Evaluation of Operational Z-S Relationships in Marquette, Michigan

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Gauge Technicians
David Beachler - NWS Weather Station
John & Monique Wright - Citizen Weather Station

Motivation and Objective

- Accurate ground-based radar snow estimation is an integral component of NASA's Global Precipitation Measurement (GPM) mission validation network over the United States.

- This study aims to provide guidance on which reflectivity - snow water equivalent relationship to use given the atmospheric conditions.

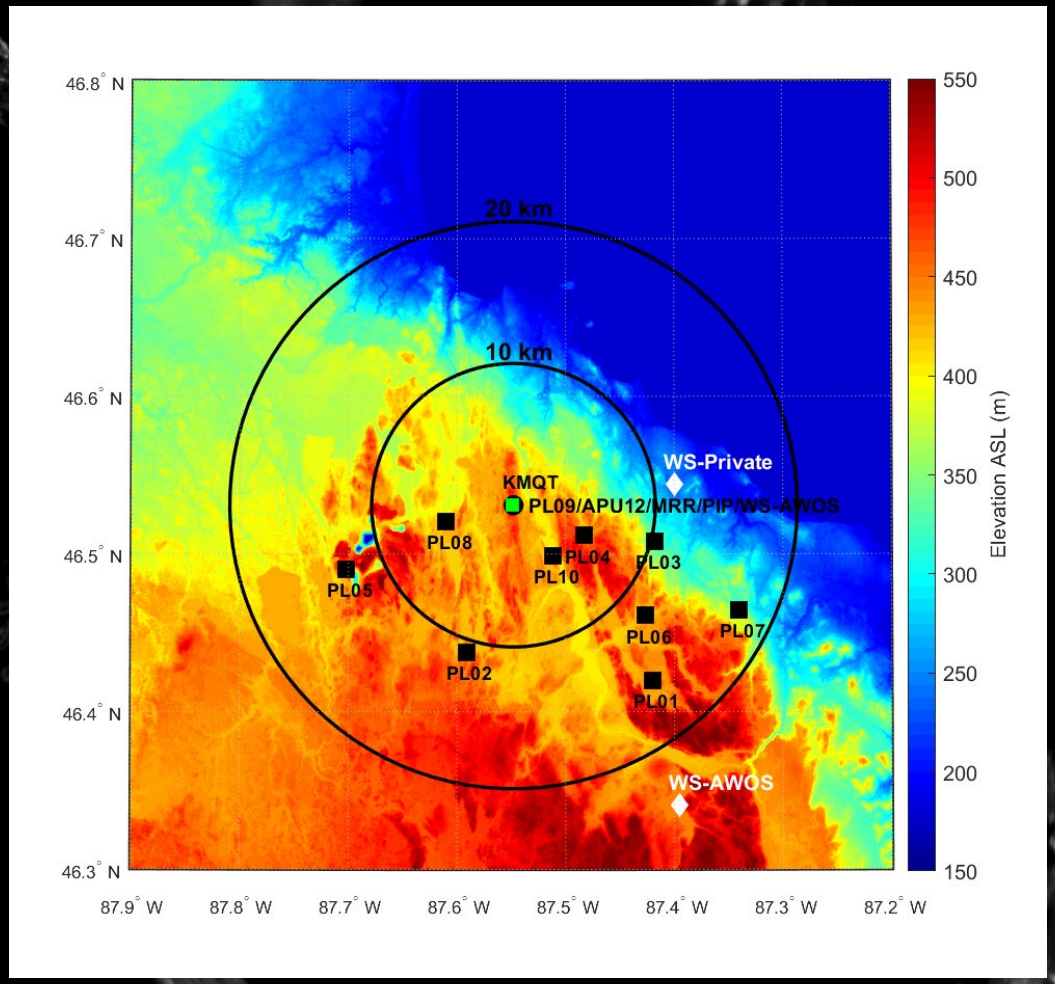
Instrumentation

- NWS Dual-Polarization Radar (KMQT)

- Pluvio 200 & 400
  - Weighing bucket
  - 5 Heated and 4 Unheated
  - Single alter shield

- Surface Weather Stations
  - NWS
  - Citizen

MQT Data Acquisition Network



Site	Dis-88D (km)	H_elev1 (km)	H_elev2 (km)
PL01	15.81	0.236	0.518
PL02	10.87	0.166	0.360
PL03	10.29	0.313	0.495
PL04	5.40	0.126	0.223
PL05	12.60	0.141	0.365
PL06	12.12	0.228	0.443
PL07	17.50	0.423	0.735
PL08	4.91	0.075	0.163
PL10	4.52	0.108	0.189

Radar Data Processing

- Used WS88-D Radar
  - 1 deg beam width
  - 1 km radial distance
- Data received at 10 min intervals and downscaled to 1 min intervals
- The center pixel (5) used as the equivalent radar reflectivity value
- If the center pixel is invalid, then a composite of the adjacent 4 pixels is used
- If the first elevation is invalid, then the same process is applied to the 2nd elevation

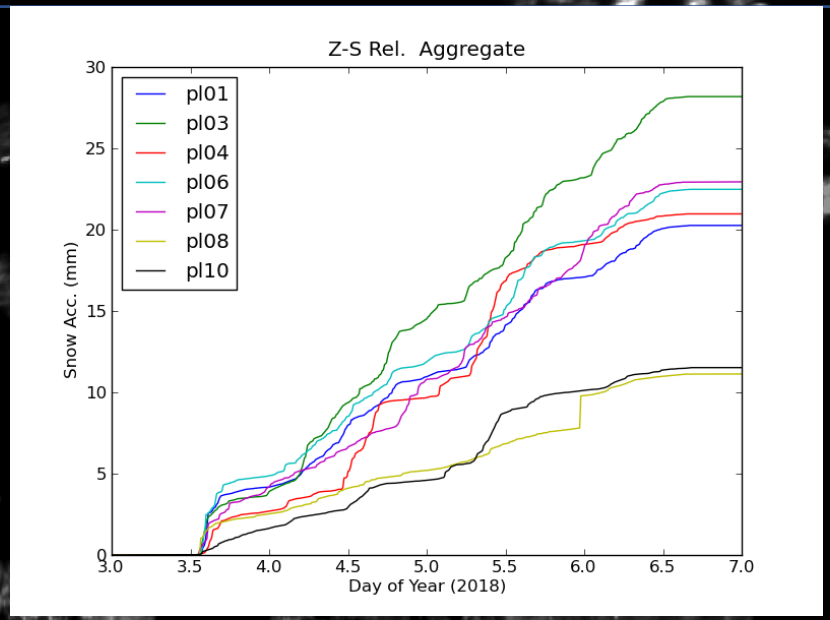
7	8	9
4	5	6
1	2	3

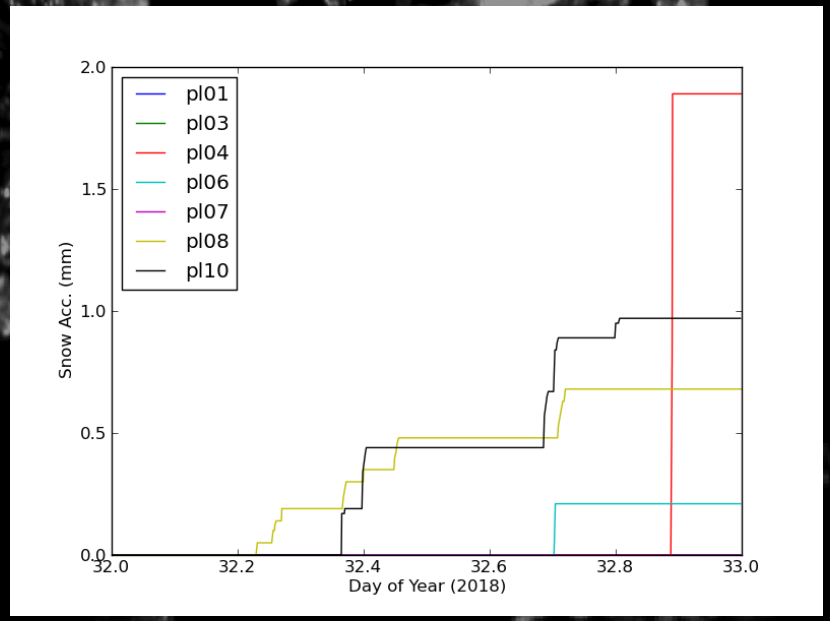
Gauge Data Processing

- Pluvio Details:
  - 0.01 mm resolution
  - 1 min sampling interval
  - Non-real time accumulation for periods of 10 min or longer
- Data Processing:
  - Sets of three accumulation time series were constructed
  - 2 wind corrected, 1 uncorrected
  - Only the uncorrected time series was used

Data Analysis

- Both Pluvio and Radar data are subject to systematic and random error
- Observed spikes in radar data, which were then filtered out
- Malfunctioning Pluvio gauges were omitted from analysis





Methodology

$$Z_e = aS^b$$

Z_e is the equivalent radar reflectivity

S is the liquid water equivalent snowfall rate

- Operational & Habit Relationships
  - 16 relationships applied to every event
- Event Specific Relationships
  - 16 event-based relationships applied individually

Dual Polarization Parameters

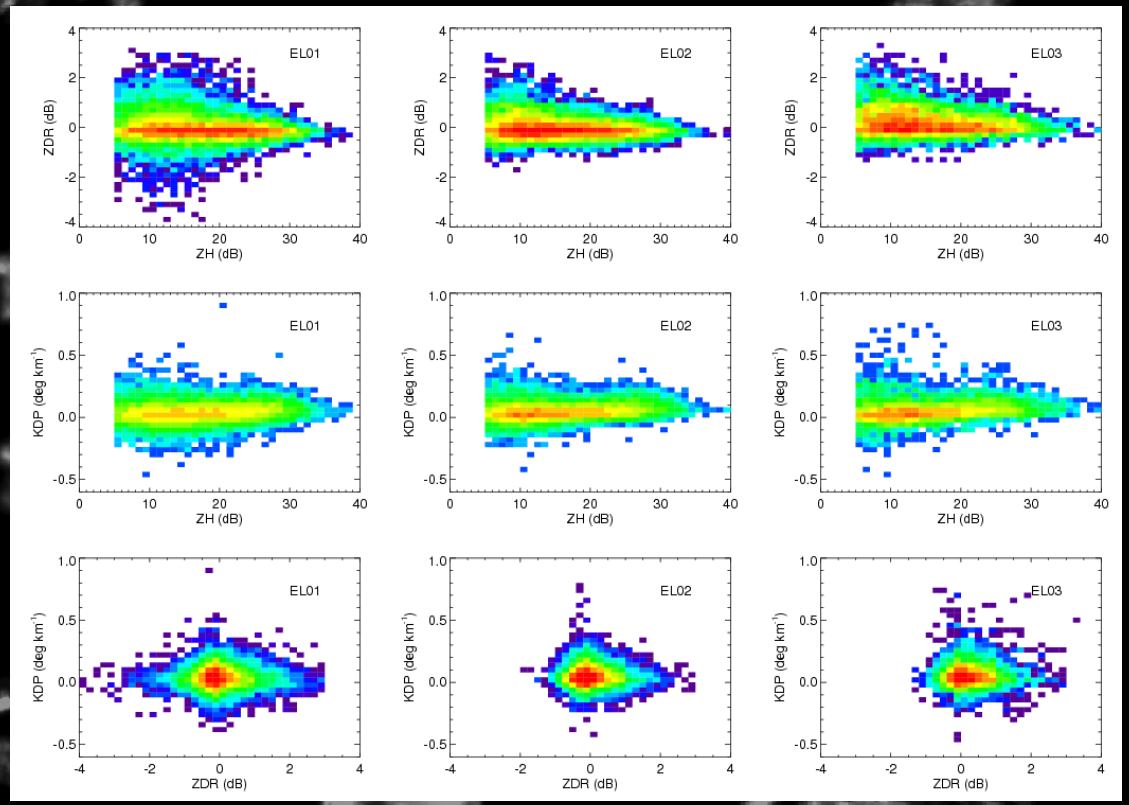
$$S(Z_e) = aZ_e^{\,b}$$

$$S(K_{DP},Z_H) = a'K_{DP}^{\,b'}Z_H^{\,c'}$$

$$S(K_{DP},Z_{DR}) = a''K_{DP}^{\,b''}Z_{DR}^{\,c''}$$

$$S(Z_H,Z_{DR}) = a^*Z_H^{\,b^*}Z_{DR}^{\,c^*}$$

- Equivalent radar reflectivity (Ze) was the only radar parameter used, as differential phase shift (KDP) and differential reflectivity(ZDR) were unused because hydrometeors sampled are both horizontally and vertically oriented.

