Session 84-GNC-49: "Highlights from the FAA Support of the National Airspace System "

Paper AIAA-2009-6081:

"Examination of Airborne Position-Time Estimates from Enroute Automatic Dependent Surveillance"

Presented to: AIAA GNC, Chicago, IL

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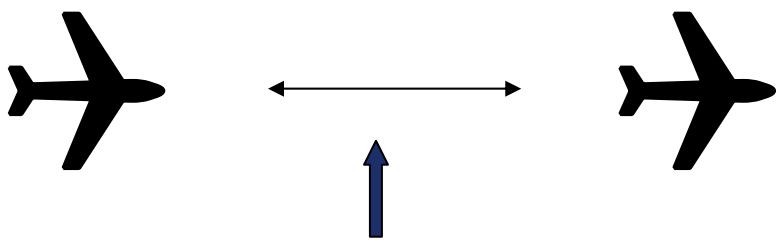
Date: August 12, 2009

Federal Aviation Administration

Introduction

- **Separation standards are the minimum distances required to be maintained between pairs of aircraft to limit the probability of collision**
  - This paper focuses on the longitudinal separation standard in oceanic airspace

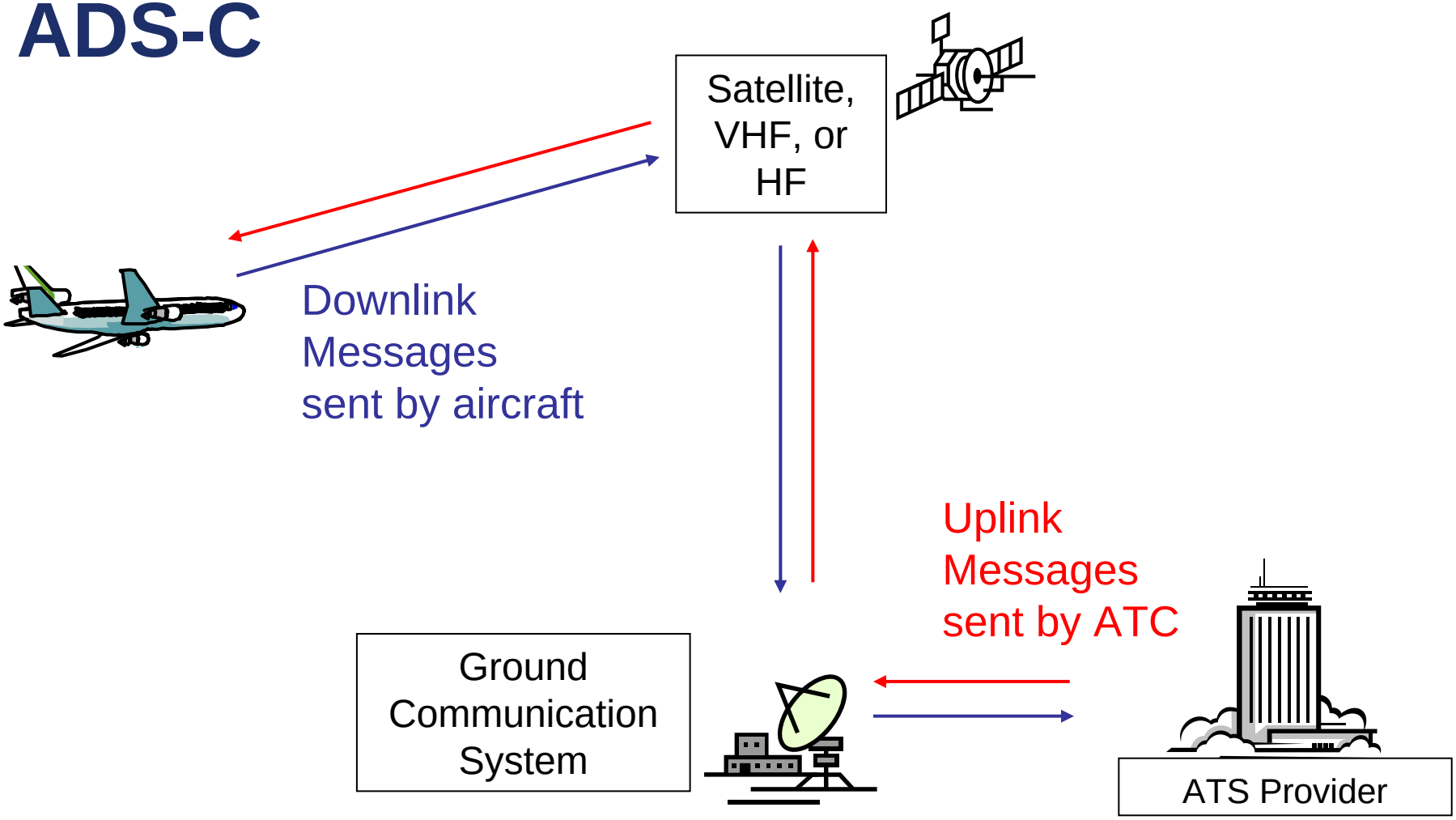


Minimum longitudinal spacing (time or distance) between aircraft pairs operating on same track and at the same flight level

Introduction

- **In oceanic airspace, ATS use procedural control to ensure the separation standards are in place**
  - Procedural ATC is the application of aircraft separation based solely on position reports received from aircraft
- **Automatic Dependent Surveillance - Contract (ADS-C) used in a procedural ATC environment**
  - A ‘contract’ is established between the ATS provider and the aircraft
  - Main purpose of ADS-C is for the aircraft to provide ATC with frequent current position reports as well as estimates of future position

ADS-C


Satellite, VHF, or HF
Downlink Messages sent by aircraft
Uplink Messages sent by ATC
Ground Communication System
ATS Provider

Introduction

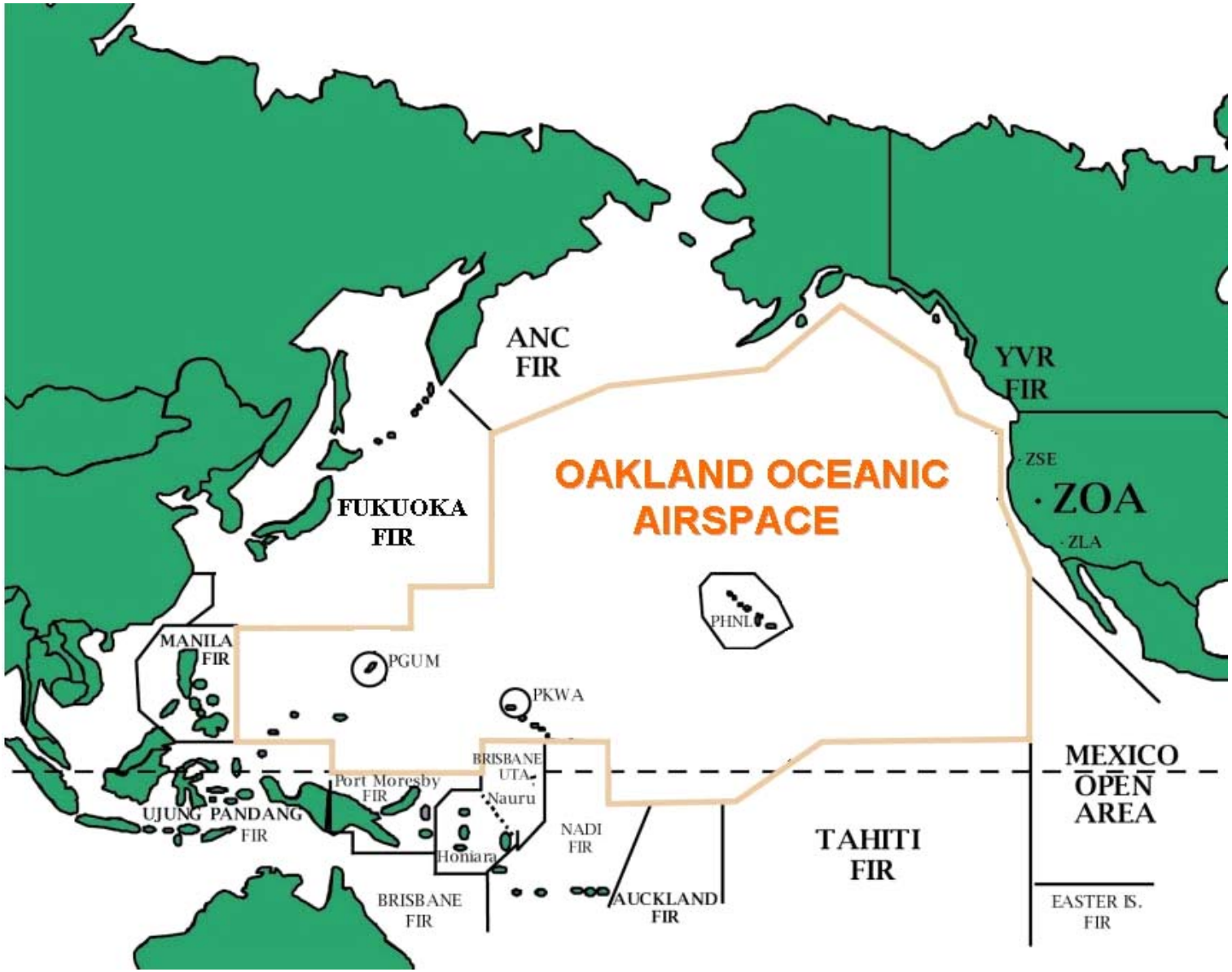
- **Reduction in the longitudinal separation standard for aircraft using ADS-C**
  - the accuracy of the aircraft-provided estimates of next position is a primary influence on the collision risk

