Federal Aviation Administration

Session 35-GNC-21: “Innovations and Support of the NAS at the FAA”

Paper AIAA-2007-6520: “Correlation of Airborne Position Estimates to Ground Based Independent Estimates and Deviations from Flight-Planned Tracks”

Presented to: AIAA GNC, Hilton Head, S.C.

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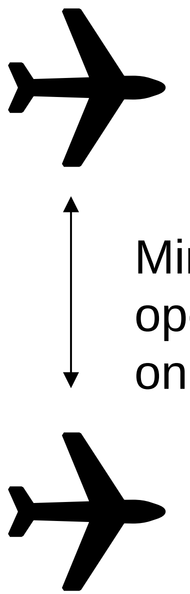
Overview

- **Introduction**
  - Motivation for this work
- **Objectives**
- **Background**
  - Description of the airspace studied
- **Data Sources**
- **Methodology**
- **Results**
- **Conclusion**

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 lateral separation standard

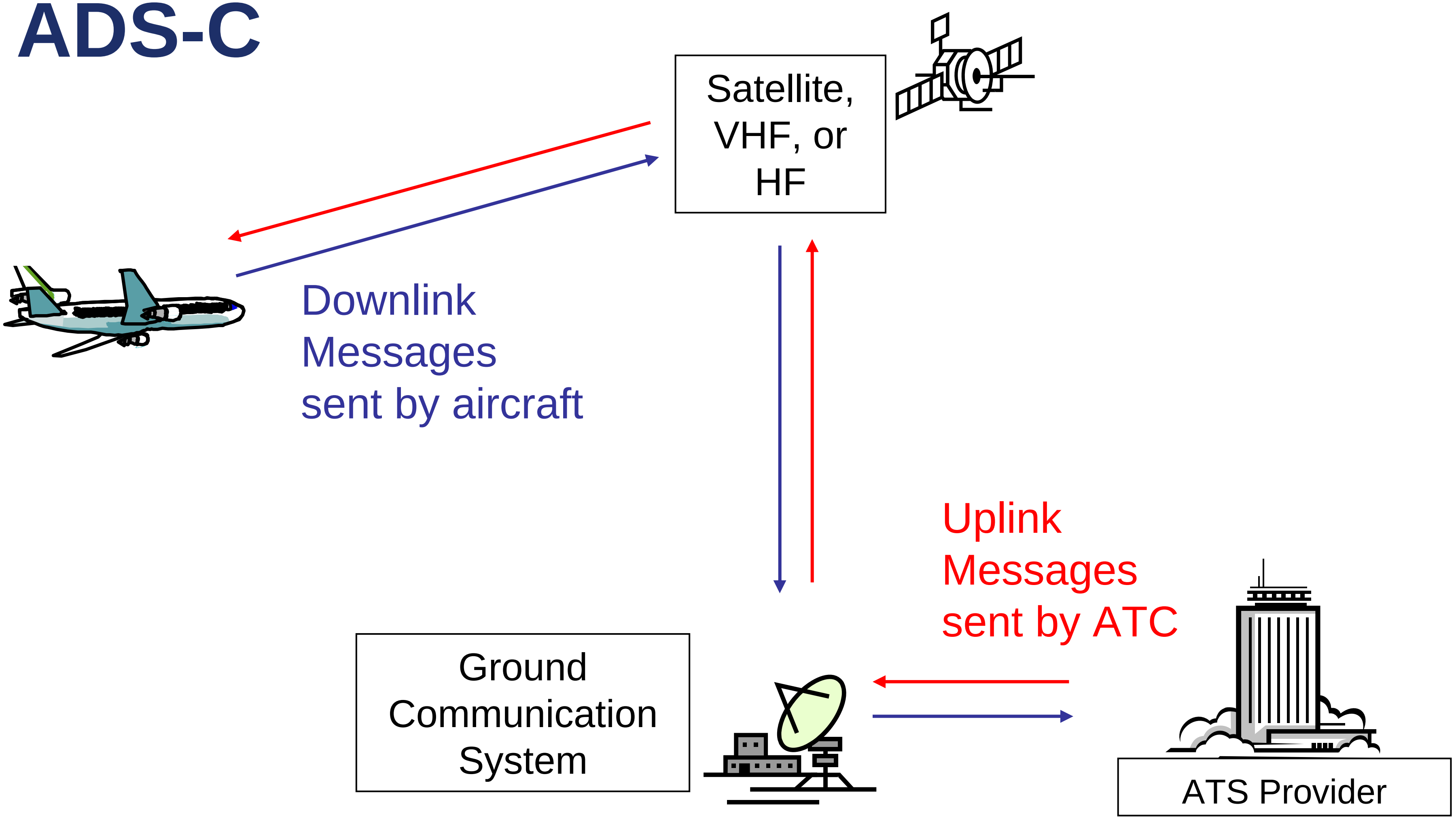


Minimum lateral distance between aircraft pairs operating at the same flight level and on adjacent tracks

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 appropriate ATS provider and the aircraft
  - Main purpose of ADS-C is for the aircraft to provide ATC with frequent position reports as well as future intent information

ADS-C


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

Introduction

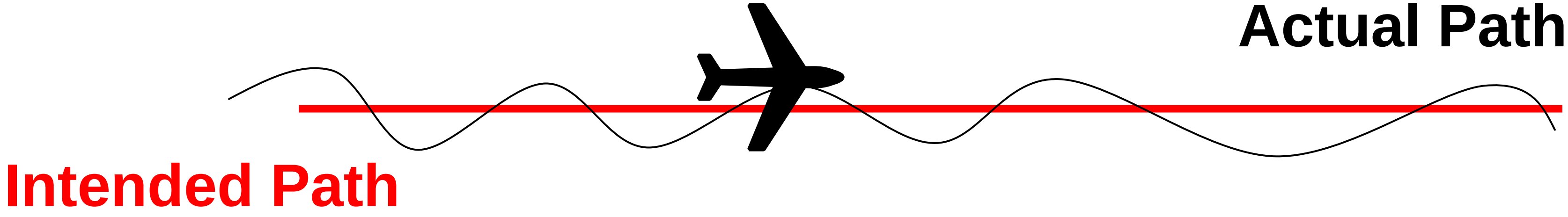
- The addition of ADS-C to a procedural ATC environment allows for significant reductions in separation minima between suitably equipped aircraft are possible

