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Title: How Common are Noise Sources on the Crash Arc of Malaysian Flight 370

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How Common are Noise Sources on the Crash Arc of Malaysian Flight 370?

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Abstract

Malaysian Flight 370 disappeared nearly without a trace. Besides some communication handshakes to the INMASAT satellite, the Comprehensive Test Ban Treaty monitoring system could have heard the aircraft crash into the southern Indian Ocean. One noise event from Cape Leeuwin has been suggested by Stead as the crash and occurs within the crash location suggested by Kunkle at el. We analyze the hydrophone data from Cape Leeuwin to understand how common such noise events are on the arc of possible locations where Malaysian Flight 370 might have crashed. Few other noise sources were found on the arc. The noise event found by Stead is the strongest. No noise events are seen within the Australian Transportation Safety Board (ATSB) new search location until the 10^{th} strongest event, an event which is very close to the noise level.

Introduction

Malaysian Flight 370 disappeared somewhere in the southern Indian Ocean. INMASAT satellite data has been used by the Australian Transportation Safety Board (ATSB) to derive a search area near -29 degree latitude, -99 degree longitude (see ATSB Transport Safety Report AE-2014-054). The INMASAT data consists of communication times that can be turned into distances from the satellite which can give arcs on the Earth where MF 370 was at the time of the attempted communication. Fitting to those times can give a crash location which depends crucially on where one assumes the plane started to move south. Using a different starting location, that same data has been used by Kunkle et al to derive a location much further south: -40 degree latitude, -83 degree longitude (see Los Alamos report LA-UR 14-25015).

Other data has been searched for clues that might give the final location of the plane. Stead analyzed hydrophones that are a part of the Comprehensive Test Ban Treaty (CTCB) International Monitoring System to detect nuclear explosions (see Stead, Los Alamos report LA-UR 14-24972). Stead found a candidate noise event near the Kunkle et al location in the Cape Leeuwin hydrophone data. That event was near (in time) to an Antarctic ice event which is why it might have gone unnoticed.

The purpose of this paper is to determine how common the Stead-like noise events are. If they are very common, the association with the Kunkle et al final location is not significant.

Data Processing

We used the same data as Stead. The Cape Leeuwin hydrophone station consists of three hydrophones arranged in a triangle at a depth in the ocean that places them in the SOFAR channel where noise can propagate huge distances. The triangle provides a way to find a direction to the location of a noise source. Depending on the direction to the source, one of the three hydrophones will be hit first, then another, then the third.

The hydrophone data consisted of 532,505 samples (each 0.004 sec) for each of the three Hydrophones. Thus, the duration of the data set was 2130 sec with a Nyquist frequency of 125 Hz. Stead concluded that the best frequency range to use was 10 to 20 Hz. We filtered the data with an 11^{th} order, 10-20 Hz Butterworth filter.

Normally one uses cross-correlations between the three hydrophone signals to determine a direction to a noise source. If one has two sets of three hydrophones, triangulation can be used to determine a unique location for the noise. We do not have two sets of hydrophones. However, we can assume a location/time and determine how strong the signal would be if it came from that location/time. We will investigate all locations/times consistent with the final INMASAT communication time, that is, an arc through the southern Indian Ocean. Some of the

INMASAT times are separated by an hour implying that they were due to some scheduled attempts to communicate with the plane. The last time (at 00:19 UTC on March 8 2014) is thought to be initiated by the plane's engines because something was going wrong such as running out of fuel. Considering the time it might take for the airplane to fall from 33,000 ft, we use 1215 sec UTC on March 8 2014 as the time it hit the ocean. We give the arc some width (+/- 0.5 degree) to accommodate uncertainties in the crash time and the distance from the satellite to the plane.

