The Use of Spectral Content to Improve Earthquake Early Warning Systems in Central Asia: Case Study of Bishkek, Kyrgyzstan

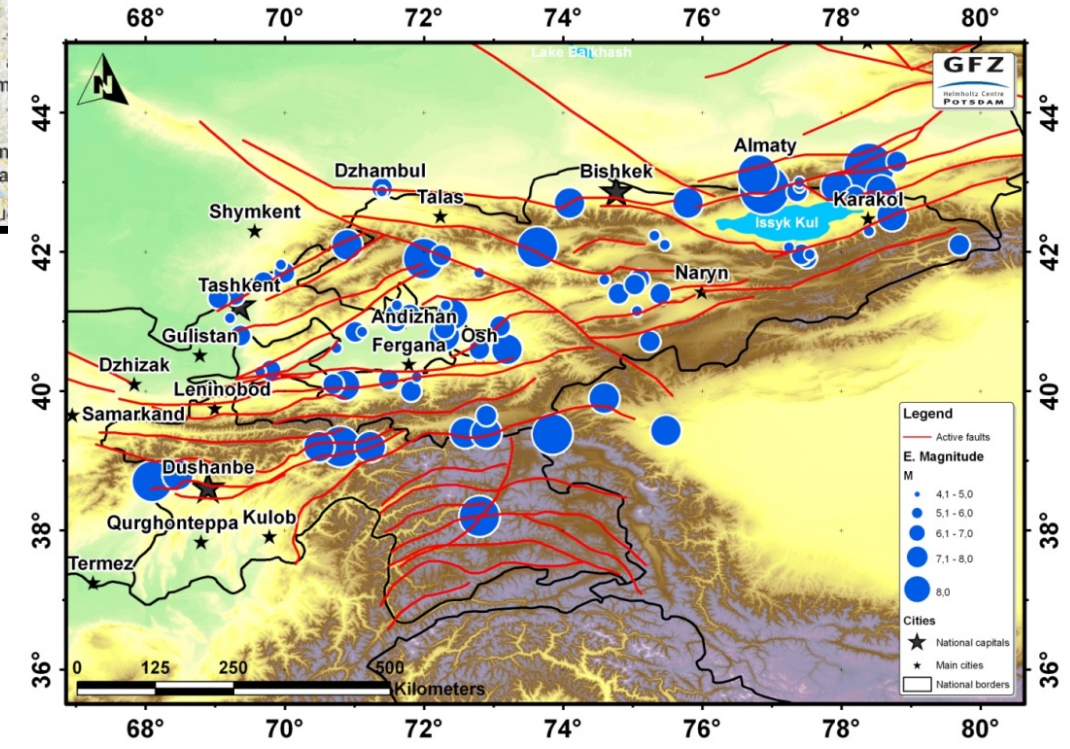
Jacek Stankiewicz, Dino Bindi, Adrien Oth,
Massimiliano Pittore, Stefano Parolai

european center for geodynamics and seismology
centre européen de géodynamique et de séismologie

GFZ
Helmholtz-Zentrum
Potsdam

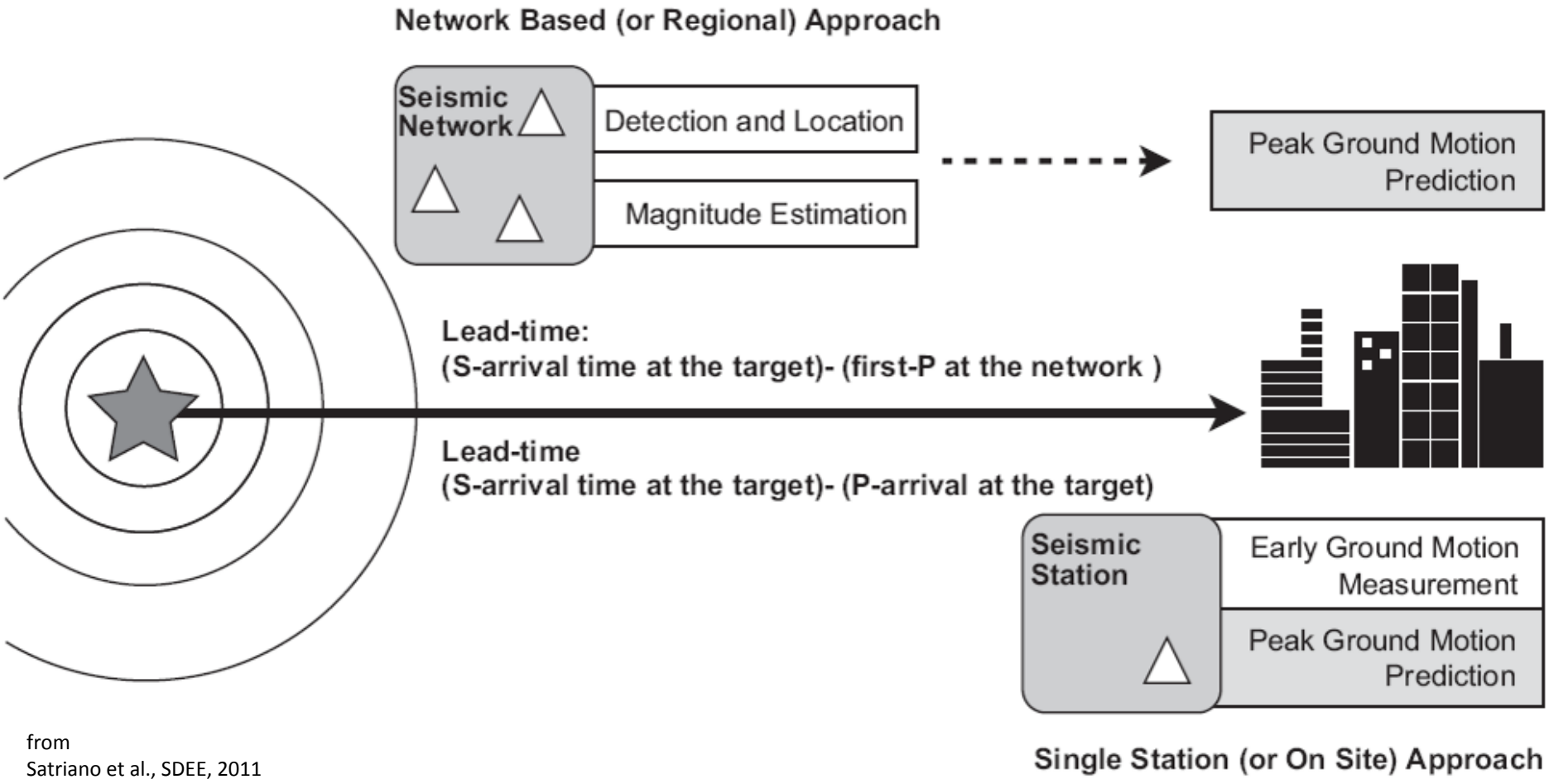
Fonds National de la
Recherche Luxembourg


Kazakhstan
Almaty
Bishkek
Uzbekistan
Kyrgyzstan
Tashkent
Xinjiang
Samarkand
Turkmenistan
Tajikistan
Ashgabat
Dushanbe
Mashhad
Kabul
Peshawar
Afghanistan
Islamabad
Lahore
Faisalabad


68°
70°
72°
74°
76°
78°
80°
44°
42°
40°
38°
36°
GFZ
Helmholtz Centre Potsdam
Almaty
Bishkek
Dzhambul
Talas
Karakol
Shymkent
Issyk Kul
Naryn
Tashkent
Andizhan
Osh
Gulistan
Fergana
Dzhizak
Leninobod
Samarkand
Dushanbe
Qurghonteppa
Kulob
Termez
Legend
Active faults
E. Magnitude
M
4,1 - 5,0
5,1 - 6,0
6,1 - 7,0
7,1 - 8,0
8,0
Cities
National capitals
Main cities
National borders
0
125
250
500
Kilometers

