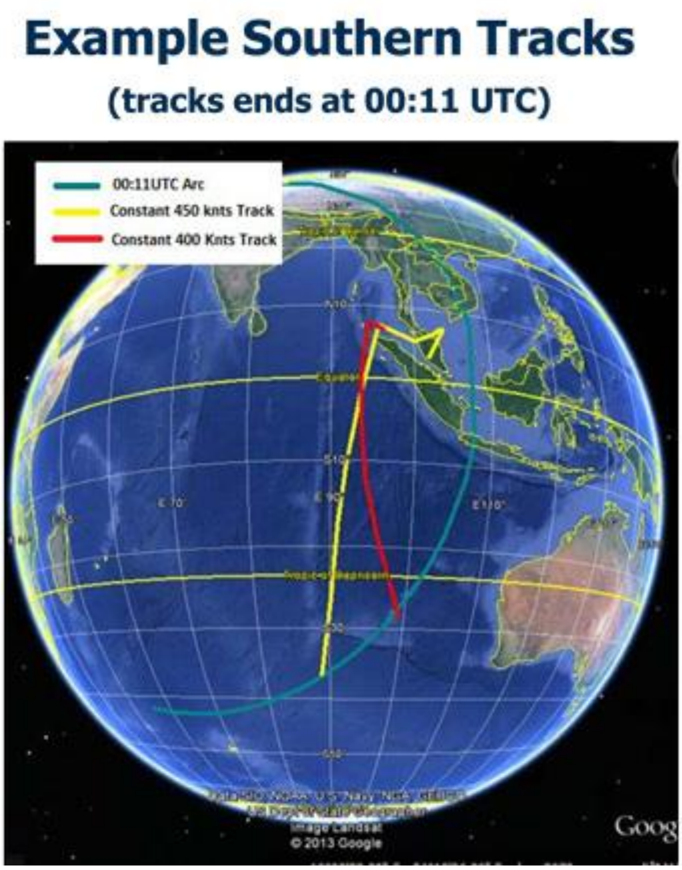
MH370 northerly flight path – waypoint approach (v. 2.0)
by 'Nederland' (3/2017)

Abstract

Reconstructions of the route MH370 took after it left Malaysian military radar have so far presumed that the aircraft did not change its route at any time between the final major turn and the end of flight. There is, however, general agreement that MH370 was passing through navigational waypoints while it was tracked by primary radar. Building on a flight trajectory previously identified by Inmarsat, the present paper presents a route exclusively based on navigational waypoints and assuming just one change in speed at the time the aircraft reached the penultimate waypoint, while discussing the alternative scenario of extended loiter in the northwest of Sumatra. The end of route point is consistent with the high priority area first identified by the ATSB, but soon abandoned. Drift studies in the trajectory of debris washed ashore on several beaches support the assumed end of route point (around -30.9, 97.4). Comparing this potential flight path with other connections between waypoints and end of flight points north of the area already searched, the paper argues that the proposed path from ~ 19:41 onwards is the only one possible that would work exclusively with waypoint navigation. The paper also attempts to discuss a potential flight path up to 19:41, taking into account radar assets in the northwest of Sumatra.

Introduction

Since search efforts in the Southern Indian Ocean have come up empty, increasing attention is being paid to a more northerly crash site of flight MH370. Underpinning the following observations is the initial Inmarsat analysis of handshake data available for the accident flight. The analysis yielded a result of two basic flight trajectories, one fundamentally different from the other. While the area around the end of the yellow path has been searched extensively, the red trajectory has yet to receive sustained consideration.



The yellow trajectory is essentially a straight line, but the red one seems to imply one change in direction in the vicinity of Cocos islands. The present paper tries to identify a viable flight path, using no more than basic maths, google earth and the BFO calculator designed by Yap Fook Fah (v. 4).

Methodology

Research by the DSTG has suggested that straight flight trajectories fit best the evidence associated with the Inmarsat data. Taking into account that the latter stages of the flight in particular do not suggest any pilot inputs, the basic idea is to try and identify a flight path based exclusively on navigational waypoints, as there is evidence to suggest that MH370 went along several waypoints on its way towards the Andaman islands. Since there is no satellite data available for the flight segment up to 19:41 (the time of the first handshake), I allow an unlimited number of waypoints and corresponding track changes for this period, taking into account other evidence in the public domain, as the DSTG simulation does not cover potential flight routes and so does not prejudge any basic flight pattern up to that time. For the flight trajectory from 19:41 until the end of the flight, I follow the Inmarsat approach to allow just one change in direction (and speed), both to keep the basic assumptions simple and to adhere to the DSTG simulation results. *This approach is different from previous ones as it does investigate the possibility that MH370 used navigational waypoints all way long, whereas others have assumed that MH370 completely changed its early 'waypoint behaviour', instead opting for continued heading flight.*

The ATSB gives one standard deviation of BFO errors as 4.3 Hz. For a statistical model involving just six data sets (the final two BFOs have little value in terms of direction as they are understood to be due to a steep dive at the end of the flight), allowing three standard deviations would seem to be far fetched. While most statisticians would opt for two standard deviations, I assume the ATSB observed error of 5 Hz gives reasonable confidence in a given route.

As a 'layperson', I'm not using professional flight simulation software, taking into account wind, autopilot modes etc., but Jeff Wise blog contributor 'TBill' indicated to me that based on an FS9 simulation, for shorter segments the autopilot mode is somewhat negligible, including for a route from BEBIM onwards.

