Horizontal and vertical velocities derived from the IDS contribution to ITRF2014, and comparisons with external models

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Guilhem Moreaux[1], Laurent Soudarin[1], Don Argus[2], Médéric Gravelle[3], Alvaro Santamaría-Gómez[3], Frank Lemoine[4], Pascal Willis[5] and Pascale Ferrage[6]

[1]CLS, Ramonville, France [2]JPL, Pasadena, USA [3]ULR, La Rochelle, France [4]NASA/GSFC, Greenbelt, USA [5]IGN, Paris, France [6]CNES, Toulouse, France

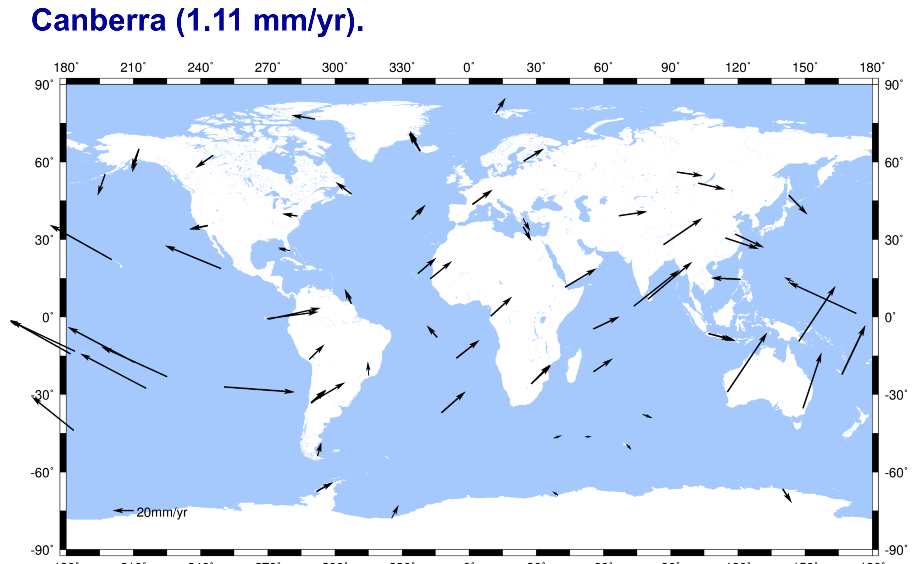
Abstract

In the context of ITRF2014, the IDS Combination Center delivered to IERS 1140 weekly SINEX files containing DORIS stations positions and Earth orientation parameters from January 1993 to December 2014 (series IDS 09). Then, a cumulative DORIS position and velocity solution was computed by stacking the IDS 09 weekly solutions and combining them with both DORIS internal local ties (3-D vector between two successive beacon installations at the same DORIS site) from IGN and a discontinuity file.

The first objective of this study is to compare DORIS horizontal velocities to estimations from tectonic models such as GEODVEL and NNR-MORVEL56. The second purpose is to evaluate DORIS vertical velocities with respect to Global Isostatic Adjustment models (for Greenland, Fennoscandia, Iceland, Antarctica sites) such as ICE-6G_C, and with respect to the GPS URL6 (from University of La Rochelle) solution at coastal sites. Sites which show higher differences in either horizontal (ex: Dionysos/Gavdos, Manila) or vertical velocities (ex: Thule and Ny-Ålesund) will be of special concern.

