Adriatic meteotsunamis...

... and their common characteristics

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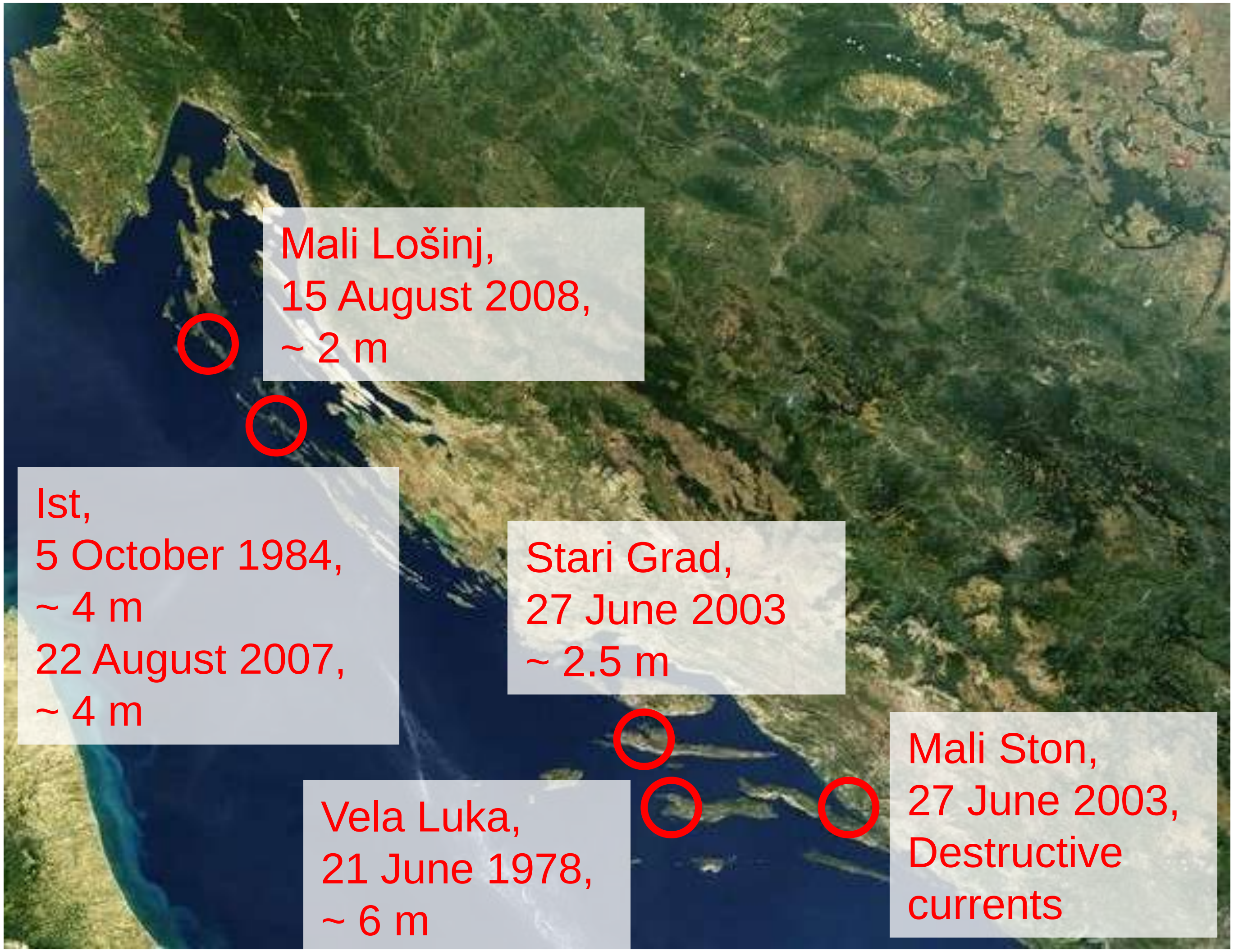
Meteosunamis with wave heights > 3 m

Adriatic meteotsunamis

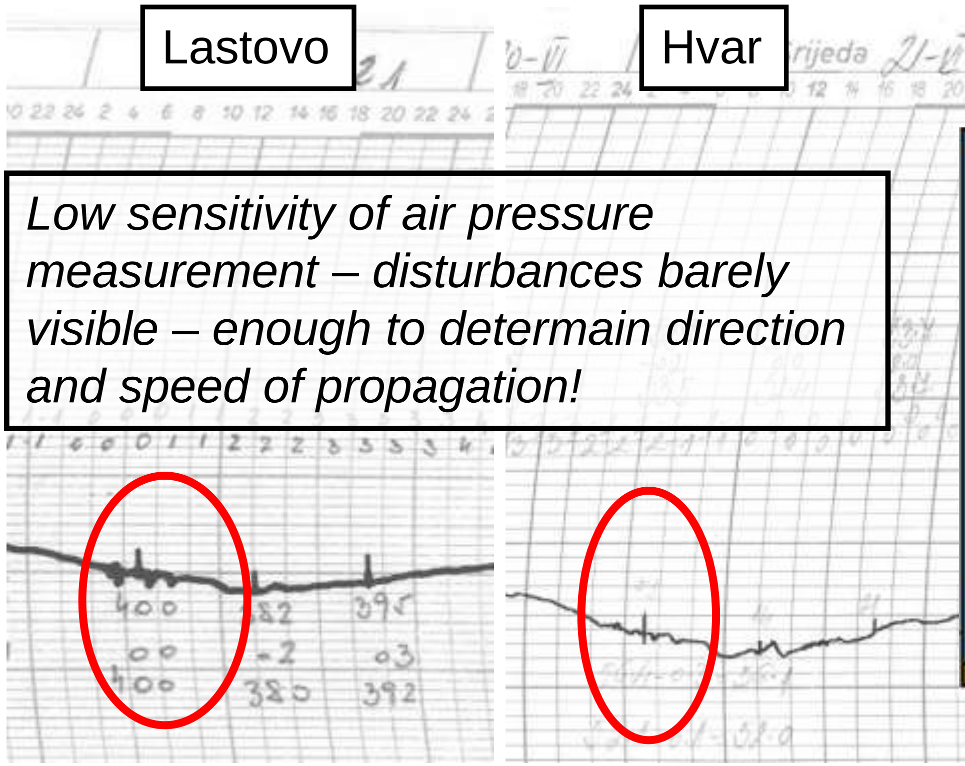


Vela Luka meteotsunami, 21 June 1978

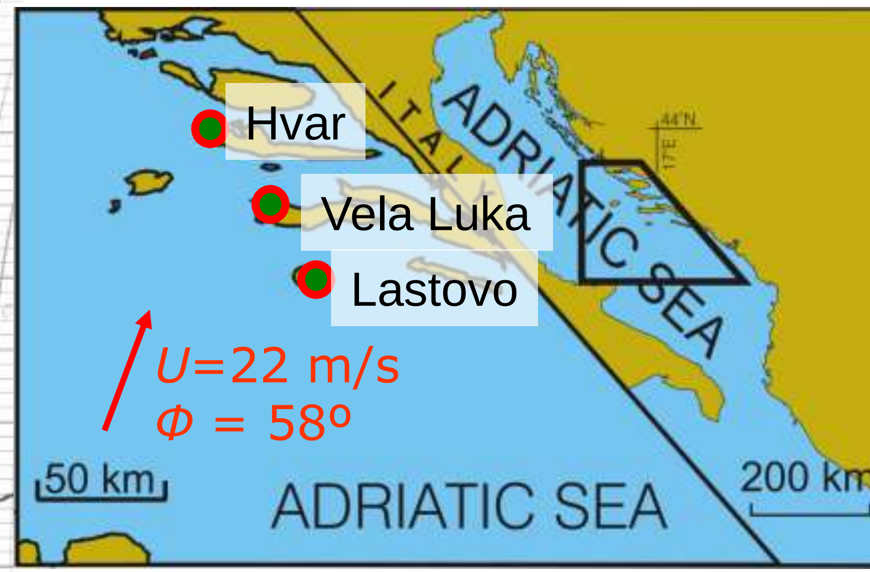
Vela Luka meteotsunami, 21 June 1978

- Observed on both Italian and Croatian coast
- Maximum wave height (6 m!) recorded in Vela Luka
- Lasted for several hours
- Several explanations:
  - Tsunami waves originating from earthquake in Greece
  - Land slide
  - Low pressure system centered over the Adriatic
  - Air pressure disturbances (*Orlić, 1980*)

Vela Luka meteotsunami, 21 June 1978

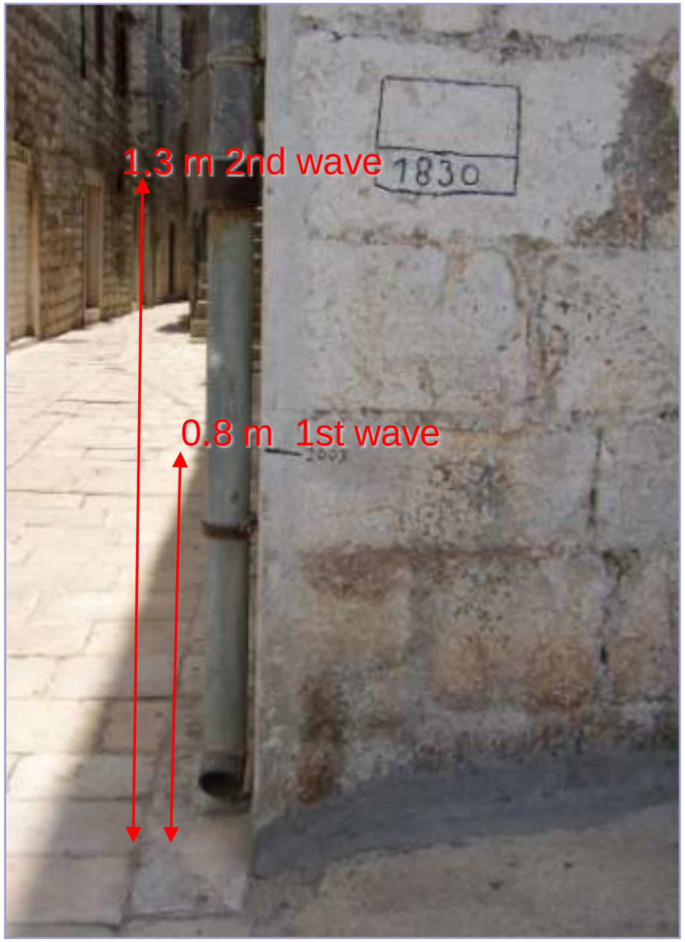


Low sensitivity of air pressure measurement – disturbances barely visible – enough to determain direction and speed of propagation!

