***9th EuroGOOS Conference** 3-5 May 2021*

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Tide in Gironde estuary

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Keywords: numerical modelling of tidal wave distortion, water level measurement, river dynamics and environmental key points, data from campaign 2018 usable for altimetry mission

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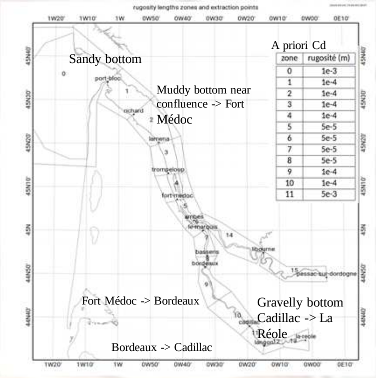
The dynamics of the Gironde estuary is investigated in order to improve the tidal wave deformation modelling in a constrained environment, under non linear dynamics (MarEst project). It aims to reduce the difference between in situ observation and tidal prediction from harmonic analysis, as highlighted by statistics over tides and surges, mainly in upper estuary. A standard deviation of tide amplitude and its error is expected to be lower than 0.10 m with a phase lag less than 10 minutes. Navigation safety along the Gironde River and the risk of flooding camp the motivations of the present study.

A numerical model has been configured and supplemented by a multi-sensor in situ measurement campaign. The objective in term of modelling is to develop a method to characterize tide in an estuary, to quantify tidal wave decay coefficients and classify different estuarine regimes. Because of the shallow depths and friction, the tide is significantly distorted in estuaries (Bordeaux and upper estuary with asymetric tide wave). In the upstream zone, this deformation, approaching a tidal mascaret wave is such that characterization by harmonic analysis loses much of its relevance, even in low water regime. In addition, the variability of the river flow causes a significant fluctuation of the range on tide gauges. It is therefore a dual problem to which the project has endeavored to try to provide new answers.

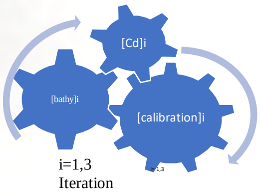
Method and model forcing



zone	rugosité (m)
0	1e-3
1	1e-4
2	1e-4
3	1e-4
4	1e-4
5	5e-5
6	5e-5
7	5e-5
8	5e-5
9	1e-4
10	1e-4
11	5e-3

Fig. 2: Initial partition of bottom friction coefficient

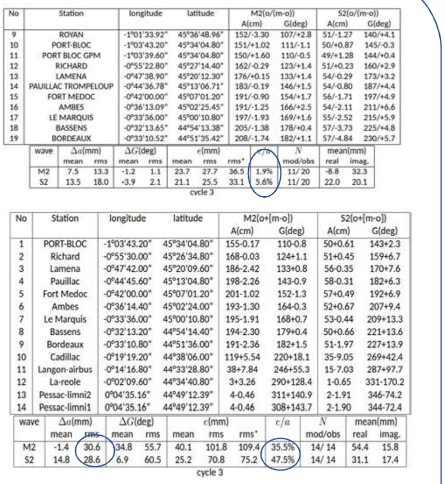
- * Method : Empirical calibration and validation preparing a realistic run. T-ugo model (Legos) in spectral mode + time stepping simulation with wetting-drying numerical parametrization. Grid size from 10 m to 1 km.
- * Tide gauges are provided by 2018 Grand Port Maritime de Bordeaux, Shom, DREAL Nouvelle-Aquitaine.
- * Tidal forcing from Atlantic Fes2014 (Legos) clamped mode: Amplitude (Complex space) applied as open boundary condition (tidal harmonics applied every 15')
- * Atmospheric forcing : hourly ERA5 (ECMWF): 10 m wind , atmospheric pressure



Empirical calibration based on bottom friction via bottom roughness: A zoning is made by compartments. Starting from the sea front and going up zone by zone towards the upstream estuary, the roughness is determined by different tests: (1) tidal energy flux equation expressed in amplitude and current linked to the rugosity (2) decomposition in lower and upper estuary for model from observation and damping factor of water level computed and adjusted in an iterative way. 3 iterations have been necessary for the method to converge: i.e. ratio (r) of water elevation model / observation tends to 1 (r=0.995 and 1.005) Obs. from Shom- Refmar analysed for the study dispersion is 0.98 and 1.01.