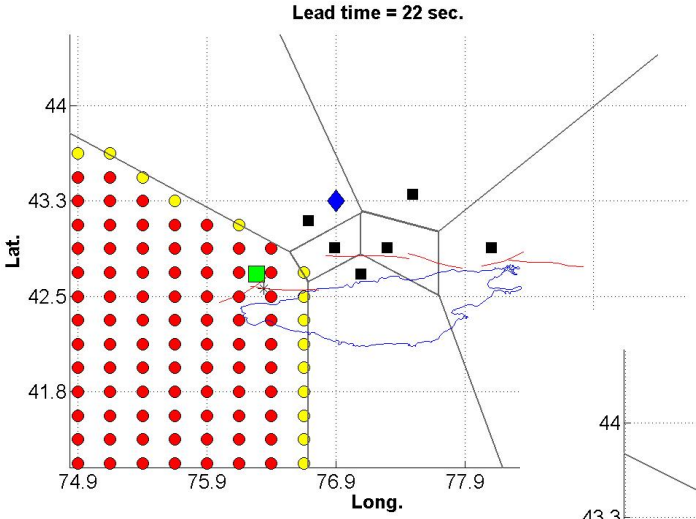
Approaches

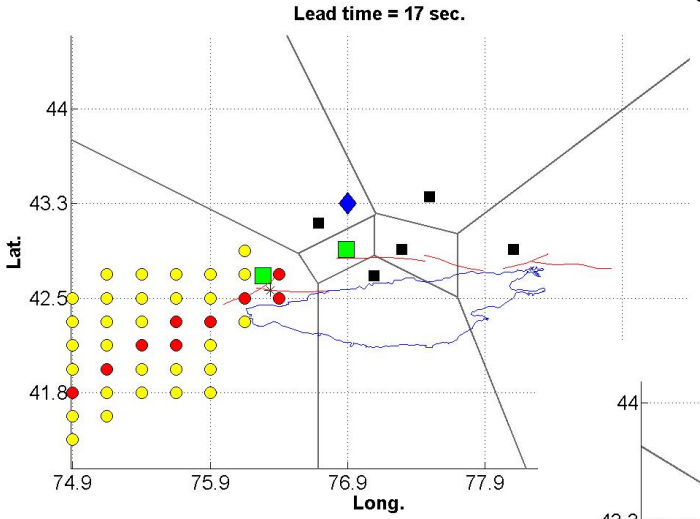
There are two main approaches: **Regional** (or network-based) EEW systems and **Onsite** (or Single-station) EEW systems. Here we deal with **Regional**



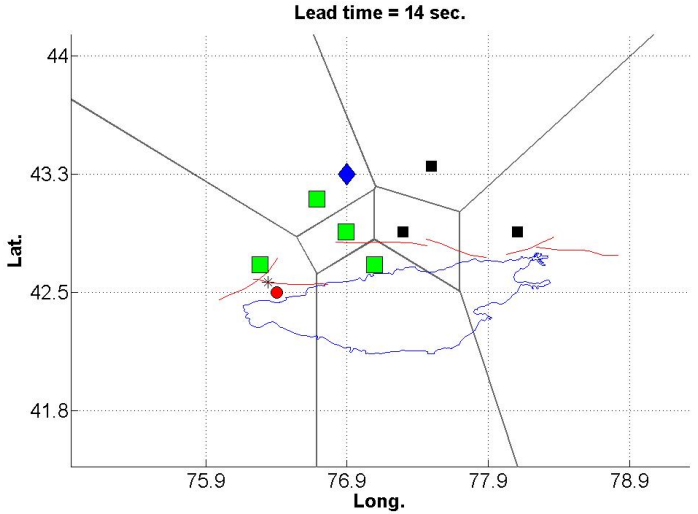
from
Satriano et al., SDEE, 2011

Event Location





Time

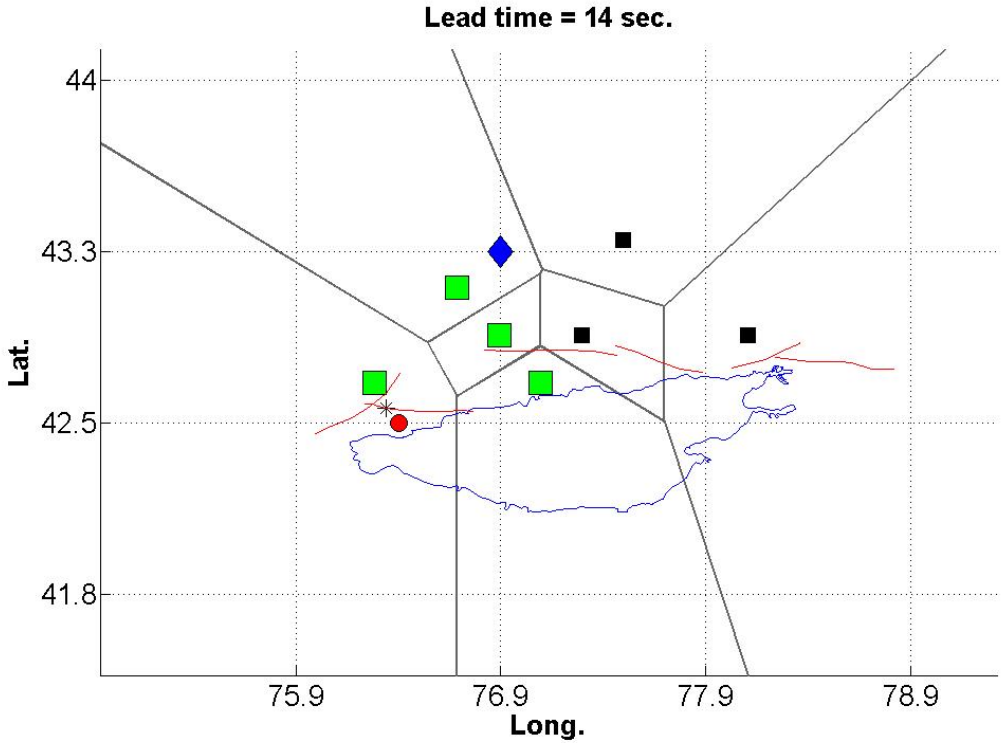


Picozzi et al, J. Seis, 2013

Location not critical to a functional warning system, though it remains a relevant by-product.

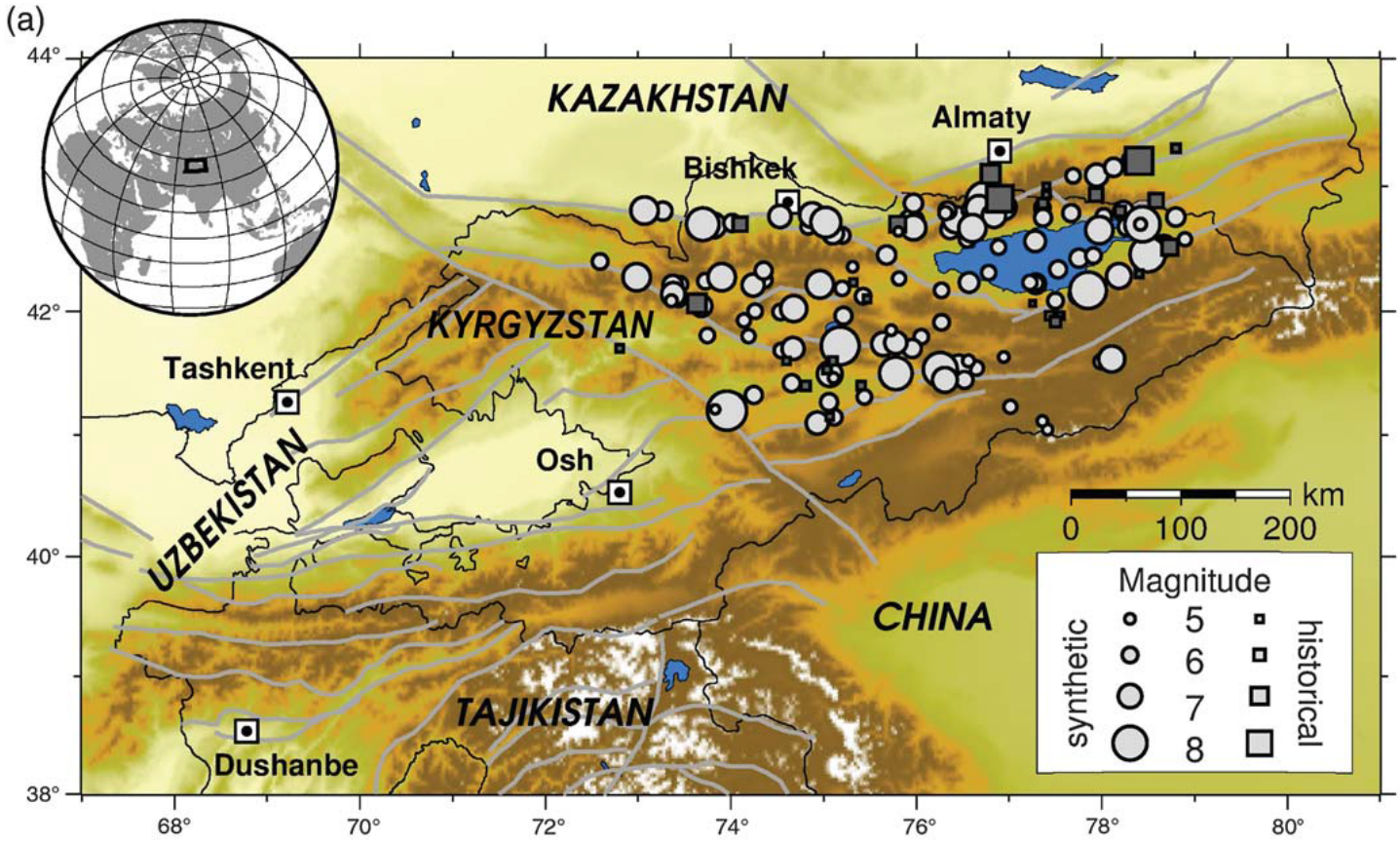
Once at least 3 stations record predefined ground acceleration, a warning is issued.

