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Comparison of local amplification factors for fast forecast coastal tsunami amplitude modeling based on the extended Green's law

A. Gailler (1), D. Giles (2)

(1) CEA, DAM, DIF, F-91297 Arpajon, France; audrey.gailler@cea.fr ; (2) School of Mathematics and Statistics, University College Dublin (UCD), Dublin, Ireland

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Challenge of near field real time coastal modeling in operational conditions

How to obtain accurate/reliable tsunami warning maps for flooding hazard in such context?
=> Two main approaches usually developed:

(1) coastal predictions with run-up computation by solving numerically high-resolution forecast models in real time
++ all local effects taken into account
-- availability of fine bathymetry/topography coastal grids
-- too time consuming in near field and operational context

(2) early prediction tools of the coastal wave amplitude calculated from empirical laws (e.g., Green, 1837) or transfer functions derived from these laws (e.g., Gailler et al., 2017)
++ suitable in near field context (ten times faster than HR runs)
-- all local effects not well taken into account
-- assessment of run-up is missing

Within the French Tsunami Warning Center (CENALT)

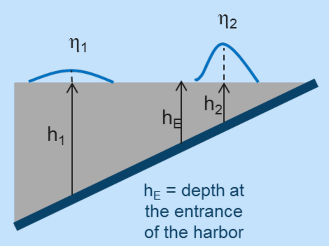
Implementation of a fast forecast method based on coastal amplification laws:
*provides a coastal tsunami height distribution, calculated from the numerical simulation of the deep ocean tsunami amplitude and using a transfer function derived from the Green's law (Reymond et al., 2012):

(1) if $h_2 \le h_1 \Rightarrow \eta_2$ (deep sea modeling)

(2) if $h_E \le h_2 < h_1 \Rightarrow \eta_2 = \eta_1 \cdot \left(\frac{h_1}{h_2}\right)^{1/4}$ (pure Green's law)

(3) if $h_0 \le h_2 < h_E \Rightarrow \eta_2 = \eta_1 \cdot \left[1 + \beta\frac{(h_E - h_2)}{h_E}\right] \cdot \left(\frac{h_1}{h_2}\right)^{1/4}$ (linear approximation response)

(4) if $0 \le h_2 < h_0 \Rightarrow \eta_2 = \eta_2$ at depth h_0



*involves maps of regionalized values of the empirical correction factor function of the coastal configuration, as a way to amplify or attenuate specific local geometries
*coastal amplification parameters defined regarding high resolution nested grids simulations on the basis of a set of historical and synthetic sources (due to a lack of tsunami observations in the NEAM basin)

Two approaches tested to obtain the coastal amplification parameters:
(1) by ***trial and error (Merit_CENALT),*** *applying the above procedure (eq. (1) to (4))*
(2) by ***minimizing a cost function*** (method based on a gradient descent algorithm, developed at UCD) to optimize these local amplification factors.
Beta values are here calculated over the whole fine grid, where eq. (3) and (4) only are applied. hE is there set as the deepest value in the HR bathymetry grid.

