Development of a New Laser Reference Profiler & Testing at MnRoad 2013

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San Antonio Texas

FHWA 2013 Reference Profiler Device Evaluation at MnRoad

- 14-16 May 2013 Experiment at MnRoad
- Candidate Reference Device Procedure
  - First calibrate DMI on 1000 foot AC section
  - Then make 6 runs on 6 Pavement Test Sections and turn in ERD or PPF data before leaving Section
    1. Dense Graded Asphalt Concrete (AC)
    2. Chip Seal (CS)
    3. Porous Asphalt Concrete, AKA Open Grade (OG)
    4. Transversely Tining *PCC (TT)
    5. Longitudinally Grinding PCC, AKA Diamond Grinding (DG)
    6. Longitudinally Tining PCC (LT)

*PCC is Portland Cement Concrete

FHWA 2013 Reference Profiler Device Evaluation at MnRoad

- FHWA Report Card Evaluation
  - Determine DMI accuracy
  - Perform Repeatability and Accuracy Cross-Correlation (CC) against Benchmark Profiler (BMP) in following wavebands
    - IRI Waveband from ~30 m (98.4 ft.) to ~1.25 m (4 ft.)
    - Long Waveband: band pass filter with cut-offs at 40 m (131.2 ft.) and 8 m (26.2 ft.)
    - Medium Waveband: band pass filter with cut-offs at 8 m (26.2 ft.) and 1.6 m (5.25 ft.)
    - Short Waveband: high pass filter with cut-off at 1.6 m (5.25 ft.). Other end is cut-off by 0.075 m tire bridging filter which resembles moving average for low height textures.

MnRoad 2013 Experiment Goals

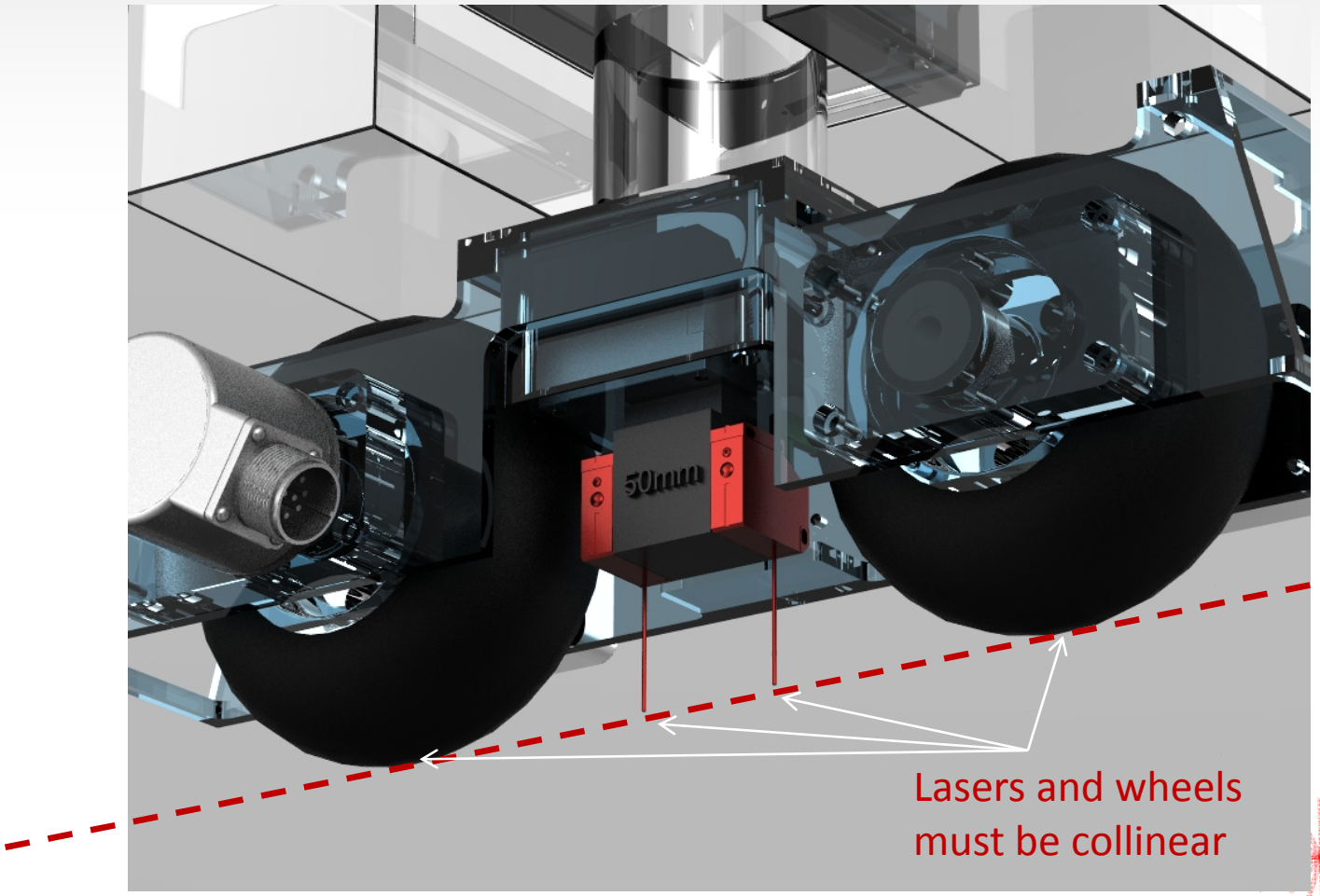
- Test Upgrades to SurPRO 4000 Incl. Profiler
  - Added High Quality processing
    - Constant distance raw data sampling (versus constant time sampling) at 1 mm (adjustable)
    - Profile processing at end of run rather than in real-time enables higher quality profile
    - 2-way digital filters with zero phase shift
    - RAW data files store all data, can be reprocessed
  - Added Optical Target Sensor System
    - Very accurate DMI
    - Automatic start and end line detection
    - Automatic start and stop of distance (DMI) cal

MnRoad 2013 Experiment Goals

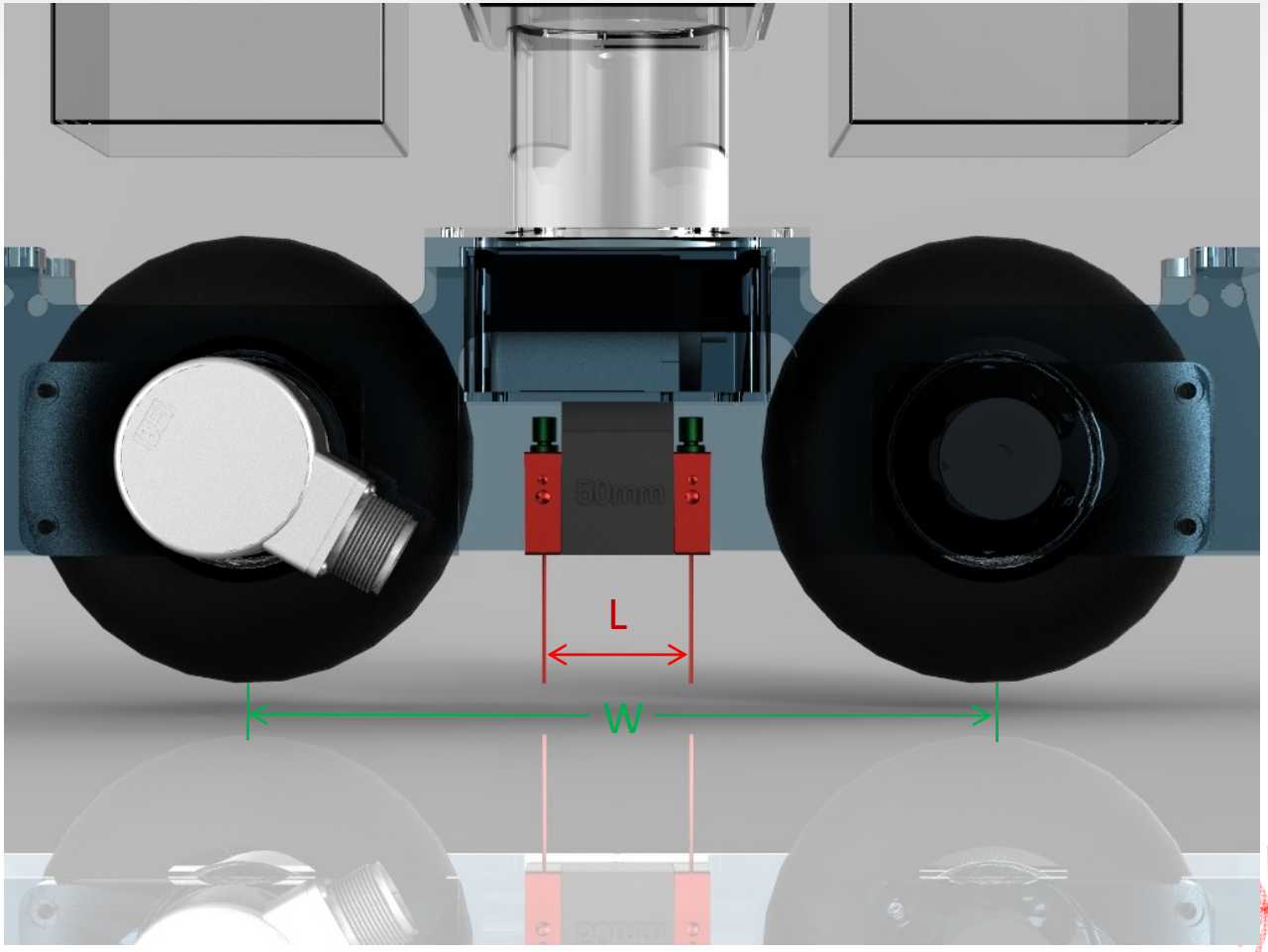
- Test New Laser Reference Profiler SurPRO 4000L
  - Builds on Upgrades to SurPRO 4000 Incl. Profiler. Uses same software. Lasers turned on using Menu.
  - Higher Repeatability and Accuracy in Short Waveband
  - Added
    - Lasers
      - Extend short wavelength performance
      - L spacing yields adjustable short wavelength to 75mm (3in)
      - Short wavelength is phase and amplitude accurate
    - Sunlight shields for lasers
    - Tire Bridging Filter
    - Macro Texture Measurement (laser can be added for texture even if short waveband not required)

