The DORIS contribution to ITRF2014

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DORIS data span

The DORIS data used for the IDS contribution to ITRF2014 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 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, Cryosat-2, HY-2A and Saral third-generation (DGXX) DORIS receiver can track up to seven beacons (*Auriol and Tourain, 2010*).

The IDS AWG 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 the start of the Jason-2 mission. Previously for ITRF2008, over that time period only data from the polar-orbiting satellites of the DORIS constellation were considered (*Valette et al., 2010*). 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) was known to exhibit high sensitivity to passage through the South Atlantic Anomaly (SAA). Thus, the analysis centers were required to use the Jason-1 SAA-corrected data from *Lemoine and Capdeville* (*2006*).

Since ITRF2008, *Štěpánek et al*. (2014) pointed out that the USO on SPOT5 also experienced perturbations after passage through the SAA, albeit at a lower level than on Jason-1. Similarily to Jason-1, H. Capdeville and J.-M. Lemoine developed a SAA data correction model for SPOT5 (*Capdeville et al., 2016*). The approach is similar to the one already used in the first Jason-1 data corrective model, based on the frequency drift grid map and the modeling of the recovery and memory effects. All the ACs were asked to use the SPOT5 SAA-corrected data starting on 2005/12/27 (2005:261 - SPOT5 cycle 138).

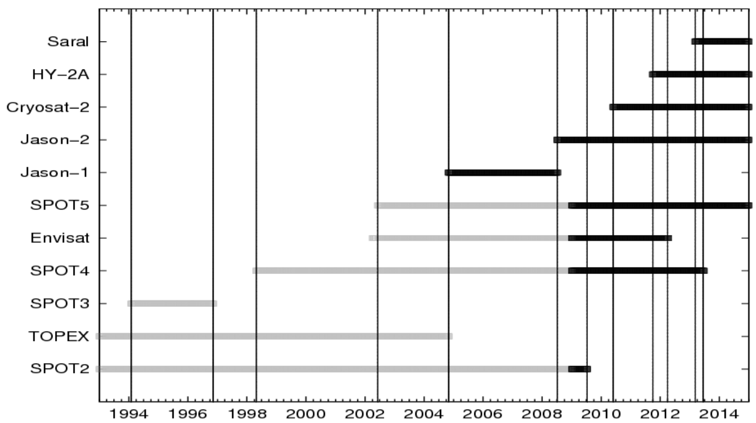

Figure 1 - Time evolution of the DORIS constellation for ITRF2014 (gray = ITRF2008 constellation – gray + black = ITRF2014 constellation). Vertical ines correspond to starting and ending dates of the DORIS missions. From Moreaux et al., 2016.

ACs contributions

Six IDS ACs contributed to the ITRF2014 DORIS combination. Among the standards for the analysis of the DORIS data and the satellite orbit dynamics model, all ACs used time-variable gravity models derived from the GRACE mission and most applied DORIS ground beacon phase center variation corrections. All SINEX deliveries were compliant with IERS call for participation to ITRF2014.

AC	AC solutions	Software	Sol. Id.	Type	Data span	EOPs
European Space Operations Center	**ESA**	NAPEOS	**wd10**	NEQ	1993.0-2014.5	Motion+rate +LOD
Geodetic Observatory Pecny	**GOP**	BERNESE	**wd43-46**	var-cov	1993.0-2015.0	Motion+rate
CNES/CLS	**GRG**	GINS/DYNAMO	**wd40**	var-cov	1993.0-2015.0	Motion
NASA Goddard Space Flight Center	**GSC**	GEODYN	**wd26**	NEQ	1993.0-2015.0	Motion
IGN/GPL	**IGN**	GYPSY/OASIS	**wd15**	var-cov	1993.0-2015.0	Motion
INASAN	**INA**	GYPSY/OASIS	**wd08**	var-cov	1993.0-2015.0	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. As a validation step and before the weekly combination, each SINEX series was preprocessed with the following steps being applied:

(1) Verification of DORIS station identification (dome number, station mnemo),
(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 ITRF2008 at the epoch of each weekly solution.
(8) Analysis and rejection of high residual stations.

