<u>Updated</u> Analysis of MH370 Kota Bharu PSR Data

Michael Exner

2018-04-23

Introduction

Recently, primary radar data from the Kota Bharu (KB) and Butterworth (BU) radar sites became available from a reliable source. This data can be used to accurately estimate the MH370 speed and path following the diversion near IGARI at 17:21 UTC. In addition, the data can be used to estimate the altitude as the plane passed Koto Bharu at 17:38 UTC.

On 2018-04-13, a preliminary report was published listing 5 principle findings from this radar data. Since then, I have been collaborating with several colleagues to further analyze the data, and consider alternative interpretations of the data. The additional analysis has only served to confirm the principle findings reported on 2018-04-13. Below follows a more in-depth and refined look at the KB data and implications.

Data Processing

Further review of the Excel model used to analyze the data (based on Victor Iannello's basic "geometric math engine") has unearthed no material model errors. The few geometric simplifying assumptions used in the model are estimated to cause position errors less than 100m. Furthermore, the radar range error (critical to the altitude estimate) has been confirmed to be ~-0.03 nm, thus inconsequential. Thus, the accuracy of the path and speeds computed by the model are believed to be limited primarily by the accuracy of the data (time, range and azimuth), not the model. These radar errors are estimated as follows:

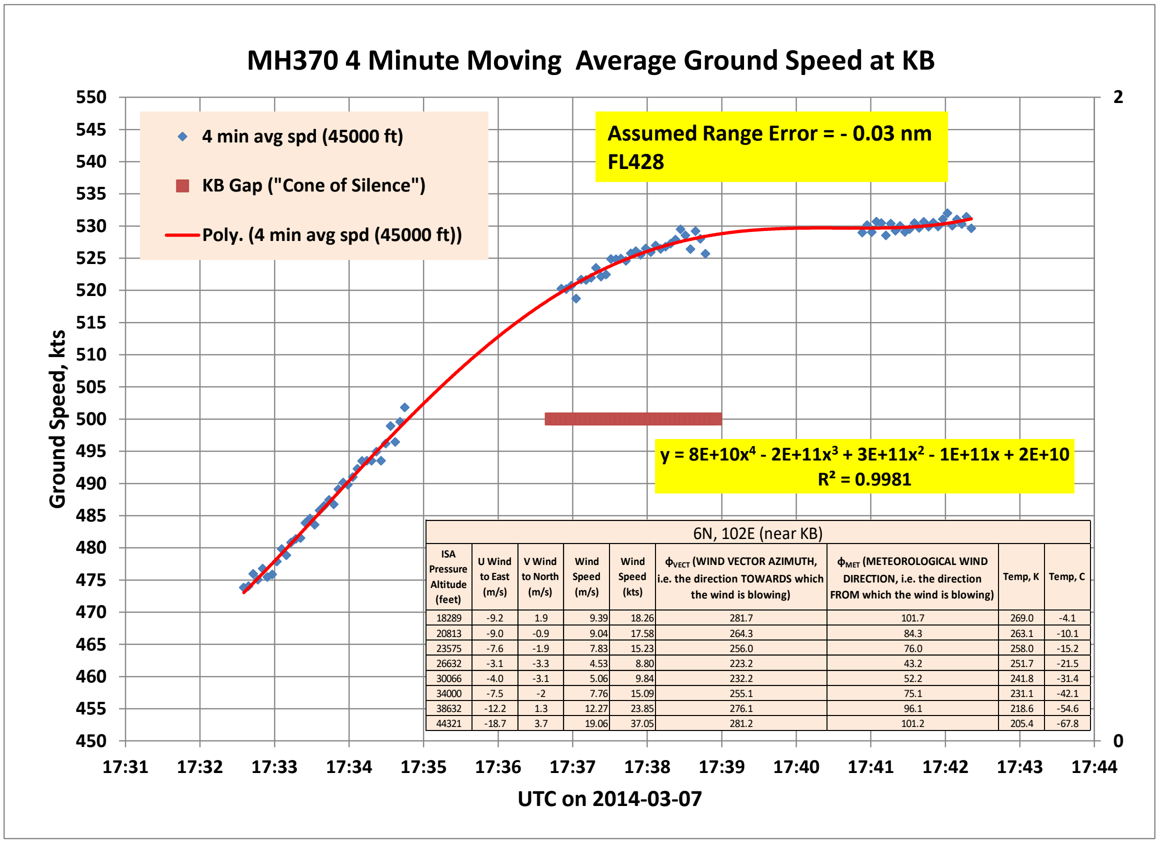
- Range: -0.03 nm
- Azimuth: ±0.16º
- Relative Target Times: <0.1 seconds over short periods

The original data contained time stamps believed to be produced by SASS-C software. This software reads the raw ASTERIX data from the radar head and logs that data asynchronously using a nominal 4 second clock. But the radar antenna rotation speed is slightly different, measured at 3.814 seconds. Thus, the observations in the SASS-C file were mapped back to the original radar time base, adjusted for azimuth angle changes. Changes in azimuth add to the target observation time a "phase correction" of 3.814*(az/360) seconds. These radar target times were then substituted for the original SASS-C Time stamps. This substantially reduced the observation time "noise" observed in the original analysis, but did not change the fundamental results reported on April 13, 2018.