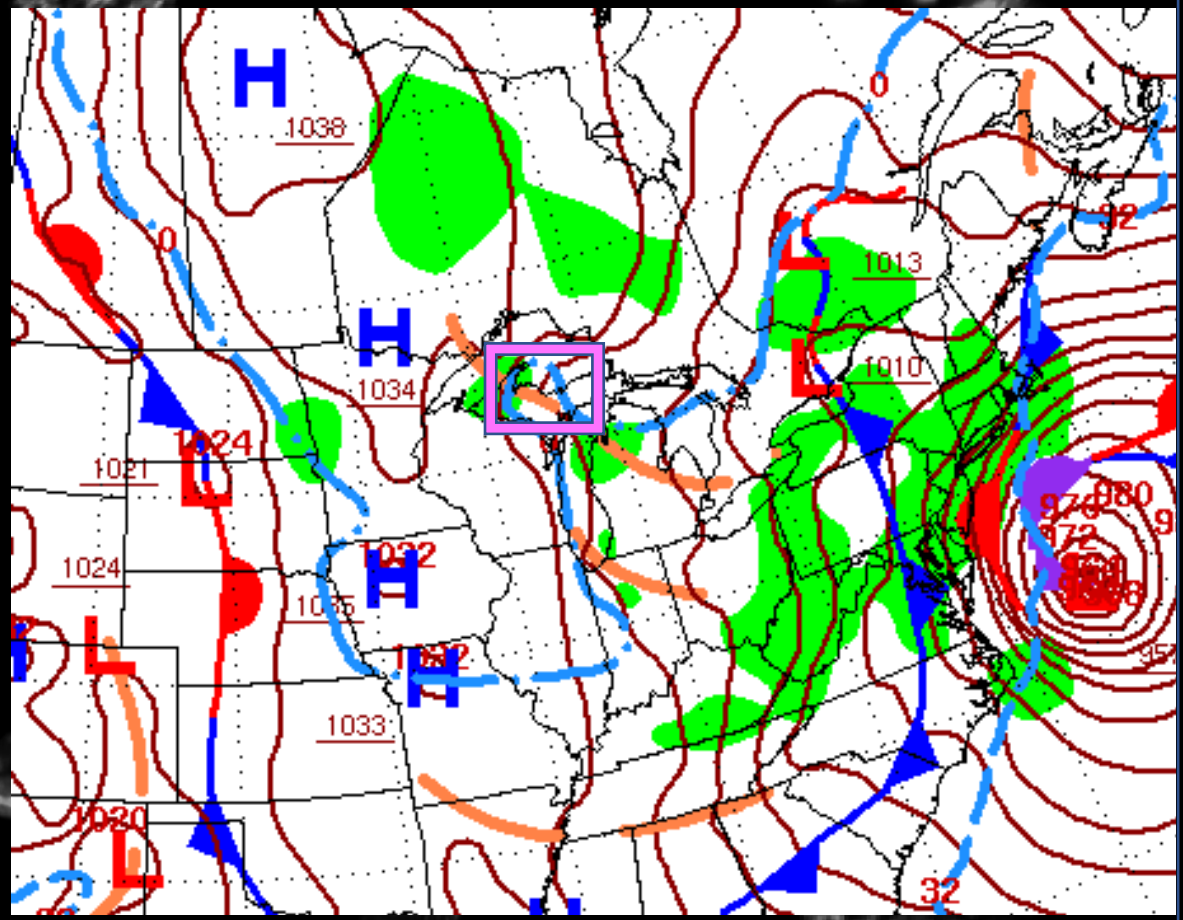


Operational & Habit Z_e-S Relationships

Ze-S	A-coeff	B-exp	**Ze-S**	A-coeff	B-exp
Wet Snow[2]	614	1.4	Sierra Nevada[1]	222	2.0
Graupel[2]	410	1.4	Canadian[3]	1797	2.2
Dry Snow[2]	300	1.4	MRMS[6]	75	2.0
Dry Snow BB[2]	71	1.4	Finland[5]	100	2.0
Northeast[1]	120	2.0	Crystal[4]	170	1.5
N-Plains Mid-W[1]	180	2.0	Aggregate[4]	70	1.3
High Plains[1]	130	2.0	Rime[4]	140	1.6
Mountain-West[1]	40	2.0	Graupel[4]	202	1.6

Event 003 - Description

- 01/03/2018 – 01/06/2018
- Shallow lake effect storm
- Maximum wet bulb temperature: -13 C
- Average wind speed 3.6 m/s
- Habit type: 90% Dendrites, 9% Needles
- PIP Maximum particle size < 5 mm
- MRR Doppler Velocity ~1 m/s
- MRR reflectivity < 15 dBZe

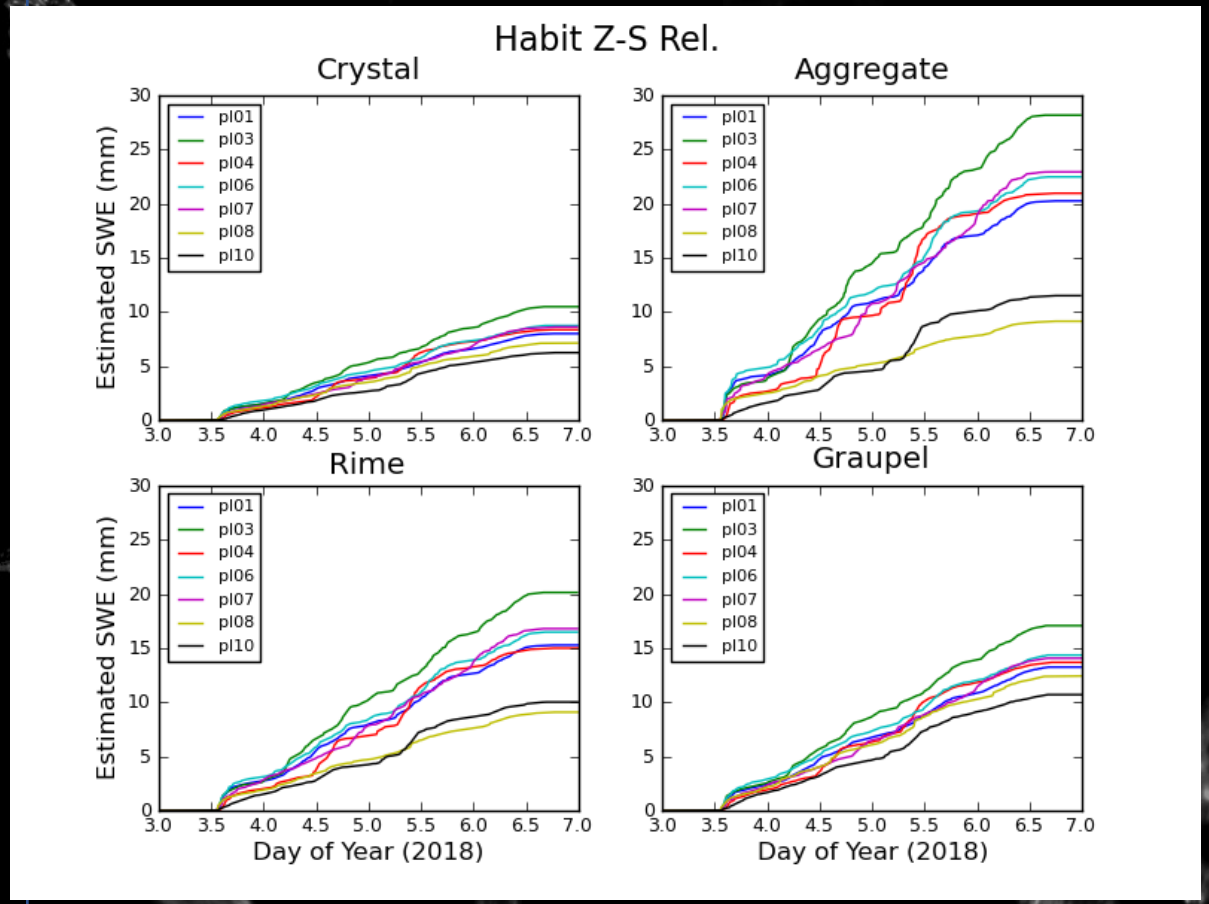


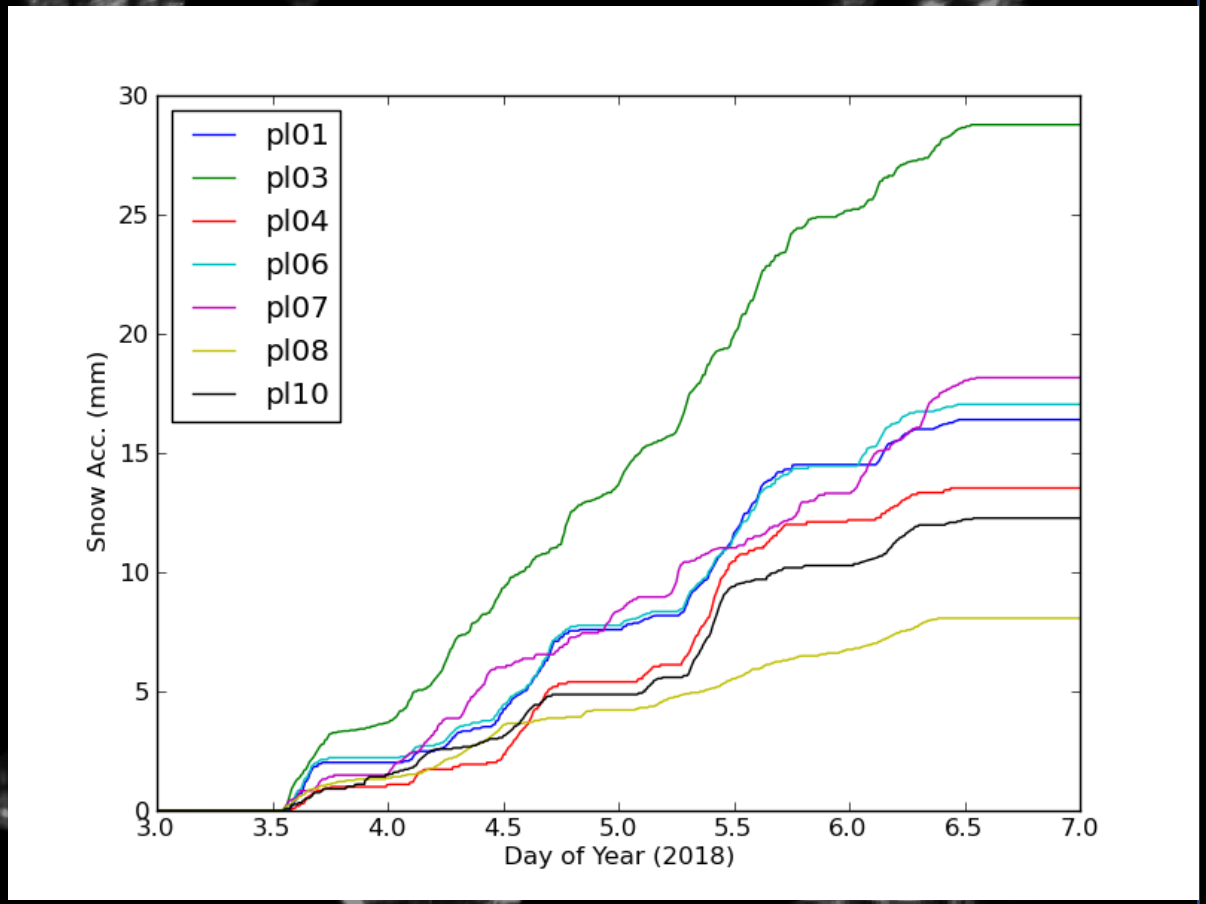
Event 003 – PIP Based Relationships

- Derived from Particle Imaging Package (PIP)
- Provided by Ali Tokay
- BM, HW, KC, MH are different methods for mass calculation
- x = 1.2, 1.3, 1.4, 1.5 and the maximum dimensions as a function of equivalent diameter (Dmax = xDpip)

Ze-S	A-coeff ($1.2D_{PIP}$)	-exp ($1.2D_{PIP}$)	A-coeff ($1.3D_{PIP}$)	b-exp ($1.3D_{PIP}$)	A-coeff ($1.4D_{PIP}$)	b-exp ($1.4D_{PIP}$)	A-coeff ($1.5D_{PIP}$)	b-exp ($1.5D_{PIP}$)
BM	34.49	1.25	37.40	1.26	38.75	1.25	47.44	1.25
HW	20.83	1.23	20.20	1.20	20.70	1.21	25.11	1.21
KC	28.02	1.29	29.19	1.28	31.12	1.28	36.47	1.27
MH	29.15	1.28	31.40	1.29	32.63	1.28	39.22	1.27