Three predefined thresholds, corresponding to warning levels for the tartget.



When is the issued warning accurate?

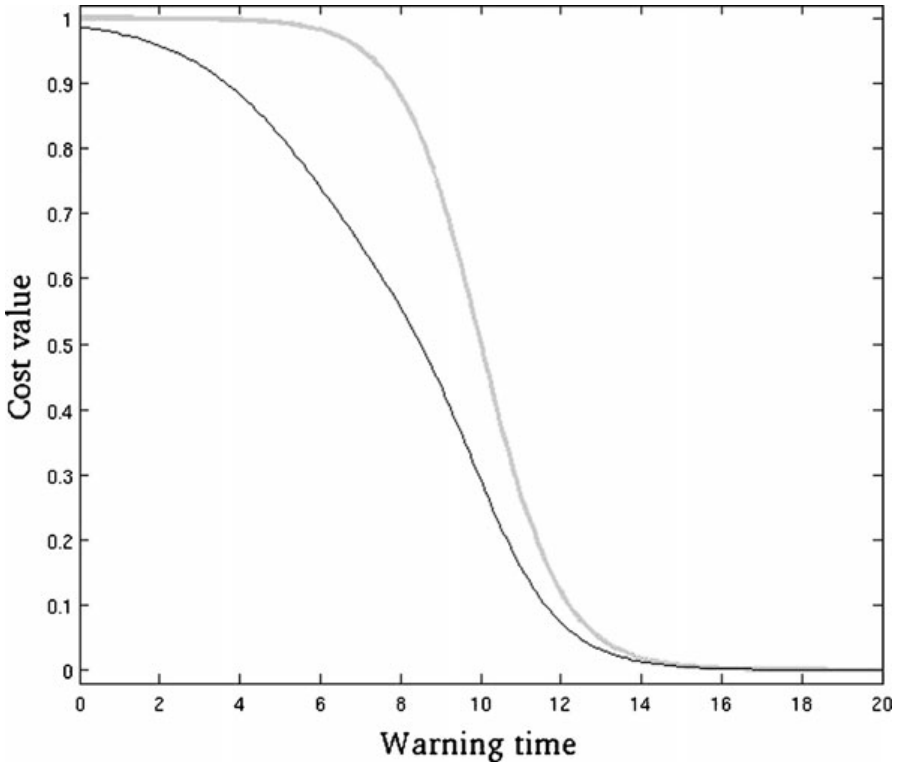
We use a representative database of scenarios events,
each event assigned a class based on PGA at target:
class 0: no warning, and specific warnings for classes I, II, III



Pittore et al, SRL, 2014

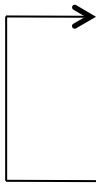
How do we quantify the quality of a network?
Define a cost function:

• Cost of a single event tends to 0 if correct class predicted with a large lead time
• Cost is 1 if event class wrongly predicted, also tends to 1 with decreasing warning time
• Cost of the network is the weighed average of individual event costs



Finding a network with a low cost using genetic algorithm

• Generate 15 random networks, each consisting of station locations and the three ground acceleration detection thresholds



• Evaluate the cost of each available network

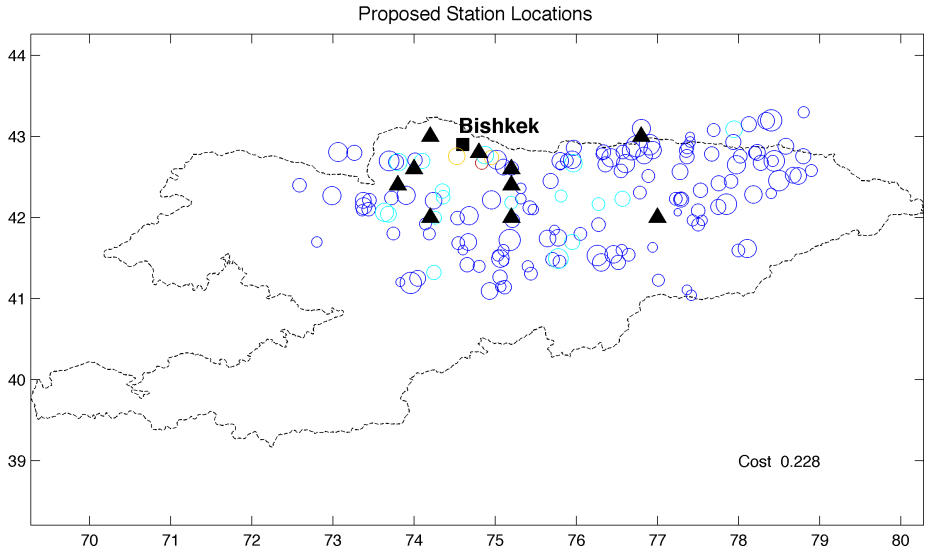
• Exchange information between the networks with the lowest costs to produce the next generation of networks

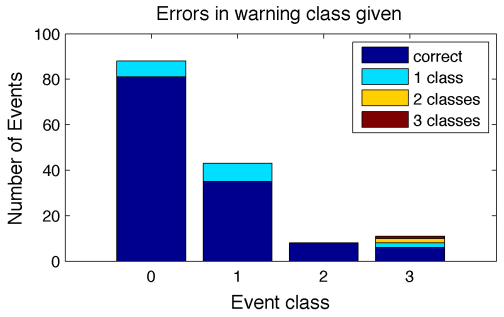
• Repeat until satisfactory convergence

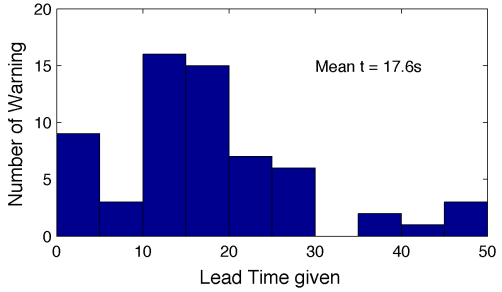
• Randomness present in the algorithm, so needs to be run repeatedly, producing different results each time

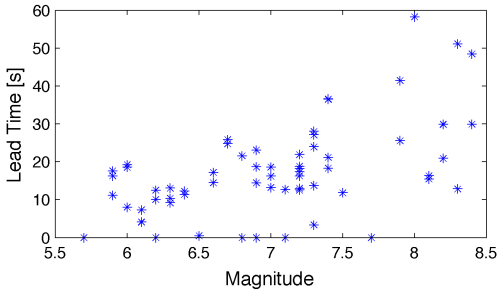
• The result is not just „the“ best network, but a number of efficient networks with similar cost values.

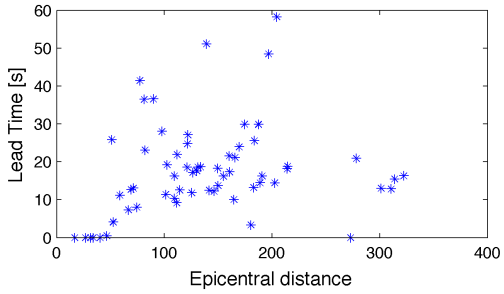
• Further criteria (e.g. accessability to a potential site, use of existing sites) can be incorporated both during the search, or afterwards.