Objectives

- **Estimate the longitudinal speed prediction error for ADS-C operations in Oakland and New York Oceanic Airspace**
- **Develop a tool to examine the clock-setting accuracy of ADS-C aircraft**
  - Compare the aircraft master clock to the ARTCC time using ADS-C position reports and an independent position/time source (radar-derived position estimates)

Background

- **Oakland Oceanic Airspace**
  - The Oakland Oceanic ARTCC is an ATS provider, responsible for roughly 18 million square miles of airspace over the Pacific Ocean
  - New ATC automation system, Ocean21, became fully operational in October 2005


ANC
FIR
YVR
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OAKLAND OCEANIC
AIRSPACE
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ZLA
FUKUOKA
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MANILA
FIR
PGUM
PKWA
BRISBANE
UTA
Nauru
Port Moresby
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OPEN
AREA
TAHITI
FIR
BRISBANE
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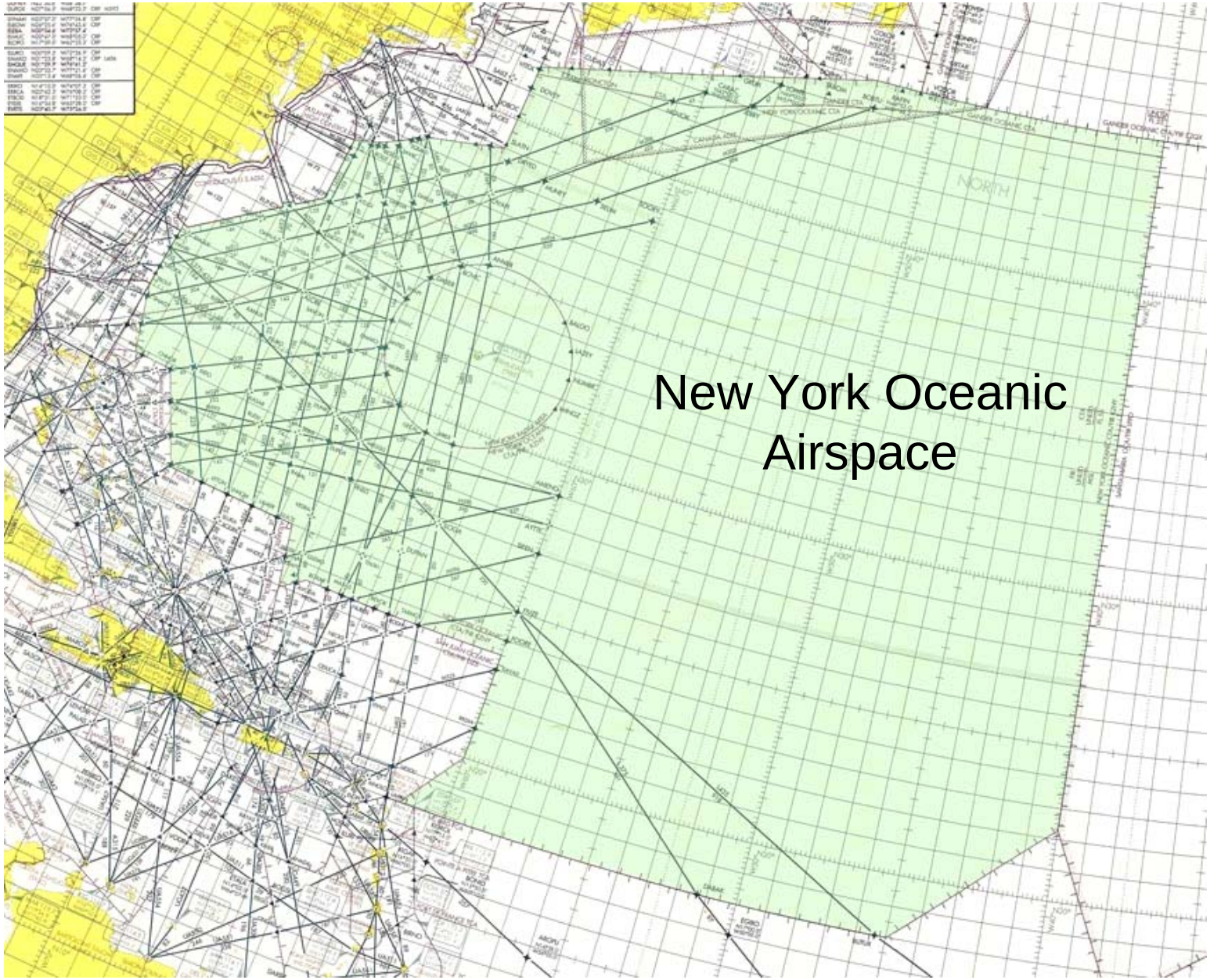
Background

- **New York Oceanic Airspace**
  - New York ARTCC is an ATS provider responsible for a portion of the North Atlantic Traffic Flow
  - The New York Oceanic ARTCC is also responsible for the majority of the Western Atlantic Route System (WATRS) – airspace connecting the East Coast of North America with the Caribbean-South American region
  - New ATC automation system, Ocean21, became fully operational in June 2006

