



**Universitat**  
de les Illes Balears



*A **TRAM-BASED** Pragmatic Approach for the  
Numerical Prediction of **METEOTSUNAMIS** in  
**CIUTADELLA** Harbour (Balearic Islands)*

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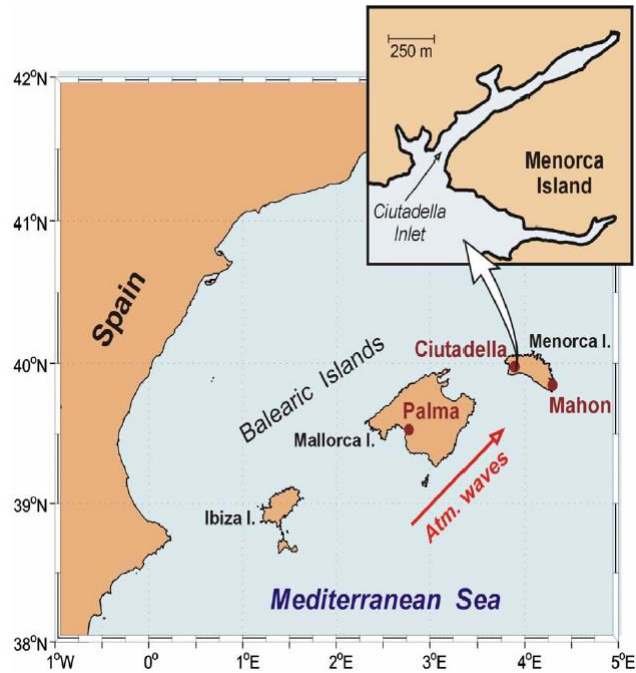
MINISTERIO  
DE ECONOMÍA, INDUSTRIA  
Y COMPETITIVIDAD



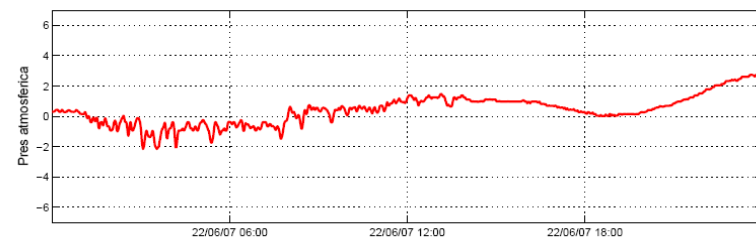
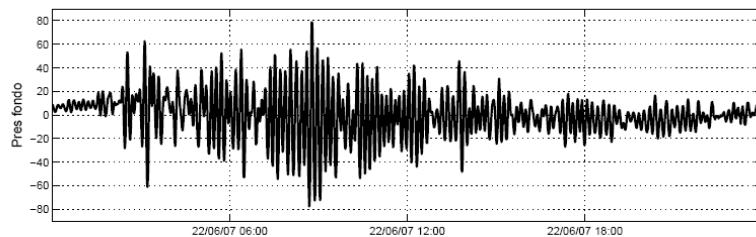
**COASTEPS**  
**CGL2017-82868-R**



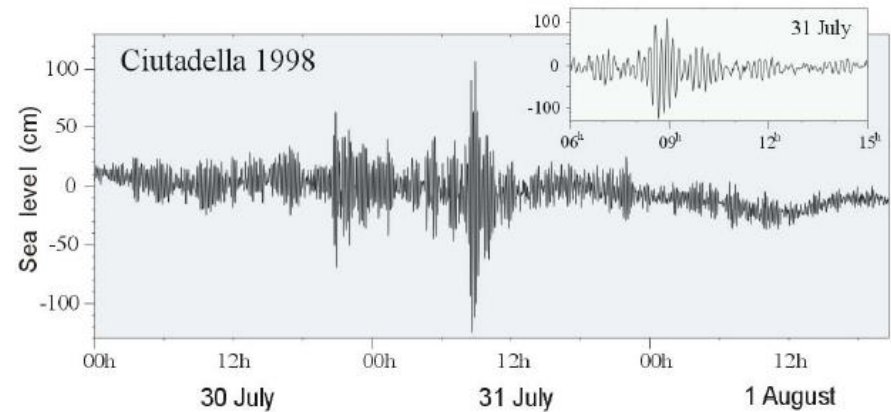
**EUROPEAN UNION**  
EUROPEAN REGIONAL  
DEVELOPMENT FUND  
"A way to make Europe"



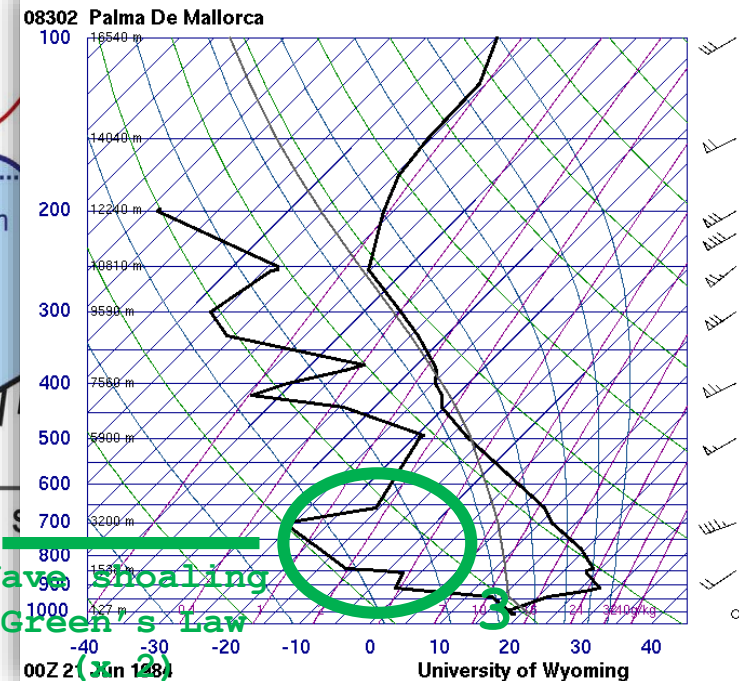
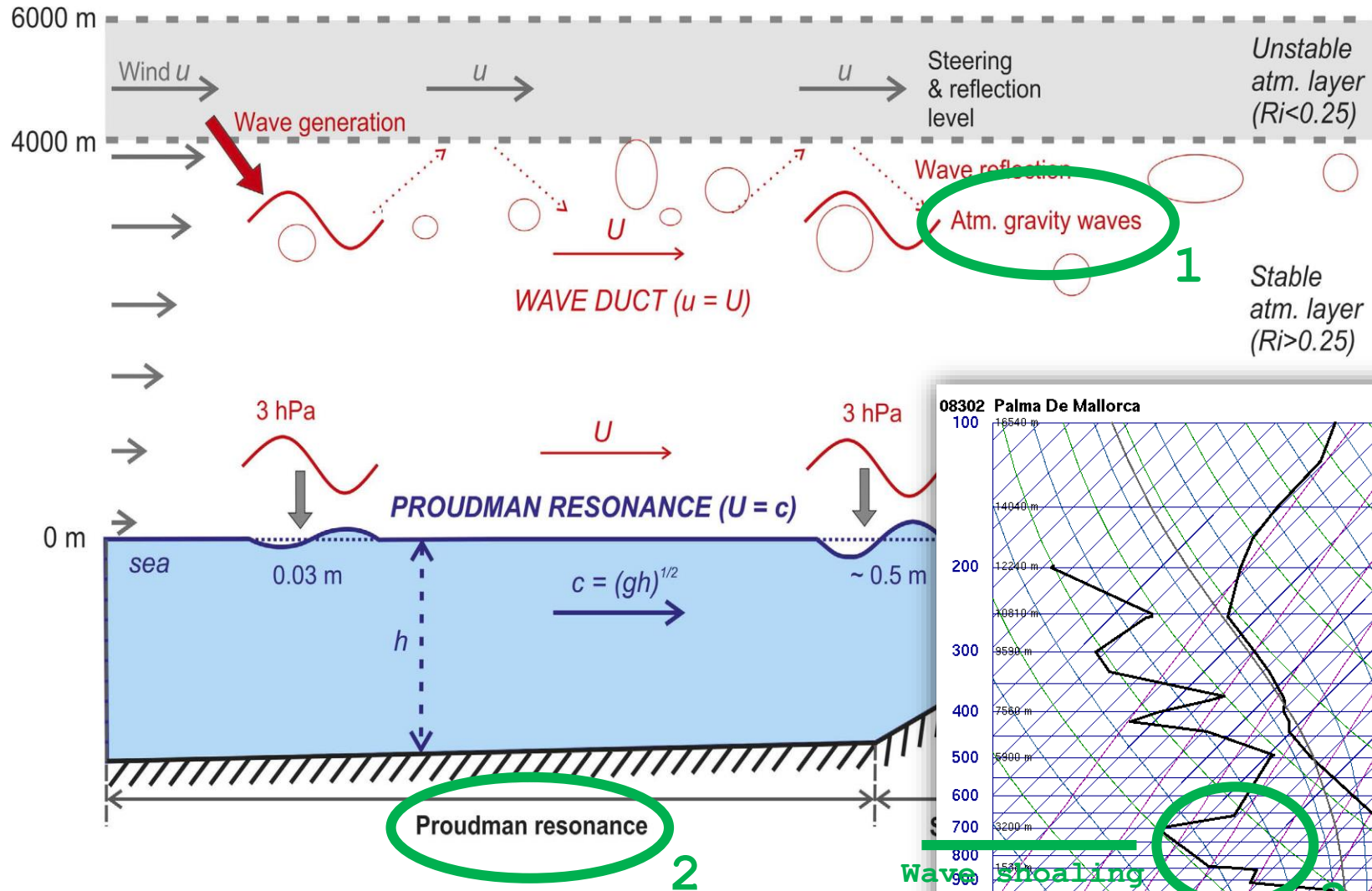
Jansà et al. (2007)