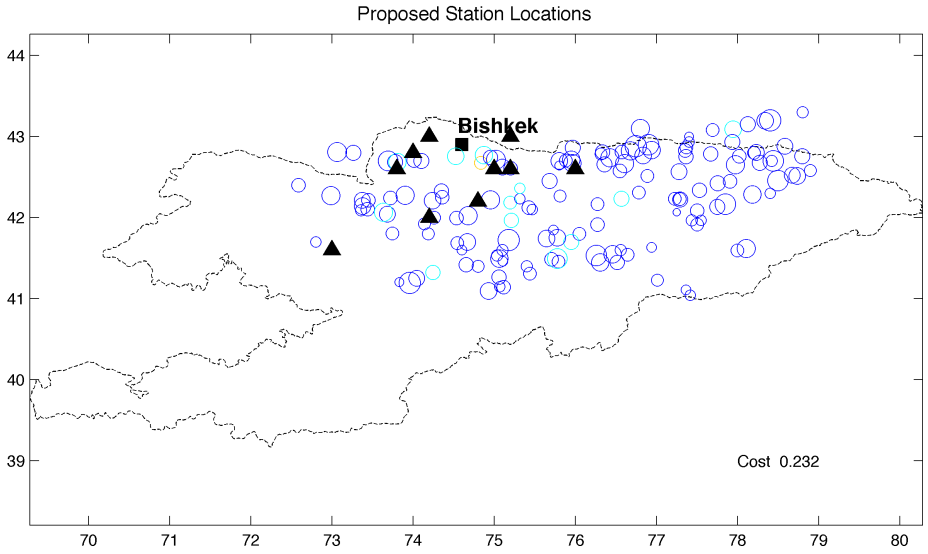

Proposed Station Locations
Bishkek
Cost 0.228
44
43
42
41
40
39
70
71
72
73
74
75
76
77
78
79
80

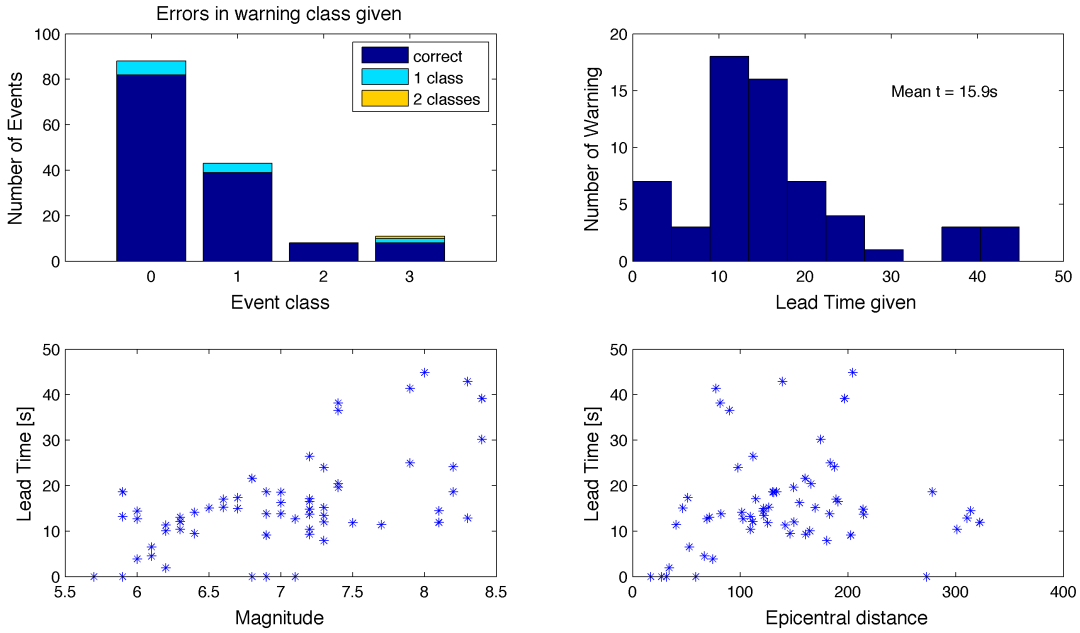

Errors in warning class given
correct
1 class
2 classes
3 classes
Number of Events
Event class
0
1
2
3
100
80
60
40
20
0


Mean t = 17.6s
Number of Warning
Lead Time given
20
15
10
5
0
0
10
20
30
40
50


Lead Time [s]
Magnitude
60
50
40
30
20
10
0
5.5
6
6.5
7
7.5
8
8.5


Lead Time [s]
Epicentral distance
60
50
40
30
20
10
0
0
100
200
300
400


Proposed Station Locations
Bishkek
Cost 0.232
44
43
42
41
40
39
70
71
72
73
74
75
76
77
78
79
80


Errors in warning class given
correct
1 class
2 classes
Number of Events
Event class
Number of Warning
Mean t = 15.9s
Lead Time given
Lead Time [s]
Magnitude
Lead Time [s]
Epicentral distance

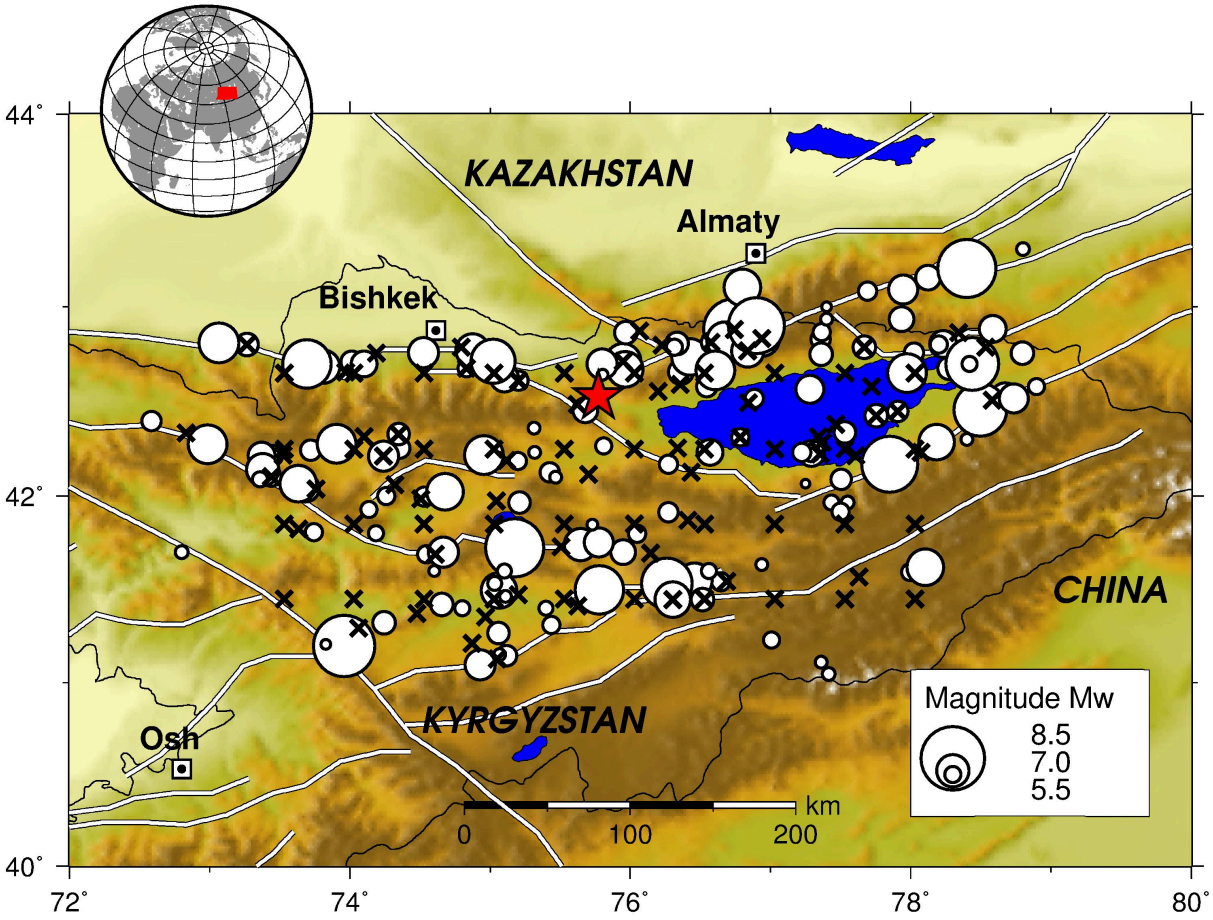
How to incorporate spectral information

• First few seconds of the P-wave signal contain a lot more information than just ground acceleration.

• Compute the spectrum and compare it to a precomputed library of spectra associated with a given recording station.

