DE LA RECHERCHE À L'INDUSTRIE

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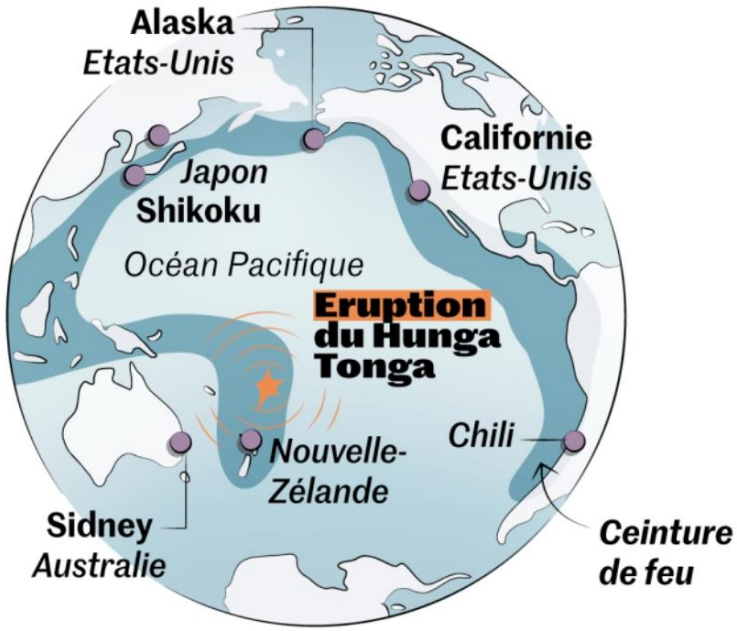
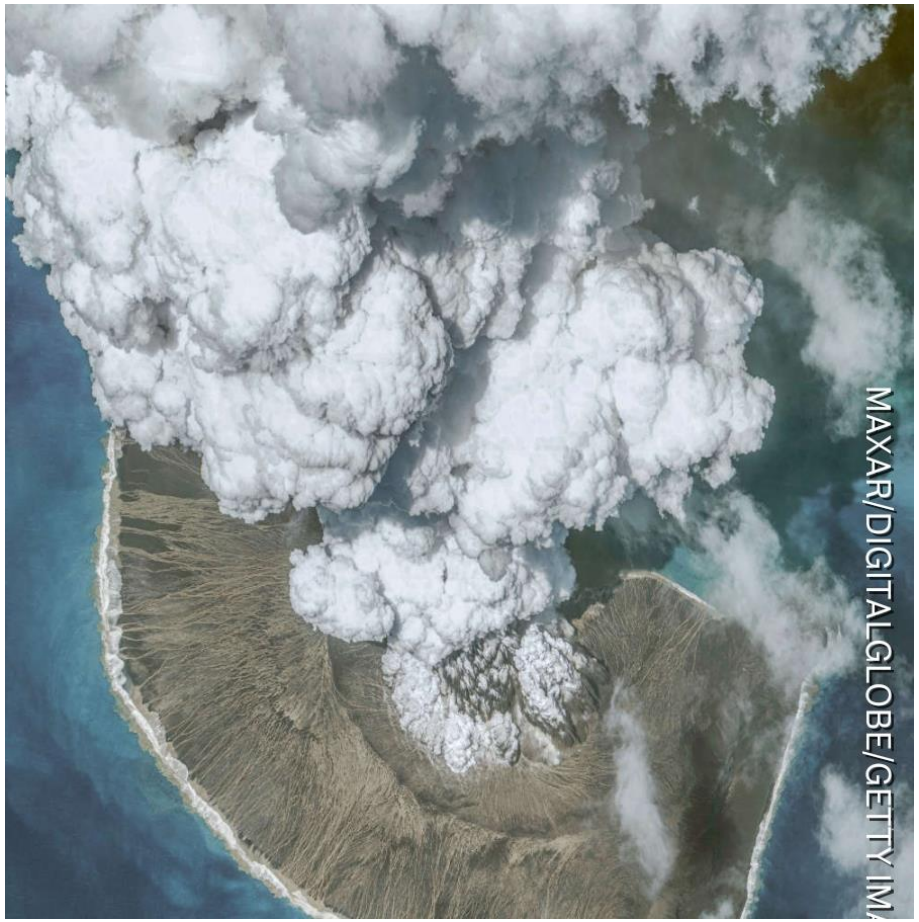
OBSERVATION AND SIMULATION OF THE METEO-TSUNAMI GENERATED IN THE MEDITERRANEAN SEA BY THE TONGA ERUPTION ON 15 JAN. 2022

18/10/2022

Philippe Heinrich, Hélène Hébert, Audrey Gailler, Aurélien Dupont, Vincent Rey (Univ. Toulon), Anthony Jamelot, Constantino Listowski





L'éruption du Hunga Tonga (★) a été suivie d'une série de tsunamis (●) qui se sont propagés sur toutes les mers du globe avec une rapidité jamais encore observée.
Des vagues d'une hauteur exceptionnelle ont frappé les côtes du Pacifique, mais également celles de l'Atlantique et de la Méditerranée. Certaines régions ont connu des perturbations importantes pendant trois ou quatre jours.

(lemonde.fr)

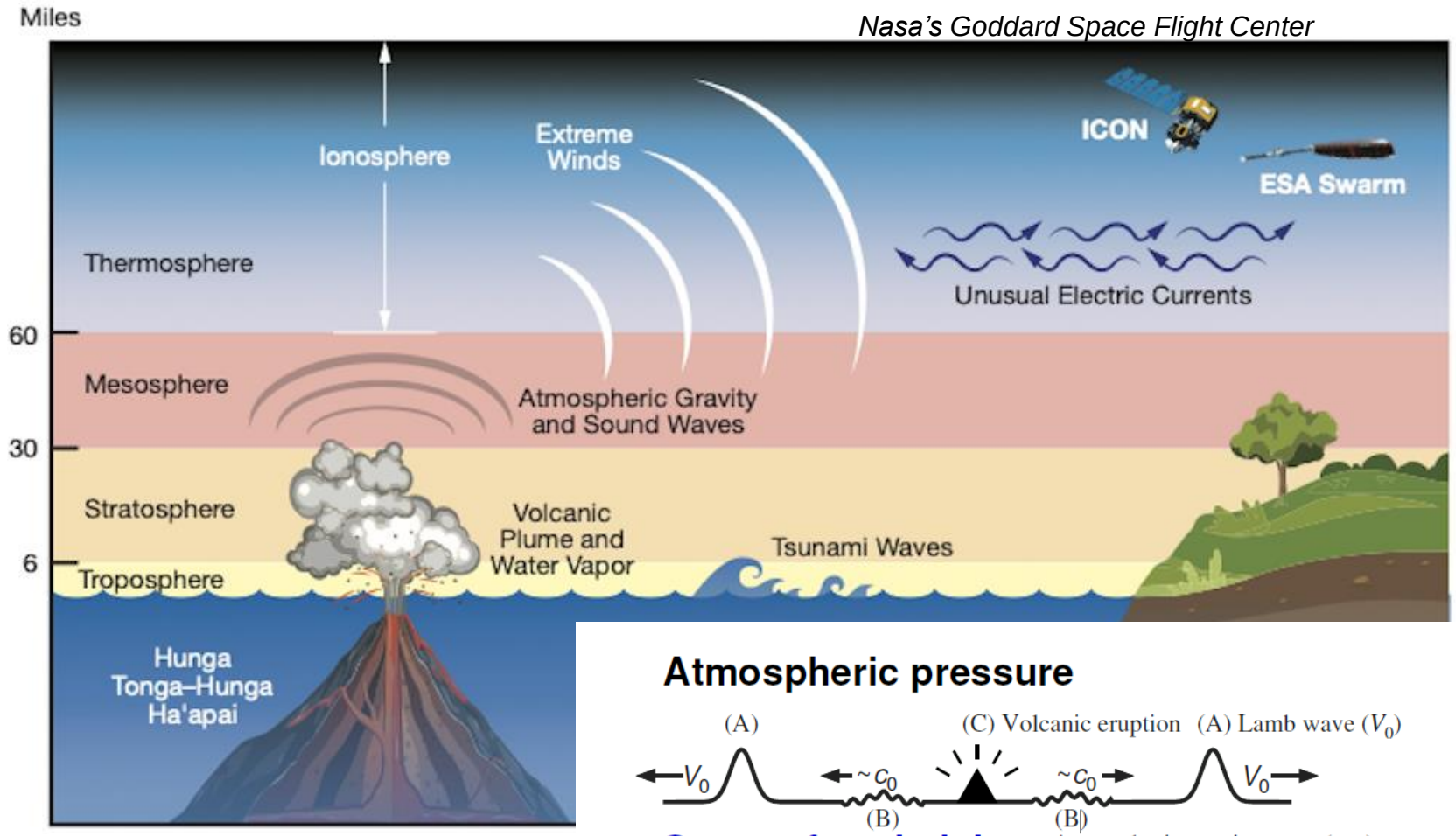
Waves have hit Tonga's main island, Tongatapu, after an eruption at the Hunga-Tonga-Hunga-Ha'apai underwater volcano. Photo: Tonga Geological

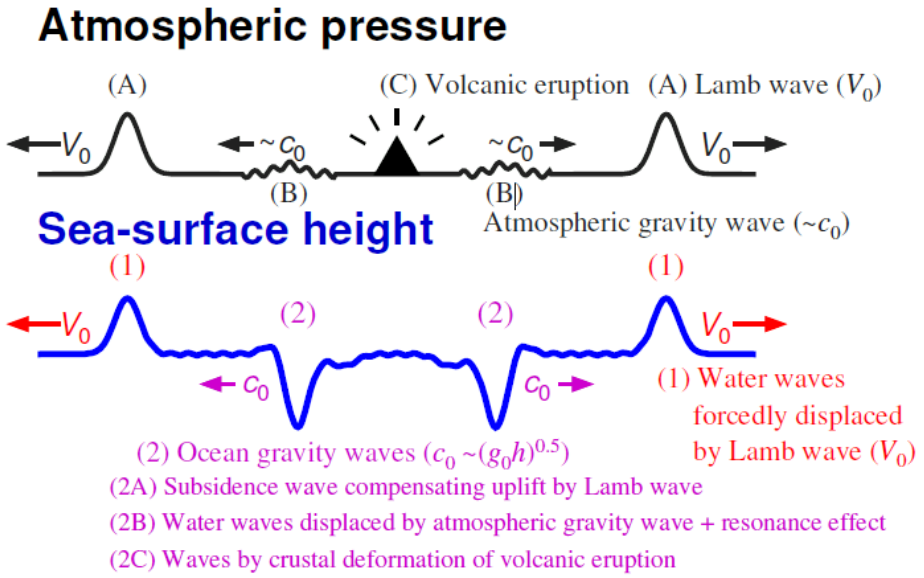
Tonga's main island

© *UNICEF/Consulate of the Kingdom of Tonga.* Damage caused in Tonga's capital, Nuku'alofa, by the volcano eruption and subsequent tsunami on 15 January 2022.

