The probable End Point of MH370

by Richard Godfrey

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Introduction

MH370 disappeared almost 3 years ago. The aircraft's last known position was a primary radar sighting 10 nautical miles beyond waypoint MEKAR on 7th March 2014 at 18:22 UTC in the Malacca Straits at 6.5795°N 96.3417°E, whilst flying along flight route N571. Inmarsat satellite data shows the aircraft continued flying for almost 6 hours after the last known position, until it reached the so called 7th Arc. A detailed analysis of the satellite data shows that by 19:41 UTC the aircraft was definitely flying in a southerly direction and continued on a steady course until 00:19 UTC. The satellite data between 18:25 UTC and 18:28 UTC shows the aircraft flew a lateral offset of around 15 nautical miles to the right of flight route N571, heading north west toward the Andaman Islands.

The deciding factor in determining the probable end point of MH370 is the next step. The satellite data between 18:39 UTC and 18:40 UTC can be interpreted in 2 ways. The first option is that the aircraft remained in level flight and had already turned southwards by 18:39 UTC. The second option is that the aircraft remained on the north west heading but descended at a normal rate of around 2,350 feet per minute. The first option places the probable end point of MH370 between 33.0°S and 39.5°S along the 7th Arc. The second option places the probable end point of MH370 between 26.5°S and 33.0°S along the 7th Arc.

The ATSB defined the underwater search area of 120,000 km2 using the first option between 33.0°S and 39.5°S and up to 40 nautical miles either side of the 7th Arc. This underwater search has been concluded and to a 97% level of certainty the aircraft is not in this area.

Victor Iannello and I wrote a paper entitled "Possible Flight Path of MH370 towards McMurdo Station, Antarctica" dated 24th August 2016, which can be found at the following link:

https://www.dropbox.com/s/au5w29f7eyescei/2016-08-25%20MH370%20Path%20Towards%20McMurdo%20Station.pdf?dl=0

Our paper used the second option above, but also examined the hypothesis that the data recovered from Captain Zaharie Shah's home flight computer indicates a southerly path toward McMurdo Station Pegasus Airfield (NZPG) in the Antartica. The satellite data is used to determine a best fit aircraft track from 19:41 UTC to 00:19 UTC. This track starts near Car Nicobar Airport in the Andaman Islands and ends at fuel exhaustion near the 7th Arc at 26.9°S.

Meanwhile 25 items of aircraft debris have washed up on the shores of Indian Ocean and a number have been confirmed as being from MH370. The focus of this present paper is an analysis of the drift patterns of the floating debris from MH370 to help narrow down the probable end point. MH370 floating debris have been found as far apart as Tanzania and South Africa. Some debris has been found covered in barnacles and other debris has been clear of barnacles. This fact offers important clues to the sea water temperature that the debris passed through, especially in the last 90 days before beaching. A sea water temperature between 19°C and 25°C fosters barnacle growth. There is a sharp cut-off in barnacle growth above 25°C.

Background

The Global Drifter Program (GDP) maintains 10,000 buoys covering the oceans of the world, that each send back position, speed and sea water temperature data every 6 hours via satellite. There is a significant amount of data from GDP buoys that tracked across the Indian Ocean from the area around the 7th Arc to the island shores of Rodrigues, Mauritius, Reunion, Madagascar or mainland shores of Tanzania, Mozambique and South Africa. MH370 floating debris has been found in all these locations.

The fastest transoceanic GDP buoy (AOML buoy identification number 101702) took 330 days to cover 3,121 nautical miles from the 7th Arc to Madagascar, but actually travelled a distance of 5,601 nautical miles in the process. The slowest transoceanic GDP buoy (AOML buoy identification number 9525792) took 6 years to cover 4,249 nautical miles from Australia to Southern Mozambique and actually covered 29,745 nautical miles along its track.

From these 2 extreme examples, you can see the effect of winds, waves, storms, gyres, jets, upwelling and other oceanic processes and floating debris either efficiently moving in a straight line or going around in circles or a completely random pattern. The first example had an efficiency factor of 3,121 / 5,601 = 0.557. The second example had an efficiency factor of 4,249 / 29,745 = 0.143. The 2 extreme examples are depicted on the next page.

The next problem is that there are seasonal variations which effect the speed, bearing, efficiency and sea water temperature. There can be significant changes from one month to the next.

Finally, some items of MH370 floating debris were covered in barnacles and others were not. Bhupendra Patel found that the optimum water temperature for barnacle reproduction and growth was between 19°C and 25°C. The rate of reproduction was slowest at 19°C and increased as the water temperature increased toward 25°C. There was a marked cut off in reproduction at water temperatures above 25°C. I examined the optimum sea temperature for barnacle growth in a previous paper, which can be found at the following link:

https://www.dropbox.com/s/pveb004xil0egml/Optimum%20Sea%20Temperatures%20for%20Barnacle%20Growth.pdf?dl=0

By comparison, the MH370 Flaperon took 508 days to arrive in Reunion, which is quite fast for floating debris. We know that the Flaperon left the 7th Arc on 8th March 2014 and arrived at some point before 29th July 2015 at Reunion. We also know that it was full of barnacles, but we do not know the efficiency factor of the track across the Indian Ocean.

