International Civil Aviation Organization

The Nineteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/19)

Pattaya, Thailand, 27-30 May 2014

Agenda Item 5: Airspace Safety Monitoring Activities/Requirements in Asia/Pacific Region

HEIGHT MONITORING RESULTS FROM THE AAMA TO APRIL 2014

(Presented by the AAMA)

SUMMARY

This paper provides details of a paper presented at the Regional Monitoring Agencies Coordination Group (RMACG) meeting held in Paris in May 2014. The paper summarises the latest height monitoring results from the Australian Airspace Monitoring Agency (AAMA) up to April 2014.

1. INTRODUCTION

1.1 The Ninth meeting of the Regional Monitoring Agencies Coordination Group (RMACG/9) was recently held in Paris during the period 19-23 May 2014. All 13 ICAO endorsed RMAs were in attendance. The AAMA provided a number of papers to the meeting including details of current ADSB monitoring outcomes.

2. DISCUSSION

2.1 Attachment 1 provides a paper presented by the AAMA to the RMACG/9 meeting. This paper discusses the latest height monitoring conducted by the Australian Airspace Monitoring Agency (AAMA) using the Automatic Data Surveillance Broadcast (ADS-B) network. Basic statistics are given along with example cases.

1.2 Currently the AAMA has monitored 85% of all Australian registered RVSM approved aircraft and approximately 99% of all major Australian airline fleets. Those unmonitored are so because of lack of ADS-B fitment and difficulties in accessing GMU monitoring.

3. ACTION BY THE MEETING

3.1 The meeting is invited to note the information contained in Attachment 1.

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International Civil Aviation Organisation

WORKING PAPER

SEPARATION AND AIRSPACE SAFETY PANEL (SASP)
WORKING GROUP MEETING

NINTH MEETING

Paris, France, May 2014

Agenda Item 7: Long Term Monitoring Requirements Implementation

HEIGHT MONITORING RESULTS FROM THE AAMA TO APRIL 2014

(Presented by AAMA)

(Prepared by Dr Steven Barry)

Summary

This paper summarises the latest height monitoring results from the Australian Airspace Monitoring Agency (AAMA) up to April 2014. Results are given for overall statistics, Altimetry System Error (ASE) and geoid height reference for different aircraft types, and monitored aircraft types broken down by operator. Typical ASE behaviour is also illustrated as well as a selection of atypical ASE behaviours.

01/01/2012		The first date of ASE testing.
31/03/2014		The last date of ASE testing.
820		The number of days in time period.
2359	100%	Total number of aircraft seen in our data.
2317	98.2%	The number of aircraft seen in our data suitable for monitoring.
2124	90.0%	The number of aircraft with ASE values that can be determined.
248	10.0%	The number of aircraft monitored but with undetermined geoid.
1413	59.9%	The number of aircraft using Height Above Mean Sea Level.
637	27.0%	The number of aircraft using Height Above Ellipsoid.
17	0.7 %	The number of aircraft with variable geoid reference.
290	12.3 %	The number of aircraft with unknown geoid reference.

Table 1: Basic statistics for AAMA height monitoring using ADS-B data

1 INTRODUCTION

1.1 This paper discusses the latest height monitoring conducted by the Australian Airspace Monitoring Agency (AAMA) using the Automatic Data Surveillance Broadcast (ADS-B) network. Basic statistics are given along with example cases.

1.2 Currently the AAMA has monitored 85% of of all Australian registered RVSM approved aircraft and approximately 99% of all major Australian airline fleets. Those unmonitored are so because of lack of ADS-B fitment and difficulties in accessing GMU monitoring.

1.3 A major issue with using ADS-B data for calculation of Altimetry System Error (ASE) is establishment of which height geoid is being transmitted by the aircraft; height above mean sea level (HAMSL) or height above ellipsoid (HAE or WGS 84). This can be statistically determined if sufficiently good quality data is obtained from a wide range of geographic regions. Some aircraft switch between HAMSL and HAE when pilot or co-pilot avionics are used and this is termed a variable geoid.

1.4 Given sufficient data the ASE can be determined to high degree of accuracy (±10 ft). For some aircraft which have limited data a precise ASE value can not be determined, however if the range of possible ASE is still acceptably below the $\pm 245 ft$ limit then the aircraft can be considered monitored.

1.5 In line with previous work the data was corrected for due to HAMSL data interpolation errors and bias in time of day or location, as determined from sampling against 1500 aircraft with accurate ASE results.

1.6 The Altimetry System Error (ASE) data was obtained by processing ADS-B messages for aircraft from the Australian ADS-B network with additional data provided from Indonesian ground stations and a station in Bangkok. The data spans 1 January 2014 to 31 March 2014. Table 1 shows the main statistics for the data.

1.7 Figure 1 shows the ASE values for the most common 17 aircraft types in our sample. For each aircraft type a box plot is given with each accompanying red dot indicating the ASE

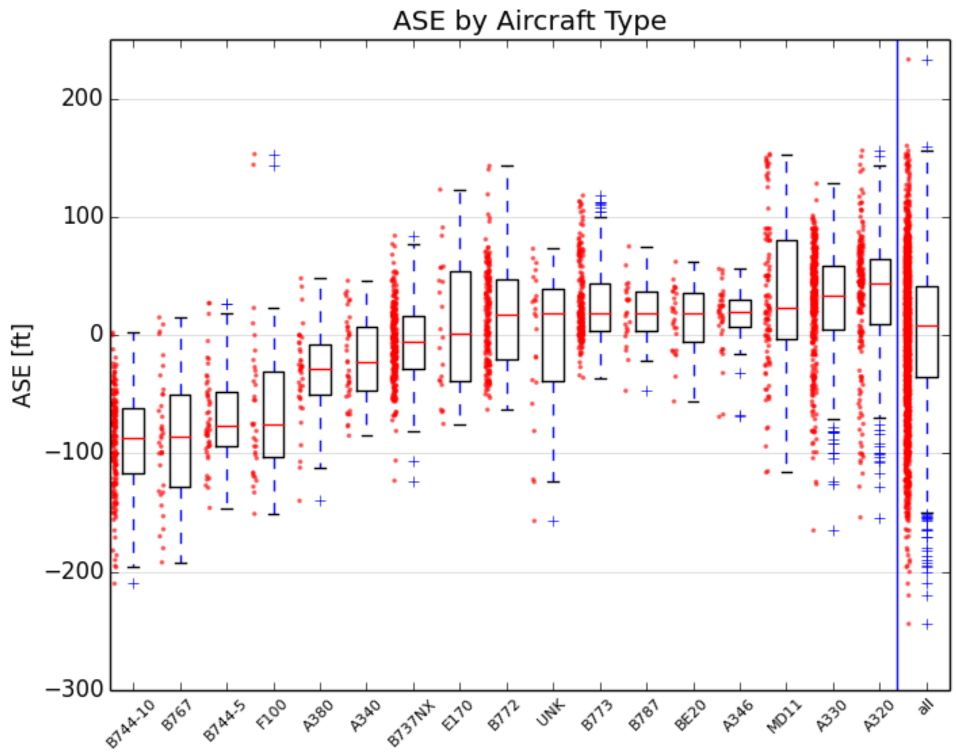

Figure 1: ASE by aircraft type for 17 of the most common aircraft types ordered by median ASE. Box plots are given for each distribution with the accompanying red dots visually representing the ASE for each aircraft in that sample.

value for that aircraft. The results here are for the 2124 aircraft for which ASE values can be determined.

1.8 Figure 2 shows the ASE values for the less common aircraft types in our sample. For each aircraft type a box plot is given with each accompanying red dot indicating the ASE value for that aircraft. The results here are for the 2124 aircraft for which ASE values can be determined.

1.9 Table 2 shows the data that accompanies Figure 1; that is, ASE by aircraft type including the mean, lower and upper bounds, and standard deviation.

1.10 Figure 3 shows the ASE distribution for the 2124 aircraft for which ASE values can be determined. The distribution is a Kernal Density Estimate caculated using the Python default routine (scipy.stats.gaussian_kde). The extreme ASE values are discussed later in this paper.

1.11 Table 2 shows the data that accompanies Figure 1; that is, ASE by aircraft type including the mean, lower and upper bounds, and standard deviation.

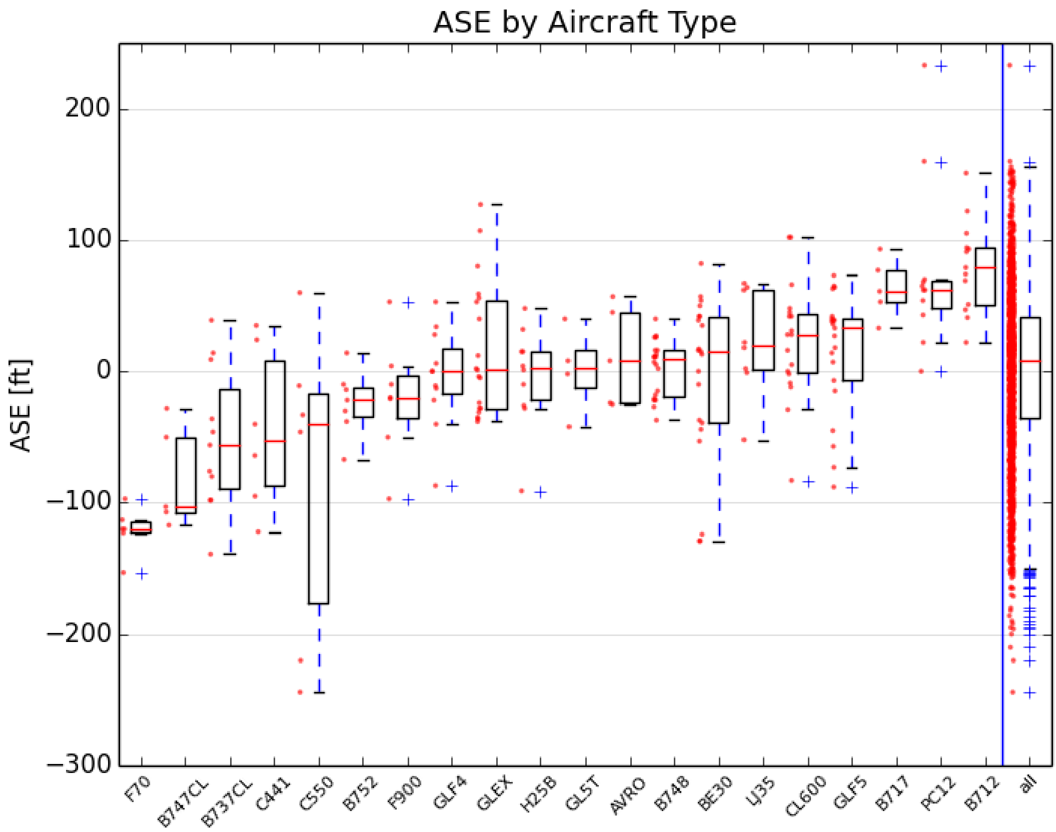

Figure 2: ASE by aircraft type for less common aircraft types ordered by median ASE. Box plots are given for each distribution with the accompanying red dots visually representing the ASE for each aircraft in that sample.

