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Testing ElarmS with Japanese Earthquakes

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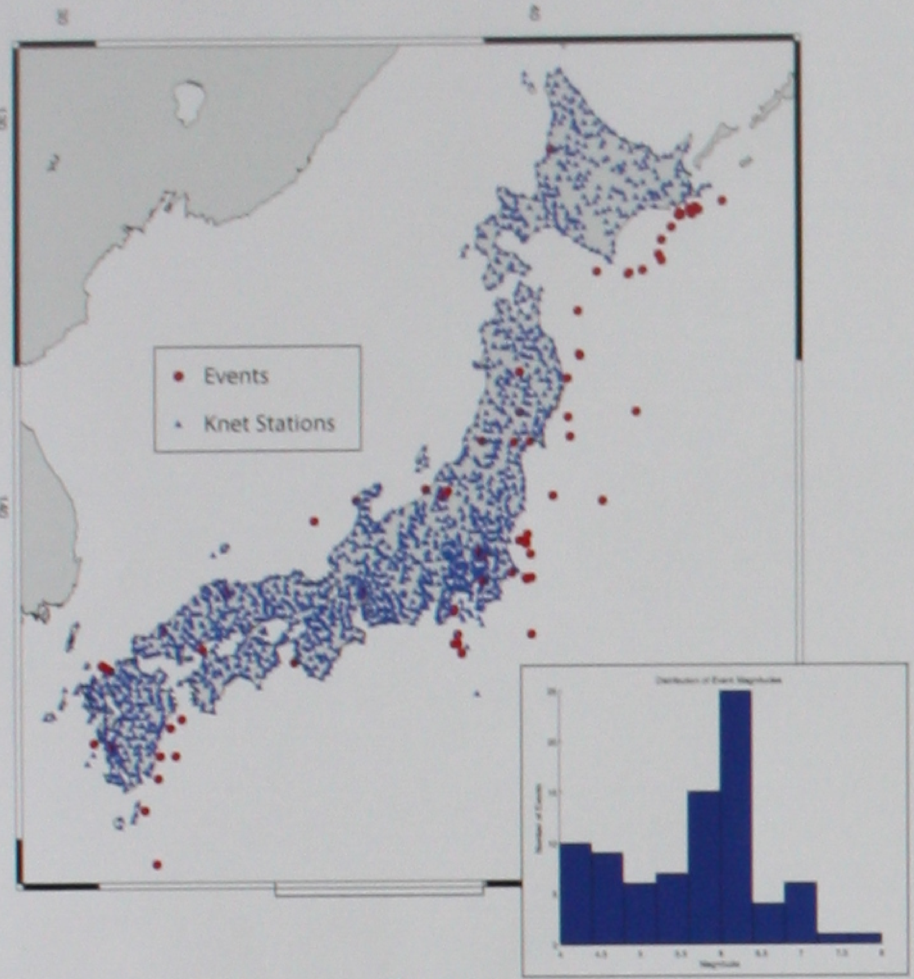
Introduction

Earthquake Alarm Systems, or ElarmS, is a network-based earthquake early warning methodology developed in California. It is currently processing seismic data in realtime from stations throughout California. Here we test the methodology's ability to process large-magnitude events, using a dataset of 84 Japanese earthquakes recorded by the K-NET strong motion seismic network.



Dataset

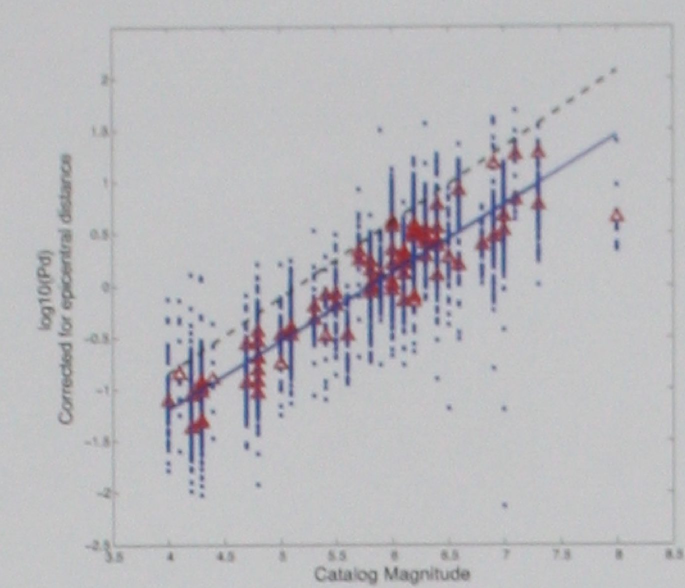
K-NET consists of 1,000 digital strong-motion seismometers spaced at approximately 25km intervals throughout Japan. Each station is capable of recording acceleration up to 2000 cm/s2. Our K-NET dataset contains 84 earthquakes occurring within 100km of K-NET stations between September 1996 and June 2008 (above). The magnitudes range from 4.0 to 8.0, the largest being the 26 September 2003 Tokachi-Oki event. Forty-three of the events are of magnitude 6.0 or greater.

