Efficiency of Earthquake Early Warning Systems

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Introduction

Components of Early Warning System

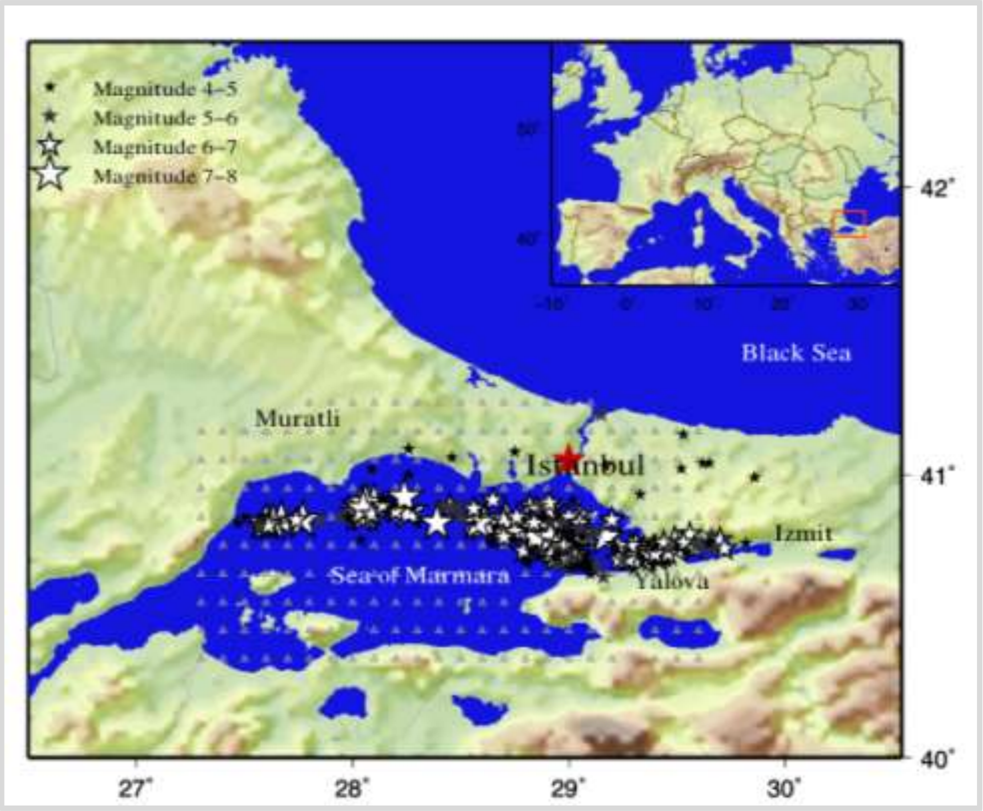
- User Information (Alarm)
- Seismological Network plus communication
- Methodology (Parameter)

Question: Given a certain user requirement
what is the best network configuration?
what are the best parameters?

Introduction

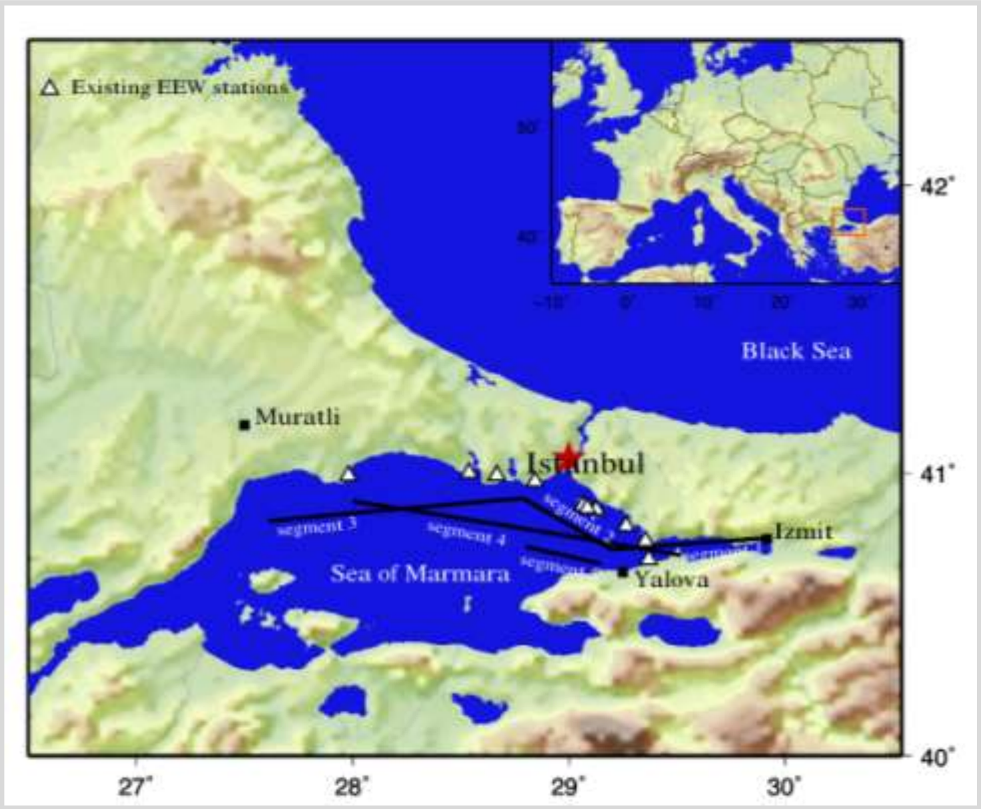
- The **simplest approach** to earthquake early warning (EEW) is **based on thresholds**: when the ground motion at a given number of stations of the network exceeds a given threshold, an alarm is declared
- Or, rephrased: What are
  a) the optimal station locations,
  b) the optimal thresholds,
  c) the minimum necessary number of stations and, in our case, the benefit of a given number of ocean bottom stations?
- As an **example** to address these questions, we use the case of **Istanbul & the Sea of Marmara**