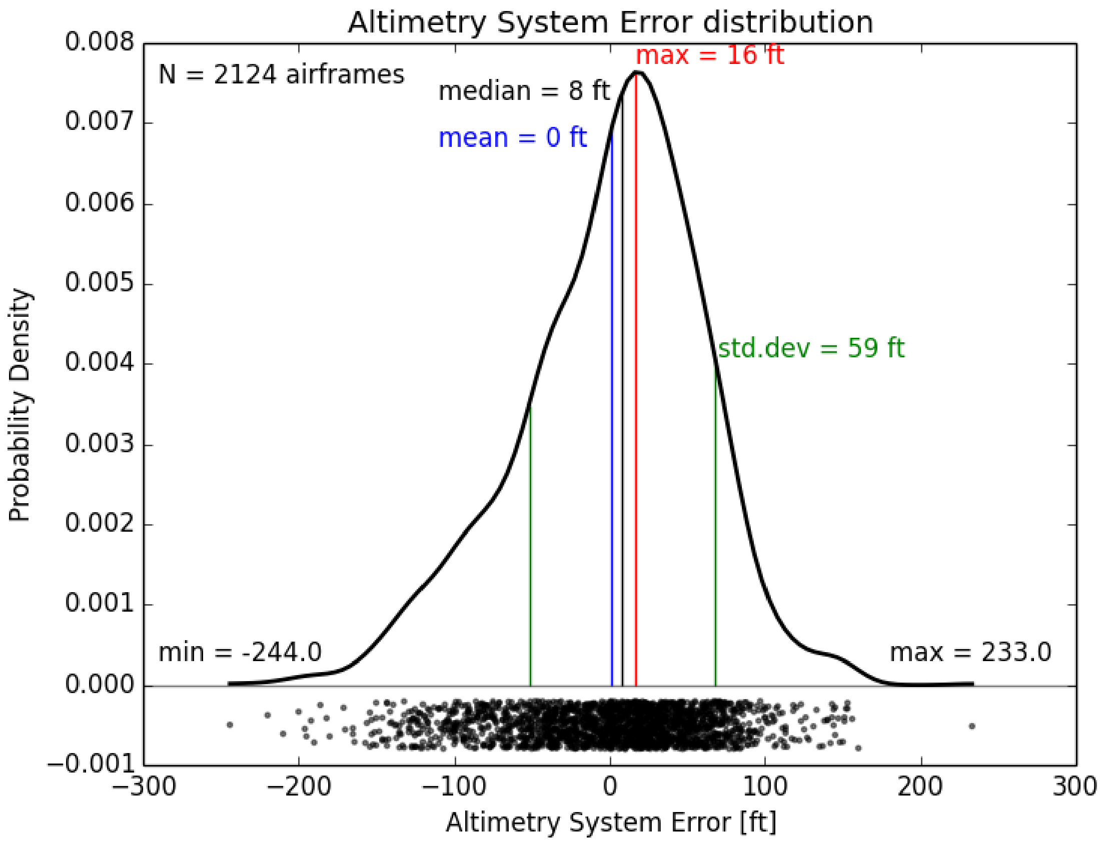

Figure 3: The kernal density estimate of the ASE distribution for the 2124 aircraft for which ASE values could be determined. Numerical values for mean (0 ft), median (8 ft), mode (16 ft), minimum (-244 ft), standard deviation (59ft), and maximum (233 ft) are shown.

Type	ASE_mean	ASE_lb	ASE_ub	ASE_st.dev	Number
B772	16.0	-63.0	143.0	40.0	195
B773	27.0	-36.0	118.0	32.0	220
A320	33.0	-154.0	156.0	55.0	222
B737NX	-7.0	-123.0	84.0	32.0	297
B767	-86.0	-192.0	15.0	53.0	44
E170	8.0	-75.0	123.0	56.0	22
B744-10	-90.0	-210.0	2.0	41.0	186
B744-5	-68.0	-146.0	27.0	39.0	48
A340	-20.0	-85.0	46.0	36.0	62
A346	14.0	-69.0	56.0	28.0	45
BE20	13.0	-56.0	62.0	27.0	38
B748	2.0	-37.0	40.0	21.0	20
MD11	33.0	-116.0	153.0	63.0	101
F100	-59.0	-151.0	153.0	68.0	42
BE30	-5.0	-129.0	82.0	61.0	24
A380	-33.0	-140.0	48.0	39.0	38

Table 2: ASE values (mean, lower bound, upper bound, standard deviation) for the main aircraft types.

op	op	A330	B737NX	B773	A320	B772	B744-10	MD11	B744-5	A340	A380	B767	A346	F100	BE20	B787	UNK	E170
AAR	Asiana Airlines	5				11												
ACA	Air Canada			5		6												
ACI	Air Caledonia	2			1													
AFE	Airfast Indones																	
AGC	Strategicairlin	1																
AIC	Air India															13		
AIQ	Thai Airasia				4													
AMSA	Australian Mari																	
ANA	All Nippon Airw			1														
ANG	Air Niugini		3									2		3				
ANO	Capiteq																	4
ANZ	Air New Zealand			5	18	8	2		1			5						
ARES	Aerorescue																	
ARG	Aerolineas									7								
AUH	Abu Dhabi Amini		1															
AVN	Air Vanuatu		1															
AWK	Airwork																	
AWQ	Indonesia Air A				14													
AXM	Air Asia				1													
BAW	British Airways			10		9	22		8									
BKP	Bangkok Airways				1													
BOE	Boeing															1		
BOM	Bombardier																	
BTV	Metro Batavia A				1													
CAL	China Airlines	17					6											

Continued on Next Page

Table Results – Continued

op	op	A330	B737NX	B773	A320	B772	B744-10	MD11	B744-5	A340	A380	B767	A346	F100	BE20	B787	UNK	E170
CBJ	Beijing Capital		1		1													
CCA	Air China	28		16			1											
CEB	Cebu Pacific Ai				2													
CES	China Eastern A	33											4			4		
CFH	Careflight														4			
CHH	Hainan Airlines	3																
CKS	Kalitta Air																	
CLX	Cargolux						1											
CNV	Us Navy		2														2	
CON	Conocophillips																	
CPA	Cathay Pacific	31		1		1	25		8	11								
CRK	Hong Kong Airli	3																
CSC	Sichuan Airline	3																
CSH	China Eastern A	2										2						
CSN	China Southern	29				2										4		
CTM	French Air Forc	1								2								
DAL	Delta Airlines					10												
DCS	Dca Gmbh				1													
DHK	Airtours Intern																	
DUB	Dubai Air Wing						1											
EDG	Western Air Cha																	
EJA	Netjets Av. In																	
EJM	Executive Jet M																	
ETD	Etihad Airways	17		15		4				3			7					
EVA	Eva Airways	10																
FDX	Federal Express							63										
FJI	Airpacific	3	4															
FOP	Fokker Services													1				
FVS	Falcon Aviation																	
GAJ	Gama Charters																	
GFA	Gulf Air				1													
GIA	Garuda Indonesi	18	51															
GLF	Bank Of Utah Tr																	
GNJ	Gainjet																	
GSS	Global Supply S																	
GTI	Atlas Air						18		4			2						
GZP	Gazpromovia		1															
HAL	Hawiian Air	16										9						
HDA	Dragon Air Carg	1					1		1									
HFY	Hifly									3								
HINT	Hinterland Avia														1			
HVN	Vietnam Airline	9				1												
ICE	Icelandair																	
IGA	Shortstop Jet C		12		6					3		2		1	6		3	
JAI	Jet Airways									1								
JAL	Japan Air Lines			8		10						2						
JAS	Jet Aviation Fl																	
JDC	Deere Company A																	
JSA	Jetstar Asia				22													

Continued on Next Page

Table Results – Continued

op	op	A330	B737NX	B773	A320	B772	B744-10	MD11	B744-5	A340	A380	B767	A346	F100	BE20	B787	UNK	E170
JST	Jetstar Airline	10			66											3		
JTE	National Jet Ex																5	
KAC	Kuwait Airways				1													
KAL	Korean Airlines	18				13	26											
KKK	Atlas Jet	1																
KLM	Klm Royal Dutch						1											
LAN	Lan Chile									5								
LNI	Lion Air		20															
MAS	Malaysia Airlin	26	29			17	10											
MAU	Air Mauritiius	2								5								
MEA	Middle East Air	1																
MIL	Japanese Air Fo								1			1						
MMD	Air Alsie A/S																	
MMZ	Euroatlantic Ai					1												
MTJ	Metrojet		1															
Mil	Royal Malaysian		1															
NAF	Koninklijke Luc																	
NCA	Nippon Cargo Ai						4											
NHN	Network Aviatio													11				
NJS	National Jet Sy													1				
OZW	Skywest Airline				2									10				
PAC	Polar Air Cargo						6											
PAL	Philippine Airl	7		5	19					7								
PBI	Polynesian Blue		4															
PBN	Pacific Blue		6															
PEARL	Pearl Aviation																	
PFY	Pel-Air Aviatio														1			
PJS	Jet Aviation B				1													
PVJ	Privajet		1		1													
PWA	Priester Aviati																	
QFA	Qantas Airways	20	62				13		12		12	17						
QLK	Qantaslink																	
QNZ	Qantas Jet Conn		8															
QTR	Qatar Airways			20		9												
RAAF	Raaf		2															
RBA	Royal Brunei Ai					6												
RDX	Airflite																	
REU	Air Austral			3		1												
RFDS	Royal Flying Do														17			
ROJ	Royal Jet		3															
RON	Nauru Air Corp																	
RSY	I-Fly	1																
RUN	Act Airlines						1											
Ross	Rossair Charter																	
SAA	South African A									9			9					
SAPF	Sa Police																	
SAS	Sunshine Air Se														1			
SAZ	Swiss Air-Ambul																	
SCO	Scoot					6												

