# *Crosswind Sniper System (CWINS)*

## Investigation of Algorithms and Proof of Concept Field Test

20 November 2006

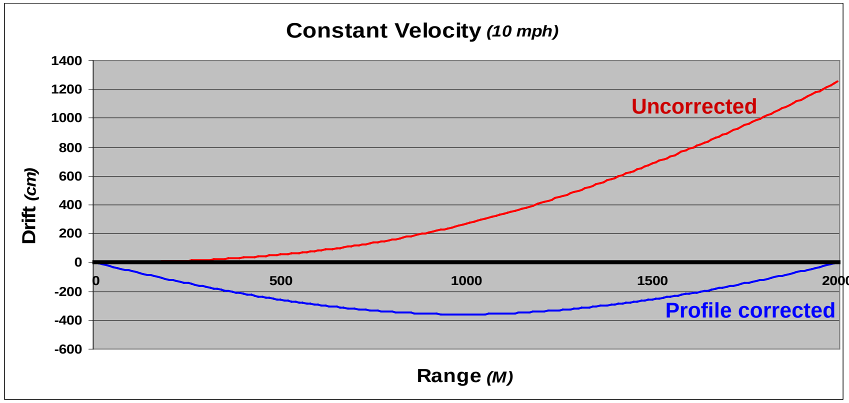
**Distribution A: Approved for Public Release, Distribution Unlimited, Case 8267**

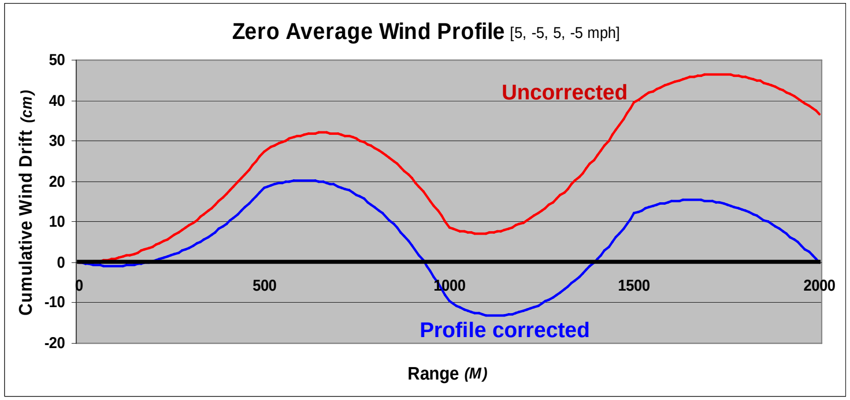
# Overview

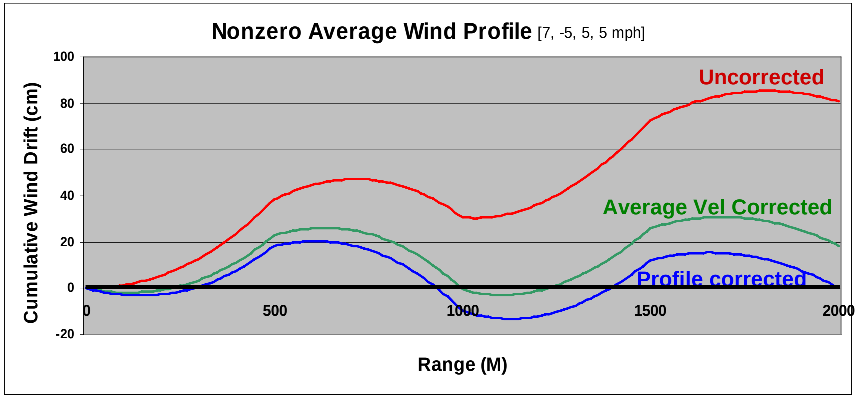
- **Requirements Analysis: Why Profile?**
- **How to Measure Crosswind?**
  - Key Principals of Measurement
  - Algorithm Conceptual Descriptions
    - 1A-G: Single Beam with Array Sampling Active using Gradient Measurements
    - 1A-I: Single Beam with Array Sampling Active using Subaperture Intensity Measurements
    - 2A-I: Dual Beam or Dual Aperture Active using Full Aperture Intensity Measurements
  - Candidate Algorithm Details
  - Example Simulation Results
- **Risk Reduction Analysis**
  - Link Budget
  - Frozen Flow Hypothesis (Example Results from Earl Spillar)
- **Proof of Concept Test Plan**
- **Path Forward**

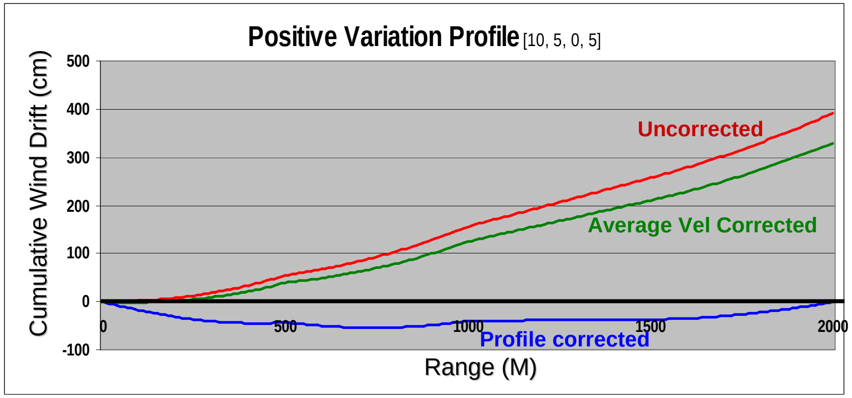
# Why Profile?

