MH370: Finding the Debris Origin

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Introduction

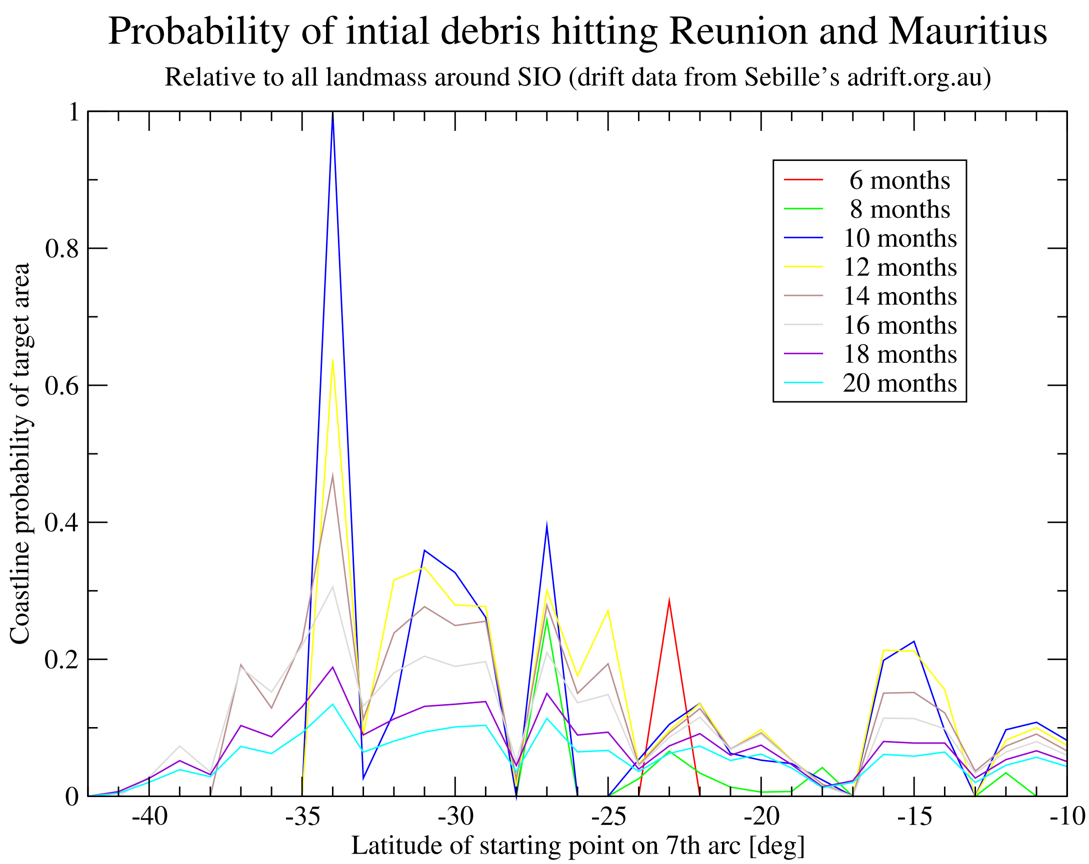
On July 29, 2015, a 777 flaperon was found on the shores of la Reunion, east of Madagascar. As of this writing, the debris is very likely to be confirmed as coming from MH370 [1]. There are unconfirmed reports of additional debris (luggage, water bottle) found in the vicinity of the flaperon. There are even claims that debris was first found three months ago [2]. In spite of search efforts in other areas around the South Indian Ocean (SIO), nothing has yet been found. Taken together, it is not unlikely that la Reunion and nearby Mauritius are in fact the initial recipients of debris from MH370. The notion of initial recipient is important. With that assumption, it turns out that we can work out approximately where the debris originated.

Results

The most likely origin of the flaperon is currently a 2 by 2 degree area, centered at (34S, 94E). The assumptions used to arrive at this result are

- We are only now, or some months ago, starting to receive debris from the crash site
- We have not missed to find any major debris on other major landmasses
- The drift simulation is accurate to within 2 degrees in latitude and longitude
- The drift simulation time scale is accurate to within 30%
- The coastal landmass used overlaps the edge of the ocean simulation data

The first two assumptions are the introductory and important ones. They allow for a direct link between the Reunion finding and a coastline probability distribution, defined later in the text. The result of that distribution, applied to the probability of hitting the islands la Reunion and Mauritius, is shown below.



