Testing and Enhancing the NET-VISA Software of the Commission
Fusion of Seismic and Hydro-Acoustic Propagation

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Introduction

We present a probabilistic generative model for describing underwater explosions, and the propagation of the resulting hydro-acoustic energy (the *H*-phase) to the network of hydrophone stations maintained by the International Monitoring System (IMS). The model, whose components are calibrated on historical data, gives a formal criteria for accepting, or rejecting, events as well as the posterior probability distribution of their locations. Offline comparisons against Global Association (GA) [4], whose results are published in the Secure Event List (SEL) 3 bulletin, demonstrate that the new algorithm can locate upto twice as many *interesting* hydro events (Table 1 on rightmost panel). The software is currently deployed at the International Data Centre (IDC) for evaluation, where results on a recent underwater volcano demonstrated the ability to recover nearly 4 times the number of eruption events near the known ground truth location (Figure 4). Also, the number of events that qualified the criteria for the Reviewed Event Bulletin (REB) were more than twice that in SEL3.

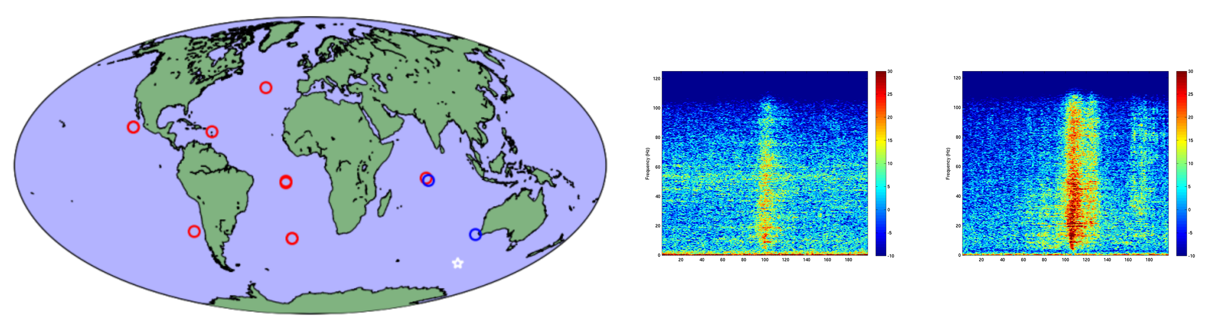
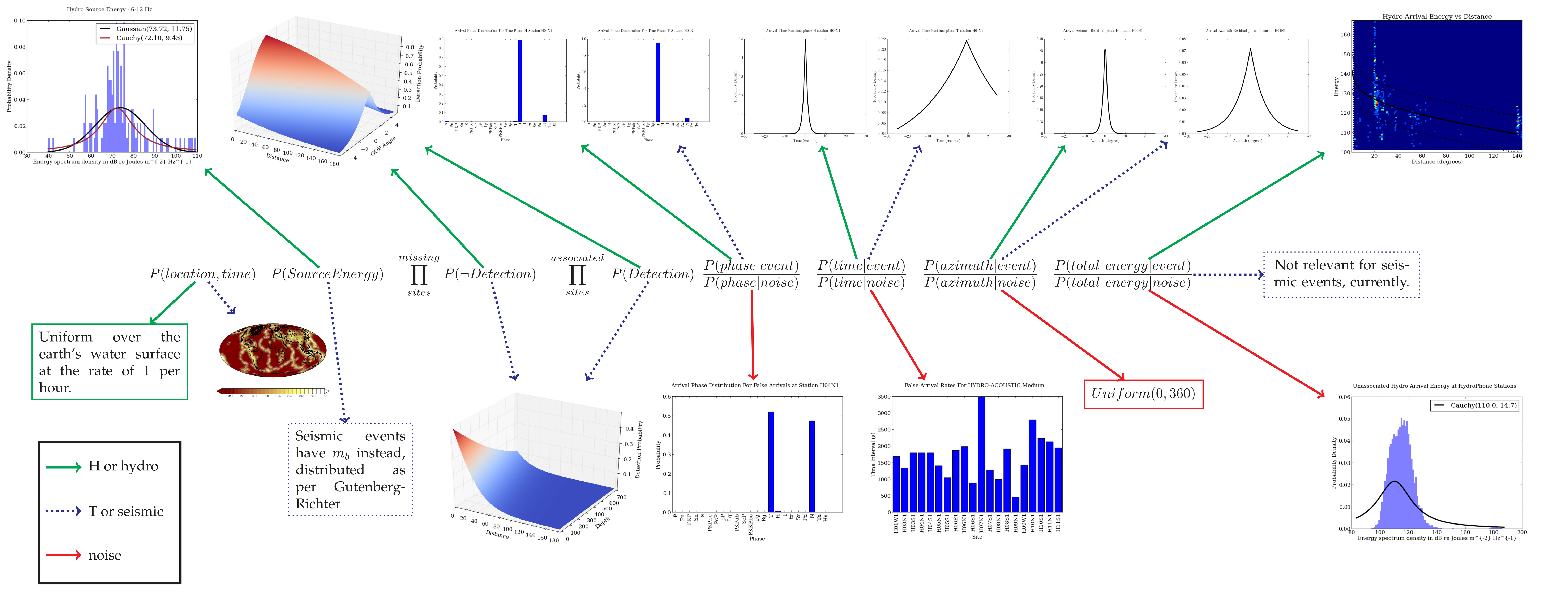