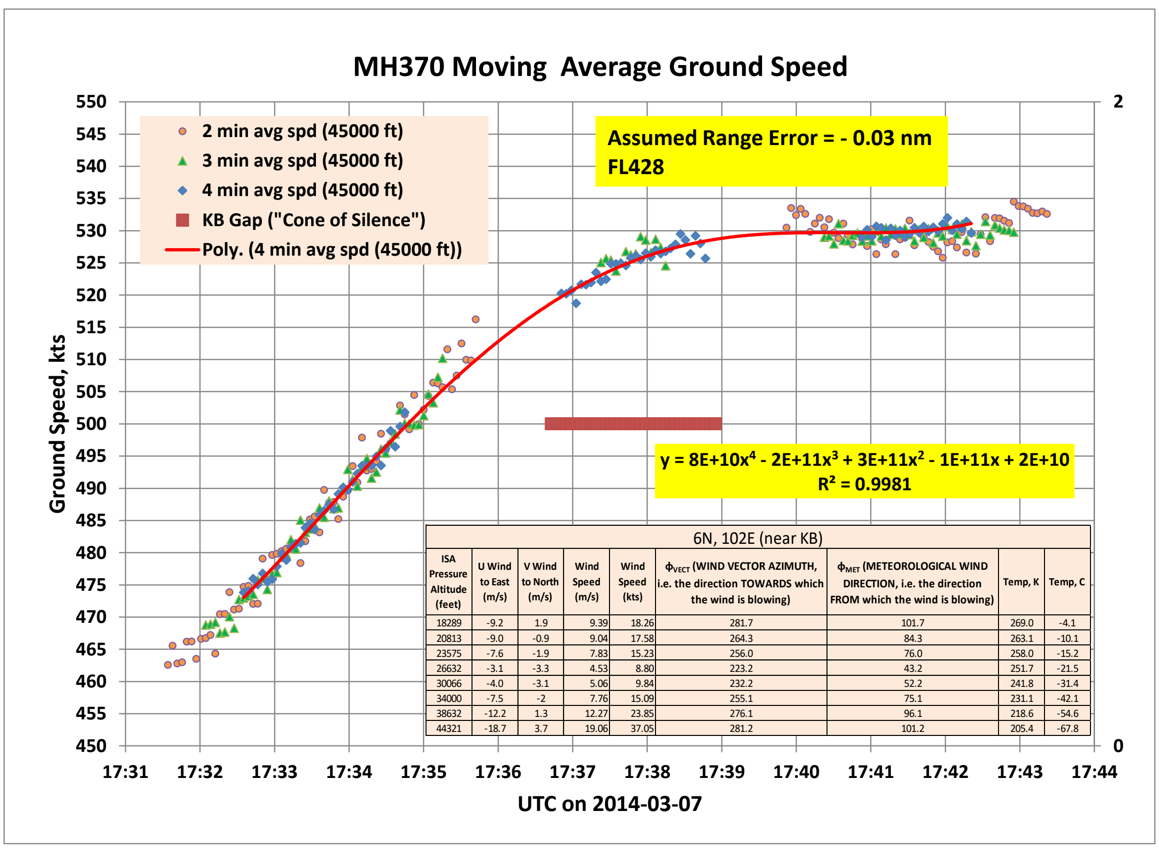
Several methods of filtering and smoothing the noisy data have been demonstrated by several colleagues. I have used box car averages and point to point averages. Others have used polynomial fits of various degrees. My preference is to use the 1, 2, 3 and 4 minute point to point average speeds to estimate altitude. See examples below.

Discussion

The model has been used to estimate the altitude by adjusting the *assumed altitude* and observing the effects on the speed profile. Below are examples at 45,000, 40,000 and 50,000 feet to illustrate the sensitivity to the altitude assumption. The speed profile assuming an altitude of 45,000 feet is obviously more realistic than the profiles at 40,000 and 50,000 feet. Trials have been conducted at 1,000 foot intervals, and the altitude assumption that is most consistent with a speed build-up within the capabilities of the aircraft is about 45,000 feet. However, the actual speed profile is unknown, so it could be in the range of ~43000-47000 feet and still be possible. An altitude above or below that range is increasingly inconsistent with a reasonable interpretation of the speed profile. 45,000 feet is actually slightly above the B777-200ER performance limits according to some analysis. Thus, 45,000 to 47,000 feet is less likely than 43,000 to 45,000 feet.



6N, 102E (near KB)								
ISA Pressure Altitude (feet)	U Wind to East (m/s)	V Wind to North (m/s)	Wind Speed (m/s)	Wind Speed (kts)	ϕ_{VECT} (WIND VECTOR AZIMUTH, i.e. the direction TOWARDS which the wind is blowing)	ϕ_{MET} (METEOROLOGICAL WIND DIRECTION, i.e. the direction FROM which the wind is blowing)	Temp, K	Temp, C
18289	-9.2	1.9	9.39	18.26	281.7	101.7	269.0	-4.1
20813	-9.0	-0.9	9.04	17.58	264.3	84.3	263.1	-10.1
23575	-7.6	-1.9	7.83	15.23	256.0	76.0	258.0	-15.2
26632	-3.1	-3.3	4.53	8.80	223.2	43.2	251.7	-21.5
30066	-4.0	-3.1	5.06	9.84	232.2	52.2	241.8	-31.4
34000	-7.5	-2	7.76	15.09	255.1	75.1	231.1	-42.1
38632	-12.2	1.3	12.27	23.85	276.1	96.1	218.6	-54.6
44321	-18.7	3.7	19.06	37.05	281.2	101.2	205.4	-67.8



