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Improvements in DORIS Processing for ITRF2013 at the GSC Analysis Center

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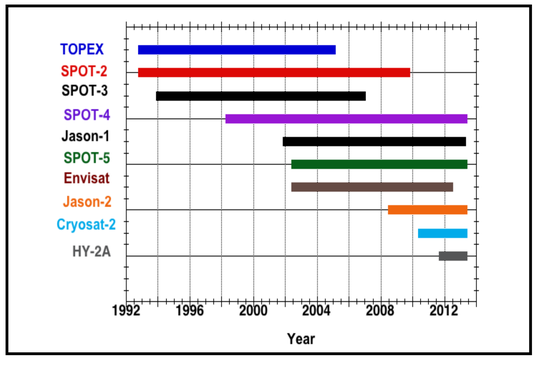
SUMMARY

DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) is one of the fundamental geodetic techniques that contributes to the International Terrestrial Reference Frame (ITRF). The data from DORIS also find a strong application in Precision Orbit Determination (POD) for altimeter satellites such as **TOPEX/Poseidon, Jason-1, Jason-2, Envisat and Cryosat-2**. At GSFC we have processed DORIS data for POD, and for the ITRF, routinely submitting SINEX solutions to the IDS Combination Center in Toulouse. In the context of the preparation for the next ITRF (ITRF2013), we have conducted an intensive effort to improve the DORIS processing and deliver a new complete SINEX series based on processing data from all DORIS satellite from 1993 to 2013. In this paper, we discuss the improvements that have been implemented in the GSC analysis center processing, which have been undertaken under the aegis of the DORIS Analysis Working Group (AWG). **These improvements have included the following: (1) Application of improved macromodels for the DORIS satellites, to better characterize the nonconservative forces; (2) Better modelling of the frequency changes at the DORIS sites, removing sporadic spurious jumps in the time series of estimated heights at some stations; (3) Application of a Phase law for the Starec and the Alcatel Antennae, in line with the recommendations of the IDS AWG; (4) Processing of Jason-1 data for inclusion in the ITRF from Nov. 2004 to July 2008 for inclusion in the weekly SINEX solutions; (5) Application of improved models of time-variable gravity**. We summarize the improvements in the DORIS processing since the last complete SINEX delivery of GSC for ITRF2008, and we characterize the impact on the POD, and on the intrinsic products of interest to the derivation of the IDS technique combination.

Satellite Constellation and Data

The DORIS system consists of a network of 50-60 operating ground stations with a a near-homogeneous worldwide distribution (**Fagard, 2006**; **Willis et al., 2010**). The ground beacons transmit on two frequencies, 2.03625 Ghz, and 401.25 Mhz, and the dual-frequency signals are received onboard the satellites of the orbiting DORIS constellation. The DORIS constellation over time has consisted of two to six satellites, all altimeter and remote sensing satellites in low-Earth orbit. For ITRF2008 (**Le Bail et al., 2010; Valette et al., 2010**), we used data through Dec. 31, 2008, exclusive of Jason-2. For ITRF2013, we include the newer DORIS satellites, **Jason-2** and **Cryosat-2**, and have evaluated the contribution of **HY-2A**. The newer DORIS satellites carry the DGXX receiver that can track up to seven DORIS beacons simultaneously, if there are that many in view (**Auriol and Tourain, 2010**), dramatically increasing the quantity of DORIS data available compared to the satellite receivers of the earlier generation on **SPOT-2**, **SPOT-3**, **TOPEX/Poseidon** (*1-channel receivers*), and **SPOT-4,5**, **Jason-1**, **Envisat** (*2-channel receivers*). The data of **Saral**, launched in 2013, will likely not be included in ITRF2013.



Notes: (1) Satellites with **DG1** (1-channel receivers): **TOPEX**, **SPOT-2**, **SPOT-3**, **SPOT-4**.
Satellites with **DG2** (2-channel receivers): **Envisat**, **Jason-1**, **SPOT-5**.
Satellites with **DGXX** (7-channel receivers): **Jason-2**, **Cryosat-2**, **HY-2A**, **Saral**.
(2) In ITRF2013 we will include all DORIS data (1993-2013) except for **Jason-1** for which only data will be included from Nov. 2004 to July 2008. For both **SPOT-5** and **Jason-1**, these data will be corrected for the perturbations induced by the **South Atlantic Anomaly (SAA)** (c.f. **J.M.Lemoine and H. Capdeville, 2006; Stepanek et al., 2010**).