PARAMETERS AND SCENARIOS OF REFERENCE

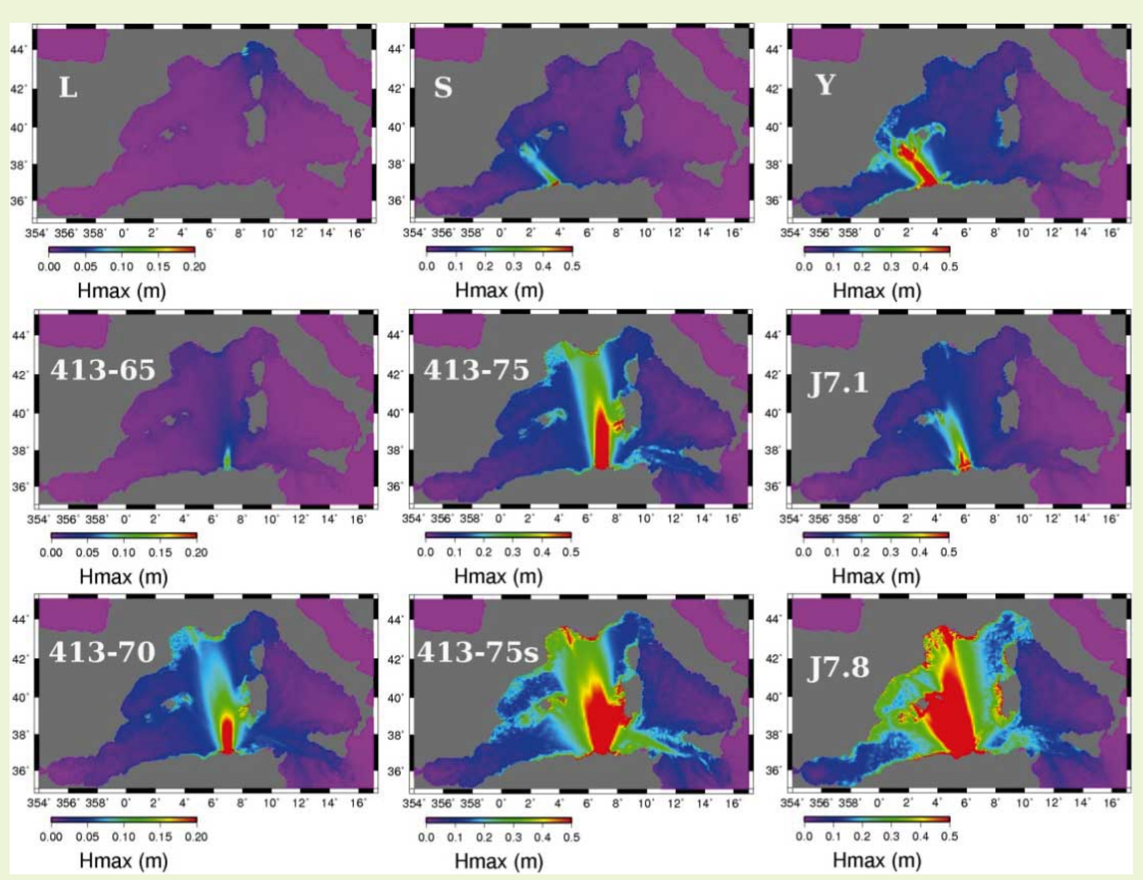
			Rupture zone parameters						
Scenario	ID	Magnitude	nb of source segments	Slip (m)	Strike (°)	Dip (°)	Rake (°)	Length (km)	Width (km)
Ligure 1887 (Eva et al., 1997)	L	6.5	1	0.45	71	85	90	45	10
Boumerdes 2003 (Semmane et al., 2005)	S	7.2	128	0.007 3.5	54	47	90	4 (*128)	4 (*128)
Boumerdes 2003 (from Yelles et al., 2004) inflated	Y	7.5	1	2.5	60	42	84	85	35
Jijel 1856 (Roger & Hébert, 2008)	J7.1	7.1	3	1.0	75	40	90	25	20
				1.5	85	40	90	37	20
				1.5	75	40	90	44	20
Jijel 1856 inflated	J7.8	7.8	3	6.0	75	40	90	25	22
				6.0	85	40	90	37	22
				6.0	75	40	90	44	22
CASST-413 (fault param. from the CENALT pre-computed tsunami database)	413-65	6.5	1	0.45	91	50	90	45	10
	413-70	7.0	1	1.5	91	50	90	42	18
	413-75	7.5	1	2.6	91	50	90	85	29
	413-75s	7.5	1	8	91	50	90	33	22

Source parameters for the 9 Mediterranean reference scenarios.

*Reference scenarios (**HR_run**):*
=> various source azimuths and locations based on seismotectonic context and historical events
=> exploring the Magnitude range of the decision matrix
=> High Resolution (HR) nested grids modeling down to 10 m resolution, using CLIONA code developped at CEA.

