CAPTIO Debris Drift Analysis

by the CAPTIO team

In CAPTIO report « A plausible trajectory for MH370 » v3.4 published in January 2018 [1], a preliminary study of forward tracing of the Debris drift departing from the CAPTIO End of Flight (EoF) zone was presented. The partial conclusions were that until Nov. 2014, the simulated debris drift paths provided evidences of the compatibility of the results with the actual debris discovery of some pieces like the flaperon on the shore of l'Ile de la Reunion.

The objective of this report is to present the results of the complementary study completed in Dec. 2018 and covering the extended period from the End of Flight on 8 March 2014 until 31 January 2016 to analyse the potential landing zones of the 5 flap type debris including East coast of Africa.

1- Computed simulation of the debris drift

The method used is a forward tracing algorithm using a computational model based on both Pengam's conclusions [2] and on CSIRO's experimental conclusions [3]. The forward tracing consists of computing the drift of debris at constant time intervals and building the full path from an originating point and chaining all the computed segments from 8 March 2014 till 31 January 2016.

The starting grid:

The starting points of the drift paths simulation have been selected on a regular square grid around the location of MH370 End Point defined by the CAPTIO trajectory (12°S/107°E approximately). The grid dimensions are 11 by 11 points at 1 Nautical Mile (NM) intervals making a total of 121 simulated drift paths covering a geographical area of 100 NM^2. These dimensions are compatible with the computing power and time at disposal to the CAPTIO team and have been found sufficient to obtain results pertinent to the point made in this report.

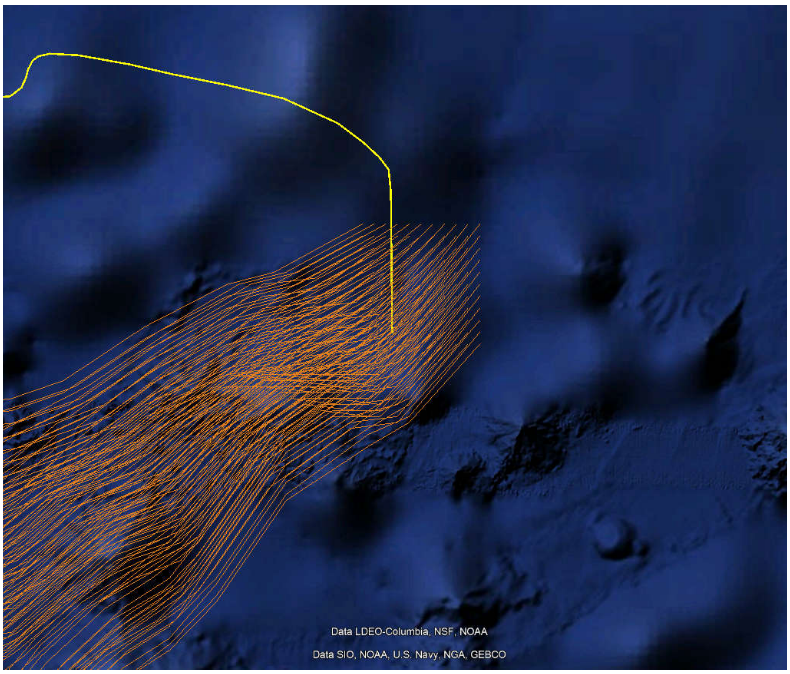


Figure 1: The starting points grid around the CAPTION End of Flight location. These points are the seeding points for the simulation computation of the forward tracing of the drift paths.

Actual meteo data:

In contrast with all simulations performed up to date, the meteo and ocean current data are both coming from actual measurements made between 8 March 2016 and 31 January 2016. The data is available on the internet at the https://earth.nullschool.net website. For example, it is not based on average current data over 30 years as used in [3]. The data used here is from actual measurement made on the locations of interest by the Global Forecast System (GFS) of NOAA and the Earth and Space Research Institute via Ocean Surface Current Analyses (OSCAR) derived from satellite data.

An important aspect calling for the use of actual meteo data (wind and current) comes from the consideration of the South-West Indian Ocean cyclone seasons for 2014 until 2016. The list of cyclones is long, even if not all of them have crossed the debris drift path. Figure 2 provides an indicative view of the paths of the cyclones showing the high probability to have crossed the debris paths. The potential impact of these cyclones on the debris speed and direction dramatically increased the randomness of the drift of debris leading to huge deviations from averaged statistical current models. This demonstrates the importance of using actual meteo data.
Appendix 1 presents the lists of 13 cyclones, which most certainly influenced the drift of debris, along with 8 additional, less influencing cyclones.