Synthetic dataset



- Istanbul: seismic hazard determined by fault segments of North Anatolian fault below the Sea of Marmara
- 5 segments (Böse et al., 2008)
- Istanbul is the user site for EEW
- 180 earthquakes with 4.5 ≤ M ≤ 7.5 simulated with FINSIM (Beresnev & Atkinson,1997) (extended to P-waves, Böse et al., 2008) on a grid of stations (150 events on 5 segments, 30 smaller events randomly distributed)

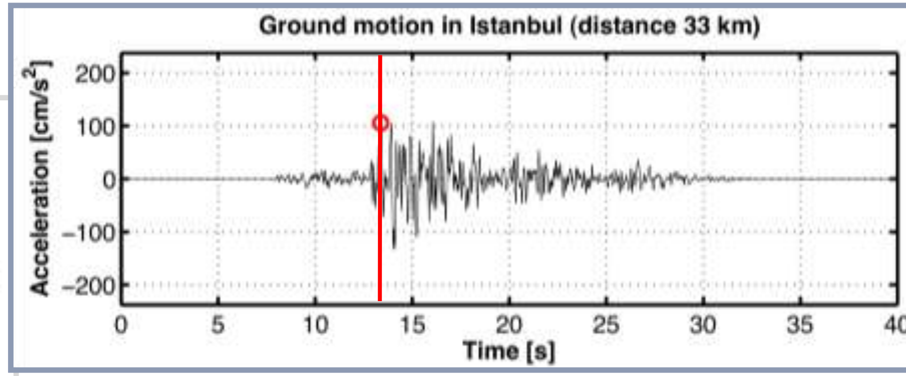
Current early warning system



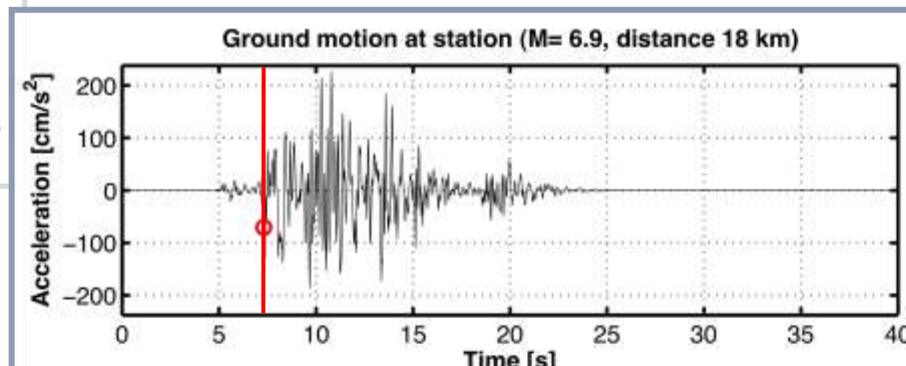
- Current EEW system implemented within the *Istanbul Earthquake Rapid Response and Early Warning System* (IERREWS, Erdik et al., 2003)
- 10 real-time stations along the shoreline of the Sea of Marmara (further 10 shall be added soon)
- 3 warn classes defined by thresholds 0.02g, 0.05g & 0.10g, which have to be exceeded at 3 stations within 5 sec

Principle of thresholds-based system

Exceedance of threshold defining a given warn class in Istanbul (e.g. 0.1g)