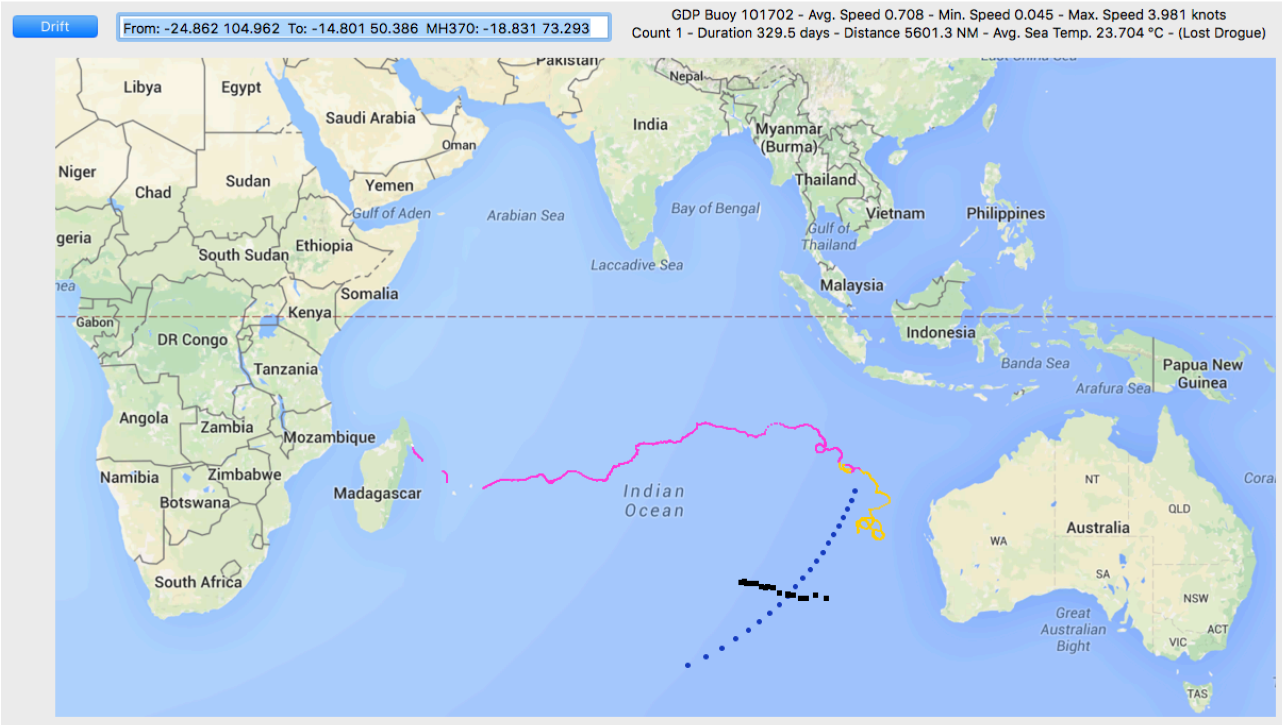
The MH370 Rolls Royce engine panel found in South Africa was first found on 23rd December 2015 after 655 days full of barnacles, then subsequently re-discovered on the same beach on 21st March 2016 clear of barnacles. This provides a note of caution, that being clear of barnacles can be the result of a delay between the beaching and the finding.

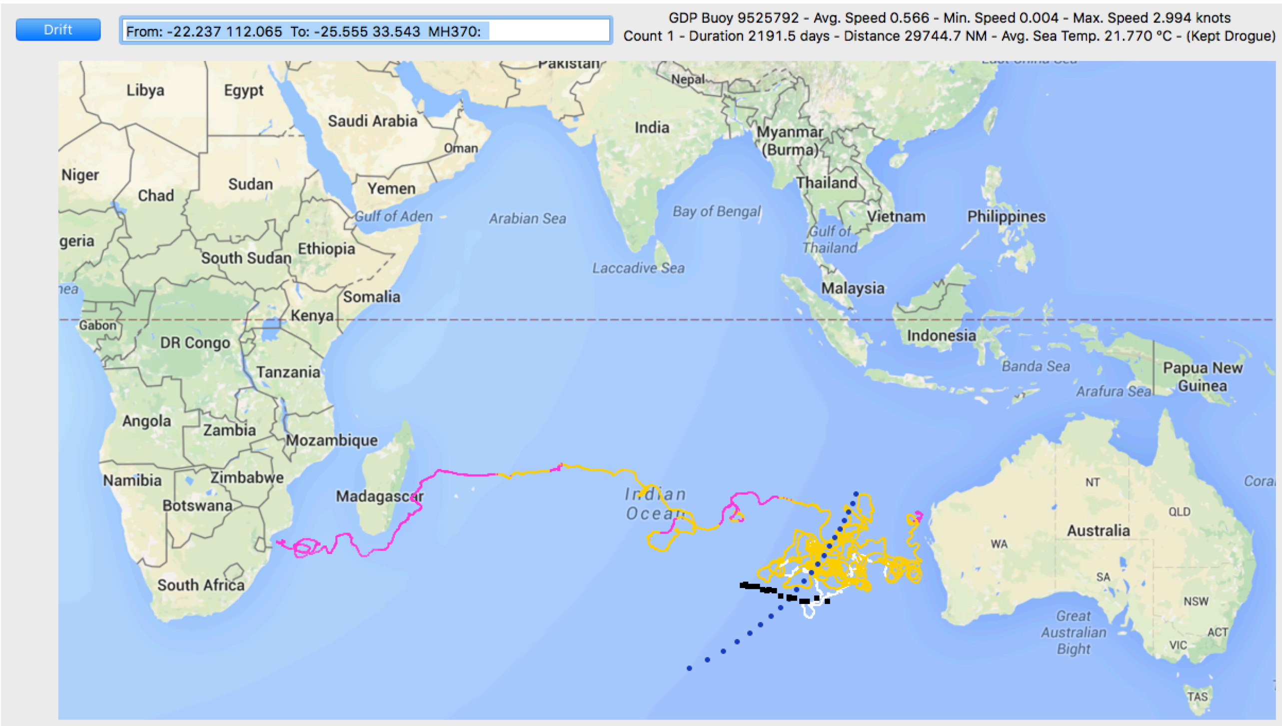
The MH370 Cabin Divider found in Rodrigues on 30th March 2016 after 753 days had the shortest distance to travel from the 7th Arc and was also clear of barnacles.

The MH370 Outboard Flap found in Tanzania on 20th June 2016 after 835 days was clear of barnacles.

Other floating debris were found in South Africa, Mozambique, Madagascar and Mauritius. The largest amount of debris turned up at Nosy Boraha Island, Madagascar and many items were recovered there by Blaine Gibson.

There are more items of floating debris still out there to be found on some beach or still on the ocean. As new discoveries of floating debris are made, the picture will become more complete.


