REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE:	CROATIA
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Project Title:	Using stochastic surrogate methods for advancing towards reliable meteotsunami early warning systems

If this is a continuation of an existing project, please state the computer project account assigned previously.		
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☒	NO

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	20,000,000	15,000,000	10,000,000
Accumulated data storage (total archive volume)[2]	(GB)	30,000	50,000	65,000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

1) State-of-the-art

Meteotsunamis or meteorological tsunamis (Fig. 1) – atmospherically-induced destructive ocean waves in a tsunami frequency band – started to be exhaustively studied in the last decades, although they are known to affect the coastlines for centuries, being recognized by local names and legends (Monserrat et al., 2006; Vilibić and Šepić, 2009; Pattiaratchi and Wijeratne, 2015; Rabinovich, 2020). They might appear at coastlines of all continents, while being manifested as waves of several metres and associate with strong currents, in particularly researched at Ciutadella Inlet (Harbour), Menorca Island, Spain (Tintoré et al., 1988; Gomis et al., 1993); Vela Luka Bay, Korčula Island, Croatia (Orlić, 1980; Šepić et al., 2015); Mazara del Vallo, Sicily, Italy (Candela et al., 1999); Nagasaki Bay, Japan (Hibiya and Kajiura 1982); Longkou Harbour, China (Wang et al. 1987), Great Lakes (Bechle et al., 2016; Linares et al., 2019); Western Australian shelf (Pattiaratchi an Wijeratne, 2014), and other.

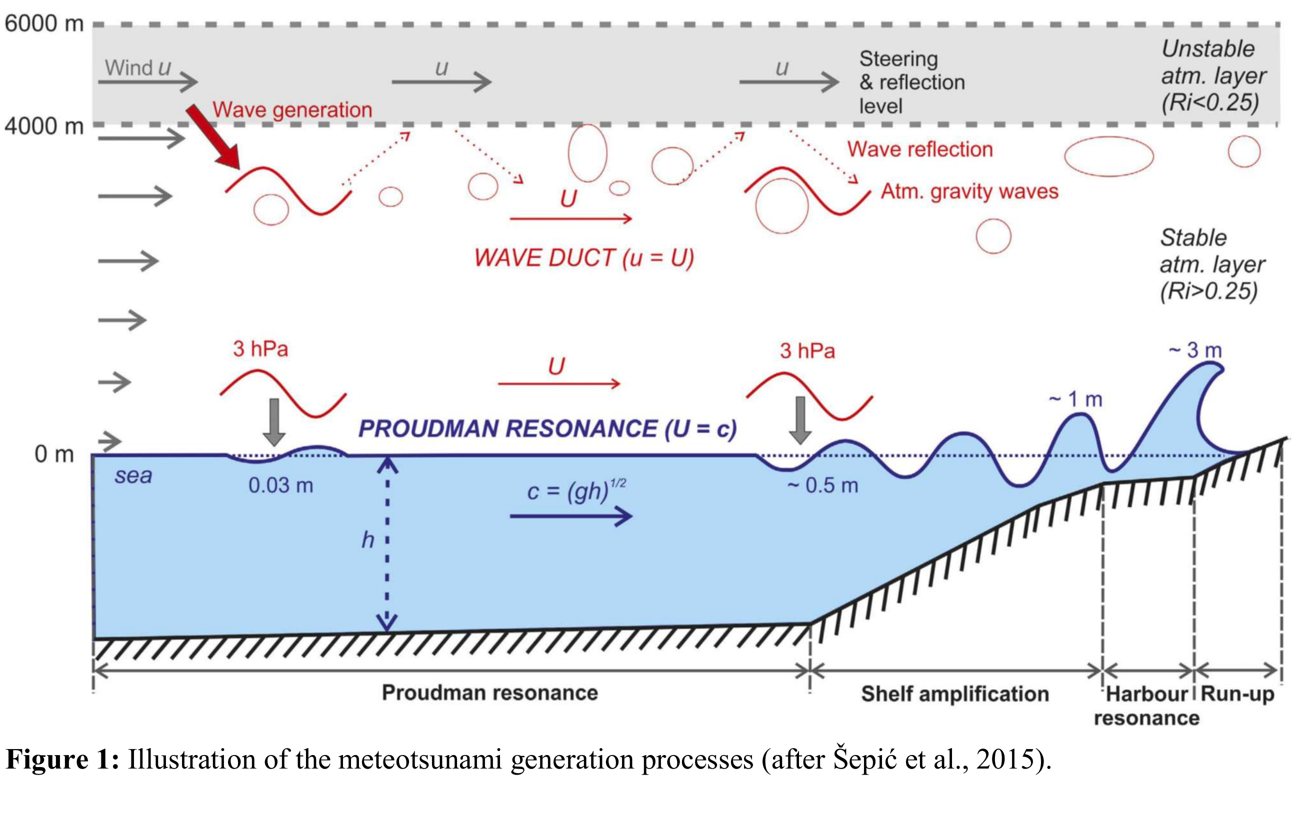

Figure 1: Illustration of the meteotsunami generation processes (after Šepić et al., 2015).

