NWRA

NorthWest Research Associates, Inc.
Redmond, WA

Assessment of Pulsed Lidar Measurements of Aircraft Wake Vortex Positions Using a Lidar Simulator

Presenter: Dr. Donald P. Delisi
NorthWest Research Associates

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Contributors

David Lai – NorthWest Research Associates

Don Jacob – Lockheed Martin Coherent Technologies, Inc.

Steve Hannon – Lockheed Martin Coherent Technologies, Inc.

Fred Proctor - NASA Langley Research Center

Neil O'Connor – NASA Langley Research Center, Contract Technical Monitor

Outline

- Background
- Summary of simulation runs
- Major findings
- Additional simulations in progress

Background

- Lidar measurements are used to estimate the lateral and vertical positions of wake vortices and their circulations as they change with time
- Understanding the accuracy of lidar wake measurements is important for:
  - Validation of wake prediction models, since the models use the field data as “truth”
  - Development of probabilistic wake prediction models

Accuracy of the Pulsed Lidar Measurements

- We do not know the accuracy of the pulsed Lidar measurements since we do not have known data to compare to the measurements
- Here, we show the results of a study to evaluate the accuracy of pulsed Lidar measurements for tracking wake vortices and estimating their strength using known “truth” data

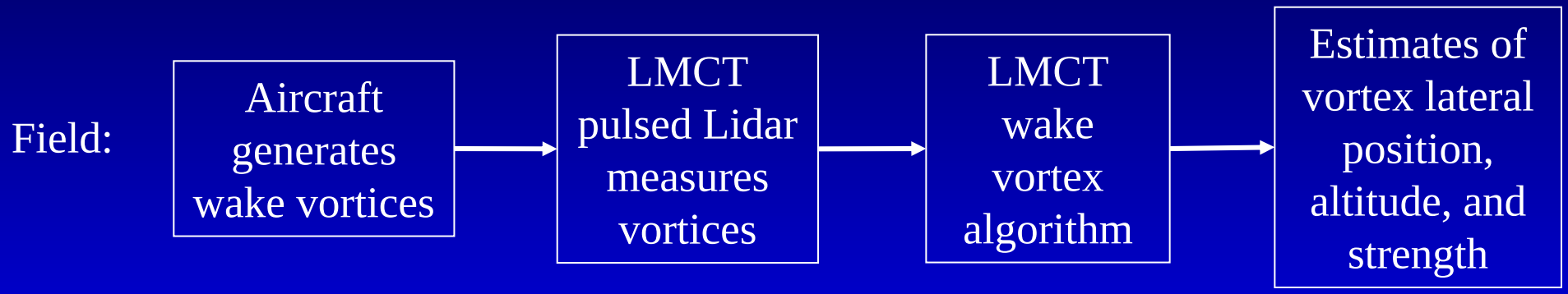
Lidar Simulator Tool

- Study utilizes a Lidar Simulator Tool, built by LMCT, to simulate the LMCT pulsed Lidar
  - Assumes the same LMCT Lidar used in field measurements of aircraft wake vortices by the FAA, Eurocontrol, DLR and others
  - Uses the same processing software as in many field measurements for determining vortex position and circulation