Figure 1 shows how we processed the data. We, in turn, selected each point on the arc. We calculate the three propagation times (ΔT_1, ΔT_2, ΔT_3) from the selected point on the arc to the three hydrophones using a sound speed of 1.466 km/sec in the SOFAR channel. The red, green, and blue line in the insert on the right shows the data as recorded. The red, green, and blue lines in the insert on the left shows the data shifted by ΔT_1, ΔT_2, and ΔT_3. The insert on the left shows the alignment of the three signals if they originated at the selected latitude, longitude, and time. We call these the de-propagated signals. Once we have the de-propagated signals at a location, we need a measure of how strong the noise is. Although several formulations are possible, we use the sum of the three cross-correlations over a coherence time, ΔT_{coh}. That is, the measure of the de-propagated noise strength at latitude θ and longitude ψ is

$$S(\theta,\psi) = \sum_{T_i=T_0-\Delta T_{coh}}^{T_0+\Delta T_{coh}} P_1(T_i+\Delta T_1)P_3(T_i+\Delta T_2) + P_1(T_i+\Delta T_1)P_3(T_i+\Delta T_3) + P_2(T_i+\Delta T_2)P_3(T_i+\Delta T_3)$$

Where P_i is the signal at the hydrophone, T_0 is the crash time (1215 sec on March 8), and we used 2 sec for the coherence time.

The largest signal during the 2130 sec of data was identified as an Antarctic Ice event by Stead. This occurred between 3124 and 3126 sec on March 8 in hydrophones 1 and 3 and between 3123 and 3125 sec in hydrophone number 2. For most of the processing we set those points to zero since it is known that they did not come from the arc.

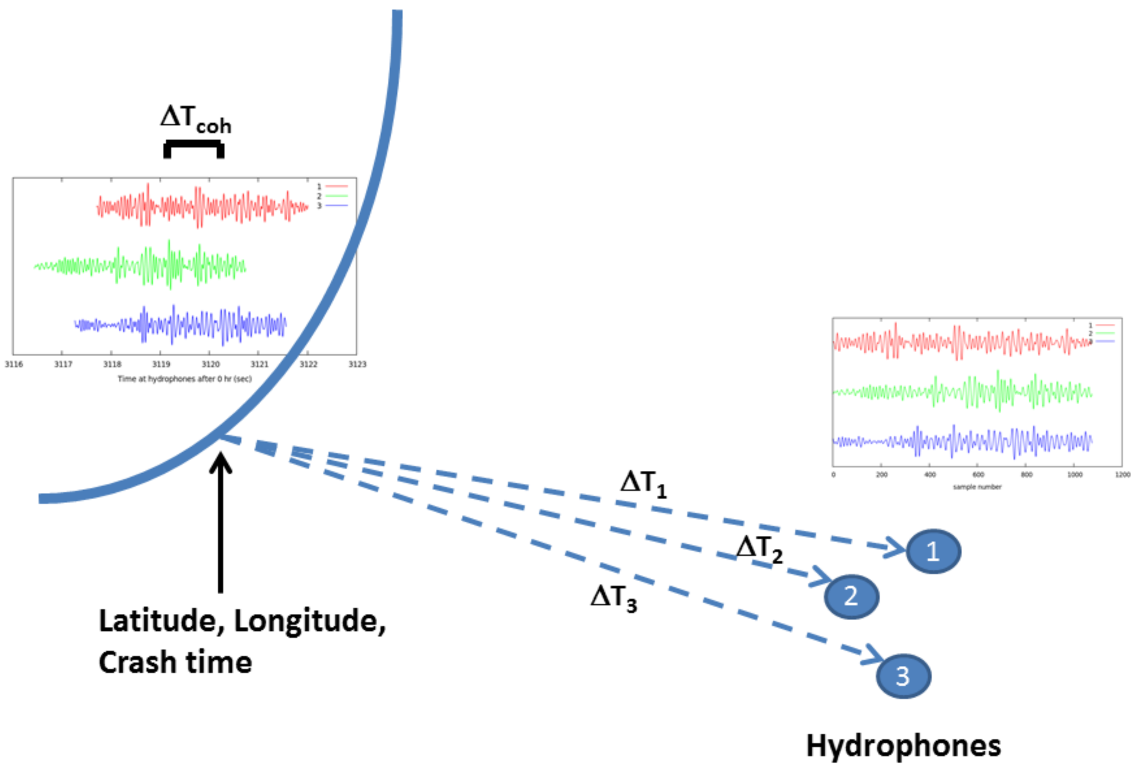

Figure 1: The processing to produce the hydroacoustic signal on the arc.