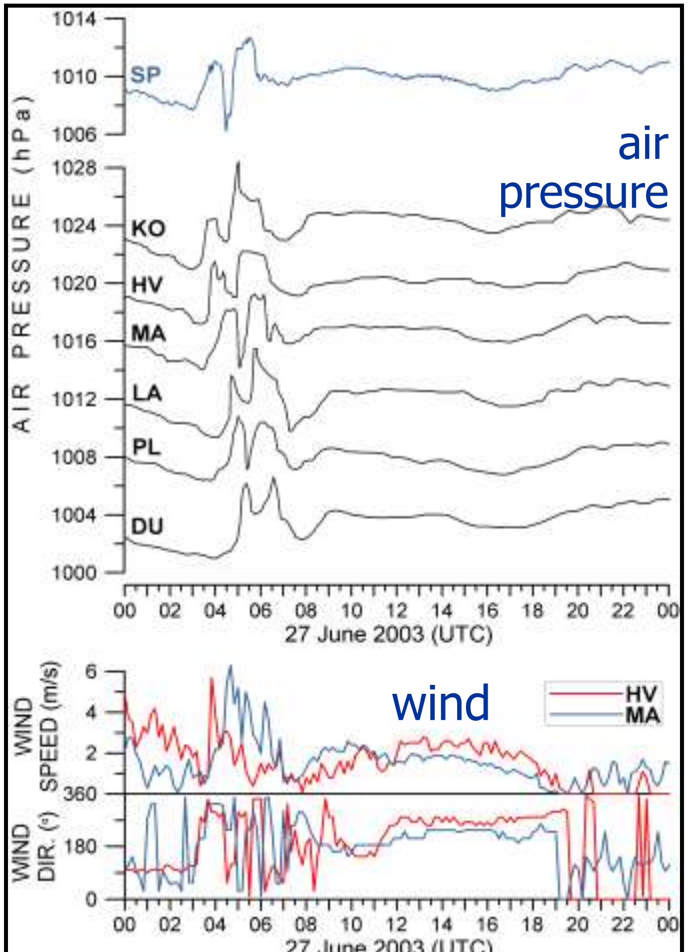


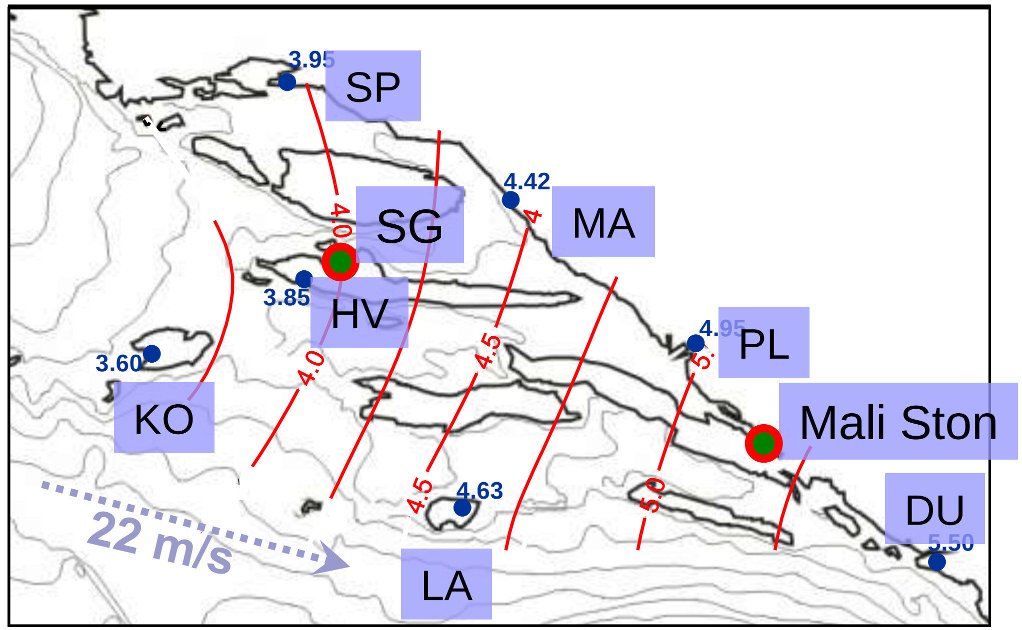
(*Orlić, 1980*)

Stari Grad and Mali Ston meteotsunami, 27 June 2003



Stari Grad and Mali Ston meteotsunami, 27 June 2003





(*Vilibić et al., 2004*)

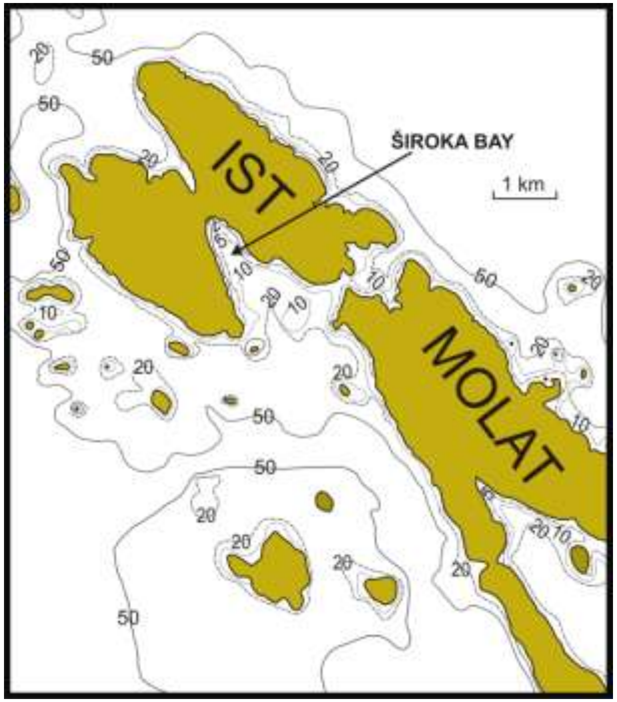
The Ist meteotsunamis, 22 august 2007

22 august 2007

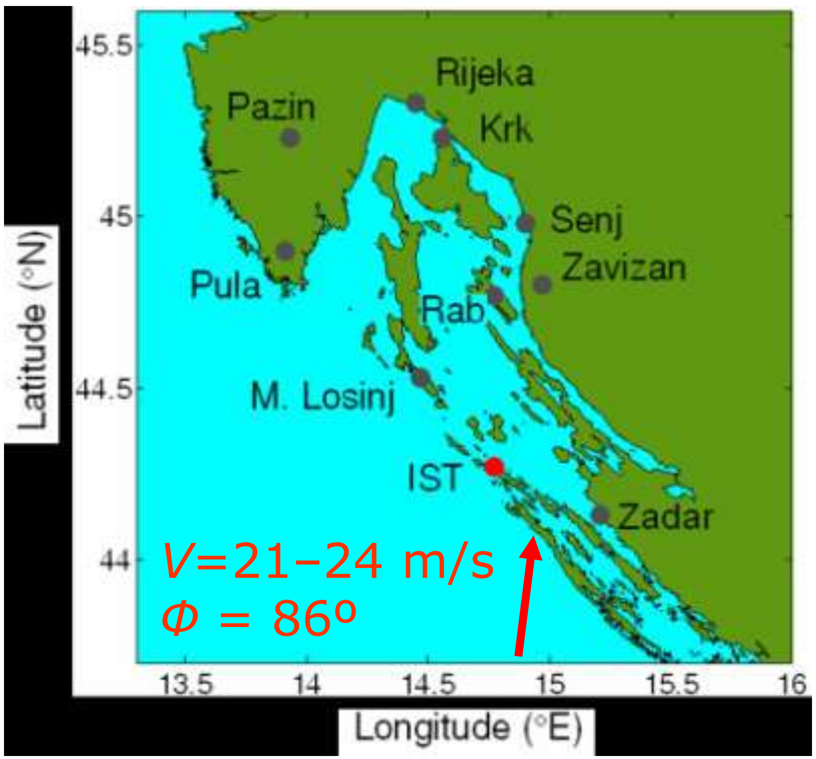

Široka Bay

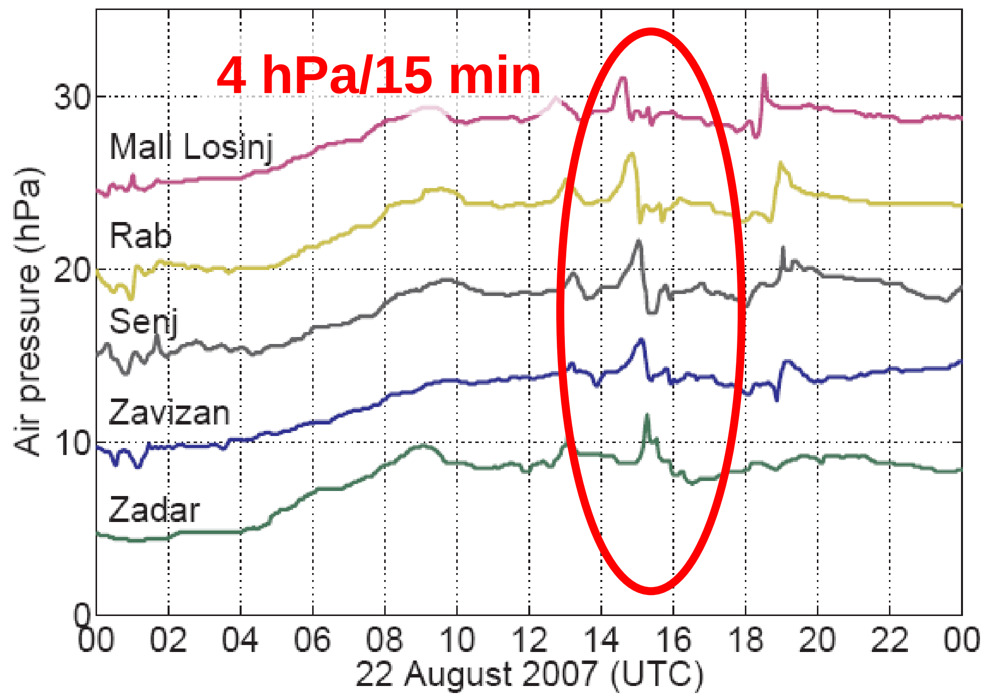
Two meteotsunamis in last 30 years:

5 October 1984: *4 m high waves*
22 August 2007: *4 m high waves*



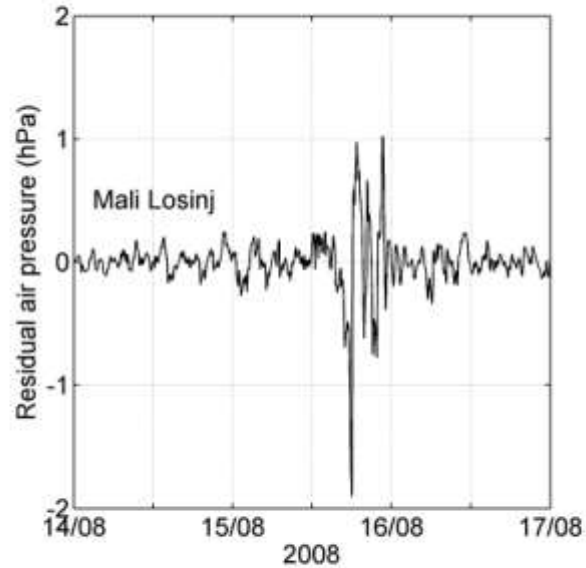
The Ist meteotsunamis, 22 august 2007





(*Šepić et al., 2009*)