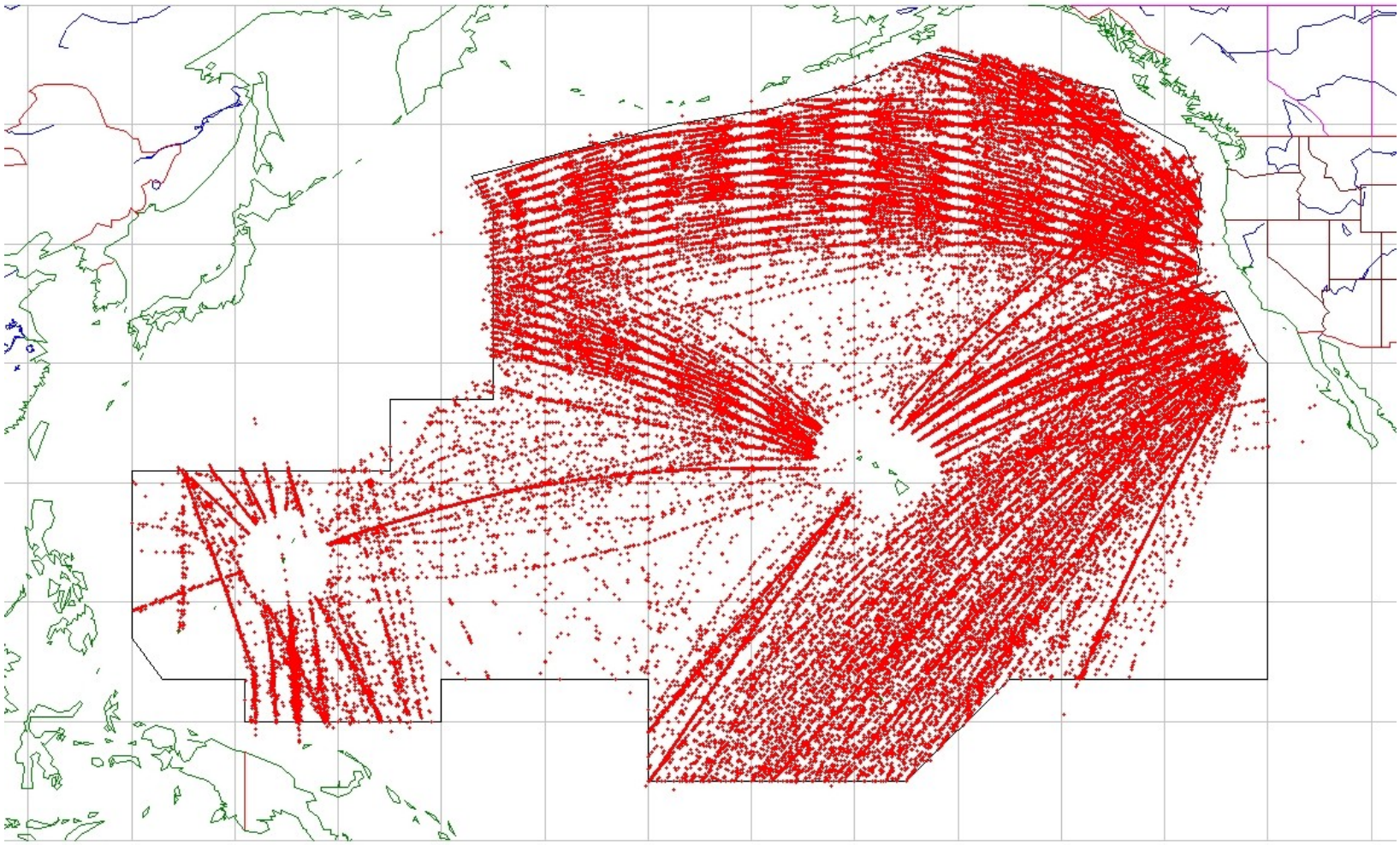

New York Oceanic
Airspace

Data Sources

- **Historical data archived from the Ocean21 system**
  - Four months of data; February – May 2009
  - ADS-C position reports
    - The most frequently occurring position report for each flight operation is the Basic Periodic Report
    - Contains current position report and estimate of future position
  - Aircraft filed flight plans