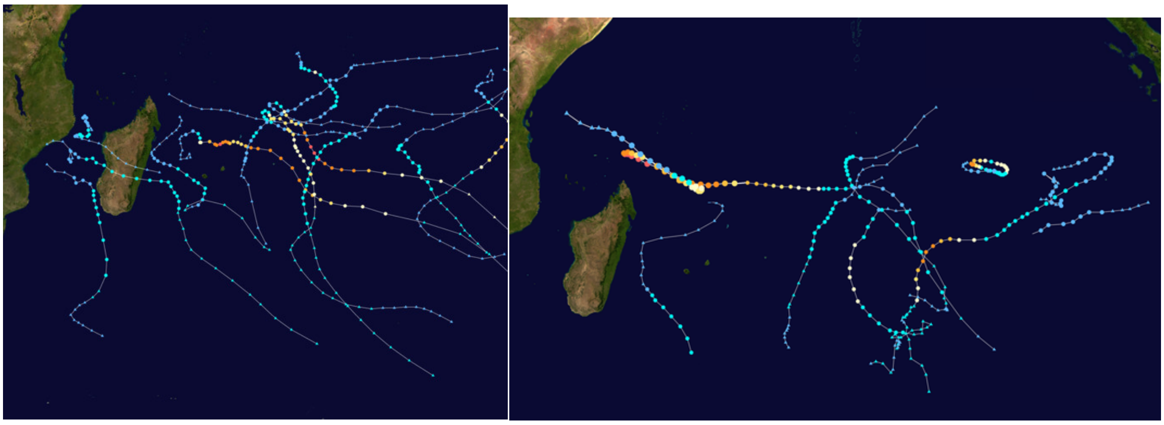


Figure 2: Schematics of the paths of South West Indian Ocean cyclones (source Wikipedia) which most certainly impacted the drift of debris in adding a high random component.
Left: Nov. 2014-April 2015 / Right : Nov 2015-April 2016.

This massive data is publically available under different formats that have evolved in time, which complicated its use for our computations. In fact the data is "coded" and structured as well as encrypted. The last encryption is such that only data until 31 January 2016 could be accessed using the same previous method. This is actually 5 months longer than the previous study [4].

CAPTIO chose to analyse the drift with data as close as possible to the actual weather during this limited period of time rather than on a longer period but with statistically modelled data. Thus the focus will be put on the flaperon, which landed during this time period.

The time period considered:

Under the constraint explained above, the drift computation covers the full period from March 8th, 2014 until January 31st, 2016. This allows covering the arrival at l'Ile de la Reunion by the flaperon. By extension, debris falling in the "flaperon type" family is also analysed in this report as simulated arrival at l'Ile Maurice and also in the vicinity of the east coast of Africa fall in this time period.

The selected computational model:

The computed simulation of the natural drift is performed using a mix of the CSIRO mathematical drift model provided in the latest CSIRO report [3] enhanced with the finding from Pengam [2].

In their simulations, CSIRO did not use the full set of experimental values found during the measurements of the genuine flaperon behaviour in real situation. They used 1.2% of the windspeed for the Stokes component but they overruled their estimated drift angle (16°) with the wind direction by a factor (20°) to force a matched arrival at La Reunion on time.
In our model we chose to implement genuine Pengam's findings i.e. 18° as it is well documented and justified. This angle was used for simulating the complete leeway, as the flaperon type of debris with its surrounding water cannot be considered as one solid moving in translation pushed by the Stockes. In fact, the water flowed around the flaperon whose semi-vertical position created a lateral deviation of its trajectory as computed by Pengam [2] and experimented by CSIRO [3].

Thus actual surface current and surface wind were input for drift calculation. The algorithm of the model produces the flaperon drift as the sum of the surface current plus the surface wind with 18-degree orientation to the left and an additional speed of 0.1m/s in the wind direction.

For each path, the geographical coordinates from one location to the next is calculated using a 2D linear interpolation by time intervals of 3 hours for the wind and every 5 days for the current of the ocean. The standard weather grid (over the Indian Ocean) is used i.e. 1 degree for the wind and 1/3 of a degree for the current.

One piece of debris is assigned to each departing sub-zone and its journey is modelled independently. One originating point leads to only one single path. When two paths cross each other, we don't create new extra paths like in [3] where 2 crossing paths would generate 2 different ends for each path in exchanging the second part with each other.

It should be underlined that it is not a statistical study with a quantified probability that a found piece of debris on shore would originate from the MH370 End Point area. Instead, since CAPTIO MH370 End Point is known à priori, this drift analysis determines the end of the drift journey and the subsequent potential shore landing point if applicable.

2- Findings:

First, let's consider some characteristics of some of the debris. There are 5 pieces of debris (called "items" in the Final Report [5]), which can be considered as pieces of debris behaving similarly to a flaperon and will be considered under this analysis. They are listed in the table below:

Item #	Alphabetical Reference in the Final Report	Description of the piece of debris	Landing Location
1	A	Right Flaperon	Saint-Denis, Ile de la Réunion
10	H	Left Outboard Flap	Ilôt Bernache, Mauritius
19	O	Right Outboard Flap	Pemba Island, East of Tanzania
26	V	Right Aileron	Nautilus Bay, South Africa
27	W	Right Wing No. 7 Flap Support Fairing	Mpame Beach, South Africa

They are likely to behave like the "original" flaperon (item #1) i.e. not floating horizontally because of mass inhomogeneity in its volume and of penetrating water in the composite or in the empty space. Consequently, after having studied the flaperon in the first place, the 4 additional items will be considered in this analysis for consistency with the caveat that the direction of the drift compared to the wind direction is unknown (left or right for example).

The full set of computed paths for "flaperon type" debris is illustrated in Figure 3 below. The 5 "flaperon type" items are included in lettered red pins according to the nomenclature of the relevant appendices to the Final Report [5].