• General lack of strong motion data in the region: resort to stochastic simulations to create the library from a source dataset.

• So now we need two datasets independent of each other, yet both representative of local seismicity.

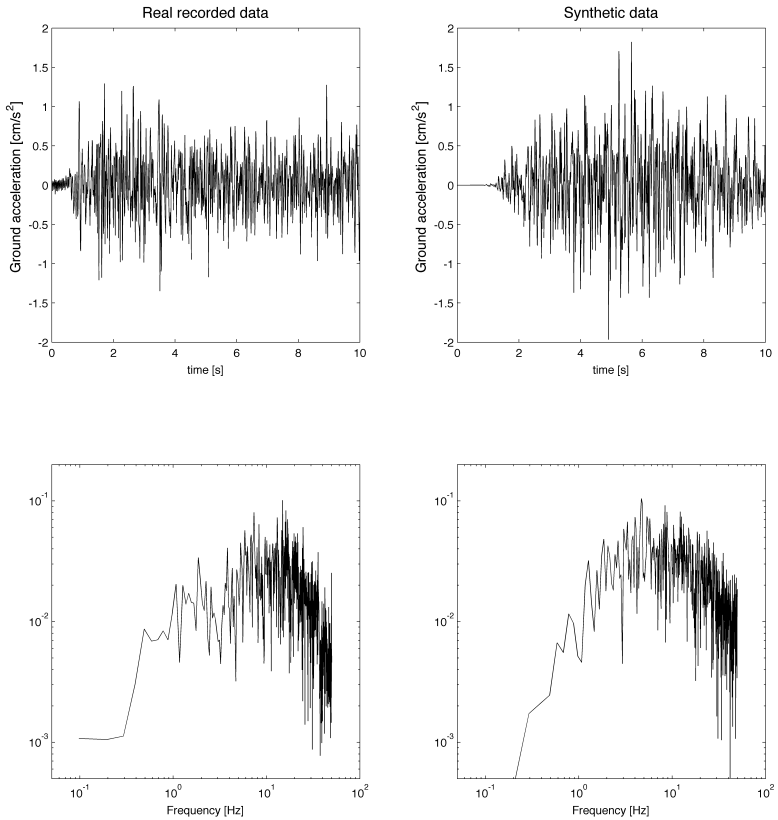


o - 150 scenario earthquakes

x - 100 source locations, each with 204 parameters

Simulations: EXSIM

- All events simulated at 256 prospective station locations and 19 sites in Bishkek
- 100 samples per second
- P and S waves computed separately, and added with the right time shift
- Anelastic attenuation, Q = 570 when f < 1.4 Hz, for higher f scaled with $f^{0.7}$
- Qp / Qs = 9 / 4
- Parameters checked against the few real recordings we do have (Trial and error)



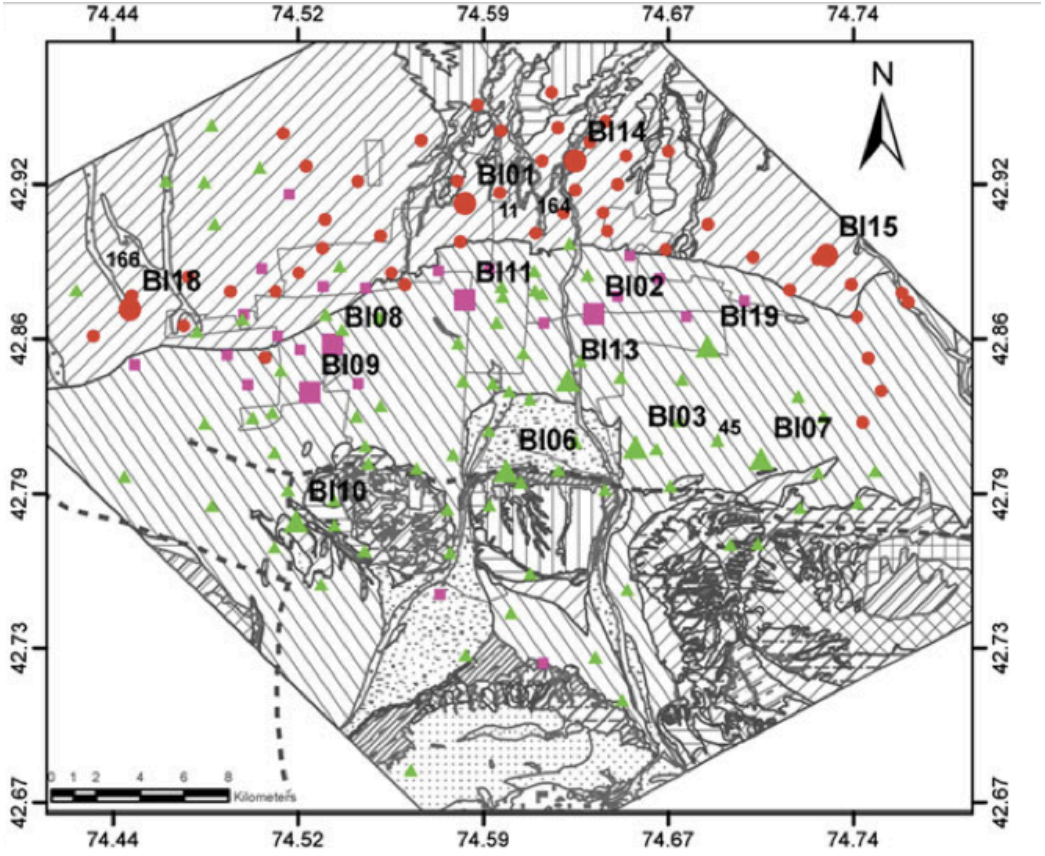
Mw 5.1, 90 km from Bishkek
23 November 2013

Intensity

Using spectra: use Intensity instead of PGA to quantify the class of each scenario

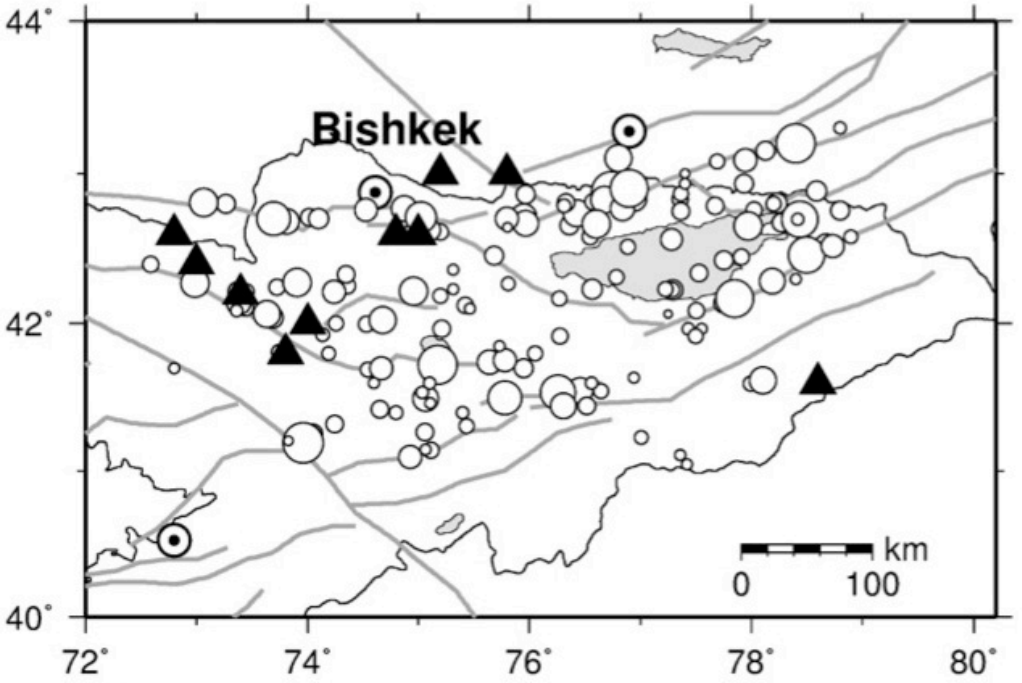
19 sites in Bishkek for site effects.

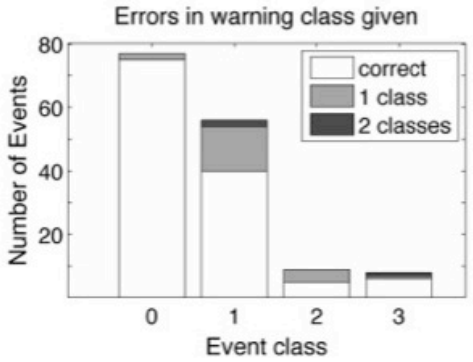
For all scenarios:
Calculate Intensity at all sites. If IV not reached at ANY site, scenario given class 0, i.e. warning not needed.
Classes I, II, III separated by intensity values of IV, VI and VII.