- Average Cross Wind Velocity is sufficient only for constant wind case
- Wind Profiling yields significant targeting improvement for all other cases



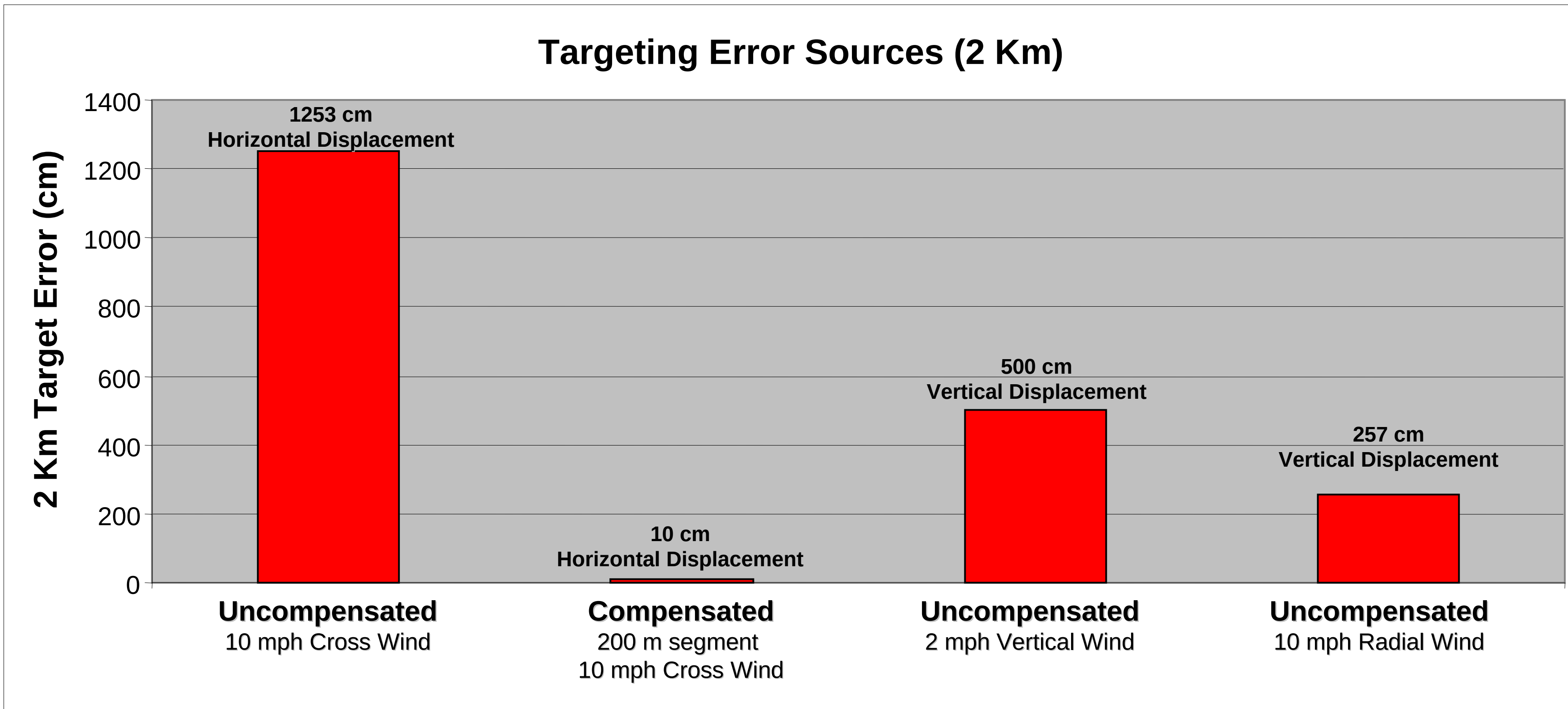



# Targeting Error Sources

**Effective at 2 Km**

- **Crosswind induced aimpoint error is the largest single error source**
- **3D wind measurement may be required for precision targeting**