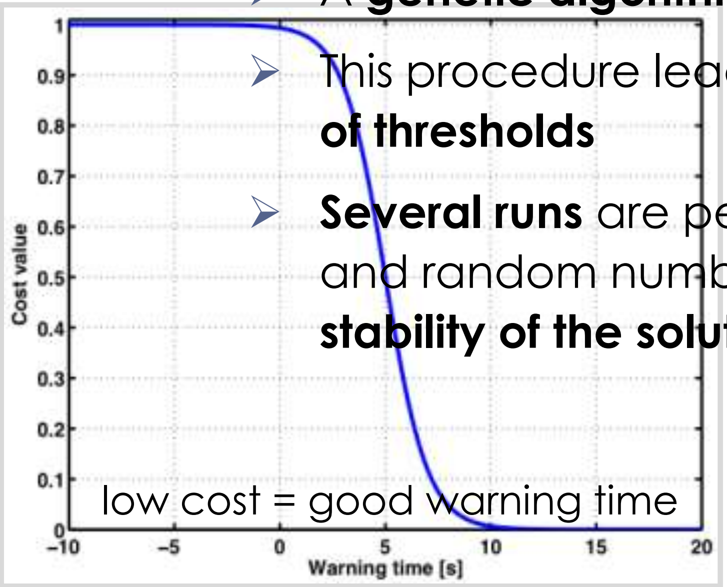
If waiting for 3 exceedances in 5 sec and if (in best case) 3 stations one close to the other in grid, minimum loss of 2-3 sec!



Exceedance of given threshold (e.g.) 0.05g

Optimization approach

- **Start** with an **random station configuration** of a given number (e.g. 10) on grid and 3 thresholds in the range 0.01g – 0.32g
- **Warning times** for correctly classified events **are determined**
- **Warning times** are **evaluated** with a cost function based on a **sigmoid** centered around a certain t_{center} (e.g. 5 sec)
- A **genetic algorithm** is used to minimize the cost (micro-GA)
- This procedure leads **of thresholds**
- **Several runs** are perf and random numbe **stability of the solutio**



$$cost = \sum_{i=1}^{N_{evt}} W_i \{(1-K)[1 - sigm(t_{warn,i}, t_{center}, S)] + K\}$$

Minimization of cost function → simultaneous **maximization** of number of **correctly classified events** and their **warning times**!

Optimization approach

- **Two subgrids** where stations can be placed in the GA: stations **(a) on land** and **(b) in the Sea of Marmara**
- This way, the **benefit** of adding a certain **number of ocean bottom seismometers** (OBS) (and their best positions!) can be easily evaluated

Important note:

- **Thresholds** as used **in current EEW system** defined **without a direct link to** ground motion to be expected at the **user site** (Istanbul)!
- **We establish this link!** Following PGA in Istanbul, we classify the events and minimize classification errors

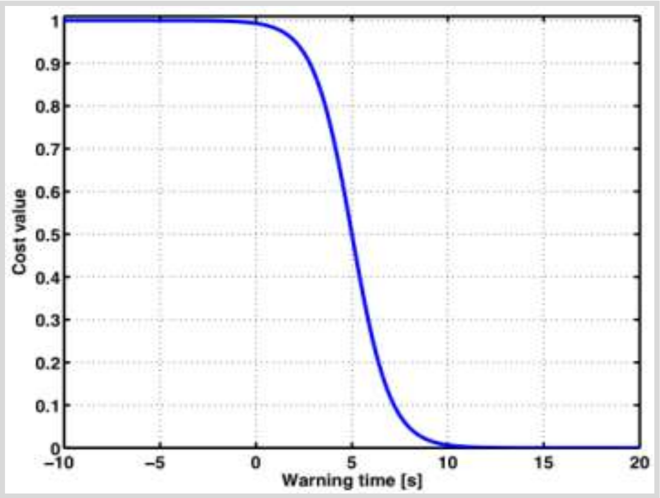
→ **lowest possible rate of missed and false alarms!**

Classification of events:

- **Class 0:** PGA in Istanbul < 0.02g (no warning)
- **Class I:** PGA in Istanbul ≥ 0.02g
- **Class II:** PGA in Istanbul ≥ 0.05g
- **Class III:** PGA in Istanbul ≥ 0.10g

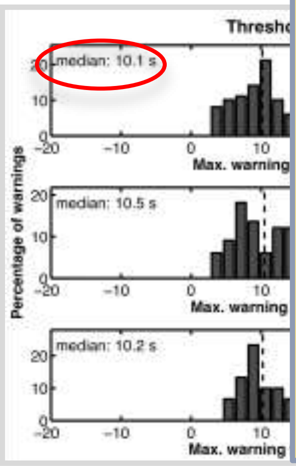
Simulations in the dataset are for rock (NEHRP B) sites!