Tahiti (North coast)

Nasa's Goddard Space Flight Center





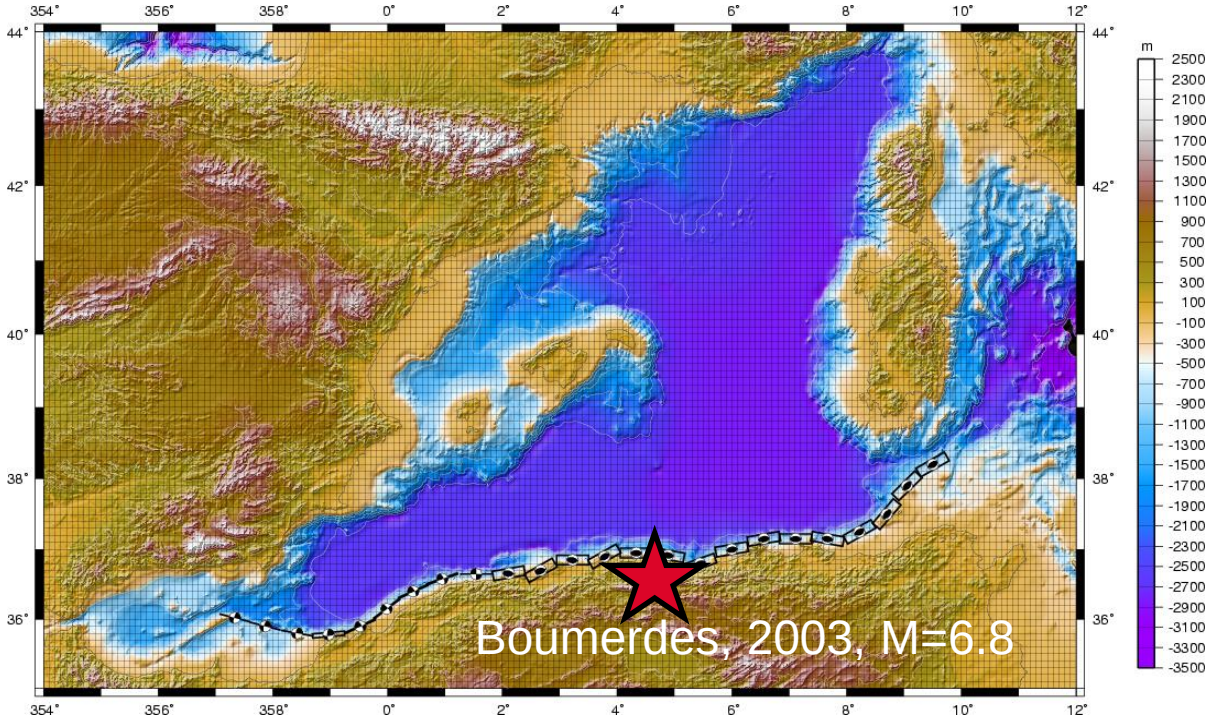
Lamb wave (310m/s) + Gravity waves 200m/s (close to c=$\sqrt{gd}$) in the Pacific Ocean → Proudman resonance

CENTRE ALERTE TSUNAMIS /Simulation of tsunamis at Bruyeres, Papeete

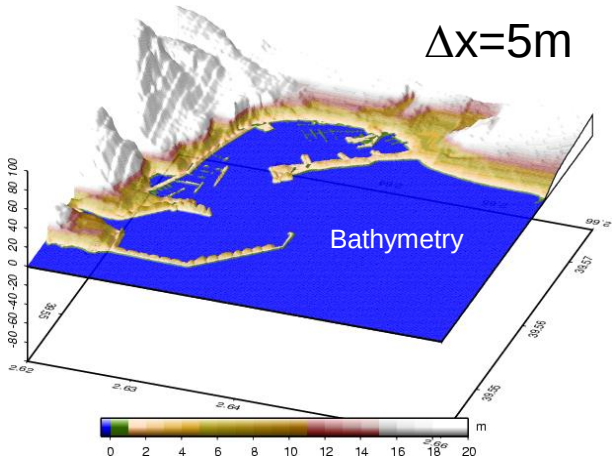
Tsunamis of tectonic origin

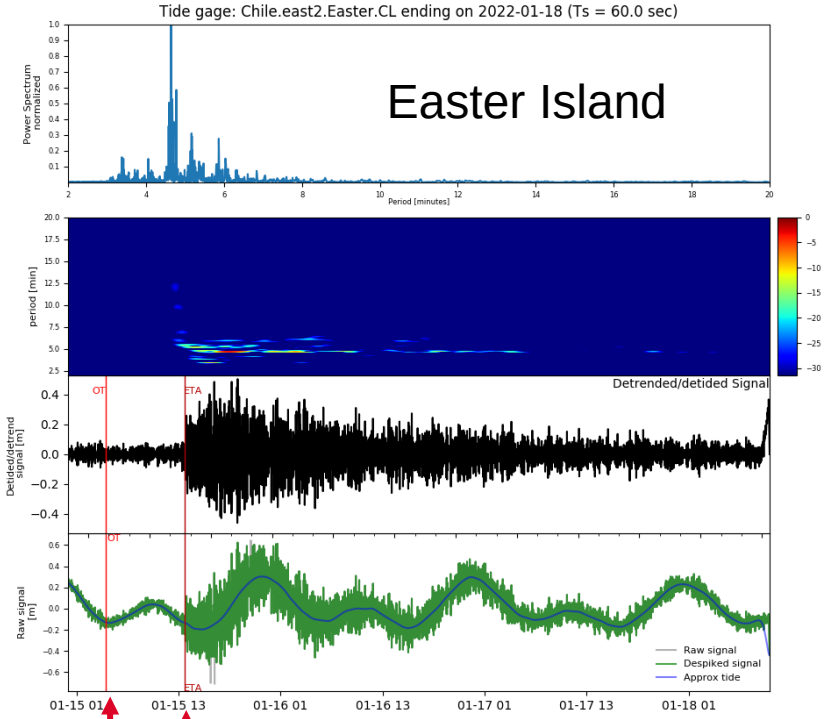
Tsunamis generated by landslides
Meteo-Tsunamis (+ of volcanic origin)

