Assessment and Analysis of Ocean Tide Loading Effect in Western Mediterranean Region Using GNSS

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Abstract: Water masses displaced by ocean tides are one of the causes of periodic deformation of the Earth's crust, which is propagated by flexure into the interior of the continent - the Ocean Tide Loading (OTL) effect. These displacements are of the millimetre to centimetre level and mainly affect the vertical component, but also, to a lesser extent, the horizontal components. Recent developments in permanent GNSS station networks (e.g. IGS) have made it possible to map displacements due to ocean tide loading. The aim of the work is, on the one hand, to estimate the displacement due to ocean tide loading at sites located in the Mediterranean region, based on the processing of GNSS observations in PPP mode, and on the other hand, to study the impact of using different ocean tide loading models on the repeatabilities of daily solutions derived from an analysis of GNSS data in relative mode, particularly when some stations in the network show a significant effect of this phenomenon.

Key words: GNSS, ocean tide loading, Mediterranean region, repeatability.

1.Introduction

Gravitational attraction coupled with the Earth's rotation deforms the Earth over time, both directly (solid earth and ocean tide) and indirectly in response to pressure variations exerted on the crust by the displacement of water masses (ocean tide loading).

The aim of this work is to study the ocean tide loading effect on GNSS stations position in the Mediterranean region. Through this study we hope to be able to answer the following questions:

- May the GNSS tool be used to measure the displacement related to ocean tide loading in absolute terms even at locations with low tide loading effects, such as in the Mediterranean region? Would these displacement values be well-correlated with the values given by the models?
- In terms of the effectiveness of ocean tide loading models and their impact on daily coordinates repeatability, can we confirm that 24-hour sessions should have only a negligible average effect?

2. Methodology and Data

This work is divided into two parts:

Part 1: In this part, approximately one year of GNSS data were analysed in Precise Point Positioning (PPP) mode using the PRIDE PPP-AR software in order to estimate the displacement caused by ocean tide loading at 06 IGS stations located in the Mediterranean region (AJAC/France, GRAS/France, MATG/Italy, BRST/France, MELI/Spain et OPMT/France).

To highlight the ocean tide loading effect, the BREST station, located on the west coast of France (facing the Atlantic Ocean), was included in the processing. Three (03) hours GNSS observation sessions were analysed in order to allow the estimation of sub-daily periodic effects.

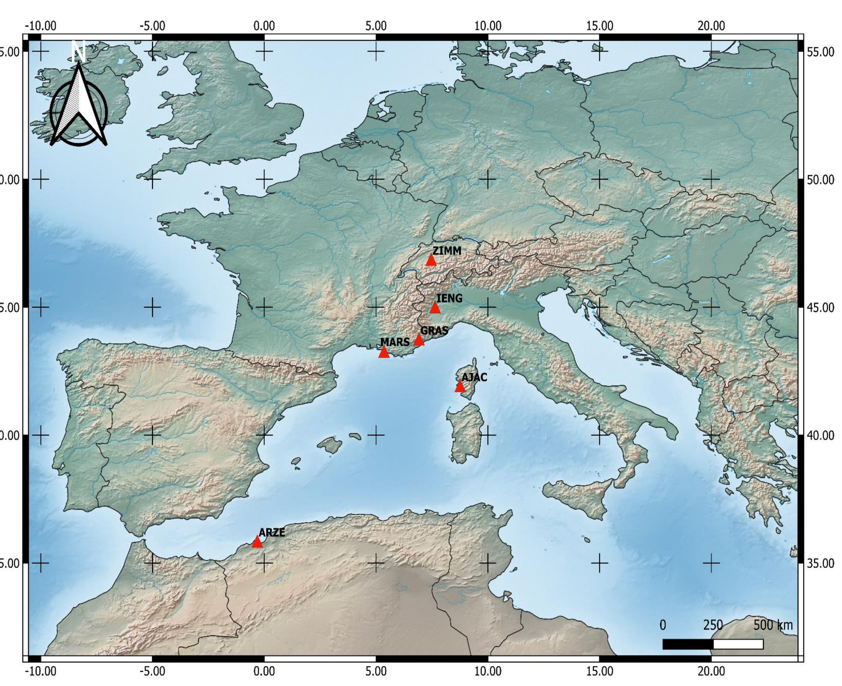
The displacements obtained on the three ENU components (East, North and Up) are then compared with values estimated by a the FES2004 model.