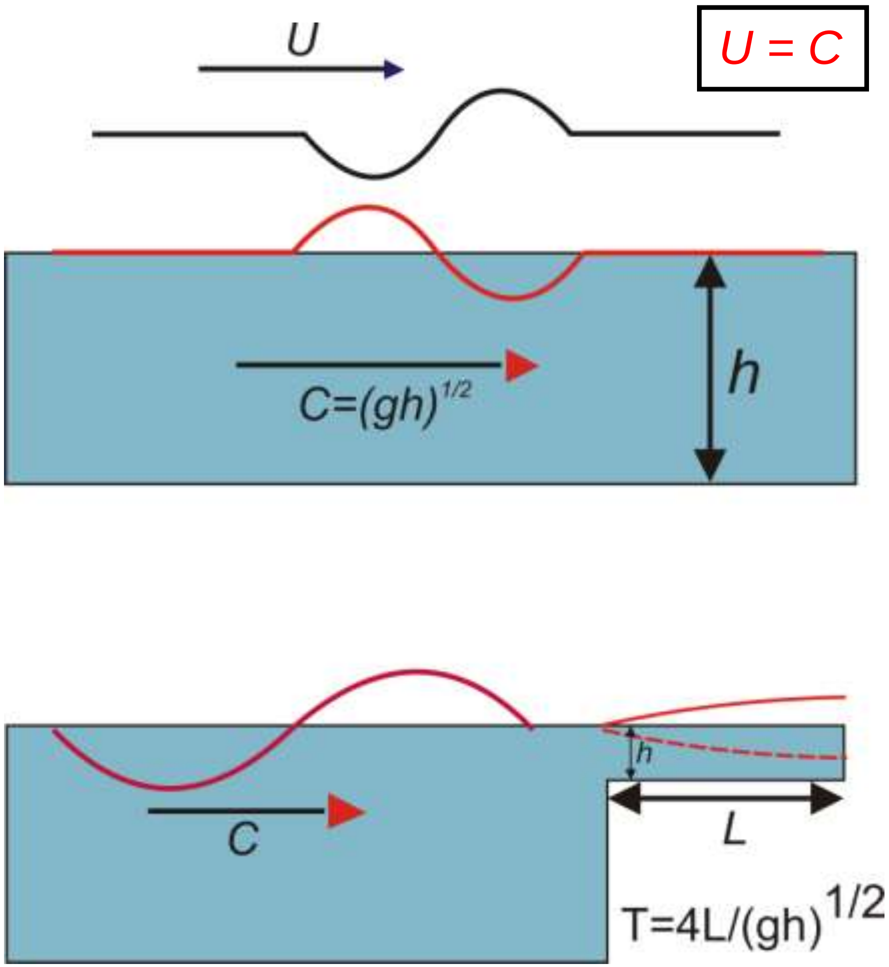
The Mali Lošinj meteotsunami, 15 August 2008



Common characteristics of the Adriatic meteotsunamis

- Wave heights: > 2 m
- Occurring at elongated shallow bays
- Associated with pronounced air pressure disturbances (several hPa/ 10 min)
- Estimated speed of air pressure disturbances: 21 – 24 m/s
- Estimated direction: southern to western

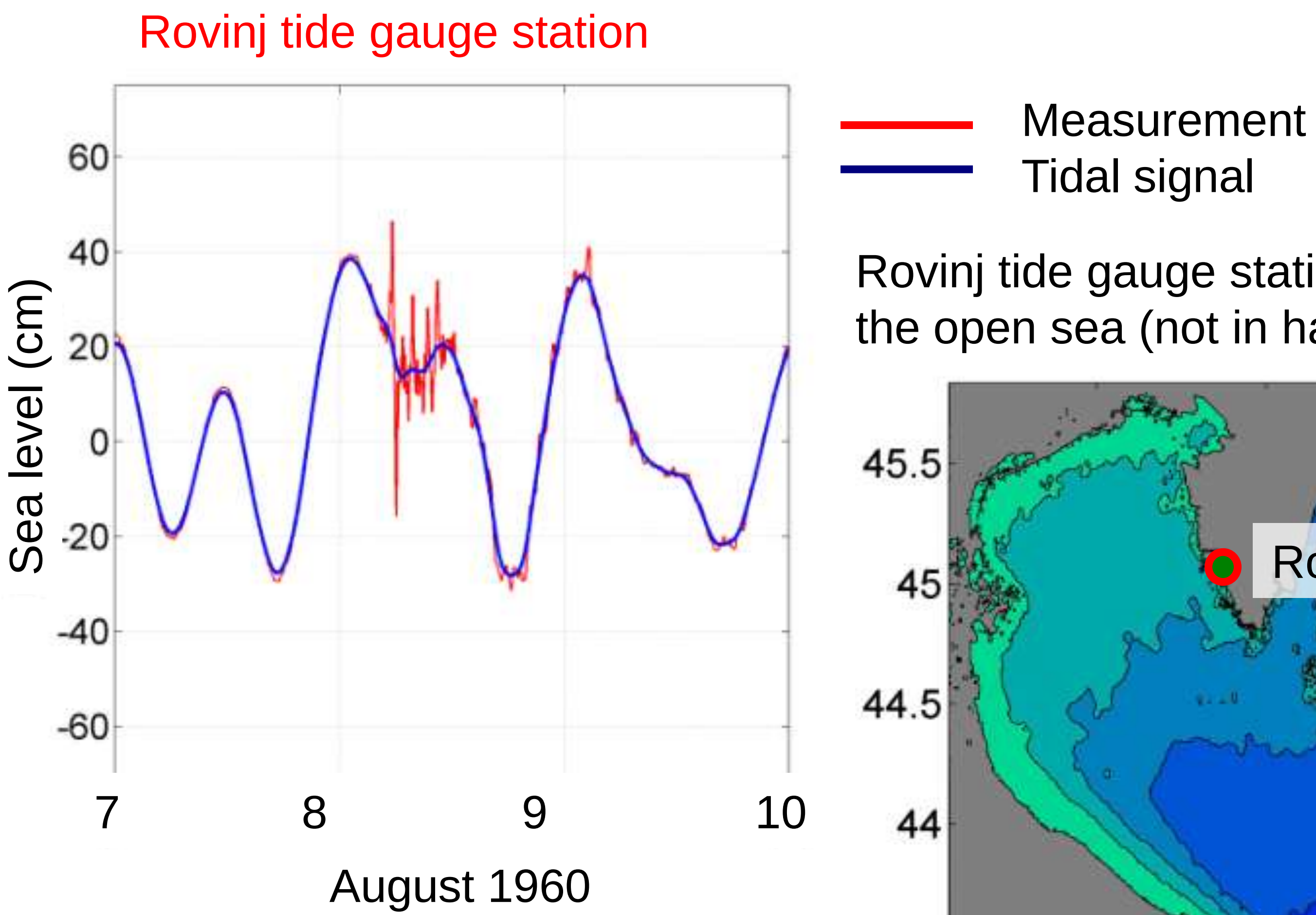
Generation mechanism



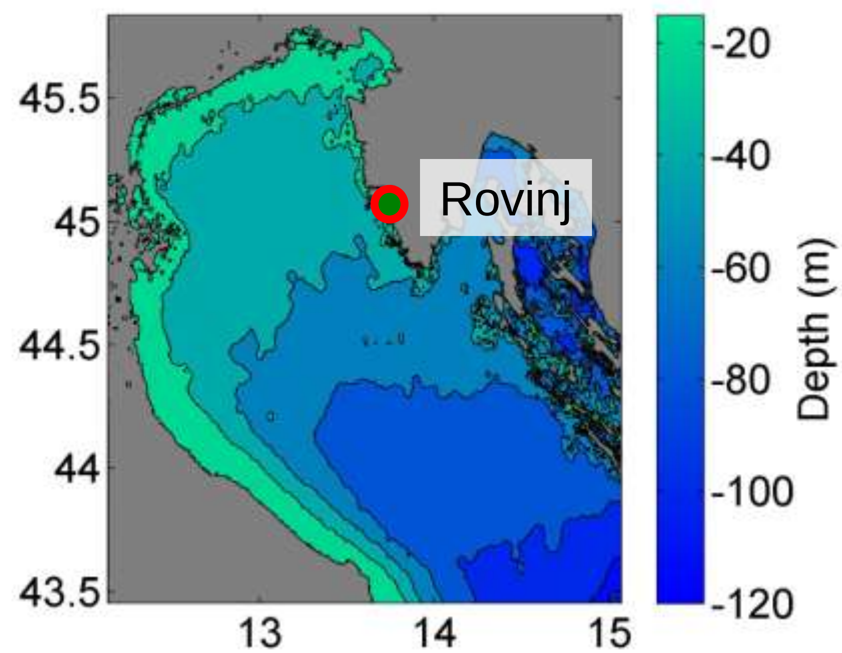
- Air pressure disturbance generates and enhances barotropic ocean waves via Proudman resonance

- Open sea waves generate seiches in harbors and bays via harbor resonance (open sea waves should have high energies at seiche periods!)

Sea level measurements - the northern Adriatic



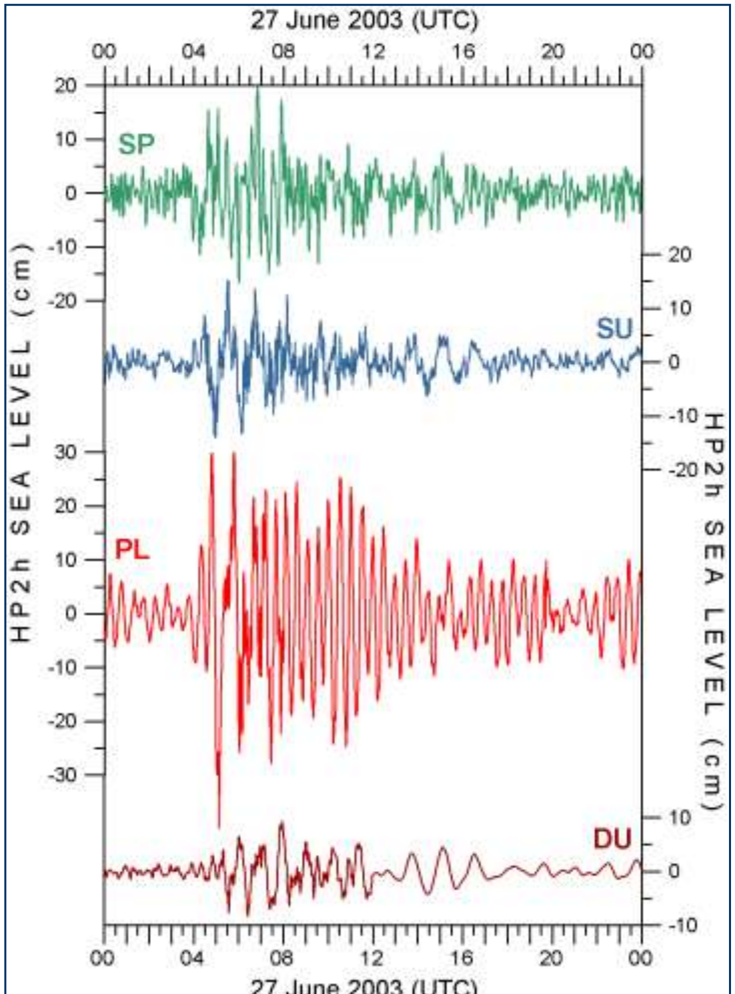
Rovinj tide gauge station is placed at the open sea (not in harbor, bay!)