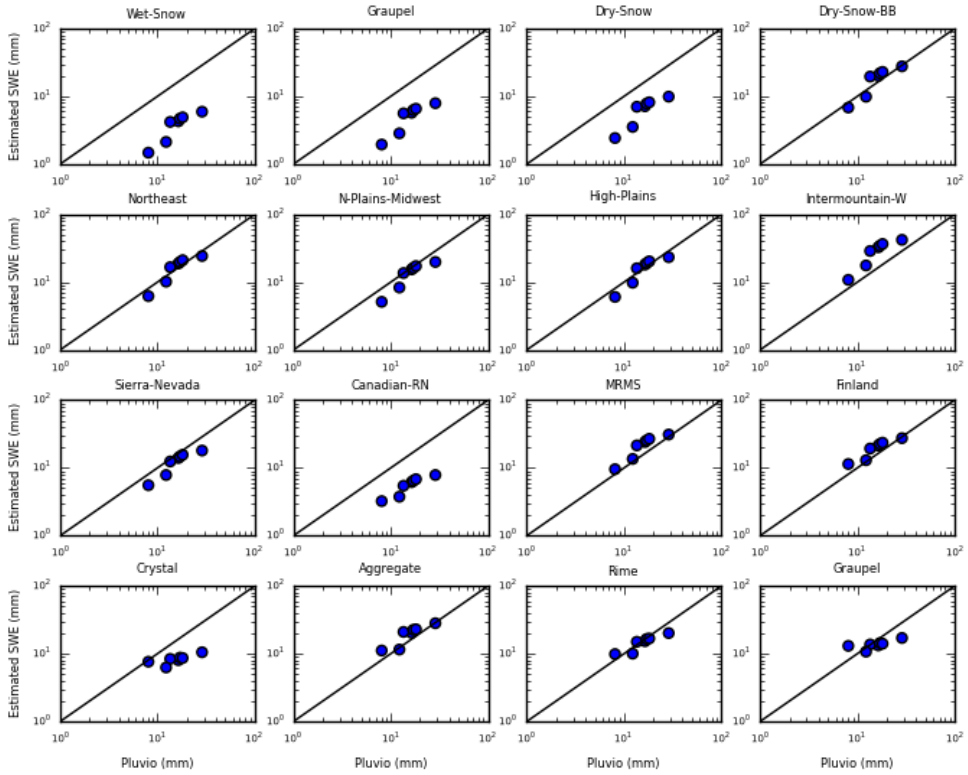
Event 003 – Est. vs Measured



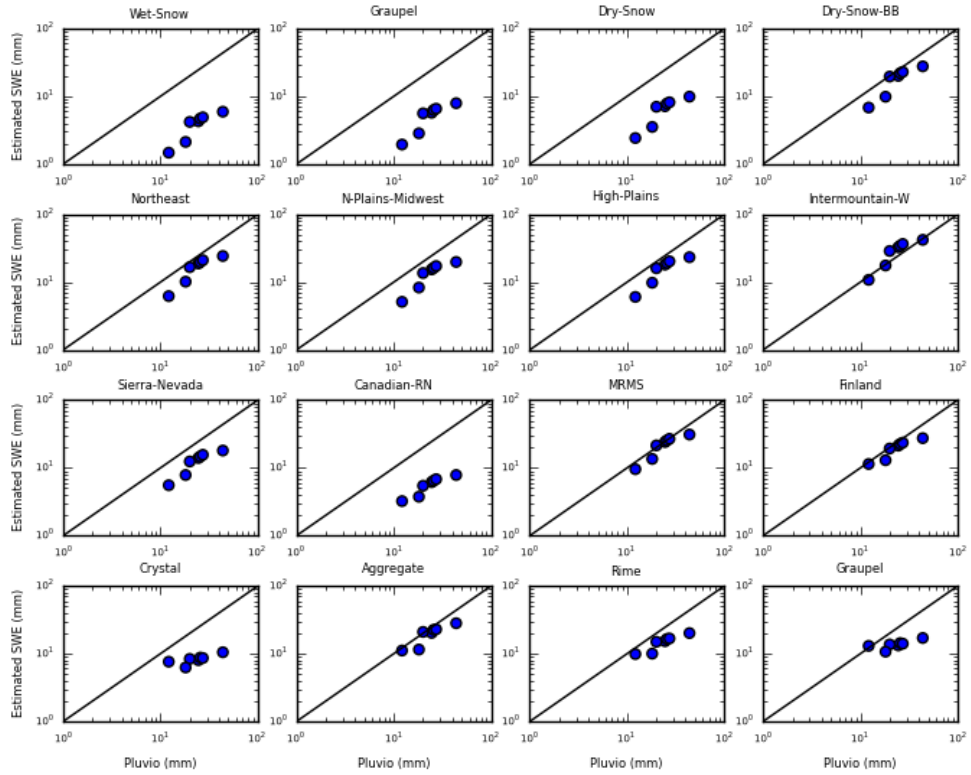


Event 003 – Operational & Habit

Uncorrected

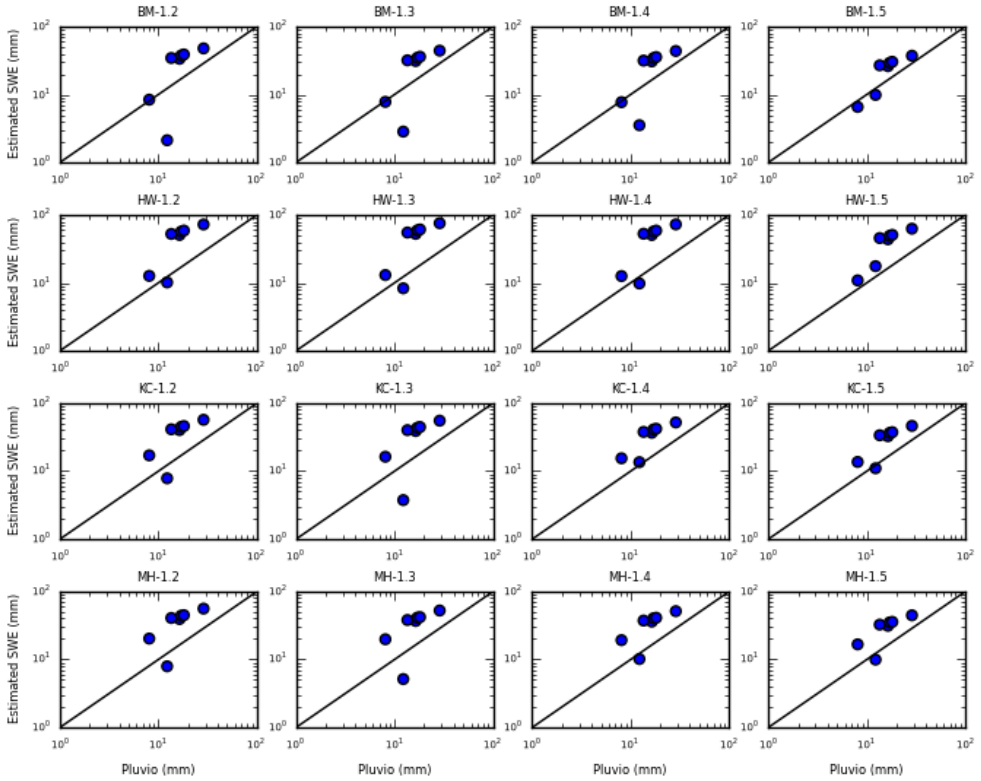


NWS Wind Corrected



Event 003 - PIP Event Specific

Uncorrected



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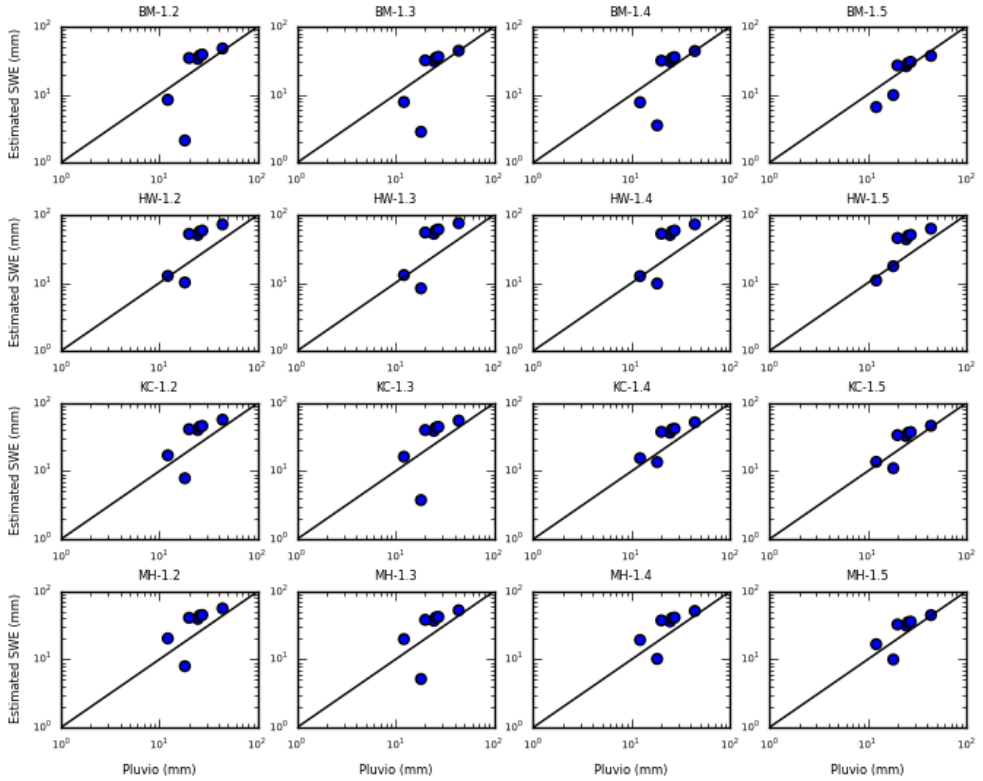


Event 003

- Red-Green represents lowest to highest % absolute bias

Uncorrected

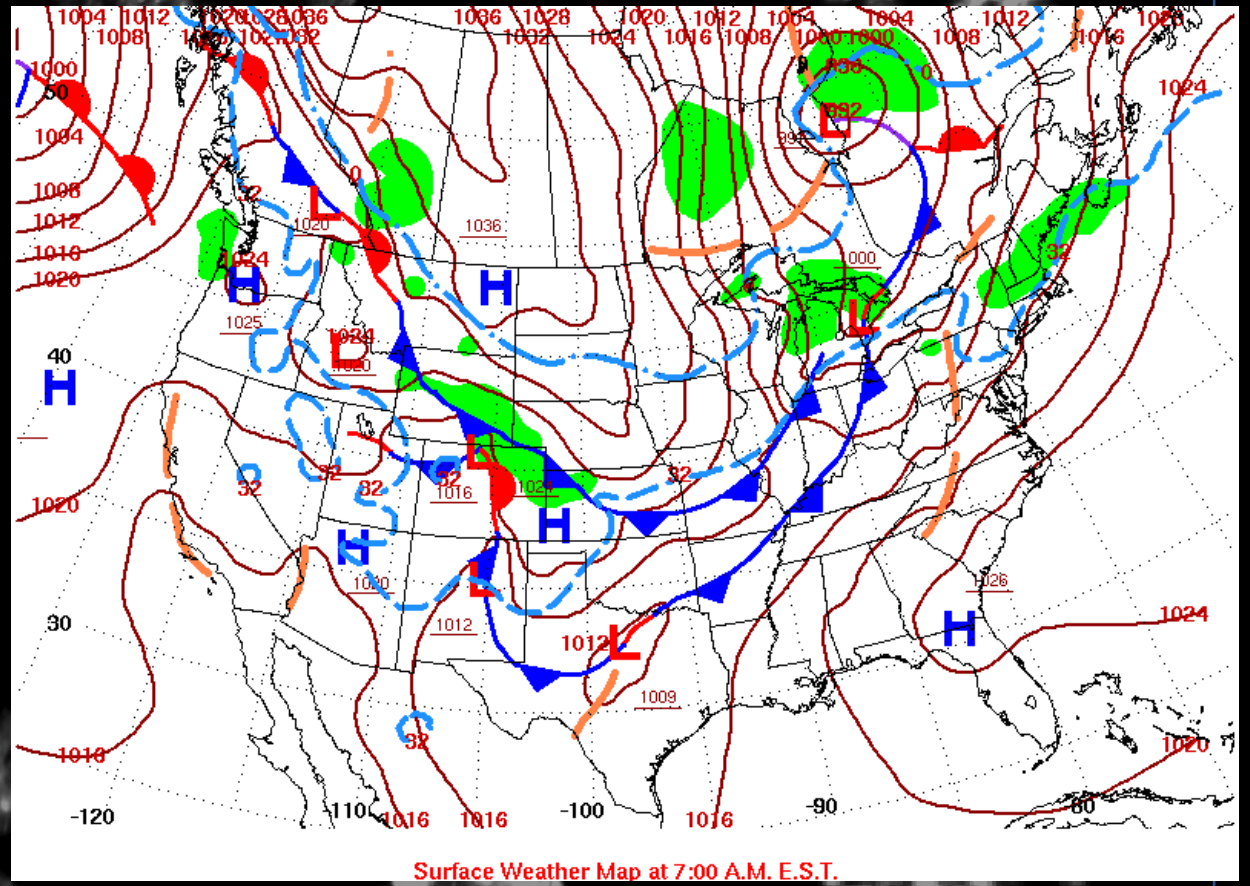
Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	75.88	BM-1.2	95.14
Graupel	67.76	BM-1.3	82.05
Dry-Snow	59.79	BM-1.4	79.75
Dry-Snow-BB	20.99	BM-1.5	52.33
Northeast	17.17	HW-1.2	178.60
N-Plains/Mid-W	16.37	HW-1.3	191.29
High-Plains	15.97	HW-1.4	179.28
Mountain-W	77.56	HW-1.5	145.61
Sierra-Nevada	22.81	KC-1.2	130.82
Canadian	65.23	KC-1.3	127.58
MRMS	33.13	KC-1.4	109.34
Finland	23.55	KC-1.5	87.49
Crystal	49.08	MH-1.2	129.80
Aggregate	22.68	MH-1.3	119.25
Rime	15.06	MH-1.4	110.35
Graupel	24.80	MH-1.5	84.74

NWS Wind Corrected

Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	83.95	BM-1.2	41.11
Graupel	78.55	BM-1.3	32.7
Dry-Snow	73.24	BM-1.4	31.38
Dry-Snow-BB	24.97	BM-1.5	20.71
Northeast	31.89	HW-1.2	92.25
N-Plains/Midwest	44.27	HW-1.3	100.69
High-Plains	34.40	HW-1.4	92.70
Mountain-W	22.42	HW-1.5	65.60
Sierra-Nevada	48.63	KC-1.2	60.4
Canadian	76.86	KC-1.3	58.29
MRMS	13.10	KC-1.4	44.69
Finland	19.26	KC-1.5	31.61
Crystal	66.12	MH-1.2	59.77
Aggregate	21.02	MH-1.3	52.75
Rime	39.68	MH-1.4	46.8
Graupel	45.01	MH-1.5	29.78