SurPRO 4000L

Laser Profiler Arrangement



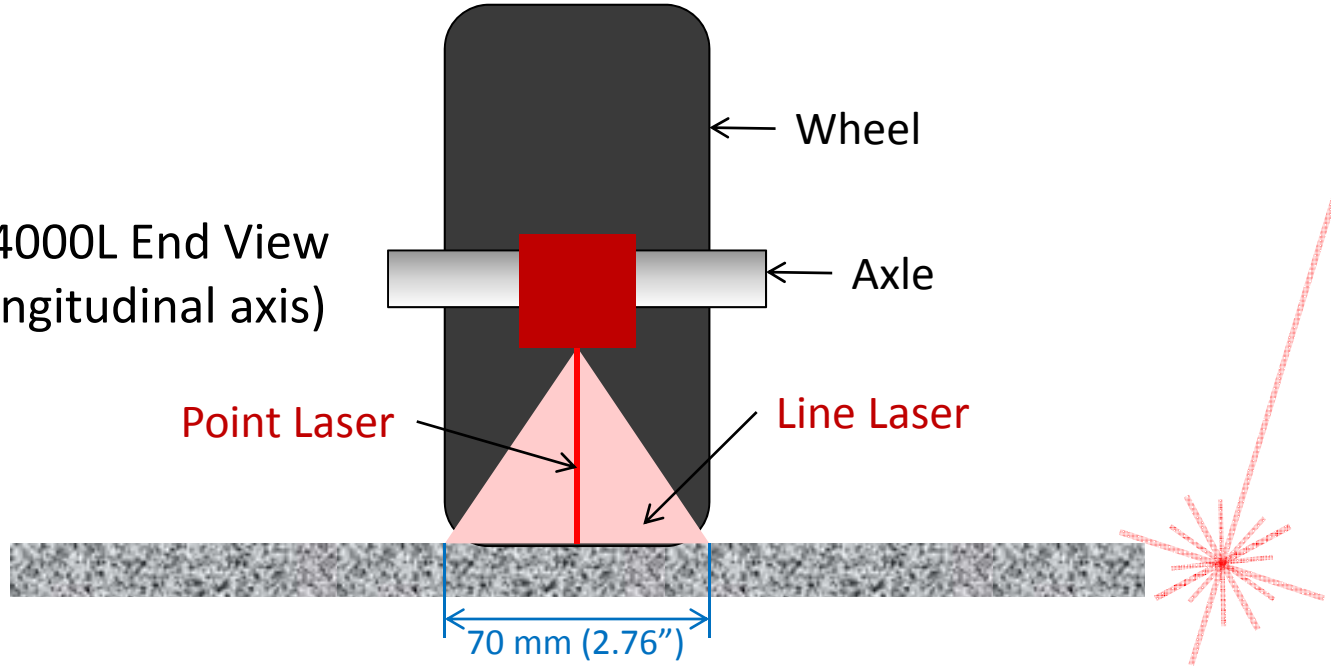
Laser Profiler Arrangement



Point (Spot) vs Line Laser

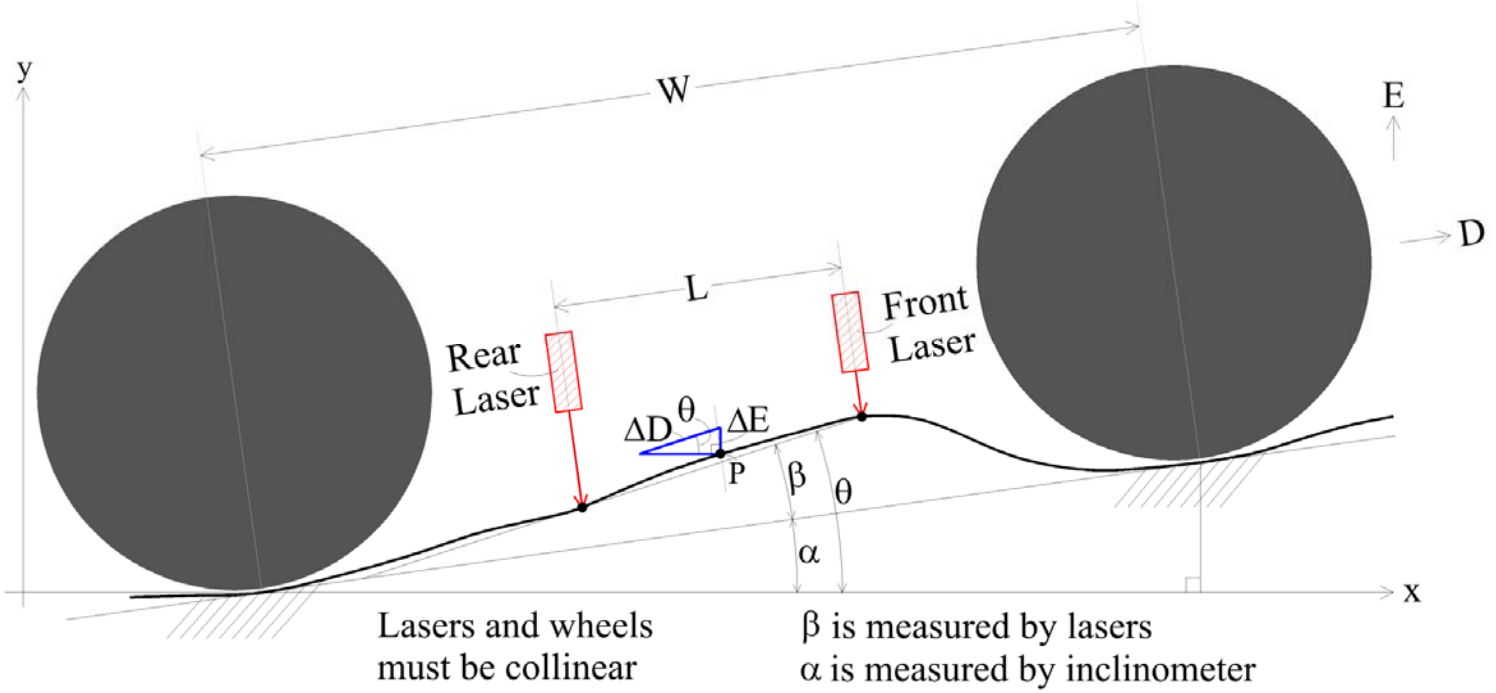
- SurPRO 4000L uses point lasers with longitudinal tire bridging because of cost and size
- Agrees with 70 mm transverse line laser with tire bridging if transverse variation is small

SurPRO 4000L End View
(along longitudinal axis)



New Laser Profiler Method

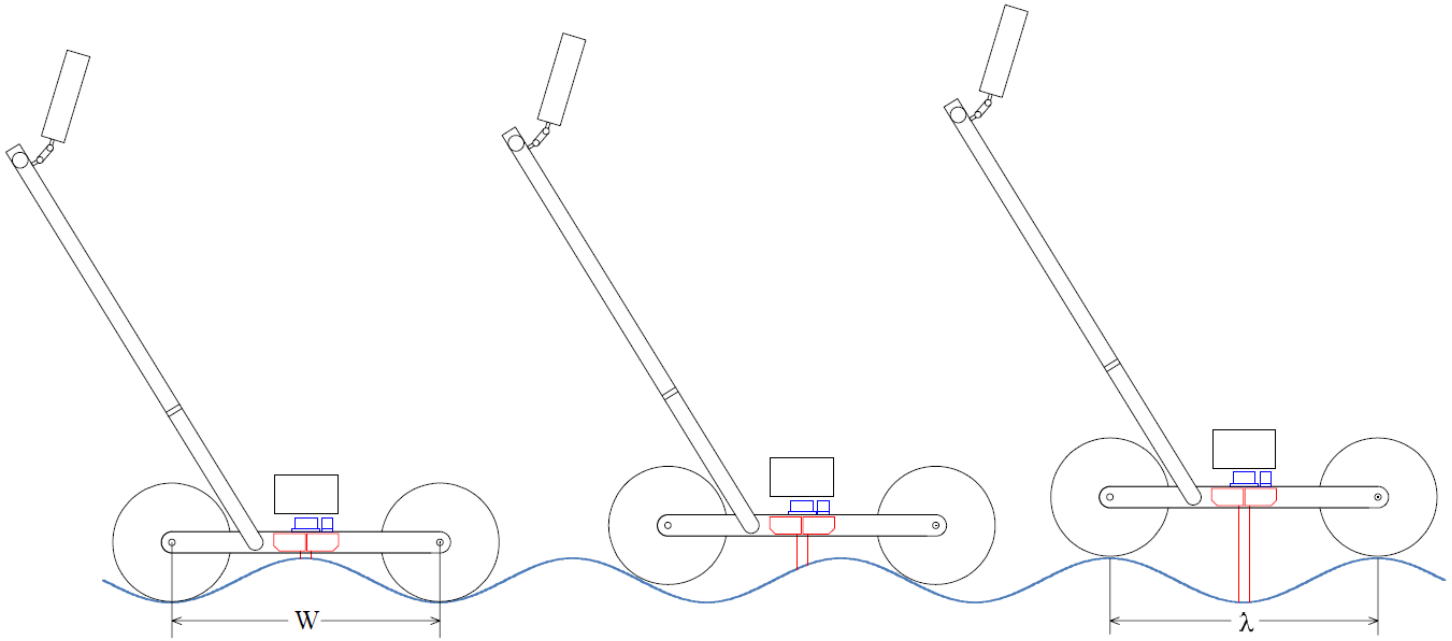
- Elevation changes ΔE are calculated from change in distance travelled ΔD and angle θ which is total of α and β



Apparatus & Method Patent Pending

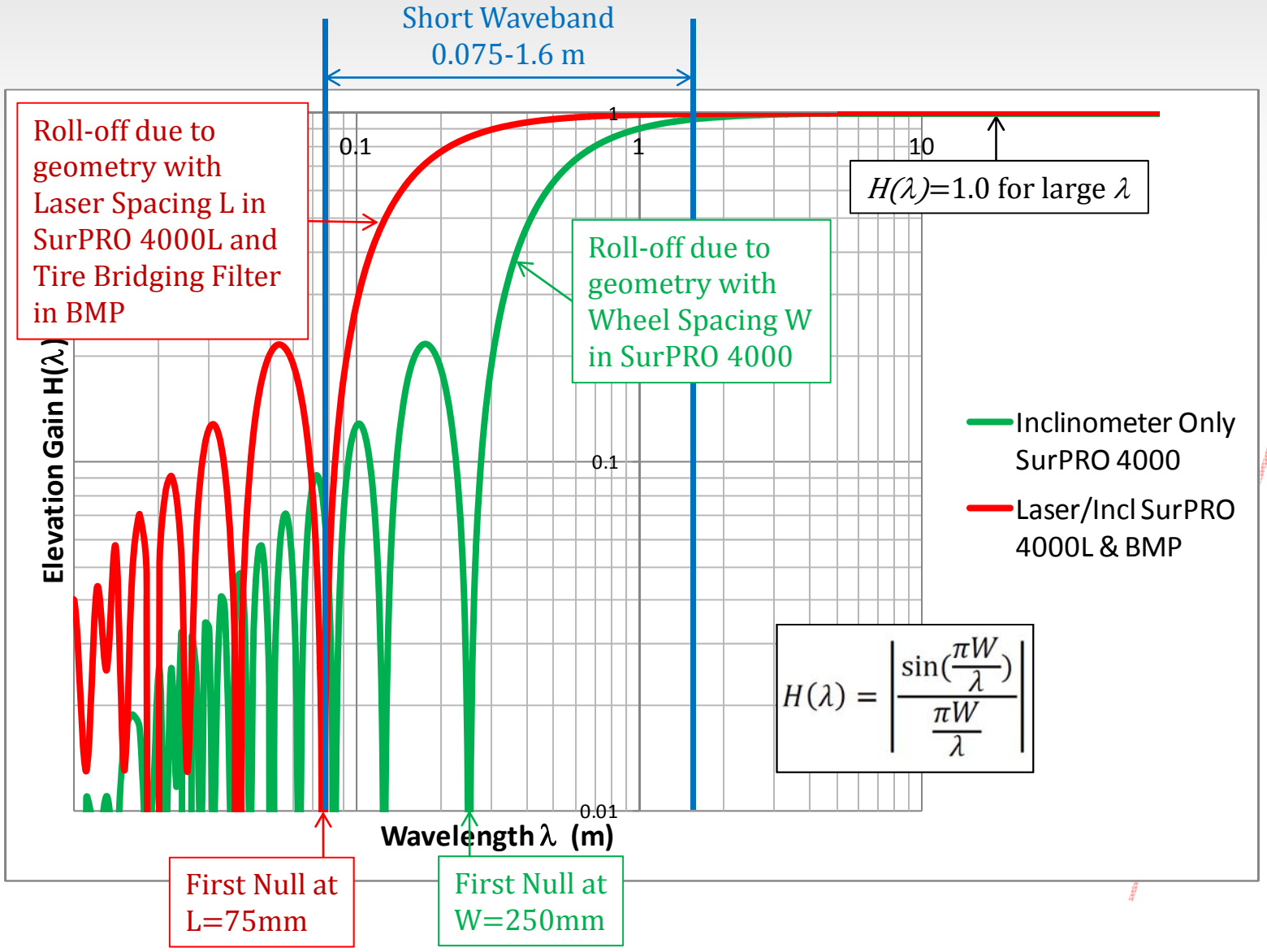
Nulls

- Nulls are wavelengths λ_N of sine wave profile input where inclinometer profiler output is zero because profiler frame always has zero tilt.



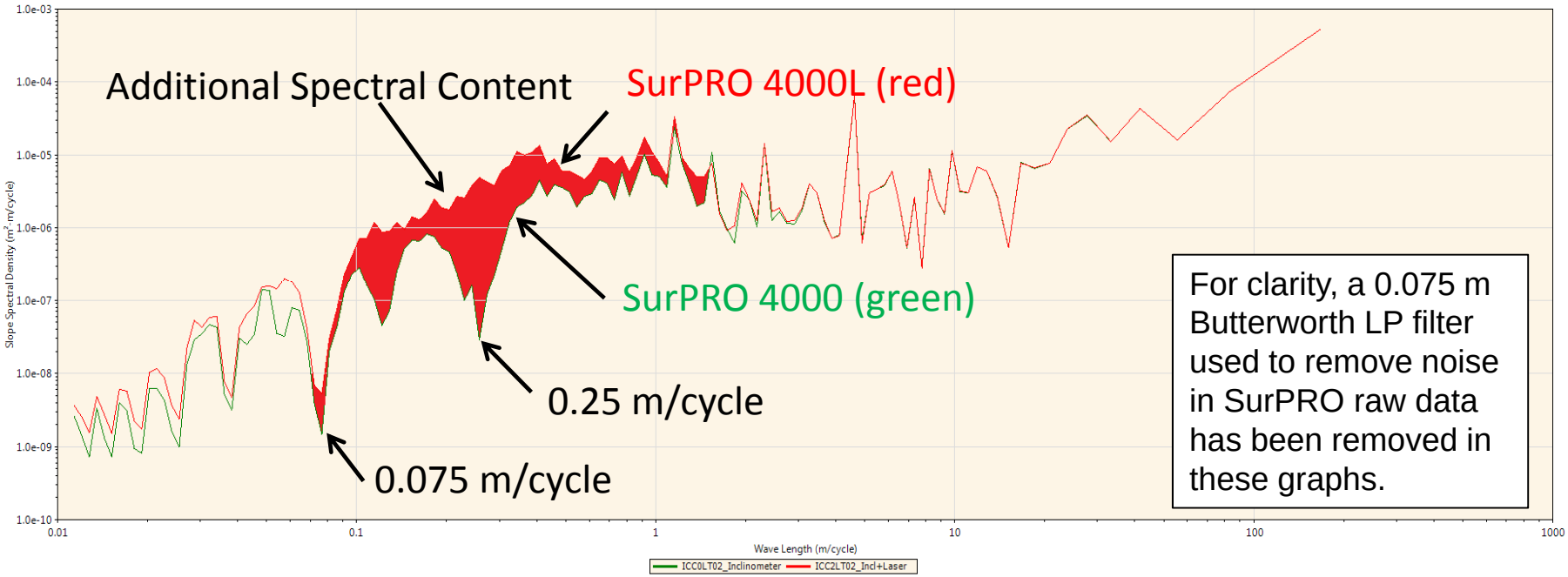
Nulls where $\lambda_N = W/n$, $n = 1,2,3 \ldots \infty$

Wavelength Response



SurPRO 4000L
Short Wavelength Extension

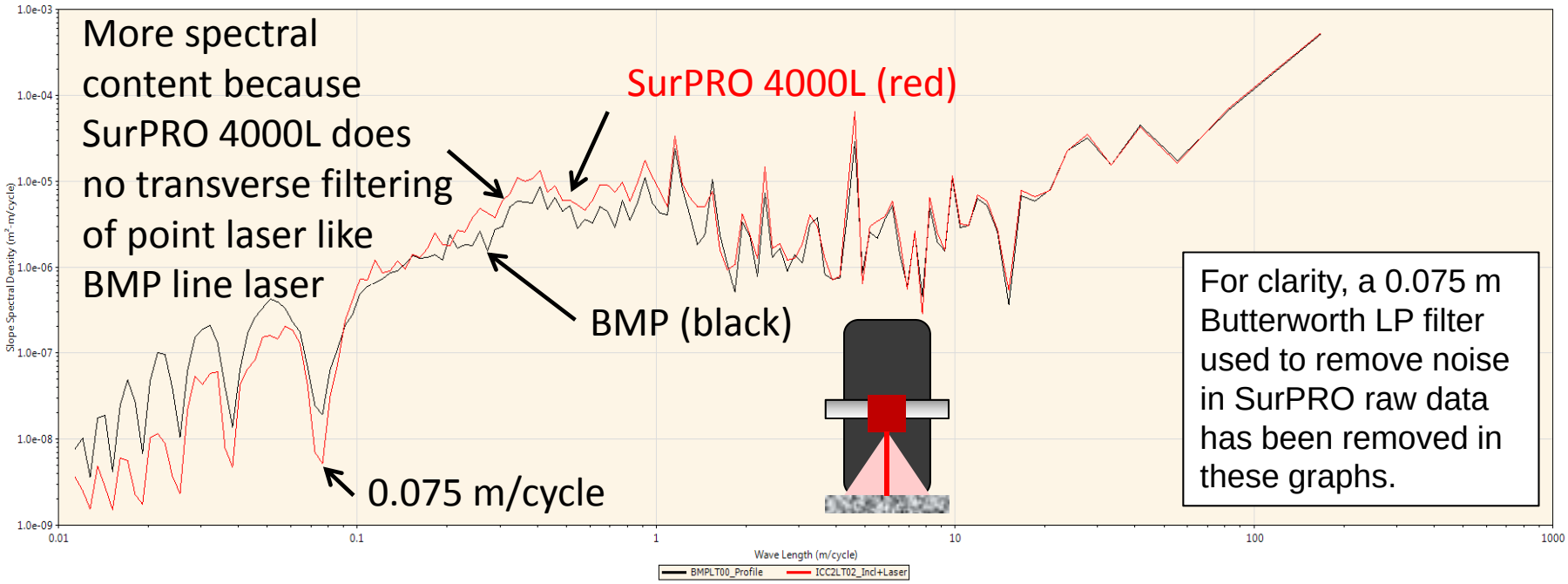
- SurPRO 4000 extends to 250 mm sufficient for IRI, medium and long wavebands
- SurPRO 4000L extends to 75 mm to add short waveband cross-correlation of 94%