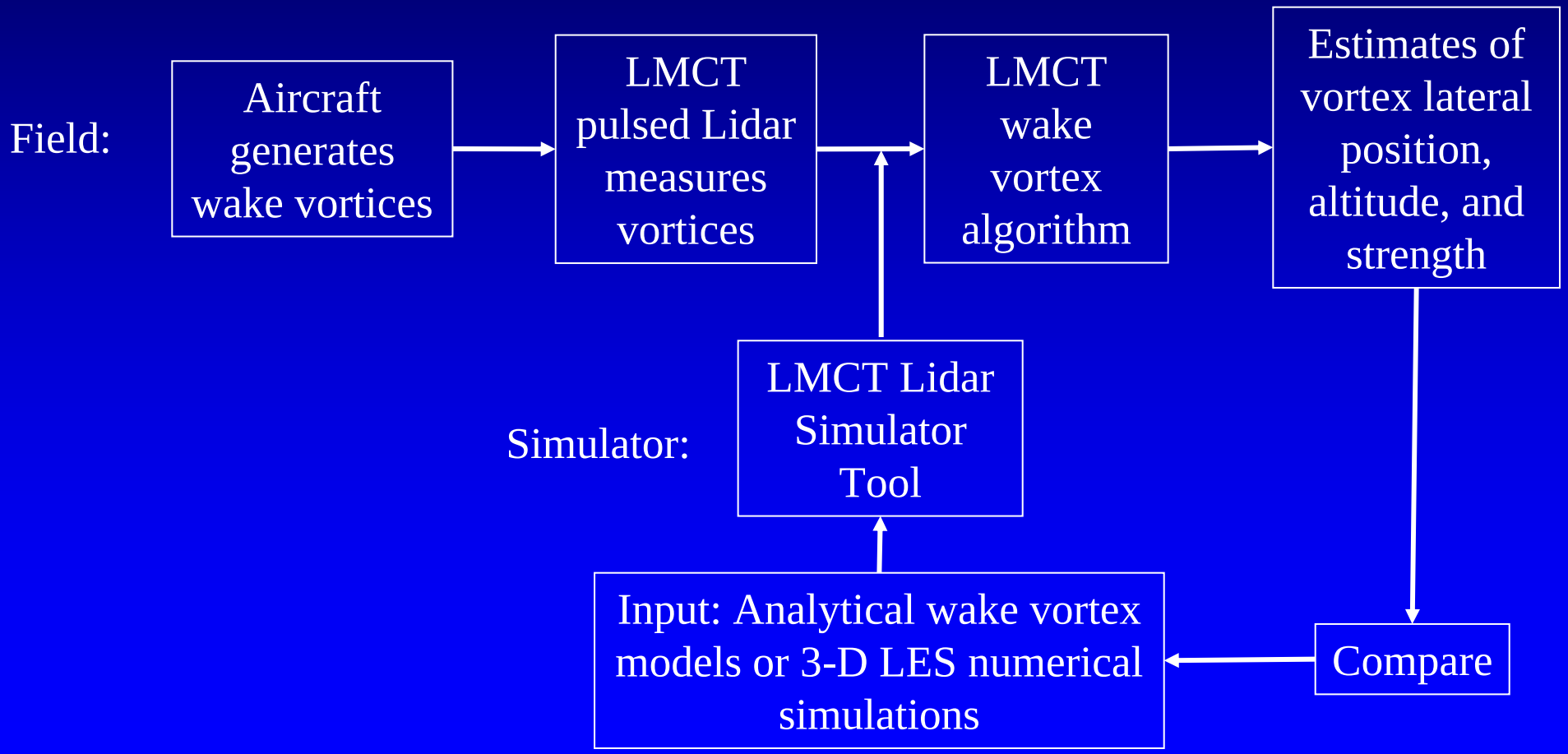
Input to the Lidar Simulation Tool

- Simulator uses input from analytical models and 3-D Large Eddy Simulation (LES) numerical model output (provided by NASA) as “truth” velocity fields
- Differences between the simulator results and the analytical and LES model results (used as input) are used to estimate the accuracy of the Lidar wake vortex measurements