Method

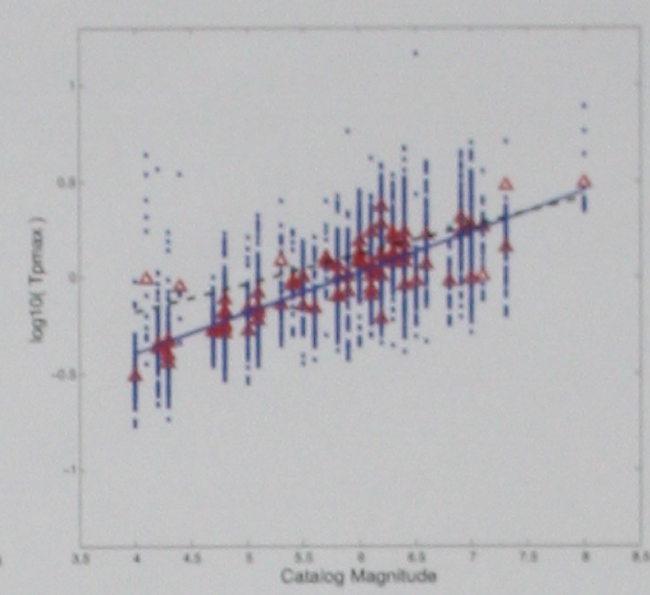
ElarmS estimates magnitude from the amplitude and frequency content of the P-wave. Maximum predominant period, Tpmax, and peak displacement, Pd, are recorded in the first several seconds of P-wave arrival at each station. ElarmS utilizes both relationships to calculate two magnitude estimates, which it then averages together to improve accuracy in the final event estimate. As more stations report P-wave arrivals, ElarmS incorporates their Tpmax and Pd measurements into the average for an overall estimate of event magnitude. The estimated magnitude and location are applied to regional attenuation relations to predict impending ground shaking.

Performance

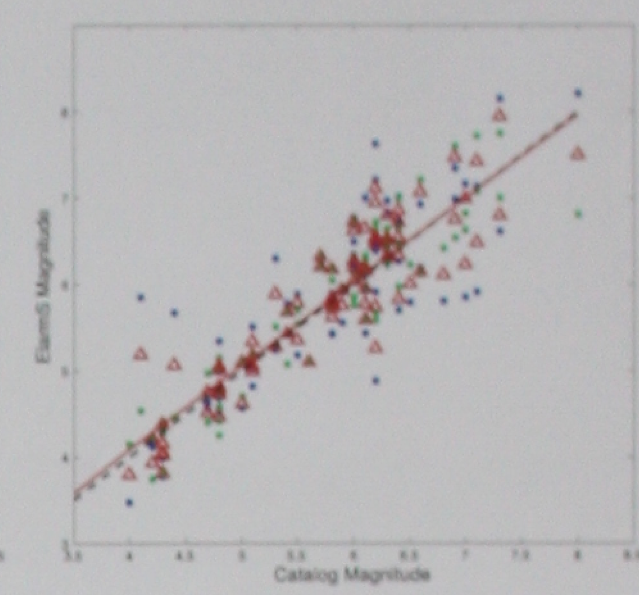
Magnitude Estimation



Peak Displacement, Pd:
We find a local relationship between magnitude and peak displacement of log10(Pd) = -4.02 + 0.66*M, corrected for epicentral distance (above). The Pd relations have comparable slopes for Japan and Northern California, but Japan displays lower observed Pd values, implying greater attenuation in the region.