SurPRO 4000L

Short Wavelength Comparison to BMP

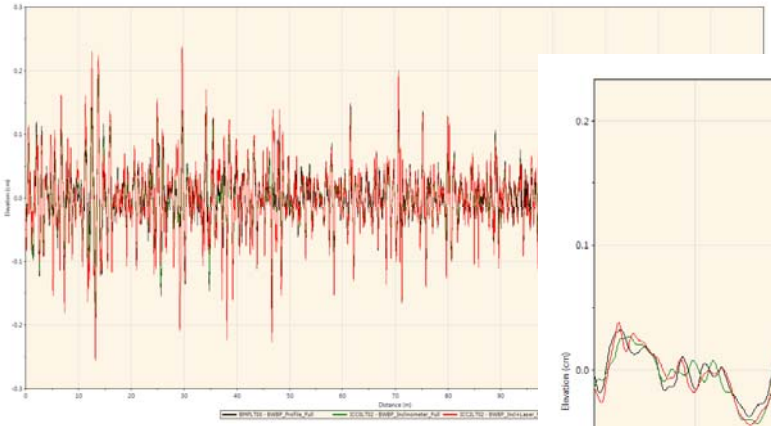
- SurPRO 4000L spectrum matches BMP fairly well from 0.075m to infinity
- SurPRO 4000L has higher spectra from 0.1-2 m since point laser is not filtered like line laser

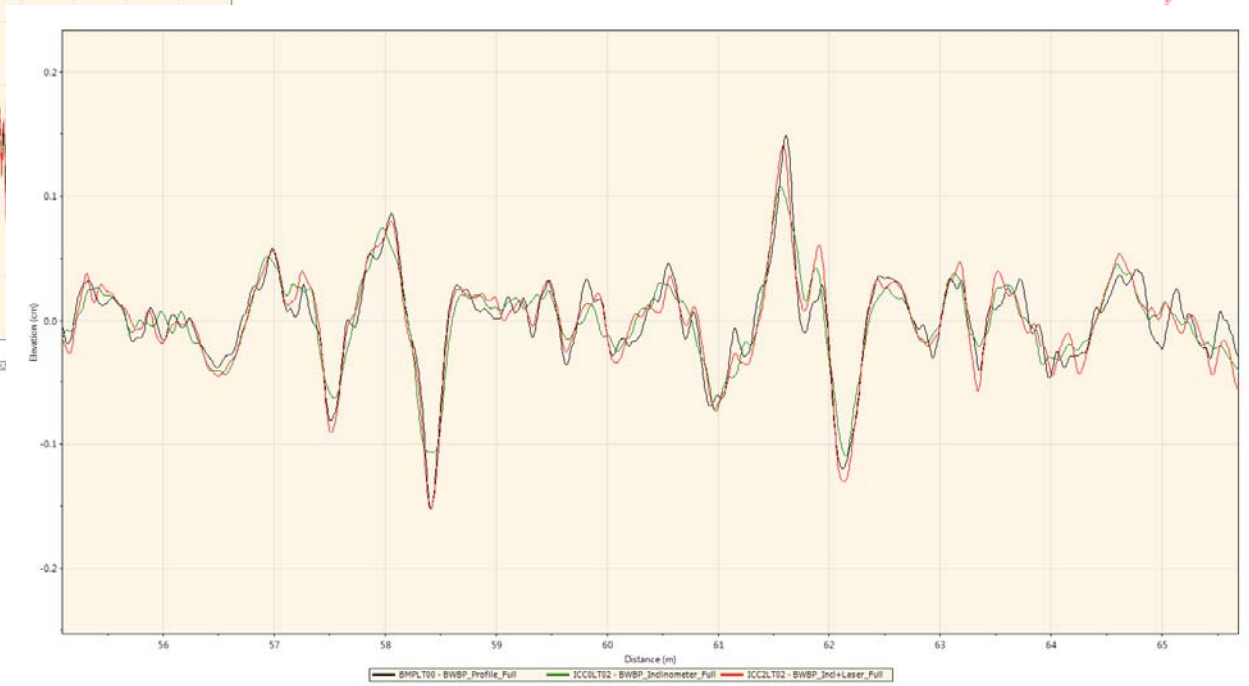


Short Waveband Comparison

BMP, SurPRO 4000 & 4000L

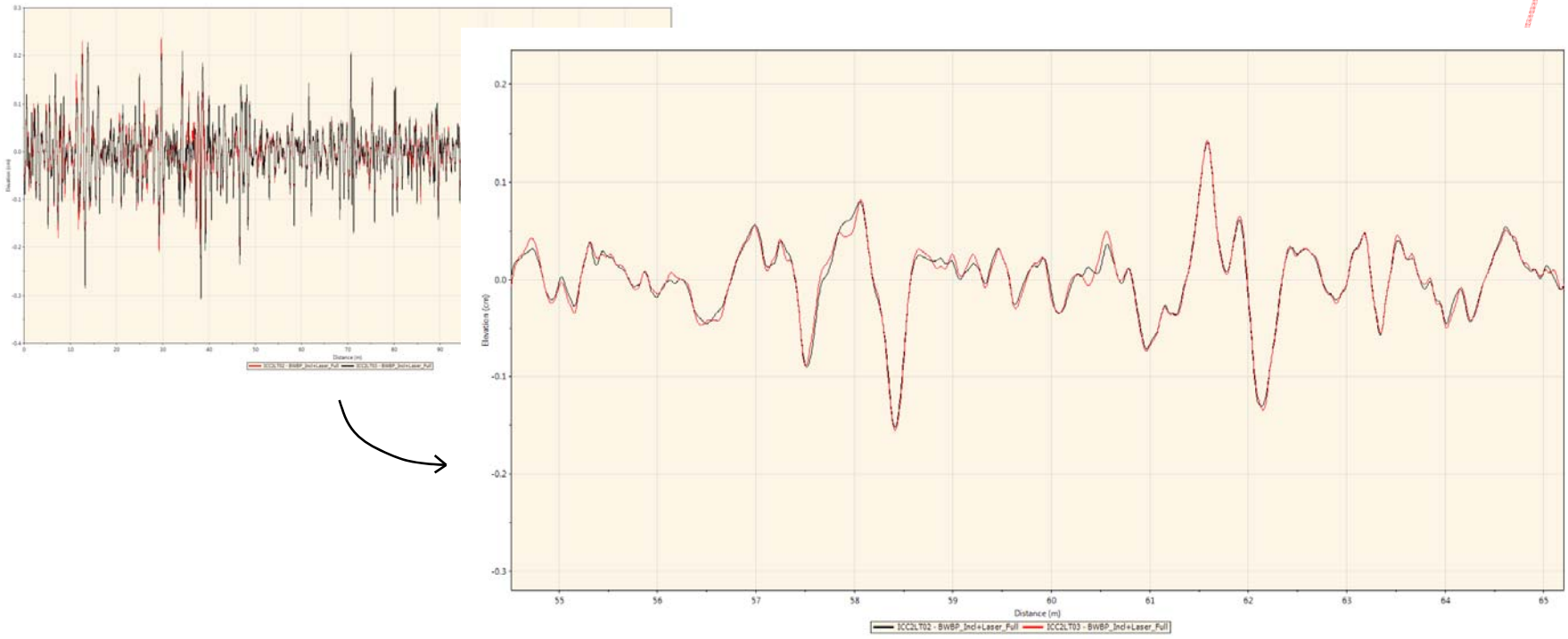
- LT runs zoomed in to show 1.6m BW high pass filtered elevation detail matching
- 4000, with inclinometer only, has lower peaks





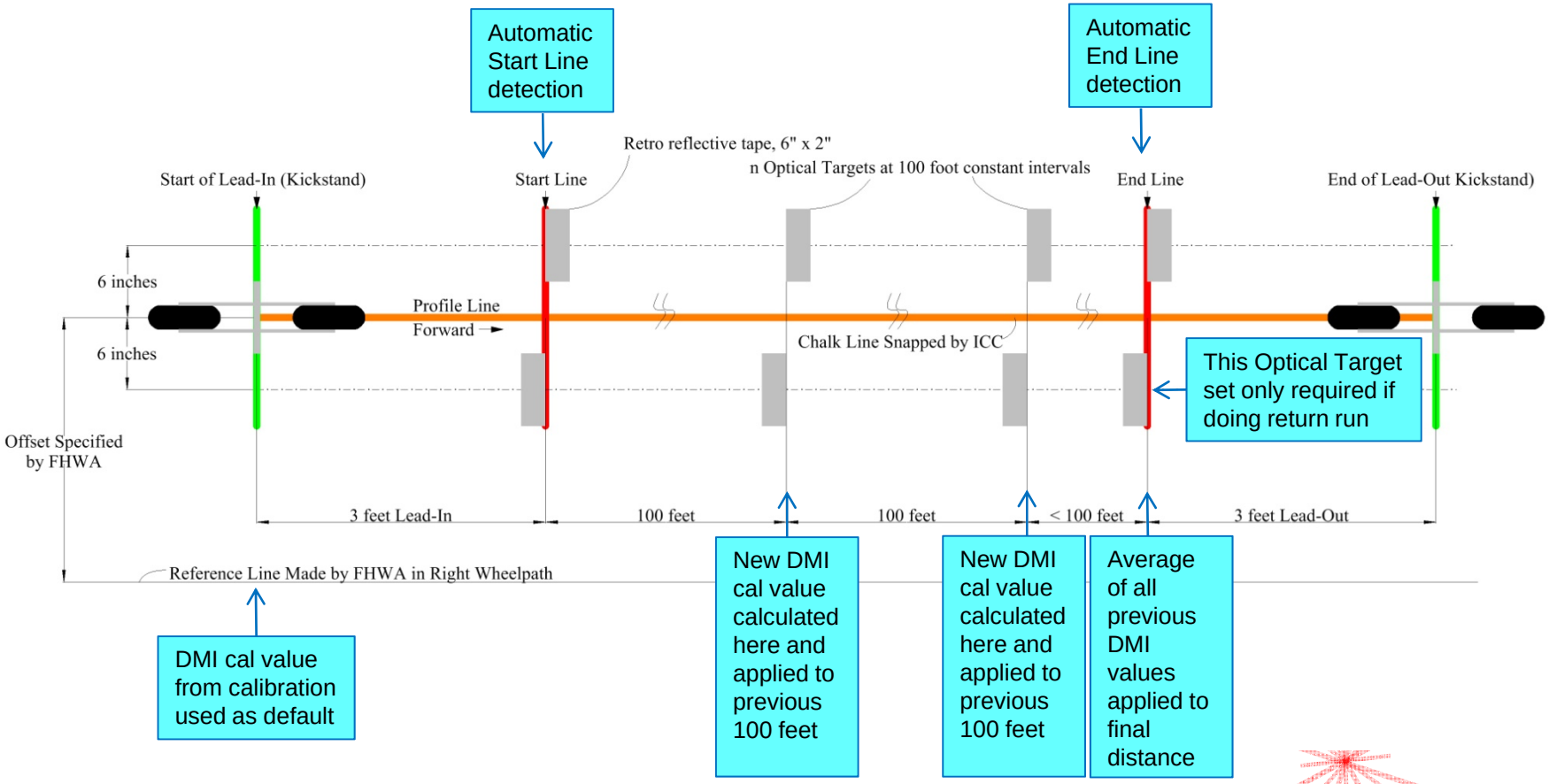
Short Waveband Repeatability
SurPRO 4000L

- LT runs zoomed in to show 1.6 m BW high pass filtered elevation detail matching
- 4000L has high repeatability on LT



Optical Target Sensor

Optical Target Arrangement



FHWA Reference Profiler

Data Collection 14-15 May 2013

- Record High Temperatures
- Checked out unit
- Calibrated distance on 1000' DMI site
- Collected 7 runs on 6 test sections in 2 days
- Repeated DG on 15 May because of concrete slab curling (DG1 set is first attempt on 14 May)

It was a scorcher: 98-degree reading breaks Twin Cities records, wildfires break out

By Will Ashenmacher
washenmacher@pioneerpress.com
Posted: 05/13/2013 12:01:00 AM CDT
Updated: 05/15/2013 09:00:17 AM CDT

You know those record books for high temperatures on May 14?

Just throw them out.

After a spring that sometimes seemed nowhere to be found, both the Twin Cities and other locations in southern Minnesota topped daily high temperature records Tuesday.

