Annual Project Summary

Early warning of earthquake shaking in southern California

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Investigations undertaken

(1) Development of rapid magnitude determination algorithms for southern California using data from California, the Pacific Northwest and Japan.
(2) Implementation of improved algorithms into early warning package for southern California.

Results

This work builds on previous observations of a scaling relation between the predominant period of a P-wave and earthquake magnitude. We have found this scaling relation to be useful for rapid magnitude estimation as it requires only the first 4 sec of the P-wave recoded within ~100 km of the epicenter. This relation was first observed for southern California [*Allen and Kanamori*, 2003] and is shown in Figure 1.

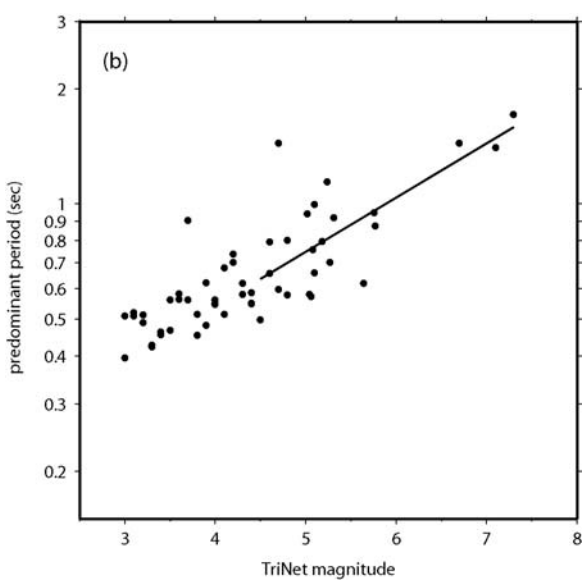

Figure 1. Scaling relation between predominant period and magnitude for events in southern California. The points are event averages of predominant period observations at all broadband stations within 100 km. The best fit line is also shown.

For the purpose of earthquake early warning it is the larger magnitude events which are important (M > 6). The existing dataset for southern California includes only 3 such events (Figure 1). We therefore look to other regions of the world for suitable datasets to test the predominant period scaling relation in order to verify that it is sufficiently robust for use in an early warning system.

We have gathered waveform datasets for the Pacific Northwest (PNW) and Japan. For the PNW we use 27 events ranging in magnitude from 3.5 to 6.8 recorded by the broadband Pacific Northwest Seismic Network. We use sensors within 150 km of the epicenter (Figure 2a) providing a total of 417 waveforms. Data from Japan comes from the broadband F-net. We use 62 events ranging in magnitude from 3.8 to 7.4 and recorded at stations within 150 km providing 305 waveforms (Figure 2b).