Results

Figure 2 shows $S(\theta,\psi)$ for hydrophone data with the Antarctic ice event zeroed out. The strongest point has a magnitude of 1.53E-7. We mark all points with magnitudes greater than 1.0E-7 with a red "+". There are 26 of them in three groups. The 14 largest points form a cluster at the southern end of the arc (near -41 degree latitude, -83 degree longitude). These are within the area identifier by Kunkle et al as the likely crash location. There is a cluster near -40 degree latitude, -85.5 degree longitude that contain the next 7 largest points and a cluster of 5 points with the smallest points of the top 26 near -32 degree latitude, -96 degree longitude.

The Antarctic ice event is, by far, the largest event in the data. If we include it, it only adds one point (at -40.32 degree latitude, -82.99 degree longitude) above 1.0E-7. Its magnitude makes it the 10th largest point and its location is north and slightly west of the cluster of 14 points. The fact that the ice event has such a small effect even though it is the largest signal indicates that our de-propagation technique is effective in isolating the signals on the arc.

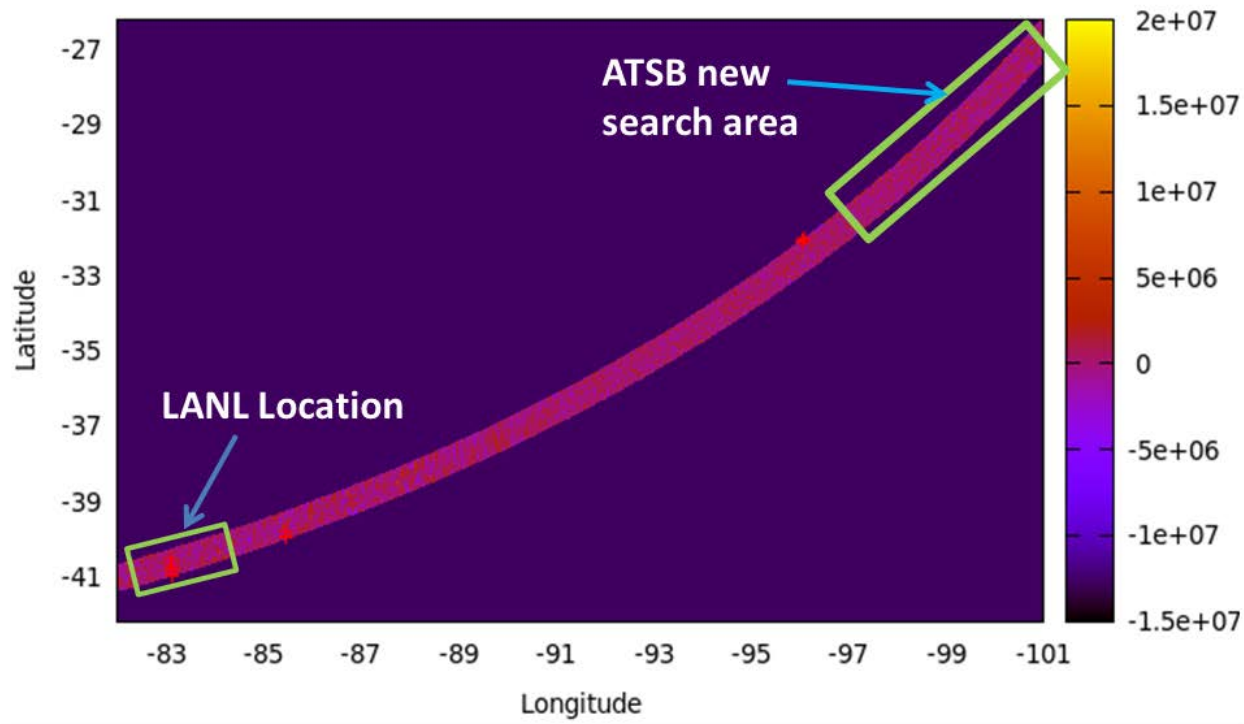

Figure 2: The noise sources of the arc down to a level of 1E-7. The strongest cluster is within the LANL location, the second strongest is nearby at -40 latitude, -85.5 longitude, and the third strongest cluster is near, but not in, the ATSB search area.