Continued on Next Page

Table Results – Continued

op	op	A330	B737NX	B773	A320	B772	B744-10	MD11	B744-5	A340	A380	B767	A346	F100	BE20	B787	UNK	E170
SHE	Shell Aircraft																	
SIA	Singapore Airli	26		29		38	3				17							
SJY	Sriwijaya Air		2															
SKTK	Sky Trek														1			
SLK	Silk Air				18													
SOO	Southern Air					1	1											
SQC	Singapore Airli						12		1									
SUI	Swiss Air Force																	
SVA	Saudi Arabian A					1												
SVW	Global Jet Luxe		1															
SXA	Southern Cross																	
TAY	Tnt Airways						1											
TGM	Tag Aviation Es																	
TGW	Tiger Airways				38													
THA	Thai Airways	15		15		14	15		3	3			6					
THT	Air Tahiti Nui									2								
TMN	Tasman Cargo Ai																	
TOM	Thomsonfly																	
TSO	Transaero Airli						1											
TVS	Travel Service		2															
TWJ	Twinjet Aircraf				1													
UAE	Emirates			82		22					9							
UAL	United Airlines		12			4	14		9									
UNA	Cgl Poly Energy				1													
UNK	Flight Options													1	5		28	
UPS	United Parcel S							38										
USCG	Us Coast Guard																	
UTY	Alliance Airlin													14				
UZB	Uzbekistan Air											2						
VAAA	Vaa														2			
VAU	Virgin Blue Air		10	5														
VDA	Volga-Dnepr																	
VIR	Virgin Atlantic												19					
VJS	Vistajet																	
VJT	Vistajet																	
VOZ	Virgin Blue Air	7	57															18
WHT	White				1													
WOA	World Airways						1											
XAX	Air Asia X	18								1								
XPE	Amira Air Gmbh																	

2 GEOID HEIGHT REFERENCE BY AIRCRAFT TYPE

2.1 Table 5 shows the geoid height reference broken down by aircraft type. The notation is Height Above Mean Sea Level (HAMSL), Height Above Ellipsoid (HAE), VARiable (switching between geoid references) VAR, and Unown (UNK).

type	HAMSL	HAE	VAR	UNK	Total
overall	1413 (60%)	637 (27%)	17 (1%)	290 (12%)	2317
A320	188	12		22	222
A330	356	13		15	384
A340	37			25	62
A345	1				1
A346	36			9	45
A380	38				38
AC90				1	1
AVRO	5				5
B300				1	1
B350				1	1
B712	13				13
B717	5			1	6
B737		1		1	2
B737CL	1	10			11
B737NX	120	142	6	29	297
B744-10	172	10		4	186
B744-5	48				48
B747		1			1
B747CL	2			3	5
B748		19		1	20
B752	7			3	10
B767	32	3		9	44
B772	140	45	7	3	195
B773	83	122		15	220
B787		24		1	25
BD100		1		2	3
BD700				1	1
BE20		25		13	38
BE30	1	18		5	24
BE40		1		1	2
C25A		3			3
C25B		1		1	2
C25C		2			2
C441	1			6	7
C500				1	1
C501		3			3
C510		2			2
C525	1	1		3	5
C550		6		1	7
C560		2			2
C650		1			1
C680		1			1
CL600	2	15		5	22
D328		3		1	4
E120				2	2
E135		1			1
E170		22			22
E50P				2	2
F100	20	4		18	42
F28		1		1	2
F2TH		3		1	4
F70	2	1		3	6

3 TYPICAL BEHAVIOUR

3.1 This section illustrates a typical example of ASE behaviour indicative of 80-90 % of aircraft in our sample.

3.2 Figure 4 shows a typical ASE result expressed graphically. Each symbol on the top plot represents the ASE averaged over a single day for one aircraft. In this case the symbols are blue squares indicating an aircraft using HAMSL. If the aircraft was referencing HAE the symbols would be red circles. Also shown in this plot is a black horizontal line giving the estimated ASE value for this aircraft. The shaded yellow rectangle either side of this line represents the bounds of the estimate. A green line is also (barely) visible and this indicates a regression line through the data: in this case it is flat and indistinguishable from the blak line.

3.3 Figure 4 also shows a density plot (the default Python scipy Gausian kernel density estimate) of the ASE as a blue shaded region in the bottom left graph. The result is clearly Gaussian and in this case has a standard deviation of 21 ft and mean 70. These values are illustrated by the vertical black lines and the yellow shaded region. Given the quantity of data available for this aircraft the actual ASE estimate is within $\pm 5ft$. Other estimates of ASE are given by different vertical lines as shown in the legend. In this case all estimates agree.

3.4 In Figure 4 the bottom right graph illustrates the track data along wth a color map of the geoid difference (HAMSL-HAE).

4 RECOGNISED BEHAVIOUR

4.1 The following figures give examples of different aircraft ASE behaviour in our sample. See each caption for a description.

5 Acknowledgements

5.1 The use of computer code to calculate the ASE, and continued provision of NOAA meteorological data, by the FAA is gratefully acknowledged. MAAR and China RMA generously provided data which has enabled improved determination of geoid height references and ASE and this cooperation proves to be a valuable contribution to this work which is appreciated.

6 ACTION PROPOSED

6.1 The Meeting is invited to review and discuss to contents.

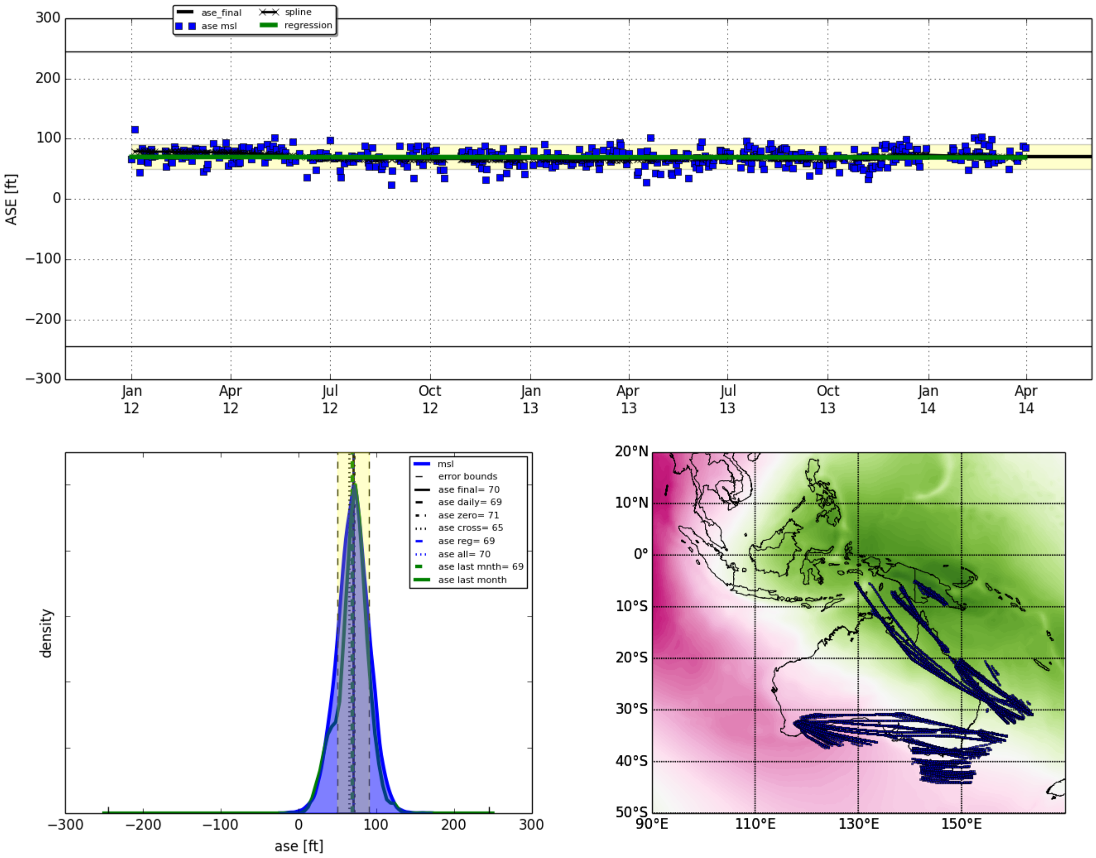

Figure 4: **<u>Normal ASE behaviour for an aircraft.</u>** The top plot shows ASE versus date with each blue symbol the average over a given day. The bottom left plot shows a Gaussian KDE distribution fit to the ASE for every data point along with numerous estimates of the ASE given in the legend and as vertical lines on the graph. The yellow shaded region on both graphs indicate conservative (1 standard deviaiton) upper and lower bounds for the ASE estimate. The bottom right graph illustrates the track data along wth a color map of the geoid difference (HAMSL-HAE).