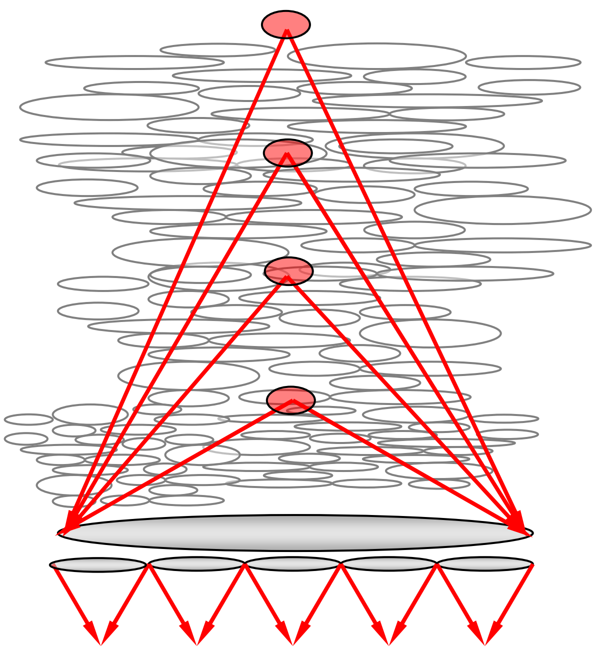


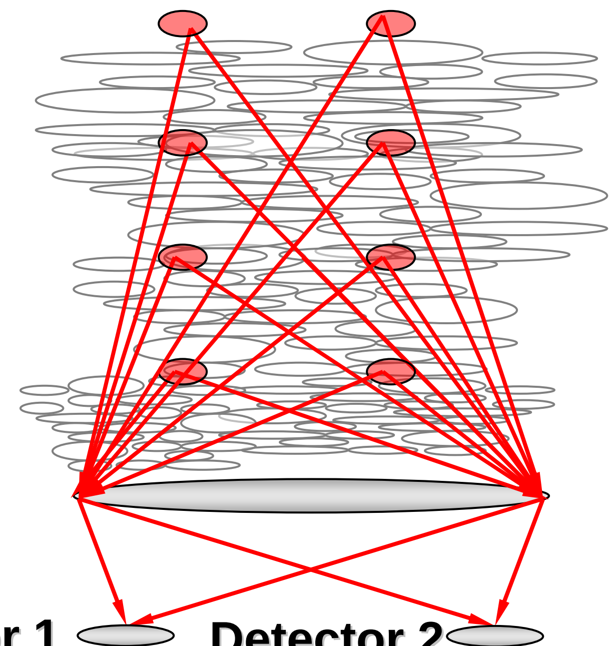
# Measurement Algorithms



## Algorithms considered are variations on space-time auto-correlation

- **1A-G**: Hartmann Lenslet Array (Gradient Pattern measurement – at least a 2x2 or 4x4 array)
- **1A-I**: Detector Array to measure (Intensity Pattern measurement – at least a 2x2 or 4x4 array)
- **2A-I**: Steer beam back and forth or use two detectors
- **2x2A-I**: Steer beam in 2-d pattern or use 2x2 detectors