We also ran the analysis using crash times that were -30 sec and +30 sec relative to our best estimated crash time of 1215 sec on March 8th 2014. The results are basically the same: 3 clusters of ~ 26 points above 1.0E-7. Effectively, our use of an arc that is 1 degree wide covers variations in the crash time as well.

Figure 3 is the same as Figure 2 except we have marked with a red "+" all points with magnitudes greater than 0.75E-7. There are 80 such points in 10 clusters. Within the ATSB search area there is one cluster with 2 points which were the 79th and 80th ranked points. In Figure 4 we show the 2130 sec of data that was analyzed and mark where the first three clusters and the weakest cluster in Figure 3 come from. Note that the third strongest cluster (from ~ 2380 sec) is not the third strongest noise recorded at the hydrophones. There are much stronger noise at ~ 2900, 3120, and 3270 sec. This is another indicator that our de-propagation technique is effective in isolating the signals on the arc.

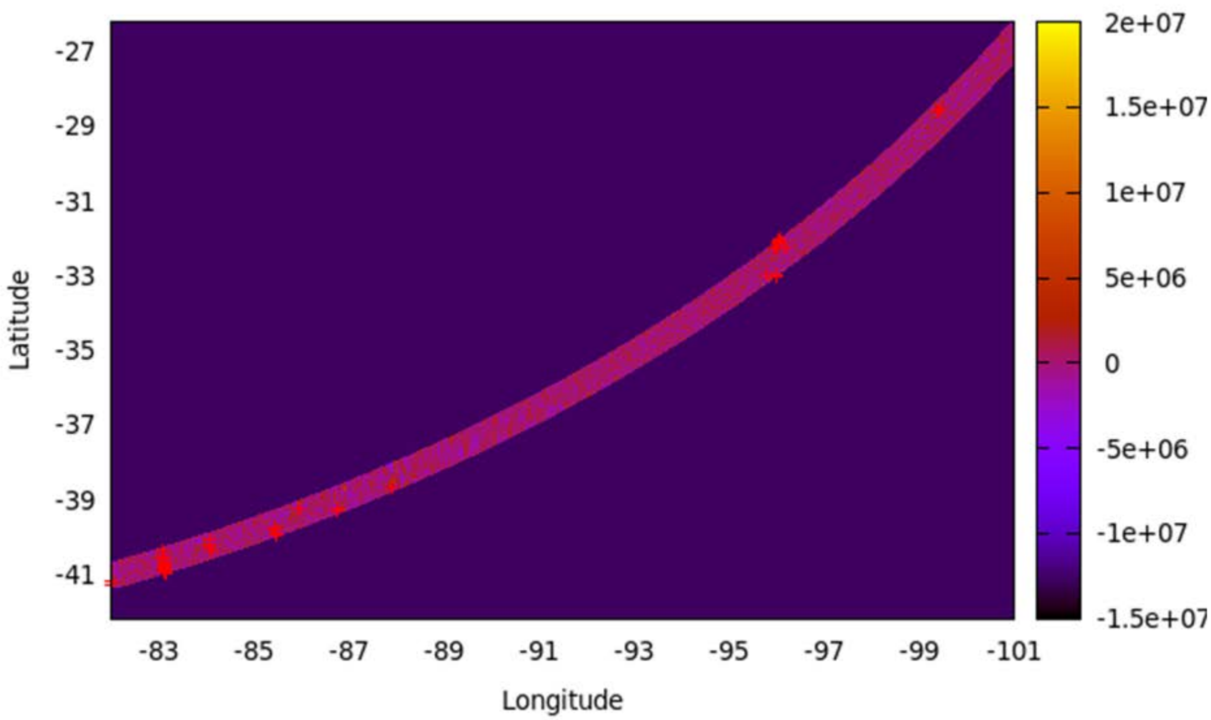

Figure 3: The top 80 strongest noise points on the arc, down to a level of 0.75E-7.