The graph shows the relative probability to hit the islands, as a function of the origin of the debris, expressed as a latitude along the 7th arc. A sensitivity analysis of off-arc locations is given later in the text. One function for each available time step between 6 and 20 months is shown. The function is zero for prior times. There is a strong peak in space and time, occuring at 34S and approximately 10 simulation-months, respectively. At the time of writing, we are 16.7 months into the drift, but there is considerable uncertainty as to the timing of the initial appearance of the debris. Many factors affect the drift speed and path of individual flotsam, and the peak is in probability, not actual debris deposit. The qualitative expected picture is that as we first hit the "closest" shores, where closest is defined by the actual drift, the coastline distribution is concentrated to that first location. With time, the distribution broadens as more locations become within reach. This is precisely what we see in the graph. Moreover, the peak latitude shows a probability of one. This means that out of all landmass around SIO, *all* debris is initially concentrated to the Reunion and Mauritius islands. This is somewhat of a lucky strike, since there is nothing inherent in the model that enforces it; it just happens to be the result when the debris is injected at 34S.

The drift model

The drift model used in the present analysis is due to Erik van Sebille et al [3]. The work is incorporated in their easily accessible web site adrift.org.au [4], where simulations can be set up and data be retrieved for further analysis. The drift model has been used to study long-term entrapment of garbage in the world oceans, including the SIO. The refined model and the easy access to simulation data makes Sebille's model a natural first choice. Other models are likely to yield slightly different results from the ones presented here, but the qualitative picture is not expected to change.

The present analysis uses 35 simulations along the so-called 7th arc, one for each integral latitude degree. Additional simulations have been used to establish the robustness of the solution, showing an area around the arc to be the most likely origin.

The average fraction ashore

The drift model gives the time evolution of the probability distribution $p(t_0, \mathbf{r}_0; t, \mathbf{r})$ across the ocean, given the injection of a piece of debris at $(t_0, \mathbf{r}_0)$. From this measure we need to estimate how much debris will be washed ashore at any particular coastline point. A simple model is to assume that a constant area, A, of the distribution found in the immediate vincinity of a coastline, $dA(\mathbf{r})$, will be washed ashore, and that the items will stay ashore long term unless the distribution changes drastically. To that end, we define the average fraction ashore, $F(t_0, \mathbf{r}_0; t, \mathbf{r}_s)$, as

$$F(t_0, \mathbf{r}_0; t, \mathbf{r}) = \frac{1}{t - t_0} \int_{t_0}^{t} dt' \int dA'(r) p(t_0, \mathbf{r}_0; t', \mathbf{r}'). \tag{1}$$

The total fraction ashore is then the time average of the fraction of the total distribution that is found near the coastline. The resolution of the distribution from adrift.org.au is one square degree. The actual coastal area is likely smaller than that, so for simplicity, we set $A = 1\,\mathrm{deg}^2$, leading to the simplest possible formula for the discrete version:

$$F_{ij}(t) = \frac{f}{t - t_0} \int_{t_0}^{t} dt' p_{ij}(t'). \tag{2}$$

Here, $p_{ij}(t)$ represents the probability to find debris injected at cell i in the coastal cell j, at time t. This is precisely the data returned by the simulation. We set $t_0 = 0$ without loss of generality. The constant f is an arbitrary factor less than unity representing the true capture area.

The coastline

The one-degree coastline map used is depicted below as ascii art.