IDS Contribution to ITRF2014

DORIS station velocities are deduced by accumulation of the coordinate time series of the 71 sites from the 1140 IDS 09 weekly SINEX files delivered to IERS as the IDS contribution to ITRF2014. In addition, discontinuities in positions and velocities are applied to the weekly free datum normal equations. In total, 58 discontinuities have been defined through an iterative process with the IERS Combination Centers (DGFI, IGN, JPL). These discontinuities concern 31 over the 71 DORIS sites. Each weekly terrestrial frame was aligned onto the long-term frame by estimating the seven similarity transformation parameters (translations, rotations and scale). To overcome rank-deficiency of the normal equation system while computing the long-term frame and to apply the No-Net-Rotation (NNR) condition, minimal constraints on origin, scale and orientation were added to align the long-term frame on ITRF2008. Hereafter, we only retain velocities with formal error less than 1 mm/yr in either horizontal (Figures 1.a, 1.b) or vertical plane (Figures 2.a, 2.b). Over the 218 stations at 71 sites, 186 (resp. 202) horizontal (resp. vertical) velocities at 67 (resp. 71) sites are associated with uncertainties lower than 1 mm/yr. The four rejected sites are: Arlit (1.33 mm/yr), Grasse (1.11 mm/yr), Monument Peak (1.01 mm/yr) and Canberra (1.11 mm/yr).



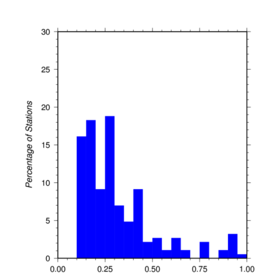
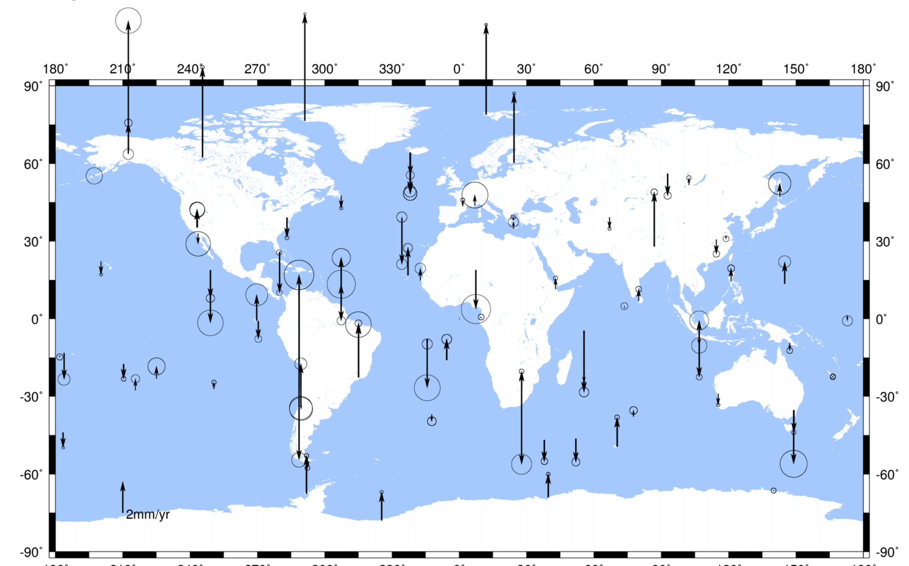


Figure 1.b – Histogram of the horizontal velocities uncertainties at the DORIS sites.

Figure 1.a - Horizontal velocities at DORIS sites from the IDS 09 cumulative solution.



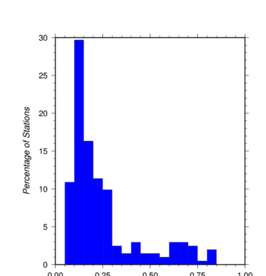


Figure 2.b – Histogram of the vertical velocities uncertainties at the DORIS sites.

Figure 2.a - Vertical velocities at DORIS sites from the IDS 09 cumulative solution.

Horizontal Velocities

That section aims at validating the horizontal velocities from the IDS 09 cumulative solution at the DORIS sites. Thus, we compare the DORIS velocities to two recent geodetical (GEODVEL) and geological (NNR-MORVEL56) plate models.

