Preliminary Analysis of Automatic Dependent Surveillance - Broadcast (ADS-B) Independent Validation Techniques

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Outline

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2. Techniques, Criteria & Approach
3. Passive Ranging
4. Angle of Arrival (AOA) using a multi-sector antenna
5. Time Difference of Arrival (TDOA)
6. Conclusions

Introduction – What is ADS-B?

Automatic

Periodically transmits information with no pilot input required

Dependent

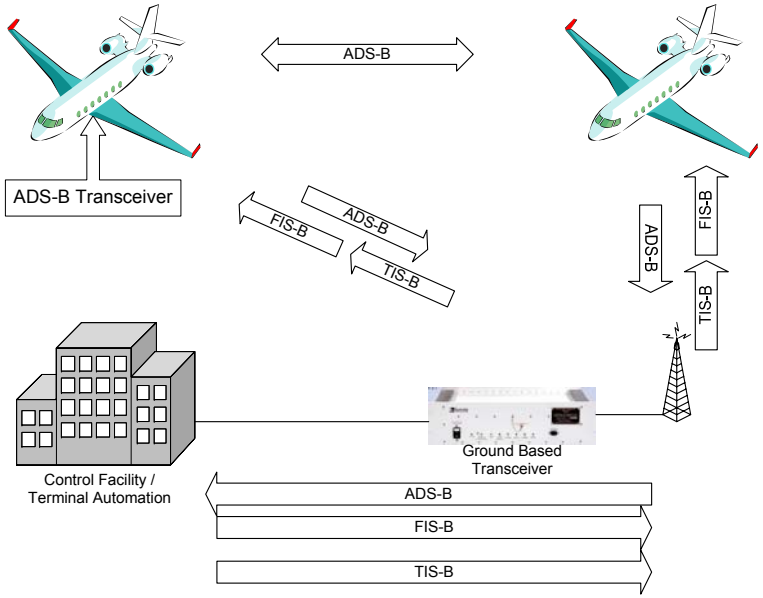
Position and velocity vector depend on Global Positioning System (GPS) or Flight Management System (FMS)

Surveillance

A method of determining position of aircraft, vehicles, or other assets

Broadcast

Transmitted information available to anyone with the appropriate receiving equipment



Introduction – Why validate ADS-B?

- Confidence (or lack of it) in ADS-B reported position messages has been a point of discussion forever
- Analysis using ADS-B real data needed to measure performance of validation techniques
- Independent ADS-B validation
  - correlates independently measured attributes to ADS-B reported values
  - assures the reported message is from a real aircraft, not a spoofer
  - assures there is no unintended malfunction in the transmitting system

Independent Validation Techniques, Criteria & Approach

Techniques:

1. **Passive Ranging**
2. **Angle of arrival (AoA) using multi-sector antennas**
3. **Time difference of arrival (TDOA)**

Criteria:

- **All techniques must achieve a 99.9% confidence in accepting valid targets**
- **False Invalidation rate must be < 10^{-3} probability**

Approach:

- **Each validation technique develops an estimate of one component of the position message (range or angle).**
  - Error = Estimate Position – True Position
  - Assuming the residuals form a normal distribution, the 99.9% interval is $\pm 3.3\sigma$
- **JHU/APL analyzed some real ADSB data to estimate performance of these methods**
  - UAT data for passive ranging and TDOA analysis
  - Technical Center and MIT-LL six-sector antenna Flight test data AoA analysis

Passive Ranging Overview

- **UAT Mode Status Message has the 6 LSB's of the Message Start Opportunity (MSO). Time of Transmission (TOT) can be recovered from MSO**
  - Passive Range = (TOR - TOT) * speed of light
  - Slant Range = calculated from encoded ADSB and known receiver position
  - Error = Slant Range – Passive Range
- **Possible to do passive ranging on UAT messages w/o MSO**

  TOT_{EST} = TOR - Slant Range / speed of light

  Error = speed of light * (TOT_{EST} – [Nearest 250 us MSO boundary])

