Asphalt Binder Quality Test (ABQT)

Binder Expert Task Group

September, 2017

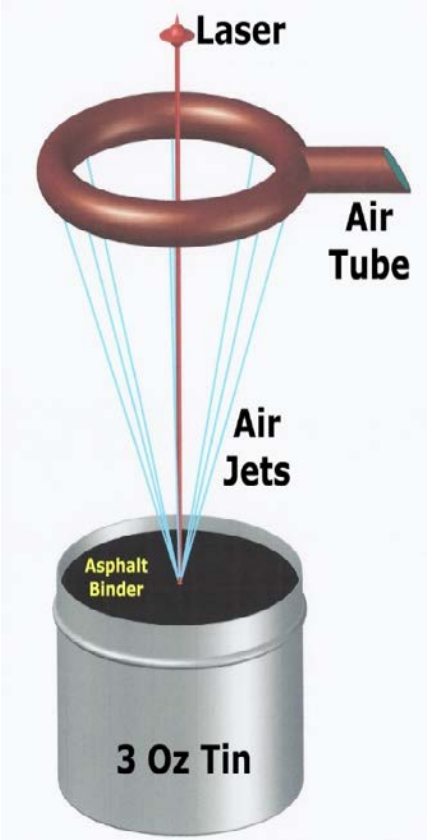
Infrastructure Materials Team, TFHRC

Why develop a Quality control Test for Asphalt Binder? - Refresher

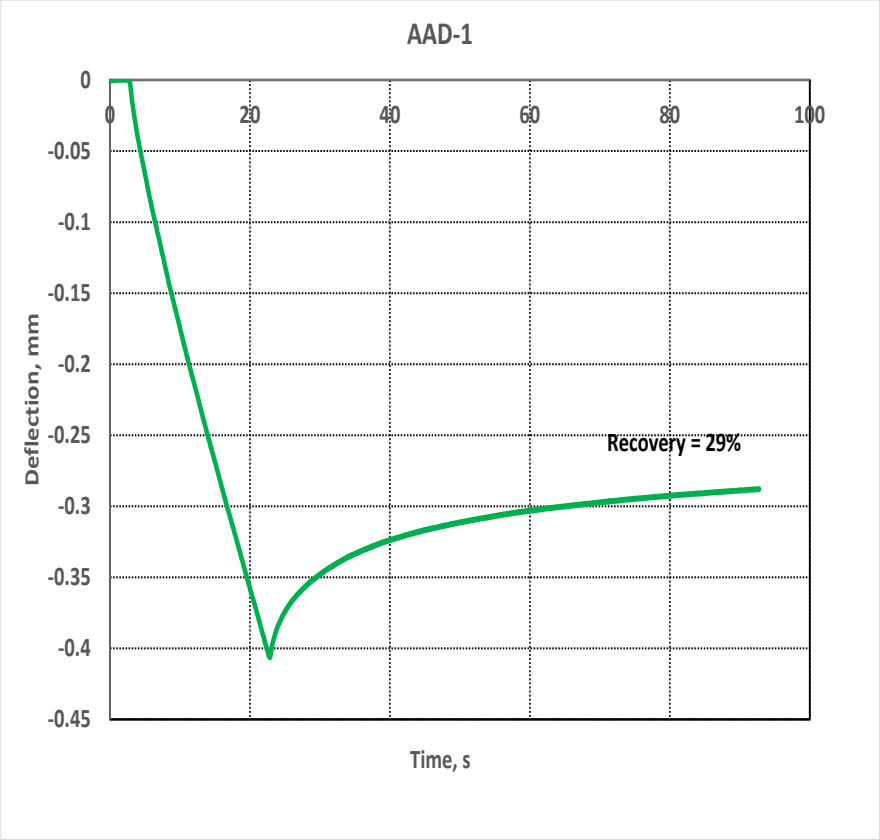
- Need a portable, quick and easy test method for day-to-day QA of production asphalt binder during a pavement construction project – UTAH DOT
- Several methods have been tried without success! – UTAH DOT
  - Dynamic Shear Rheometer – quick version
  - Melt Indexer
- A single test method that can take you from mix-design to production

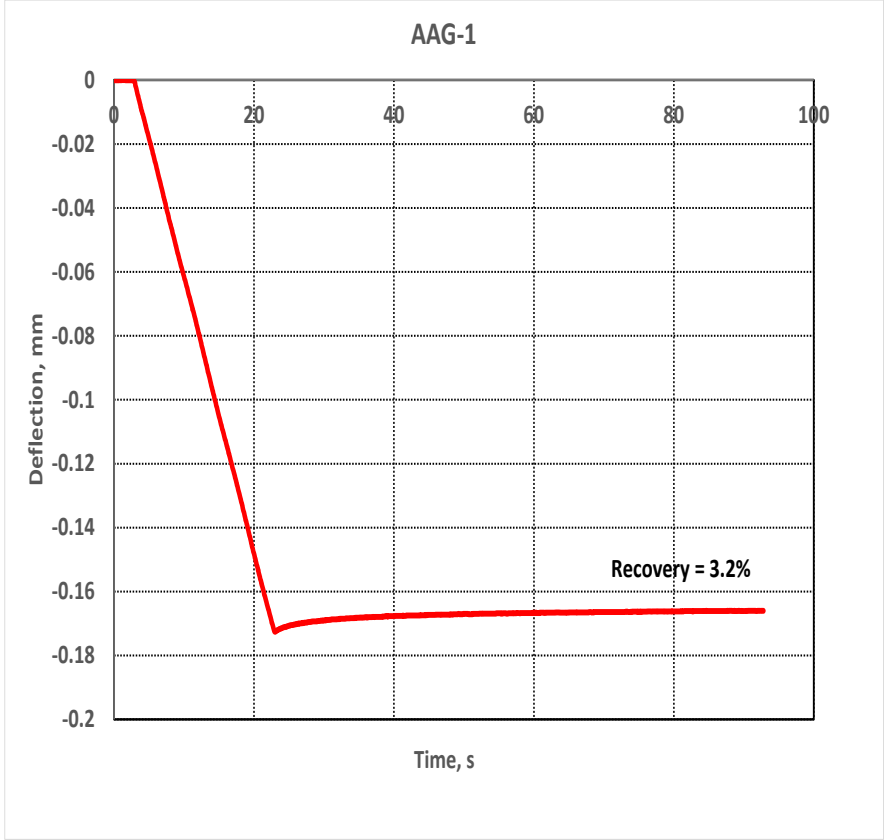
Asphalt Binder Quality Tester

Schematic of NOZZLE with Air Jet & Laser

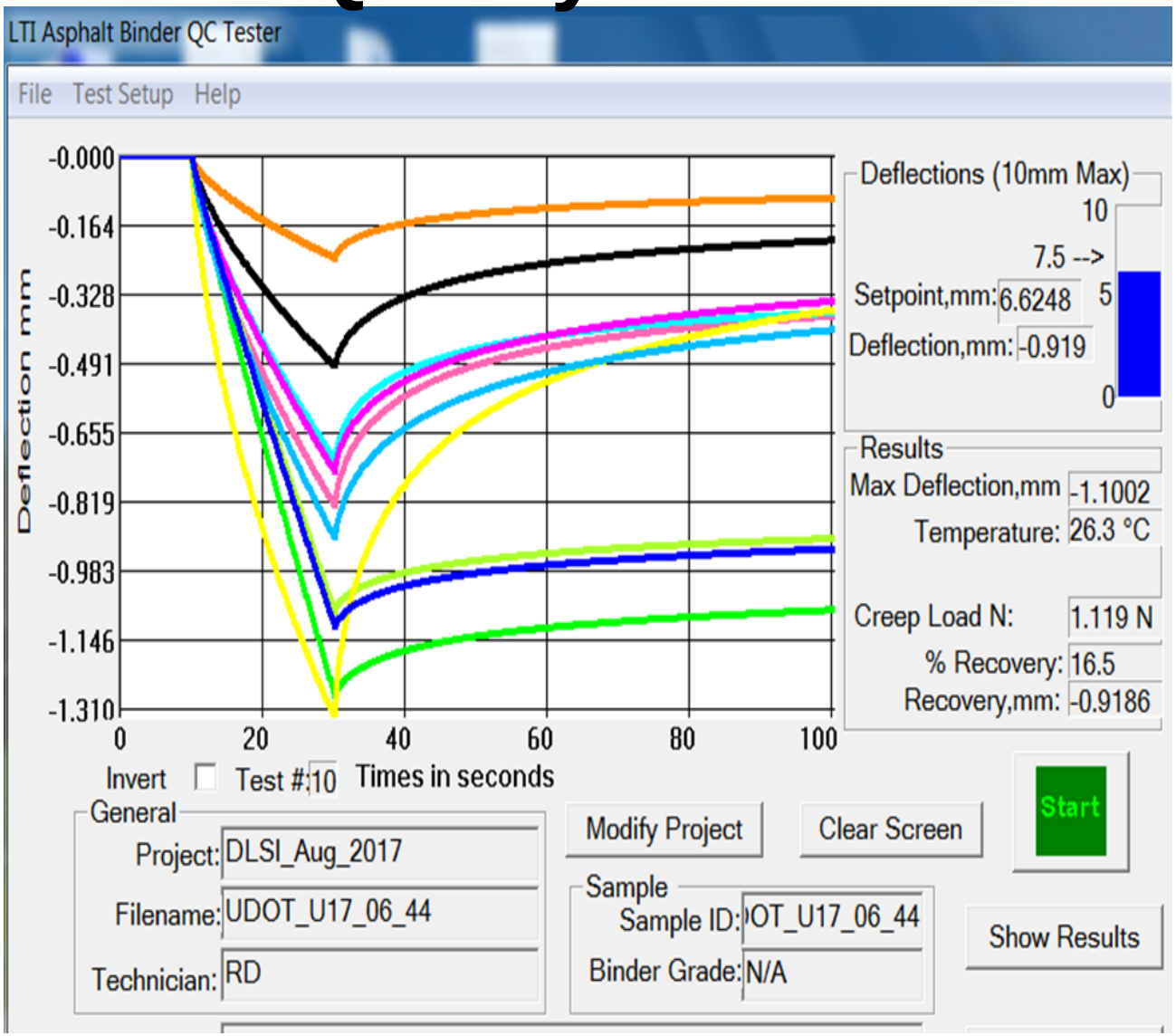


Test Results for Gel and Sol Type Asphalts





Quality Control

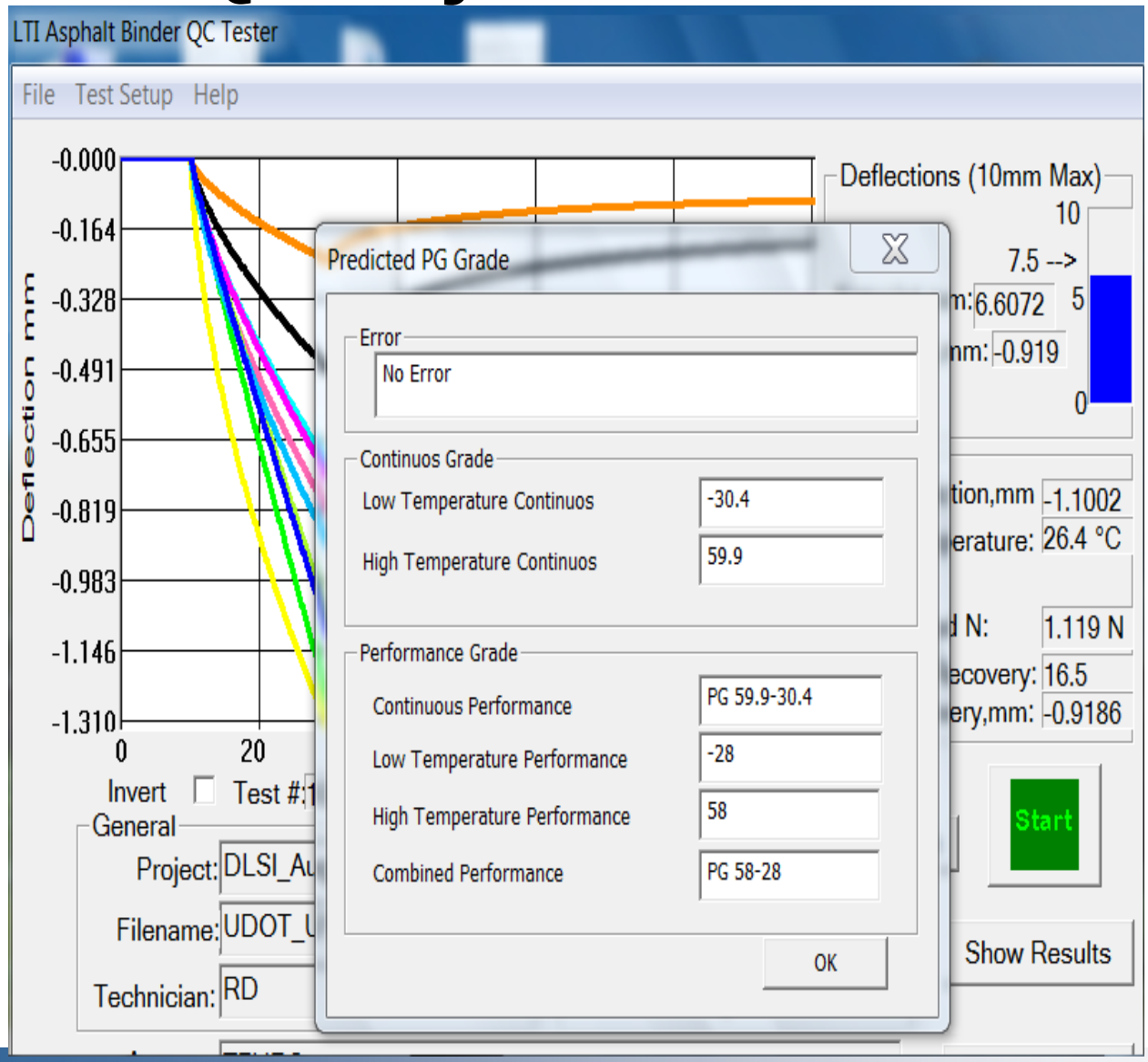


repeatability of qc data

Binder ID	Binder Type	Number of Replicates	QCT Max. Deflection, mm			QCT % Recovery		
			Average	Std. Dev	COV %	Average	Std. Dev	COV %
200/300 Pen	UnModified	5	2.8598	0.0437	2	14.4	0.4	3
#1 PG 58-28		5	0.5929	0.0370	6	20.1	1.0	5
PG 64-22		5	0.1588	0.0032	2	41.5	0.9	2
PG 76-10		5	0.0092	0.0006	6	82.0	7.8	10
#2 PG 58-28		5	0.7638	0.0192	3	15.5	0.1	1
PG 64-34	PMA	4	0.3383	0.0058	2	77.4	0.7	1
PG 76-22		5	0.0689	0.0023	3	58.0	1.1	2
PG 82-22	Crumb Rubber Modified	5	0.0533	0.0030	6	57.3	2.5	4
#1 PG 76-22		2	0.1377	0.0049	4	54.7	1.2	2
#2 PG 76-22		2	0.1055	0.0028	3	57.3	1.1	2
#3 PG 76-22		2	0.0908	0.0009	1	59.9	1.8	3
Pooled Average					**3**			**3**