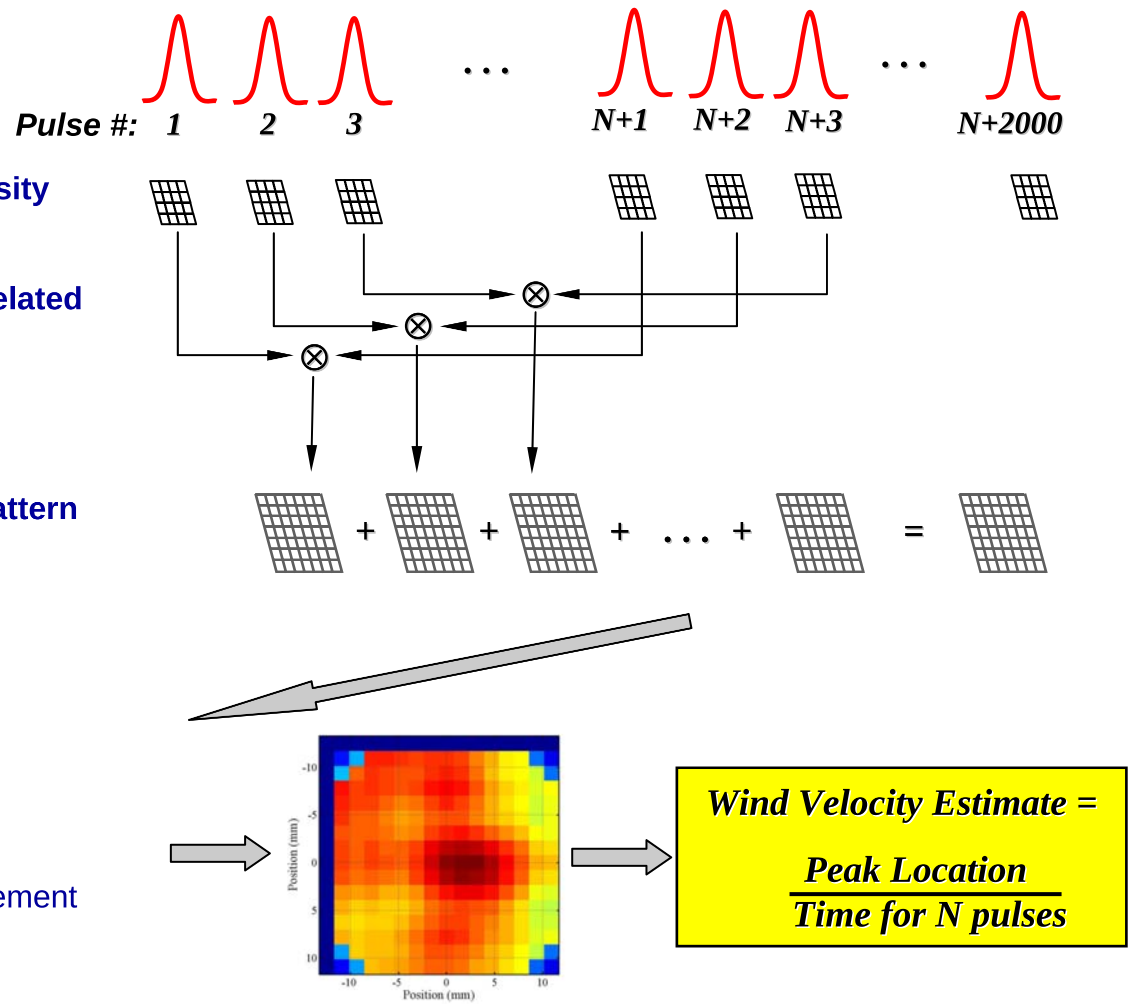



Distribution A: Approved for Public Release, Distribution Unlimited, Case 8267

# Single Layer Measurement

## Procedure:

- **N pulses transmitted**
- **Backscattered pulses produce a 4 x 4 Intensity Pattern**
- **Pulse Intensity pattern pairs are cross-correlated**
  - Pairs are separated by N frames
  - N selected for maximum correlation
- **Pulse pairs yield a 7x7 Cross-Correlation pattern**
- **Cross-Correlation patterns averaged**
- **Identify Cross-Correlation peak**
  - Interpolation employed for resolution enhancement

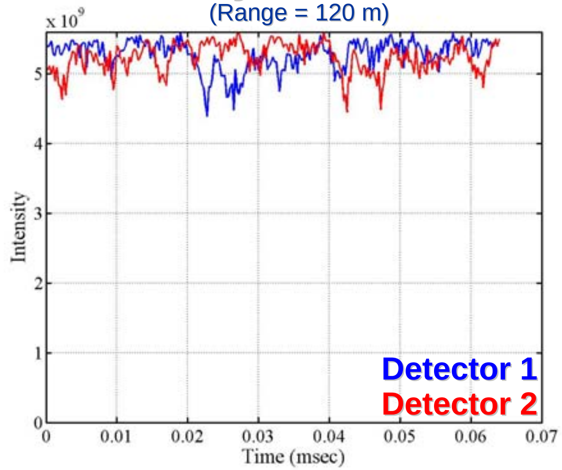


# Method 2A-I

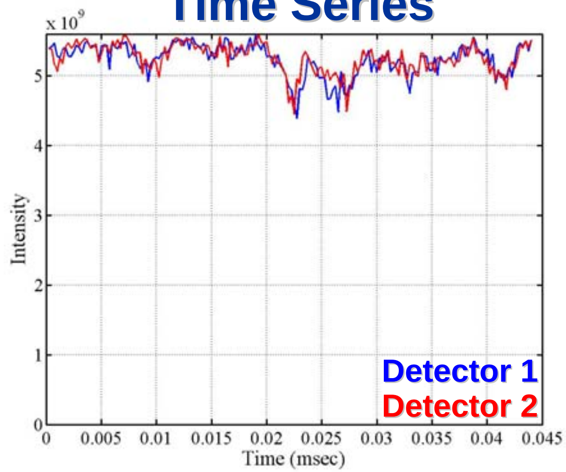
## Example Results – Uniform Wind

### Intensity Time Series

(Range = 120 m)