At starting point, mean (amplitude rms) of M2 is 471 mm; ratio [error/(amplitude obs. – model)] = 40,9%. ([e/a])
For tidal wave S2, mean amplitude rms = 81,2mm; [e/a]=35,9%

At 3rd iteration, the ratio[e/a] goes from 7.1% (M2) to 1.9% (Table 1)
At 3rd iteration, the ratio [e/a] goes from 8.4% (S2) to 5.6% (Table 1)



No	Station	longitude	latitude	M2(o/(m-o)) A(cm)	M2(o/(m-o)) G(deg)	S2(o/(m-o)) A(cm)	S2(o/(m-o)) G(deg)
9	ROYAN	-1°01'33.92"	45°36'48.96"	152/-3.30	107/+2.8	51/-1.27	140/+4.1
10	PORT-BLOC	-1°03'43.20"	45°34'04.80"	151/+1.02	111/-1.1	50/+0.87	145/-0.3
11	PORT BLOC GPM	-1°03'39.60"	45°34'04.80"	150/+1.60	110/-0.5	49/+1.28	144/+0.4
12	RICHARD	-0°55'22.80"	45°27'14.40"	162/-0.29	123/+1.4	51/+0.23	160/+2.9
13	LAMENA	-0°47'38.90"	45°20'12.30"	176/+0.15	133/+1.4	54/-0.29	173/+3.2
14	PAUILLAC TROMPELOUP	-0°44'36.78"	45°13'06.71"	183/-0.19	146/+1.5	54/-0.80	187/+4.4
15	FORT MEDOC	-0°42'00.00"	45°07'01.20"	191/-0.90	154/+1.7	56/-1.71	197/+4.9
16	AMBES	-0°36'13.09"	45°02'25.45"	191/-1.25	166/+2.5	54/-2.11	211/+6.6
17	LE MARQUIS	-0°33'36.00"	45°00'10.80"	197/-1.93	169/+1.6	55/-2.52	215/+5.9
18	BASSENS	-0°32'13.65"	44°54'13.38"	205/-1.38	178/+0.4	57/-3.73	225/+4.8
19	BORDEAUX	-0°33'10.52"	44°51'35.42"	208/-1.74	182/+1.1	57/-4.84	230/+5.7

wave	Δa(mm) mean	Δa(mm) rms	ΔG(deg) mean	ΔG(deg) rms	ϵ(mm) mean	ϵ(mm) rms	ϵ(mm) rms*	ϵ/a	N mod/obs	mean(mm) real	mean(mm) imag.
M2	7.5	13.3	-1.2	1.1	23.7	27.7	36.5	1.9%	11/ 20	-8.8	32.3
S2	13.5	18.0	-3.9	2.1	21.1	25.5	33.1	5.6%	11/ 20	22.0	20.1

cycle 3

No	Station	longitude	latitude	M2(o+[m-o]) A(cm)	M2(o+[m-o]) G(deg)	S2(o+[m-o]) A(cm)	S2(o+[m-o]) G(deg)
1	PORT-BLOC	-1°03'43.20"	45°34'04.80"	155-0.17	110-0.8	50+0.61	143+2.3
2	Richard	-0°55'30.00"	45°26'34.80"	168-0.03	124+1.1	51+0.45	159+6.7
3	Lamena	-0°47'42.00"	45°20'09.60"	186-2.42	133+0.8	56-0.35	170+7.6
4	Pauillac	-0°44'45.60"	45°13'04.80"	198-2.26	143-0.9	58-0.31	182+6.3
5	Fort Medoc	-0°42'00.00"	45°07'01.20"	201-1.02	152-1.3	57+0.49	192+6.9
6	Ambes	-0°36'14.40"	45°02'24.00"	193-1.30	164-0.3	52+0.67	207+9.4
7	Le Marquis	-0°33'36.00"	45°00'10.80"	195-1.91	168+0.7	53-0.44	209+13.3
8	Bassens	-0°32'13.20"	44°54'14.40"	194-2.30	179+0.4	50+0.66	221+13.6
9	Bordeaux	-0°33'10.80"	44°51'36.00"	191-2.36	182+1.5	51-1.97	227+13.9
10	Cadillac	-0°19'19.20"	44°38'06.00"	119+5.54	220+18.1	35-9.05	269+42.4
11	Langon-airbus	-0°14'16.80"	44°33'28.80"	38+7.84	246+55.3	15-7.03	287+97.7
12	La-reole	-0°02'09.60"	44°34'40.80"	3+3.26	290+128.4	1-0.65	331-170.2
13	Pessac-limni2	0°04'35.16"	44°49'12.39"	4-0.46	311+140.9	2-1.91	346-74.2
14	Pessac-limni1	0°04'35.16"	44°49'12.39"	4-0.46	308+143.7	2-1.90	344-72.4

wave	Δa(mm) mean	Δa(mm) rms	ΔG(deg) mean	ΔG(deg) rms	ϵ(mm) mean	ϵ(mm) rms	ϵ(mm) rms*	ϵ/a	N mod/obs	mean(mm) real	mean(mm) imag.
M2	-1.4	30.6	34.8	55.7	40.1	101.8	109.4	35.5%	14/ 14	54.4	15.8
S2	14.8	28.6	6.9	60.5	25.2	70.8	75.2	47.5%	14/ 14	31.1	17.4

cycle 3

Table 1 : Validation result from empirical method (upper panel) and from automated method. Realistic run with rievr and tide flux model (m) and tide gauge (o (osb).; N number of station used. River flux Delta a: amplitude diff. and standard deviation (rms) Delta G (phase lag diff. and standard deviation) ;e error and its rms; e/a: e normalized by a (mean delta a) (units mm and degree)

