A Computationally Cheap Atmosphere-Ocean Modelling System Aimed At Anticipating METEOTSUNAMI Occurrence in CIUTADELLA Harbour

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**Physical Mechanisms**

Šepić et al. (2015)

1. **Wave shoaling**
   - Wind $U$ → Wave generation → $U$ → Steering & reflection level → $U$ → Unstable atm. layer ($Ri<0.25$)
   - Atm. gravity waves
   - Wave reflection
   - WAVE DUCT ($u = U$)

2. **Proudman resonance**
   - PROUDMAN RESONANCE ($U = c$)
   - $c = (gh)^{1/2}$
   - Sea level $0.03$ m
   - Shelf amplification
   - Wave shoaling
   - Green’s Law ($x \times 2$)

3. **Harbour run-up**
   - Stable atm. layer ($Ri>0.25$)
   - $3$ hPa
   - ~ $1$ m
> 2D version of Euler equations (dry-adiabatic)

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

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

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

\[
\text{NO rotation}
\]

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

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

* 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

Schär Mountain

T-REX Intense Mountain-Wave

Density Current

VALIDATION Tests
12-h SIMULATION
DOMAIN: 300km x 20km
IC: Palma Sounding
NE: Relaxation
SW: Set \( w = -8.5 \) m/s

With ORIGINAL
(t=5h)
SLP at entrance of the CHANNEL

GRAVITY WAVE Generation & Propagation

a) Sea level pressure (anomaly)

b) Wavelet Power Spectrum

10 min 20 min 45 min

45 min 20 min 10 min

Period (min)

Power (hPa²)

0 1 2 3 4 5 6 7 8 9 10 11 12

Time (hour)

0 1 2 3 4 5 6 7 8 9 10 11

SLP-wave speed in the CHANNEL

BEST Scenario
2. OCEANIC Component (MALLORCA–MENORCA Channel)

> Shallow-Water equations

\[
\frac{\partial h}{\partial t} = -u \frac{\partial h}{\partial x} - h \frac{\partial u}{\partial x}
\]

\[
\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - g \frac{\partial h}{\partial x} - \frac{1}{\rho} \frac{\partial P}{\partial x} - \frac{gu^2}{hc^2}
\]
Depth at MOUTH of the harbour

LONG OCEAN WAVES (Proudman Resonance & Wave Shoaling)
> **Shallow-Water equations**

\[
\frac{\partial h}{\partial t} = -u \frac{\partial h}{\partial x} - h \frac{\partial u}{\partial x} \\
\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - g \frac{\partial h}{\partial x} - \frac{gu^2}{hc^2}
\]
RISSAGA (Harbour Resonance)

Depth at END of the harbour
### RISSAGA (CATEGORIES of Practical Interest)

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

### 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