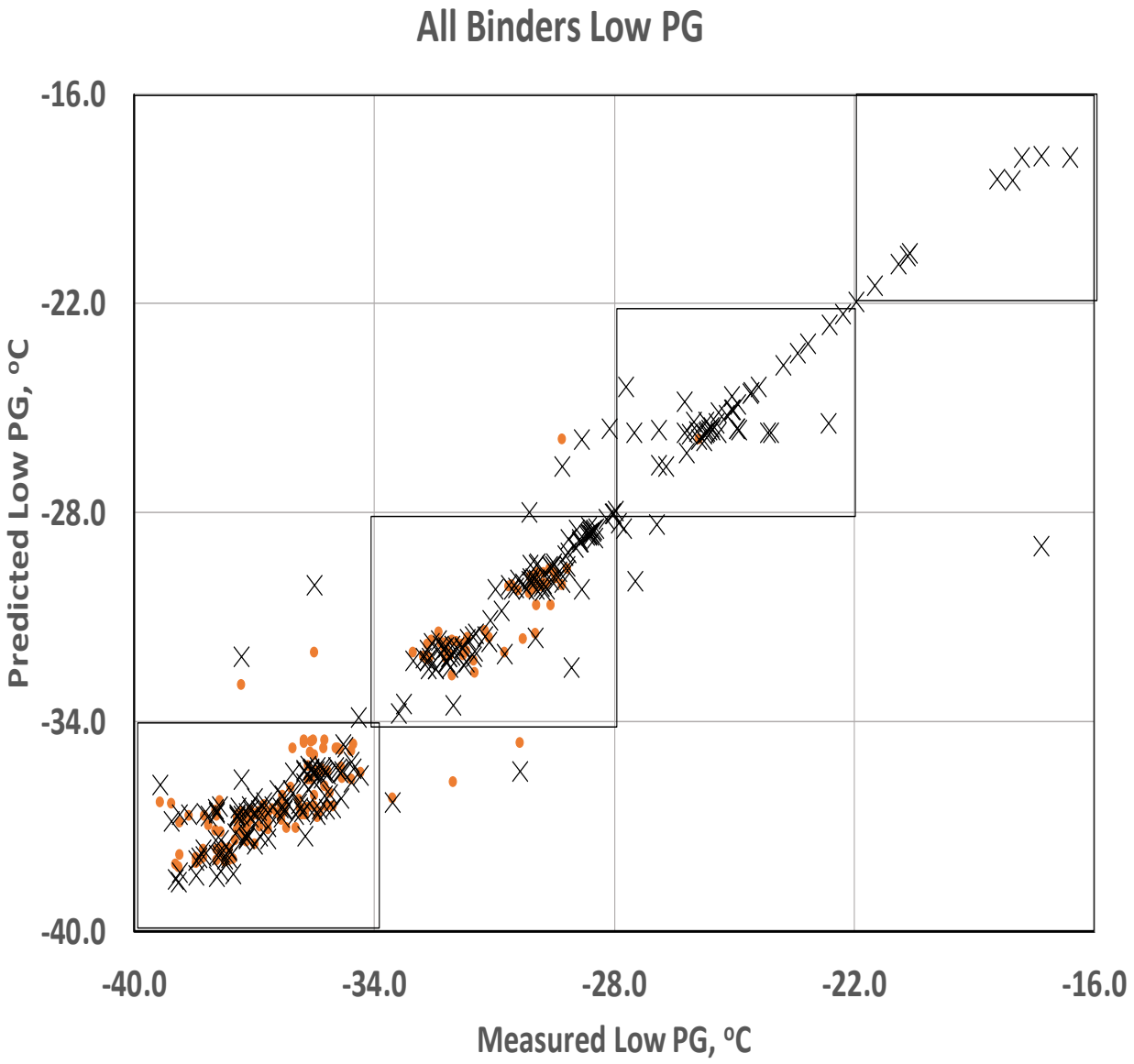
ABQT Verfication Kit

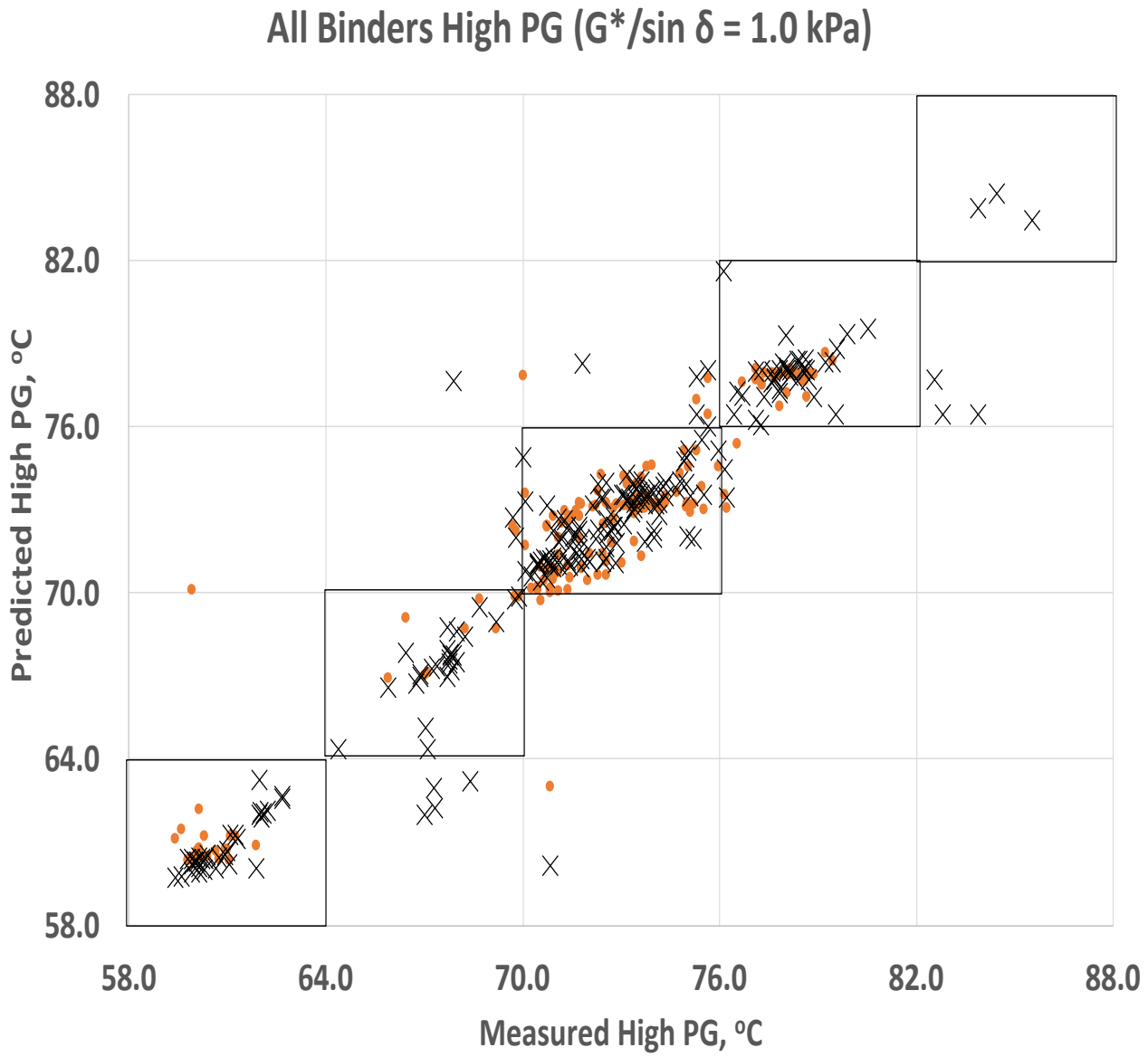
Quality Assurance

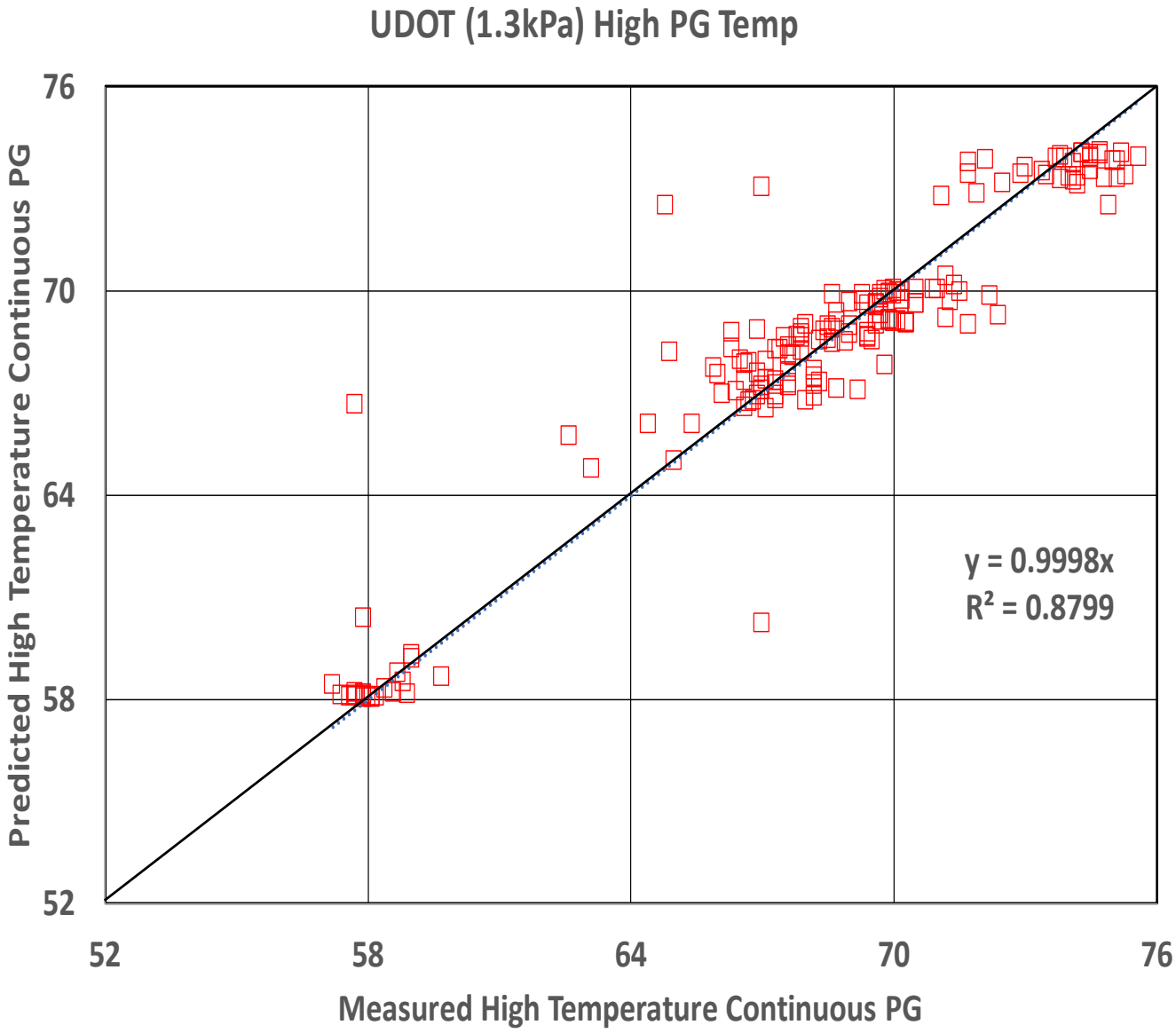


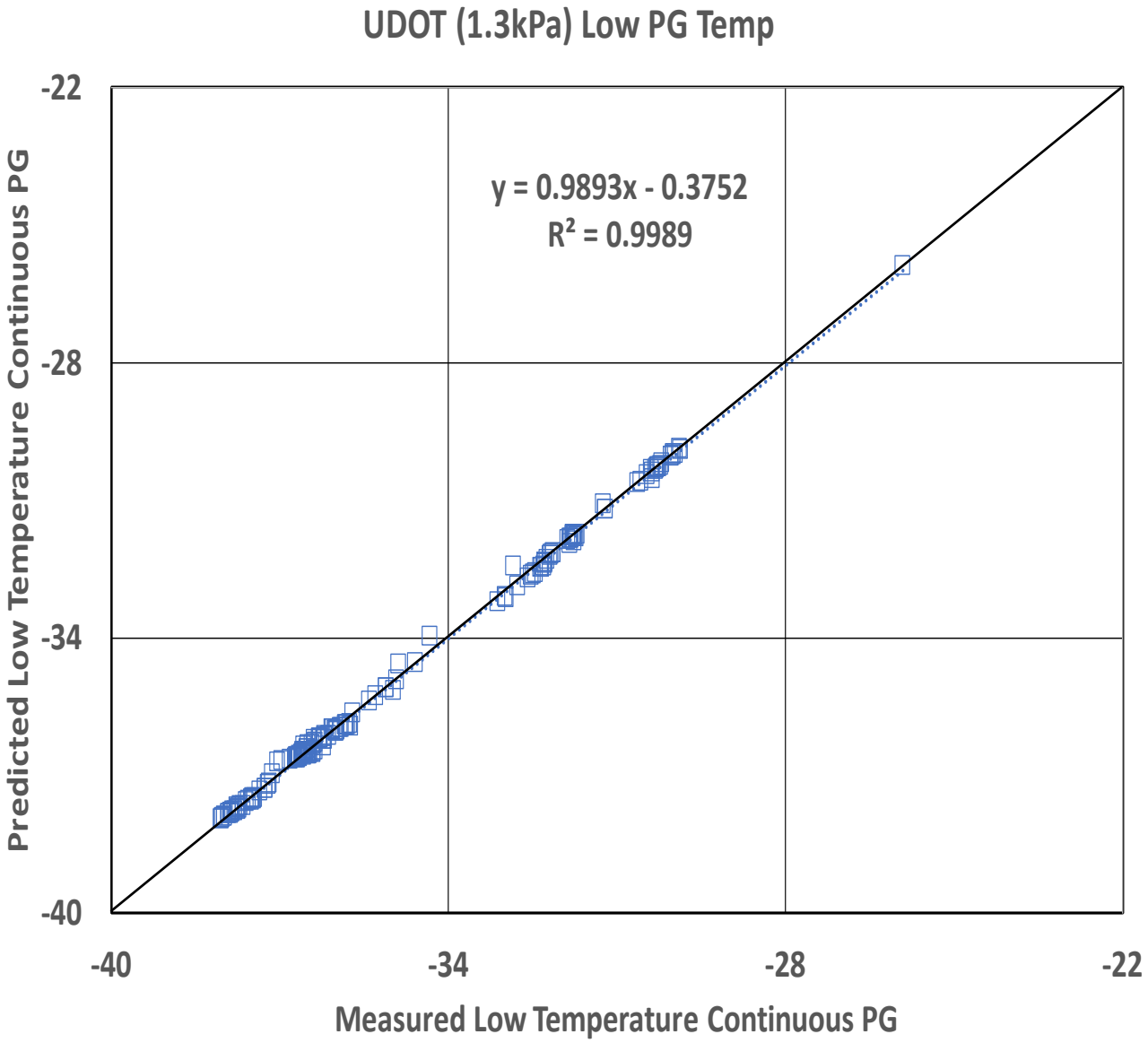
Prediction of Continuous PG Grades AASHTO M320

- Continuous PG grades are predicted using creep recovery data on unaged binder
  - Standard test protocol
- A proprietary Algorithm was developed to predict continuous PG grades
  - Based on models that use artificial neural network learning algorithms
  - Training database of more than 500 asphalt binders
    - Different crude sources including Europe
  - Greater than 95% accuracy of prediction of PG grades
  - Accuracy will be better as more data gets added
    - Models are tailored to variation in PG specification