(*Šepić and Vilibić, 2012*)

Sea level measurements

Stari Grad and Mali Ston meteotsunami, 27 June 2003



- No sea level measurements from meteotsunamis hot-spots (Vela Luka, Stari Grad, Mali Lošinj, Ist)
- Sea level measurement from coastal tide gauges: meteotsunami waves detectable

(*Vilibić et al., 2004*)

Ocean numerical models– Stari Grad and Mali Ston, 27 June 2003 (*Vilibić et al., 2004*)

- Two-dimensional ocean numerical model forced by air pressure measured at Split
- Air pressure disturbance assumed to propagate over the domain with constant speed and direction
- Nested high-resolution two-dimensional models of Stari Grad and Mali Ston bays

Ocean numerical models– Stari Grad and Mali Ston, 27 June 2003 (*Vilibić et al., 2004*)

Comparison of model and measurements:

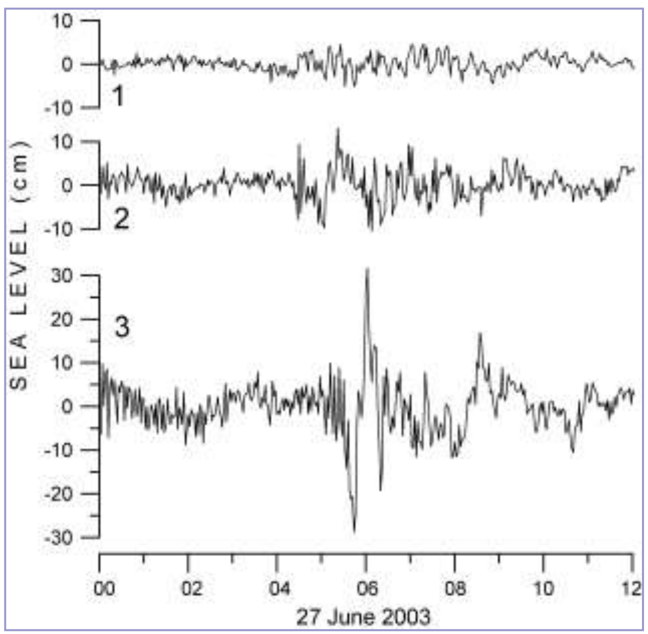
- Observed height of sea level oscillations at Stari Grad: **250 cm**
- Modeled height of sea level oscillations at Stari Grad: **120 cm**
- Modeled currents in Mali Ston Bay: **> 150 cm/s**
- Observed currents in Mali Ston Bay: **Not available – but strong enough to destroy a shell fish farm**

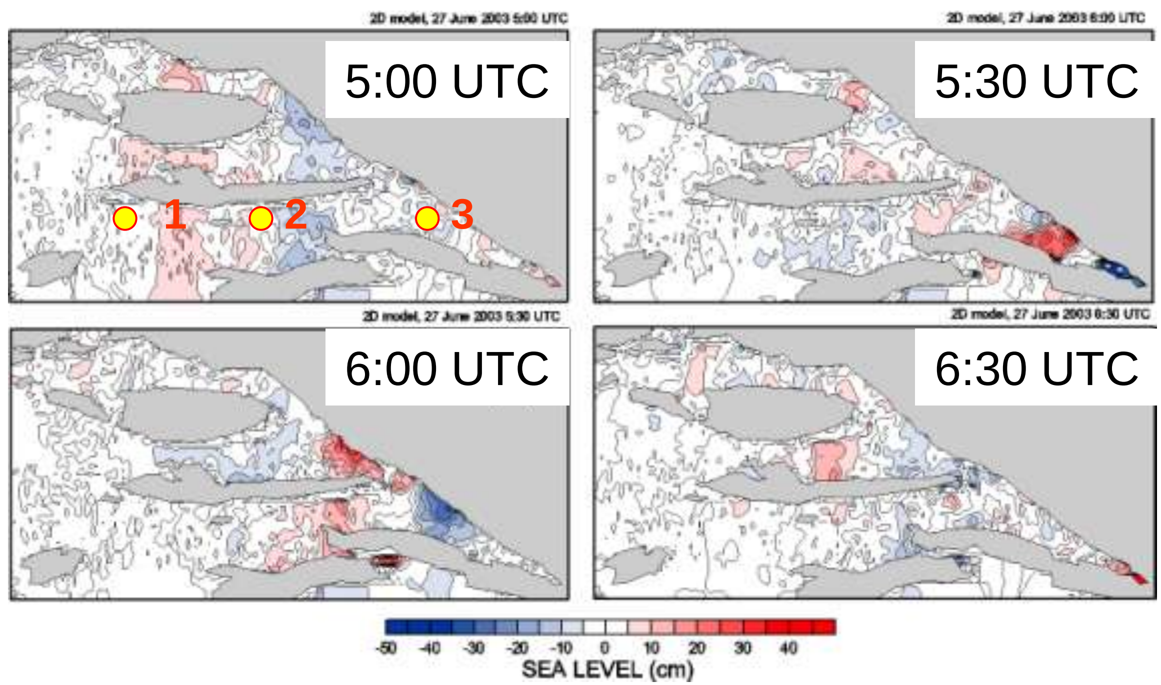
Ocean numerical models– Stari Grad and Mali Ston, 27 June 2003 (*Vilibić et al., 2004*)

Numerical model successfully reproduces:

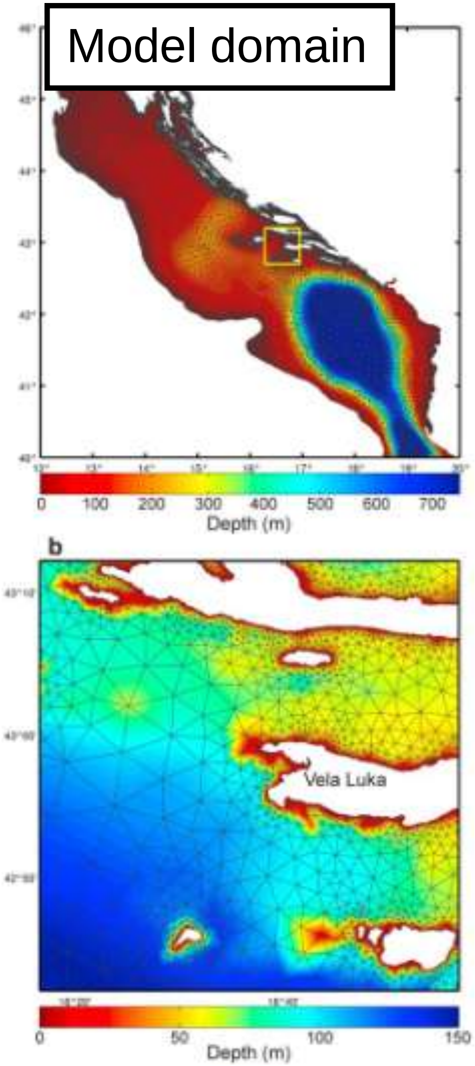
- *Proudman resonance over the open sea*
- *Harbour resonance and topographical enhancement in Stari Grad and Mali Ston bays*

Proudman resonance





Ocean numerical models – Vela Luka (*Orlić et al., 2010*)

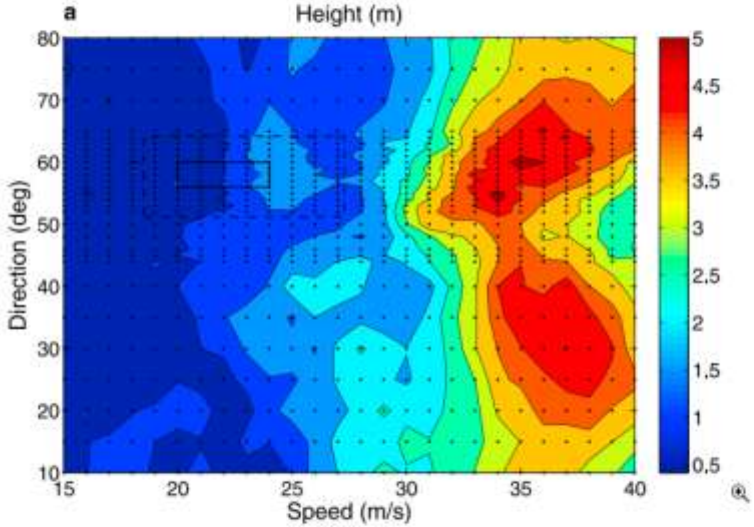


2-dimensional barotropic ADCIRC-2DDI model.

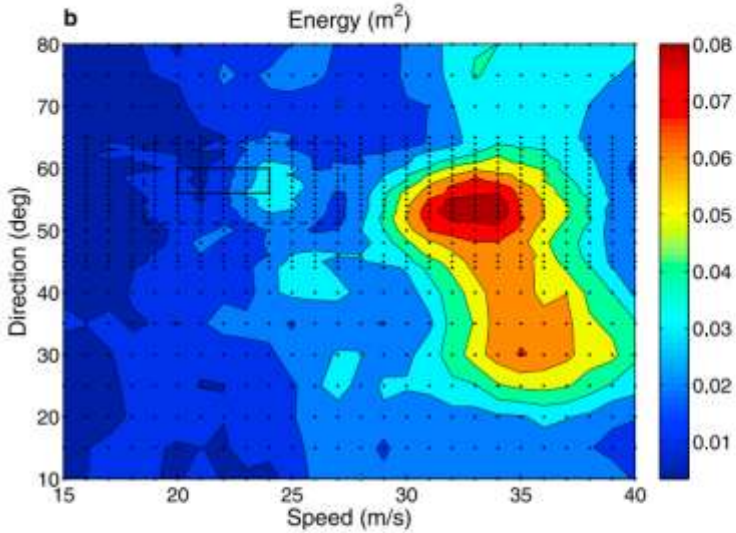
Triangular irregular grid: 7 km between nodes at open sea, 150 m in Vela Luka.

Model forced with boxcar air pressure disturbance of 3 hPa over 10 minutes.