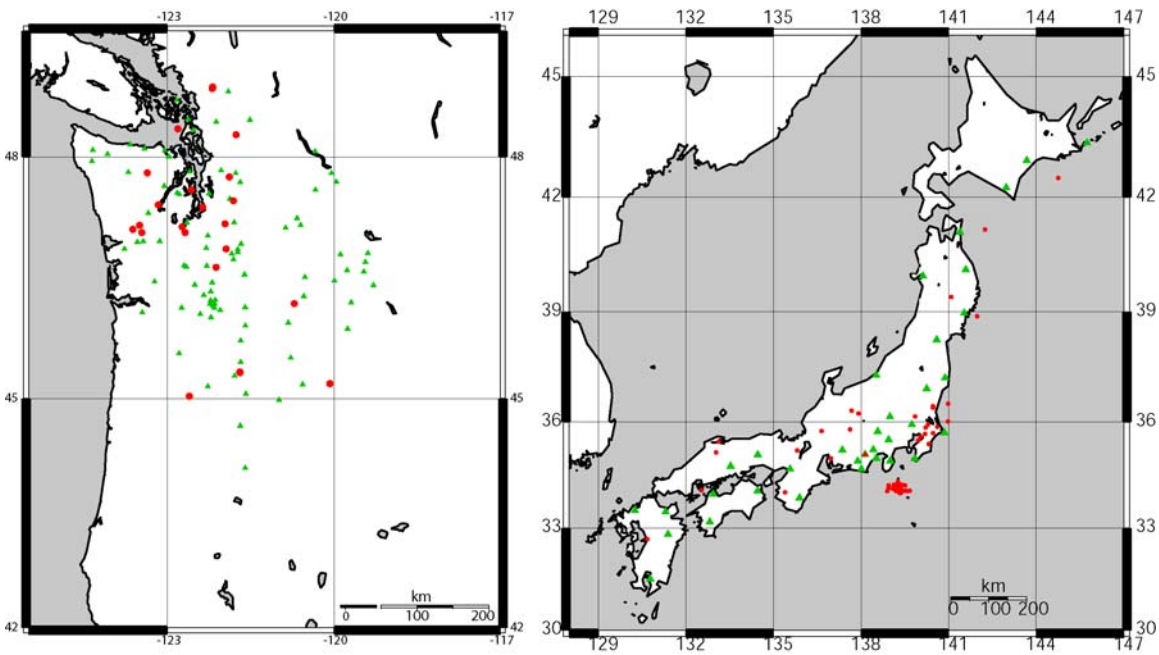

Figure 2. Maps of earthquake epicenters and broadband stations used in our study. (a) Stations of the Pacific Northwest Seismic Network (green triangles) and events (red dots). (b) Stations of F-net (green triangles) and events (red dots).

Using these datasets we applied the same algorithms used in southern California to measure predominant period. The results from the PNW dataset are very similar to those of southern California. Figure 3a shows the predominant period recorded within 4 sec, having low-passed the data at 3 Hz (as was done for California). When the PNW data is plotted with the southern California data we see a similar scaling relation (Figure 3b). The results from the PNW suggest that:

(1) The information contained within the first 4 sec of the P-wave is sufficient to estimate the magnitude of an earthquake.

(2) Although the best estimates require 4 sec of data, preliminary estimates are available prior to this and may not require the full 4 sec.
(3) The similarity of the scaling relation for southern California and the PNW suggests that the differences in attenuation characteristics between these regions do not have a significant effect on the frequency content of the P-wave.

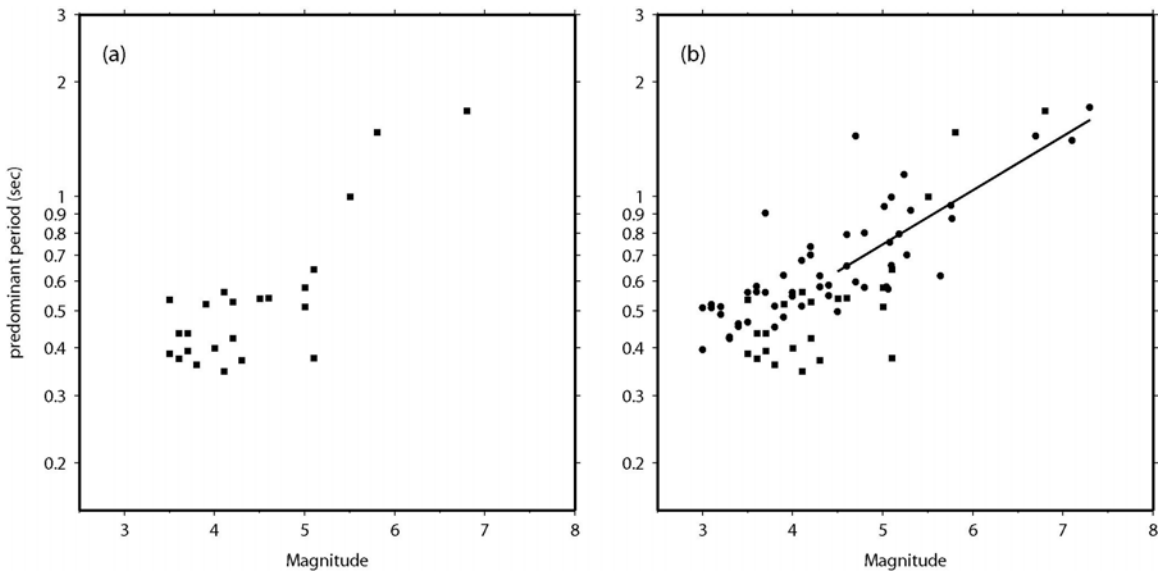

Figure 3. Scaling relations between predominant period and magnitude. (a) Data from events in the Pacific Northwest. (b) Data from the Pacific Northwest (squares) and southern California (circles) showing that a similar scaling relation exists for the two regions.

The predominant period observations from the Japanese dataset show different characteristics from those of the western US. Figure 4a shows the event-averaged predominant periods measured in the same way as southern California (low-pass filtered at 3 Hz). The periods are greater than those observed in the US, and the scatter is more substantial. The data also shows an apparent saturation of the predominant period for events with magnitudes greater than 6. We have experimented with the predominant period measurement in an attempt to improve the sensitivity of the measurements to magnitude for these large magnitude events. We find that this is possible by low-passing the data 0.3 Hz and using the first 5 sec of data. The results are shown in Figure 4b. The results of our study of Japanese earthquakes are:

(1) A scaling relation between predominant period and magnitude is observed in Japan, however, the uncertainty in the relation is greater and its sensitivity to M > 6 events is reduced in comparison with the western US.
(2) Low-pass filtering at lower frequencies (0.3 Hz in this case) improves the magnitude sensitivity.