Loosely constrained network solutions were projected over its proper space using minimal constraints. Some partial or complete rejections of stations from the SINEX were done resulting from analysis in the SSALTO DORIS ground processing segment or from 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 three ACs. In addition, each week, we only estimated positions of stations which had been estimated by at least three ACs. As applying DORIS antennae PCVs induced a scale offset, in order to not perturb the combined scale, since INA was the only AC not able to include DORIS PCVs in its ITRF2014 processing the INA solution was not allowed to contribute to the scale of the IDS solution. In addition we found that the SPOT2 satellite was identified as the source of spurious scale solutions in early 1994. As half of the ACs (GOP, GRG and GSC) did not include that mission in their multi-satellites solutions for the corresponding time period, to get a more accurate combined scale, we did not include ESA and IGN, in addition to INA, contributions at the scale level during this period of time. Analysis of all ACs scales showed an increase late 2011. Further investigations revealed that increase could be associated with either Jason-2, or Cryosat-2 or HY-2A. In addition, regarding to the scale increase, two groups of ACs could be identified (ESA/GRG/GSC vs. GOP/IGN/INA). The two groups were differentiated according to whether or not they computed the DORIS phase center corrections using their orbit determination software (ESA/GRG/GSC), or used phase center corrections provided by CNES in the DORIS data files (GOP/IGN/INA). Then, to minimize the scale increase of the combined solution, the IDS CC decided to not include the GOP, IGN and INA scale contributions to the combined scale starting in year 2011:275 (2011/10/02), as these three ACs presented large scale increases.
Analysis of differences of EOPs of the individual series with respect to the IERS C04 series (*Bizouard and Gambis,* 2009) showed that i) ESA series gave both larger differences and standard deviations and ii) GOP contribution presented spurious periodic signals with periods lower than 30 days, mainly in the X direction. Therefore, these two AC contributions were not included in the estimation of the combined pole. Table 4 of Moreaux et al. (2016) summarizes the contribution of each AC to the IDS 09 combined solution. For more information on the combination strategy, please refer to *Moreaux et al. (2016).*

The final IDS 09 combination included solutions for 160 DORIS stations on 71 different sites with 38 sites located in the northern hemisphere and 33 in the southern hemisphere (see Figure 2). For reference, the IDS network for ITRF2008 included 130 stations located at 66 sites with 34 (resp. 32) sites in the northern (resp. southern) hemisphere. The five new sites are: Betio, Cold Bay, Grasse, Socorro in the northern hemisphere and Rikitea in the southern hemisphere.

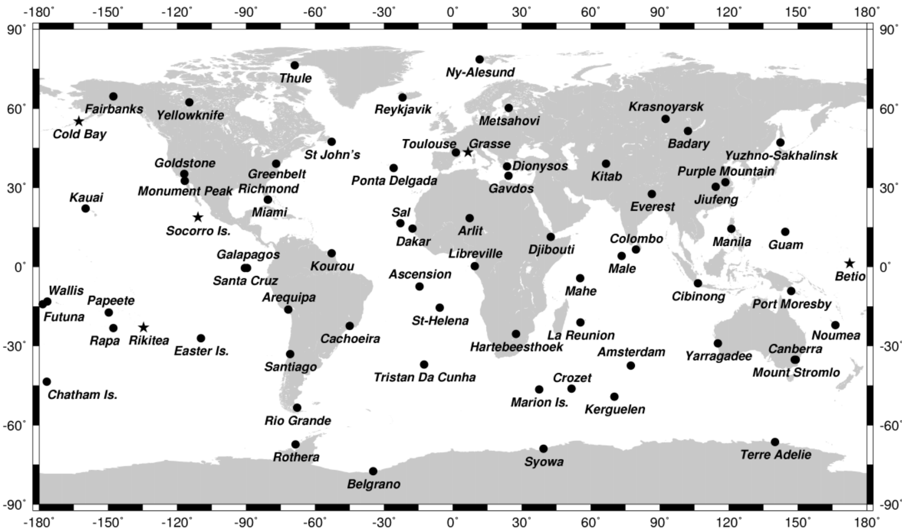

Figure 2 - Geographical distribution of the DORIS stations included in the IDS contribution to ITRF2014 (black stars indicate new sites with regards to ITRF2008). From Moreaux et al., 2016.

TRF parameters

The intrinsic TRF parameters of IDS-09 series are compared in Figure 3 to ITRF2008 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 -75 to +75 mm). We also see that from 1993.0 to 2008.5, the standard deviation of all the IDS 09 translations is lower than the IDS 03 ones. The most important reductions occur for the Z-component. These improvements may reflect a better solar radiation pressure modeling in the new series. Spectral analysis of the geocenter translations (see Table 6 of *Moreaux et al. 2016*) shows that TX and TY present annual signals of nearly 3 mm in amplitude, so a reduction of nearly 15% compared to IDS 03 thanks to use of time variable gravity fields in ITRF2014 processing. The spectral analysis also reveals that X and Y translations of the IDS 09 solution no longer contain any significant signal at 15 days. Meanwhile, the inclusion of Jason-1 and Jason-2 data introduced a 118-day signal in TY (draconitic period for these satellites) with amplitudes of nearly 1 mm. In addition, thanks to a longer time span, spectral analysis of TZ shows that, even if there is a decrease of around 25% in amplitude, IDS 09 is still dominated by an 11 year signal. That solar dependence of the TZ can also be observed from 2000 to 2002 with a TZ maximum which coincides with the peak of the solar cycle. Due to the inclusion of Jason-2, the TZ is more centered after July 2008.