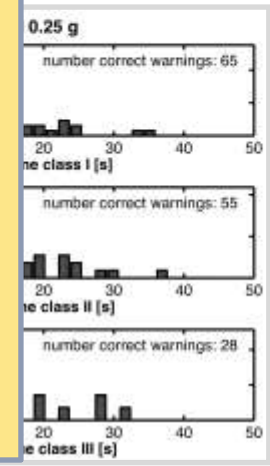
Problem: how to set reasonable t_{center}?



- **Sigmoid function:** a center time has to be chosen
- **Question:** what is the range of warning times that are reasonable to be expected?
- **Possible answer** from the **distribution of maximum possible warning times** (for fixed threshold, choosing for each event the station location on the grid where the threshold is first exceeded)

Max. t_{warn} di



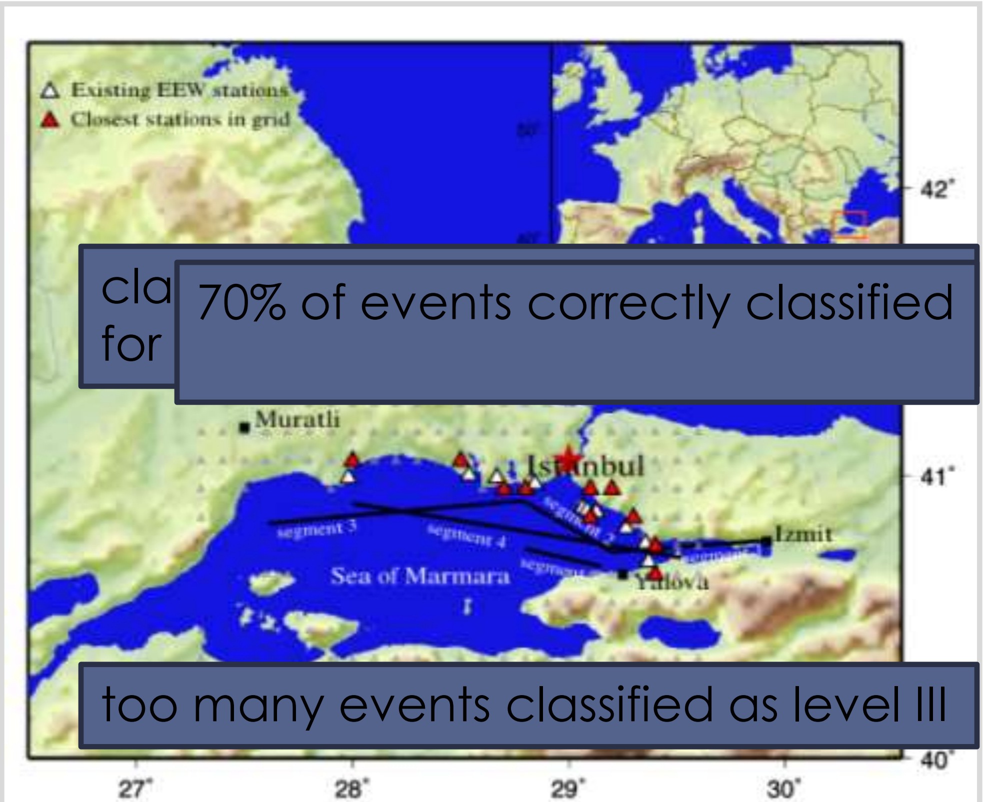


Chosen t_{center} in our runs:

- **If warning already after first exceedance:**
  - t_{center} = [8 8 5] sec for level [I II III] (only land)
  - t_{center} = [9 9 9] sec for level [I II III] (land & OBS)
- **If warning after three exceedances within 5 sec:**
  - t_{center} = [6 6 3] sec for level [I II III] (only land)
  - t_{center} = [8 8 5] sec for level [I II III] (land & OBS)
- **Spread factor S** → max. indiv. cost reached for t_{warn}= 0 sec

Evaluation of current system

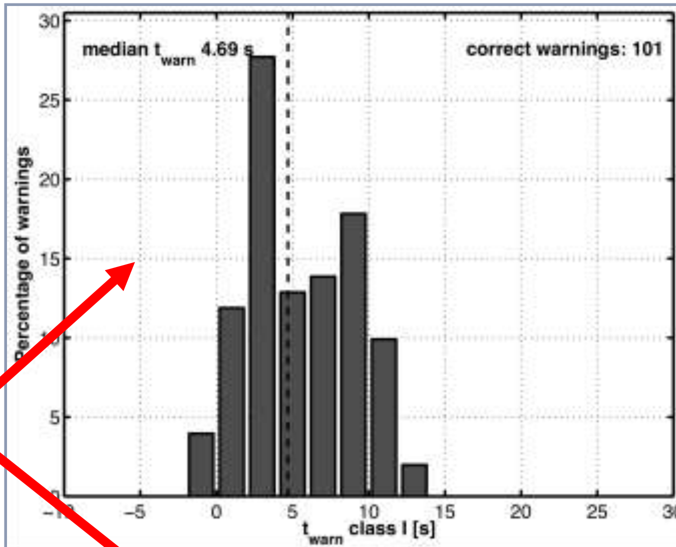
Thresholds: 0.02g (L1) 0.05g (L2) 0.10g (L3)