- When changes to separation minima are considered, the Manual on Airspace Planning Methodology (ICAO Doc 9689) calls for an evaluation of collision risk

Introduction

- **For changes in lateral separation standard, the lateral navigation performance is a primary influence on the collision risk**
  – The lateral navigational performance determines the lateral overlap probability
  – Lateral overlap probability can be estimated from the distribution of lateral deviations from route centerline

Lateral Deviations



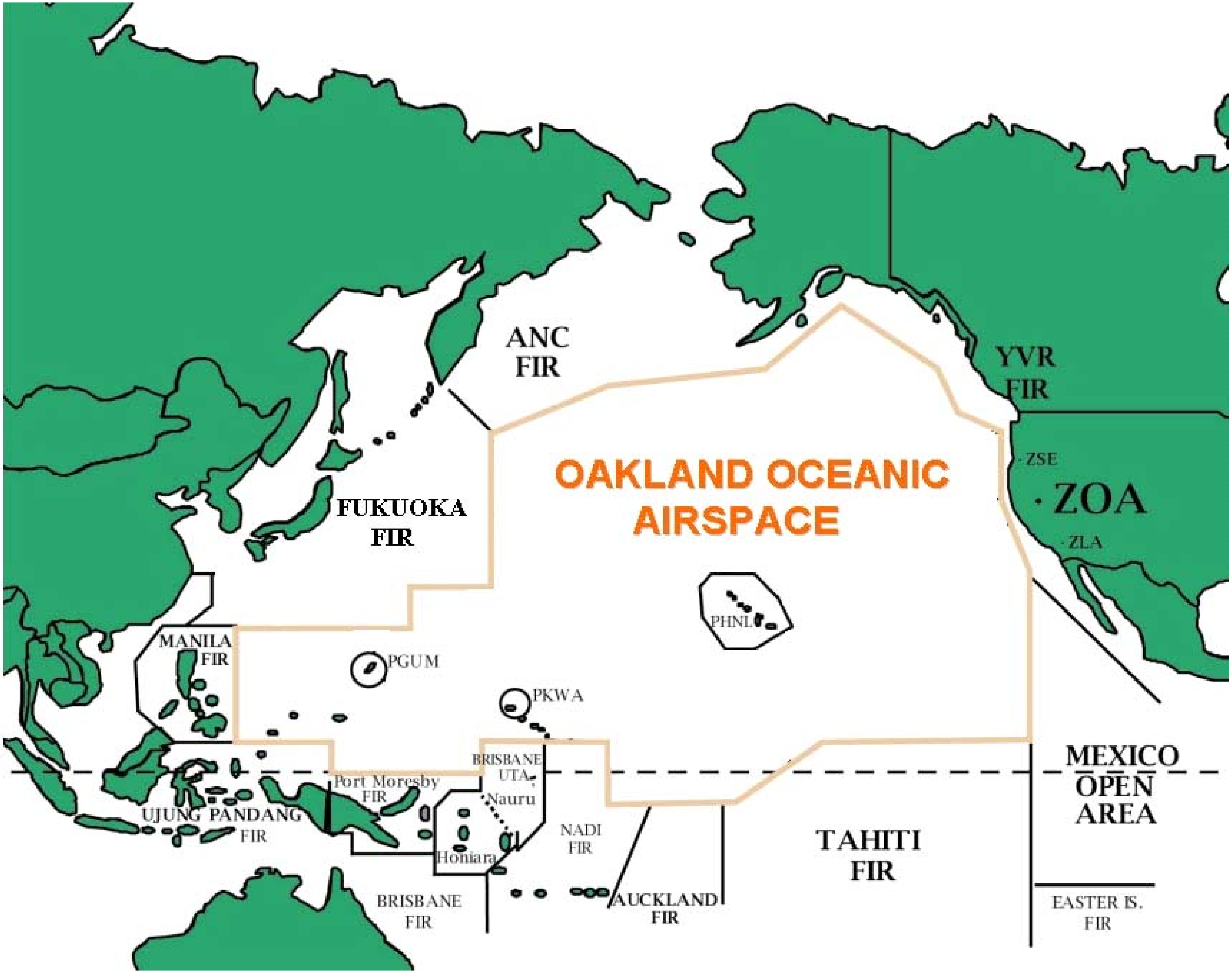
Objectives

- Compare the lateral deviations estimated from ADS-C positions with those estimated from an independent source (radar-derived position estimates)

- Estimate the lateral deviation distribution from route centerline for ADS aircraft operating in Pacific oceanic airspace and the resulting lateral overlap probability

Background

- **The Oakland Oceanic Airspace is the airspace under consideration**
  - 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
FUKUOKA FIR
OAKLAND OCEANIC AIRSPACE
YVR FIR
ZSE
ZOA
ZLA
PHNL
MANILA FIR
PGUM
PKWA
BRISBANE UTA
Port Moresby FIR
Nauru
UJUNG PANDANG FIR
Honiara
NADI FIR
TAHITI FIR
MEXICO OPEN AREA
BRISBANE FIR
AUCKLAND FIR
EASTER IS. FIR

Background

- **Reductions in the lateral separation standard between pairs of suitably equipped aircraft in Oakland oceanic airspace are possible due to:**
  - Decision-support tools provided by Ocean21
  - Communication-navigation-surveillance (CNS) improvements made by the user community
    - Navigation enhanced or provided by Global Navigation Satellite System (GNSS)
    - Satellite data and voice communication
    - Surveillance enhanced by ADS
- **The benefits of the reduced separation standards include:**
  - Enhanced capacity of the airspace
  - Increased efficiency of operations (time & schedule/fuel)