GEODVEL (Argus et al. 2010) is a plate model obtained by combination of solutions from the four space geodetic techniques: DORIS, GNSS, SLR and VLBI. Each technique solution was determined by one analysis institution. Estimations of angular velocities of 11 major plates (Antarctica, Arabia, Australia, Eurasia, India, Nazca, North America, Nubia, Pacific, Somalia, South America) are based on nearly 31 years of observations (from 1976 to 2007). The NNR-MORVEL56 model (Argus et al. 2011) is a complemented version of the geological plate model MORVEL (De Mets et al. 2010). The complement consists in addition of 31 plates from Bird (2003) to the 25 original major plates. More than three-fourths of the MORVEL data come from the mid-ocean ridges.

Whereas the linear velocities resulting from the IDS combination are affected by GIA (Glacial Isostatic Adjustment), the geological models are free of GIA. Therefore, GIA must be subtracted to the DORIS velocities. We selected the ICE-6G (VM5a) model from Peltier et al. (2015) as it provides both horizontal and vertical motions at geodetic sites due to GIA. Sites rising or moving horizontally faster than 1 mm/yr were assumed to be affected by GIA.

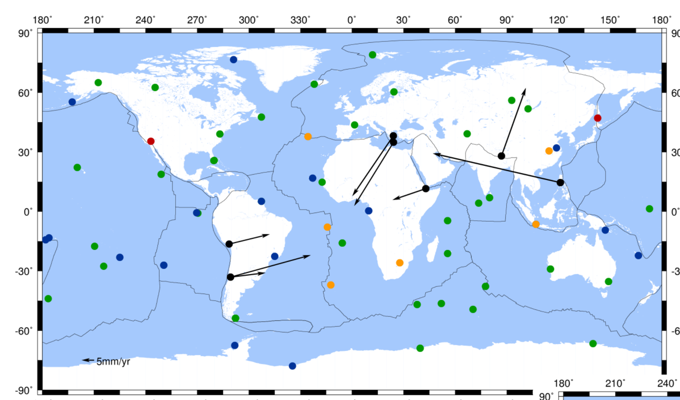
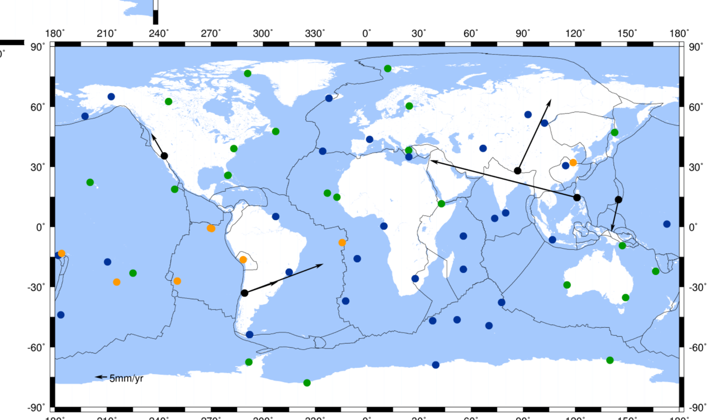


Figure 3 - Velocity differences between IDS 09 and GEODVEL (left), NNR-MORVEL56 (right). (Green: less than 2.5mm/yr. Blue: between 2.5−5.0mm/yr. Orange: between 5.0−7.5mm/yr. Red: between 7.5−10.0mm/yr. Black: larger than 10mm/yr, and rates of velocity differences are shown only in this case. Grey lines indicate plate boundaries used in the NUVEL-1A model in case of GEODVEL and NNR-MORVEL56 model in case of MORVEL.



	North	East
IDS – GEODVEL	6.2	10.9
IDS – NNR MORVEL 56	5.6	11.7

Table 1 – RMS of horizontal velocity differences between IDS 09 and GEODVEL, NNR-MORVEL56. Unit is mm/yr.

As expected since plate models do not use observations close to plate boundaries while estimating the angular velocity of the plates, the larger differences (see Figure 3 and Figure 4) between the DORIS estimates and the two plate models occur in majority close to the plate boundaries. These differences may also reflect that whereas the DORIS estimations reveal current motions, the plate models account for deformation over older (and longer) time period. Meanwhile, hereafter we discuss on the validity of the DORIS horizontal velocities in Dionysos/Gavdos (Greece) and in Manila (Philippines).