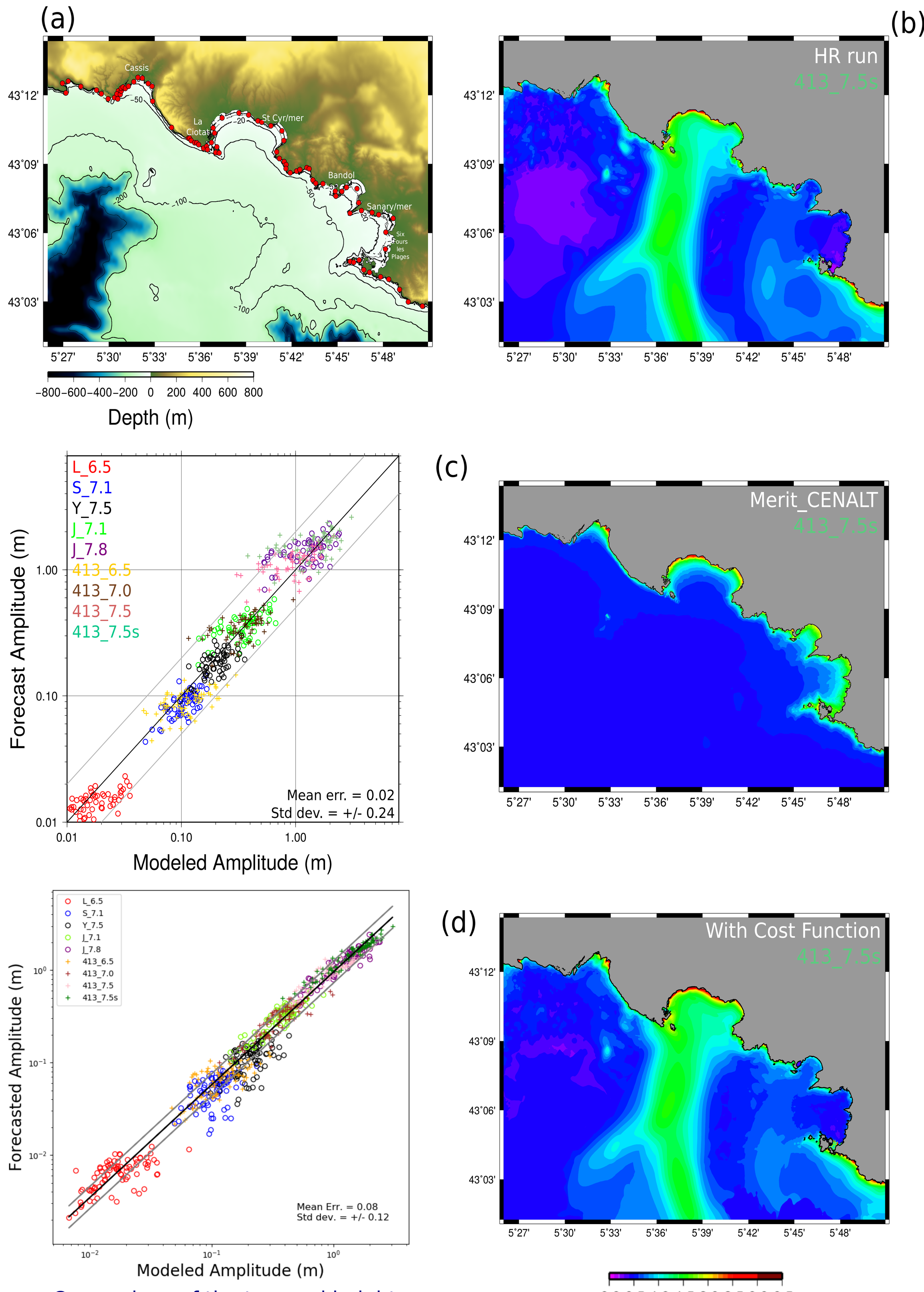
*Rapid forecast (**Merit_CENALT** and **with cost function**):*
--Numerical simulation of the deep ocean tsunami amplitude (providing n1) performed on the 30" GEBCO bathymetry grid to account for small wavelengths of Mw 6.5 sources.
--Empirical correction factor varying as a function of the coastal configuration, ranging form -1 to 3.

--Best results using trial & error approach obtained with: h1 = 100 m; hE = 50 m; h2 = 0.5 m.