Ocean numerical models – Vela Luka (*Orlić et al., 2010*)



Maximum modeled height of sea level oscillations at the head of Vela Luka Bay vs. speed and direction of air pressure disturbance



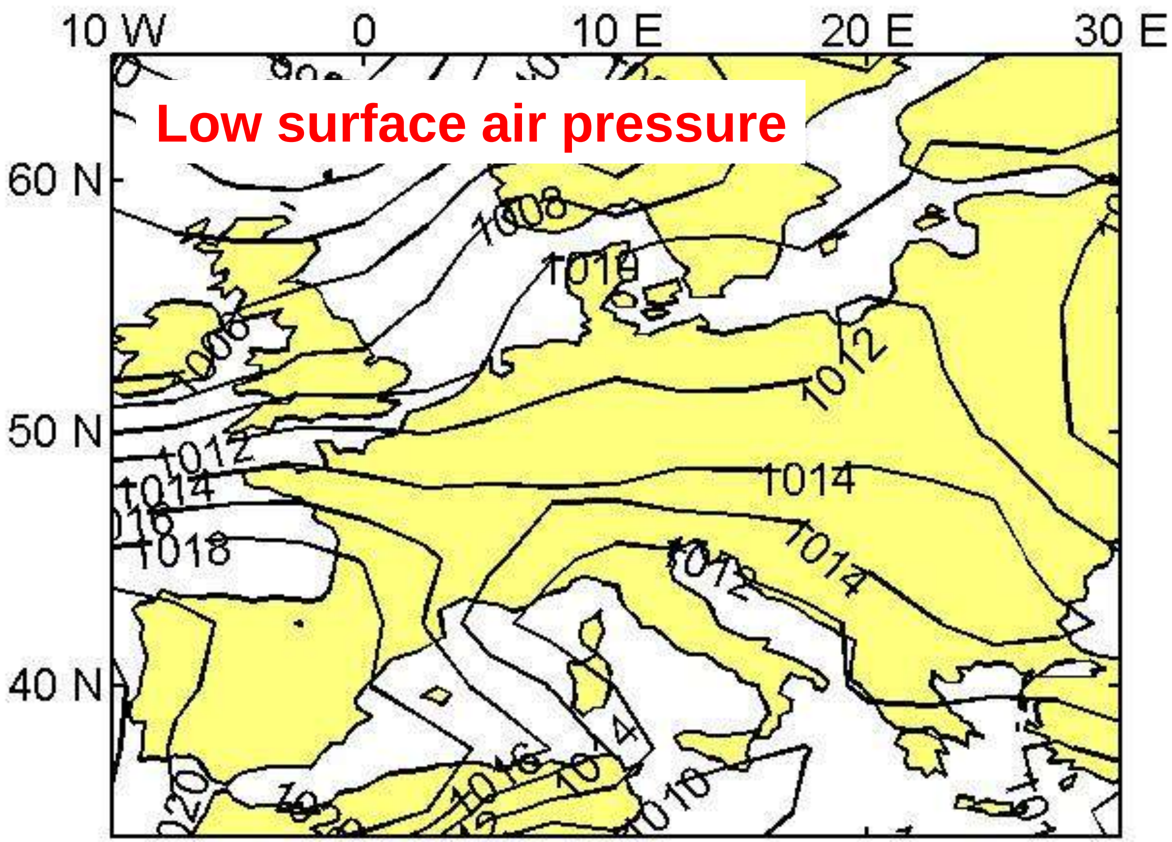
The integral of sea level energy density spectrum obtained for the head of Vela Luka Bay vs. speed and direction of air pressure disturbance

Common characteristics of the Adriatic meteotsunamis

- Wave heights: > 3 m.
- Occurring at elongated shallow bays.
- Associated with pronounced air pressure disturbances (several hPa/ 10 min).
- Estimated speed of air pressure disturbances: 21 – 24 m/s.
- Estimated direction: southern to western.
- Generated via Proudman and harbor resonance.
- Events can be successfully reproduced with 2 dimensional ocean numerical models.

Typical synoptic conditions

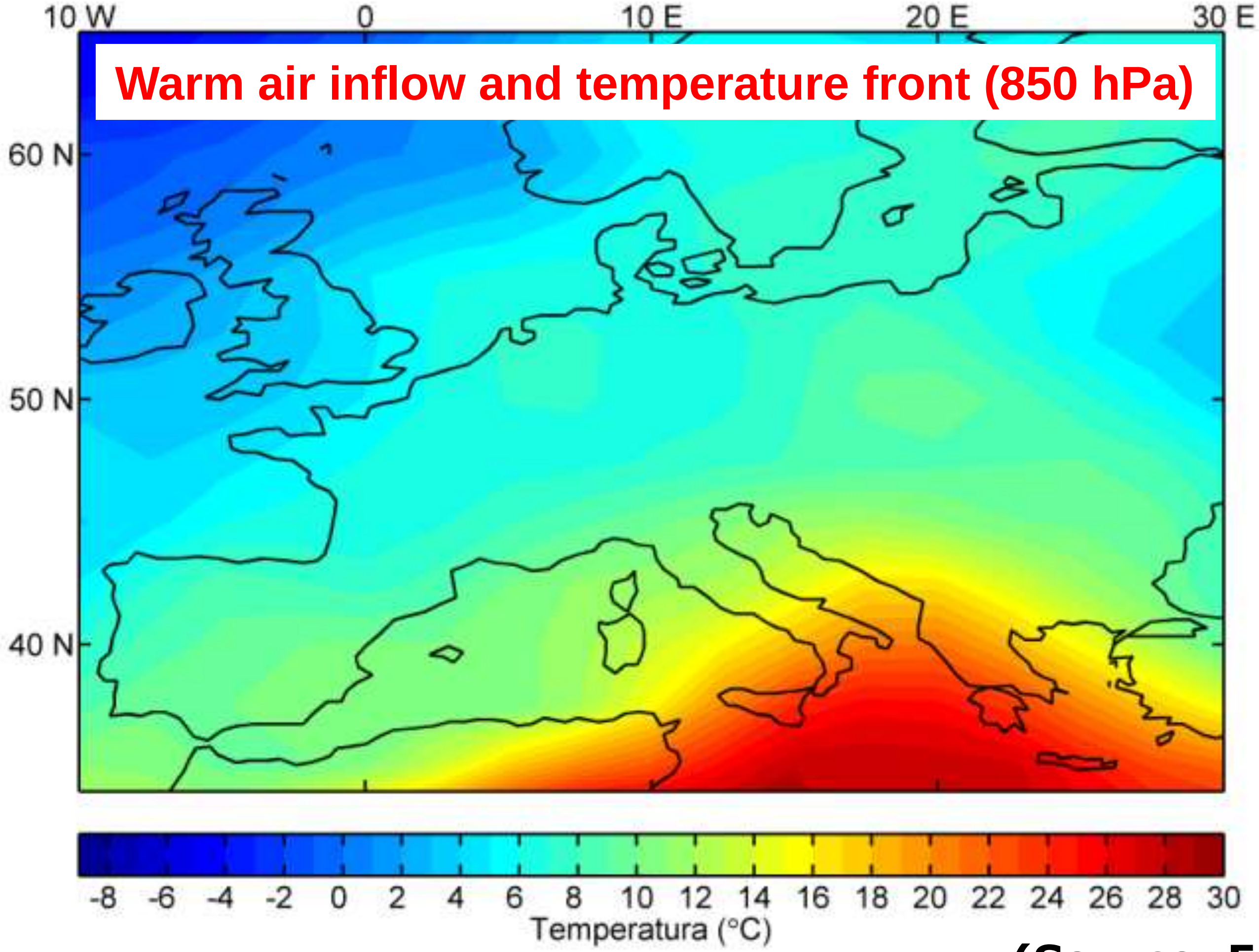
21 June 1978, Vela Luka meteotsunami



(Source: ECMWF reanalysis)

Typical synoptic conditions

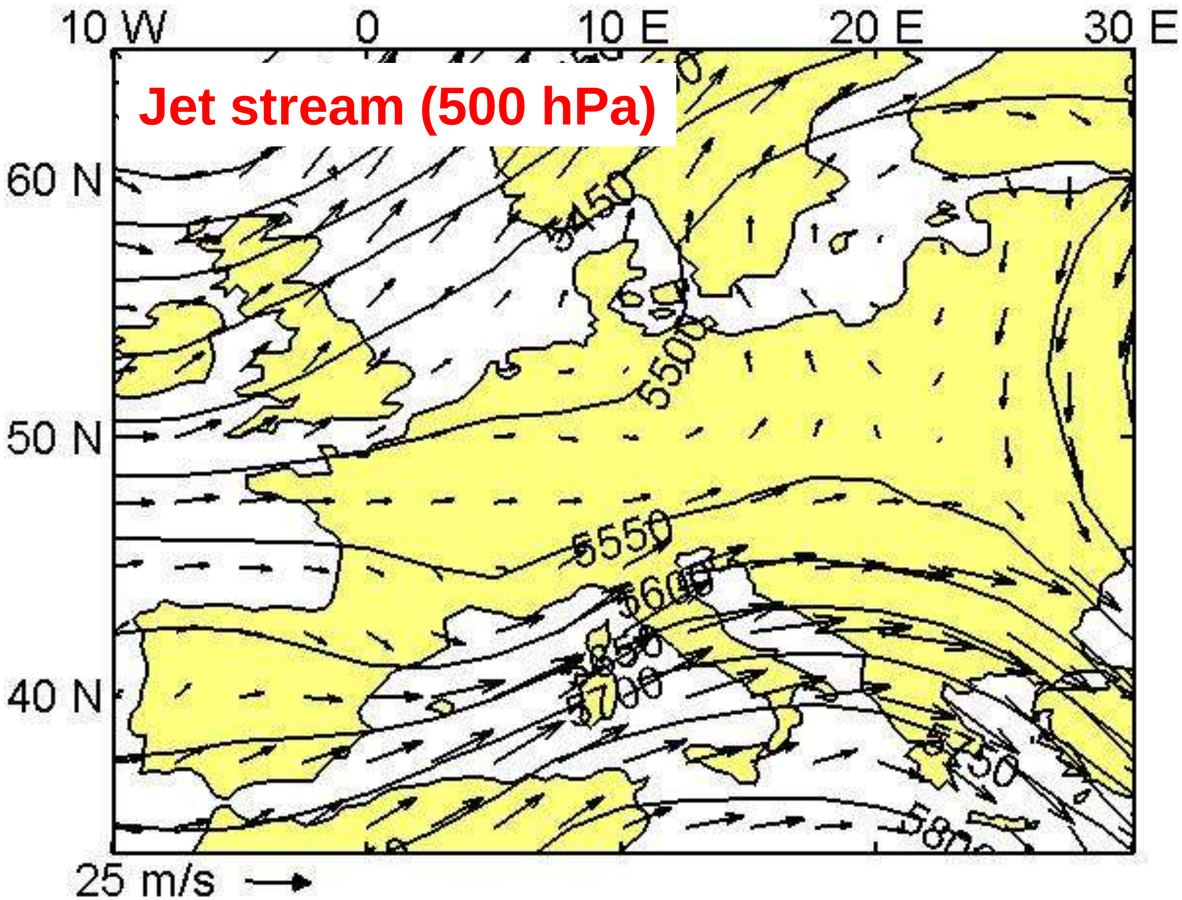
21 June 1978, Vela Luka meteotsunami



(Source: ECMWF reanalysis)