15 June 2006



Šepić et al. (2015)



# 1. ATMOSPHERIC Component (Balearic Islands)

## > 2D version of Euler equations (dry-adiabatic)

$$\frac{\partial \pi'}{\partial t} = -u \frac{\partial \pi'}{\partial x} - w \frac{\partial \pi'}{\partial z} - w \frac{\partial \bar{\pi}}{\partial z} - \frac{R}{c_v} (\bar{\pi} + \pi') \left[ \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \right]$$

$$\frac{\partial \theta'}{\partial t} = -u \frac{\partial \theta'}{\partial x} - w \frac{\partial \theta'}{\partial z} - w \frac{\partial \bar{\theta}}{\partial z}$$

$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - w \frac{\partial u}{\partial z} - c_p (\bar{\theta} + \theta') \frac{\partial \pi'}{\partial x}$$

NO rotation

NO physics, etc ...

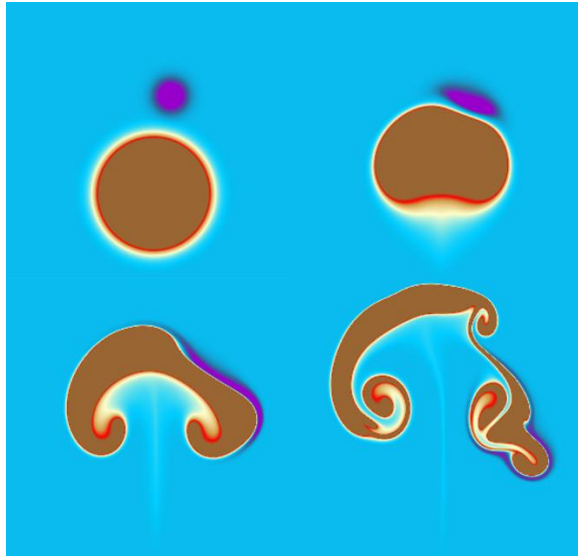
$$\frac{\partial w}{\partial t} = -u \frac{\partial w}{\partial x} - w \frac{\partial w}{\partial z} - c_p (\bar{\theta} + \theta') \frac{\partial \pi'}{\partial z} + g \frac{\theta'}{\bar{\theta}}$$

## > Numerical implementation [CFL $\xrightarrow{c_s > 300 \text{ m/s}}$ $\Delta t \approx 3 \Delta x (\Delta z)$ ]

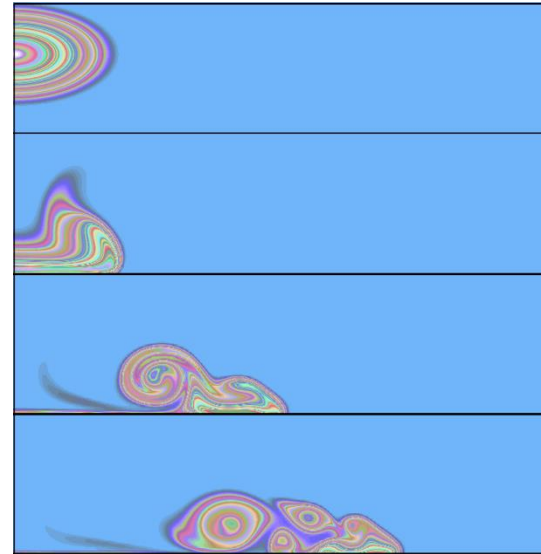
- \* Forward-Backward integration of "forcings" in RK2 cycle
- \* REA (V and H) integration of advection every 6-10 Nsteps
- \* Stabilized acoustic vertical modes (Implicit Scheme)