Conclusion (2) is similar to the observation in southern California that the best scaling relation for smaller events (M < 4.5) requires data low-passed at 10 Hz while for M > 4.5 data low-passed at 3 Hz provides the best results.

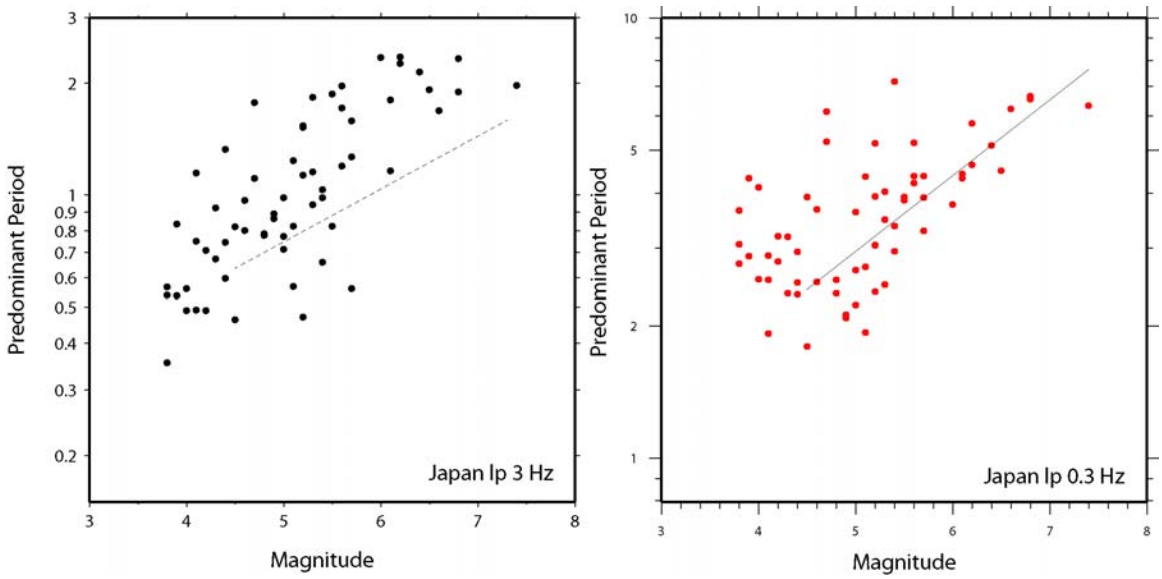

Figure 4. Scaling relations for Japan. (a) Maximum predominant periods observed within 4 sec having low-passed the data at 3 Hz (points). The dashed line is the best fit relation for southern California. (b) Maximum predominant periods observed within 5 sec having low-passed the data at 0.3 Hz (points) and the best fit relation (line).

We have also determined the accuracy of the magnitude estimate as a function of the number of stations that have recorded a P-wave arrival, and can thus provide a predominant period observation. This is to illustrate the application of our best fit scaling relations to early warning. The magnitude of an event is estimated sequentially using the closest station, then the closest two stations, then three etc. Once more than one station has recorded the P-wave, the predominant period estimates from each station are averaged. The average predominant period is then converted to a magnitude using our best fit relations for each region. Figure 5 shows histograms of the error in the magnitude estimate for the PNW and Japan. The average absolute error is initially greater that 0.5 magnitude units but reduces as more station observations are available. The final average magnitude error is 0.32 and 0.22 for the PNW and Japan respectively.

In addition to the above described investigation into the predominant period scaling relation we have incorporated improved relations into our suite of early warning algorithms for southern California. These algorithms now include all the necessary components to trigger on P-wave arrivals, determine the best available hypocenter (using one, then two, then three etc station arrival times), estimate the magnitude and determine maps of predicted peak ground motion across southern California.