Drift
From: -24.862 104.962 To: -14.801 50.386 MH370: -18.831 73.293
GDP Buoy 101702 - Avg. Speed 0.708 - Min. Speed 0.045 - Max. Speed 3.981 knots
Count 1 - Duration 329.5 days - Distance 5601.3 NM - Avg. Sea Temp. 23.704 °C - (Lost Drogue)
Libya
Egypt
Saudi Arabia
Oman
Niger
Chad
Sudan
Yemen
Gulf of Aden
Arabian Sea
India
Nepal
Myanmar (Burma)
Thailand
Bay of Bengal
Gulf of Thailand
Vietnam
Philippines
South Sudan
Ethiopia
Laccadive Sea
Somalia
Malaysia
Kenya
Gabon
DR Congo
Indonesia
Tanzania
Banda Sea
Arafura Sea
Papua New Guinea
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
Indian Ocean
NT
QLD
WA
Australia
SA
NSW
South Africa
Great Australian Bight
ACT
VIC
TAS

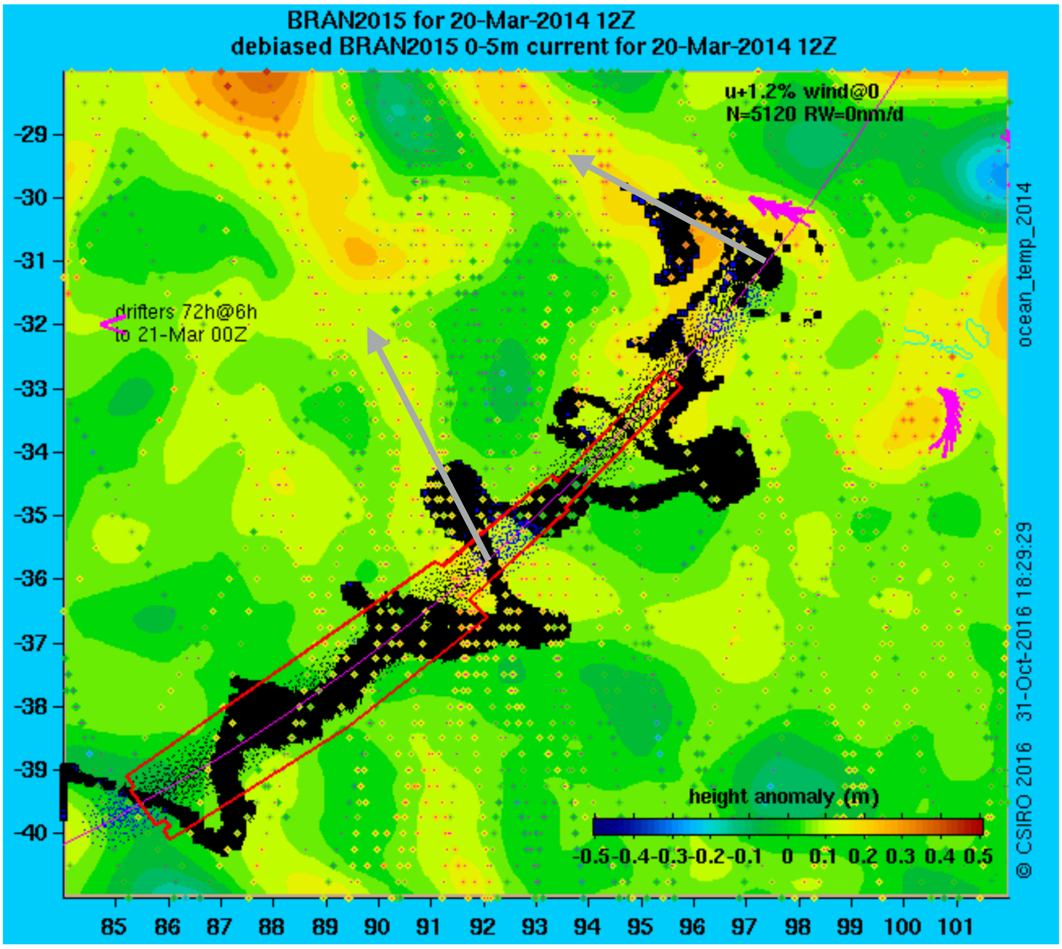

Drift
From: -22.237 112.065 To: -25.555 33.543 MH370:
GDP Buoy 9525792 - Avg. Speed 0.566 - Min. Speed 0.004 - Max. Speed 2.994 knots
Count 1 - Duration 2191.5 days - Distance 29744.7 NM - Avg. Sea Temp. 21.770 °C - (Kept Drogue)
Libya
Egypt
Saudi Arabia
Oman
Niger
Chad
Sudan
Yemen
Gulf of Aden
Arabian Sea
India
Nepal
Myanmar (Burma)
Thailand
Bay of Bengal
Gulf of Thailand
Vietnam
Philippines
South Sudan
Ethiopia
Laccadive Sea
Somalia
Malaysia
Kenya
Gabon
DR Congo
Indonesia
Tanzania
Banda Sea
Arafura Sea
Papua New Guinea
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
Indian Ocean
NT
QLD
WA
Australia
SA
NSW
South Africa
Great Australian Bight
ACT
VIC
TAS

Method

I used the GDP buoy data to build a model of the Indian Ocean from 30°E to 105°E and from the Equator to 40°S, for each month of the year.

Individual data sets from transoceanic GDP buoys contain between 1,000 and 9,000 rows of data, including date, time, latitude, longitude, speed and sea water temperature. I used a software application to calculate bearing and the efficiency factor at each position. I then used a second software application to look for the underlying bearings and efficiency factors over periods of 60 days, at each location and month of the year. This was designed to remove distortions from local storms, gyres, jets and upwellings. These disturbances were still reflected in the efficiency factor but not in the underlying bearing. I used data over several years from 1995 to 2016, but always using the month of the year to build the database by position and by month.

CSIRO observed in their paper entitled “The search for MH370 and ocean surface drift” dated 8th December 2016, the importance of the initial direction of movement of debris from the 7th Arc in March 2014. I found the initial underlying bearing from the 7th Arc in March always to be north westerly, which aligns with the CSIRO finding.



Finally I used a third software application to simulate the floating debris tracks from the 7th Arc and different latitudes.

Three databases were built for this analysis.

Firstly, a database with the raw data, which contains for each drifter buoy, date, time, latitude, longitude, sea water temperature, velocity, velocity east, velocity north, every 6 hours.

Secondly, a database, where I aggregated the data for each drifter buoy in 5° slots of longitude across the Indian Ocean, where I store the slot entry date, slot departure date and within each slot the average latitude, average speed, average bearing and average temperature. This is stored by calendar month for each drifter buoy.

