

**2020**

# WEBINAR SERIES



**Cross Correlation and IRI Error**

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## AASHTO R56-14 “Certification of Inertial Profiling Systems”

- Current cross correlation threshold is 0.92
- Cross correlation threshold for repeatability of reference systems is 0.98

## ESTM E-950 “Standard Test Method for Measuring Longitudinal Profile of Traveled Surfaces with an Accelerometer-Established Inertial Profiling Reference”

- On-going revisions.
- Cross correlation proposed for verifying inertial profilers.

# Outline

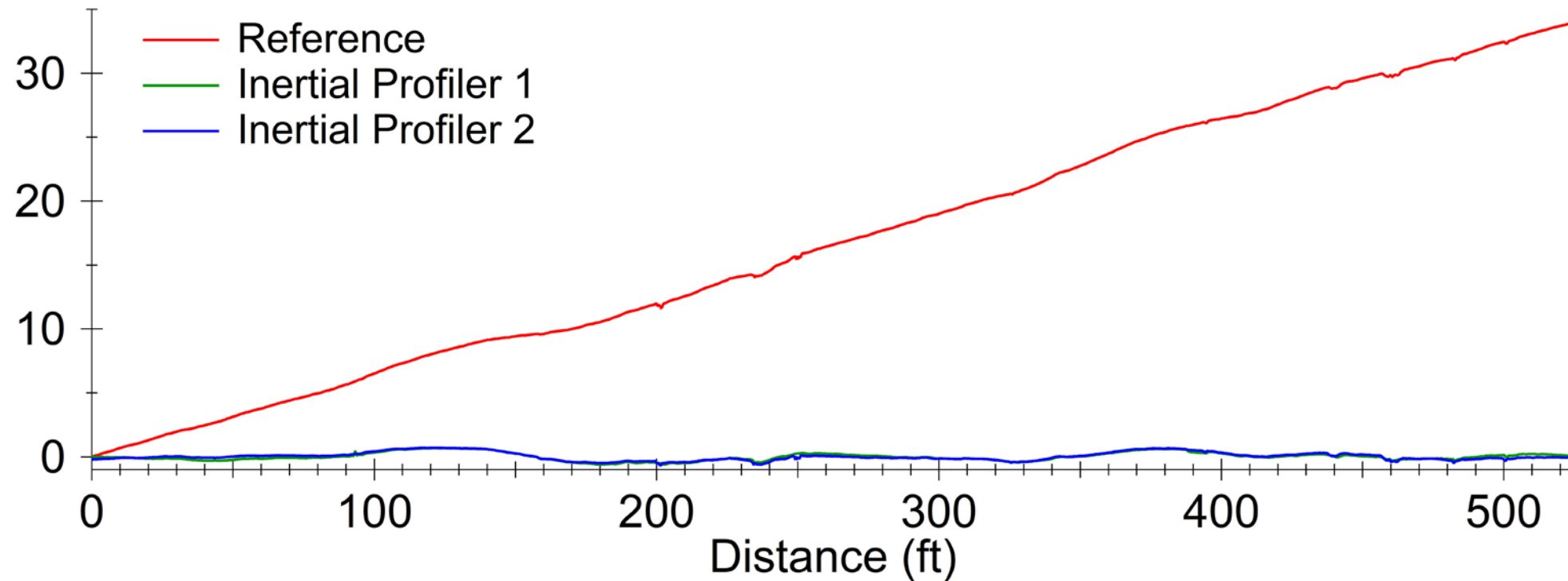
- Introduction to Cross Correlation
- Errors in Longitudinal Distance
- Effect of High-Pass Filtering
- Relationship to IRI Error

# Outline

- **Introduction to Cross Correlation**
- Errors in Longitudinal Distance
- Effect of High-Pass Filtering
- Relationship to IRI Error

# Reference Profile and Two Inertial Profiles

Elevation (in)



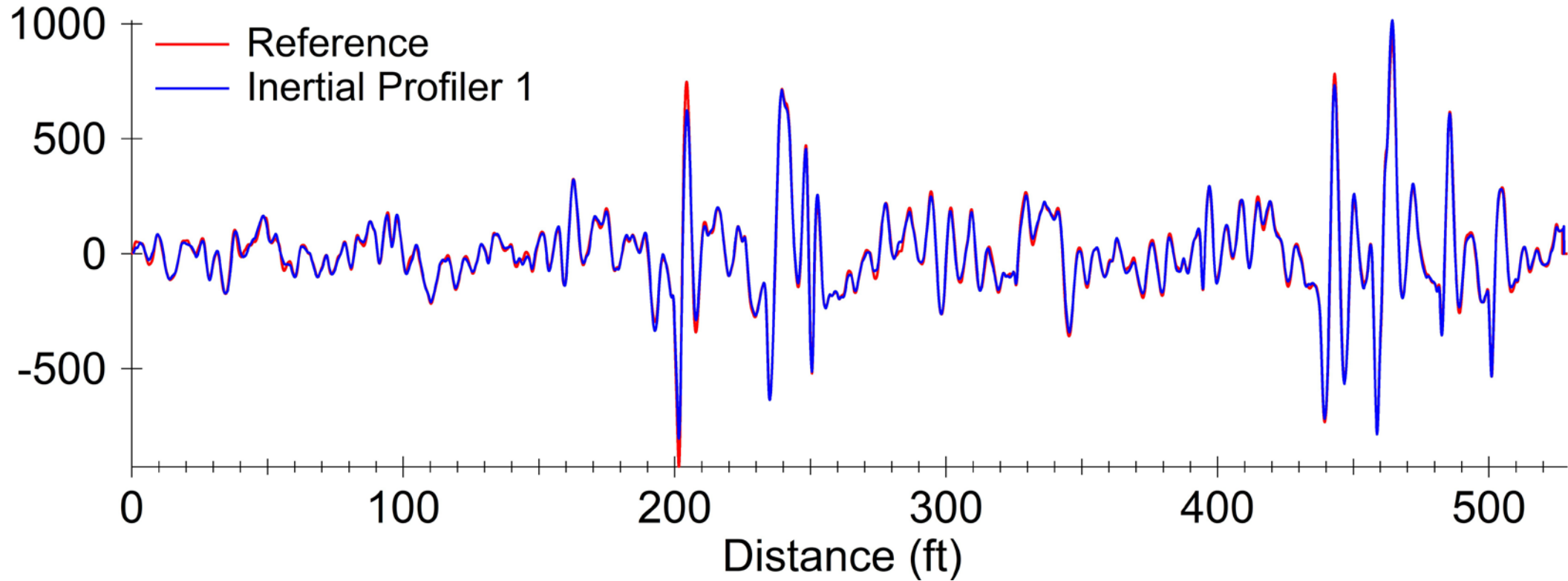
Reference IRI = 125.3 in/mi

Inertial Profiler 1 IRI = 123.5 in/mi

Inertial Profiler 2 IRI = 120.2 in/mi

# Raw IRI Filter Output, Reference v Inertial Profiler 1

Raw IRI Filter Output (in/mi)



