GEOD-ESIS : geodetic combinations to improve the realisation of the Terrestrial Reference Frame

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Adrian Banos Garcia (1)
Sylvain Loyer (1)
Paul Rebischung (2)
Guilhem Moreaux (1)
Hugues Capdeville (1)

(1) CLS, France
(2) IGN, France

Motivation and context

Our group (CNES/CLS):

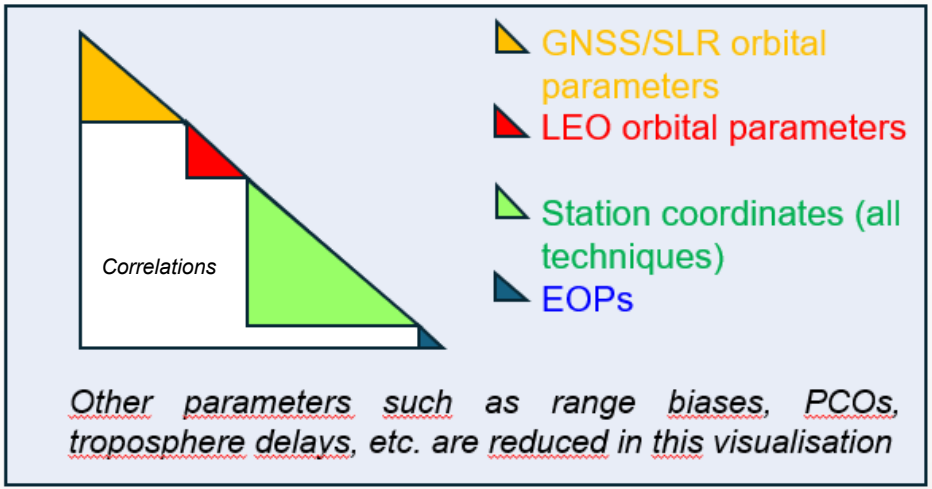
- Holds IDS (DORIS), IGS (GNSS) and ILRS (SLR) Analysis Centers.
- Uses a single POD software (GINS from CNES).

In view of the forthcoming ESA GENESIS mission with the four space geodetic techniques onboard, we began a multi-technique project by processing Sentinel-6A data, since its platform is equipped with three (DORIS, GNSS, SLR) out of the four techniques. The idea is to:

1) Be prepared for the processing of future GENESIS observations.
2) Asses the benefits of the inclusion of LEO satellites into the classical IGS/ILRS solutions.
3) Assess the benefits of a multi-technique space mission (space tie) to TRF realizations.

Joint processing of GNSS, DORIS and SLR observations

1) We do either a single multi-technique processing…
2) …or a technique-specific processing with the same models, initial state vector, arc length, software, etc. and perform a combination of the resulting normal equations.



Advantages:

- Real « space tie »
- Correlations between station coordinates of different techniques available thanks to LEO observations → No need for constraints
- All techniques should benefit from each other's strengths

Steps towards a combined 'space tie' solution (1)

	Processing	Classical satellites	Classical + LEO
STEP 0	GNSS (ground-only)	**IGS contribution**	
	SLR (spherical satellites)	**ILRS contribution**	
	DORIS	**IDS contribution**	

Steps towards a combined 'space tie' solution (2)

	Processing	Classical satellites	Classical + LEO
STEP 0	GNSS (ground-only)	**IGS contribution**	
	SLR (spherical satellites)	**ILRS contribution**	
	DORIS	**IDS contribution**	
STEP 1	GNSS + SE6A		**IGS Workshop, June 2024**
	SLR + SE6A		**ILRS Workshop, October 2024**

Steps towards a combined 'space tie' solution (3)

	Processing	Classical satellites	Classical + LEO
STEP 0	GNSS (ground-only)	**IGS contribution**	
	SLR (spherical satellites)	**ILRS contribution**	
	DORIS	**IDS contribution**	
STEP 1	GNSS + SE6A		**IGS Workshop, June 2024**
	SLR + SE6A		**ILRS Workshop, October 2024**
STEP 2	GNSS + DORIS + SLR + LEO (*)	**GEOD-ESIS**	

(*) SE6A for now. Eventually, other LEO satellites such as SE3A and SE3B

How to perform a good inter-technique combination

In order to perform a good combination, several questions need to be answered first :