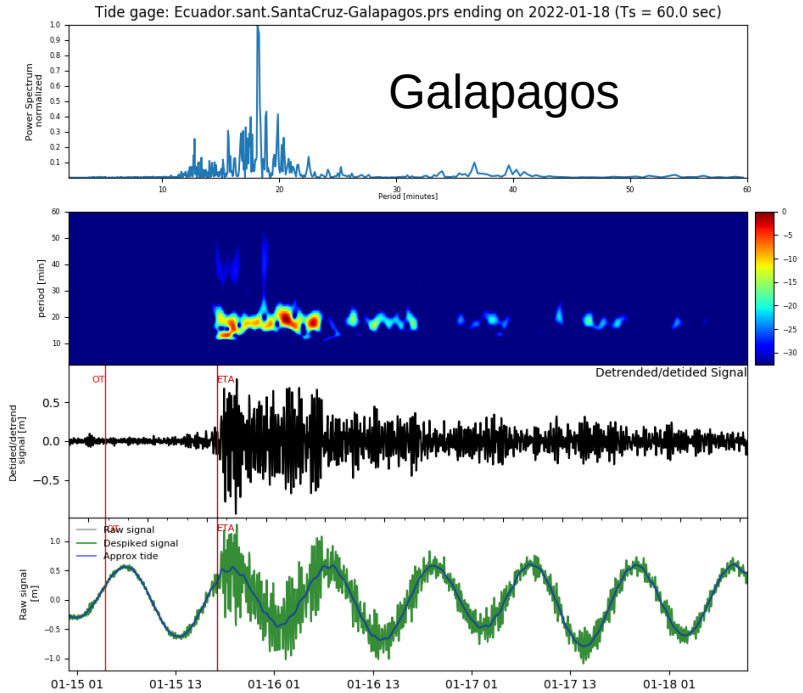
$\Delta x=\Delta y=1$ km



$\Delta x=5$m

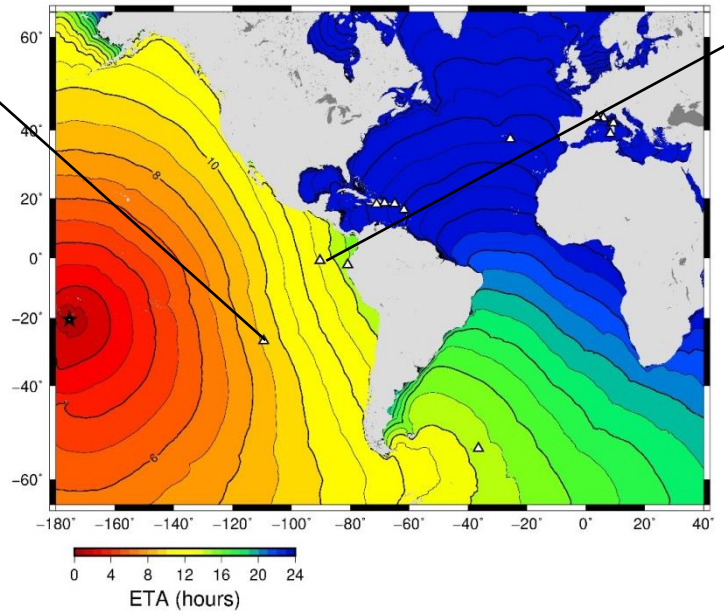


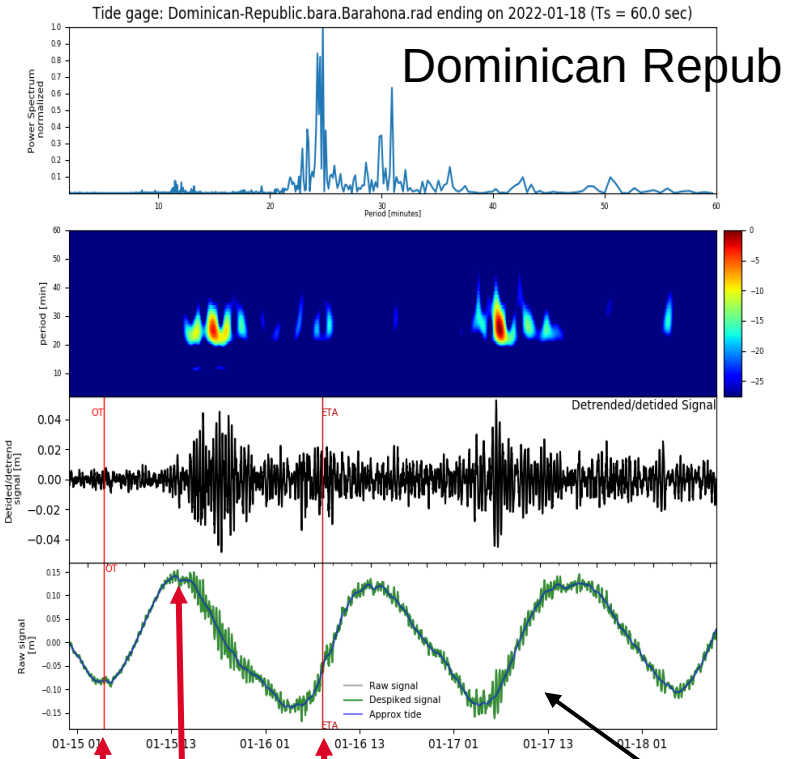




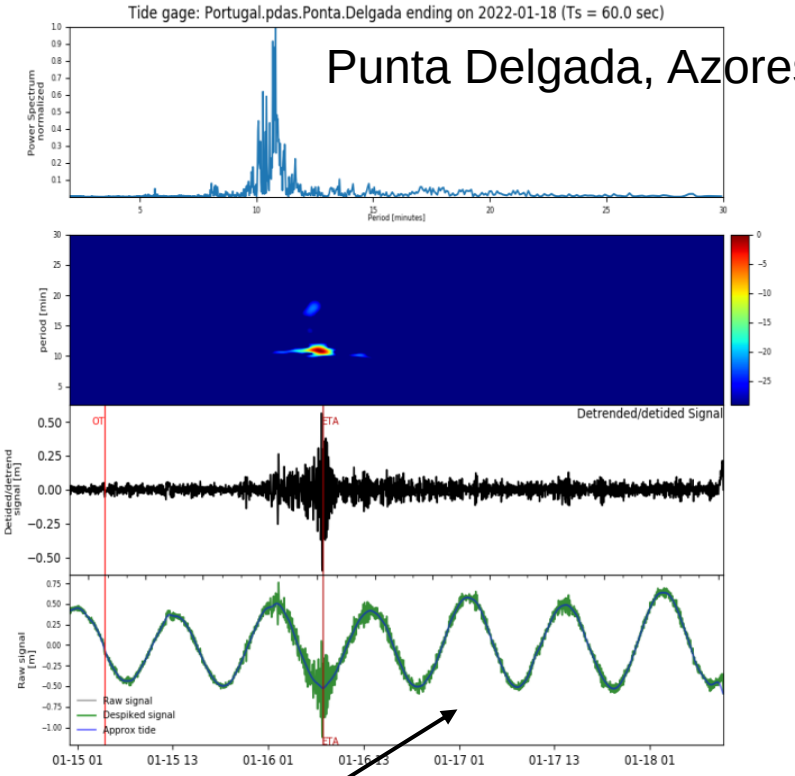
Explosion time

Theoretical arrival time
($\sqrt{gd}$, d=water depth)
~Tsunami detection





Dominican Republic



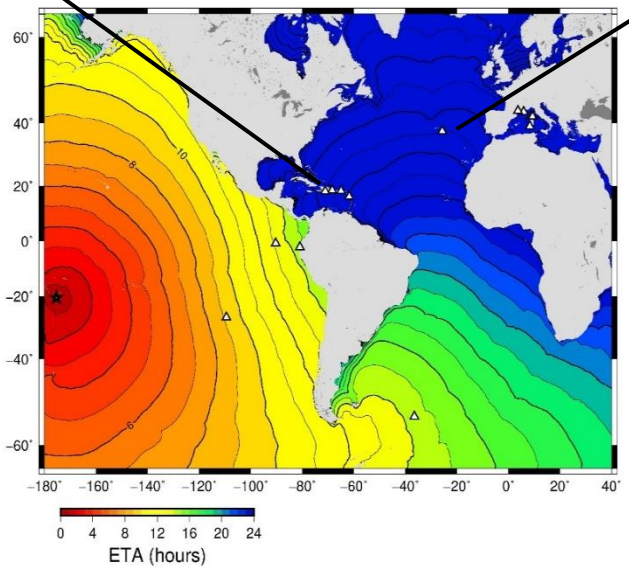
Punta Delgada, Azores

Explosion time

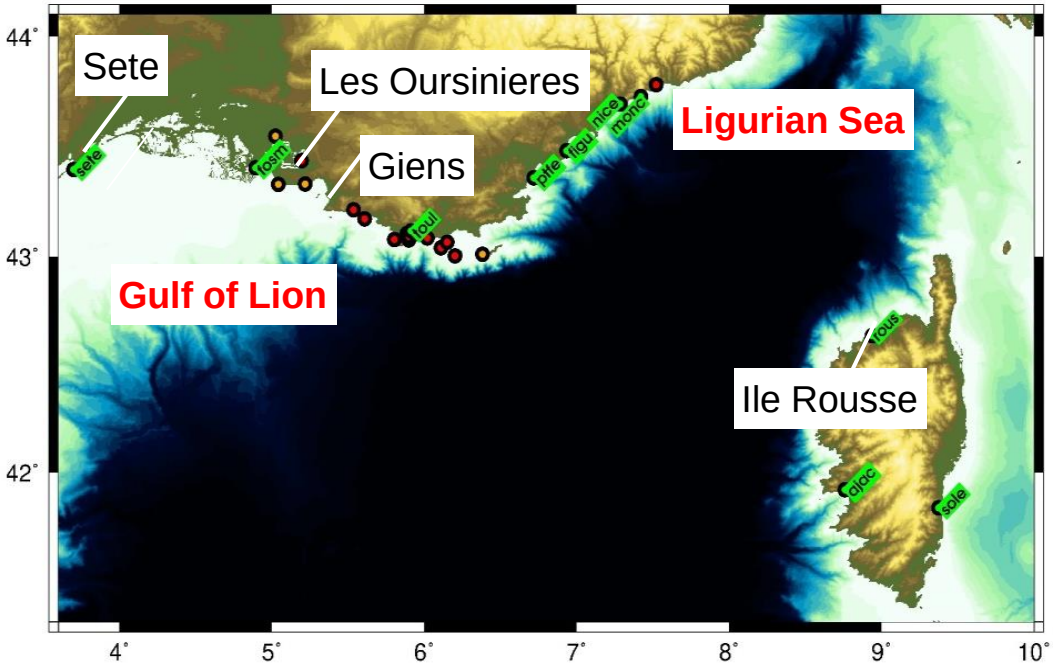
Tsunami detection

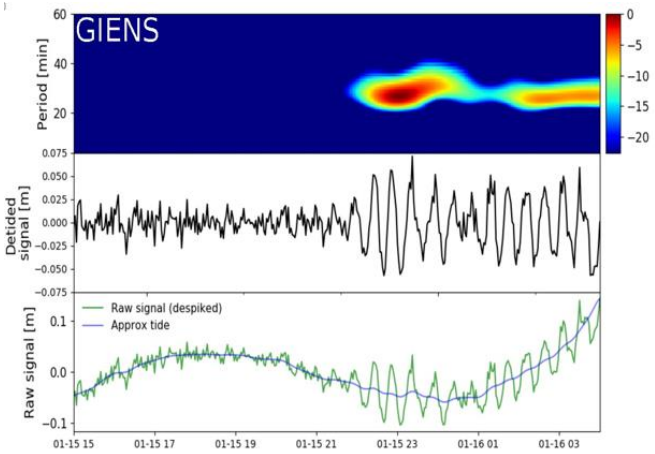
Theoretical arrival time

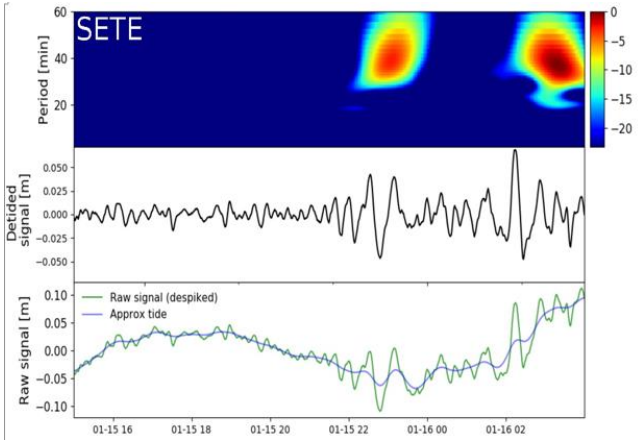
$\sqrt{gd}$, *d*=water depth

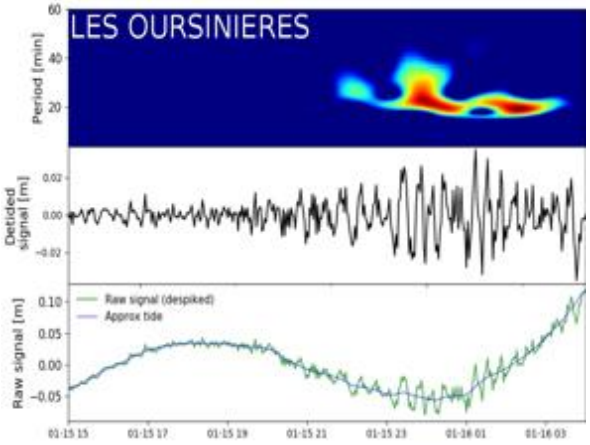


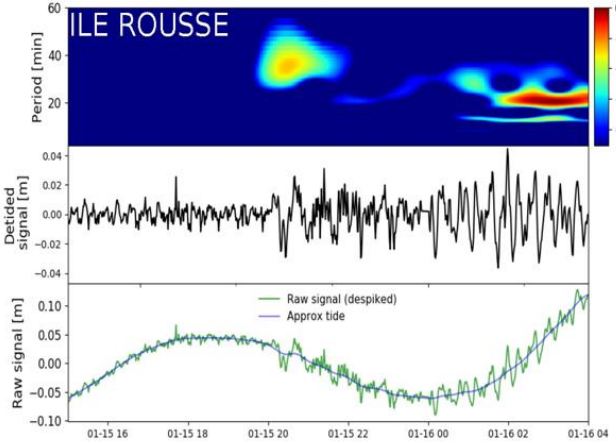
Mediterranean Sea : observed by ~30 tide-gauge stations, ~17 hours after the explosion time











Code Taitoko (Heinrich, Jamelot, Gailler et al., 2021)

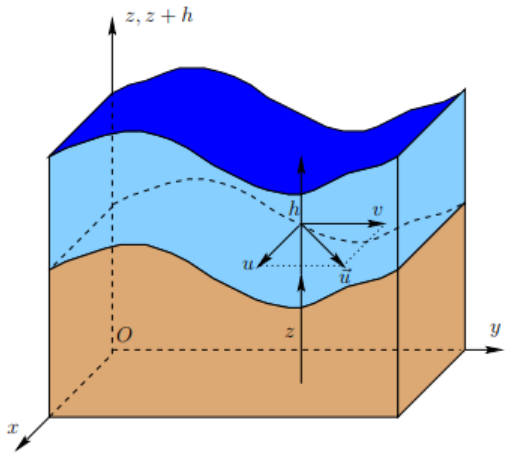
« Shallow Water » equations