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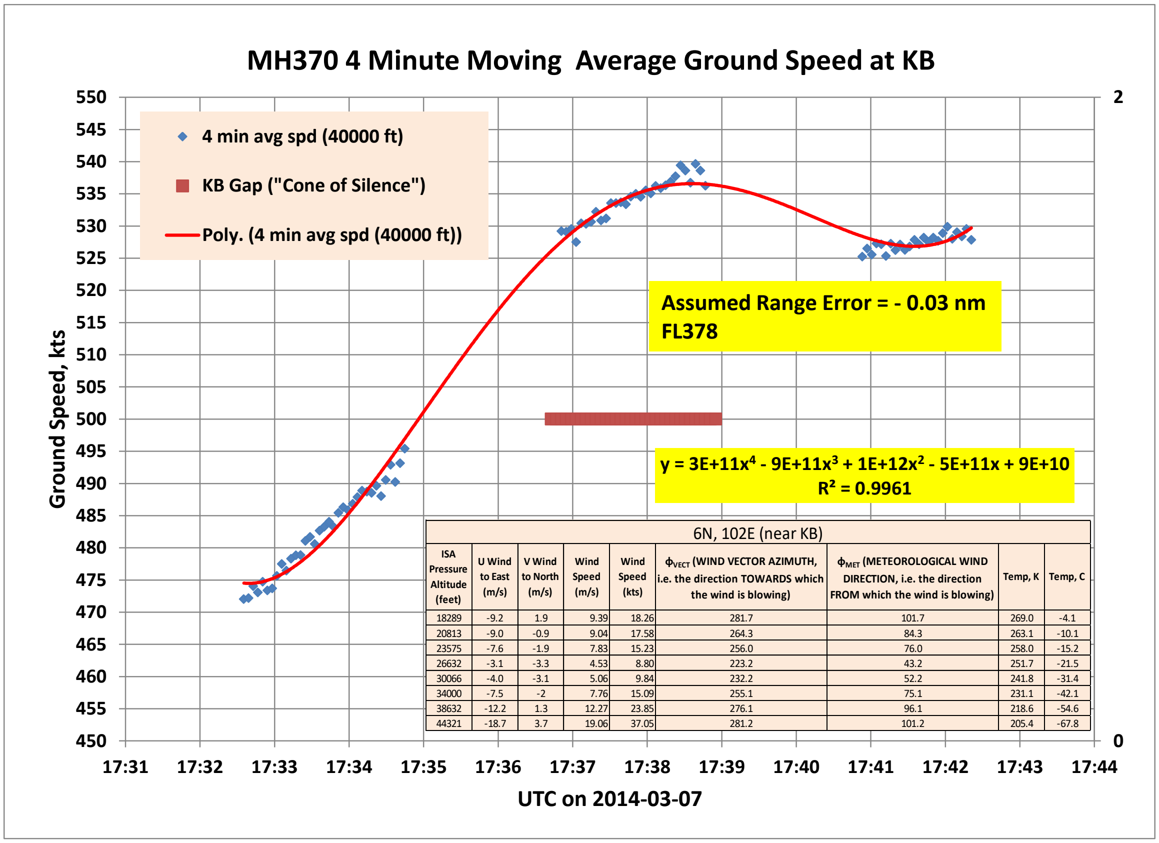

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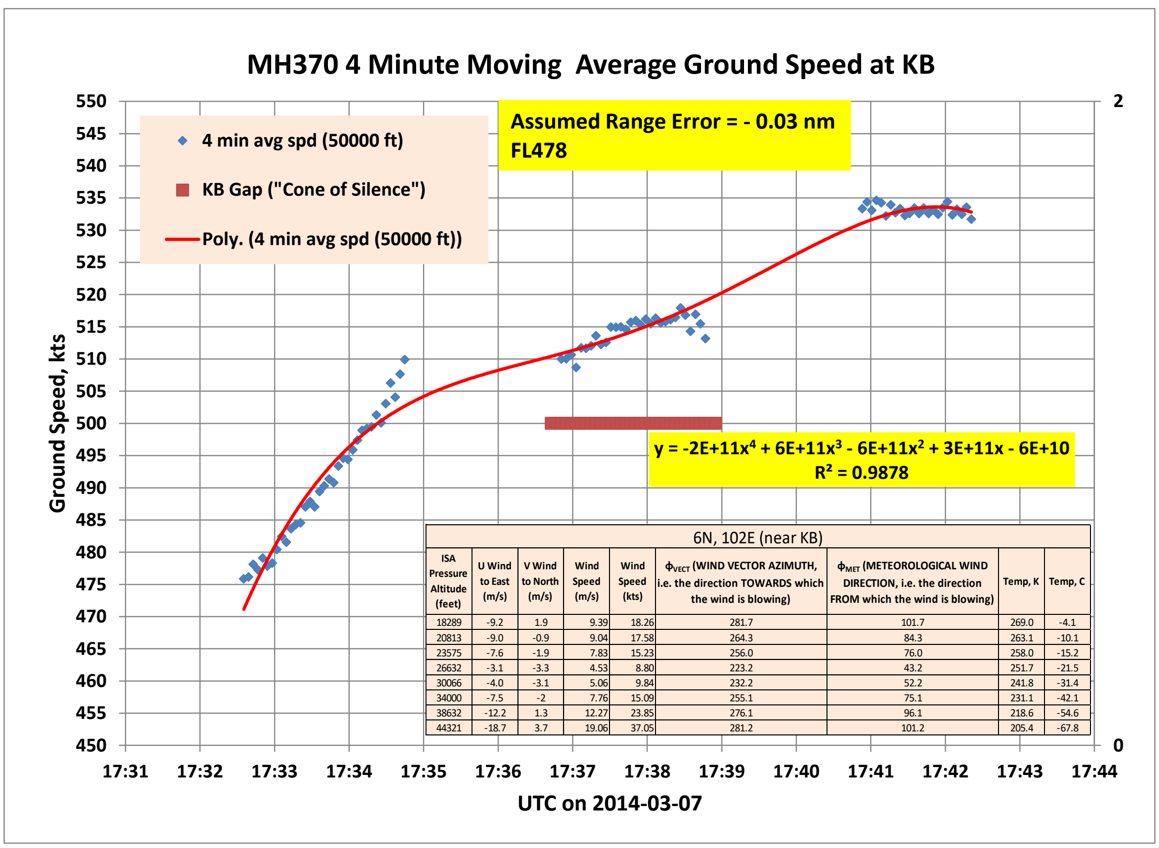

