Verification of ADS-B Performance to Provide 5 Nautical Mile Separation Services in the Gulf of Mexico

ICNS 2010

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May 13, 2010

Federal Aviation Administration

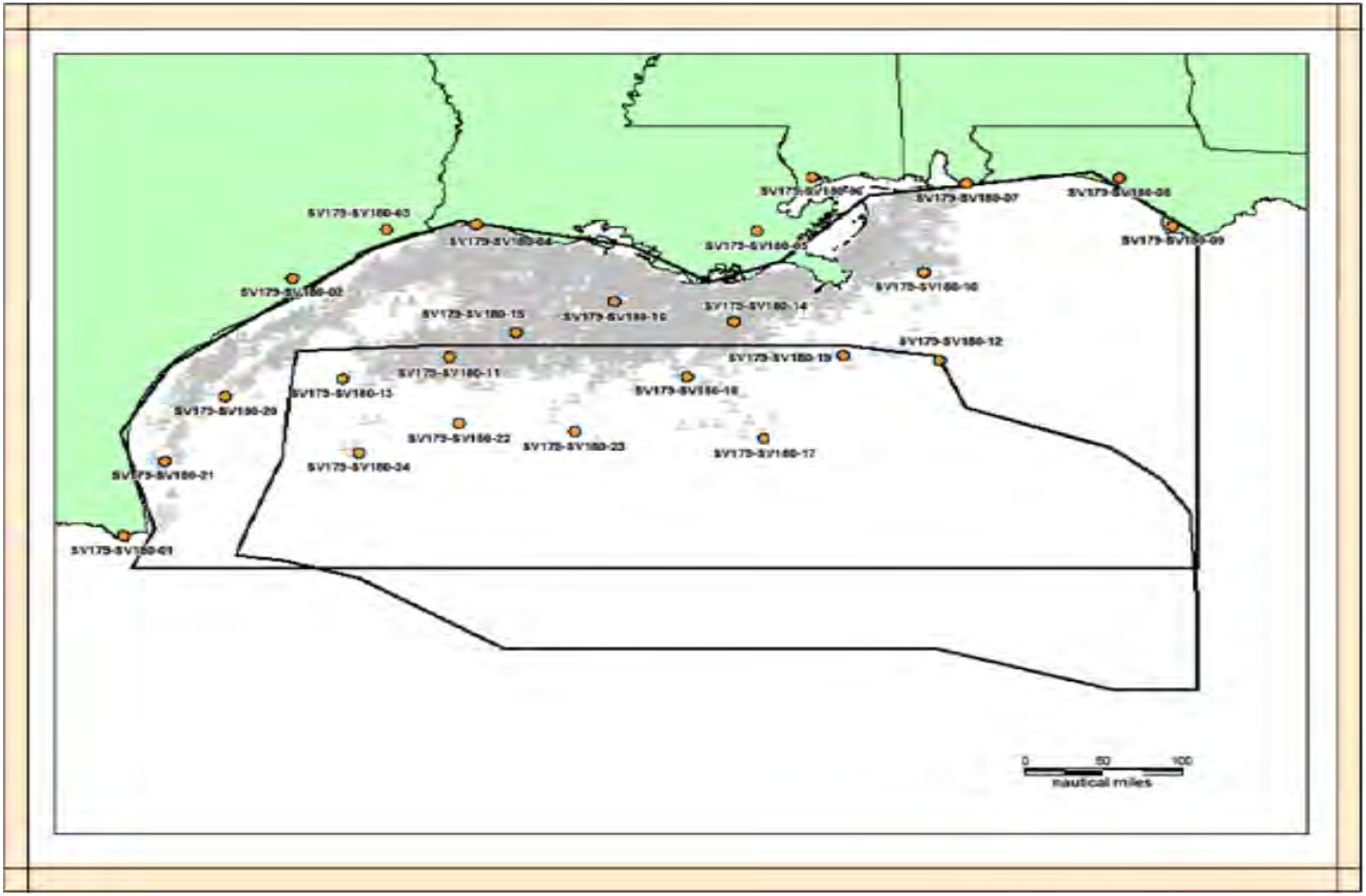
Overview

- Background
- General Approach
- Analysis of Flight Tests
- Analysis of Targets of Opportunity
- Conclusions

Background

- **Motivation**
  - Prior to Automatic Dependent Surveillance – Broadcast (ADS-B), non-radar separation was necessary in the Gulf of Mexico due to limited surveillance and air-ground communication
  - 5 NM separation using ADS-B improves capacity and streamlines IFR operations for helicopter operators, higher-altitude en route traffic, and other airspace users
- **Objective**
  - Verify ADS-B supports 5 NM en route separation services in the Gulf of Mexico using Virtual Radars
- **Automation system considerations**
  - ADS-B data was transformed to emulate MSSR data by establishing two virtual radars (VRs)
  - Host automation platform does not ingest ASTERIX data format

SBS Key Site: Gulf of Mexico

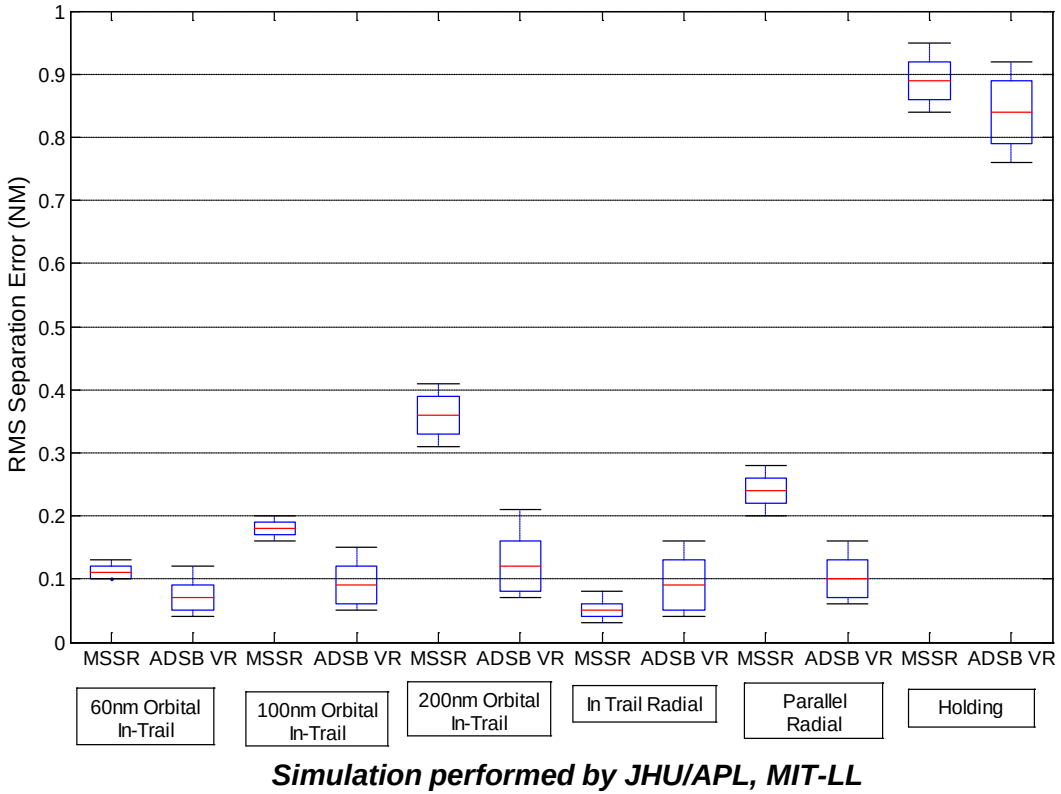


Approach

- Conduct a comparative analysis assessing existing separation standards of VRs to existing radar surveillance systems:
  - Simulation of sensor performance
  - Automation analysis
  - Flight Tests
  - Targets of Opportunity (TOO)
- Data collection required flight in airspace with coverage from MSSRs and VRs