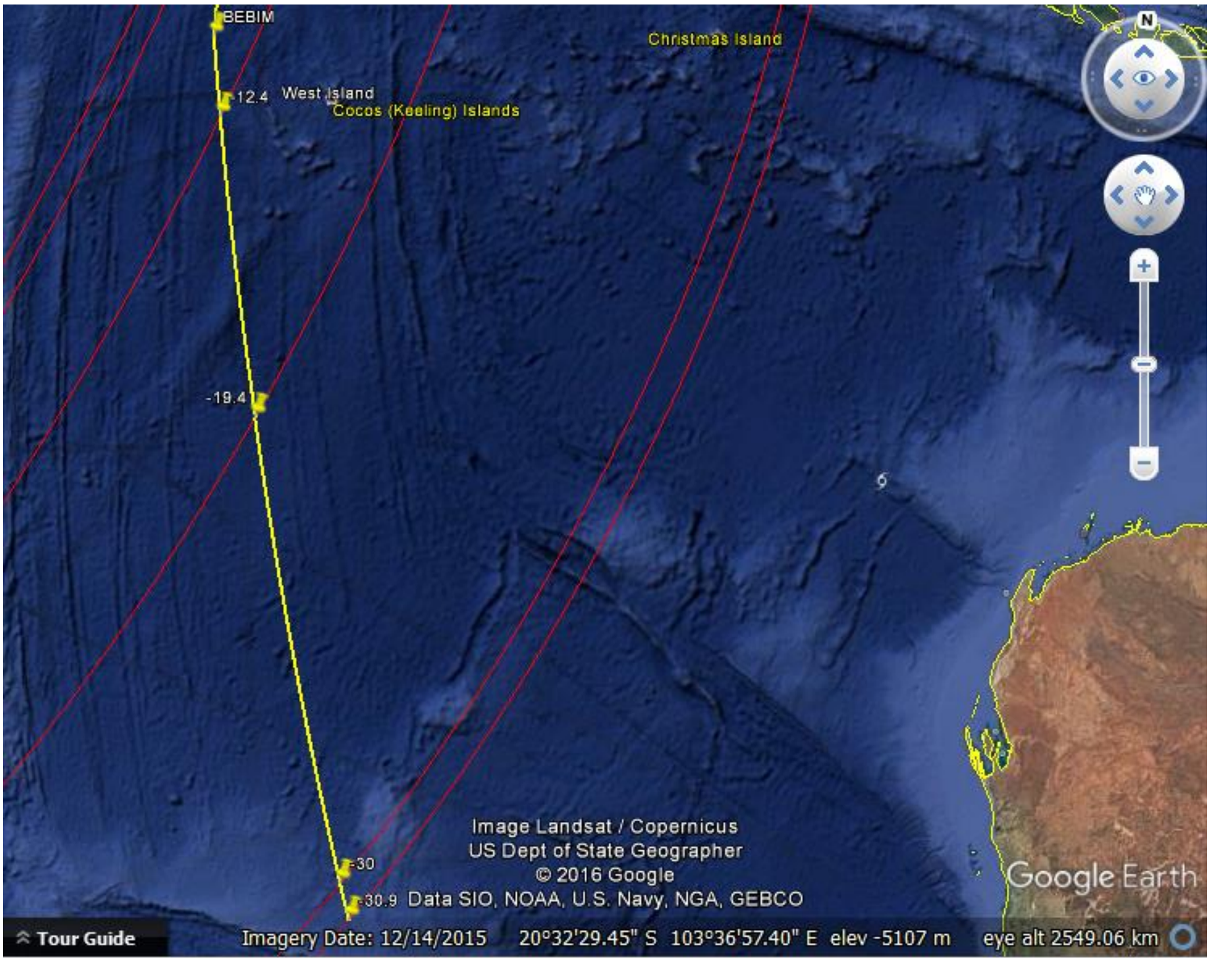
The present paper is simply an exercise in basic maths rather than an attempt to discuss the motivation for the flight path it identifies, although save for the final segment a flight route up to BEBIM would seem to be consistent with further connections to landing sites such as Cocos and Christmas Island, Learmonth and Java. Despite intense media speculation, personally I don't think either pilot intended to commit suicide.

Approach to the southern trajectory:

The sixth handshake occurred nearly 1½ times later than the fifth one in relation to the respective previous handshakes. (This is because of an intermittent unanswered sat phone call). Assuming a straight flight path, this means the distance covered from fifth to sixth associated 'ping ring' is 1½ times as long as the distance between the fourth and the fifth ring.

Trying to reproduce that proportion, I observed that a heading of around 170 degree works best in relation to the red Inmarsat trajectory. Since there are few waypoints in that part of the Indian Ocean, the waypoint BEBIM and a heading of around 170 degree seems to be the only one to fit the bill thus far. BEBIM sits on T41, a connection passing through Cocos Islands runway and ending in Learmonth, Australia.

Incidentally, I found that a 171 degree heading is the one from BEBIM to McMurdo Station (navigational waypoint NOBEY) as indicated by skyvector. Richard Godfrey and Victor Iannello have found some evidence to suggest that this could be a possible waypoint/route end point. (Since NOBEY is a waypoint, to my mind the route end point remains unknown, and may not reflect the original flight plan after the diversion. It may have been entered by someone with limited knowledge but no ability to glide and ditch the plane after fuel exhaustion. It is, however, unclear whether or not this waypoint was available in the database of the accident flight). Comparing the two paths, I found that the 171 degree heading yields slightly better results in the BFO calculator (on this below):



The associated ground speed is approximately 425 kts needed to cover the distance between the respective rings (headings and distances are as per google earth). Geolocations of placemarks are exactly the same as the ones used in the BFO calculator (slightly tweaked to reproduce exact BTOs), while placemark names indicate rounded latitude. A speed of 425 kts is consistent with fuel calculations provided by the ATSB in their June/August 2014 report (p. 46). The calculated crash point is close to the centre of, and within, the priority area identified by the ATSB in that report, but later abandoned.

It is not clear why a change in speed may have occurred. Fuel considerations and/or a calculated end of flight in the Broken Ridge area can only be supposition and may point to deliberate action, perhaps by someone with little knowledge of aircraft control (hence no further pilot inputs).

I have also tried and checked other waypoint connections involving an end point north of the previous search area, but I was unable to reconcile any with the evidence to date. For example, it is possible to assume a straight line, at a generally high speed (probably too high at ~ 500 kts for most of the flight), from PILEK to YPCC and up to the seventh ring, which delivers BFOs outside the 5 Hz observed error range, but still within 11 Hz error margin consistently on the lower end. Because of the distances between the rings, however, a speed reduction has to be assumed at some point between 22:41 and 0:11, unrelated to a waypoint. Trying to connect this route with the earlier ping rings, it is perhaps possible to posit an intersection with the 20:41 ring and a straight line between UPROB and NISOK, or a waypoint further north on that latitude, but that would in turn mean that MH370 must have crossed the 19:41 ring at a point north of the 1912 NW point. The same holds true for a direct connection from ISBIX to PILEK (which also requires an implausibly low ground speed for this segment compared to the following). A path via waypoint RUNUT has been excluded in the June/August 2014 ATSB report. This seems to exhaust other waypoint routes.

For the 1912 NW point, see Iannello, 2/2017

Approach to the northern trajectory

As intimated earlier, the DSTG simulation suggests few, if any, changes in the flight trajectory after MH370 first crossed the 19:41 ping ring (on this, see Holland, 2017). Since a ground speed of 425 kts, posited for the segment from BEBIM to the end of flight, requires at least on change of speed for the northern trajectory, I allow one simultaneous change of speed and direction at waypoint BEBIM. The obvious candidate waypoint from which MH370 could have continued to BEBIM is ISBIX, as it sits so close to the 19:41 ping ring to that many have speculated it was the final waypoint.