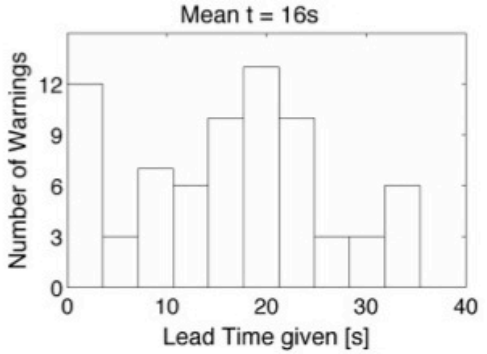


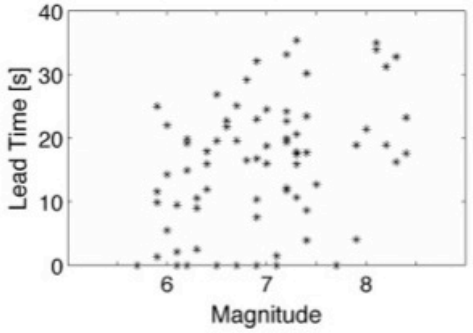
Ullah et al, BEE, 2013

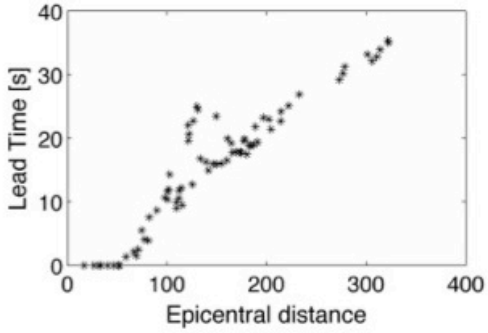
- These systems can start working with just one trigger: 5 sec after detection compute spectrum, find closest match in the station's library, and look up associated Intensity.
- As more stations trigger, find closest average match. For earlier stations use longer time window if available. Update warning if necessary.
- Network's cost again a function of accuracy and warning time it can provide for the scenarios.
- Use GAs as before to find efficient networks.

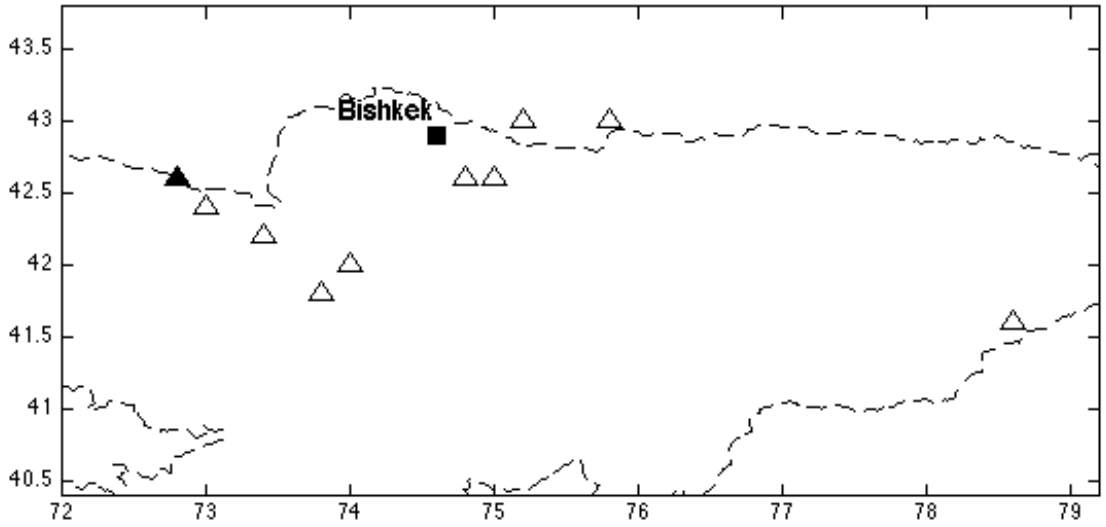

Bishkek
44°
42°
40°
72°
74°
76°
78°
80°
km
0
100

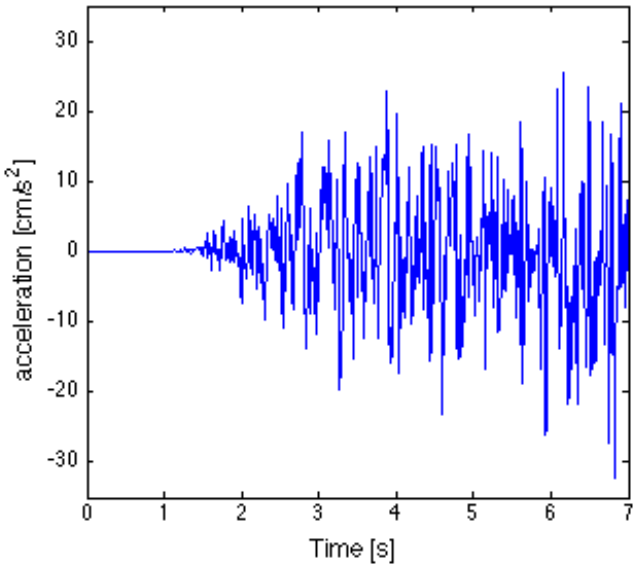

Errors in warning class given
Number of Events
Event class
correct
1 class
2 classes

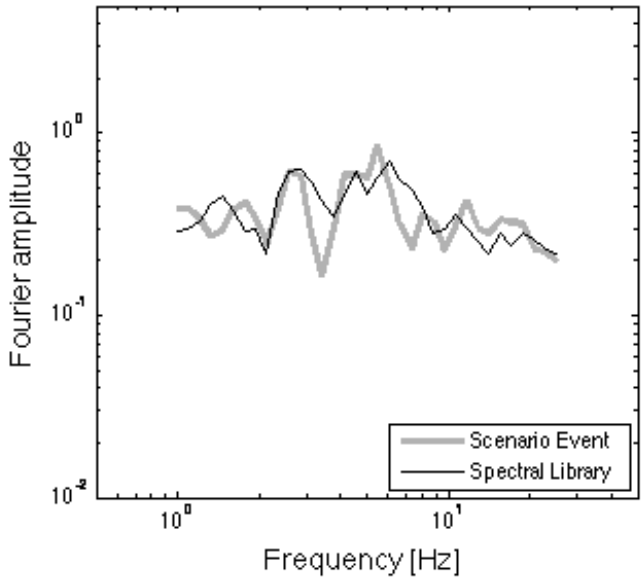

Mean t = 16s
Number of Warnings
Lead Time given [s]