      - For example: Utah dot
- MSCR grades can also be predicted – AASHTO M332


All Binders Low PG
-16.0
-22.0
-28.0
-34.0
-40.0
Predicted Low PG, °C
-40.0
-34.0
-28.0
-22.0
-16.0
Measured Low PG, °C

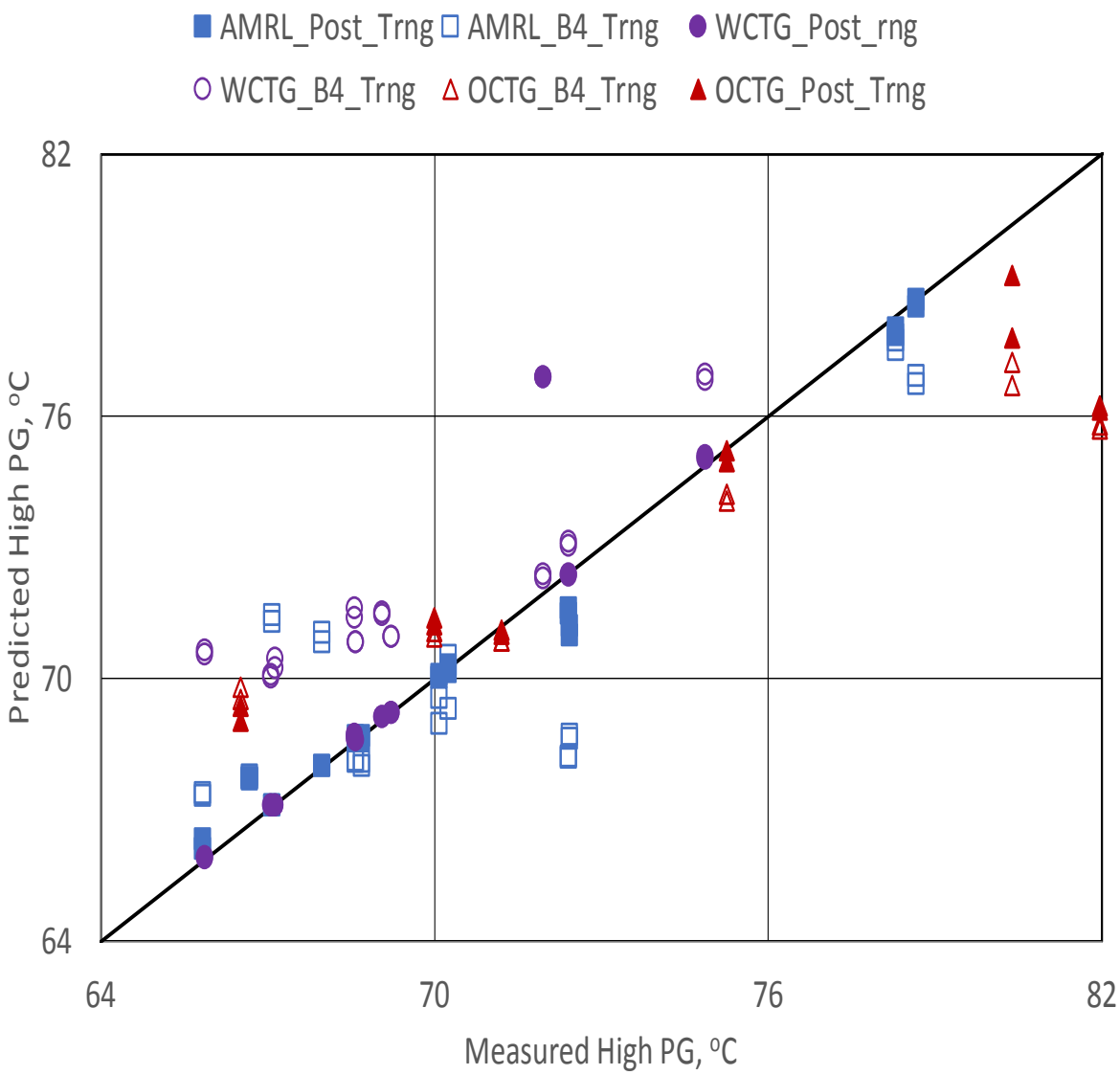

All Binders High PG (G*/sin δ = 1.0 kPa)
Predicted High PG, °C
88.0
82.0
76.0
70.0
64.0
58.0
58.0
64.0
70.0
76.0
82.0
88.0
Measured High PG, °C

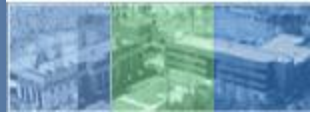

UDOT (1.3kPa) High PG Temp
Predicted High Temperature Continuous PG
76
70
64
58
52
52
58
64
70
76
Measured High Temperature Continuous PG
y = 0.9998x
R² = 0.8799


UDOT (1.3kPa) Low PG Temp
y = 0.9893x - 0.3752
R² = 0.9989
Predicted Low Temperature Continuous PG
-22
-28
-34
-40
-40
-34
-28
-22
Measured Low Temperature Continuous PG