Still, the physical explanation of their nature was developed lately (Fig. 1), due to their multi-resonant nature dependent on the very mesoscale source in the atmosphere and quite large sensitivity to bathymetry changes in the ocean (Belušić et al., 2007; Vilibić, 2008; Williams et al., 2020). The Proudman resonance (Proudman, 1929) is a key but not the only resonant process that transfers the energy of intense, rapid and persistent atmospheric disturbances to long ocean waves, while the intensity of the coastal hazards – as for seismic tsunamis – is larger for harbours and bays with strong amplification factors (Rabinovich, 2009; 2020). As for the atmosphere, wave-ducting mechanism

(Lindzen and Tung, 1976) has been found to proposed for the Mediterranean meteotsunamis (Monserrat et al., 2006), while they might be the results of many processes, like squall lines, derechos, frontal zones, hurricanes and other (Churchill et al., 1995; Šepić and Rabinovich, 2014; Shi et al., 2019).

There was a great number of attempts to fairly reproduce by numerical models both generation and propagation of meteotsunami waves in the ocean and the source in the atmosphere (Belušić et al., 2007; Vilibić et al., 2008; Orlić et al., 2010; Horvath and Vilibić, 2014; Šepić et al., 2016; Ličer et al., 2017; Romero et al., 2019; Denamiel et al., 2019a). Still, there are several bottlenecks which prevent their reproduction in a reliable way (Vilibić et al., 2016), as the reproduction of generation and propagation of meteotsunamis is at the edge of what present state-of-the-art numerical models can reproduce. In particular, it requires (1) to carefully check the numerical stability of the atmospheric model which should be set-up to handle internal gravity waves (i.e. high spatial resolution and reduced time step), (2) to use accurate orography, bathymetry and coastline data in high-resolution atmospheric and ocean models, and (3) to evaluate the model high-frequency results with various statistical tools in order to draw a clear picture of the model skills. For these reasons, the use a stochastic approach to estimate the meteotsunami hazard linked to each modelled pressure disturbance was found more appropriate (Denamiel et al., 2019b)

2) Meteotsunami early warning system prototype

The meteotsunami early warning prototype is based on the Adriatic Sea and Coast (AdriSC) modelling suite (Denamiel et al., 2019a), developed to accurately represent the Adriatic atmospheric and oceanic processes. In brief, the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) modelling system (Warner et al., 2010) couples (online) (1) the Regional Ocean Modeling System (ROMS; Shchepetkin & McWilliams, 2005, 2009), with nested grids of 3 km (covering the entire Adriatic and Ionian Seas) and 1 km (covering the Adriatic Sea only), and (2) the Weather Research and Forecasting (WRF) model (Skamarock et al., 2005), with nested grids of 15 km (covering the central Mediterranean basin) and 3 km (identical to the 3-km ROMS grid). The dedicated meteotsunami module couples (offline) the WRF model, which downscales the hourly 3-km WRF results of the basic module to a 1.5-km resolution for a grid covering the entire Adriatic Sea, with the 2DDI ADvanced CIRCulation (ADCIRC) model (Luettich et al., 1991) using a mesh of up to 10-m resolution in the areas sensitive to meteotsunami hazard. In this deterministic configuration, the ADCIRC model is forced (1) every minute by the WRF 1.5-km wind and pressure fields and (2) every hour by the ROMS 1-km sea-level fields (including tides).

The deterministic model results are then examined for existence of meteotsunamigenic disturbances (Fig. 2). Every day, at least 30 hr before any meteotsunami event, the high-pass filtered pressure is extracted from the AdriSC forecast and used to automatically detect meteotsunamis by checking the spatial coverage of the values above 20 Pa per 4-min interval of the maximal pressure temporal rate. If this coverage is below 5%, then no meteotsunami is forecasted —"silent" warning mode, otherwise a potential meteotsunami M is foreseen to occur (red box)—"event" warning mode, and an email is sent to the AdriSC team. At least 24 hr before the potential meteotsunami M occurs, the first forecast of hazard assessment is derived from the stochastic surrogate model used with ranges of pressure wave parameters manually extracted from the modelled filtered pressure. Finally, when the real-time observations become available, the hazard assessment may be updated with new parameters extracted from the measurements.

Within the prototype, the extreme sea level hazard assessment relies on the newly developed meteotsunami stochastic surrogate model. This model is based on generalized polynomial chaos expansion (gPCE) methods (Soize and Ghanem, 2004; Xiu and Karniadakis, 2002), which, compared to sampling approaches (e.g., Monte Carlo simulations), are highly efficient for propagating the uncertainties of model inputs to outputs (e.g., Knio and Le Maître, 2006, Najm et al., 2009). The stochastic surrogate model, based on polynomials expansions that decompose into deterministic coefficients and random orthogonal bases, is used to propagate the uncertainties from the meteorological input (i.e., the IGWs responsible for the meteotsunami generation) to the maximum sea levels at different locations along the Croatian coastline. As the input parameters to the stochastic model are assumed to be uniformly distributed, (1) the delayed Gauss Patterson sparse grid method (Smolyak, 1963) is applied to automatically select all the combined values of the six stochastic parameters of the synthetic pressure forcing and thus to define the number of simulations.