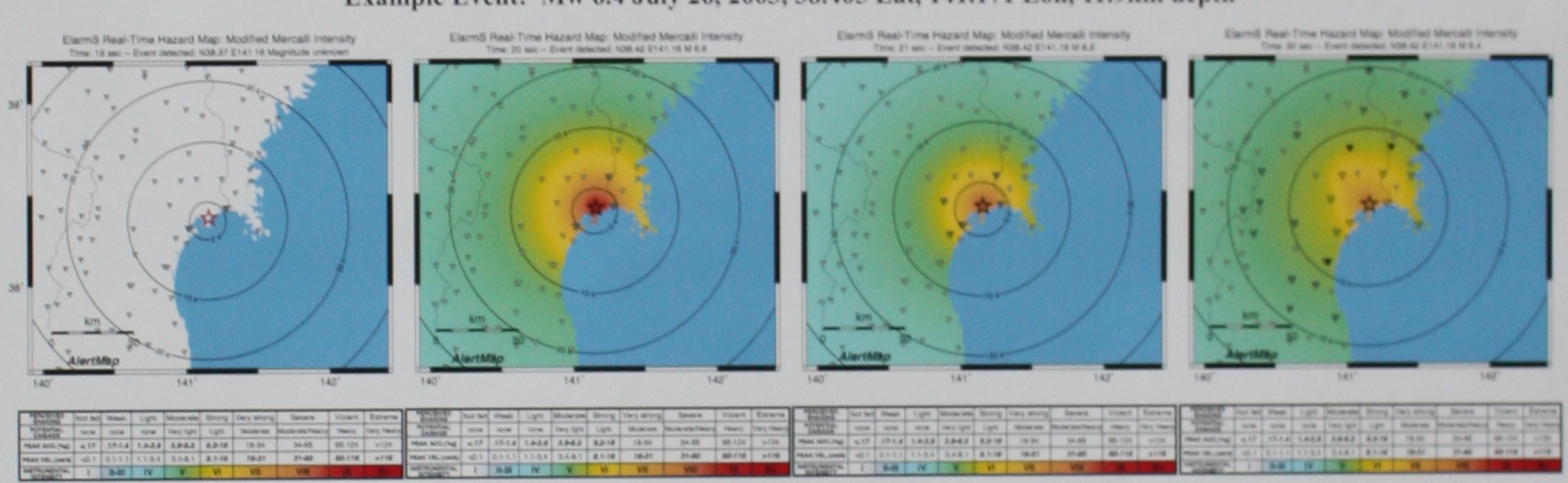


Maximum Predominant Period, Tpmax:
We use a least-squares fit to calculate a local relationship between magnitude and Tpmax of log10(Tpmax) = -1.22 + 0.21*M (above), compared to log10(Tpmax) = -0.78 + 0.15*M for Northern California (Wurman et al, 2007). The observed Tpmax values from Japan are similar to those of Northern California, with a slightly steeper slope for Japan.



The "ElarmS" magnitude is a linear average of the magnitudes estimated from Pd and Tpmax.

Example Event: Mw 6.4 July 26, 2003, 38.405 Lat, 141.171 Lon, 11.9km depth



The first triggers are recognized at 07:13:19 at two stations simultaneously. A location estimate is available immediately.

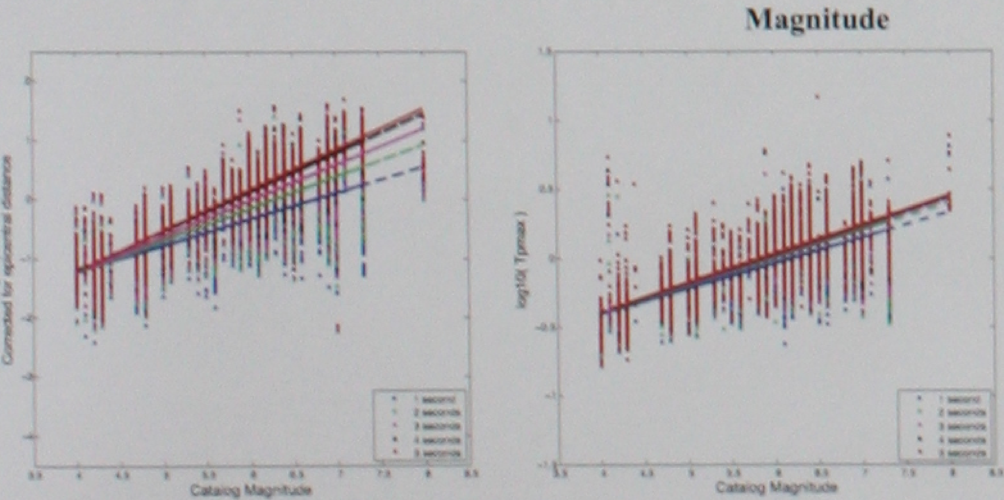
After one second magnitude is estimated at 6.6. A third station triggers and the location estimate is adjusted. Peak ground shaking is predicted in the region based on the magnitude and location.