Event 032 - Description

- 01/03/2018 – 01/06/2018
- Shallow lake effect storm
- Maximum wet bulb temperature: -10 C
- Average wind speed 5.3 m/s
- Habit type: 76% Dendrites, 20% Needles
- PIP Maximum particle size < 5 mm
- MRR Doppler Velocity ~1 m/s
- MRR reflectivity < 15 dBZe

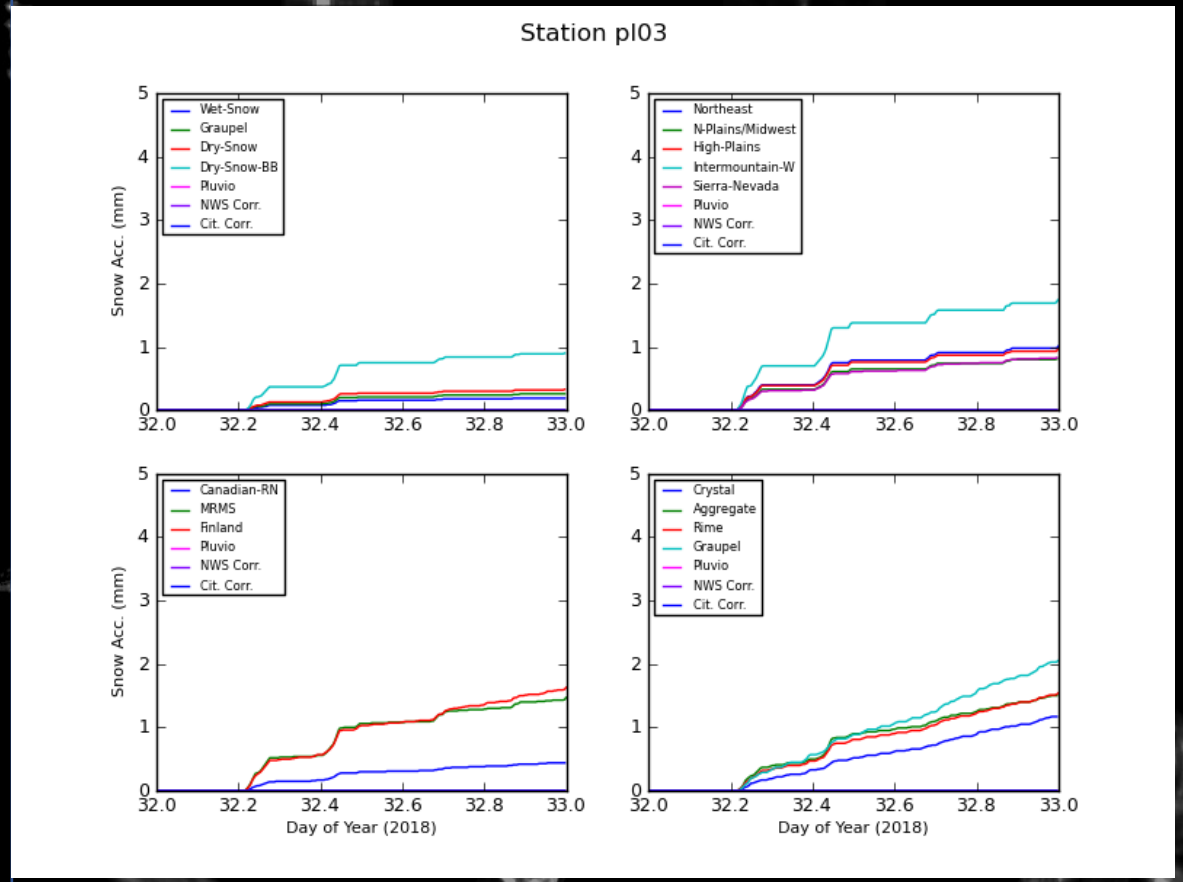


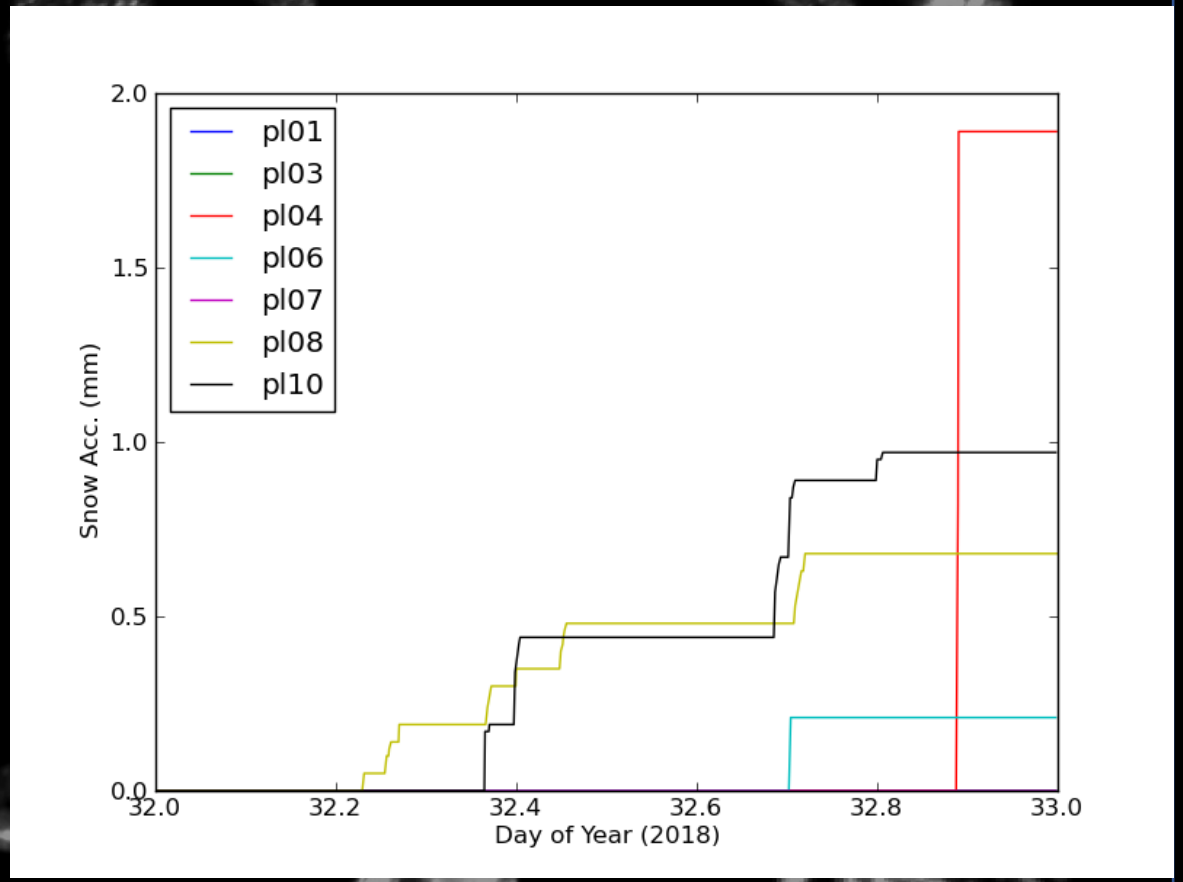
Event 032 – PIP Based Relationships

- Derived from Particle Imaging Package (PIP)
- Provided by Ali Tokay
- BM, HW, KC, MH are different methods for mass calculation
- x = 1.2, 1.3, 1.4, 1.5 and the maximum dimensions as a function of equivalent diameter (Dmax = xDpip)

Z-S	A-coeff ($1.2\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.3\ D_{PIP}$)	B-exp ($1.3D_{PIP}$)	A-coeff ($1.4\ D_{PIP}$)	B-exp ($1.4D_{PIP}$)	A-coeff ($1.5\ D_{PIP}$)	B-exp ($1.5D_{PIP}$)
BM	33.74	1.19	37.09	1.21	37.80	1.19	45.43	1.20
HW	19.07	1.14	20.64	1.16	20.76	1.15	23.71	1.16
KC	27.83	1.24	28.53	1.22	31.05	1.23	34.67	1.21
MH	38.05	1.22	31.90	1.22	31.30	1.23	28.44	1.22

