Loran C Accuracy Considerations: Terminal Area and En Route

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Overview

- Use of locally measured and/or calculated ASF values is key for Loran C to meet accuracy requirements of RNP (0.3)
- Ohio University has been collecting Loran C data at six east coast/mid west airport over the past three years
- Flights are conducted in early spring and late summer seeking to establish patterns for ASF values

Overview (con't)

- Goal is to verify if a single set of ASF values can serve an entire airport, including the terminal area, covering all runway approaches
- New interest in Loran as backup for GPS in the ADS-B arena (data at FL 180 desired)
- En route data for three Loran receivers is presented

Outline

- Loran-C Signal Propagation
- ASF Measurement System
- ASF* Derivation
- Required Navigation Performance
- Flight Test Results
- Summary and Conclusion

Loran C Signal Propagation

- "Primary" factor (PF) is signal delay through the atmosphere as compared to a vacuum
- "Secondary" factor (SF) is signal delay over seawater
- "Additional" secondary factor (ASF) accounts for additional delays over terrain due to ground conductivity (moisture/temperature dependent)
- Incorporation of ASFs is essential for terminal and en-route accuracy

ASF Measurement System

- 2 SatMates (E and H-field)
- 12 channel GPS/WAAS
- Notebook PC with ASF software utility for rapid on-site ASF calculation
- Flashcard for easy data storage and transfer to the aircraft receiver
- UPS/ruggedized unit for field use

ASF* Derivation

- Collect ~ 1 hour Loran and GPS data at airport site
- ASF software utility generates local ASF* values
  - •TOAs are measured using Loran C receiver clock locked to a composite frequency derived from all stations being tracked
  - Measured TOAs are differenced from TOAs calculated using GPS-derived position and the PF and SF yielding AFS*
  - •ASF* contains UTC offset, receiver delays
  - •Common receivers (ground/air) are used to account for the receiver delays
  - •Loran C system is well managed and UTC offsets within the system remain reasonably constant over time
- Second utility reads ASF* values and burns flashcard
- Flashcard is used to initialize aircraft Loran C receiver

ASF System in Operation

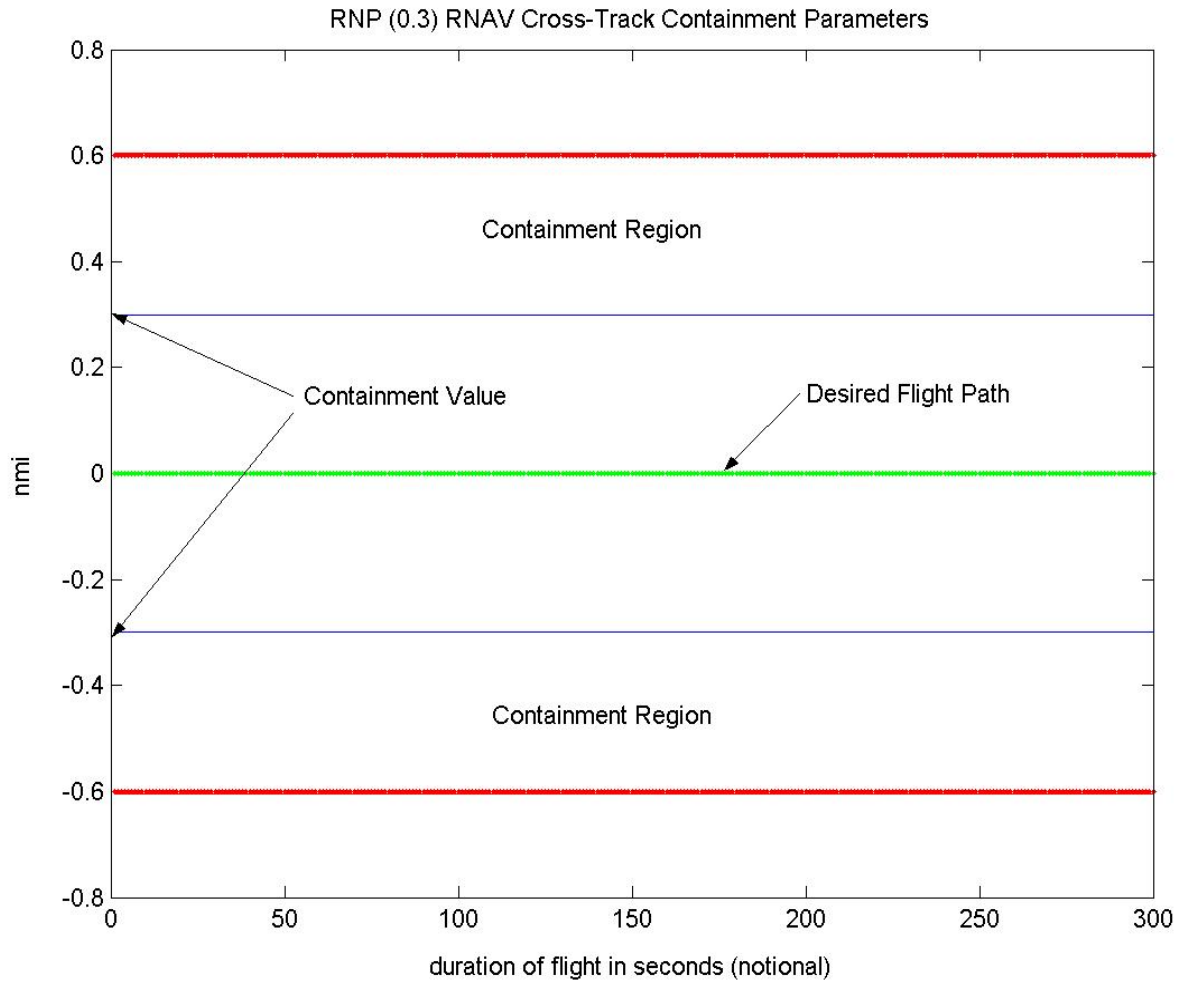
- ASF Measurement System
- Tripod holds GPS, E-field and H-field Loran antennas
- Shown here in operation at Jacksonville, Florida
  - Craig Municipal Airport

Example ASF* File for an Airport

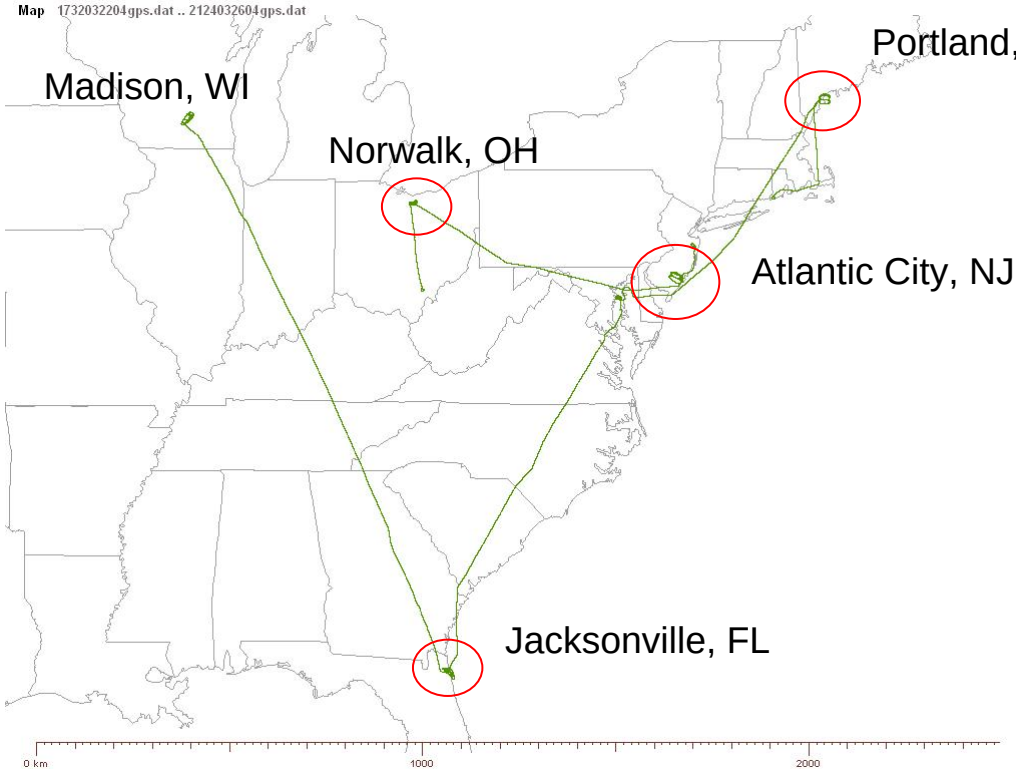
Typical ASF* values:
#ASF 8970M -0.906us [13500]
#ASF 8970X 0.429us [13498]
#ASF 8970Y 0.685us [13500]
#ASF 9960M 0.39us [13500]
#ASF 9960W 27.5us [8]
#ASF 9960Z -0.83us [13500]
#ASF 9960X 2.18us [13314]
#ASF 8970W 2.88us [13486]
#ASF 7980M -0.589us [13456]
#ASF 7980W -1.4us [13470]
#ASF 8970Z 0.118us [13468]
#ASF 7980Z -0.271us [13444]
#ASF 8290M 0.324us [13450]
#ASF 8290W 0.665us [13456]
#ASF 8290X 0.24us [13364]
#ASF 9610X 0.495us [12358]
#ASF 9610Y 0.523us [11932]
#ASF 9960Y 2.56us [13220]
#ASF 9610M -1.49us [13064]
#ASF 9610V -0.846us [13064]
#ASF 9610Z 0.261us [13064]
#ASF 7980X -0.544us [11690]
#ASF 7980Y 0.799us [6610]

Required Navigation Performance (RNP) 0.3

(From RTCA DO-236B)



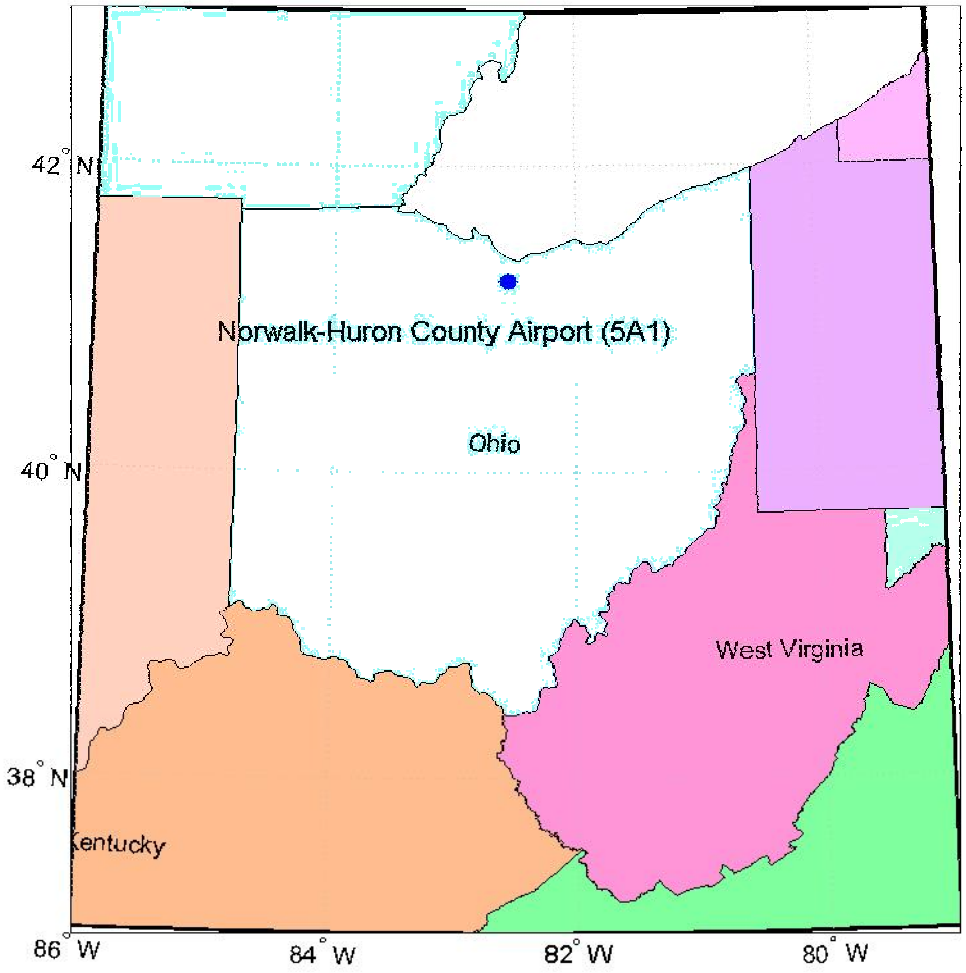
Usual Flight Test Route



Ongoing flight tests performed by Ohio University's Avionics Engineering Center (AEC) using King Air, C-90SE twin turboprop