Validation of model

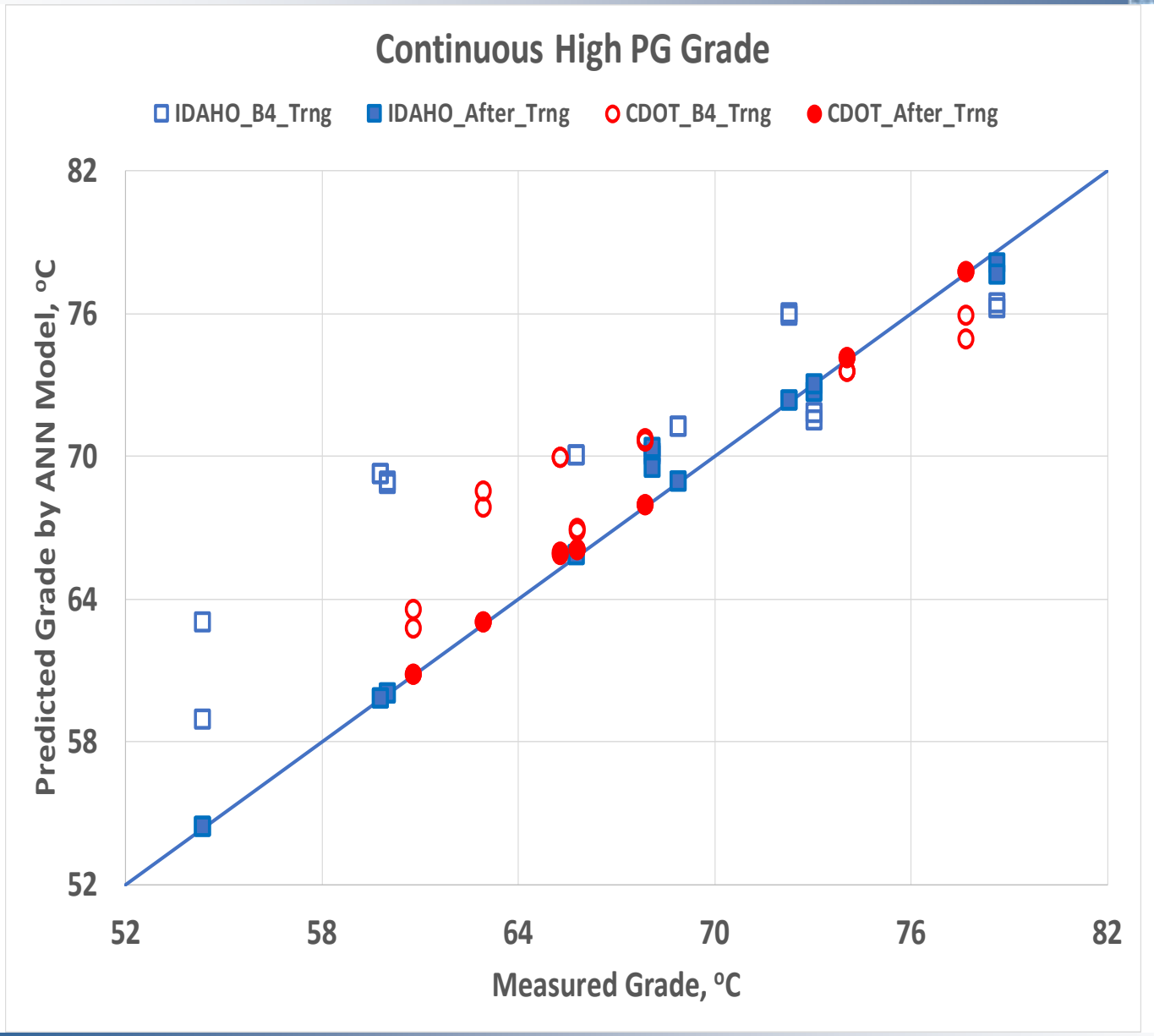
Effect of database size

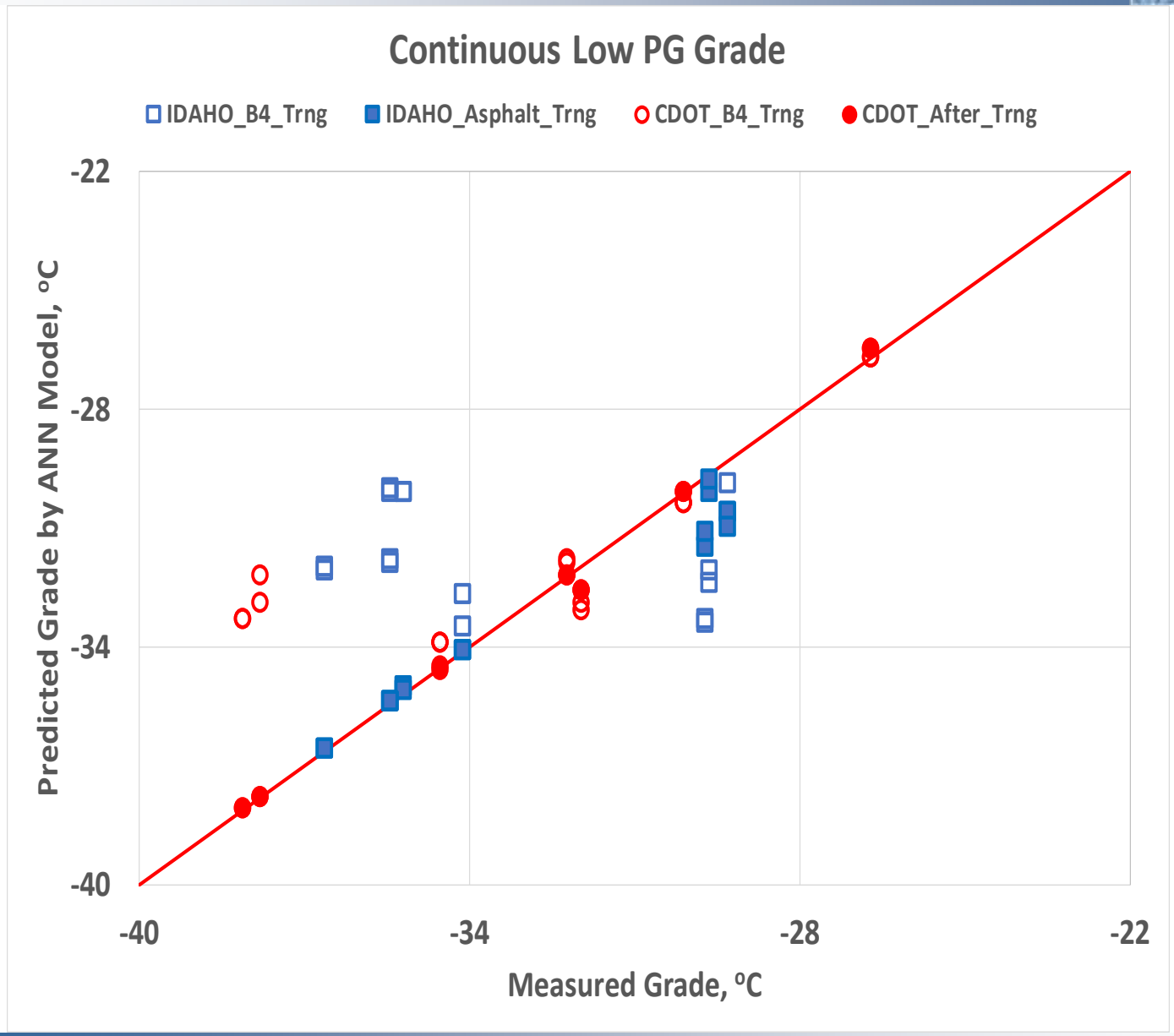

AMRL_Post_Trng
AMRL_B4_Trng
WCTG_Post_rng
WCTG_B4_Trng
OCTG_B4_Trng
OCTG_Post_Trng
82
76
70
64
Predicted High PG, °C
64
70
76
82
Measured High PG, °C

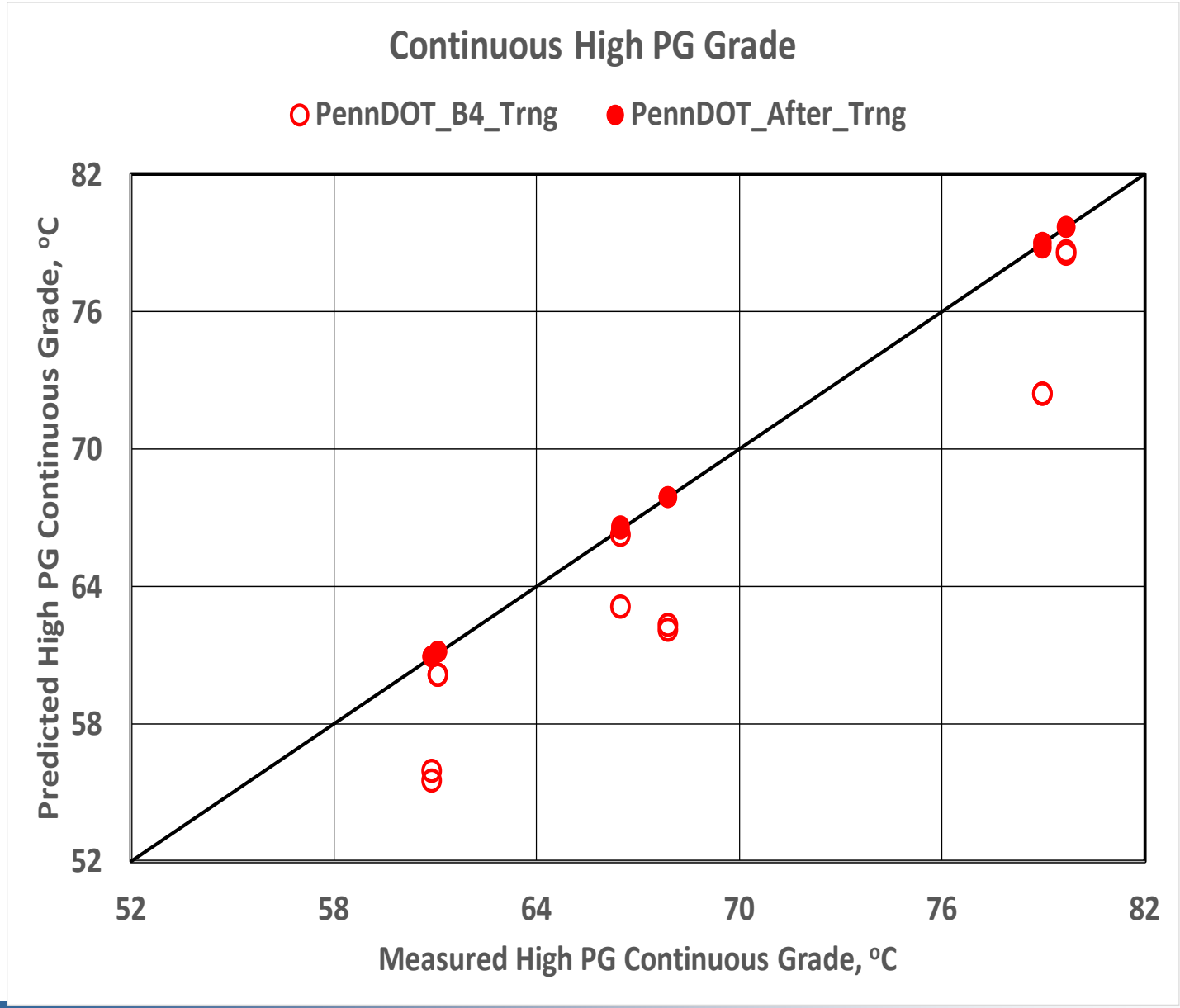


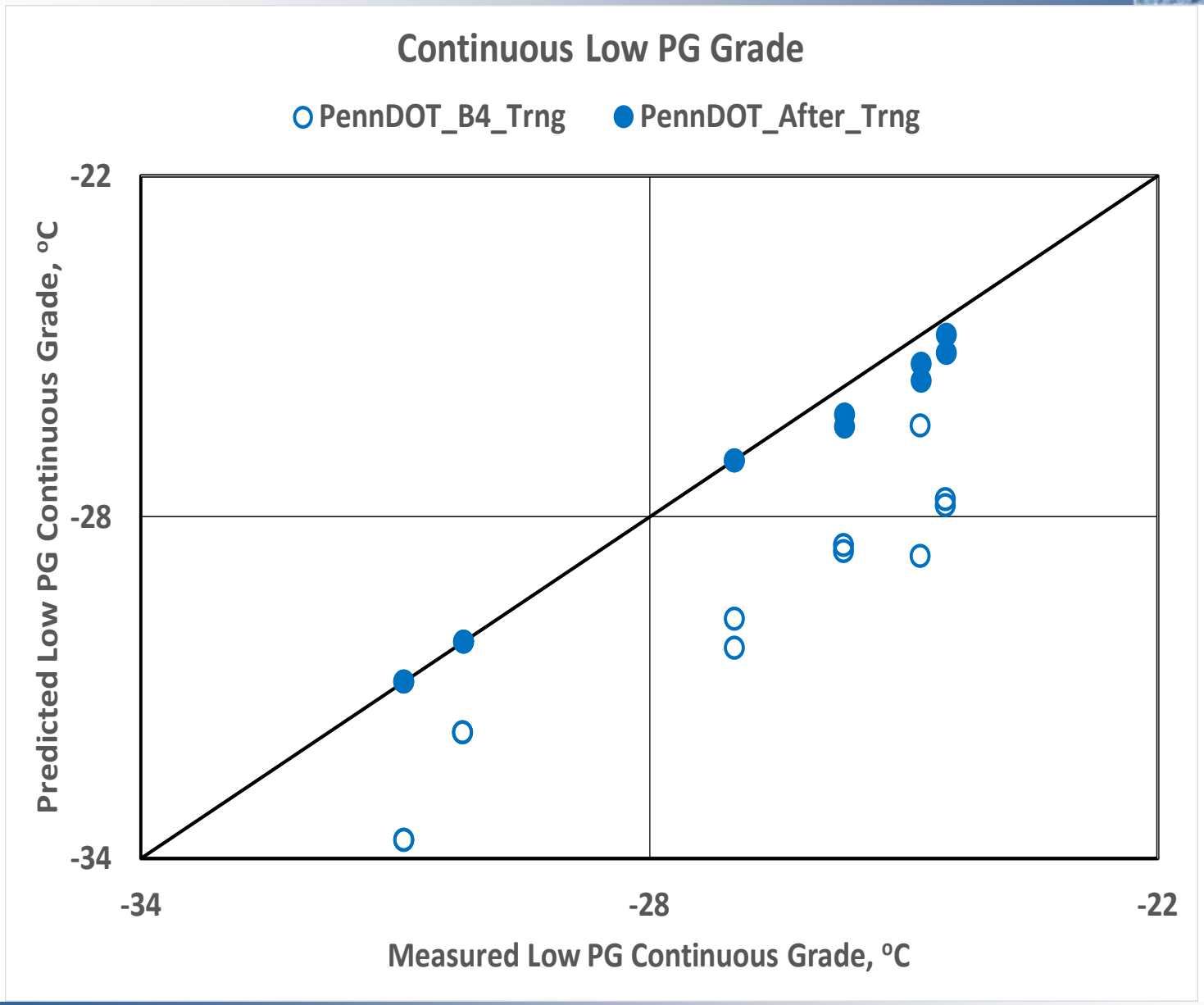
ABQT

STATE AGENCY VALIDATION DATA


Continuous High PG Grade
IDAHO_B4_Trng
IDAHO_After_Trng
CDOT_B4_Trng
CDOT_After_Trng
Predicted Grade by ANN Model, °C
82
76
70
64
58
52
52
58
64
70
76
82
Measured Grade, °C


Continuous Low PG Grade
IDAHO_B4_Trng
IDAHO_Asphalt_Trng
CDOT_B4_Trng
CDOT_After_Trng
Predicted Grade by ANN Model, °C
-22
-28
-34
-40
-40
-34
-28
-22
Measured Grade, °C


Continuous High PG Grade
PennDOT_B4_Trng
PennDOT_After_Trng
Predicted High PG Continuous Grade, °C
82
76
70
64
58
52
52
58
64
70
76
82
Measured High PG Continuous Grade, °C


Continuous Low PG Grade
PennDOT_B4_Trng
PennDOT_After_Trng
-22
-28
-34
Predicted Low PG Continuous Grade, °C
-34
-28
-22
Measured Low PG Continuous Grade, °C

Potential Applications

- Quick Screening of Binders
- Identify Presence of Contaminants
- Monitor Addition of Additives/asphalt blending
- Relationship to MSCR
- Monitor Binder During Paving
  - UTAH DOT 2015 Season
- Characterize Crumb Rubber Modified Binders
  - High crumb rubber content – Granite binders
  - FHWA Terminal blend binders

Summary and future

- Developed quick easy to use QC/QA test that measures loading and recovery characteristics of Binders (and mixes)
  - PREDICTS Continuous PG Grade Accurately (95% Accuracy)
  - Predicts MSCR Grades
- Asphalt Binder QUALITY Test is ready for use