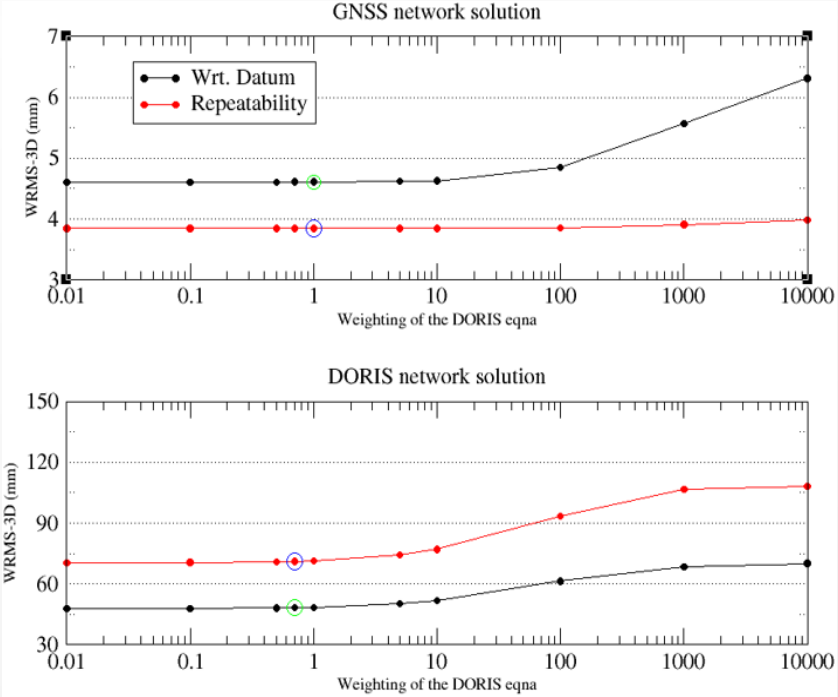
1) Do we have the same models ? We need to make sure the same loading models, gravity potential and satellite parametrisation is applied.
2) What is the length of the arc ? Easier if it's the same amongst the techniques. IGS solutions are daily whereas IDS and ILRS solutions are weekly. A daily solution is chosen as a compromise : keep the link with GNSS as a reference avoiding an increase in CPU time.
3) How do we weight each technique (GNSS, DORIS, SLR) in the combined solution? Working with normal equations makes this point much easier to tackle.
4) How and to what do we align the combined solution ? For EOP determination, we align the combined solution in orientation/rotation (NNR) to the IGS core network. The solution is free to move in translation.

How to weight each technique

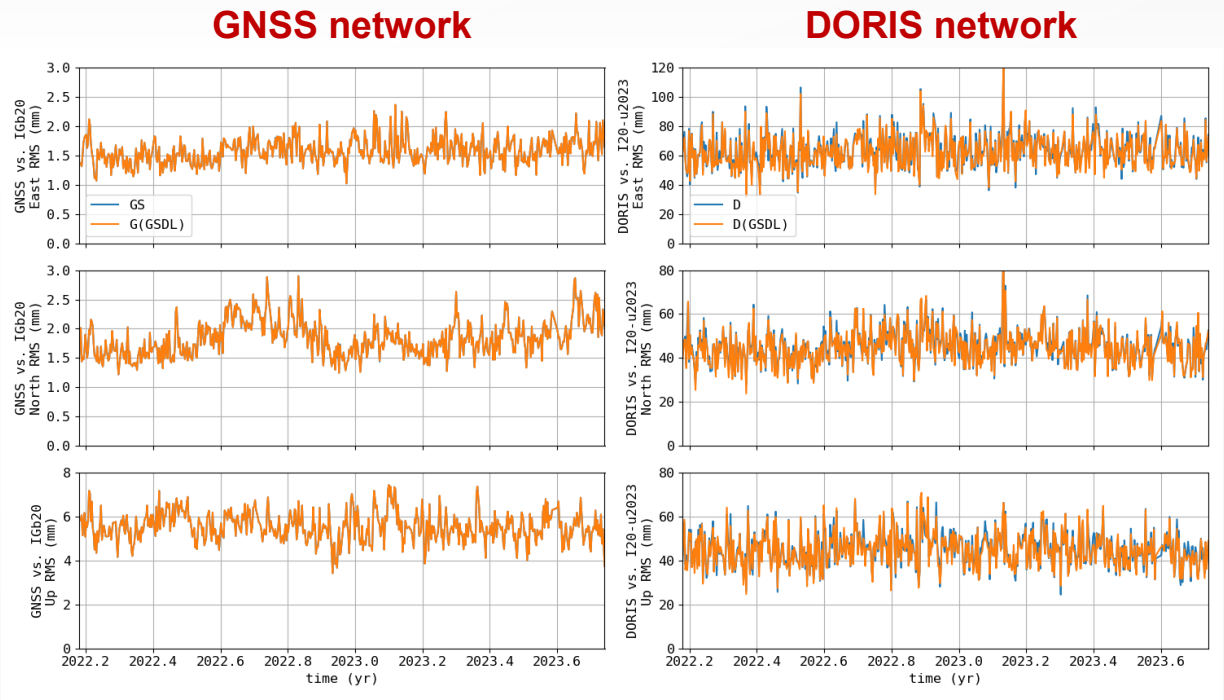
To find the optimal weight between the techniques, several tests were carried out over one month of data by varying the weights of the normal equations in the stacking process. In all cases, the GNSS weight remains equal to 1 and the weight of the tested technique (SLR or DORIS) is changed.