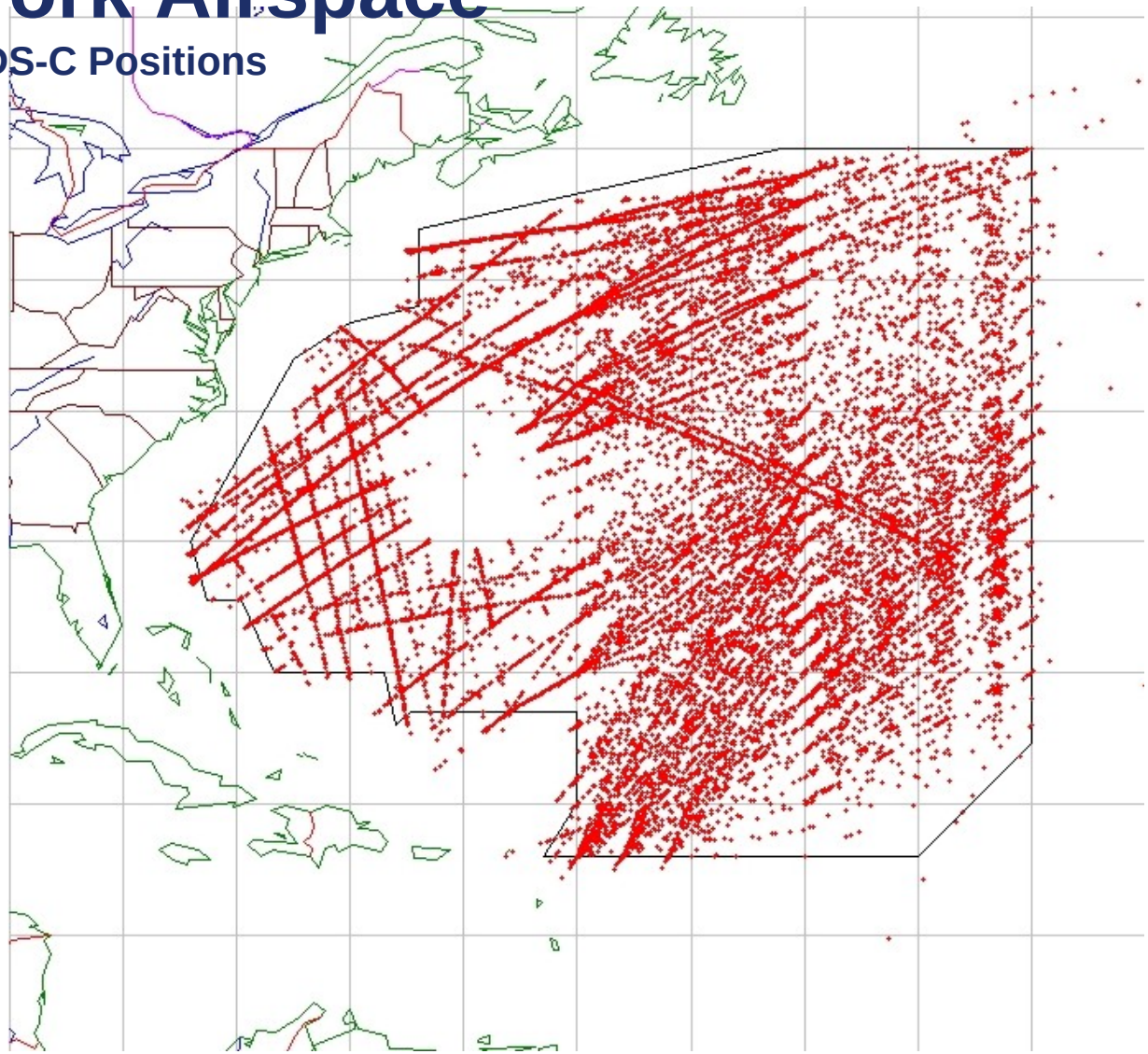
Oakland Airspace

Feb 2009 ADS-C Positions



New York Airspace

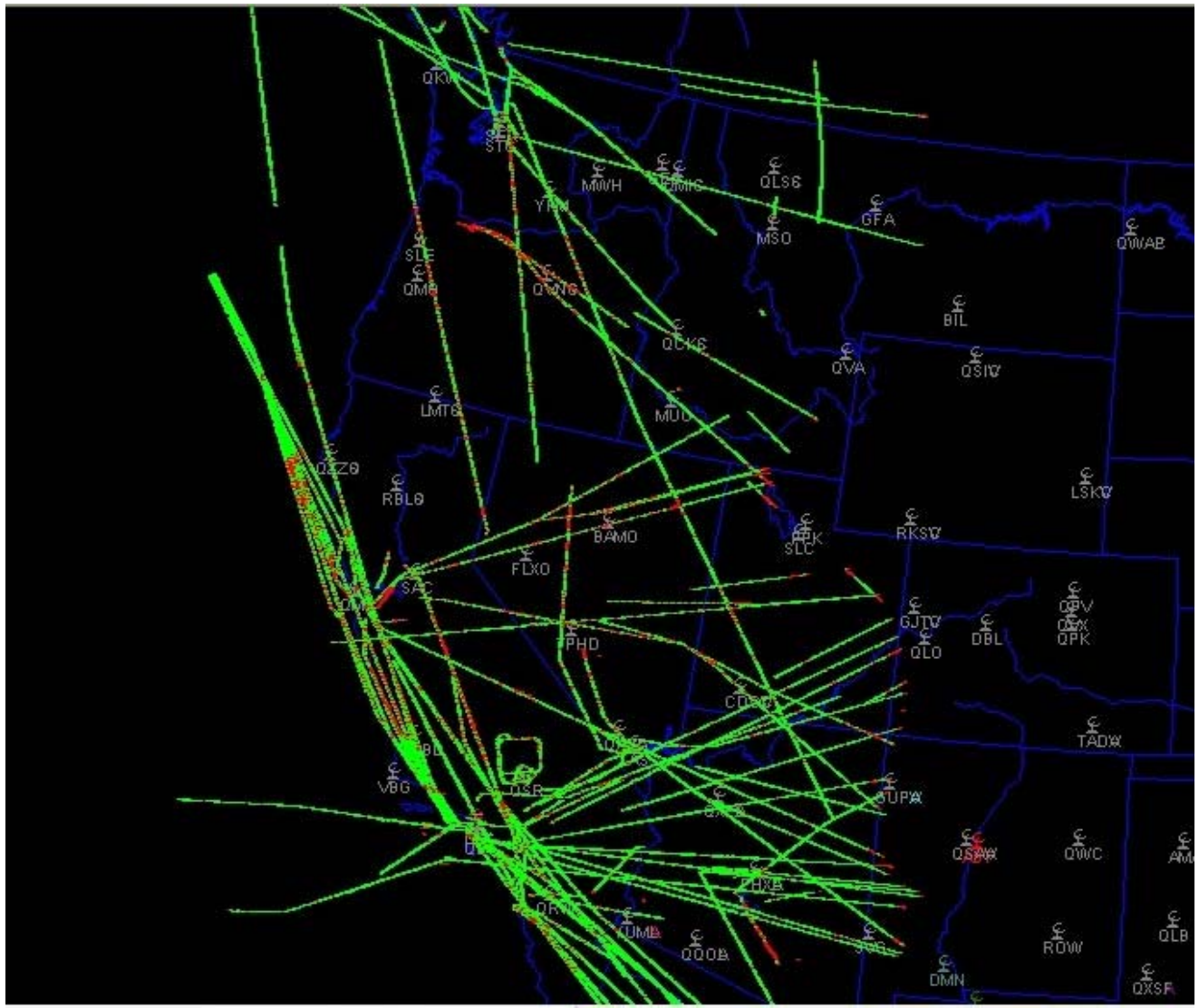
Feb 2009 ADS-C Positions



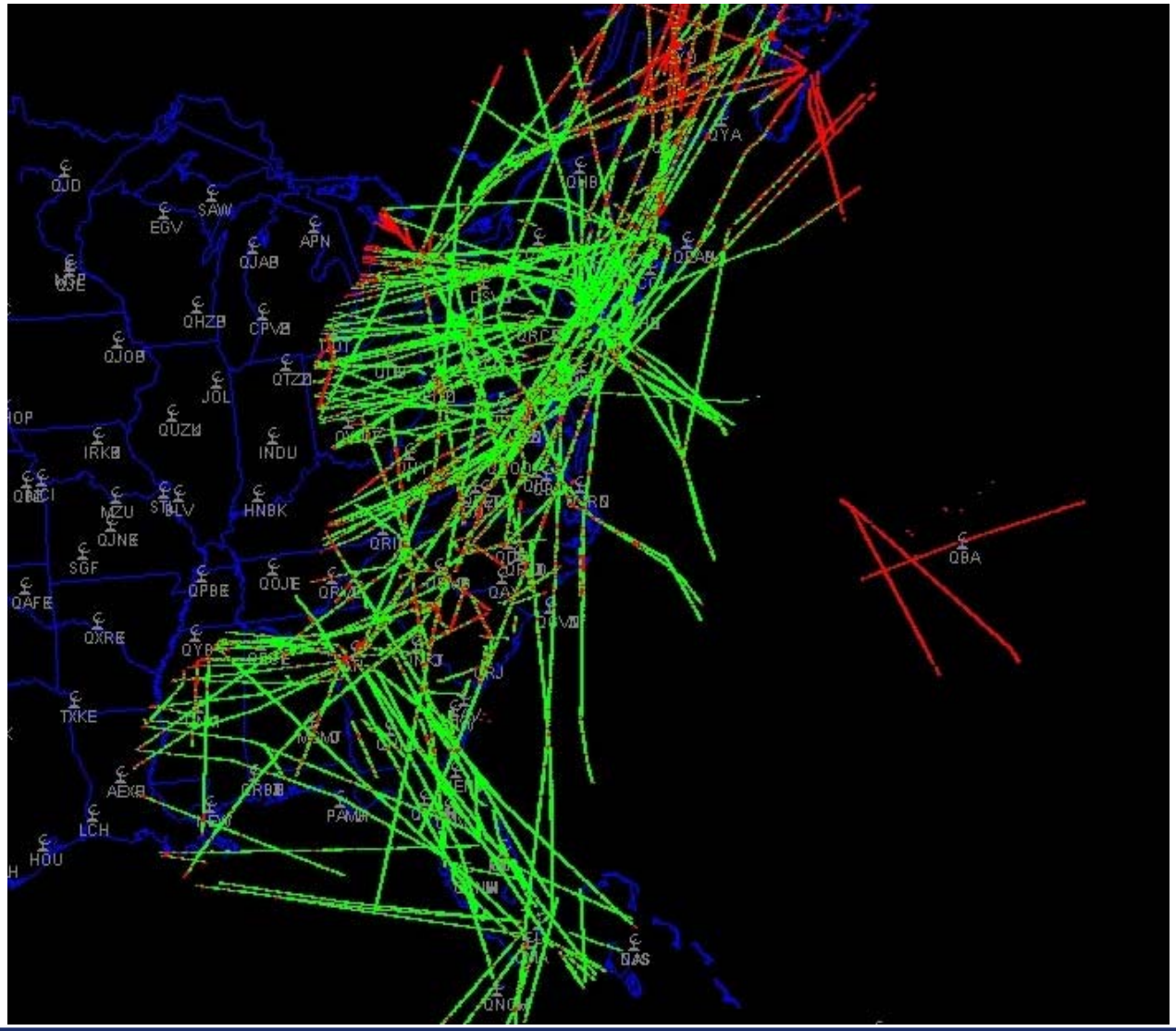
Data Sources

- **Enroute radar data collected from east and west coast ARTCCs**
  - 53 days were available between March and April 2009
- **FAA's Enhanced Traffic Management System (ETMS) data**
  - ETMS records were matched and appended to the enroute radar data to provide flight-identification information not available in the radar data

West Coast Enroute Radar



East Coast Enroute Radar



Review of Related Studies

- **Recent studies which estimate longitudinal speed prediction error**
  - Japan Civil Aviation Bureau (JCAB) study
    - Fujita, M. "Distribution of Longitudinal Speed Prediction Error of ADS-C System", Third International Conference on Research in Air Transportation, Fairfax, VA, June 1-4, 2008, ISBN: 978-0-615-20720-9
- **Important differences between Japan and US ground ATC systems are:**
  - Additional information requested in the ADS contract and utilized by Japan
  - ADS-C aircraft intent data are used by Japan ground systems
  - ADS-C aircraft intent data are not requested or provided to US ground systems