Figure 1: One of the interesting events, which is missed in SEL3. The white star in the first figure is the event location, while the blue and red circles are the stations that detect and miss, respectively, the event. The next two figures show the H-phase spectrograms.

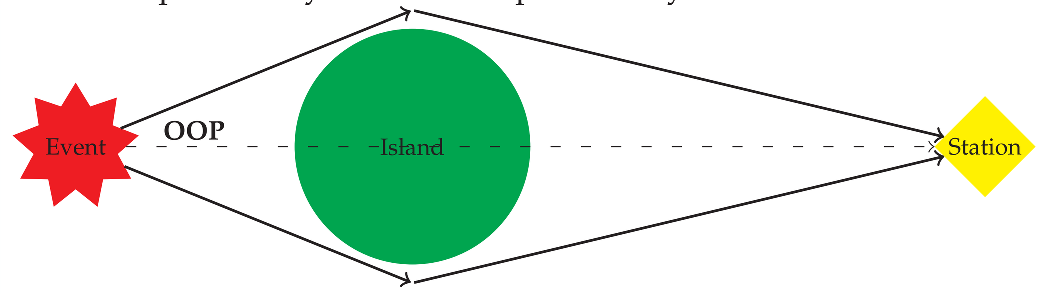
The new model is built as an extension of the seismic generative model in NET-VISA [2], now to be known as NET-VIS*HA* [1]. It includes the possibility of energy from seismic sources crossing over into the oceans, and getting detected as hydro-acoustic energy (the so called *T*-phase). We describe here some of the relevant concepts in the hydro-acoustic domain, as well as our generative model.
One of the new concepts for underwater explosions, or other types of pure hydro events, which don't have a magnitude, is a *source energy* attribute measured in dB re $Joules\ m^{-2}\ Hz^{-1}$ to represent the size of the event.