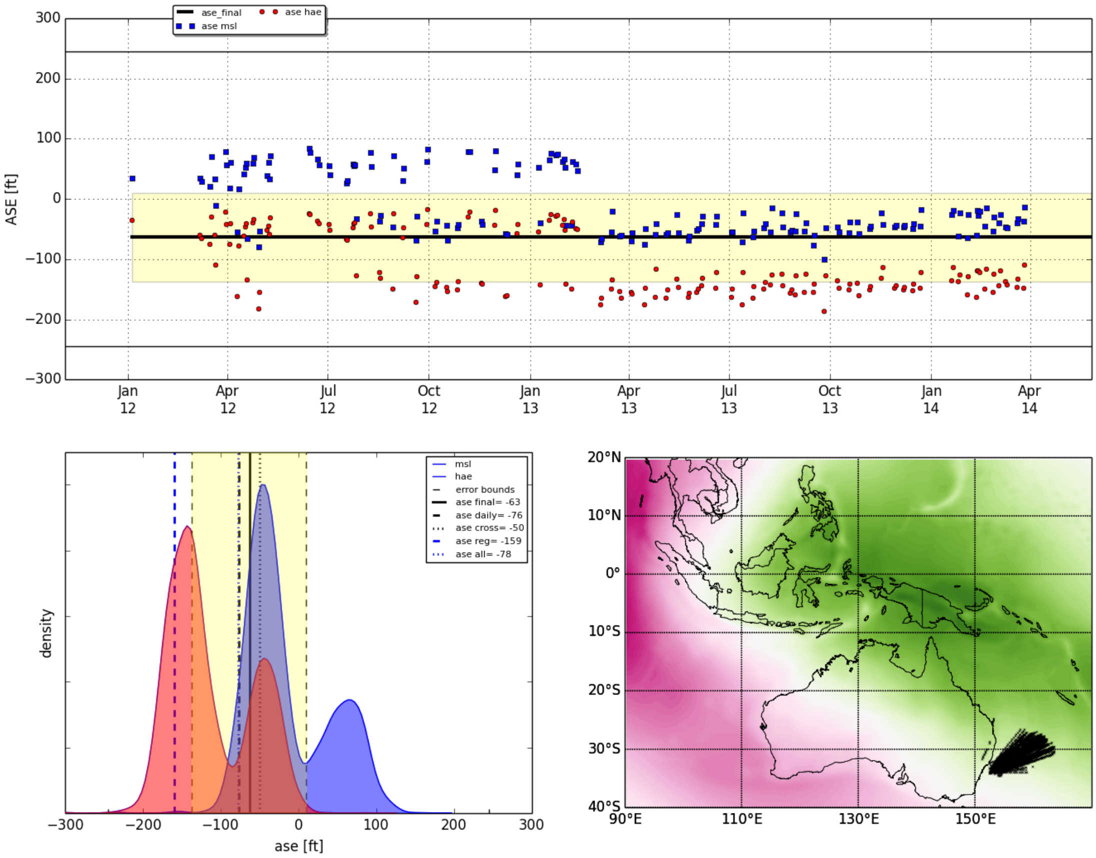

Figure 5: Example ASE behaviour for a B772 aircraft switching between HAMSL and HAE. The correct valie is clear in the middle. It appears this aircraft may now be using HAMSLsolely.

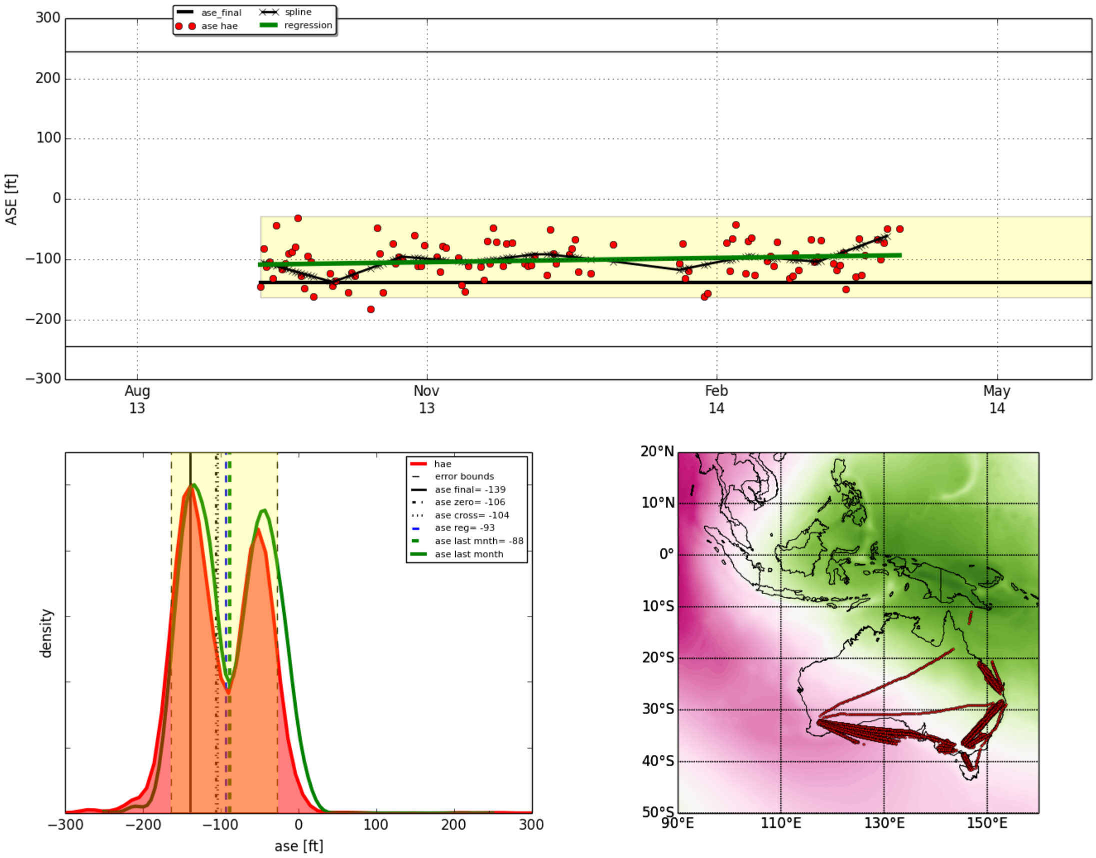

Figure 6: Example ASE behaviour for a B737CL with two values for ASE. The worst value of ASE is recorded.

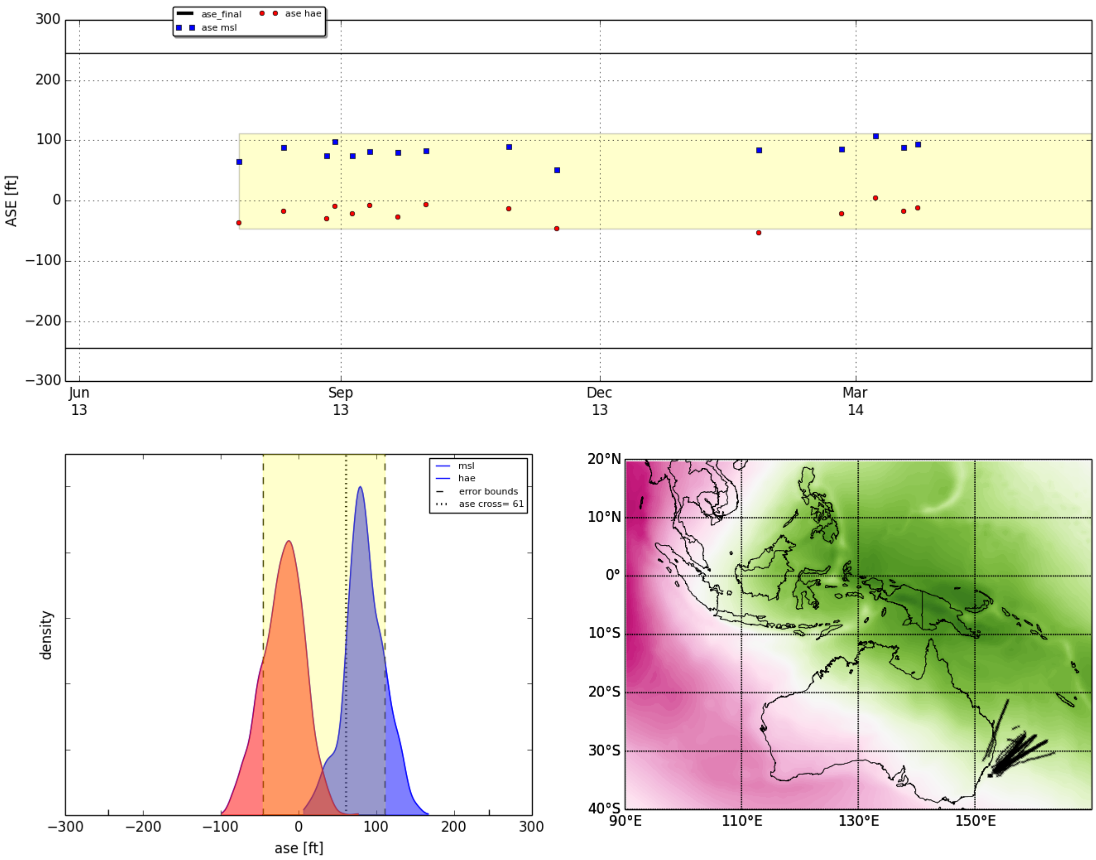

Figure 7: Example ASE behaviour for anA330 aircraft with unknown geoid. None of the statistics usually used anable the geoid height reference to be used, however the aircraft can still be considered monitored since results with either geoid are acceptable.

