Testing Three Earthquake Early Warning Algorithms (EPIC, FinDer and PLUM) on Simulated Composite Offshore Earthquakes

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goal

Test existing and future ShakeAlert earthquake early warning (EEW) algorithms (EPIC, FinDer, and PLUM) using composite earthquake sequence pairs to better understand the behavior of each algorithm, as applied to offshore earthquakes.

issue

Properly detecting west coast USA offshore earthquakes is challenging for EEW systems and can be even more challenging for complex sequences (i.e., foreshock/mainshock/aftershock).

cause

The problem is two-fold. First, by definition, there is a lack of near-source stations and second there is a paucity of large offshore events that can be used to test and improve the EEW algorithms.

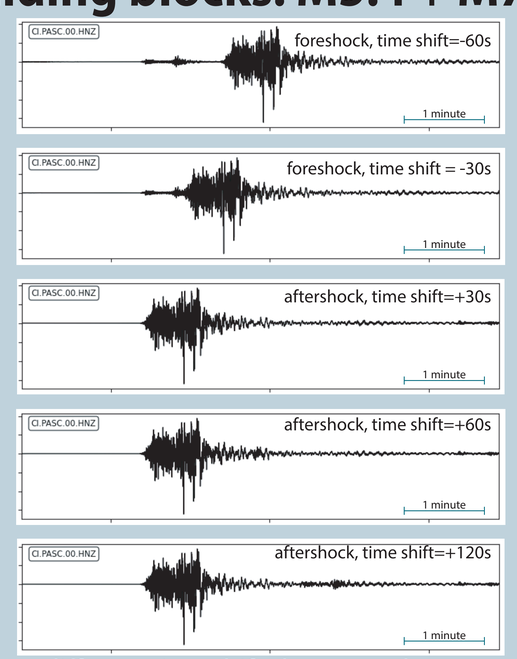
solution

To simulate offshore earthquake scenarios, we remove stations near the epicenter of the M7.1 Ridgecrest 2019 earthquake to create an artificial "coastline" at increasing distances from the source (ranges 25 - 150 km).

added complexity

Taking the tests to the extreme, we build test data using various scenarios of composite waveforms built from summation of pairs of time-shifted Ridgecrest M7.1 and M5.4 quakes recorded at the same stations.