Mapping function	GMF
Orbits	final IGS held fixed
Tide	Solid, Pole
Cut-off angle	5 degrees
Zenith Delay estimation	1 h interval
Horizontal Atmospheric Gradients	2 per day
Ambiguities status	Fixed (GPS, Galileo and BDS)

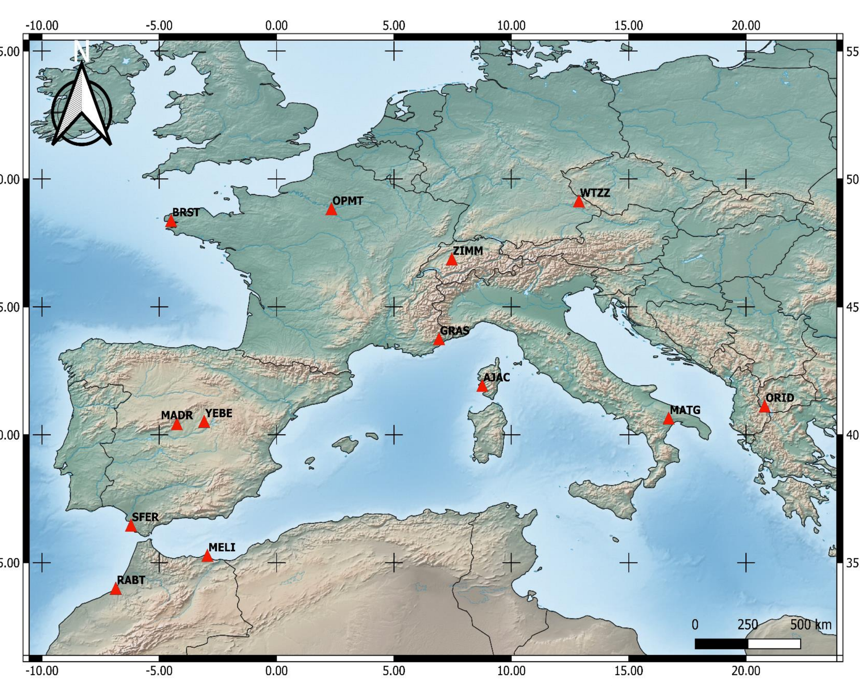
PPP processing parameters (PRIDE PPP-AR)

Part 2: In this part, two datasets from two different campaigns are used. The first campaign is a network of 06 stations located in the Mediterranean region. The GAMIT/GLOBK software was used in differential network processing mode to study the impact of using different ocean tide loading models on the repeatability of daily coordinate time series.

For the second campaign, a more extensive network was chosen, including sites outside the Mediterranean region. The aim is to evaluate the effectiveness of the FES2004 model in correcting the effect of ocean tide loading by analysing the repeatability of daily coordinates, particularly when particular stations in the network (e.g. the Brest station) are subject to a significant effect of this phenomenon.



Geographic location of used stations – 1st dataset



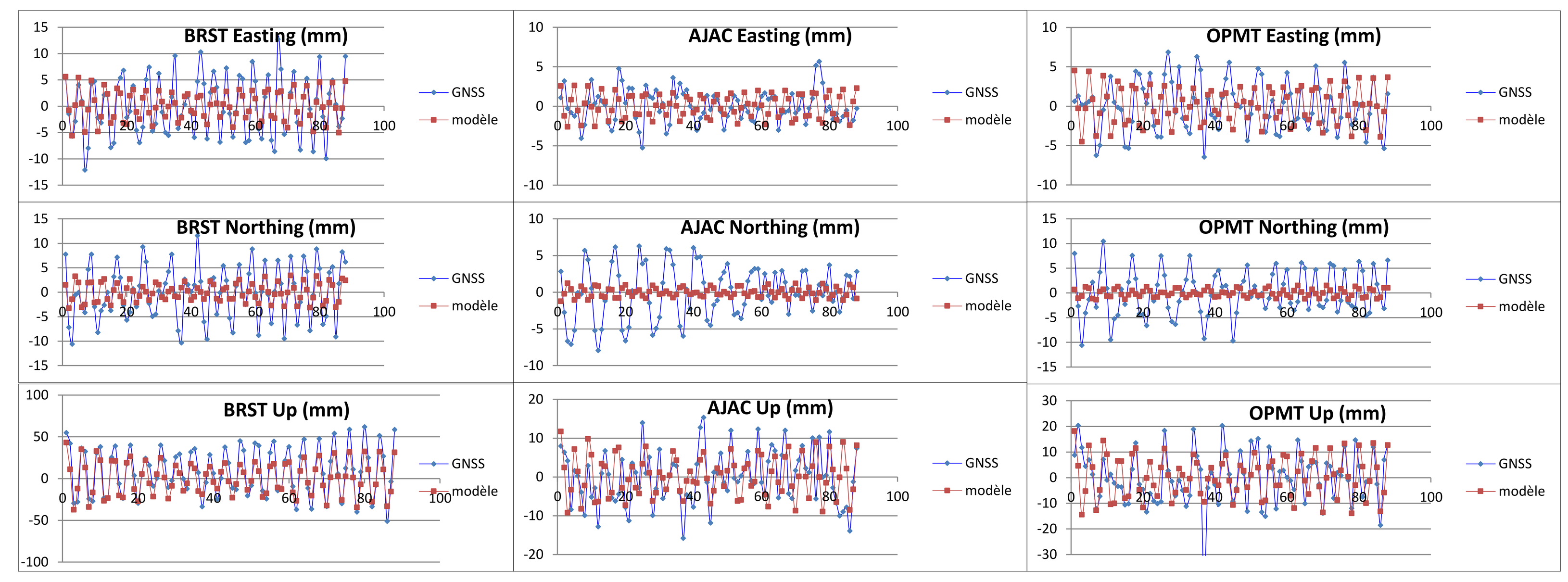
Geographic location of used stations – 2nd dataset