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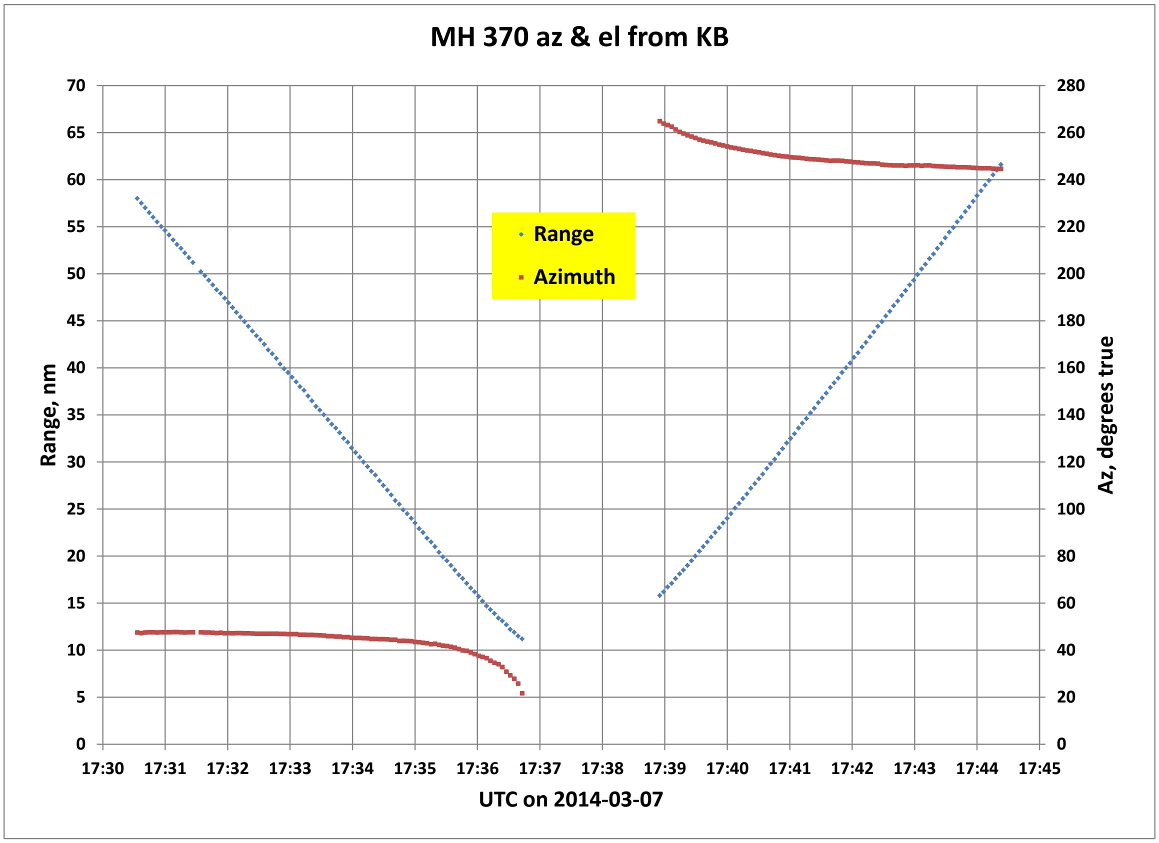
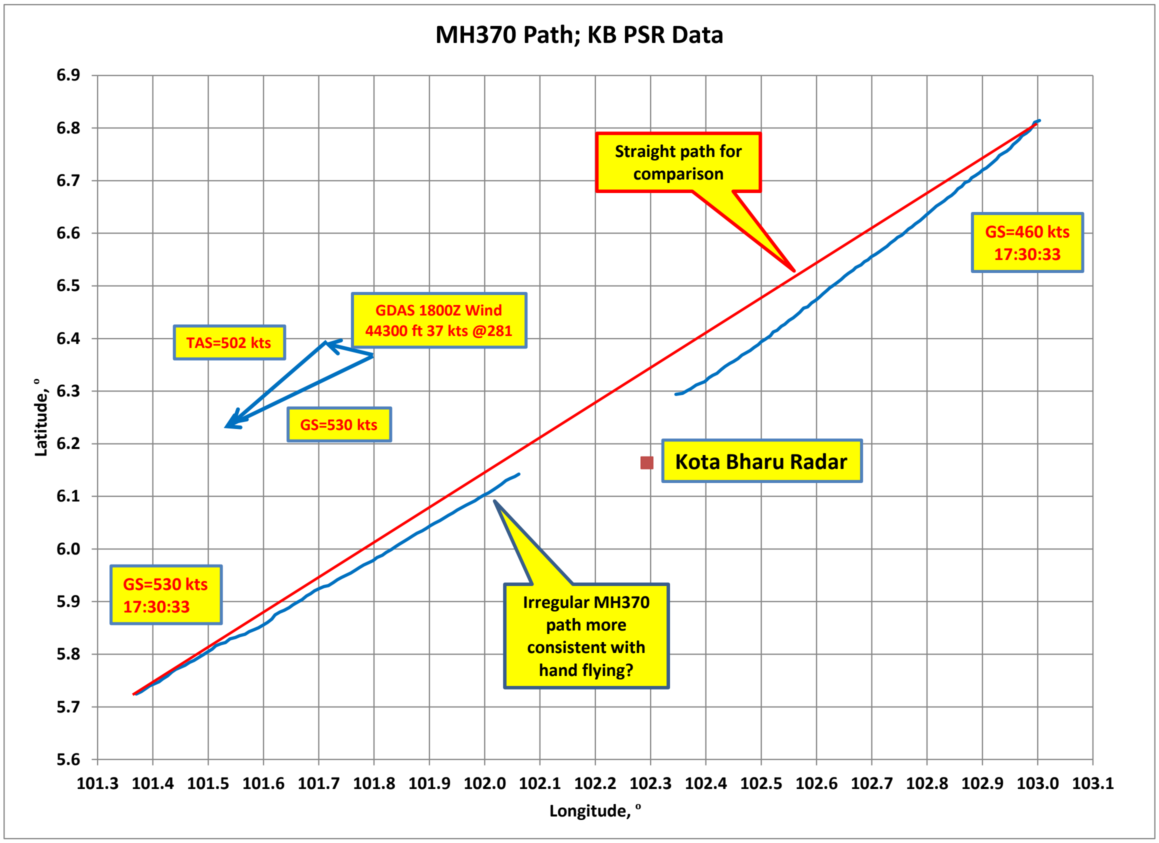