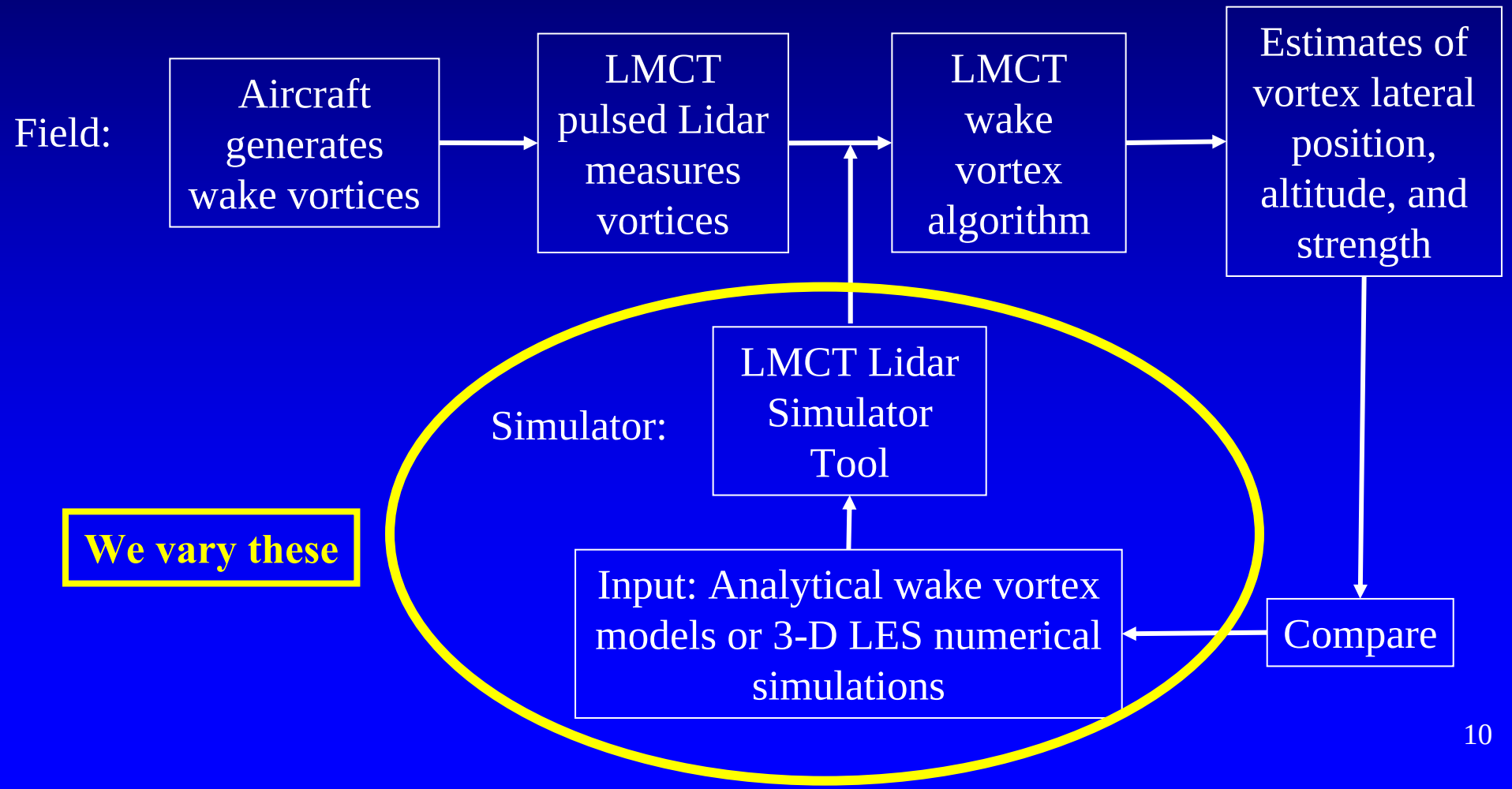
Lidar Field Measurements



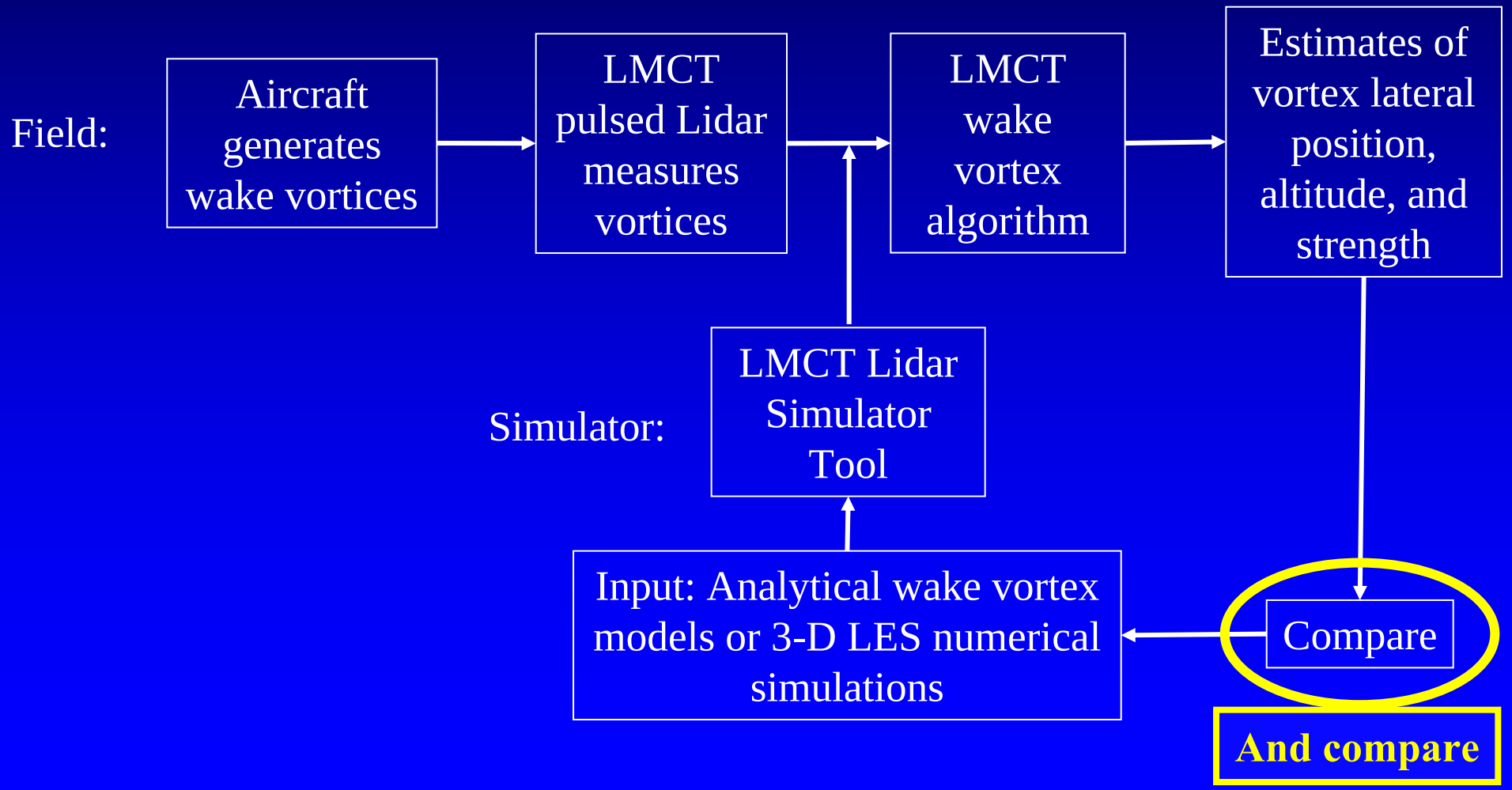
Lidar Simulator Tool



Lidar Simulator Tool



Lidar Simulator Tool



Lidar Simulation Runs Performed and Underway

- Simulations have been or are being performed to assess the Lidar sensitivity to:
  - Different aircraft (B747 and A319)
  - Region of Interest (ROI) edges
  - Signal to Noise Ratio (SNR)
  - Matched filter (MF) core size
  - Different analytical models (Burnham-Hallock (BH), Lamb-Oseen, and TASS initial vortex profiles)
  - Crosswind (analytical models only)
  - Different atmospheric turbulence intensities
  - Different glide slope regions (LES data only)
  - Linking and ring formation (LES data only)

Vortex Conditions Used in the Analytical Vortex Models

	B747	A319
Γo (m^2/s)	565	255
bo (m)	50	27
Vortex Core Radius (m)	3.8	2
Decay Time (s)	167	108
SNR (dB)	5, 10, 15	5, 10, 15
MF Core Size (m)	2.5, 3.8, 4.5	1.0, 2.0, 3.0
Crosswind (m/s)	0, ± 2, ± 5	0, ± 2, ± 5

Vortex Conditions Used in the Analytical Vortex Models

	B747	A319
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Decay Time (s)	167	108
SNR (dB)	5, 10, 15	5, 10, 15
MF Core Size (m)	2.5, 3.8, 4.5	1.0, 2.0, 3.0
Crosswind (m/s)	0, ± 2, ± 5	0, ± 2, ± 5

9 combinations each

Vortex Conditions Used in the 3D Numerical LES Simulations

	B747	A319
Γo (m^2/s)	565	255
bo (m)	50	27
Vortex Core Radius (m)	3.8	2.0
Turbulence, ε (m^2/s^3)	$1.45x10^{-2}$, $5x10^{-4}$, $4x10^{-5}$	
SNR (dB)	5, 10, 15	5, 10, 15
MF Core Size (m)	2.5, 3.8, 4.5	1.0, 2.0, 3.0
Glide Slope Region	OGE, IGE	OGE, IGE
Crosswind (m/s)	0	0

Vortex Conditions Used in the 3D Numerical LES Simulations

	B747	A319
Γo (m^2/s)	565	255
bo (m)	50	27
Vortex Core Radius (m)	3.8	2.0
Turbulence, ε (m^2/s^3)	$1.45x10^{-2}$, $5x10^{-4}$, $4x10^{-5}$	
SNR (dB)	5, 10, 15	5, 10, 15
MF Core Size (m)	2.5, 3.8, 4.5	1.0, 2.0, 3.0
Glide Slope Region	OGE, IGE	OGE, IGE
Crosswind (m/s)	0	0

18 combinations each

Focus of This Presentation

- In this presentation, only position errors are examined
- No crosswinds are used
- Lidar scan plane perpendicular to aircraft track, with the lidar located 1250 m (4100 ft) from the initial wake vortices
- Wake vortices are out of ground effect (OGE)