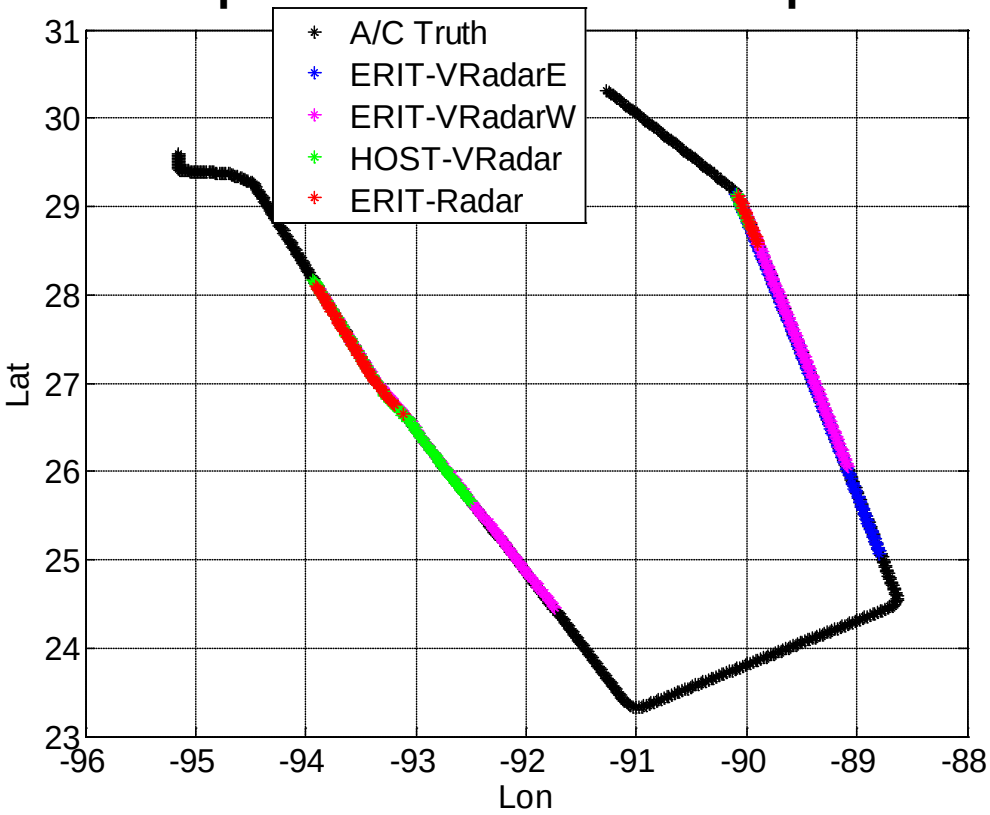
Summary of Simulation and Automation Results

Simulation Results (400 runs/scenario)



Simulation performed by JHU/APL, MIT-LL

Automation Results: Example of Aircraft Track Comparison



- Simulation results indicate that VR separation error is less than MSSR separation error in all scenarios (except *In-Trail Radial*, similar to other analyses)
- Automation results demonstrate the fidelity of the Host virtual radar reports to the reports received from the ERIT virtual radar and aircraft truth data

Flight Test Analysis

Flight Tests: Background

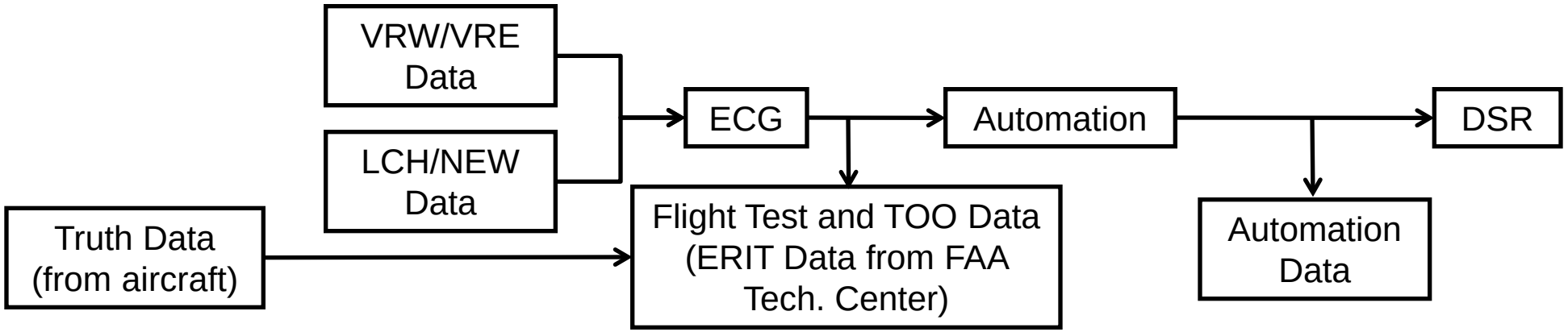
- **Overview:** Flight tests intended to validate the modeling and simulation results by assessing surveillance sensor accuracy
- Flown November 4-6, 2009 using two aircraft:

Registration	Model	General Description	Operator	1090ES Transponder	UAT Transponder
N56	Learjet 60	Twinjet	FAA/AVN	ACSS XS950	Garmin GDL 90
N200U	King Air C90A	Twin turboprop	Ohio University	ACSS XS950	Garmin GDL 90

- Aircraft were also equipped with Ashtech DGPS units to collect truth data, as well as TCAS to maintain at least 5 NM separation

Flight Tests: Data Collection

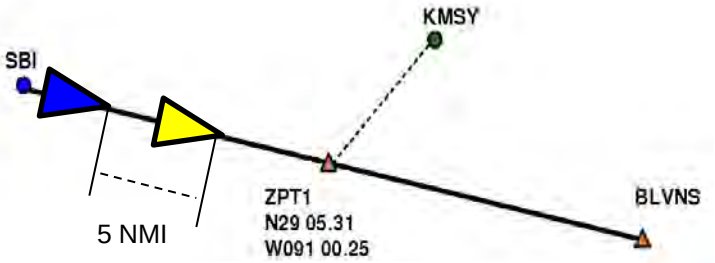
- **Data Collection:**
  - DGPS truth data provided by flight crews (1 report / second)
  - ERIT data for MSSRs and VRs provided by the FAA Technical Center via secure FTP site:
    - MSSRs: Slidell (NEW) and Lake Charles (LCH) in CD-2 format (1 report / 12 seconds)
    - Virtual radars: VRW and VRE in CD-2 format (1 report / 12 seconds)



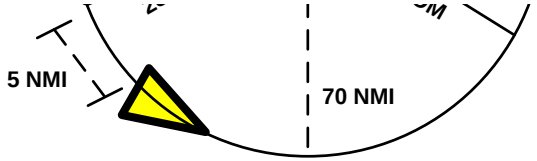
Flight Test Profiles

Equivalent to profiles flown other ADS-B key sites

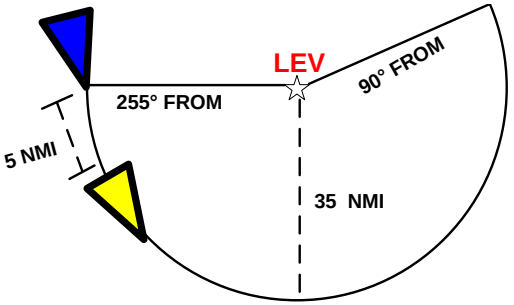
dards analysis at



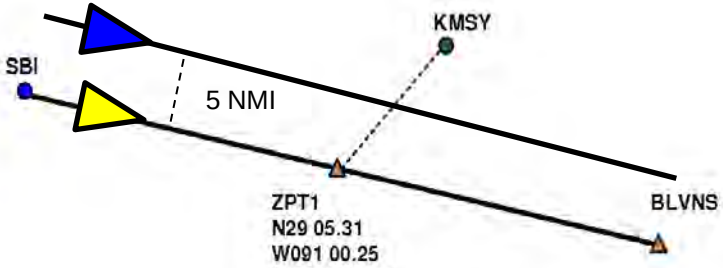
In-Trail [Sabine Pass VOR/DME (SBI) to BLVNS]