Analysis of IDS 09 scale parameter with respect to ITRF2008 show stability until late 2011 (2011:275, i.e. 2011/10/02) and an increase up to 10 mm afterwards. Evaluation of single-satellite series for 2011-2014 with respect to ITRF2008 showed: i) HY-2A mission, which started in 2011:275, presented a high positive scale value; ii) the Jason-2 and Cryosat-2 scales were affected by an increase between 2012:092 (2012/04/01) and 2012:162 (2012/06/10). Unfortunately, so far, the reasons for both the Jason-2 and Cryosat-2 scale increases are still unknown and under investigation. Moreover, the origin of the high HY-2A scale values is unexplained. Then, if we restrict scale values from 1993 to mid-2011, the scale slope of IDS 09 is close to zero (0.029 mm/yr).

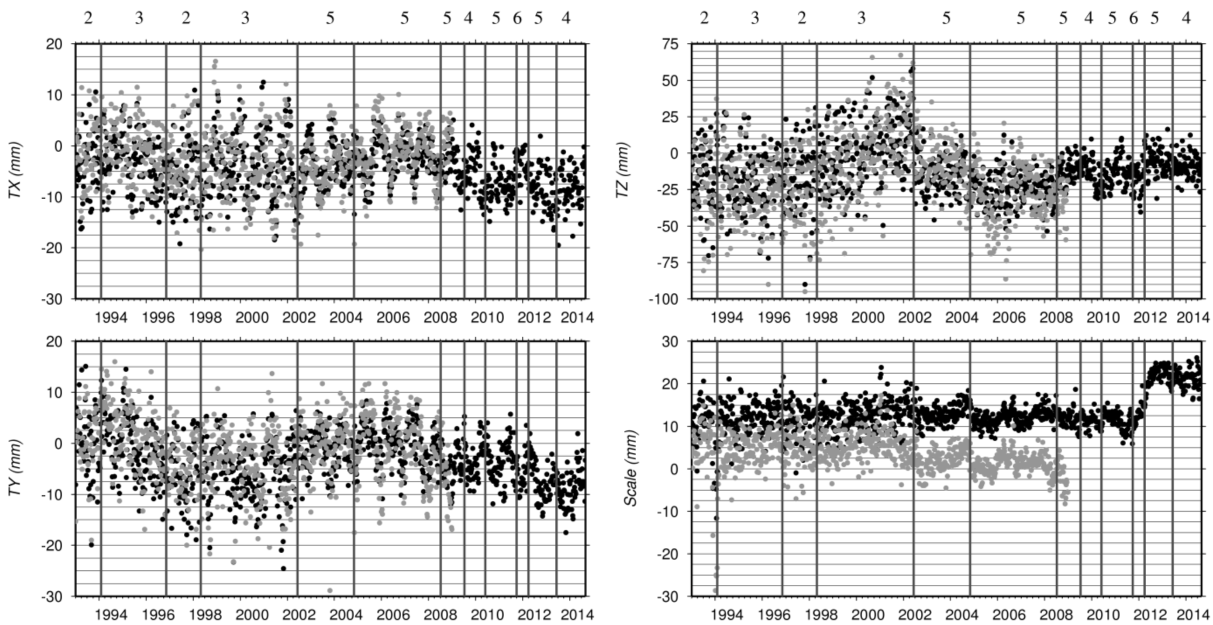

Figure 3 – IDS 09 (ITRF2014) and IDS 03 (ITRF2008) translation and scale parameters with respect to ITRF2008. Vertical lines correspond to DORIS satellite constellation changes and top numbers to satellites number. From Moreaux et al., 2016.

Residuals

From Figure 4, the North component is always the best determined, while the East is the worst one and whereas the Vertical is in the middle. 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 see that the WRMS of both IDS 03 and IDS 09 are correlated with the number of satellites. For instance, after April 2002, the WRMS in all the directions are below 15 mm with an improvement of around 30% and 50% for IDS 03 and IDS 09, respectively, as soon as more than three satellites are available. We also observe that IDS 09 performs less well than IDS 03 before April 2002, mainly in the East direction where the differences are at the order of 5 mm in mean value. However, from 1993 to 2002, if we use for the IDS 09 evaluation the weekly DORIS network of IDS 03, then the degradation is below 2 mm.