- **INVALID if |Error| > 3.3 * 0.5 * (0.7 NM + σ_r)**

Passive Ranging Analysis Setup and Exclusions

- **Examined data recorded using CRABS playback for all GBTs on East Coast for all of January 2006**
- **Not all messages during January were able to be used for validation data. Excluded data were:**
  - fixed beacon test messages
  - messages where NAC_P had not yet been received
  - all messages from one GBT because of constant error of 35.8 NM (w/ MSO) and 4.7 NM (w/o MSO)
  - all messages from one GBT because of higher invalid rates
  - all messages not UTC coupled or have NIC values of 0
  - messages with TOT > TOR

Passive Ranging Analysis Results

	w/ MSO	w/o MSO
Valid Messages	9,339,810*	28,782,122*
Invalid Messages	388*	1110*
Valid Messages Error Mean (NM)	0.07	0.07
Valid Messages Error Std. Dev. (NM)	0.12	0.13
False Invalidation Rate	4.15×10^{-5}	3.86×10^{-5}

Assuming all position reports were VALID, the probability of accepting a valid target using the above data is 99.996%. (both types of Messages)

** The number of messages indicates the number of GBT receptions. One message may be received by two GBTs, in which case it is counted as two messages.*

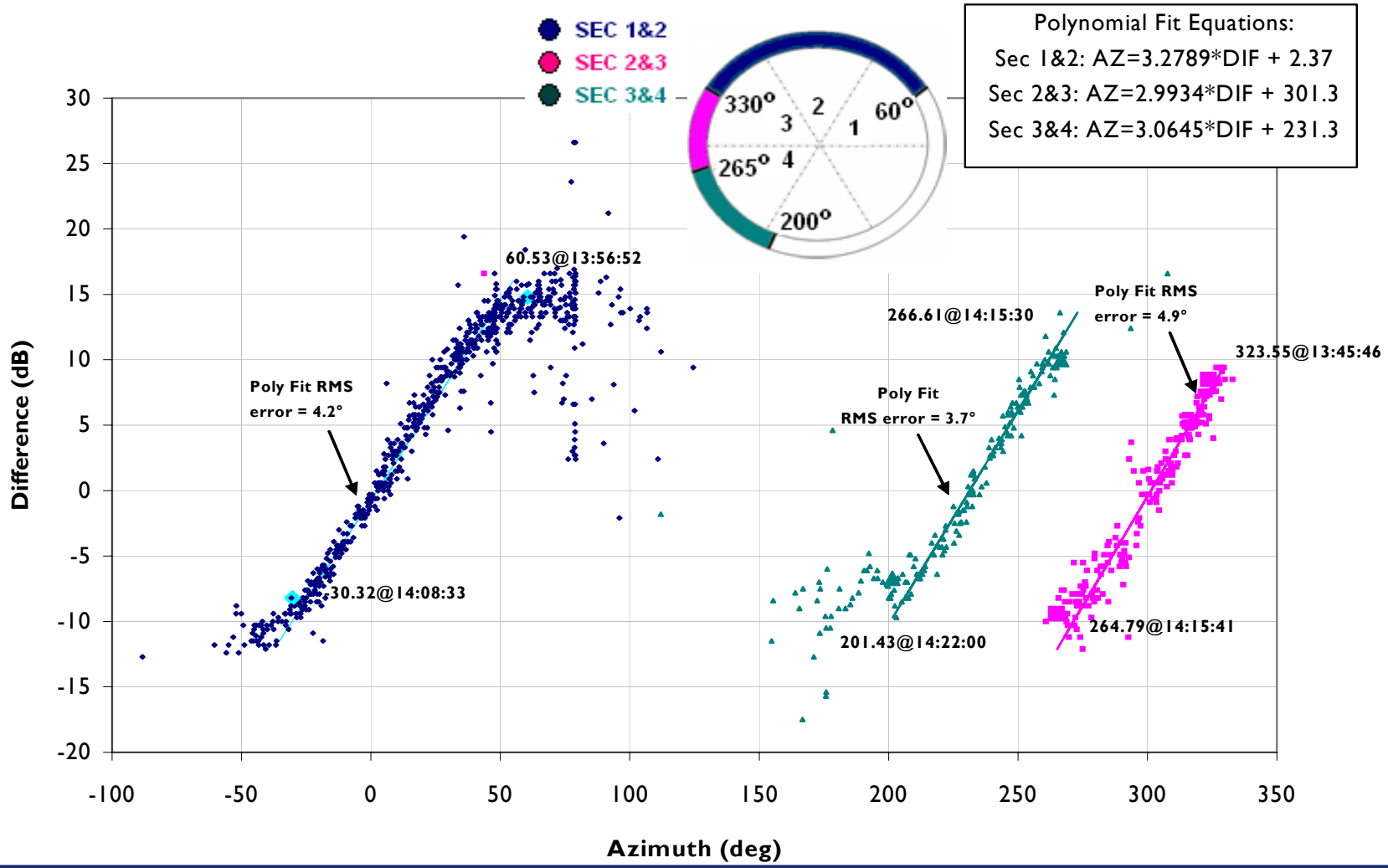
Angle of Arrival with Multi-Sector Antenna Overview