MANILA (Philippines)

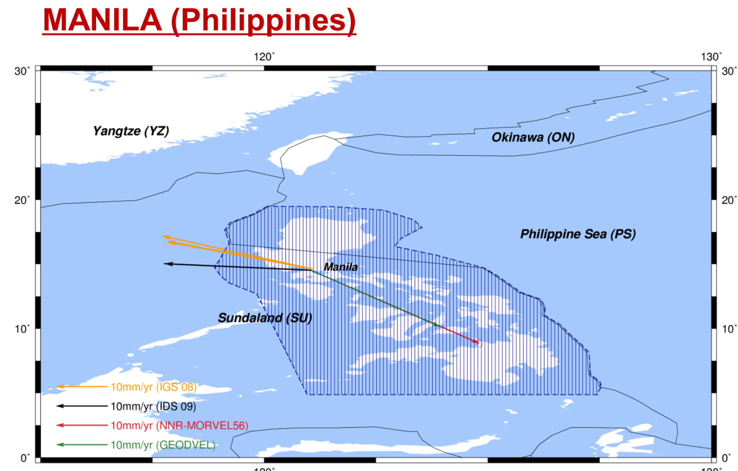


Figure 4 – Horizontal velocities at the DORIS site of Manila.

- ❑ **For the site of Manila (Philippines), the IDS 09 vector is nearly in the opposite direction of the horizontal vectors from the two plate models.**
- ❑ **The disagreement must be explained by the complexity of the Manila zone.**
- ❑ **IDS vector is similar to the IGS solution of PIMO (10 km North-East from the DORIS station).**
- ❑ **IDS and IGS horizontal vectors are consistent with the counterclockwise rotation of the Luzon microblock with respect to the Sundaland plate.**

DIONYSOS / GAVDOS (Greece)

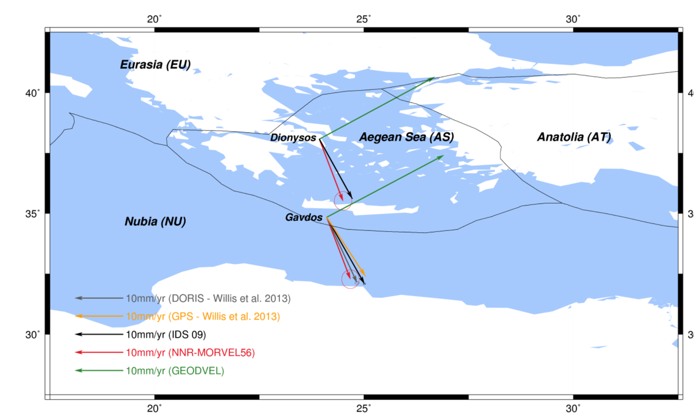


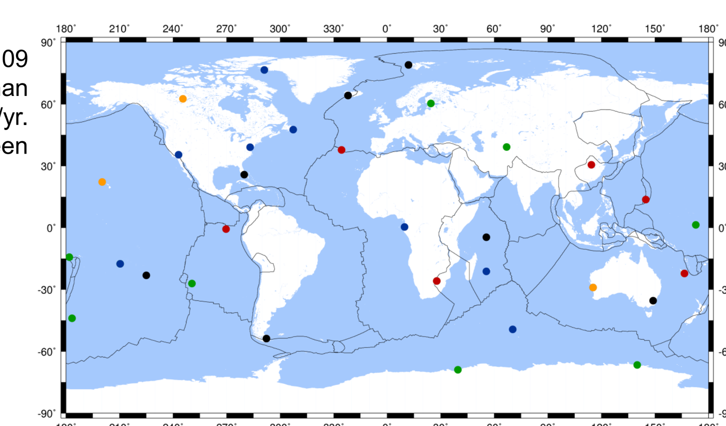
Figure 5 – Horizontal velocities at the DORIS sites of Dionysos and Gavdos (Greece).