Mapping function	VMF
Orbits	final IGS held fixed
Measurements weighting	Elevation
Ocean Tide Loading (OTL)	TPOX.7, CSR.4, GOT00.2, NAO.99b, FES99, FES2004, FES2014b
Cut-off angle	5 degrees
Zenith Tropospheric Delay	2 h interval
Atmospheric Gradients	2 per day

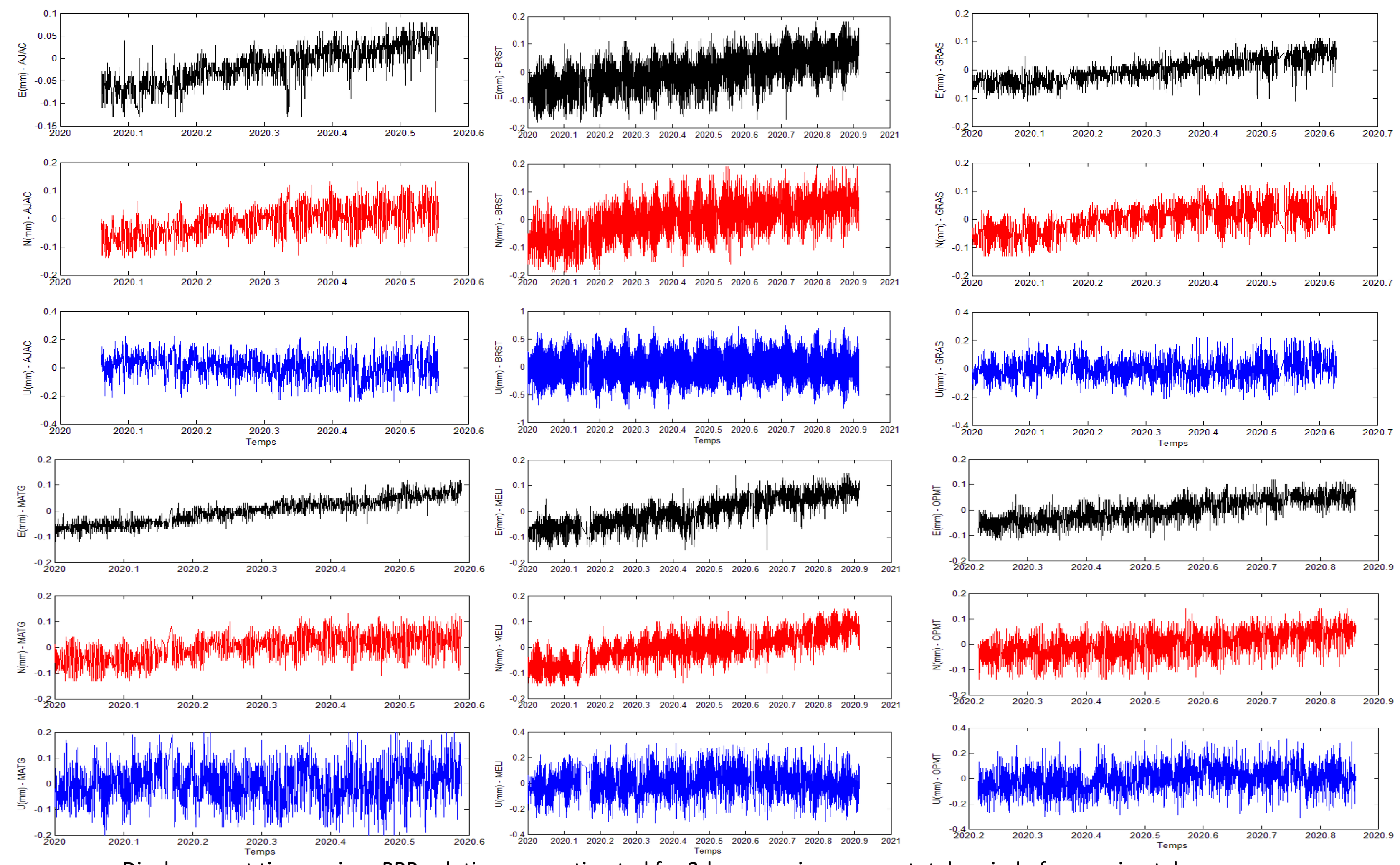
Parameters of relative Processing (GAMIT/GLOBK)