Delta Tc
Range and Magnitude

Binder Expert Task Group

September, 2017

Infrastructure Materials Team,
TFHRC

Background

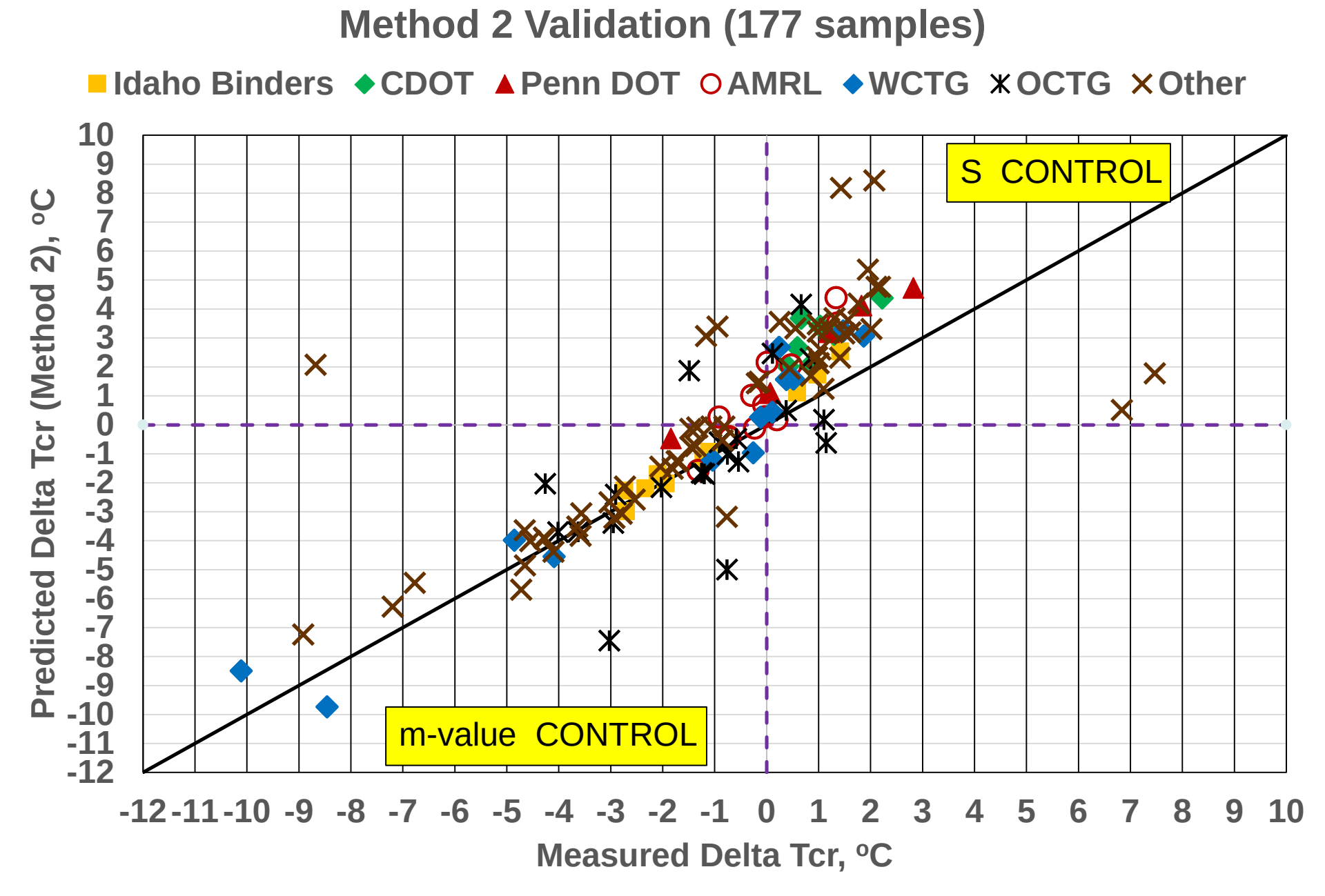
- **SHRP Premise**
  - **No lower limit to S(60s) value – 0 to 300 MPa allowed**
  - **A minimum of 0.300 m-value is required as long as S is lower than or equal to 300 Mpa**
  - **Delta Tc = Tc (S =300) – Tc (m = 0.3) was not considered**
    - **Delta Tc = Positive indicates → S – controlled binders**
    - **Delta Tc = Negative indicates → m – controlled binders**

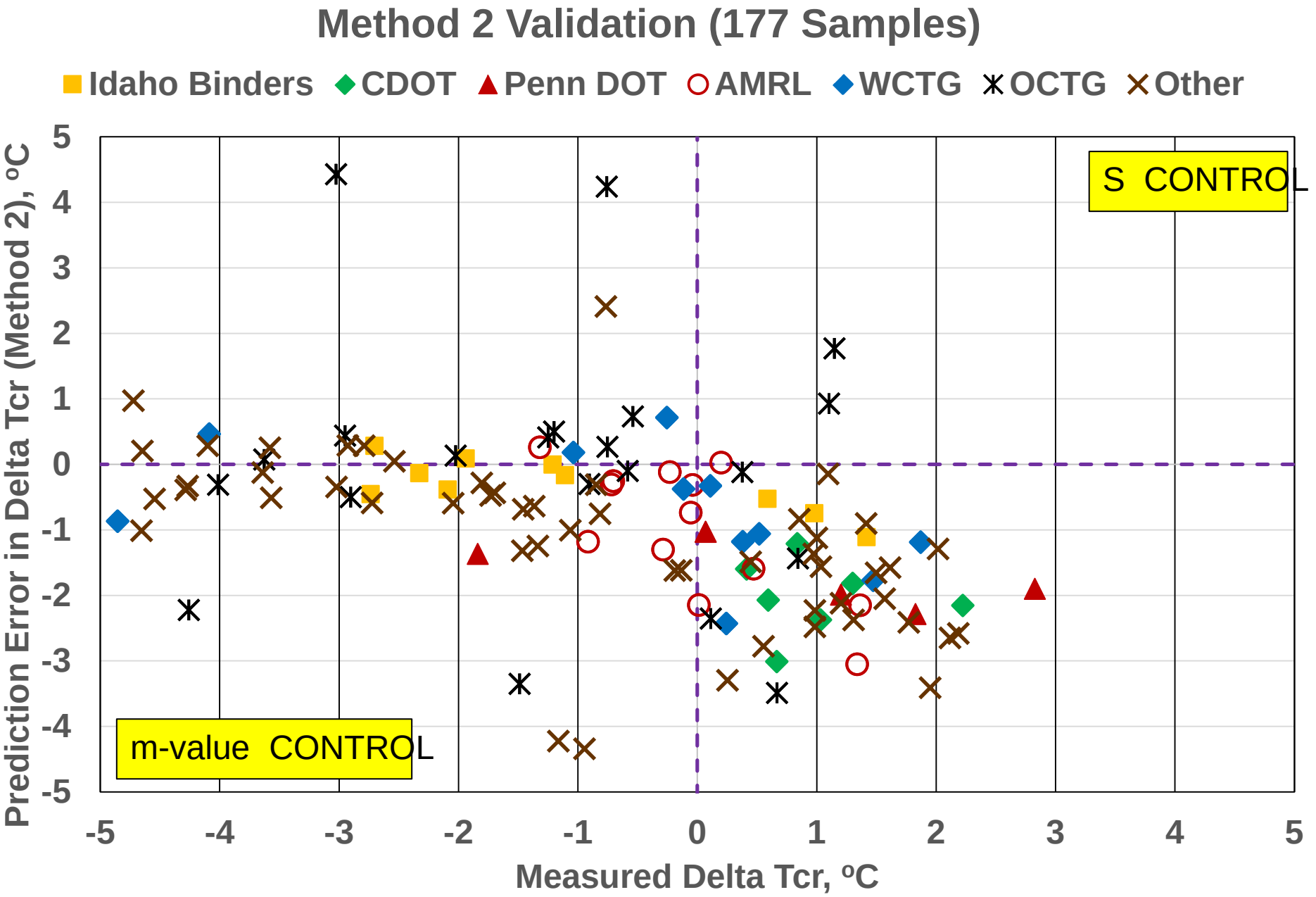
FHWA's Approach at TFHRC

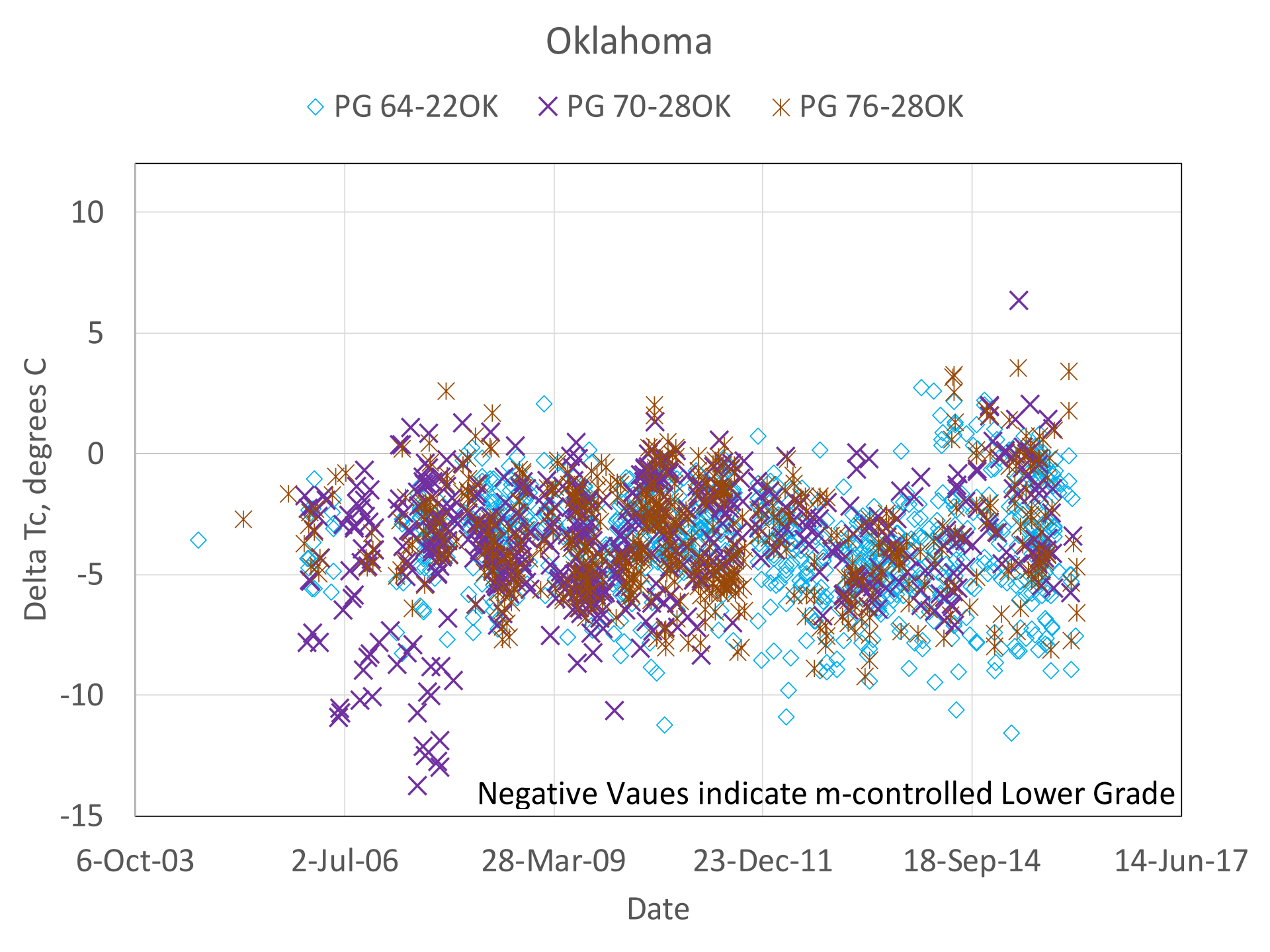
- Collect State DOT Low Temperature BBR Validation Data
- Calculate Delta Tc using Data Mining Techniques
  - Consider performance relation where available
- Make Recommendations
  - Perhaps an acceptable Delta Tc
  - OR – Specify S where m-value is 0.3