- ❑ **Horizontal speed vectors of Dionysos and Gavdos from IDS 09 agree well in both amplitude and azimuth with NNR-MORVEL56 predictions but are nearly orthogonal to the GEODVEL vectors.**
- ❑ **IDS vectors are compatible with GNSS and other DORIS estimations.**
- ❑ **The disagreement of GEODVEL must be explained by the fact that NNR-MORVEL56 makes use of a local small plate (Aegean Sea) whereas for GEODVEL these two sites belong to the Eurasia (EU) plate.**
- ❑ **Gavdos and Dionysos are in line with southwestward motion of the Aegean region with respect to Eurasia at 30 mm/yr.**
- ❑ **The similarity in both magnitude and orientation of Dionysos and Gavdos supports the observation from McClusky (2010) that Dionysos and Gavdos appear to belong to the same small SW Aegean/Pelopponnisos plate.**

Vertical Velocities

To assess the quality of the IDS 09 vertical velocities, we compared it to the latest GNSS cumulative solution (designated by ULR6) from La Rochelle University. That GNSS solutions was selected for several reasons: i) it is based on a different geodetic space technique, ii) the time span of ULR6 (1995.0-2014.0) is consistent with the IDS 09 (1993.0-2015.0) one, iii) more than 45 percent of the DORIS sites are co-located with GNSS sites included in ULR6 and, iv) La Rochelle University actively contributed to the IGS combined solution to ITRF2014.

Figure 6 - Velocity differences between IDS 09 and ULR6 GNSS solution. (Green: less than 0.5 mm/yr. Blue: between 0.5-1.0 mm/yr. Orange: between 1.0-1.5 mm/yr. Red: between 1.5-2.0 mm/yr. Black: larger than 2 mm/yr.



THULE (Greenland)

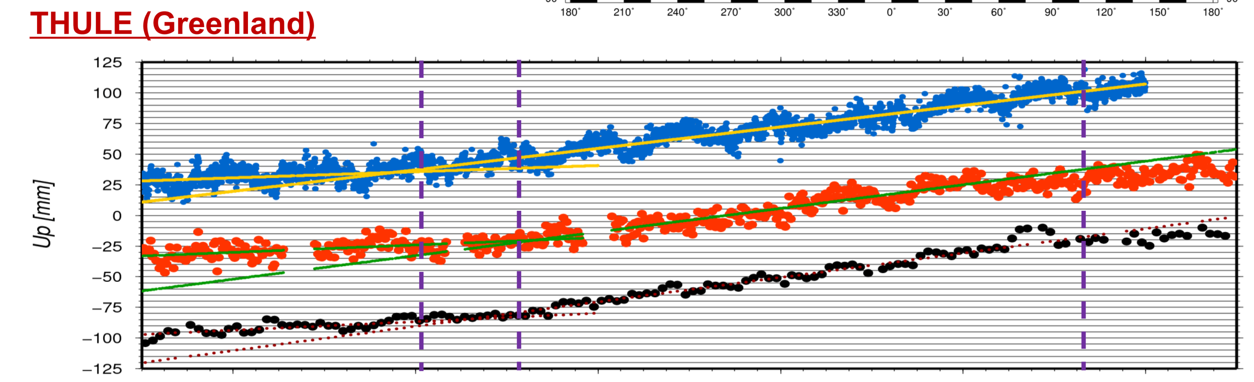


Figure 7 – Time series of the vertical component at long term DORIS (THUB - red) and GNSS (THU3 - blue) stations in Thule. Black dots correspond to minus the water height variations from monthly GRACE gravity fields. Each dot represents a daily solution for GNSS, a weekly solution for DORIS and a monthly solution for GRACE.