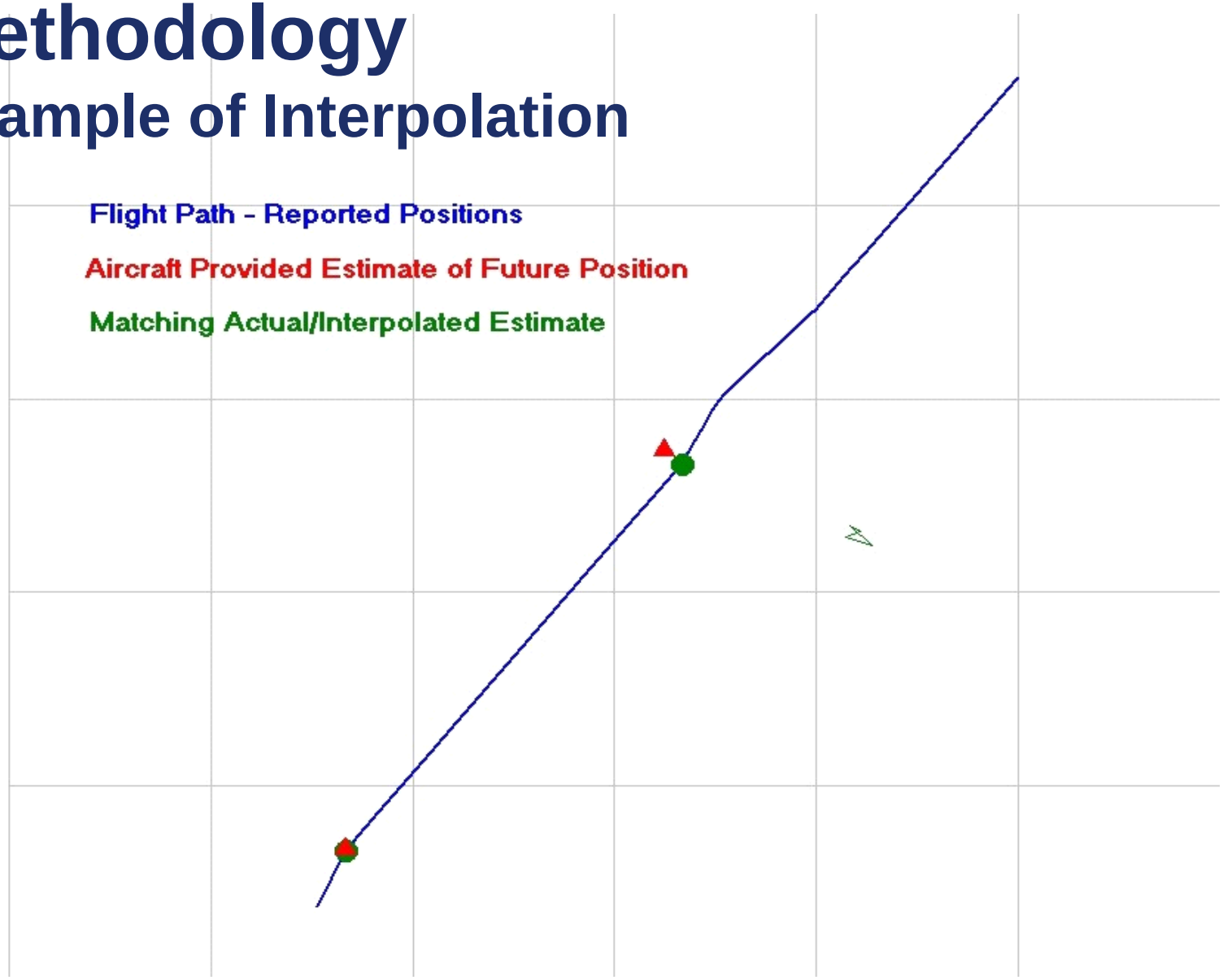
Methodology

- **Match the actual waypoint position report for each aircraft-provided estimate of future position**
- **Assume aircraft follow great circle paths between consecutive waypoints**

Methodology

- **Interpolation was needed in most cases to match either the aircraft-provided latitude and longitude estimate or the position directly abeam the aircraft provided estimate**

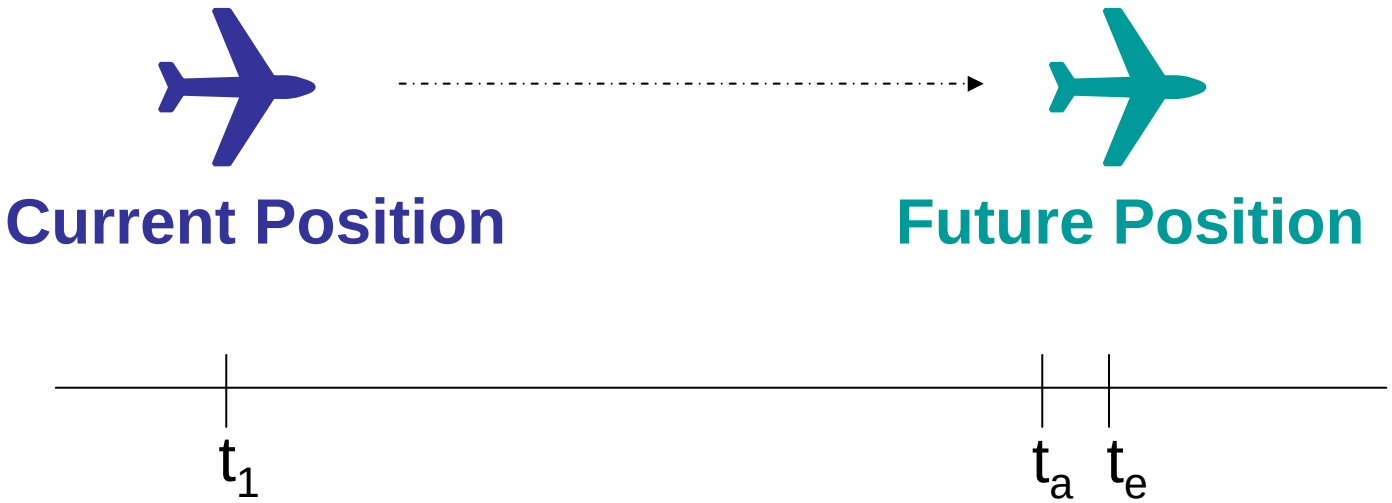
Methodology
Example of Interpolation



Methodology

- **Two measurements of error were recorded**
  - Time Error = aircraft-provided time estimate at next waypoint – actual time at waypoint
  - Speed Error = speed estimate using aircraft-provided time estimate at next waypoint – actual speed using reported time at waypoint

Longitudinal Speed Error



$$\text{Time Error} = Time_e - Time_a$$

$$\text{Speed Error} = Speed_e - Speed_a$$

Results

- **Number of unique ADS-C flights examined**
  - 65,449 in New York Oceanic Airspace
  - 63,703 Oakland Oceanic Airspace
- **Number of ADS-C position reports examined**
  - 242,206 from New York Oceanic Airspace
  - 695,456 from Oakland Oceanic Airspace
- **The flying time for operations conducted in Oakland Oceanic Airspace is much longer than those conducted in New York Oceanic Airspace resulting in many more messages received by the Oakland ARTCC than by the New York ARTCC**

Results

Categories for Frequently Observed Errors in Aircraft-Provided Estimate

Category	Description
1	Future waypoint position located outside airspace. Actual position report for the aircraft over the estimated waypoint was unavailable.
2	Actual position report over waypoint was unavailable due to ADS/datalink connection. This problem can cause the ADS-C report to arrive late and/or require a change to backup systems (HF) for position reporting.
3	The ADS-C message was incomplete. The estimated time and/or position of the next waypoint were missing.
4	Error in the aircraft-provided estimate. Aircraft had already crossed over the estimated waypoint prior to the current position contained in the ADS-C report.
5	Error in the aircraft-provided time estimate at future position. Either the aircraft-provided time estimate at next waypoint was equivalent to the current message time, or the time estimate at waypoint resulted in an abnormally low estimate of speed.
6	Multiple changes observed in aircraft-provided future positions. Matching actual position not found for all adjusted estimates. Some cases were combined with messages indicating a possible change in course.

Results

- **Additional parameter introduced**
  - The total time which the current estimate of future position was used by ATC was considered
  - This time was calculated as the time between consecutive ADS-C messages
  - Referred to as the time until the next update
- **If the time until the next update was 2 minutes or less, the estimate was removed from the analysis**