Generative Model – Probability of an event occurring, and producing the associated arrivals, versus noise generating the same arrivals



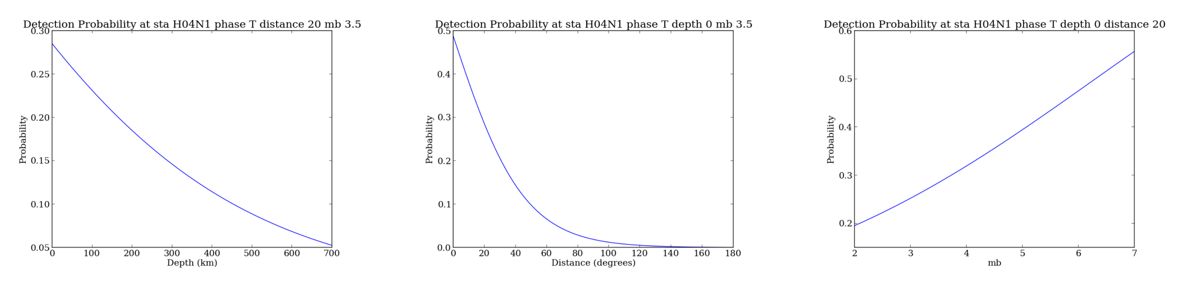
Blockage and Out-Of-Plane (OOP) Angle

The hydrophone network relies on the fact that sound can travel for thousands of kilometers underwater along the deep sound channel (also known as the SOFAR, Sound Fixing and Ranging, channel), with very little loss, as long as there is a direct unblocked path from event to station. The network of stations has thus been carefully placed to cover all of the oceans. Sometimes sound can bend around obstacles, for example islands, or shallow regions. We call this deviation from the direct path, the out-of-plane (OOP) angle. The generative model accounts for this angle when computing the detection probability of an event. In general, the detection probability decreases exponentially with distance and OOP angle.



Cross-over of seismic to hydro

Seismic events that are under, or close to, the ocean floor can generate hydro-acoustic energy that could reach the deep sound channel, and be detected by the hydrophone network. This coupling is due to a complex interaction of the seismic energy with the ocean bathymetry, and is hard to predict precisely. We have therefore built an empirical model of this coupling, as shown below.



(a) Depth (b) Distance (c) m_b.

Figure 2: Detection probability of a seismic event at a hydrophone station, as a function of depth, distance, and m_b.

Transmission Loss

The hydro-acoustic energy propagating from the event is lost due to two main factors – absorption (AT), which is primarily due to the presence of magnesium sulfate and boric acid in the oceans, in addition to the effect of water viscosity, and geometric spreading (GS), which is initially spherical, and later cylindrical in the SOFAR channel. As given by:

$$AT = \alpha \times range \qquad GS = 20\ log_{10}(3000) + 10\ log_{10}(range - 3000)$$

Where range is in meters. The absorption coefficient, α, for the oceans is not available in the literature for frequencies in the 1-100 Hz that are used by IMS.

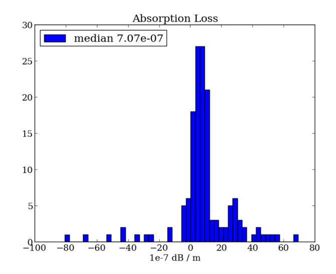


Figure 3: We directly estimate α by looking at differences in transmission loss between pairs of detections from the same event. After accounting for GS, the remaining loss is due to AT. Our estimate of α is $\mathbf{7 \times 10^{-7}}$ dB per meter in the 6-12 Hz frequency range.