Terminal-Area Flight-Test Results from Four Locations

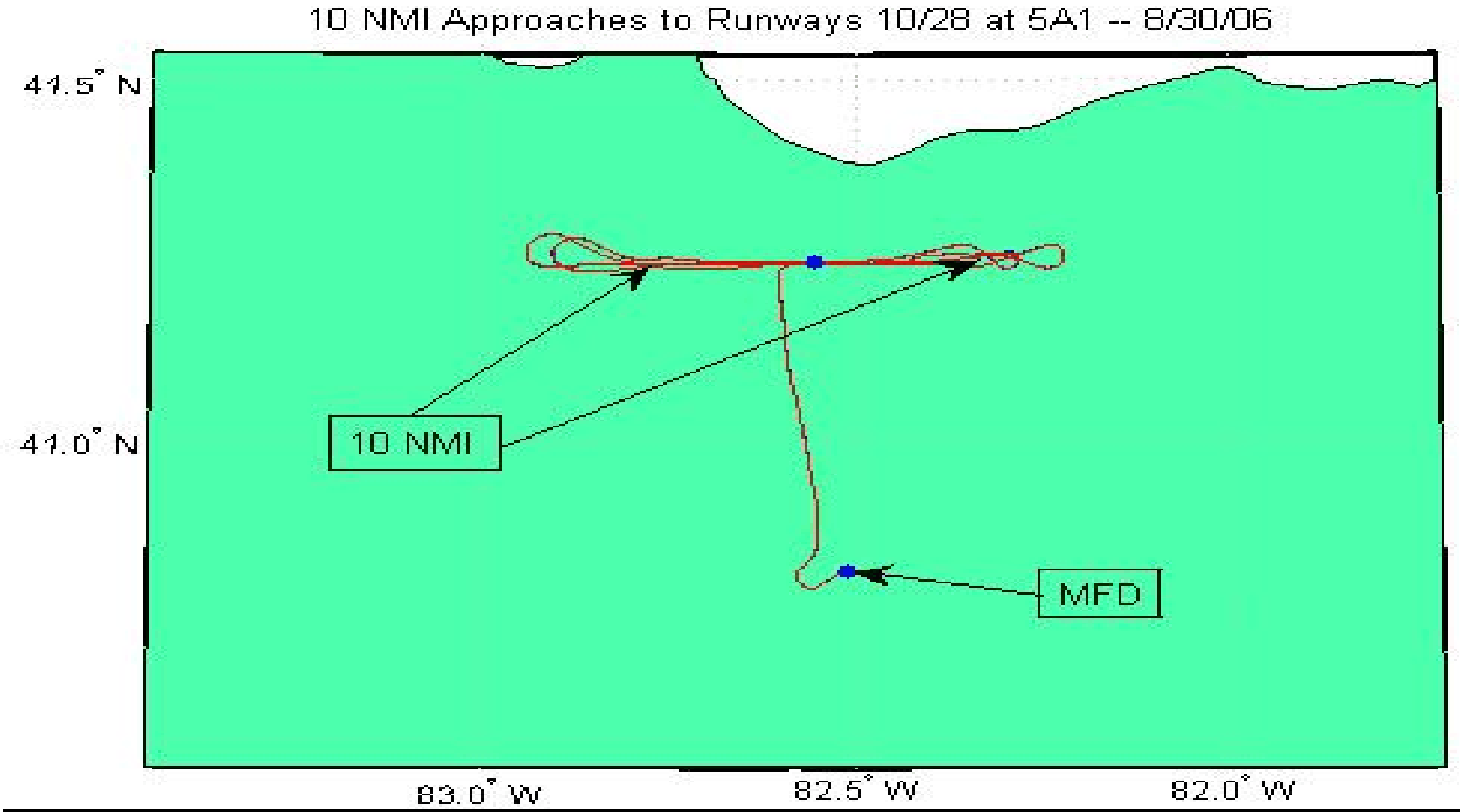
- Norwalk-Huron County Airport (5A1) Ohio
- Atlantic City International Airport (ACY)
- Portland International Jetport (PWM)
- Craig Municipal/Jacksonville Airport(CRG)


42° N
40° N
38° N
86° W
84° W
82° W
80° W
Norwalk-Huron County Airport (5A1)
Ohio
West Virginia
Kentucky

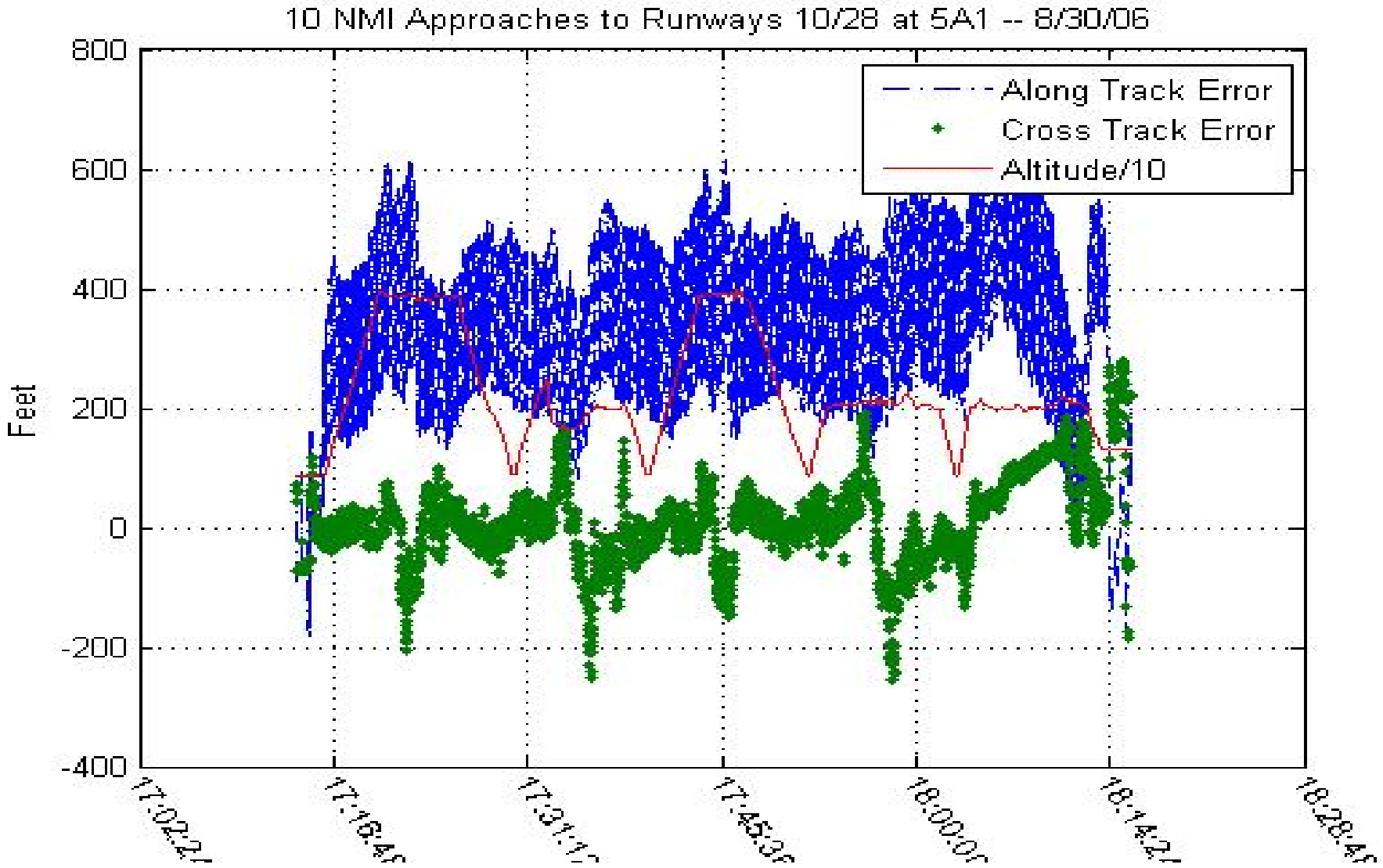
Frame

ASF* Values for Norwalk, OH (5A1)

	NORWALK-HURON COUNTY AIRPORT (5A1) OHIO (values in microseconds)																					
Chain	8970					9960					7980					8290			9610			
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	M	V	X	Y	Z
3/26/2004	-0.88	4.42	0.56	1.75	0.86	0.44	2.02	2.52	2.27	-0.60	3.10	2.61	2.25	1.89	1.54	-1.92	-2.20	-2.64	-2.05	-1.15	0.29	0.00	0.89
4/5/2005	-0.84	4.41	0.59	1.84	0.82	0.45	1.93	2.49	2.31	-0.61	3.07	2.56	2.12	1.89	1.54	-1.98	-2.20	-2.75	-2.06	-1.20	0.18	-0.07	0.87
3/29/2006	-0.83	4.27	0.56	1.67	0.80	0.46	1.94	2.45	2.18	-0.60	3.02	2.58	2.10	1.79	1.43		-2.10	-2.59	-2.02	-1.23		-0.24	0.85
Mean	-0.85	4.37	0.57	1.75	0.83	0.45	1.96	2.49	2.25	-0.60	3.06	2.58	2.16	1.86	1.50	-1.95	-2.17	-2.66	-2.04	-1.19	0.23	-0.10	0.87
Sigma	0.025	0.084	0.019	0.085	0.028	0.008	0.049	0.035	0.067	0.005	0.04	0.025	0.081	0.058	0.064	0.042	0.058	0.082	0.021	0.04	0.078	0.122	0.022
8/20/2004	-0.93	4.27	0.651	1.72	0.89	0.478		2.7	2.29	-0.63	3.04	2.63	2.28	1.85	1.51	-1.87	-2.21	-2.64	-2.04	-1.23		-0.04	0.822
8/24/2005	-0.93	4.25	0.655	1.89	0.924	0.487	1.88	2.68	2.31	-0.65	3.02	2.63		1.89	1.51	-1.92	-2.19	-2.66	-2.03	-1.18	0.296	-0.12	0.802
8/30/2006	-0.94	4.26	0.671	1.73		0.489	1.82	2.64	2.21	-0.64	3.01	2.58	2.16	1.86	1.47		-2.16	-2.57	-2.03	-1.27		-0.24	0.806
Mean	-0.93	4.26	0.659	1.78	0.907	0.485	1.85	2.673	2.27	-0.64	3.023	2.613	2.22	1.867	1.497	-1.9	-2.19	-2.62	-2.03	-1.23	0.296	-0.13	0.81
Sigma	0.005	0.01	0.011	0.095	0.024	0.006	0.042	0.031	0.053	0.008	0.015	0.029	0.085	0.021	0.023	0.035	0.025	0.047	0.006	0.045		0.1	0.011
Year Mean	-0.89	4.31	0.61	1.77	0.87	0.47	1.91	2.58	2.26	-0.62	3.04	2.60	2.19	1.86	1.50	-1.92	-2.18	-2.64	-2.04	-1.21	0.26	-0.12	0.84