Automated method for configuration settings calibration and Gironde numerical experiment validation

This empirical approach is efficient in terms of final configuration setting, but requires a very important investment in operator time. This is why an automated method has been developed: From empirical bottom friction (Cd) calibration, a numerical experiment combined with the analysis of in situ data from campaign 2018 and completed with river flux. Variation of flows' energy is considered, including erosion due to friction, from station to station tide gauge, using a zoning similar to Fig. 2. Roughness is adjusted so that the free surface elevation is matching with the observations downstream of the open boundary. Calibration of the upstream configuration is done from upstream to downstream. The method refers to considering a numerical river with slope modulation and constraint dimension. Sensitivity of tidal wave propagation to the disturbance from river flow is approached by water elevation time series.

Results are presented for 2018-10-15 to 18 including a low river flux, a low tide amplitude and a flood that occurred from 2018-10-17. Significantly decreases the water height difference between model and observation (e.g. M2 tidal harmonic from 197 mm to 31 mm at the 3rd validation circle (Table 1 lower panel (30,6 mm; e/a= 35,5%). The result of validation is presented under weak tidal condition, at Bordeaux station, where the phasing of tide is improved (Fig.3, 4).

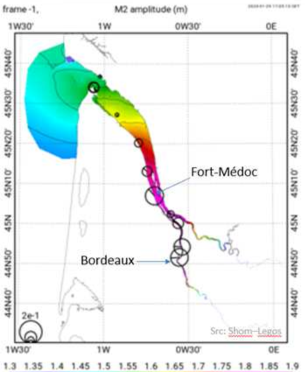


Fig.3: M2 amplitude (Complex, (m)) over Gironde color scale; M2 amplitude. Difference model – tide gauge (circle size in cm) (MarEst Project, Shom, Legos)

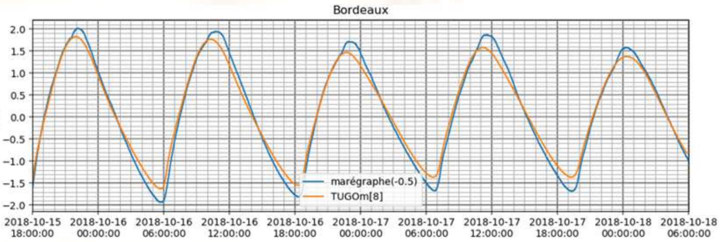


Fig. 4: Water height (m) at Bordeaux tide gauge (Grand Port Maritime de Bordeaux), relative to the mean level of the study. Modelled (orange curve, Legos, Shom, MarEst) and observed (blue curve) (MarEst Project and partners of CalNaGironde2018 campaign (Cnes, DT Insu, Legos, Shom, Syrte, et al.).

High density of sensors and prototypes

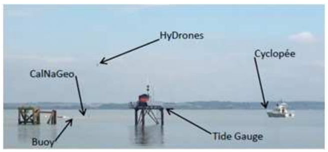


Fig 5: CalNaGironde campaign (2018-10) multi sensors- (credit CalNaGironde campaign partners)

Model evaluation is done by comparison with synchronous in situ measurements. In complement, an accurate vertical datum is a key to the project due to the applications related to water level and requirement on tide prediction uncertainty. The realistic tidal modelling is based on a measurement campaign prepared for this study, then carried out in a cooperation with Cnes and partners which greatly enlarged the scope of the deployed instruments, notably, in the framework of the SWOT space mission project (Cnes, Nasa) and its CalVal-related requirements (Ayoub N. et al. 2019, Picot N. *et al.* 2020). The set of in situ data is made of (a) radar tide gauges from Grand Port Maritime de Bordeaux, from Shom and from DREAL Aquitaine who provided also river flux; radar gauge onboard (Insu prototype), (b) GNSS floating carpet (La Rochelle University, operated by Insu and Syrte); fixed buoys; (c) GPS-GNSS land network. These data are the validators of the numerical simulation.

* This new approach is particularly effective in terms of accuracy of tidal restitution, adapted to different types of hydrodynamic model, and limiting the operator intervention.

* Error in tidal amplitude (Table 1, 2) is divided by 2 at each validation iteration, RMS of the total error is reduced, even if it is at the expense of a certain increase in the phase error. This phase error could be due to the model. TUGOm does not take into account the advection of tidal wave by the mean river flow in spectral mode. A sequential could improve result and is planned for a next step.

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Acknowledgements
DGA for financial support: PROTEVS upstream study, piloted by Shom in the MarEst project; CNES; DT INSU (C. Brachet, C. Drezen, L. Fichen, A. Guillot, E. Poirier, B. Blanke), Energie de la Lune (C. Giry), Grand Port Maritime de Bordeaux; DREAL Nouvelle-Aquitaine; Syrte, Obs. de Paris (P. Bonnefond); University of La Rochelle for GNSS carpet; UniCaen, Circle.