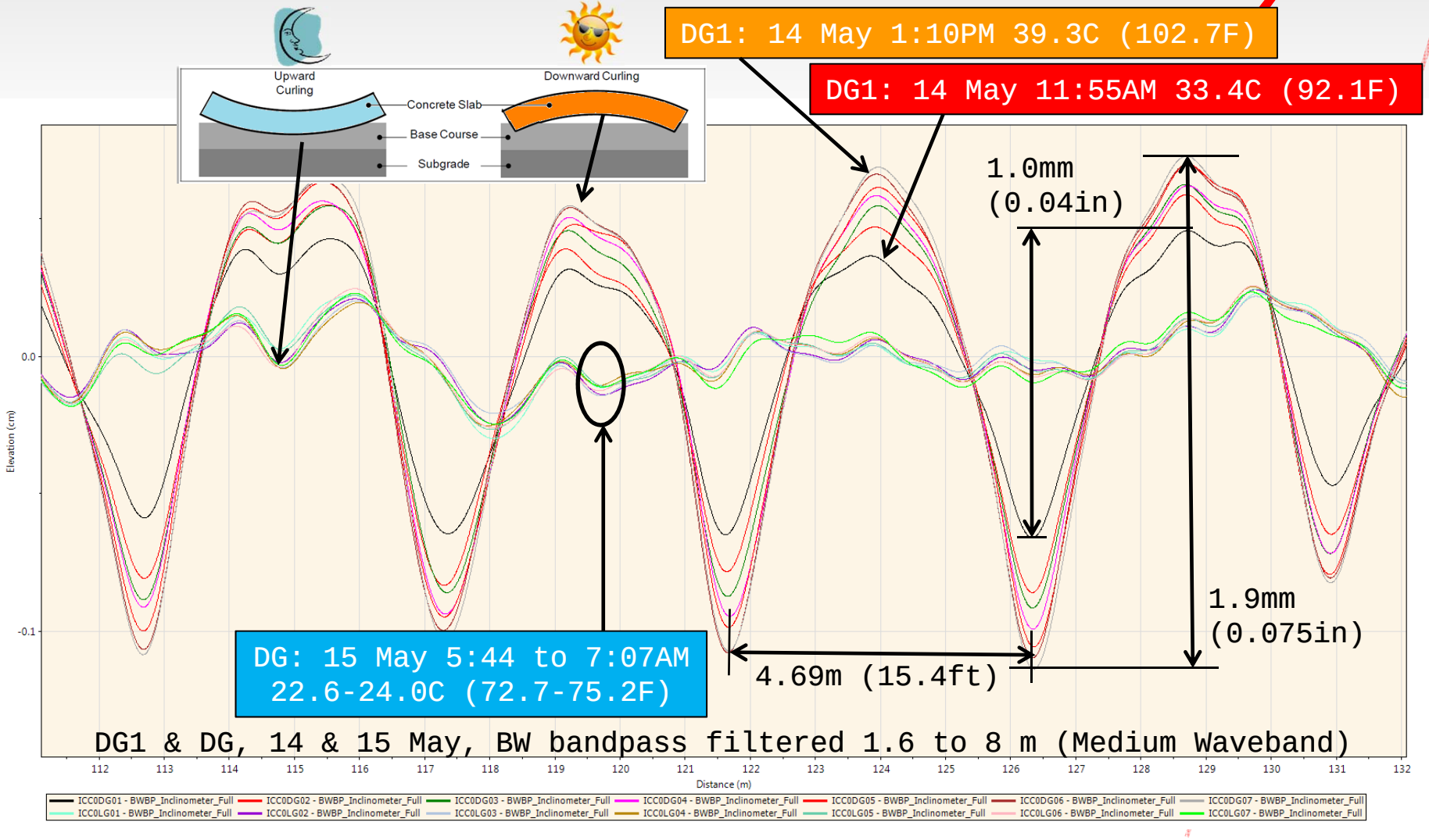
Minneapolis-St. Paul beat the record of 95 degrees set in 1932 by topping out at 98 at 3:25 p.m., according to Shawn DeVinny, a meteorologist with the National Weather Service in Chanhassen.

That was also the hottest temperature recorded this early in the season in the Twin Cities.

Delilah (no last name given) enjoyed dipping her feet into St. Paul's Lake Como as the temperatures reached the high 90s on Tuesday, May 14, 2013. "I am living for the weather," Delilah said. (Pioneer Press: Scott Takushi)

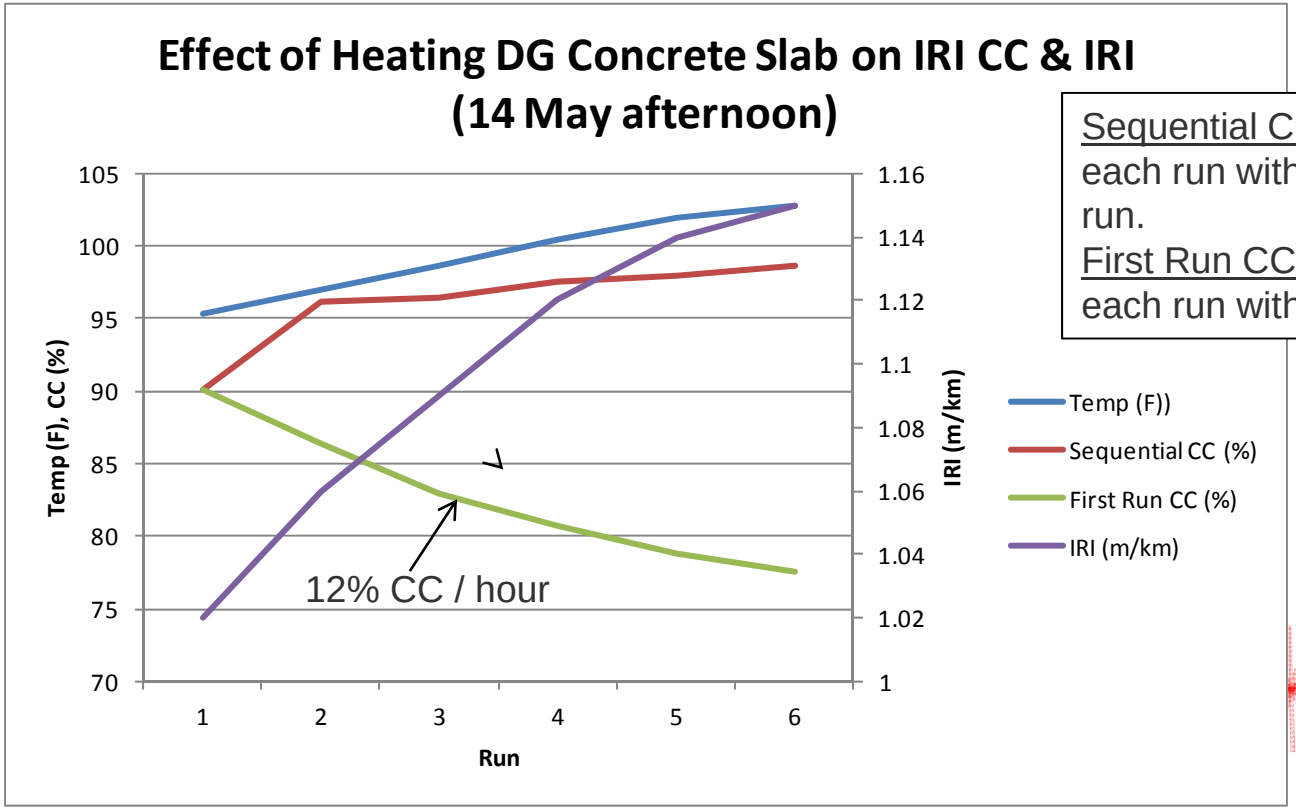
Concrete Slab Curling

DG Test Section 14 & 15 May



Concrete Slab Curling
Hot Condition

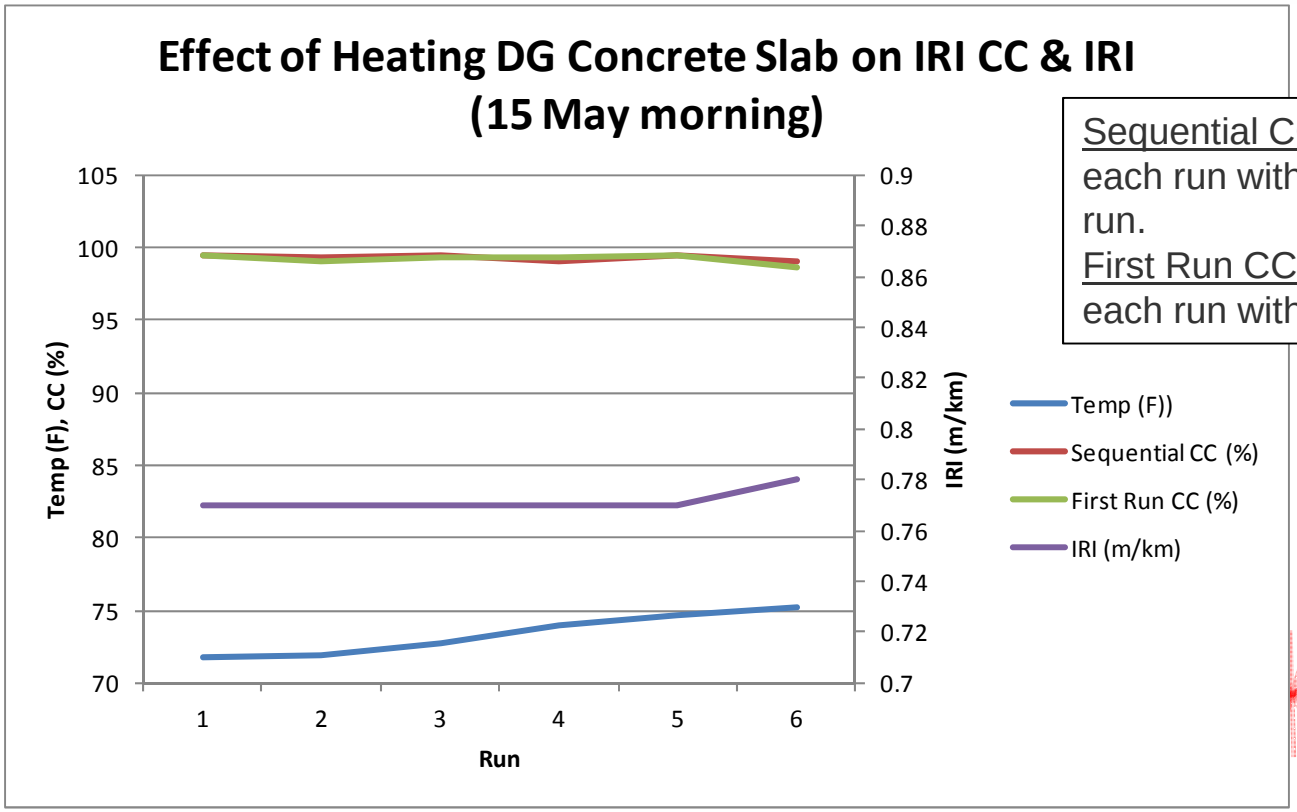
- DG slab curling during scorcher (DG1 runs)
- Data collected 11:45AM-1:10PM at 10 min per run



Sequential CC Correlates each run with preceding run.
First Run CC Correlates each run with first run.

Concrete Slab Curling
Cool Condition

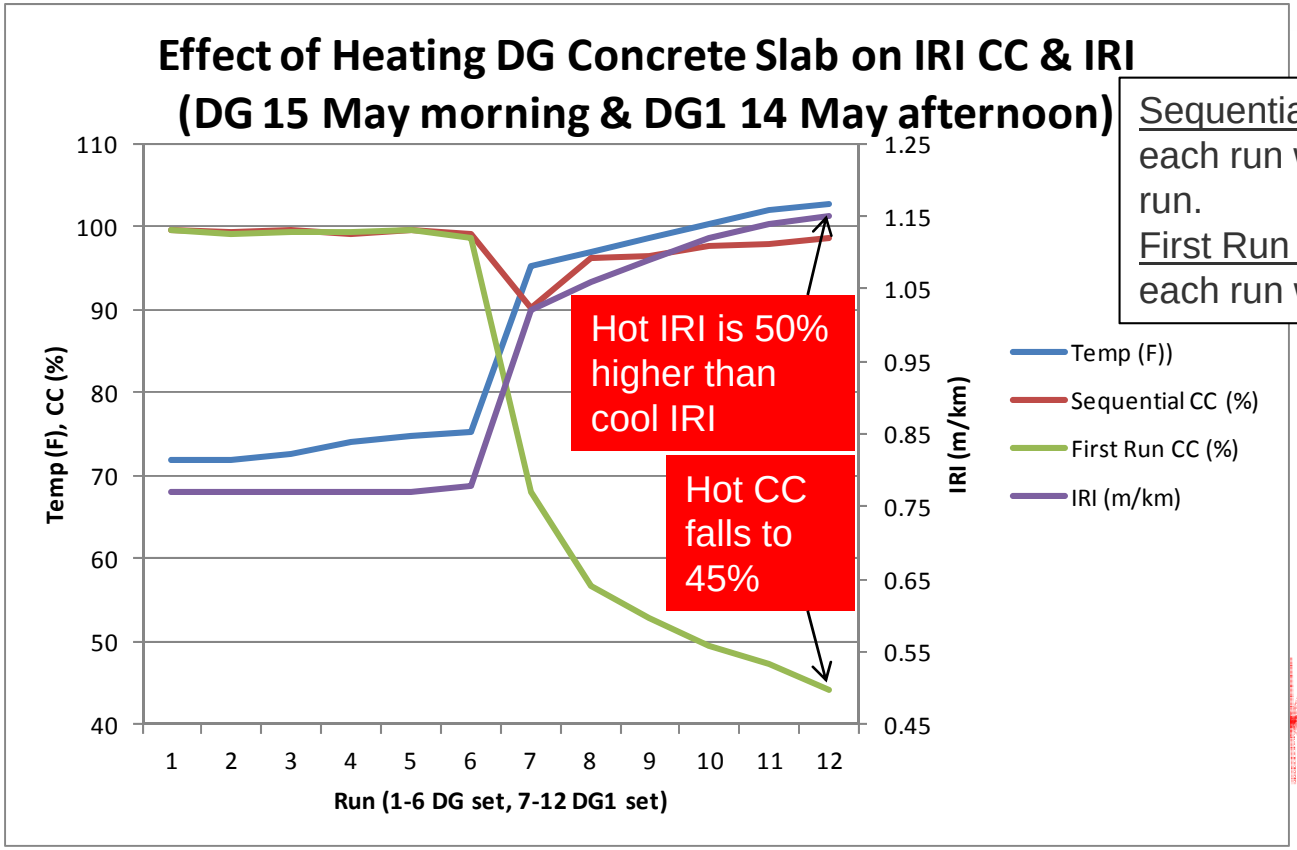
- DG slab stable temp at sunrise (DG runs)
- Data collected 5:45AM-7:07AM at 10 min per run



Sequential CC Correlates each run with preceding run.
First Run CC Correlates each run with first run.