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Model Improvements for ITRF2013

A large number of improvements to DORIS processing have been implemented and tested. The previous operational series (**gscwd12**) – which was derived from the standards used for ITRF2008 has been updated. The updates include changes to the geopotential model, the ocean tide model, a priori station coordinates to the macromodels for some DORIS satellites, and the import of new data provided by the IDS for certain satellites and time periods. The most significant changes concern the application of the estimation of a frequency correction for the DORIS sites – where there is a departure from the nominal frequency, and the application of both an **Alcatel** and **Starec antenna phase law**. Several interim **SINEX** series were produced – including **gscwd15**, **gscwd18** (first series with the frequency correction), **gscwd20** (new baseline applying **IERS2010** standards for the pole and solid Earth tide), **gscwd21** (with application of the phase law). One further updated series is planned for delivery to the IDS combination center that incorporates improvements to modelling of time-variable gravity and to correct any anomalies detected by the combination center in their preliminary analyses. In the Table below, unless otherwise indicated, the changes are always carried forward to the next series.

SUMMARY OF GSC SINEX SERIES

gscwd12	Previous operational series. Continuation of ITRF2008 modelling and standards.
gscwd15	Complete new time series (1992-2012) with new modelling standards. Many updates. DORISReport 3258 (28-Feb-2013)
gscwd17	Internal series. Test of macromodel-related changes only (SPOT-2, SPOT-3, Envisat)
gscwd18	New complete time series (1992-2012) with macromodel updates (SPOT-2, SPOT-3, Envisat) + implementation of modelling to handle DORIS station frequency changes.
gscwd20	Apply IERS2010 standards (pole, C_{21}, S_{21}). Add SPOT-5 SAA data (2006-2013).
gscwd21	Apply DORIS COM & offsets (in conjunction with attitude law or quaternions), and apply Phase Law for Alcatel and Starec antennae.

MODEL	UPDATE	NEW Series
Static gravity model	GOCO2s vs. EIGEN-GL04S1	wd15, wd18, wd20, wd21
Time-variable gravity	Fit to SLR-DORIS-derived 4x4 time series vs. secular rates for only a few coefficients (C_{20}, C_{30}, C_{40})	
Troposphere (1)	GMF/Saastmoinen vs. Niell/Hopfield	
Troposphere (2)	Adjust wet-only vs. Adjust dry+wet	
Ocean Tides	GOT4.8 vs. GOT4.7	
Ocean pole tide	Applied.	
Station coordinates	updated to the latest version of DPOD2008.	
New Data:	Envisat (2002-2006; *DORISMAIL 0823*) SPOT-4 (1998-1999; *DORISMAIL 0801*)	
New data: GR3B, & GAVB	Imported for Cryosat2, Jason2 (*DORISMAIL 0750*)	
Weekly Station editing	More rigorous editing at weekly SINEX Level. 1. Edit stations with large adjustments; 2. Edit stations with < 250 obs/wk.	wd15, wd18, wd20, wd21
SPOT-5 attitude modelling	Model pitch of Solar array (-40 deg after Jan 2008). No more Cr tuning.	wd15, wd18, wd20, wd21
New Macromodels	SPOT-2, SPOT-3	
Corrected Macromodel	Envisat. (Now correctly applied for Drag & Planetary Radiation Pressure)	
Correction to UCL model	Surface Area for Solar Array Thermal Re-Radiation (Envisat)	wd17, wd18, wd20, wd21
Station Frequency change modelling	Partial derivatives and bias estimation modified in GEODYN	wd18, wd20, wd21
Pole model	IERS2010. (Table 6.6, Petit and Luzum, 2010)	wd20, wd21
Background C_{21} S_{21}	IERS2010. (Eq. 6.5, Petit and Luzum, 2010)	
DORIS time bias	Applied for TOPEX from SLR/DORIS solutions	
Cd adjustments	More frequent for ~800 km satellites per AWG.	
SPOT-5 data	Use SAA-corrected data (2006 – 2013) from H. Capdeville	
SPOT-5 solar array	Model pitch changes after March 2012.	
NEQ factors	Not unity. Proportional to RMS of fit, by satellite.	
DORIS COM & offsets	Apply COM and offsets in GEODYN instead of using DORIS2.2 data-supplied corrections.	wd21
Antenna Phase Law	Applied for Starec and Alcatel antennae per information from CNES.	wd21

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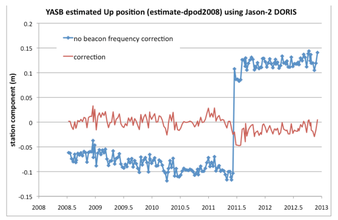
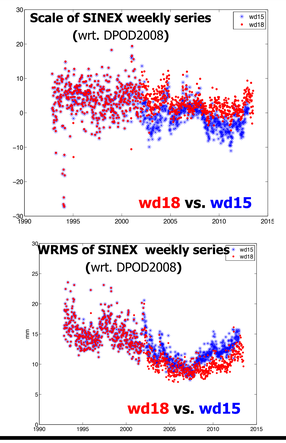
International DORIS Service (IDS) & DORIS System Information available at http://ids-doris.org

Impact of Improved Frequency bias modelling

From 2002 onward, the DORIS2.2 files, used systematically a nominal value of the beacon frequency, rather than the actual frequency. Hence, the partial derivatives in GEODYN must be updated to allow for a correction (deviation) from this nominal frquency. The change alters dramatically the scale of the series, and removes sporadic jumps in the station height for some stations, as in the example below for Yarragadee (YASB).