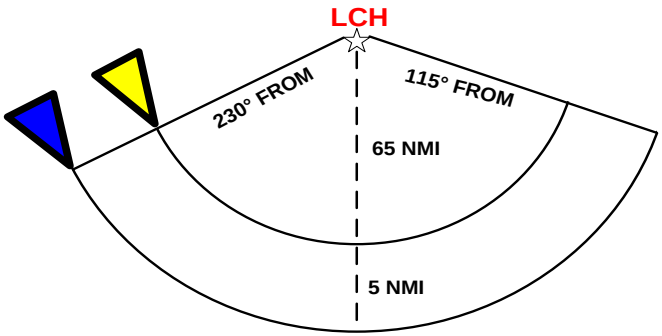
Lake Charles VORTAC (LCH) In-Trail Arc



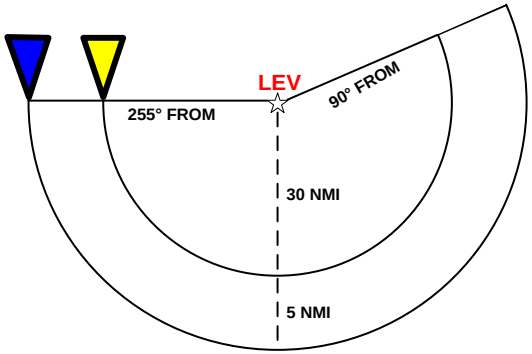
Leeville VORTAC (LEV) In-Trail Arc



Parallel [Sabine Pass VOR/DME (SBI) to BLVNS]



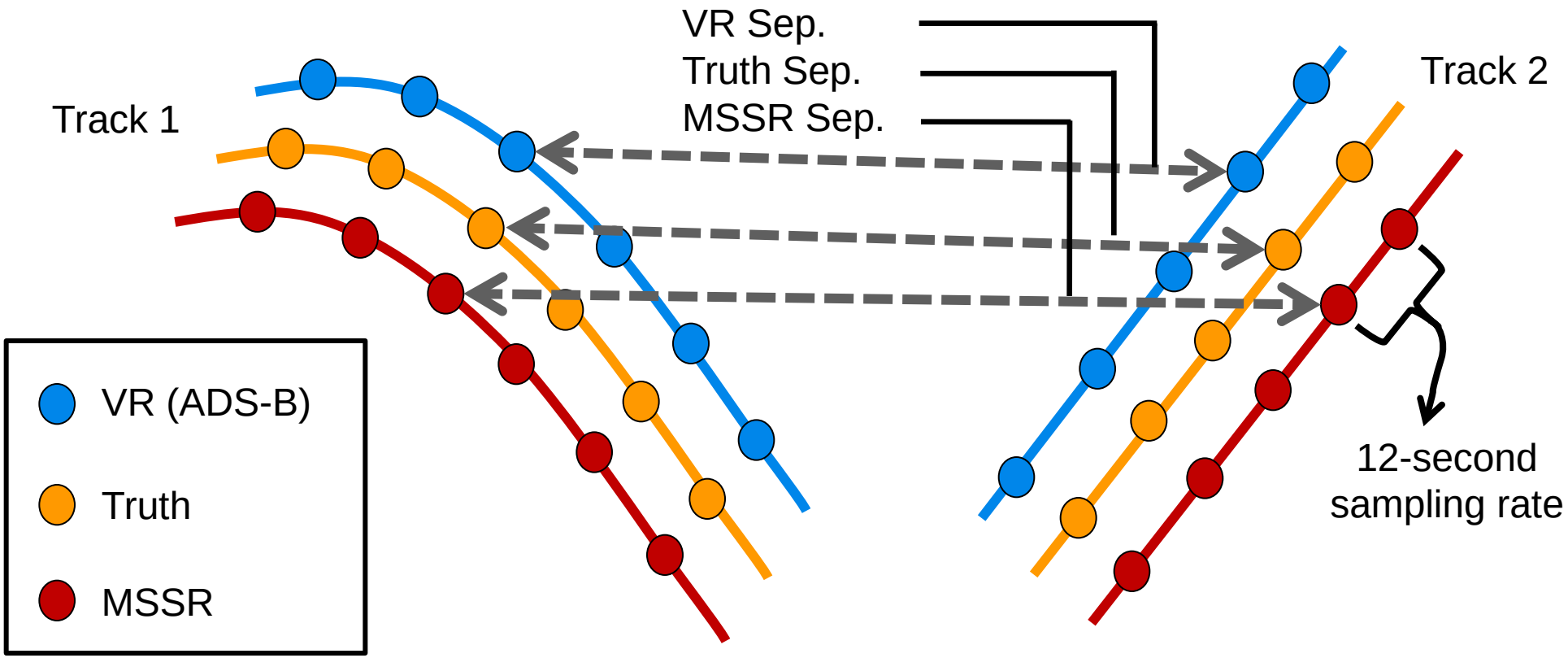
Lake Charles VORTAC (LCH) Parallel Arc



Leeville VORTAC (LEV) Parallel Arc

Separation Error Calculation

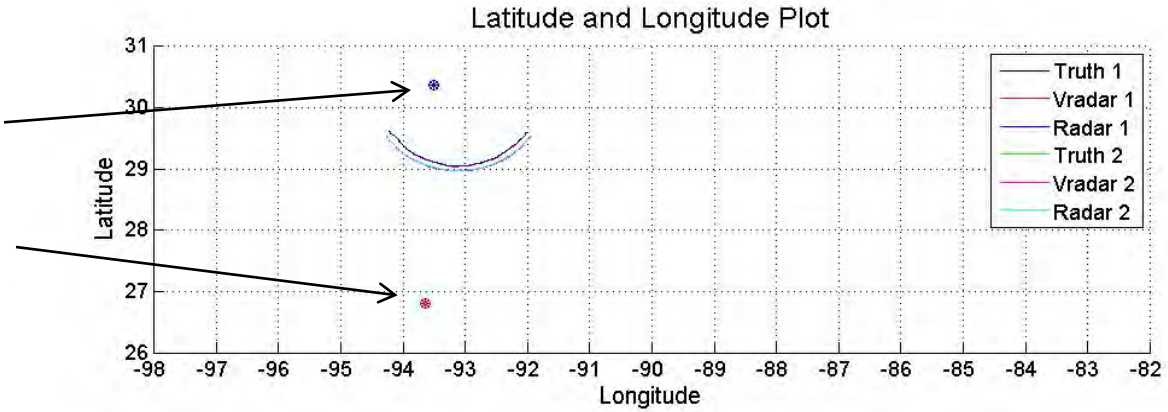
- **Quantities of Interest:**
  - Separation error of MSSRs = MSSR separation – truth separation
  - Separation error of VRs = VR separation – truth separation

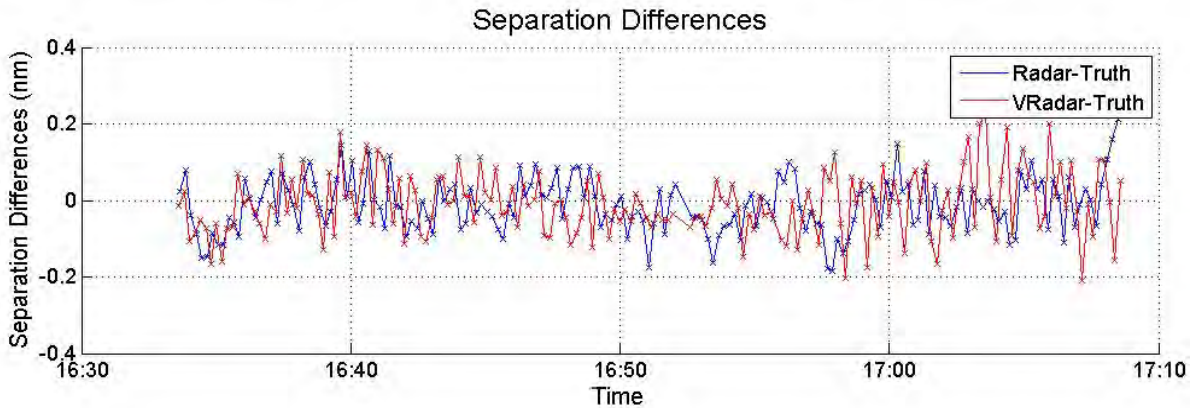


Example Results – Parallel Arc about Lake Charles VOR (LCH), both Aircraft Operating 1090ES