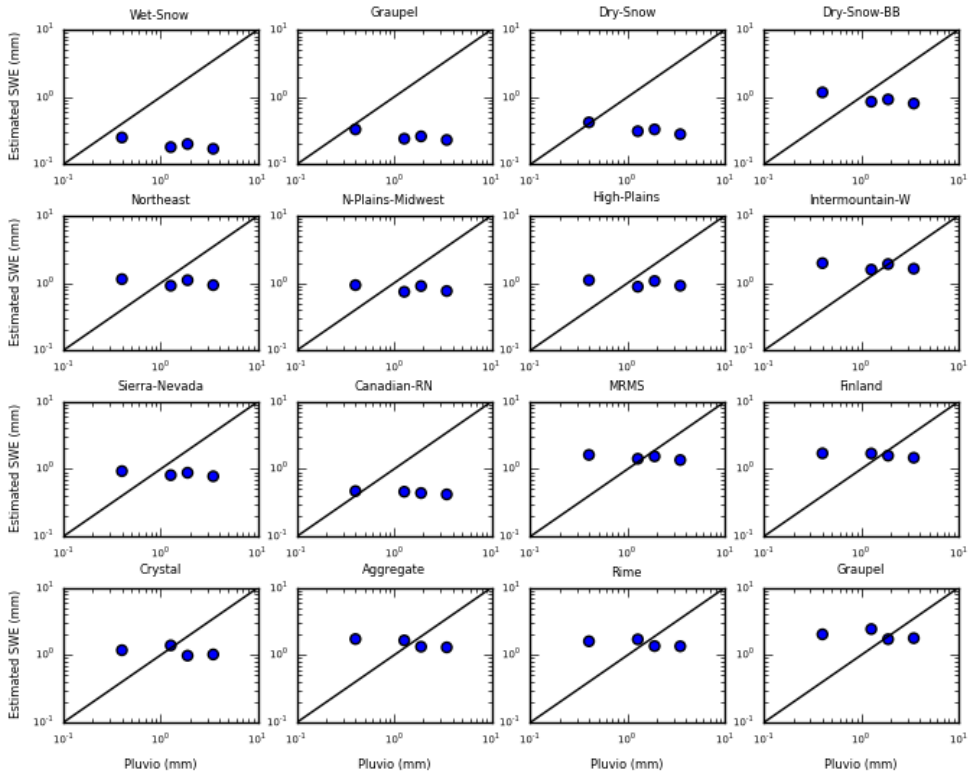
Event 032 – Est. vs Measured



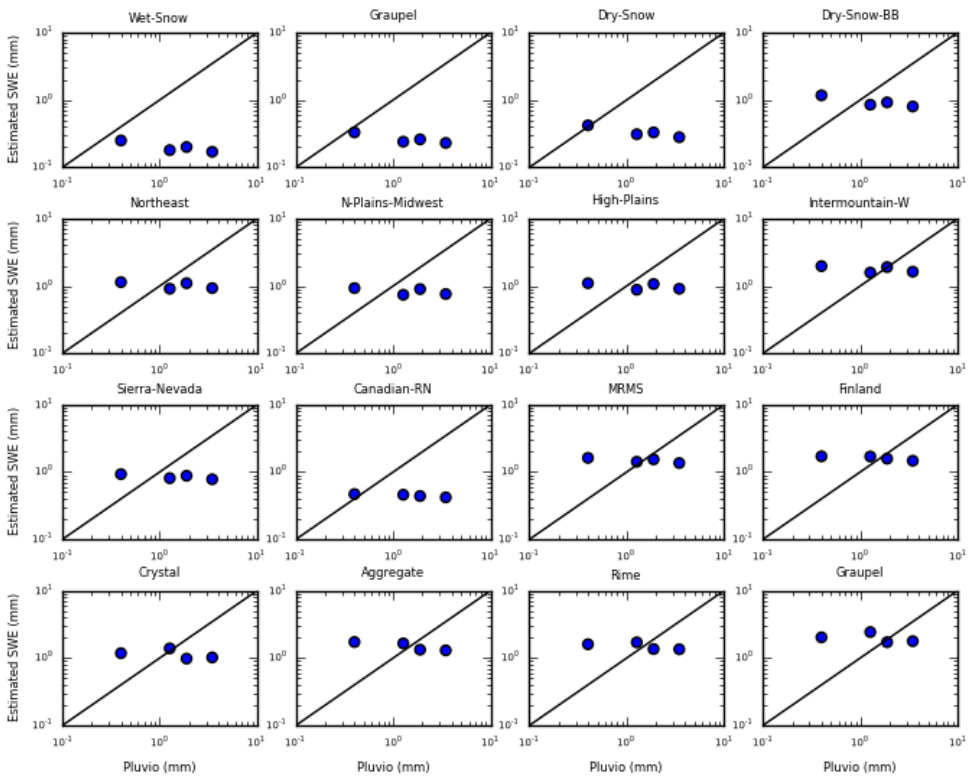


Event 032 – Operational & Habit

Uncorrected

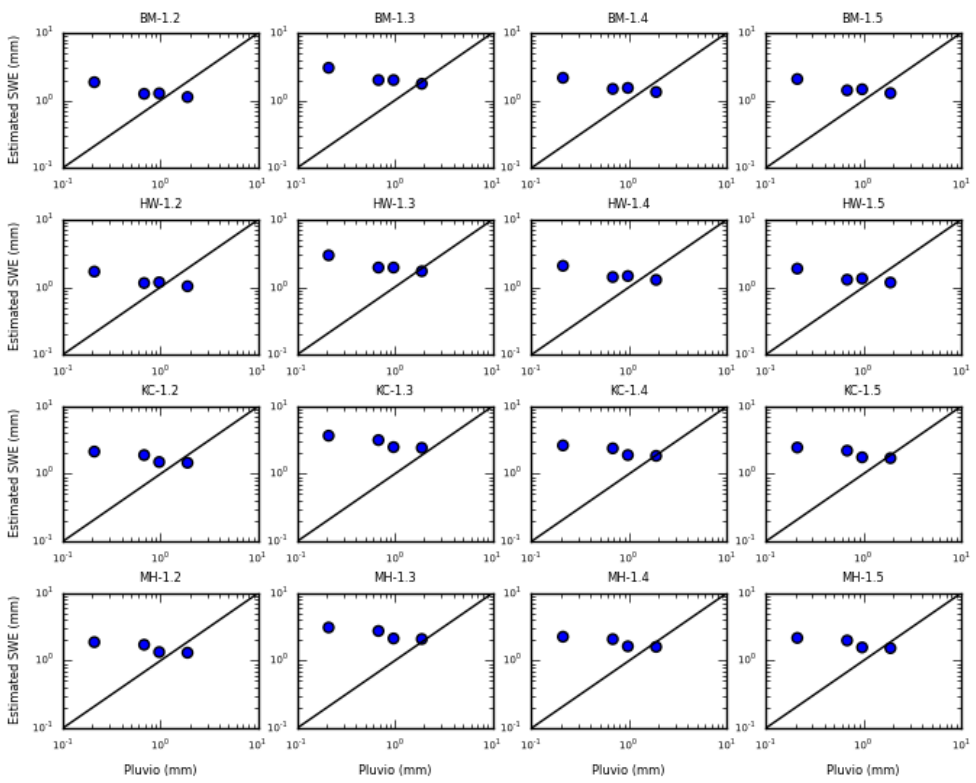


NWS Wind Corrected

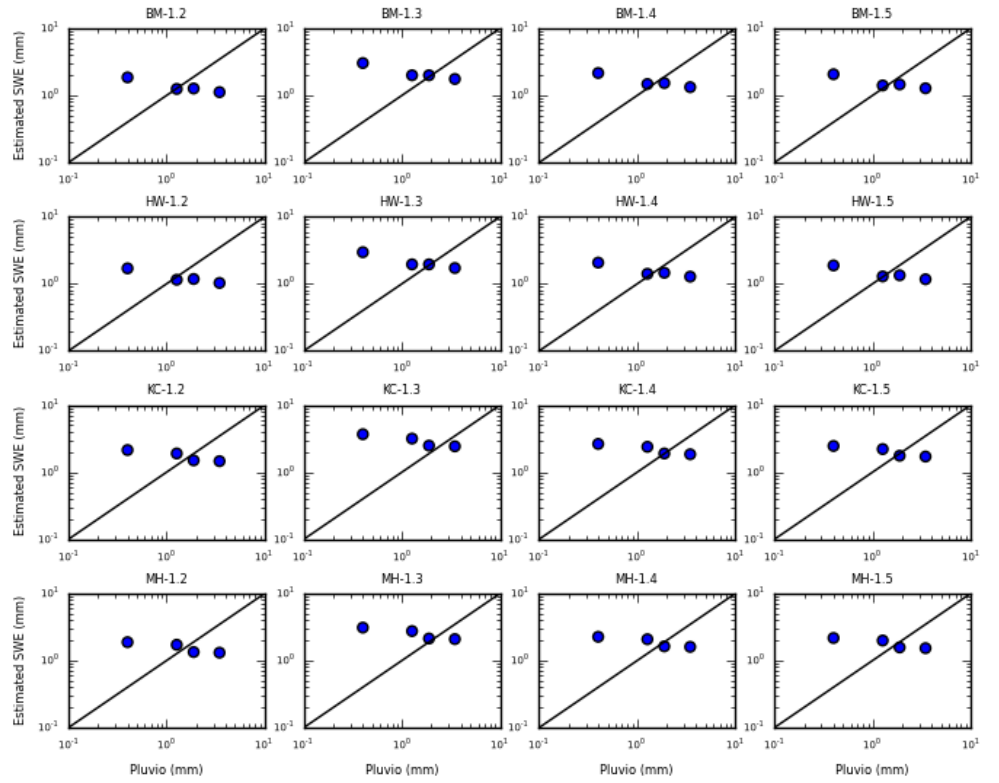


Event 032 - PIP Event Specific

Uncorrected



NWS Wind Corrected



Event 032

- Red-Green represents lowest to highest % absolute bias

Uncorrected

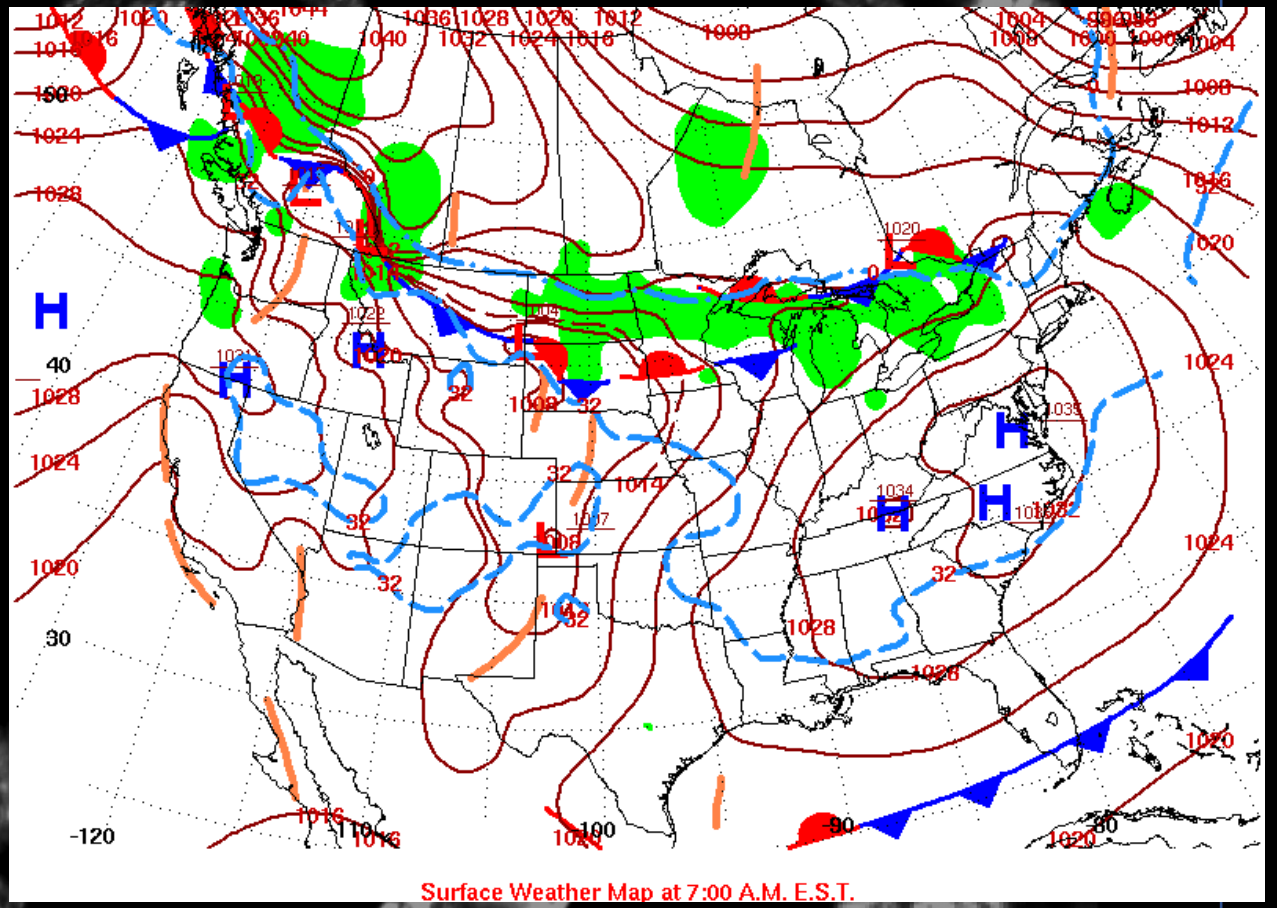
Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	80.80	BM-1.2	87.73
Graupel	78.13	BM-1.3	141.60
Dry-Snow	75.46	BM-1.4	103.20
Dry-Snow-BB	60.53	BM-1.5	98.40
Northeast	60.00	HW-1.2	80.80
N-Plains/Mid-W	52.80	HW-1.3	137.87
High-Plains	57.86	HW-1.4	98.40
Mountain-W	102.93	HW-1.5	89.86
Sierra-Nevada	54.66	KC-1.2	109.60
Canadian	66.13	KC-1.3	213.86
MRMS	86.66	KC-1.4	136.26
Finland	94.66	KC-1.5	126.66
Crystal	68.26	MH-1.2	97.60
Aggregate	91.73	MH-1.3	168.53
Rime	89.33	MH-1.4	117.33
Graupel	118.13	MH-1.5	112.80

NWS Wind Corrected

Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	88.62	BM-1.2	63.30
Graupel	84.92	BM-1.3	73.82
Dry-Snow	81.50	BM-1.4	63.58
Dry-Snow-BB	68.70	BM-1.5	63.01
Northeast	63.01	HW-1.2	65.00
N-Plains/Midwest	67.70	HW-1.3	71.8
High-Plains	63.58	HW-1.4	63.01
Mountain-W	53.20	HW-1.5	61.87
Sierra-Nevada	66.71	KC-1.2	67.85
Canadian	76.52	KC-1.3	97.01
MRMS	54.48	KC-1.4	70.98
Finland	57.61	KC-1.5	69.50
Crystal	60.59	MH-1.2	66.00
Aggregate	63.15	MH-1.3	82.50
Rime	61.02	MH-1.4	68.27
Graupel	66.14	MH-1.5	67.56

Event 034 - Description

- 01/03/2018 – 01/06/2018
- Deep lake effect storm
- Maximum wet bulb temperature: -12 C
- Average wind speed 2 m/s
- Habit type: 63% Dendrites, 14% Needles, 22% Plates
- PIP Maximum particle size < 5 mm
- MRR Doppler Velocity ~1 m/s
- MRR reflectivity < 15 dBZe