Date	Airport	Runway	Cross-track Error (ft)			Along-track Error (ft)		
			|Mean| (ft)	Sigma(ft)	95% (ft)	|Mean| (ft)	Sigma (ft)	95% (ft)
8/30/2006	5A1	10 & 28	51.8	71	193.8	312.5	171.7	655.9


10 NMI Approaches to Runways 10/28 at 5A1 -- 8/30/06
Along Track Error
Cross Track Error
Altitude/10
Feet
800
600
400
200
0
-200
-400
17:02:21
17:16:45
17:31:11
17:45:36
18:00:01
18:14:21
18:28:45

Accuracy Results with ASF* Values Approaches from August/September 2006

Date	Airport	Runway	Cross-track Error (ft)			Along-track Error (ft)		
			|Mean| (ft)	Sigma(ft)	95% (ft)	|Mean| (ft)	Sigma (ft)	95% (ft)
8/30/2006	5A1	10 & 28	51.8	71.0	193.8	312.5	171.7	655.9
9/5/2006	ACY	13	178.2	213.6	605.4	308.5	235.5	779.5
9/7/2006	PWM	11	110.0	135.3	380.6	301.3	202.8	706.9
9/12/2006	CRG	32	142.5	178.9	500.3	268.1	331.8	931.7

Averaged ASF* Flight-Test Results

- Two-and-one-half year's of ASF* data used
  - Five sets from each of the four airports
- SatMate 1030 loaded en route to destination
- Approach flown under ATC guidance
- Along-track and Cross-track errors computed

ASF* Values for Norwalk, OH (5A1)

	NORWALK-HURON COUNTY AIRPORT (5A1) OHIO (values in microseconds)																					
Chain	8970					9960					7980					8290			9610			
Station	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	Y	Z	M	W	X	M	V	X	Y	Z
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3/29/2006	-0.83	4.27	0.56	1.67	0.80	0.46	1.94	2.45	2.18	-0.60	3.02	2.58	2.10	1.79	1.43		-2.10	-2.59	-2.02	-1.23		-0.24	0.85
Mean	-0.85	4.37	0.57	1.75	0.83	0.45	1.96	2.49	2.25	-0.60	3.06	2.58	2.16	1.86	1.50	-1.95	-2.17	-2.66	-2.04	-1.19	0.23	-0.10	0.87
Sigma	0.025	0.084	0.019	0.085	0.028	0.008	0.049	0.035	0.067	0.005	0.04	0.025	0.081	0.058	0.064	0.042	0.058	0.082	0.021	0.04	0.078	0.122	0.022
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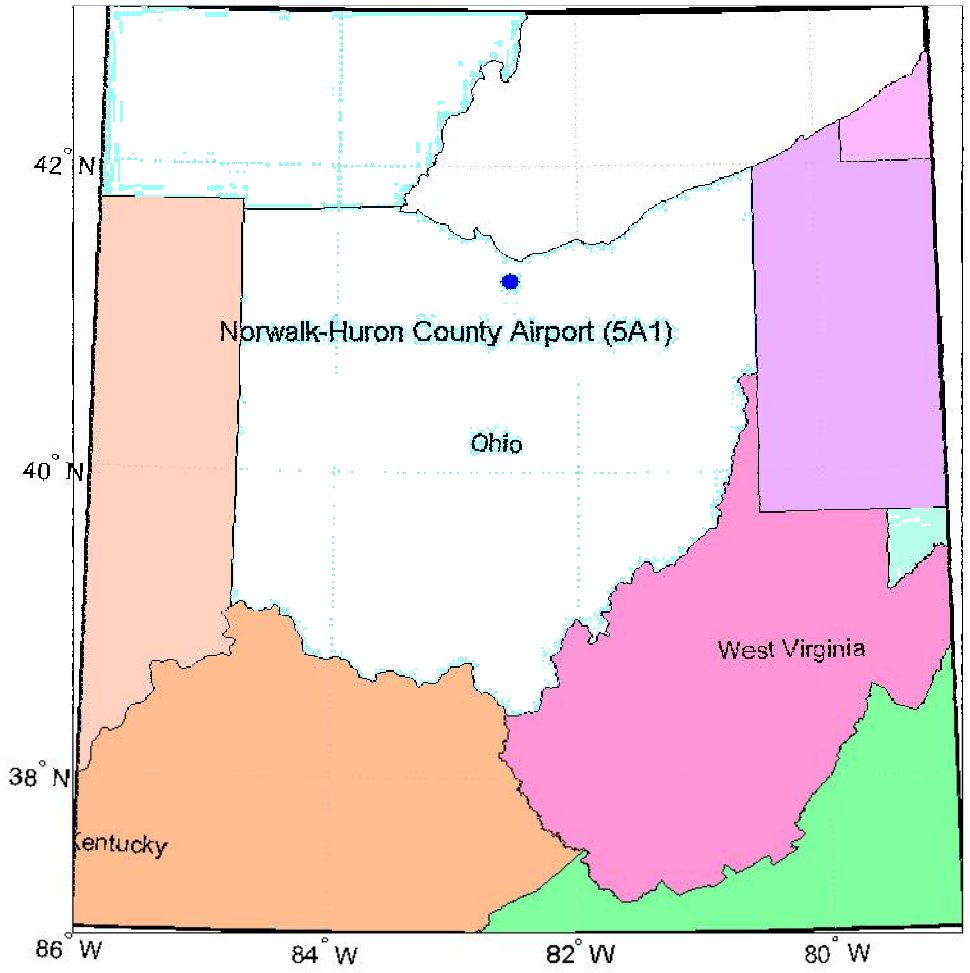
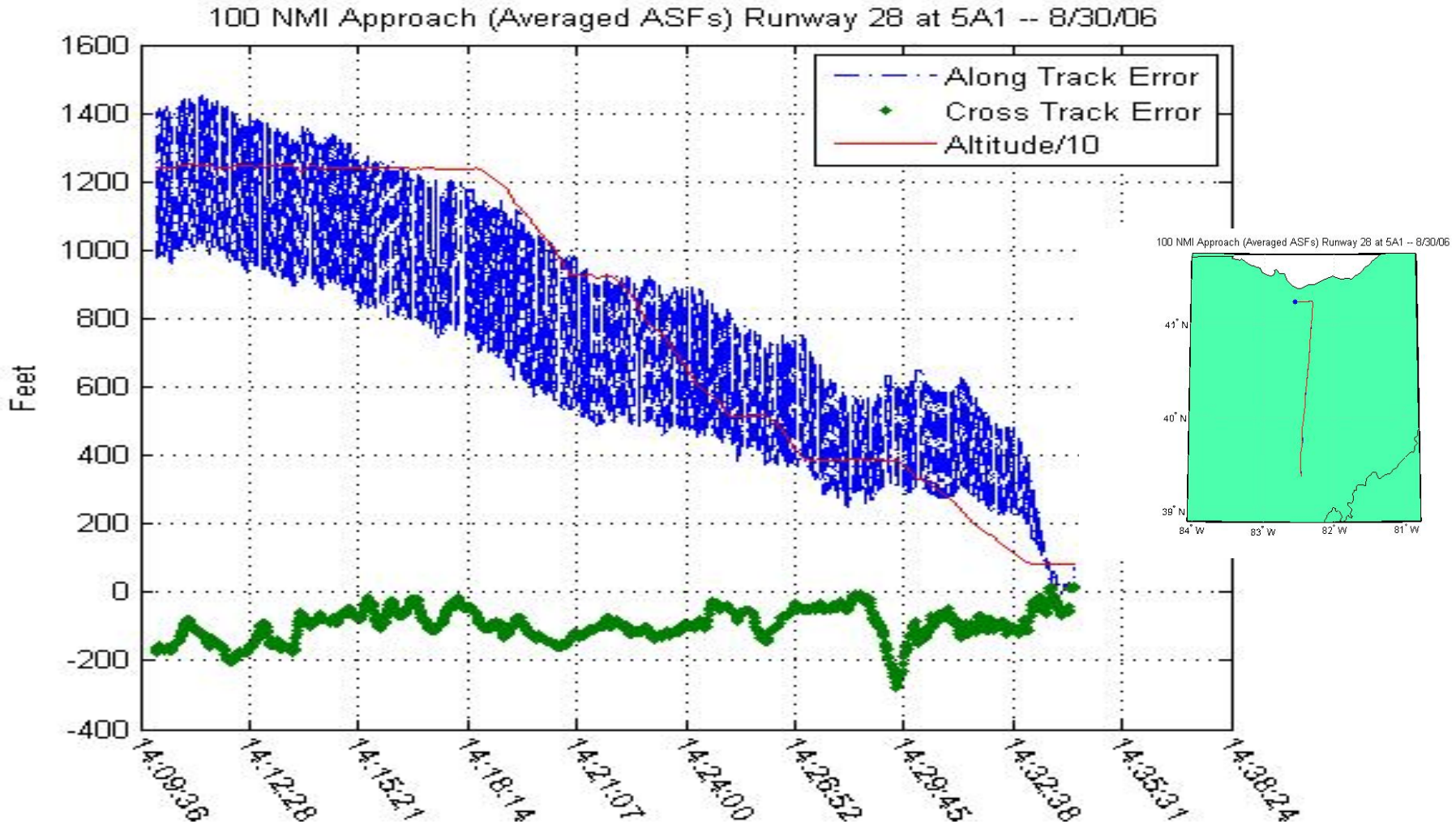
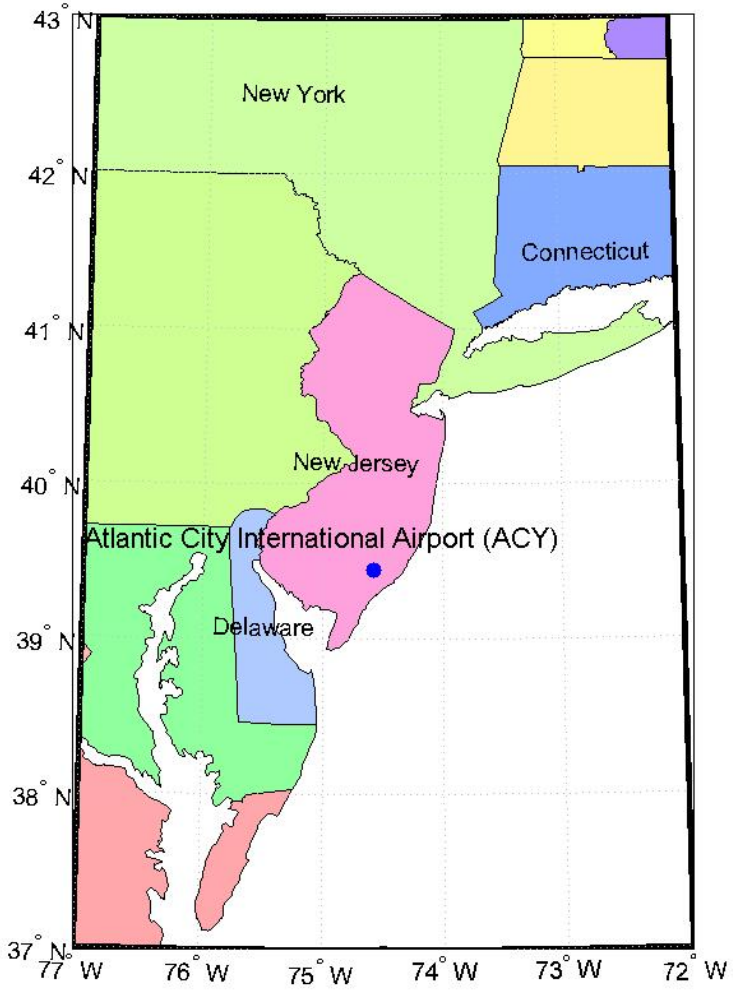
Sigma	0.005	0.01	0.011	0.095	0.024	0.006	0.042	0.031	0.053	0.008	0.015	0.029	0.085	0.021	0.023	0.035	0.025	0.047	0.006	0.045		0.1	0.011
Year Mean	-0.89	4.31	0.61	1.77	0.87	0.47	1.91	2.58	2.26	-0.62	3.04	2.60	2.19	1.86	1.50	-1.92	-2.18	-2.64	-2.04	-1.21	0.26	-0.12	0.84