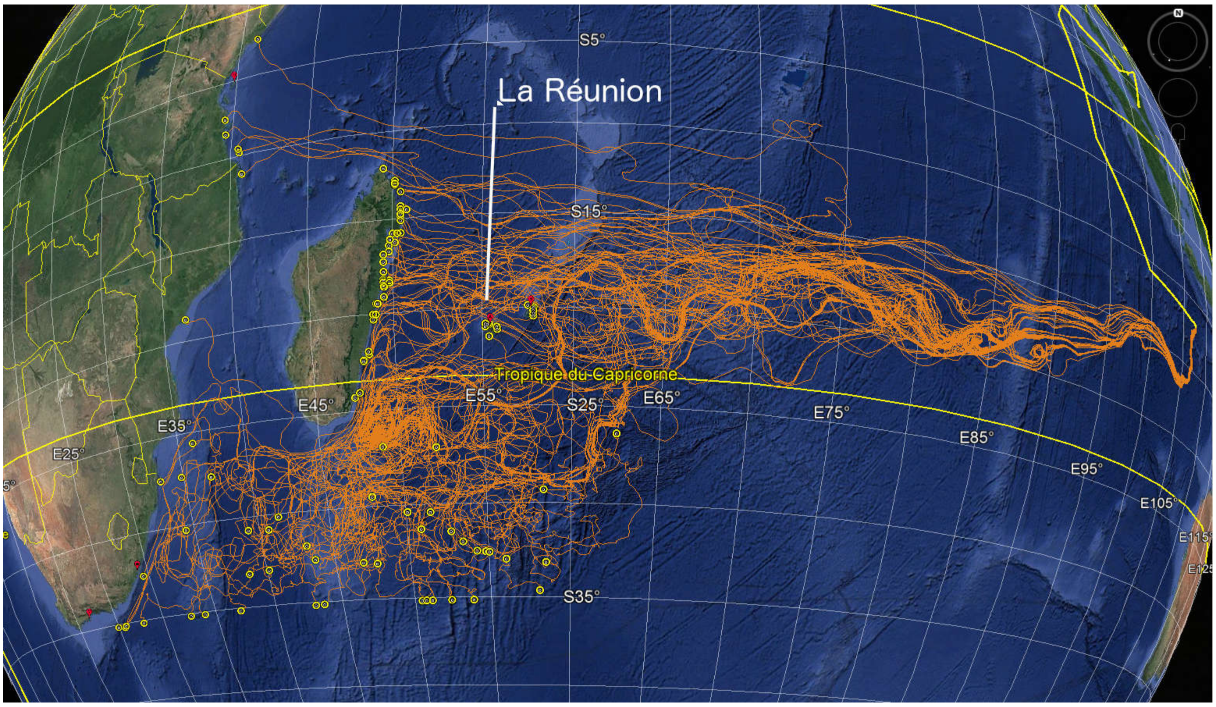


Figure 3: Full set of 121 simulated drift paths from CAPTIO estimated End of Flight location (to the far right of the picture) until one of these 3 events occurs 1) landing somewhere or 2) 31st January 2016 is reached or 3) latitude 35°S is crossed.

Considering the Flaperon (item #1 or A in Figure 4) found at Saint Denis, La Réunion, there are 7 (6% of the total) simulated paths that land at La Réunion between 19 March and 18 May 2015. Four paths are coming from the northeast down to Saint Denis showing a strong compatibility to the found debris location. In addition the time line of the landings is <u>earlier</u> than the debris reporting (29 July 2015) by approximately 4 months.

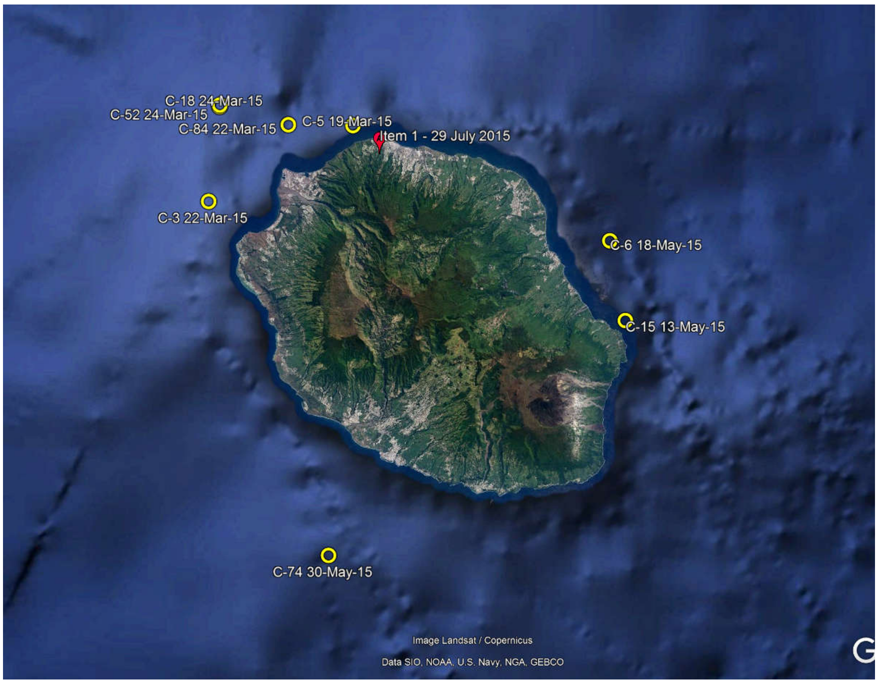


Figure 4: Locations of the 7 landings sites of the simulated paths that arrived at La Réunion with their arrival date. C-xx is a CAPTIO internal numbering. The gap between the yellow donuts and the coast are due to a misalignment of Google Earth coordinates representation and NOAA & OSCAR grid points and their grid boundaries.