LCH MSSR

VRW

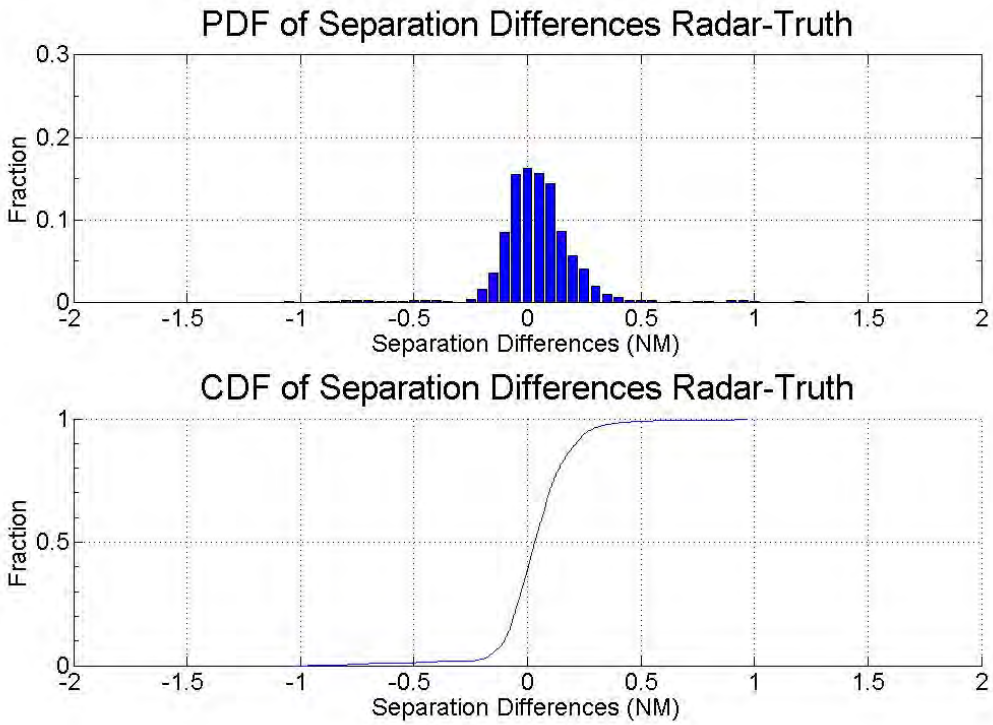




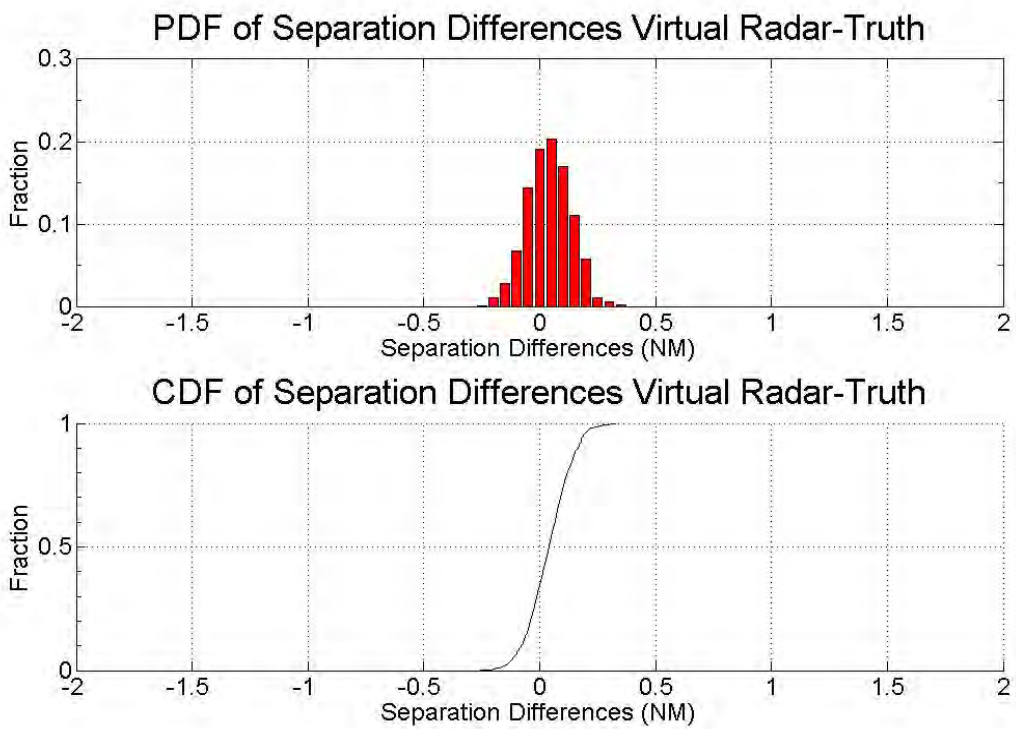
	Mean Sep. Error [NM]	Median Sep. Error [NM]	Standard Dev. [NM]	Chi Squared Value	Critical Value	5% CDF [NM]	95% CDF [NM]
Radar – Truth	-0.01	-0.02	0.07	1.03	204.69	-0.12	0.10
Virtual Radar – Truth	-0.01	-0.01	0.08	1.01	204.69	-0.14	0.13

Flight Test Summary Statistics

Radar - Truth



Virtual Radar - Truth



	Mean Sep. Error [NM]	Median Sep. Error [NM]	Standard Dev. [NM]	Chi Squared Value	Critical Value	5% CDF [NM]	95% CDF [NM]
Radar – Truth	0.04	0.03	0.17	1.05	1,922.42	-0.15	0.27
Virtual Radar – Truth	0.04	0.04	0.09	1.18	1,922.42	-0.12	0.19

Summary: Flight Test Analysis

- The mean and median of the separation errors for the virtual radars closely matched those for the MSSRs (within 0.01NM)
- The standard deviation of the separation errors for the virtual radars was 47% lower than the standard deviation of the separation errors for the MSSRs (0.09NM versus 0.17NM)
- no anomalous data was observed and no significant errors were reported by the automation systems for the remainder of the profiles