3. Results

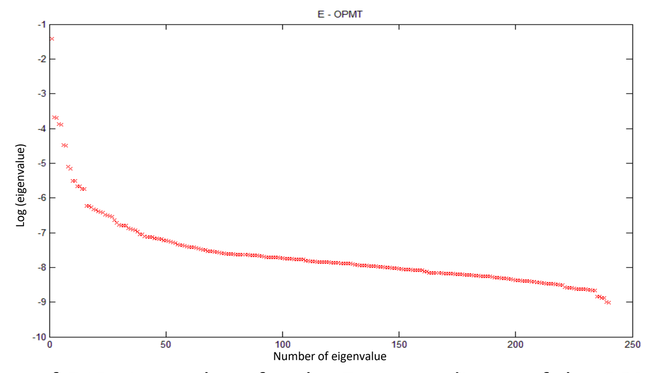
3.1 Estimating displacements due to OTL using GNSS PPP method



Displacements from GNSS and FES2004 model : PPP solutions are estimated for 3-hour sessions over a total period of 10 days



Displacement time series : PPP solutions are estimated for 3-hour sessions over a total period of approximately one year



Ex: Diagram of 240 eigenvalues for the East coordinate of the OPMT station

The Singular Spectral Analysis (SSA) method is used to determine the periodic signals contained in the displacement time series. The analysis revealed the presence of the M2, O1 and k1 components at all stations. The other waves appear in some stations.

3.2 OTL effect on daily coordinate repeatabilities (Network solution)

Stations	Repeatability	Coordinates	TPOX.7	CSR.4	GOT00.2	NAO.99b	FES99	FES2004	FES2014b
ARZE	WRMS	N	3,9	3,9	3,8	3,9	3,8	4,3	3,9
		E	3,4	3,4	3,4	3,4	3,3	2,7	3,3
		U	16,3	16,3	16,4	13,7	16,6	15	17,5
	NRMS	N	0,63	0,63	0,62	0,63	0,6	0,59	0,64
		E	0,73	0,72	0,72	0,73	0,71	0,51	0,7
		U	0,56	0,56	0,57	0,47	0,57	0,46	0,61
AJAC	WRMS	N	0,9	0,9	0,9	0,9	0,9	1	0,9
		E	0,7	0,7	0,7	0,7	0,8	0,7	0,8
		U	0,9	0,9	0,9	0,9	0,9	0,9	0,9
	NRMS	N	0,58	0,59	0,59	0,56	0,57	0,51	0,58
		E	0,65	0,66	0,62	0,62	0,66	0,55	0,69
		U	0,78	0,77	0,78	0,77	0,76	0,62	0,77
GRAS	WRMS	N	0,8	0,8	0,8	0,8	0,8	0,8	0,8
		E	1	1	1	0,9	1	0,9	1
		U	1,3	1,2	1,2	1,2	1,2	0,9	1,2
	NRMS	N	0,72	0,73	0,73	0,71	0,75	0,62	0,74
		E	0,94	0,94	0,94	0,9	0,94	0,85	0,94
		U	0,86	0,85	0,86	0,84	0,84	0,61	0,84
IENG	WRMS	N	1,7	1,7	1,7	1,7	1,7	1,7	1,7
		E	1,2	1,2	1,2	1,2	1,2	1,2	1,2
		U	3,8	3,8	3,9	3,7	3,8	4	3,7
	NRMS	N	0,94	0,94	0,93	0,95	0,95	0,7	0,96
		E	0,76	0,77	0,76	0,77	0,76	0,7	0,75
		U	0,63	0,63	0,64	0,61	0,62	0,57	0,62
MARS	WRMS	N	1	0,9	1	1	1	0,9	1
		E	1,1	1,1	1,1	1,1	1,1	1,2	1,1
		U	2	2	2	2	2	2,1	2
	NRMS	N	0,61	0,6	0,61	0,62	0,63	0,45	0,65
		E	0,66	0,66	0,64	0,66	0,65	0,62	0,66
		U	0,69	0,68	0,68	0,68	0,69	0,6	0,7
ZIMM	WRMS	N	1,5	1,4	1,4	1,4	1,5	1,2	1,4
		E	0,8	0,8	0,8	0,8	0,8	0,7	0,8
		U	1,1	1,1	1,1	1,1	1,1	0,9	1,1
	NRMS	N	0,6	0,59	0,6	0,59	0,6	0,46	0,6
		E	0,86	0,85	0,85	0,87	0,84	0,65	0,85
		U	0,76	0,75	0,76	0,74	0,75	0,6	0,75