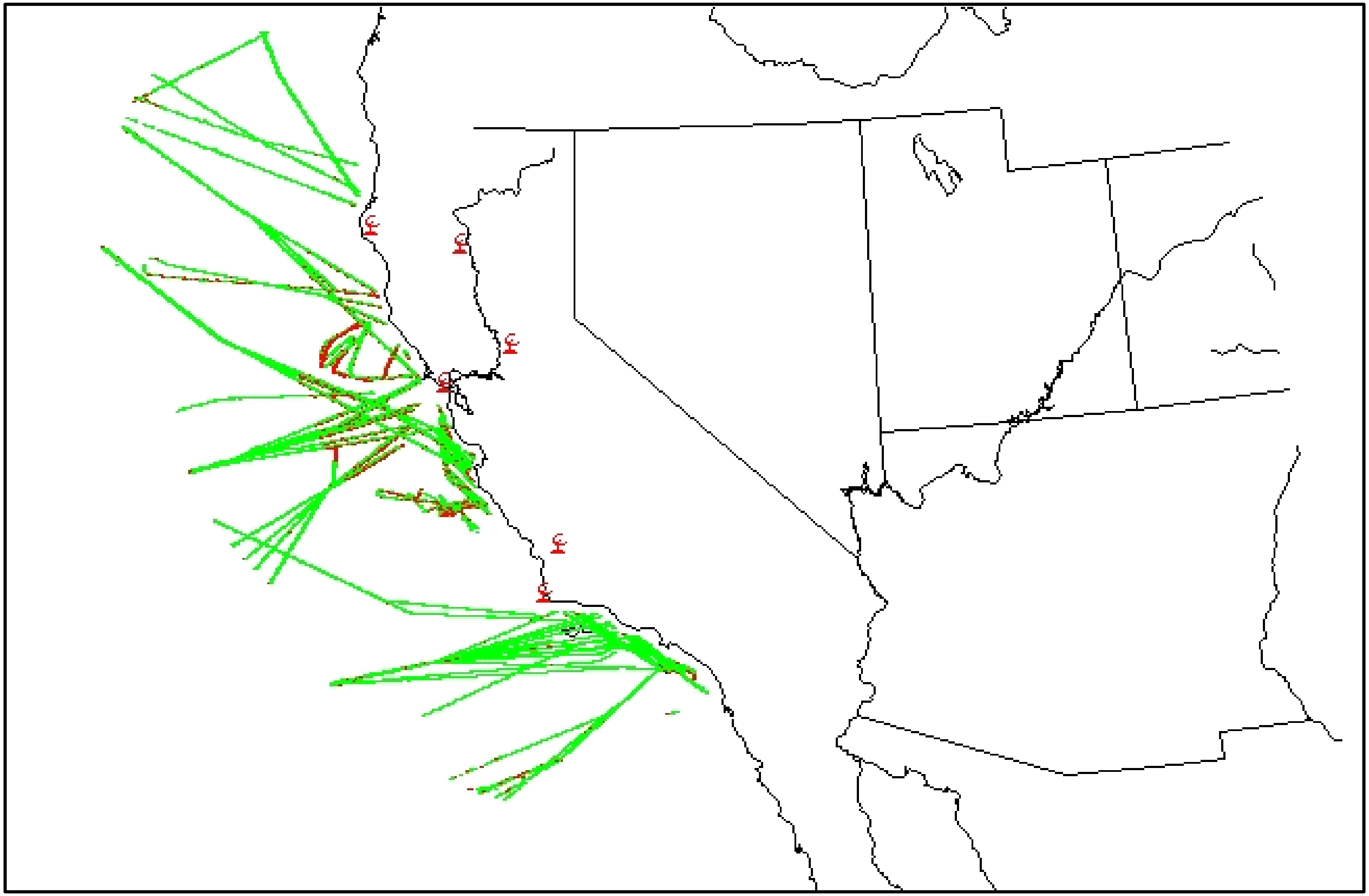
Data Sources

- **Historical data from the Ocean21 system**
  - ADS-C position reports
  - Aircraft filed flight plans
- **ADS-C position reports**
  - The most frequently occurring position report is the Basic Periodic Report – either 14 or 27 minutes
  - Contain estimate of current position and next position

Data Sources

- **En route radar data from Los Angeles and Oakland ARTCC**
  - 105 days were available between January – June 2007
- **FAA's Enhanced Traffic Management System (ETMS) data**
  - ETMS records were matched and appended to the en route radar data to provide flight-identification information not available in the en route radar data

Data Sources – En Route Radar



Review of Related Studies

- **Recent studies which compare ADS-B position data to radar environments**
  - FAA/MITRE study compared ADS-B positions to position estimates obtained from a single radar
  - France's Direction des Services de la Navigation Aérienne (DSNA) study compared ADS-B to position estimate obtained in a multi-radar environment

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- **Important differences between ADS-B and ADS-C avionics are:**
  - reporting frequencies
  - method of report transmission

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- **Important differences between ADS-B and ADS-C avionics are:**
  - reporting frequencies
  - method of report transmission
- **Because of the differences between ADS-B and ADS-C it is not possible to make any direct conclusions about the accuracy of ADS-C from the studies which compare ADS-B to radar**

Methodology

- **Determination of the intended route from which lateral deviations are measured**
  - Estimates of the next positions, known as the Predicted Route Group (PRG), contained in ADS-C position reports
- **Assume aircraft follow great circle paths between consecutive waypoints**