There is thus a straight connection between ISBIX and BEBIM and a fixed intersection with the 20:41 ring (at 4°51'3.94"S, 93°43'16.81"E)

While the distance measured from BEBIM to the 21:41 ring amounts to 123 nm, the distance from the 20:41 ring to BEBIM is 334 nm. There is also a given speed from BEBIM onwards.

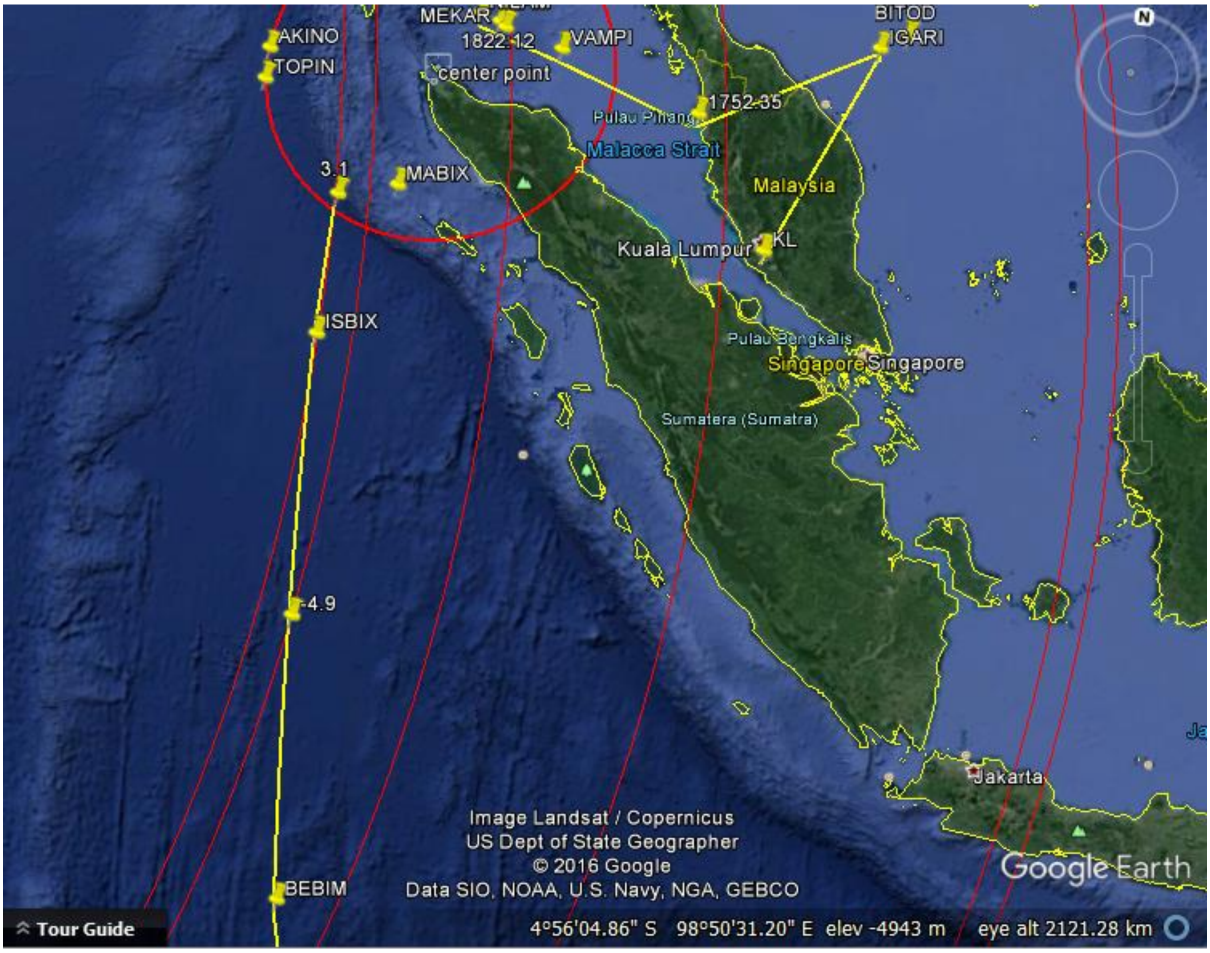
The time spent between BEBIM and the 21:41 ring is 123 / 425 * 60 = ~ 17.36 min (decimal unit, approximately 17 min 20 sec).

In proportion, the speed between the 20:41 ring and BEBIM is 334 (distance) * 60 (hour) / 42.64 (time left) = ~ 470 kts.

Therefore, the ground speed up to BEBIM amounts to 470 kts.

The line between ISBIX and BEBIM has a heading of 179.35 degree and this amounts to a BFO of 141 at its intersection with the 20:41 ring (same as measured).

Assuming no further change in speed, the given distance to the 19:41 ring is 470 nm and this amounts to an intersection with the ring at geolocation 3.022378, 93.7340821 (via ISBIX) and a heading of 181.6 for the connection between the 19:41 ring and ISBIX. The corresponding BFO is 104 and thus just off the 5 Hz deviance observed by the ATSB (measured 111). A slightly positive rate of climb (while MH370 was leaving Sabang radar line of sight) would mitigate that, but there are also different possibilities worth considering.



Speculations on the flight Segment around Sumatra ("northern hook route")

Any attempt to reconstruct the flight around Sumatra can only be supposition. To some observers, the flight path, which MH370 was following up to the point it left Malaysian military radar, suggests that MH370 was a) following waypoints b) avoiding Indonesian FIR and c) flying on, or close to, established air routes, at times appearing like a regular flight or an aircraft in distress.

This section discusses a viable flight path, assuming that MH370 was following this pattern up to the point it had left Indonesian radar range, taking into account media reports, quoting Indonesian officials:

> it could very likely have cleared Sumatra island in the north before making another turn to the south until it was 2,500 kilometers from Perth. (Jakarta post, 3/2014)
>
> I have received a report that our air defense radar system in Sabang is strong and it did not detect an airplane (flying over the Indonesian territory) (Antara news, 3/2014)

Even if Sabang radar was off during the night on that weekend, it is possible to think that MH370, following a pattern of 'avoidance behaviour', did not intend to pass through Indonesian airspace, otherwise it could have done so long ago. The same could be said about

Aceh radar at the more distant Lhokseumawe. The path proposed by Godfrey/Iannello (which requires a standard deviation greater than the one I allow in this paper), on the other hand, does mean the plane would necessarily have flown through Indonesian airspace and radar range (of Sabang and Lhokseumawe).

