Modelling of extreme sea-level hazards: state-of-the-art and future challenges

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Why developing a meteotsunami warning system?

- atmospherically driven extreme sea-level events - major threats to people in coastal regions
- substanital damages during meteotsunami events (7 mil. US dollars, 7 human lives...)
- minimizing damages to houses, goods, infrastructures, and humans

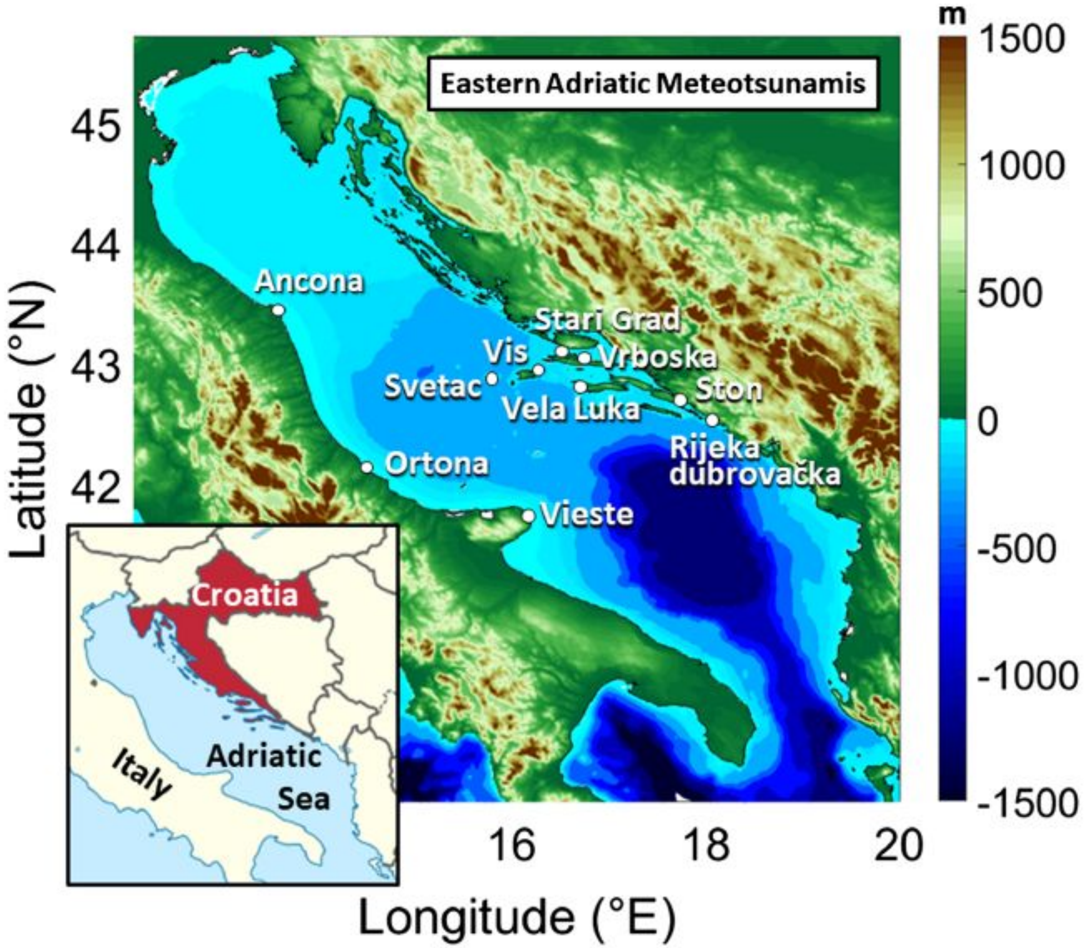
Croatian Meteotsunami Early Warning System (CMeEWS)

- provides meteotsunami hazard forecasts depending on:

(1) daily deterministic forecasts by numerical models

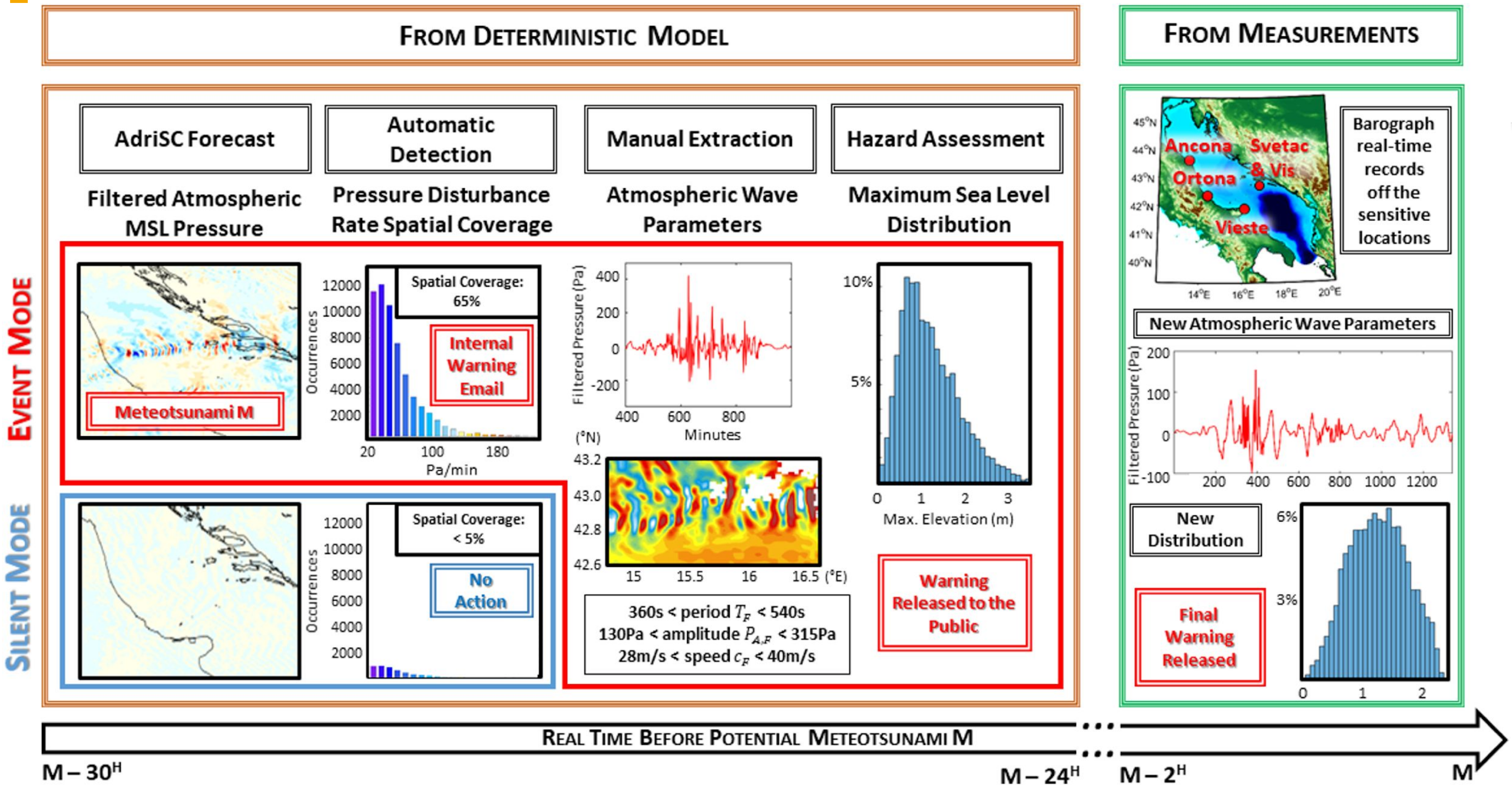
(2) atmospheric observations

(3) stochastic forecasts of maximum elevations at endangered location

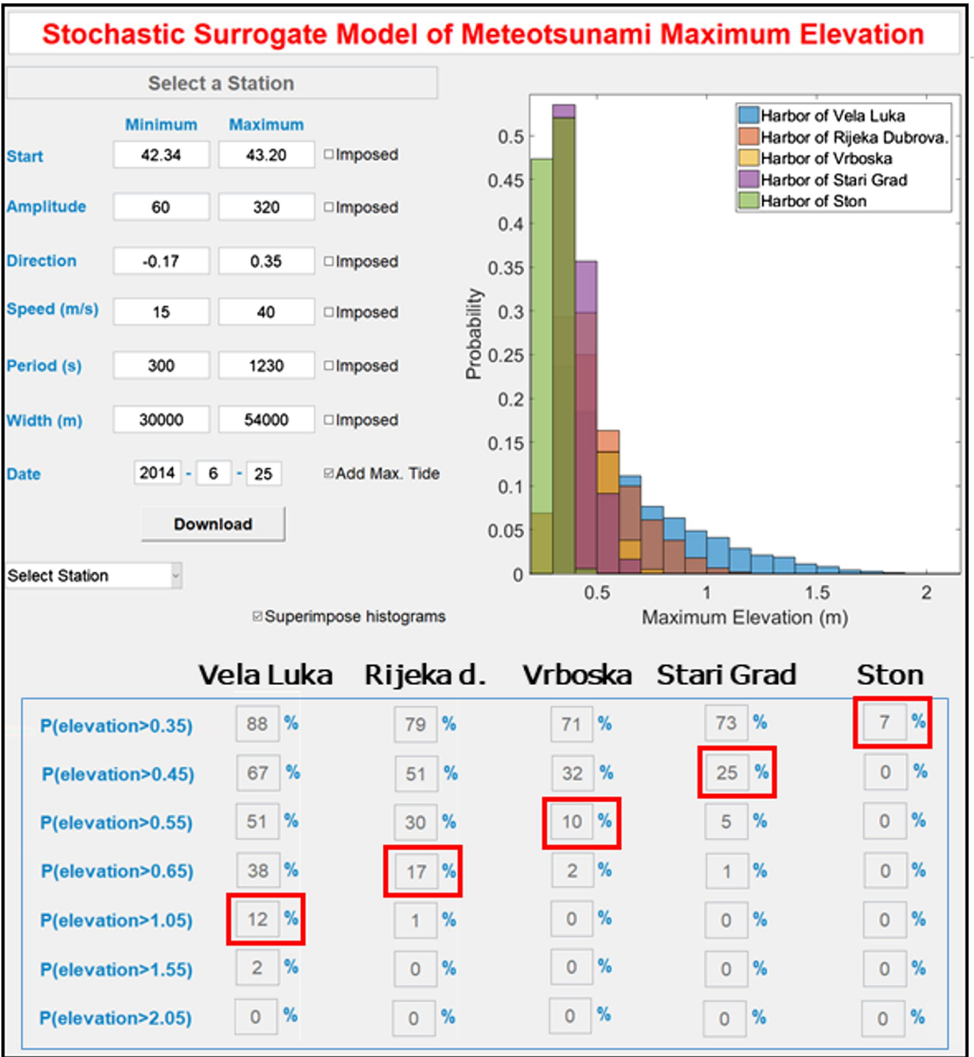


- MESSI observational system:
  - eight air pressure sensors in Ancona, Ortona, Vieste, Vis, Svetac, Vela Luka, Stari Grad, and Vrboska
  - tide gauges in Vela Luka and Stari Grad

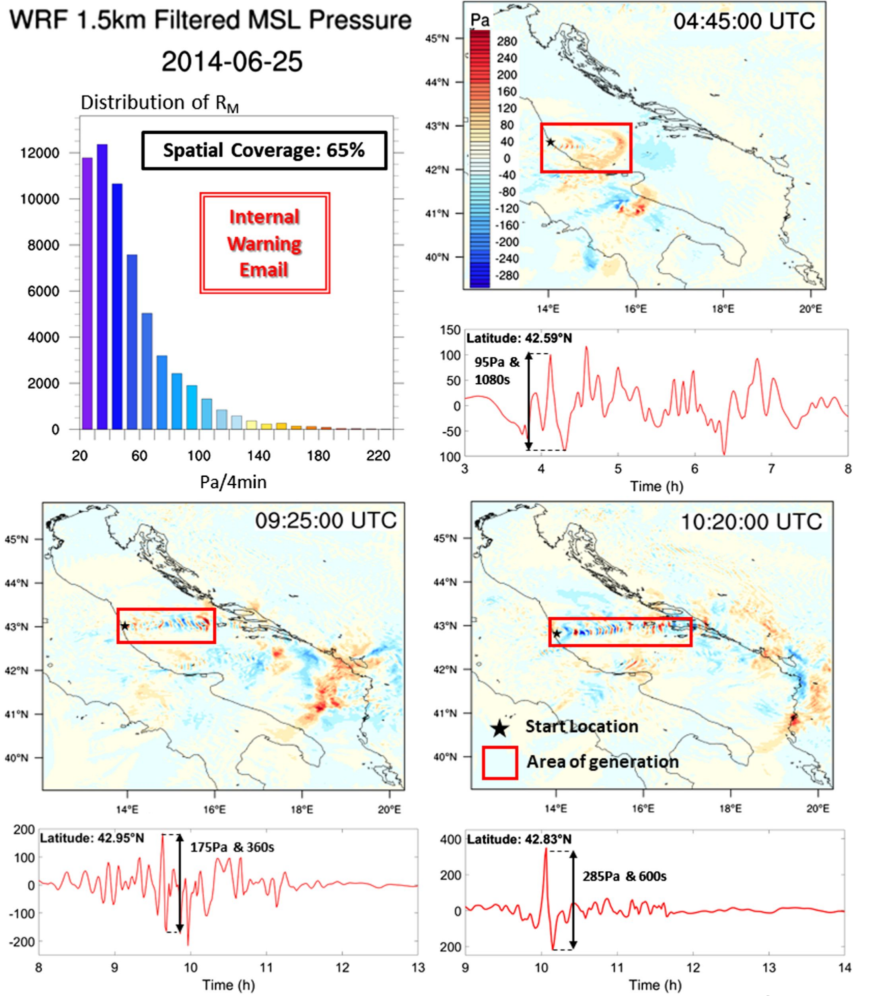
Operational meteotsunami hazard forecast within the CMeEWS



