Possible Flight Path of MH370 towards McMurdo Station, Antarctica
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Preface

This paper examines the simulator data found on Captain Zaharie Shah's home computer, as reported by the Royal Malaysia Police, as it might relate to the flight of MH370. As far as we know, there is no evidence that directly links the captain to the intentional disappearance of the aircraft. However, this paper does hypothesize that the flight data found on the captain's computer is related to the actual flight of MH370, and reconstructs a hypothetical flight path based on the simulator data as well as well as satellite, meteorological, and aircraft performance data.

The views expressed here are solely the authors' and do not represent the views of the MH370 Independent Group (IG) or any other group or individual.

Introduction

The underwater search for debris from MH370 has been unsuccessful so far. The current search zone in the Southern Indian Ocean (SIO) consists of a total of 120,000 square kilometers of seabed, of which 110,000 square kilometers (92%) have been searched to date. Malaysian, Australian, and Chinese officials have announced that unless new credible information becomes available, the search will be suspended after completion of the current search zone.

Recently, the MH370 Independent Group (IG) released a preliminary assessment of data found on Captain Zaharie Shah's home computer that were related to the Microsoft Flight Simulator X (FSX) game [1]. The data includes flight and navigation parameters that are "snapshots in time" that are associated with six coordinates. If these coordinates were all from a single simulation, it suggests the simulated flight of a B777-200LR aircraft with a departure Kuala Lumpur International Airport (KLIA), a flight up the Malacca Strait, a turn to the south, and a termination in the Southern Indian Ocean near 45S 104E. This path is shown as a black line in Figure 1. Also shown is a path reconstructed by the ATSB (yellow) that leads to the current search area (green).

The IG further determined that if a great circle path is drawn that connects the northernmost coordinates with the final coordinates, and if this path is extrapolated further as a great circle, the path passes near airfields servicing the McMurdo Station in Antarctica, which may have been chosen as the destination in the simulation. This extrapolation is also indicated in Figure 1 (grey).

Although we cannot determine with certainty that the six points are all from a single flight simulation run, the alignments of the points, the banked turn towards the south at the northernmost point, and the progressive depletion in fuel level suggest the coordinates may be related to the same flight simulation. On the other hand, the fuel consumption for the flight segment to the SIO exceeds what would be expected for normal cruise conditions, which suggests that if the six coordinates are related to a single simulation, the fuel level

might have been manually altered during the simulation. The steep descent from an altitude of 37,600 ft down to 4,000 ft over a short 3.6-nm distance also suggests that the altitude might have been manually altered during the simulation.

In this work, we investigate a possible flight path of MH370 with the assumption that the same destination of McMurdo Station, Antarctica, was chosen for the actual flight as was possibly selected for the simulation. The purpose of this work is not to determine whether or not Captain Zaharie Shah committed a crime. However, we do feel it is our obligation to consider the possibility that the captain chose McMurdo Station as the destination for MH370 because it defines a relatively small area for the crash site and it may prove useful if the search is extended to the northeast of the current search area.

Flight Segment from KLIA to 18:22 UTC

The flight path from the departure from KLIA at 16:42 UTC until the last radar capture at 18:22 UTC is shown in Figure 2 as the yellow line. The path has been shown graphically in several official reports, including the Factual Information from March 2015 [2]. After passing waypoint IGARI and before reaching waypoint BITOD, the path shows a sharp turn to the left that continues southwest on a track towards Kota Bharu Airport (WMKC). After passing north of WMKC, the path follows the Thai-Malaysian border, continuing towards Penang Airport (WMKP). After passing south of WMKP, the path curves towards the northwest towards waypoint VAMPI in the Malacca Strait. The last radar capture at 18:22 UTC occurs after passing waypoint MEKAR.