Target of Opportunity (TOO) Analysis

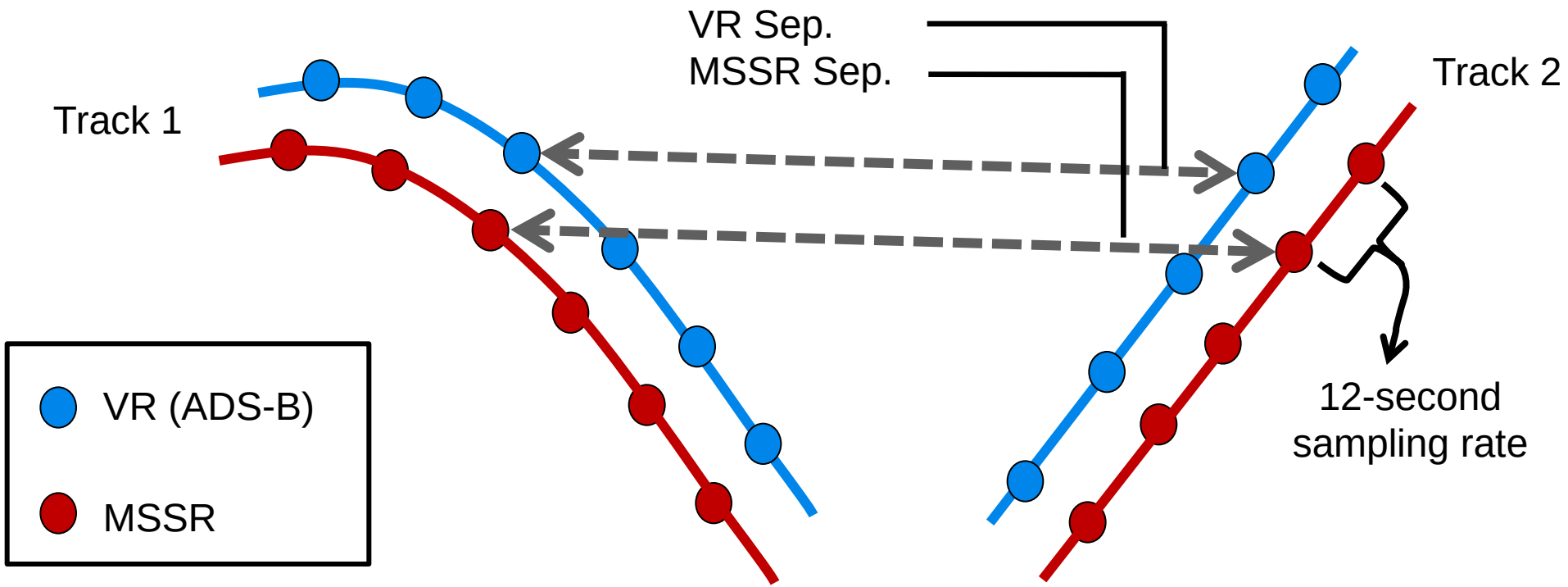
Targets of Opportunity: Background

- **TOO definition:** two aircraft which are concurrently under the surveillance of the same MSSR and VR
- **Objective:** to assess differences in the separation reported under each of six sensor permutations
  - HOU and VRW, HOU and VRE
  - LCH and VRW, LCH and VRE
  - NEW and VRW, NEW and VRE
- Data collected from September 12-21, 2009
- No truth data was collected

Note: *TOO s*tatistics report separation difference, not separation error (as reported for flight tests)

Separation Difference Calculation

- **Quantity of Interest:**
  - Separation difference = MSSR separation – VR separation
- **Analysis was performed with / without:**
  - Interpolation of MSSR reports to VR time
  - Filter for max. 5,000’ vertical separation between aircraft in the pair

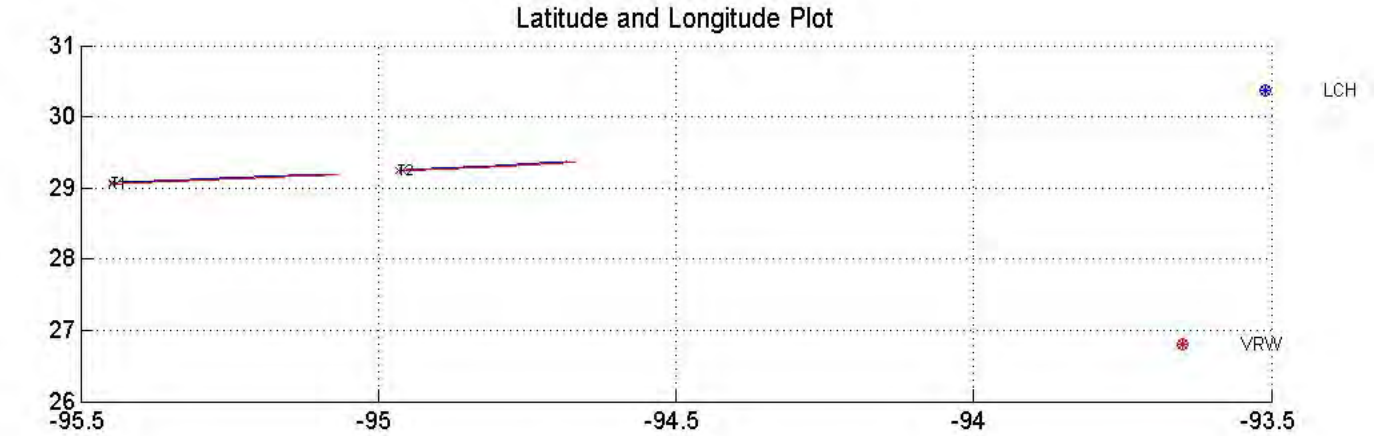


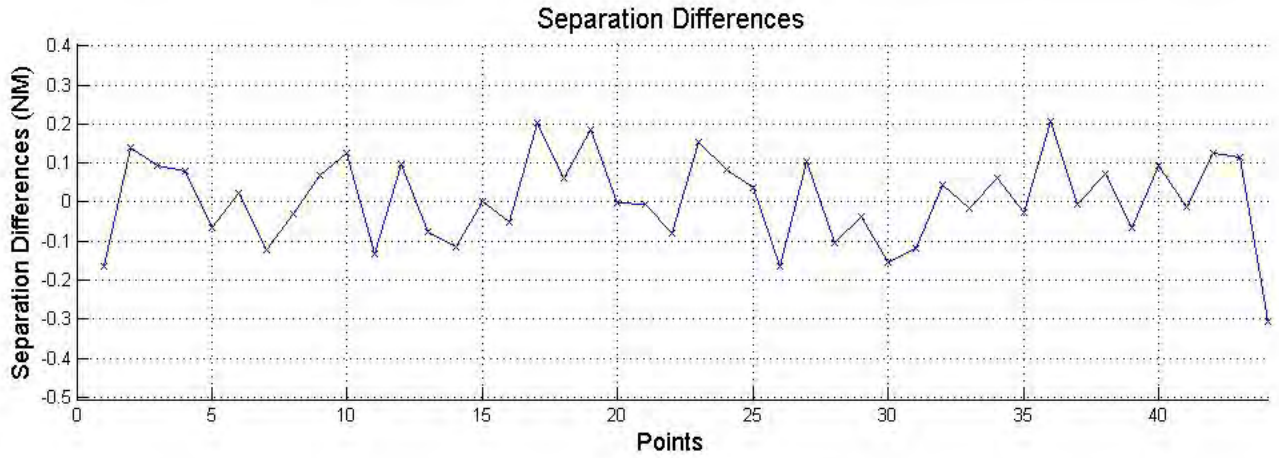
Targets of Opportunity: Data Collection

- Data delivery same as Flight Test
- Dataset contains:
  - ***General TOOs:*** Includes all operations within the airspace under consideration except for controlled TOOs
  - ***Controlled TOOs:*** Includes flights operated by Embry Riddle Aeronautical University with four aircraft between September 12-21

	General TOOs	Controlled TOOs	Percent Controlled
Total TOOs	174	124	71%
Total Data Points	32,341	29,439	91%