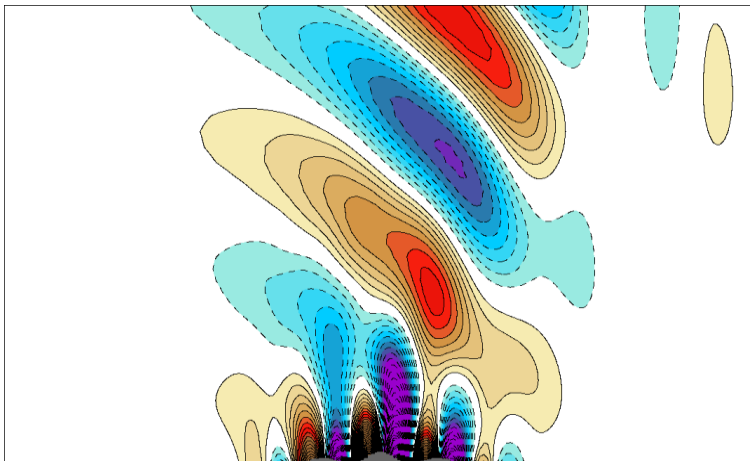
Large Warm & Small Cold Bubble



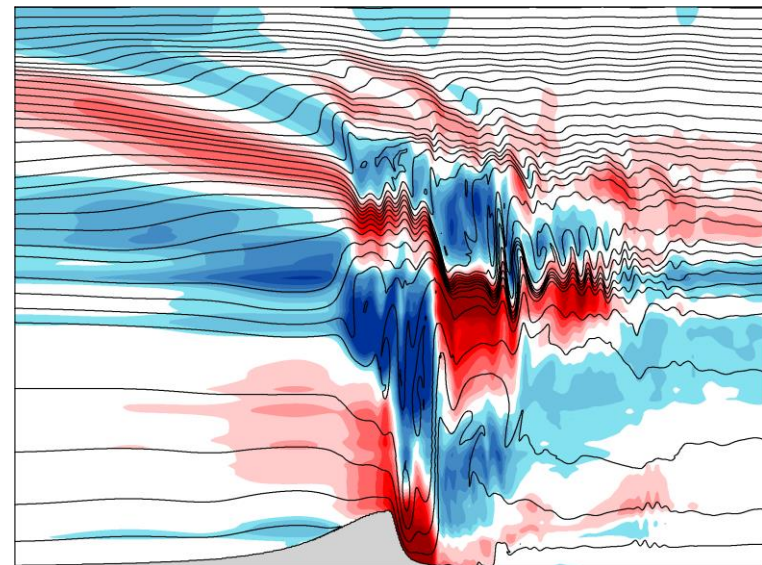
Density  
Current



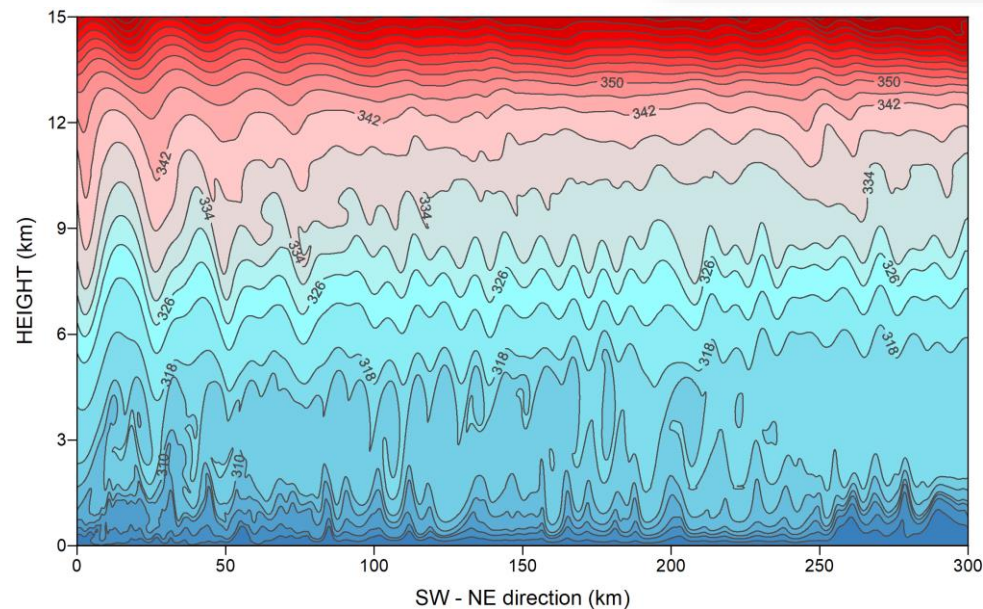
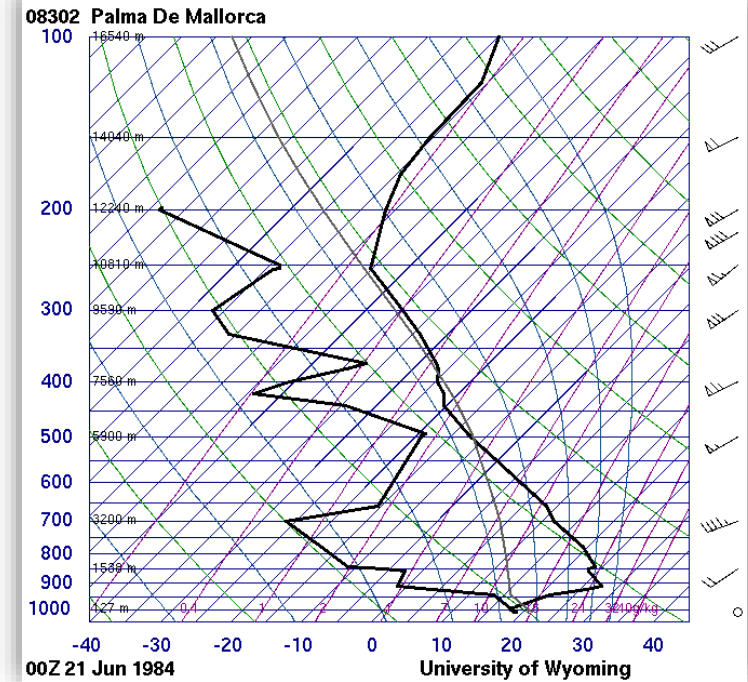
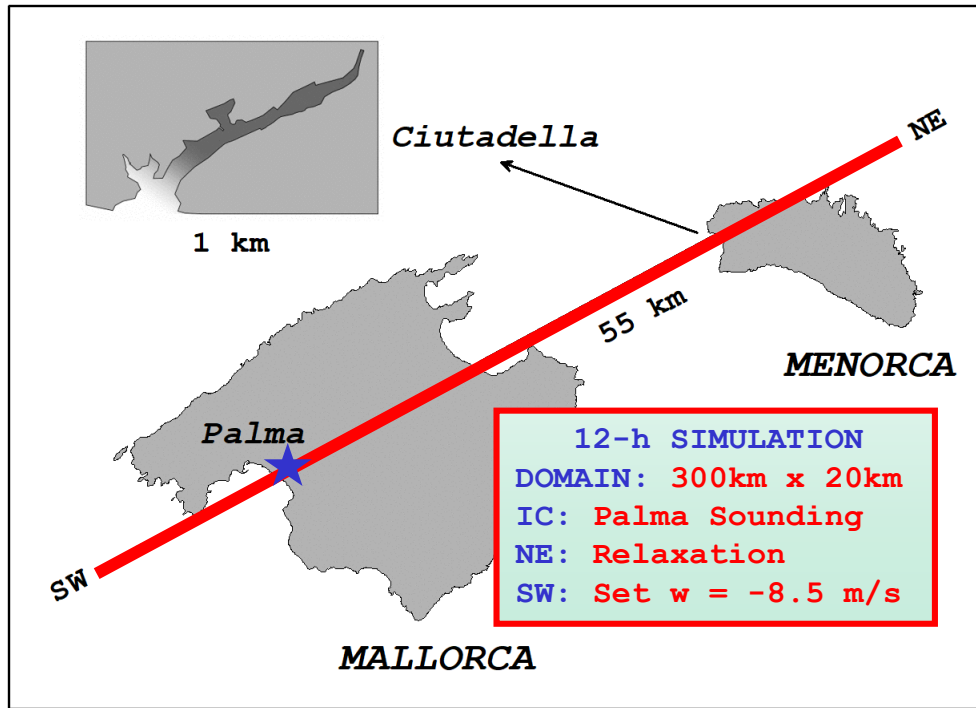
Schär Mountain