Methodology

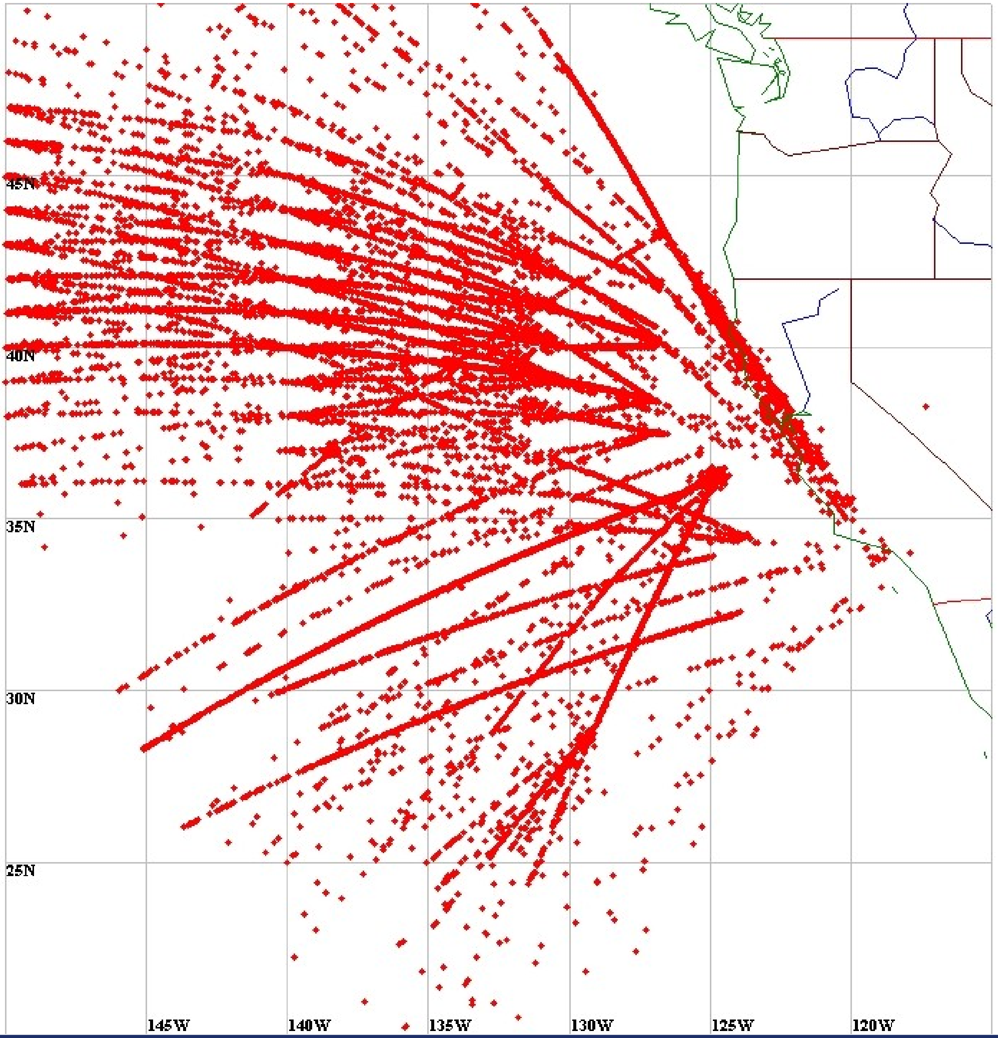
- **Flight segments examined were taken from eastbound flights ending their oceanic crossing, and entering radar coverage along the west coast of the United States**
  - The small period in which the ADS-C position reports and radar position estimation overlap are extracted

Methodology

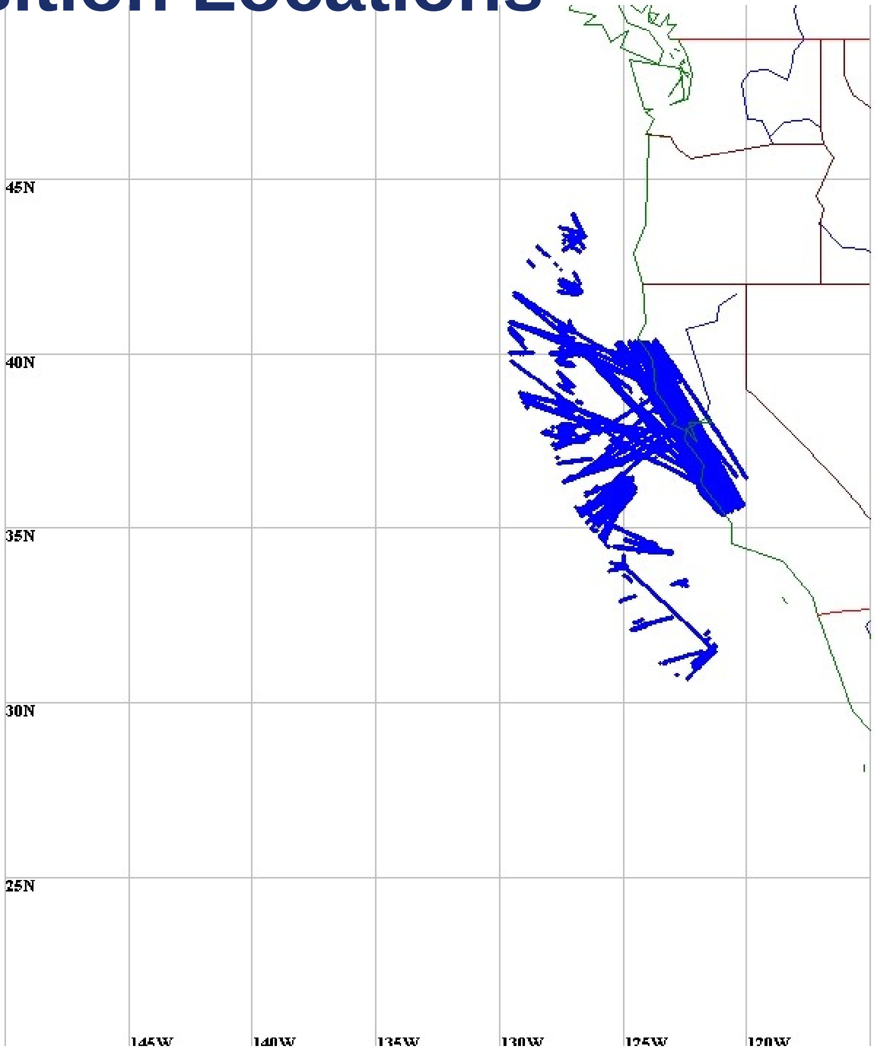
- Radar-derived position estimates are smoothed using the method of least squares to reduce known radar error