Cross Correlation = 0.978

# Cross Correlation

- Filter to emphasize the waveband of interest.
- Correlate the filtered signals.
- Shape score (seek the best distance offset):

$$\rho_{pq}(i\Delta x) = \frac{1}{\sigma_p \sigma_q} \sum_{k=1}^N \hat{p}(x_k) \hat{q}(x_{k+i})$$

- Level score:

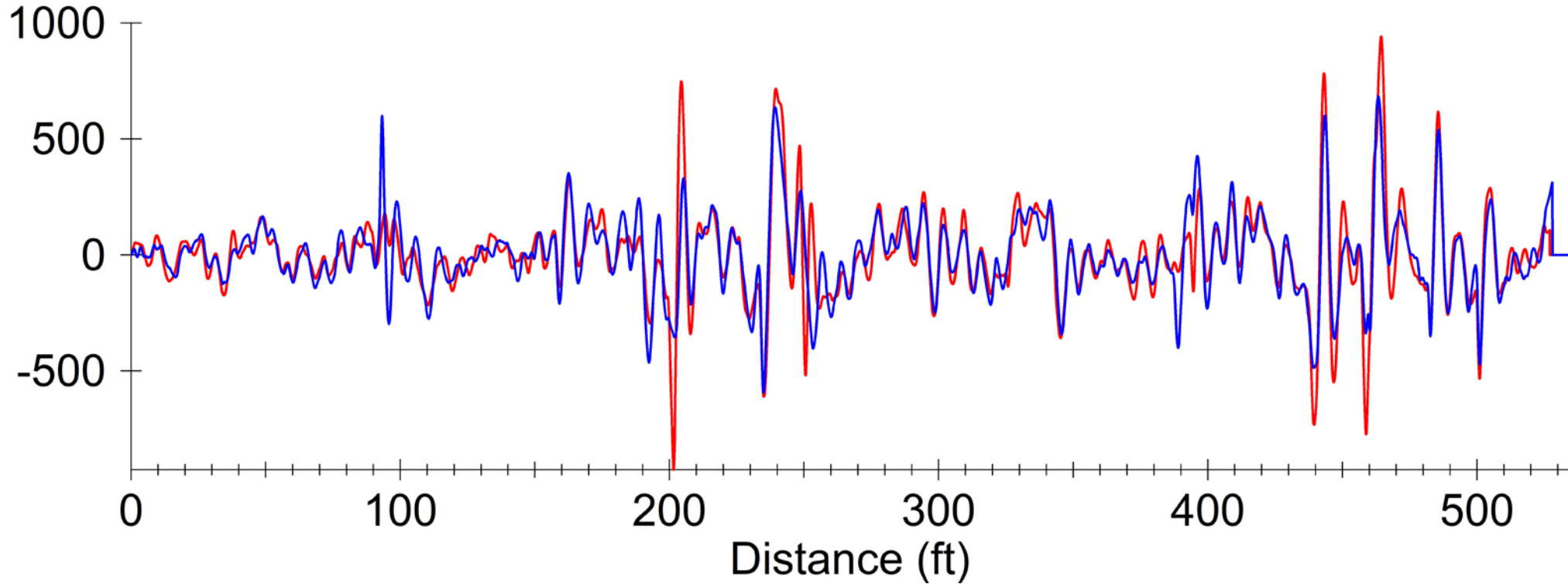
$$\gamma = \frac{\min(\sigma_p, \sigma_q)}{\max(\sigma_p, \sigma_q)}$$

- Agreement score:

$$\text{Agreement score} = \rho_{\max} \cdot \gamma$$

# Raw IRI Filter Output, Reference v Inertial Profiler 2

Raw IRI Filter Output (in/mi)

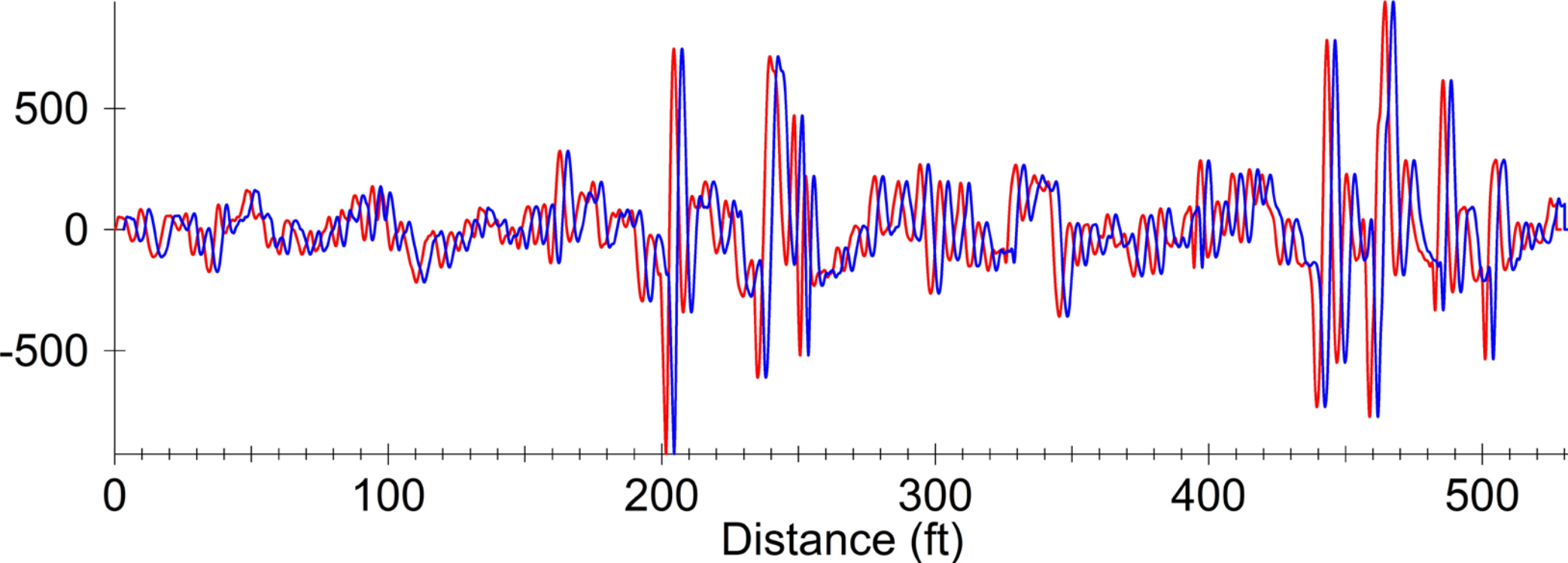


Cross Correlation = 0.729



# Distance Offset

Raw IRI Filter Output (in/mi)