Lidar Simulation Runs Presented

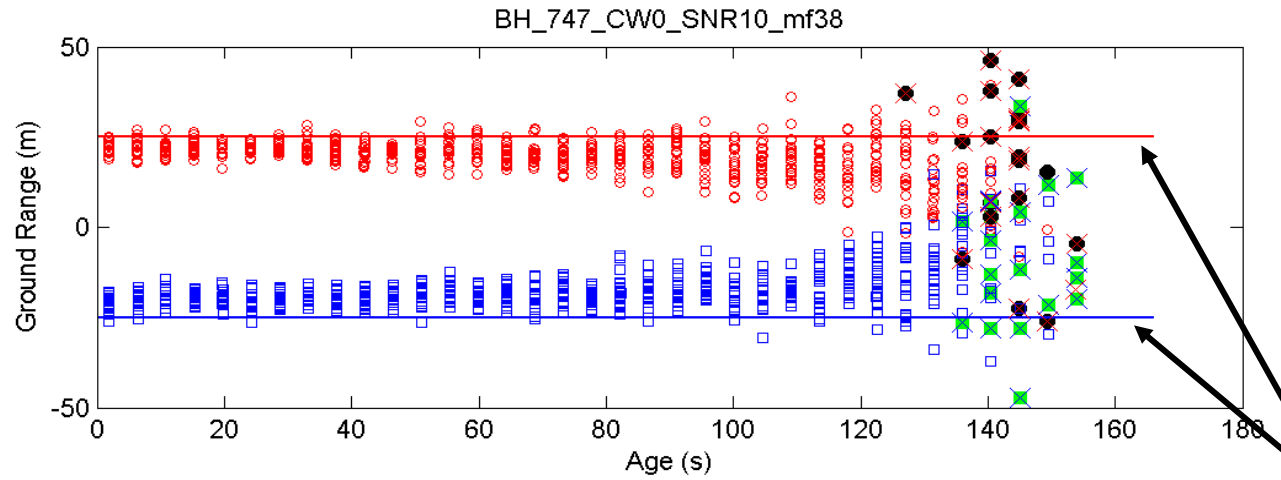
	Number of Cases (vary SNR, MF core size)	Total Simulations*	Remarks
BH - B747	9	180	No crosswind
BH - A319	9	180	No crosswind
LES - B747 OGE	18	360	Moderate and weak turbulence
LES - A319 OGE	18	360	Moderate and weak turbulence

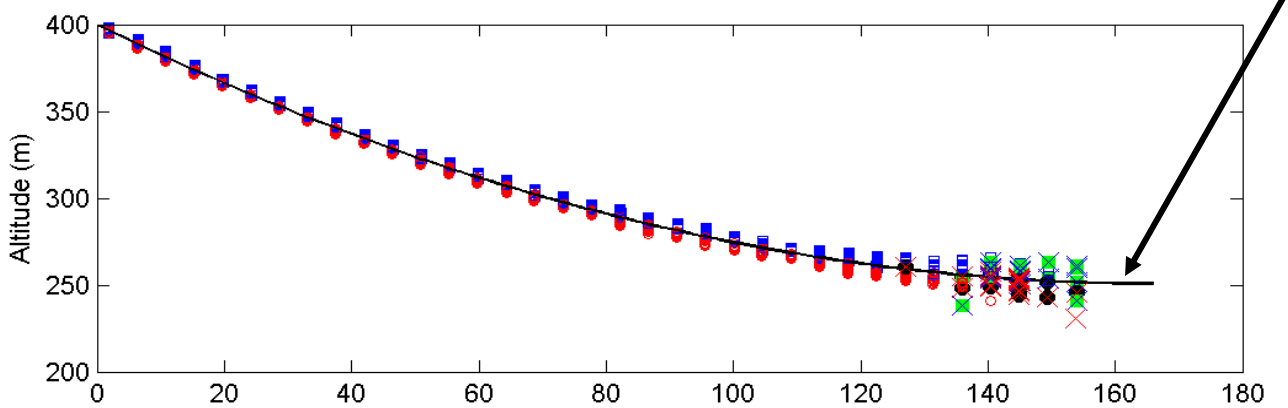
* 20 simulation runs (random realizations) per case: simulation results vary due to particle scatter

Major Findings for Lateral and Vertical Position

- Lateral position and altitude estimates are
  - Insensitive to SNR
  - Insensitive to combinations of vortex core radius and matched filter core radius
- Mean bias for lateral position: 4-8 m
- Mean bias for altitude: 2-4 m
- Vortex lateral separation errors are larger at large wake ages (weak circulations)

Example of Lidar Simulation Output: B747 (BH Model)