Methodology

ADS-C Position Locations

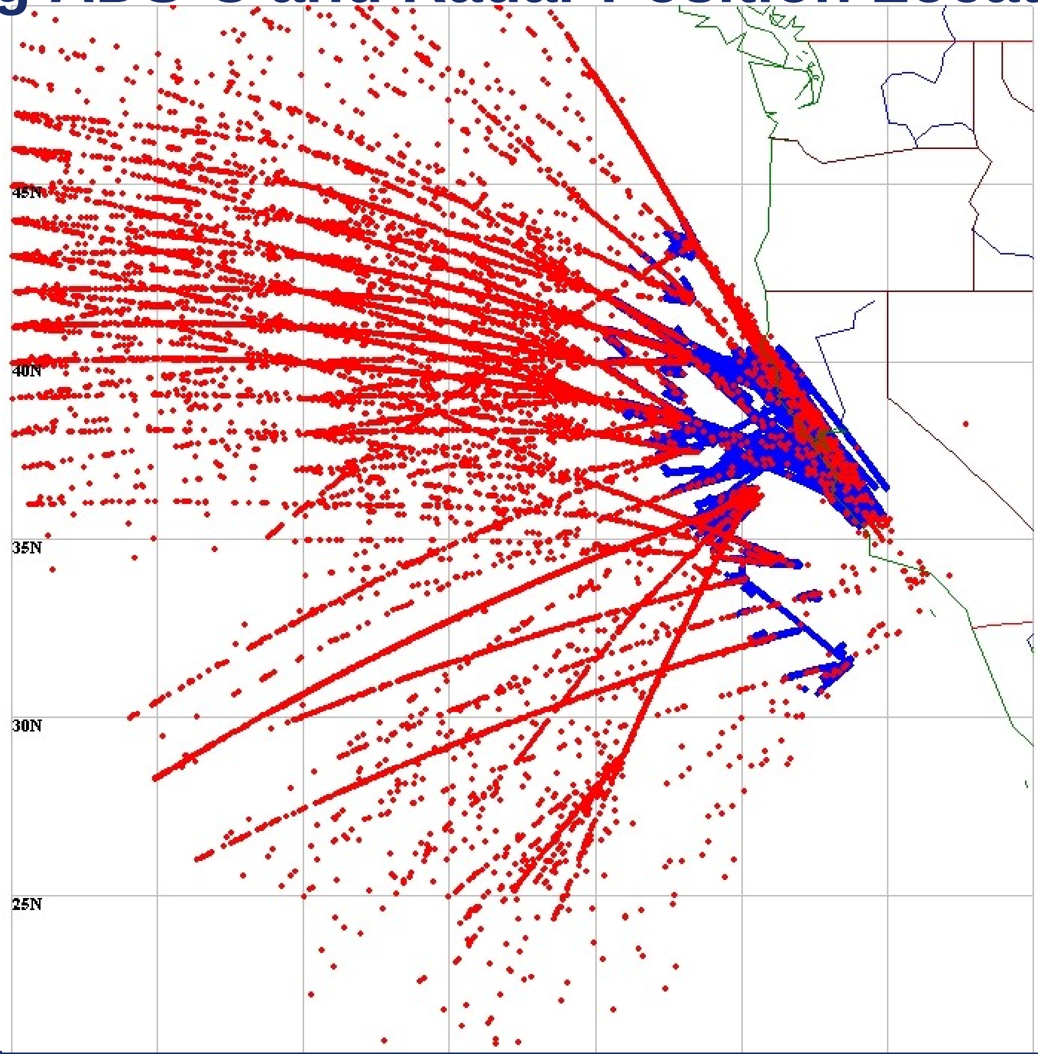


Methodology
Radar Position Locations