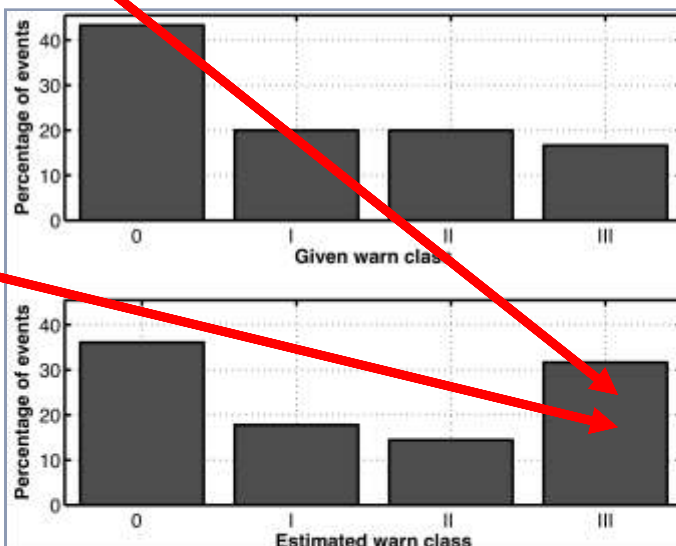


cla
for

70% of events correctly classified

too many events classified as level III





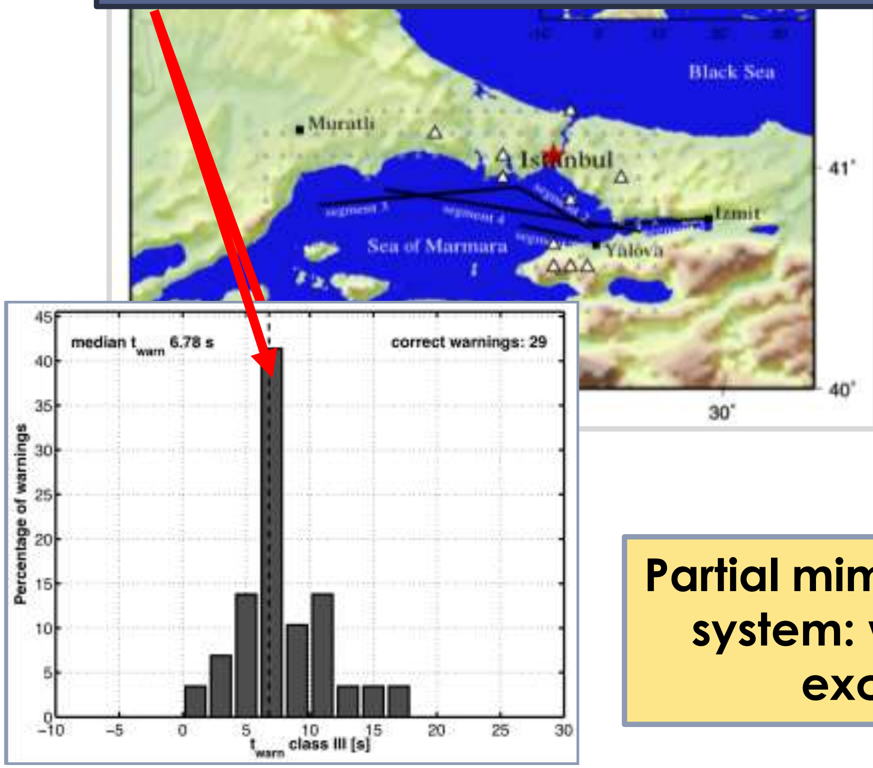
warning after three exceedances in 5 sec

Optimization: warning on 1st exceedance

Only land stations

0.04g (L1) 0.12g (L2) 0.18g (L3)

