RADAR QPE AND MACHINE LEARNING

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INTRODUCTION

Phenom / Year	2014	2015	2016	2017	2018
Lightning	26 $30	27 $16	38 $23	16 $16	20 $16
Tornado	47 $636	36 $320	18 $183	35 $649	10 $672
Wind	31 $376	41 $268	20 $149	30 $266	24 $156
Hail	0 $1,711	0 $719	0 $3,536	0 $1,782	0 $810
Temp	63 $18	98 $3	125 $0.37	133 $954	140 $150
Flooding	**97** **$2,816**	**246** **$2,185**	**185** **$14,214**	**232** **$84,397**	**164** **$19,268**
Winter	42 $86	28 $589	30 $33	14 $309	10 $82
Fire	2 $325	7 $23	4 $184	20 $157	98 $19,109

Fatalities

Cost (in millions)

Among natural hazards, weather events related to flooding and extreme precipitation typically result in the costliest expenses, both in terms of property and life.

Source: NWS & NCDC

QUANTIFYING PRECIPITATION WITH MACHINE LEARNING

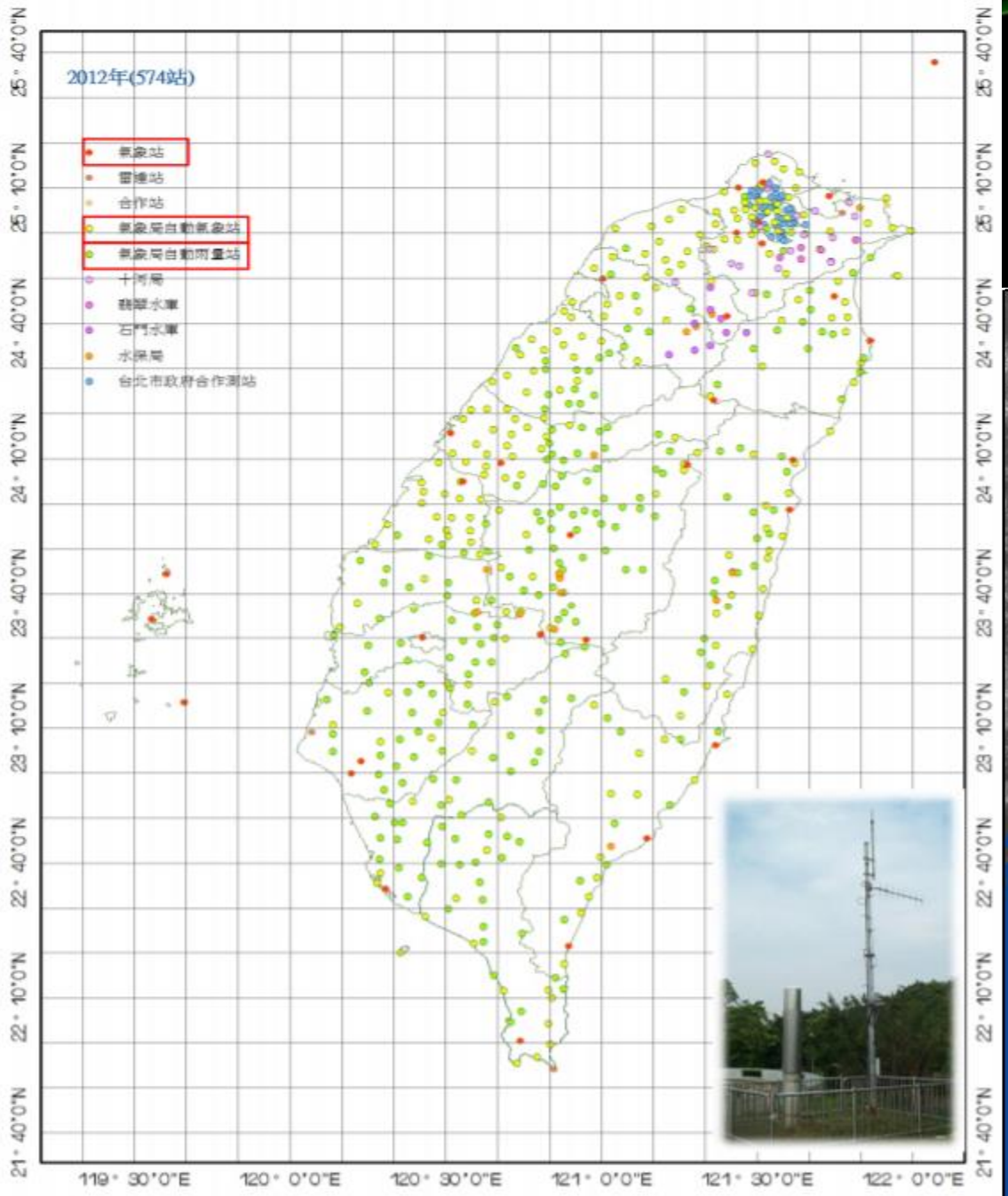
- Within the Multi-Radar Multi-Sensor (MRMS) system, 1-km products are produced every 2-min, providing for some of the highest resolution of blended radar, model, gauge, lightning, and satellite data available.

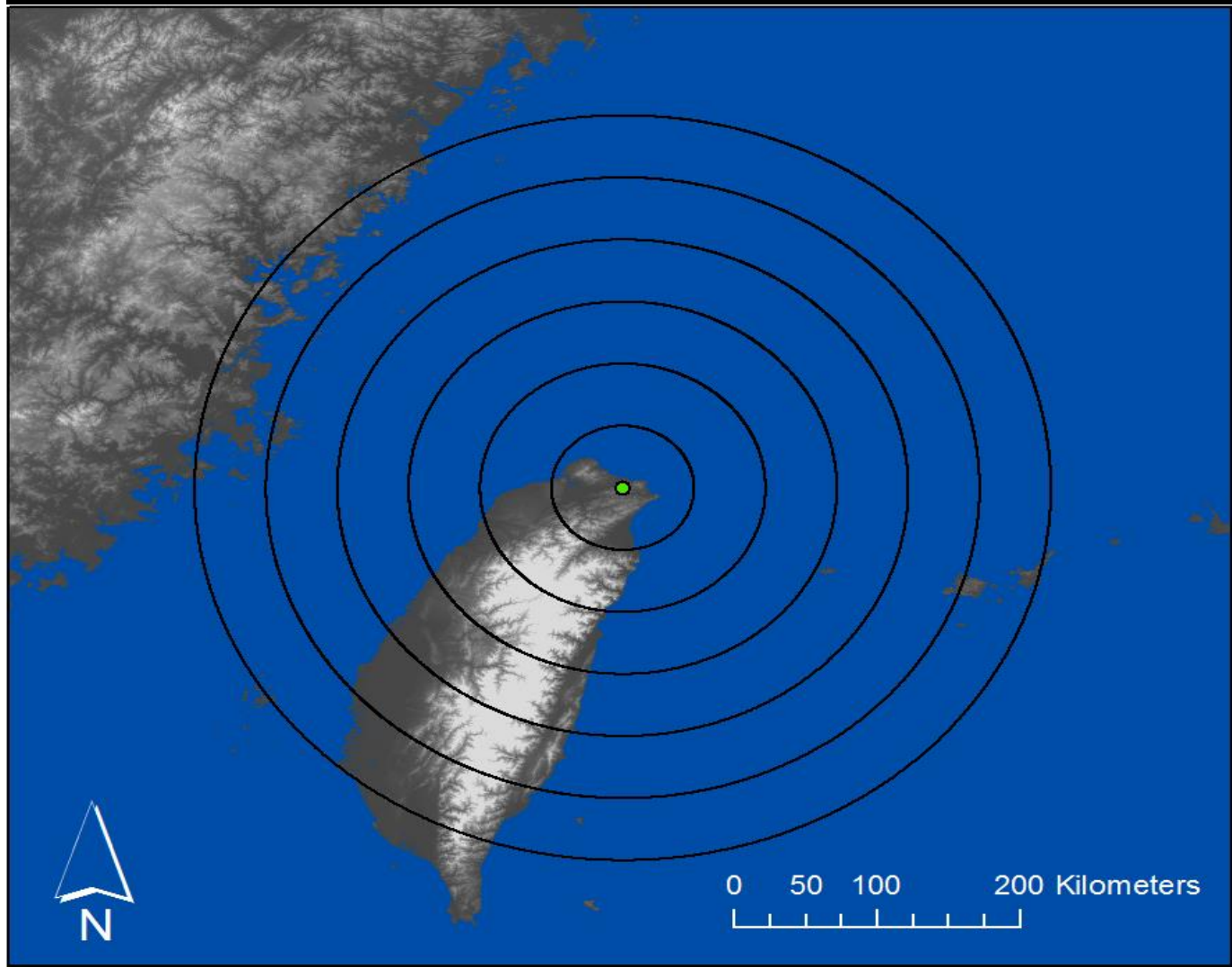
- Nearly 1 TB of products are produced every day over domains such as CONUS, Hawaii, Alaska, Canada, etc.