The range of the Sabang radar is not known exactly. Given that MH370 must have been descending during the unanswered 18:40 sat phone call by 2000 ft/min to satisfy the BFO measured and that the distance from Sabang to the border of Indonesian air territory is nearly 200 nm, I assume this distance as a 'safe' one for the eventual turn south.

This assumption seems to be confirmed in a table provided by the Duncan Steel website:

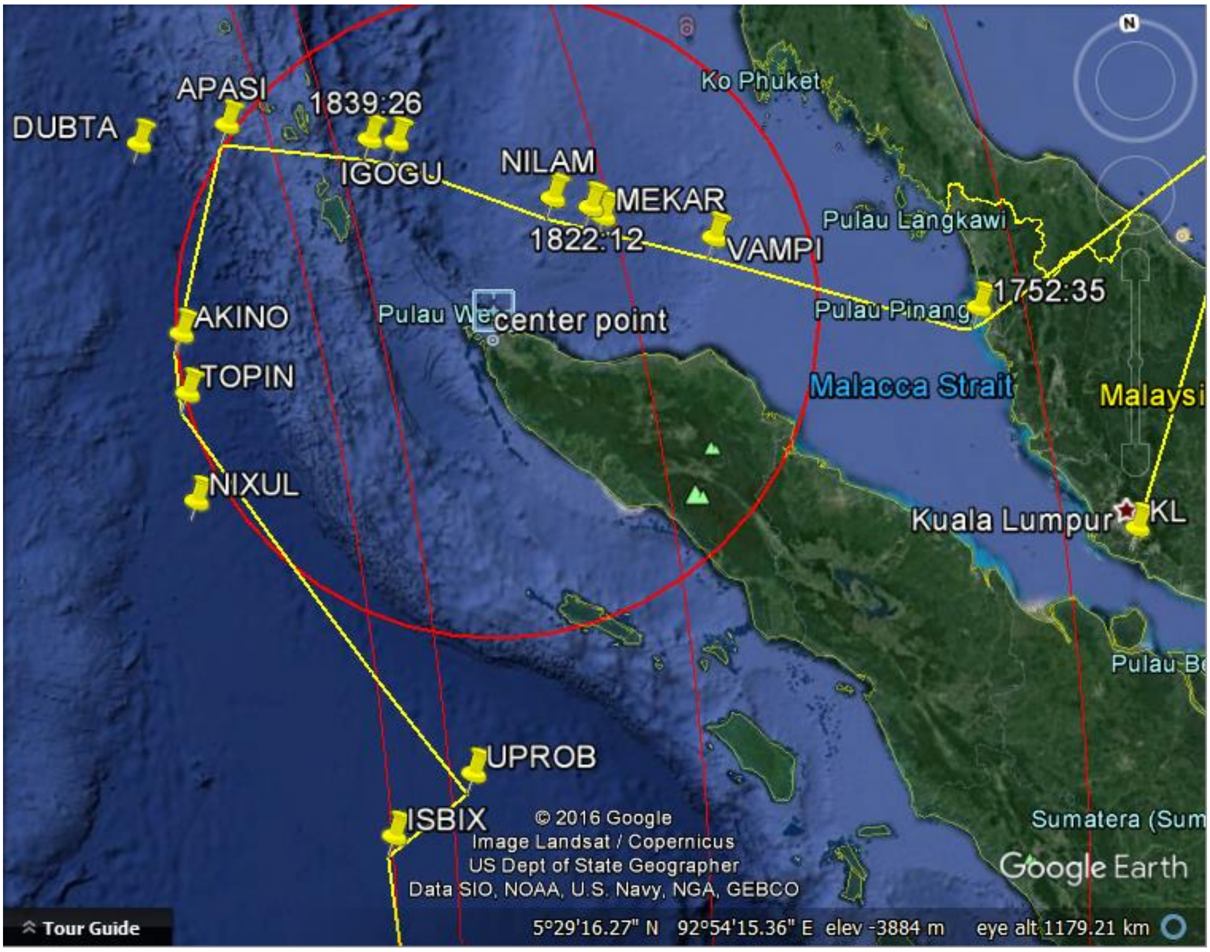
Location	Reference Label	Latitude (degrees North)	Longitude (degrees East)	Elevation (metres)	Range at 5,000 feet	Range at 10,000 feet	Range at 20,000 feet	Range at 35,000 feet
Malaysia								
Western Hill, Penang Island	M1	05.425	100.251	812	241	299	381	471
Bukit Puteri, Jertih, Terengannu	M2	05.786	102.504	170	186	244	325	416
Bukit Ibam, Muadzam Shah, Pahang	M3	03.181	102.983	529	222	279	361	451
Bukit Lunchu, Johor	M4	01.518	103.850	163	185	243	325	415
Kuching, Sarawak	M5	01.430	110.388	057	166	224	306	396
Bukit Kubong, Labuan, Sabah	M6	05.377	115.241	079	171	229	311	401

Location	Reference Label	Latitude (degrees North)	Longitude (degrees East)	Elevation (metres)	Range at 5,000 feet	Range at 10,000 feet	Range at 20,000 feet	Range at 35,000 feet
Thailand								
Phuket	T1	07.881	098.316	509	220	278	359	450
Ko Samui Island	T2	09.493	099.987	614	228	286	367	458
Khok Muang	T3	06.844	100.420	304	202	259	341	431

Location	Reference Label	Latitude (degrees North)	Longitude (degrees East)	Elevation (metres)	Range at 5,000 feet	Range at 10,000 feet	Range at 20,000 feet	Range at 35,000 feet
Indonesia								
Lhokseumawe, Aceh	I1	05.111	097.156	031	159	217	299	389
Sabang, Aceh	I2	05.888	095.229	457	216	274	355	445

Units are given in km and the range of Sabang radar therefore amounts to less than 200 nm (191 nm) at 20,000 ft. At a presumed ground speed of 507 kts (calculated for the flight segment between Penang and 18:22) MH370 was ~ 91 nm away from APASI at the time the first of two BFO values at 18:39 were measured. At the same ground speed, the time it took to reach APASI would be 10 to 11 minutes. The corresponding RoC would be -2000 ft/min and thus a flight level change from cruising altitude to 20,000 ft (or less) could be accomplished within five to eight minutes. This means that had the descent first occurred at or shortly before 18:39, MH370 would have been out of radar range by the time it reached the target altitude.