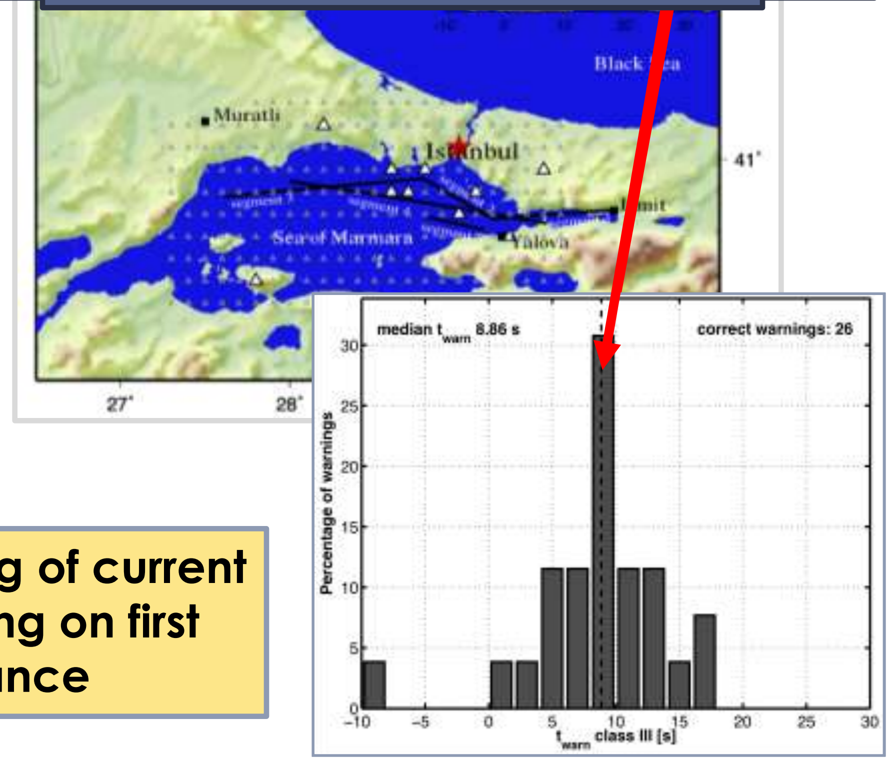
Thresholds higher than for current system



7 land stations, 3OBS

0.06g (L1) 0.15g (L2) 0.30g (L3)

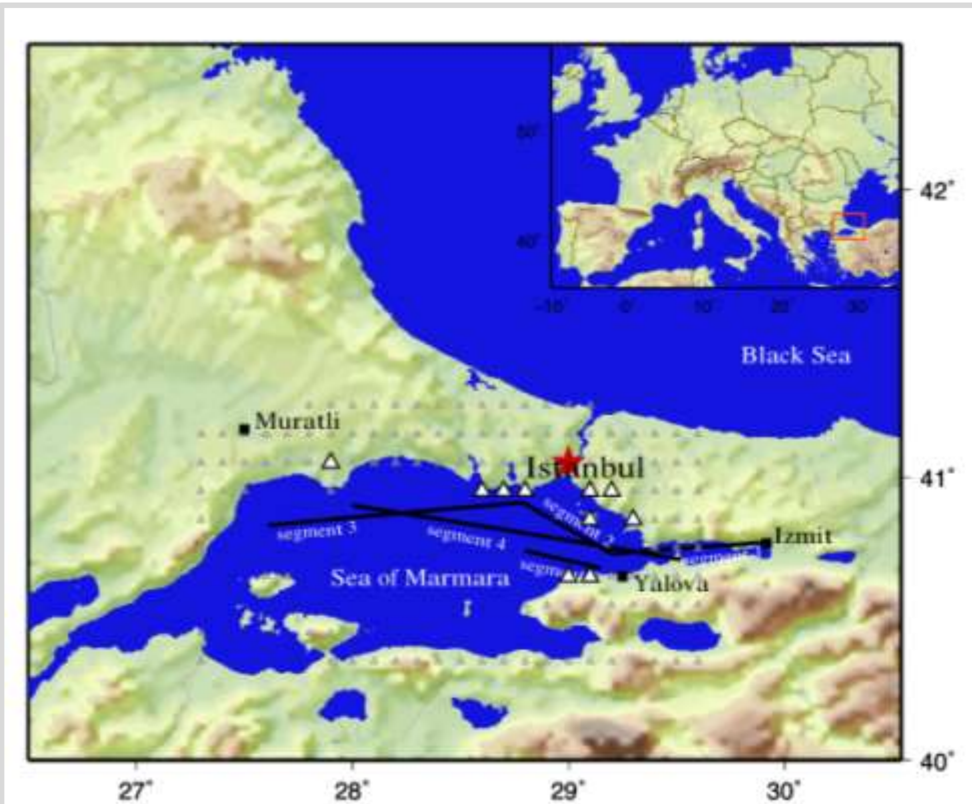
Thresholds higher than if only land stations are considered (especially class III)