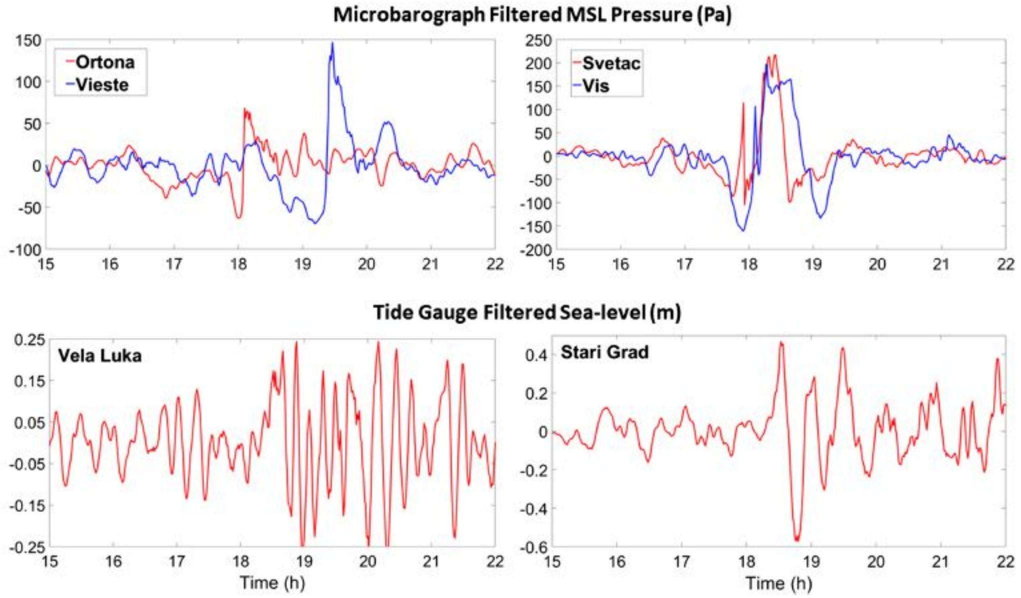
First evaluation of the CMeEWS



	Vela Luka	Rijeka d.	Vrboska	Stari Grad	Ston
P(elevation>0.35)	88 %	79 %	71 %	73 %	7 %
P(elevation>0.45)	67 %	51 %	32 %	25 %	0 %
P(elevation>0.55)	51 %	30 %	10 %	5 %	0 %
P(elevation>0.65)	38 %	17 %	2 %	1 %	0 %
P(elevation>1.05)	12 %	1 %	0 %	0 %	0 %
P(elevation>1.55)	2 %	0 %	0 %	0 %	0 %
P(elevation>2.05)	0 %	0 %	0 %	0 %	0 %



- 5 locations of interest: Vela Luka, Rijeka dubrovačka, Stari Grad, Vrboska, Ston
- shift in location of modelled atmospheric disturbances -> incapability of ADC model to reproduce meteotsunamis in deterministic mode => stochastic approach is developed
- surrogate model of meteotsunami maximum elevation:
  - forecasts meteotsunami hazard in flooded areas ✓
  - gives false alarms ✗



(1) propagation of uncertainties associated with atmospheric disturbances to the maximum elevation results

(2) using both deterministic forecast results and measurements to provide the surrogate model input parameters

(3) few minutes of computation needed to assess a hazard of any studied event

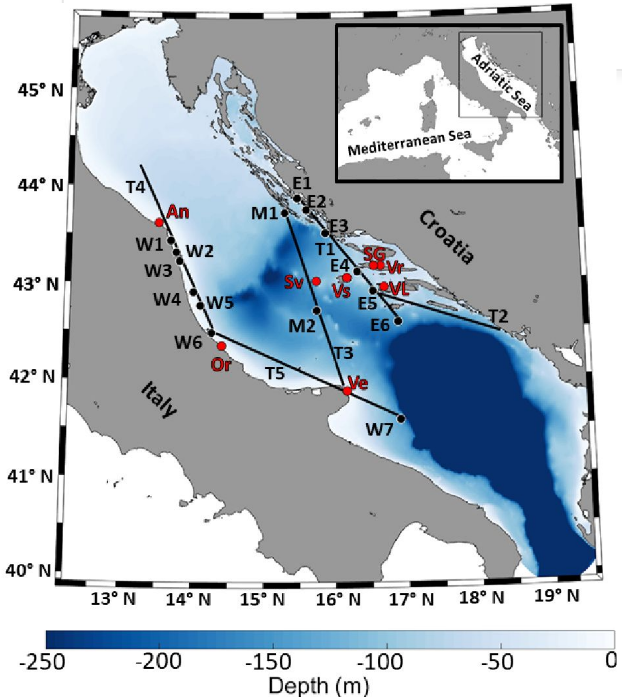
(1) surrogate model only relies on ocean numerical results forced by synthetic atmospheric disturbances

(2) large number of synthetic simulations required to build a model with good accuracy