If fallen in CAPTIO MH370 End of Flight Point area, the flaperon would have travelled permanently in warm tropical waters favourable for growth and development of barnacles that were actually found on the recovered flaperon. Appendix 2.6B of the Final Report [6] mentions that the young Barnacles grew in waters at about 25.4°C which can be found at the North-East of La Réunion while the oldest barnacles grew in much warmer waters at about 28.5°C located typically between Latitudes 15°S and 18°S (cf Appendix 3). Figure 5 clearly shows that the simulated paths satisfy this dual constraint.

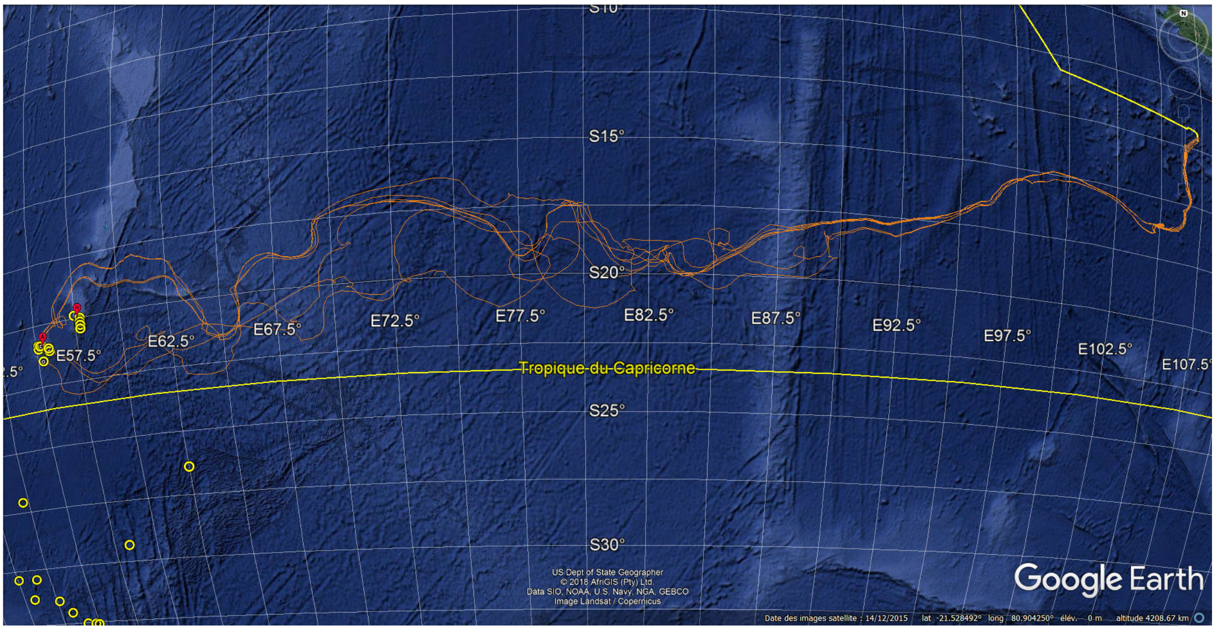


Figure 5: The seven full paths landing at La Réunion. A remarkable feature is their relatively constant latitude between 15°S and 23°S which warm tropical waters favourable for barnacles development.

Note: The temperature evolution of the waters determined by Appendix 2.6B [6] of the Final Report [5] is not matched by the other main debris drift studies as they consider starting zones outside tropical waters and typically below latitude 25°S encompassing cooler waters. Thus the oldest barnacles could not have started their growth (measured by [6] at 28.5°C) in waters at ~24°C at most at these low latitudes.

Considering, the Left Outboard Flap found at Ilôt Bernache, Mauritius in May 2016, the picture examination in the official report shows that the waterline of the debris is oblique somehow similar to Item#1 floating stand. This is the reason why we classified it in the flaperon type family. Figure 6 presents the 9 simulated paths (more than 7% of the total) that lead to Mauritius Island. They arrive on the east coast coming from an eastern direction except one coming from the west. There is an interesting correspondence with the found debris actual landing site considering the small size of the island. They arrive 15 to 12 months before the official reporting date.