A rough estimation is that the flight segment from 18:22 to a point close to APASI (the end of the descent) is 180 nm, the final segment after safely exiting Sabang radar range to the 19:41 ring is 64 nm, the intermediate segment would then be 360 nm. I estimate the average speed of the first segment to be 500 kts (eventually going slower when descending), time passed as 21.6 min (decimal). The speed for the final segment up to the 19:41 ring is 470 as per the considerations above (8.4 min). The 50 min in between at ground speed x accordingly is 360/0.83333 with x = 432 kts. If MH370 had gone further via waypoint DUBTA, that would add another 50 nm and would come at a speed of 492 for the intermediate segment (the average speed for the whole 80 mins is 460 or 490 kts, respectively). Since the DSTG calculated that MH370 must have gone slower at some point after leaving Malaysian military radar to satisfy endurance, and in my scenario at a lower altitude at that, ASPASI rather than DUBTA seems to be the waypoint at which the southern turn occurred.



It so happens that the distance between the 19:41 ring and ISBIX via UPROB is the same as the one posited above for the intersection of the path reversing from the 20:41 ring at a ground speed of 470 kts. Based on these parameters, the BFO calculated for 19:41 is 111 (as measured).

Why would MH370 continue to UPROB rather than directly to ISBIX?

As you can see on skyvector, there is nowhere near a civilian air route from TOPIN to ISBIX:

Although outside Sabang military radar range, had MH370 been tracked, unexpectedly but still in the vicinity of Sumatra, it would have looked like an aircraft in distress or otherwise on its way to some airport in Sumatra, such as Minangkabau International, while passing close to, and eventually intersecting with, L896 before joining L774 to ISBIX.

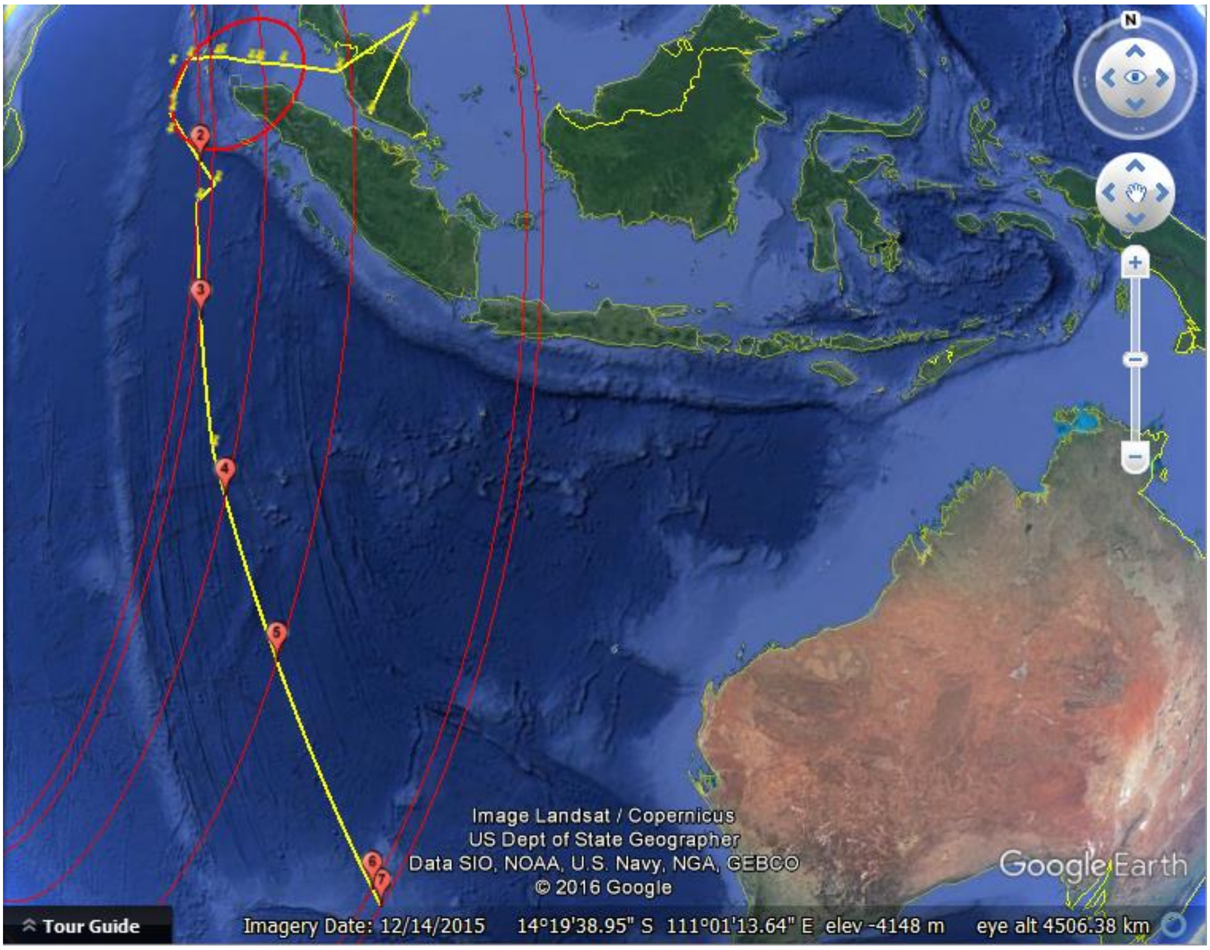
Alternatively, it could have gone further south to waypoint NIXUL before moving on to UPROB. In that case the parameters still satisfy the BFO within one standard deviance, but an unexplained change in speed has to be assumed. The angle from waypoint NISOK, at the intersection of L896, is too flat to satisfy the BFO, however.

The suggested flight path is not at odds with the so called 1912 NW point as MH370 would have been south of that point. The scenario proposed by Godfrey/Iannello, on the other hand, which requires a loiter northwest of Sumatra has to presume that the Singapore radar asset maintains a position west or southwest of the 1912 NW point. However, as the ATSB has taken this information as limiting the endurance limit of MH370, it is likely that the 1912 NW point defines the northern rather than the western limit at which the plane could have travelled at the time. If correct, this would exclude the possibility of such a loiter as has been proposed (on this see Iannello, 2/2017).

It is important to note, however, that this is just one possible flight path with which to explain the following route along waypoints. There is no need to assume that this was the actual route up to the 19:41 ping ring. MH370 may have followed a different path, using custom waypoints and meeting the 19:41 ring at point 3.1 above.

Conclusion

The above considerations amount to the route below and require a descent while exiting Sabang radar line of sight and one change in speed at waypoint BEBIM from 470 to 425 kts at ground.