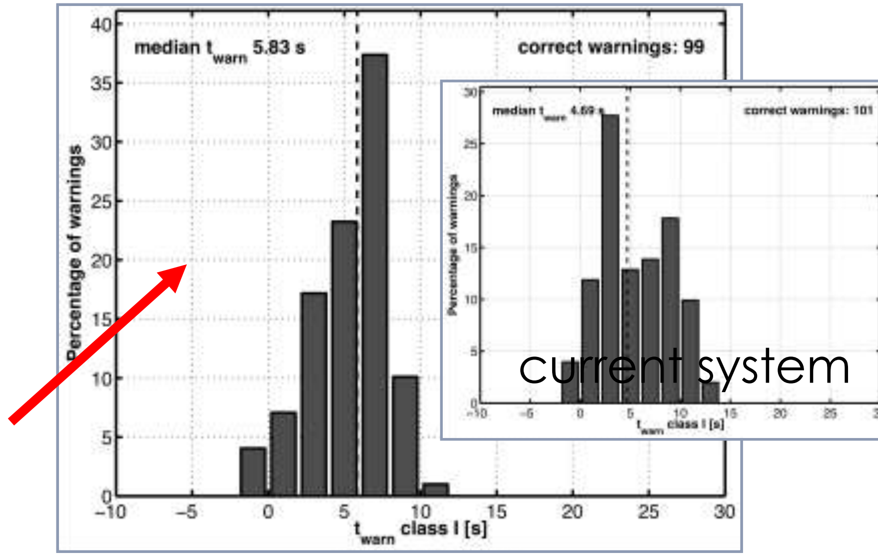


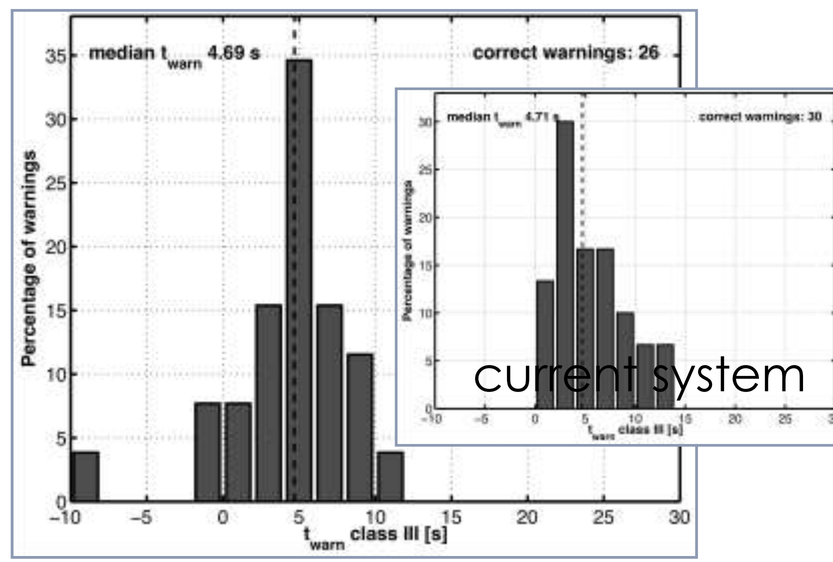
Partial mimicking of current system: warning on first exceedance

Full optimization: 10 land stations

Thresholds: 0.03g (L1) 0.07g (L2) 0.17g (L3)