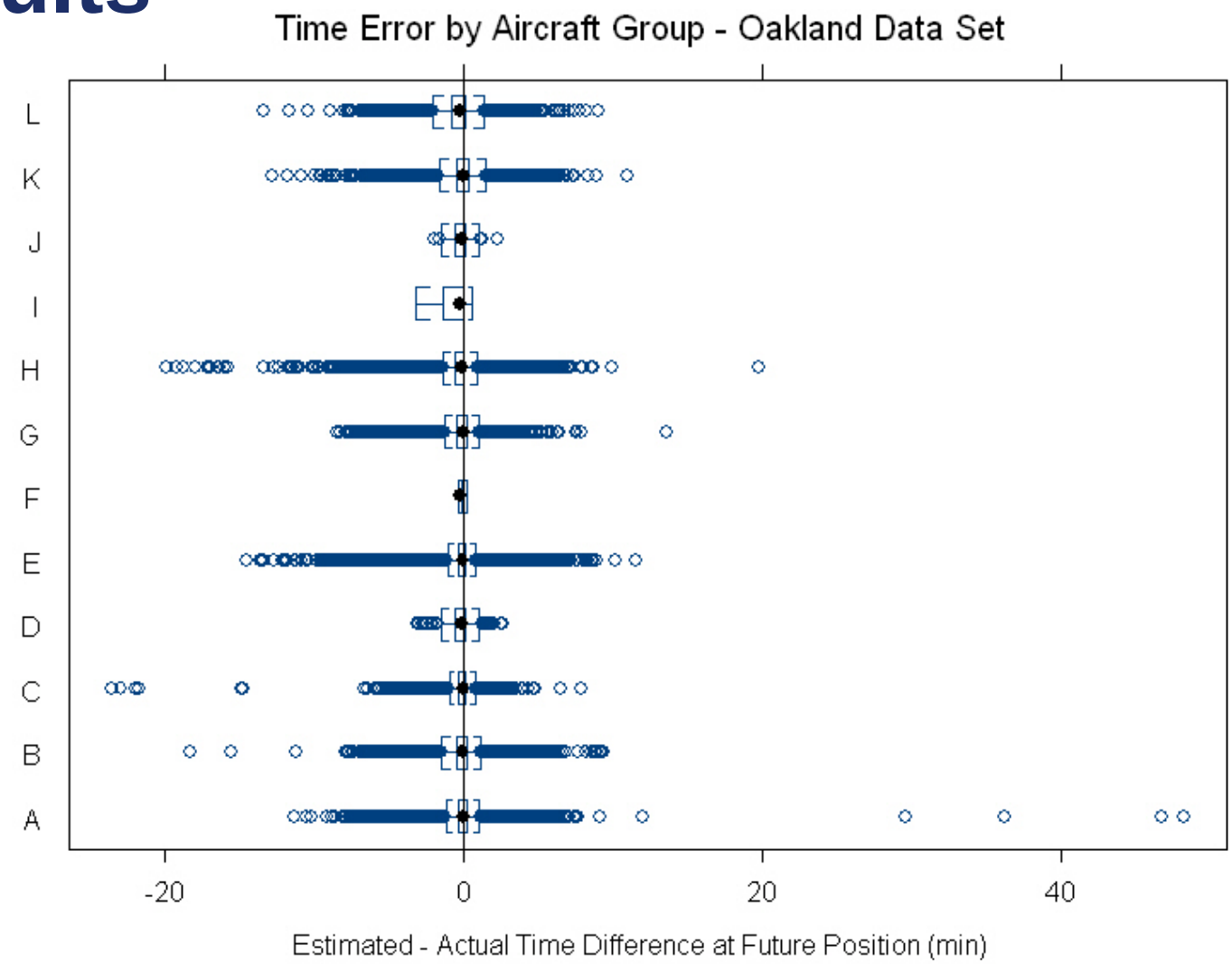
Results

Summary Statistics	Speed Error, E_s, for New York Oceanic Airspace (knots)	Time Error, E_t, for New York Oceanic Airspace (min)	Speed Error, E_s, for Oakland Oceanic Airspace (knots)	Time Error, E_t, for Oakland Oceanic Airspace (min)
Number of Estimates	105,758	105,758	396,654	396,654
1st Quantile	-4.229	-0.350	-2.640	-0.450
3rd Quantile	5.402	0.150	6.995	0.100
Mean	0.601	-0.267	2.364	-0.203
Variance	98.353	10.938	96.638	0.802
Skewness	-0.205	-22.174	0.825	-0.308
Kurtosis	14.134	591.146	34.317	75.291

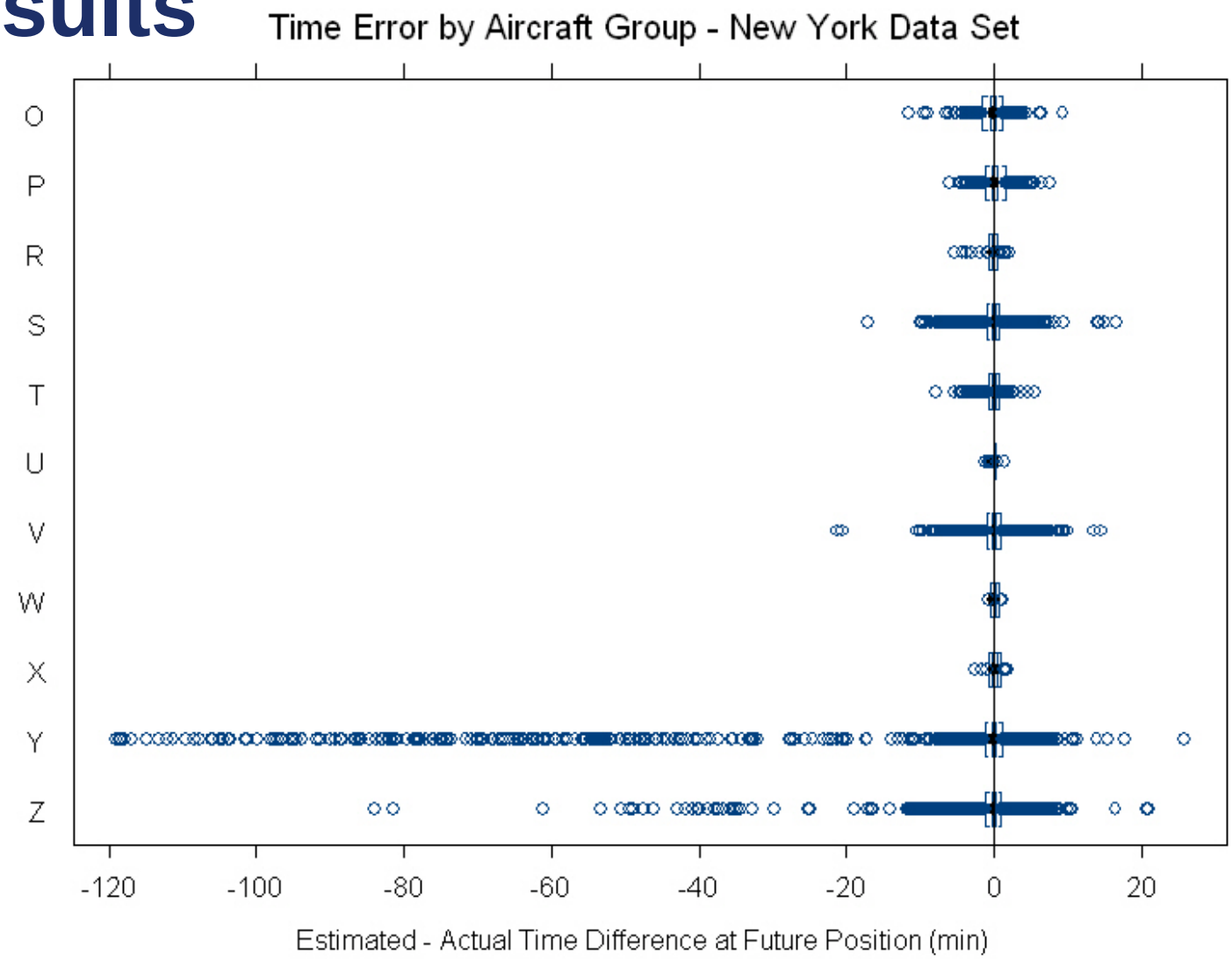
Results

- **A large number of aircraft-provided estimates of waypoint were observed with errors in the New York data having relatively long time durations for the time until the next update**
  - These estimates remain in the analysis for now; however, future plans include an evaluation of these data by a group of operational experts
  - Following this review, the analysis will be revised accordingly