The solutions are evaluated via the WRMS with regard to ITRF2020 and the daily repeatability of the solutions. For the GNSS & DORIS networks we can see that :

- GNSS network is degraded if the weight of the DORIS normal equation exceeds 10.
- If the weight of the DORIS normal equation is very low, we find the results of the individual GNSS solution. Analogously, if the weight is very high, we find the results of the individual DORIS solution.
- The chosen weight for the DORIS normal equation is such that neither network is degraded while trying to keep it as significant as possible.



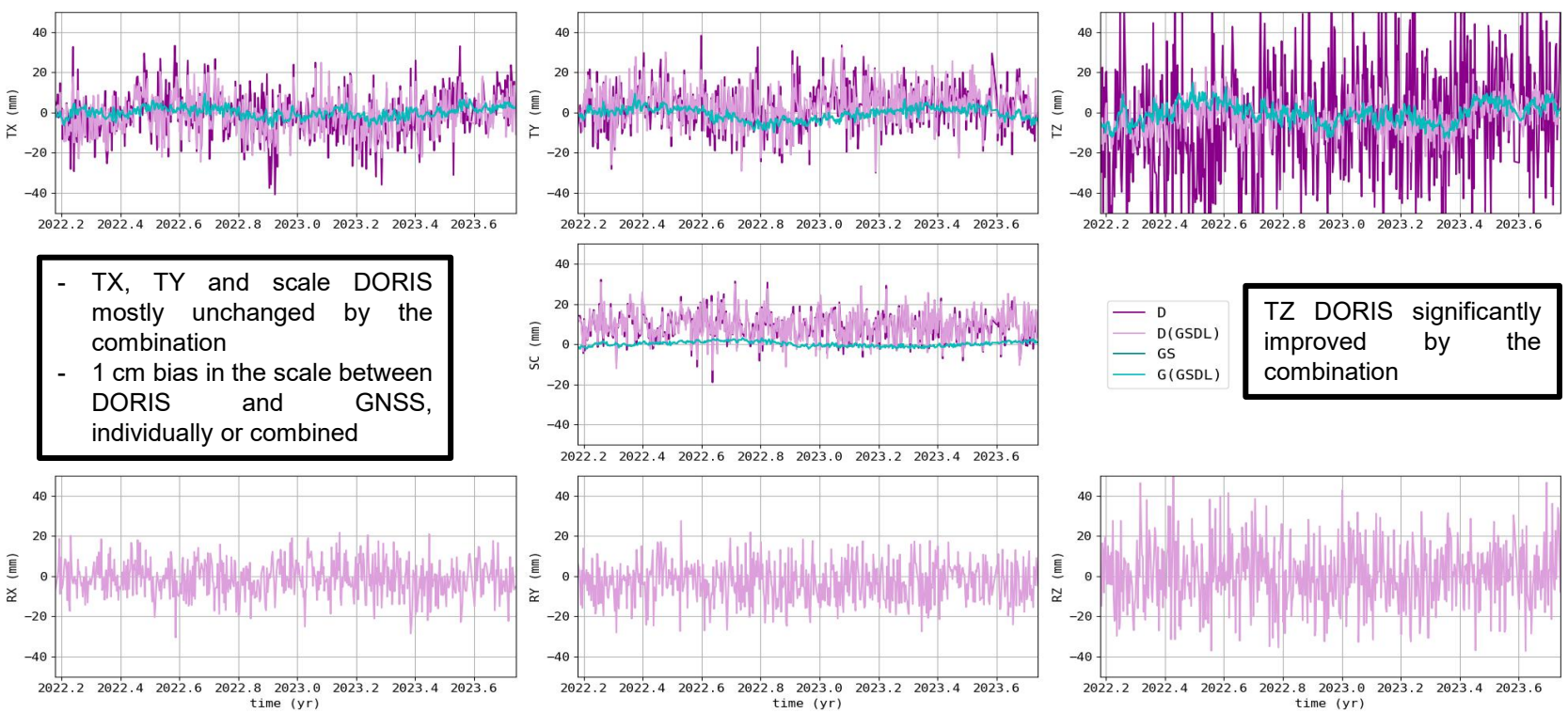
Results of the combination (1)