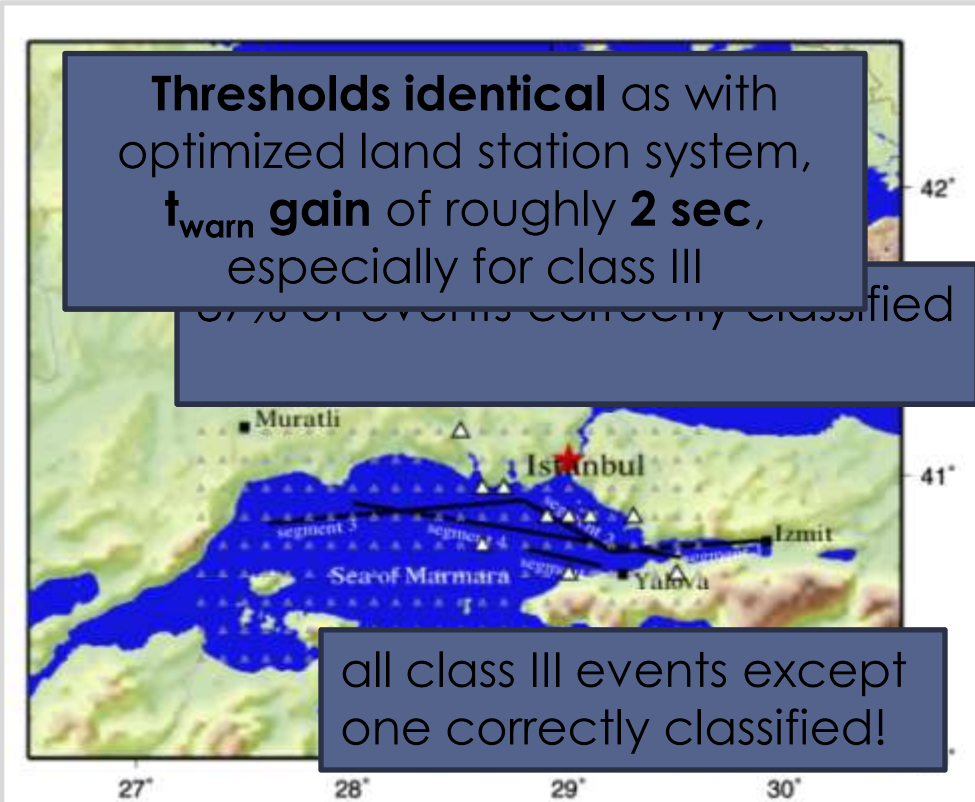




Full mimicking of current system: warning after three exceedances in 5 sec

Full optimization: 7 land stations, 3 OBS

Thresholds: 0.03g (L1) 0.07g (L2) 0.17g (L3)

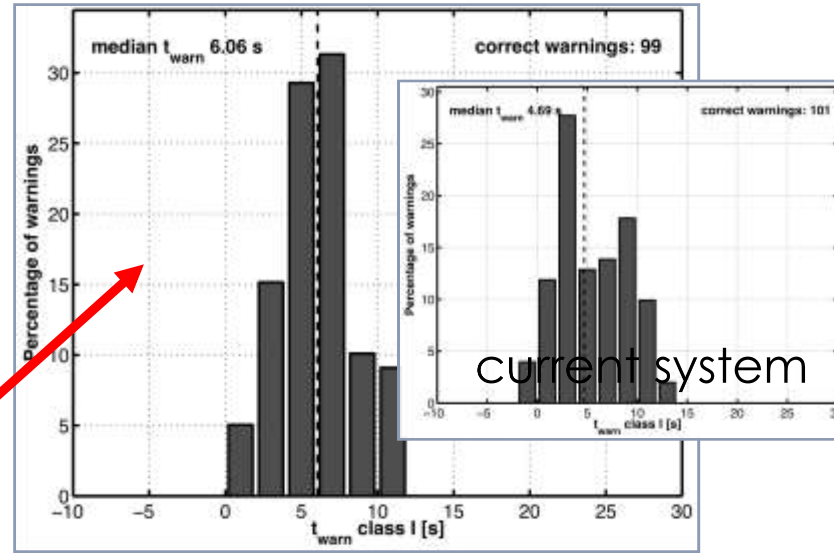


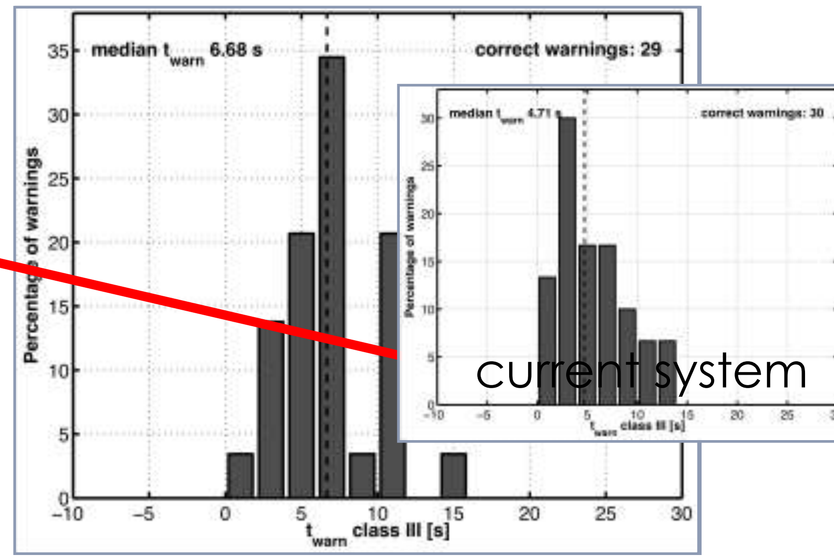
Thresholds identical as with optimized land station system, t_{warn} **gain** of roughly **2 sec**, especially for class III

fied

all class III events except one correctly classified!

Full mimicking of current system: warning after three exceedances in 5 sec





Conclusions

- The presented methodology can **optimize the seismic network (sites) and the parameter** for early warning.
- Optimization approach as such **not limited to threshold-based systems**, but might also be applicable when using e.g. predominant period as indicator for earthquake magnitude
- **The current Istanbul EEW system performs quite well**. There is **however room for improvement**, as the optimization shows:
  - by *increasing class III threshold* to avoid class III false alarms
  - by *slightly modifying the station distribution*
- **Using three OBS** would generally **increase the available warning times** by 2 – 3 sec on average (especially noticeable for class III events)