After two seconds estimated magnitude is adjusted down to 6.2. Two more stations trigger.

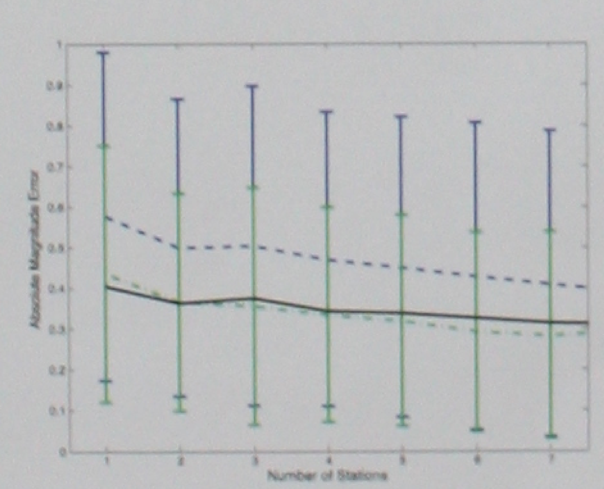
As the peak ground shaking is observed at stations close to the epicenter these observations are incorporated into the ground shaking prediction. The final ElarmS magnitude estimate is 6.4, 12 seconds after the first trigger, and with 26 stations triggering.

Error Dependencies

Magnitude

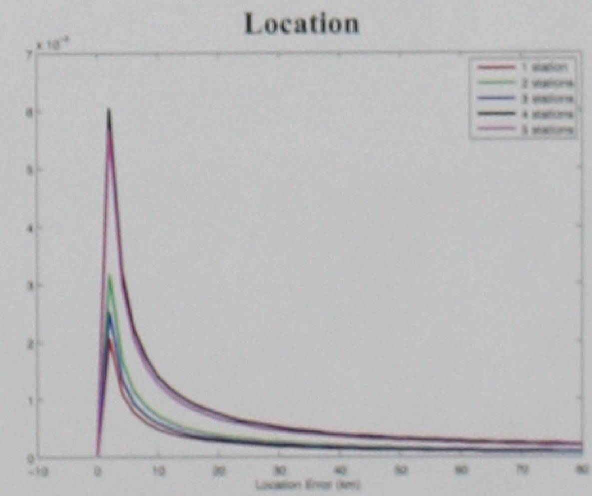


Magnitude estimates improve with additional seconds of P-wave data at each station. Peak displacement is more sensitive to number of seconds than Tpmax is.



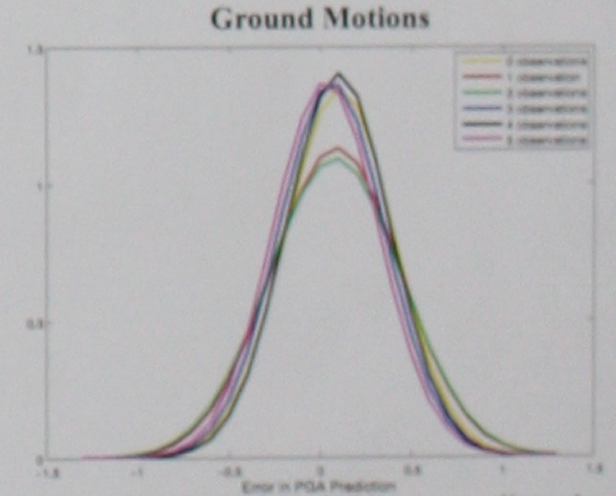
Magnitude is also dependent on the number of stations providing Pd and Tpmax data. Magnitude error decreases as additional stations trigger.