- **AoA is accomplished using RF data from received signals**
  - the amplitude of a decoded message is used to determine the azimuthal angle of the aircraft relative to the receiver
- **"Power Ratio" method is used in two adjacent sectors:**
  - DIF = $a_1 - a_2$ (a_i is signal power in dBm in i^{th} Sector)
- **This 'DIF' value must be calibrated to azimuth using a known set of positions for each pair of sectors**

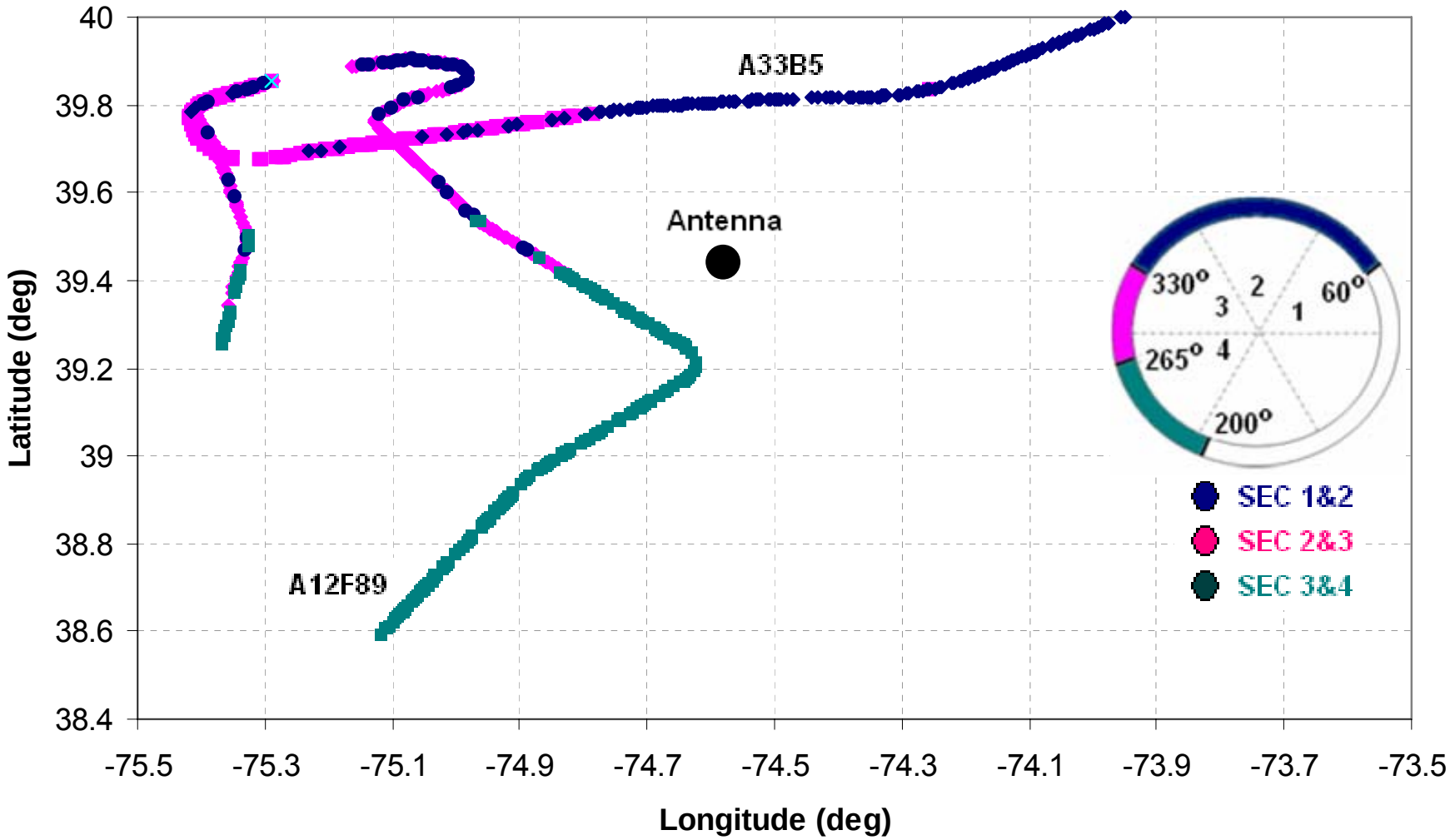
Exclusions to AoA Data