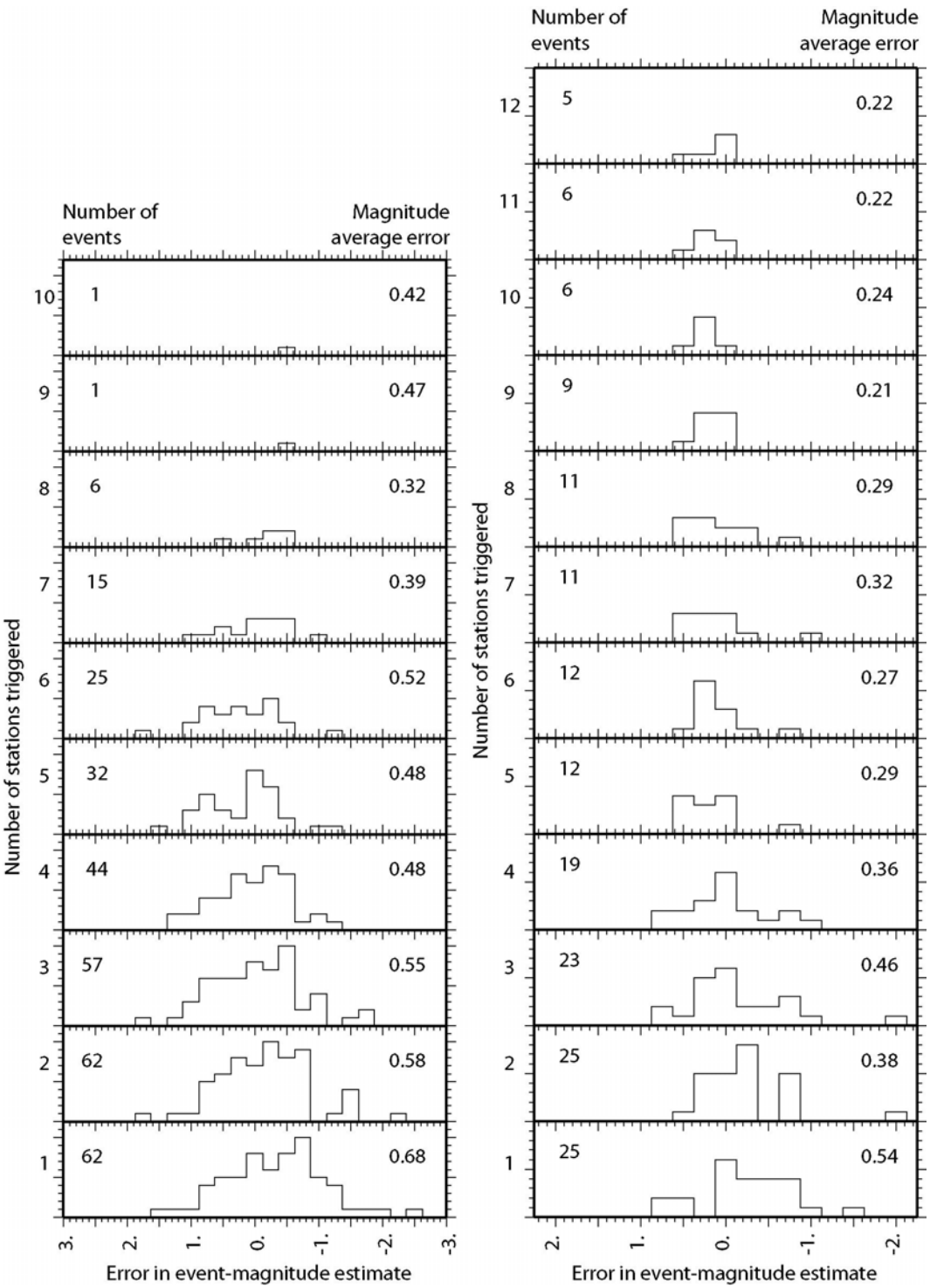

Figure 5. Histograms showing the error in the magnitude estimate using the best-fit scaling relations for (a) the Pacific Northwest and, (b) Japan. Histograms of the error are determined using the average predominant period observation from one, two and three stations etc., showing the improvement in the magnitude estimate as more station data becomes available.

Abstracts resulting

Lockman, A., and R.M. Allen, Rapid magnitude determination using P-wave arrivals: Magnitude period relations for Japan and the Pacific Northwest. To be presented at AGU Fall Meeting 2003.

Allen, R.M., H. Kanamori. ElarmS: Earthquake early warning for southern California. To be presented at AGU Fall Meeting 2003.

Publications resulting

Lockman, A., and R.M. Allen, Rapid magnitude determination for earthquakes in Japan and the Pacific Northwest, in preparation.

Allen, R.M., H. Kanamori. A methodology for earthquake early warning in southern California, in preparation.

References

Allen, R.M., and H. Kanamori, The Potential for Earthquake Early Warning in Southern California, *Science*, *300* (5620), 786-789, 2003.