Concrete Slab Curling
Cool & Hot Condition

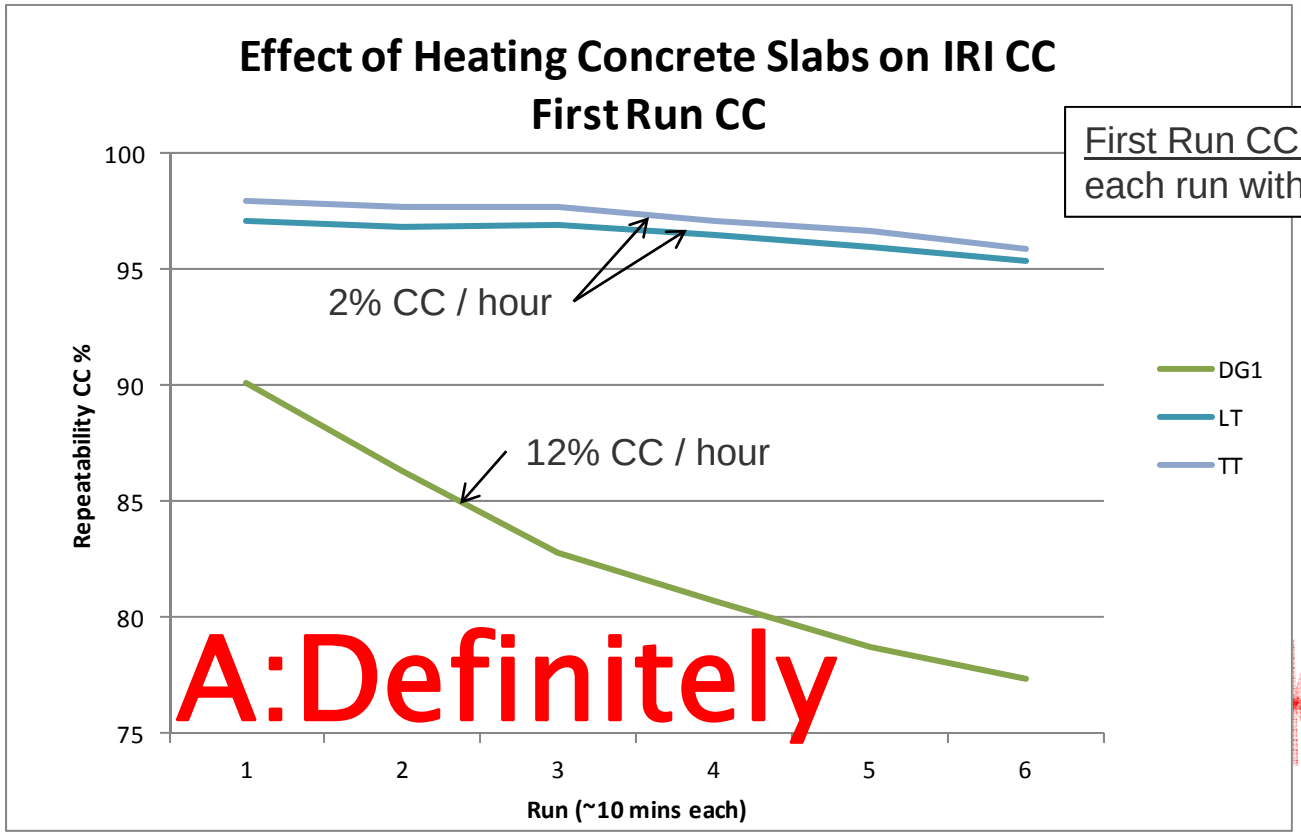
- DG slab at dawn (DG set) and mid-day (DG1 set). Run 1 on 15 May is reference for First Run CC.



Sequential CC Correlates each run with preceding run.
First Run CC Correlates each run with first run.

Q:Is the Concrete Pavement Changing During the Run?

- DG, LT and TT slab curling detected each 10 min
- Movement caused 2-12% IRI CC/hour decrease



SurPRO #90 vs SurPRO #91

- TT, 5 runs from each cross-correlated in PCM
- TT, 1 run from #91 cross-correlated with 5 runs from #90 in PSM, avg. CC of 99.5

Profiler Certification: Summary Results

Statistics

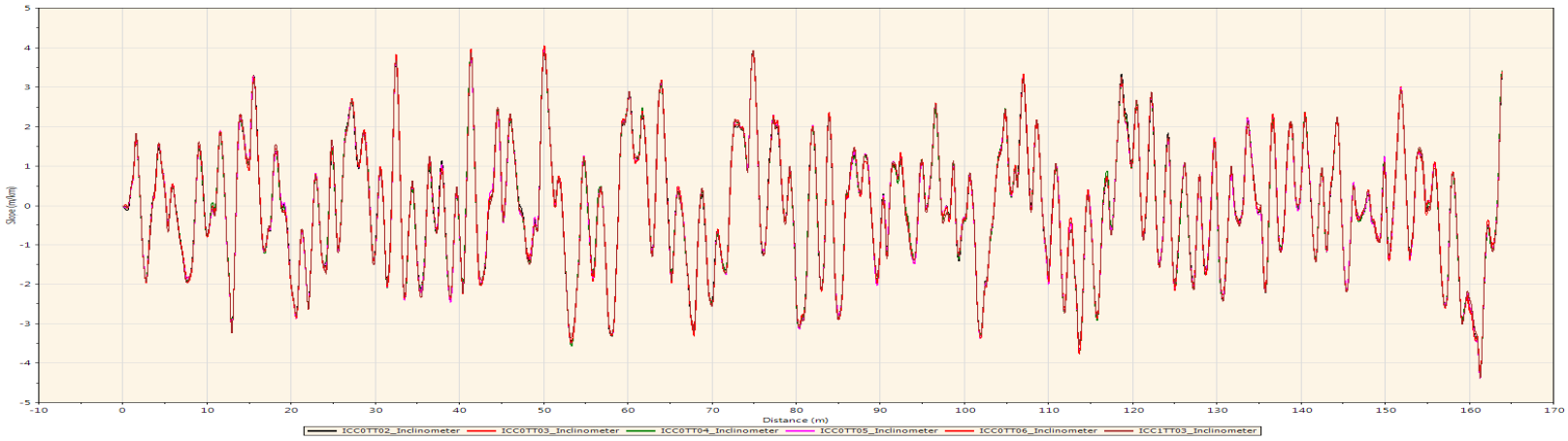
Statistic	Repeatability - Left
Comparison Count	45
% Passing	100.00
Mean	99.21
Minimum	98.40
Maximum	99.89
Standard Deviation	0.4
Grade	Passed

Repeatability - Left Correlations (%)

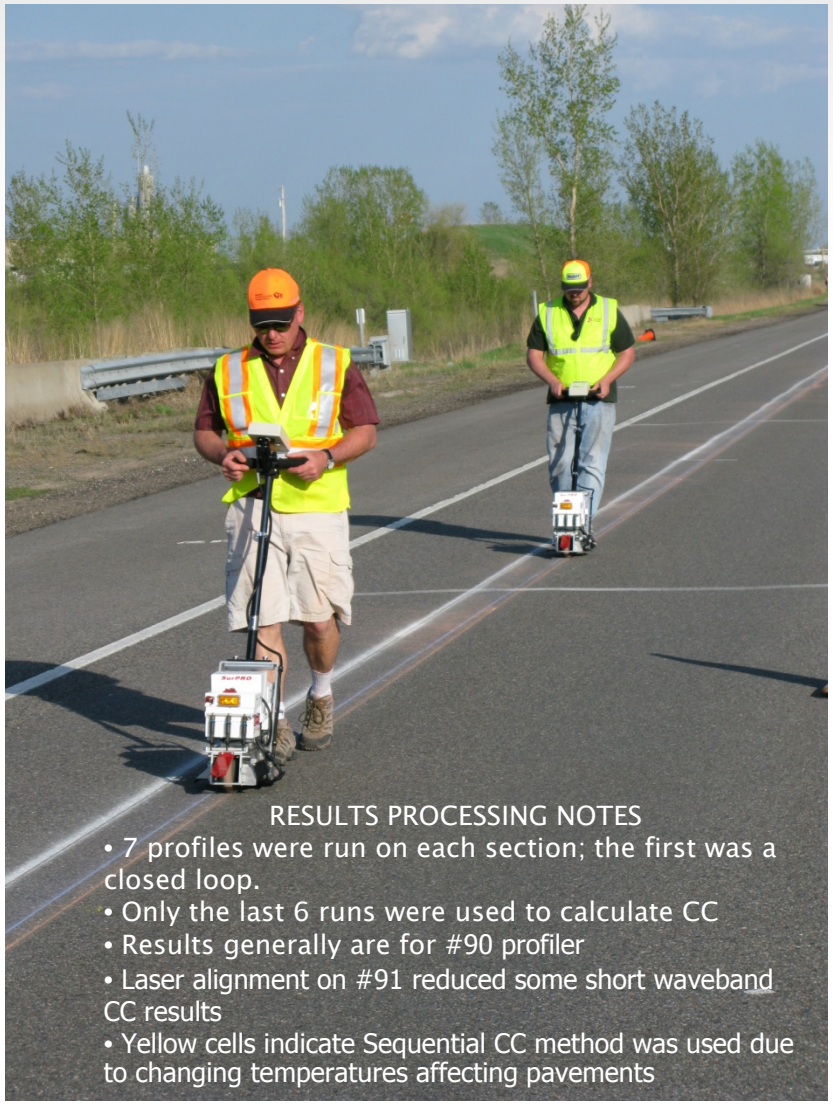
Run	2	3	4	5	6	7	8	9	10
1	100	99	99	100	99	99	99	99	100
2		100	100	100	99	99	99	99	100
3			100	99	99	98	99	98	100
4				99	99	98	99	98	100
5					100	99	99	99	99
6						99	100	99	99
7							99	100	98
8								99	99
9									99

Repeatability - Left Offsets (m)

Run	2	3	4	5	6	7	8	9	10
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3			0.0	0.0	0.0	0.0	0.0	0.0	0.0
4				0.0	0.0	0.0	0.0	0.0	0.0
5					0.0	0.0	0.0	0.0	0.0
6						0.0	0.0	0.0	0.0
7							0.0	0.0	0.0
8								0.0	0.0
9									0.0



Asphalt Concrete (AC)

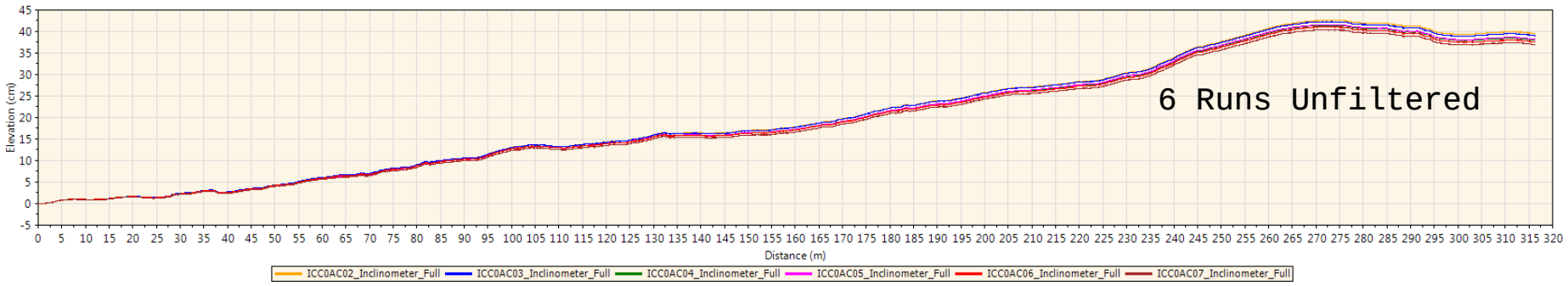


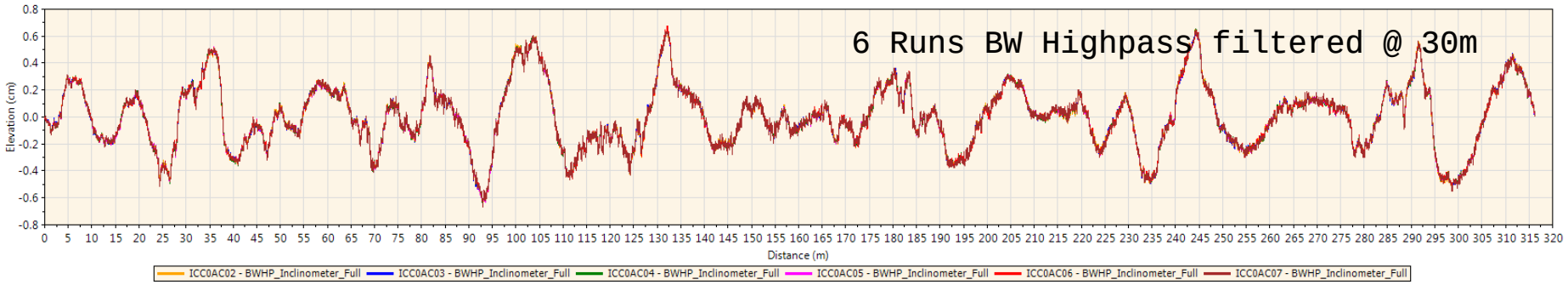
RESULTS PROCESSING NOTES

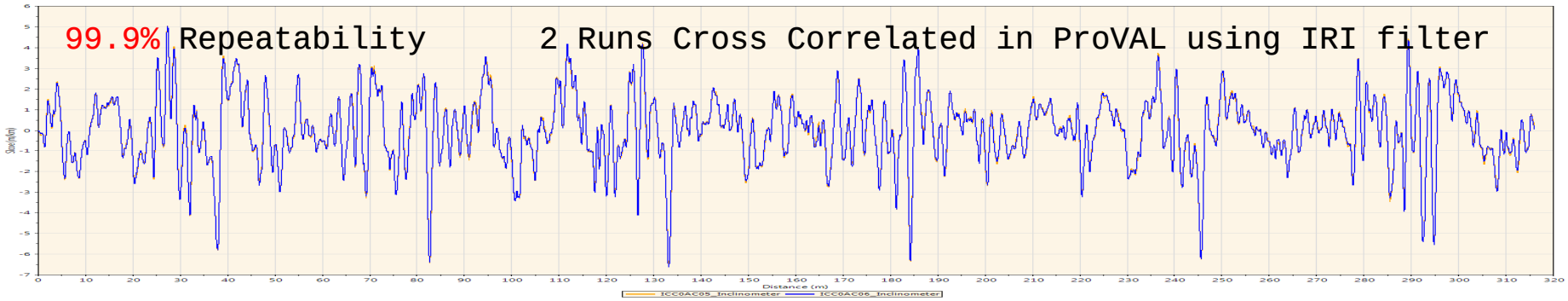
- 7 profiles were run on each section; the first was a closed loop.
- Only the last 6 runs were used to calculate CC
- Results generally are for #90 profiler
- Laser alignment on #91 reduced some short waveband CC results
- Yellow cells indicate Sequential CC method was used due to changing temperatures affecting pavements