$$\frac{\partial \eta}{\partial t} + \frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} = 0$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial \eta}{\partial x} + F_x$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial \eta}{\partial y} + F_y$$

$$F_x = -\frac{1}{\rho_w}\frac{\partial p_s}{\partial x} \; ; F_y = -\frac{1}{\rho_w}\frac{\partial p_s}{\partial y}$$



d=(-z)= bathymetry

η= water surface elevation ; (u, v) velocities along (x, y)

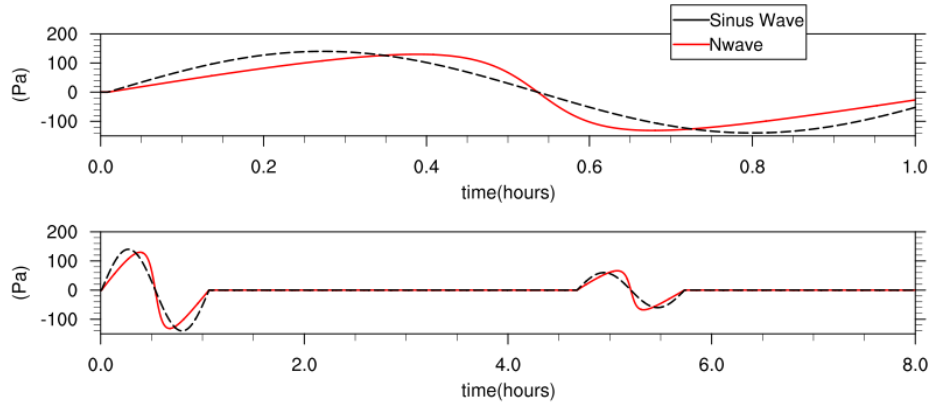
h= η+d

p_s (x,y,t)= atmospheric surface pressure

p_s= sinusoidal wave or N-wave : analytical formulas introduced in Taitoko

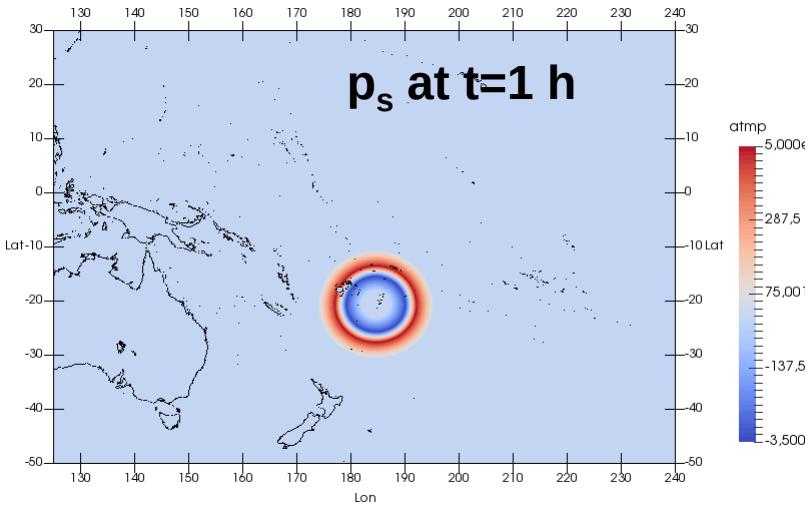
Harmonic planar progressive wave (x_0, y_0= Tonga volcano)

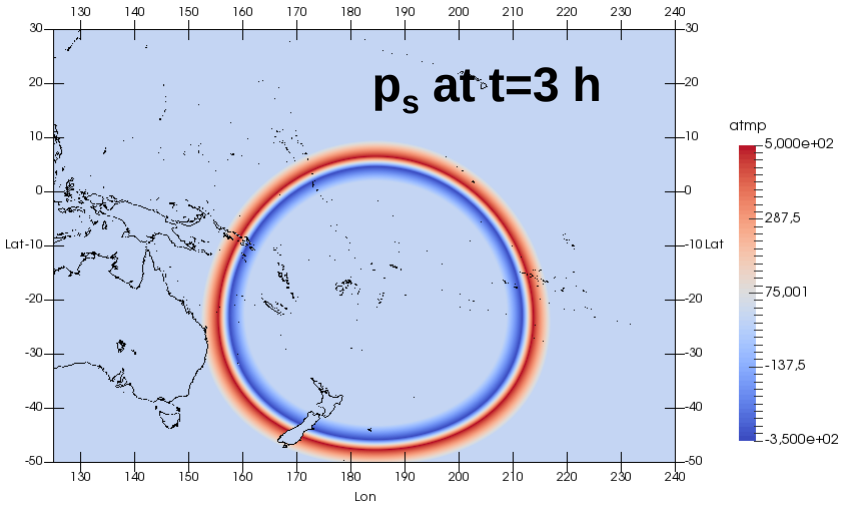
$$p_s(x, y, t) = A\sin(k_x(x - x_0) + k_y(y - y_0) - \omega t)$$

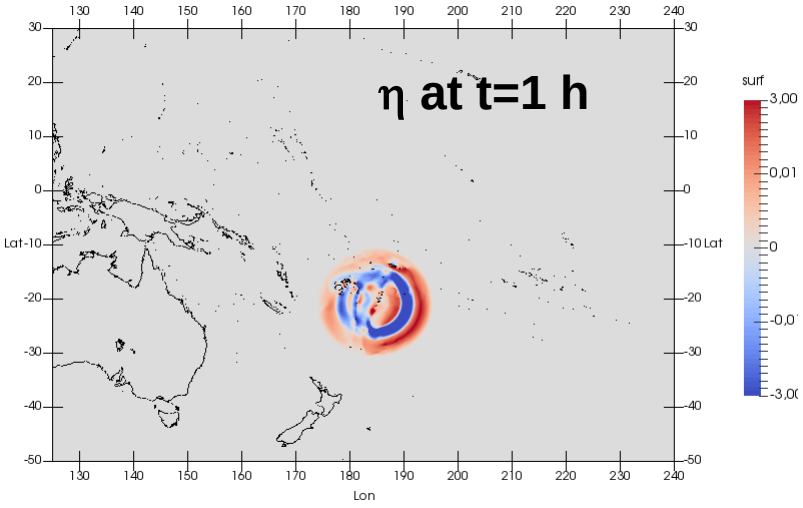


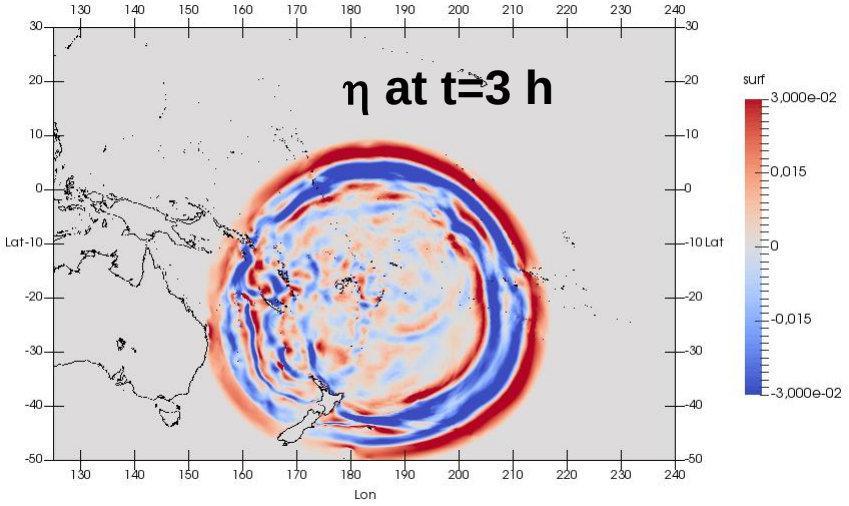
Propagation of an atmospheric sinusoidal wave and of the associated tsunami in Taitoko