- Products are validated against independent hourly and daily gauge networks, which can exceed 15,000 gauges / hour

- Could data mining and implementing ML / AI produce comparable results than physically-based Quantitative Precipitation Estimates (QPEs)?
  - Single radar input
  - Mosaicked input

DOMAIN: RCWF

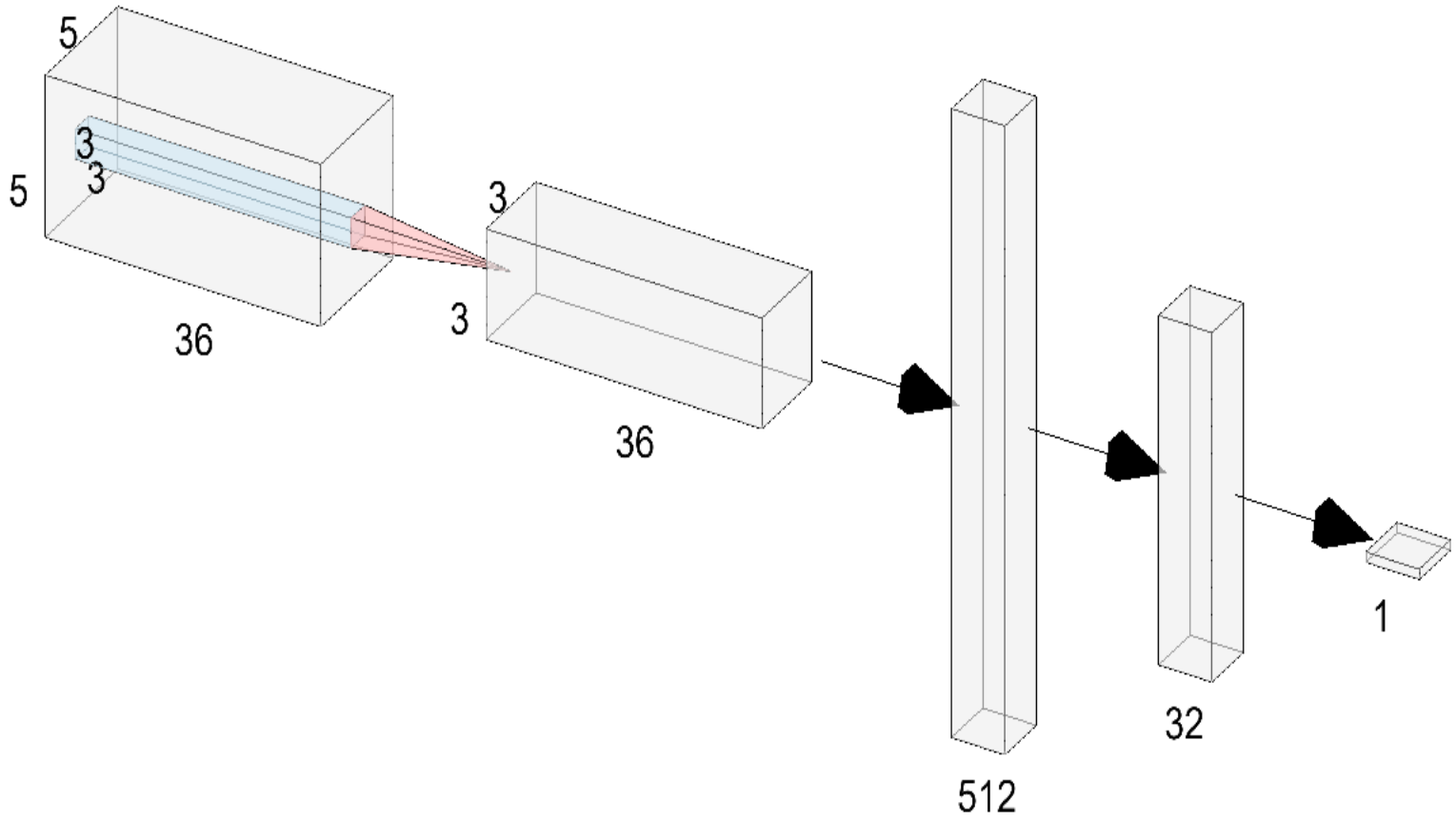

2012年(574站)
氣象站
雷達站
合作站
氣象局自動氣象站
氣象局自動雨量站
十河局
翡翠水庫
石門水庫
水保局
台北市政府合作測站
25° 40'0"N
25° 10'0"N
24° 40'0"N
24° 10'0"N
23° 40'0"N
23° 10'0"N
22° 40'0"N
22° 10'0"N
21° 40'0"N
119° 30'0"E
120° 0'0"E
120° 30'0"E
121° 0'0"E
121° 30'0"E
122° 0'0"E


N
0 50 100 200 Kilometers

SETTING UP THE DATA
RADAR AND GAUGE DATA

- Radar fields were extracted from 5 x 5 1-km Cartesian grids centered on each gauge (ground truth).
  - Reflectivity, ZDR, KDP, and RhoHV = input variables
  - 267 gauges within 250-km radius of RCWF domain.
- Gauge values: hourly accumulation.
- Gauge – Radar matching.
  - Find number of single radar scans within previous hour (~ 10 or 11 usually for RCWF) and accumulate radar moments within previous hour.
- Total number of days = 18.
  - 18 days $* \frac{6\ x10-\min\ obs}{1\ hr} * \frac{24\ hr}{day} * 267\ gauges\ * 5\ * 5 \sim 17{,}300{,}000\ observations$

CNN MODEL ARCHITECTURE



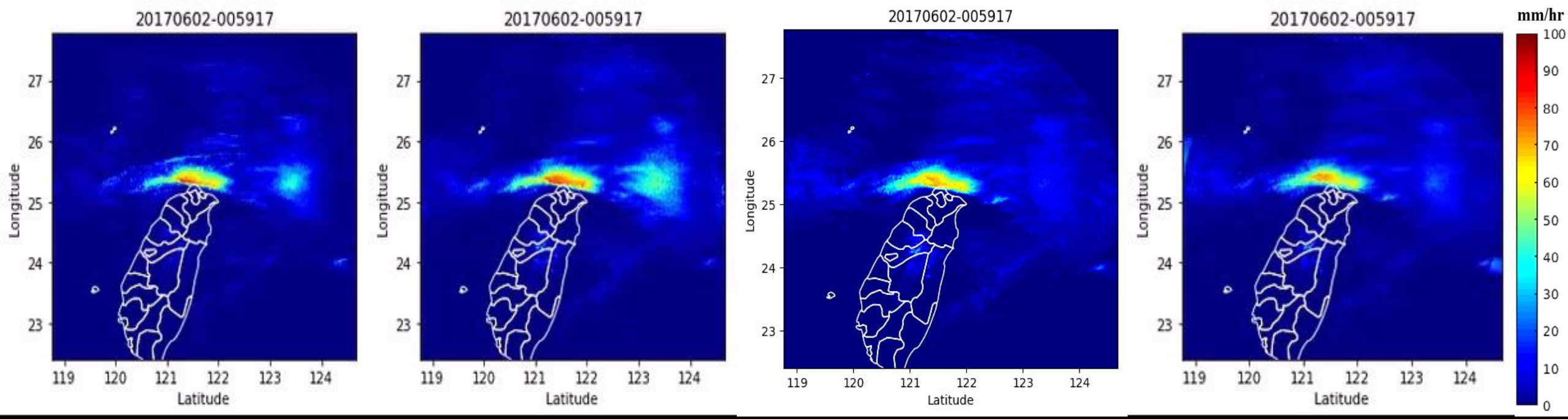
1 convolution-pooling layer
64 convolution channels
Leaky-RelU activator