T-REX Intense Mountain-Wave



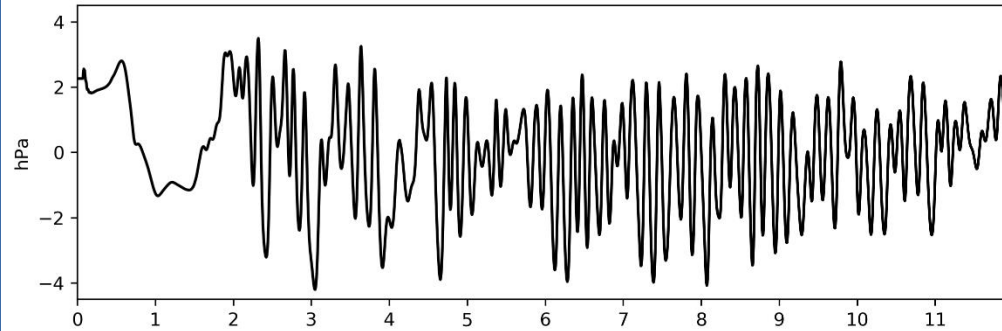
# GRAVITY WAVE Generation & Propagation



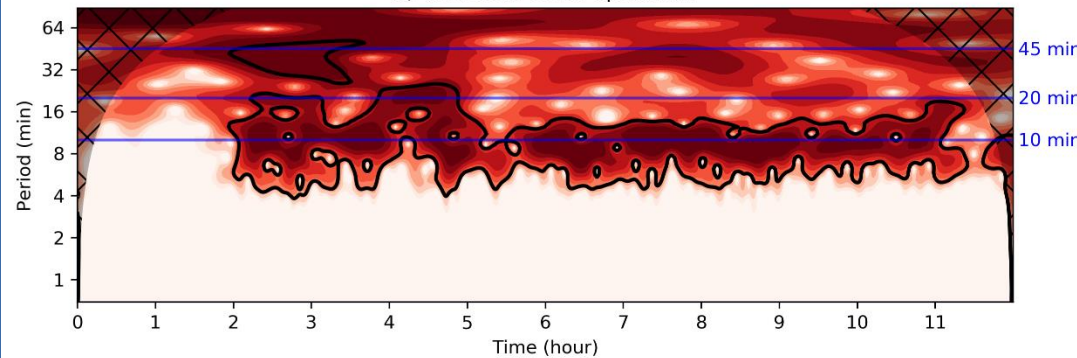
With ORIGINAL  
( $t=5h$ )

# GRAVITY WAVE Generation & Propagation

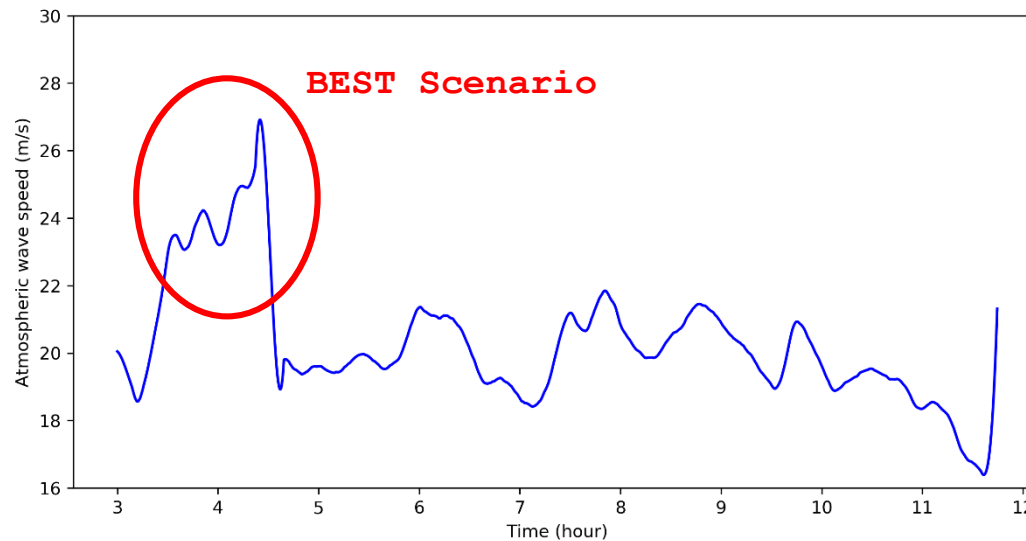
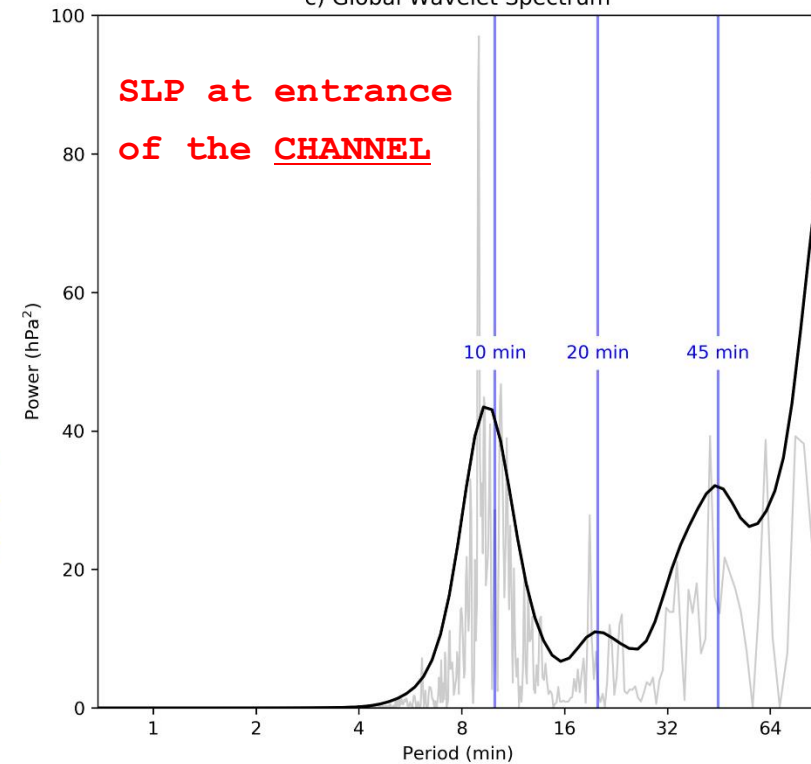
a) Sea level pressure (anomaly)