Sinus wave
A=500 Pa
T=45 min



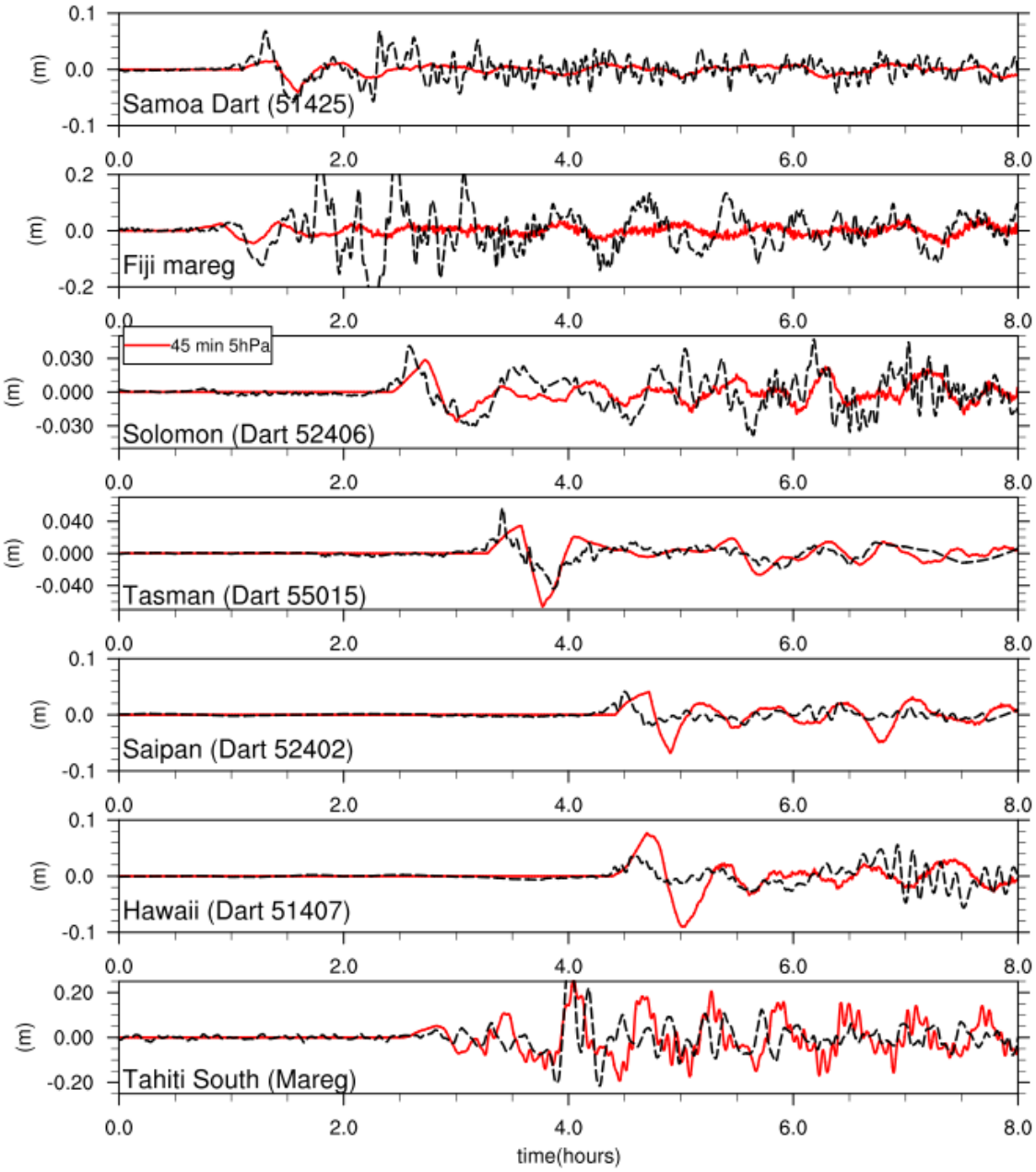




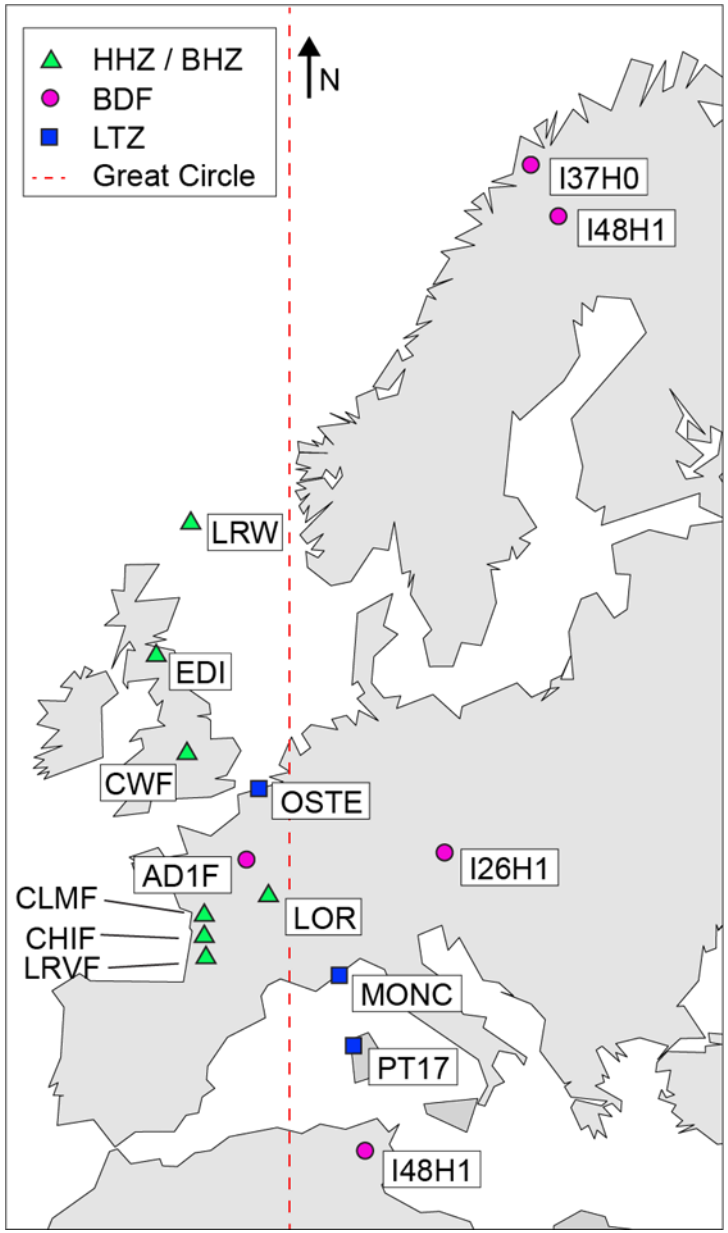


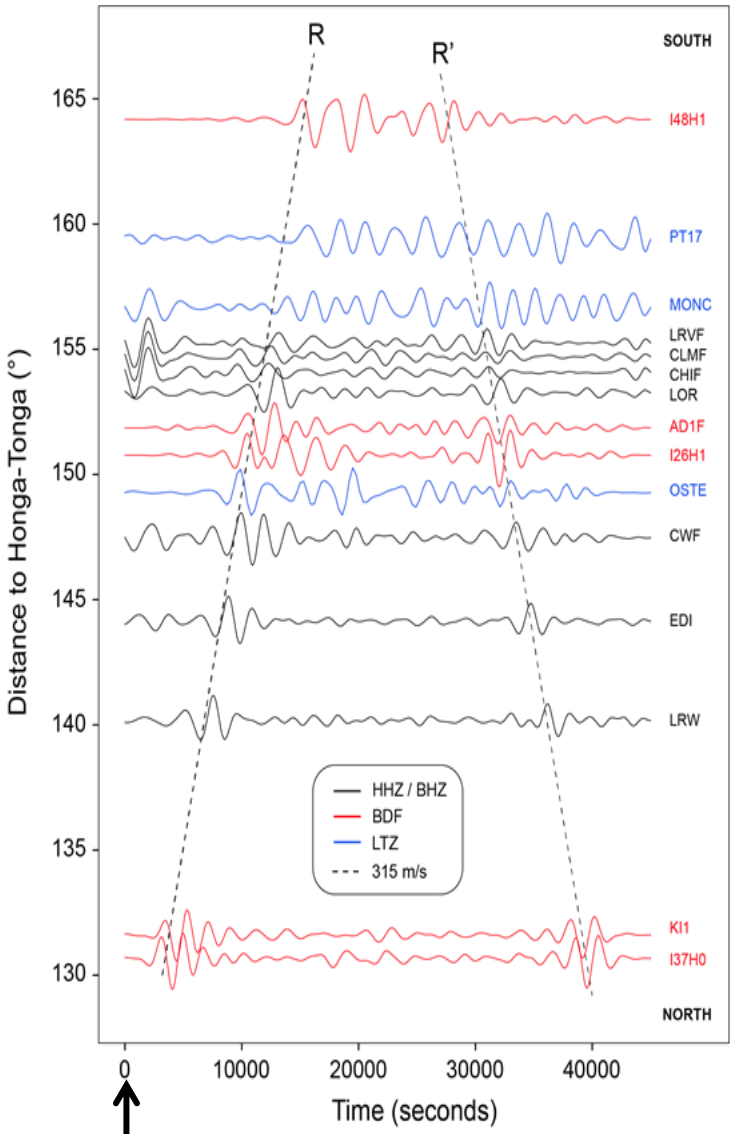
Simulation of the meteotsunami in the Pacific Ocean