Dropout = 50%

Optimizer = adam
Loss = MAE

3 dense layers

150 epochs
Batch size = 1000
~5 mins per simulation

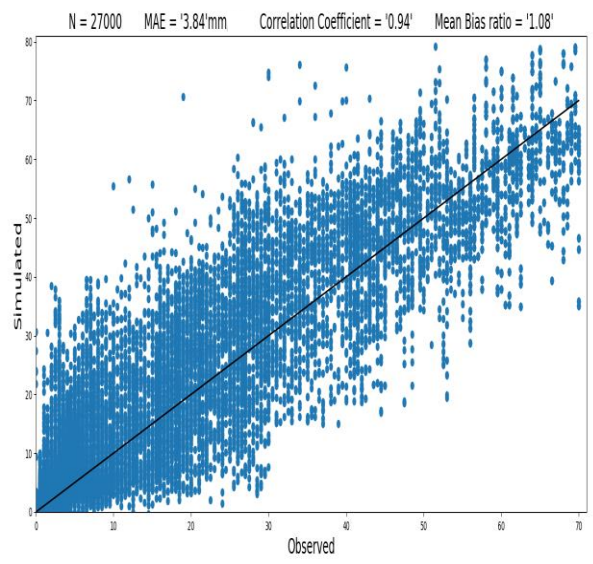


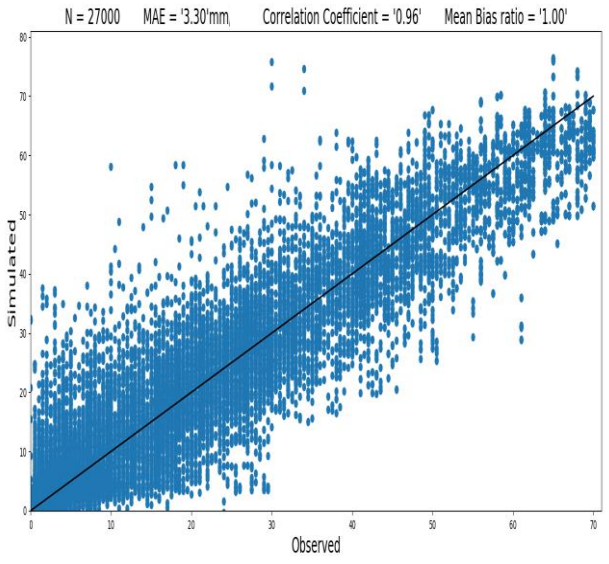
Z

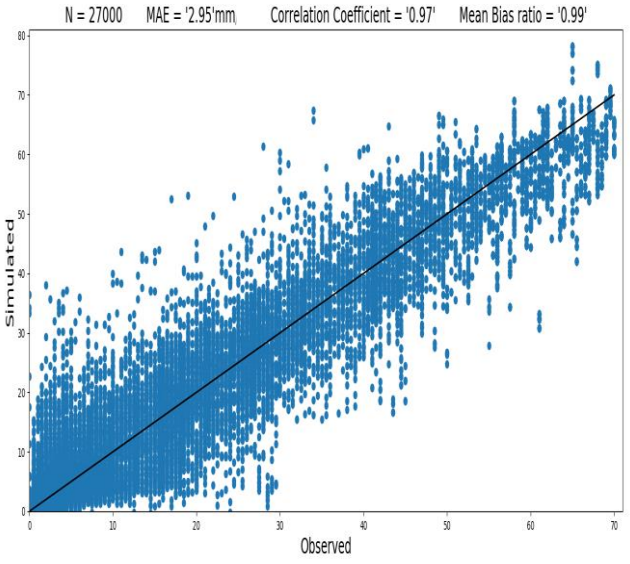
Z + ZDR

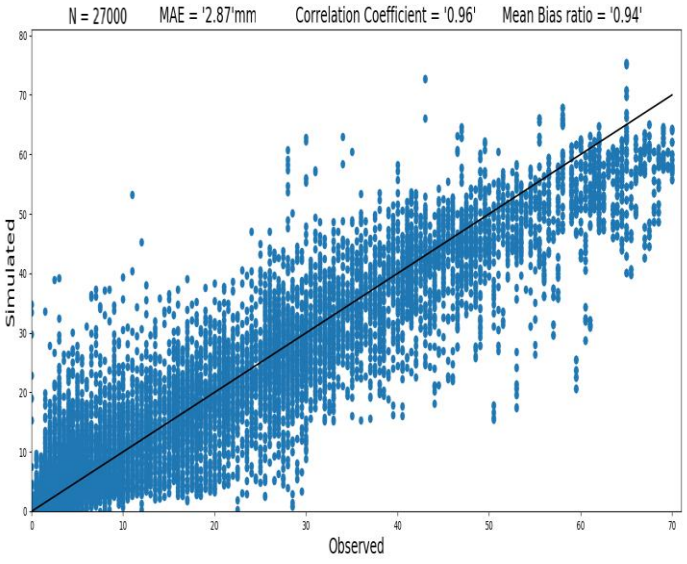
Z + ZDR
+ KDP

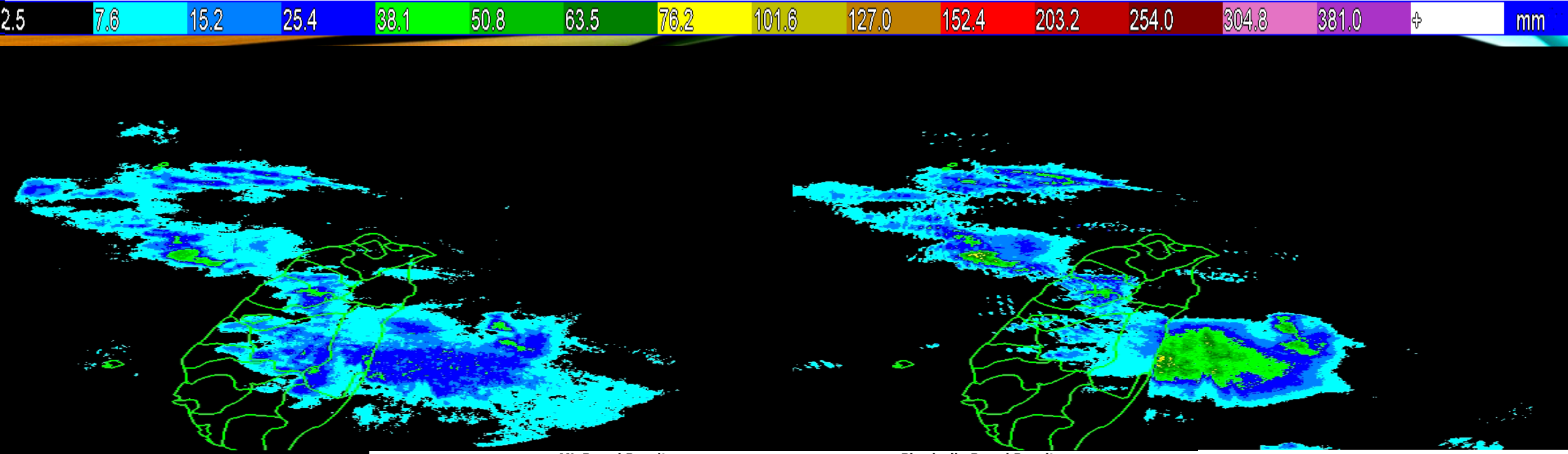
Z + ZDR
+ KDP + RHO

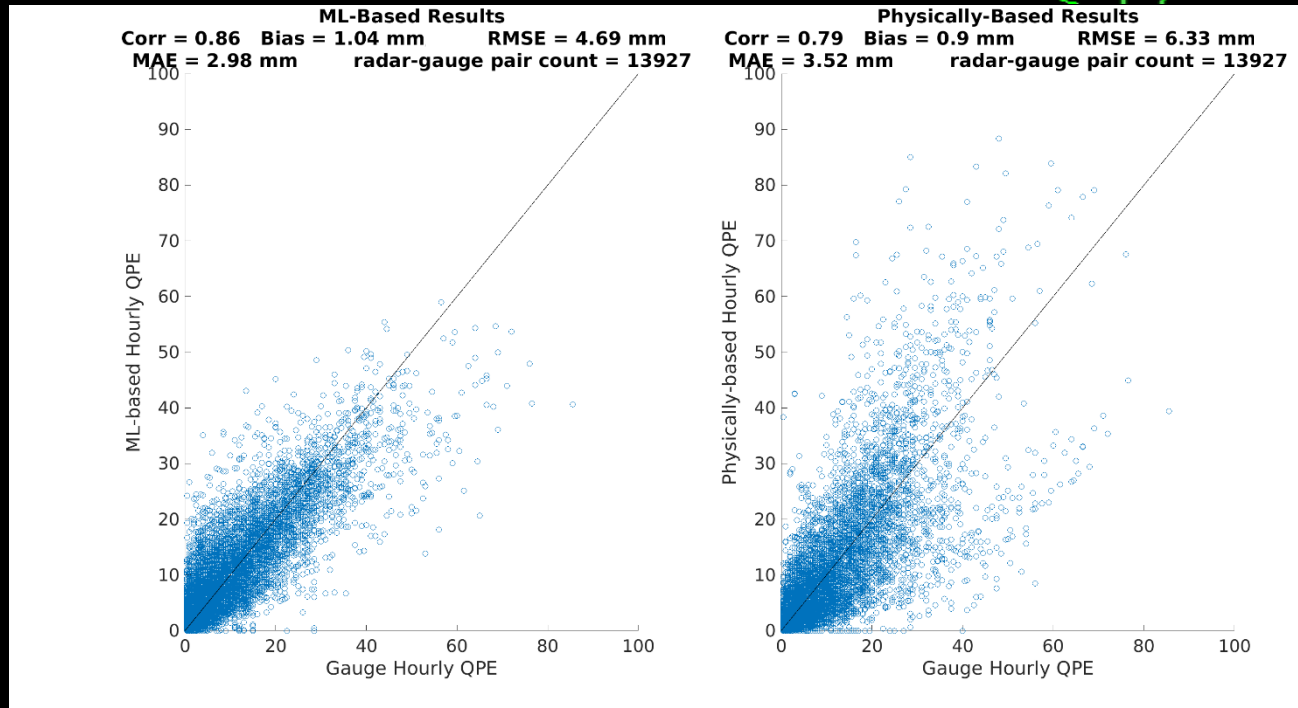