MH 370 az & el from KB
Range
Azimuth
Range, nm
Az, degrees true
UTC on 2014-03-07
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
17:30
17:31
17:32
17:33
17:34
17:35
17:36
17:37
17:38
17:39
17:40
17:41
17:42
17:43
17:44
17:45


MH370 Path; KB PSR Data
Straight path for comparison
GS=460 kts
17:30:33
GDAS 1800Z Wind
44300 ft 37 kts @281
TAS=502 kts
GS=530 kts
Kota Bharu Radar
GS=530 kts
17:30:33
Irregular MH370 path more consistent with hand flying?
Latitude, °
Longitude, °
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
101.3
101.4
101.5
101.6
101.7
101.8
101.9
102.0
102.1
102.2
102.3
102.4
102.5
102.6
102.7
102.8
102.9
103.0
103.1

Attachment A
Analysis of MH370 PSR Data
Michael Exner
2018-04-13

Recently, primary radar data from the Kota Bharu (KB) and Butterworth (BU) radar sites became available to me for analysis of the MH370 speed and path estimates. Two days ago, I shared that data with the independent community for analysis while continuing to analyze the data myself. Victor Iannello, Paul Smithson and Andrew Banks all contributed to my analysis. Bobby Ulich provided met data.

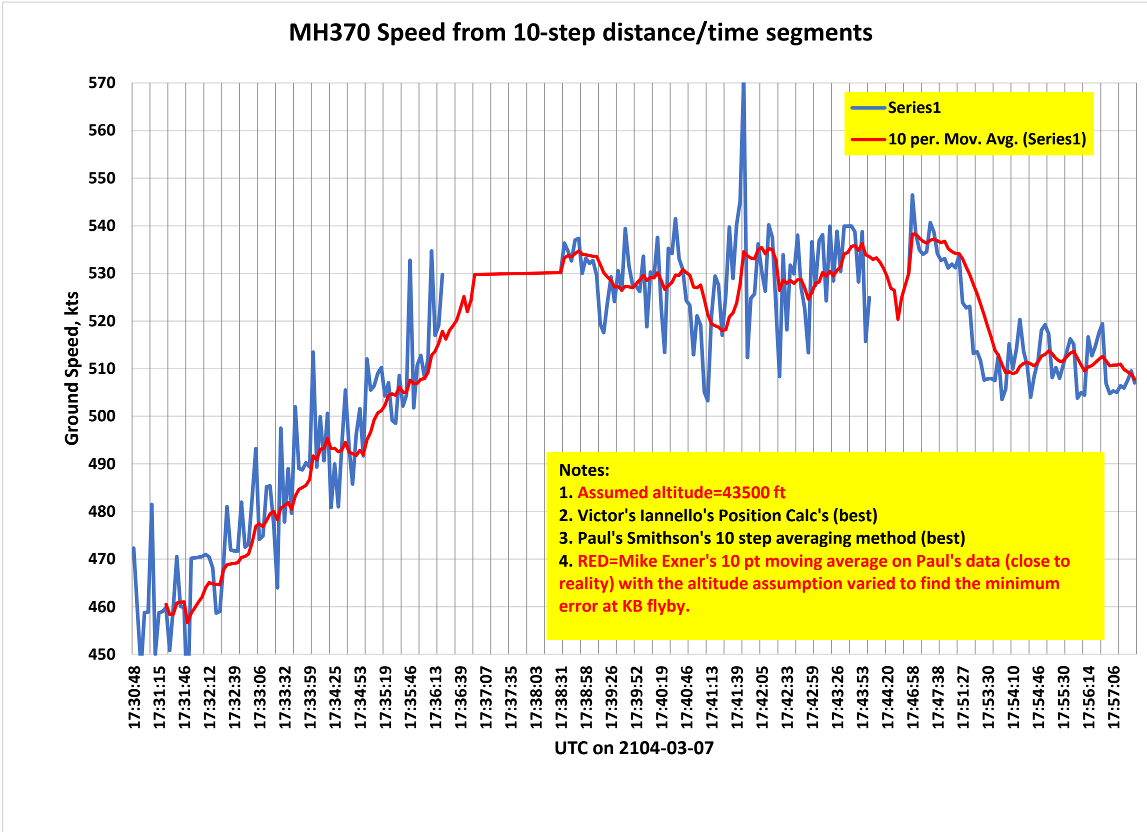
Although I was successful estimating the target positions from the range and azimuth data using a few simplifying assumptions, Victor Iannello produced better estimates using a more precise method. His results have been published (see below). Paul and I are both using Victor's positions now. My early estimates of speed were quite noisy, but revealed interesting trends. Paul suggested an improved filtering method which works better, and is now the method I use. Paul has also published his results (see below).

Bobby Ulich also developed a model and published his results. His model uses a different method to estimate KB altitude, but finds essentially the same result found by Paul and me. It is remarkable that Paul, Bobby and I independently arrived at essentially the same key findings only 2 days after I released the data.