Sinus wave
A=500 Pa
T=45 min



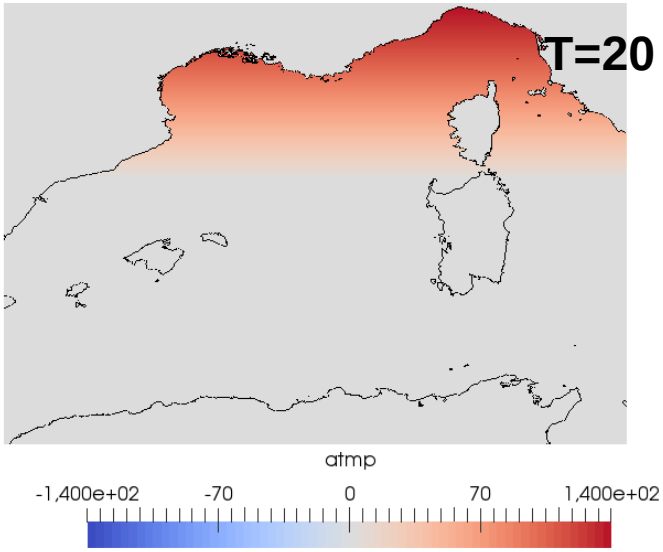
Observations in Europe (Infrasound, seismic stations, tide-gauges)

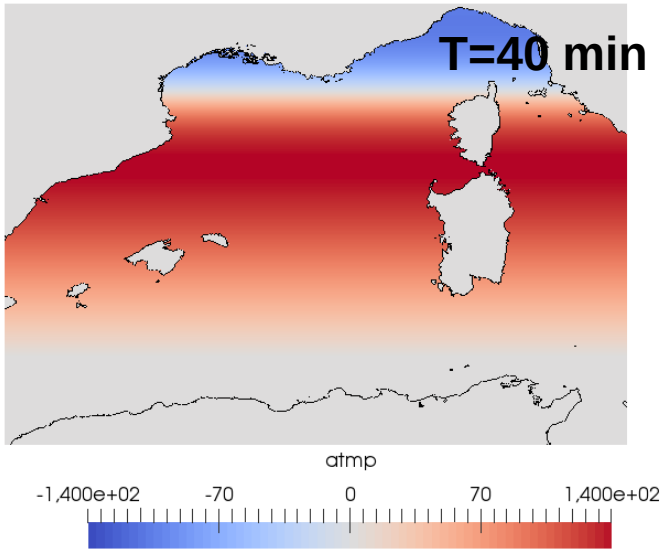


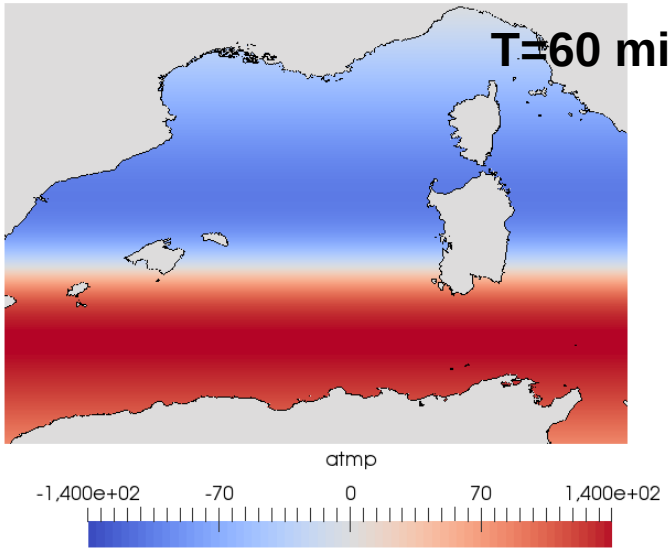


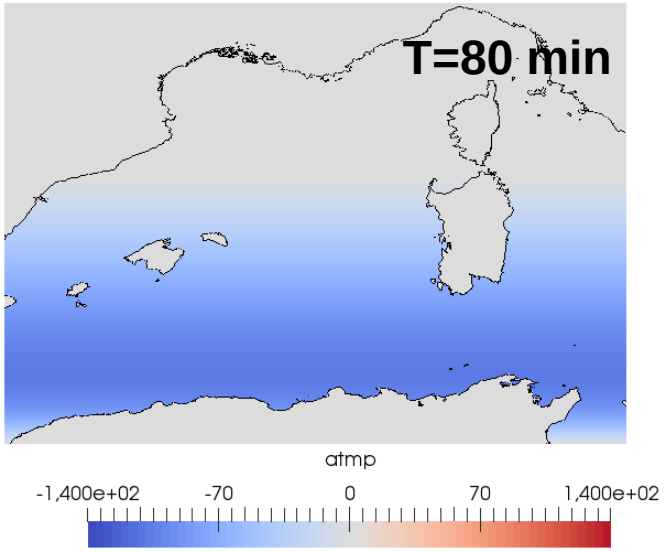
16h40 UTC (15 Jan)