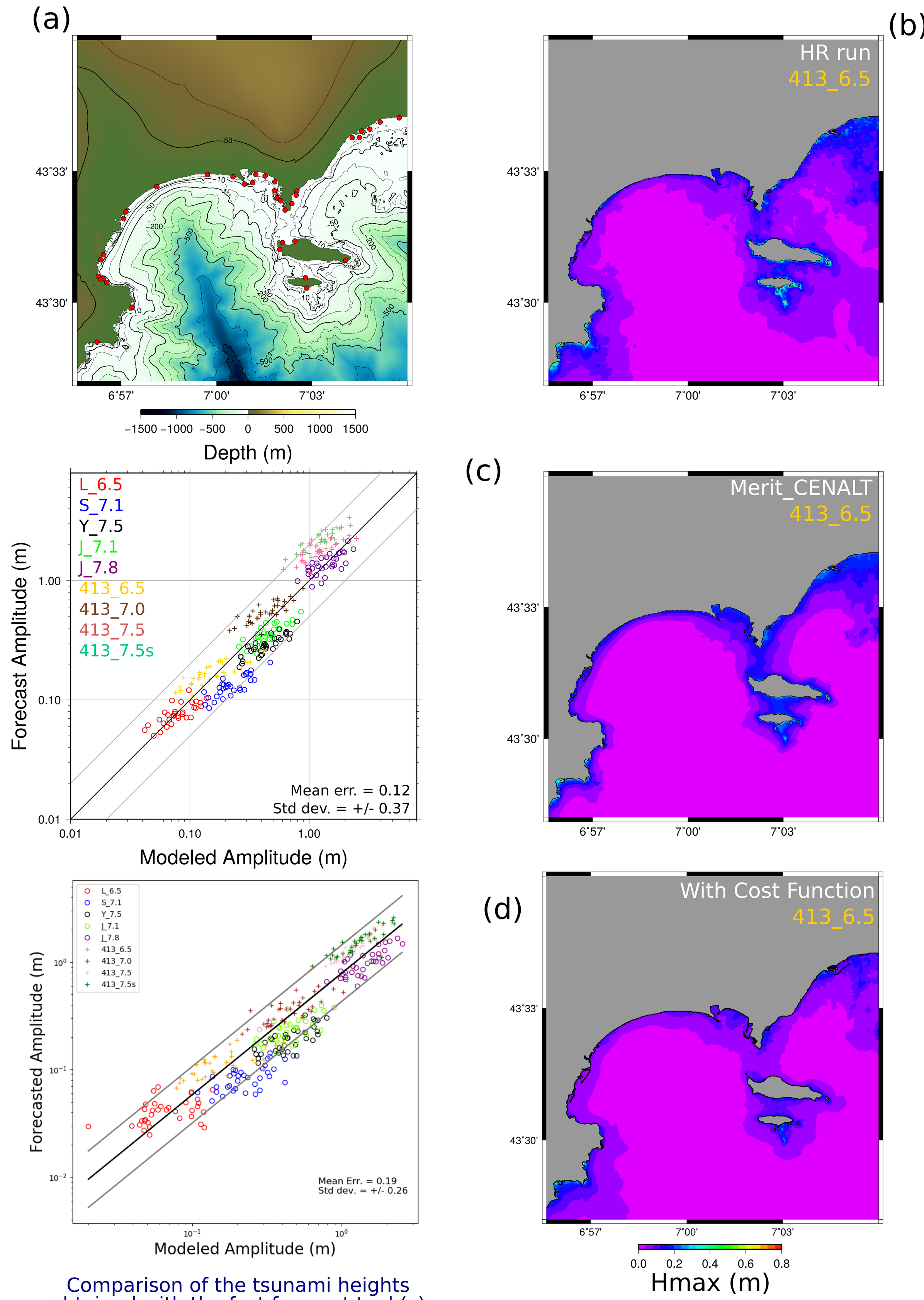
Maximum water heights modeled for each of the 9 reference scenarios in the 30 s coarse grid (3 hours of tsunami propagation; Gailler et al., 2018)