SurPRO PERFORMANCE RESULTS			
AC		4000	4000L
IRI (m/km)		1.23	1.24
Cross-Correlation	IRI	**99.5**	99.4
	SHORT	89.3	90.8
	MEDIUM	99.3	99.3
	LONG	99.7	99.7

Asphalt Concrete (AC)



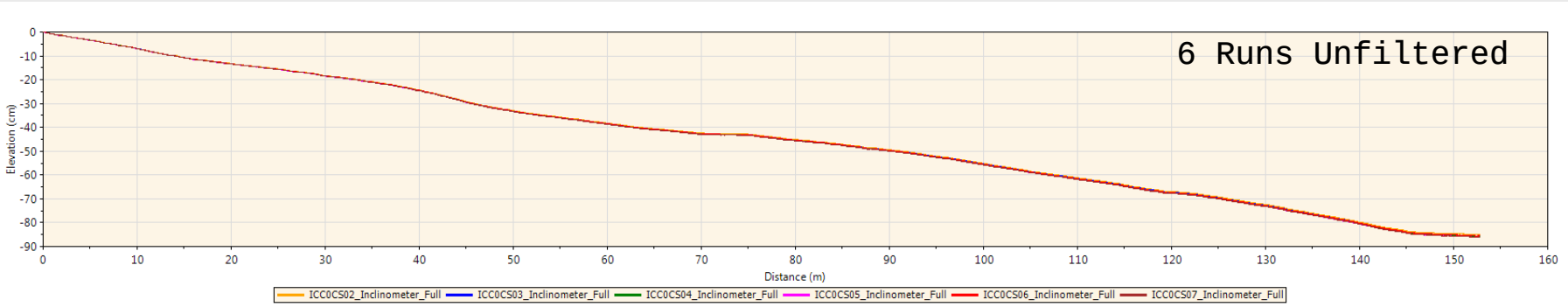


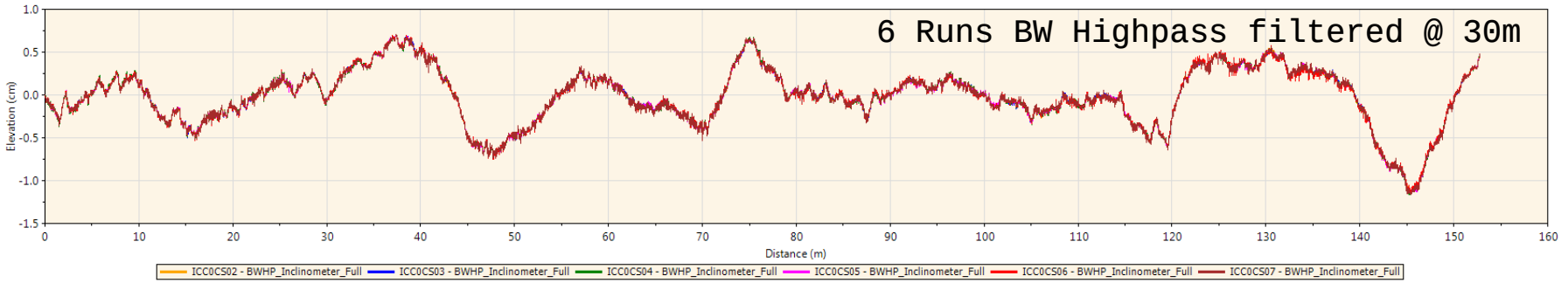


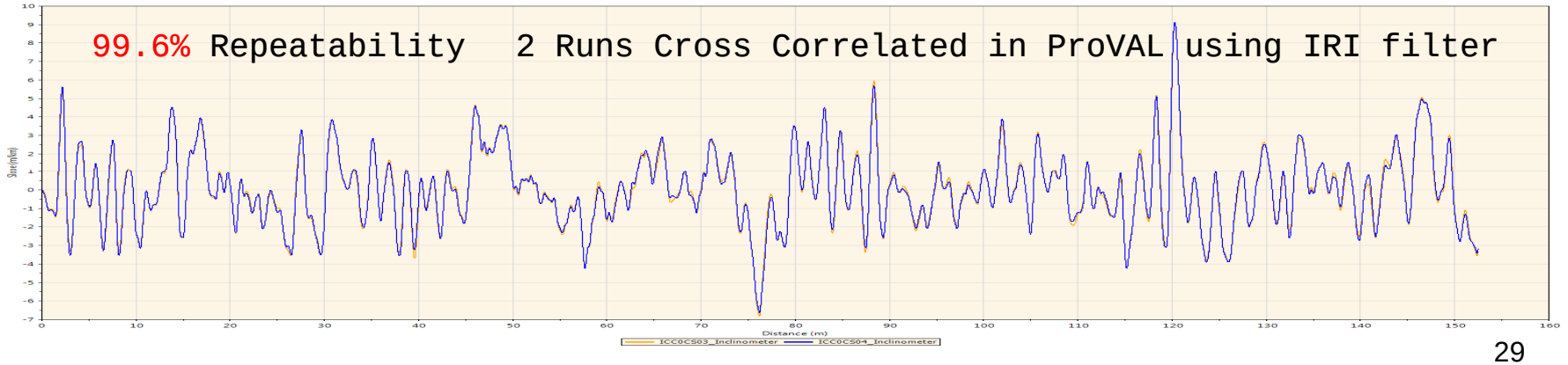
Chip Seal (CS)

SurPRO PERFORMANCE RESULTS			
CS		4000	4000L
IRI (m/km)		1.51	1.53
Cross-Correlation	IRI	**99.1**	98.8
	SHORT	90.9	87.7
	MEDIUM	99.6	99.3
	LONG	99.8	99.8

Chip Seal (CS)

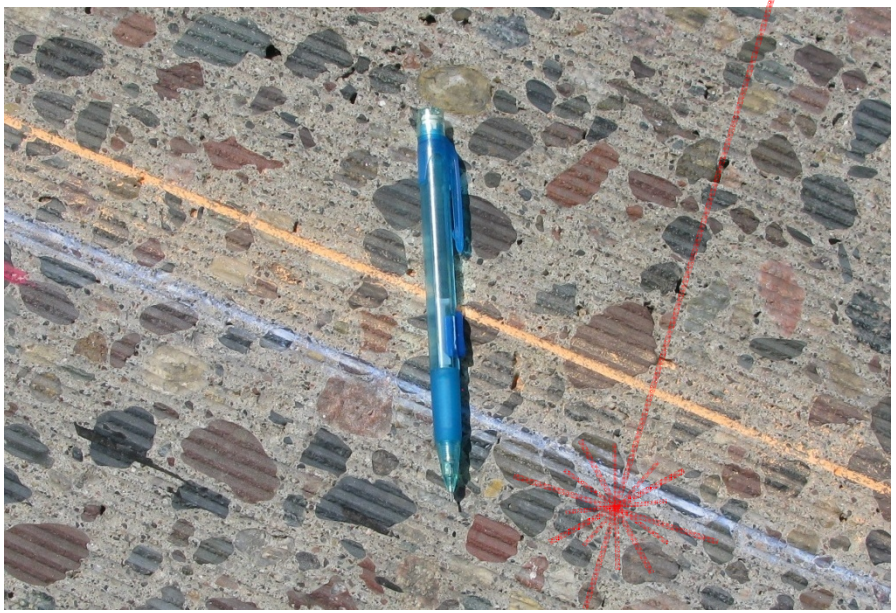

6 Runs Unfiltered
Elevation (cm)
Distance (m)
ICC0CS02_Inclinometer_Full
ICC0CS03_Inclinometer_Full
ICC0CS04_Inclinometer_Full
ICC0CS05_Inclinometer_Full
ICC0CS06_Inclinometer_Full
ICC0CS07_Inclinometer_Full


6 Runs BW Highpass filtered @ 30m
Elevation (cm)
Distance (m)
ICC0CS02 - BWHP_Inclinometer_Full
ICC0CS03 - BWHP_Inclinometer_Full
ICC0CS04 - BWHP_Inclinometer_Full
ICC0CS05 - BWHP_Inclinometer_Full
ICC0CS06 - BWHP_Inclinometer_Full
ICC0CS07 - BWHP_Inclinometer_Full

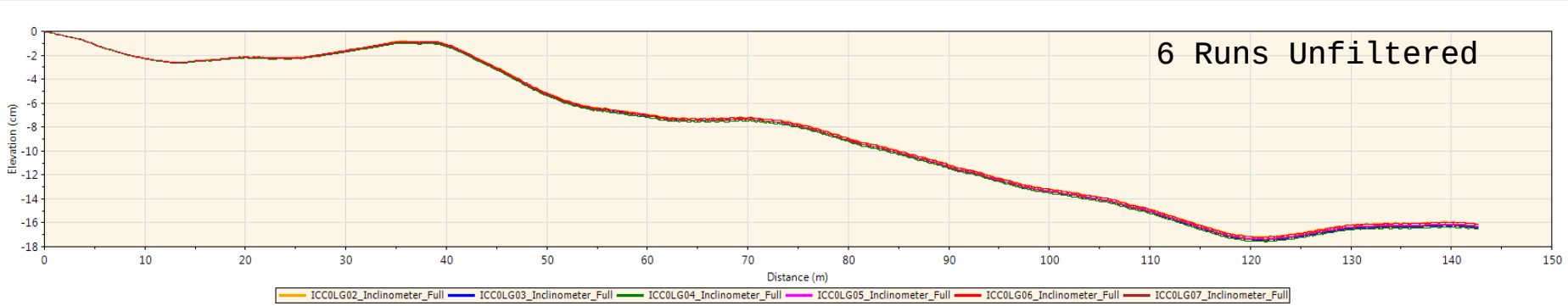

99.6% Repeatability 2 Runs Cross Correlated in ProVAL using IRI filter
Distance (m)
ICC0CS03_Inclinometer
ICC0CS04_Inclinometer

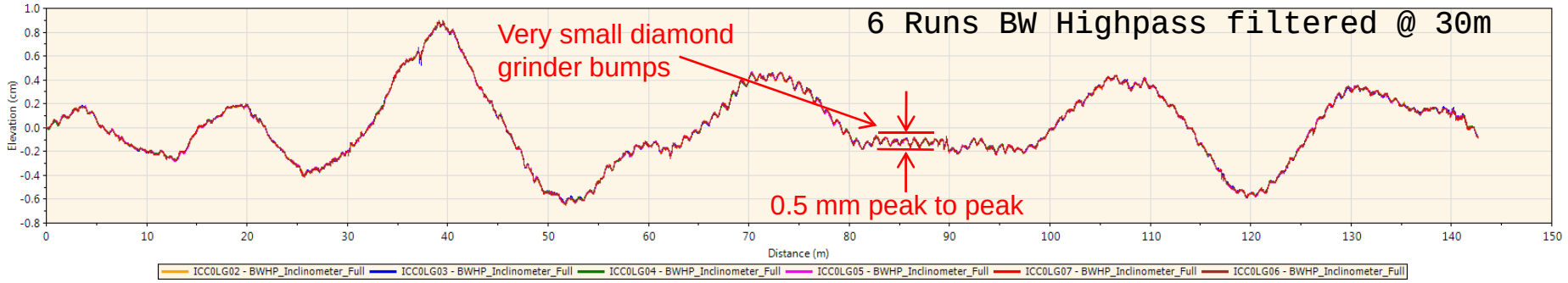
Diamond Grinding (DG)

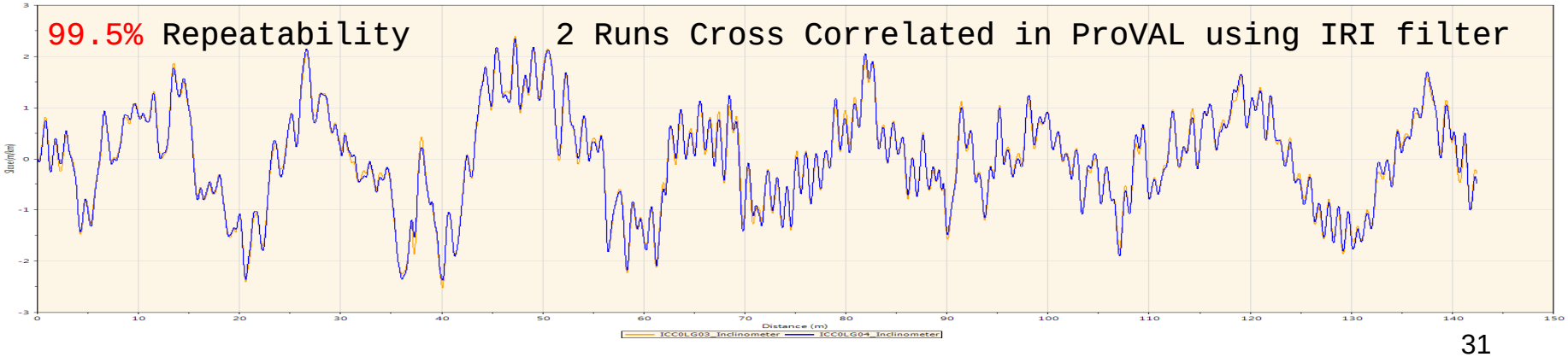
SurPRO PERFORMANCE RESULTS			
DG (LG)		4000	4000L
IRI (m/km)		0.77	N/R
Cross-Correlation	IRI	**99.3**	N/R
	SHORT	94.5	N/R
	MEDIUM	97.6	N/R
	LONG	99.8	99.8