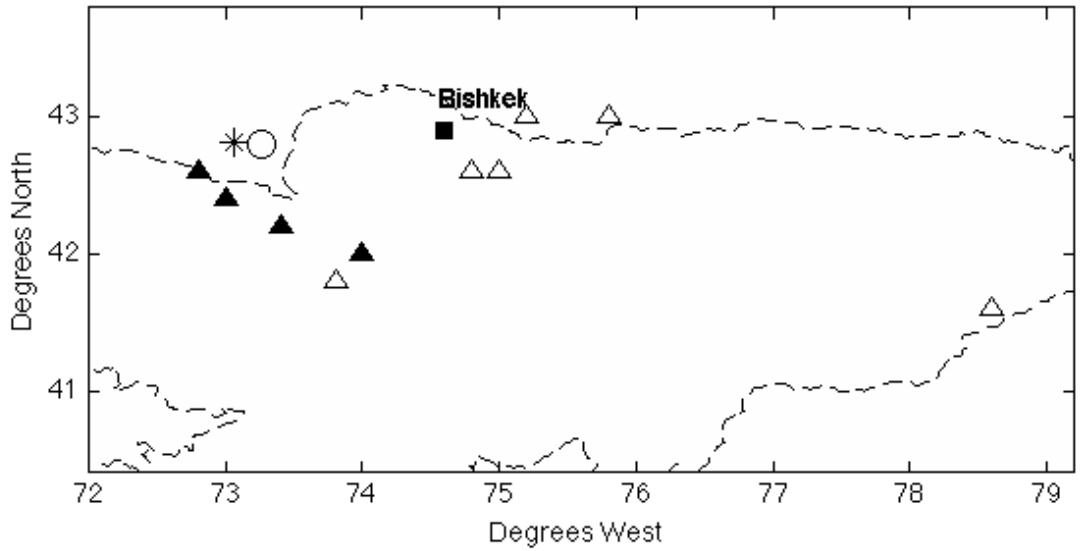

Lead Time [s]
Magnitude

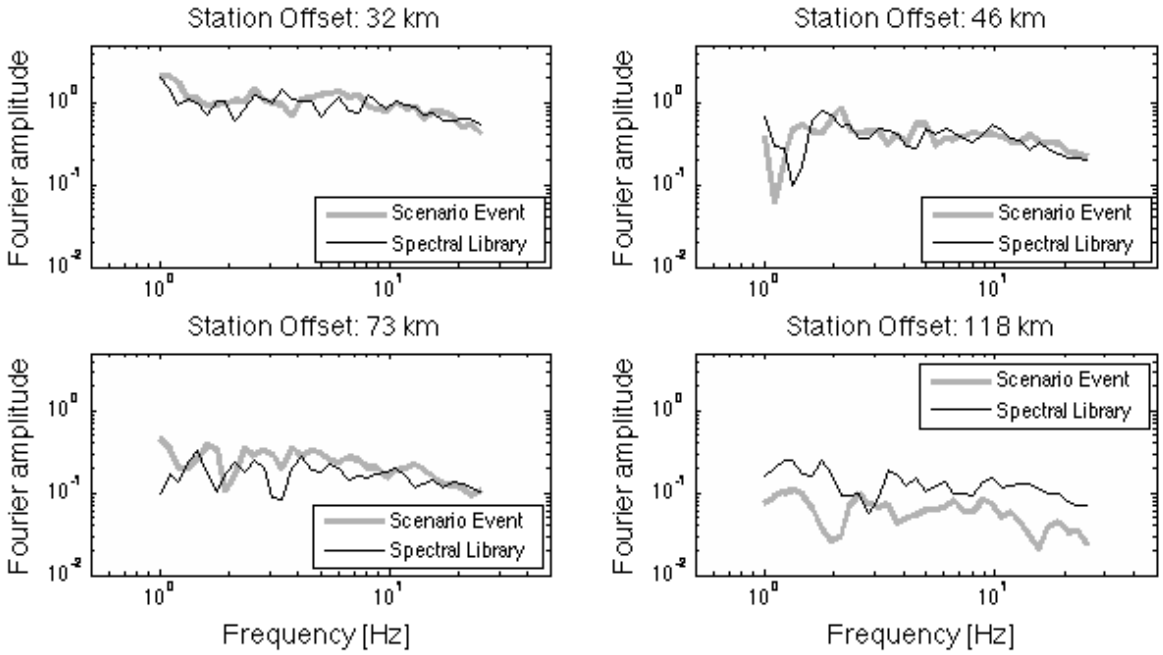

Lead Time [s]
Epicentral distance

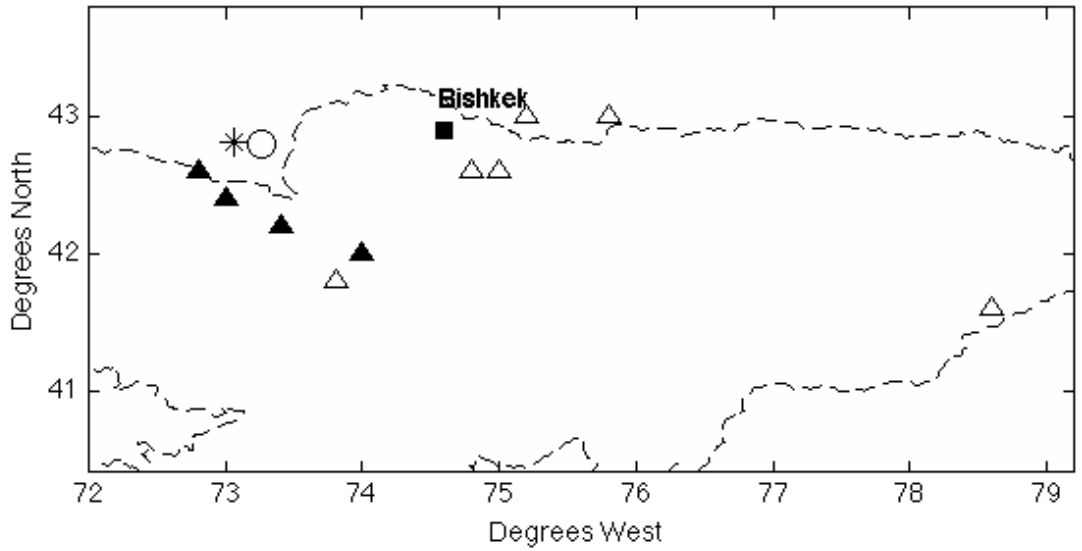

Bishkek
43.5
43
42.5
42
41.5
41
40.5
72
73
74
75
76
77
78
79

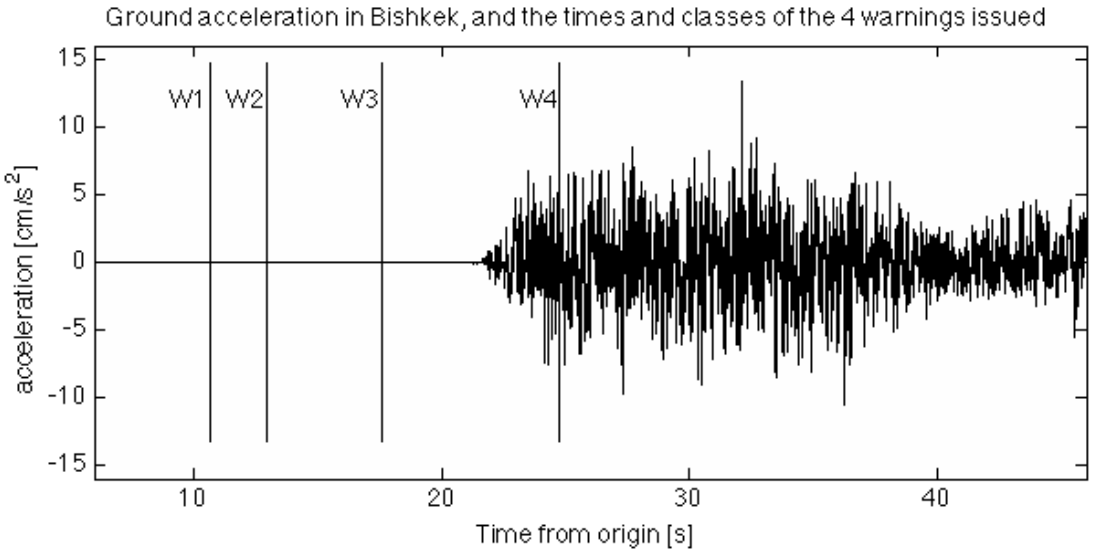

acceleration [cm/s^2]
30
20
10
0
-10
-20
-30
0
1
2
3
4
5
6
7
Time [s]


Fourier amplitude
10^0
10^{-1}
10^{-2}
10^0
10^1
Frequency [Hz]
Scenario Event
Spectral Library


Bishkek
Degrees North
Degrees West
43
42
41
72
73
74
75
76
77
78
79


Station Offset: 32 km
Station Offset: 46 km
Station Offset: 73 km
Station Offset: 118 km
Fourier amplitude
Frequency [Hz]
Scenario Event
Spectral Library