Thirdly I have a database, where I calculate the average efficiency factor for each buoy from the actual distance travelled in 60 days compared to the point to point distance between the start and end position of the 60 days. For example if the drifter travelled 770 km from 8th March to 7th May by summing the distance between each 6 hourly positions, but the point to point distance between the start and end position is 445 km, then the efficiency factor is 445 / 770 = 0.578 for that drifter buoy in that timeframe.

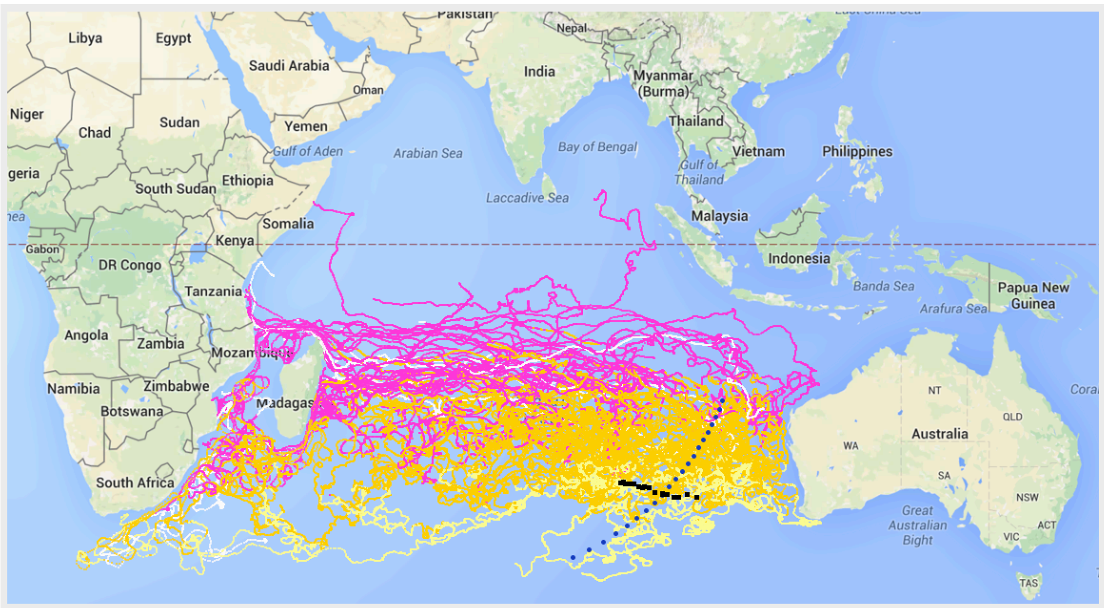
The resolution of database 1 is 0.001° latitude, 0.001° longitude and 6 hours. It contains 180,000 rows of data from 67 drifter buoys that between them covered tracks totalling just under 600,000 nautical miles of the Indian Ocean.

The resolution of database 2 is 0.001° latitude, 5° longitude and 1 month. The spatial frame of 5° of longitude was chosen to find the underlying trends in drift tracks.

The resolution of database 3 is 0.001° latitude, 0.001° longitude and 60 days. The temporal frame of 60 days was chosen to verify the underlying trends in drift tracks.

The floating debris simulator uses all 3 databases and can average (where there are several values available for a position and month) or interpolate (where there are several close values available but not the exact position and/or not the exact month). The data points are plotted every 60 days. A map of the database coverage is shown below.

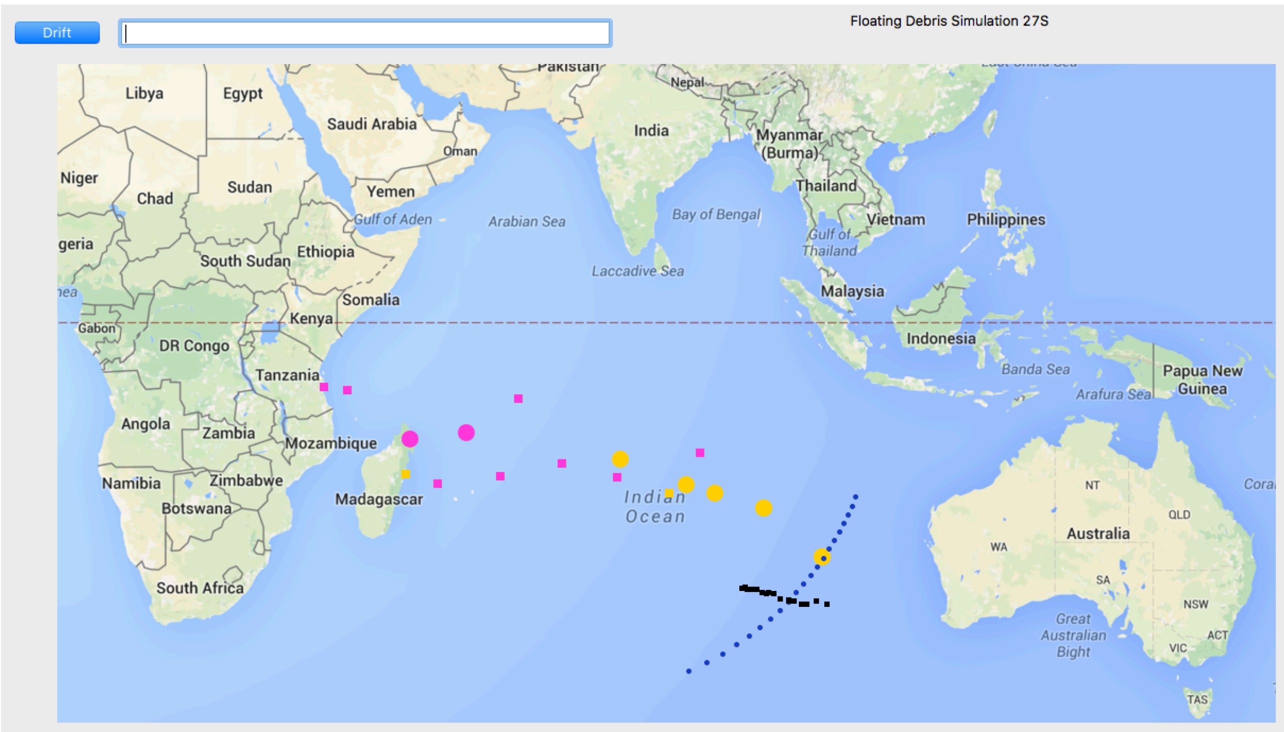
Finally 7 drifter buoys were chosen to validate the model from 20°S to 40°S on the 7th Arc and close to the 508 days timeframe of the Flaperon.