20170603-010948

CONUS CNN MODEL AND RESULTS

- Similar setup for CONUS compared to Taiwan, but with more variables

- Trained and simulations over the West coast USA
  - 13 mosaicked MRMS input variables
  - 2 months training / validation data

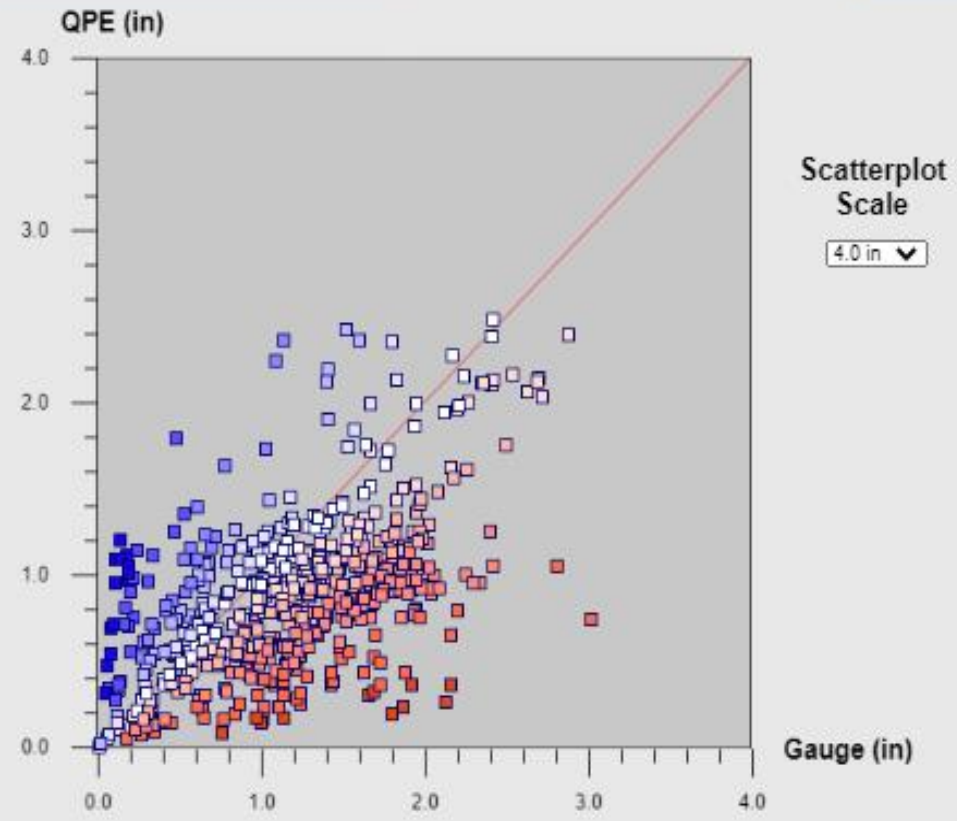
- Trained and simulations over Hawaii
  - 27 mosaicked MRMS input variables
  - 3 months training / validation data