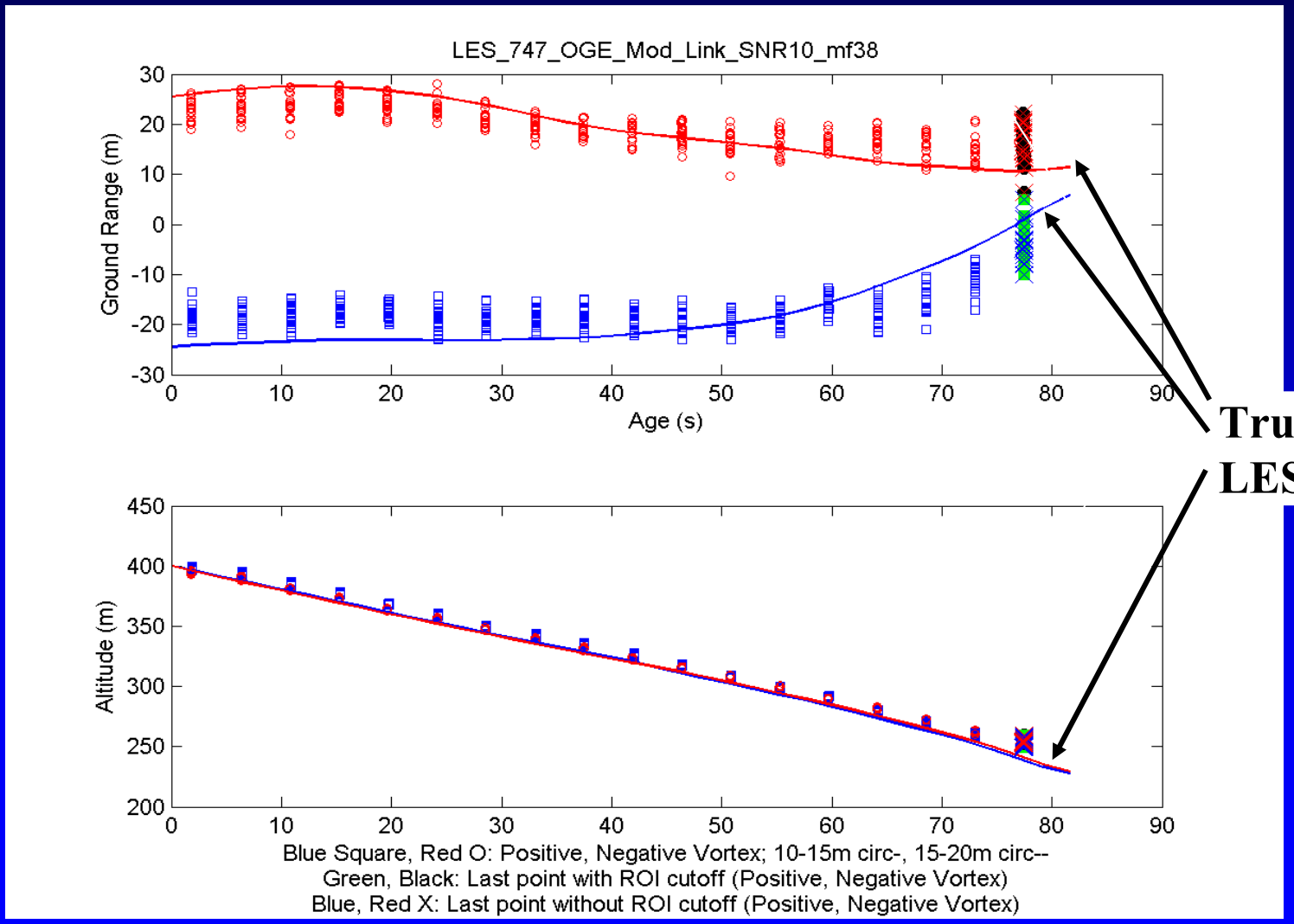




Truth: BH Model

Blue Square, Red O: Positive, Negative Vortex; 10-15m circ-, 15-20m circ--
Green, Black: Last point with ROI cutoff (Positive, Negative Vortex)
Blue, Red X: Last point without ROI cutoff (Positive, Negative Vortex)

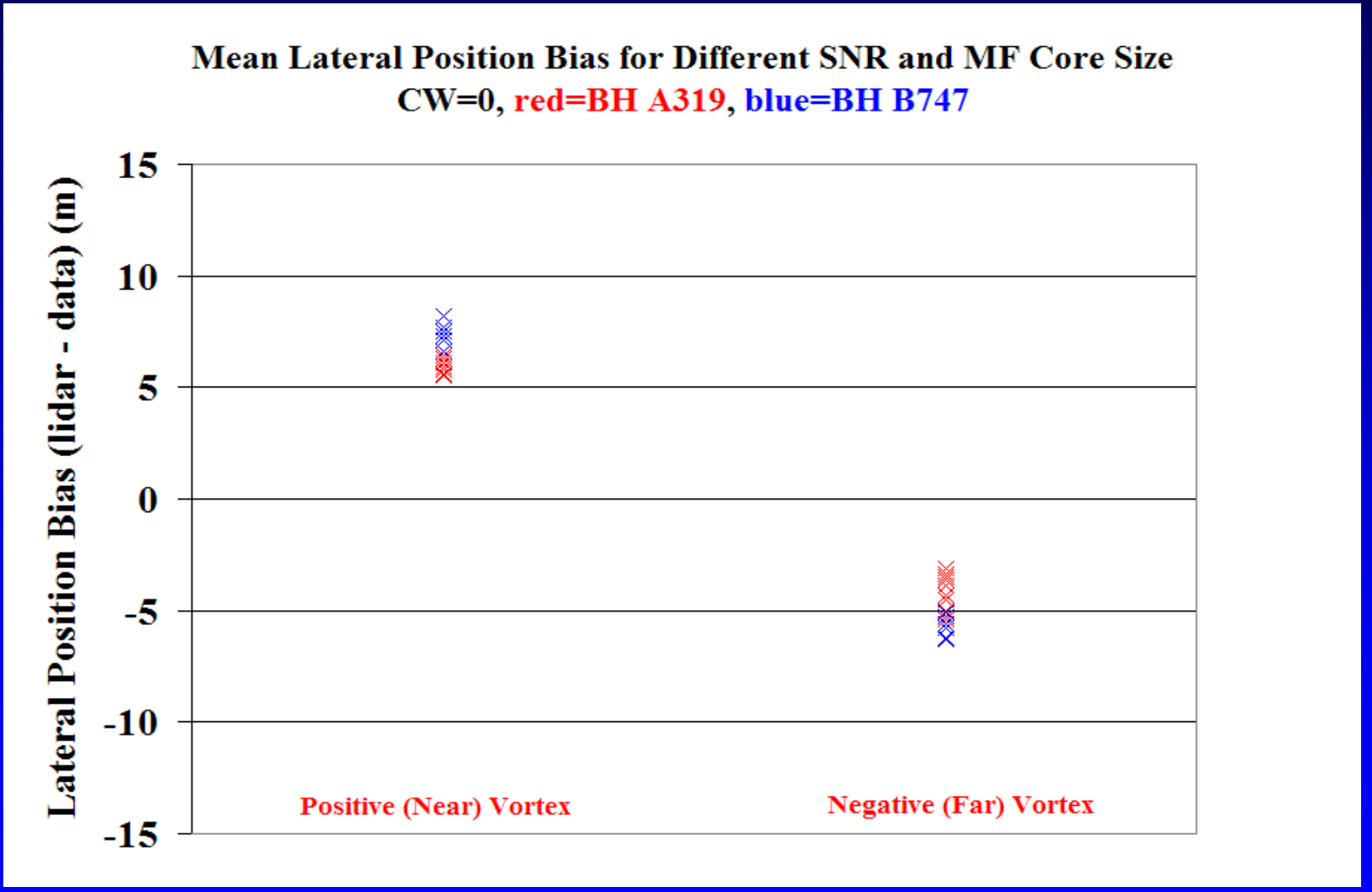
Example of Lidar Simulation Output: B747 (LES Model; Moderate Turbulence)