Flight Segment from 19:41 UTC to Fuel Exhaustion

Rather than make assumptions about the flight path between the last radar capture at 18:22 UTC and the satellite handshake at 19:41 UTC, we instead reconstruct the path from 19:41 UTC until the log-on to the Inmarsat network at 00:19 UTC. A portion of the path is shown as the black line in Figure 2, and is reconstructed based on the following assumptions:

1. During the time interval of 19:41 UTC to 00:19 UTC, the aircraft followed a great circle path towards the Pegasus Airfield (NZPG), which services McMurdo Station in Antarctica.
2. During the time interval of 19:41 UTC to 00:11 UTC, the aircraft flew at constant Mach number and constant flight level.
3. At some point in the time interval of 00:11 to 00:19, the aircraft exhausted its fuel, and the aircraft slowed.
4. Meteorological conditions at all times are consistent with the GDAS database for March 8, 2014, at 00:00 UTC.

The position at 19:41 UTC is determined by varying the Mach number and by minimizing the RMS BTO error subject to the following constraints:

1. At 19:41, 20:41, 21:41, 22:41, and 00:11 UTC, the predicted value of BTO should be within 50 μs of the values measured at these times.
2. The track at 19:41 UTC should be on a great circle path towards NZPG.
3. The pressure altitude is held constant at 35,000 ft. (The solution is relatively independent of selected altitude between about 34,000 and 40,000 ft.)

With these assumptions, constraints, and solution procedure, the position at 19:41 UTC is estimated to be 8.5219°N 92.9501°E. The details of this path are included in Table 1. The path crosses the 7th arc near 26.9032°S 100.5675°E. This is about 850 nm away from the center of the current search area.

Remarkably, if we start at the estimated position at 19:41 UTC and extend the path backwards in time by just five minutes of flight time along the great circle path, it passes very near Car Nicobar Airport (VOCX), a military airport in the Andaman and Nicobar Islands, which is a territory of India. This suggest that the final waypoints for MH370 might have been VOCX and NZPG.

Table 1. Flight Path from 19:41 to 00:19 UTC

Time (UTC)	Latitude (degs)	Longitude (degs)	Altitude (feet)	Track (degs True)	Mach	TAS (knots)	GS (knots)	ROC (fpm)	BTO Error (km)	BFO Error (Hz)
19:41:03	8.5219	92.9501	35,000	168.4	0.798	472.3683	469.3109	0.00	7.7469	5.1105
20:41:05	0.8562	94.5119	35,000	168.5	0.798	472.9798	469.4051	0.00	-6.7620	2.2106
21:41:27	-6.8537	96.0760	35,000	168.4	0.798	473.3870	472.5246	0.00	-5.3565	6.2862
22:41:22	-14.5538	97.6908	35,000	168.1	0.798	472.9798	474.9338	0.00	8.1468	11.7504
23:14:20	-18.8117	98.6304	35,000	167.8	0.798	472.7760	473.4096	0.00	n/a	1.5017
0:11:00	-26.0833	100.3596	35,000	167.2	0.798	470.9384	483.8598	0.00	-3.5409	10.8706
0:19:29	-26.9032	100.5675	22,300	167.1	0.500	316.8917	323.0071	-4,780.00	4.9549	0.0051
0:19:37	-26.9148	100.5705	21,659	167.1	0.494	313.0890	319.2100	-15,255.00	4.2233	0.0342

Flight Segment from 18:22 to 19:41 UTC

The flight segment in the interval from 18:22 to 19:41 UTC is the white line in Figure 2. After the last radar capture at 18:22 UTC, we have the BTO and BFO values of the satellite communication from the log-on sequence in the time interval of 18:25 – 18:28 UTC. The data suggests that after passing waypoint NILAM, the aircraft flew north before it continued on its track towards the northwest. (We won't discuss the details here of this "lateral offset manoeuver" because it has little effect on the predicted crash site in the SIO.) After the log-on sequence was completed at 18:28 UTC, we assume the aircraft continued on a northwest track towards Car Nicobar Airport.