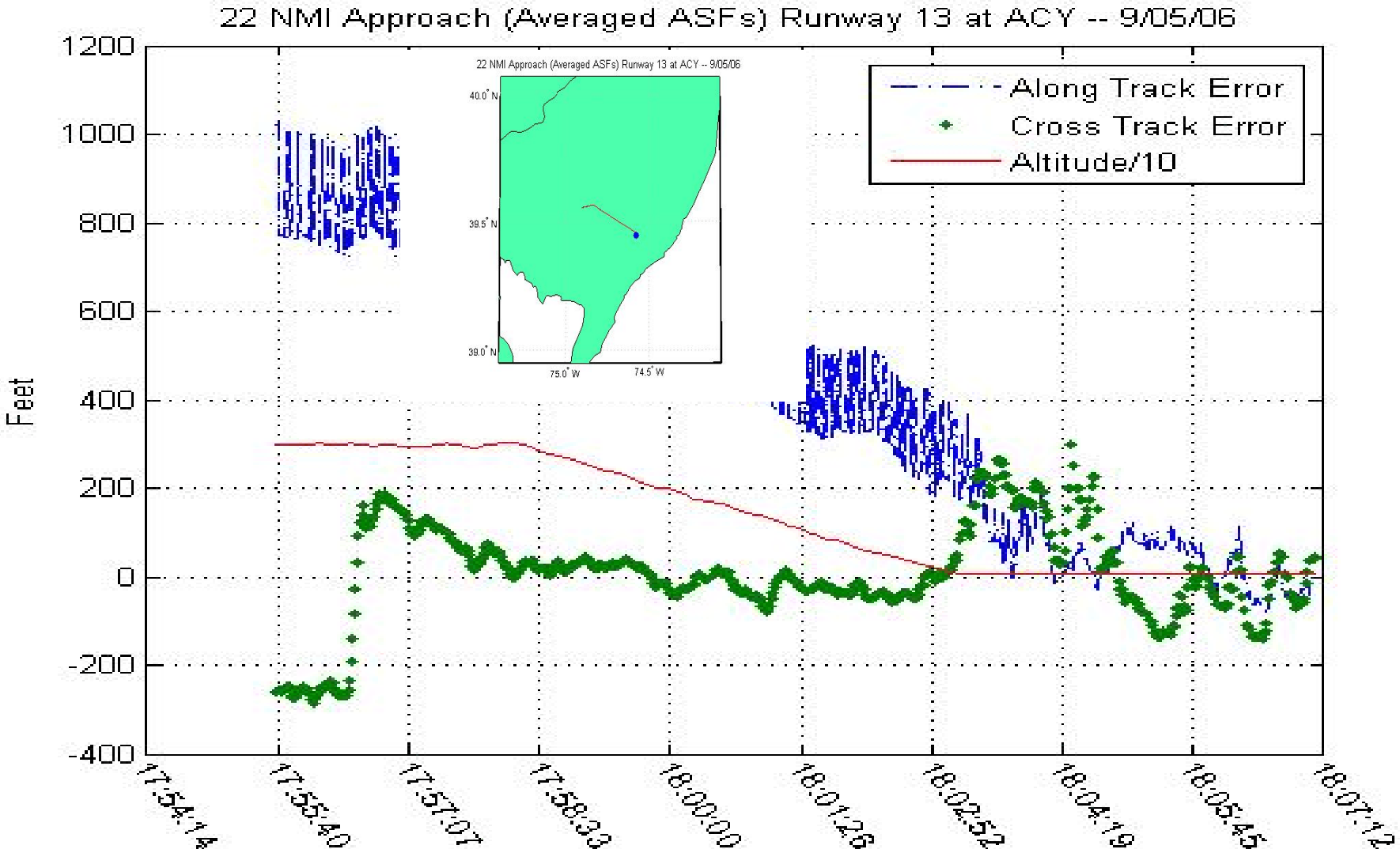

42° N
40° N
38° N
86° W
84° W
82° W
80° W
Norwalk-Huron County Airport (5A1)
Ohio
West Virginia
Kentucky

Frame

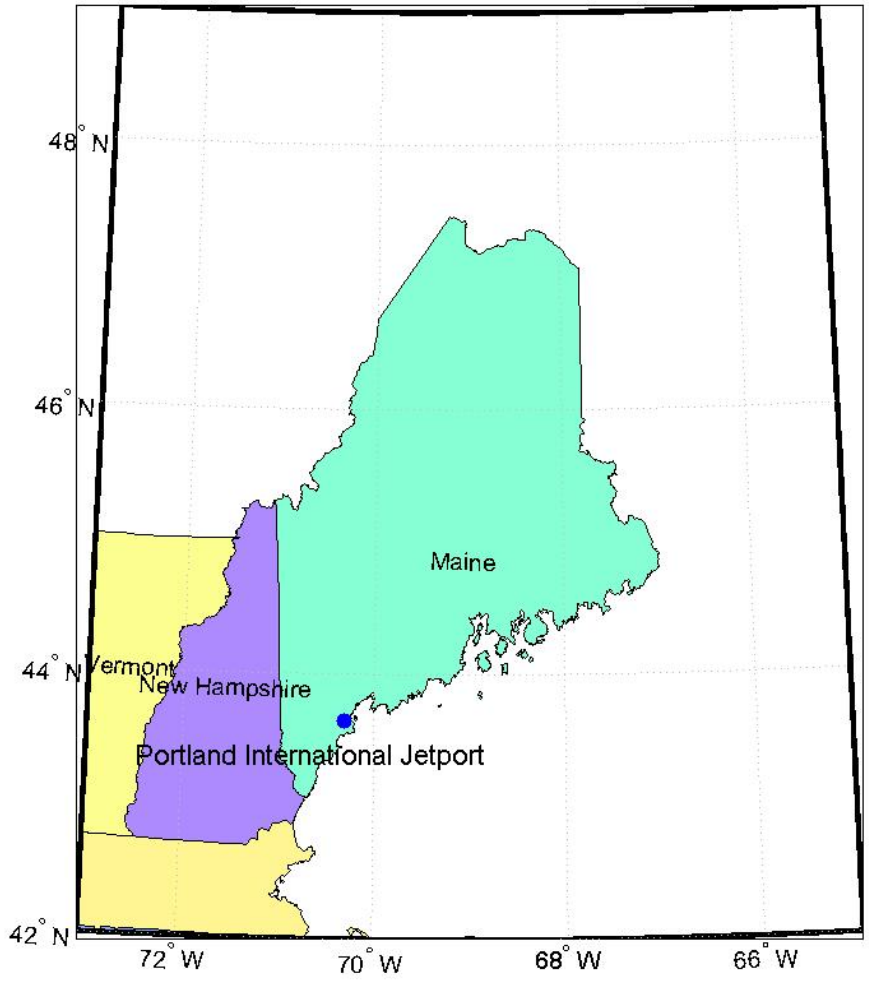


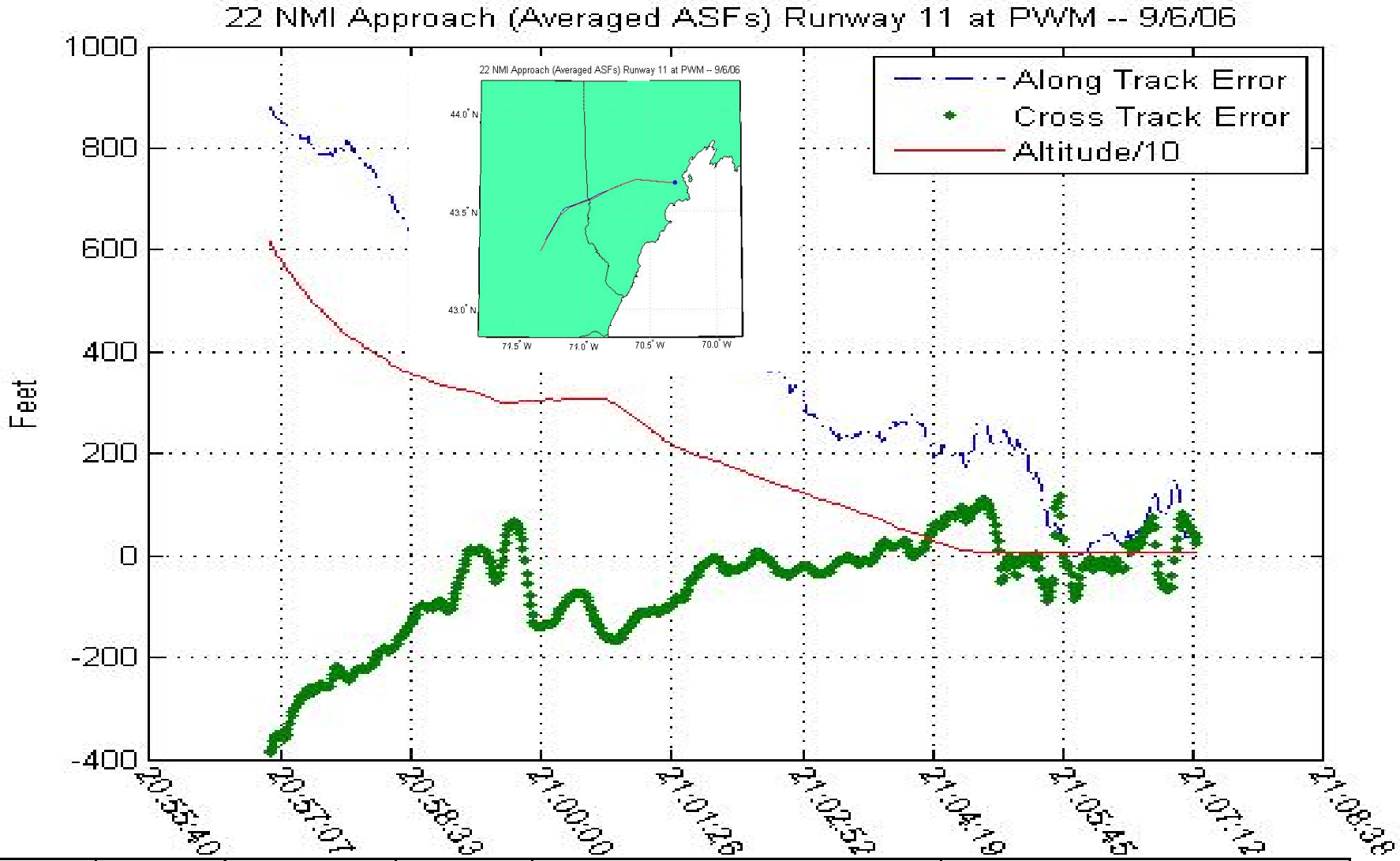
Airport	Distance (NMI)	Runway	Cross-track Error (ft)			Along-track Error (ft)		
			|Mean|	Sigma	95%	|Mean|	Sigma	95%
5A1	100	28	95.2	46.3	187.8	727.5	361.7	1450.9