More details on the prototype, the AdriSC modelling suite, stochastic surrogate model and gPCE method are provided by Denamiel et al. (2018, 2019a, 2019b, 2020).

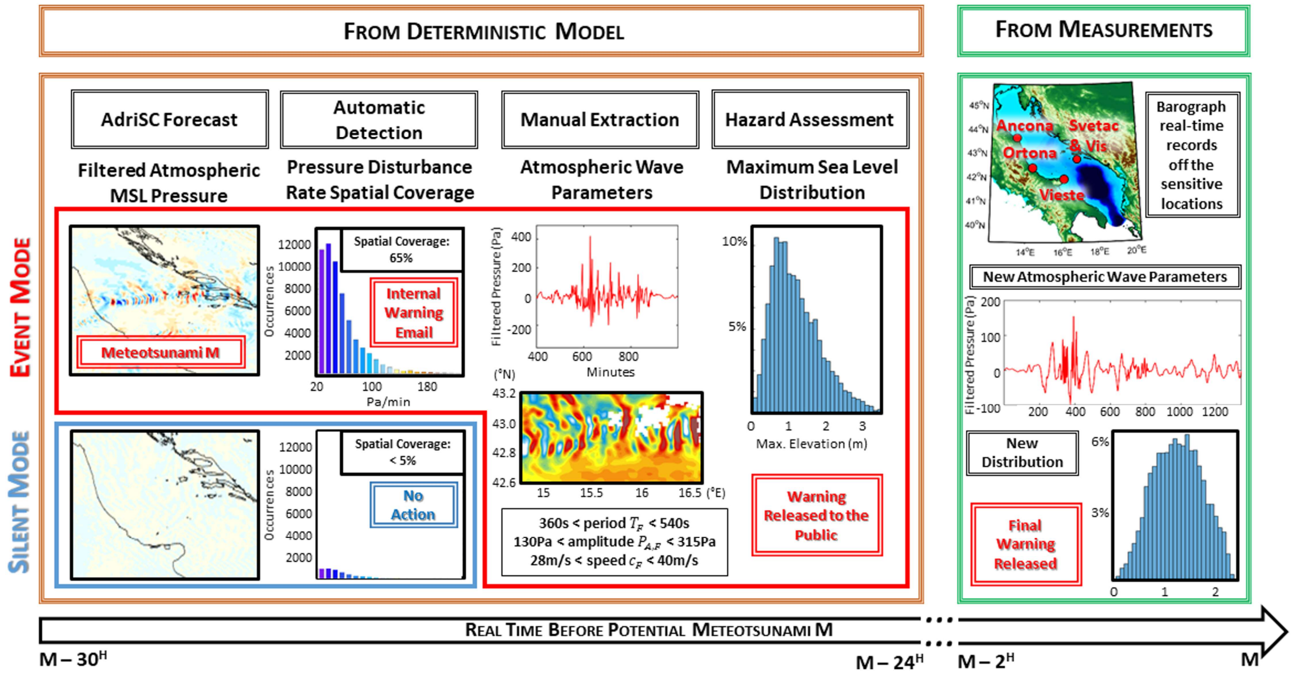

Figure 2: Illustration of the meteotsunami early warning prototype (after Denamiel et al., 2019b).

3) Proposed Work

The proposed work consists of two basic modules, which are:

(i) Improving the stochastic surrogate model

The stochastic surrogate model, as described by Denamiel et al. (2019b, 2020), has been tested by using a pseudo-spectral approximation (PSA) method, for which convergence in solution has been achieved with unsatisfactory precision. The PSA method required 10 689 of short AdriSC ADCIRC meteotsunami simulations, when varying six parameters of a meteotsunamigenic disturbance (air pressure amplitude, speed, direction, period, width, start point) and for using Gauss–Patterson level 5 and delayed Gauss–Patterson level 6 rules. In this module, we will test the methodology on higher level of the PSA method (delayed Gauss–Patterson levels 7, 8, 9, 10) and to see if any improvement in reproduction of meteotsunami stochastic forecast is reached.

Computing resources needed:

It has been found that the AdriSC ADCIRC deterministic simulations are executed in parallel on 260 CPUs in about 3 minute (elapse time). Thus the amount of credits needed to simulation is: **260 CPUs * 3 min * 60 s * P * 53 729 simulations = ~ 12 000 000 SBUs**. Concerning the storage needed, we estimate that about **20 000 GB** will be needed.

(ii) Testing the meteotsunami early warning system prototype

The prototype of the meteotsunami warning system will be tested with the improved PCA methodology, for which it should run in the operational mode. The base of the prototype, the AdriSC modelling suite, has been already installed on the ECMWF supercomputers.

Computing resources needed:

As the AdriSC operational modelling suite runs in parallel on 260 CPUs, and takes about 24h of computation (elapse time) to produce the forecast needed for determining the parameters for the stochastic surrogate model, the amount of credits needed to run the simulation is: **260 CPUs * 300 days * 86 400 s * P ~ 33 000 000 SBUs**. Concerning the storage needed, we estimate that about **45 000 GB** will be needed.

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