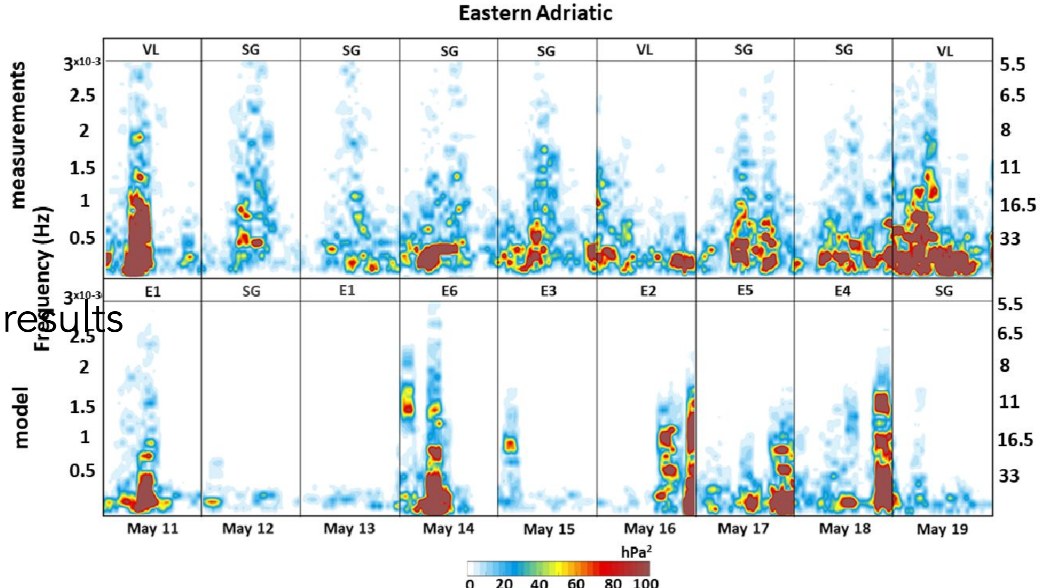
Table 1
Input and Output of the Surrogate Model During the Five Events Used in the Evaluation Against Historical Events

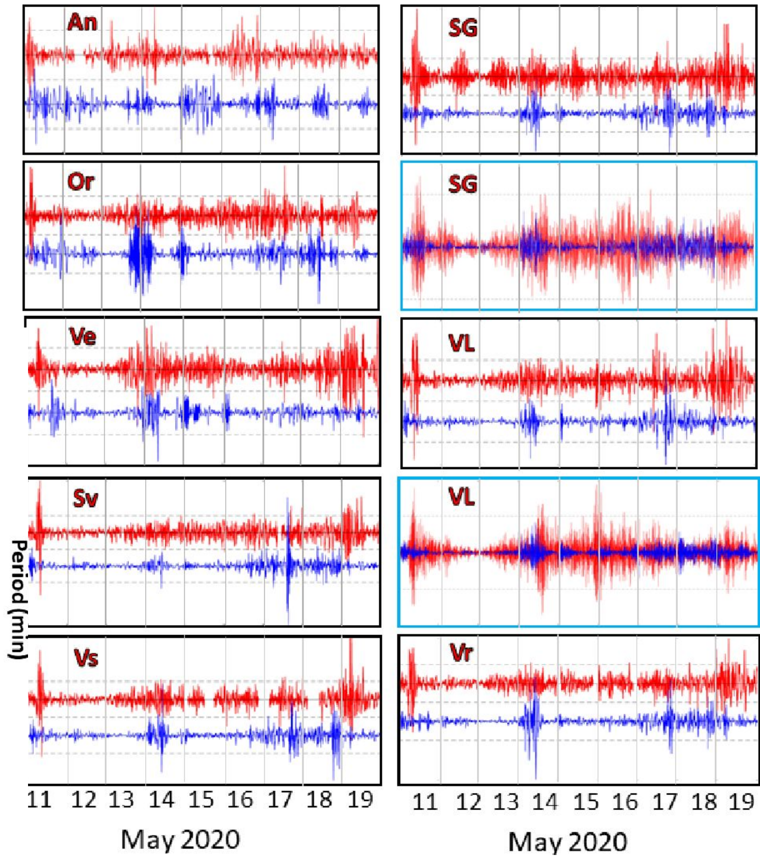
			25/06/14	26/06/14	28/06/17	01/07/17	31/03/18
Range of the input parameters	Latitude	Minimum	42.34	41.25	42.24	41.25	42.03
	(°N)	Maximum	43.20	41.70	43.13	42.81	42.79
	Amplitude	Minimum	60	255	85	100	85
	(Pa)	Maximum	320	340	185	275	215
	Direction	Minimum	-0.17	0.08	-0.17	0.35	0.26
	(rad)	Maximum	0.35	0.60	0.70	1.04	0.78
	Period	Minimum	300	330	1290	300	330
	(s)	Maximum	1230	630	1800	1410	1350
	Width	Minimum	30	30	88	30	30
	(km)	Maximum	54	54	112	92	54
Probability (%)	Vela Luka	$P(\xi_{max} \geq 1.05\text{m})$	***12***	**10**	**20**	7	**19**
	R. dubro.	$P(\xi_{max} \geq 0.65\text{m})$	***17***	1	5	3	**12**
	Stari Grad	$P(\xi_{max} \geq 0.45\text{m})$	***25***	0	***15***	2	***25***
	Vrboska	$P(\xi_{max} \geq 0.55\text{m})$	***10***	**16**	**50**	***10***	**23**
	Ston	$P(\xi_{max} \geq 0.35\text{m})$	7	***27***	7	2	**11**