- **Only Position Messages were used**
  - Velocity messages could have been validated using extrapolated position
- **Messages must be received by at least 2 sectors**
- **Messages where the two highest amplitudes come from non-adjacent sectors were excluded from this analysis:**
  - Due to System 2 (decoder 3&4) performance problems, System I (decoder 1&2) has more presence
  - There were no receivers to cover sectors 5 & 6

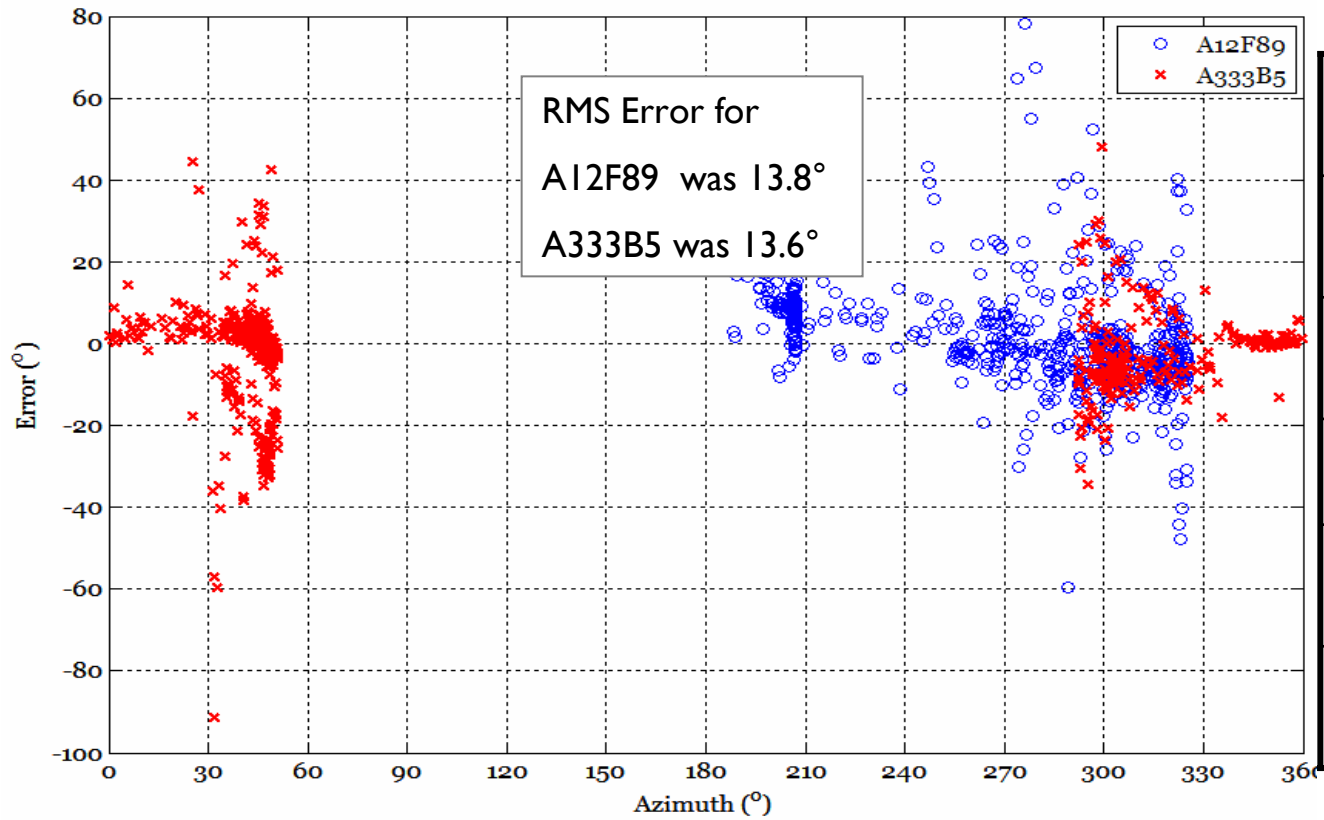
Calibrating Test Data Using N39/A4806F Aircraft