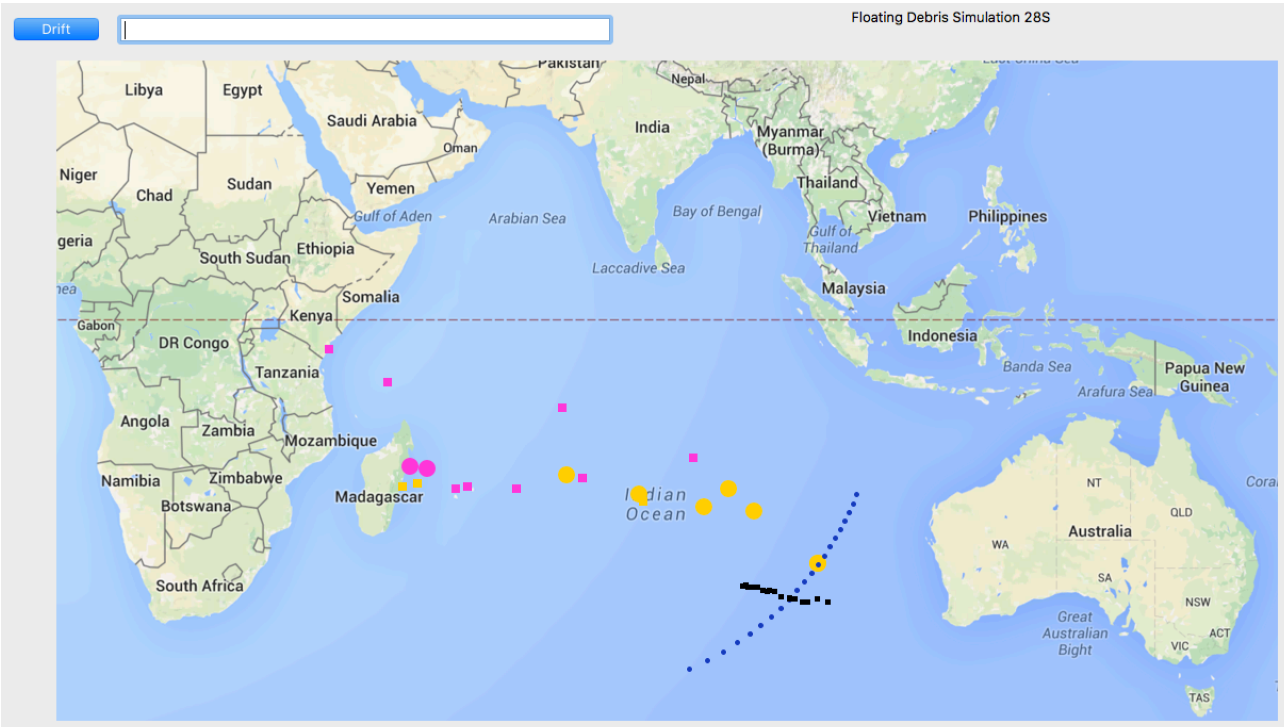
Results

In the maps below, the large circles show the simulated path of floating debris using the speed, bearing and efficiency factor as calculated for each month and position. The small squares depict the simulated path using the smallest and largest efficiency factors, giving an idea of the possible spread. Sea water temperatures below 19°C are shown in white, between 19°C and 25°C are shown in orange and above 25°C are shown in magenta. The 7th Arc is marked with dark blue dots and the Broken Ridge is marked with black squares.

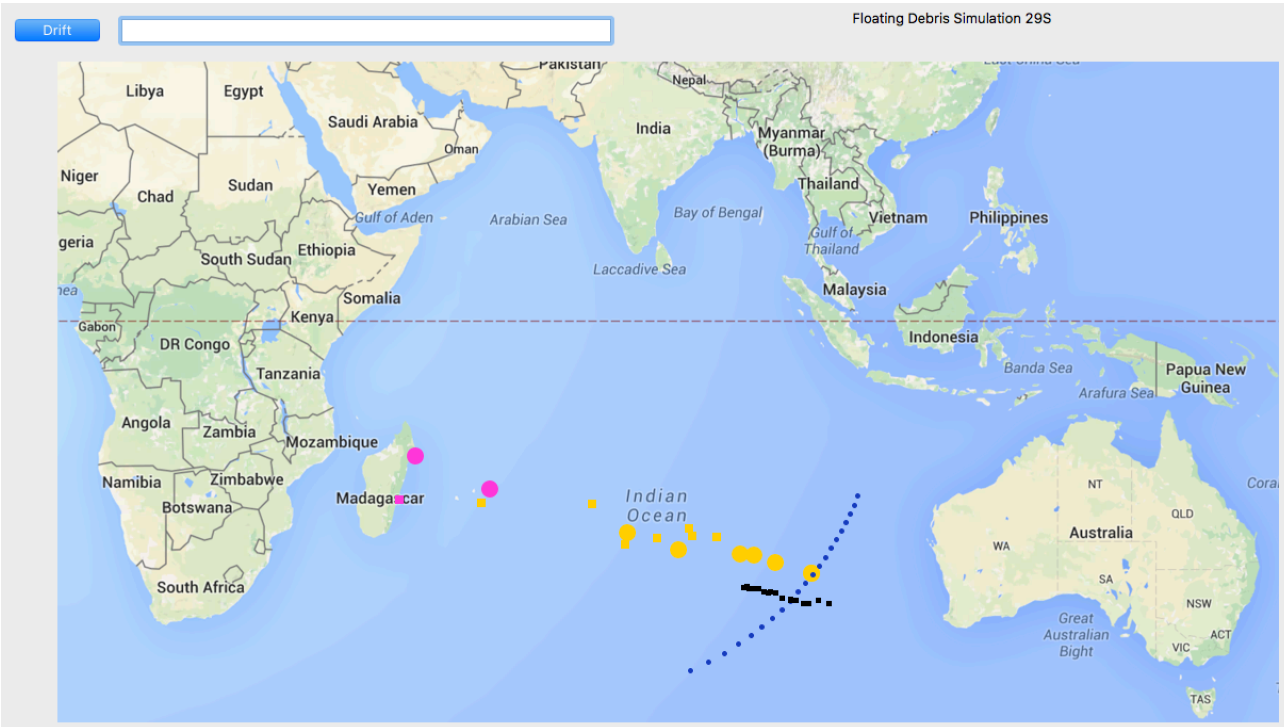
From a starting point on the 7th Arc at 27°S, the simulation shows debris arriving in Madagascar after 272 days. As CSIRO has already pointed out, this is too fast. The possible tracks are also too far north, just missing Reunion and Mauritius and excluding South Africa. The sea water temperatures are also too hot for barnacle growth in the last 90 days before any possible beaching at Reunion.



