Vertically Integrated Seismological Analysis I : Modeling

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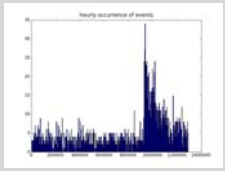
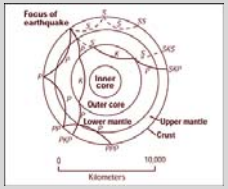
Locating and identifying seismic events is hard

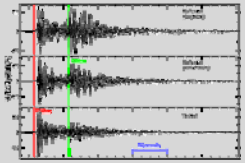
Many events occur on the earth in any given hour



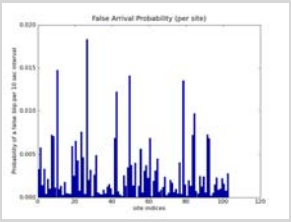
The events produce many different types of waves



Seismic Waves are very noisy



Stations may generate false signals



Probabilistic Inference

Extends the age old principles of logical inference to make deductions about the world in the presence of uncertainties.

It is based on an assumed state of the world before seeing any evidence (the so called "prior" belief) and a probabilistic model of how the world evolves.

When we see evidence we update our belief about the state of the world . Possible states of the world which are more likely to have produced the observed evidence are considered more likely to be true. This is the so-called posterior belief.

Prior Belief → Seismic Evidence → Posterior Belief

Learning Models from historical data

Hierarchical statistical models allow us to learn from noisy or partially observed historical data.

Historical Data → Statistical Machine Learning → Prior Belief

Humans do it all the time..

Season → Cloud Color → Rain

We know from experience that black clouds tend to cause rain more often than white clouds. Now, if we see rain outside we would assume that the clouds are probably black.

During the rainy season we would expect the clouds to be black even before knowing whether or not its raining. But if we find out that its not raining then our belief that the clouds are black would be diminished.

General Benefits of Probabilistic Inference

Precise mathematical specification of beliefs

Robust in the presence of missing or noisy data.

Example

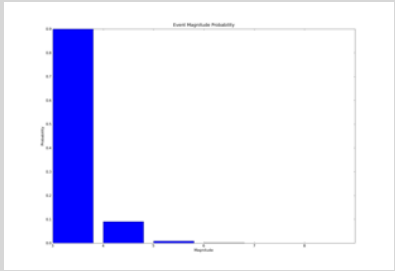
Sub-threshold signals can be used to detect weak events

Prior beliefs about Seismic Events

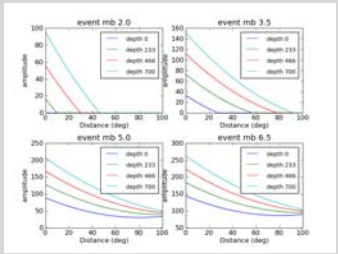
The number of magnitude 3 or higher events occurring anywhere on the earth has a mean of 6.

Informative prior over locations of earthquakes and a uniform prior for man-made seismic events.

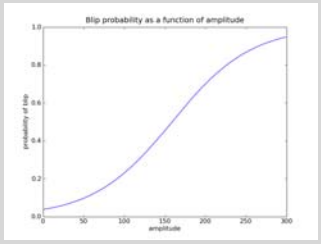
The magnitude of the event is 10 times more likely to be 3 than 4 and so on



Wave amplitude weakens as it travels through the earth



Probability of a wave generating a blip increases with wave amplitude



Waves are expected to arrive around their predicted travel time.

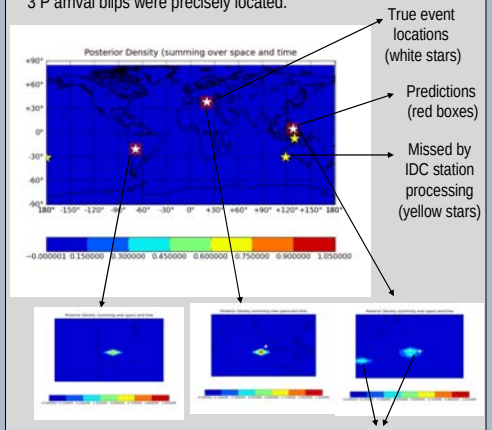
Preliminary Results

Input: IDC station processed P-wave arrivals marked as "blip" or "no blip"

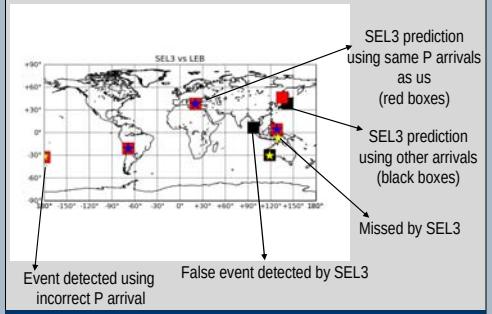
Output: Location, time, and magnitude of seismic events

Evaluation: Events which produced 3 or more P-wave arrival blips in the IDC station processing.

Early Results: On 2 hours of data, all the events which generated 3 P arrival blips were precisely located.



Bimodal posterior density
Gives more information to analysts



Conclusions

Posterior probability of event locations eliminates spurious events

Doesn't miss any event which it is supposed to have detected

Slightly worse in terms of precise event location. This is perhaps due to an approximation of the travel time table.

Can't rely on station processing. Need a vertically integrated model which models wave-forms directly from event parameters