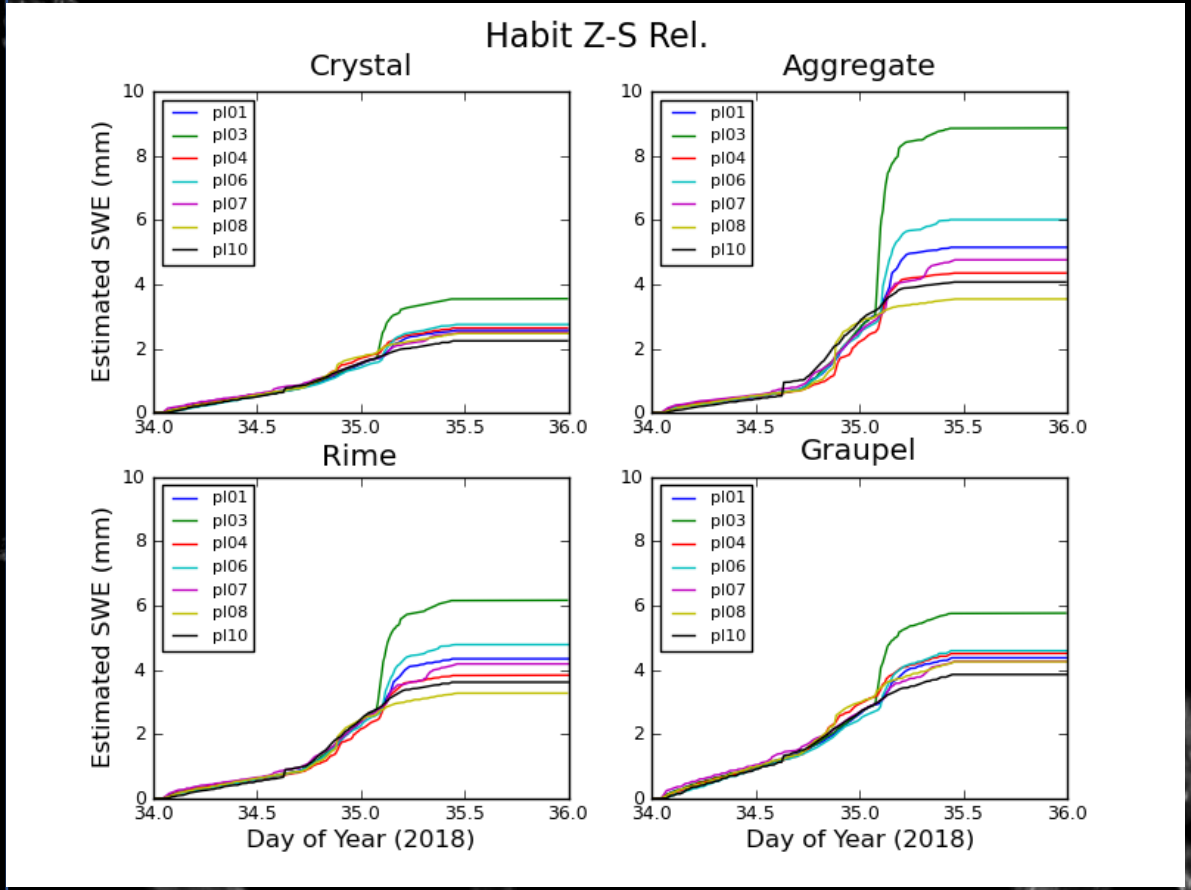


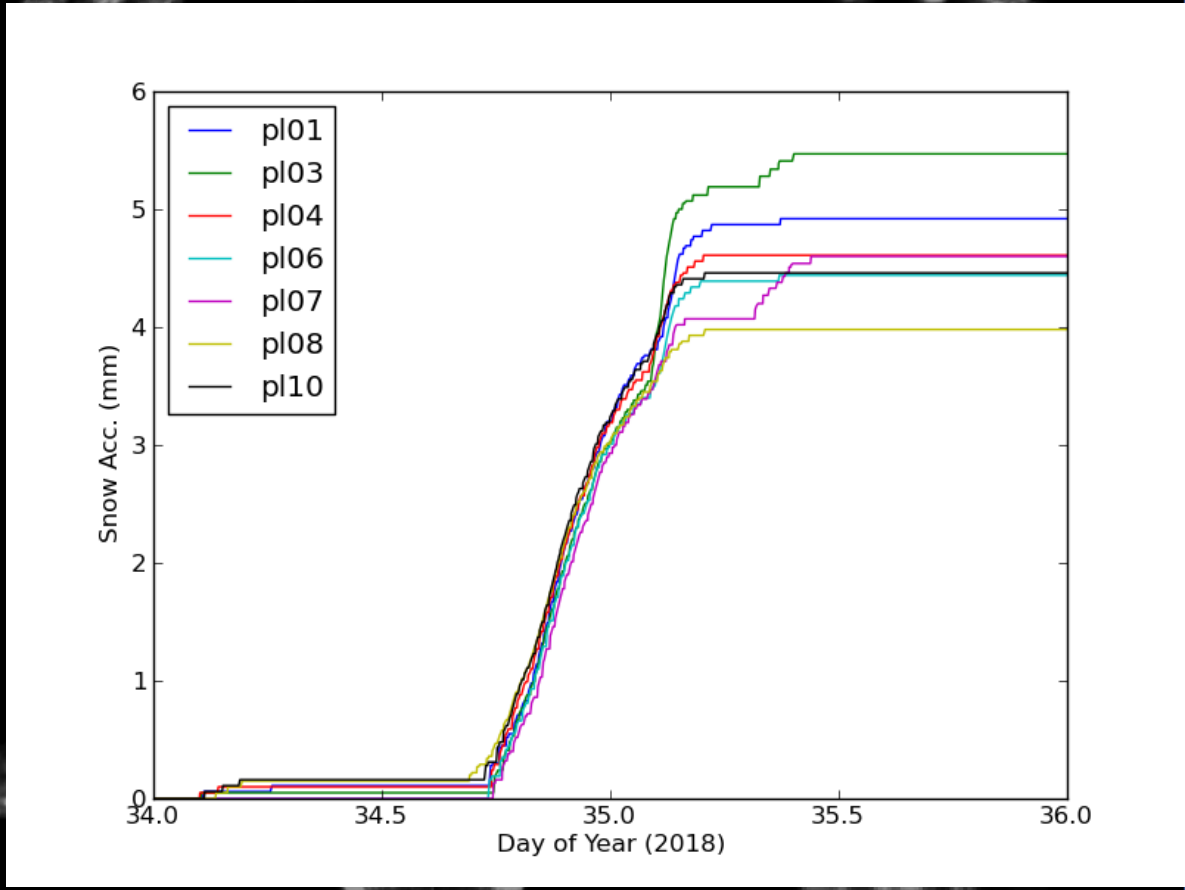
Event 034 – PIP Based Relationships

- Derived from Particle Imaging Package (PIP)
- Provided by Ali Tokay
- BM, HW, KC, MH are different methods for mass calculation
- x = 1.2, 1.3, 1.4, 1.5 and the maximum dimensions as a function of equivalent diameter (Dmax = xDpip)

Z-S	A-coeff ($1.2\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.3\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.4\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.5\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)
BM	33.74	1.19	37.09	1.21	37.80	1.19	45.43	1.20
HW	19.07	1.14	20.64	1.16	20.76	1.15	23.71	1.16
KC	27.83	1.24	28.53	1.22	31.05	1.23	34.67	1.21
MH	38.05	1.22	31.90	1.22	31.30	1.23	28.44	1.22