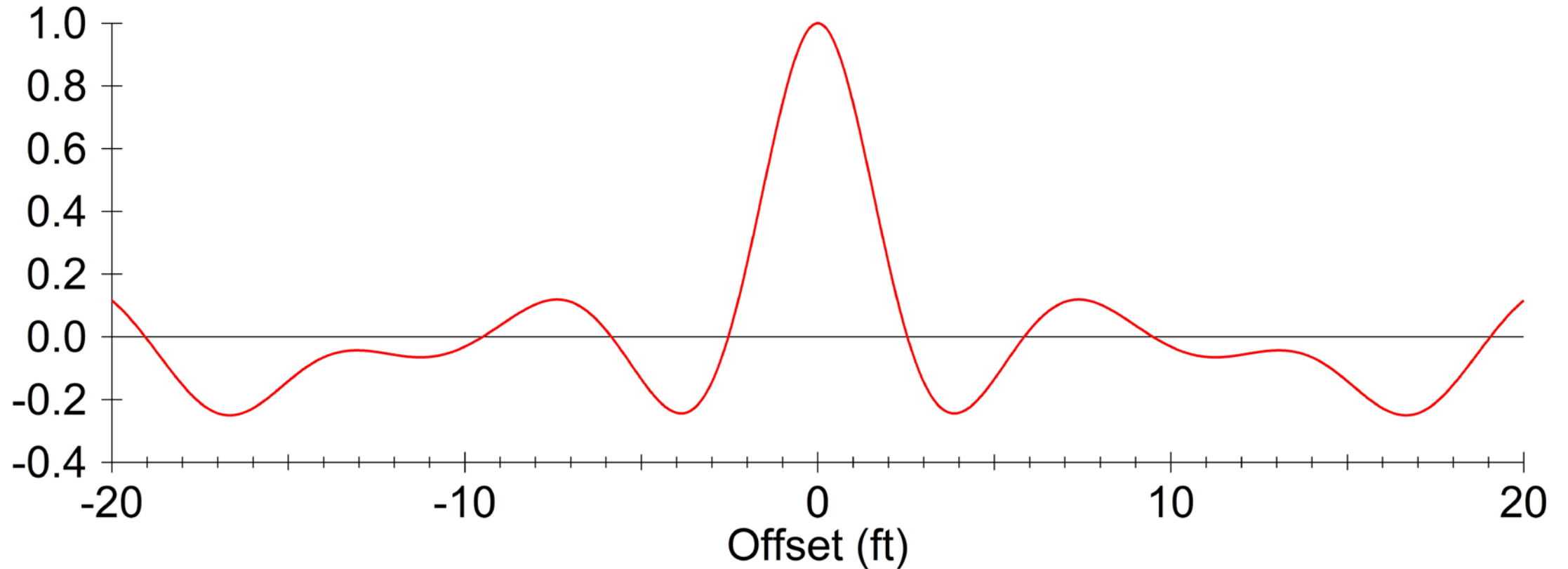


Offset = 3 ft

Cross Correlation < 0

# Raw IRI Filter Output, Reference v Inertial Profiler 2

Cross Correlation (-)

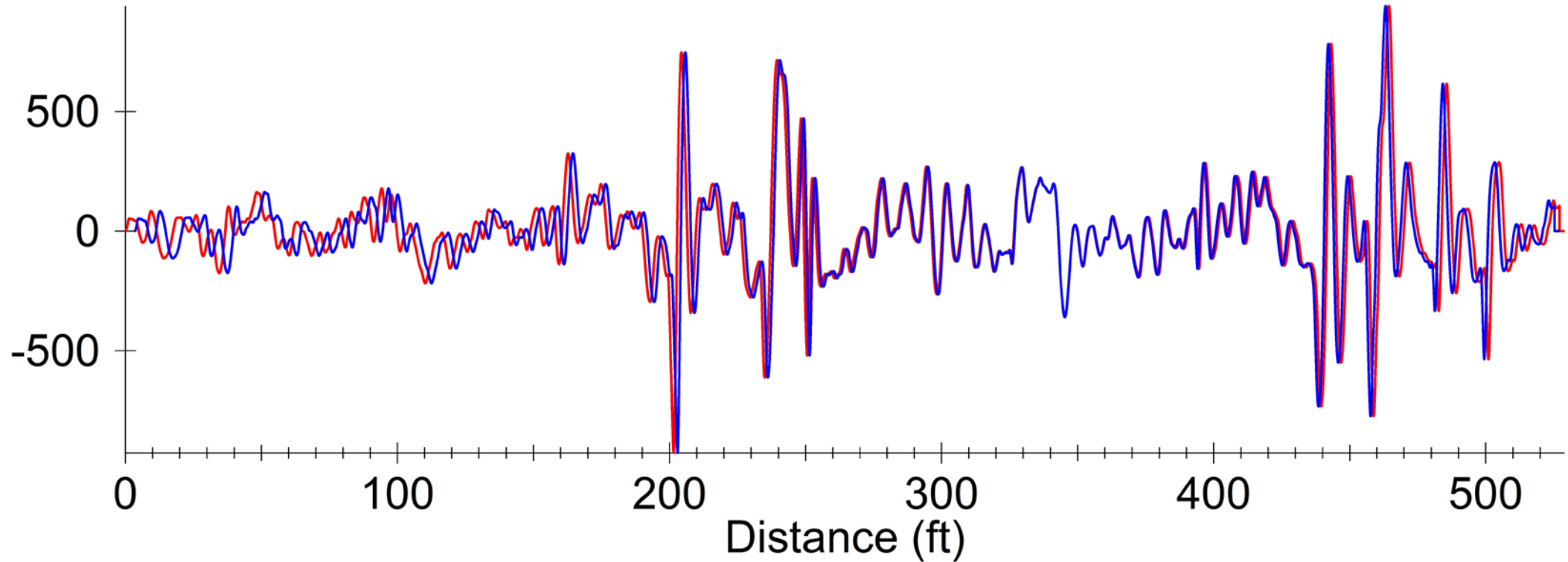


# Outline

- Introduction to Cross Correlation
- **Errors in Longitudinal Distance**
- Effect of High-Pass Filtering
- Relationship to IRI Error