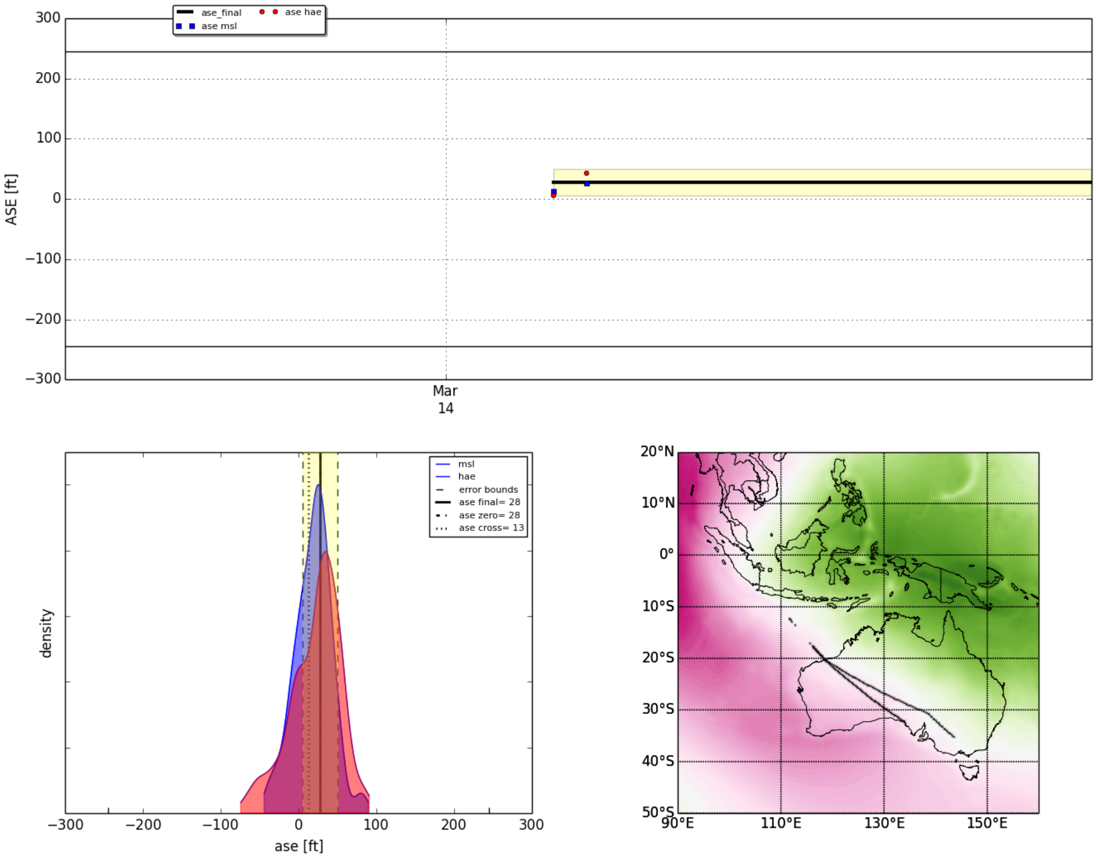

Figure 8: Example ASE behaviour for a B737NX aircraft with unknown geoid. None of the statistics usually used anable the geoid height reference to be found as this aircraft tracks almost exactly over the contour where HAMSL ≈ HAE. Hence an ASE value can be recorded without knowledge of the geoid reference.

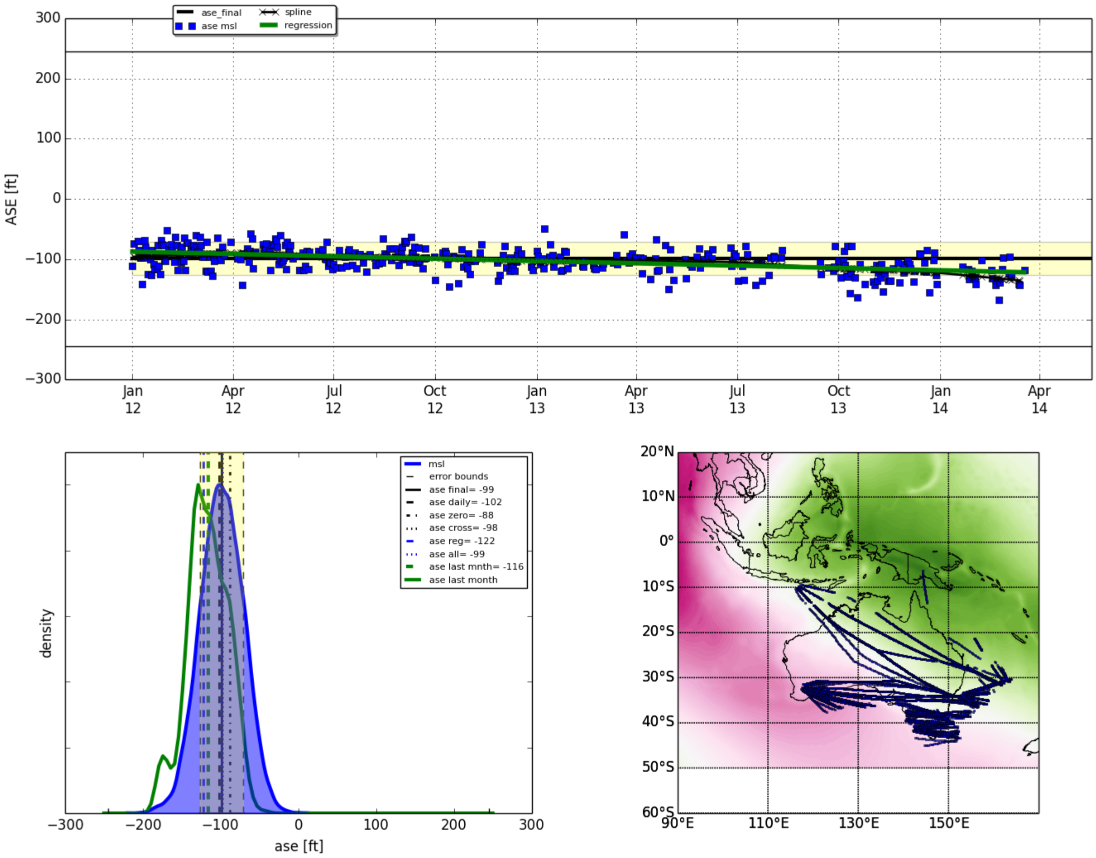

Figure 9: Example ASE behaviour for a B767 with degrading performance.

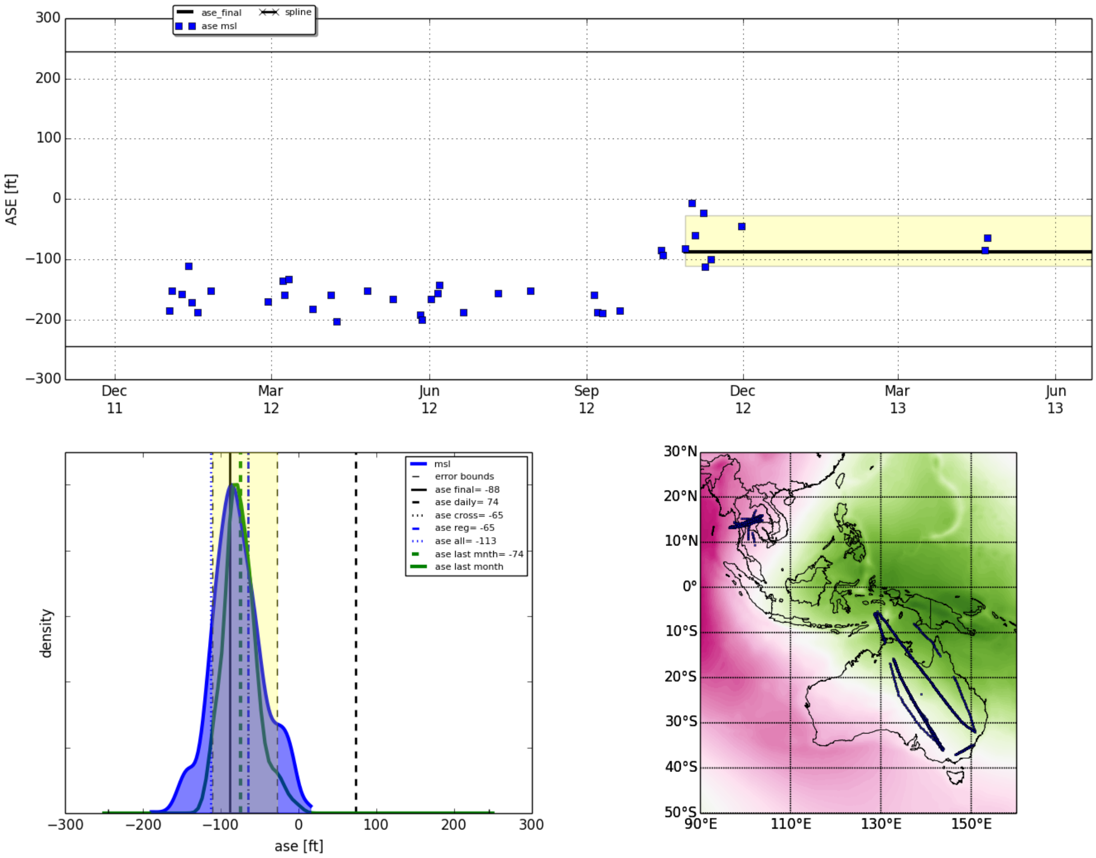

Figure 10: Example ASE behaviour for a B744-10 with degrading poor performance fixed by maintenance.