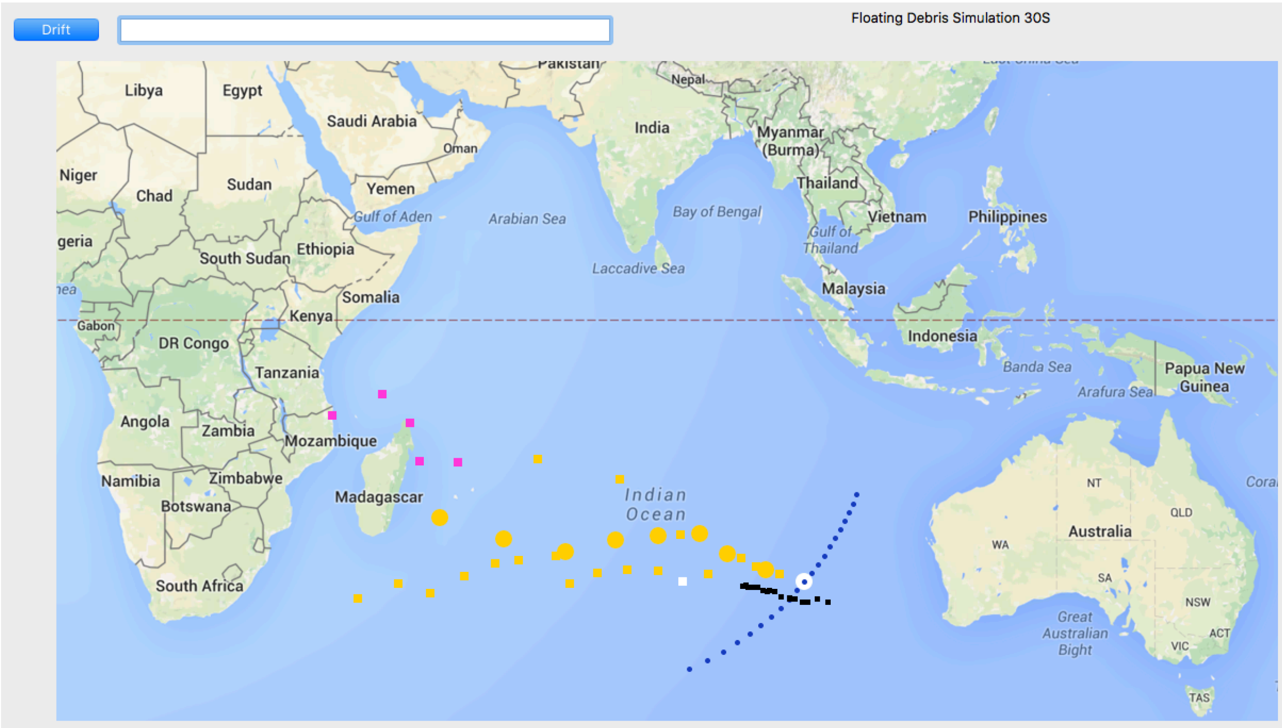
From a starting point on the 7th Arc at 28°S, the simulation shows debris arriving in Madagascar after 253 days. This is even faster than a starting point at 27°S. The possible tracks are also too far north, hitting Reunion and Mauritius but still excluding South Africa. The sea water temperatures are also too hot for barnacle growth in the last 90 days before any possible beaching at Reunion. It is noteworthy, that the simulation gives an end point at Nosy Boraha Island, Madagascar, where Blaine Gibson found a large number of debris items.



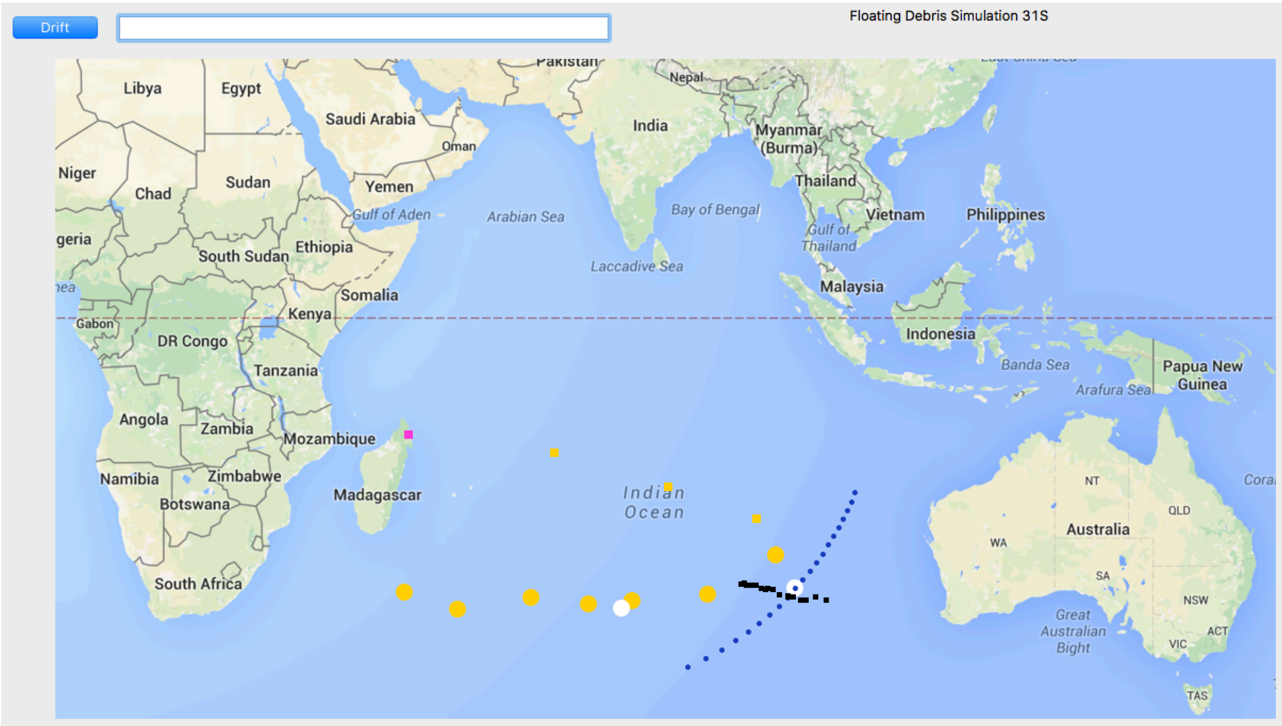
From a starting point on the 7th Arc at 29°S, the simulation shows debris arriving in Madagascar after 278 days. This is still too fast. The possible tracks show little dispersion as the efficiency factor is varied and are still too far north, hitting Reunion and Mauritius but still excluding South Africa. The sea water temperatures are borderline for barnacle growth in the last 90 days before any possible beaching at Reunion.