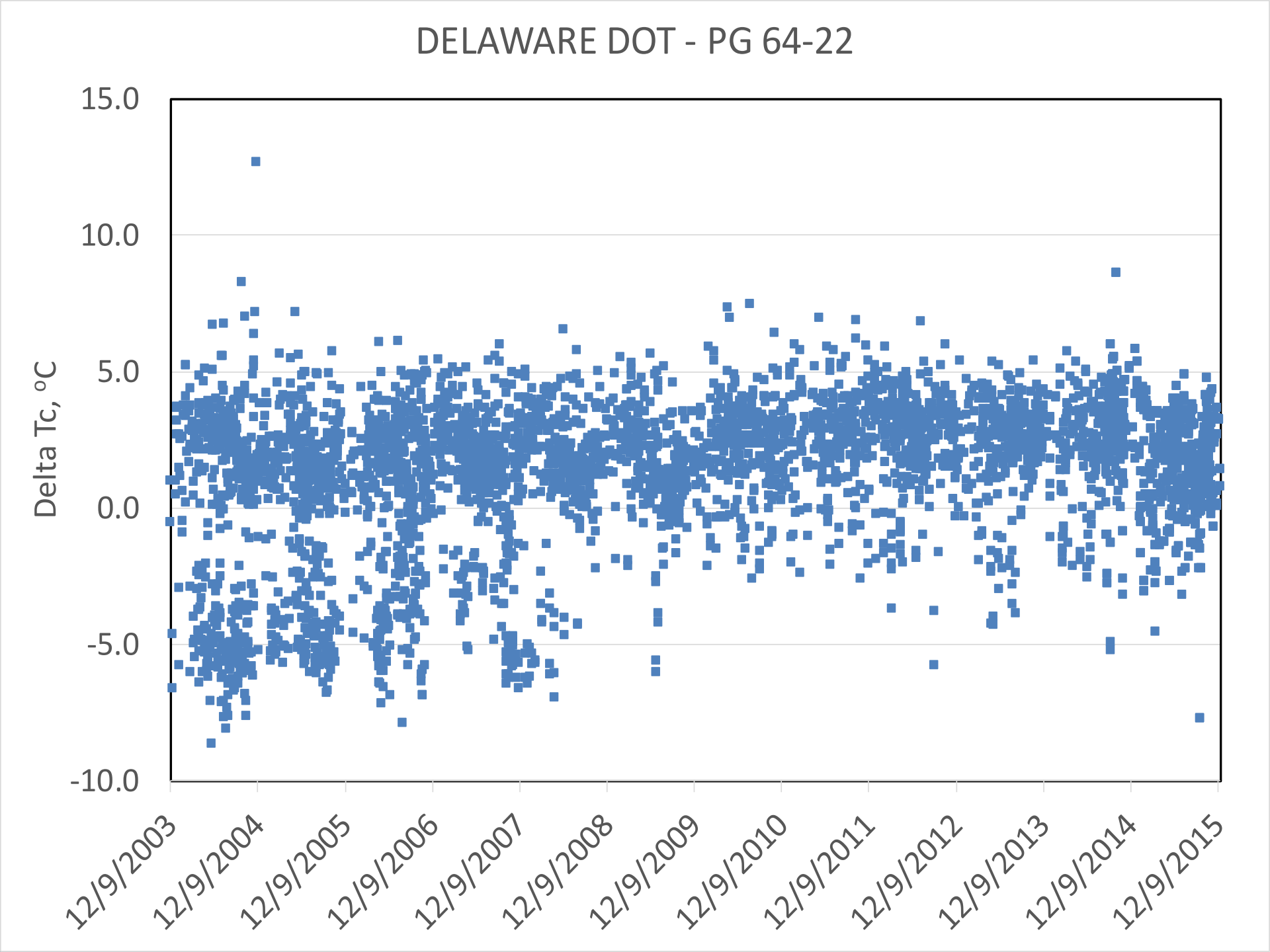
FHWA's Approach at TFHRC

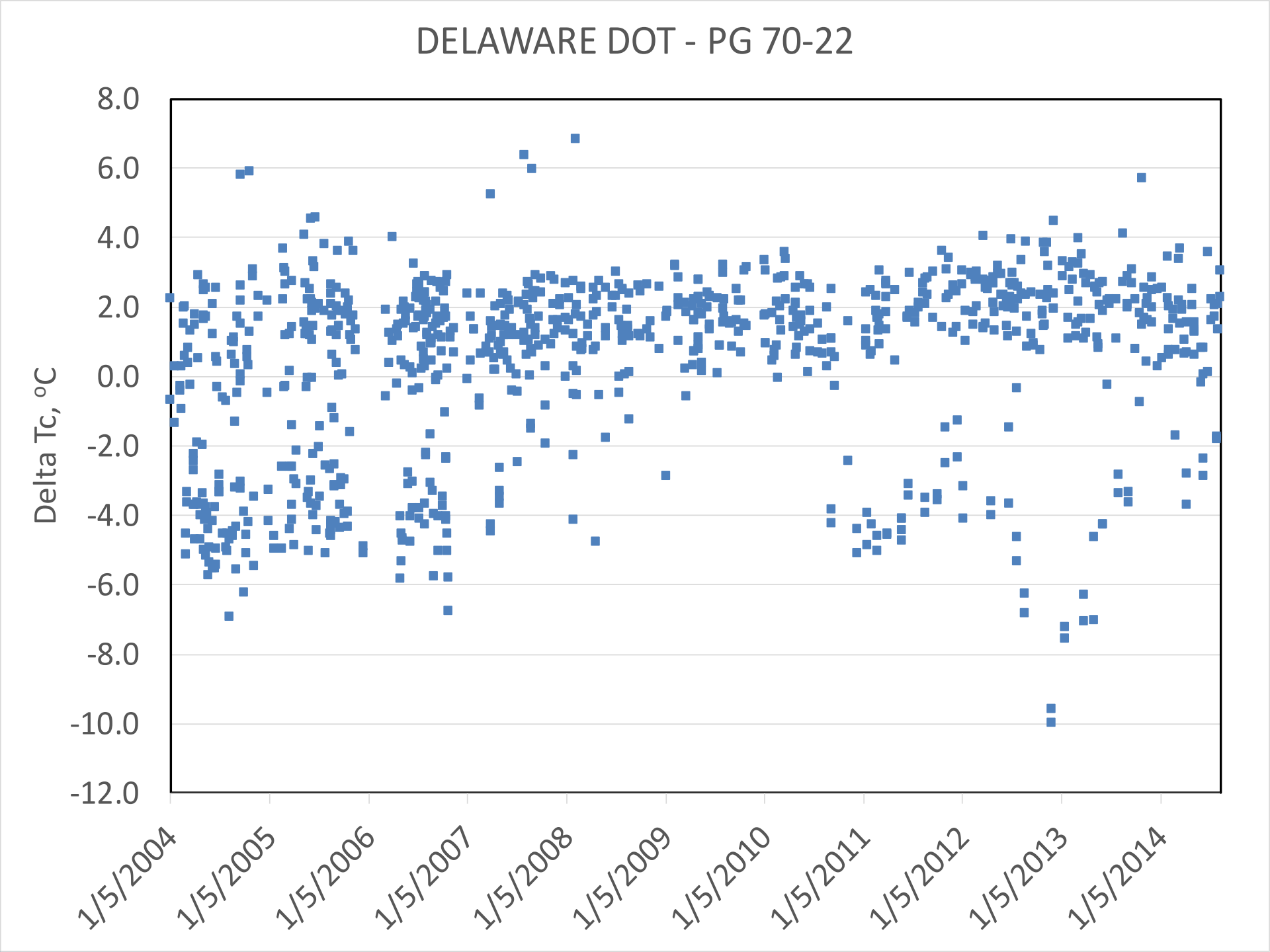
- **Calculate Delta Tc using Data Mining Techniques**
  - **Challenge – State validation data contains BBR info. at only one temperature!**
  - **To calculate Delta Tc – Need BBR S and m-value data at two temperatures!**
  - **Approach – Determine prediction algorithms to calculate Delta Tc.**
- **Delta Tc Prediction from single point BBR data**
  - **Average of all PG specific changes in S and m-value**
  - **ANN approach**

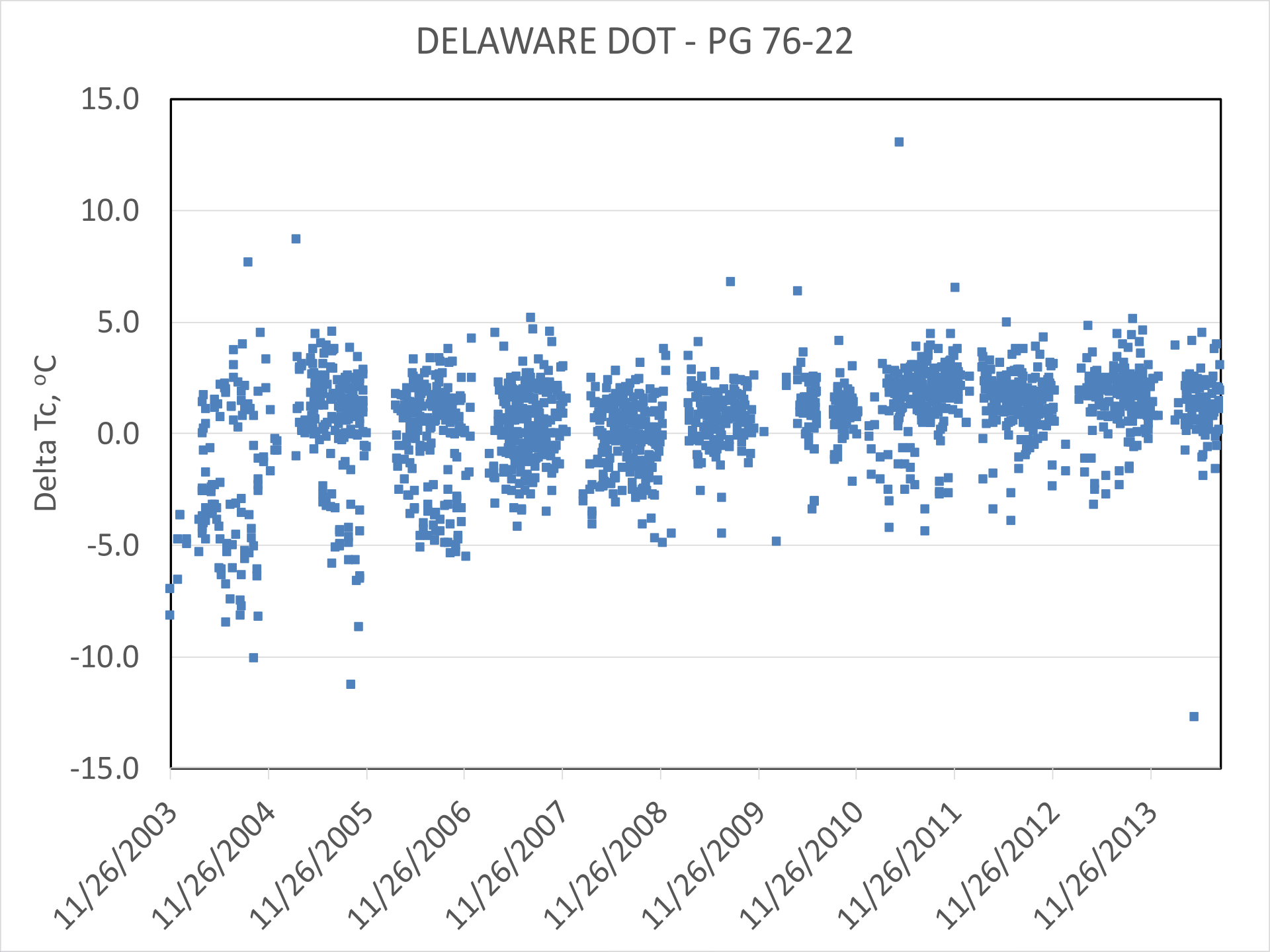

Method 2 Validation (177 samples)
Idaho Binders
CDOT
Penn DOT
AMRL
WCTG
OCTG
Other
S CONTROL
m-value CONTROL
Predicted Delta Tcr (Method 2), ºC
Measured Delta Tcr, ºC
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10

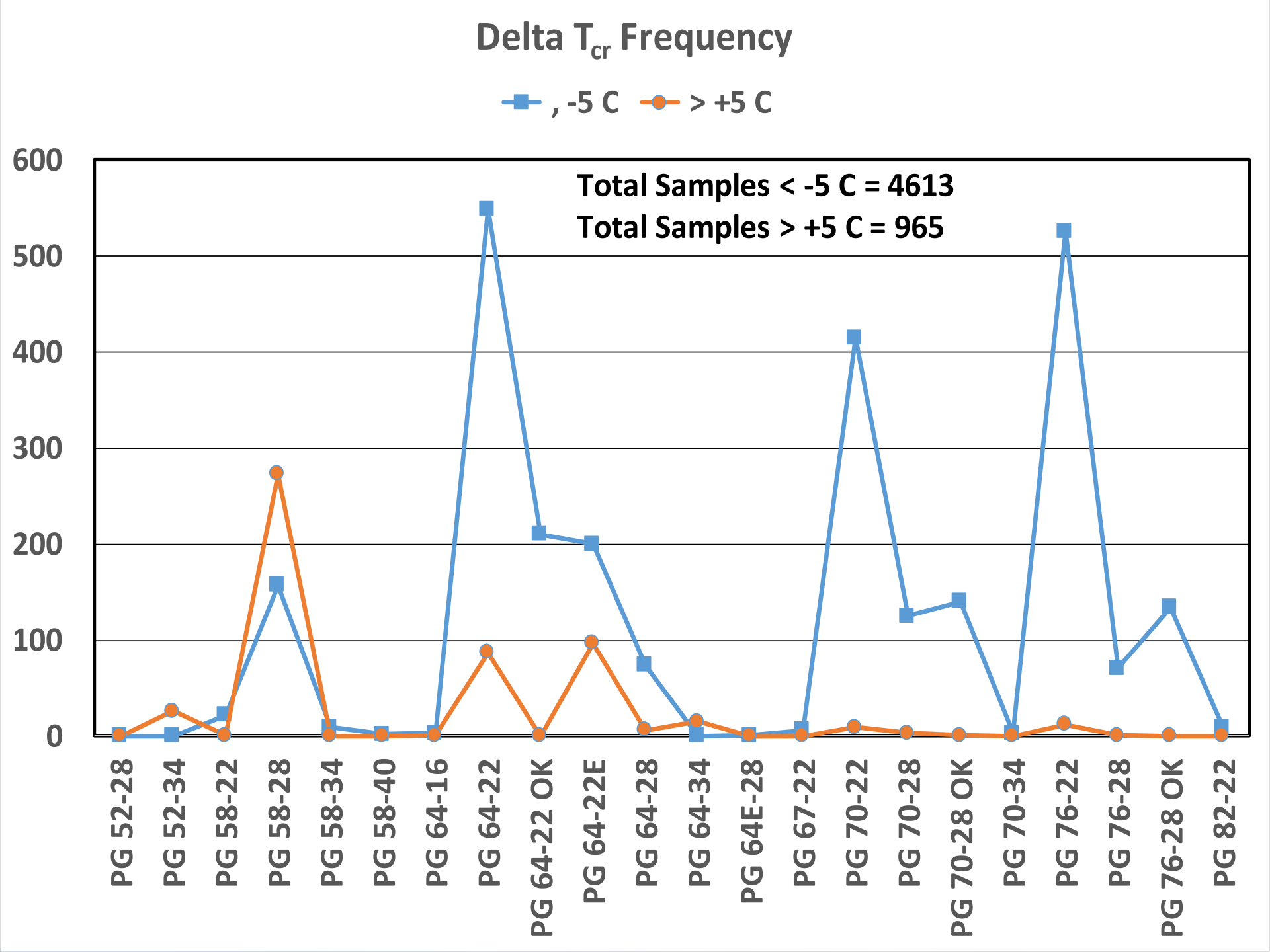

Method 2 Validation (177 Samples)
Idaho Binders
CDOT
Penn DOT
AMRL
WCTG
OCTG
Other
S CONTROL
m-value CONTROL
Prediction Error in Delta Tcr (Method 2), °C
Measured Delta Tcr, °C
5
4
3
2
1
0
-1
-2
-3
-4
-5