There was an unanswered satellite phone call to MH370 at 18:40 UTC which produced BFO values, and these can be used to infer the track of the aircraft at this time. If the flight was

level at 18:40 UTC, the track would be towards to the south. For this reason, the BFO values at 18:40 UTC have been used in the past as justification for a turn to the south preceding the call at 18:40 UTC. However, recognizing that vertical speed has a strong effect on the BFO of the received signal, it is possible that the plane was still traveling to the northwest at 18:40 UTC and descending at about 2900 ft/min as it approached Car Nicobar Airport. Understanding that fuel flow would have been minimized if MH370 flew at a holding speed of around 293 KTAS and at a pressure altitude of around 20,000 ft, it is possible that MH370 reached Car Nicobar around 18:53 UTC and entered a holding pattern, as shown by the racetrack pattern near Car Nicobar in Figure 2. Similarly, around 19:36 UTC, the holding pattern might have been terminated, initiating the flight leg towards McMurdo Station.

The calculated and measured BFO values are listed in Table 1 and shown in Figure 4. With the assumption of level flight from 19:41 to 00:11 UTC, the maximum BFO error is 12 Hz, which is within the 20-Hz drift window that has been observed on other flights [3].

Discussion

As can be seen in Figure 3, the reconstructed path based on a destination of McMurdo Station, Antarctica, crosses the 7th arc a large distance (850 nm) from the center of the current search area. The methodology used for determining the current search area is discussed in detail in a report authored by Australia's Defense Science and Technology Group (DSTG) from November 2015 [3] entitled "Bayesian Methods in the Search for MH370". Specific reasons why the reconstructed path from this work does not cross the 7th arc in the search area defined by the DSTG report include:

- In the DSTG study, paths were reconstructed assuming prior distributions for the number of turns after 18:02 UTC. The peak of this distribution was one turn based on a study of prior flights. Therefore, a path that requires a large number of manoeuvers such as a holding pattern would have a low probability using this methodology.
- The BFO model in the DSTG study did not consider the effect of vertical speed on the measured values. Therefore, the possibility was not considered that the aircraft was traveling to the northwest and descending at the time of the unanswered call at 18:40 UTC. The assumptions in the DSTG study effectively forced a turn to the south prior to 18:40 UTC.

The current work suggests that a final flight segment towards McMurdo Station, Antarctica, would originate close to Car Nicobar Airport, and is preceded by a holding pattern, turnback, or some other manoeuver that would effectively minimize the distance traveled in the interval of around 18:53 to 19:36 UTC. We can only speculate as to why this manoeuver close to Car Nicobar Airport and the subsequent flight towards Antarctica, leading to fuel exhaustion near the 7th arc, might have occurred.

The Flight Management System (FMS) of 9M-MRO had limited capacity, and likely did not have sufficient memory for an entire navigation database (NDB) [4]. Depending on how Malaysia Airline System (MAS) chose to manage the size of the NDB that was stored in the FMS of 9M-MRO, the aerodromes at McMurdo Station may or may not have been available to choose as a destination. We have asked the Australia Transport Safety Bureau (ATSB) to determine what was available as stored aerodromes and waypoints near McMurdo Station. Alternatively, the pilot could have entered a pilot-defined waypoint as the final fix for the last leg of the route.

It is important to emphasize that the reconstructed path presented here is predicated on a route with a hypothetical destination of McMurdo Station, Antarctica for the final leg. Although there is evidence suggesting that a route with this destination was found on Captain Zaharie Shah's computer, the determination that this destination was chosen for MH370 would require access to the flight data recorder.

Acknowledgement

References

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[2] "Factual Information Safety Investigation for MH370", Ministry of Transport, Malaysia, Mar 8, 2015, http://mh370.mot.gov.my/download/FactualInformation.pdf

[3] Davey, S. et al., "Bayesian Methods in the Search for MH370", Defence Science and Technology Group, Australia, Nov 30, 2015, https://www.atsb.gov.au/media/5733804/Bayesian_Methods_MH370_Search_3Dec2015.pdf