Targets of Opportunity – Flight Profiles



AoA Estimation Error using Targets of Opportunity

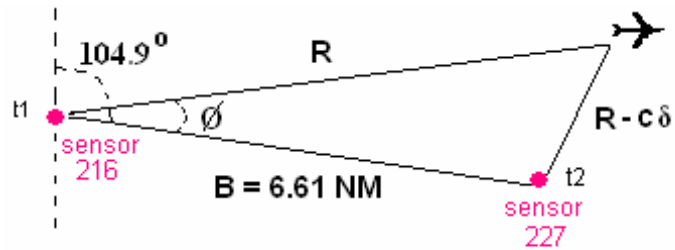


Total Count of Valid* Reports	**238**
Total Count of Invalid* Reports	**953**
Overall P_{False} Invalidation	**20%**
Sec 1 & 2 P_{False} Invalidation	**27%**
Sec 2 & 3 P_{False} Invalidation	**12%**
Sec 3 & 4 P_{False} Invalidation	**24%**

*Invalid if |Error| > 3.3σ (σ is Std. Dev. from calibration fit error)

Time Difference Of Arrival (TDOA) Overview

- **TDOA is accomplished by using precise relative timing information on a given successfully decoded message at two or more receivers**
- **This technique is used extensively in other communication systems, e.g. cellular telephone systems, ASDE-X**



Actual = Azimuth calculated from GBT 216 location and the UAT position message
Estimated = Baseline Azimuth ± ø, where Baseline Azimuth = 104.92°
Error = Actual – Estimated
Invalid if |Error| > $3.3\sigma_{ø}$

$$\phi(\delta, R, B) = \operatorname{acos}\left[\left[\frac{B^2 + (2 \cdot c \cdot \delta \cdot R) - (c \cdot \delta)^2}{2 \cdot R \cdot B}\right]\right]$$