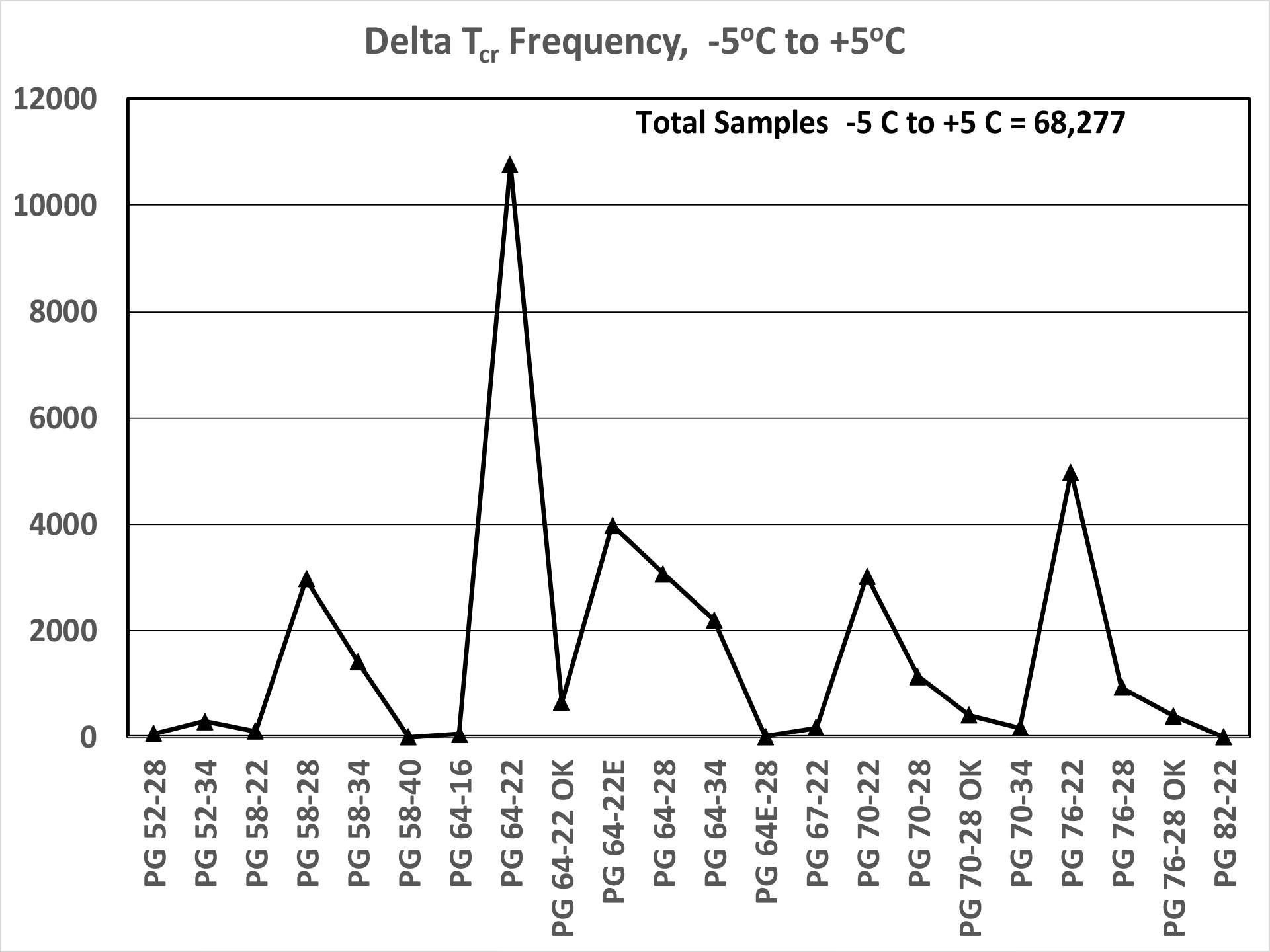

Oklahoma
PG 64-22OK
PG 70-28OK
PG 76-28OK
10
5
0
-5
-10
-15
Delta Tc, degrees C
6-Oct-03
2-Jul-06
28-Mar-09
23-Dec-11
18-Sep-14
14-Jun-17
Date
Negative Vaues indicate m-controlled Lower Grade


DELAWARE DOT - PG 64-22
15.0
10.0
5.0
0.0
-5.0
-10.0
Delta Tc, °C
12/9/2003
12/9/2004
12/9/2005
12/9/2006
12/9/2007
12/9/2008
12/9/2009
12/9/2010
12/9/2011
12/9/2012
12/9/2013
12/9/2014
12/9/2015


DELAWARE DOT - PG 70-22
Delta Tc, °C
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
1/5/2004
1/5/2005
1/5/2006
1/5/2007
1/5/2008
1/5/2009
1/5/2010
1/5/2011
1/5/2012
1/5/2013
1/5/2014


DELAWARE DOT - PG 76-22
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
Delta Tc, °C
11/26/2003
11/26/2004
11/26/2005
11/26/2006
11/26/2007
11/26/2008
11/26/2009
11/26/2010
11/26/2011
11/26/2012
11/26/2013


Delta T_{cr} Frequency
, -5 C
> +5 C
Total Samples < -5 C = 4613
Total Samples > +5 C = 965
600
500
400
300
200
100
0
PG 52-28
PG 52-34
PG 58-22
PG 58-28
PG 58-34
PG 58-40
PG 64-16
PG 64-22
PG 64-22 OK
PG 64-22E
PG 64-28
PG 64-34
PG 64E-28
PG 67-22
PG 70-22
PG 70-28
PG 70-28 OK
PG 70-34
PG 76-22
PG 76-28
PG 76-28 OK
PG 82-22

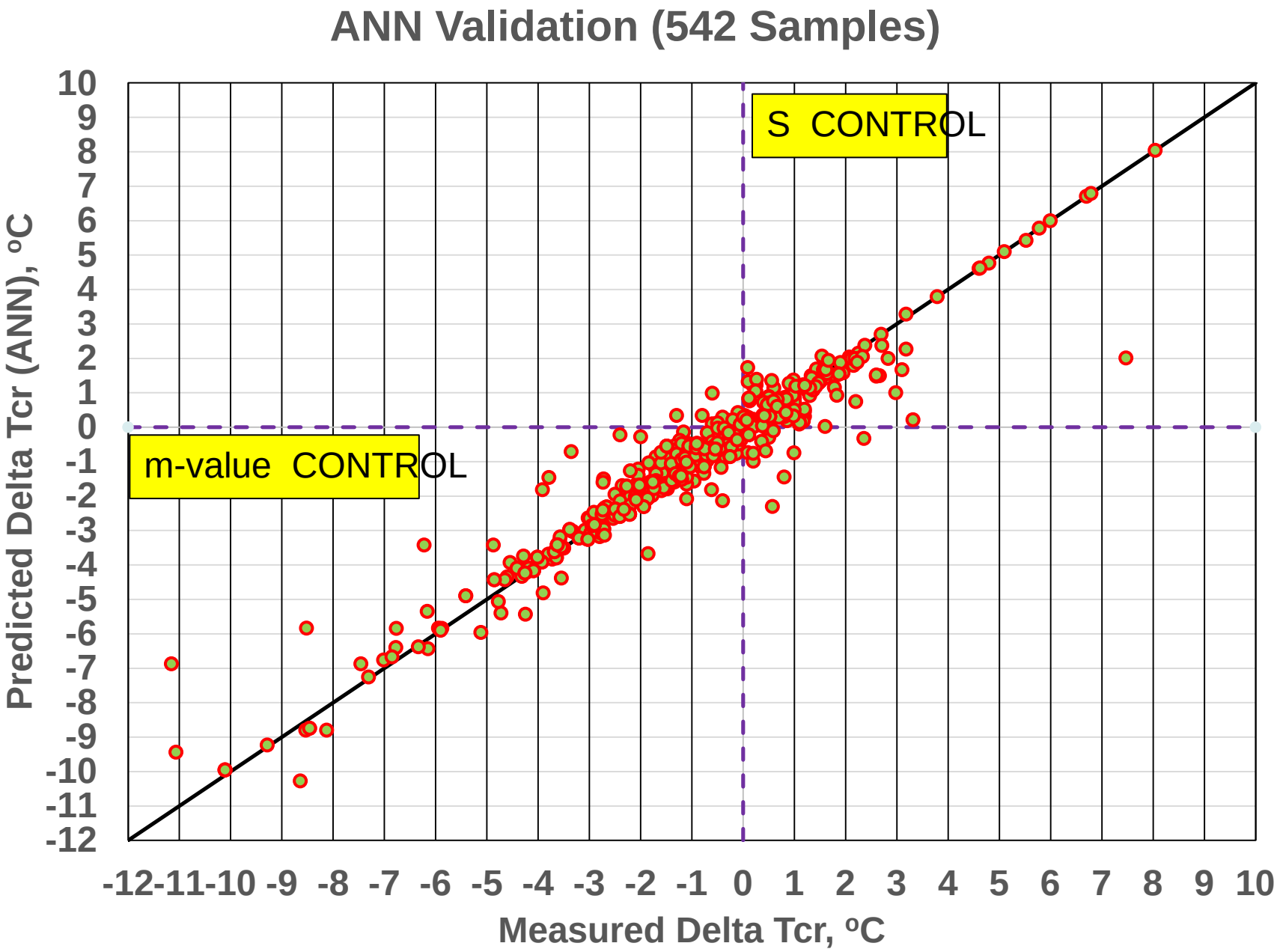

Delta T_{cr} Frequency, -5°C to +5°C
Total Samples -5 C to +5 C = 68,277
12000
10000
8000
6000
4000
2000
0
PG 52-28
PG 52-34
PG 58-22
PG 58-28
PG 58-34
PG 58-40
PG 64-16
PG 64-22
PG 64-22 OK
PG 64-22E
PG 64-28
PG 64-34
PG 64E-28
PG 67-22
PG 70-22
PG 70-28
PG 70-28 OK
PG 70-34
PG 76-22
PG 76-28
PG 76-28 OK
PG 82-22