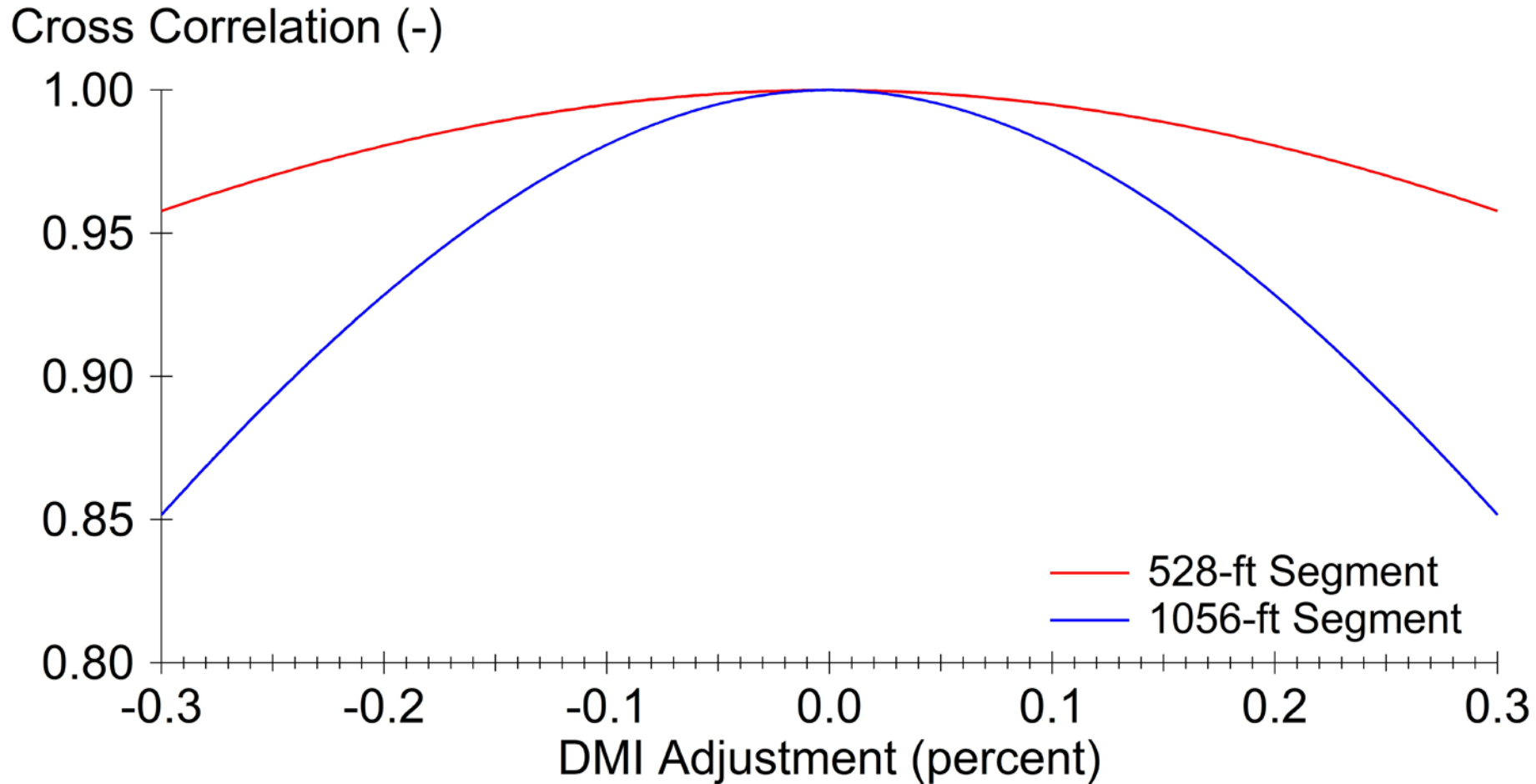
# Longitudinal Distance Measurement Error

Raw IRI Filter Output (in/mi)



Distance Measurement Error 1 percent  
Cross Correlation = 0.647

# Longitudinal Distance Measurement Error



For 0.15 percent DMI error:

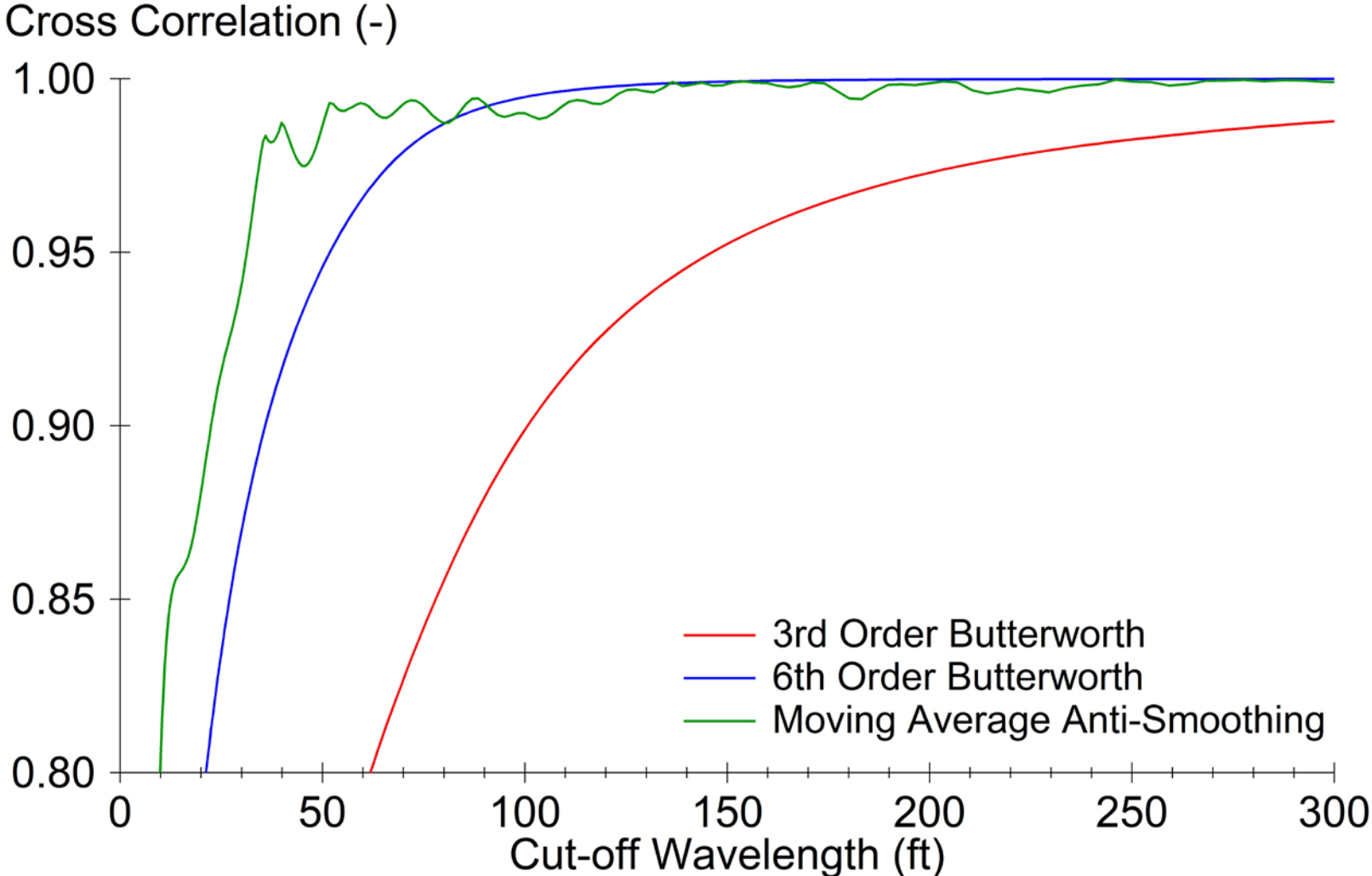
528 ft (0.989)