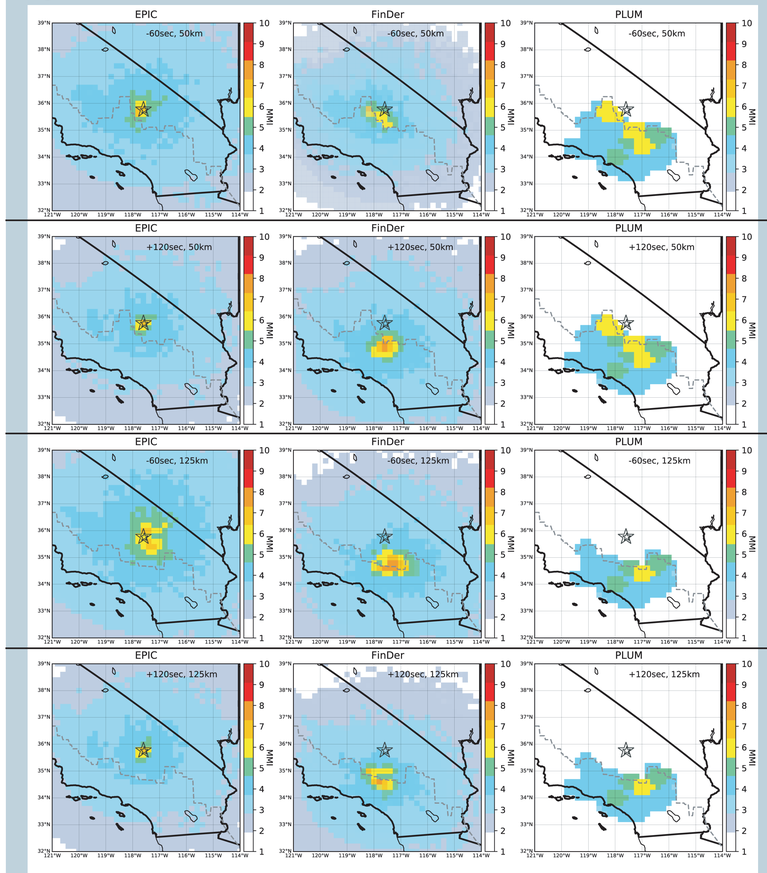
building blocks: M5.4 + M7.1



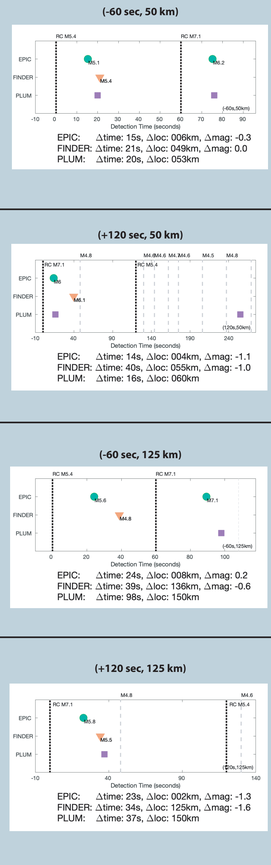
We use different time shifts between the earthquake pairs (-60 to 120s), where negative time shifts build a foreshock/mainshock and positive time shifts build a mainshock/aftershock.

results

ground motion



source based



algorithms

EPIC - traditional point-source, determines location and magnitude
FinDer - ground-motion based finite-source, determines a line-source
PLUM - ground-motion based, detects sites with strong-motions

Inclusion of a M5.4 foreshock/aftershock: only slightly modifies the final ground motion forecasts, whereas in source based methods the magnitude estimates can be in error by 1-2 magnitude units.

EPIC

>> robust epicenter estimates (errors < ~20 km).
>> detection speeds equal or exceed other algorithms.
>> underestimates ground shaking in the LA basin, but as we move to ground motion space the incorporation of the other two algorithms can assist.

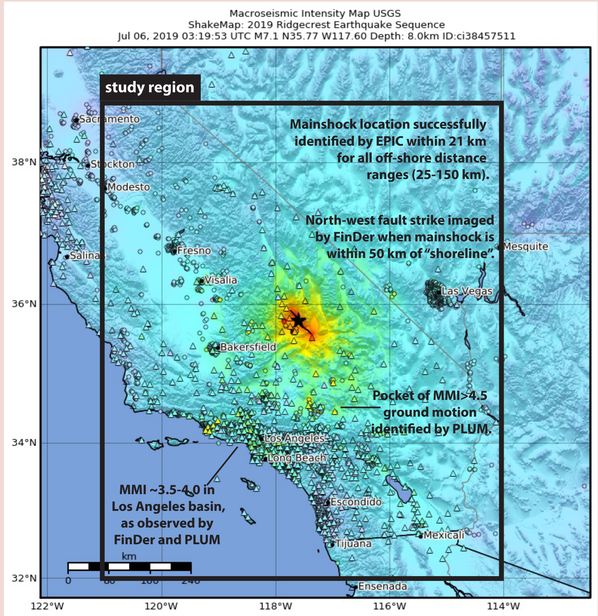
FinDer

>> line-source strike and length mimics true rupture for events within 50 km of 'shoreline'.
>> can chart the evolution of increasing ground motion of complex sequences.
>> earthquake location estimate is degraded when the earthquake is more than 75 km off-shore (likely not a problem in ground-motion space).

PLUM

>> can identify pockets of high-ground motions.
>> can successfully identify large ground motions produced by the summation of multiple aftershocks.
>> not able to determine the epicenter of off-shore events (likely not a problem in ground-motion space).

ground truth



discussion

Leveraging ground motion information can potentially sidestep the need for:

>> refining magnitude estimates for offshore and out-of-network earthquakes.
>> updating algorithms to detect multiple quakes.
>> requiring PLUM to estimate epicenter and magnitude.
>> aggregating both magnitude and location information (i.e., aggregating only ground motion).
>> retooling methods to account for various pockets of high ground motions (i.e., basin effects).
>> untangling each individual foreshock and aftershock.

conclusions & summary

1) A ~M7.1 earthquake within 150 km of the "shoreline" is detectable by all algorithms as it will produce large on land ground motions.
2) In all cases, if the M5.4 aftershock is within 120 seconds of the mainshock, it is indistinguishable as the mainshock coda overprints the M5.4 signal.
3) Identification of the location and magnitude of individual foreshocks and aftershocks is difficult, and we favor using ground motion estimates instead.
4) Using all three algorithms in concert will provide more robust ground motion estimates.

Consistent with ShakeAlert's future plans, this work indicates that moving to ground-motion-based alert association and aggregation has the potential to obviate some identified challenges and can produce more robust EEW alerts for off-shore events.

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