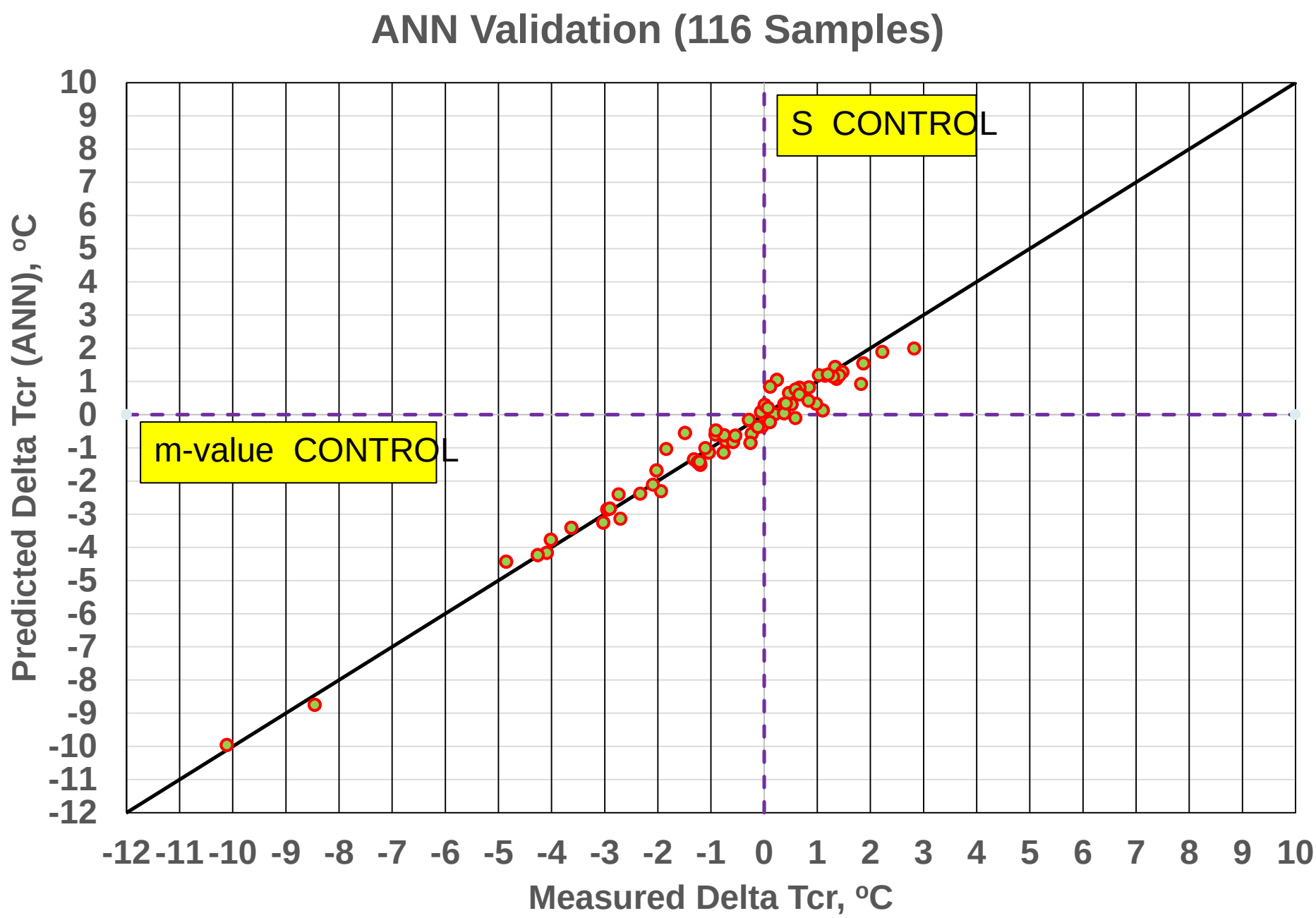
All Participating States								
Number of States	PG Grade	Sample Size	Delta Tc, degrees C			Delta T_{cr} Frequency		
			Median	Minimum	Maximum	< -5 °C	-5 to +5 °C	> +5 °C
3	PG 52-28	73	0.0	-4.6	5.0	0	73	0
2	PG 52-34	322	3	-1	7	0	296	26
3	PG 58-22	133	-1.8	-13.5	12.4	22	110	1
10	PG 58-28	3402	0	-12	11	157	2972	273
4	PG 58-34	1438	2	-6	5	9	1429	0
1	PG 58-40	9	-2.8	-5.8	-1.3	2	7	0
1	PG 64-16	59	2.6	-11.1	6.5	3	55	1
10	PG 64-22	11403	0	-15	31	549	10767	87
1	PG 64-22 OK	869	-3.6	-11.6	2.7	210	659	0
1	PG 64-22E	4283	0.9	-5.8	4.7	200	3985	97
7	PG 64-28	3155	0	-11	14	74	3075	6
3	PG 64-34	2216	1.8	-4.9	6.1	0	2201	15
1	PG 64E-28	16	-0.2	-6.7	0.8	1	15	0
2	PG 67-22	182	-3	-6	1	6	176	0
5	PG 70-22	3456	-3	-13	7	415	3032	9
7	PG 70-28	1265	0	-14	14	125	1137	3
1	PG 70-28 OK	552	-3.6	-13.8	6.4	140	411	1
3	PG 70-34	181	1.4	-8.8	5.1	3	178	0
5	PG 76-22	5517	-2	-16	13	526	4979	12
3	PG 76-28	1013	-0.6	-9.3	5.6	71	941	1
1	PG 76-28 OK	542	-3.6	-9.2	3.5	134	408	0
1	PG 82-22	14	-6	-12	-4	9	5	0
Totals		73856				4613	68277	965
Percentages						6.2	92.4	1.3

OKLOHOMA								
State ID	PG Grade	Sample Size	Delta Tc, degrees C			Delta T_{cr} Frequency		
			Median	Minimum	Maximum	< -5 °C	-5 to +5 °C	> -5 °C
OK	PG 58-28	10	-1.9	-3.8	0.5	0	10	0
OK	PG 64-22 OK	869	-3.6	-11.6	2.7	210	659	0
OK	PG 70-28 OK	552	-3.6	-13.8	6.4	140	411	1
OK	PG 76-28 OK	542	-3.6	-9.2	3.5	134	408	0
Totals		1973				484	1488	1
Percentages						25	75	0

UTAH								
State ID	PG Grade	Sample Size	Delta Tc, degrees C			Delta T_{cr} Frequency		
			Median	Minimum	Maximum	< -5 °C	-5 to +5 °C	> -5 °C
UT	PG 58-28	322	0.3	-3.2	4.7	0	322	0
UT	PG 58-34	1115	1.5	-4.3	4.5	0	1115	0
UT	PG 64-22	27	-0.2	-2.9	2.7	0	27	0
UT	PG 64-28	220	0.3	-9.5	7.3	1	218	1
UT	PG 64-34	928	1.0	-4.9	6.0	0	927	1
UT	PG 70-28	545	0.3	-3.3	4.9	0	545	0
Totals		3157				1	3154	2
Percentages						0	100	0

DELAWARE								
State ID	PG Grade	Sample Size	Delta Tc, degrees C			Delta T_{cr} Frequency		
			Median	Minimum	Maximum	< -5 °C	-5 to +5 °C	> -5 °C
DE	PG 58-28	593	4.1	-5.4	11	1	408	184
DE	PG 64-22E	4282	0.9	-5.8	4.7	200	3985	97
DE	PG 64-22	315	1.9	-8.6	12.7	1	314	0
DE	PG 70-22	949	1.3	-10	6.8	36	906	7
DE	PG 76-22	1961	1	-12.7	13	40	1913	8
DE	PG 82-22	14	-6	-12	-4	9	5	0
Totals		8114				287	7531	296
Percentages						3.5	92.8	3.6


ANN Validation (542 Samples)
S CONTROL
m-value CONTROL
Predicted Delta Tcr (ANN), °C
Measured Delta Tcr, °C
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10


ANN Validation (116 Samples)
S CONTROL
m-value CONTROL
Predicted Delta Tcr (ANN), °C
Measured Delta Tcr, °C
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10

Findings to date

- Delta Tc may be predicted using simple rules based on PG Averages
- Error in prediction is within +/- 2 degrees C for most grades and binders
- ANN can reduce this to within +/- 1 degree C
- Data mining effort
  - Delta Tc range for over 92% of binders is ± 5C
  - There are a considerable number outside this range that should show performance differences
  - Suggests that acceptable Delta Tcs might be related to climatic conditions

ΔT_c and CTOD variation for the ALF binders

Binder Expert Task Group

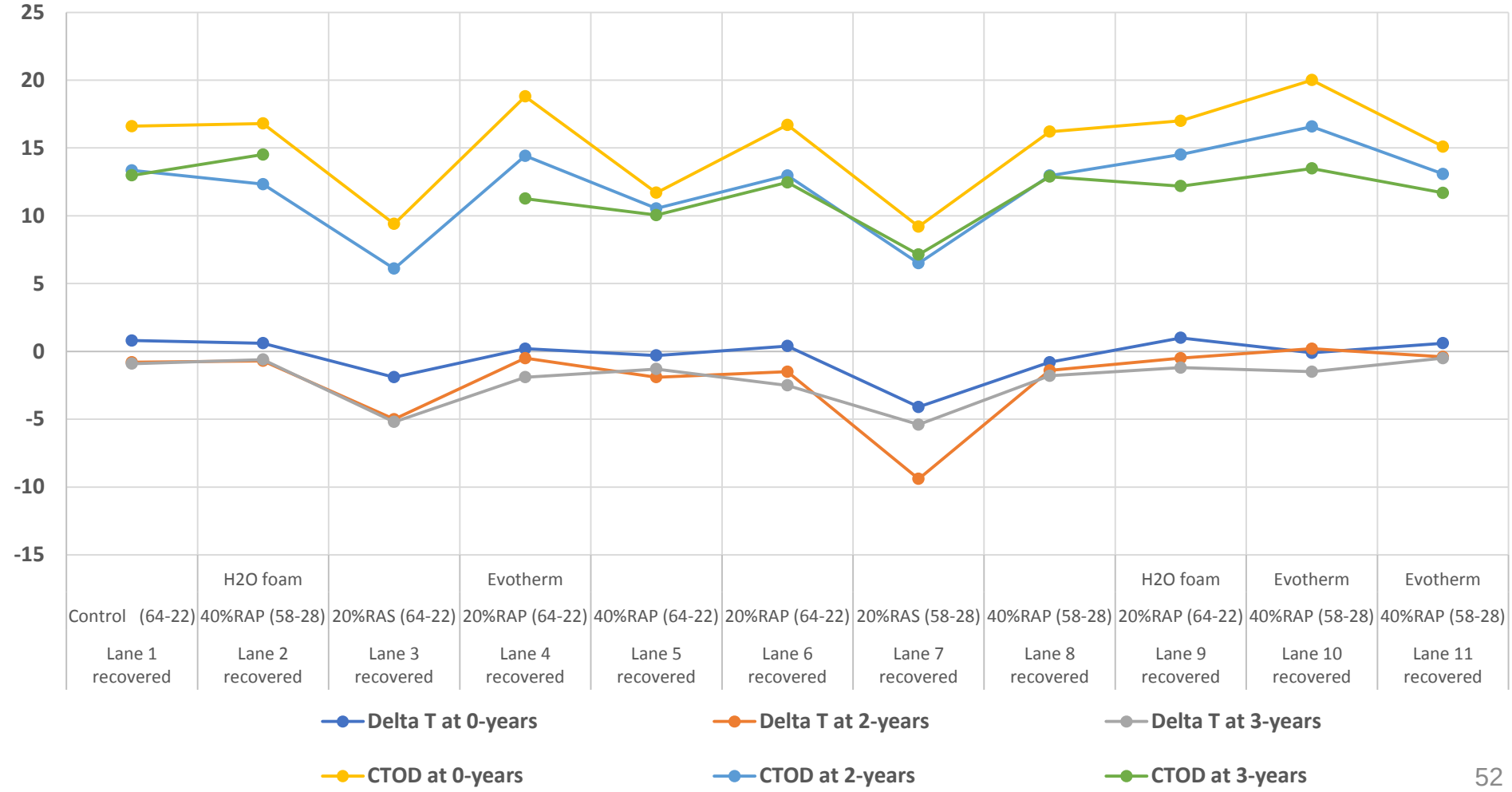
September, 2017

Pavement Materials Team, TFHRC

ALF Binder Properties

Lane	Binder PG	V Content, level	REOB Content, %	Delta Tc
1 and 3	64-22	A		1.7
4	64-22	C		1.5
5	64-22	B		1.5
6	64-22	C		2.4
8	58-28	A	8-10	1.2
9	64-22	A		2.9
11	58-28	D	3-4	2.4

Delta (T) (degrees Celsius) and CTOD (millimeters) variation - binder recovered from ALF lanes at 0, 2 and 3-years

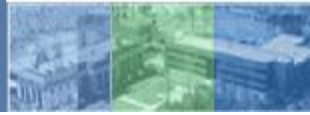


Final Thoughts

- Advantages of ANN based prediction software
  - As States begin implementation, each year ANN software gets smarter
  - States can further refine by adding supplier info, performance, etc.
- Need feedback from States regarding “problem” binders

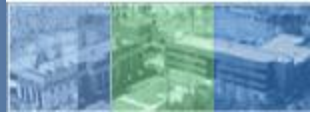
BBR $\Delta T_{critical}$ Spread: $PG_{(S)tiffness} - PG_{(m)-creep}$

	Base		Exploratory Blends			Final Blends	
			+PG100-0	+REOB Source 1	+REOB Source 2	+REOB Source 3	
	PAV	2 X PAV				PAV	2 X PAV
Holly 58-28	**-2.0°C** **60-30**	**-1.1°C** **□-29**	*-0.8°C* *0% / 20%* *69-24*	*-10°C* *20% / 20%* *59-28*	*-14°C* *20% / 20%* *51-28*	**-5.7°C** **15% / 20%** **58-33**	**-10°C** **15% / 20%** **□-26**
			-1.6°C *0% / 30%* *72-20*	*-13°C* *25% / 30%* *59-25*		*-5.1°C* *15% / 0%* *51-40*	*-10°C* *15% / 0%* *□-34*
						-0.2°C **2.5%** **59-33**	**-2.8°C** **2.5%** **□-29**
BP 64-22	+0.8°C 67-27	-1.9°C □-23		*-1.7°C* *10%* *61-31*	*-4.0°C* *10%* *58-29*	**-2.2°C** **6%** **61-28**	**-2.9°C** **6%** **□-23**



WRI/ARC Field Validation Sites-update

- Five sites remain: AZ (2), MN, MB (2)
- Pecking order for AZ sections maintained



Thank You.

Questions?