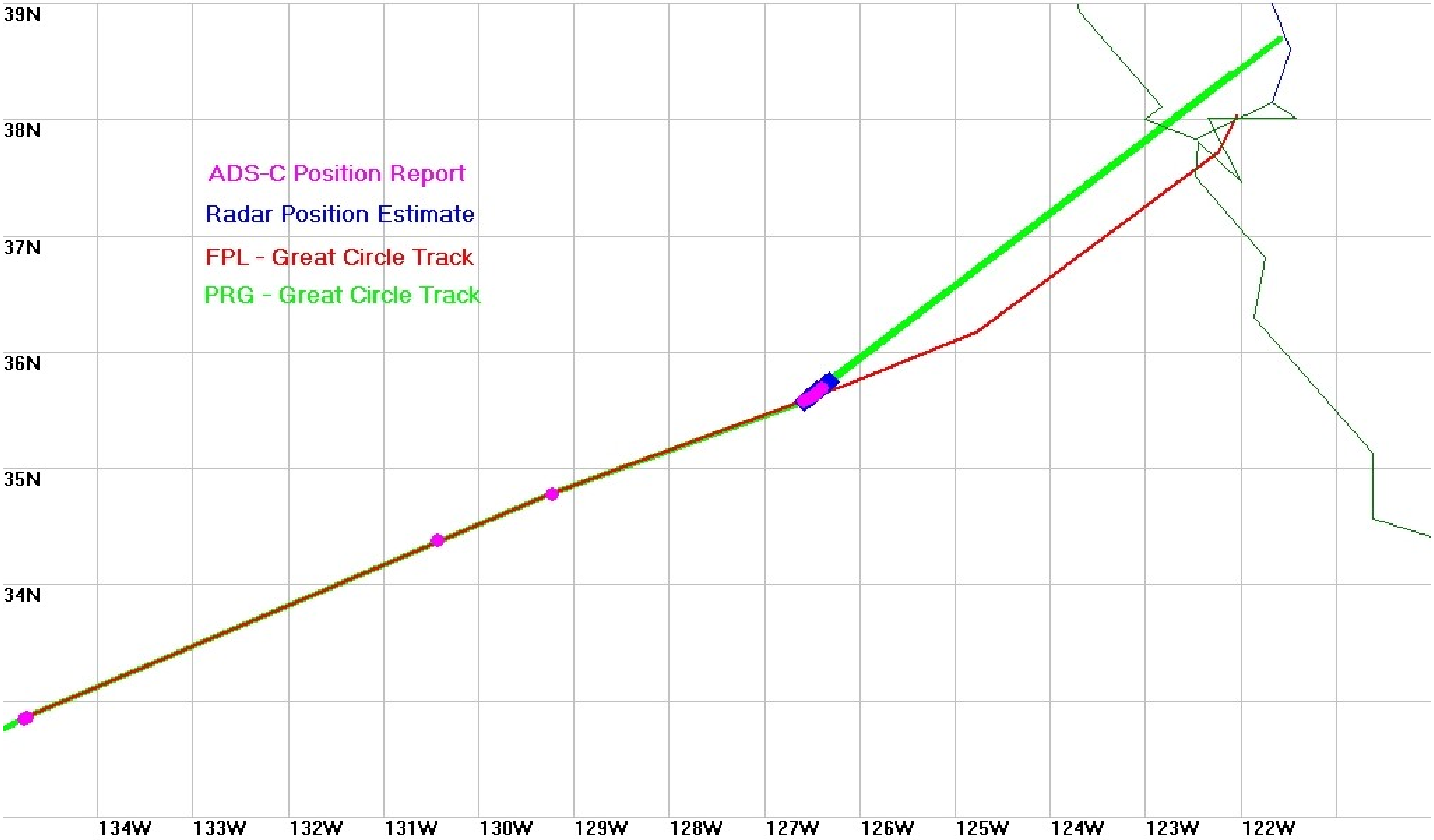


Methodology

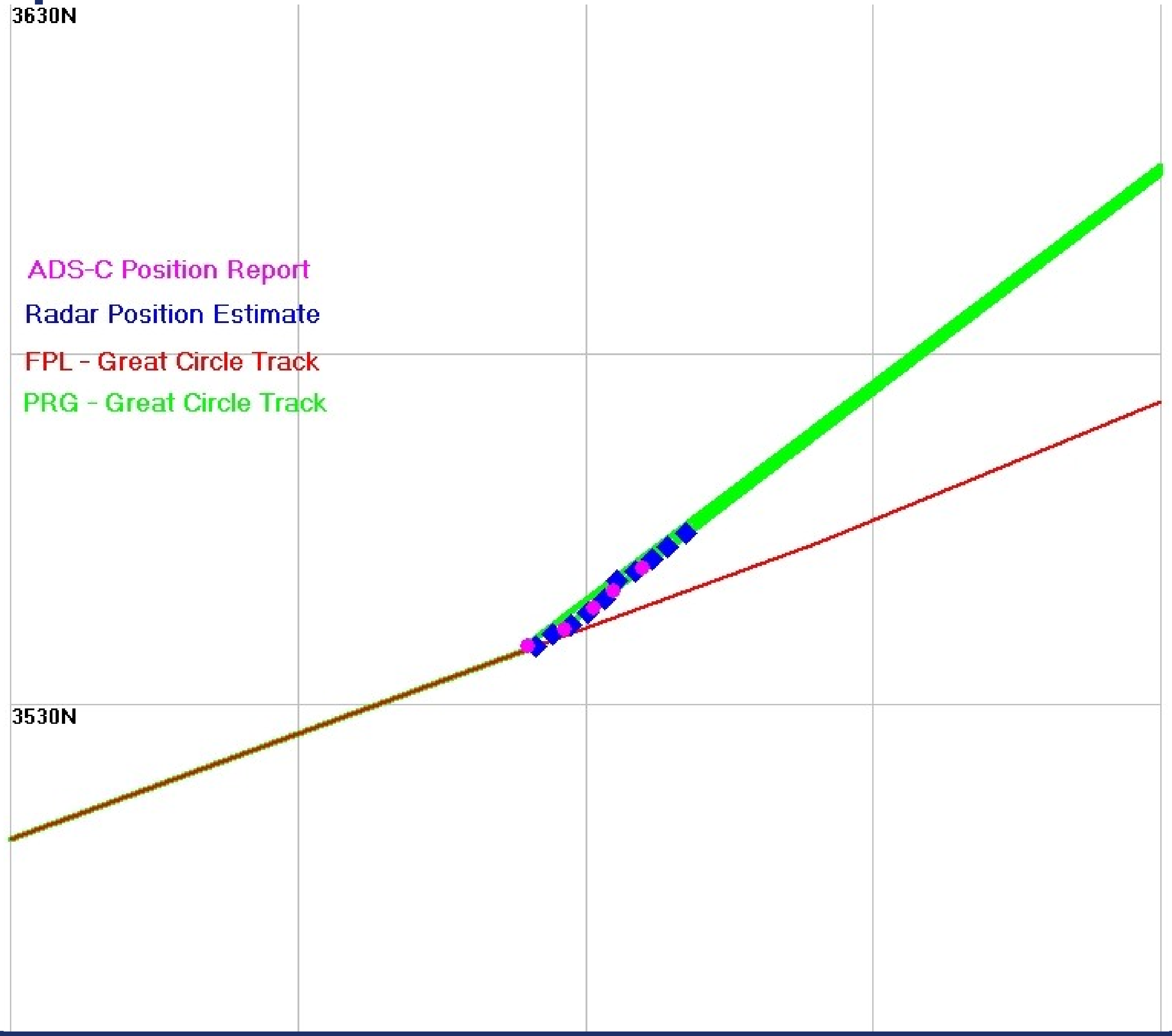
Overlapping ADS-C and Radar Position Locations