Performance of the Adriatic early warning system during the multi-meteotsunami event of 11–19 May 2020



- AdriSC modelling suite run in operational (hindcast) mode after the multi-meteotsunami event took place
- direct comparison of modelled and measured high-pass-filtered air pressure and sea level time series
- 10-20 min periods in frequency–time spectrogram composites



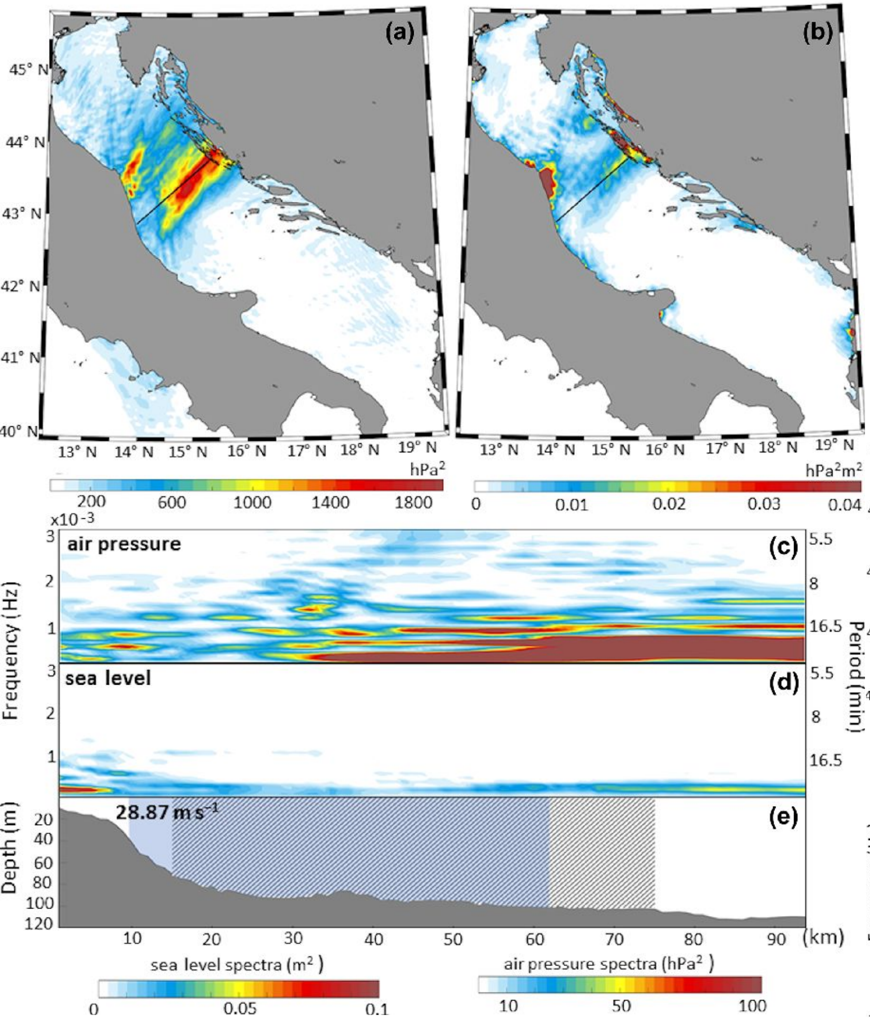


- two transect sampling criteria:
  1) based solely on the atmospheric results

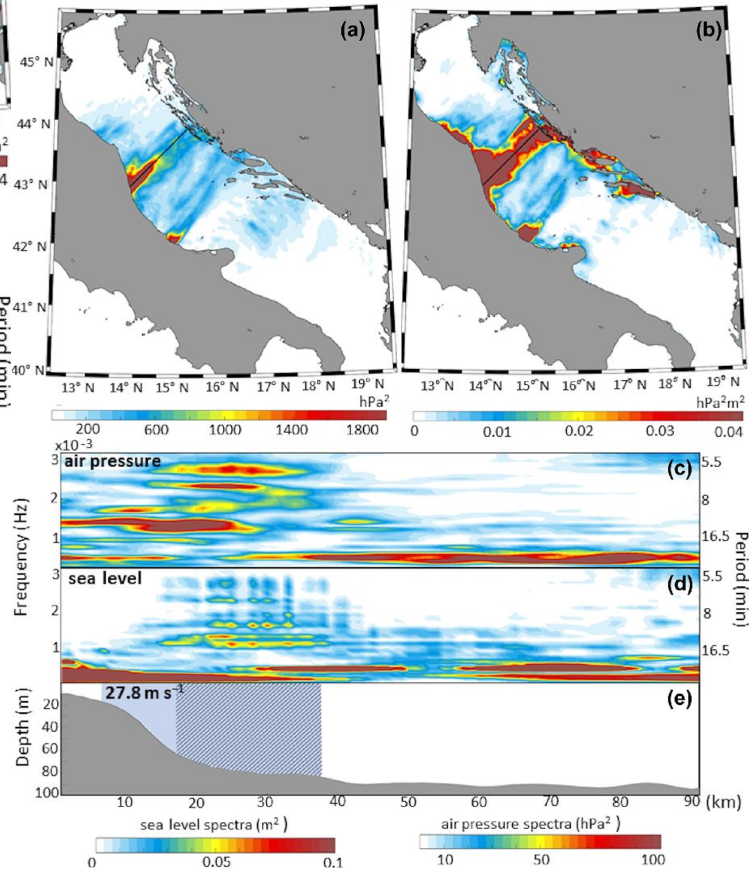
  2) taking into account the ocean results

- new transect sampling criterion:
  - doesn't facilitate the decision-making process in terms of the transect selection
  - time-consuming with no significant added value