b) Wavelet Power Spectrum



c) Global Wavelet Spectrum



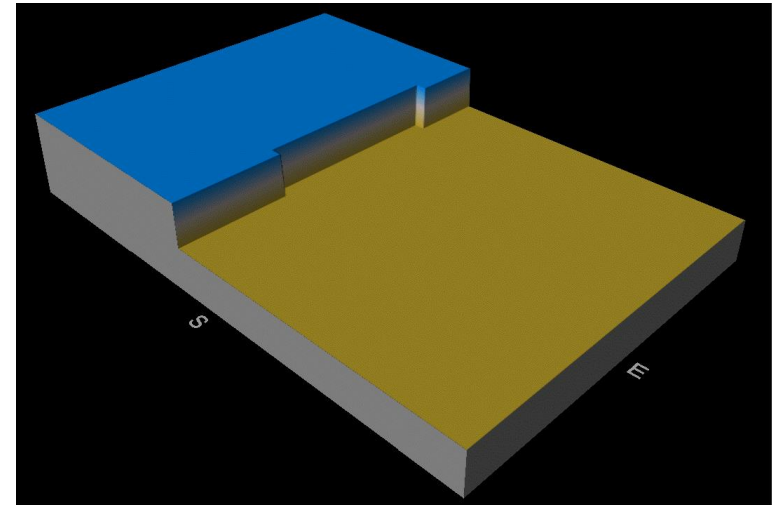
SLP-wave speed  
in the CHANNEL

## 2. OCEANIC Component (MALLORCA-MENORCA Channel)

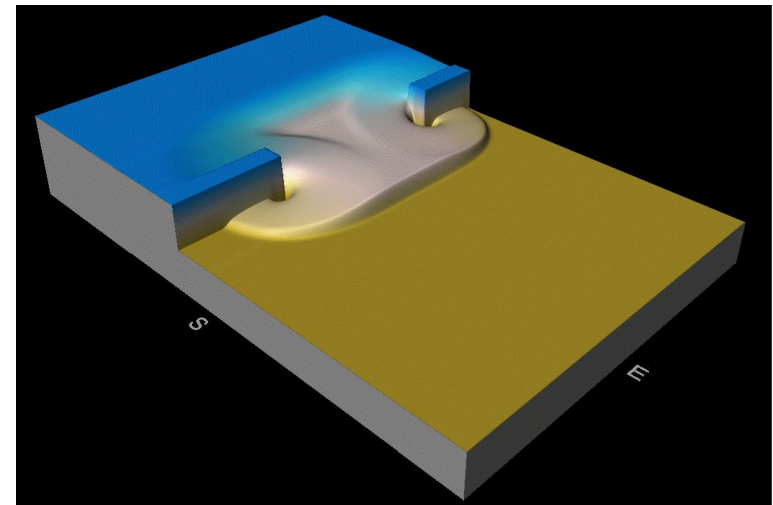
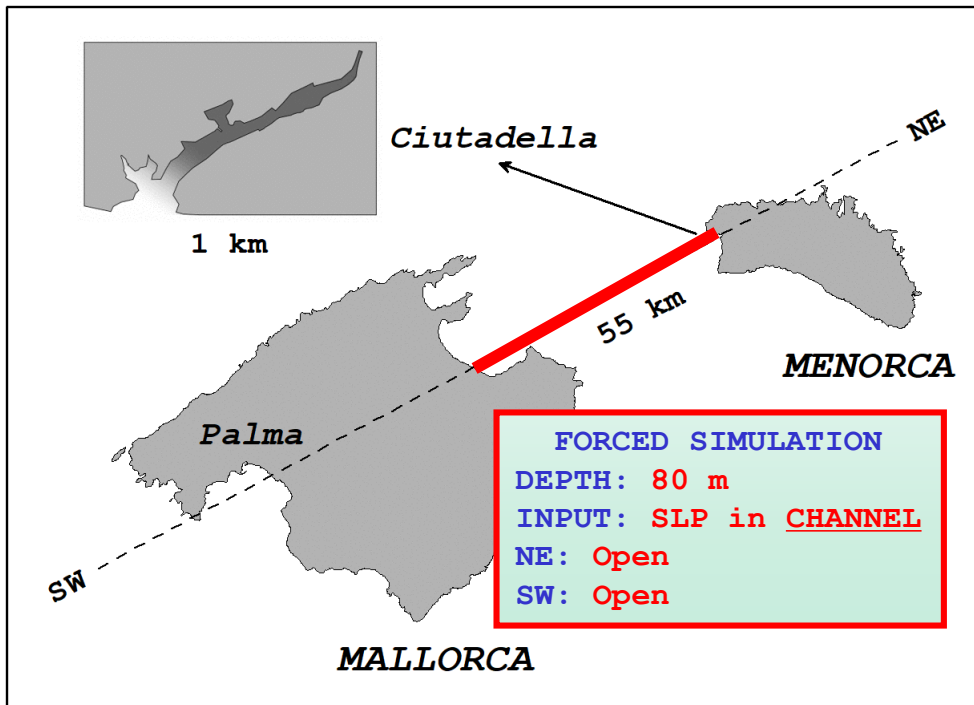
### > Shallow-Water equations

$$\frac{\partial h}{\partial t} = -u \frac{\partial h}{\partial x} - h \frac{\partial u}{\partial x}$$

$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - g \frac{\partial h}{\partial x} - \frac{1}{\rho} \frac{\partial P}{\partial x} - \frac{gu^2}{hC^2}$$