The peak in Figure 4 associated with the 79th and 80th points in Figure 3 is quite small. That region has three small peaks and it is only the third and last peak that contributes to the 79th and 80th points.

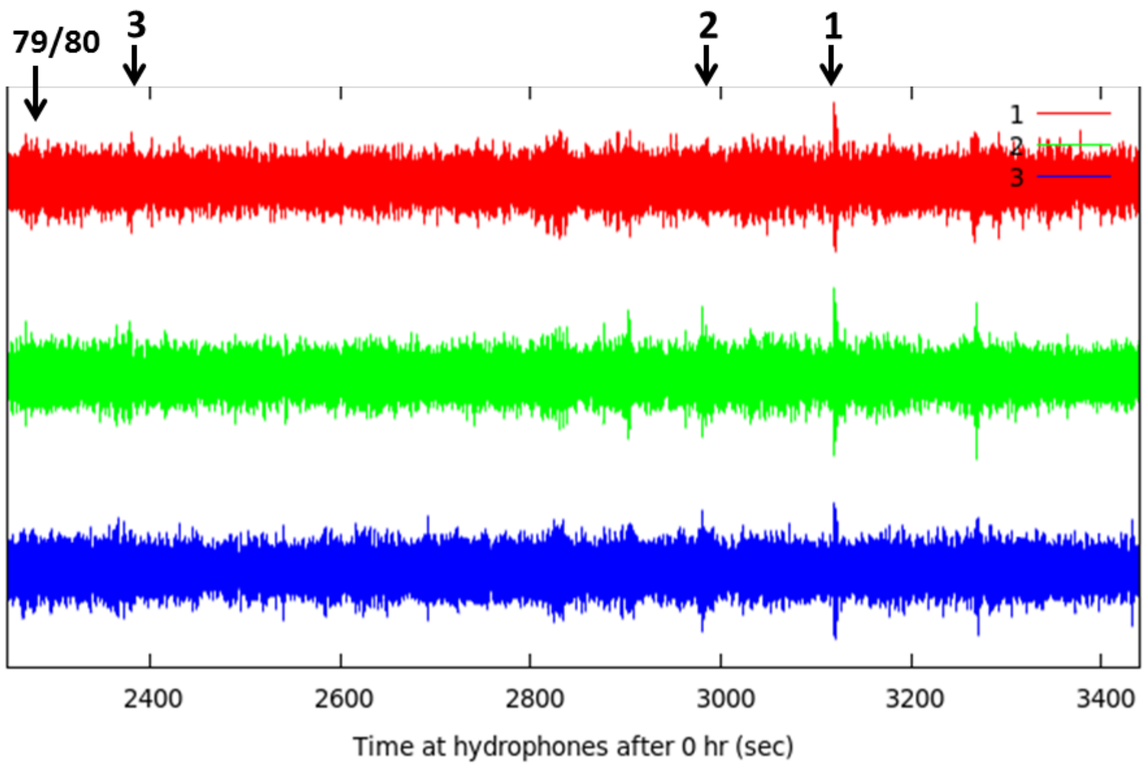

Figure 4: The time series from the 3 hydrophones. Marked as 1, 2, and 3, are where the strongest cluster, the second strongest cluster, and the third strongest cluster come from. Also marked is the only source within the ATSB search box, which is the 70th and 80th strongest noise source.

Our technique finds the strength of the noise sources on the arc. That does not mean that those noise sources are strongest on the arc. We further analyzed the strongest source (which resulted in the cluster of 14 points). We modified the data so that it was only nonzero within +/- 3 sec of the strongest source (I. e., near the data indicated by the “1” in Figure 4). In Figure 5 we found $S(\theta,\psi)$ for all points, not just those on the arc. There are two other places (in the circles in Figure 5) where $S(\theta,\psi)$ is larger than it is on the arc. This does not mean that the source on the arc is false. The signals at the three hydrophones are not expected to be coherent. Thus, depending on how the peaks line up, there could be places where the ΔT_1, ΔT_2, and ΔT_3 shifts give a larger cross-correlation.