- 24 hour accumulations
  - 24 x 1 hour accumulations

Gauge vs QPE Comparison

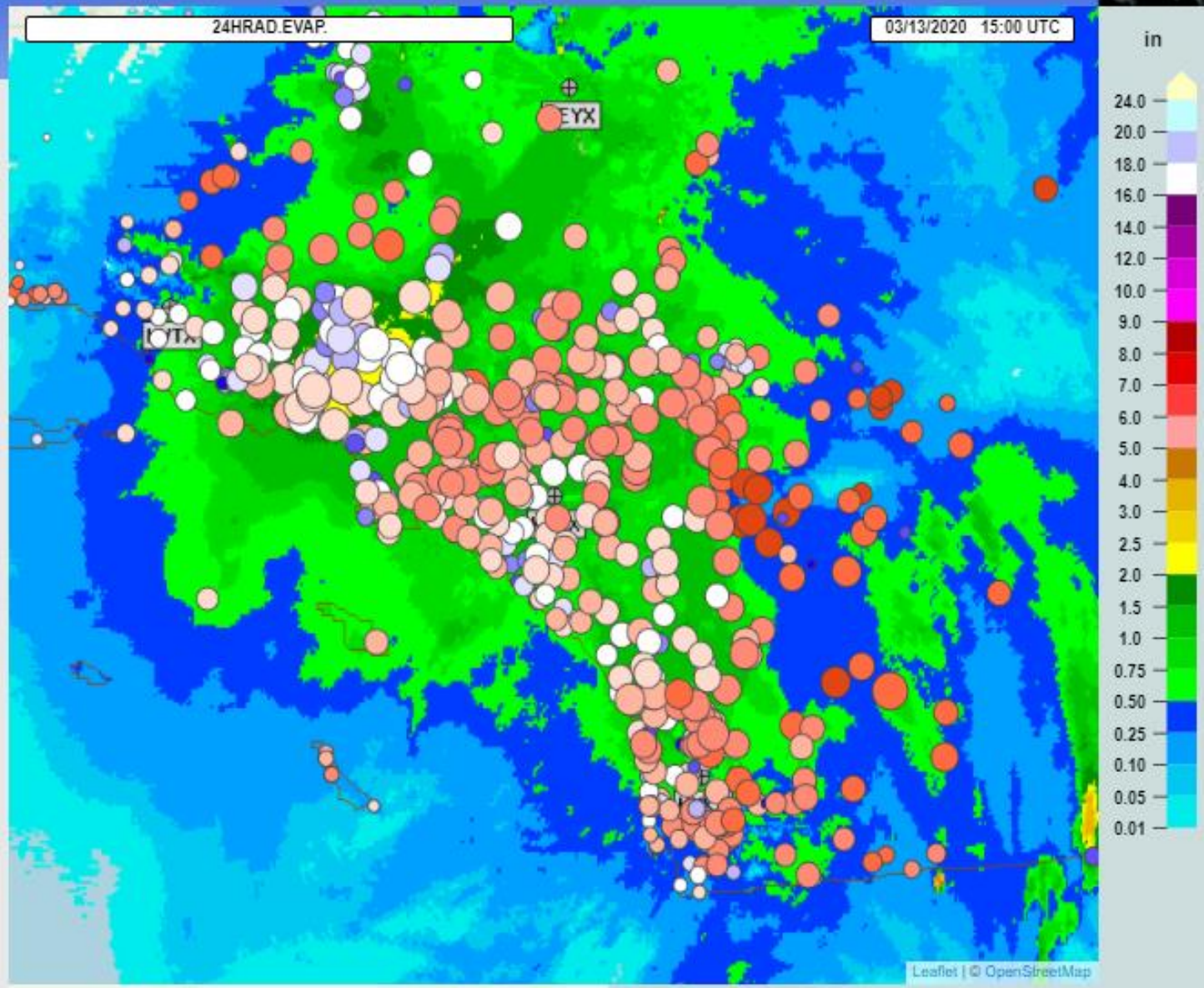
METOP Analysis Tools

General | Gauge Filtering | Scatterplot & Statistics | Time Series



Scatterplot Scale: 4.0 in

	Gauges:	QPE:				
Min	0.01	0.01	Mean Bias(G/R):	1.318	G-R Err Std Dev:	0.461
Avg	1.18	0.89	Add Bias (G-R):	160.31	Corr Coeff:	0.567
Max	3.02	2.49	Mean Err (G-R)/N:	0.285	Fract Bias:	0.241
			Mean Abs Error:	0.461	Fract RMSE:	0.496
			RMSE:	0.585	Fract Std Dev:	0.433



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

End Shift: From:

Overlays

Base Map Layer

Inventory History

CA 24HR OP

Gauge vs QPE Comparison

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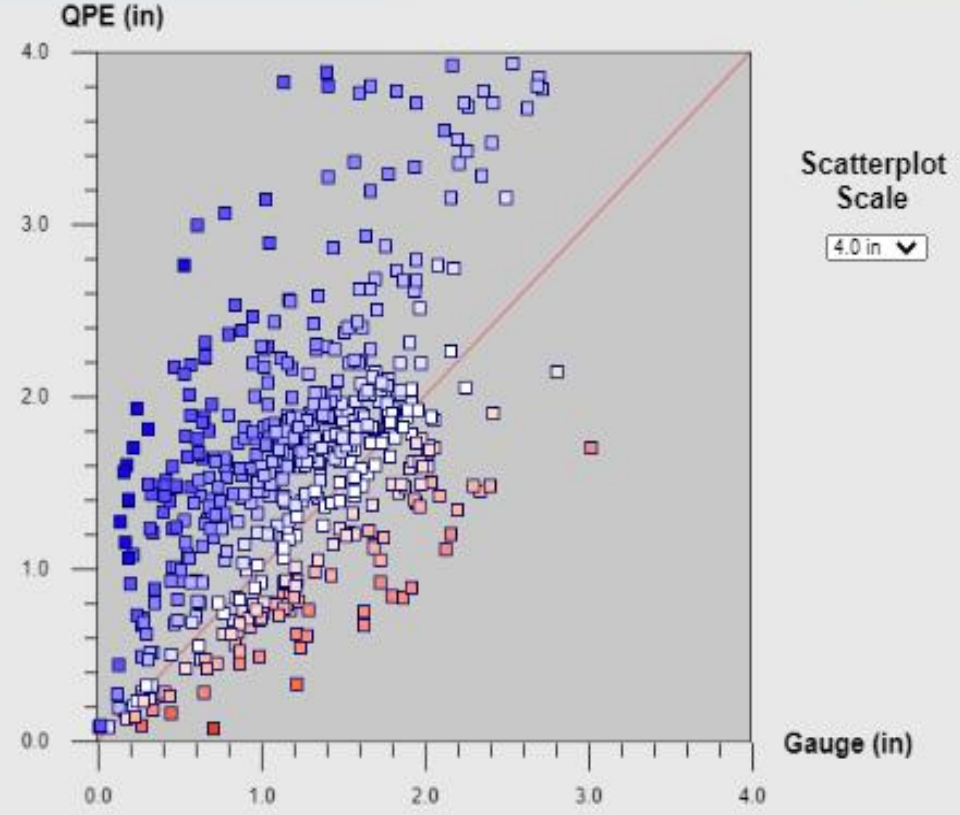
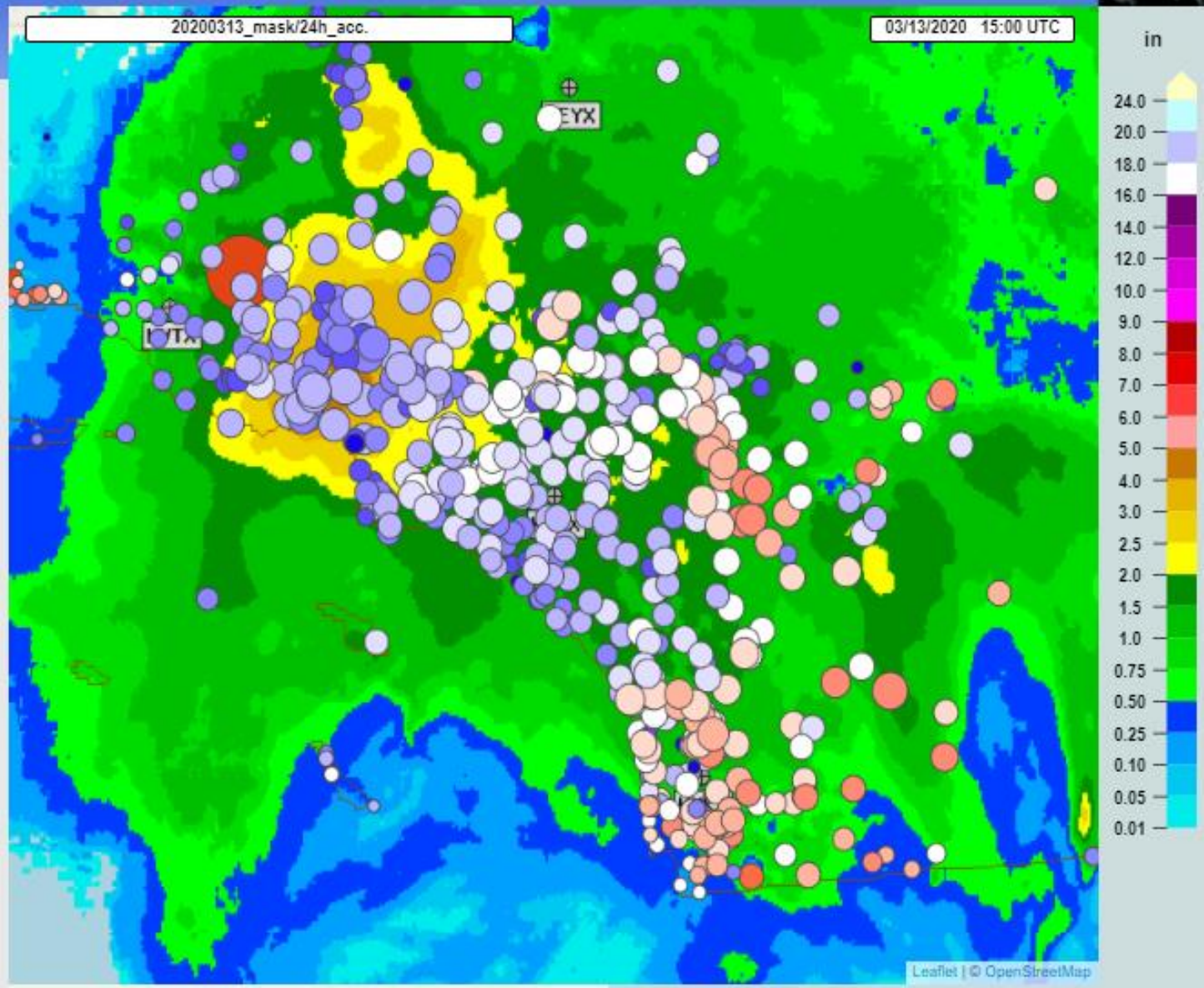