43° N
42° N
41° N
40° N
39° N
38° N
37° N
77° W
76° W
75° W
74° W
73° W
72° W
New York
Connecticut
New Jersey
Atlantic City International Airport (ACY)
Delaware

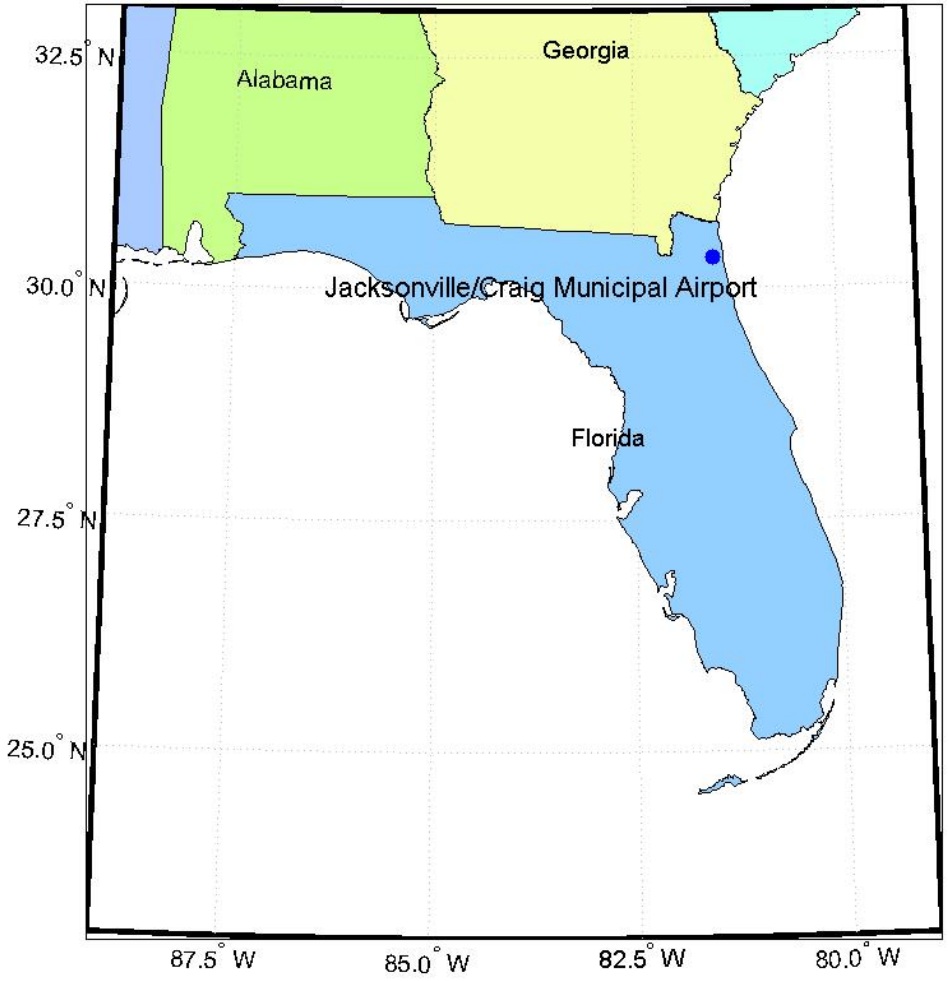


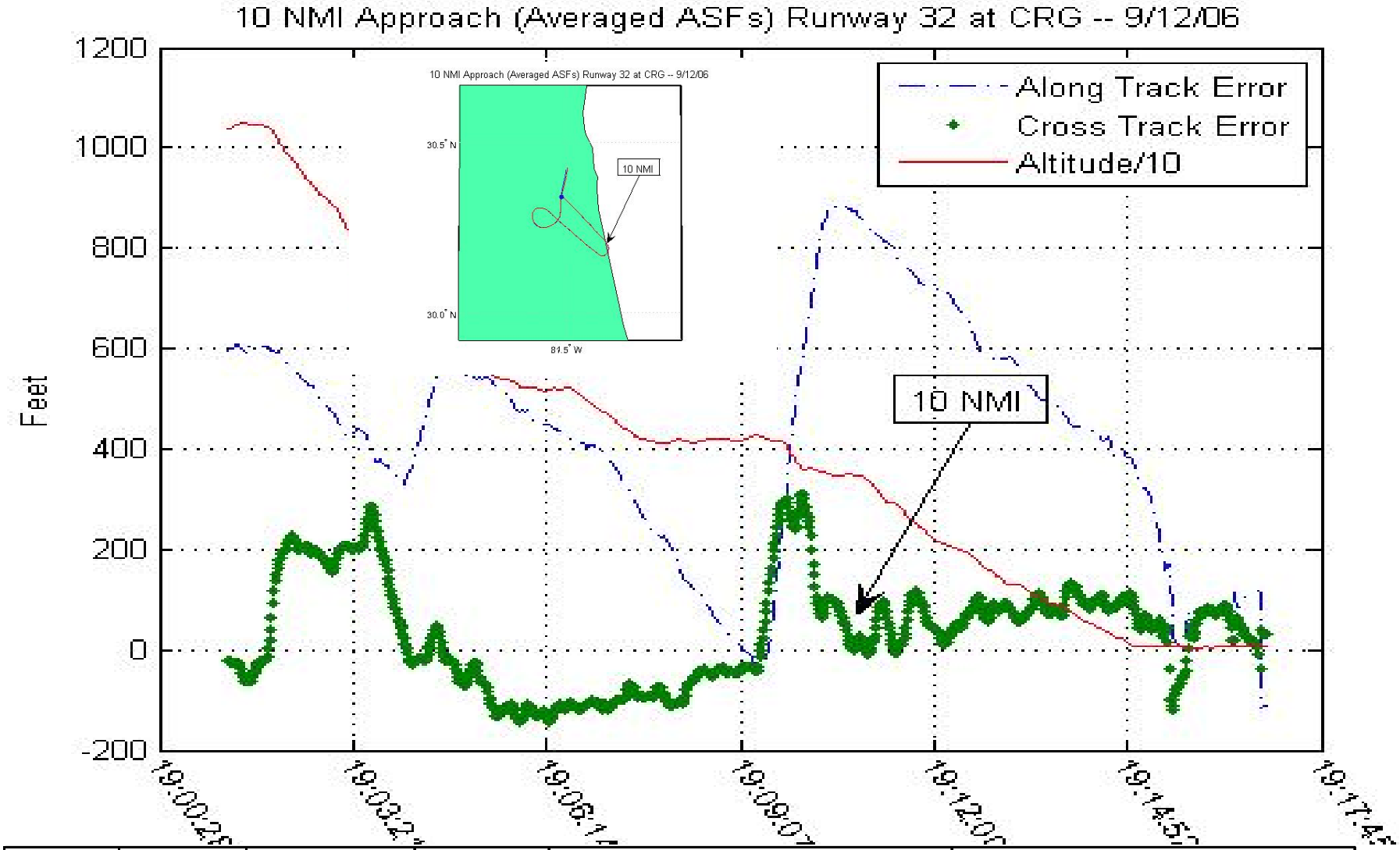
Airport	Distance (NMI)	Runway	Cross-track Error (ft)			Along-track Error (ft)		
			|Mean|	Sigma	95%	|Mean|	Sigma	95%
ACY	22	13	80.0	111.5	303.0	434.5	330.6	1095.7


48° N
46° N
44° N
42° N
72° W
70° W
68° W
66° W
Maine
Vermont
New Hampshire
Portland International Jetport



Date	Airport	Distance (NMI)	Runway	Cross-track Error (ft)			Along-track Error (ft)		
				|Mean|	Sigma	95%	|Mean|	Sigma	95%
9/7/2006	PWM	22	11	83.1	101.1	285.3	406.4	244.3	895.0


32.5° N
30.0° N
27.5° N
25.0° N
87.5° W
85.0° W
82.5° W
80.0° W
Alabama
Georgia
Florida
Jacksonville/Craig Municipal Airport



Date	Airport	Distance (NMI)	Runway	Cross-track Error (ft)			Along-track Error (ft)		
				|Mean|	Sigma	95%	|Mean|	Sigma	95%
9/12/2006	CRG	10	32	91.8	106.9	305.6	430.0	235.4	900.8

Accuracy Results
Approaches Using Averaged ASF* Values

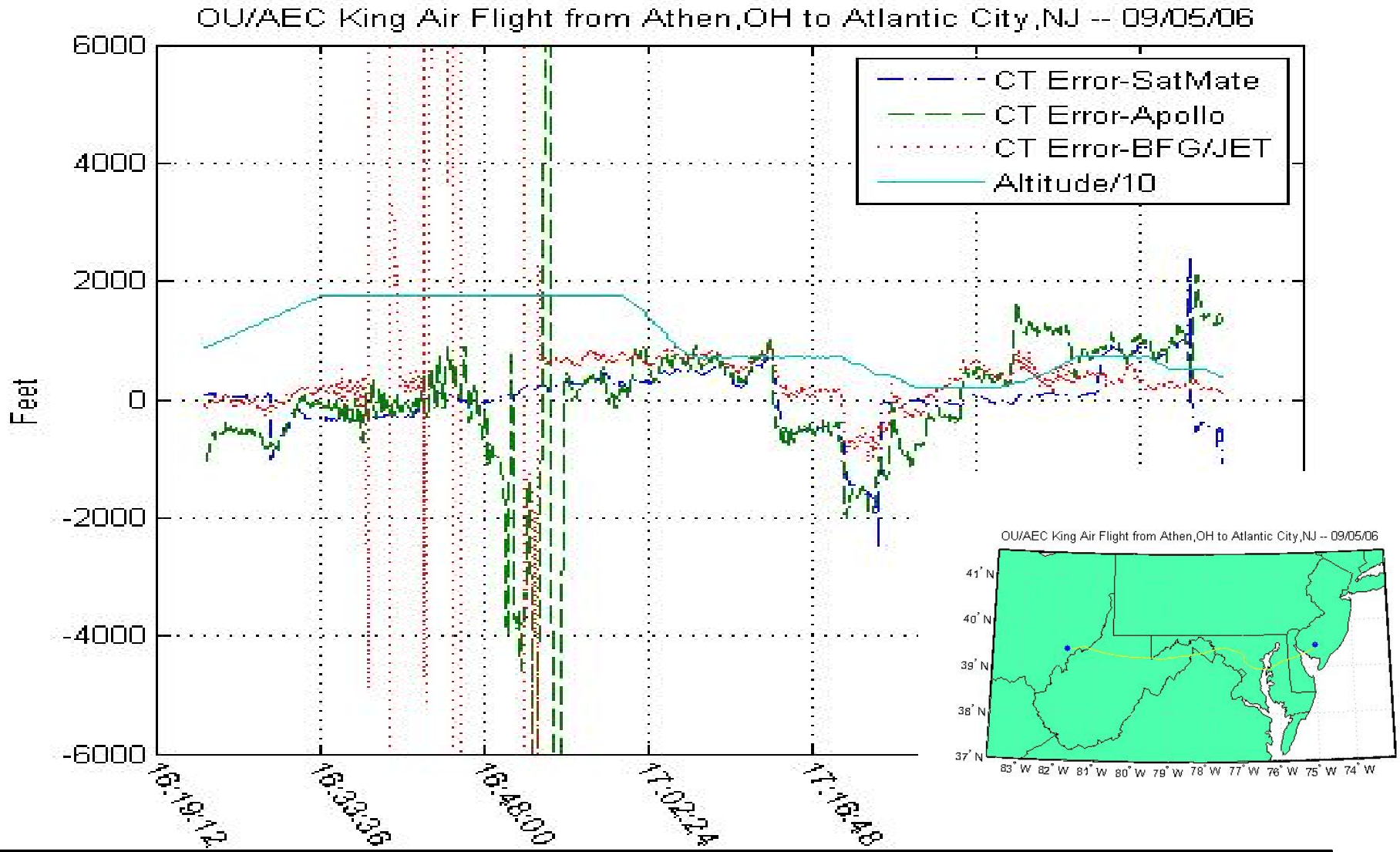
Airport	Distance (NMI)	Runway	Cross-track Error (ft)			Along-track Error (ft)		
			|Mean|	Sigma	95%	|Mean|	Sigma	95%
5A1	100	28	95.2	46.3	187.8	727.5	361.7	1450.9
ACY	22	13	80.0	111.5	303.0	434.5	330.6	1095.7
PWM	22	11	83.1	101.1	285.3	406.4	244.3	895.0
CRG	10	32	91.8	106.9	305.6	430.0	235.4	900.8