1056 ft (0.958)

# Outline

- Introduction to Cross Correlation
- Errors in Longitudinal Distance
- **Effect of High-Pass Filtering**
- Relationship to IRI Error

# Effect of Filtering



3<sup>rd</sup> Order Butterworth,  
300-ft Cut-off:  
CC=0.988

# Outline

- Introduction to Cross Correlation
- Errors in Longitudinal Distance
- Effect of High-Pass Filtering
- **Relationship to IRI Error**



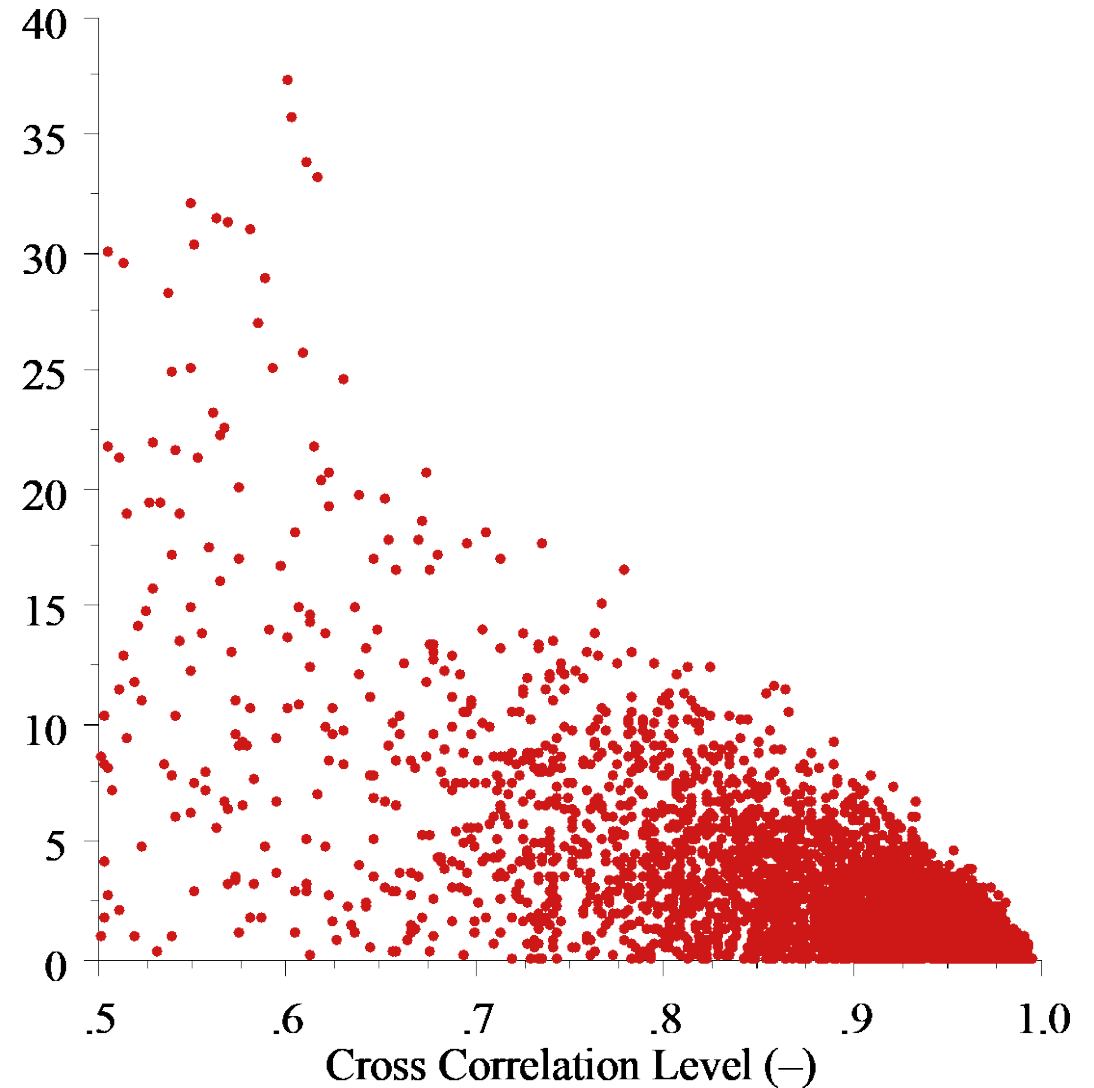
# 2004 FHWA Profiler Round-Up

- 68 profilers
- 9 test sections  
(4 in PA, 5 at Smart Road)
- 445,669 possible comparisons