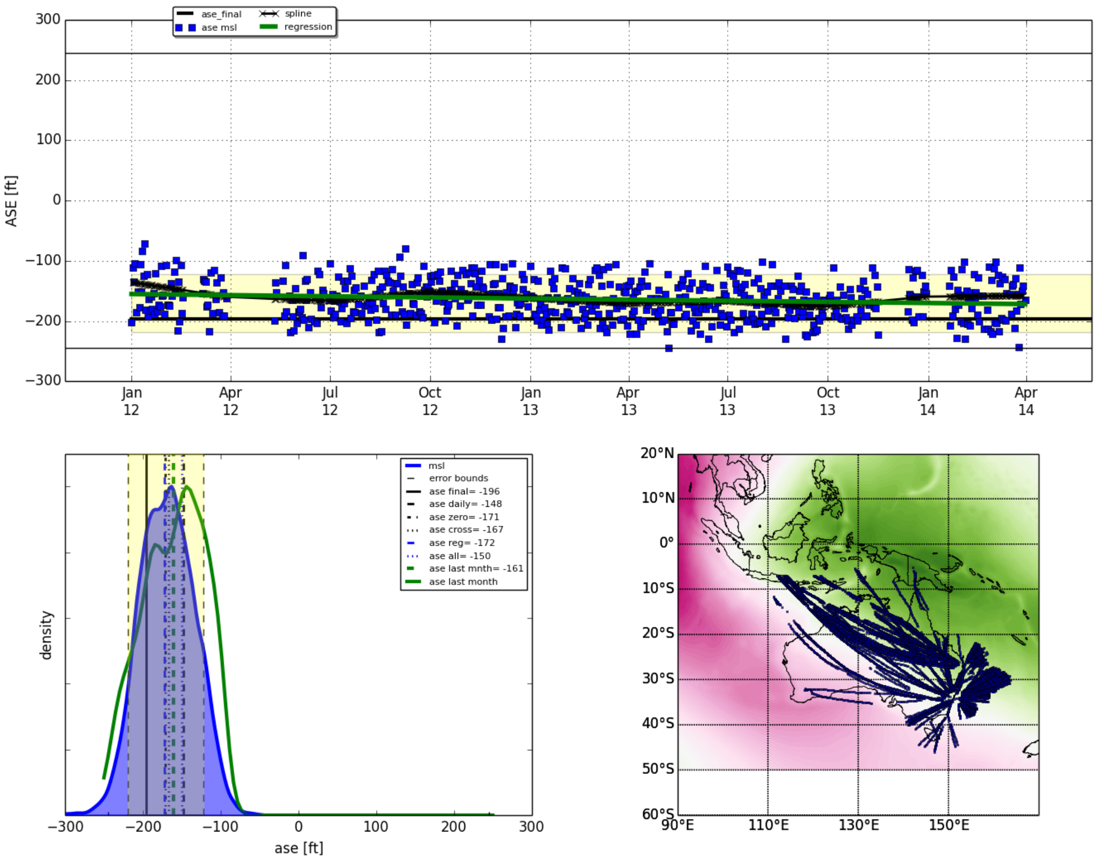

Figure 11: Example ASE behaviour for a B744-10 with poor performance at the limit of our acceptable range. For most aircraft this range is ±150 ft but for B744-10 aircraft this is ±200 ft due to the unknown reason behind this aircraft types consistently low value for ASE.

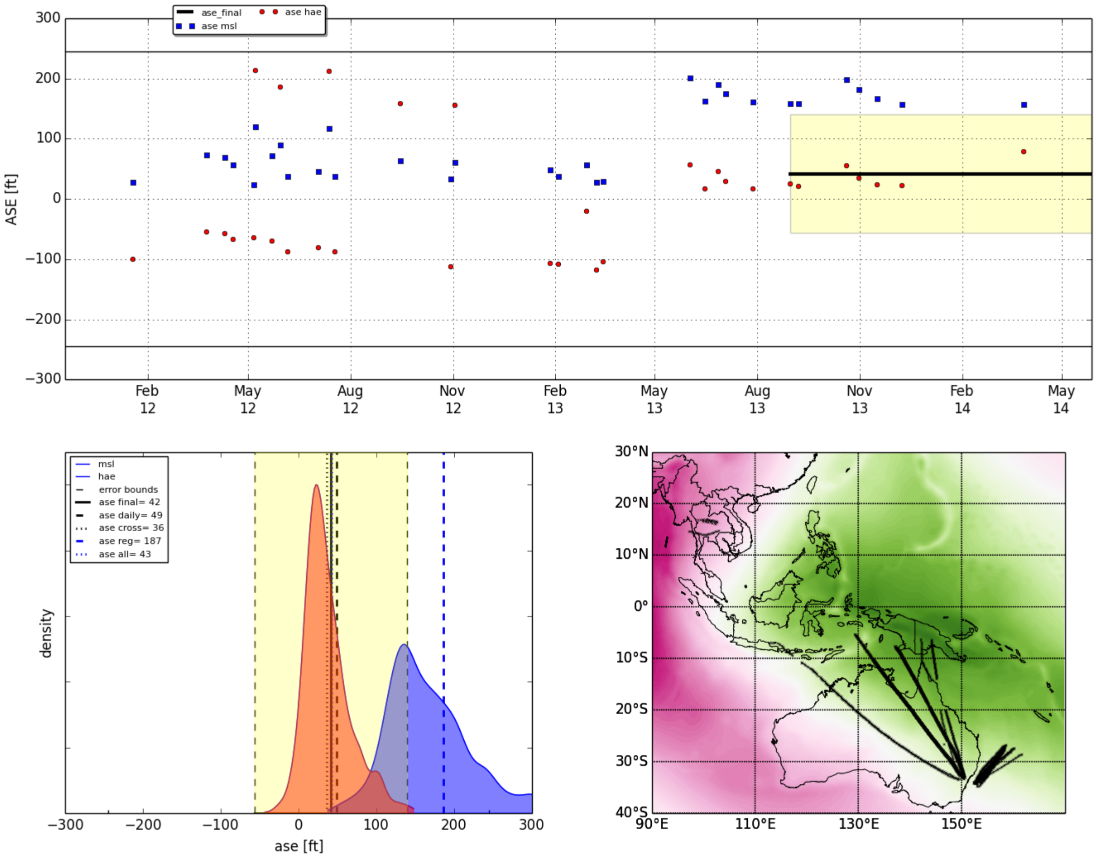

Figure 12: A MD11 aircraft which changes from HAMSL to HAE geoid reference. This operator updated most of their fleet.

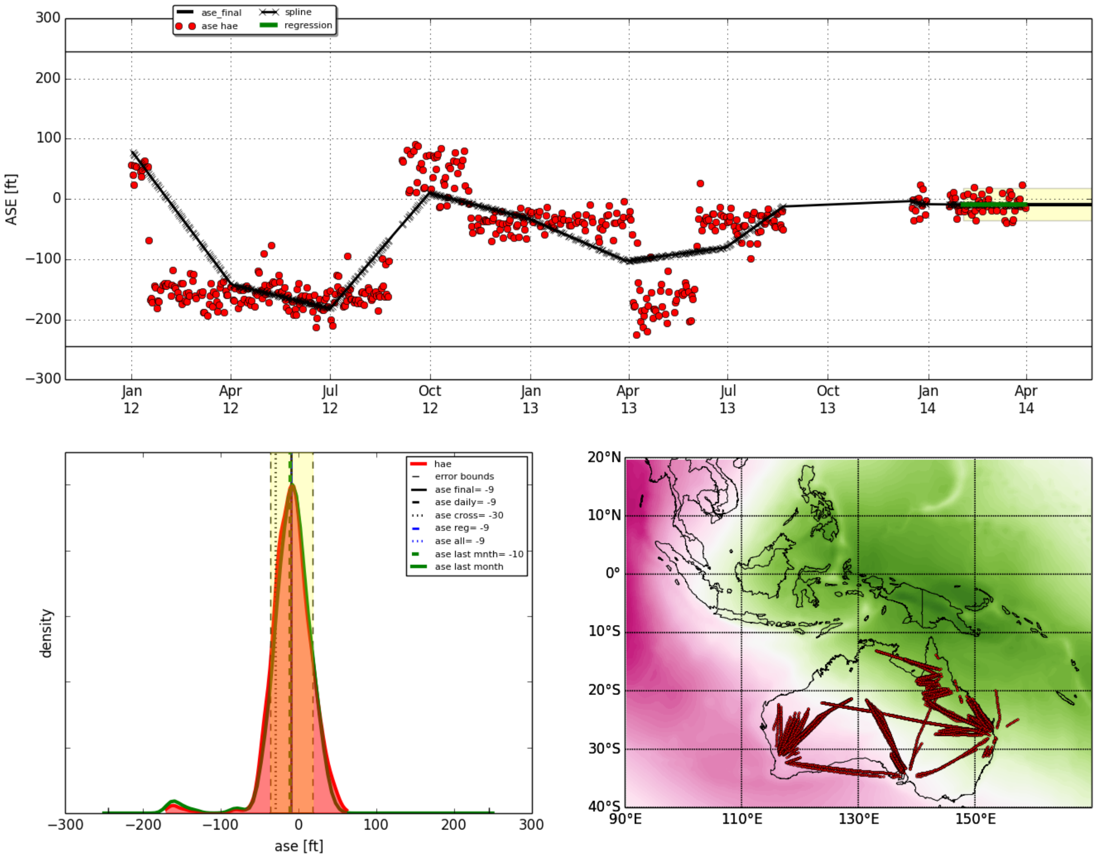

Figure 13: An F100 aircraft which underwent several maintenance procedures as the operator expanded their fleet. The distribution to the bottom left is only for the latest range of data.

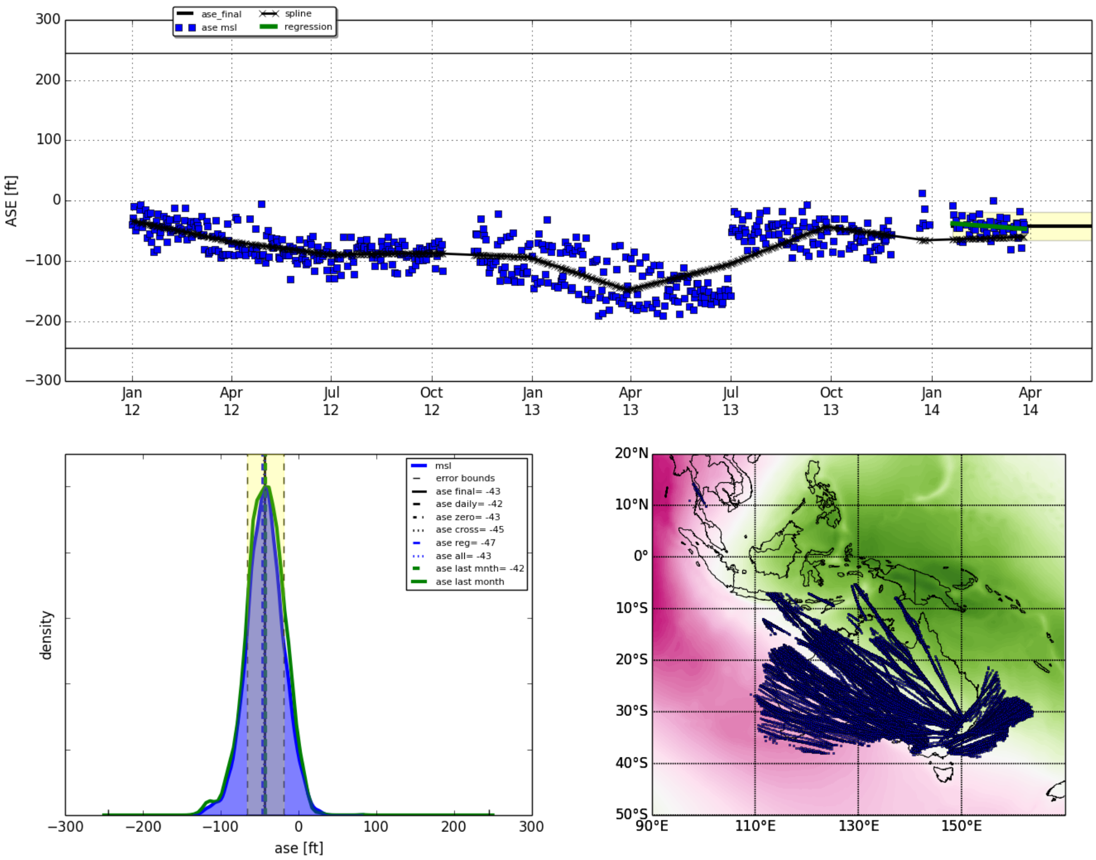

Figure 14: An A380 aircraft with alarming and degrading performance stopped by maintenance.