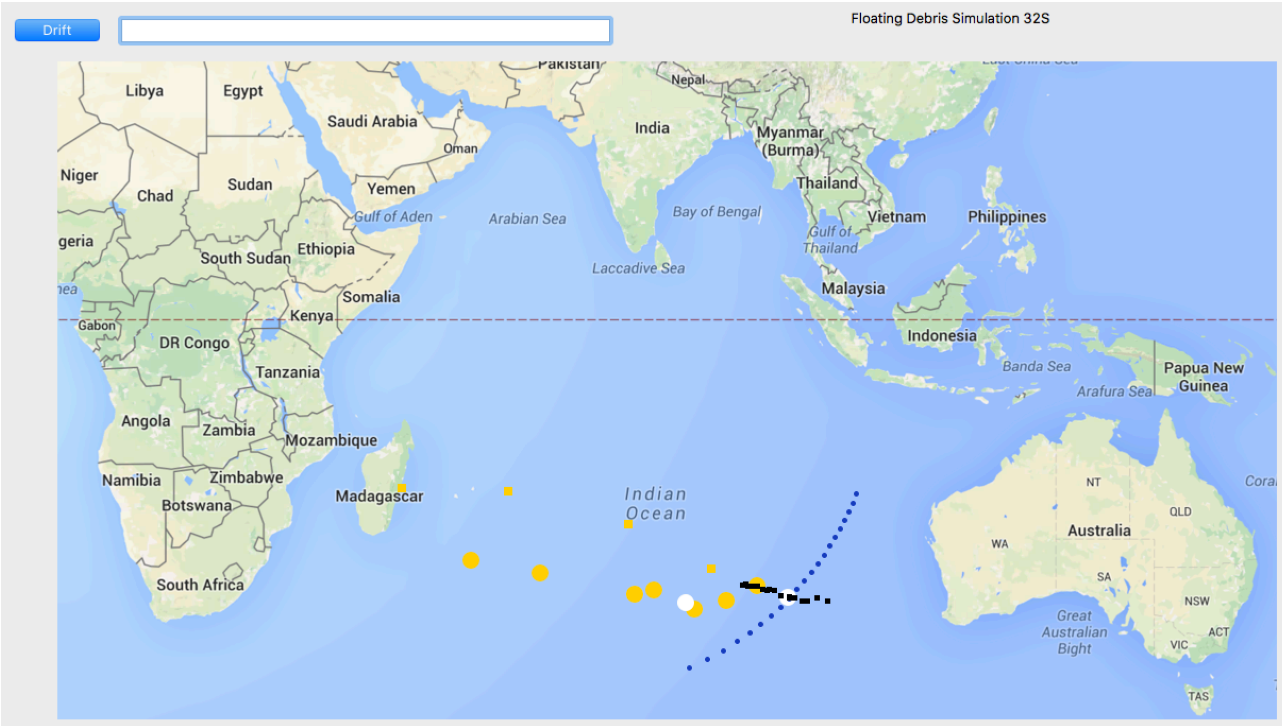
From a starting point on the 7th Arc at 30°S, the simulation shows debris arriving south west of Reunion after 487 days. This fits the timeframe of the Flaperon find after 508 days. The possible tracks show significant dispersion as the efficiency factor is varied, hitting Reunion and Mauritius but now including South Africa and Tanzania. The sea water temperatures also fit barnacle growth in the last 90 days before any possible beaching at Reunion and South Africa and exclude barnacle growth in the last 90 days before any possible beaching in Madagascar, northern Mozambique or Tanzania.