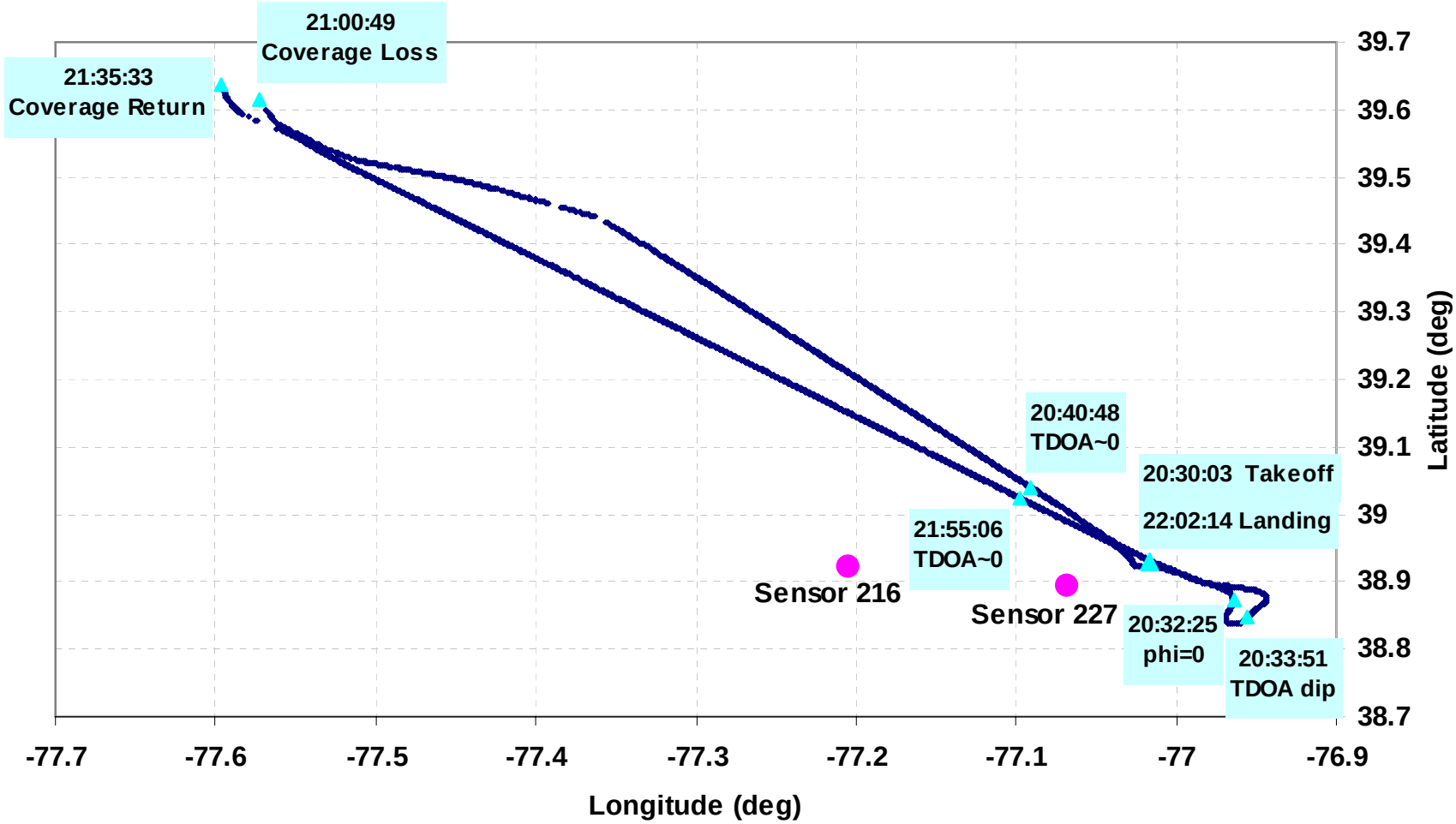
$$\sigma_{\phi}(\delta, R, B) = \frac{c^2\delta - c\,R}{R\,B\,\sin(\phi)}\,\sigma_{\delta} + \frac{B^2 - (c\,\delta)^2}{2\,R^2 B\,\sin(\phi)}\,\sigma_{R}$$

where
$\delta = t1 - t2$
$c = 3 \times 10^8$ m/s
σ_{δ} = 12 nano sec
σ_{R} = derived from NACp