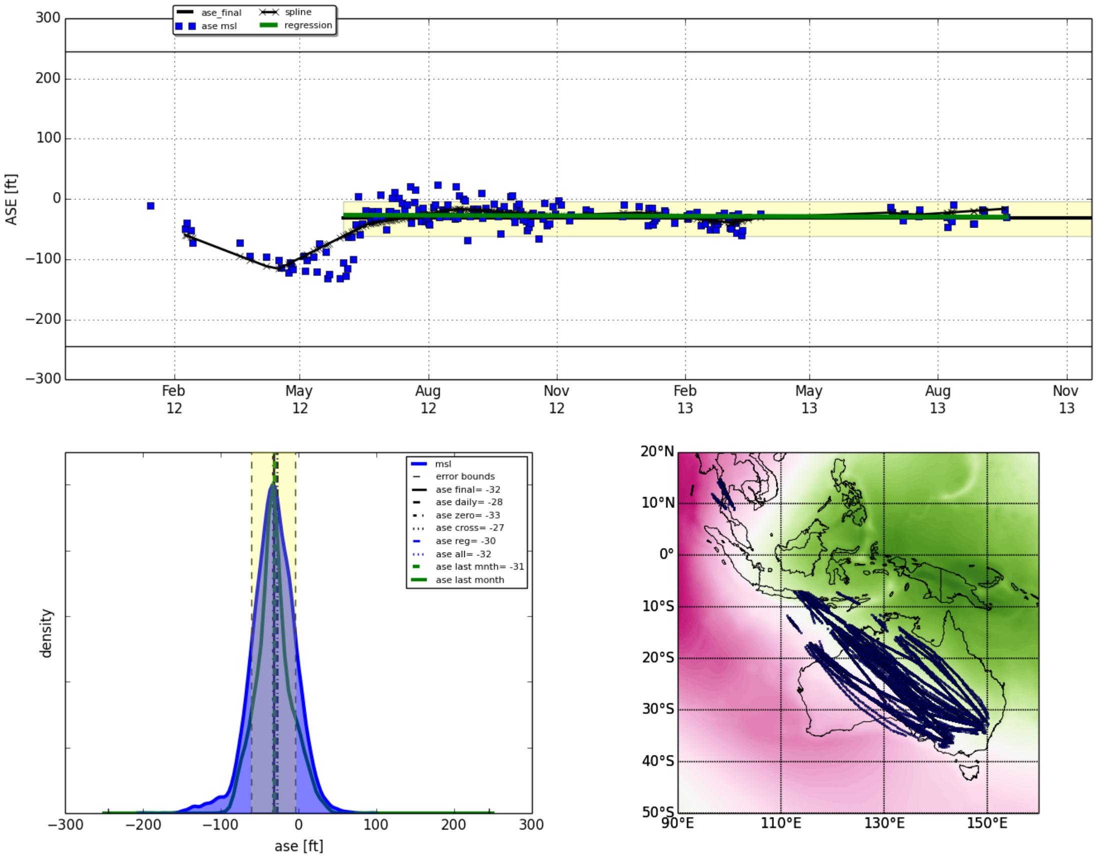

Figure 15: Another A380 aircraft with alarming and degrading performance stopped by maintenance.

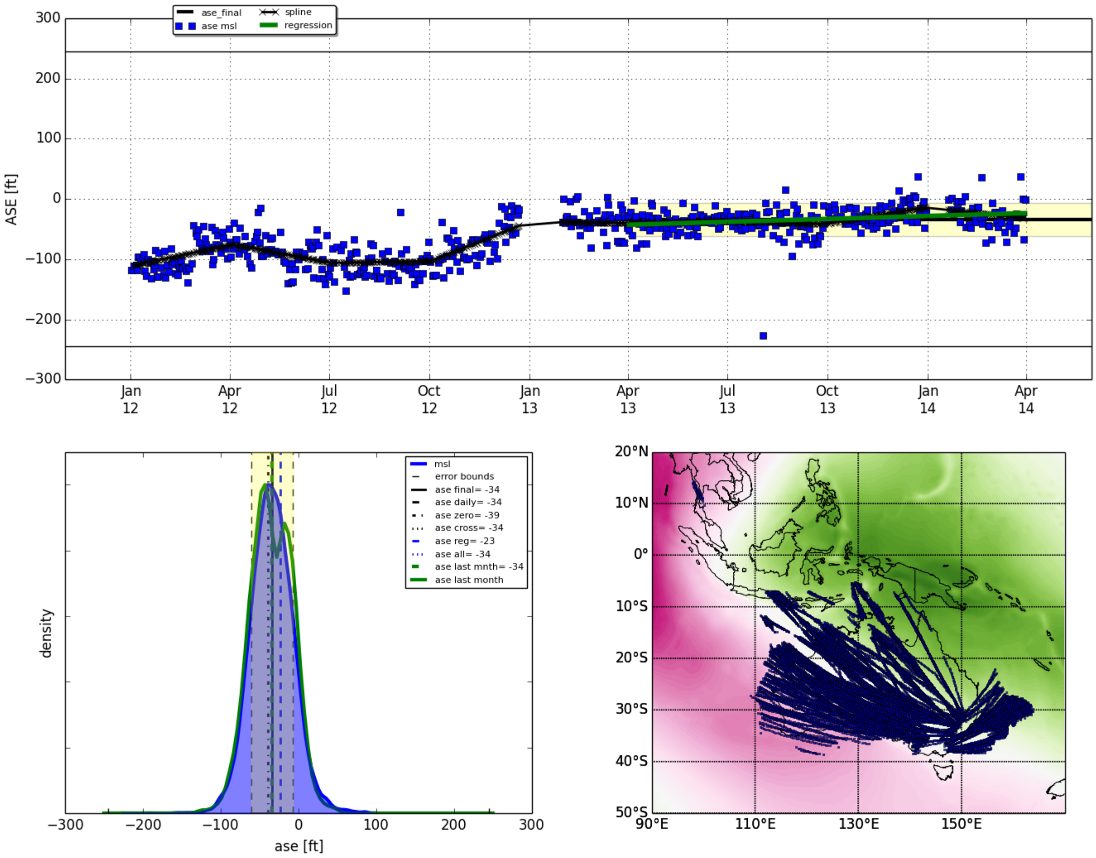

Figure 16: A third A380 aircraft with degrading performance to the left of the figure stopped by maintenance.

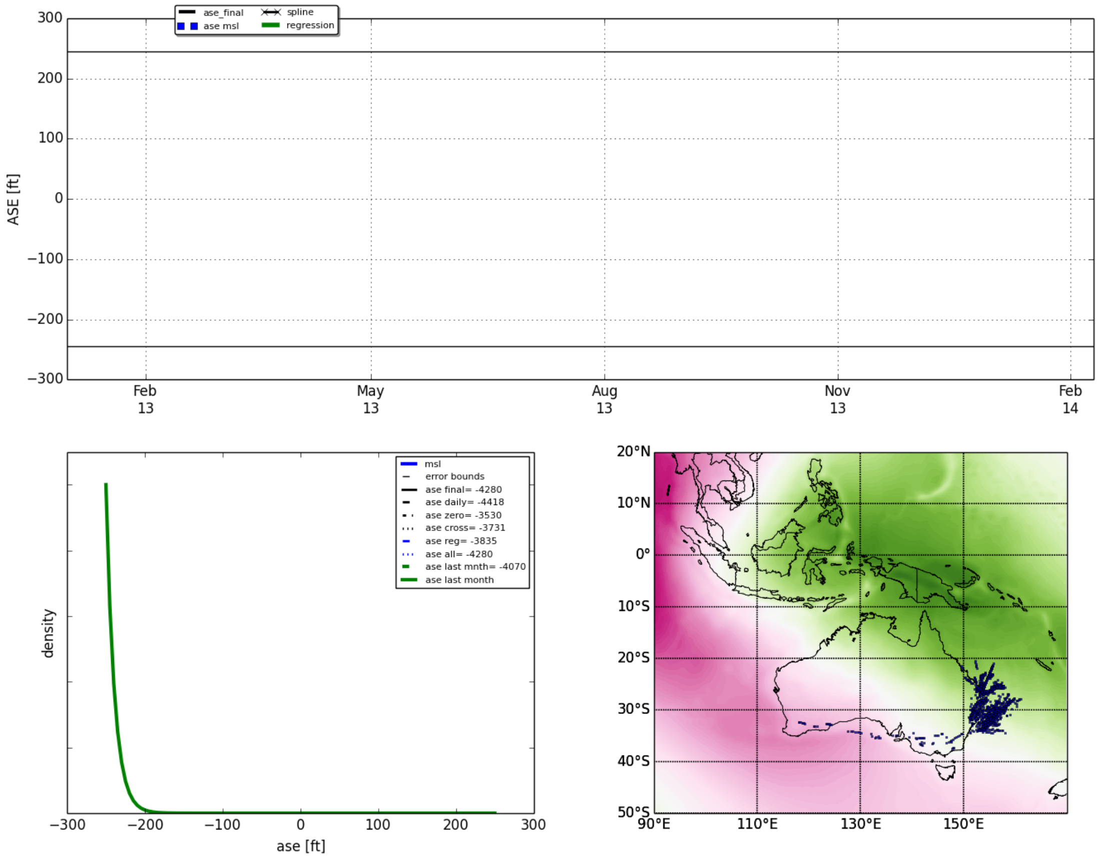

Figure 17: Data from an aircrft transmitting FOM=0. The track data shows significant scatter and the ASE result can show results of the order of 4000 ft.

