIS satellite constellation changes. From Moreaux et al., 2022.

For more information on the IDS-16 please contact
Guilhem Moreaux (CLS) at the IDS Combination Center (Email: Guilhem.Moreaux@cls.fr)
and refer to Moreaux et al. 2022.

References

Altamimi, Z., Boucher, C., and Sillard, P. (2002) New trends for the realization of the international terrestrial reference system. Adv. Space Res. 30(2), 175-184, http://dx.doi.org/10.1016/S0273-1177(02)00282-X

Capdeville, H., Štěpánek, P., Lemoine, J.-M., et al. (2016) Update of the corrective model for Jason-1 DORIS data in relation to the South Atlantic Anomaly and a corrective model for Spot-5. Adv. Space Res., 58(12), 2628-2650, http://dx.doi.org/10.1016/j.asr.2016.02.009

Jalabert, E., Mercier, F. (2018) Analysis of South Atlantic Anomaly perturbations on Sentinel-3A Ultra Stable Oscillator. Impact on DORIS phase measurement and DORIS station positioning. Adv. Space Res, 62(1), 174-190, http://dx.doi.org/10.1016/j.asr.2018.04.005

Lemoine, J.-M., Capdeville, H. (2006) A corrective model for Jason-1 DORIS Doppler data in relation to the South Atlantic anomaly. J. Geod. 80 (811), 507–523. http://dx.doi.org/10.1007/s00190-006-0068-2.

Moreaux, G., Lemoine, F.-G., Capdeville, H., et al. (2022) The International DORIS Service contribution to ITRF2020. Adv. Space Res., in press.

Štěpánek, P., Dousa, J., Filler, V. (2014) SPOT-5 DORIS oscillator instability due to South Atlantic anomaly: mapping the effect and application of data corrective model. Adv. Space Res. 52 (7), 1355-1365. http://dx.doi.org/10.1016/j.asr.2013.07.010.

Štěpánek, P., Bingbing, D., Filler, V., et al. (2020) Inclusion of GPS clock estimates for satellites Sentinel-3A/3B in DORIS geodetic solutions. J. Geod, 94, 116, http://dx.doi.org/10.1007/s00190-020-01428-x, 2020.

Willis, P., Helfin, M.B., Haines, B.J., et al. (2016) Is the Jason-2 DORIS oscillator also affected by the South Atlantic Anomaly? Adv. Space Res., 58(12), 2617-2627, http://dx.doi.org/10.1016/j.asr.2016.09.015