Typical synoptic conditions

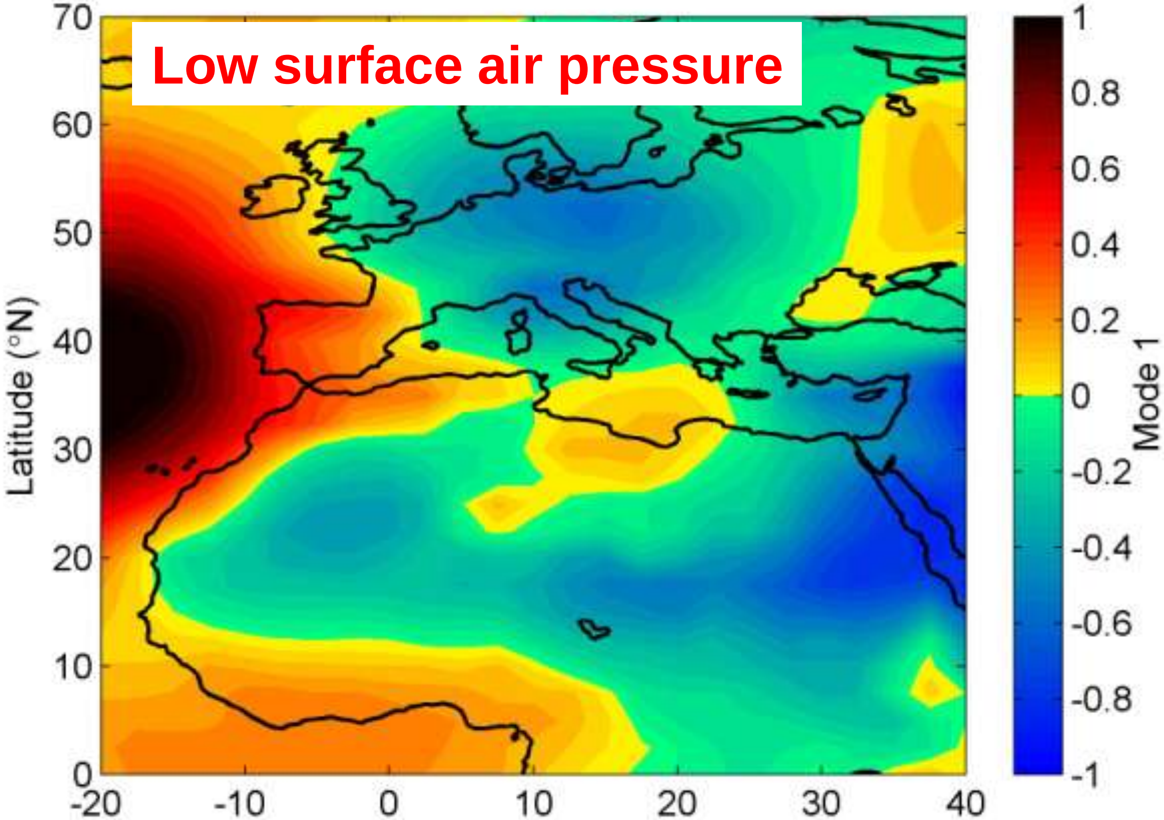
21 June 1978, Vela Luka meteotsunami



Matching between speed and direction of jet stream at ~500 hPa and speed and direction of air pressure disturbance!

(Source: ECMWF reanalysis)

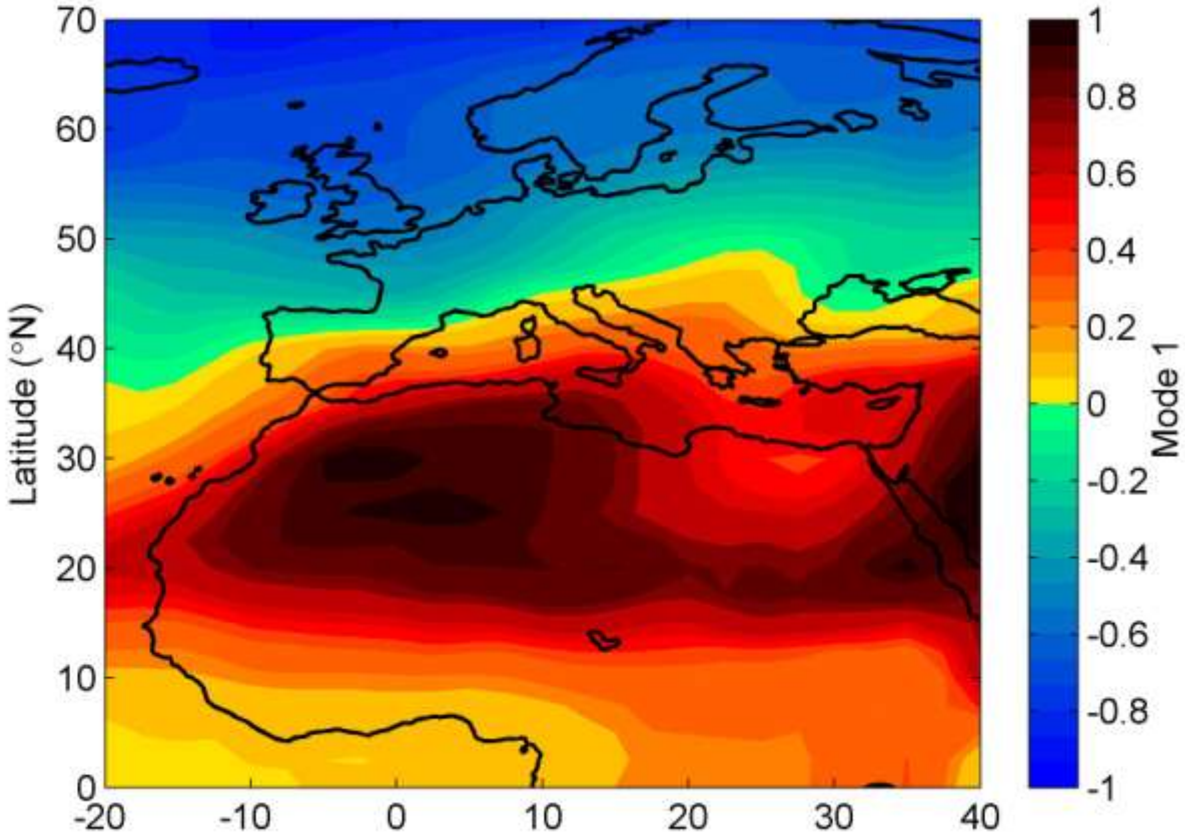
Typical synoptic conditions, northern Adriatic meteotsunamis, EOF analysis



(Source: ECMWF reanalysis)

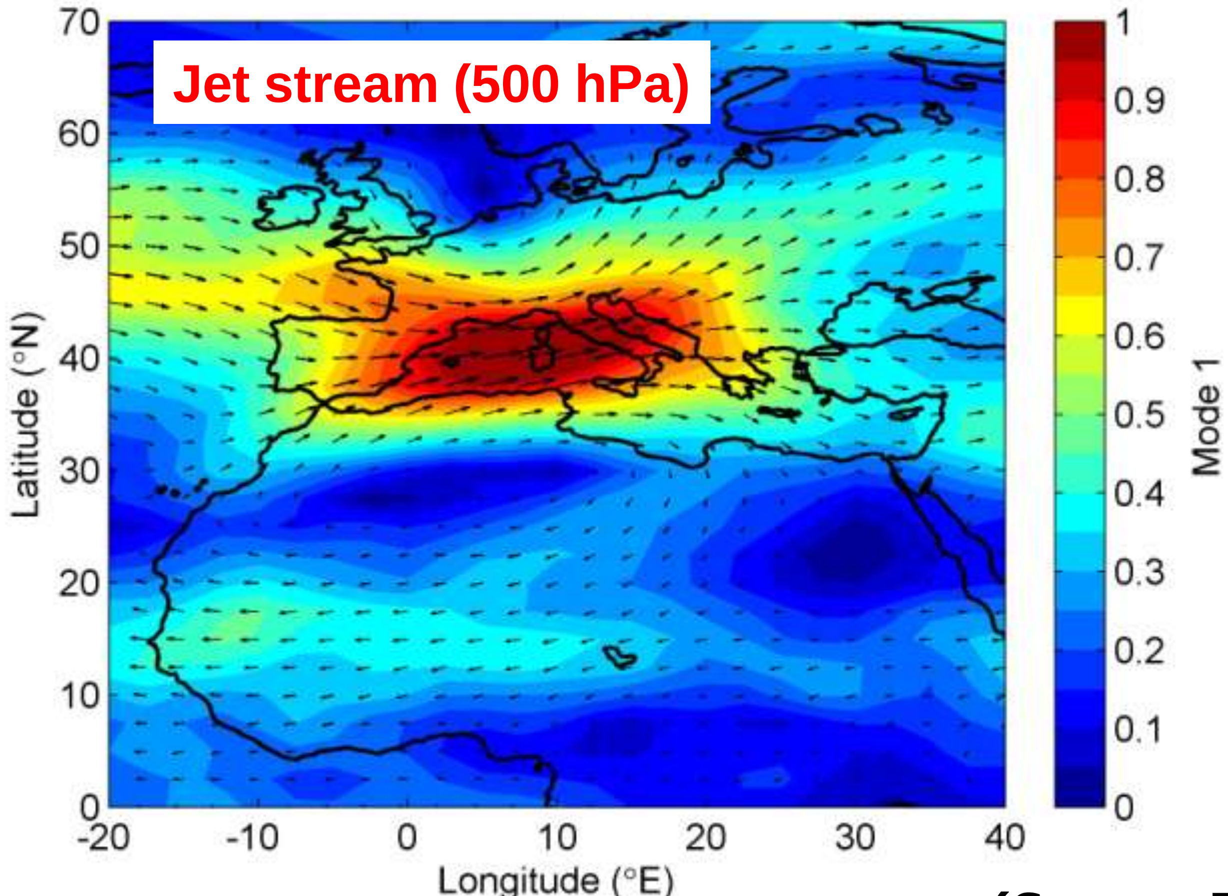
Typical synoptic conditions, northern Adriatic meteotsunamis, EOF analysis

Warm air inflow and temperature front (850 hPa)



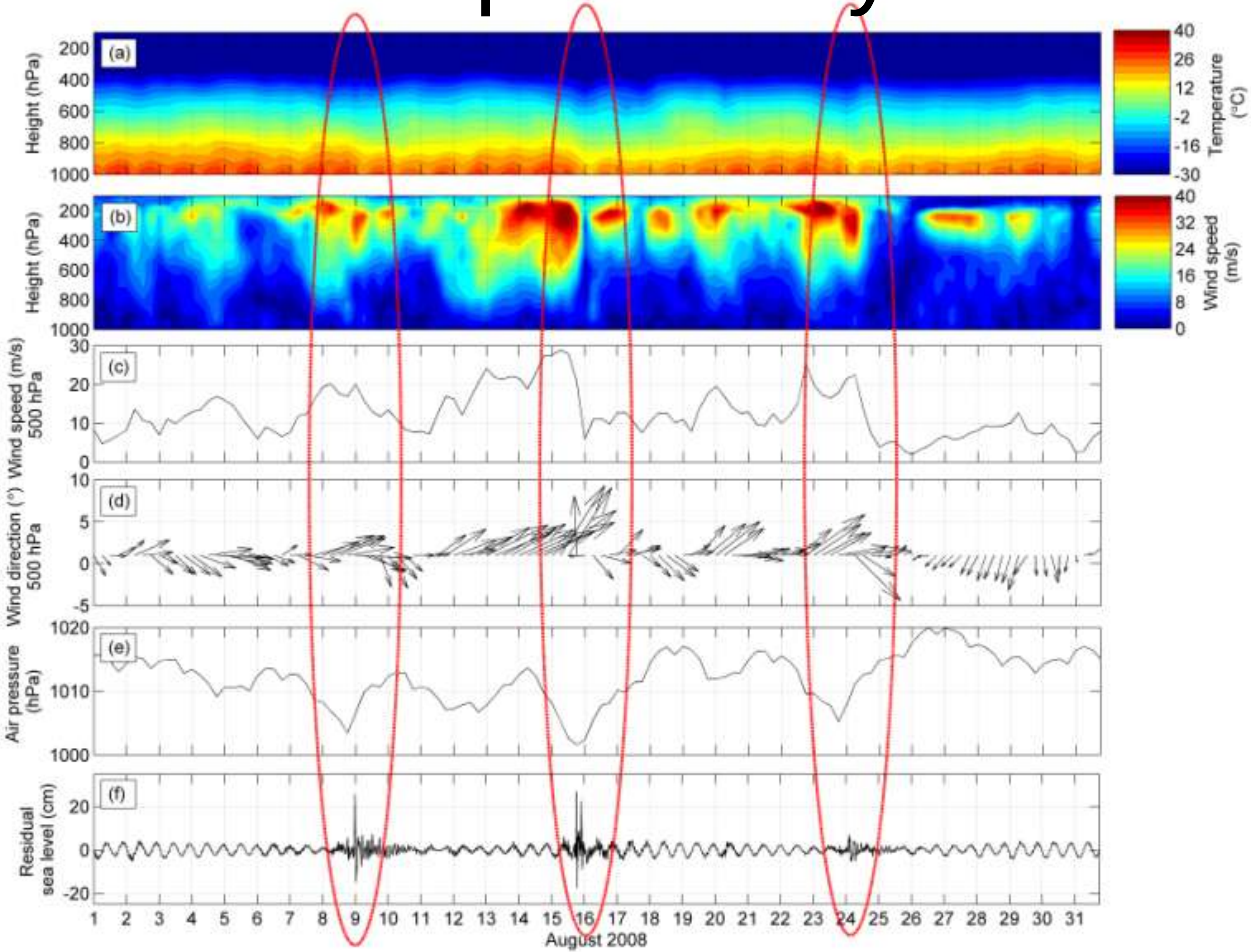
(Source: ECMWF reanalysis)