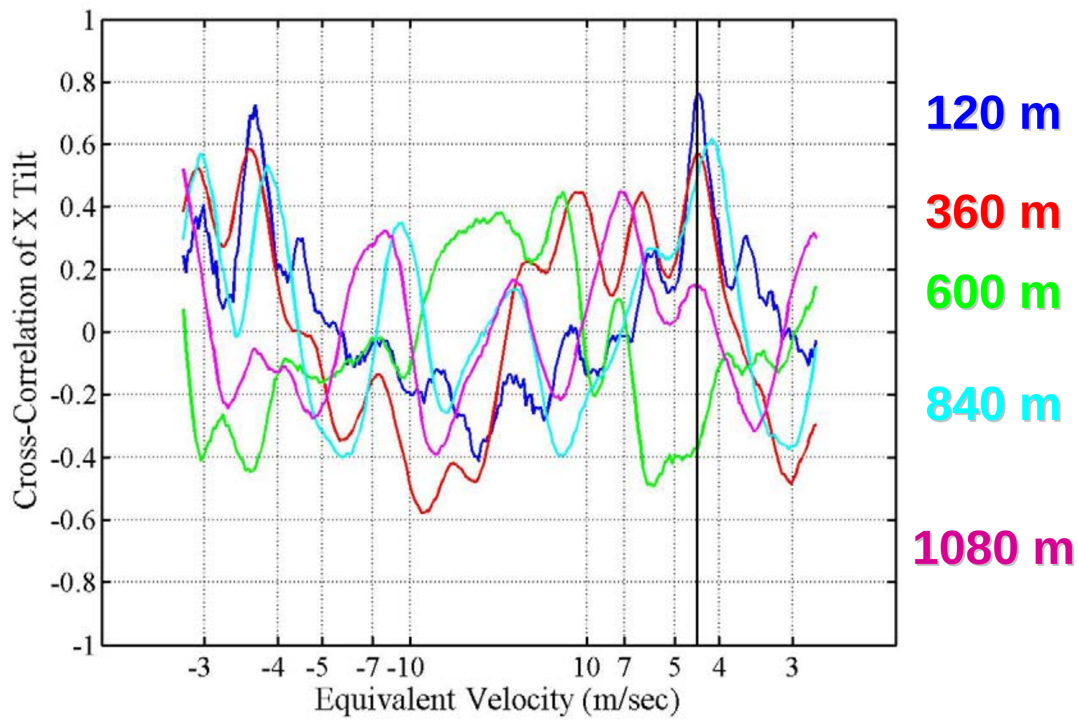



### Delay compensated Time Series




- **Evidence of correlation peaks at correct speed**
- **Longer range data corrupted by intensity variations in outgoing beam – leads to correlation wash out**

Intensity fluctuations in the outgoing beam result in pulse-to-pulse variation of backscatter initial condition at the layer of interest. This variation increases with range and in turn reduces contrast in the space-time correlation function of the return beam.

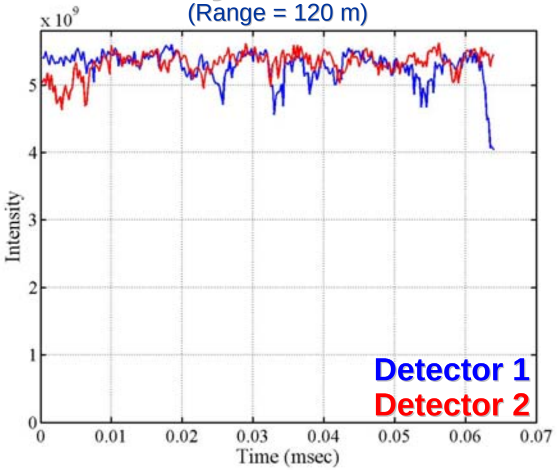


# Method 2A-I Example Results

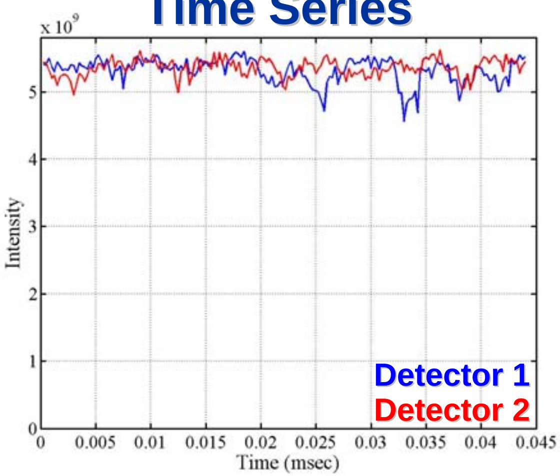
## 10% Wind Variation Along path

### Intensity Time Series

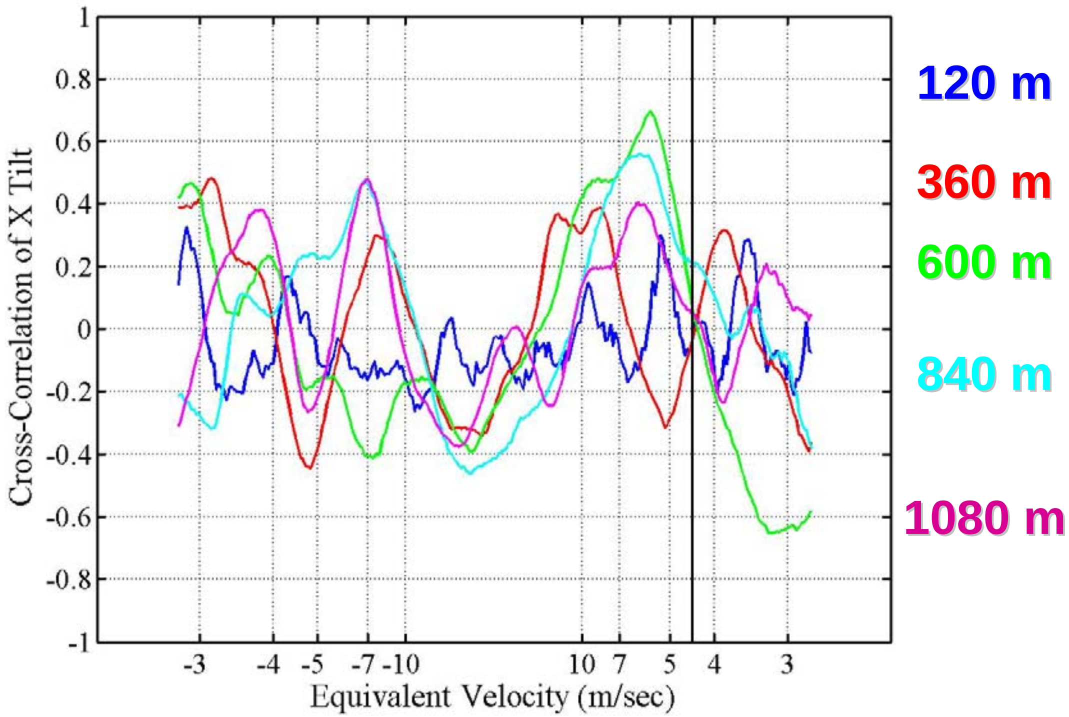
(Range = 120 m)