The principle findings from this radar data are as follows:

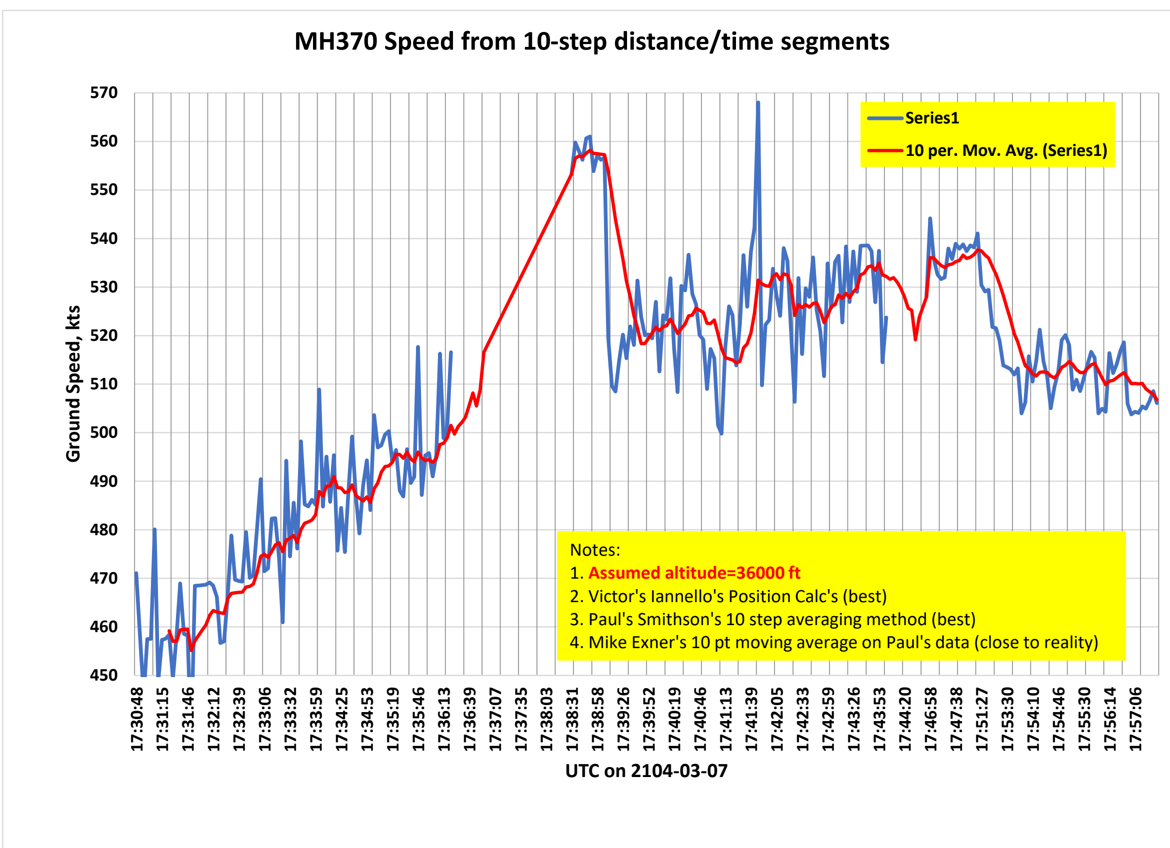
1. The path taken by MH370 from IGARI to a point west of Penang circa 18:01 is essentially the same path reported in the FI, ATSB, DSTG and independent investigator reports. See plots below.
2. The geo altitude circa 17:37 UTC, near Kota Bharu, was approximately 43,500 feet.
3. The GS at 17:30 UTC was ~460 kts and accelerated to 530 kts at 17:37 UTC. (The tail wind at 44000 feet was ~28 kts, thus the TAS was ~ 430 kts at 17:30 UTC and 500 kts at 17:37 UTC, assuming the same altitude.)
4. The TAS remained high, about 500 kts from 17:37 UTC until about 17:52 UTC as MH370 turned at Penang.
5. The GS decreased from 530 kts to 510 kts between 17:52 UTC and 18:01 UTC.