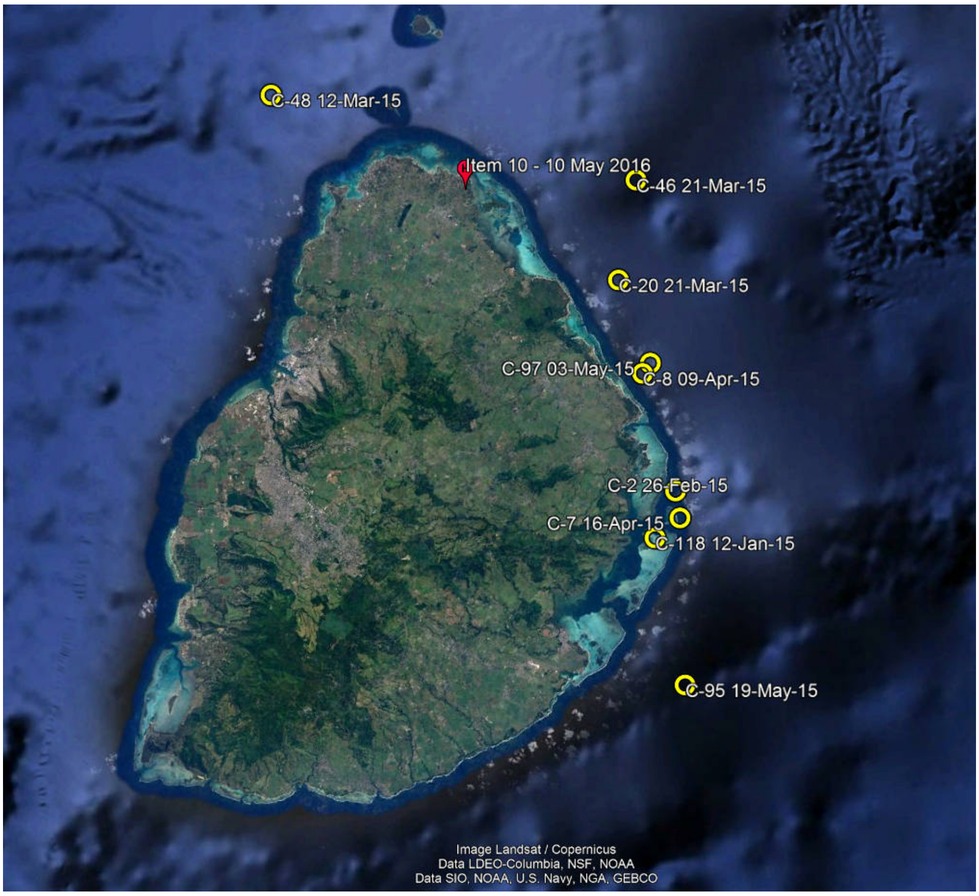


Figure 6: The 9 landing sites at Mauritius Island.
The pin point H-Item #10 of the Final report (i.e. the Left Outboard Flap) is in red.

Considering the other 3 items #19, 26 and 27 (resp. O, V and W) Figure 7 illustrates that the locations of the found debris are "approached" by some simulated paths. Item #19 is bracketed between several paths while item #26 landing site could have potentially been reached (4 paths) but both computational limits were reached i.e. crossing 35°S or exhausting the time limit of the available data (31 Jan. 2016). Item #27 landing site was reached by 1 simulated path showing it is reachable from CAPTIO End of Flight zone.

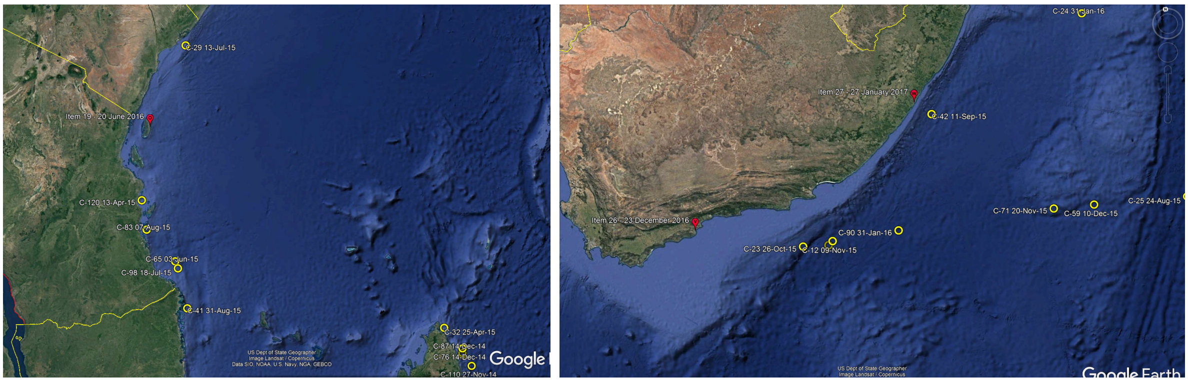


Figure 7: Computed paths arriving in the vicinity of Items #19 (left image) in Tanzania and 26 & 27 (right image) in South Africa. For the later, the end of the path is the result of one of these 3 events: 1) landing or 2) 31st January 2016 is reached or 3) latitude 35°S is crossed.

Note: In addition to the above, about 15 paths reached also the mentioned limits (time or geographical) as illustrated in Appendix 2. Thus considering the speed and direction of their move, it not impossible to think that some of them would have gone towards items #26 and 27. But this is pure conjecture as the lack of data after January 2016 is a key limiting factor here.