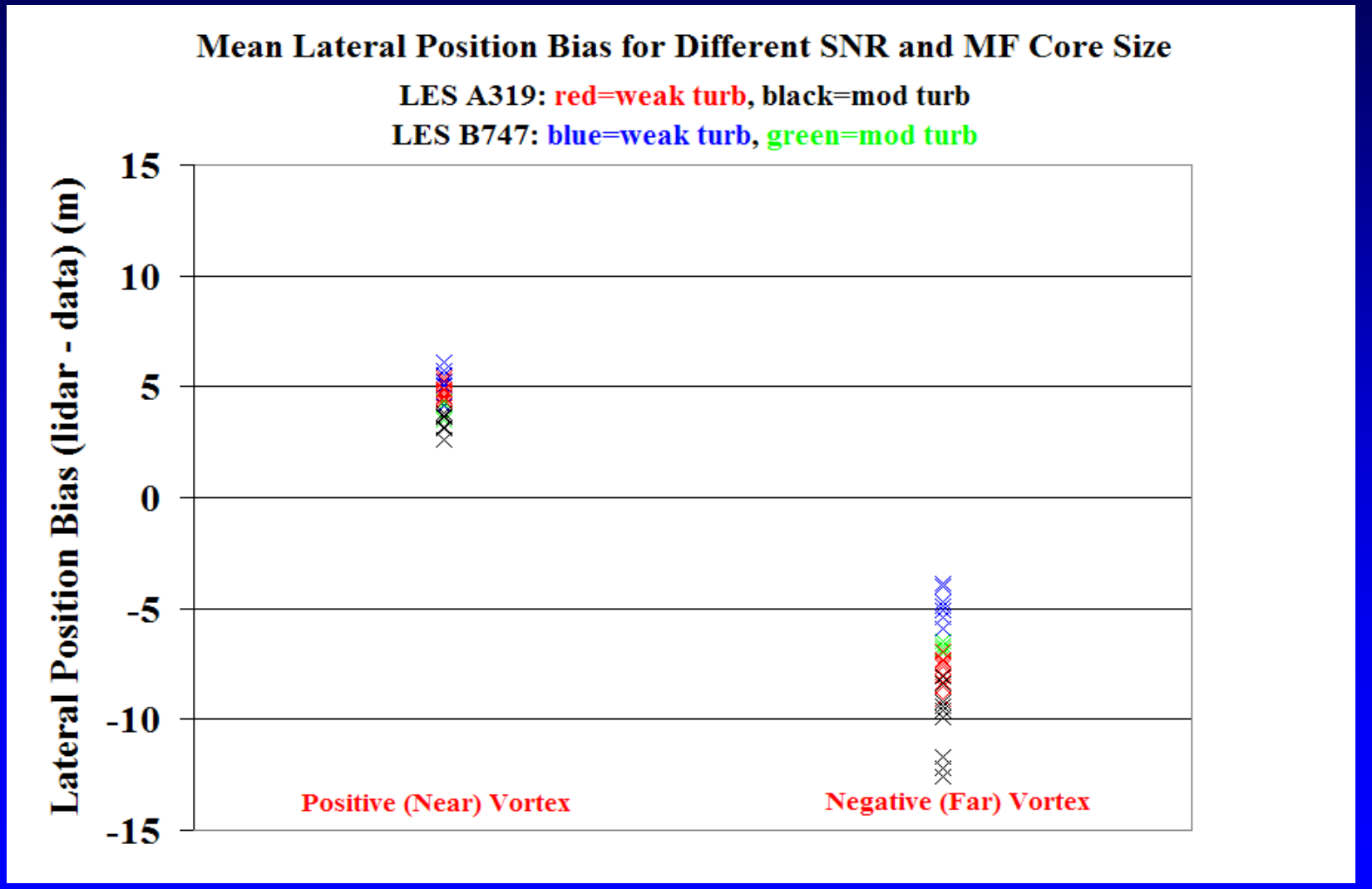
Sensitivity to SNR and Matched Filter Core Size

- For BH with no crosswind and for LES cases with no crosswind:
  - Lateral position and altitude estimates are insensitive to SNR (5-15 dB)
  - Lateral position and altitude estimates are insensitive to combinations of vortex core radius and matched filter core radius