Typical synoptic conditions, northern Adriatic meteotsunamis, EOF analysis



(Source: ECMWF reanalysis)

Forecast possibility



Temperature

Wind

Wind speed (500 hPa)

Wind direction (500 hPa)

Surface pressure

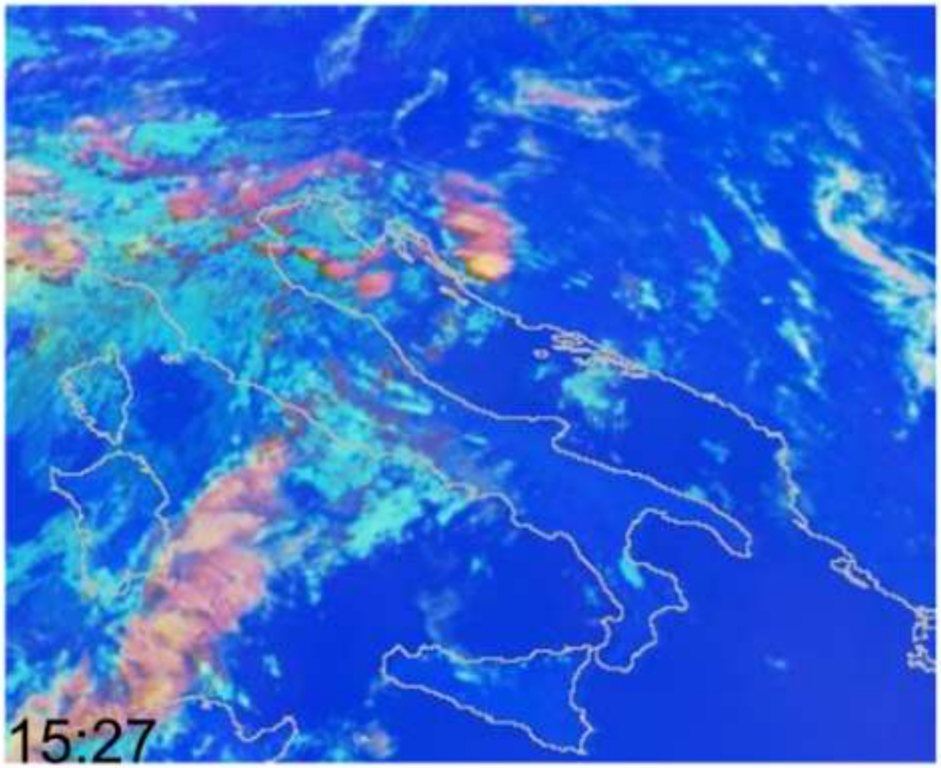
Sea level (Rovinj)

Common characteristics of the Adriatic meteotsunamis

- Typical synoptic conditions during the events:
  - Low surface pressure over the Adriatic
  - Inflow of warm African air; temperature front over the Adriatic (~850 hPa)
  - Jet stream at ~ 500 hPa over the Adriatic
  - Speed and direction of jet stream at 500 hPa matching speed and direction of propagation of air pressure disturbances
- If typical synoptic conditions are present over the area, some sea level oscillations are likely to happen – but we can’t say anything of their strength!

Source of air pressure disturbances

22 August 2007, the Ist meteotsunami



(Source: EUMETSAT)

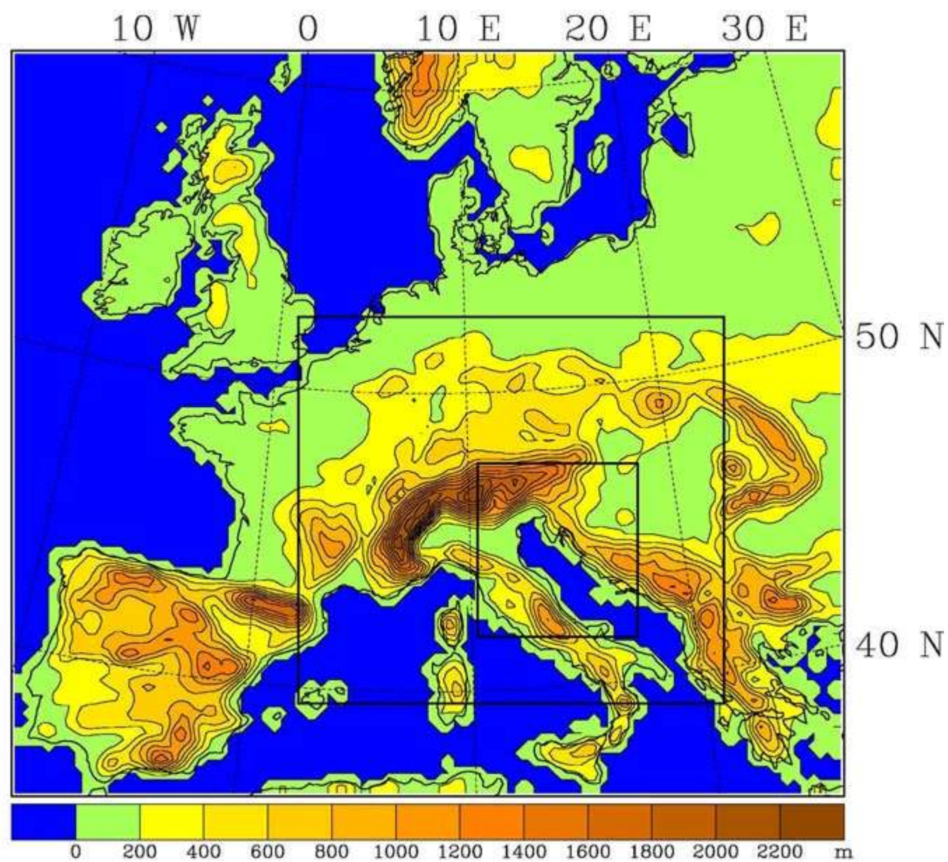
Air pressure disturbances related to the Adriatic meteotsunamis are often associated with convective thunderstorm clouds.

Thunderstorm clouds observed preceeding the Stari Grad and Mali Ston 2003, the Ist 2007, the Mali Lošinj 2008 meteotsunamis (and possibly the Vela Luka 1978 metetsunami).

Possibility for meteotsunami forecast from convective cloud tracking (Belušić & Strelec Mahović, 2009).

Meteorological numerical models – Stari Grad and Mali Ston

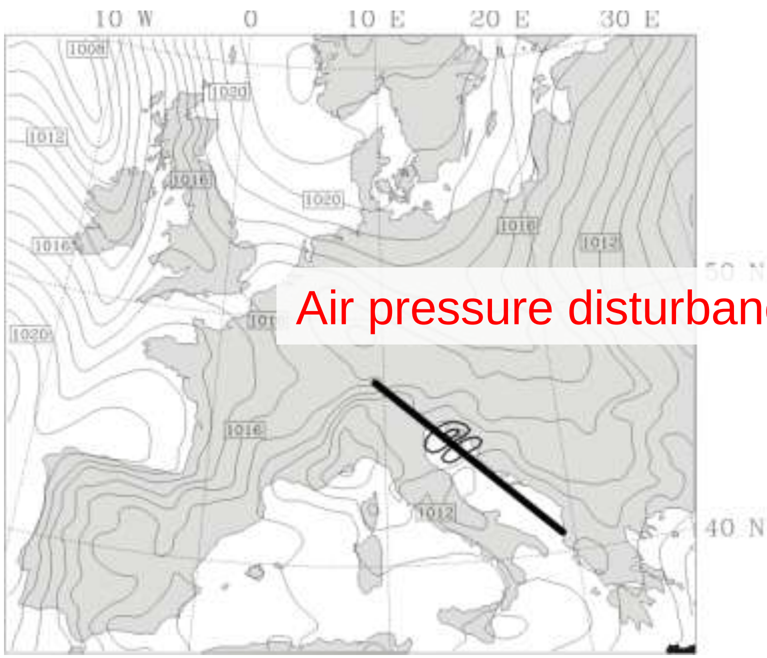
- Numerical modelling of the meteotsunami:
  - MM5 model
  - 1 way nesting, 3 domains
    - 24, 12 & 4 km
    - 113x126, 117x129 & 157x145 grid points
    - 39, 39 & 62 σ levels
  - Grell convection
    (except 4-km domain)
  - Simple-ice microphysics
    (test case with Reisner 2)
  - ECMWF initial and boundary conditions



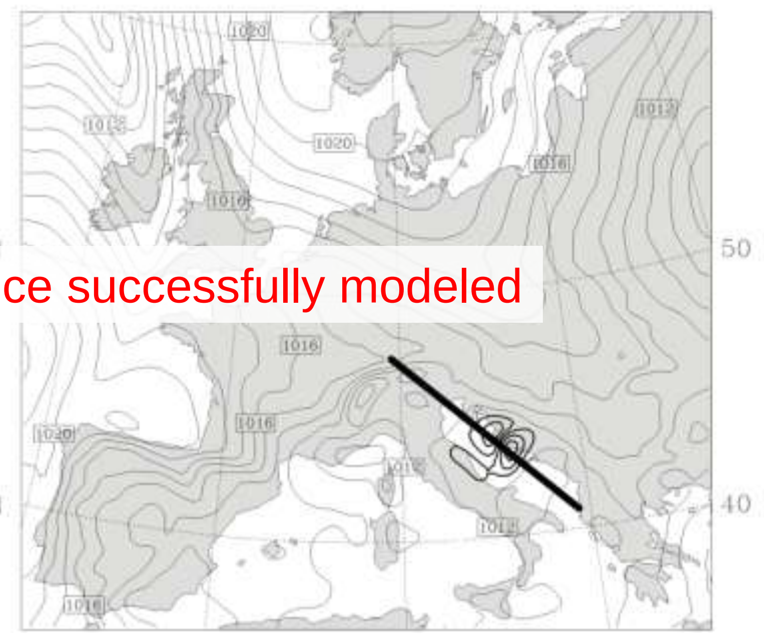
(Belušić et al., 2007)

