Threshold Monitoring Maps for Under-Water Explosions (S41B-4470)

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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, known as NET-VISHA, 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 5). Also, the number of events that qualified the criteria for the Reviewed Event Bulletin (REB) were roughly 20 to 50 % more than in SEL3.

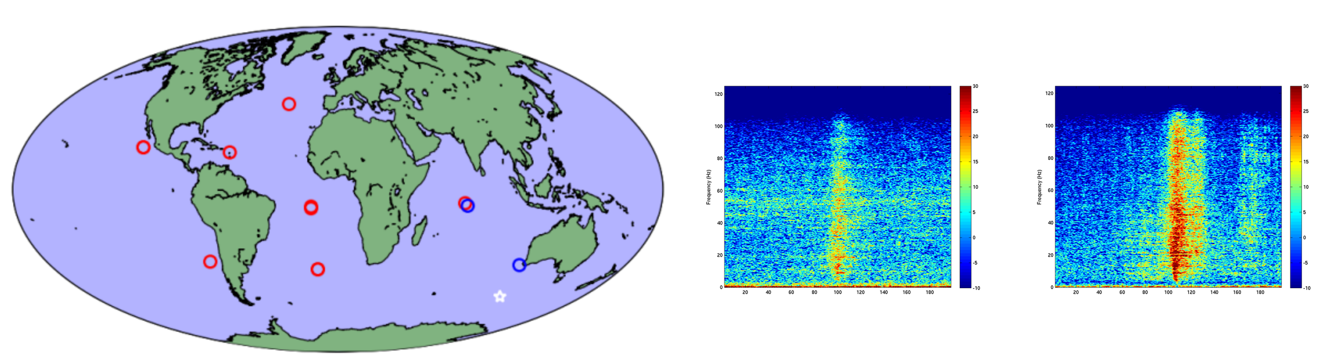
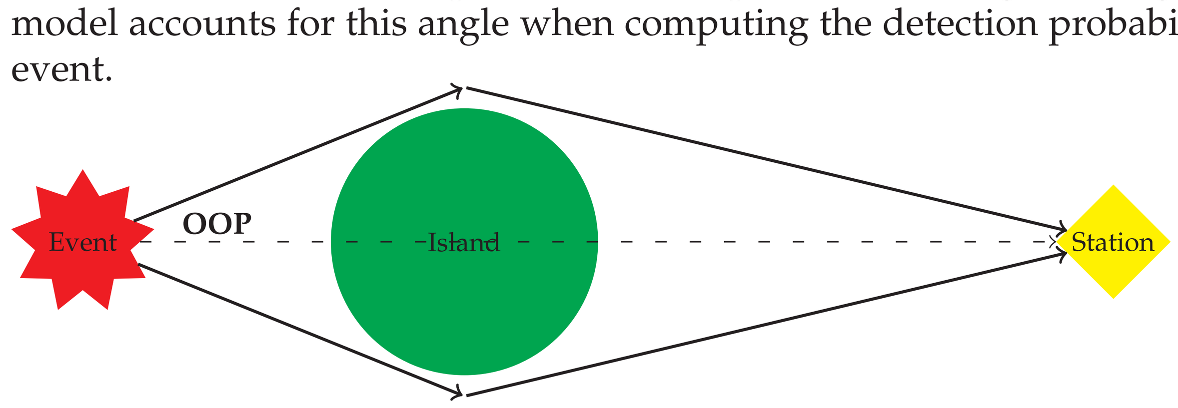


Figure 1: One of the interesting events, which is missed in SEL3. The white star in the first figure is the event location, while the blue and red circles are the stations that detect and miss, respectively, the event. The next two figures show the H-phase spectrograms.

In this work we present an extension of our detection probability model for under-water events to account for the amount of the source energy of the event that coupled into the deep sound channel. This energy is measured in dB re $Joules\ m^{-2}\ Hz^{-1}$. Using our detection probability model we are able to compute threshold monitoring maps, which are presented in the center panel.

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 Range, 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.