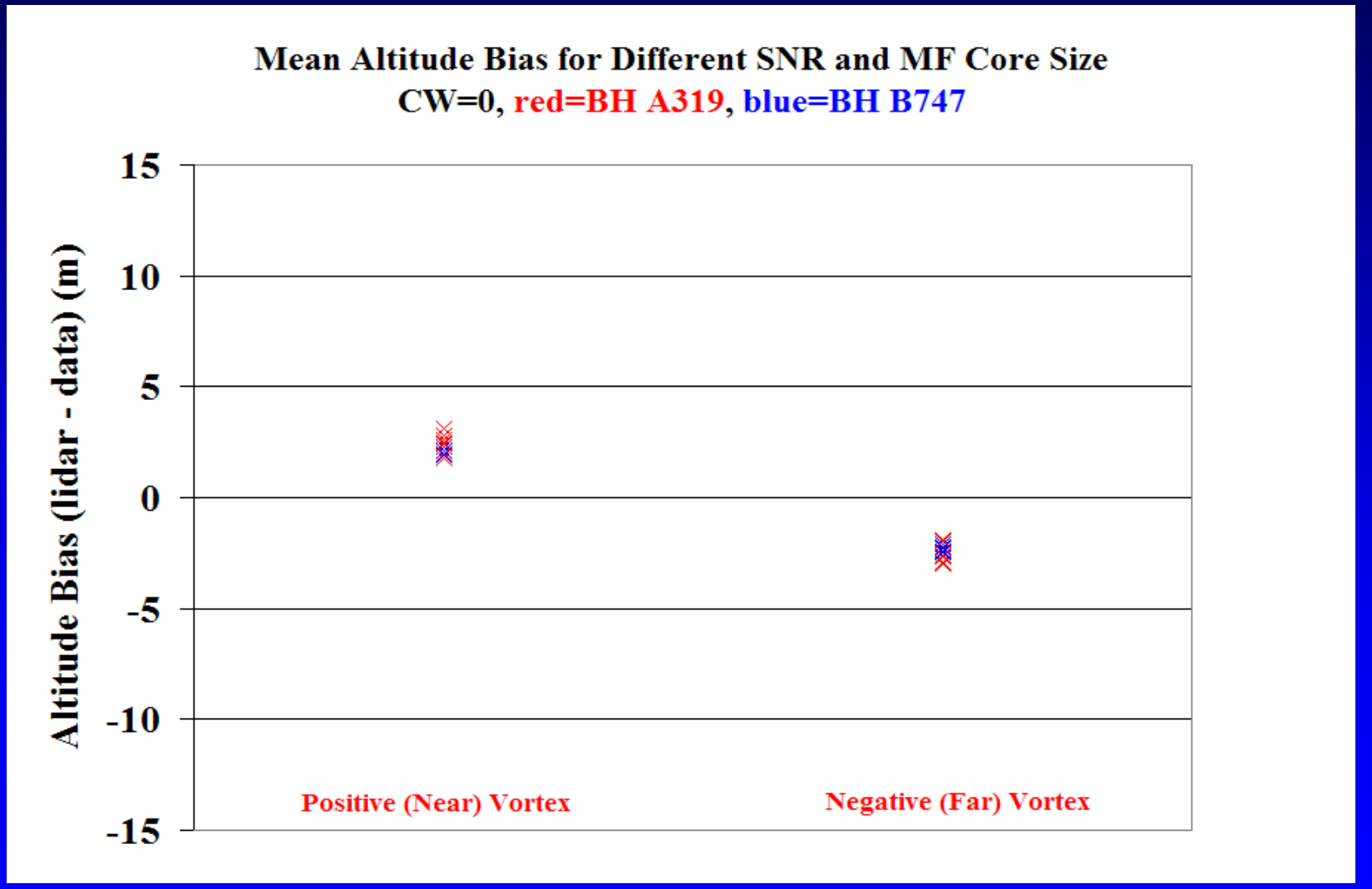
Mean Lateral Position Bias (Lidar sim – data) BH Model A319 and B747: No Crosswind



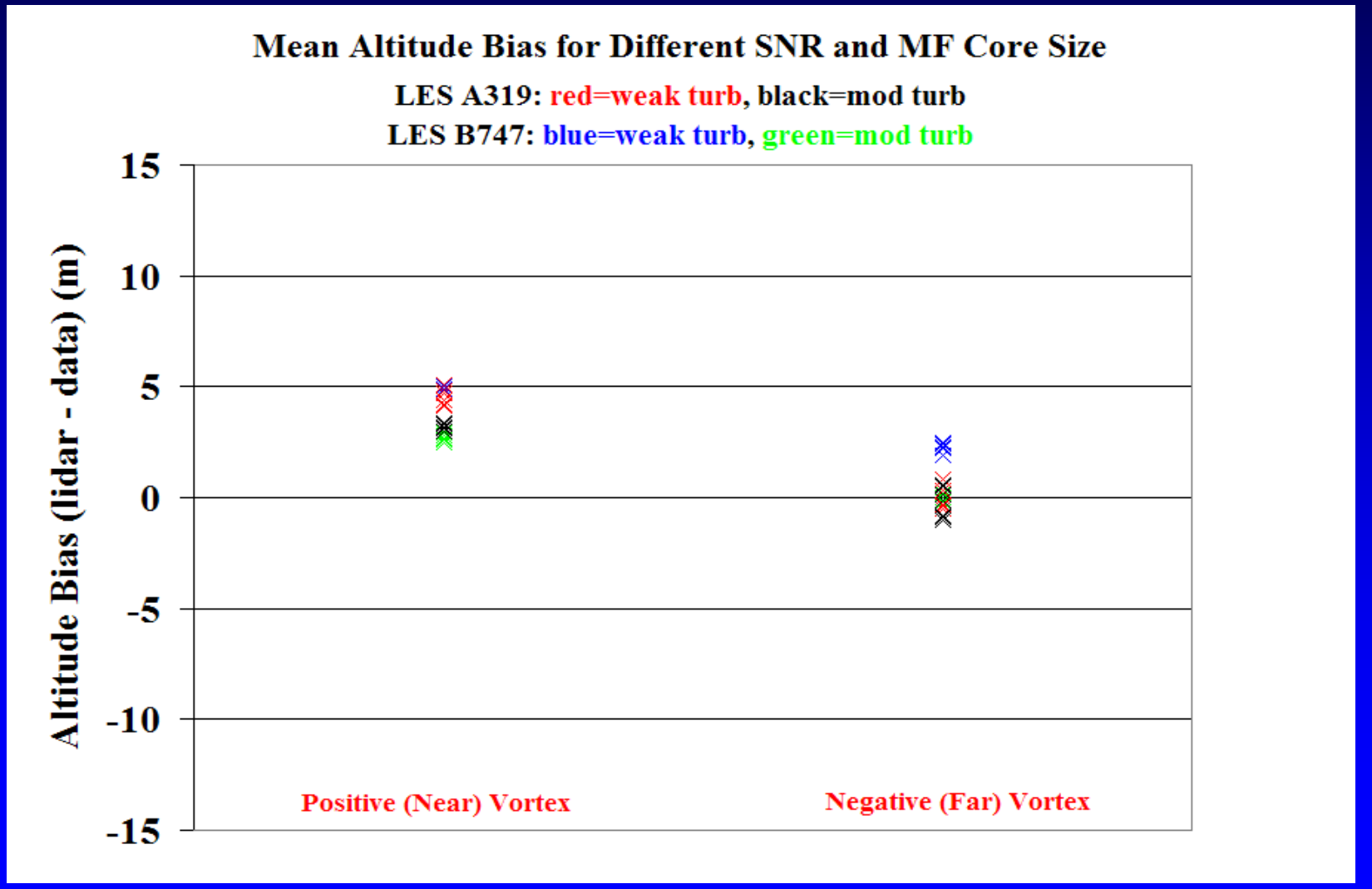
Mean Lateral Position Bias (Lidar sim – data) LES A319 and B747: No Crosswind