Propagation of the atmospheric wave in Taitoko in the Mediterranean Sea

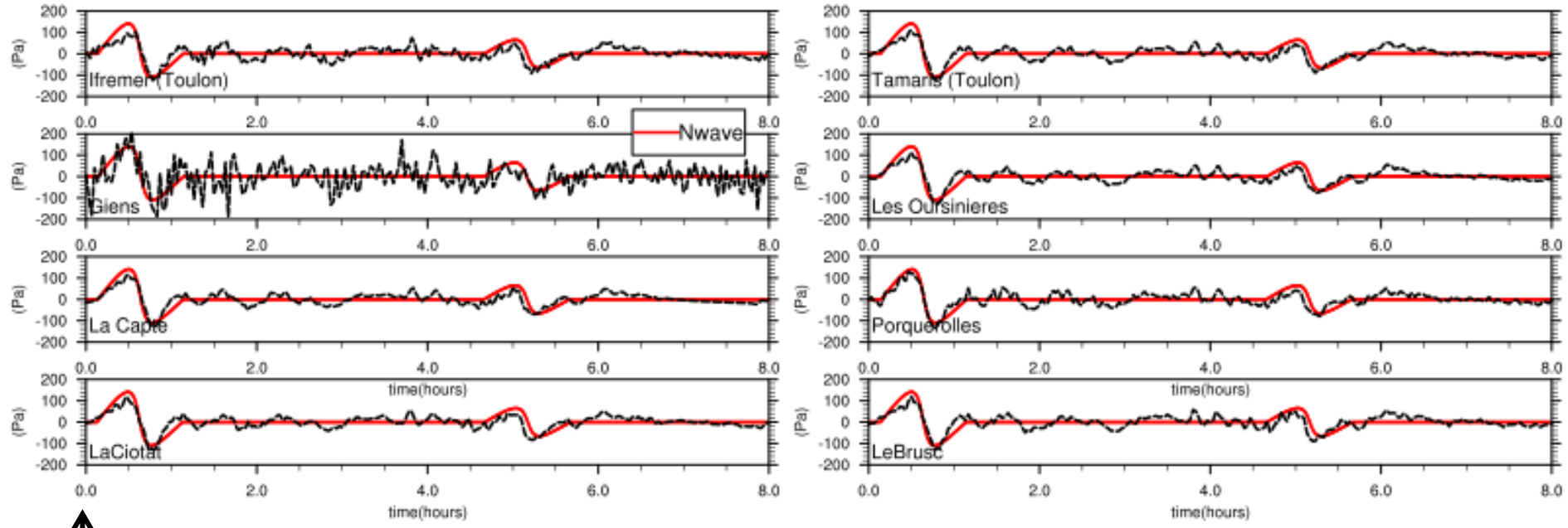






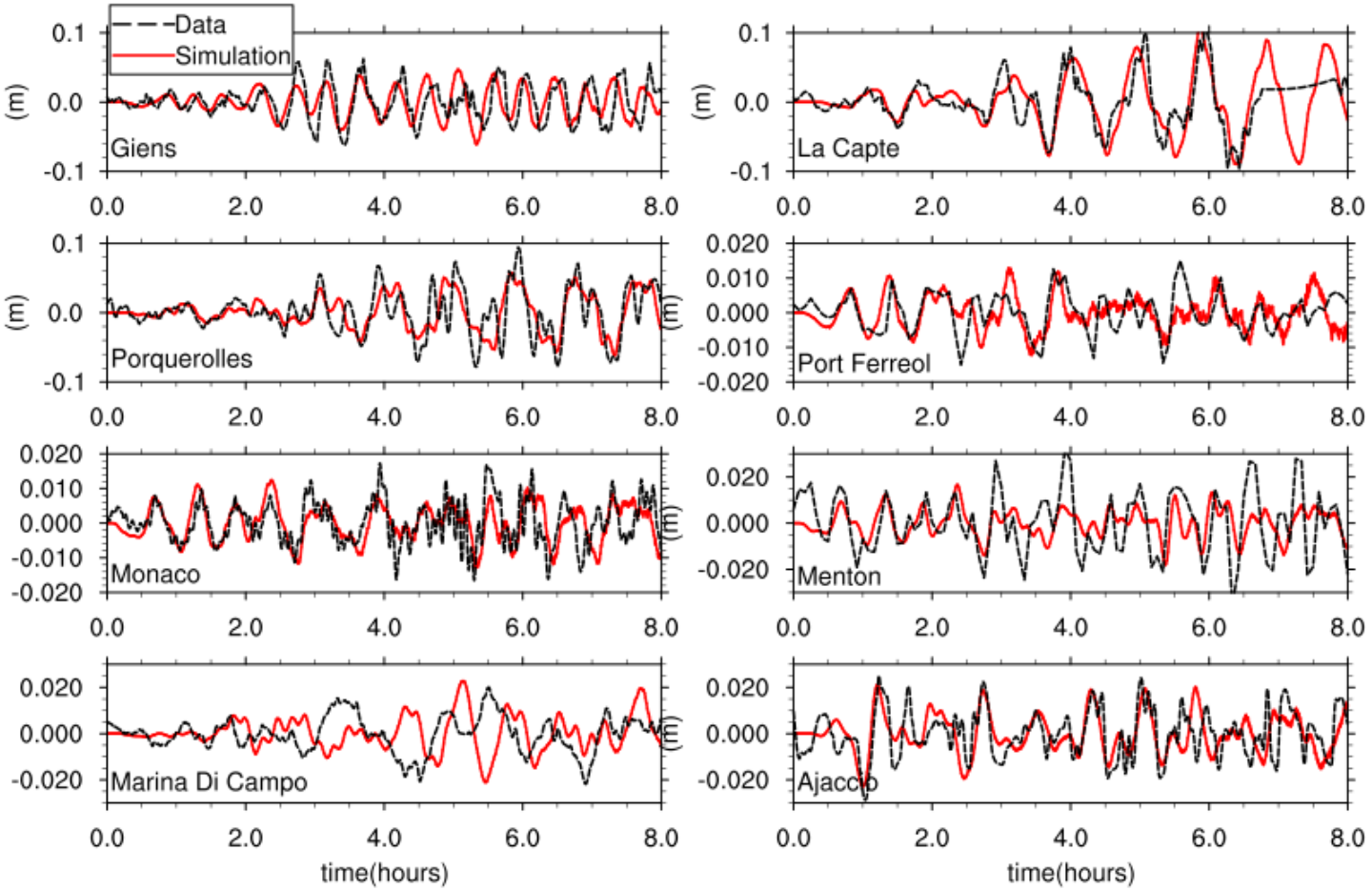


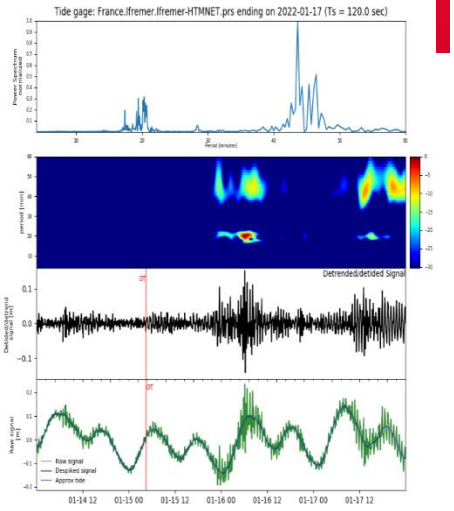
Comparisons between recorded and calculated atmospheric pressures at HTMnet stations (Toulon University)

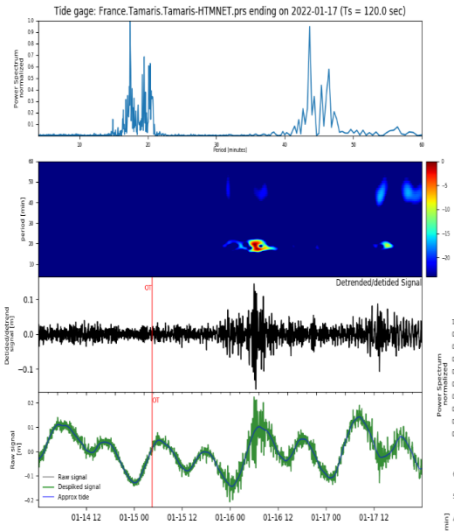


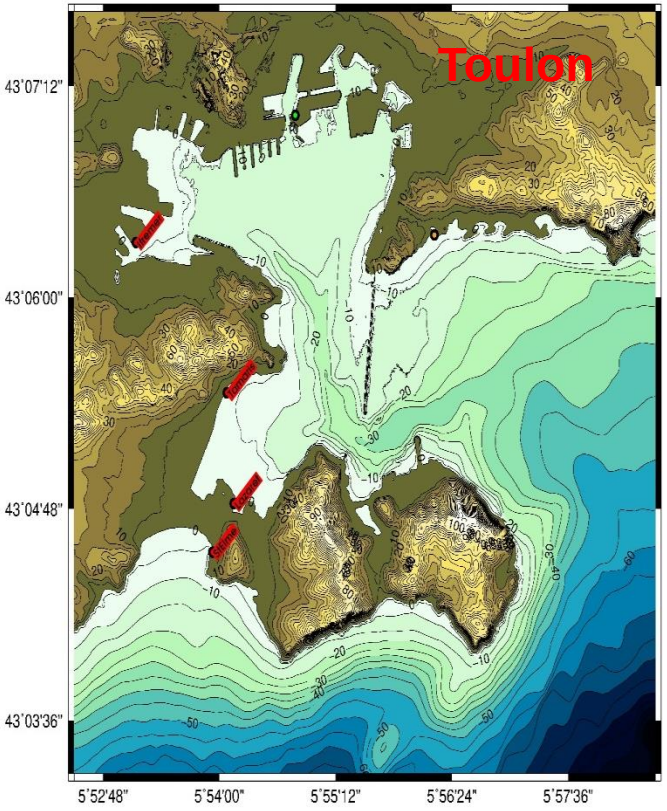
19h45 UTC (15 Jan)

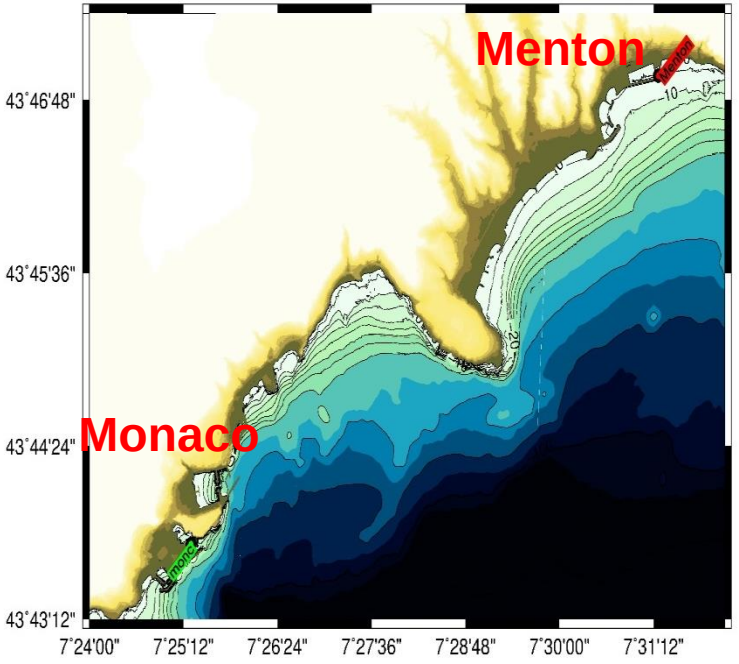
Comparisons between observed and simulated water heights in a coarse resolution grid (Δx=250m)