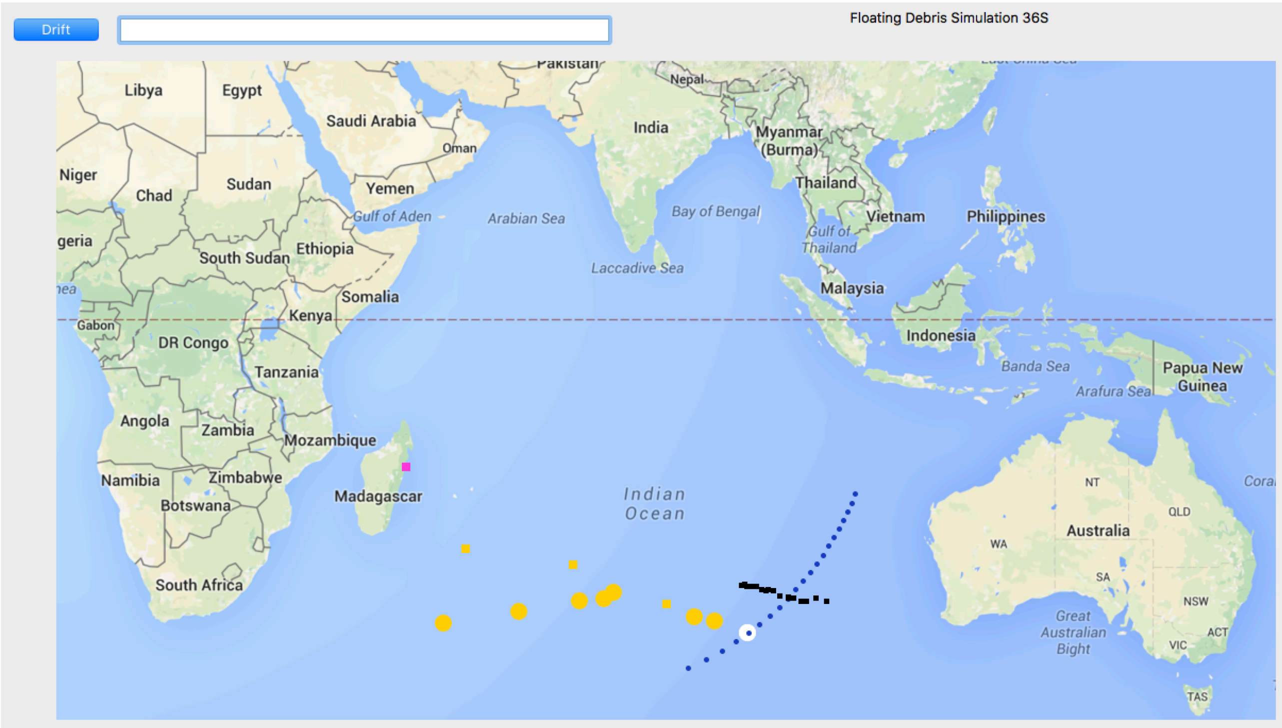
From a starting point on the 7th Arc at 31°S, the simulation shows debris arriving a long way south east of Madagascar after 487 days. The possible tracks show significant dispersion as the efficiency factor is varied, hitting Reunion, Mauritius and Madagascar, but now borderline for excluding Tanzania. The sea water temperatures also fit barnacle growth in the last 90 days before any possible beaching at Reunion and South Africa.



From a starting point on the 7th Arc at 32°S, the simulation shows debris arriving a long way south of Reunion after 487 days. The possible tracks show smaller dispersion as the efficiency factor is varied, just hitting Reunion, Mauritius and hitting central Madagascar, but now excluding Tanzania and northern Mozambique. The sea water temperatures also fit barnacle growth in the last 90 days before any possible beaching at Reunion and South Africa.



For the sake of completeness, I also ran a simulation from a starting point on the 7th Arc at 36°S, the simulation shows debris arriving a long way south of Reunion after 426 days. The possible tracks show smaller dispersion as the efficiency factor is varied, borderline to hitting Reunion, Mauritius and hitting central Madagascar, but also excluding Tanzania and northern Mozambique. The sea water temperatures also fit barnacle growth in the last 90 days before any possible beaching at Reunion and South Africa.



Discussion

The starting points between 29°S and 31°S on the 7th Arc show a possible fit to the 25 suspected and confirmed MH370 floating debris finds. A starting point of 30°S shows a perfect fit, where the speed is in the right timeframe, the possible dispersion includes locations from Tanzania to South Africa, the sea water temperature supports barnacle growth at Reunion and South Africa but not in Tanzania. A starting point of 29°S is already too fast, the sea water too hot and the dispersion too small excluding South Africa and borderline to excluding Tanzania. On the other hand, a starting point of 31°S, is already borderline to being too far south and therefore excluding Tanzania.

A MH370 end point at around 30°S implies that MH370 continued on its course following a lateral offset to the right of flight route N571 toward the Andaman Islands and was not already heading southwards at 18:40 UTC.

A MH370 end point at around 30°S implies also that the track southwards from the final major turn hypothesised in the McMurdo paper cited above at a position of 8.5219°N 92.9501°E, was not as close in time to 19:41 UTC as previously hypothesised as 19:36 UTC, or, was executed at a higher speed than previously hypothesised at 0.798 Mach, or, was not using NZPG as a waypoint as previously hypothesised.

If instead, Wilkins Runway in the Antartica (YWKS) was chosen as the final waypoint in the MH370 Flight Management System, then the great circle path from the previously hypothesised final major turn southwards at a position of 8.5219°N 92.9501°E would be on an initial bearing of 172.5499° and would cross the 7th Arc at 29.87°S. This would fit the drift analysis perfectly. Such a flight path implies a higher average ground speed of 502.5 knots, which at an air temperature of -41°C means a speed of 0.848 Mach. The Boeing 777-200ER with Rolls Royce Trent 892 engines has a cruise speed of 0.84 Mach. The satellite data shows a good fit to the aircraft track from 19:41 UTC to 00:19 UTC, but not quite as good as for McMurdo station.

Conclusion

The drift analysis appears to support a probable end point of MH370 around 30°S near the 7th Arc. This fits with a late final major turn south at 19:36 UTC and a flight at the normal cruise speed of 0.84 Mach until fuel exhaustion. There is a good fit to the satellite data and a good fit to a great circle path toward Wilkins Runway (YWKS) as the final waypoint.

The drift analysis also explains the reason why MH370 floating debris originating around 30°S near the 7th Arc could end up in Reunion and South Africa with barnacles via tracks that pass through sea water between 19°C and 25°C and end up in Madagascar, Mozambique and Tanzania without barnacles via tracks that pass through sea water above 25°C.

On 19th August 2014 07:37 Barry Carlson of the Independent Group posted on the ATSB Blog: "Strange as it may seem, the ATSB assessment for the Priority Bathymetric Survey is centred exactly where the GC track to YWKS crosses the 7th arc. If YWKS has never featured in your considerations, then I assume it would now be a further confidence booster in validating the work done to date."

Martin Dolan, Chief Commissioner responded on 20th August 2014 09:13: “Thank you, Barry, for your insight. You will be pleased to hear that the search strategy group did consider YWKS as a possible waypoint. The location of the search area however, is based on the analysis of the satellite communications data.”