[4] Herndon, A.A., "Flight Management Computer (FMC) Navigation Database Capacity", Integrated Communications, Navigation and Surveillance Conference, April 2012, https://www.mitre.org/sites/default/files/pdf/12_1324.pdf
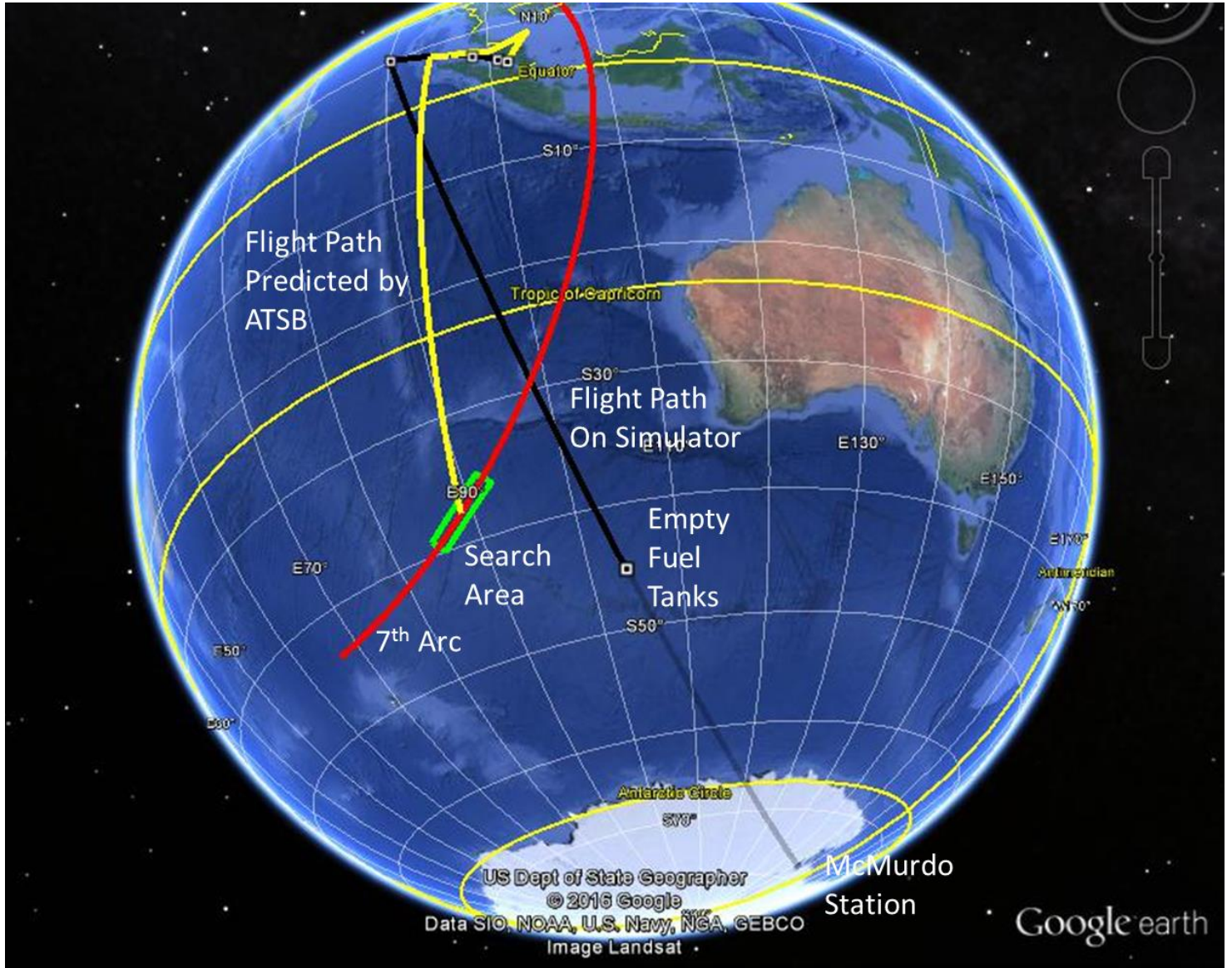
Figure 1. A flight path predicted by the ATSB (yellow) and the flight path found on simulator (black) extended to McMurdo Station (grey) [1].
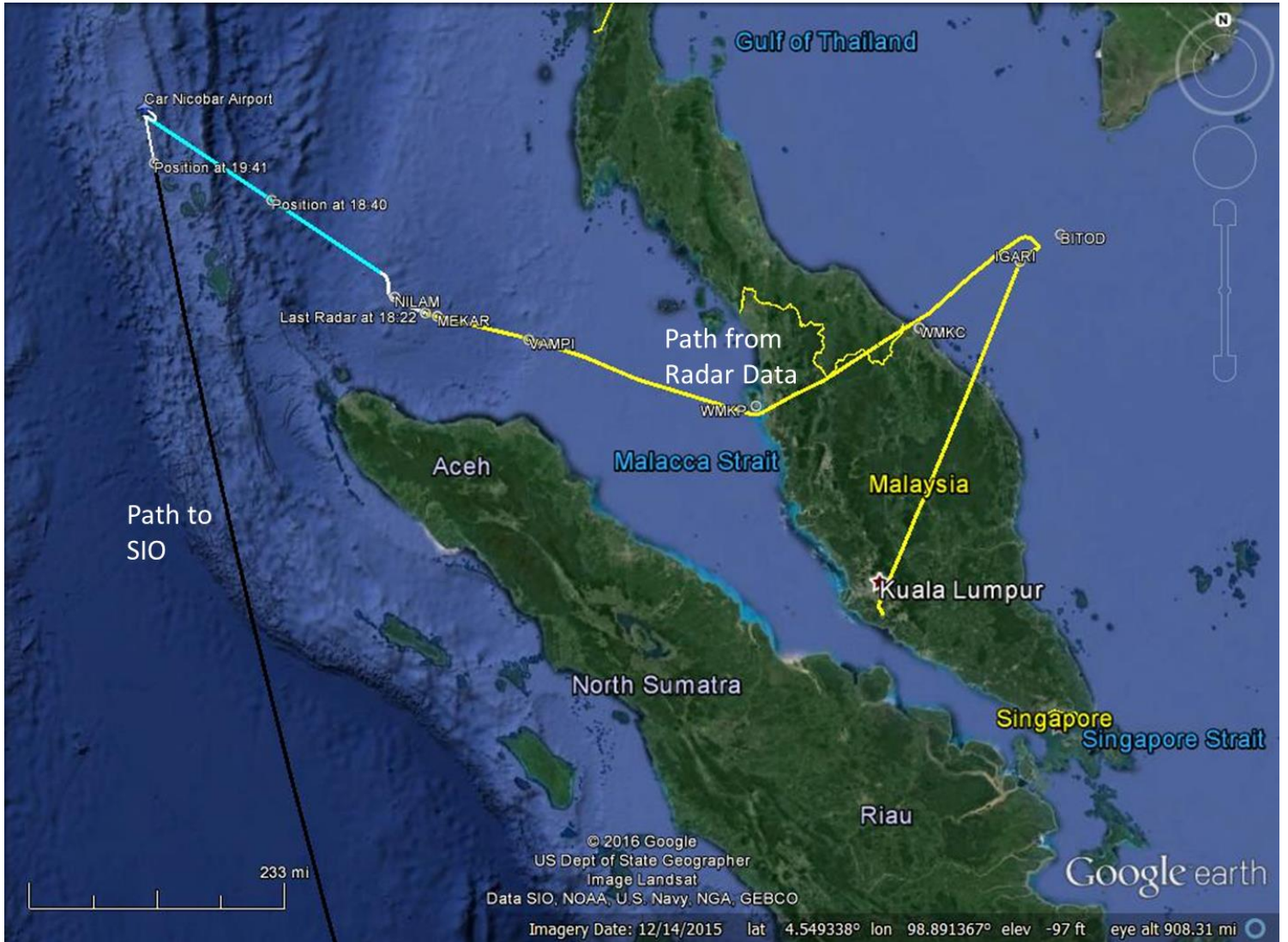