RESULTS FOR THREE MEDITERRANEAN COASTAL SITES



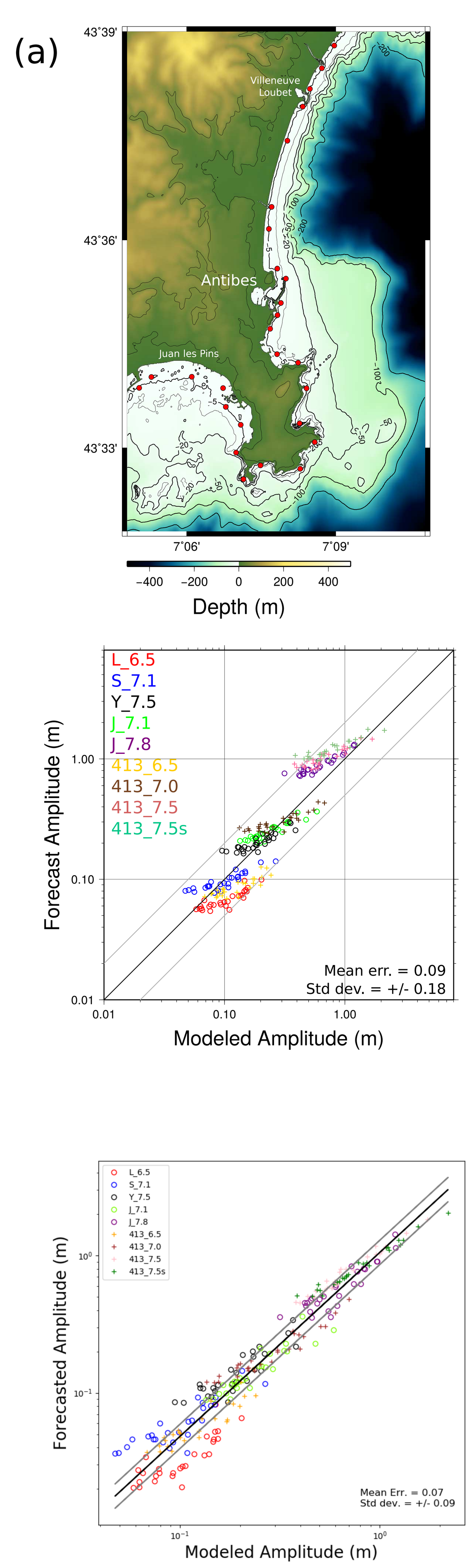
Comparison of the tsunami heights obtained with the fast forecast tool (c) and using the cost function (d) with the HR nested grid models at 10 m resolution.
The comparison is done for each of the 9 reference sources, at each red dot along the coast of Bandol area **[a]**.

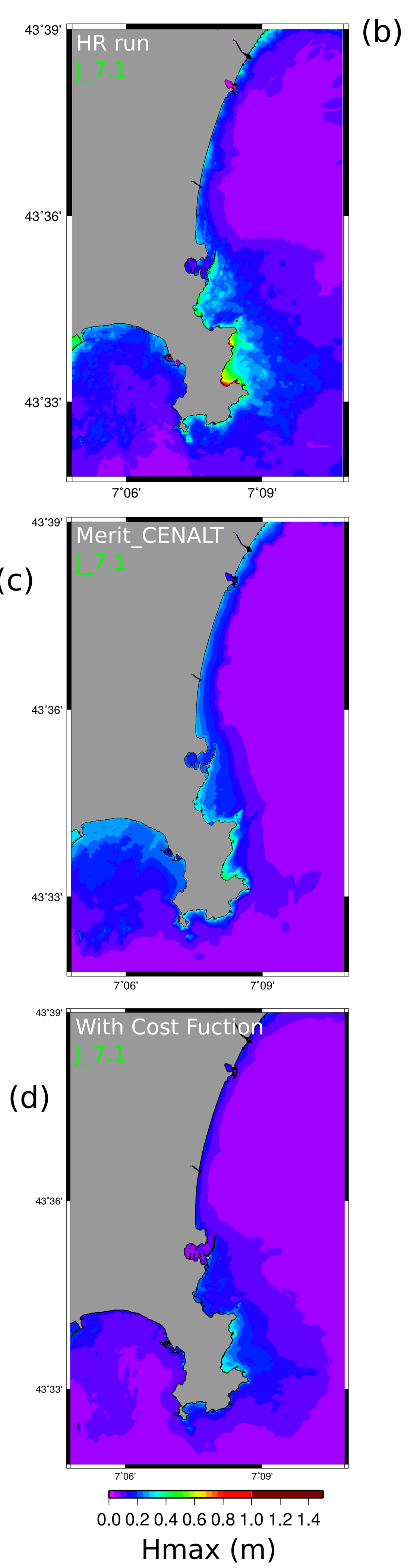
Comparison of maximum water height maps obtained for **Bandol area** in the case of CENALT fault nb413 at Mag. 7.5 compact scenario (Gailler et al., 2018) in the 10 m resolution nested grids simulation (top, HR_Run), with extrapolation given by the transfer function derived from Green's law obtained by trial and error (middle, Merit_CENALT) and using the UCD cost function minimization (bottom, with Cost Function).



Comparison of the tsunami heights obtained with the fast forecast tool (c) and using the cost function (d) with the HR nested grid models at 10 m resolution.
The comparison is done for each of the 9 reference sources, at each red dot along the coast of Cannes area **[a]**.