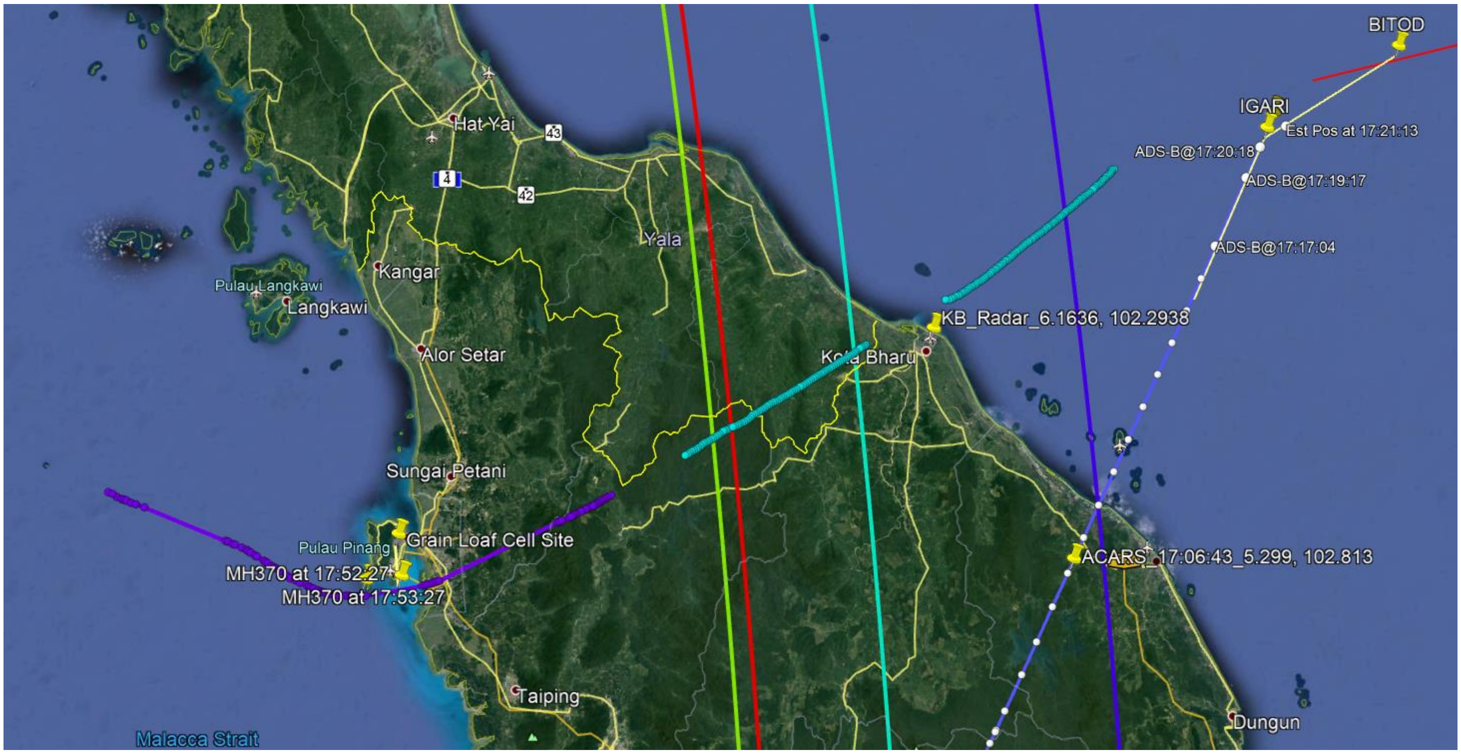
Victor's spreadsheet: https://goo.gl/3yQqJf
Paul's spreadsheet: https://goo.gl/R1BiHg
Paul's speed profile: https://goo.gl/pEXcPH
Bobby's analysis: https://goo.gl/J9GUjk



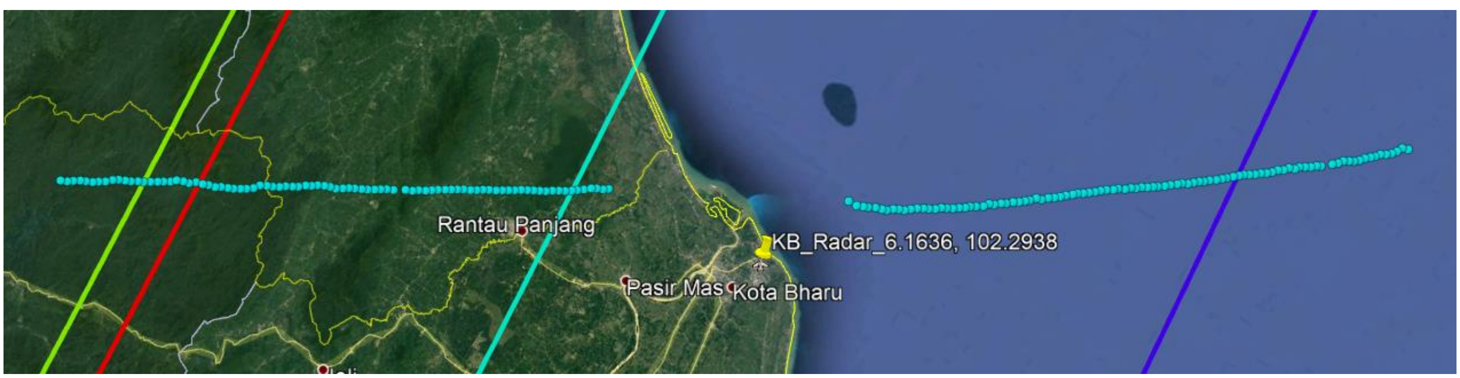
Above: GS assuming Alt=43500 ft. Notice the lack of speed error near KB.

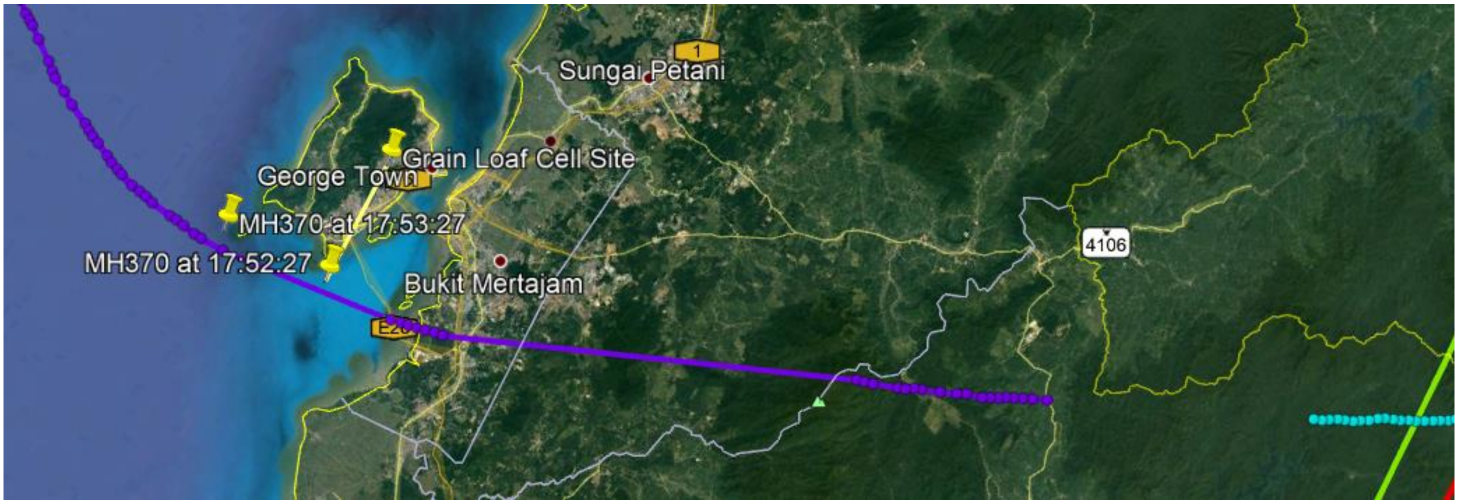
Below: GS assuming Alt=36000 ft. Note the large speed error near KB