Red placemarks indicate intersections with ping rings, yellow pins waypoints or other events en route.

The route plan would be as follows:

IGARI WMKP VAMPI NILAM IGOGU APASI AKINO TOPIN NIXUL UPROB ISBIX BEBIM NOBEY

The calculated crash location is 30°53'05.3"S 97°21'43.6"E (-30.884814, 97.362111)

It is important to note that, regardless of considerations on the early flight route, the end of flight point is fixed in the event that MH370 was flying on to NOBEY (McMurdo) or on a 171 heading from waypoint BEBIM. At any rate, if MH370 passed waypoint BEBIM, this would significantly reduce the number of possible end points.

BFO and BTO Calculator by Yap FF

Aircraft — Input position and velocity values in these columns (Position: Latitude, Longitude, Altitude; Velocity: Ground Speed, Track, Rate of climb)

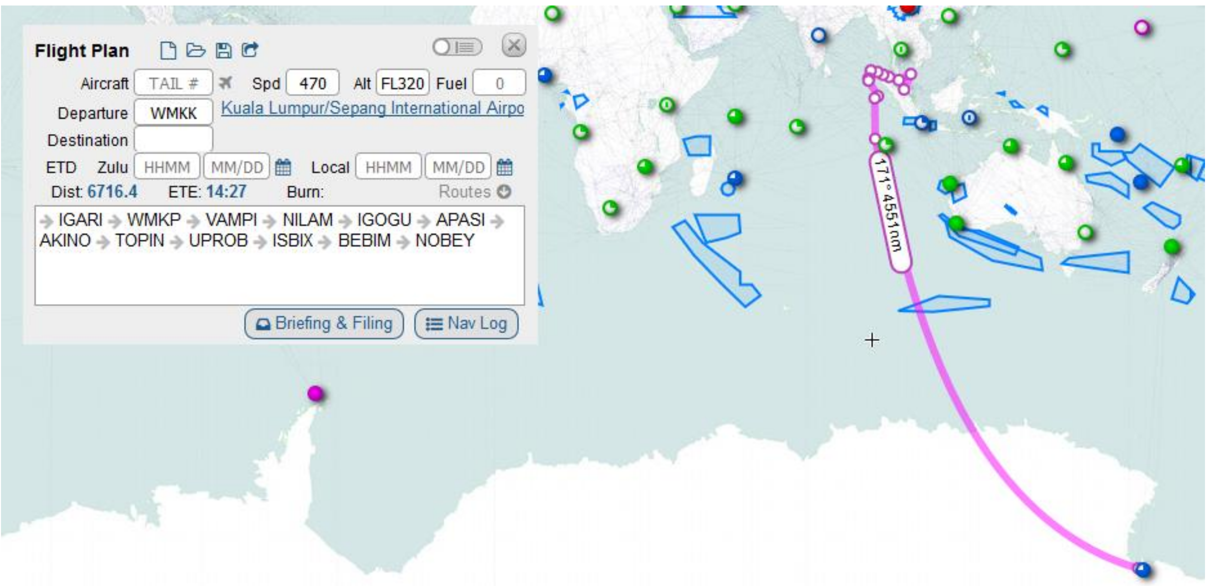
	Time (UTC)	Latitude deg	Longitude deg	Altitude km	Ground Speed knot	Track deg	Rate of climb ft/min
1	3/7/2014 16:29:52.406	2.7470	101.7130	0	0.0000	140.0000	0.0000
2	3/7/2014 16:42:31.906	2.8130	101.6800	0	210.0000	327.0000	413.2350
3	3/7/2014 16:55:37.907	3.9320	102.1620	1.65	452.0000	25.0000	1432.1518
4	3/7/2014 17:07:18.906	5.4190	102.8640	6.75	450.0000	25.0000	0.0000
5	3/7/2014 17:21:00.000	6.9367	103.5850	6.75	450.0000	25.0000	212.4478
6	3/7/2014 18:22:00.000	6.5496	96.3320	10.7	500.0000	192.8795	0.0000
7	3/7/2014 18:39:26.342	7.5916	94.0759	7	507.0000	283.0000	-2000.0000
8	3/7/2014 19:41:02.906	2.2285	93.7524	9.75	470.0000	148.5000	0.0000
9	3/7/2014 20:41:04.904	-4.8511	93.7213	9.75	470.0000	179.3500	0.0000
10	3/7/2014 21:41:26.905	-12.4388	94.1125	9.75	425.0000	171.0000	0.0000
11	3/7/2014 22:41:21.906	-19.4086	95.2637	9.75	425.0000	171.0000	0.0000
12	3/8/2014 0:10:59.928	-29.9869	97.1775	8.8	425.0000	171.0000	0.0000
13	3/8/2014 0:19:29.416	-30.8848	97.3621	3			
14							
15							
16							

	Calculated satellite to aircraft range km	Calculated BTO µs	Uplink Doppler Δfup, Hz	Downlink Doppler Δfdown, Hz	Aircraft frequency compensation δf comp, Hz	EAFC receiver frequency compensation + Satellite translation frequency δf AFC + δf sat, Hz	Fixed offset δf bias, Hz (150.2566775)	Calculated BFO Hz
1	37298.30836	14903.0157	-6.11181127	-84.66778201	0	28.86	150.2566775	88.338475
2	37296.77994	14927.48181	212.8826438	-80.28812743	-198.8649632	27.16	150.2566775	111.150947
3	37336.62287	15227.16177	-390.1876136	-75.48836243	443.3755942	25.37	150.2566775	153.3247566
4	37395.34731	15647.33772	-445.5605108	-70.99293257	472.17393	24.12	150.2566775	129.9973386
5	37463.45505	16132.71022	-469.5662644	-65.48865686	502.713566	21.99	150.2566775	139.9076361
6	36930.88882	12685.61123	297.9637278	-38.41126925	-341.841512	11.07	150.2566775	79.03368069
7	36798.79661	11824.22634	710.122908	-30.10594135	-746.9972809	7.70	150.2566775	90.98127903
8	36745.5804	11500	-382.6734105	0.1156903422	345.2162553	-1.99	150.2566775	110.9268706
9	36785.9678	11740	-158.0264947	29.18292284	120.7763935	-1.22	150.2566775	140.9714304
10	36954.72821	12780	-377.3294598	55.92167325	359.6412065	-18.30	150.2566775	170.1865395
11	37238.66294	14540	-490.5705484	78.19551065	492.7253687	-28.74	150.2566775	201.8624964
12	37803.73272	18040	-635.0838528	100.7637355	669.9376969	-37.87	150.2566775	248.0083614
13	37861.98284	18400						
14								
15								
16								