Location



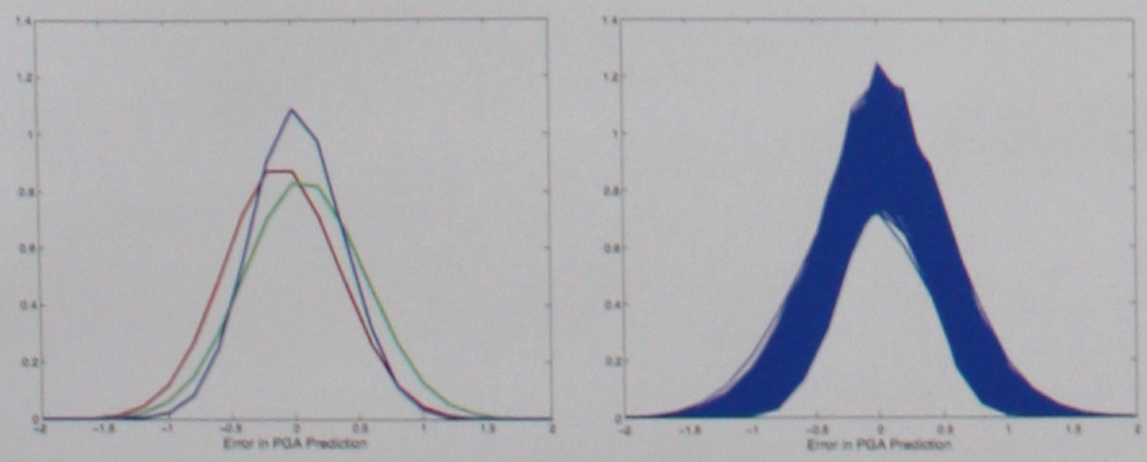
Location estimates are dependent on the number of stations providing P-wave trigger times.

Ground Motions



Predictions of ground shaking are adjusted as actual peak ground shaking is observed at stations near the epicenter. Errors in the PGA predictions are thus dependent on the number of PGA observations.

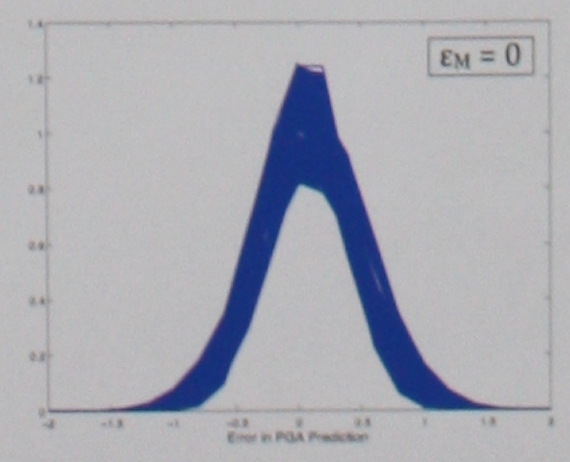
Error Model



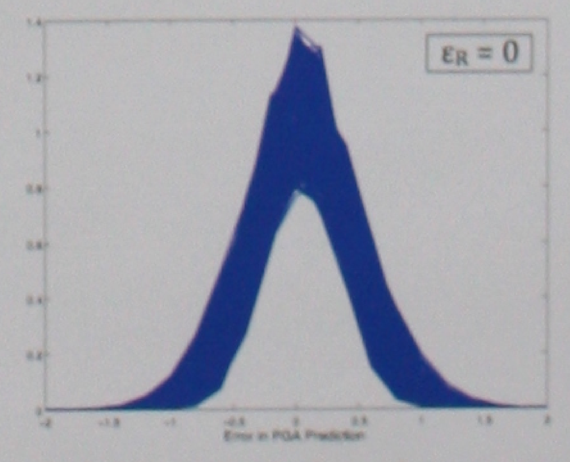
The model compares error-free PGA predictions to predictions made with the addition of simulated errors. The errors are generated with a Monte Carlo method.

1086 error distributions created by the model. Each distribution corresponds to a unique combination of data inputs.

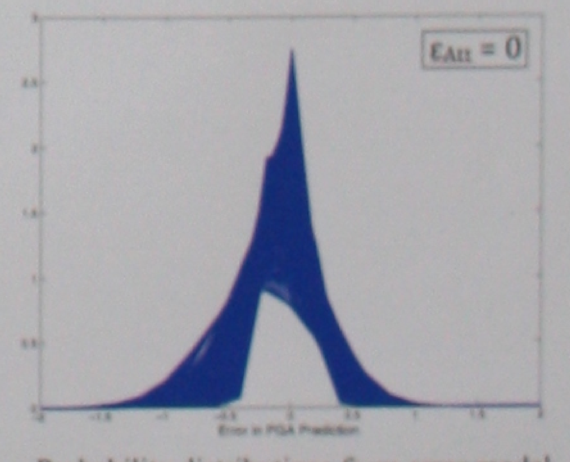
Sensitivity Analysis



Probability distributions from error model when magnitude error is set to zero.



Probability distributions from error model when location error is set to zero.



Probability distributions from error model when attenuation relation error is set to zero.

Conclusion: The largest source of error is the attenuation relations.