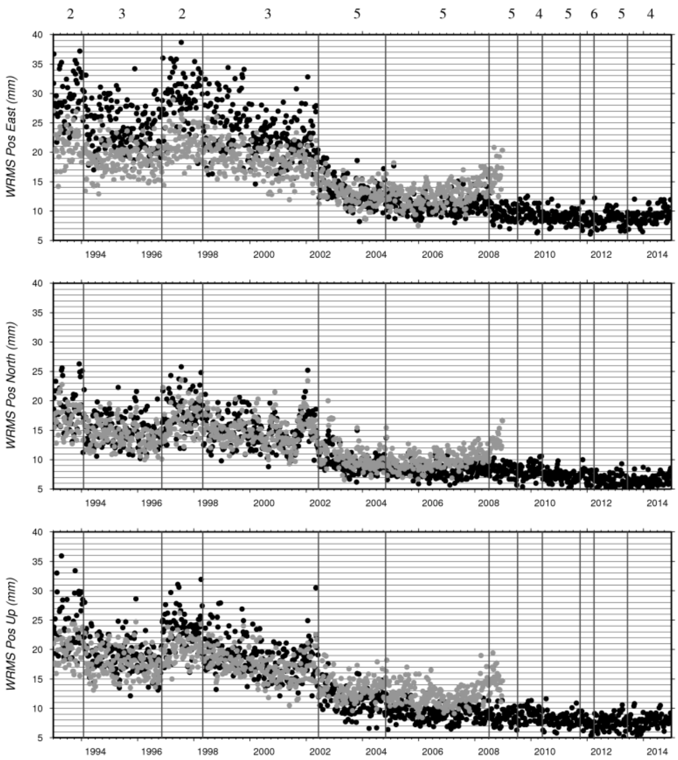

Figure 4 - IDS 03 (gray) and IDS 09 (black) weekly solutions WRMS of the station residuals wrt IDS-TRF2014. Vertical lines correspond to DORIS satellite constellation changes. From Moreaux et al., 2016.

Polar Motion

Figure 5 displays the difference of the IDS X and Y pole components with the IERS 08 C04 pole series (*Bizouard and Gambis, 2009*). 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. Comparisons of IDS 09 and IDS 03 polar motion solutions show a substantial degradation of IDS 09 differences wrt. the IERS C04 series.

That degradation could be explained in one respect by the fact that IDS 09 EOPs are the combination of four ACs while IDS 03 used six ACs.

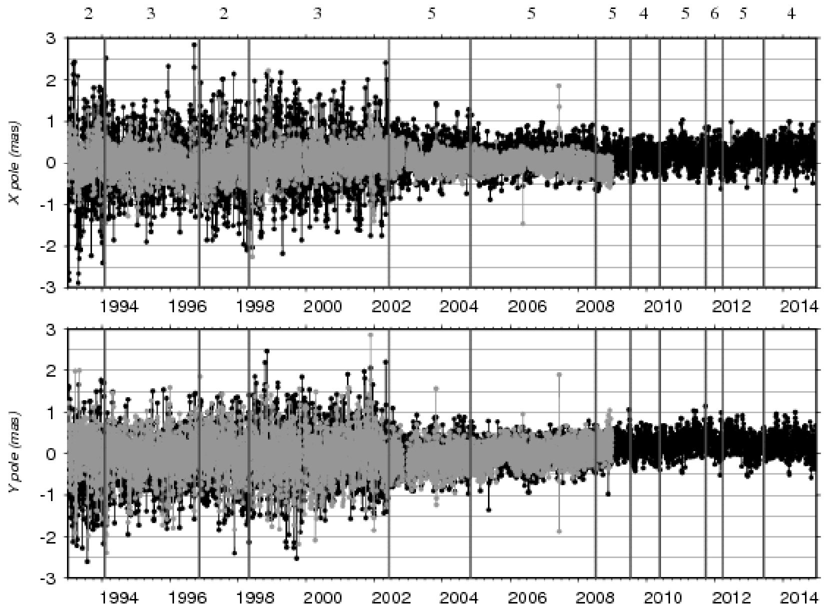

Figure 5 - IDS 03 (gray – IDS contribution to ITRF2008) and IDS 09 (black – IDS contribution to ITRF2014) polar motion compared to IERS 08 C04 series. Vertical lines correspond to DORIS satellite constellation changes. Courtesy from Moreaux et al. 2016.

For more information on the IDS-09 please contact
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and refer to Moreaux et al. 2016.

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