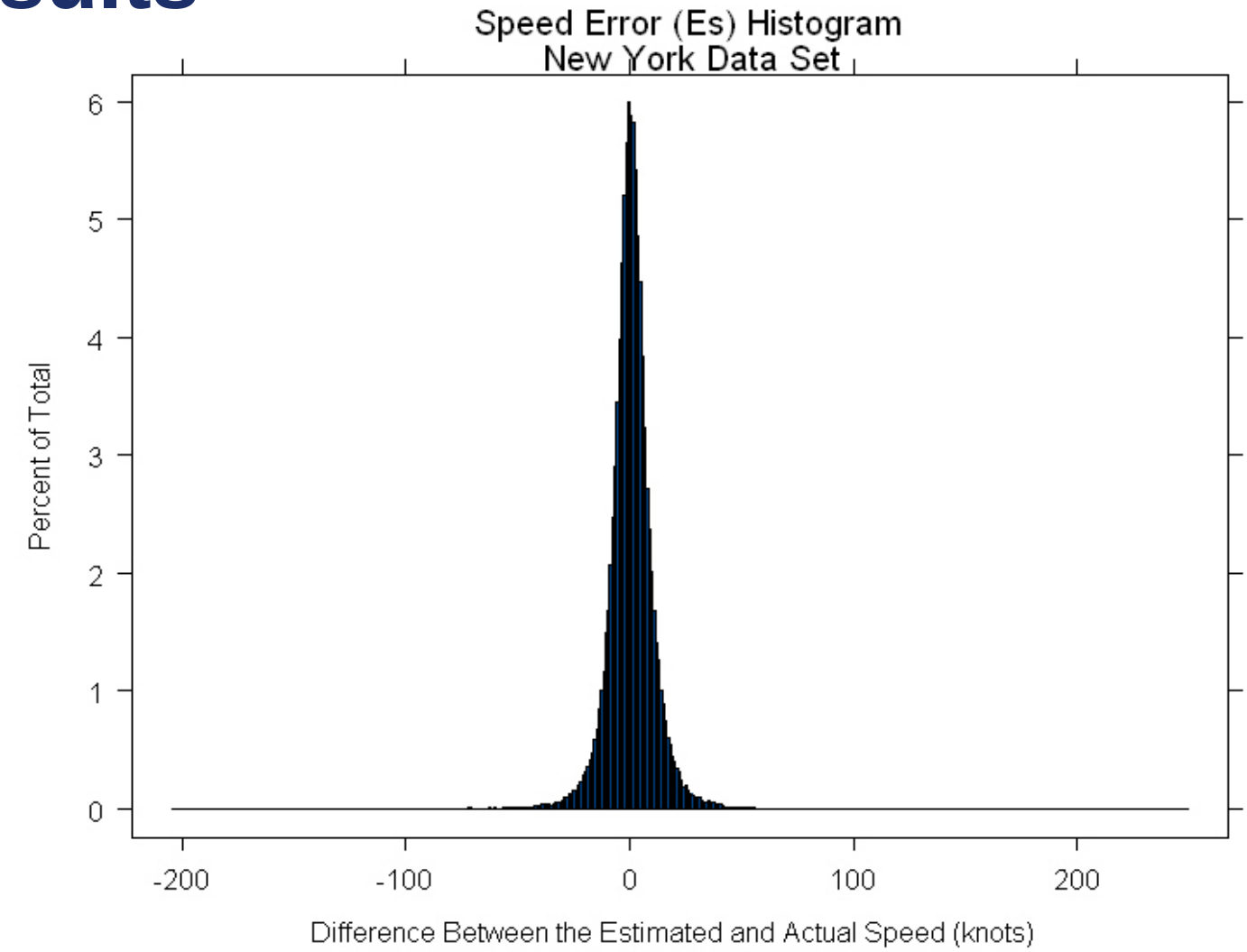
Results


Time Error by Aircraft Group - Oakland Data Set
L
K
J
I
H
G
F
E
D
C
B
A
-20
0
20
40
Estimated - Actual Time Difference at Future Position (min)

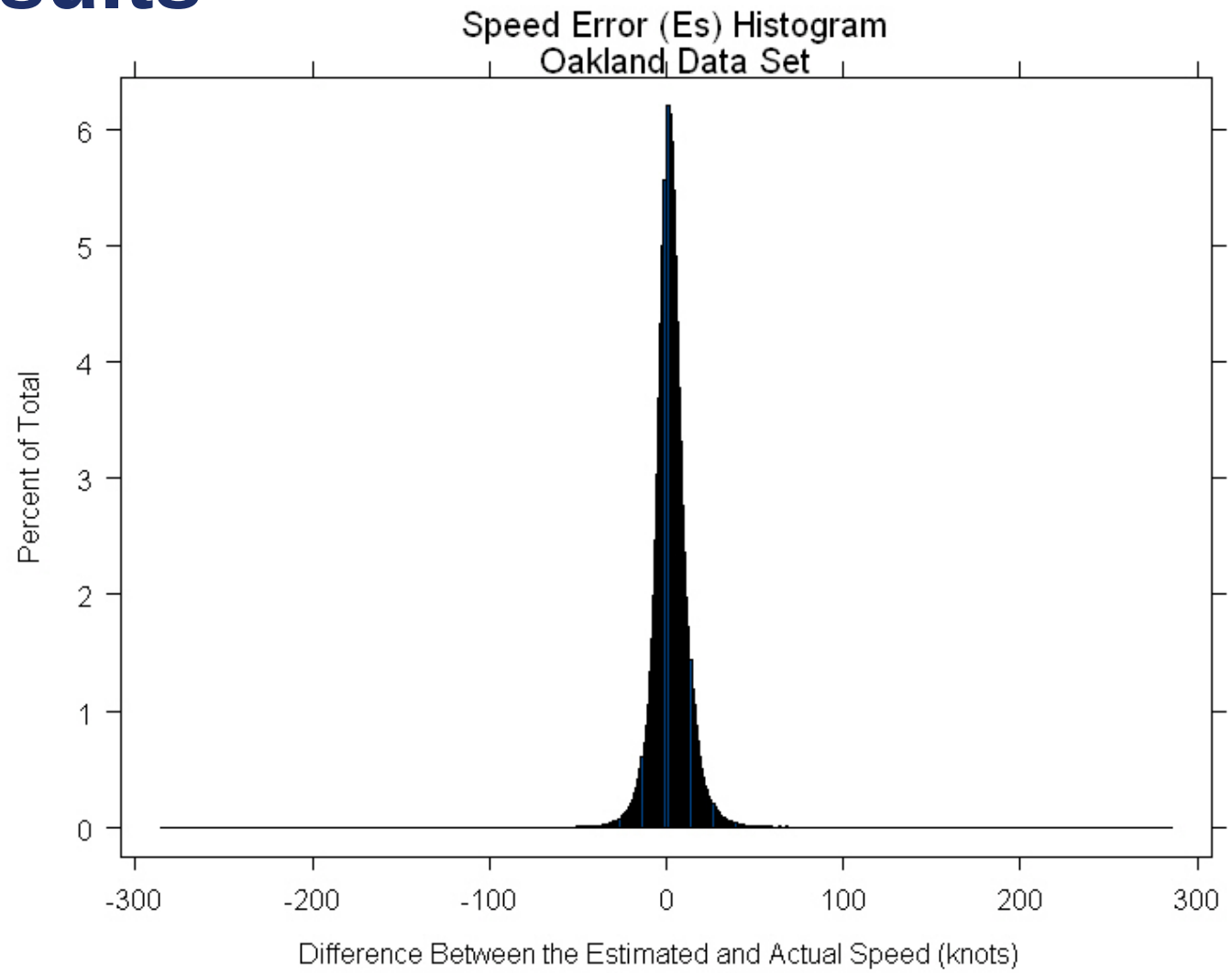
Results


Time Error by Aircraft Group - New York Data Set
O
P
R
S
T
U
V
W
X
Y
Z
-120
-100
-80
-60
-40
-20
0
20
Estimated - Actual Time Difference at Future Position (min)