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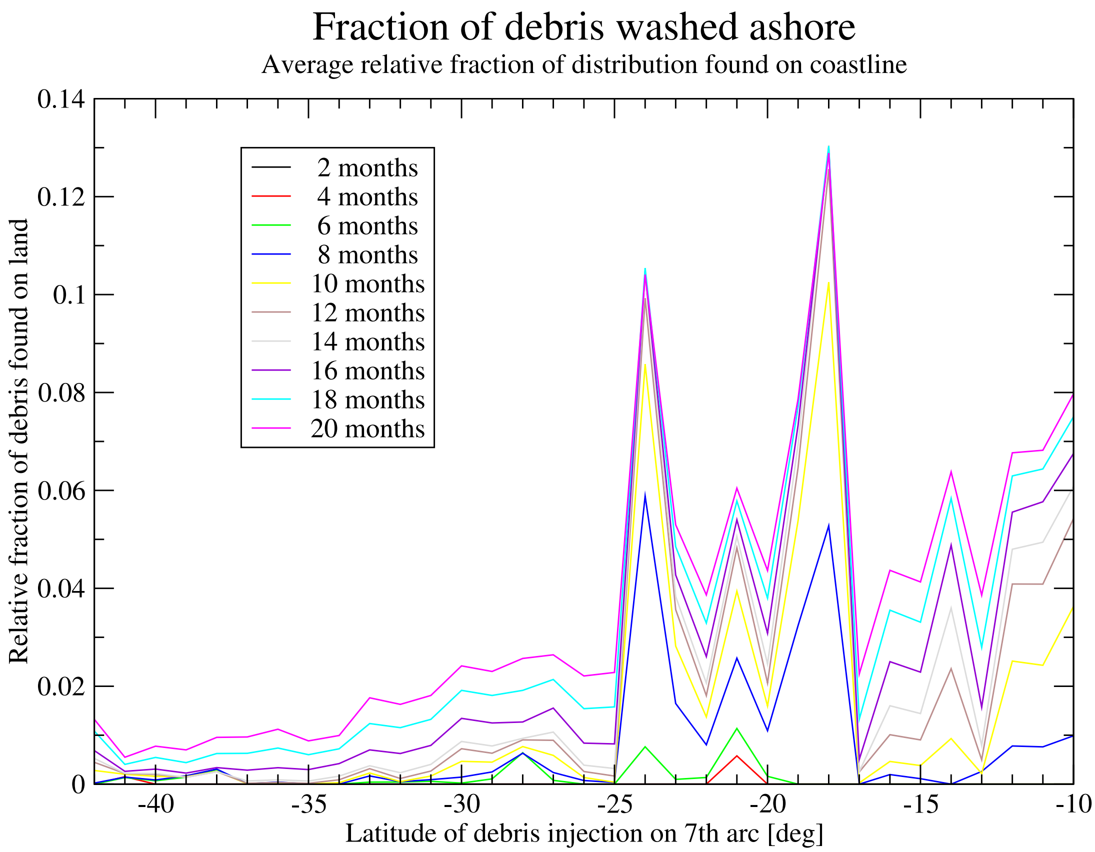
The target islands are denoted with '@'. The raw data for this map was obtained from openstreet [5]. Care has been taken to match the coastline map to the edges of a large number of drift simulations, to prevent miscounts.

Simulation details

Given the introductory assumption that we are just beginning to see debris, we can compare with the ramp-up of debris being found along the coastline of the SIO, as predicted by the drift model.