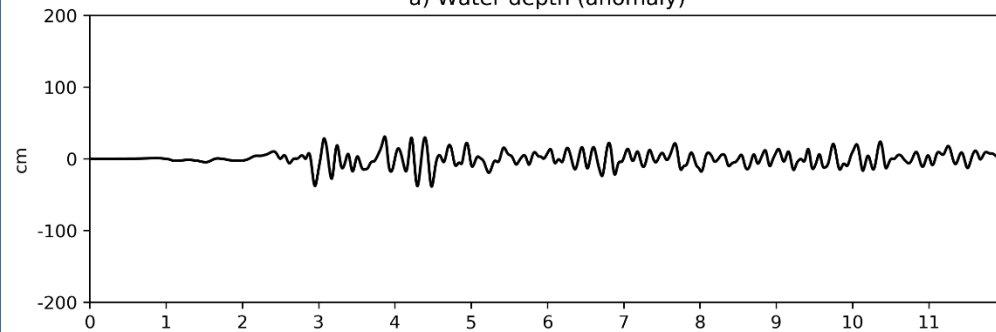
Partial Dam Break 10-5 m



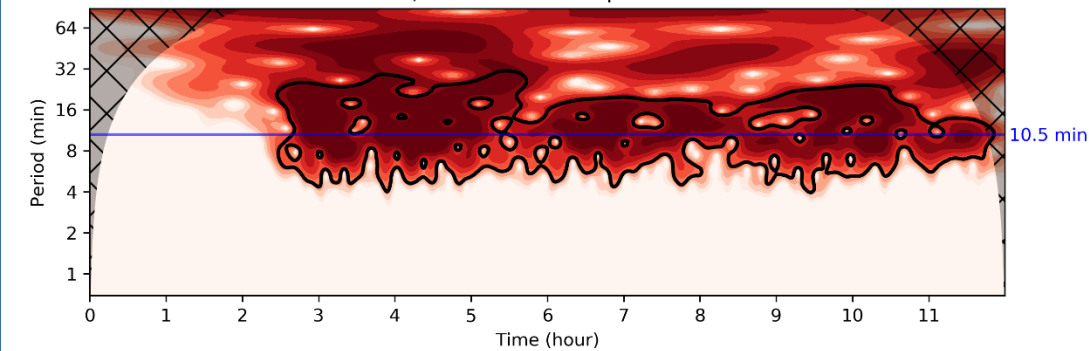


# LONG OCEAN WAVES (Proudman Resonance & Wave Shoaling)

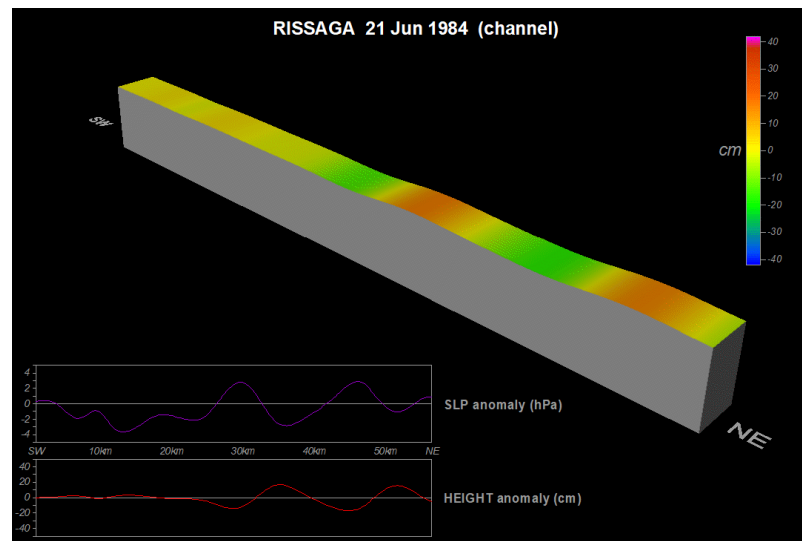
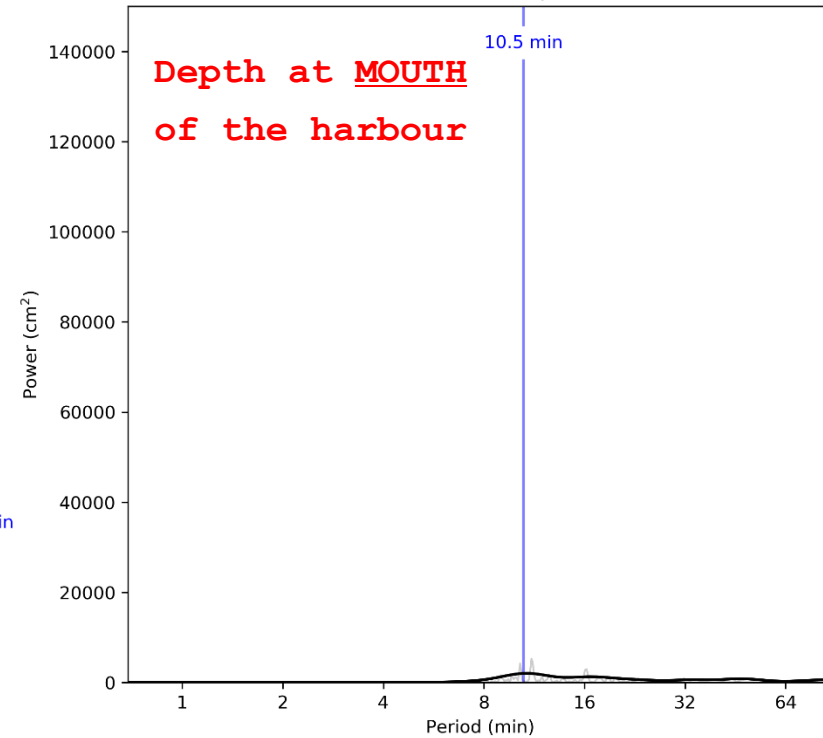
a) Water depth (anomaly)



b) Wavelet Power Spectrum



c) Global Wavelet Spectrum

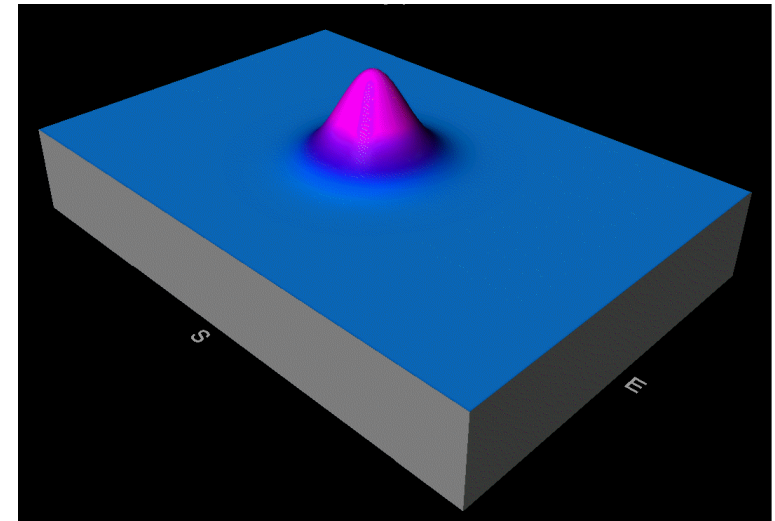


### 3. COASTAL Component (CIUTADELLA Inlet)

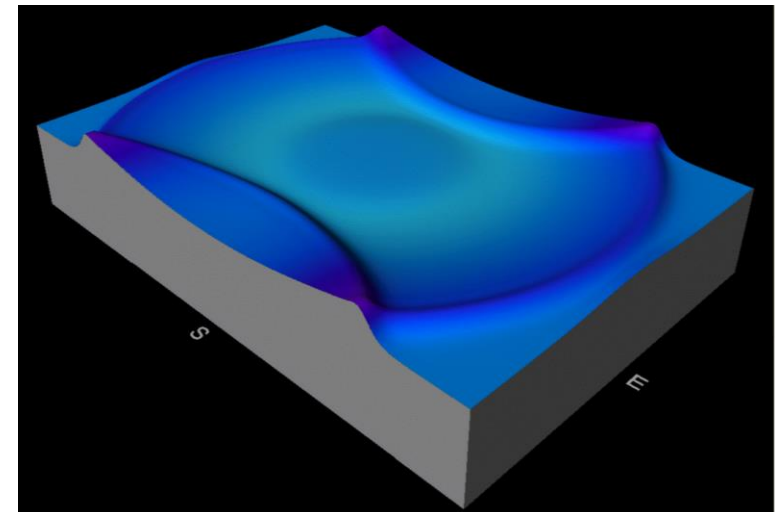
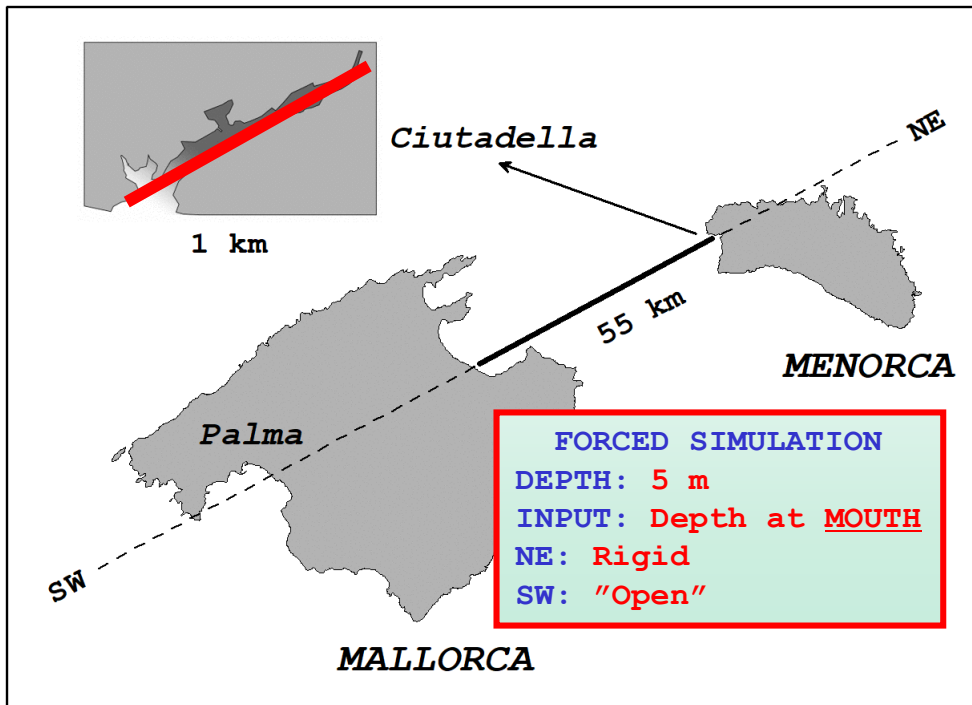
#### > Shallow-Water equations