Acknowledgements

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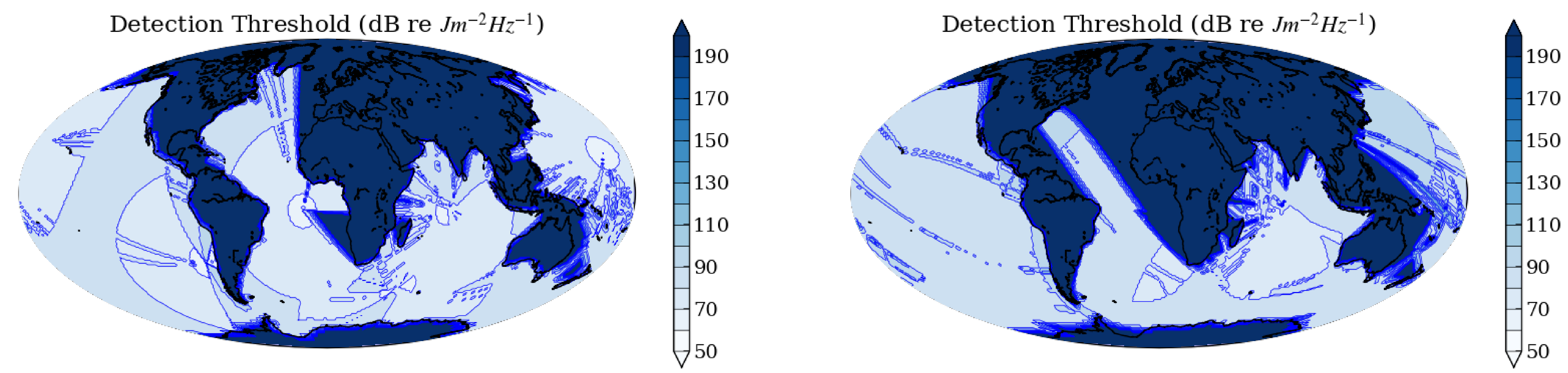
Threshold Monitoring Maps for Hydro-Acoustic Event Detection



(a) Minimum of 2 stations

(b) Minimum of 3 stations

Figure 2: Source energy threshold for 90% probability of detection.

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.

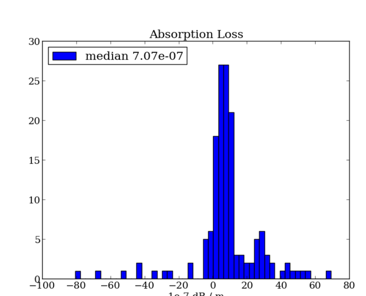


Figure 3: We directly estimate α by looking at differences in transmission loss between pairs of detections from the same event. After accounting for GS, the remaining loss is due to AT. Our estimate of α is $\mathbf{7 \times 10^{-7}}$ dB per meter in the 6-12 Hz frequency range.

Hydro Detection Probability

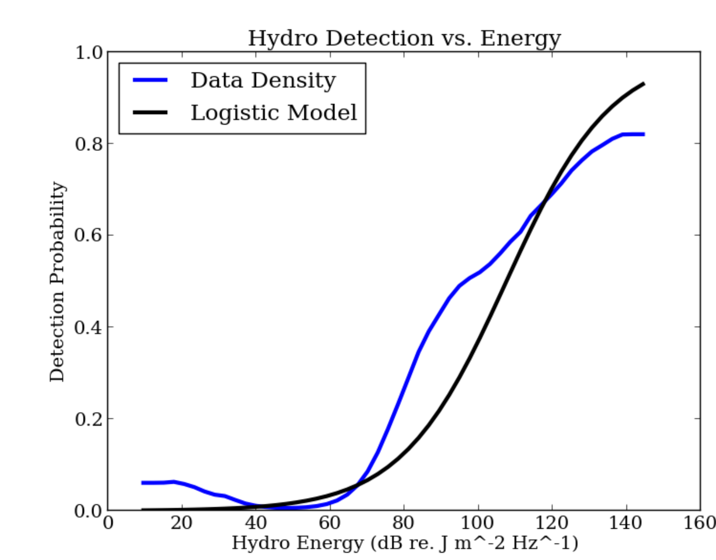
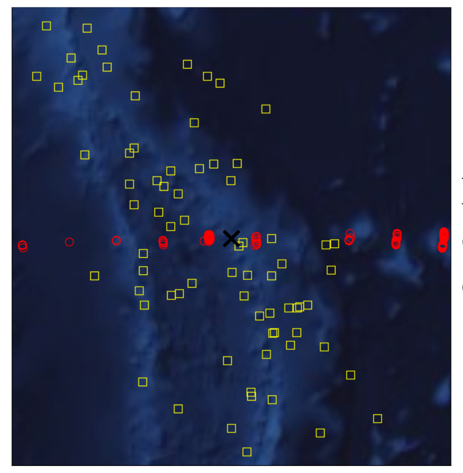


Figure 4: The detection probability is directly related to the energy arriving at the station (after accounting for transmission losses). We have modeled this probability as a logistic function of the arriving energy.

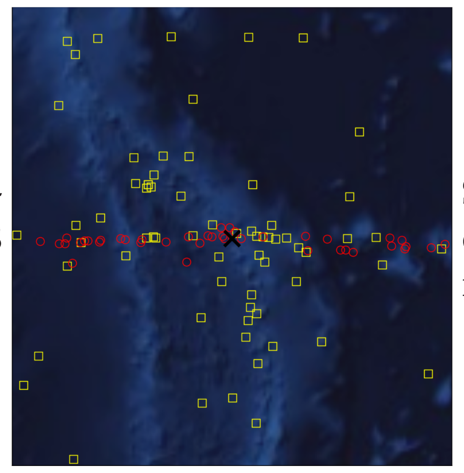
In addition to the above, the detection probability decreases exponentially with out-of-plane angle.