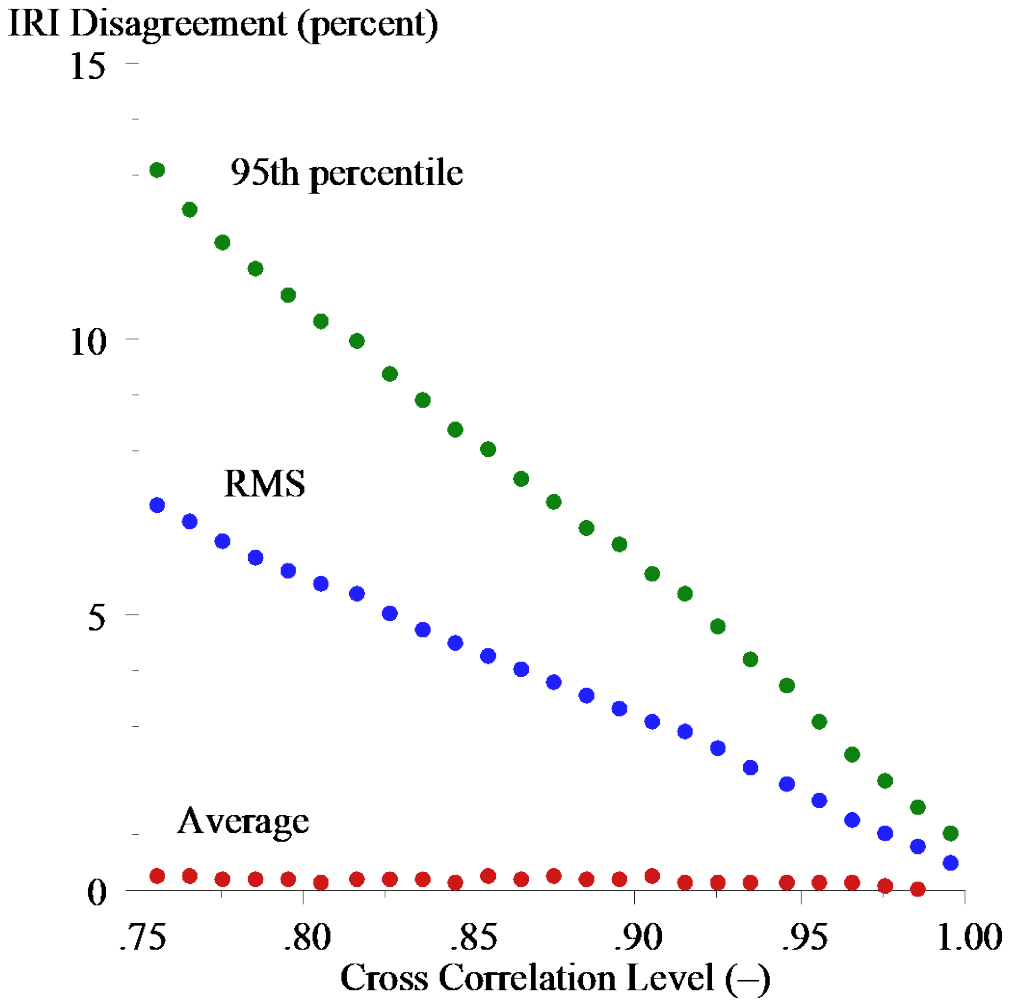
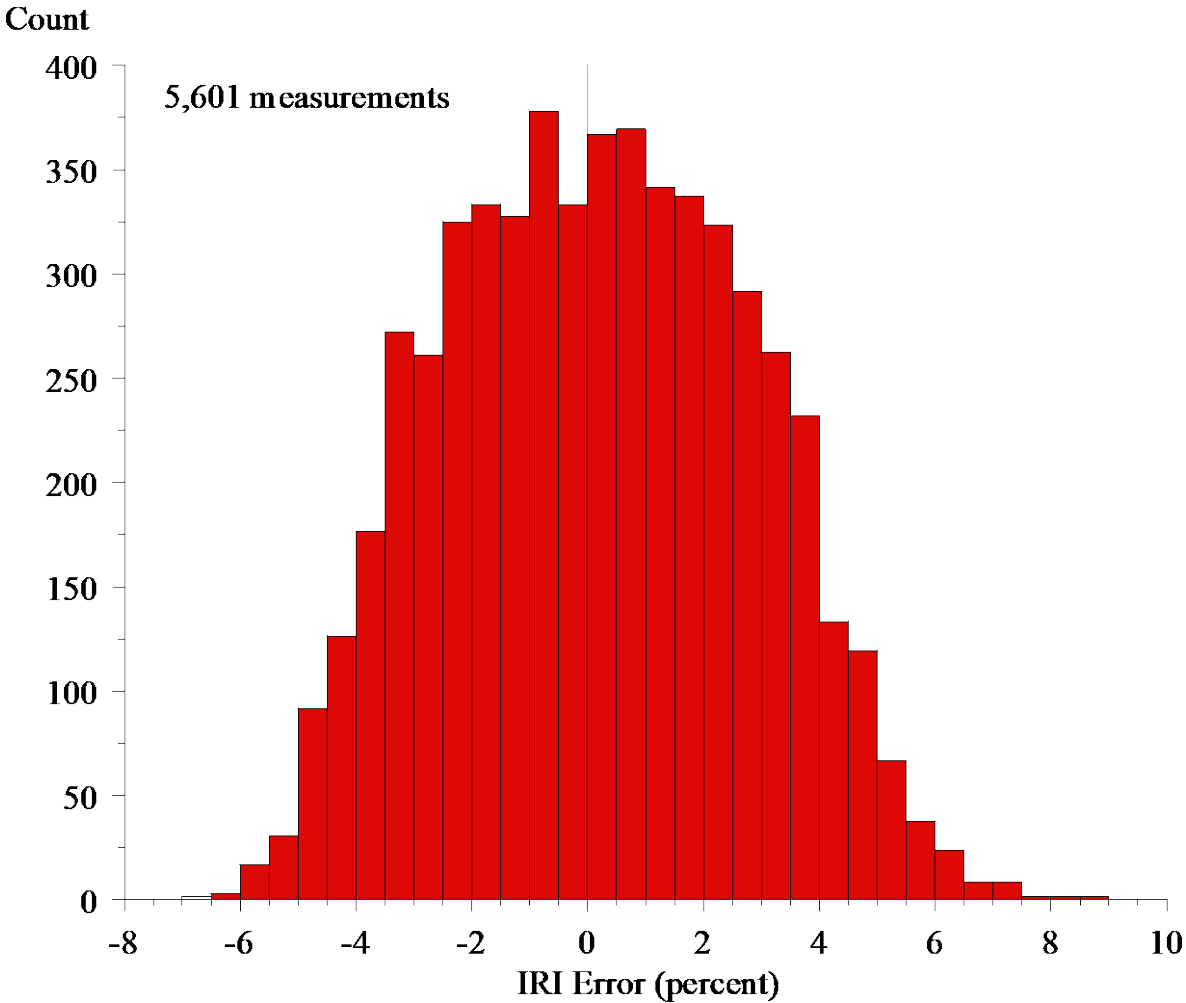