Example Results: LCH-VRW Sensor Permutation, Codes 4541, 4530 on September 18

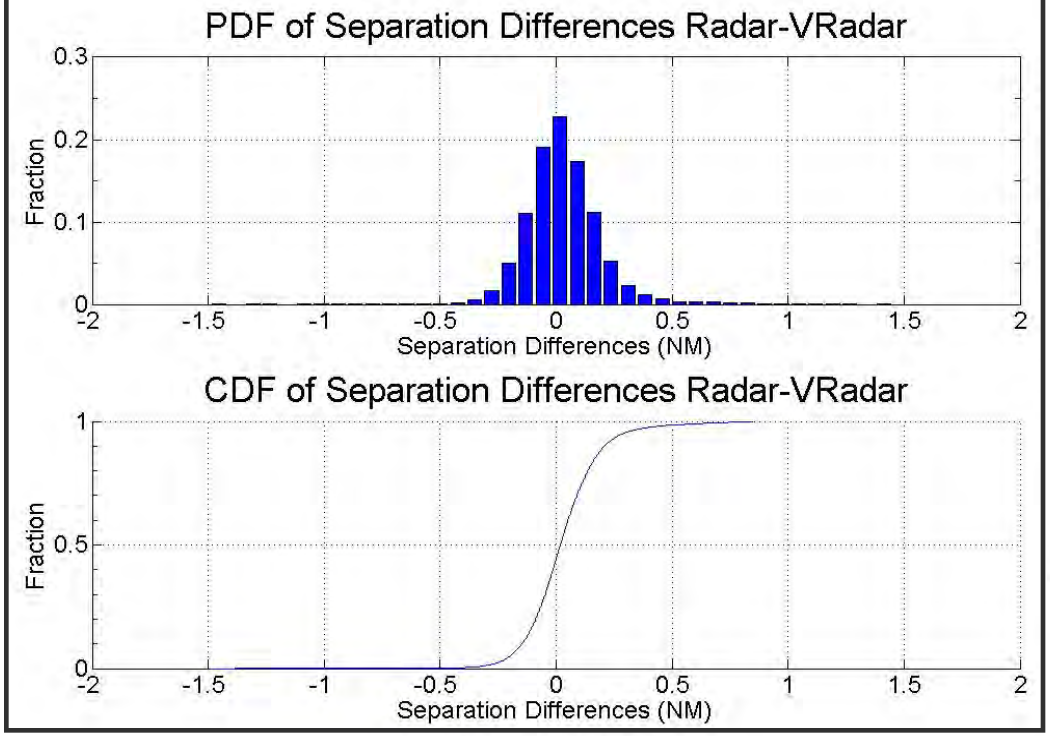




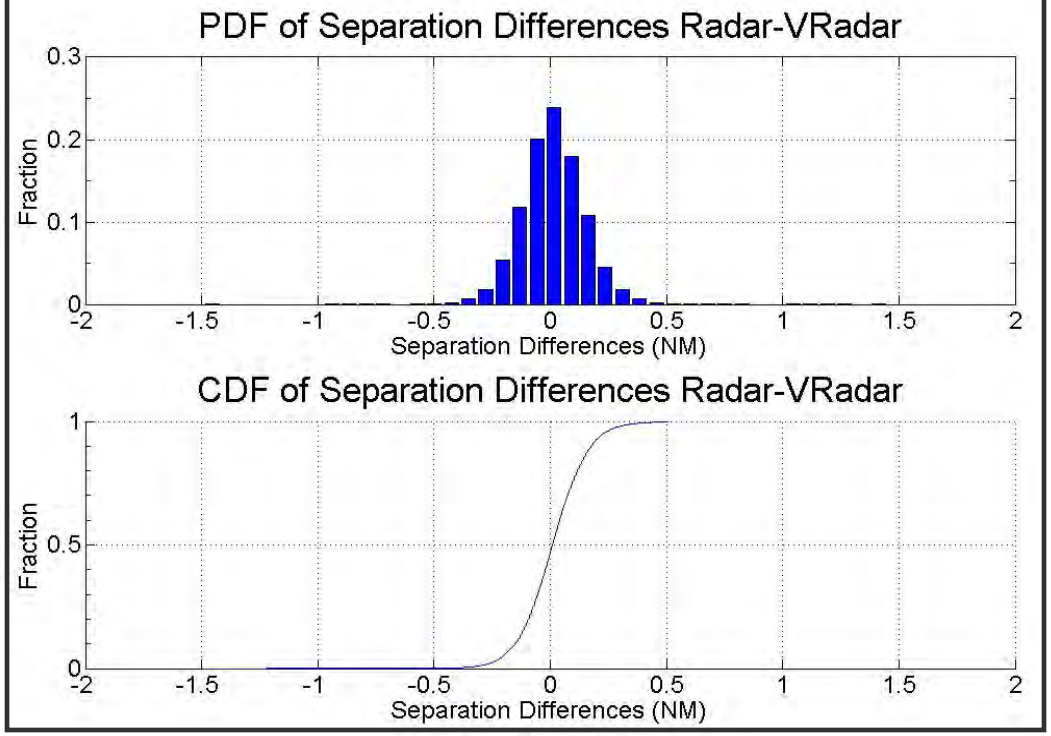
Data Points	Mean Separation Difference [NM]	Standard Dev. [NM]	Chi Squared Value	Critical Value	5% CDF [NM]	95% CDF [NM]
44	0.01	0.11	1.00	60.48	-0.16	0.19

TOO Summary Statistics

General TOOs, No Altitude Filter, No Interpolation



General TOOs, 5000' Altitude Filter, Bezier Interpolation



	TOOs	Data Points	Mean Separation Difference [NM]	Standard Dev. [NM]	Chi Squared Value	Critical Value	5% CDF [NM]	95% CDF [NM]
General, No Alt. Filter, No Interpolation	278	42,445	0.03	0.16	1.03	42,925.38	-0.20	0.29
General, 5000' Alt. Filter, Bezier Interpolation	174	32,341	0.01	0.14	1.01	32,760.46	-0.20	0.23

Summary: TOO Analysis

- The cumulative statistics demonstrate that separation differences were insignificantly different from zero with 95% confidence regardless of MSSR/virtual radar sensor permutation
- The results for “controlled” TOO pairs confirm the results for general TOO pairs
- Consistent with the flight test results, the TOO analysis reveals no discernable difference between using MSSR and virtual radar data to provide 5 NM en route separation in the Gulf of Mexico using the Host Computer System

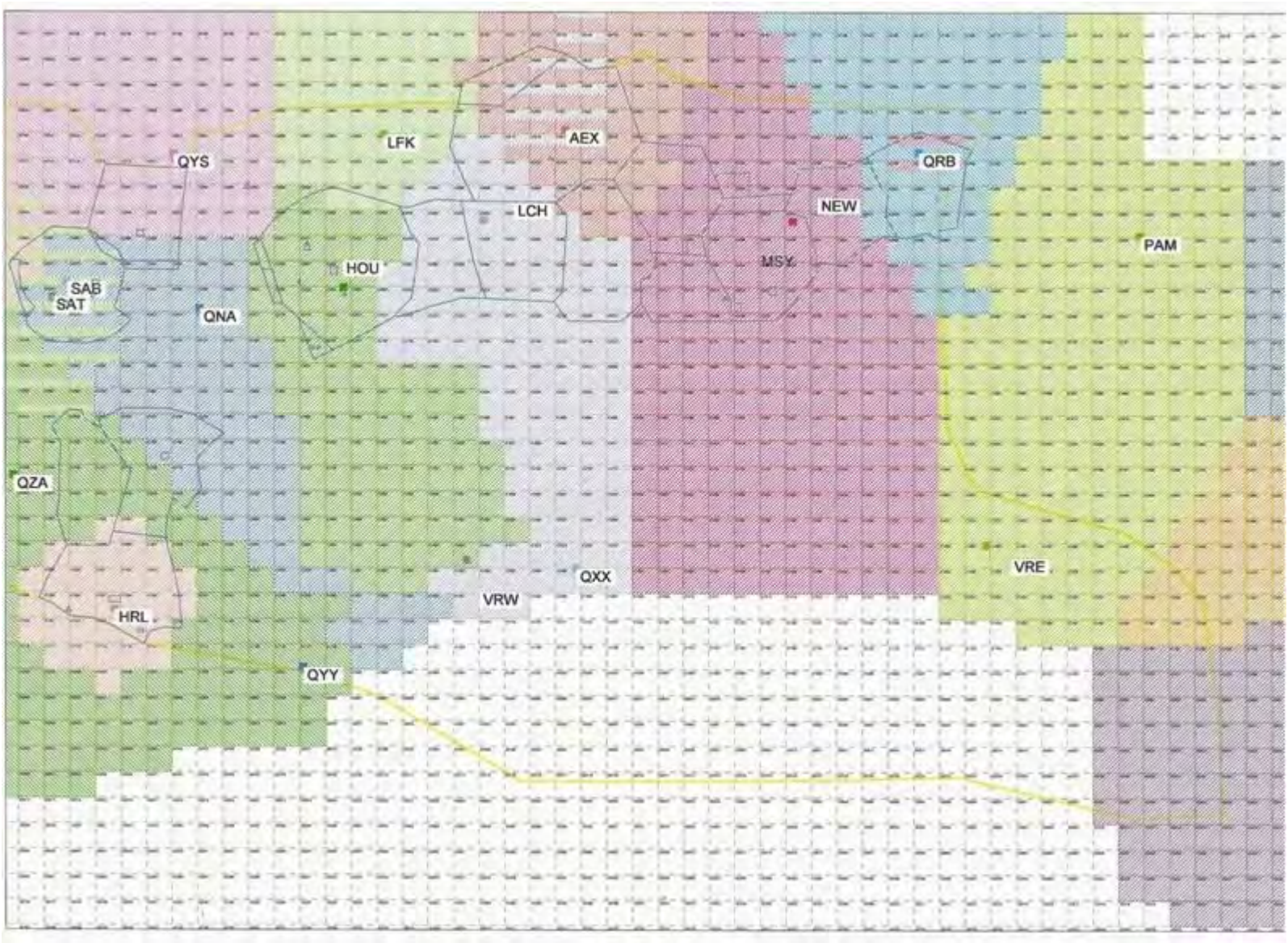
Concluding Summary

- The flight tests and TOO analysis indicate that the virtual radar system reported separation with comparable relative accuracy and equivalent absolute accuracy with respect to the radar system. The results support the conclusion that MSSR and virtual radar data may be used interchangeably to provide 5 NM en route separation using the Host Computer System.
- Initial Operating Capability (IOC) for 5 NM en route separation using ADS-B/virtual radars was declared at the Houston Air Route Traffic Control Center on December 17,2009
- Virtual radar surveillance is currently used in the provision of en route separation services in the Gulf of Mexico