Mean Altitude Bias (Lidar Sim - Data) BH Model A319 and B747: No Crosswind



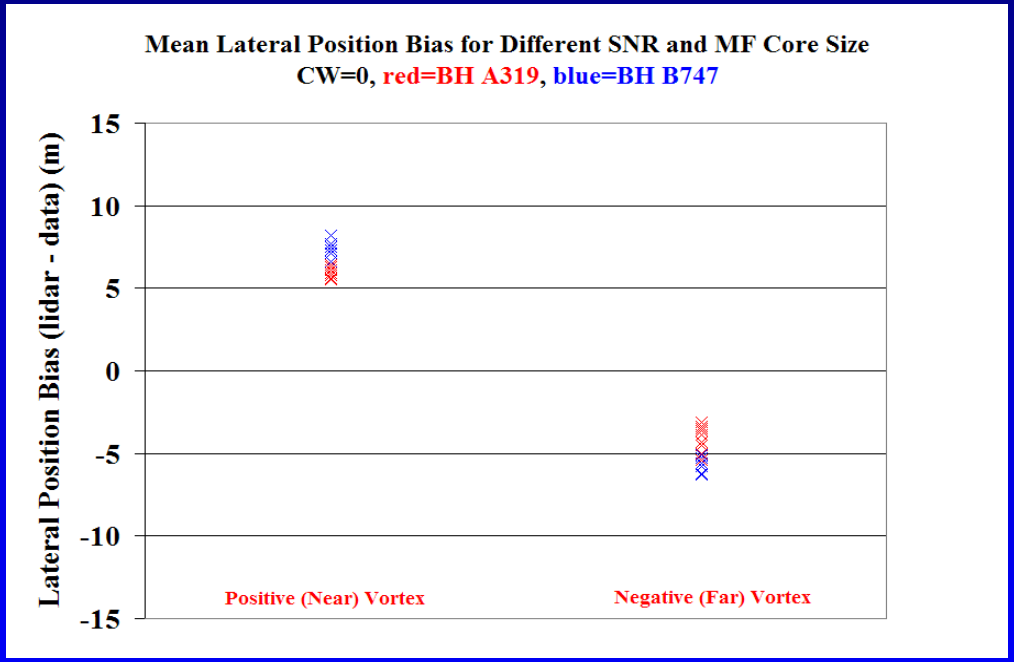
Mean Altitude Bias (lidar sim – data) LES A319 and B747

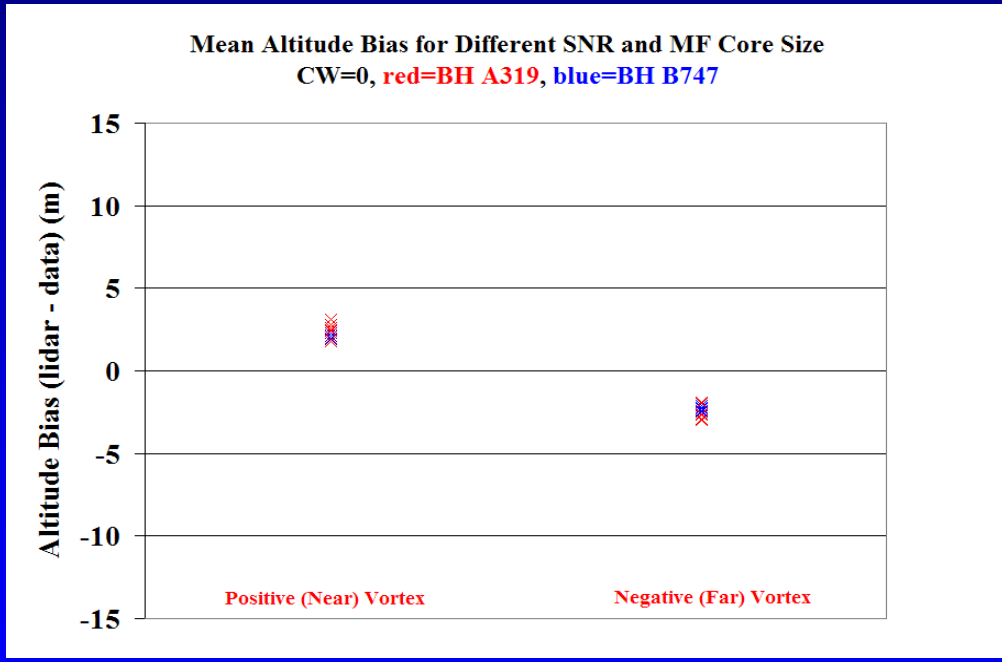


Lateral Position and Altitude Estimates

- Estimated errors for vortex altitude are half as large as those for lateral position
- Lateral position and altitude estimates for positive (nearer to lidar) and negative (farther from lidar) vortices have similar errors

Comparison of Lateral Position Bias (Left) and Altitude Bias (Right) for BH Model: A319 and B747 (Showing Lateral Position Errors Are Twice as Large as Altitude Errors)





Summary

- Ongoing studies with the LMCT Lidar simulator indicate that the Lidar can estimate vortex position very well:
  - Mean bias for altitude: 2-4 m
  - Mean bias for lateral position: 4-8 m
- These errors are insensitive to SNR (5-15 dB), vortex core radius, and matched filter core radius

Lidar Simulation Runs In Progress and Planned

- Crosswind: ±2 and ±5 m/s
- LES linking
- IGE
- Different geometries for the Lidar cross-section relative to the aircraft path (e.g., oblique, vertical)
- Vary the range (distance between the Lidar and the aircraft path)
- Simulate wakes from other aircraft (e.g. B-757)
- Errors in circulation

Questions ?