Meteorological numerical models – Stari Grad and Mali Ston

23 UTC 26 June 2003



02 UTC 27 June 2003



Air pressure disturbance successfully modeled

Modelled speed:
15 – 20 m/s (North – South)
Speed from measurements: 22 m/s

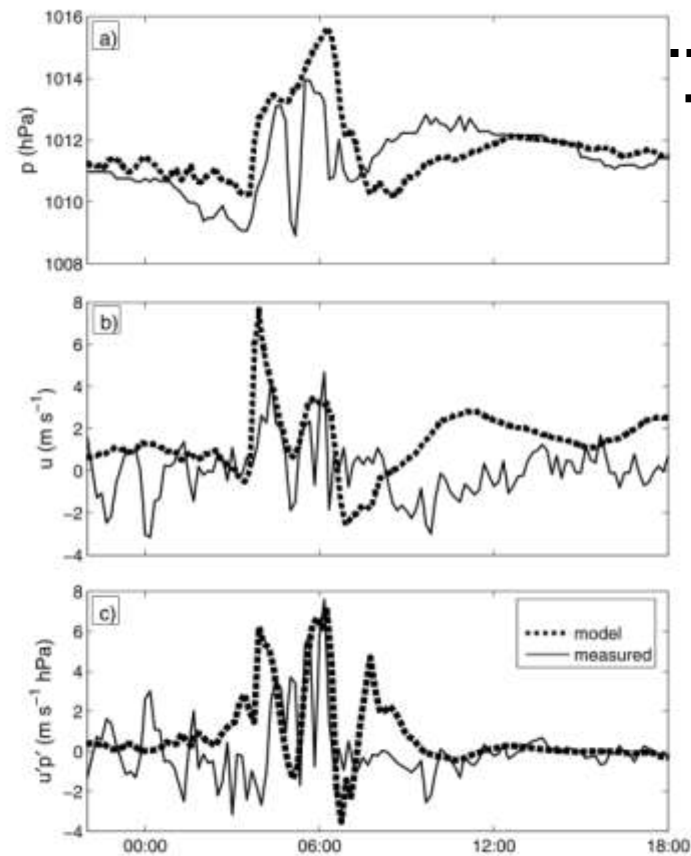
(Belušić et al., 2007)

Meteorological numerical models – Stari Grad and Mali Ston

Air pressure

Wind

Air pressure perturbation*
Wind perturbation



Model
Measurement

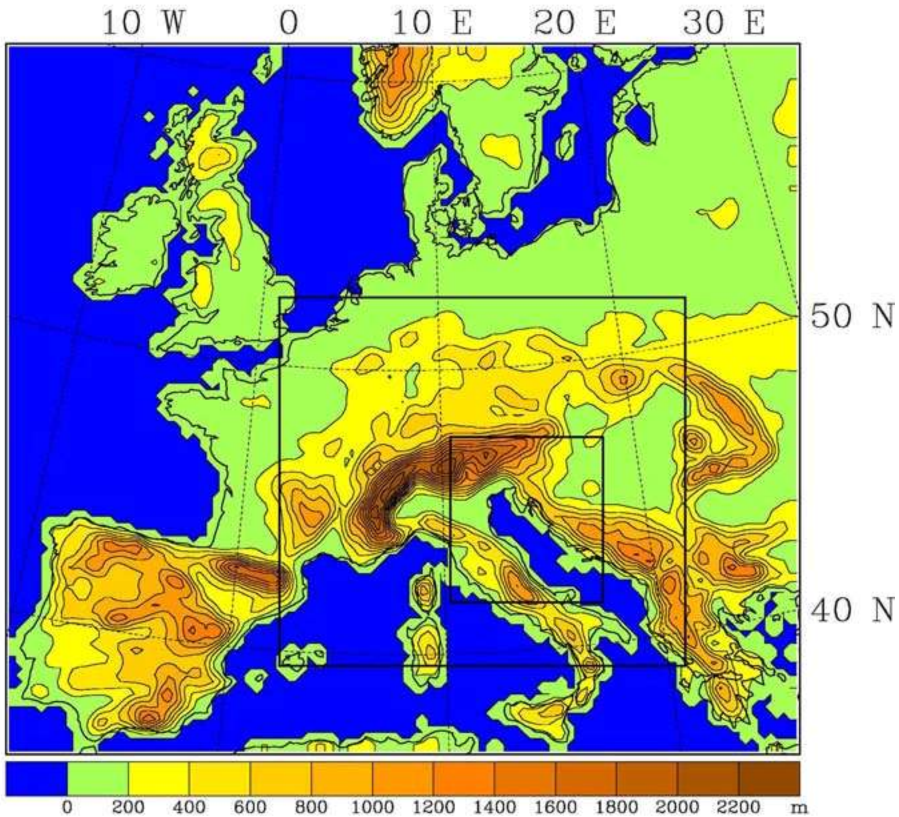
Time

Issues:
- Two hour off-set
- Not fully reproduced
- A lot of model runs needed for reproduction

(*Belušić et al., 2007*)

Meteorological numerical models – Ist meteotsunami

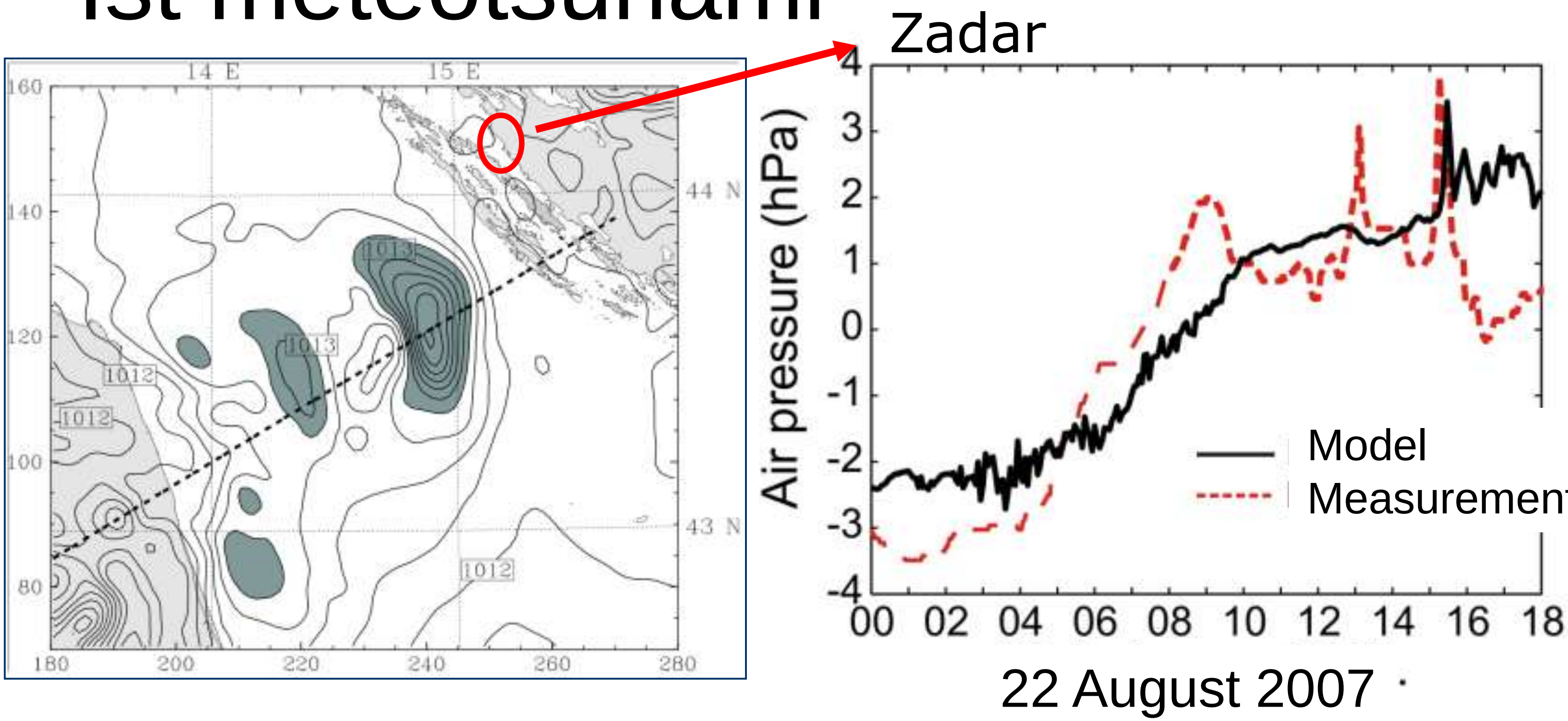
- Numerical modelling of the meteotsunami:
  - WRF model
  - 1 way nesting, 3 domains
    - 18, 6 & 2 km
    - 100x100, 217x217 & 364x364 grid points
    - 75 vertical levels
  - Grell-Devenyi convection
  - Lin scheme for microphysics
  - ECMWF initial and boundary conditions



(*Šepić et al., 2009.*)

Meteorological numerical models – Ist meteotsunami

(*Šepić et al., 2009.*)



Issues:
- Spatial offset – modeled disturbance 40 km to the south from the observed one
- Not fully reproduced (first peak missing)
- Several model runs with different parametrizations (schemes) needed for reproduction

Forecast possibility

- Although a reproduction of air pressure disturbances with atmospheric numerical model is possible, it’s not easy to achieve it!
- A lot of modeling attempts (with different domains, parameterization schemes, resolutions, ...) are needed to successfully reproduce an event -> probably still not achievable in real time!
- One way coupling between atmospheric and ocean numerical models not done yet successfully for the Adriatic – but done for the Balearic Islands (*Renault et al., 2011*).

Common characteristics of the Adriatic meteotsunamis

- Typical synoptic conditions during the events:
  - Low surface pressure over the Adriatic
  - Inflow of warm African air; temperature front over the Adriatic (~850 hPa)
  - Jet stream at ~ 500 hPa over the Adriatic
  - Speed and direction of jet stream at 500 hPa matching speed and direction of propagation of air pressure disturbances
- If typical synoptic conditions are present over the area, some sea level oscillations are likely to happen – but we can't say anything of their strength!
- Air pressure disturbances which generate meteotsunamis are often related to convective clouds.
- It's possible to reproduce air pressure disturbances leading to meteotsunamis with atmospheric models – but a lot of modeling is needed and it's not easy to do it in real time.

Thank you for your attention!

Questions?

Literature

- Belušić, D., and N. Strelec Mahović, 2009. Detecting and following atmospheric disturbances with a potential to generate meteotsunamis in the Adriatic, Physics and Chemistry of the Earth, 34, 918-927.
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