Figure 2. Reconstructed path segments over Malaysia and near Sumatra. Yellow line: 16:42 to 18:22 UTC; White line: 18:22 to 19:41 UTC; Black line: 19:41 to 00:19 UTC (partially shown).
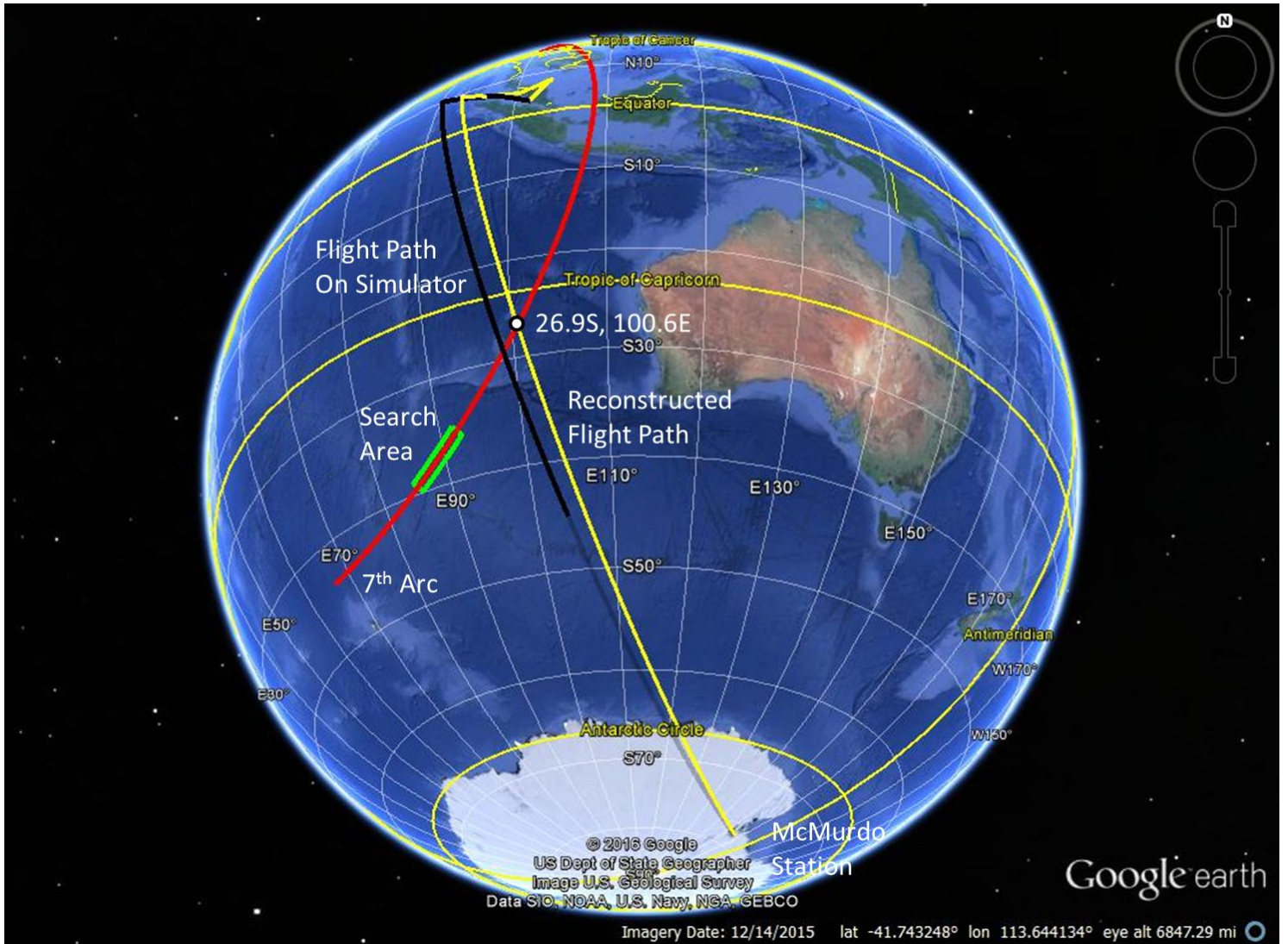