$$\frac{\partial h}{\partial t} = -u \frac{\partial h}{\partial x} - h \frac{\partial u}{\partial x}$$

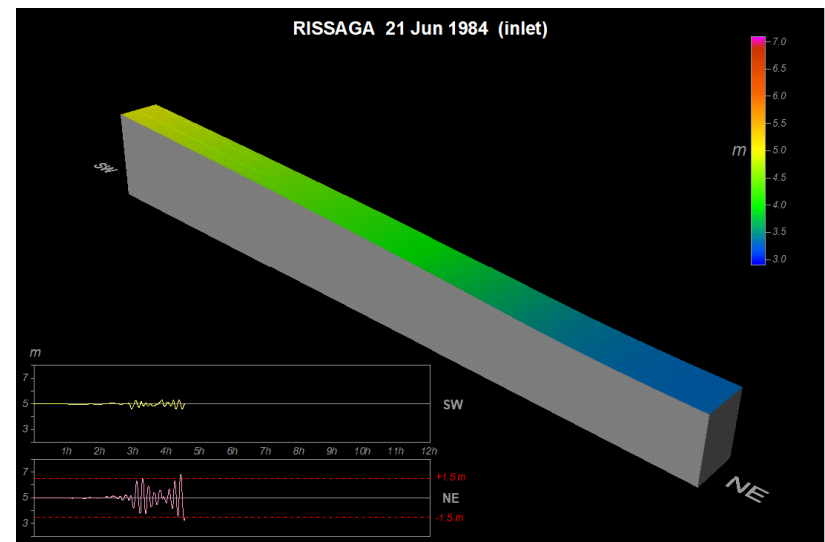
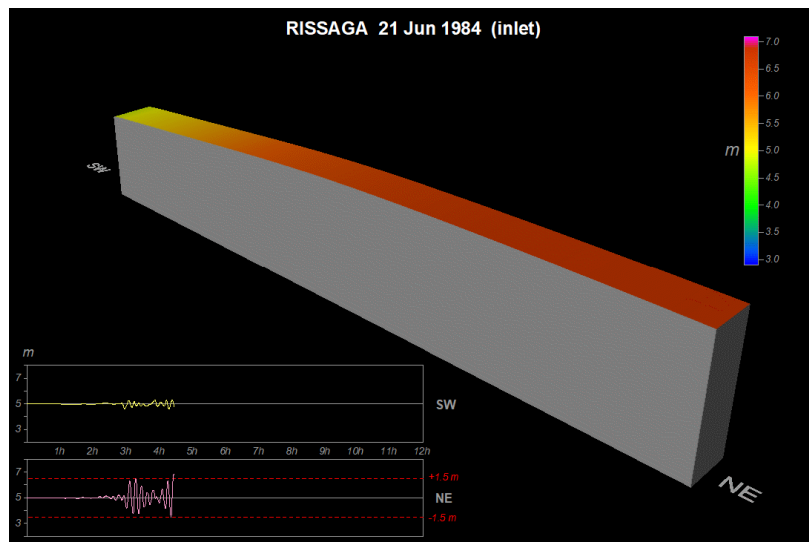
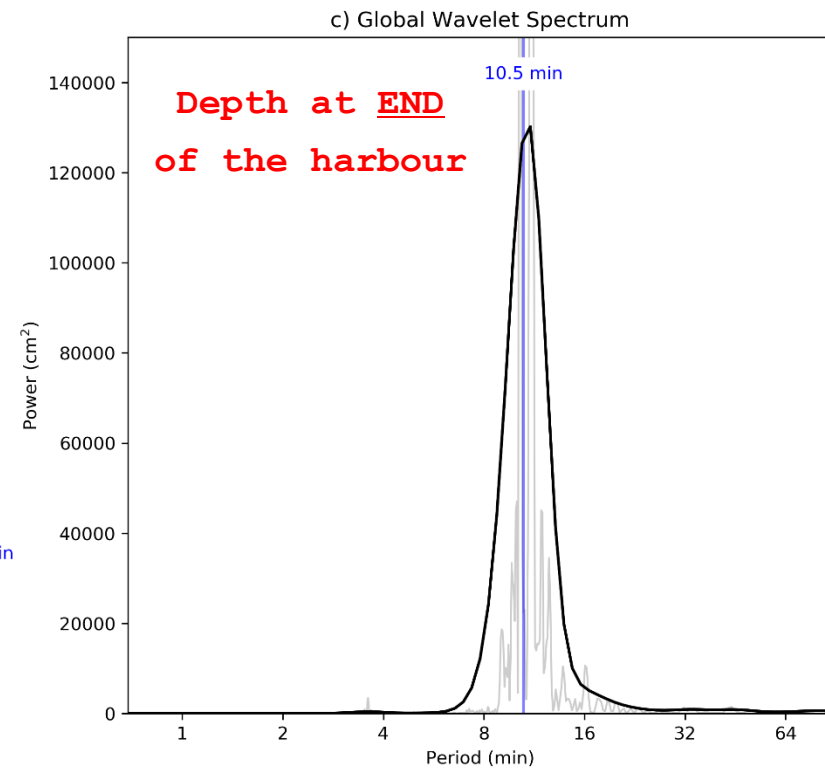
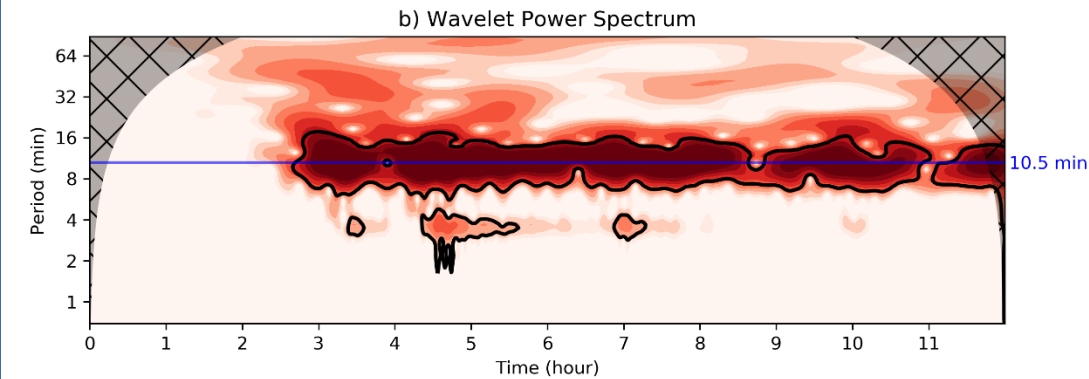
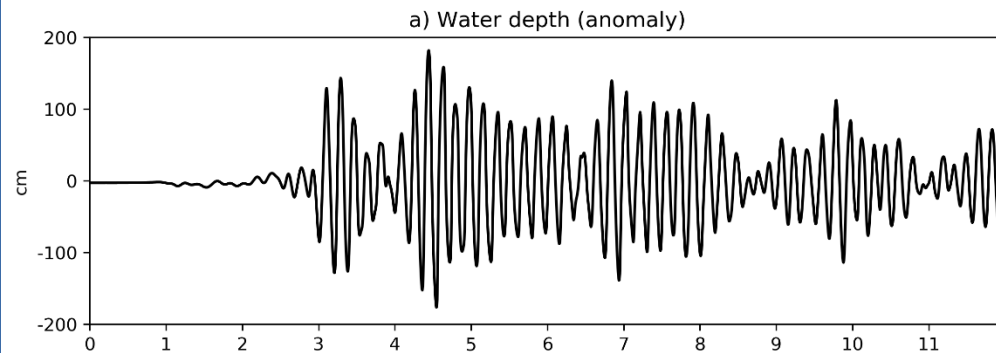
$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - g \frac{\partial h}{\partial x} - \frac{gu^2}{hC^2}$$