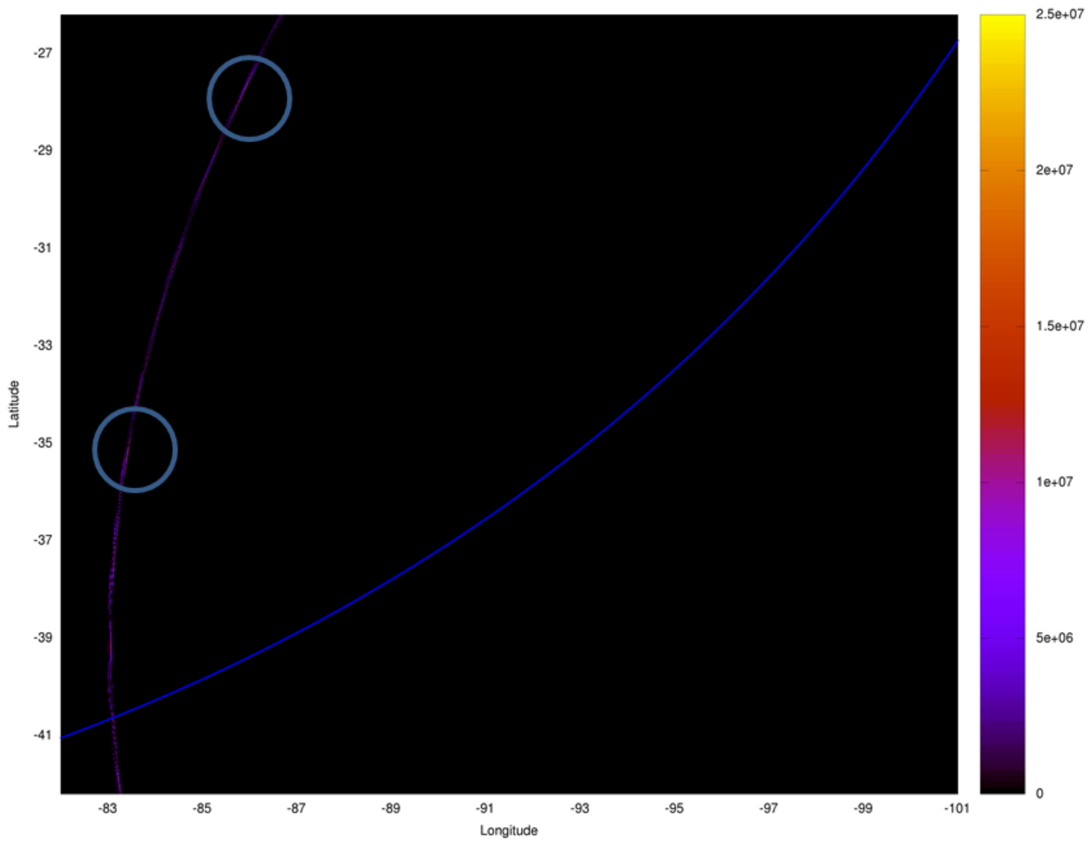

Figure 6: The strength of the strongest cluster off the arc. There are two locations (within the circles) where the signal is stronger than it is on the arc.

Conclusions

We find that the noise event identifier by Stead (LA-UR 14-24972) is the strongest noise that occurred on the crash arc of Malaysian Flight 370. That event occurs within the search area suggested by Kunkle et al (LA-UR 14-25015). Few other possible noise sources are seen on the arc. The 10th strongest cluster is close to the noise level and is the only source within the next search area suggested by the Australian Transport Safety Bureau (ATSB).

Although the strongest event reconstructs onto the arc, it also reconstructs stronger at several locations well off the arc. That could be due to the lack of coherency at the hydrophones.