4- Conclusions

The computed paths of the flaperon show that :

a. The geographical correspondence between the determined CAPTIO debris landing points and the actual debris discovery locations – especially for the flaperon – supports the conclusion that the CAPTIO estimated MH370 End of Flight Point area is a possible origin of the actual debris paths. This location was already pointed out as "possible" by GEOMAR in [7].

b. Northern latitudes like 12°S are as good candidates for a search campaign as others on Arc7. They should not be ruled out for possible future searches.

c. The travel time of CAPTIO computed drift journeys for the flaperon is compatible with the actual dates of the debris discovery as the dates for the simulated paths reaching first l'Ile de la Reunion are from March 2015. The flaperon was discovered in July. It should be reminded that the date of arrival was earlier that the actual date of discovery and no one knows how long was the delay between the two events.

d. CAPTIO estimated debris paths show that the debris found their way through the SAR (Search and Rescue) areas S1/S2 without being detected in spite of the aerial operations. The small size of these areas is one of the reasons. Another reason is that Cyclone Gillian interrupted the search for few days (from 23rd of March). And the search did not resume from there. In addition, the search coordination had been taken over by the Australian on 17th of March at a much southern longitude.

e. The 2014-2015-2016 South West Indian Ocean tropical storms scattered debris in Indian Ocean current meanders along the drift path maximizing their journey and thus minimizing the likelihood of finding them.

f. The findings about the Flaperon appear to be also applicable to the Left Outboard Flap (Item #10 or H) and also, to certain extent, to the 3 other items considered as "flaperon type". For these last 3, without being a definitive conclusion, the correlation is nevertheless striking.

g. The drift paths found here are fully matching the high temperature profile measured and reported in Appendix 2.6B of the Final Report [6] on the oldest part of the Capitulum of the attached barnacles (28.5° ±1°C) and on the youngest part (25.4° ±1°C).

4- General discussion on the other studies

Quite a few studies have been done, being them forward tracing, back tracking, statistical and/or heuristic [3], [4], [7], [8], [9], [10] & [11]. Each study made specific hypotheses and selected specific models based on the expertise field of their authors providing light on one facet of this complex problem. The CAPTIO debris drift study is one of these studies and contributes to the overall understanding and it shows that 12°S is a valid end of flight point for MH370.

But the random nature of the drift in such a long distance is a key factor of the final location of potential landing of debris. Considering the overall effort, the quality of the work and the geographical spread of the crash locations pointed by these studies, one could say that all these studies are basically statistically equally right (or wrong !).

Thus it can be concluded that all published analyses of the debris drift do not bring sufficient evidences of discriminating factors to identify the end of flight point for MH370 from the knowledge of the landing locations of the found debris.

Thus there is no reason to place à priori restrictions on the latitudes to be searched on Arc-7.

References:
[1] CAPTIO Plausible Trajectory Report V3.4, Dec. 2017
[2] Appendix 1.12A appendices of Final Report [5], Piece 3-Lot 2, DGA, Pengam, 2016
[3] The search for MH370 and ocean surface drift – Part II, 13 April 2017, CSIRO
[4] CAPTIO Debris Drift Analysis, 30 May 2018
[5] Safety Investigation Report (Final Report), 2 July 2018, The Malaysian ICAO Annex 13 Safety Investigation Team for MH370
[6] Appendix 2.6B of [5]: Appendix2.6B-MarineBiologistReport2, Estimation des températures de croissance de cirripèdes fixes sur le flaperon, Blamart & Bassinot, 23 juin 2016
[7] Backtracking of the MH370 flaperon from La Réunion, GEOMAR, Durgadoo et al, Feb. 2016
[8] "MH370 - Drift Analysis", David Griffin et al , 10 November 2018,
[9] Prof. Pattiaratchi's MH370 drift model, 22 Dec. 2016
[10] Drift Analysis of MH370 Floating Debris, Richard Godfrey, 16th July 2018 and "Beaching Map - 20S to 25S vs 30S to 35S vs Debris Locations plus Start Locations", Richard Godfrey, 16 November 2018 and later updates
[11] Consideration of various aspects in a drift study of MH370 debris, O. Nesterov, 4 June 2018

Video of Drift: http://mh370-captio.net/wp-content/uploads/2018/05/Drift-mh370-Captio_2.mp4
www.mh370-captio.net
https://youtu.be/Jd_eJIINlBw

Appendix 1: Cyclones which most certainly impacted the drift of debris

The table below list all major meteorological events, which have most certainly crossed the path of the drifting debris and subsequently impacted the debris progress. The data source is from the web site http://www.firinga.com/

Start Date	Cyclone Name	Level of Impact
2014-11-15	ADJALI	Strong
2014-11-21	CYCLONE-O2S	Strong
2014-12-22	KATE	Strong
2015-01-08	BANSI	Strong
2015-01-13	CHEDZA	Strong
2015-01-24	DIAMONDRA	Strong
2015-01-24	EUNICE	Strong
2015-02-19	GLENDA	Strong
2015-03-03	HALIBA	Low, too far up front
2015-04-02	JOALANE	Low, probably behind debris
2015-04-03	IKOLA	Low, probably behind debris
2015-11-18	ANNABELLE	Low, probably behind debris
2015-12-07	BOHALE	Strong
2016-01-20	CORENTIN	Low, probably behind debris
2016-02-07	DAYA	Strong
2016-02-11	URIAH	Low, probably behind debris
2016-03-14	EMERAUDE	Low, probably behind debris
2016-03-27	17S	Low, probably behind debris
2016-04-10	FANTALA	Strong
2016-07-20	ABELA	Strong
2016-10-02	BRANSBY	Medium, low latitude