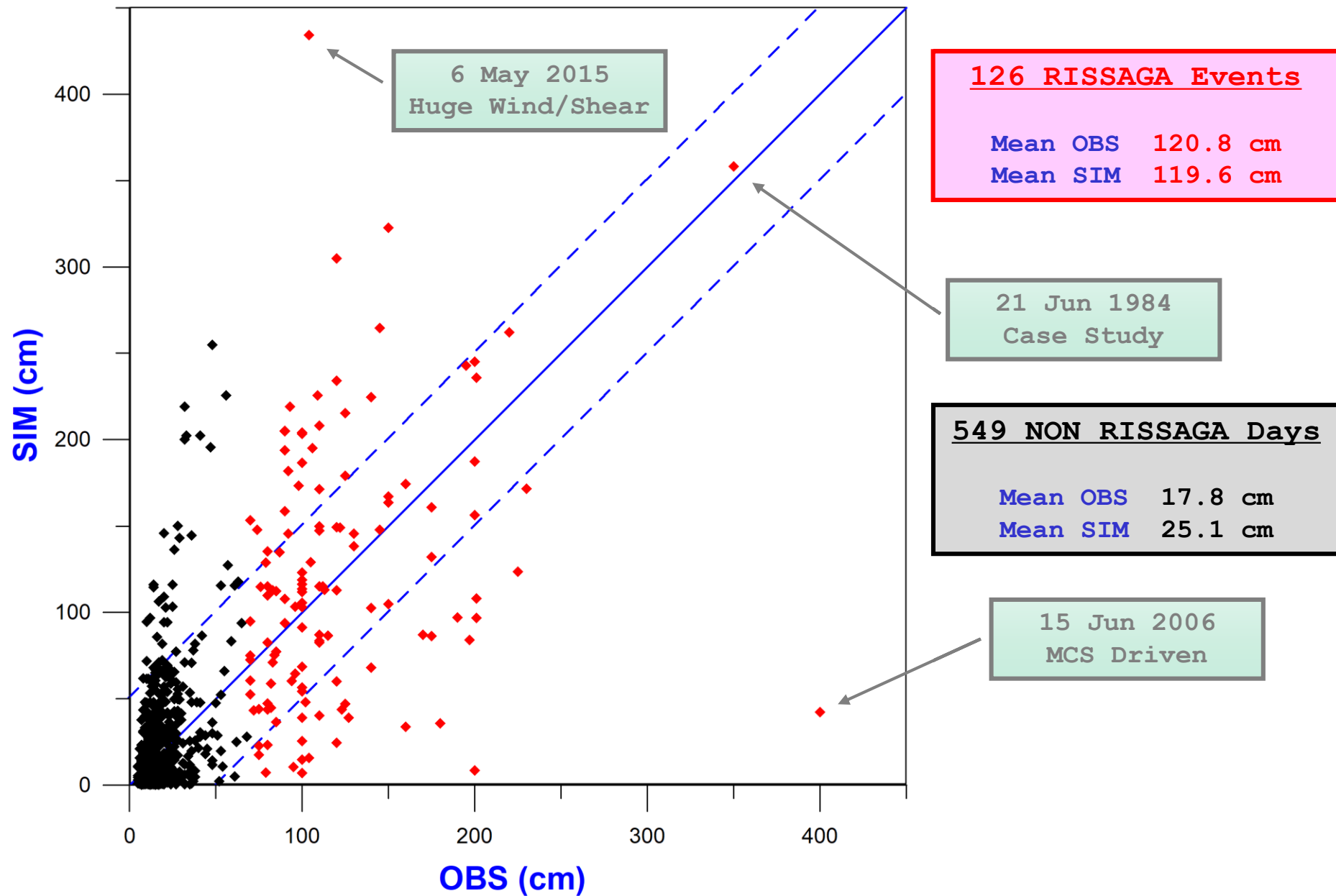


Gaussian Bump in 10 m



# RISSAGA (Harbour Resonance)







# RISSAGA (CATEGORIES of Practical Interest)

 Petites Oscil·lacions (H < 20 cm)	 Oscil·lacions Moderades (20 - 70 cm)	 Rissaga (70 - 100 cm)	 Rissaga Forta (100 - 200 cm)	 Rissaga Extrema (H > 200 cm)
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## F O R E C A S T (%)






O B S E R V E D		71.2	25.9	1.8	1.0	0.0
		43.1	38.9	6.0	8.4	3.6
		6.8	29.5	18.2	38.6	6.8
		4.3	21.4	14.3	42.9	17.1
		8.3	8.3	8.3	41.7	33.3

*What fraction of the events  
are (are not) correctly forecast ???*

## O B S E R V E D (%)



F O R E C A S T		77.5	20.5	0.9	0.9	0.3
		51.3	33.7	6.7	7.8	0.5
		19.4	27.8	22.2	27.8	2.8
		5.7	20.0	24.3	42.9	7.1
		0.0	24.0	12.0	48.0	16.0

*What fraction of the forecasts  
are (are not) correct ???*

- > A **PRAGMATIC** (and computationally **CHEAP**) numerical **APPROACH** aimed at **PREDICTING** the occurrence and magnitude of meteotsunamis in Ciutadella (**RISSAGAS**): **SKILL** for the recognition of **RISK** situations and for a categorization among **WEAK**, **MODERATE** and **INTENSE**
- > **SOME ISSUES** to explore: **Sounding** representativity; Type and amount of **GW triggering**; Inclusion of moist physics (**MCS**); **Second-order** oceanic influences...
- > The system could be applied as a **DOWNSCALING METHOD** to assess quantitatively the future risk of rissagas
- > It is now in operation, running daily driven by GFS forecast soundings for the next 3 days and providing **PROBABILISTIC PREDICTIONS**: <http://meteo.uib.es/rissaga>

THANK YOU  
for  
your attention