Summary

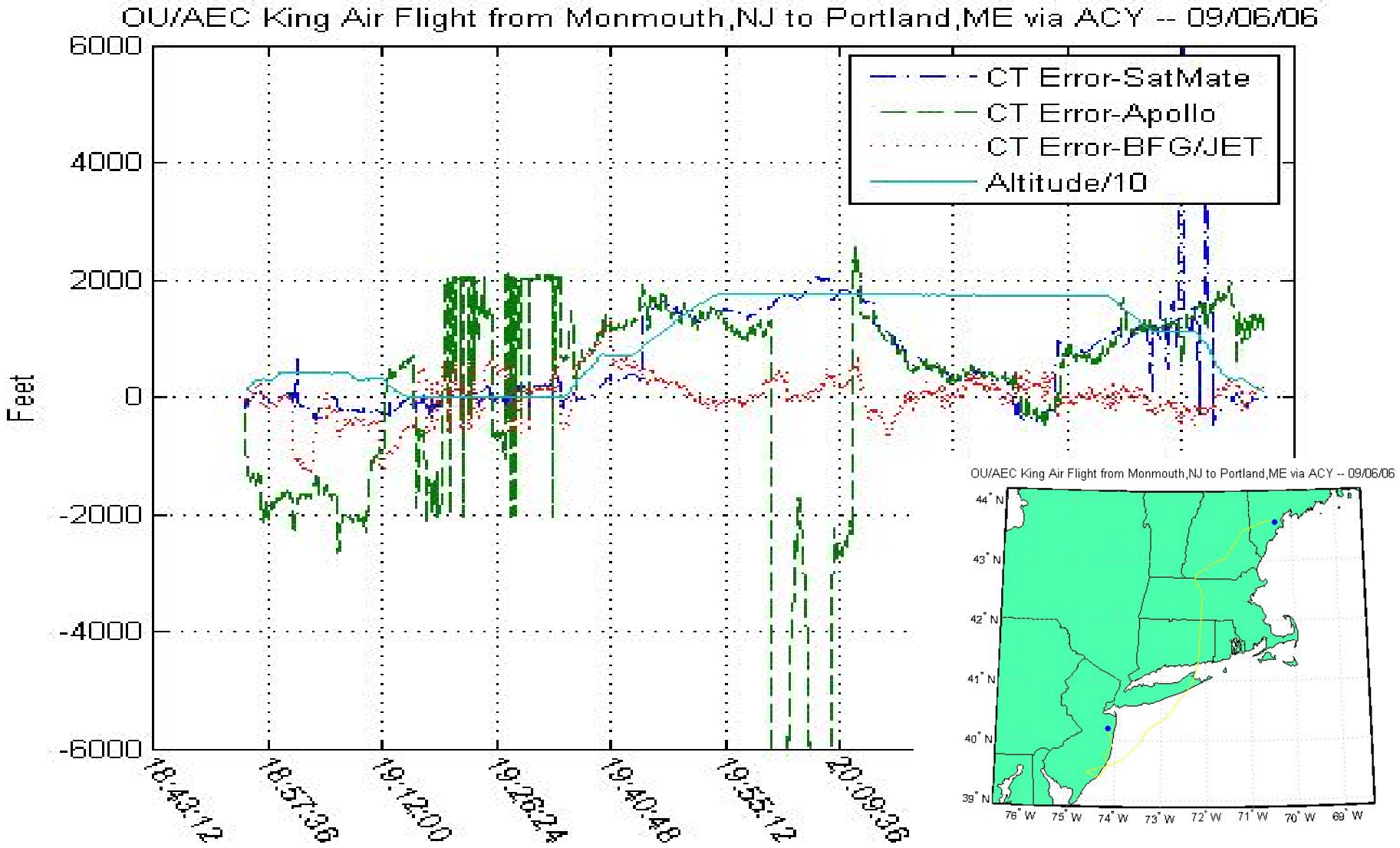
- Locally generated ASF* measurements demonstrate year-to-year (temporal) consistency; data base is increasing
- Flight measurements demonstrate that cross-track error is well behaved for stabilized approach procedures typical of those published by FAA for non-precision approach
- Numerous flight tests (these and others previously reported) have demonstrated RNP 0.3 performance over a wide area surrounding the point where ASF* values were generated.
  - with ASF corrections derived the same day
  - with ASF correction derived from a two-and-one-half-year average

En Route Accuracy Results

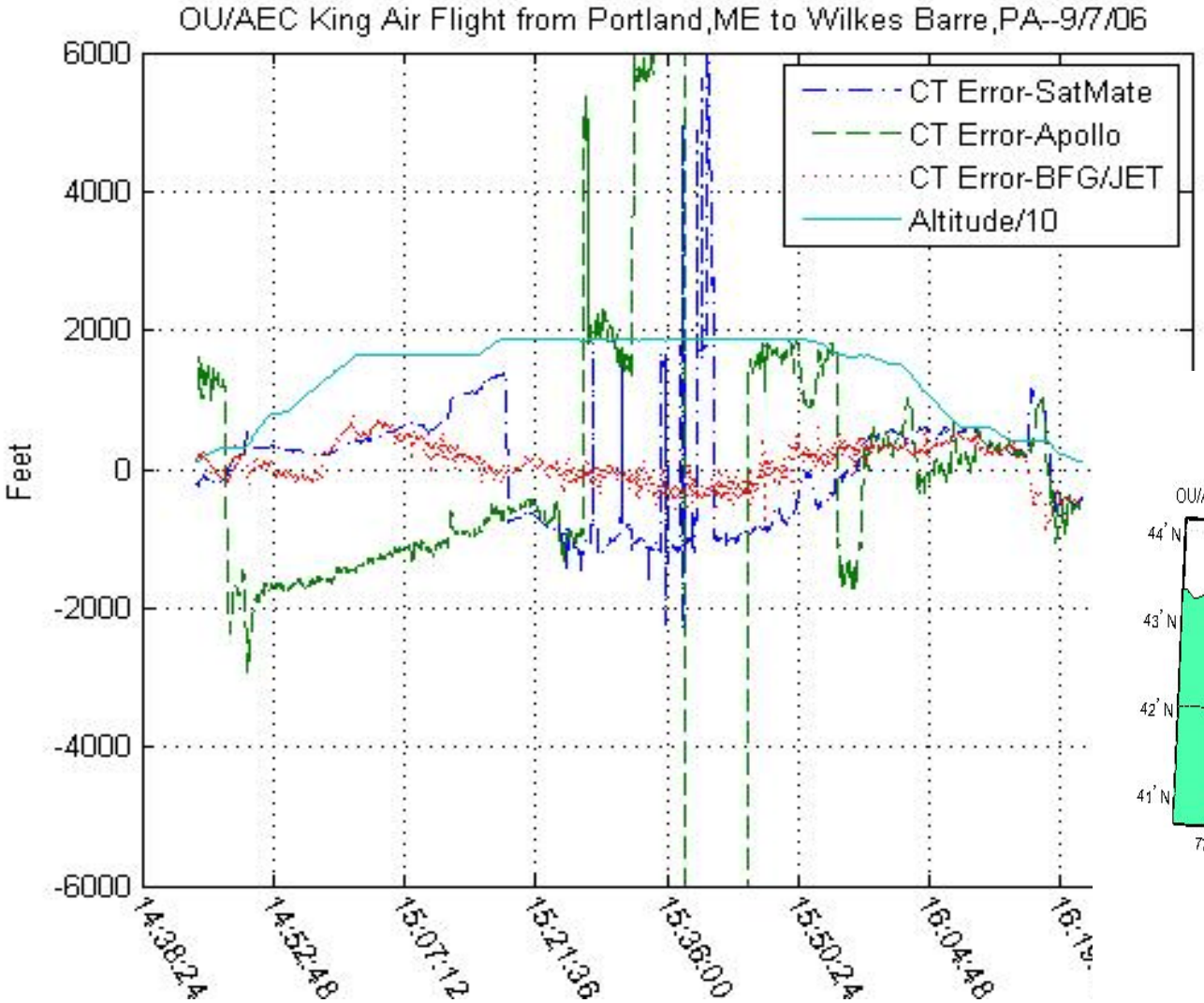
- Results from three receivers
  - BFG/Jet 7201 (All-in-view TSO'd)
  - SatMate 1030 (All-in-view, DSP-based)
  - Apollo 618 (Triad-based TSO'd)
- Only cross-track errors are shown

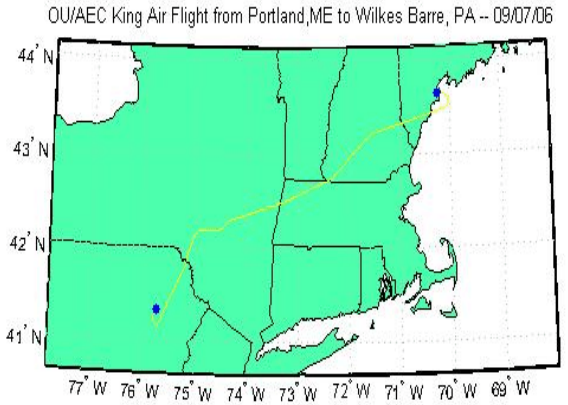


Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/5/2006	UNI-ACY	92	67	17,000 ft	SM	336.6	482.2	1301.0
					JT	1109.6	1988.1	5085.8