Below is the overview of these cyclones per season illustrating visually the reason why statistical current models could not be sufficient for such a random drift:

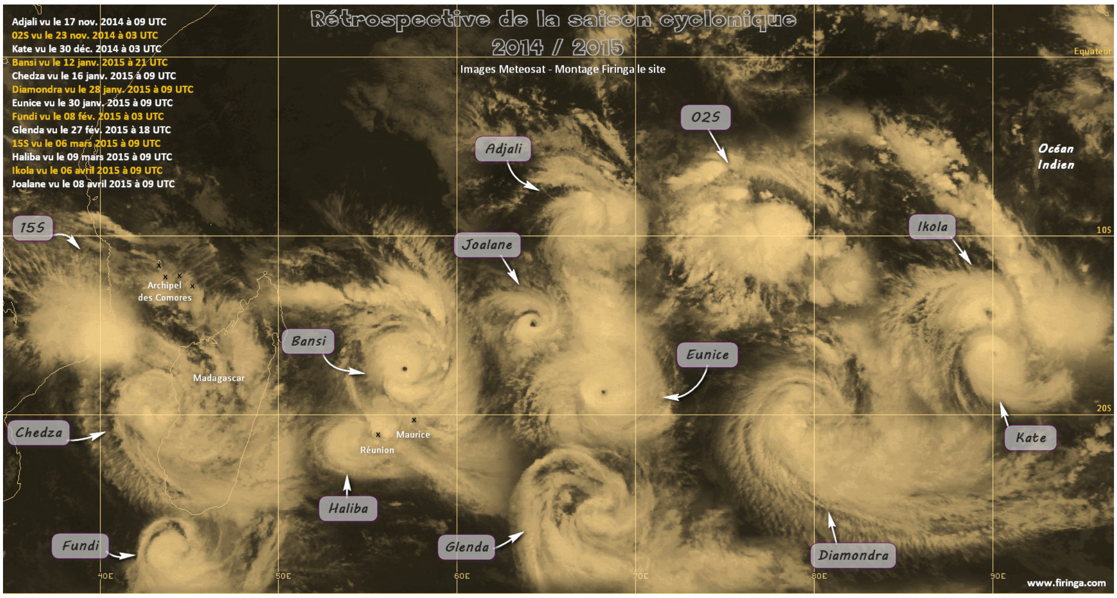


Figure I-A: Synoptic of South West Indian Ocean cyclones in Season 2014/2015.

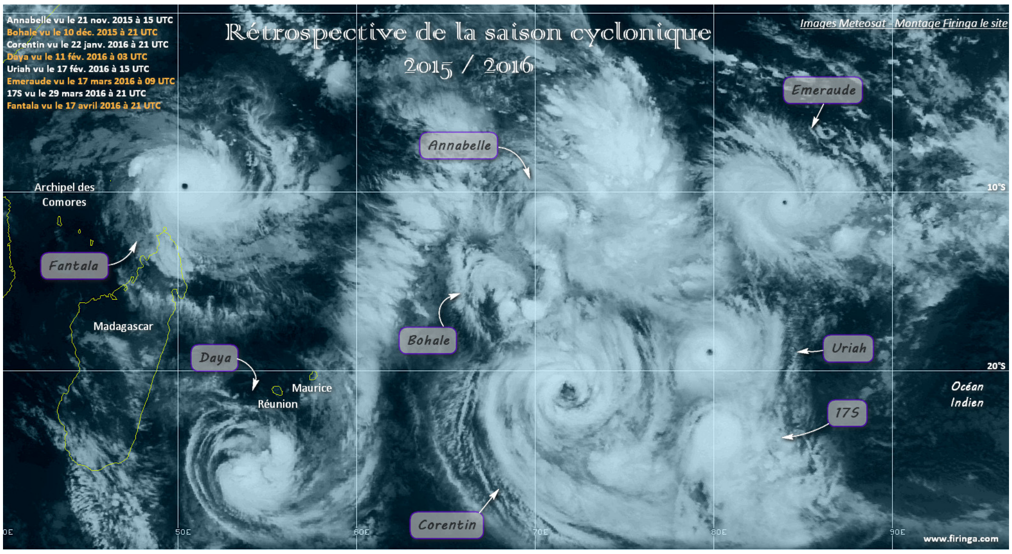


Figure I-B: Synoptic of South West Indian Ocean cyclones in Season 2015/2016.