Inference

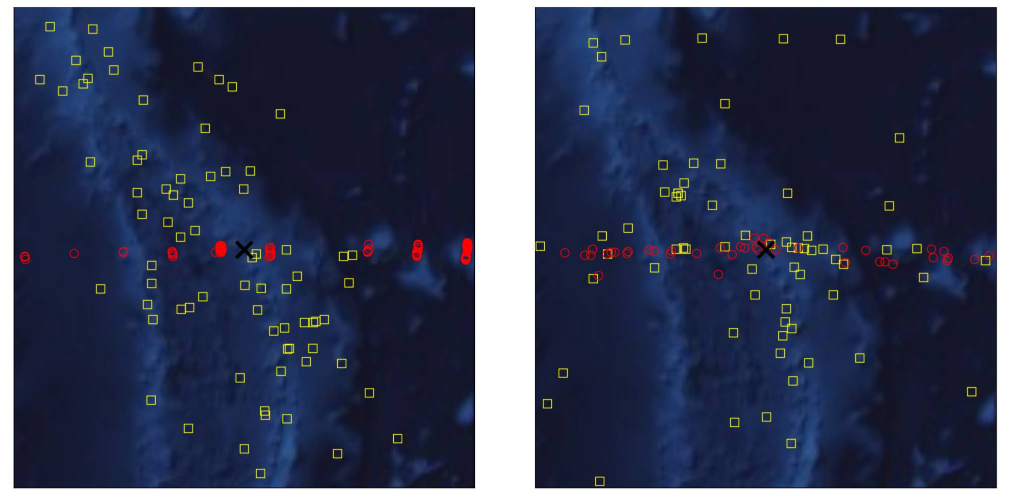
Inference involves producing a candidate list of events which are then tweaked, modified, and associated with various arrivals until a final set of events can be determined. Most of this infrastructure was already in place in NET-VISA to handle seismic events. The main change is in the way candidates are proposed.

Seismic detections have an azimuth and slowness along with time, which can be easily inverted to a single space-time location on the earth. In hydro, however, slowness is mostly constant at the inverse of the sound speed in water so there is no distance estimate. Each detection, therefore, leads to multiple candidate locations at all possible distances in steps of 1 degree.

The increase in running time due to hydro is a modest 10% or less. Even though more candidates are generated per detection, the number of hydro detections are much lower, and because there are fewer sites and phases to consider, the evaluation of the generative model is overall cheaper at each step of the inference.

Results – Under-water Volcano

The volcanic eruption of Ahyl Seamount (20.43 N, 145.04 E) in the Marianna Trench provided an unexpected blind-test for NET-VISHA, with hundreds of ground truth events.



NET-VISHA, 220 hydro events, 123 with 3 or more detections — SEL3 (GA), 57 hydro events, 53 with 3 or more detections.

Figure 4: The Location of hydro events (red circles) against the backdrop of seismic events (yellow squares) around the Ahyl Seamount (black X) as located by NET-VISHA and SEL3(GA) between April 23 and May 10, 2014.

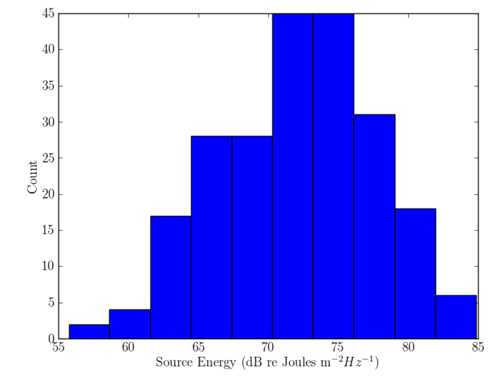


Figure 5: Source energy distribution of Ahyl eruption. For reference, 60 dB corresponds to a typical 1 kg, blast fishing, explosive.

Results – 2010

Version	Count
NET-VISHA	116
SEL3(GA)	54

Table 1: The number of interesting hydro events found in 2010. An event is interesting if it is built with two or more H phases such that all arrivals have a time residual of less than 1 second, an azimuth residual less than 1 degree, and are labeled H by station processing.

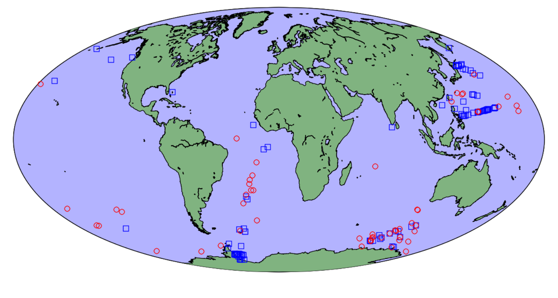


Figure 6: Locations of interesting hydro events in 2010 as found by NET-VISHA (blue squares) and SEL3 (red circles).

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