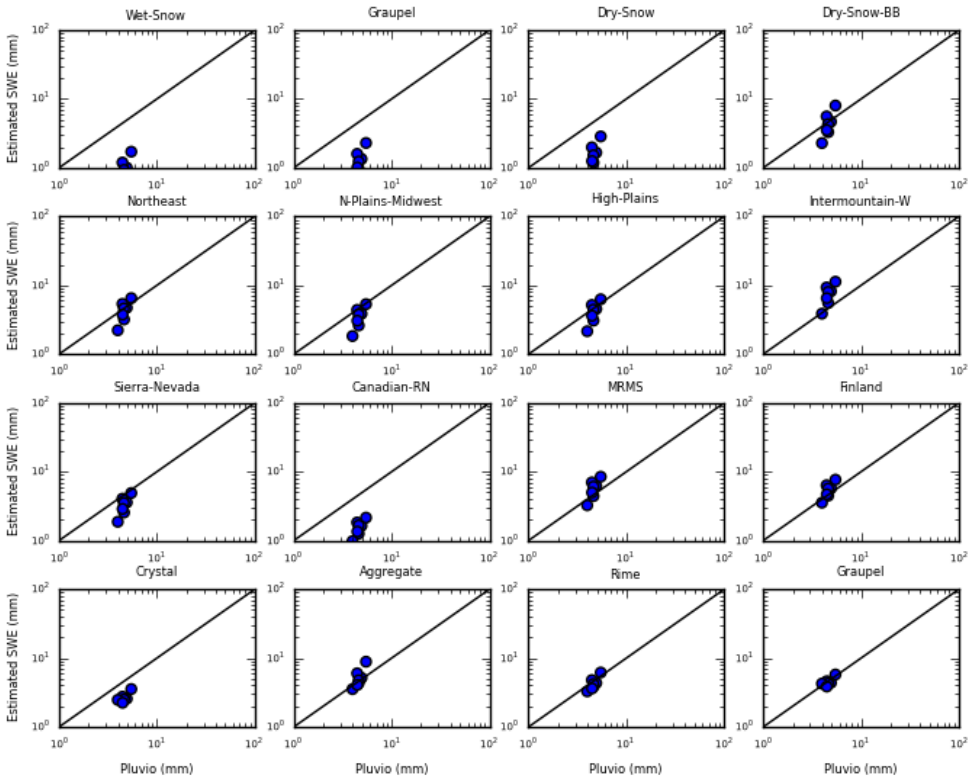
Event 034 – Est. vs Measured



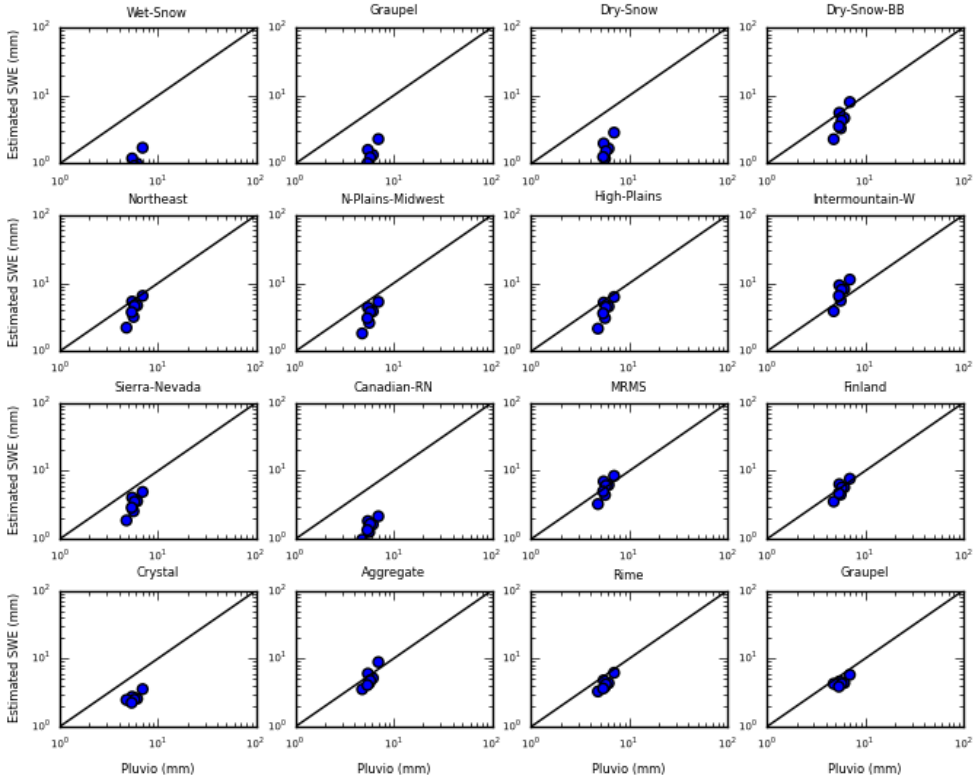


Event 034 – Operational & Habit

Uncorrected

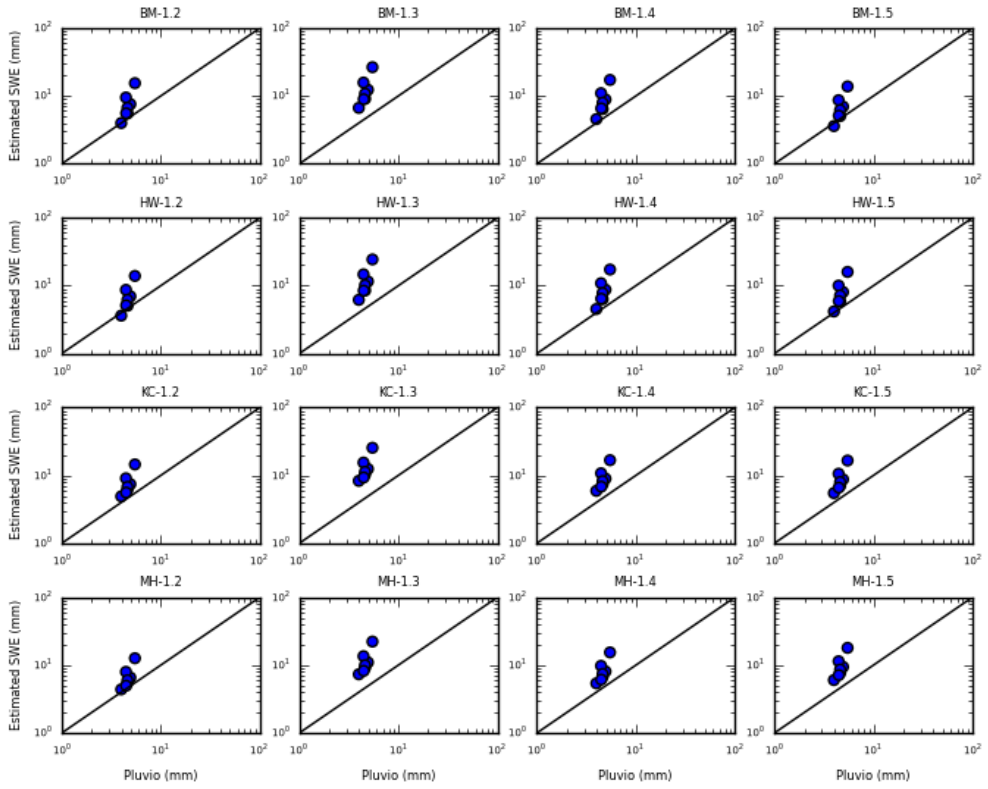


NWS Wind Corrected

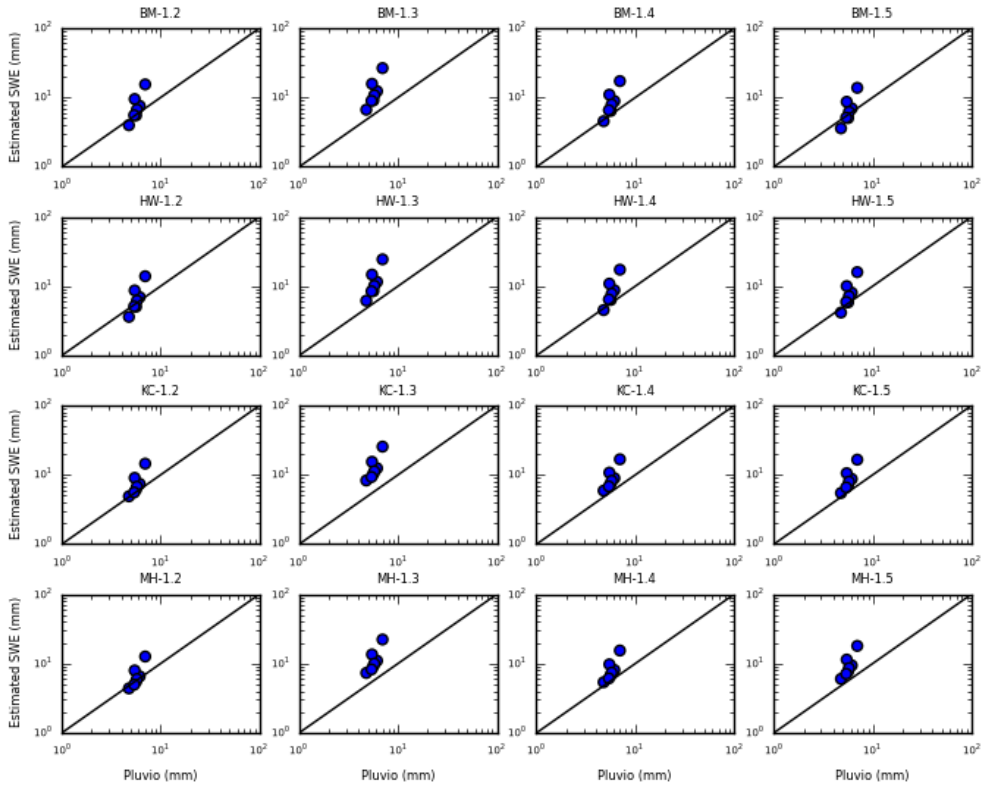


Event 034 - PIP Event Specific

Uncorrected



NWS Wind Corrected



Event 034

- Red-Green represents lowest to highest % absolute bias

Uncorrected

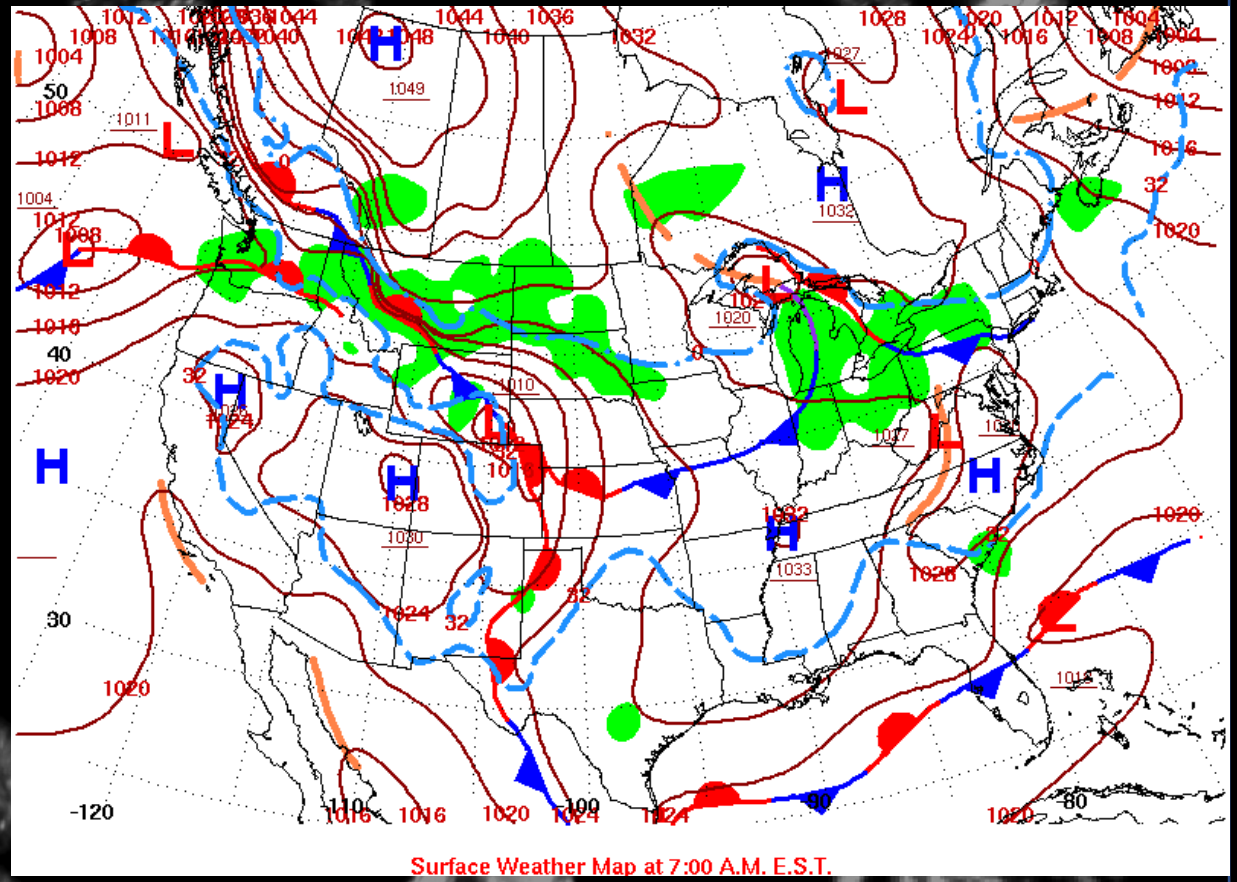
Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	79.12	BM-1.2	66.93
Graupel	72.10	BM-1.3	177.18
Dry-Snow	65.36	BM-1.4	92.39
Dry-Snow-BB	25.21	BM-1.5	54.31
Northeast	18.68	HW-1.2	54.67
N-Plains/Mid-W	23.49	HW-1.3	158.03
High-Plains	19.42	HW-1.4	90.57
Mountain-W	62.96	HW-1.5	75.70
Sierra-Nevada	28.10	KC-1.2	67.45
Canadian	66.53	KC-1.3	185.09
MRMS	29.95	KC-1.4	99.59
Finland	20.93	KC-1.5	93.71
Crystal	42.36	MH-1.2	47.56
Aggregate	19.82	MH-1.3	150.46
Rime	13.36	MH-1.4	81.15
Graupel	7.08	MH-1.5	109.75

NWS Wind Corrected

Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	83.11	BM-1.2	39.59
Graupel	77.44	BM-1.3	124.17
Dry-Snow	71.98	BM-1.4	56.74
Dry-Snow-BB	26.91	BM-1.5	33.11
Northeast	24.37	HW-1.2	33.36
N-Plains/Midwest	38.12	HW-1.3	108.69
High-Plains	27.16	HW-1.4	55.42
Mountain-W	36.32	HW-1.5	45.19
Sierra-Nevada	41.85	KC-1.2	35.43
Canadian	72.93	KC-1.3	130.57
MRMS	16.30	KC-1.4	61.42
Finland	12.89	KC-1.5	56.67
Crystal	53.38	MH-1.2	24.27
Aggregate	20.61	MH-1.3	102.56
Rime	24.70	MH-1.4	46.51
Graupel	21.16	MH-1.5	69.64

Event 362 - Description

- 01/03/2018 – 01/06/2018
- Deep lake effect storm
- Maximum wet bulb temperature: -14 C
- Average wind speed 1.7 m/s
- Habit type: 82% Dendrites, 4.5% Needles, 13.5% Plates
- PIP Maximum particle size < 5 mm
- MRR Doppler Velocity ~1 m/s
- MRR reflectivity < 15 dBZe

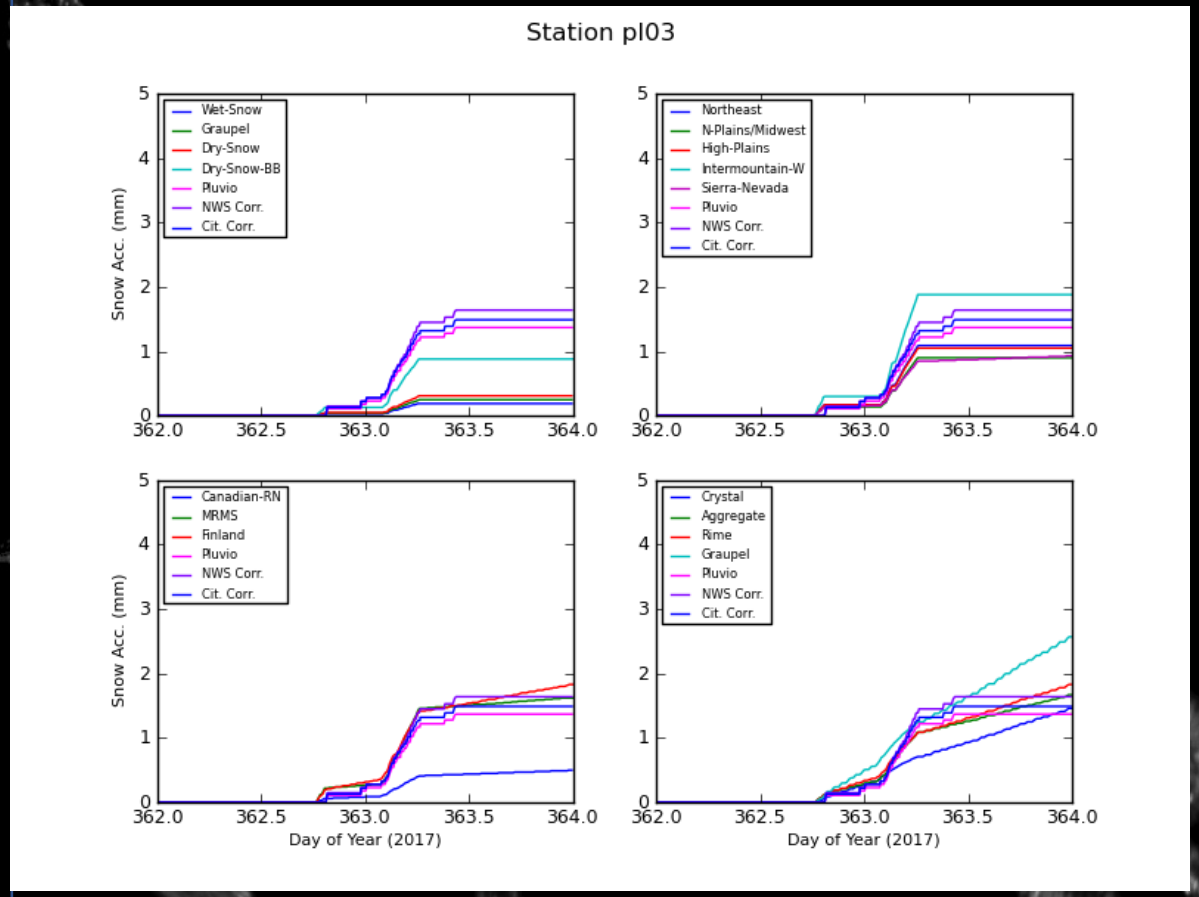


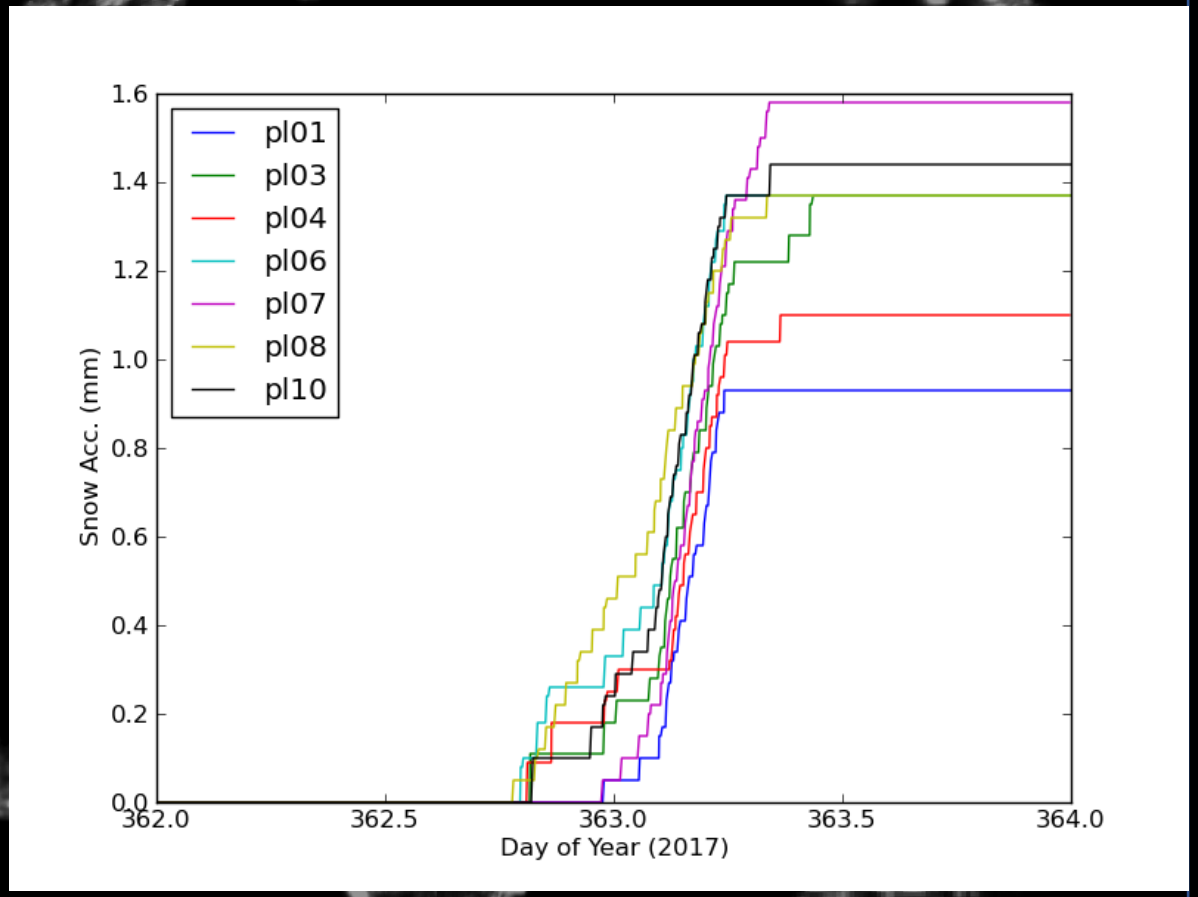
Event 362 – PIP Based Relationships

- Derived from Particle Imaging Package (PIP)
- Provided by Ali Tokay
- BM, HW, KC, MH are different methods for mass calculation
- x = 1.2, 1.3, 1.4, 1.5 and the maximum dimensions as a function of equivalent diameter (Dmax = xDpip)