Summary of WRMS and NRMS for the daily time series (1st dataset)

		With CORRECTION (FES2004)		Without CORRECTION	
Stations	Coordinates	WRMS (mm)	NRMS	WRMS (mm)	NRMS
AJAC	N	0.5	0.39	0.6	0.50
	E	0.6	0.43	0.6	0.41
	U	1.5	0.45	1.5	0.44
SFER	N	1	0.44	1	0.44
	E	1.2	0.60	1.3	0.66
	U	2.4	0.54	2.8	0.59
RABT	N	1.5	0.52	1.8	0.62
	E	1.1	0.53	1.2	0.55
	U	1.9	0.36	2.8	0.51
MADR	N	1.2	0.35	1.3	0.36
	E	1.1	0.36	1.1	0.35
	U	2.7	0.24	2.8	0.24
BRST	N	0.5	0.28	1	0.47
	E	1.2	0.59	1.5	0.71
	U	1.8	0.41	1.9	0.4
WTZZ	N	0.6	0.40	0.8	0.46
	E	0.6	0.30	0.6	0.27
	U	2.4	0.59	2.4	0.58
ORID	N	0.9	0.44	0.7	0.34
	E	1.2	0.37	1.3	0.38
	U	3.5	0.45	3.5	0.44
GRAS	N	0.5	0.33	0.5	0.32
	E	0.4	0.28	0.4	0.26
	U	1.2	0.26	1.2	0.26
MELI	N	1.2	0.44	1.2	0.45
	E	0.9	0.47	0.9	0.47
	U	3.8	0.59	3.9	0.60
OPMT	N	0.8	0.36	0.9	0.43
	E	0.5	0.36	0.5	0.35
	U	2.1	0.39	2.2	0.40
YEBE	N	0.7	0.39	0.8	0.42
	E	0.7	0.36	0.7	0.37
	U	1.5	0.28	1.6	0.29
ZIMM	N	0.4	0.33	0.5	0.34
	E	0.7	0.55	0.7	0.55
	U	2.2	0.58	2.3	0.59
MATG	N	1.1	0.56	1	0.51
	E	0.9	0.33	1	0.35
	U	3.2	0.45	3.1	0.43

Summary of WRMS and NRMS for the daily time series (2nd dataset)

4. Conclusion

The comparison between displacements obtained from GNSS measurements and FES2004 model shows agreement in the Easting and Up components, particularly in Easting. Deviations are observed in the Northing component, this is probably due to the effect of the satellite geometry, leading to uncertainties in position estimation, particularly in the Northing component, since at mid-latitudes, the northern sky region is not well covered by satellites. Furthermore, the PPP positioning accuracy depends on the quality of the available satellite orbit and clock products. In addition to these uncertainties, inherent to the used method, there are other effects, such as atmospheric pressure loading and hydrological loading, which were not taken into account in the analysis, despite the fact that their effect remains small.

For the network determination in relative processing mode, the obtained results confirm that, for most applications, the analysis of daily GNSS sessions have an insignificant average effect. However, in case of high accuracy applications, such as tectonic plate motion study or sea level monitoring, a suitable ocean tide loading model is required.