Ahyl Seamount Under-water Volcanic Eruption

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 5: 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.

References

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[2] Arora, N. S., S. Russell, and E. Sudderth, 2013, **NET-VISA: Network Processing Vertically Integrated Seismic Analysis**, *Bulletin of the Seismological Society of America, volume 103(2A), pages 709-729*, `http://dx.doi.org/10.1785/0120120107`

[3] Jensen, F., W. A. Kuperman, M. B. Porter, and H. Schmidt, 2000, **Computational Ocean Acoustics.** *Springer*.

[4] Le Bras, R., H. Swanger, T. Sereno, G. Beall, and R. Jenkins, 1994, **Global Association**, *Science Applications International Corp, ADA304805*, `http://handle.dtic.mil/100.2/ADA304805`

[5] Urick, R. J., 1983, **Principles of Underwater Sound**, *3rd Edition, McGraw-Hill*.

Results – Under-water Volcano

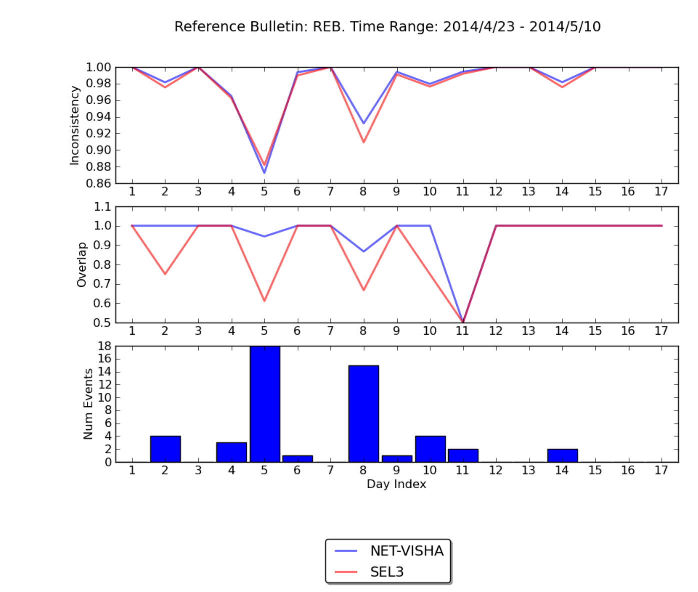

Figure 6: Inconsistency and Recall on the under-water volcano with the REB as a reference bulletin.

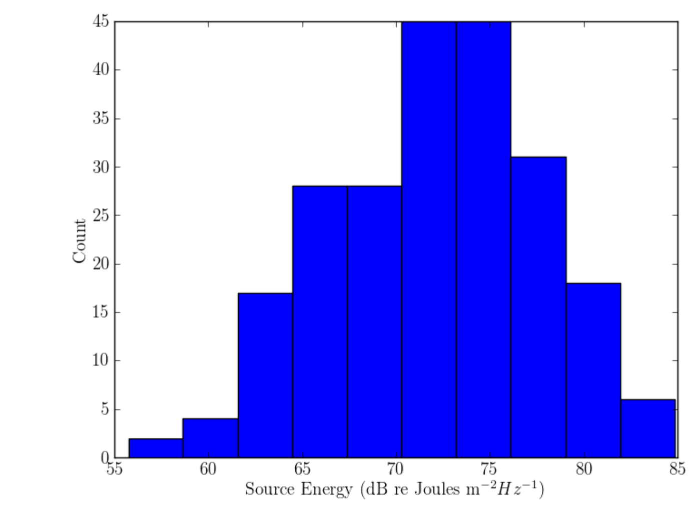

Figure 7: Source energy distribution of Ahyl eruption. For reference, 60 dB corresponds to a typical 1 kg, blast fishing, explosive.

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.

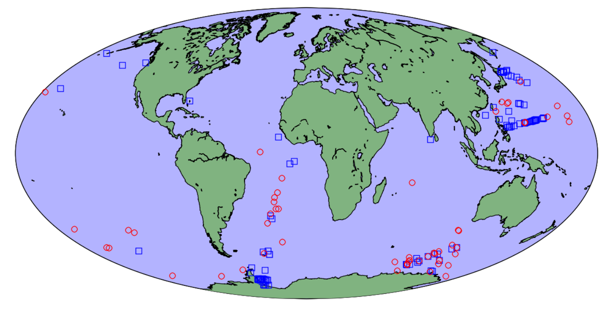

Figure 8: Locations of interesting hydro events in 2010 as found by NET-VISHA (blue squares) and SEL3 (red circles).

Disclaimer

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