Scatterplot Scale: 4.0 in

	Gauges:	QPE:				
Min	0.01	0.08	Mean Bias(G/R):	0.751	G-R Err Std Dev:	0.616
Avg	1.23	1.64	Add Bias (G-R):	-225.90	Corr Coeff:	0.466
Max	14.16	4.45	Mean Err (G-R)/N:	-0.407	Fract Bias:	-0.331
			Mean Abs Error:	0.616	Fract RMSE:	0.749
			RMSE:	0.922	Fract Std Dev:	0.672



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Inventory History

CA 24HR ML

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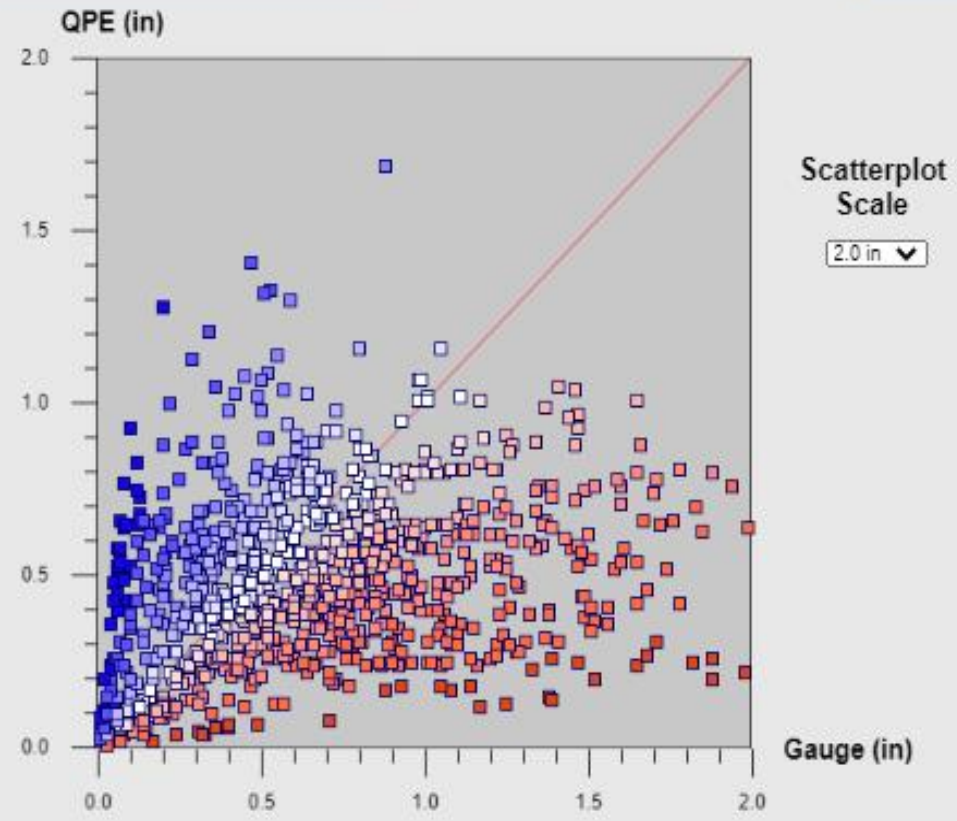
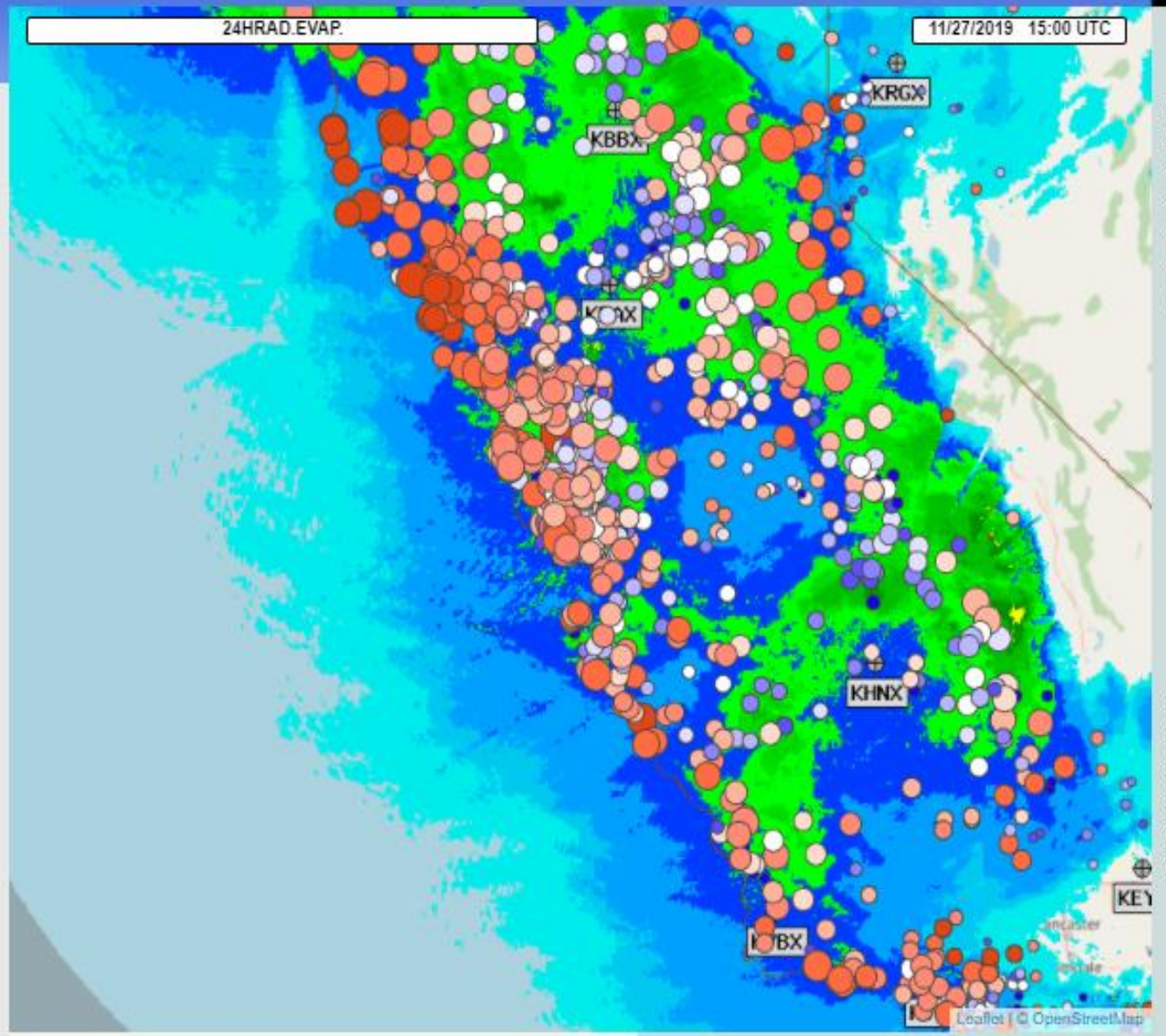
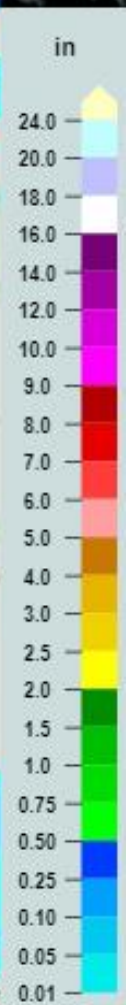


Scatterplot Scale: 2.0 in

	Gauges:	QPE:				
Min	0.01	0.01	Mean Bias(G/R):	1.392	G-R Err Std Dev:	0.345
Avg	0.66	0.47	Add Bias (G-R):	180.06	Corr Coeff:	0.323
Max	4.83	1.69	Mean Err (G-R)/N:	0.186	Fract Bias:	0.282
			Mean Abs Error:	0.345	Fract RMSE:	0.743
			RMSE:	0.491	Fract Std Dev:	0.688