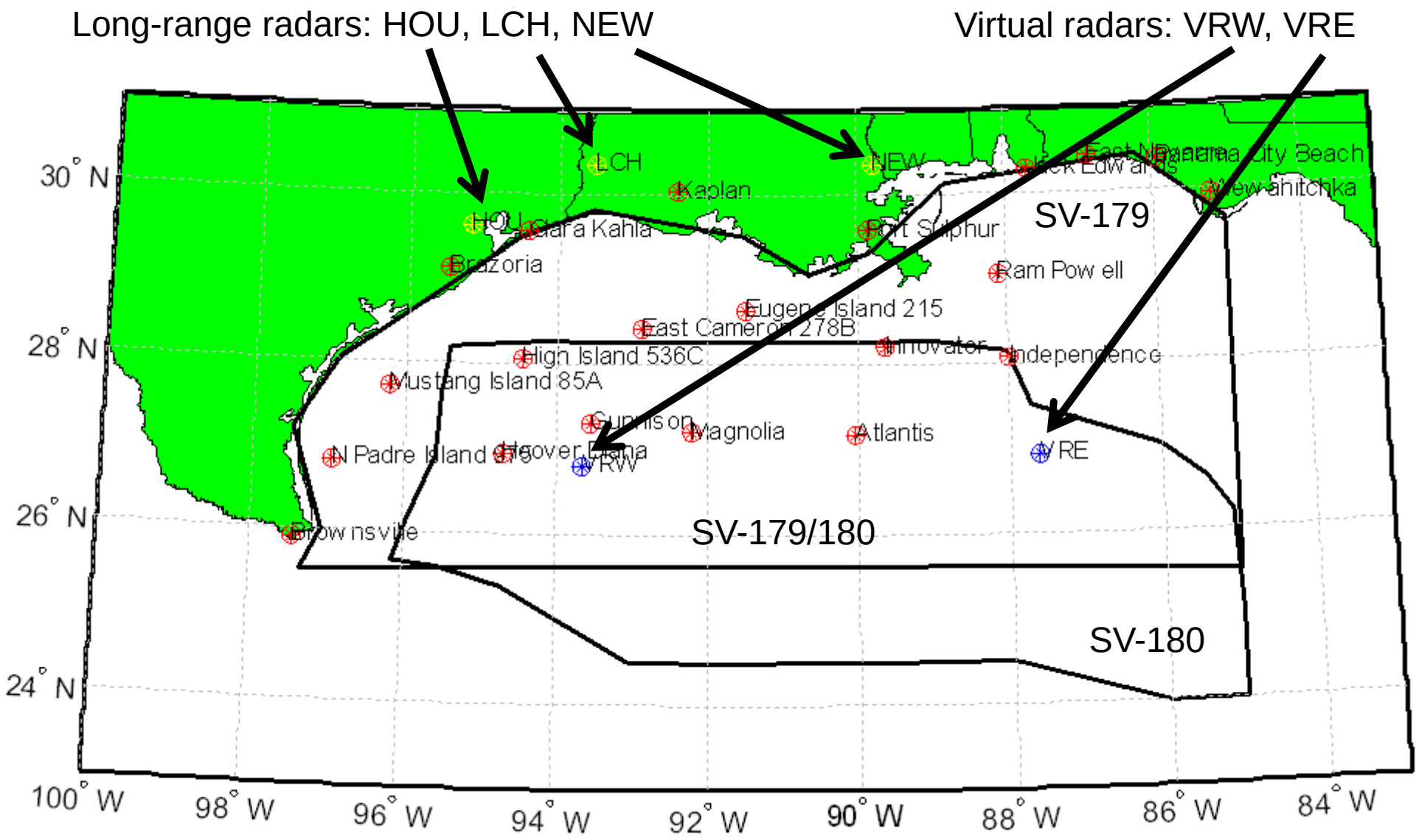
Questions

Appendix

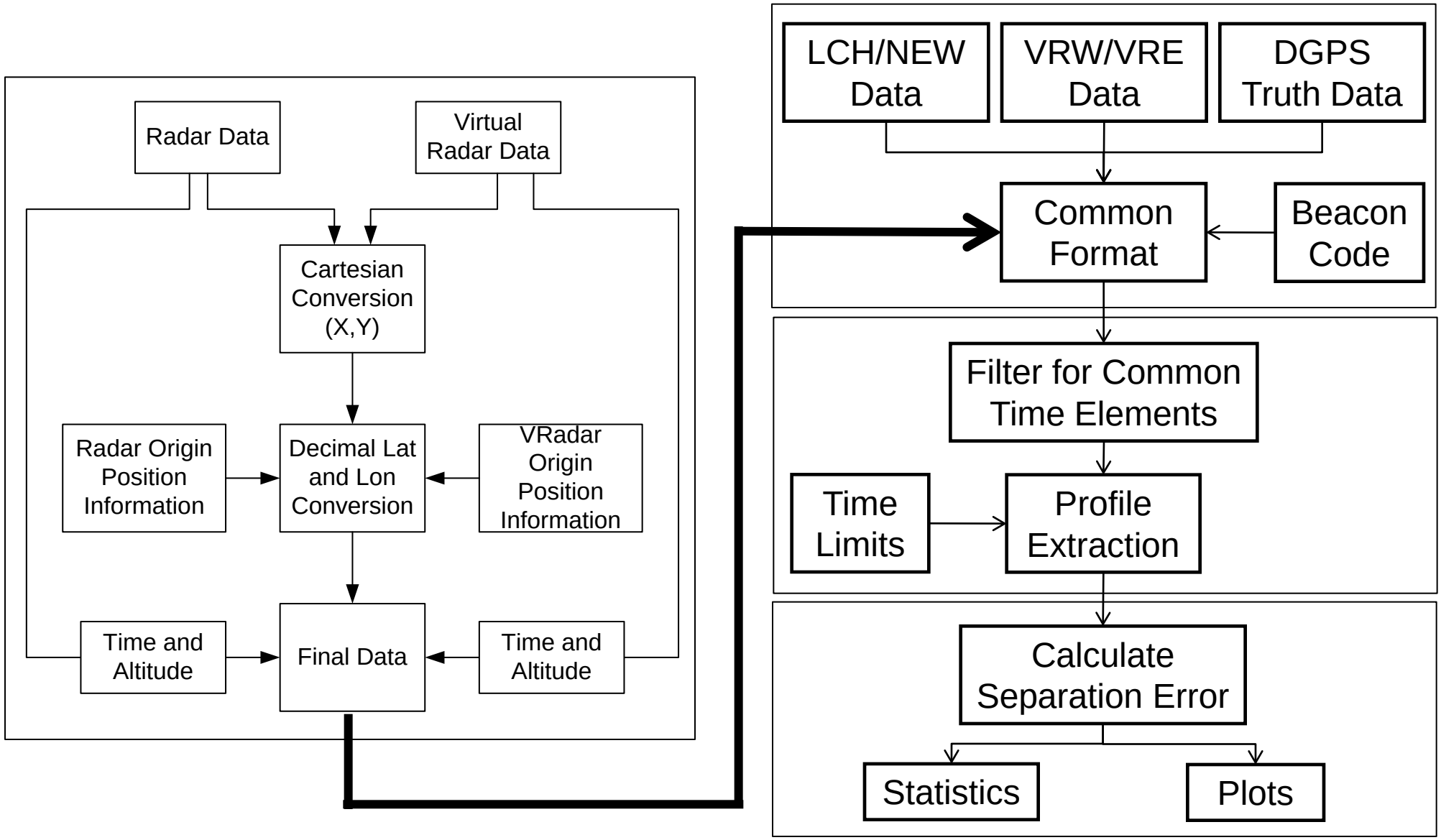
Sensor Locations



SBS Key Site: Gulf of Mexico



Flight Test Data Processing

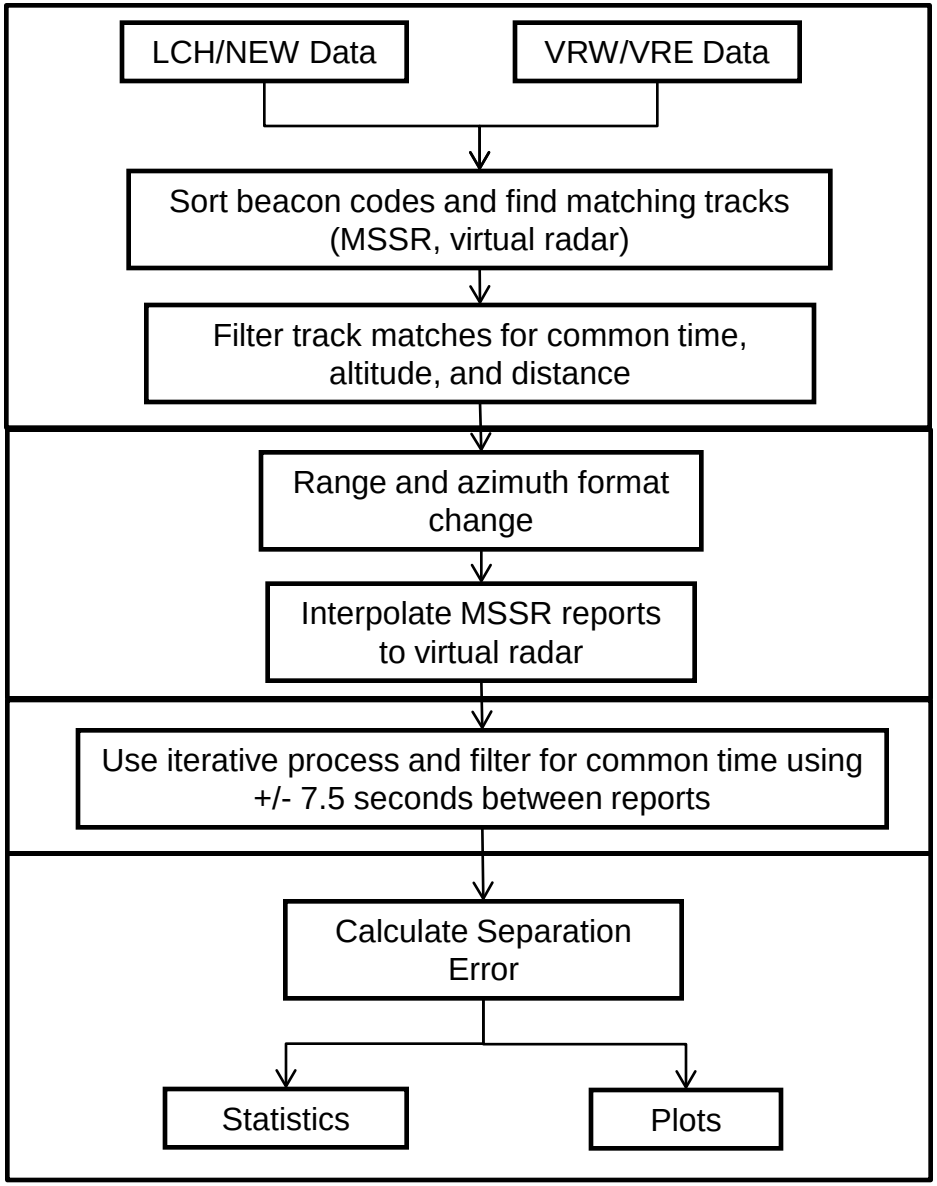


TOO Data Processing

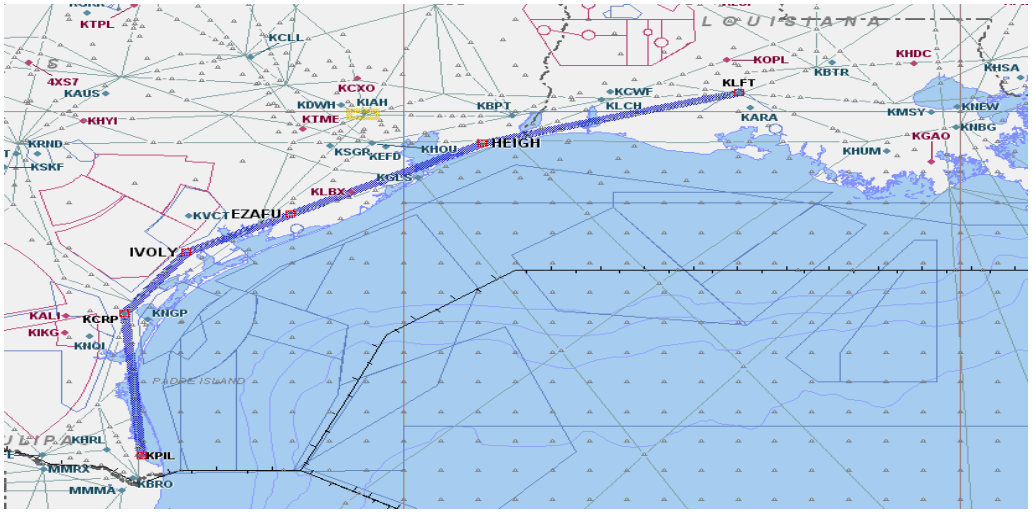
- Aircraft are matched to create a TOO pair by:
  - Time
  - Beacon code
  - Altitude (optional)
  - Distance (optional due to multiple helicopters concurrently operating on same beacon code)
- TOOs must be at least 4 points in length