### Delay compensated Time Series




- Poor 2A-I correlation observed due to noise turbulence contributions from distinct velocity layers that wash out correlations
- 2A-I correlation is further corrupted as the vertical component of wind increases



# Profile Measurement

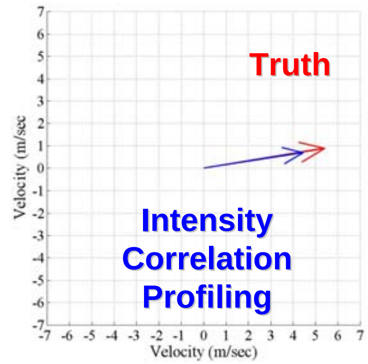
## Proof of Concept Simulation Example

From Science to Solutions™

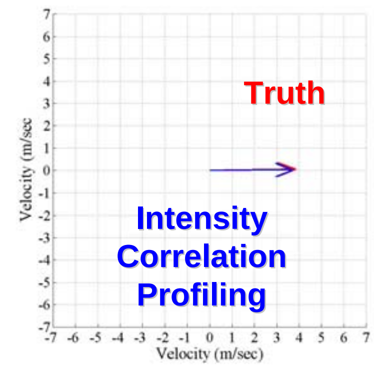
### Simulation Example

- 1A-I algorithm with 4x4 sample
- 10 mph H wind
- 25% H/V random variation
- 5 velocity layers

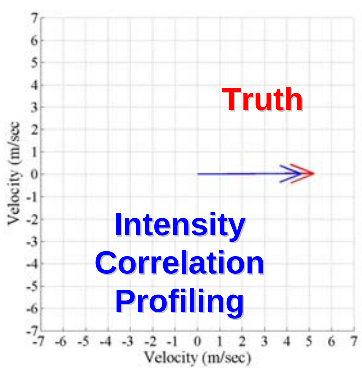
**120 m Center Range**



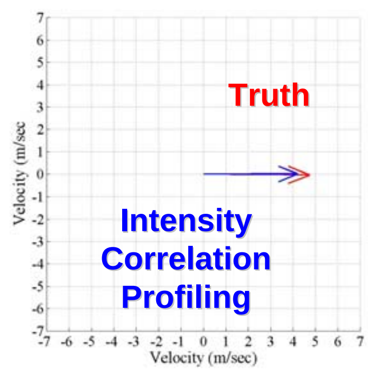

**360 m Center Range**



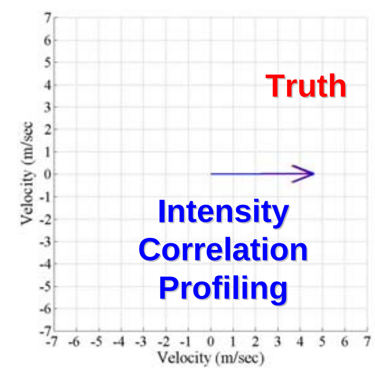

**600 m Center Range**




**840 m Center Range**




**1080 m Center Range**




***1A-I Algorithm exhibits < 10% 2D RMS velocity profile error***

# Top Level Algorithm Trades

| Method | SNR | 2D Measure ? | Ability to Profile Wind | Relative Complexity |
|---|---|---|---|---|
| 1A-G | Must Reduce array size to 2x2 to get sufficient SNR | Yes | Good if using at least 4x4 Measurements | High |
| 1A-I | Must Reduce array size to 2x2 or 4x4 to get sufficient SNR | Yes | Good if using at least 4x4 Measurements | Modest |
| 2A-I | Full Aperture Improves SNR | No | Algorithm Definition more Difficult | Modest |
| 2x2A-I | Full Aperture Improves SNR | Yes | Algorithm Definition more Difficult | Modest |