Example of Intended Route and Position Estimates



Example of Intended Route and Position Estimates

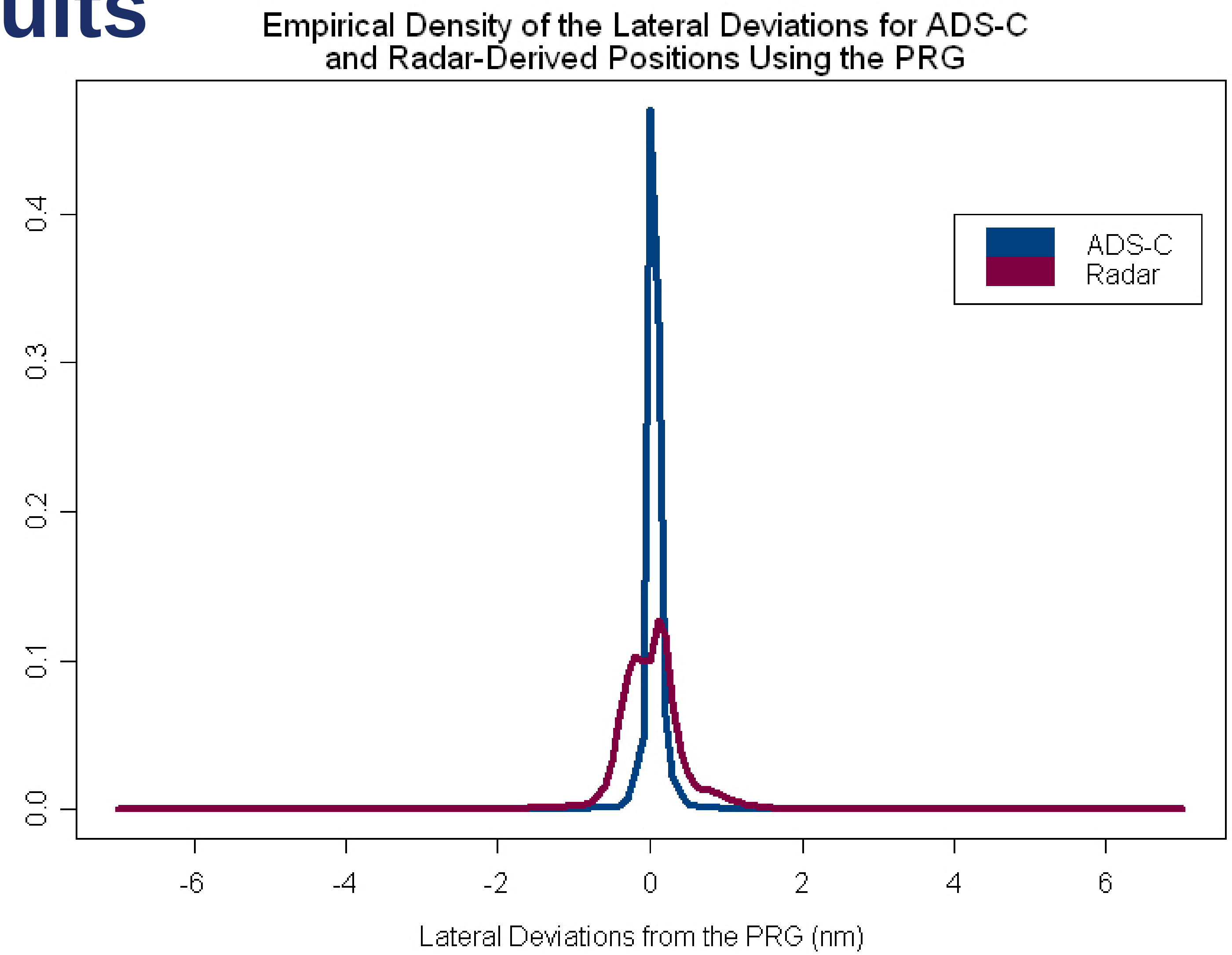


Results

4,076 unique flights examined

Summary Statistics	Lateral Deviations Estimated from Radar Positions Vs. the PRG Track	Lateral Deviations Estimated from ADS-C Vs. the PRG Track
Number of Position Estimates	78,998	39,012
Mean	-0.036	-0.001
Variance	0.219	0.034
Skewness	-0.277	-1.374
Kurtosis	15.226	80.322