BTO and BFO Calculator | Inmarsat Data | BFO Analysis | Satellite Model | Figure 10 | Figure 11

Time	Geolocation (lat, long)	BFO predicted	BFO measured
19:41	2.228522, 93.75244138	111	111
20:41	-4.8510935, 93.721336	141	141
21:41	-12.438841, 94.112453	170	168
22:41	-19.4085804, 95.2637	202	204
00:11	-29.98690406, 97.177467	248	251

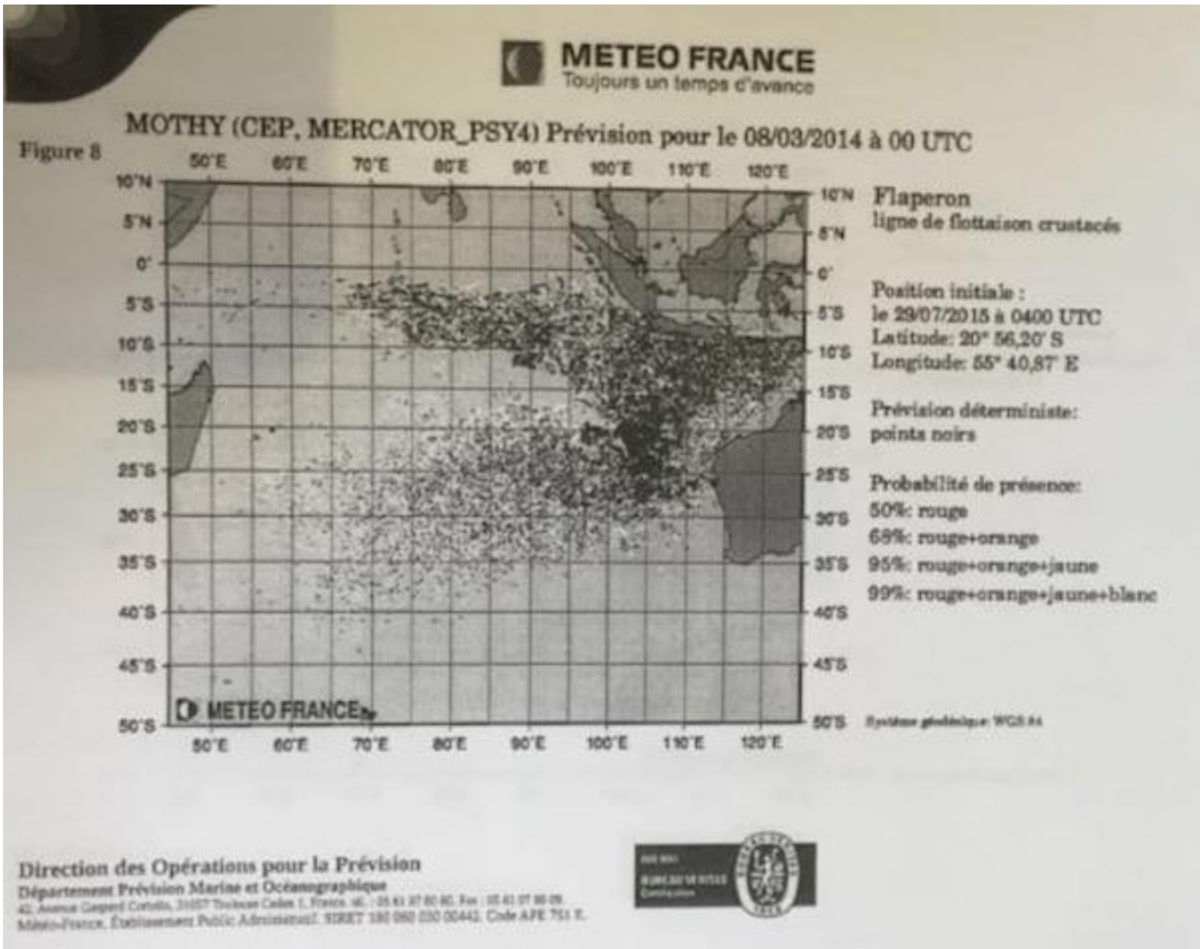
The altitude of the flight segment from 19:41 onwards is unknown. Different altitudes have a slight impact on the BTO. I assume an average cruising altitude of ~32,000 ft.



Appendix: comparison with drift studies

Among published studies in the probable drift pattern of the flaperon found on La Réunion island in late June 2015 and other debris, I have identified a total of five that do not presume that MH370 crashed in the area unsuccessfully searched by the ATSB.