CA 24HR OP





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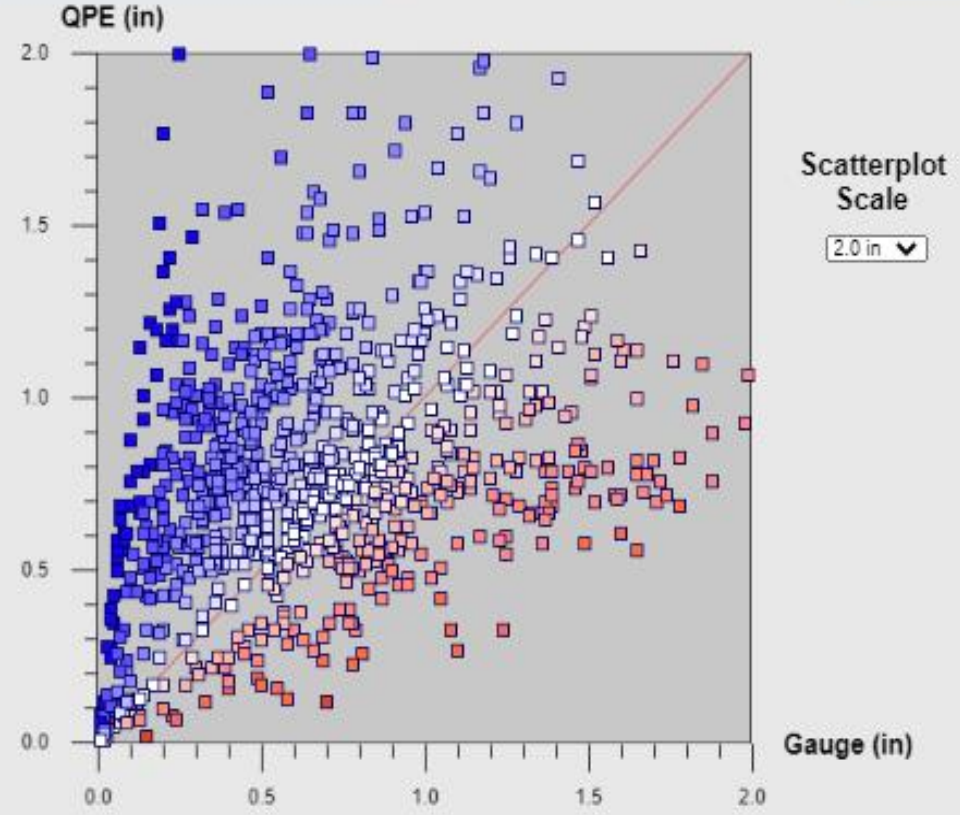
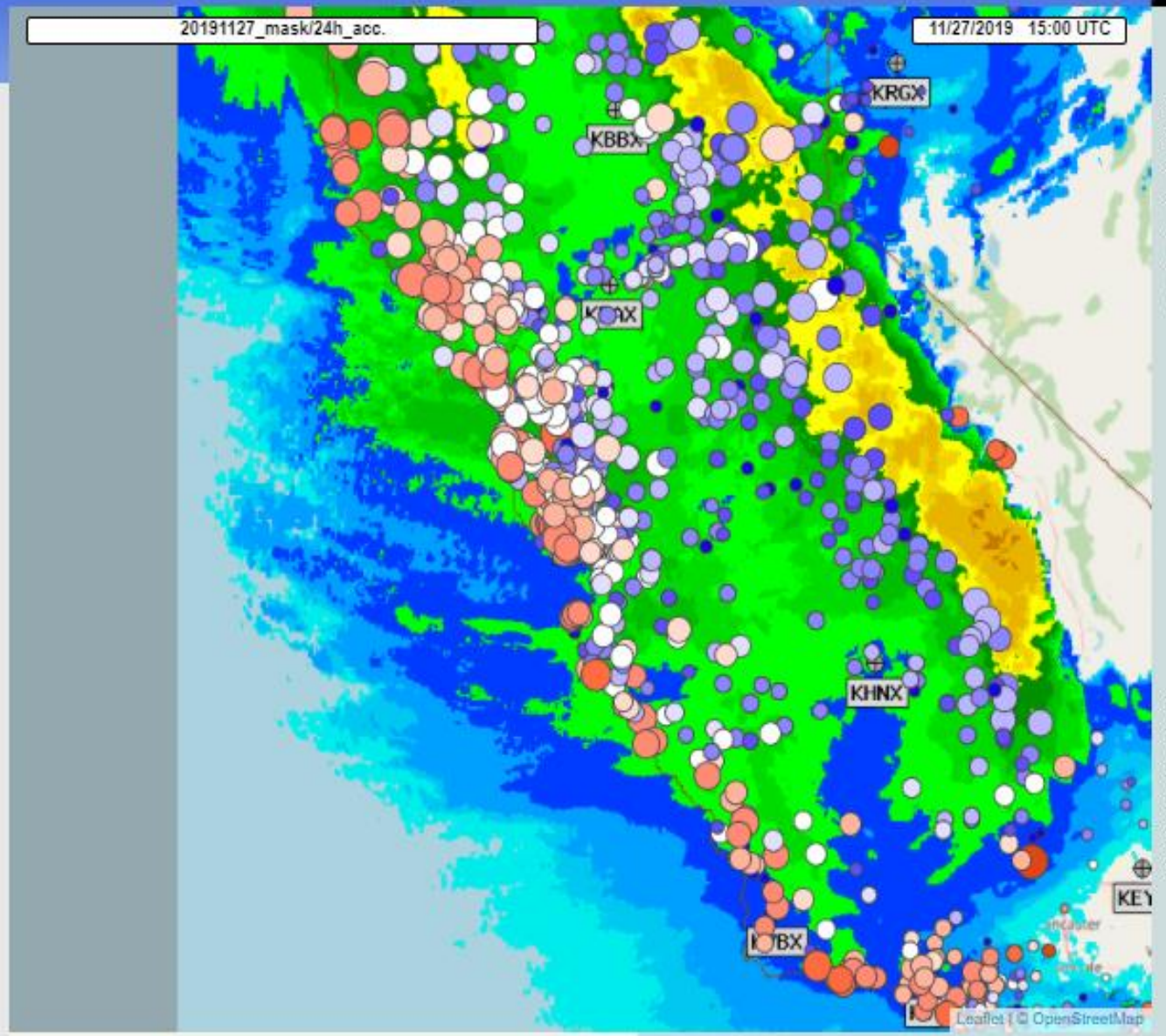


Scatterplot Scale: 2.0 in

	Gauges:	QPE:				
Min	0.01	0.01	Mean Bias(G/R):	0.840	G-R Err Std Dev:	0.377
Avg	0.69	0.82	Add Bias (G-R):	-122.97	Corr Coeff:	0.433
Max	4.83	3.64	Mean Err (G-R)/N:	-0.130	Fract Bias:	-0.190
			Mean Abs Error:	0.377	Fract RMSE:	0.741
			RMSE:	0.509	Fract Std Dev:	0.716