# Link Budget

From Science to Solutions™

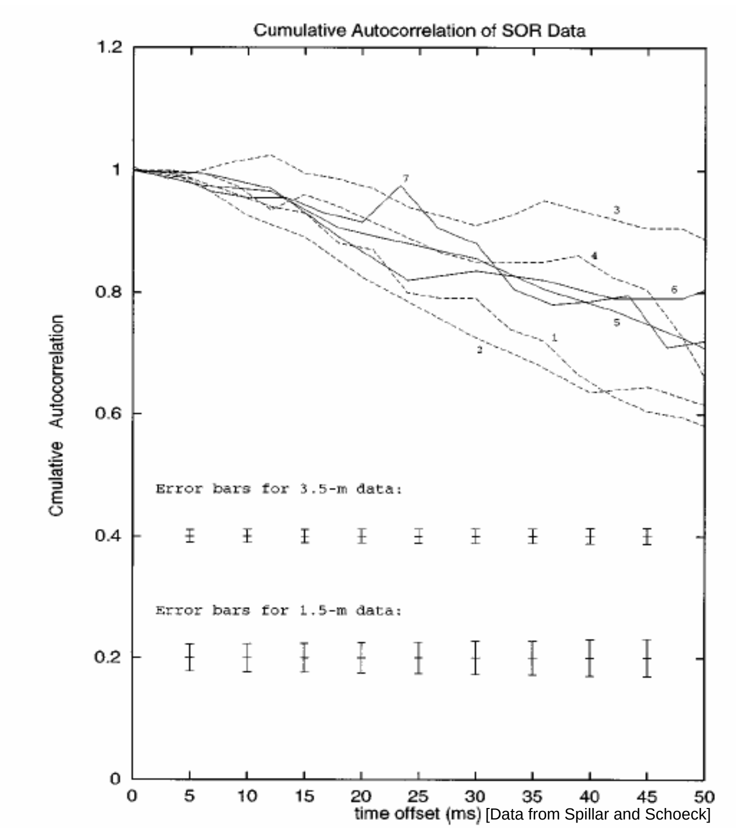
- **Link Budget is challenging at 2 km**
- **Low visibility increases Mie scattering contribution, increasing SNR**

| PARAMETER | Visibility 23 km | Visibility 10 km | Visibility 4 km | Visibility 23 km | Visibility 10 km | Visibility 4 km |
|---|---|---|---|---|---|---|
| Transmit Pulse Energy = 20 ° *J* | | | | | | |
| Range to Target (m) | 2000.00 | 2000.00 | 2000.00 | 1600.00 | 1600.00 | 1600.00 |
| Transmit Pulse Peak Power (dBm) with 6 ns pulse | 68.00 | 68.00 | 68.00 | 68.00 | 68.00 | 68.00 |
| Back-Scatter Contribution (dB) | -34.95 | -31.76 | -27.99 | -34.95 | -31.76 | -27.99 |
| 12.5 mm Aperture Collection Efficiency (dB) | -104.00 | -104.00 | -104.00 | -101.50 | -101.50 | -101.50 |
| 2 Way Transmission Loss (dB) | -0.77 | -1.71 | -4.23 | -0.60 | -1.37 | -3.40 |
| Transmitter Optical Loss (dB) | -1.25 | -1.25 | -1.25 | -1.25 | -1.25 | -1.25 |
| Receiver Optical Loss (dB) | -1.25 | -1.25 | -1.25 | -1.25 | -1.25 | -1.25 |
| Total Received Power Per Subaperture (dBm) | **-74.21** | **-71.97** | **-70.72** | **-71.55** | **-69.13** | **-67.39** |
| Detector Sensitivity at 25 MHz (dBm) | -63.00 | -63.00 | -63.00 | -63.00 | -63.00 | -63.00 |
| Filter Gain (1 MHz Operation for Profiling - 15 MHz Operation for Range-Finding) (dB) | 6.99 | 6.99 | 6.99 | 6.99 | 6.99 | 6.99 |
| SNR Required (dB) | -10.00 | -10.00 | -10.00 | -10.00 | -10.00 | -10.00 |
| Speckle Noise (dB) | -0.07 | -0.05 | -0.03 | -0.12 | -0.09 | -0.05 |
| Correlation gain from 2000 digital pulses averaging (dB) | 16.50 | 16.50 | 16.50 | 16.50 | 16.50 | 16.50 |
| **Link Margin(dB)** | **2.21** | **4.47** | **5.75** | **4.82** | **7.27** | **9.05** |
| Total Measurement Time (Seconds) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

# Frozen Flow Hypothesis

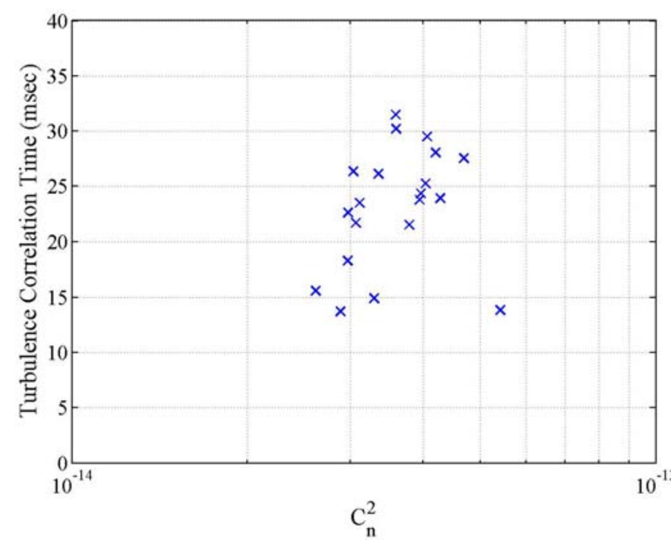
## Turbulence Correlation Times

- **For a vertical path the correlation time was measured to be long –** 100 to 500 msec
- **For a horizontal path the correlation time was measured to be short –** 10 to 30 msec
- **Weakly related to** $C_n^2$



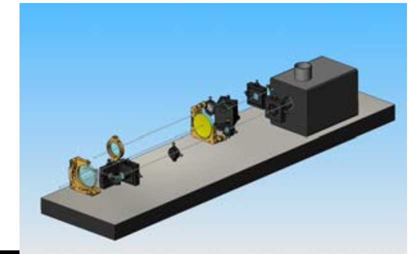
[Data from Spillar and Schoeck]