- There must be no more than 7.5 seconds between MSSR and virtual radar reports for comparison to occur
- The analysis can be performed with or without the interpolation of the MSSR reports to the virtual radar reports (using a Bezier polynomial)
- **Quantity of interest:**

  Separation Difference =

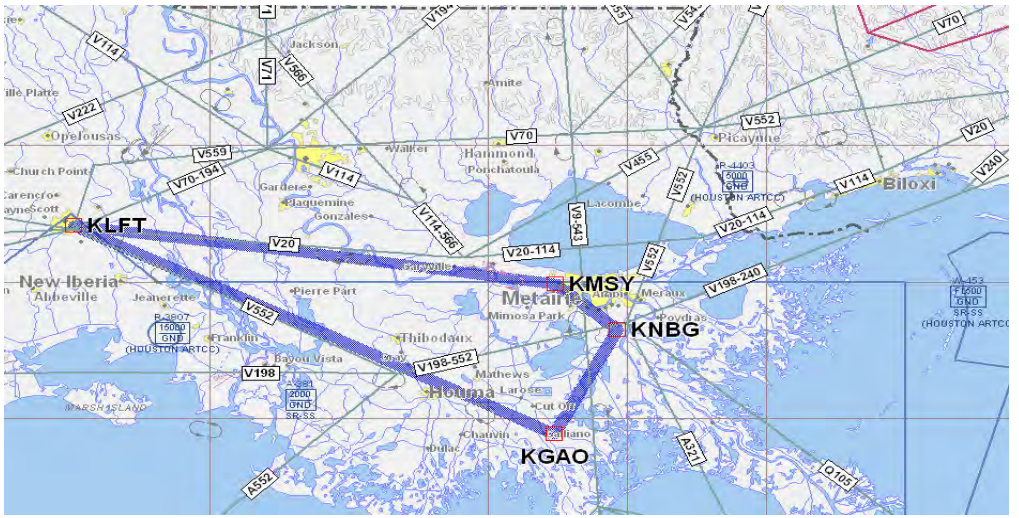
  MSSR Separation – VR Separation



Controlled TOO Flight Profiles



Lafayette, LA (KLFT) to Port Isabel, TX (KPIL)



Lafayette, LA (KLFT) to Lafayette, LA (KLFT)

Lafayette, LA (KLFT) to Corpus Christi, TX (KCRP)

Lafayette, LA (KLFT) to Mobile, AL (KMOB)