Z-S	A-coeff ($1.2\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.3\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.4\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)	A-coeff ($1.5\ D_{PIP}$)	B-exp ($1.2D_{PIP}$)
BM	26.02	1.15	29.29	1.17	29.27	1.15	35.57	1.15
HW	15.59	1.12	16.09	1.13	16.46	1.13	18.66	1.12
KC	21.94	1.20	23.35	1.19	24.27	1.19	27.24	1.16
MH	23.31	1.20	24.66	1.20	26.38	1.20	30.25	1.18

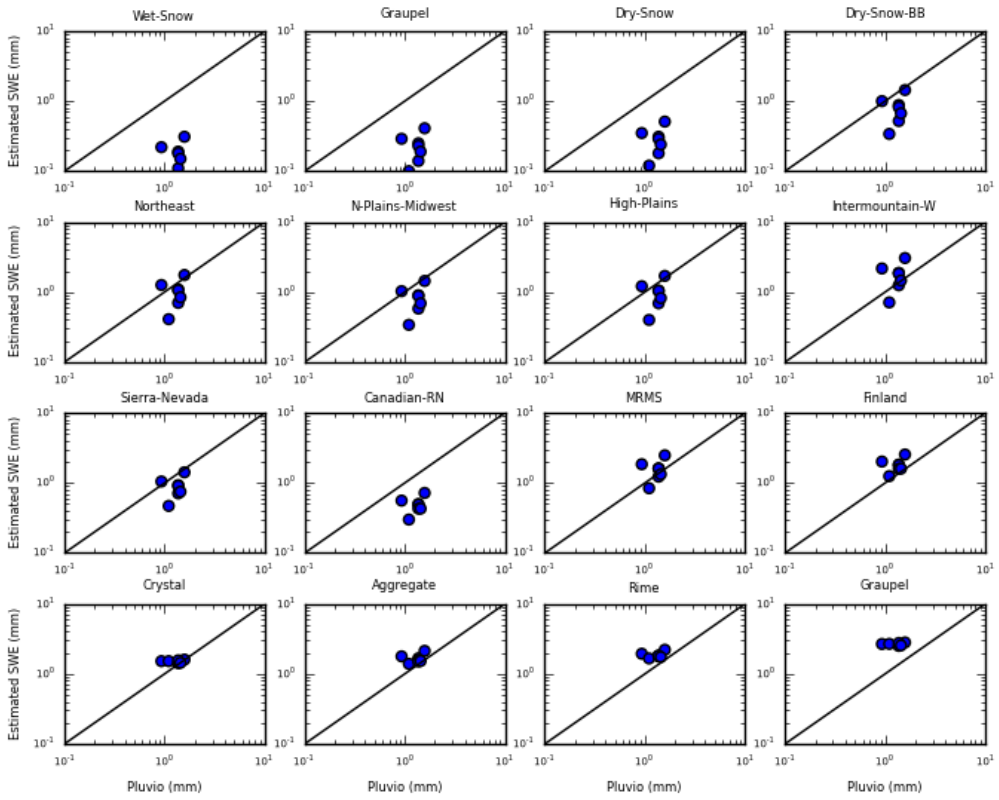
Event 362 – Est. vs Measured



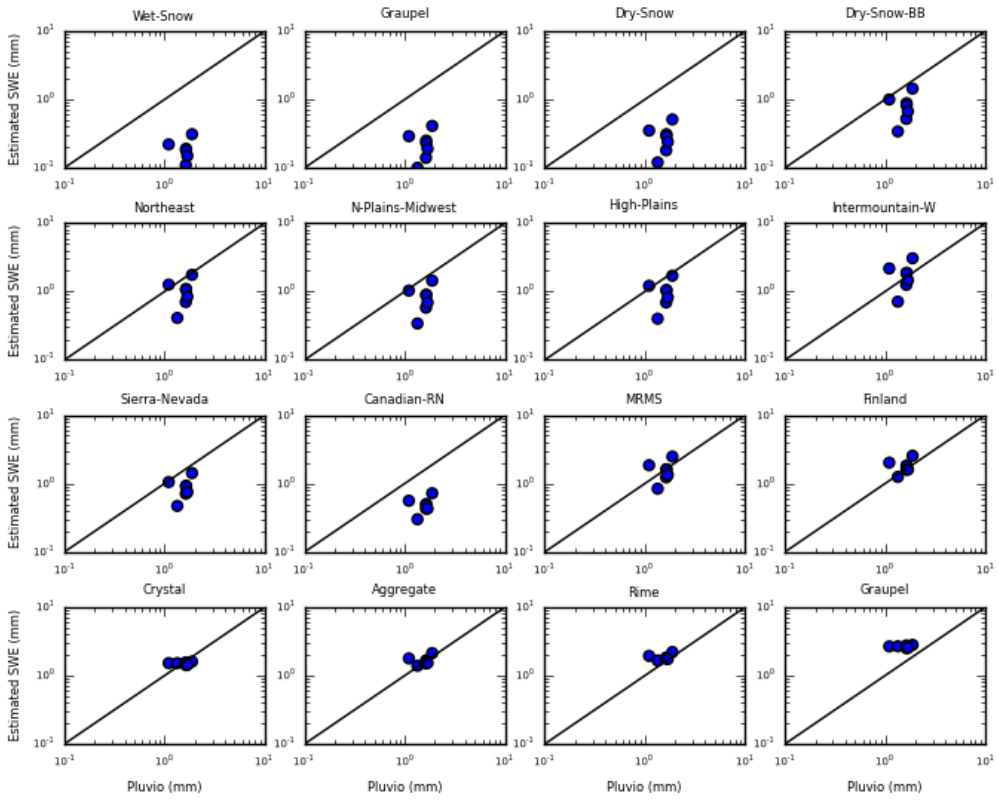


Event 362 – Operational & Habit

Uncorrected

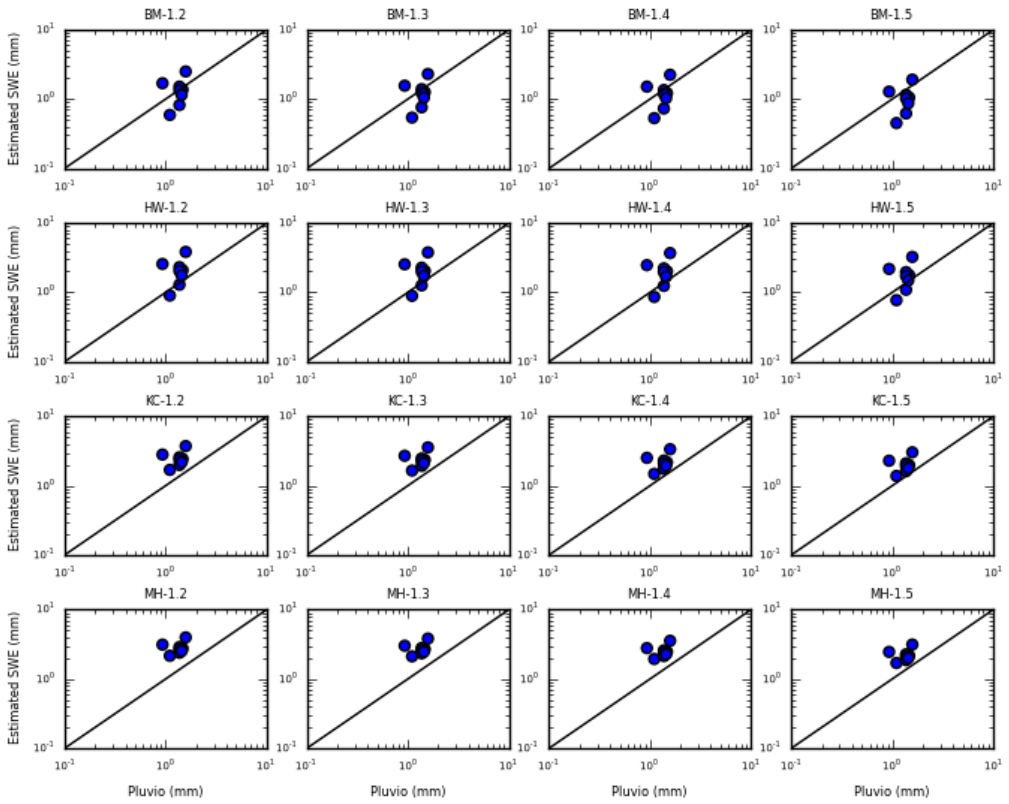


NWS Wind Corrected

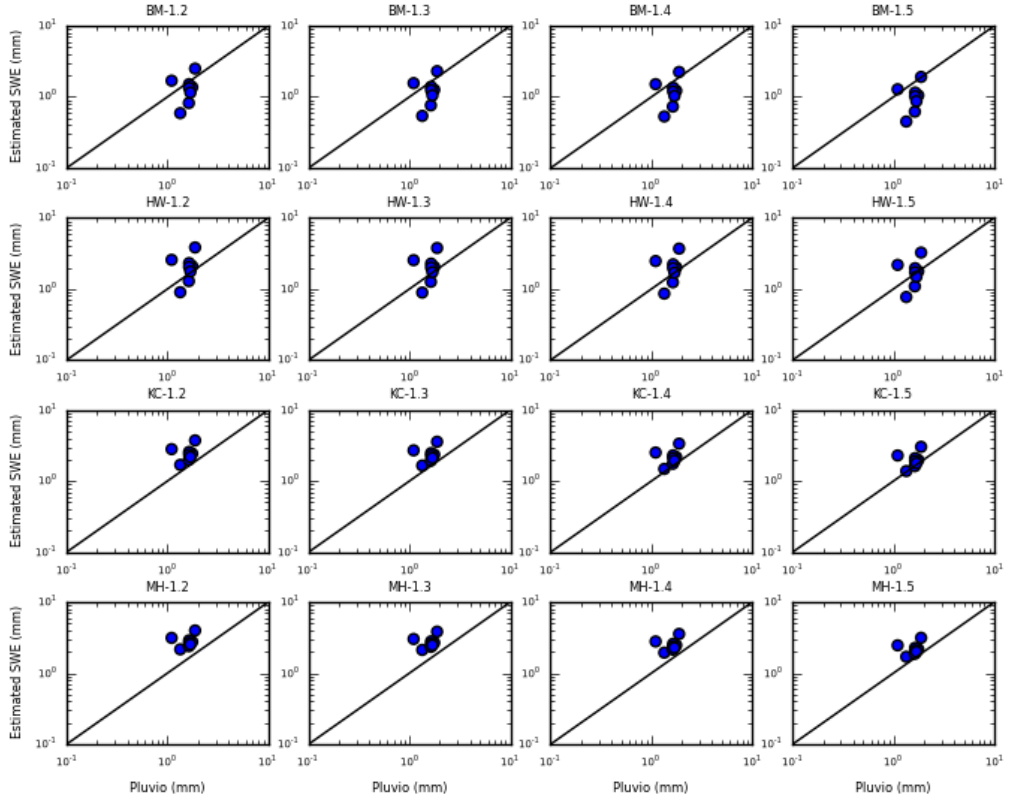


Event 362 - PIP Event Specific

Uncorrected



NWS Wind Corrected



Event 362

- Red-Green represents lowest to highest % absolute bias

Uncorrected

Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	86.57	BM-1.2	31.04
Graupel	82.42	BM-1.3	30.76
Dry-Snow	78.16	BM-1.4	31.13
Dry-Snow-BB	39.62	BM-1.5	34.24
Northeast	33.29	HW-1.2	63.31
N-Plains/Mid-W	38.20	HW-1.3	61.14
High-Plains	33.29	HW-1.4	58.79
Mountain-W	46.17	HW-1.5	45.34
Sierra-Nevada	34.49	KC-1.2	85.79
Canadian	62.55	KC-1.3	79.20
MRMS	30.67	KC-1.4	65.75
Finland	37.99	KC-1.5	51.45
Crystal	14.84	MH-1.2	111.75
Aggregate	26.41	MH-1.3	105.45
Rime	41.59	MH-1.4	89.27
Graupel	102.51	MH-1.5	66.50

NWS Wind Corrected

Op. Rel	% Abs. Bias	PIP Rel	% Abs. Bias
Wet-Snow	88.73	BM-1.2	32.57
Graupel	85.25	BM-1.3	34.22
Dry-Snow	81.68	BM-1.4	34.85
Dry-Snow-BB	48.07	BM-1.5	37.46
Northeast	37.82	HW-1.2	44.79
N-Plains/Midwest	46.33	HW-1.3	42.98
High-Plains	38.73	HW-1.4	41.00
Mountain-W	35.98	HW-1.5	32.88
Sierra-Nevada	42.85	KC-1.2	55.75
Canadian	68.58	KC-1.3	50.23
MRMS	24.45	KC-1.4	38.95
Finland	19.78	KC-1.5	27.12
Crystal	14.65	MH-1.2	77.52
Aggregate	12.45	MH-1.3	72.23
Rime	18.77	MH-1.4	58.67
Graupel	69.87	MH-1.5	39.58

Conclusion

After wind correction, the event-based relationships generally exhibited lower % absolute bias

Based on the percent absolute bias calculated from wind corrected gauge measurements, the following was found:

- Bohm Method derived relationships are typically the event-based relationship with the lowest % absolute bias for all 4 events.
- Regarding regional relationships, MRMS and Finland performed best, while the Canadian relationship consistently overestimated
- Among the NWS phase-based relationships, Dry-Snow-BB was the best
- For habit-based relationships, crystal and aggregate were the best

Future Work:

- Partner with Tim Garrett (University of Utah) and Ali Tokay
- Use Multi-Angle Snowflake Camera (MASC) and Differential Emissivity Imaging Disdrometer (DEID)
- Will analyze habit-based snowfall estimate relationships using in-situ measurements of snow habit, fall velocity, and density

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