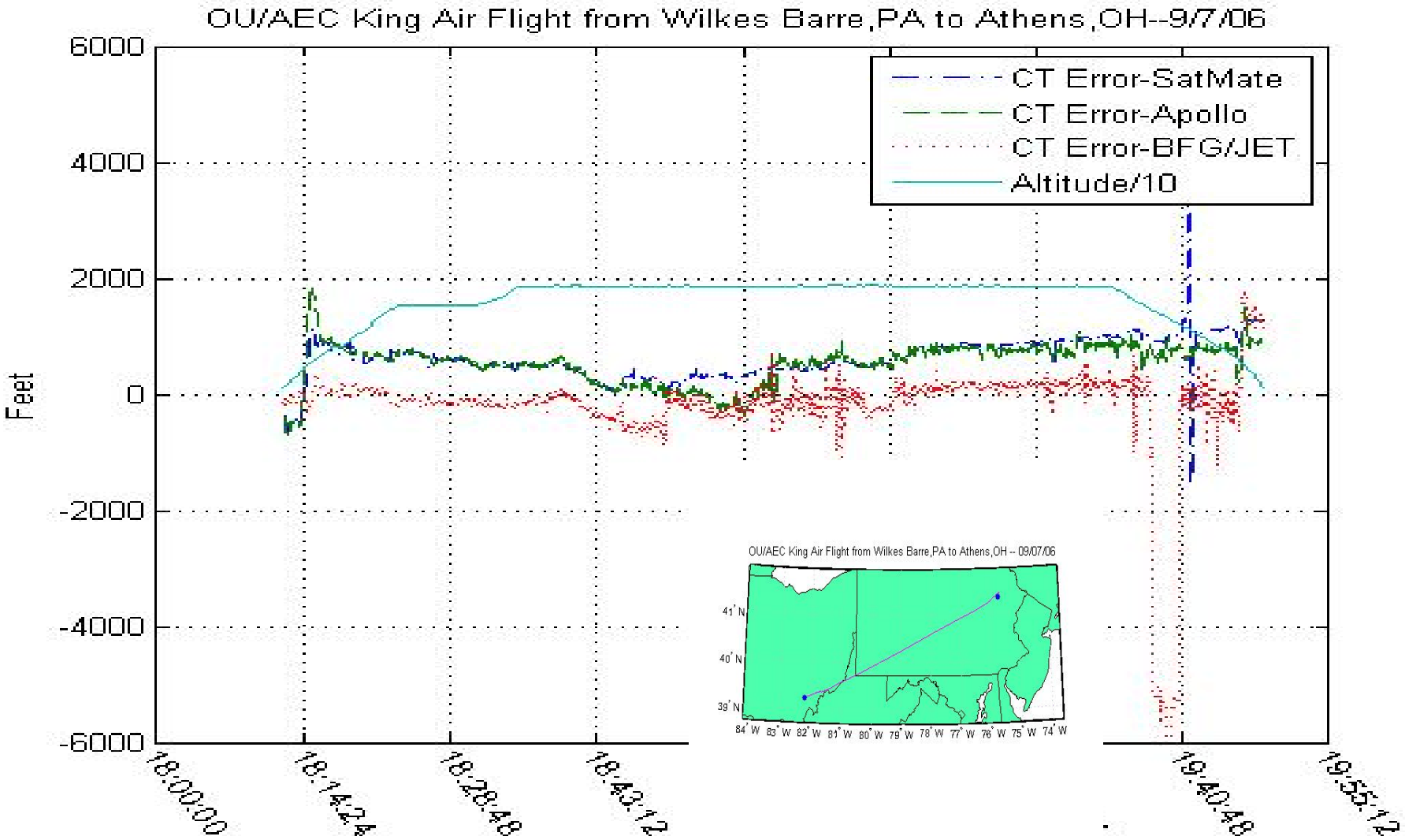


Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/6/2006	BLM-PWM	130	49	17,000ft	SM	709.8	811.2	2332.2
					JT	274.9	381.4	1037.7

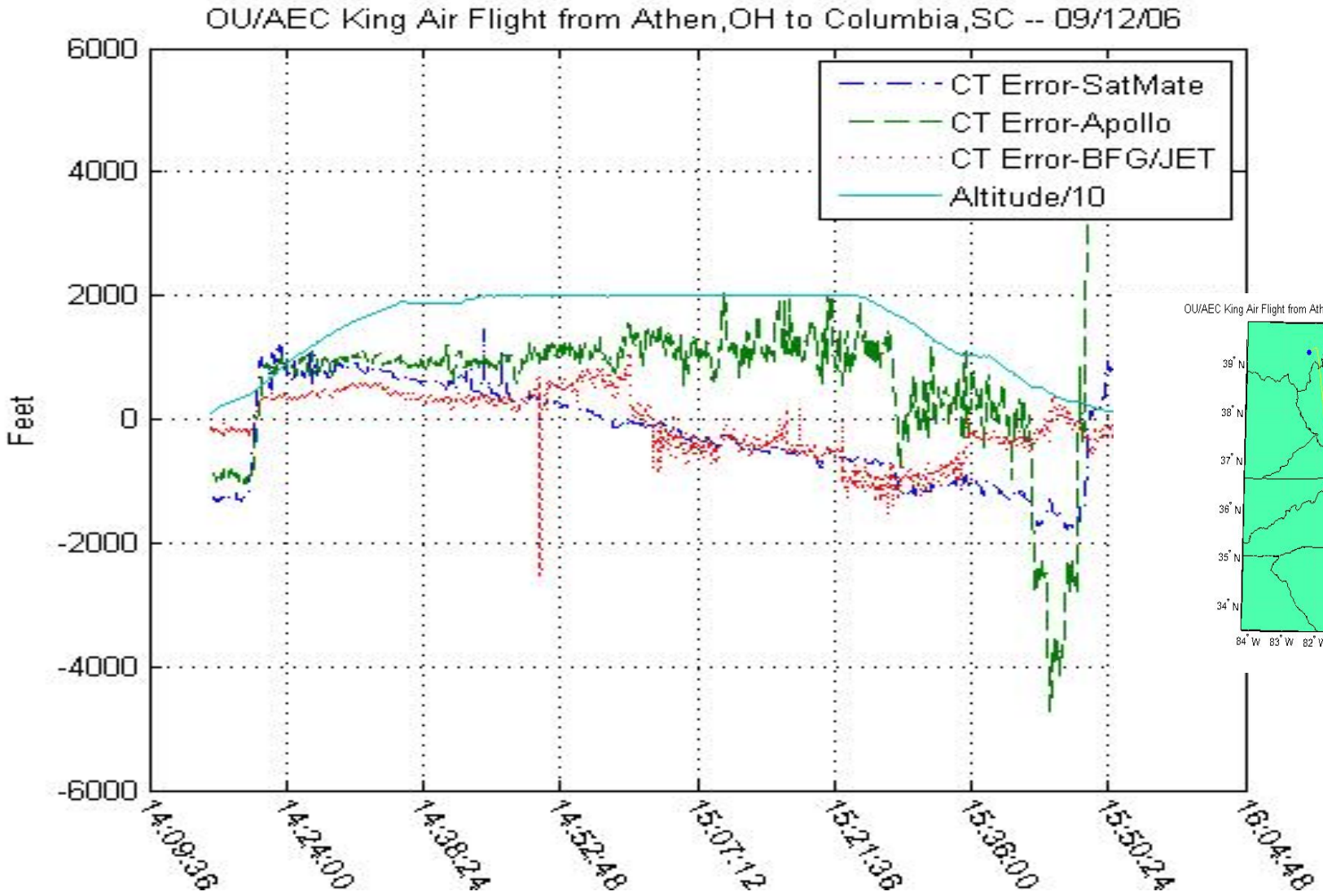


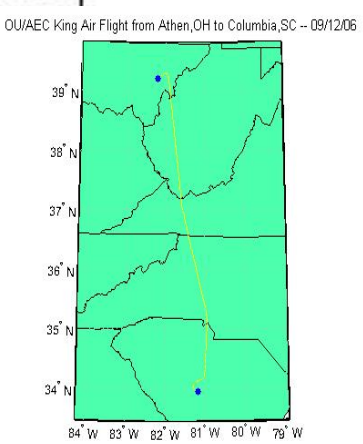


Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/7/2006	PWM-AVP	96	35	FL 180	SM	662.9	843.9	2350.7
					JT	251.0	292.3	835.6

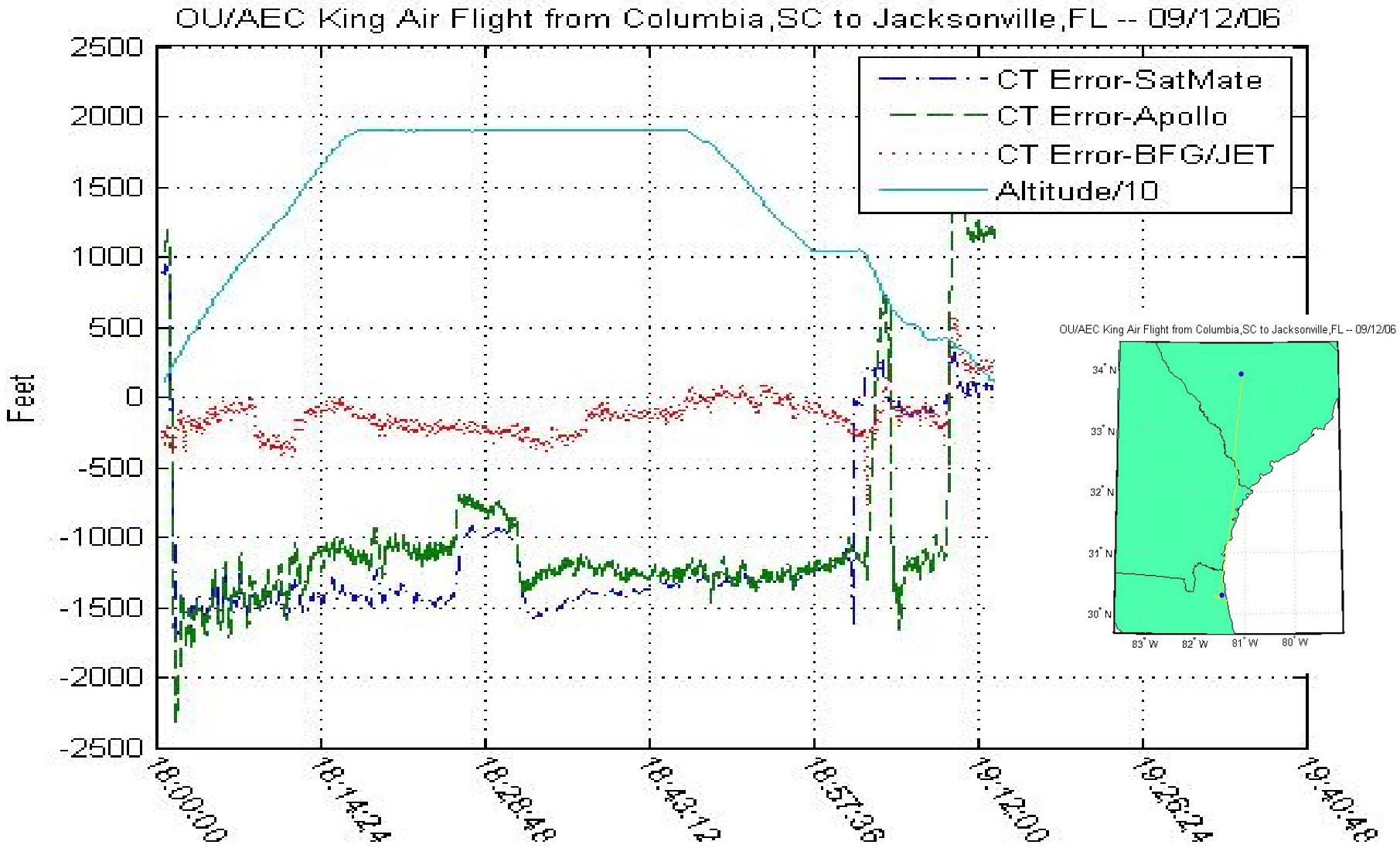


Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/7/2006	AVP-UNI	96	70	FL 180	SM	652.4	367.4	1387.2
					JT	357.8	934.1	2226.0