Diamond Grinding (DG)

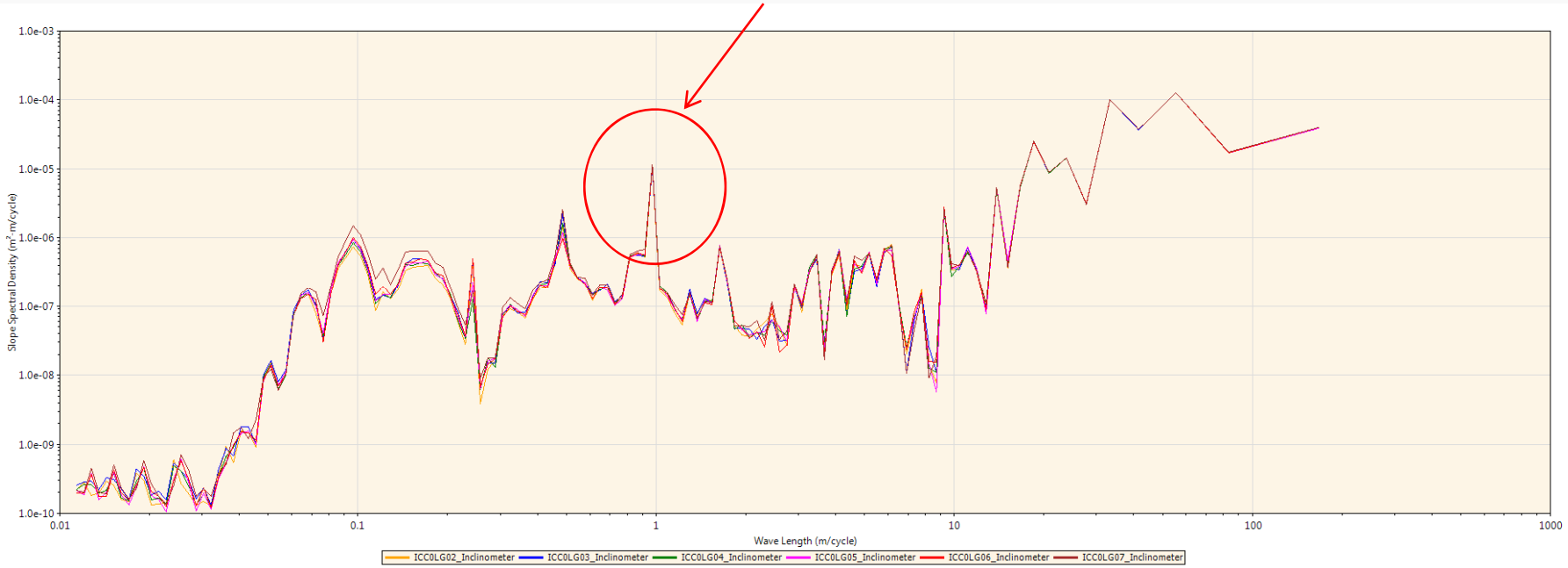






Diamond Grinding (DG)

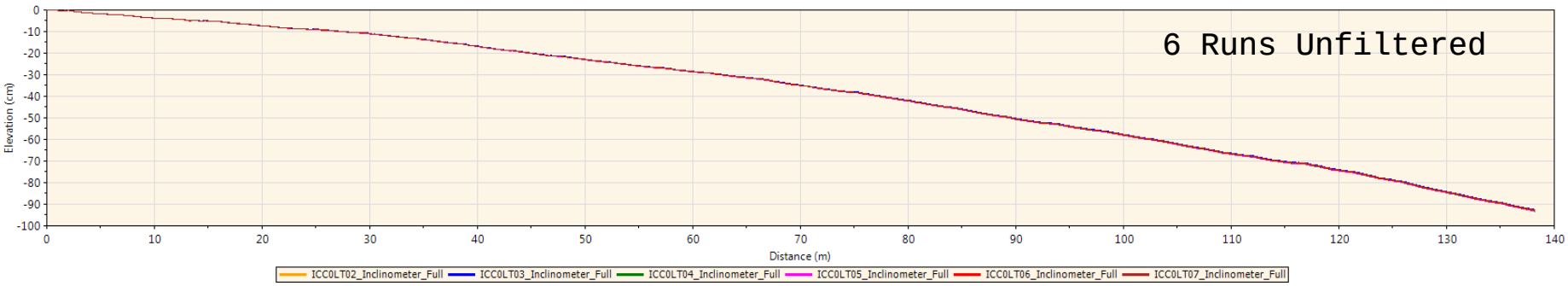
Very small diamond grinder bumps

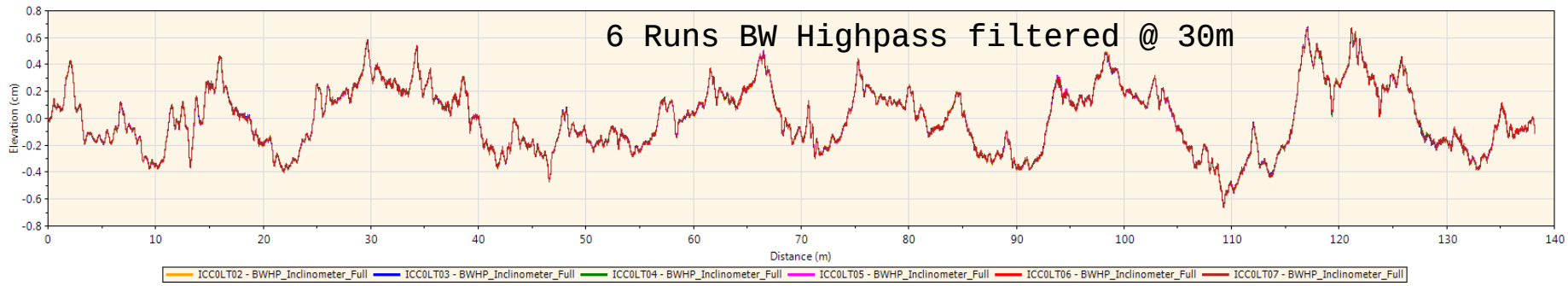


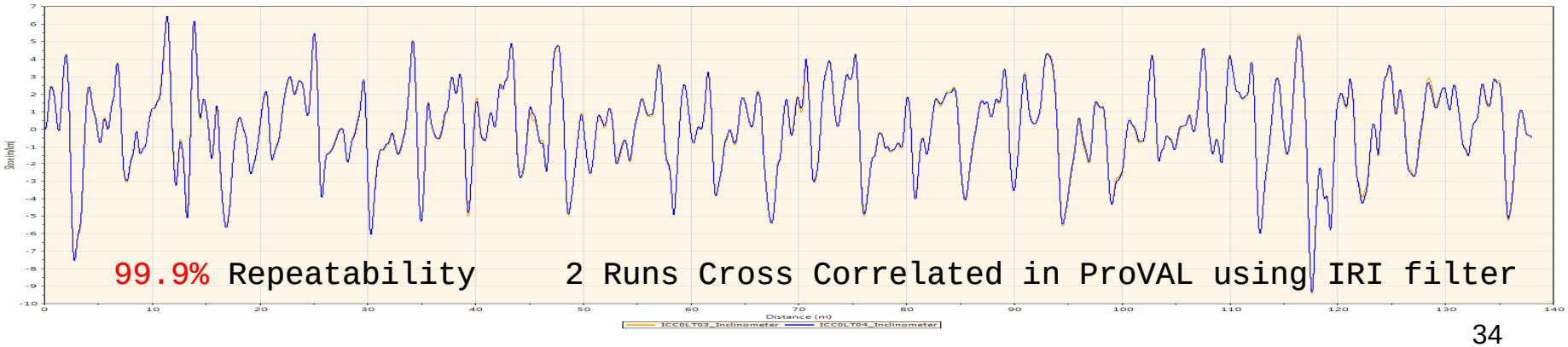
Longitudinal Tining (LT)

SurPRO PERFORMANCE RESULTS			
LT		4000	4000L
IRI (m/km)		1.89	N/R
Cross-Correlation	IRI	**99.6**	N/R
	SHORT	97.9	N/R
	MEDIUM	99.3	98.8
	LONG	99.8	99.1

Longitudinal Tining (LT)



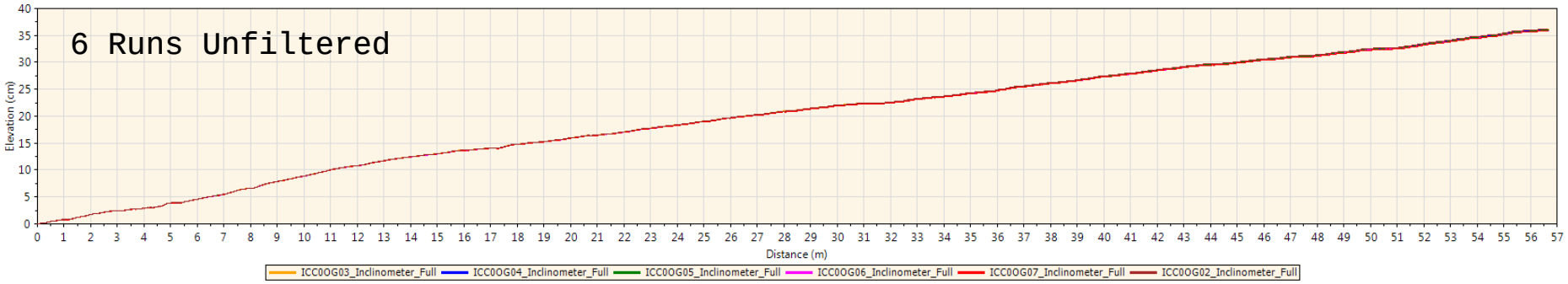


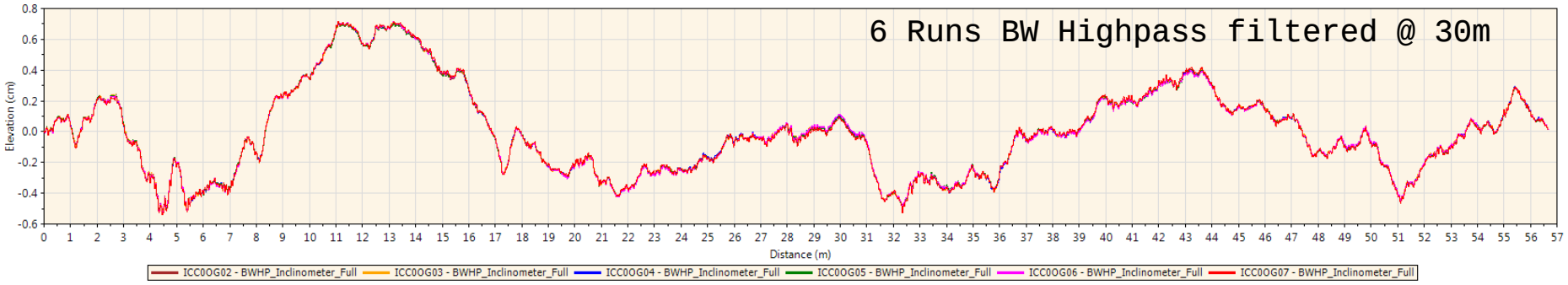


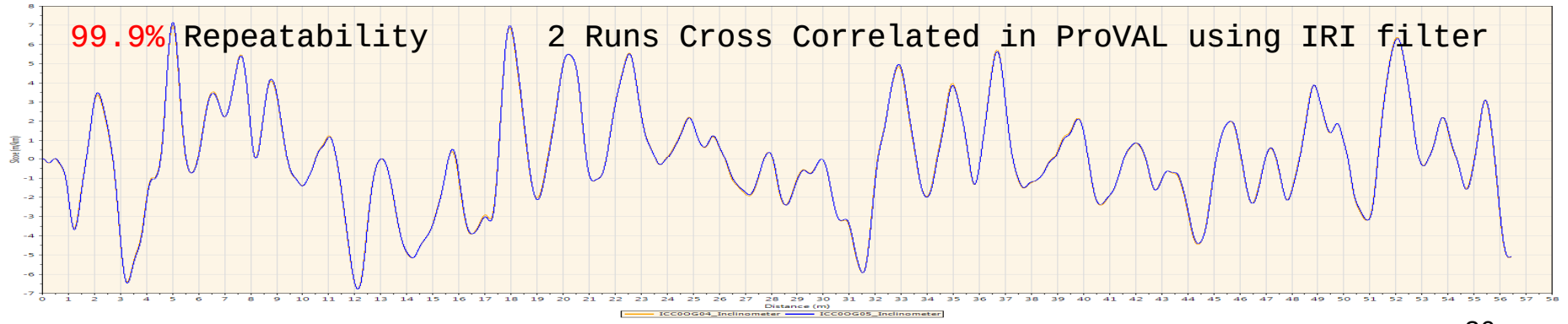
Open Grade (OG)

SurPRO PERFORMANCE RESULTS			
OG		4000	4000L
IRI (m/km)		2.10	2.12
Cross-Correlation	IRI	**99.7**	99.1
	SHORT	98.1	94.2
	MEDIUM	99.5	99.3
	LONG	99.4	99.4

Open Grade (OG)