RMS of station positions of GNSS and DORIS solutions are the same in both the individual (**GS** et **D**) and combined (**GSDL**) solutions.

Combination hardly changes the geometry of the GNSS and DORIS networks.

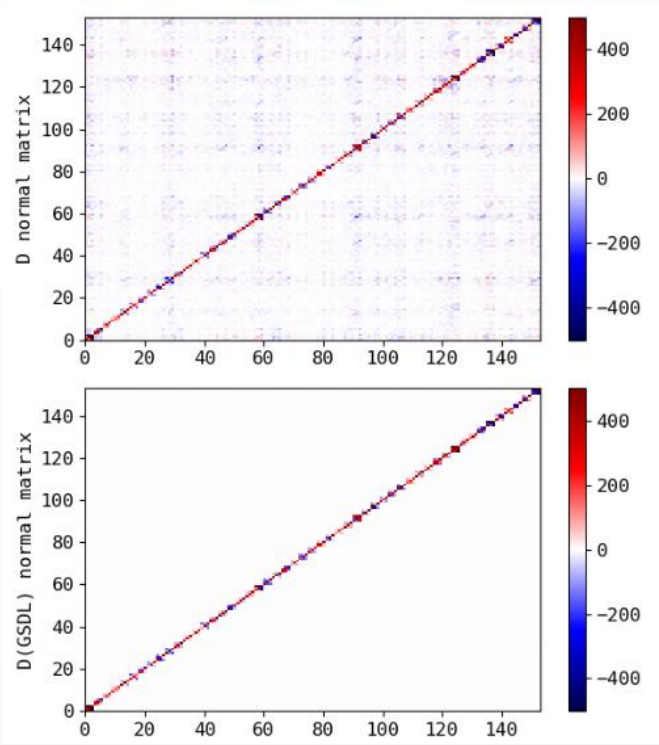
Results of the combination (2)



- TX, TY and scale DORIS mostly unchanged by the combination
- 1 cm bias in the scale between DORIS and GNSS, individually or combined

TZ DORIS significantly improved by the combination

Results of the combination (3)



The normal matrix becomes practically a block-diagonal in the combined solution, as if the DORIS station positions were obtained using PPP. This is not necessarily expected.

It’s true that, from the DORIS perspective, the Sentinel-6A orbit is essentially fixed to the orbit estimated by GNSS in the combined solution. However, the Sentinel-6A DORIS clock remains estimated and not combined with the GNSS clock.

Shouldn't we therefore expect some correlations to remain between the positions of the different DORIS stations in the GSDL solution?

Conclusions & Perspectives

We started to investigate space ties using a unique software for all techniques. First results show that :

- Combination doesn't degrade either the GNSS or the DORIS network:
  1) Geometry stays the same.
  2) GNSS origin and scale too.
  3) TX, TY and scale DORIS mostly unchanged ; 1 cm scale bias between GNSS and DORIS still present.
  4) TZ DORIS improves significantly.

Future work :

- Use of new space ties via other LEO satellites such as Sentinel-3A and -3B (ongoing)
- Understand the offset between the GNSS and DORIS scale. Antenna calibrations/PCOs ? (ongoing)
- Evaluate local ties within the combined solution.
- Adding more common parameters (tropospheric delays at collocated sites, clock parameters).

This project has been made possible thanks to the technical and financial support of CNES