Figure 3. Comparison of flight path on simulator (black) and reconstructed flight path (yellow), both leading to McMurdo Station, Antarctica.
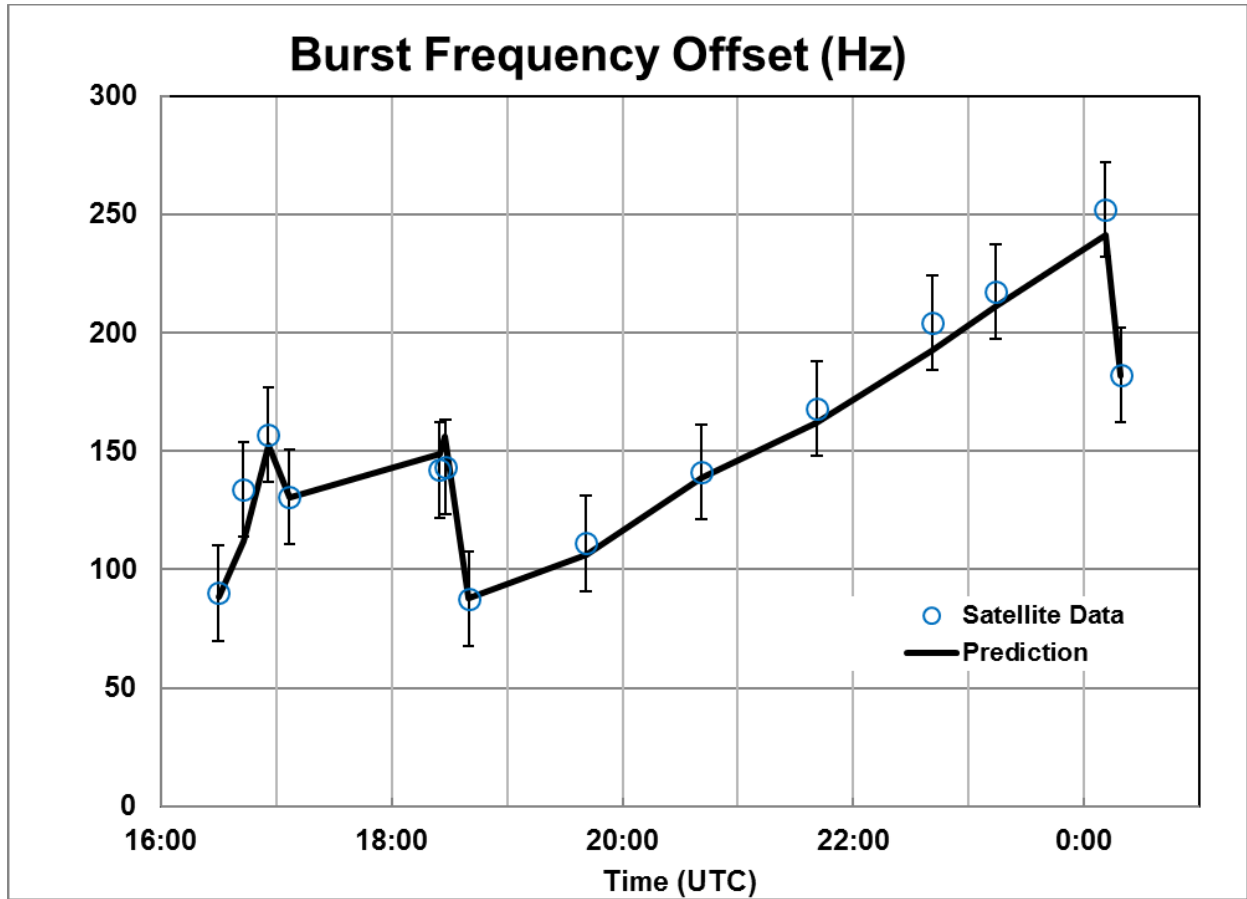
Figure 4. BFO values for path to McMurdo Station