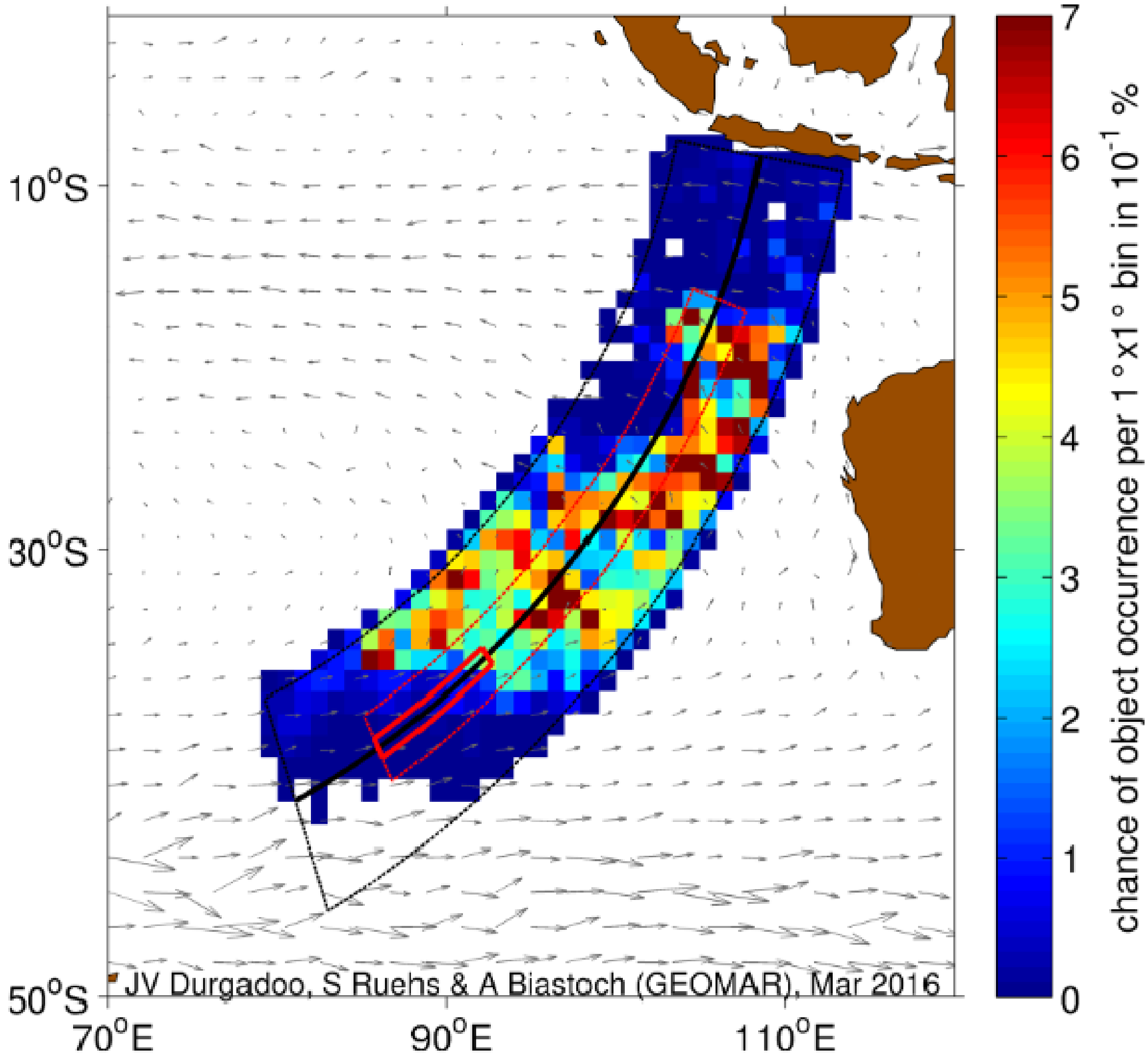
Pierre Daniel (Météo-France) observed that the flaperon was covered by barnacles on both sides. As the flaperon must therefore have drifted partly submerged, he concluded it is likely the flaperon originated from the area indicated below:



According to this study, the flaperon could not have originated from the original search area, but it could have originated from a point close to -30.9, 97.4

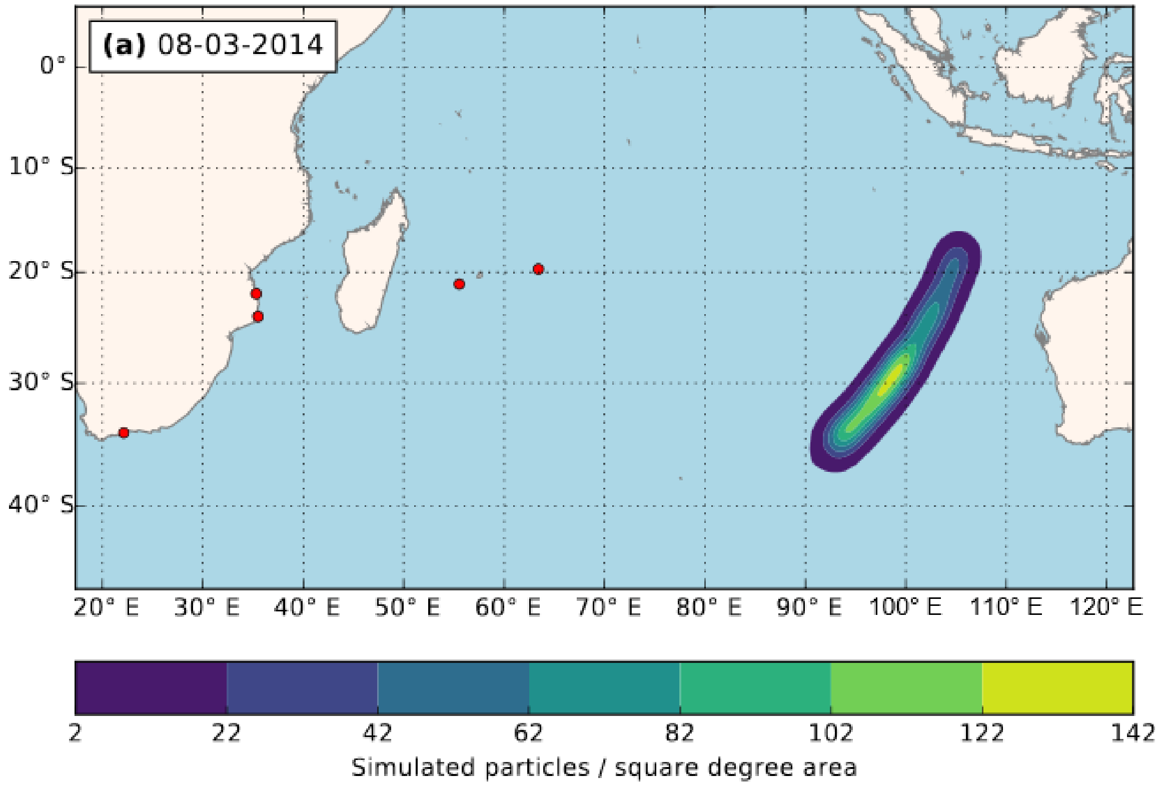
http://031c074.netsolhost.com/WordPress/wp-content/uploads/2016/05/Pierre-Daniel-report.pdf

Durgadoo et al. (Geomar) observe a far greater likelihood that the flaperon originated from this point than from the area investigated:



http://www.geomar.de/fileadmin/content/service/presse/Pressemitteilungen/2016/MH370_Report_May2016.pdf

Examining the drift trajectory of the flaperon and further debris washed ashore in South Africa, Mozambique and Rodrigues, Jansen et al. found that the most likely common area of origin intersects with -30.9, 97.4.



http://www.nat-hazards-earth-syst-sci.net/16/1623/2016/nhess-16-1623-2016.pdf

A paper authored by Richard Godfrey and based on 25 suspected and confirmed MH370 floating debris finds suggests an endpoint between -31 and -29, consistent with the endpoint identified in this paper.

https://www.dropbox.com/s/6g82uw9b24r7qf4/The%20probable%20End%20Point%20of%20MH370.pdf?dl=0

Based on 22 pieces of debris found, Charitha Pattiaratchi's (University of Western Australia) reverse-drift modelling put MH370 at Longitude 96.5 E Latitude 32.5 S with a 40km radius, close to the endpoint identified in this paper.

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