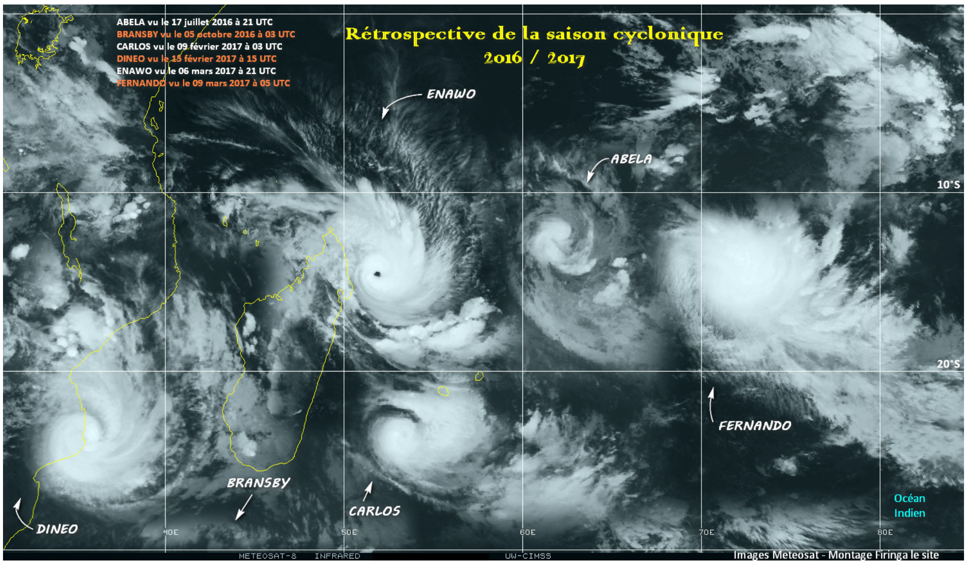
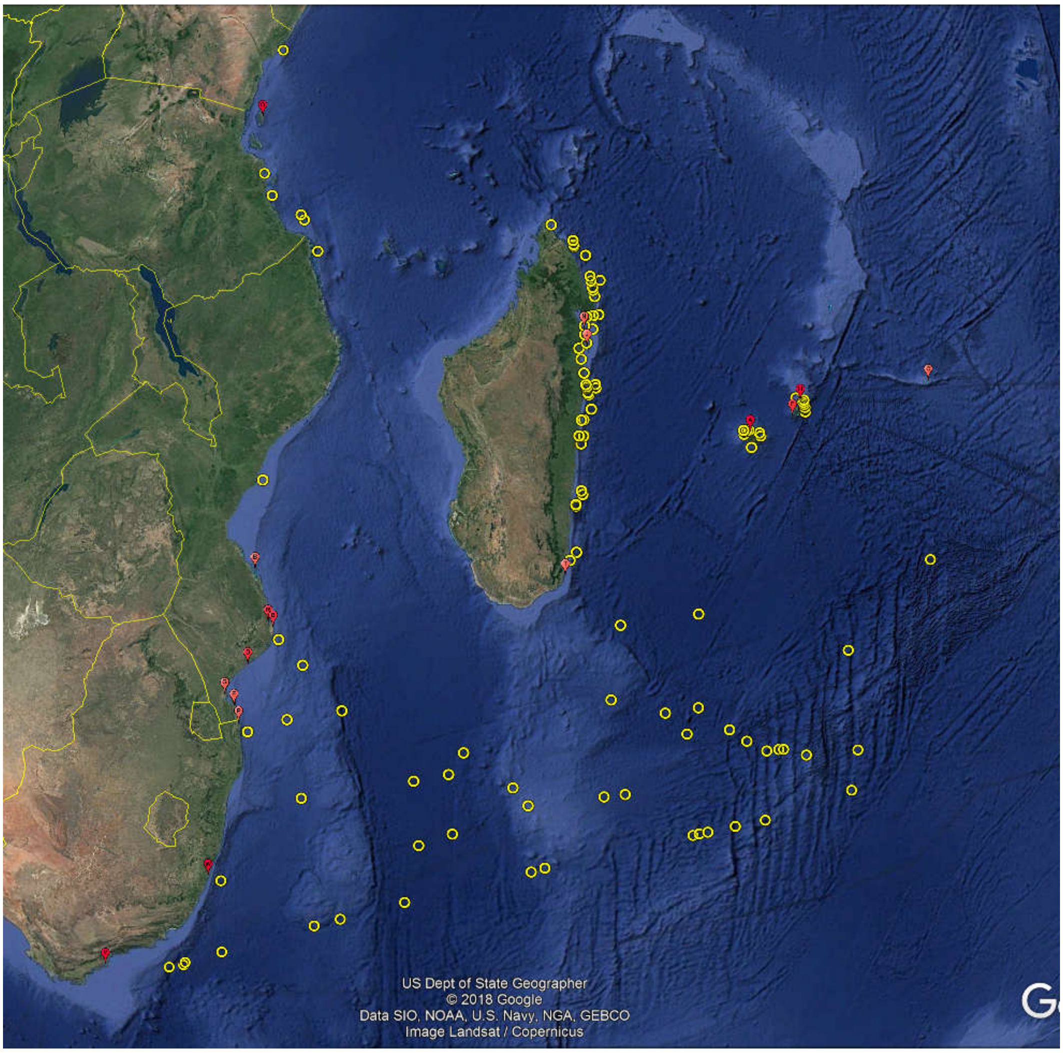


Figure I-C: Synoptic of South West Indian Ocean cyclones in Season 2016/2017.

Appendix 2: Synoptic of CAPTIO end of 121 simulated paths (yellow donuts) with all MH370 found debris (red and orange pin points) as presented in the Final Report [5]



Appendix 3: Indian Ocean surface water temperature on 8 March and 8 June 2014 (*source [11]*)