Photo courtesy of George Chang

Absolute IRI Difference (percent)



## IRI Error, CC from 0.92 to 0.93



# 2004 Round-Up: Cross Correlation and IRI Error

<u>CC Range</u>	<u>95 Percentile IRI Error</u>
0.97-0.98	2.00
0.92-0.93	4.80
0.81-0.82	10.00

Cross Correlation Range		Number of Comparisons	Error Level in IRI Measurement (Percent)				
From	To		Average	RMS	95th Percentile	Low	High
0.99	1.00	13	-0.15	0.52	1.07	-1.07	0.81
0.98	0.99	171	0.04	0.83	1.54	-1.38	3.42
0.97	0.98	849	0.10	1.04	2.00	-3.49	3.79
0.96	0.97	2054	0.16	1.31	2.48	-4.16	4.81
0.95	0.96	3095	0.20	1.64	3.12	-4.87	5.21
0.94	0.95	3963	0.18	1.96	3.73	-5.78	6.84
0.93	0.94	4965	0.18	2.26	4.23	-6.22	6.82
0.92	0.93	5601	0.18	2.62	4.80	-6.62	8.92
0.91	0.92	6398	0.20	2.93	5.43	-7.65	9.12
0.90	0.91	7096	0.27	3.11	5.76	-8.11	9.57
0.89	0.90	7490	0.24	3.33	6.30	-8.71	11.72
0.88	0.89	8028	0.23	3.56	6.63	-10.77	11.82
0.87	0.88	8432	0.29	3.80	7.10	-10.38	12.23
0.86	0.87	8485	0.21	4.04	7.50	-10.97	13.36

# 2015 Pilot Certification and Reference Testing

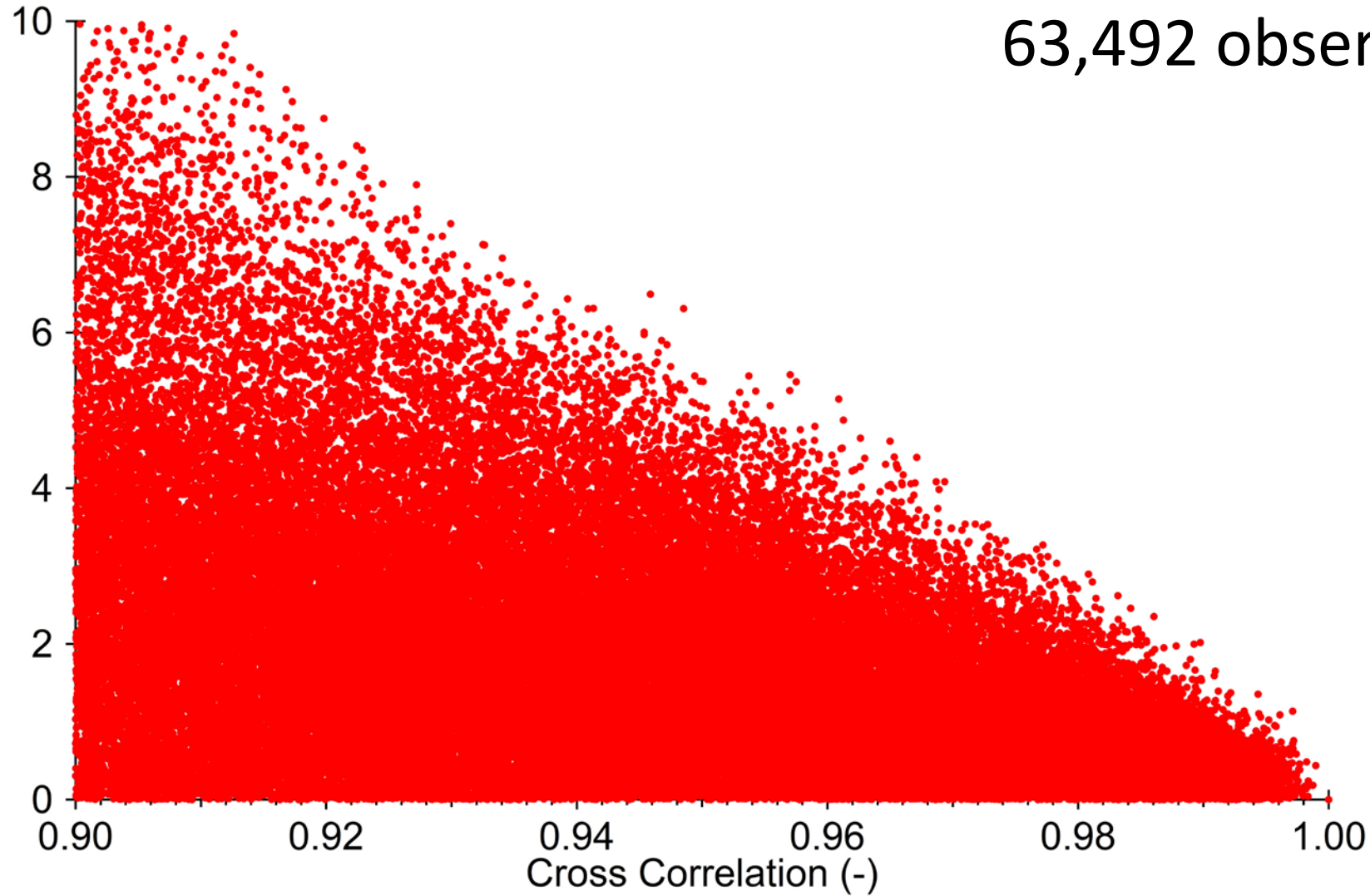
- 16 profilers (10 high-speed; 4 walking-speed; 2 robots)
- 9 test sections (MnRoad)
- FHWA Contract DTFH61-10-D-00026 issued to SME
- Project director Rohan Perera (SME)
- COTR Bob Orthmeyer was the COTR
- 138,572 possible comparisons

# Cross Correlation Procedures

- Pad the profiles with its reflection in both directions.
- Resample profiles to an interval of 5.08 mm.
- Filtering using the IRI algorithm.  
(Omit the 250 mm moving average when appropriate.)
- Seek the best linear adjustment to the sample interval.
- Seek the best distance offset.