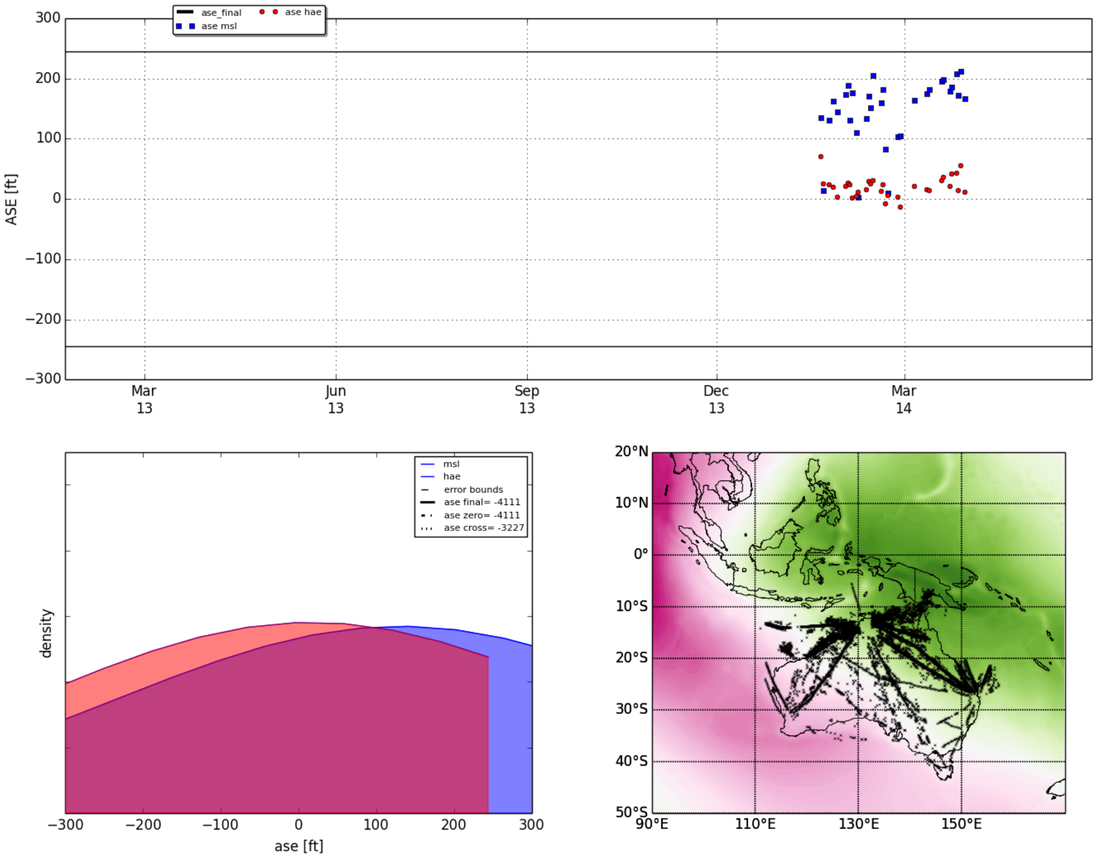

Figure 18: Data from a B737CL aircrft transmitting FOM=0. The track data shows significant scatter and outages and the ASE result has a very wide scatter. However, in this case the large amount of data provides, what we believe is a reasonable measure of good ASE performance.

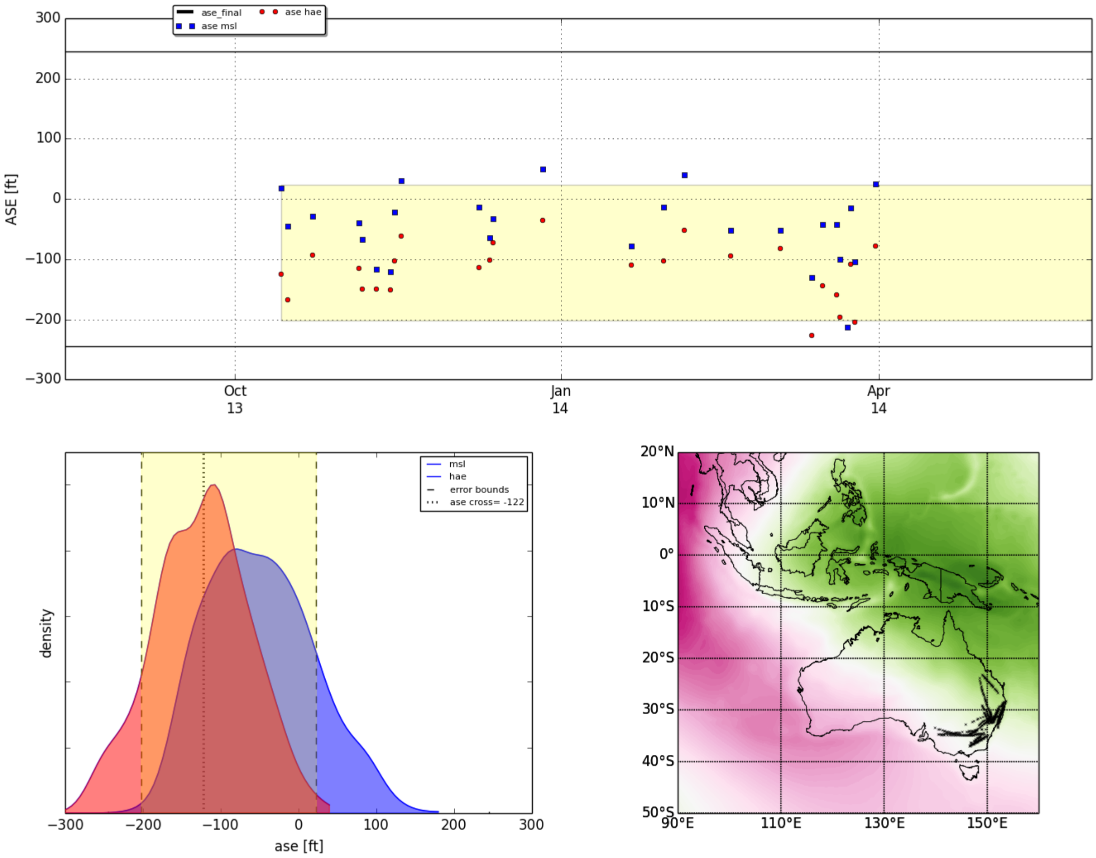

Figure 19: Data from a non-RVSM approved aircraft. The ASE shows considerable scatter with broad results for both geoid references. This aircraft is not considered to be monitored.

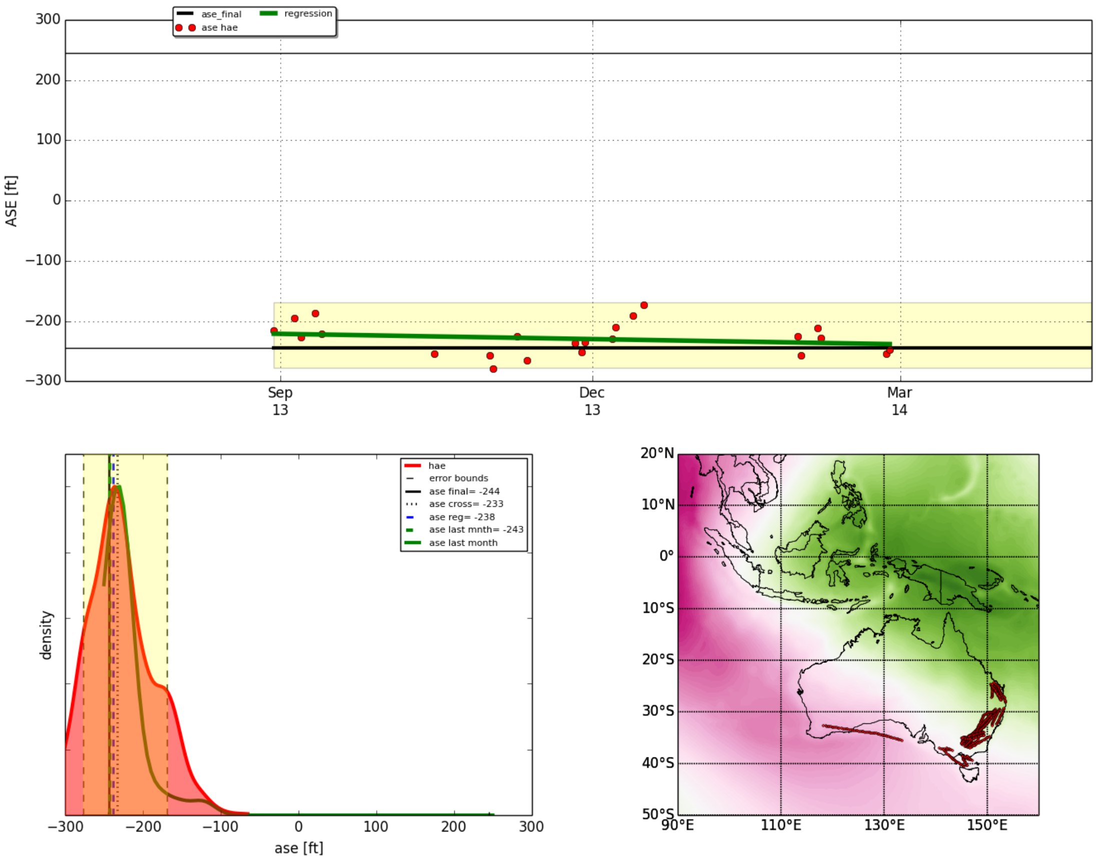

Figure 20: Data from a non-RVSM approved C550 aircraft. Four airframes with this level ASE (250 ft) were found in our sample and were non RVSM approved despite a significant number of flights in RVSM levels.