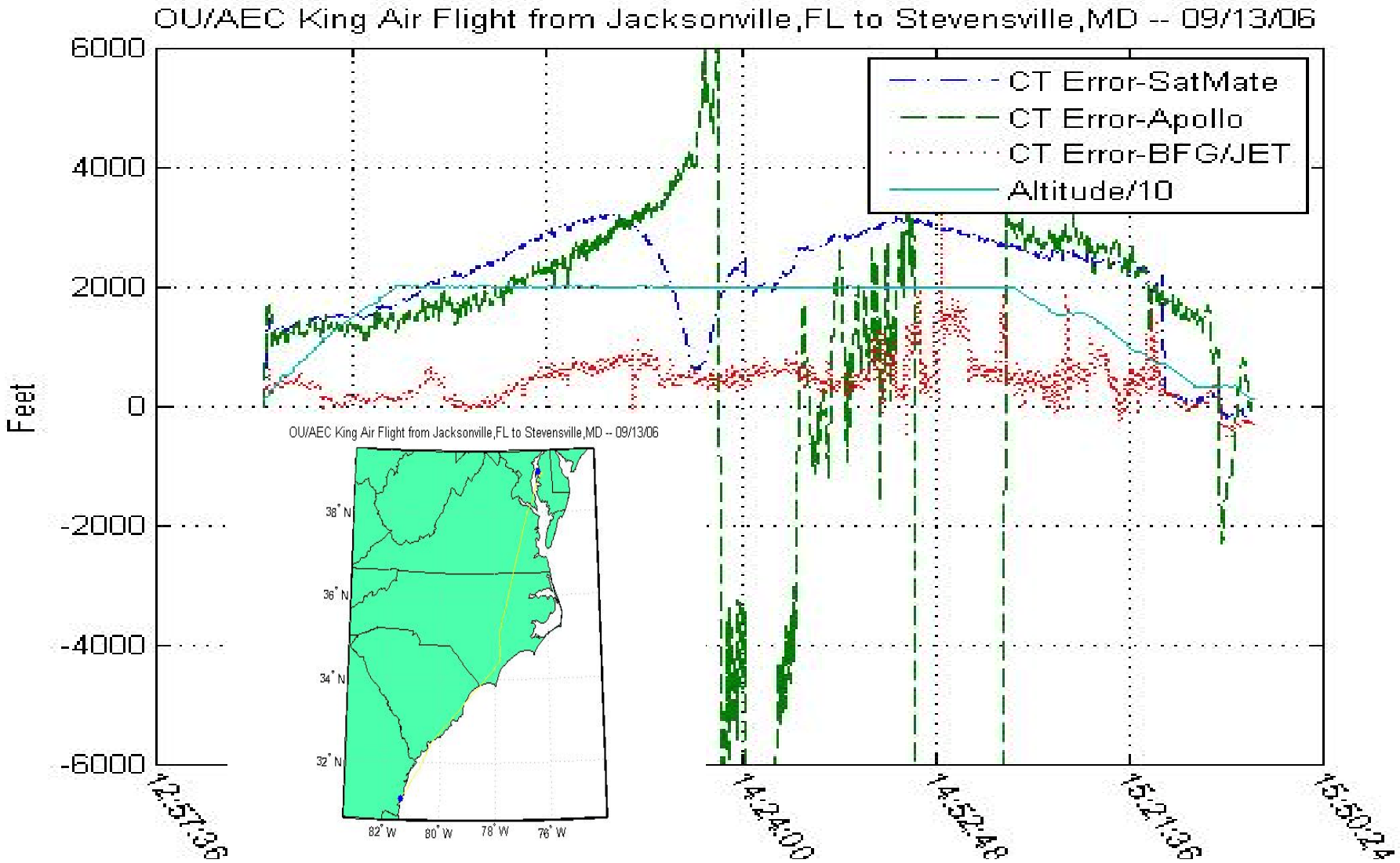




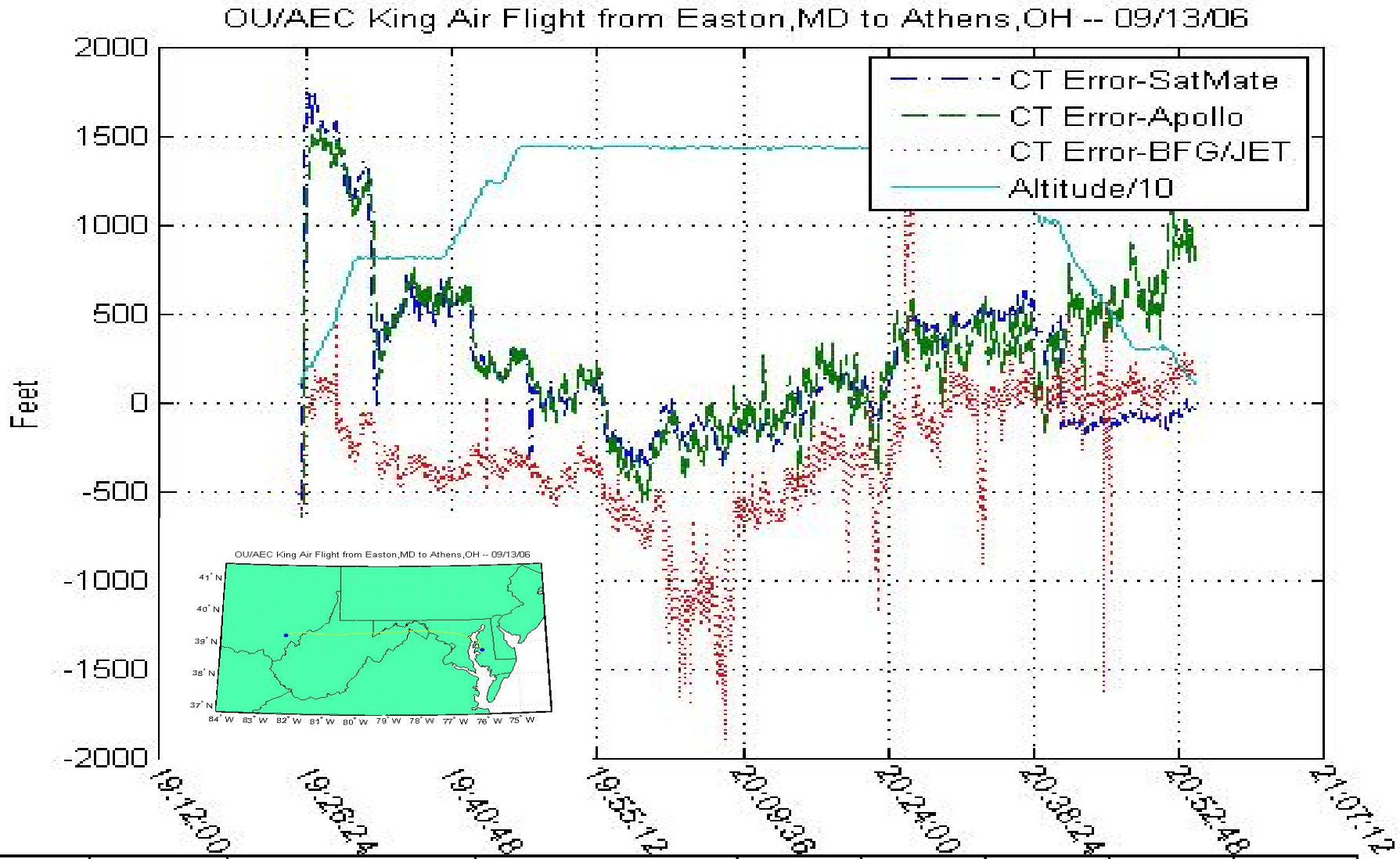
Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/12/2006	UNI-CAE	96	48	FL 180	SM	694.3	781.0	2256.3
					JT	451.8	523.3	1498.4



Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/12/2006	CAE-CRG	74	30	FL 180	SM	1313.3	569.1	2451.5
					JT	166.7	143.4	453.5



Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/13/2006	CRG-W29	146	91	FL 190	SM	2145.6	879.6	3904.8
					JT	454.3	361.8	1177.9



Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/13/2006	EST-UNI	89	46	14,000	SM	334.7	442.5	1219.7
					JT	367.4	384.1	1135.6

BFG/Jet 7201 Receiver Characteristics

- Late 1980's technology
  - 8 bit microprocesor, 64-k ram, 256-k rom
  - ASCIC linear receiver chip produced by ANI, E-field ant.
- SF/ASF data base stored inter-nally for CONUS/Alaska/Canada
- Provision for local ASF input for local approach mode
- Bendix/King KLN 88 Rx engine

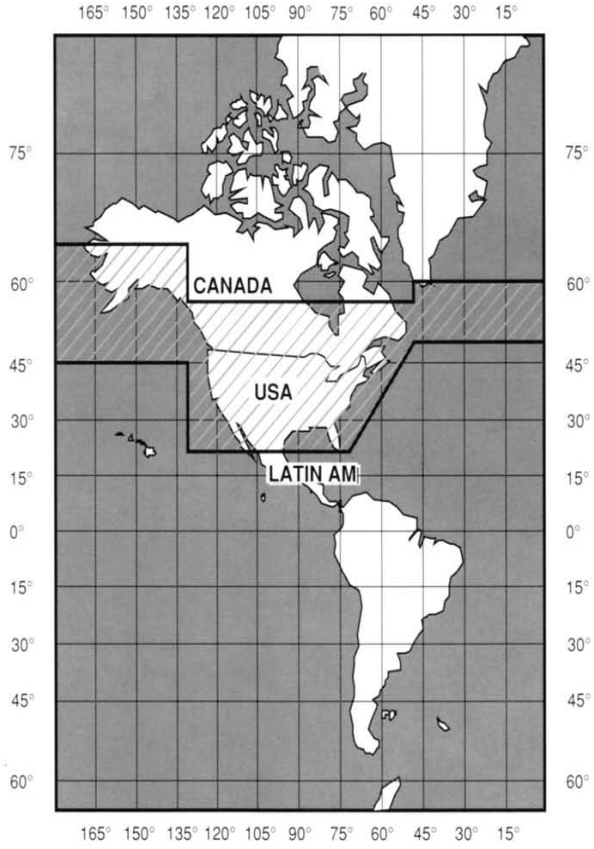


Figure 4-1 KLN 88 Navigation Coverage Area

Summary of En-Route Segments

Date	Route	Time En Route (min)	Time @ Altitude (min)	Altitude	RX	|Mean| (ft)	Sigma (ft)	95% (ft)
9/5/2006	UNI-ACY	92	67	17,000 ft	SM	336.6	482.2	1301.0
					JT	1109.6	1988.1	5085.8
9/6/2006	BLM-PWM	130	49	17,000ft	SM	709.8	811.2	2332.2
					JT	274.9	381.4	1037.7
9/7/2006	PWM-AVP	96	35	FL 180	SM	662.9	843.9	2350.7
					JT	251.0	292.3	835.6
9/7/2006	AVP-UNI	96	70	FL 180	SM	652.4	367.4	1387.2
					JT	357.8	934.1	2226.0
9/12/2006	UNI-CAE	96	48	FL 180	SM	694.3	781.0	2256.3
					JT	451.8	523.3	1498.4
9/12/2006	CAE-CRG	74	30	FL 180	SM	1313.3	569.1	2451.5
					JT	166.7	143.4	453.5
9/13/2006	CRG-W29	146	91	FL 190	SM	2145.6	879.6	3904.8
					JT	454.3	361.8	1177.9
9/13/2006	EST-UNI	89	46	14,000	SM	334.7	442.5	1219.7
					JT	367.4	384.1	1135.6

Conclusions

- It appears that a single set of ASF* values per airport will be sufficient to meet RNP 0.3 accuracy requirements for all runway ends.
- Twice annual updates may be needed for some airports where all-in-view geometry is limited.
- Airports surveyed to date are representative of those east of the Rocky Mountains. The inter-mountain and west coast areas need to be studied since ASF gradients can be steep.
- With new TFE equipment in place and a move to time-of-transmission control (e-Loran), ASFs should prove to be more stable than at present thus yielding even greater Loran C accuracy.
- Satisfactory en-route accuracy apparent with a stored SF/ASF data base

Questions

Loran C Accuracy Considerations:
Terminal Area and En Route

by
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and
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