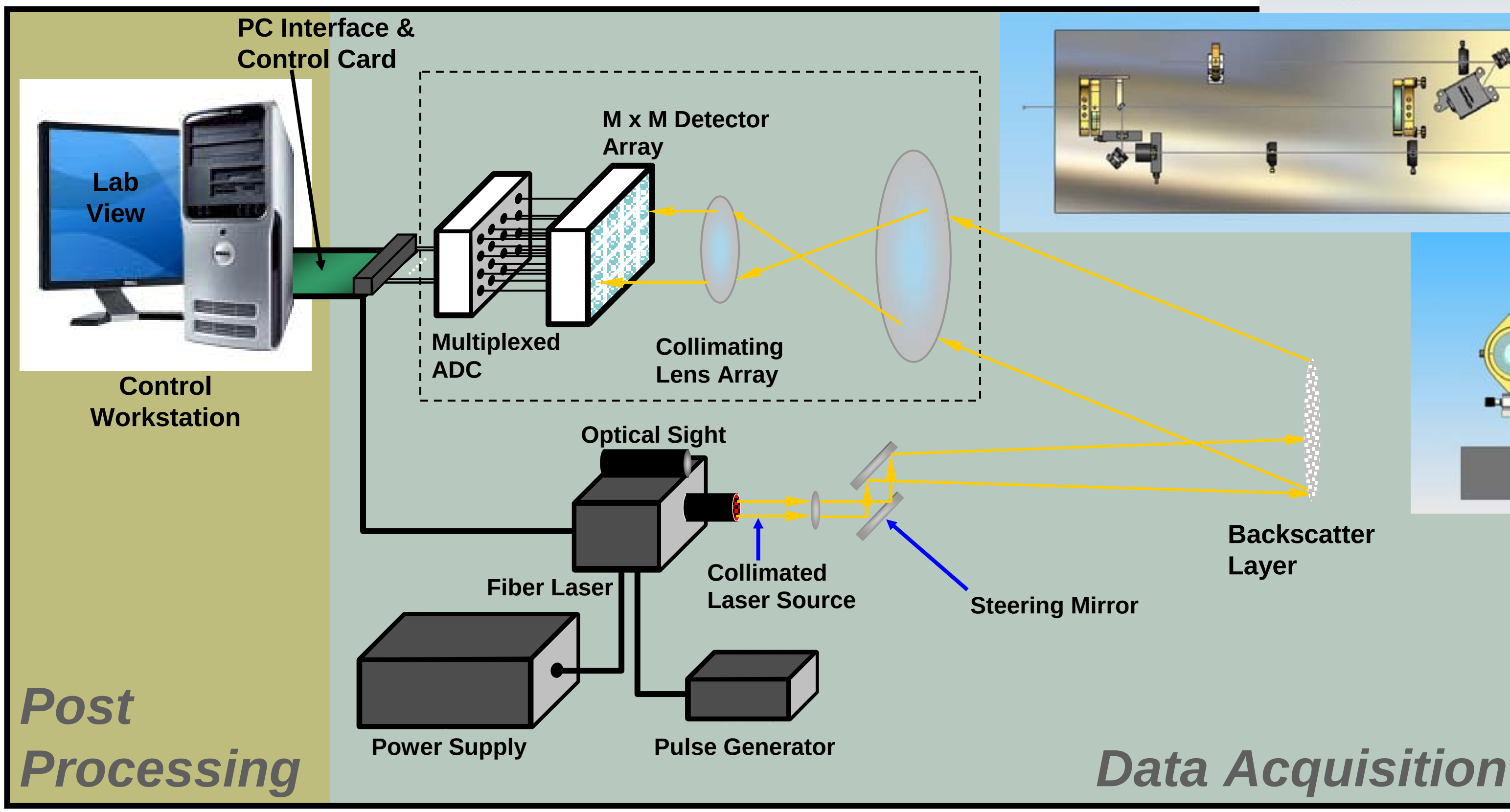
- **SAIC captured data over a 1.3 km horizontal path directly over city using compact SRI AO system**
- **Terrain comparable to sniper engagement**

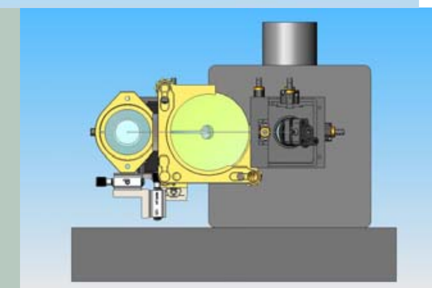


# Proof of Concept Testbed

- 50mm x 50mm view space maps to 4x4 pixel space
- Pixels can be binned to simulate 2x2 and 4x4 arrays





# Discussion / Path Forward

- **Proof of concept simulation results establish feasibility**
- **Proof of concept test planned in immediate future**
- **Important remaining work** (Future efforts)**:**
  - Complete SNR analysis including field measurement and noise statistics
  - Develop improved algorithms exploiting 2x2 data