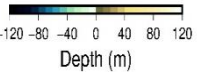


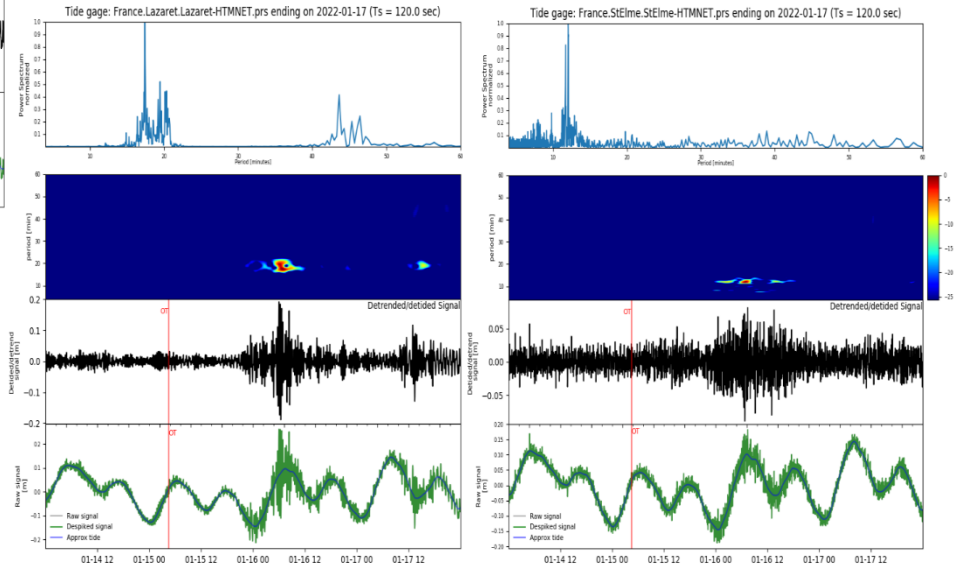


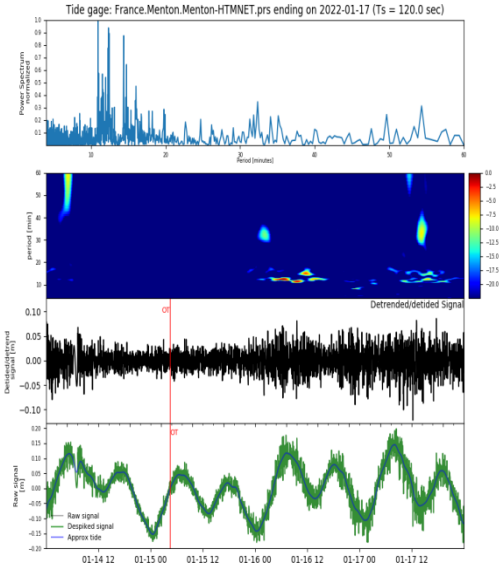










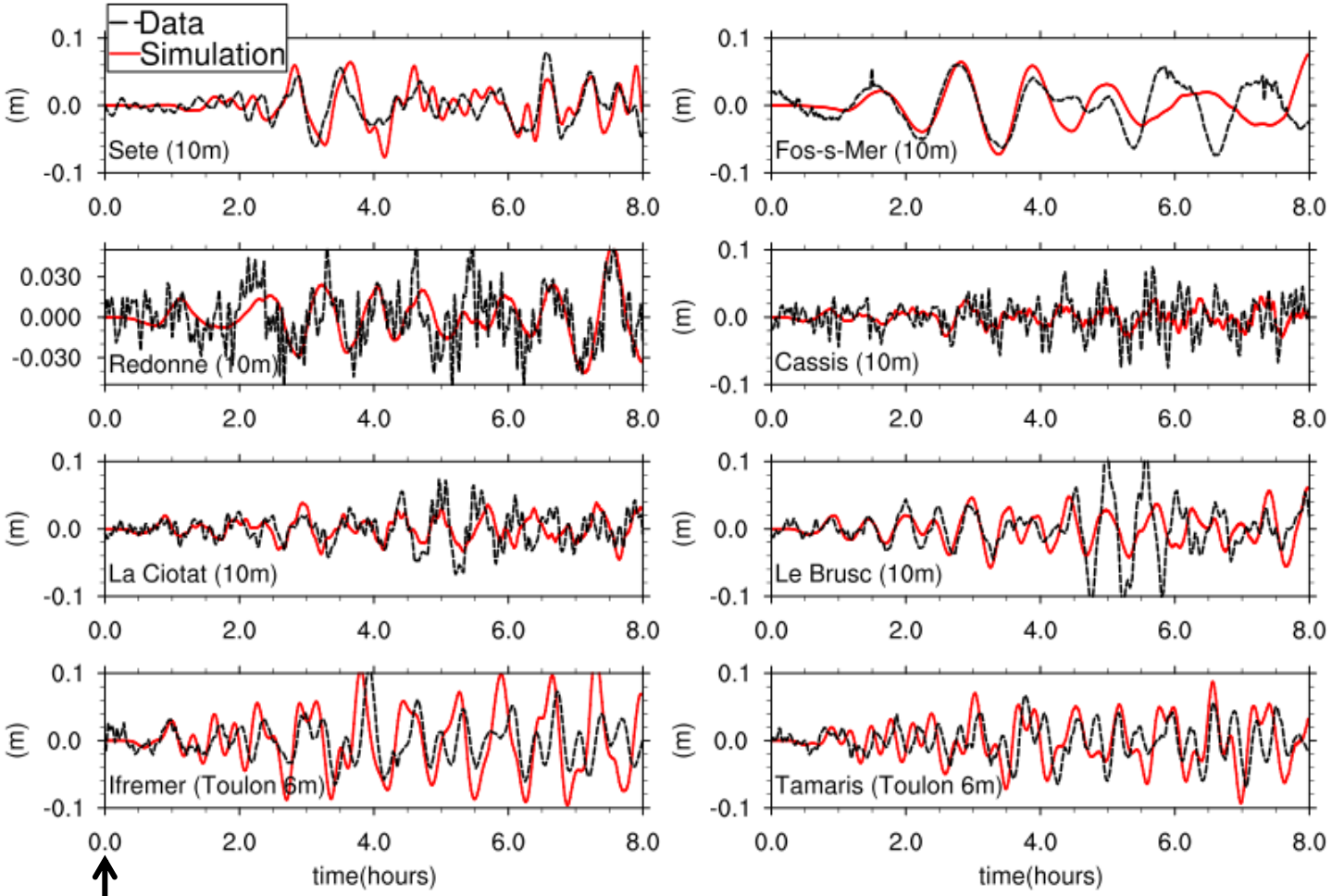


Stations HTM-Net (Rade of Toulon)

Station HTM-Net (Menton)

Comparisons between observed and recorded water heights in high resolution grids (Δx=5m or 10m)

From W to E : Sète, Fos-sur-Mer, La Redonne, Cassis, la Ciotat, Le Brusc, Rade de Toulon (Ifremer et Tamaris)



19h45 UTC (15 Jan)

Conclusion

The Mediterranean tsunami was generated by the Lamb wave propagation and the observed maregrams are reproduced using a coarse resolution grid

Sensitivity studies :
- Grids resolution
- N-wave/Sinusoidal wave
- Wave periods (30 min to 1 hour)

Next Step (Cenalt):
Development of an operational version of Taitoko to simulate meteo-tsunamis

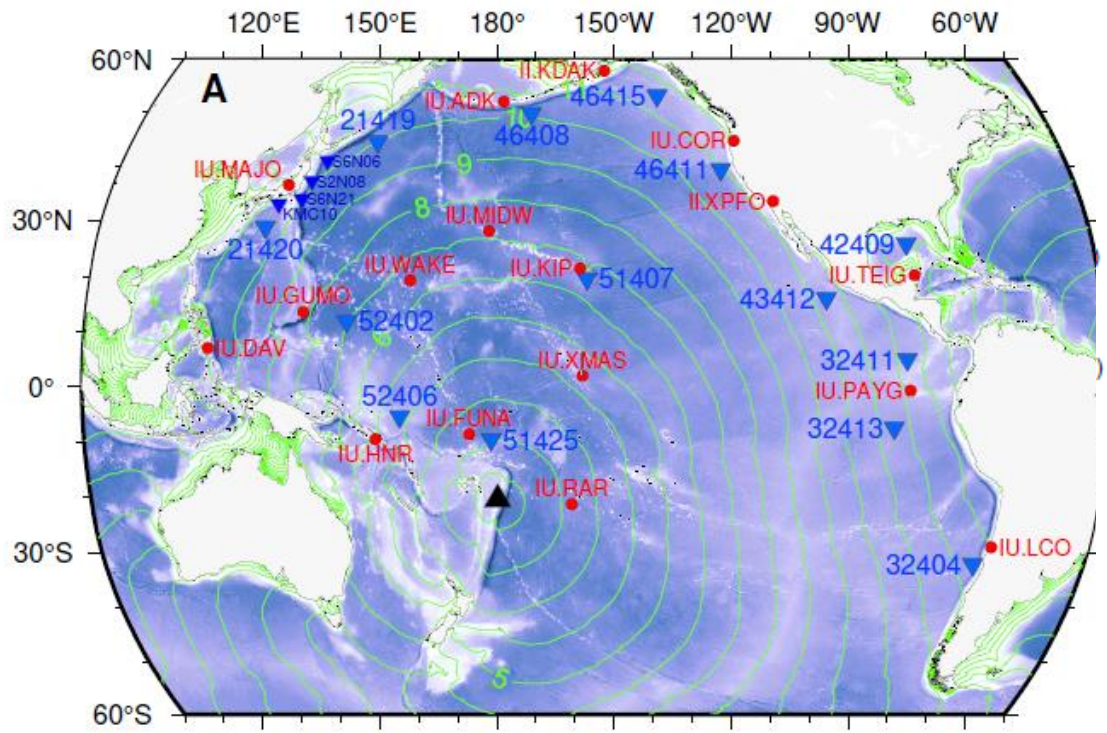
Submission to GJI

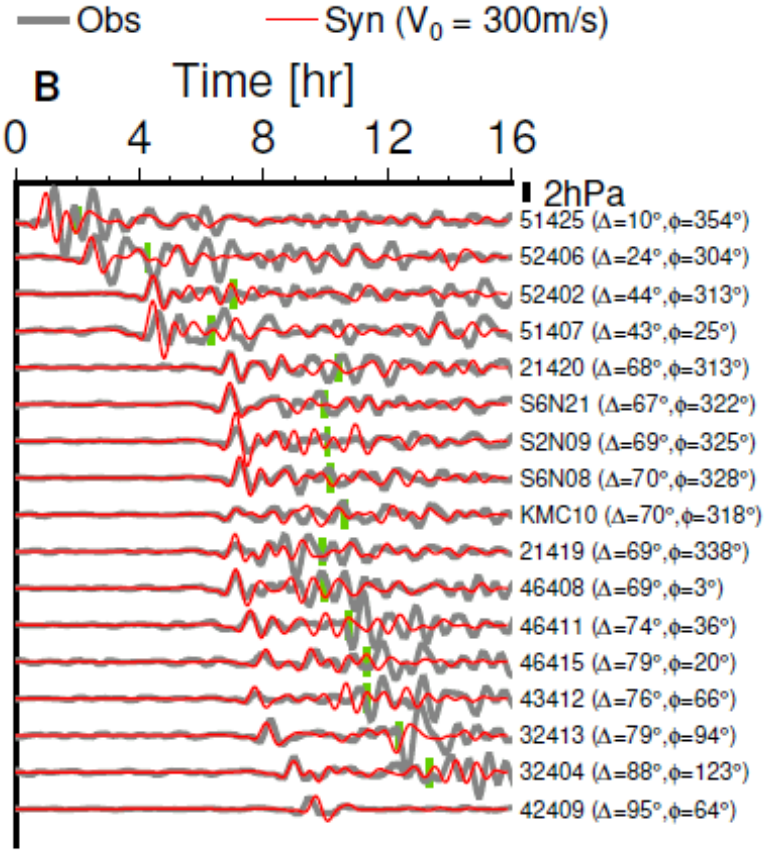
Observation and simulation of the meteotsunami generated in the Mediterranean Sea by the Tonga eruption on 15 January 2022

Heinrich P. , Gailler A., Dupont A. ; Rey V., Hébert H., Listowski C. , Forestier E.

Global fast-traveling tsunamis by atmospheric pressure waves on the 2022 Tonga eruption (Science, May 2022)
Authors: Tatsuya Kubota, Tatsuhiko Saito, Kiwamu Nishida

The simulation found that fast-moving atmospheric pressure waves drove the leading sea height rise, while the scattering of the leading waves by small islands in the Pacific Ocean triggered the coda tsunamis.





Sensitivity studies

- **N-wave/Sinusoidal wave**