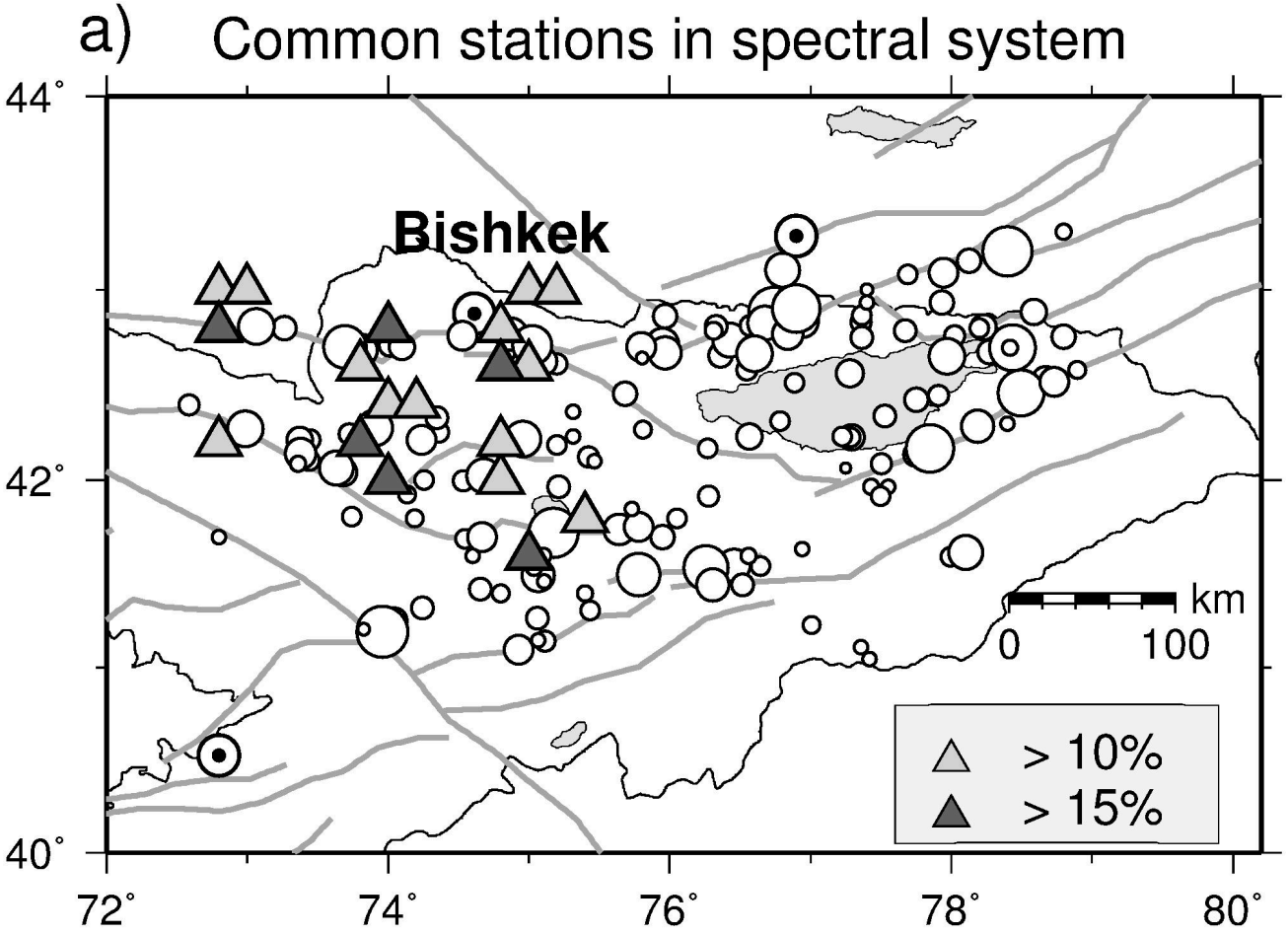

Bishkek
43
42
41
Degrees North
72
73
74
75
76
77
78
79
Degrees West


Ground acceleration in Bishkek, and the times and classes of the 4 warnings issued
W1
W2
W3
W4
15
10
5
0
-5
-10
-15
acceleration [cm/s^2]
10
20
30
40
Time from origin [s]

So which system is better?

system used	cost	% correct warming	mean lead time [s]
acceleration	0.482	84	13.4
spectral, 1 station	0.452	73	28.1
spectral, 2 stations	0.405	75	20.2
spectral, 3 stations	0.404	80	18.4
spectral, 4 stations	0.388	84	16.0
spectral, 5 stations	0.448	83	14.0

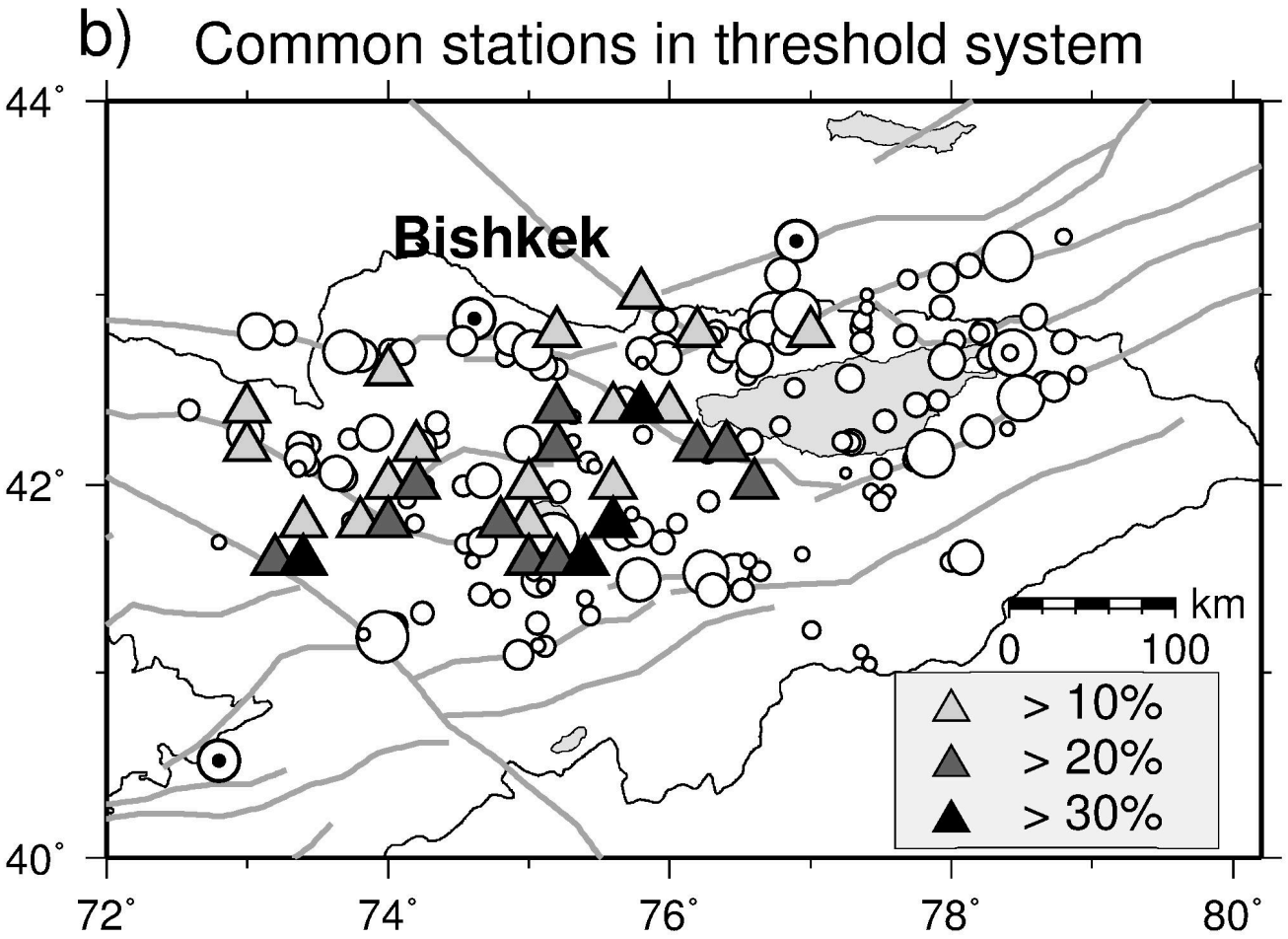
Most common stations in the 1000 networks with lowest cost



Main advantages:

- Smaller blind zone
- No critical stations locations

Most common stations in the 1000 networks with lowest cost



Conclusions

- New EEW technique which uses the waveform of the first few seconds of detected signal.
- Feasibility of these systems is demonstrated for Central Asia, where they are a component in a complex rapid response system (Talk by Pittore tomorrow).
- These spectral systems represents an improvement on systems only using ground motion thresholds, as larger warning times can be provided.
- Warnings can also be issued in an evolutionary way, starting with just a single trigger.
- Method for designing efficient system remains open for input from local civil authorities.

Conclusions

- New EEW technique which uses the waveform of the first few seconds of detected signal.
- Feasibility of these systems is demonstrated for Central Asia, where they are a component in a complex rapid response system (Talk by Pittore tomorrow).
- These spectral systems represents an improvement on systems only using ground motion thresholds, as larger warning times can be provided.
- Warnings can also be issued in an evolutionary way, starting with just a single trigger.
- Method for designing efficient system remains open for input from local civil authorities.