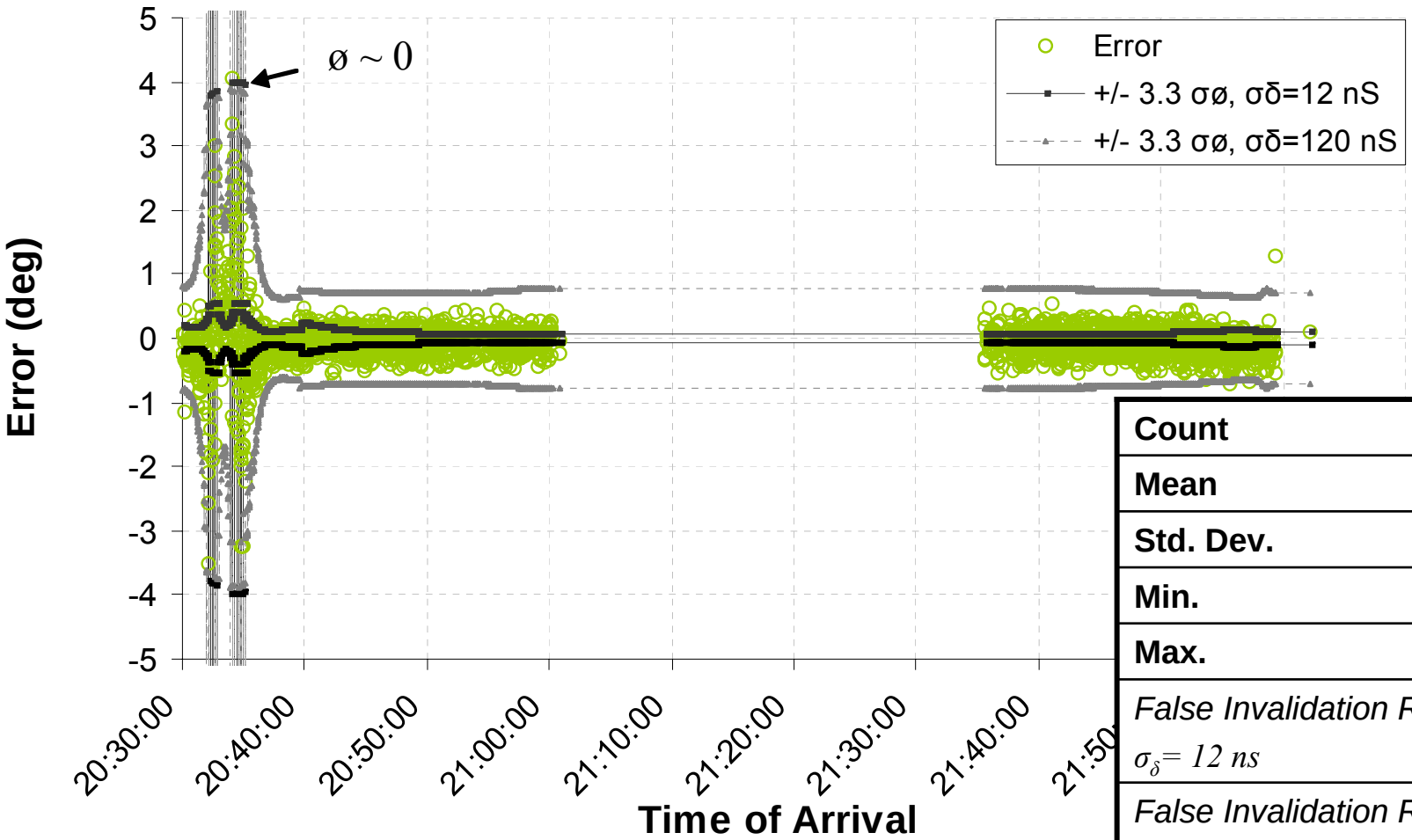
TDOA Analysis Setup and Exclusions

- **Examined UAT data recorded using CRABS playback for January 1, 2006.**
- **Selected a single track received by two GBTs - MITRE-CAASD (GBT 216) and 1000 Wilson Blvd Office Bldg (GBT 227)**
- **Some restrictions were made to select messages from this track that can be successfully validated for this analysis:**
  - Messages must have latest NAC_P available
  - Messages must be received by both receivers