White dots=ADS-B data
Teal dots= KB PSR data
Violet dots= BU data





Note the subtle turn from a track of ~301° to 292°.

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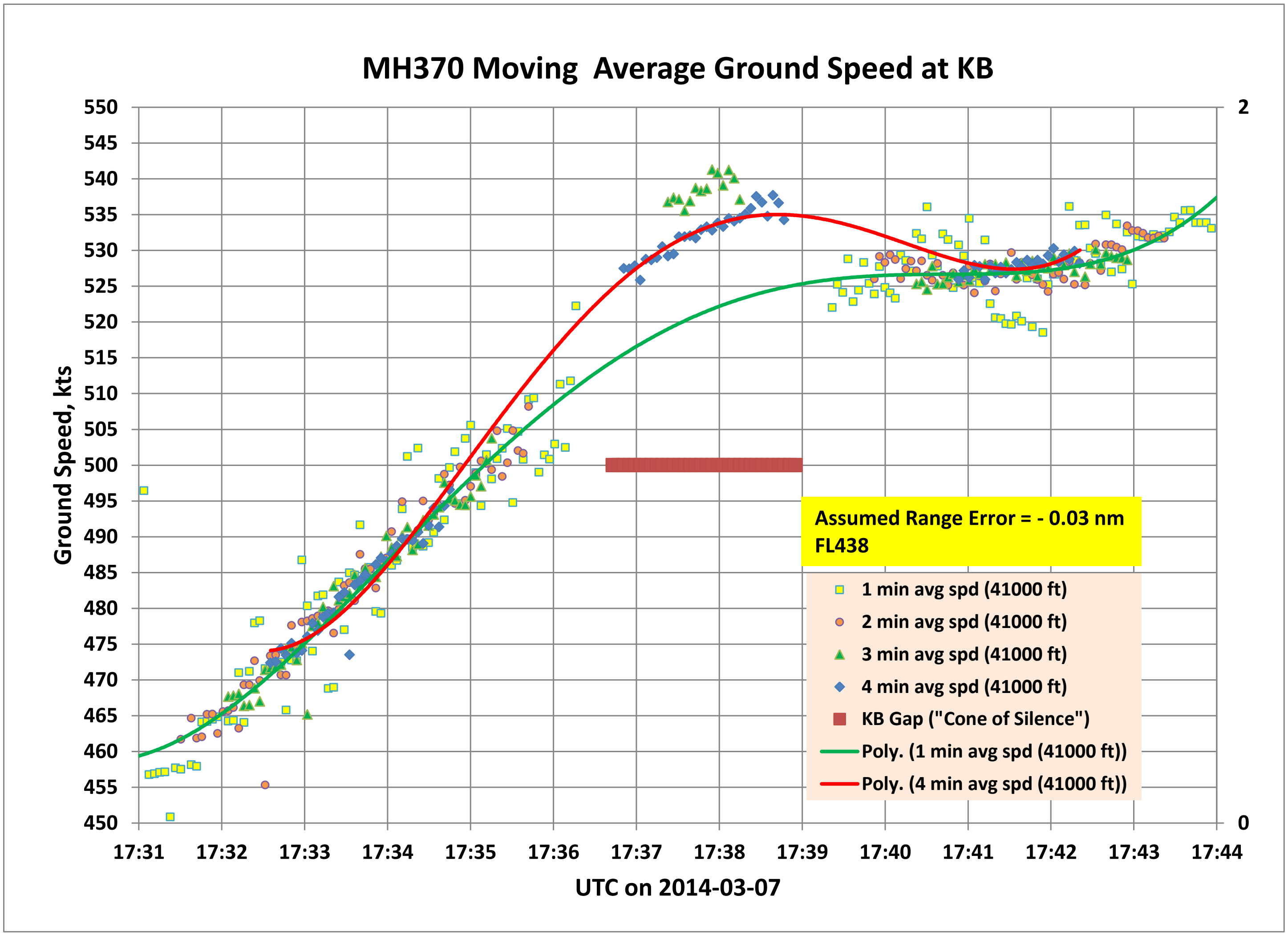
MH370 Moving Average Ground Speed at KB
Ground Speed, kts
UTC on 2014-03-07
Assumed Range Error = - 0.03 nm
FL438
1 min avg spd (41000 ft)
2 min avg spd (41000 ft)
3 min avg spd (41000 ft)
4 min avg spd (41000 ft)
KB Gap ("Cone of Silence")
Poly. (1 min avg spd (41000 ft))
Poly. (4 min avg spd (41000 ft))

Update

The following chart shows the speed vs. time series for 11 assumed altitudes (40-50kft). The series demonstrate that the true altitude must have been close to the center of this range. Due to the published B777-200ER performance limits, I now believe the altitude was closer to 43,000 feet. But the data taken at face value actually indicates a little higher than 43,000 feet.