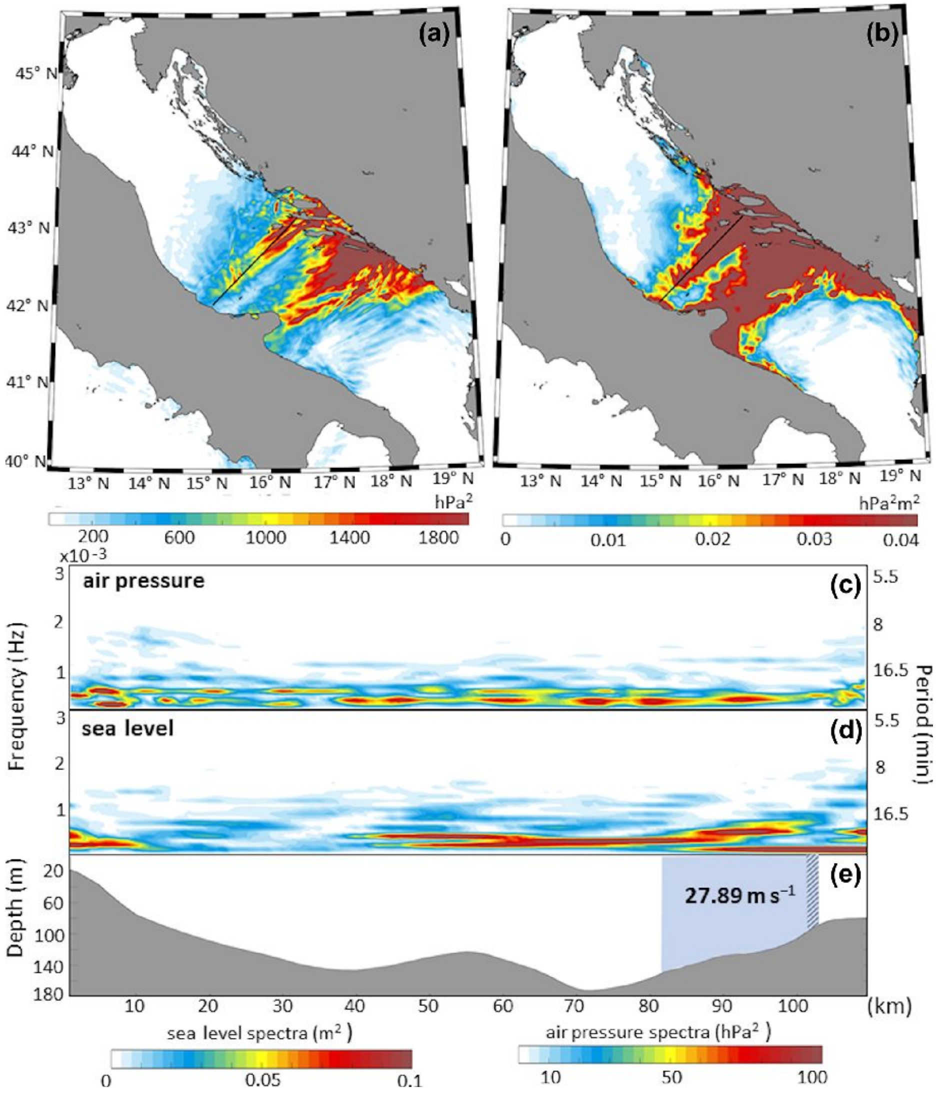
May 11, Transect 1



May 17, Transect 1



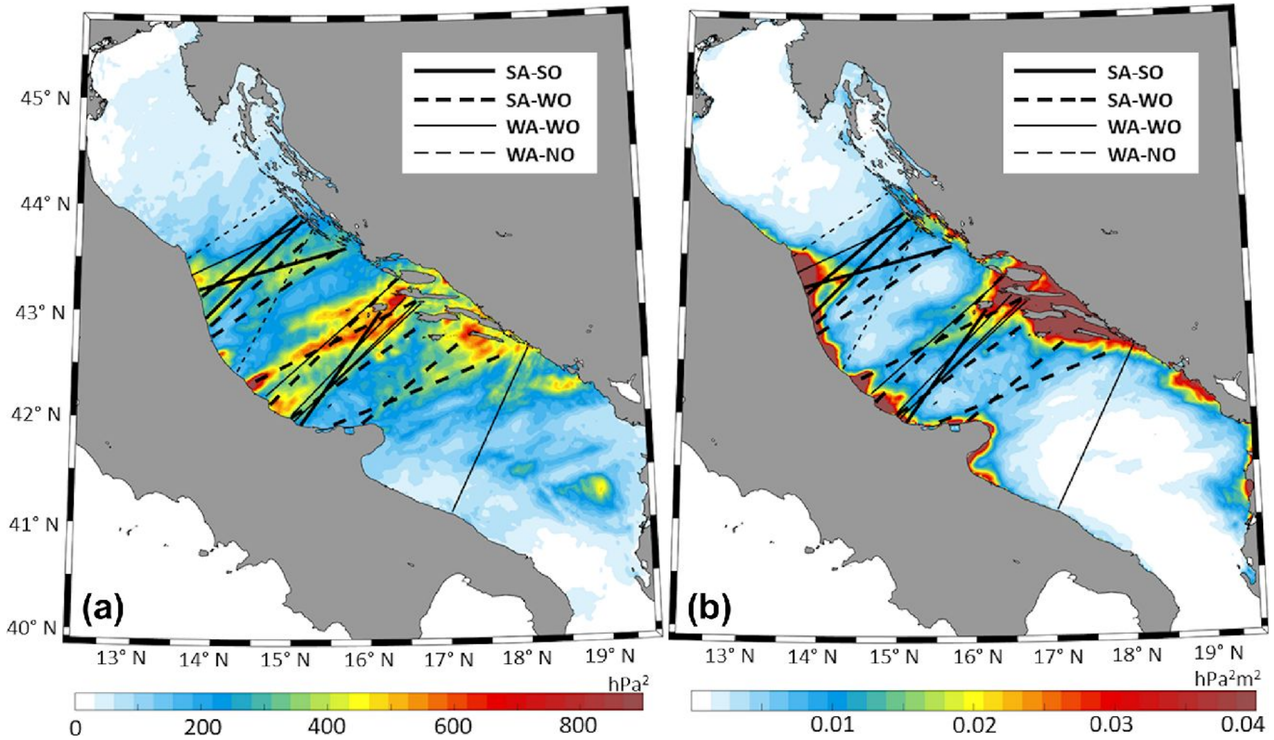
May 14, Transect 1



- ocean model response to the atmospheric forcing highly depends on both the location and the frequency of disturbances
- atmospheric disturbances often modelled too northwest

Stochastic surrogate model results

- coastal communities of Vela Luka, Stari Grad, and Vrboska would have been warned of potential meteotsunami events if the CMeEWS had been operational



- several false alarms

- warning effectiveness highly depends on resident trust

	Probability of crossing the flooding threshold (%) during the 11–19 May 2020 multi-meteotsunami event						
Location	11	14	15	16	17	18	19
Vela Luka	***16***	***10***	***19***	***14***	**10**	4	**34**
Stari Grad	***13***	2	6	6	4	1	9
Vrboska	***16***	***18***	**19**	**23**	**22**	3	**37**

Note: when the probabilities are above or equal to 10 % (highlighted in bold), the meteotsunami warning is triggered. In addition, probabilities at locations at which flooding was reported by eyewitnesses during the events are highlighted in italics.

Conclusions

- the IGWs driving the eastern Adriatic meteotsunamis are always forecasted and well detected
- deterministic model results - conservative but largely overestimated in certain locations
- importance of the uncertainties associated with forecasted meteotsunamigenic disturbances
- crucial role of microbarograph network in delivering the final warnings
- further development of stochastic approaches is needed

Thank you for your attention!

Any questions?