Results

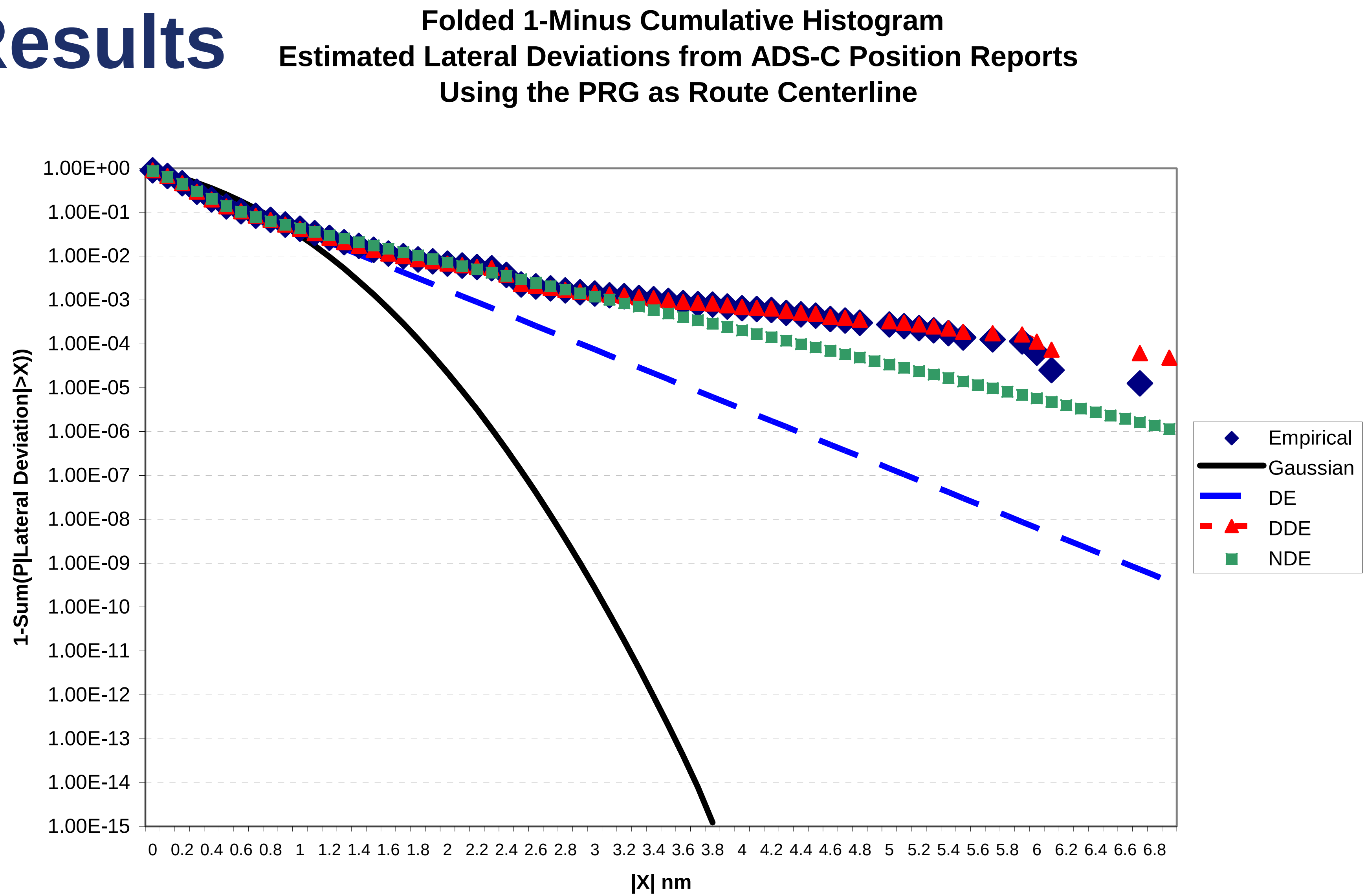


Empirical Density of the Lateral Deviations for ADS-C
and Radar-Derived Positions Using the PRG
ADS-C
Radar
0.0
0.1
0.2
0.3
0.4
-6
-4
-2
0
2
4
6
Lateral Deviations from the PRG (nm)

Results

- **Lateral deviation distribution estimated for ADS-C aircraft**
  - Several distributional forms were tested, including:
    - Gaussian (Normal)
    - Double Exponential (DE)
    - Mixed distribution with a Normal core and a DE tail (NDE)
    - Mixed distribution with a DE core and a DE tail (DDE)

Results



Folded 1-Minus Cumulative Histogram
Estimated Lateral Deviations from ADS-C Position Reports
Using the PRG as Route Centerline
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1-Sum(P|Lateral Deviation|>X))
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4 3.6 3.8 4 4.2 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8 6 6.2 6.4 6.6 6.8
|X| nm
Empirical
Gaussian
DE
DDE
NDE

Results

- **Probability of lateral overlap**
  - Using the estimated DDE distribution (with parameters $\alpha = 0.0337$, $\lambda_1 = 0.2946$ nm, and $\lambda_2 = 1.0616$ nm)
  - For a 30-nm lateral separation standard is estimate to be 1.526×10^{-15}
  - Estimate represents the typical navigation performance of the aircraft population – does not include atypical performance (gross navigation errors)

Conclusion

- **Comparison of lateral deviations from ADS-C and radar-derived position estimates**
  - The data from ADS-C and radar were not equivalent
  - The lateral deviations from the ADS-C position reports have a smaller mean and variance estimate
  - ADS-C position reports can be considered to be an accurate source for aircraft position in Oakland oceanic airspace

- **Estimated Distributional form for the lateral deviations from the ADS-C positions**
  - DDE distribution provided the best fit
  - Lateral overlap probability was estimated which represents the typical navigation performance observed in the airspace
  - Additional data on atypical performance is need to evaluate collision risk

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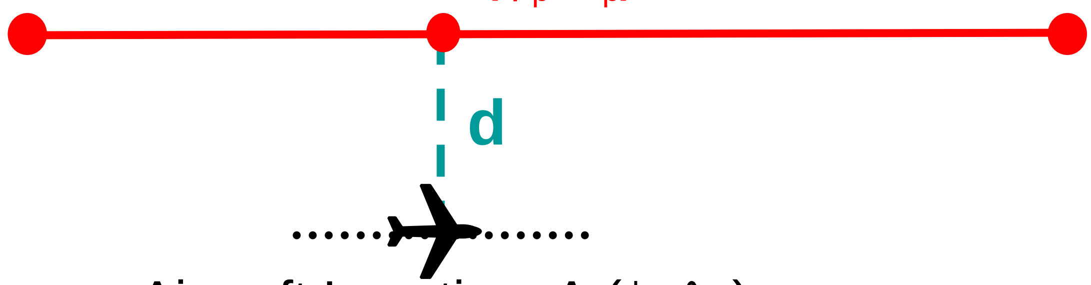
Methodology

Lateral Deviation Estimation

$$X_p = (\cos\phi_p \sin\lambda_p)$$
$$Y_p = (\cos\phi_p \cos\lambda_p)$$
$$Z_p = (\sin\phi_p)$$



$$X_a = (\cos\phi_a \sin\lambda_a)$$
$$Y_a = (\cos\phi_a \cos\lambda_a)$$
$$Z_a = (\sin\phi_a)$$

$$d = E \times \cos^{-1}(X_a X_p + Y_a Y_p + Z_a Z_p)$$