In the plots below, gscwd18 was the first series to implement the correction for the frequency bias modelling. The curvilinear pattern in scale evident in the previous series, gscwd15, is removed.



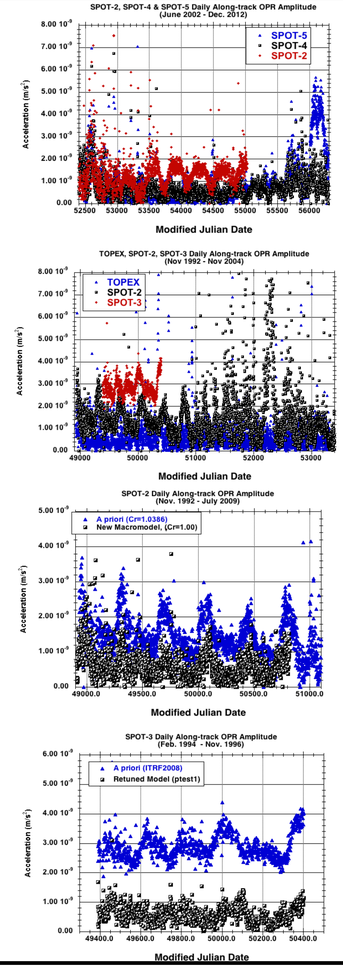


POD RMS of fit for SLR & DORIS arcs (cm, mm/s)
w. different processing standards
(over time span of available data 1993-2013)

Satellite & Data	wd12	wd15	wd17	wd18	wd20	wd21
Lageos-1	0.900	0.871	--	--	0.864	--
Lageos-2	0.881	0.842	--	--	0.836	--
Stella	1.600	1.496	--	--	1.459	--
Starlette	1.586	1.506	--	--	1.504	--
Larets	1.607	1.434	--	--	1.379	--
Envisat (SLR) (slr+dor arcs) (DORIS)	1.272 0.494	1.289 0.492	1.162 0.492	1.165 0.492	1.146 0.502	Dor only 0.492
TOPEX (SLR) (slr+dor arcs) (DORIS)	1.701 0.513	1.679 0.514	--	1.677 0.514	1.684 0.514	Dor only .510
Jason2 ((SLR) (slr+dor arcs) (DORIS)	1.215 0.361	1.165 0.376	--	1.159 0.375	1.167 0.375	Dor only .377
Cryosat-2 (SLR) (slr+dor) (DORIS)	2.131 0.437	1.850 0.445	--	1.851 0.441	1.283 0.439	Dor only .441
SPOT-2	0.471	0.471	0.471	0.477	0.475	0.476
SPOT-4	0.456	0.465	--	0.474	0.474	0.475
SPOT-5 (2002.0-2006.0 no SAA corr.) (2006.0-2013.0 w. SAA corr.)			--	.453 .425	.453 .422	.454 .422

Update of Non-conservative force modelling

We re-evaluated the performance of the non-conservative force modelling for the all the DORIS satellites, by analyzing the residual empirical accelerations (once-per-rev's) for all the DORIS satellites. The previous modelling was detailed by **Le Bail et al. (2010)**, while for **Envisat** we used the UCL model (**Sibthorpe, 2006**) for solar radiation pressure, together with a CNES-supplied macromodel for atmospheric drag and planetary radiation pressure. The **SPOT-2**, **SPOT-3** performance (from the OPR's) were clearly outliers, and after re-tuning, the residual OPR's were reduced. For **Envisat**, we corrected an error in the orientation of the normal vectors of the solar array for the macromodel. The results also showed increased OPR's associated with **SPOT-5** after March 2012 – which was traced to unmodelled changes in the **SPOT-5** solar array pitch after March 2012



Application of DORIS antenna phase laws

The **phase law** for the **Starec** antennae was derived by the CNES from measurements in an anachoeic chamber, whereas the **Alcatel** antenna phase law is as specified by the manufacturer. We compare in **gscwd21** the application of the DORIS offset and Center of Mass (COM), as well as the phase law (In GEODYN, both must be applied in tandem). The impact on the scale compared to **gscwd20** is about + 5 – 10 mm between 2002 and 2013. There are smaller changes in Tz. We see a systematic improvement in the positioning 2002-2004, due to improved residuals of **Envisat**. For **Envisat** in this time period, the GEODYN-computed offset corrections seem superior to those supplied with the DORIS data.