# 2015 Round-Up, IRI Error versus Cross Correlation

Absolute IRI Error (percent)



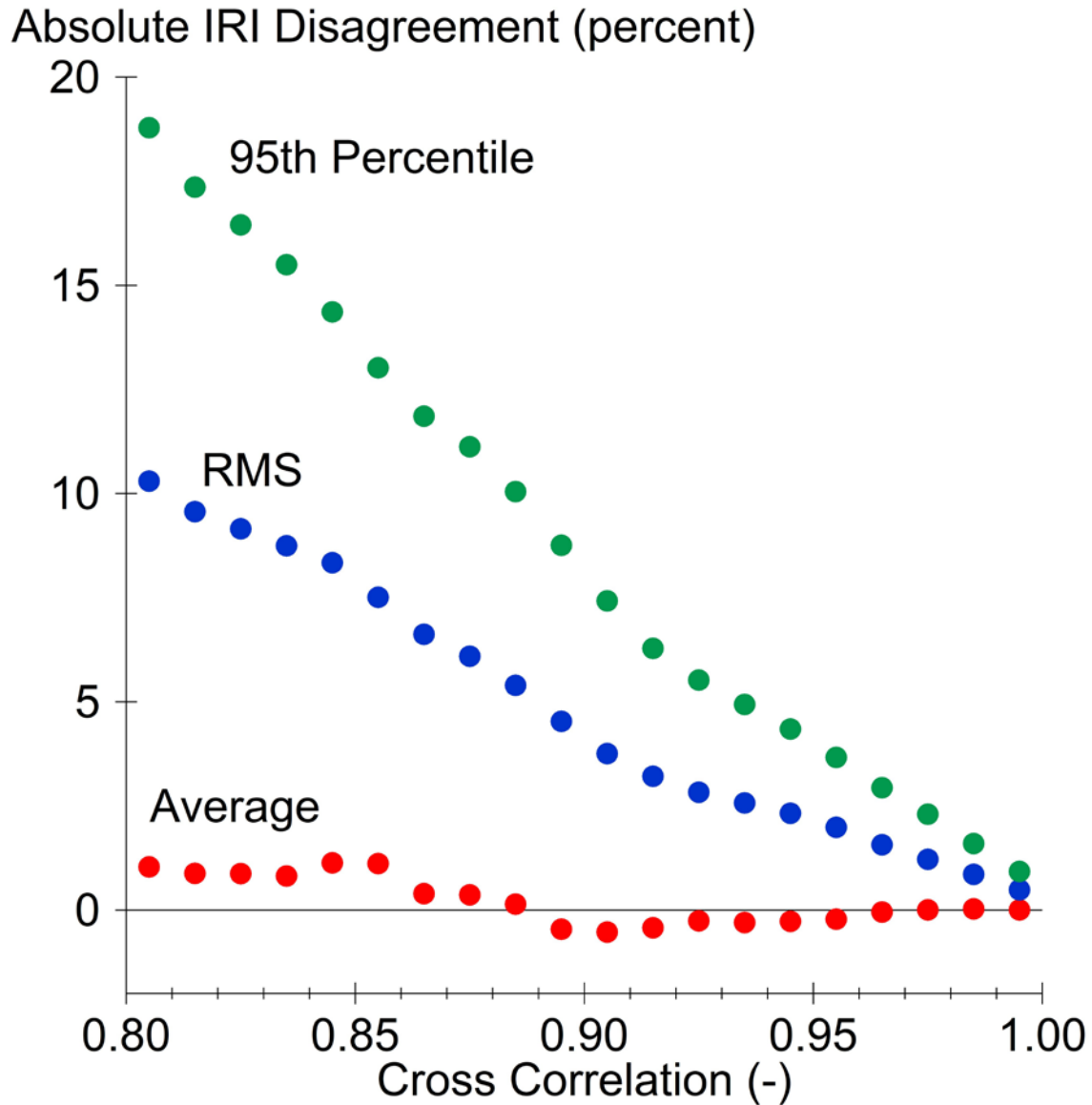
63,492 observations shown

# 2015 Round-Up, IRI Error versus Cross Correlation

Cross Correlation Range		Number of Comparisons	Error Level in IRI Measurement (Percent)				
From	To		Average	RMS	95th Percentile	Low	High
0.99	1.00	1305	0.01	0.48	0.93	-1.65	1.33
0.98	0.99	4538	0.03	0.86	1.60	-2.90	2.35
0.97	0.98	6128	0.01	1.22	2.31	-3.54	3.46
0.96	0.97	6725	-0.05	1.57	2.94	-5.15	4.88
0.95	0.96	7190	-0.22	1.99	3.67	-5.46	5.37
0.94	0.95	7590	-0.27	2.33	4.35	-6.49	6.31
0.93	0.94	7744	-0.30	2.57	4.94	-6.86	7.13
0.92	0.93	7795	-0.26	2.83	5.52	-7.69	8.40
0.91	0.92	7471	-0.43	3.21	6.29	-8.77	9.84
0.90	0.91	7006	-0.53	3.76	7.43	-9.90	10.71
0.89	0.90	7264	-0.46	4.53	8.76	-11.59	13.26
0.88	0.89	7518	0.14	5.40	10.05	-11.79	14.51
0.87	0.88	6569	0.37	6.10	11.13	-12.04	16.01
0.86	0.87	5826	0.40	6.62	11.86	-13.84	16.75
0.85	0.86	5260	1.12	7.51	13.02	-13.79	16.91
0.84	0.85	4747	1.13	8.34	14.36	-15.55	17.89
0.83	0.84	3964	0.82	8.75	15.50	-15.88	18.63
0.82	0.83	3275	0.88	9.15	16.45	-17.29	20.85
0.81	0.82	2866	0.88	9.57	17.36	-18.05	22.60



# 2015 Round-Up, Summary Results



## 2015

### CC Range

0.97-0.98

0.93-0.94

0.92-0.93

0.88-0.89

### 95 Percentile IRI Error

2.31

4.94

5.52

10.05

## 2004

### CC Range

0.97-0.98

0.92-0.93

0.81-0.82

### 95 Percentile IRI Error

2.00

4.80

10.00



# Key Points

- Good cross correlation requires agreement in roughness and the profile features that cause roughness.
- Disagreement in longitudinal distance measurement penalizes cross correlation.
- High-pass filtering may affect cross correlation results.
- Set thresholds to suit your needs.

I'd use:

0.98 reference device accuracy and repeatability

0.95 for any project-level or construction QA/QC application

0.92 for network-level applications (do not use  $< 0.88$ )