- ❑ **Similar vertical motion of Thule (Northwest coast of Greenland) as observed by DORIS (6.87±0.07 mm/yr) and GNSS (6.83±0.68 mm/yr in THU2, 7.62±0.74 mm/yr in THU3).**
- ❑ **As no GIA affects Thule, the decrease of the equivalent water height observed by GRACE (from GRGS – http://www.thegraceplotter.com) can be interpreted as vertical uplift.**
- ❑ **The high correlation between DORIS/GNSS and GRACE measurements indicates that geometric and gravimetric techniques observe the same geophysical phenomenon.**
- ❑ **Uplift acceleration 2005-2006. Already identified in Khan et al. (2010).**
- ❑ **Possible uplift deceleration in 2013-2014.**

Ny-Ålesund (Svalbard - Norway)

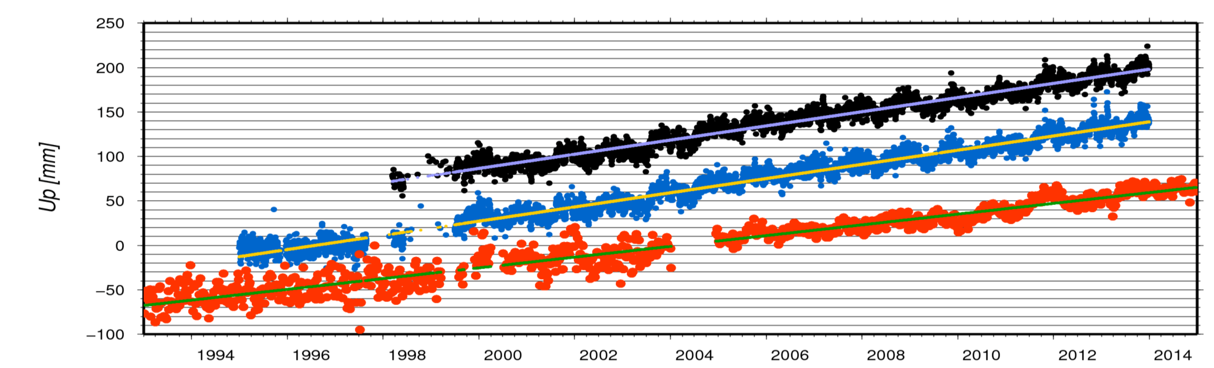


Figure 7 – Time series of the vertical component at long term DORIS (SPIA, SPIB, SPJB - red) and GNSS (NYAL - blue ; NYA1 - black) stations in Ny-Ålesund. Each dot represents a daily solution for GNSS and a weekly solution for DORIS.

- ❑ **DORIS uplift (5.79±0.07mm/yr) compatible with the sum of GIA (2.38 mm/yr – ICE6G) and PDIM (Present Day Ice Melt - 3.52 mm/yr – Mémin et al. 2009).**
- ❑ **PDIM uplift is most likely due to the viscoelastic response to the retreat of the Lovénbreen glacier in the vicinity of Ny-Ålesund.**
- ❑ **Discrepancies between DORIS and GNSS velocities (NYA1 8.02±0.50 mm/yr ; NYAL 7.97±0.48 mm/yr) is still not explained and was observed in older studies.**

Conclusions and Perspectives

- ❑ **DORIS horizontal velocities are compatible with GEODVEL and NNR-MORVEL56 models in plate interiors.**
- ❑ **At plate margins or in active zones, DORIS horizontal velocities are validated by comparisons to GNSS or VLBI estimations.**
- ❑ **Plate models may include a local small plate for the Aegean Sea by using, for example, DORIS stations in Dionysos and Gavdos.**
- ❑ **Comparisons of vertical velocities between IDS 09 and ULR6 exhibit no geographical pattern.**
- ❑ **Future cumulative solutions must include a velocity discontinuity in 2005/2006 for THULE.**
- ❑ **Extension of coordinate time series of THULE will show if a second velocity discontinuity in 2013/2014 has to be introduced.**

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Contact: gmoreaux@cls.fr

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