Comparison of maximum water height maps obtained for **Cannes area** in the case of CENALT fault nb413 at Mag. 6.5 scenario (Gailler et al., 2018) in the 10 m resolution nested grids simulation (top, HR_Run), with extrapolation given by the transfer function derived from Green's law obtained by trial and error (middle, Merit_CENALT) and using the UCD cost function minimization (bottom, with Cost Function).



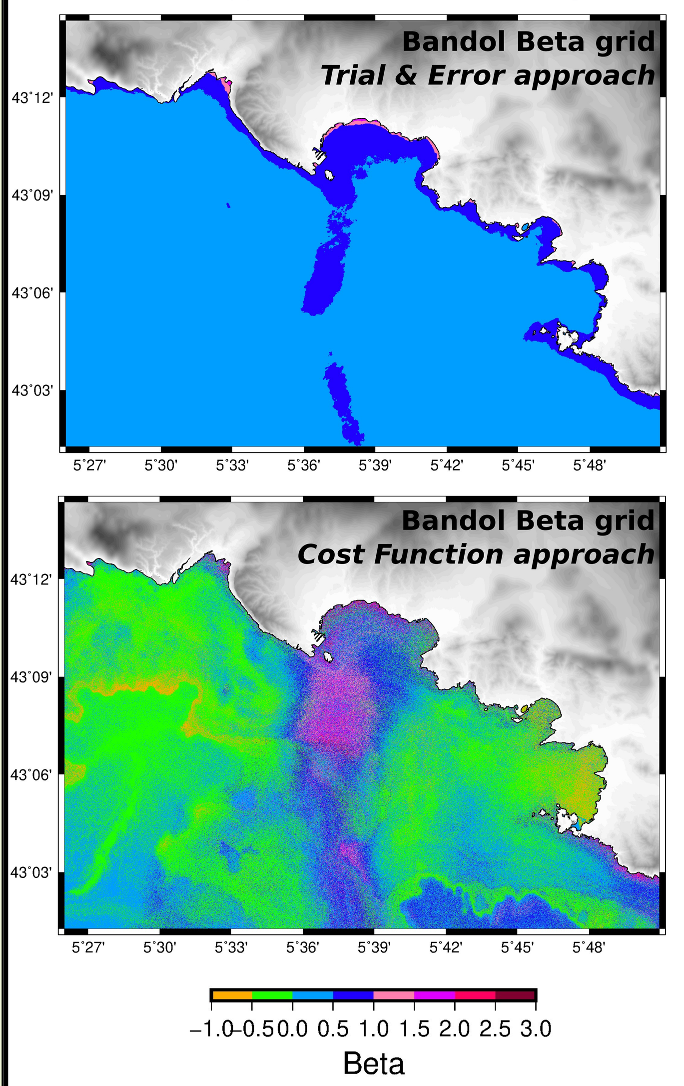


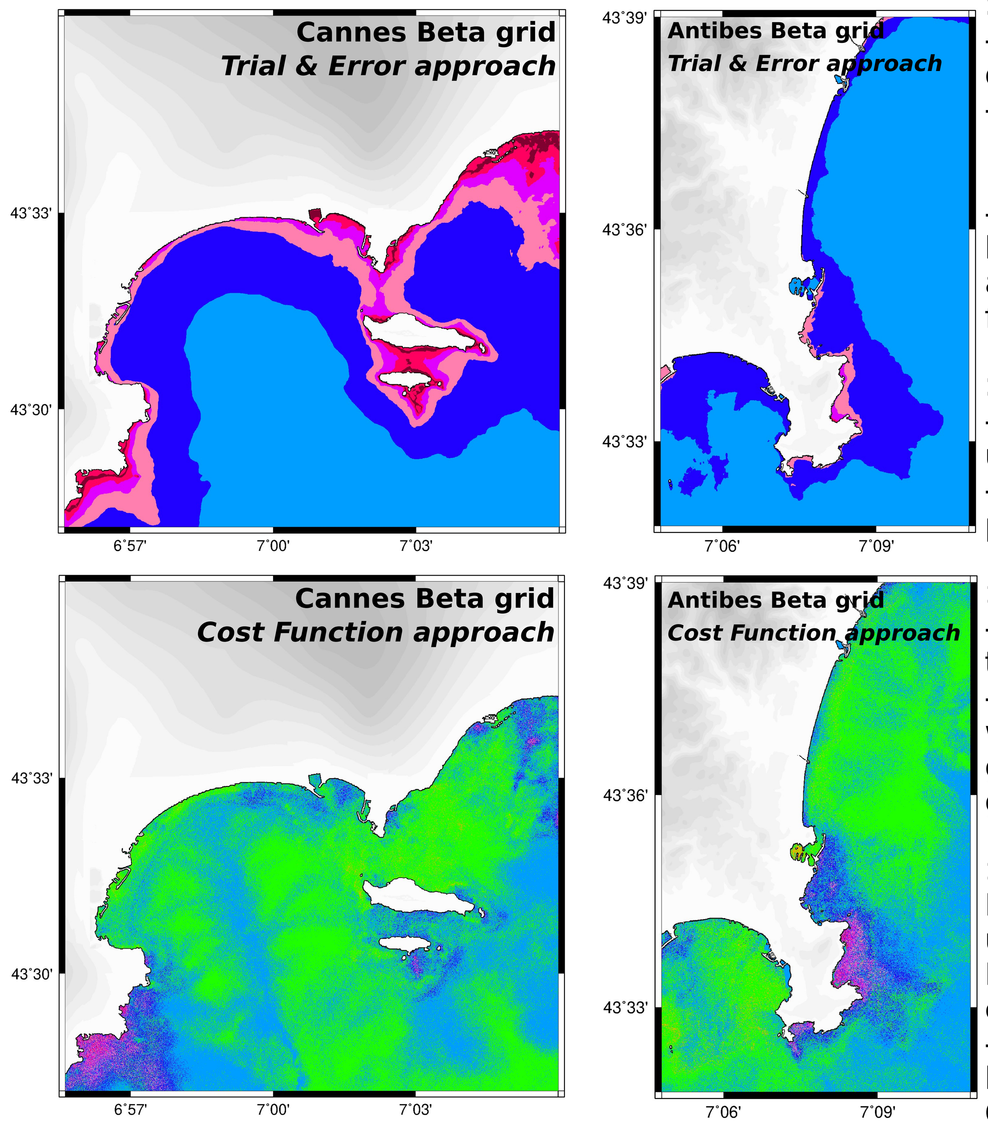
Comparison of the tsunami heights obtained with the fast forecast tool (c) and using the cost function (d) with the HR nested grid models at 10 m resolution.
The comparison is done for each of the 9 reference sources, at each red dot along the coast of Antibes area **[a]**.

Comparison of maximum water height maps obtained for **Antibes area** in the case of Djijelli Magnitude 7.1 scenario (Gailler et al., 2018) in the 10 m resolution nested grids simulation (top, HR_Run), with extrapolation given by the transfer function derived from Green's law obtained by trial and error (middle, Merit_CENALT) and using the UCD cost function minimization (bottom, with Cost Function).

BETA GRID AND RESULTS COMPARISON

Maps of regionalized values of the empirical correction factor beta used in the adapted Green's law approach for each of the target sites.





>Cost Function approach
-provides grids of Beta values within less than 5' on average
-often calculates negative Beta values (-0.5 to -1)
¤ in the greatest depth ranges (> ~50 m)
¤ inside harbors
-Test performed fixing h1 = 100 m, hE = 50m, h0 = 0.5 m and applying eq. (1) to (4) [i.e., same as in the trial & error approach] provides identical forecatsing results

>Antibes site:
-Beta values along the shoreline very similar using both apporaches
-Results are slighlty better using the Beta grid provided by the Trial & Error approach

>Cannes site:
-Beta values along the shoreline higher using the Trial & Error approach
-but comparison of the HR nested grid models with the tsunami heights obtained from Beta grids of both approaches does not provide significant difference

>Bandol site:
Beta values along the shoreline very similar using both approaches, exept inside the Cap Nègre Bay where the Cost Function approach calculates negatives values
-Results are better using the Beta grid provided by the Cost Function approach, especially in the Cap Nègre Bay where attenuation phenomenons are better taken into account

CONCLUSIONS AND FUTURE WORK

>The extended Green's law allows for extremely rapid localised forecasts
>Automative approach based on a cost function optimization calculates the Beta values very quickly

>The **linear approximation provides coastal tsunami heights with wrong estimates beyond a factor of 2 at best**
But
-- all local effects not well taken into account
-- assessment of run-up and horizontal inundation are missing

=> investigate the robustness of the Beta values calculated from the cost function approach regarding the trial & error one; further methods of optimization to be explored

=> extend the application to other French Mediterranean and Atlantic coastal sites where high resolution bathy/top grids are available
=> implementation within the CENALT automatic tools chain

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