Results

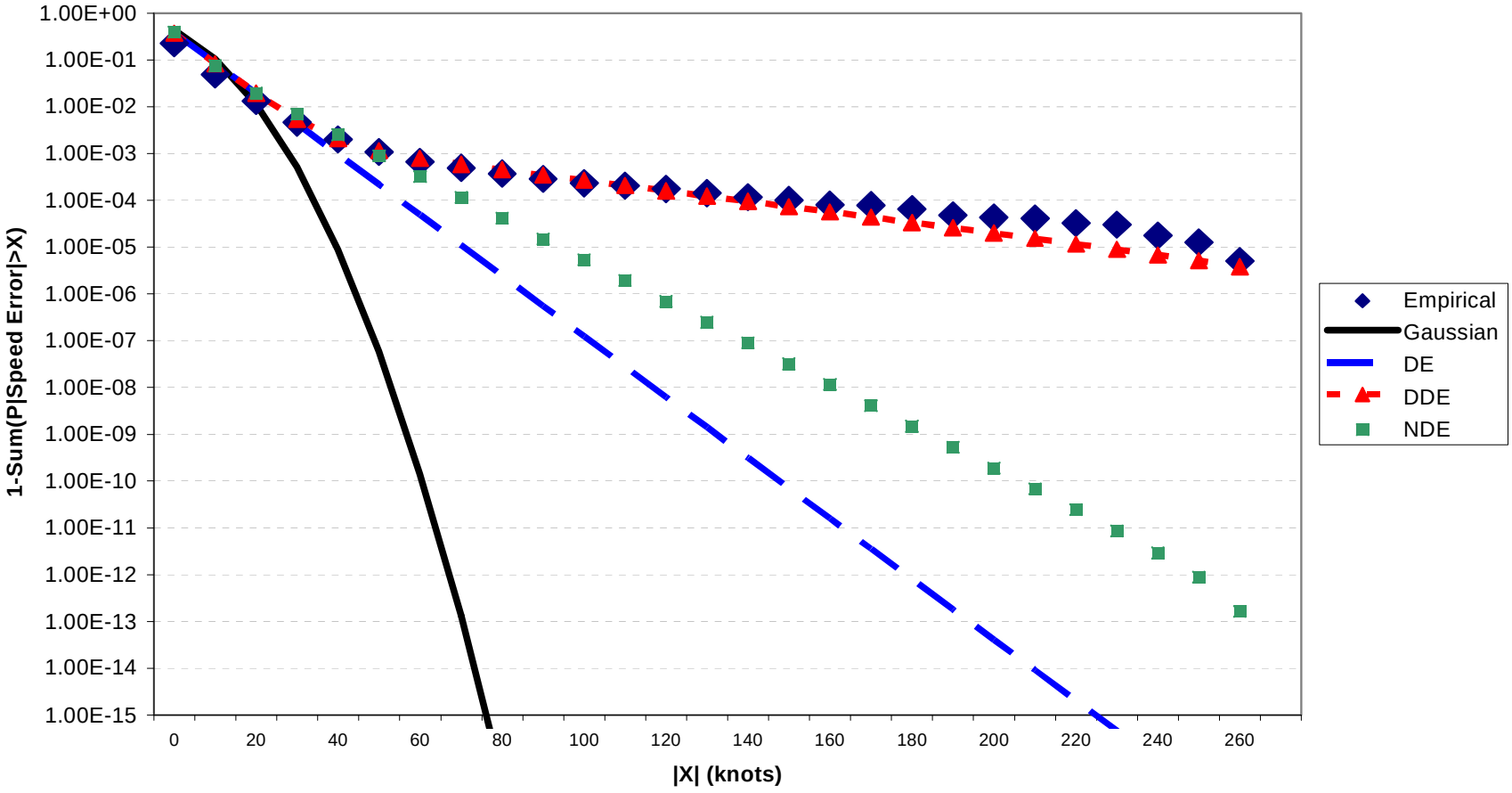

Speed Error (Es) Histogram
New York Data Set
Percent of Total
0
1
2
3
4
5
6
-200
-100
0
100
200
Difference Between the Estimated and Actual Speed (knots)

Results


Speed Error (Es) Histogram
Oakland Data Set
Percent of Total
0
1
2
3
4
5
6
-300
-200
-100
0
100
200
300
Difference Between the Estimated and Actual Speed (knots)

Results

Folded 1-Minus Cumulative Histogram
Difference in Aircraft Provided Estimates of Future Position and Matching Actual Position Reports - Speed Error for Oakland Data Set



Clock-Setting Accuracy

Methodology

- **ICAO guidance for aircraft**
  - Use Coordinated Universal Time (UTC)
  - Obtain a time check prior to operating a controlled flight
- **NAT guidance for aircraft**
  - aircraft master clock should be synchronized to an acceptable UTC signal prior to take-off
- **For en route aircraft using ADS-C, it is often assumed that the aircraft clock is synchronized to GPS time. However, this practice is not monitored and ATC is left to trust the position-time information provided by the airborne systems.**

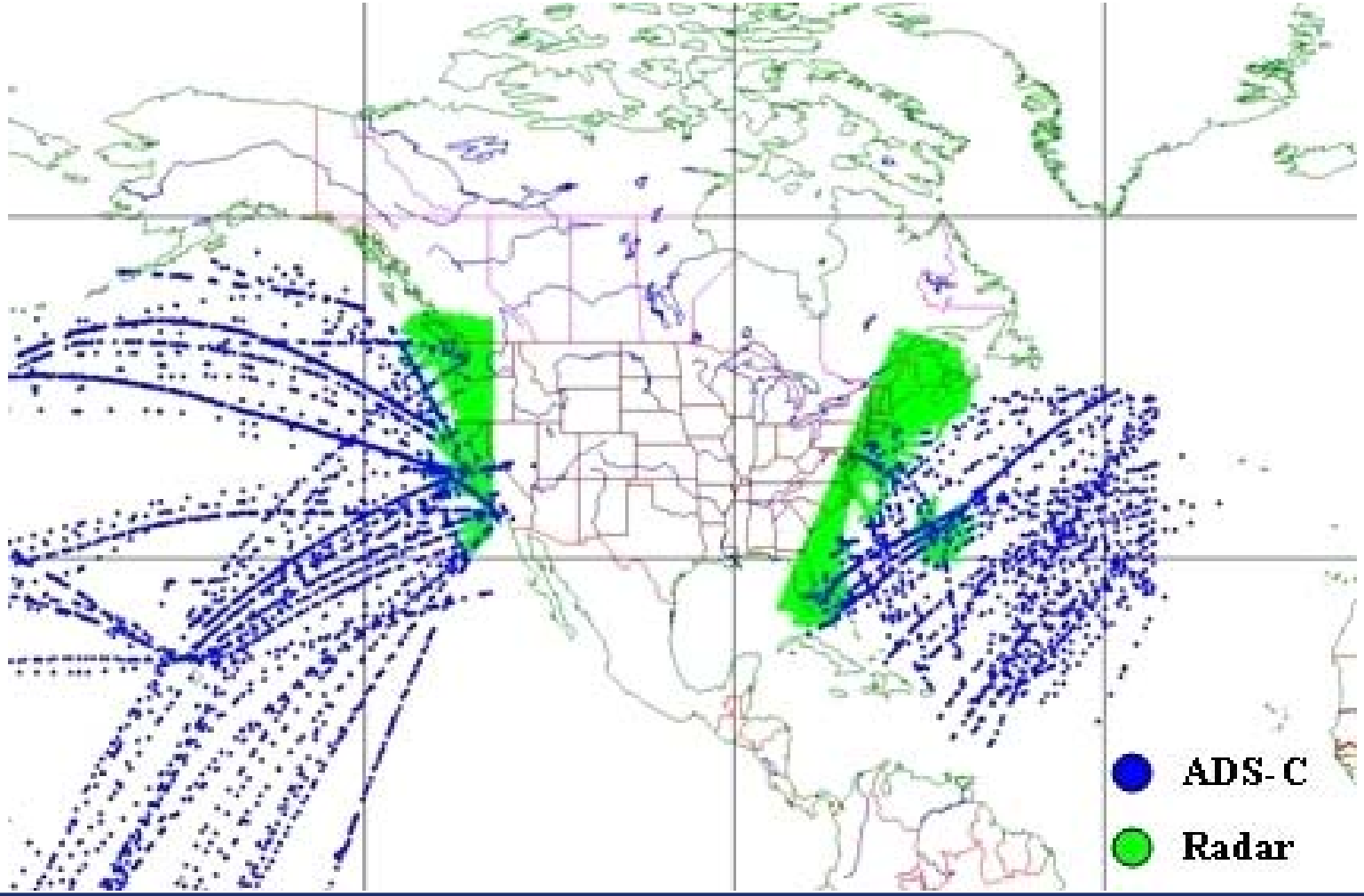
Clock-Setting Accuracy

Methodology

- **To reduce the contribution of errors in the radar position estimates, limited radar-derived positions to within 75nm of radar site**
- **Use position data from same radar source if interpolation was necessary**

Clock-Setting Accuracy

Example: March 6, 2009



Clock-Setting Accuracy

Results

- **638 aircraft examined during 53 day period**
- **The mean estimate of clock accuracy error observed was 2.39 seconds**
- **Maximum clock accuracy error observed was 6.67 seconds**
- **Minimum clock accuracy error value observed was -0.50 seconds**

Conclusion

- **Estimates of longitudinal speed prediction error**
  - The observed time and speed error data from New York and Oakland were of similar form but were not equivalent
  - The New York data contained a large number of observed errors in the aircraft provided estimates of position – this result was evident in the summary statistics for the time error
  - These data will be further examined by a group of operational experts, pending the outcome of this examination, the analysis will be modified

Conclusion

- **Clock-setting Accuracy**
  - Tool was developed to compare the aircraft master clock with the ARTCC clock using an independent source of position
  - In the data set examined, no significant differences were observed
  - This tool will be exercised periodically to monitor the clock setting of aircraft utilizing ADS-C in oceanic airspace
  - The accuracy of the aircraft master clock is critical to safe operations and application of reduced longitudinal separation standards

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