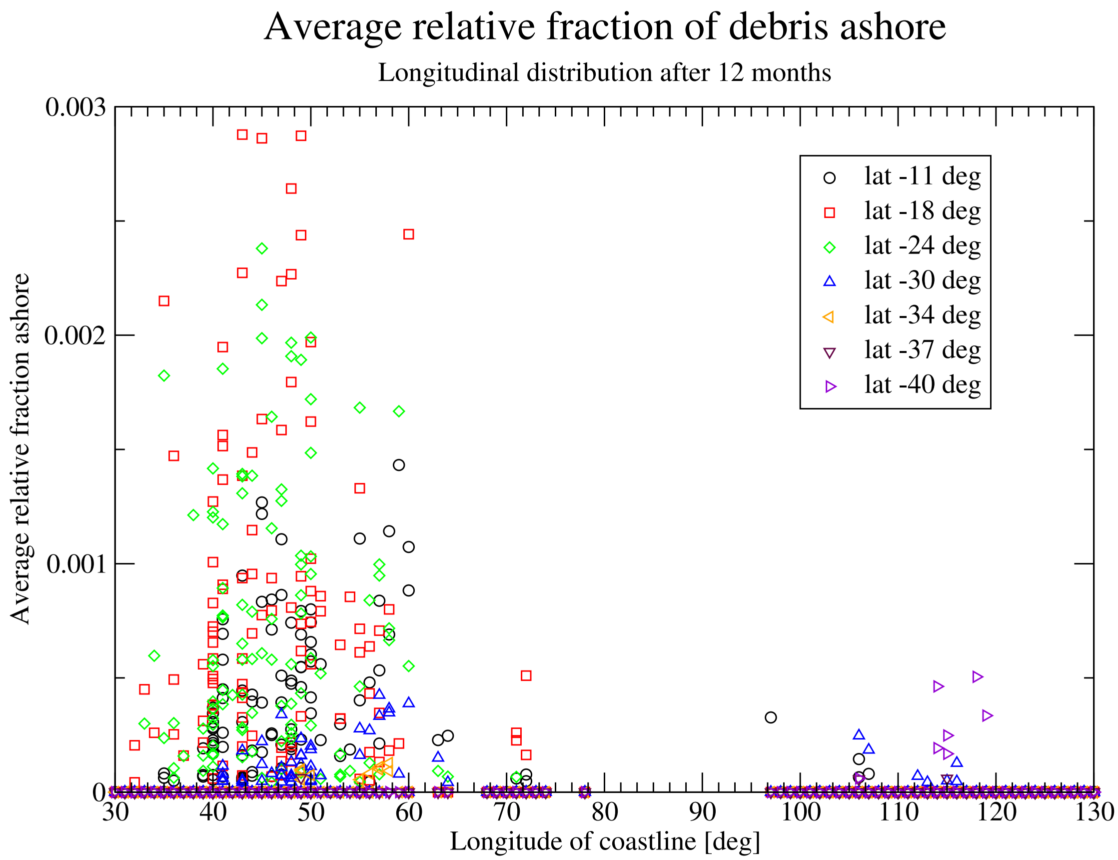


The graph shows the total integrated fraction ashore,

$$F_i(t) = \sum_{j \in C} F_{ij}(t), \tag{3}$$

where C denotes the set of coastline indices and i enumerates the points of origin along the 7th arc. There is a large amount of deposit at latitudes 25S and above, an onset at approximately 8 simulation-months, and a saturation after 12 months. The uncertainty in the timing of the initial debris may be part of the explanation to the discrepancy, but the question is left open for further study.

The large deposit is interesting, since it either says something about the time scale, or something about the debris origin, but not both. We can resolve the total deposit further, by looking at the longitudinal distribution of debris at some particular point in time. This graph, showing the distribution after 12 months, is quite revealing:



A debris injection at the northern end of the arc, here represented by 11S, is most likely to end up in Madagascar. Only a small fraction of the total deposit is found on the target islands. Hence, if what we witness now is the onset of debris from 11S, we should be seeing a lot of debris elsewhere, and not on Reunion. Similarly, injections at 18S to 24S mostly hit Madagascar and parts of Africa. The 30S origin gets split between continents, with some deposit in Madagascar and some in Java and West Australia. Conversely, injections in the other end, below 36S or so, mostly hit West Australia. In sharp contrast, an injection at 34S is very localized and exclusively hits the target islands. The most likely explanation to both the lack of debris to date *and* the initial debris turning up on la Reunion is that the debris originates from an area around 34S.

The coastline probability distribution

The preceding section gave a detailed account of several aspects of the fraction-ashore distribution that will now be generalized. We define the coastline probability distribution as

$$P_{ij}(t) = \frac{F_{ij}(t)}{F_i(t)}. \tag{4}$$

This distribution is the probability to find the debris at coastline site j at time t, given that the debris is actually deposited somewhere at time t. It is proportional to the fraction ashore, but normalized so that the deposition becomes a known fact:

$$\sum_{j \in C} P_{ij}(t) = 1. \tag{5}$$

The graph in the results section is constructed from this distribution. Every point of origin at sea corresponds to a particular coastline distribution. Given the actual observations, we can apply the maximum likelihood method to find the point of origin which maximizes the likelihood of the coastline observations. So far, we only have one or a handful of observations in the target area, so the results given here are expected to change with time. That said, the point of origin which currently maximizes the probability of the actual Reunion observation is (34S, 94E).

Sensitivity analysis

With the optimal point of origin along the 7th arc established, an analysis of how deviations from the arc affect the observed probability is of interest. The resolution of the simulations does not support any fine-grained analysis, but the table below shows the variation around the optimal point.

Latitude [deg]	Longitude [deg]	10 months	12 months	14 months
34S	93.9E	1.0	0.64	0.47
34S	92.9E	0.48	0.21	0.27
34S	94.9E	0.0	0.0	0.13
33S	93.9E	0.63	0.54	0.31
35S	93.9E	0.0	0.0	0.14

The probability of hitting the target area drops markedly in all directions. The optimal origin is thus a true local maximum.

Discussion

Prior to performing these calculations, there was an expectation that the previous search area may need to be revised. With the results at hand it appears that this is not quite the case. Rather, the analysis is consistent with the many analysis efforts over the past year. In particular, it is consistent with the ATSB priority area. We can expect the absolute numbers to change somewhat with time, as more debris deposits, and more drift models are examined.

Acknowledgements

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References

[1] BBC. http://www.bbc.com/news/world-asia-33714780.

[2] IB Times. http://www.ibtimes.co.uk/missing-flight-mh370-seat-found-reunion-island-by-beach-cleaner-1513688.

[3] M. H. England E. van Sebille and G. Froyland. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. *Environ. Res. Lett.*, 7:044040, 2012.

[4] E. van Sebille. http://www.adrift.org.au/.

[5] http://openstreetmapdata.com/.