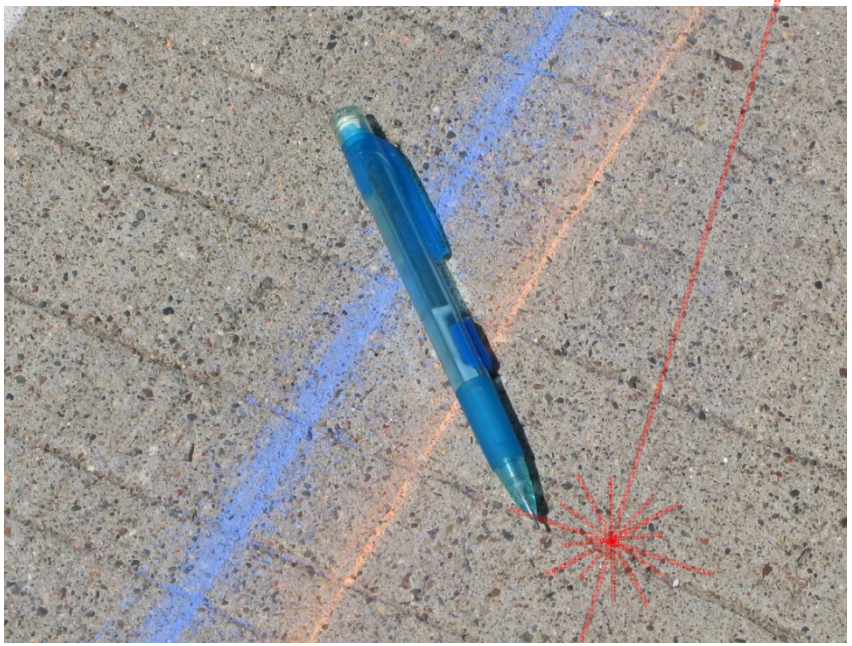




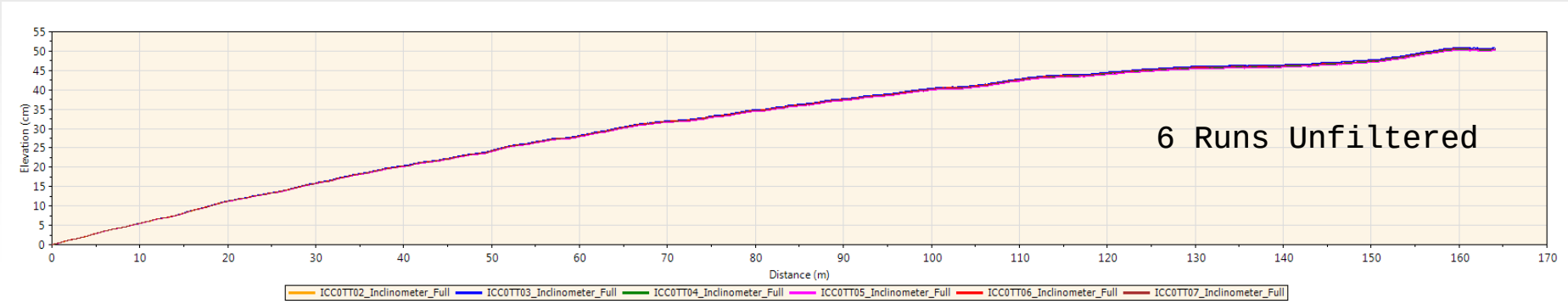


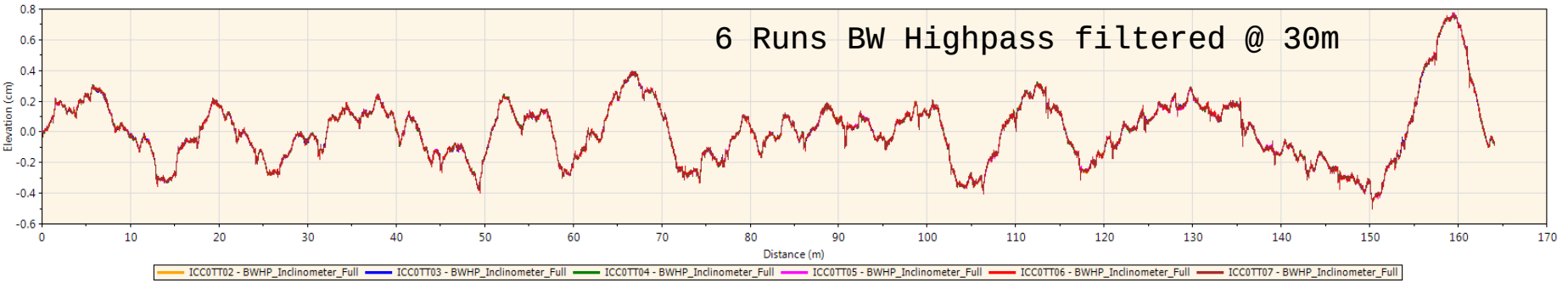
Transverse Tining (TT)

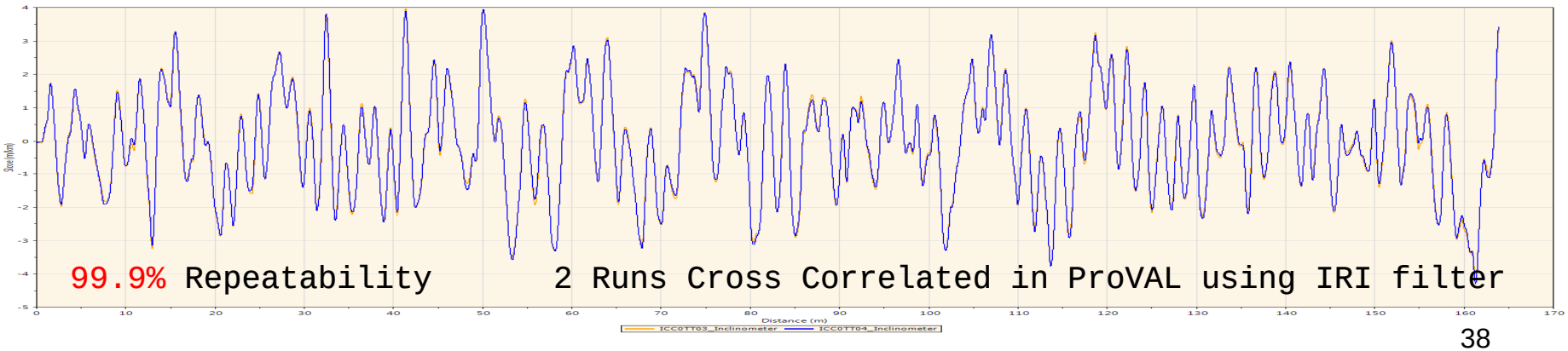
SurPRO PERFORMANCE RESULTS			
TT		4000	4000L
IRI (m/km)		1.24	1.25
Cross-Correlation	IRI	**99.6**	99.4
	SHORT	94.0	93.4
	MEDIUM	99.3	99.2
	LONG	99.8	99.7



Transverse Tining (TT)







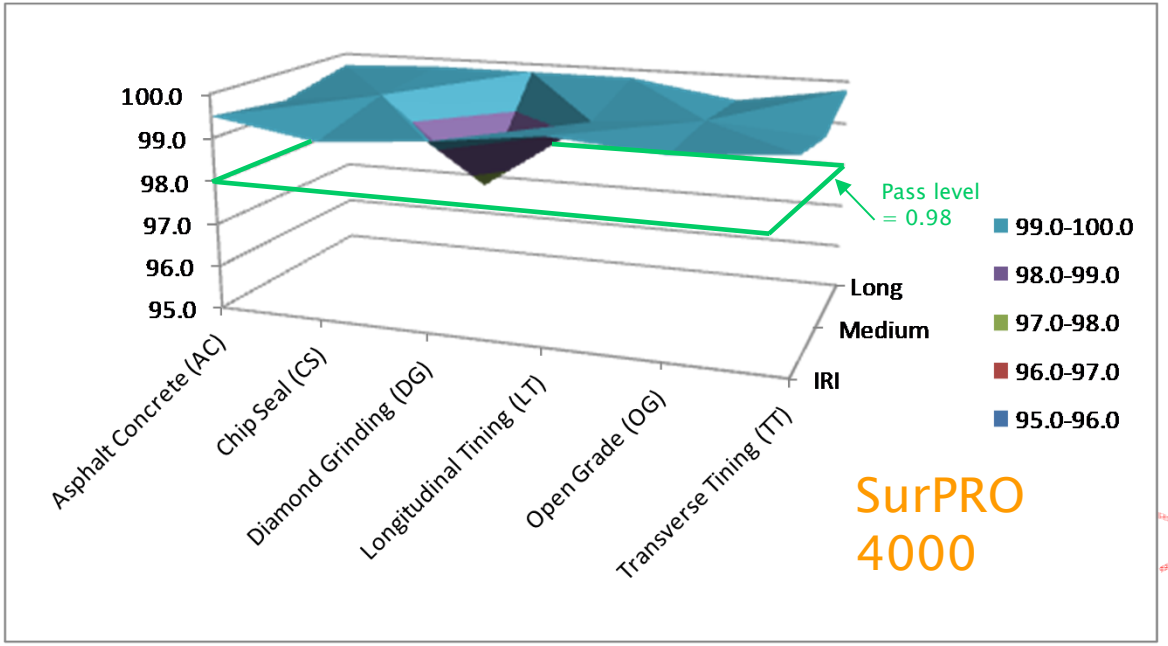
Repeatability
IRI, Medium & Long Wavebands

SurPRO 4000

Test Section	IRI	Medium	Long
Asphalt Concrete (AC)	99.5	99.3	99.7
Chip Seal (CS)	99.1	99.6	99.8
Diamond Grinding (DG)	99.3	97.6	99.8
Longitudinal Tining (LT)	99.6	99.3	99.8
Open Grade (OG)	99.4	99.5	99.4
Transverse Tining (TT)	99.6	99.3	99.8
Average	**99.4**		

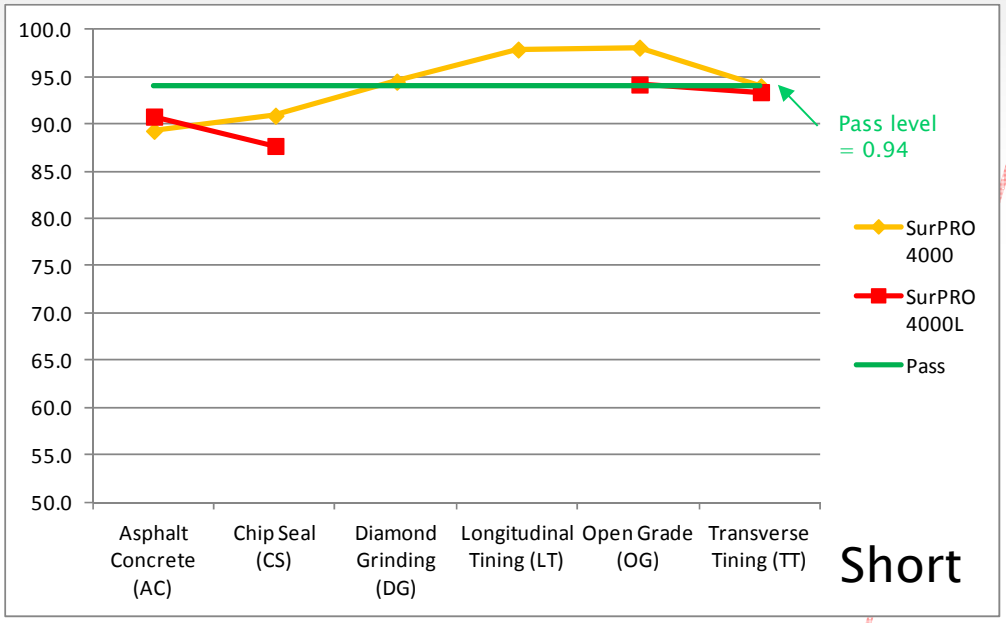
SurPRO 4000L

Test Section	IRI	Medium	Long
Asphalt Concrete (AC)	99.4	99.3	99.7
Chip Seal (CS)	98.8	99.3	99.8
Open Grade (OG)	99.1	99.3	99.4
Transverse Tining (TT)	99.4	99.2	99.7
Average	**99.4**		



Repeatability
Short Waveband

Short	Test Section	SurPRO 4000	SurPRO 4000L
	Asphalt Concrete (AC)	89.3	90.8
	Chip Seal (CS)	90.9	87.7
	Diamond Grinding (DG)	94.5	
	Longitudinal Tining (LT)	97.9	
	Open Grade (OG)	98.1	94.2
	Transverse Tining (TT)	94.0	93.4
	Average	**94.1**	**91.5**



FHWA Certification Wavebands				
Waveband	**Short Wavelength**		**Long Wavelength**	
	Wavelength	**Wave Number (cycles/m)**	**Wavelength**	**Wave Number (cycles/m)**
IRI Filter Output	1.25 m (4 ft)	0.800	30 m (98.4 ft)	0.033
Long Waveband	8 m (25 ft)	0.125	40 m (125 ft)	0.025
Medium Waveband	1.6 m (5 ft)	0.625	8 m (25 ft)	0.125
Short Waveband	0.076 m (3")	3.125	1.6 m (5 ft)	0.625

MnRoad 2013
Testing Recap

- DMI was very accurate (+/- 0.03% expected)
- Mean repeatability cross correlation for all six sections (IRI, medium & long filter) was 99.4%
  - Individual cross correlations up to 99.9%.
- Short waveband cross correlation using 4000L laser of up to 99.4%.
- SurPRO was insensitive to operator bias such as acceleration and transverse tilting motion
  - Up to 99.5% repeatability using different profilers operated by different operators

MnRoad 2013
How the Models Performed

- SurPRO 4000
  - Excellent repeatability and accuracy
  - Differences with BMP due to pavement movement
- SurPRO 4000L
  - Laser method was very successful and experiment provided data to tune up short waveband performance
  - Most differences with BMP due to pavement movement
  - Point lasers may interact with longitudinal texture
  - Short Waveband
    - Successful longitudinal line measurement, very repeatable
    - CC with BMP could be much better; differences likely due to use of point rather than line lasers

MnRoad 2013
Testing Conditions & Procedures

- Concrete Pavement Instability
  - Unusually high temperatures caused curling of concrete pavements with 2-12% CC error/hour
- Suggestions
  - At mid-day, clear sky, measure entire test section in 15 minutes or less or CC error may exceed 0.5%
  - Better yet, run concrete test sections at dawn, before sun is high enough to heat pavement
  - For calibration sites, alternate reference profiler and candidate profiler runs if possible, or run reference profiler before and after candidate profiler runs to check for differences

MnRoad 2013
Next Steps

- ASTM E950-12
  - Is short waveband required?
  - What is footprint width, point vs 70mm wide?
  - Short waveband CC fails if DMI not extremely accurate
- Line laser replacement of point lasers on 4000L promises good short waveband correlation with 70mm wide line laser BMP
- Line lasers may make reference profiler too expensive—would the need justify the cost?
- ProVAL support for CC of profiles divided into multiple fixed short segments such as 100 feet

Thanks!

To:

- Rohan Perera, SME
- Steve Karamihas, UMTRI
- Darel Mesher, EBA
- Chase Fleeman, ICC
- James Richitt, ICC
- Jeff Kitlas, ICC

For more information please go to:

- surpro.com
- intlcybernetics.com