Flight Profile 1/1/06 Track 10522335



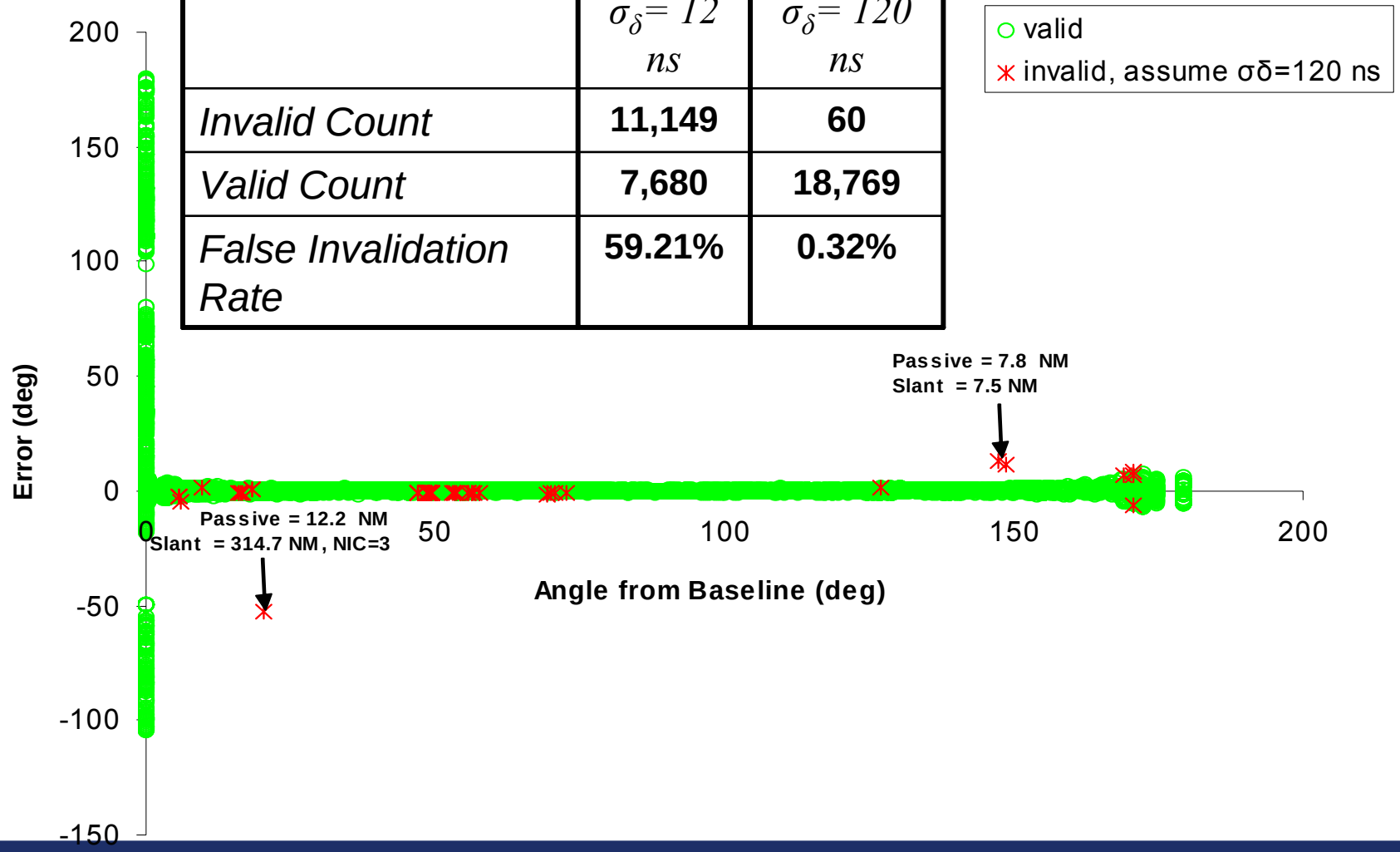
AoA Estimation Error Using TDOA 1/1/06 Track 10522335



Count	**2653**
Mean	**-0.07°**
Std. Dev.	**0.39°**
Min.	**-3.52°**
Max.	**5.06°**
False Invalidation Rate $\sigma_\delta = 12\ ns$	**60.95%**
False Invalidation Rate $\sigma_\delta = 120\ ns$	**0.15%**

TDOA Valid/Invalid Declarations 1/2/06

	$\sigma_\delta = 12$ *ns*	$\sigma_\delta = 120$ *ns*
Invalid Count	**11,149**	**60**
Valid Count	**7,680**	**18,769**
False Invalidation Rate	**59.21%**	**0.32%**



Conclusions

- **Passive Ranging with the UAT data is straightforward, meets the 99.9% confidence criterion, and can potentially be done for UAT datalink.**
- **AoA with a multi-sector antenna yielded poor result comparing to the 99.9% confidence criterion.**
  - Antenna gain side-lobes, interference, ongoing calibration, and the need for two adjacent sector reception further challenge this validation technique.
- **TDOA technique for UAT data is straightforward, and showed low false invalidation rates.**
  - Could possibly meet the 99.9% confidence criterion if relative time accuracy of receivers was known.
  - Technique could similarly be applied to 1090ES receivers.