CA 24HR ML



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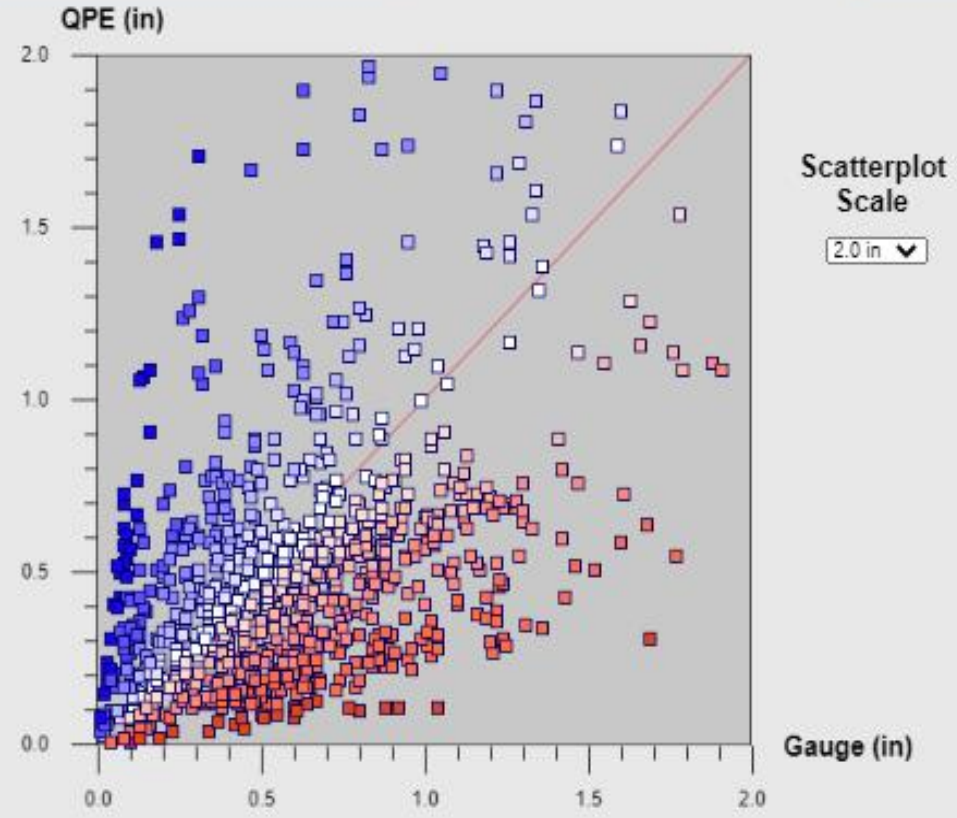
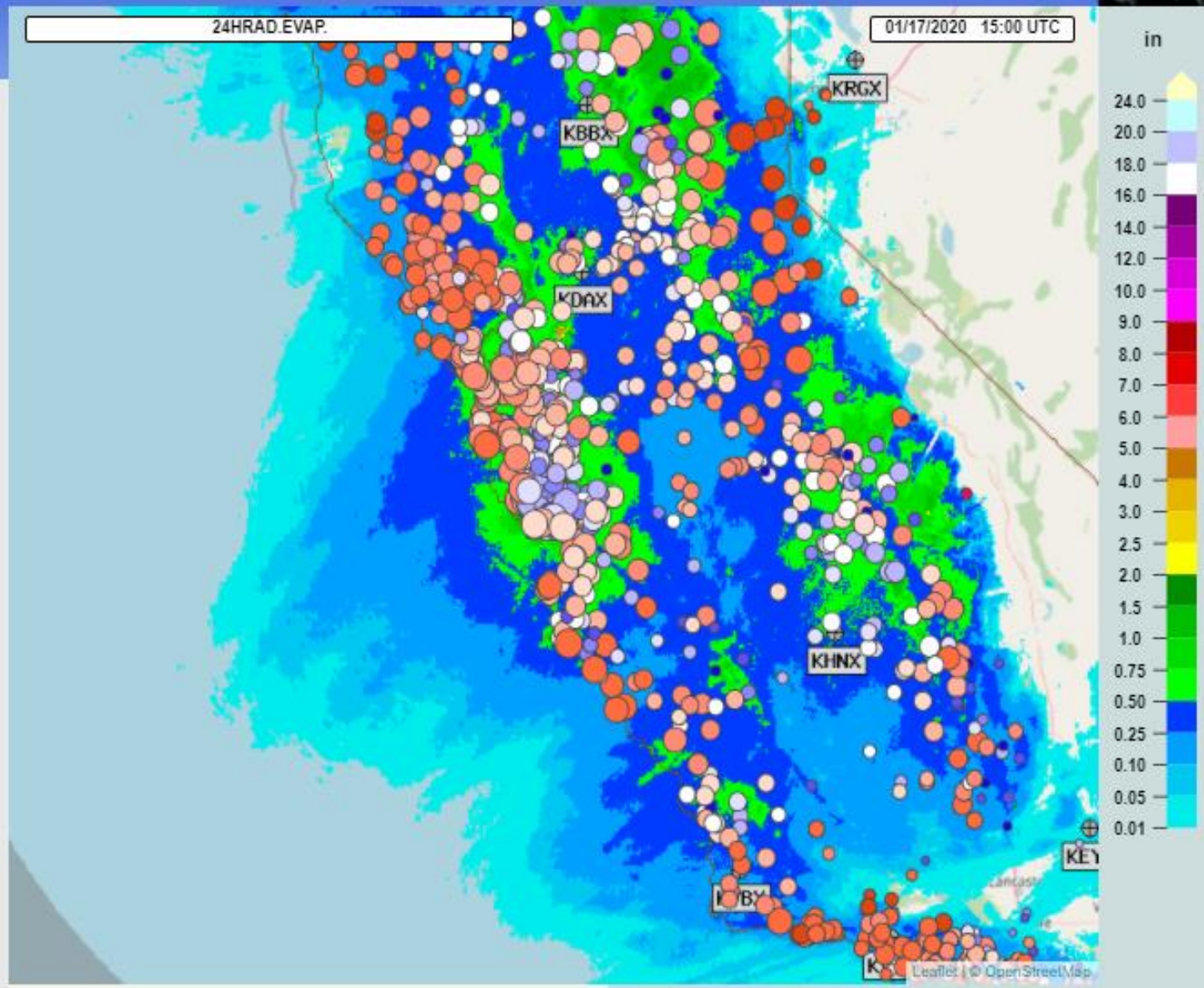


Scatterplot Scale: 2.0 in

	Gauges:	QPE:				
Min	0.01	0.01	Mean Bias(G/R):	1.183	G-R Err Std Dev:	0.285
Avg	0.59	0.49	Add Bias (G-R):	86.91	Corr Coeff:	0.471
Max	2.32	2.21	Mean Err (G-R)/N:	0.091	Fract Bias:	0.155
			Mean Abs Error:	0.285	Fract RMSE:	0.641
			RMSE:	0.375	Fract Std Dev:	0.622

CA 24HR OP



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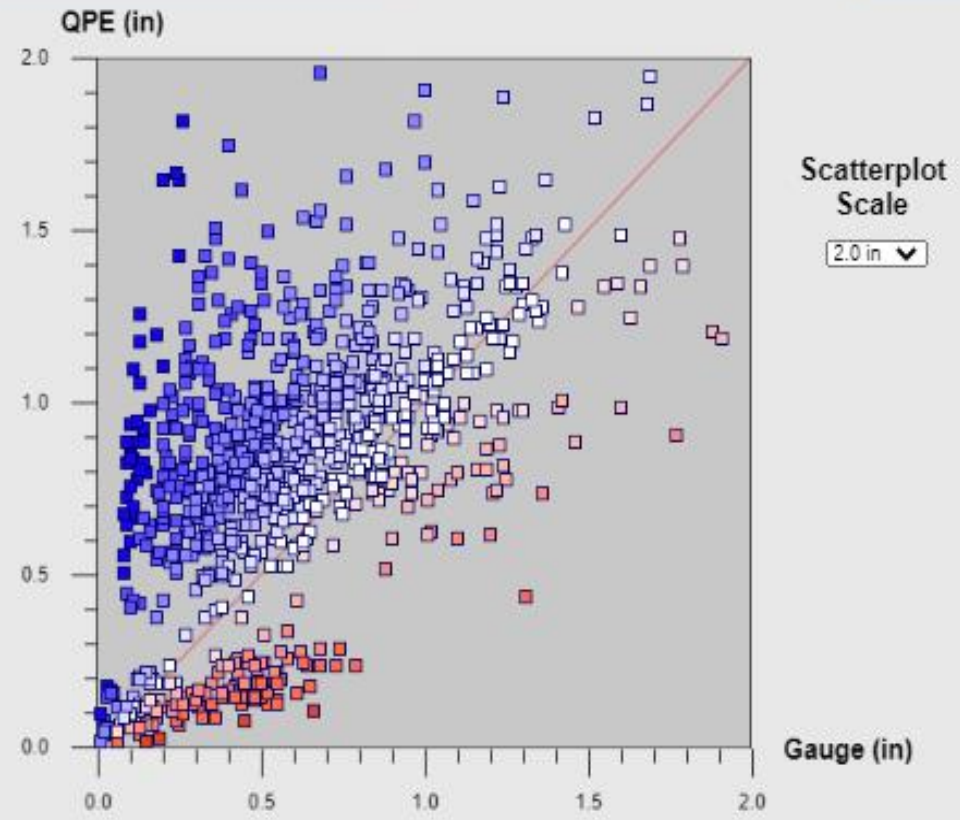
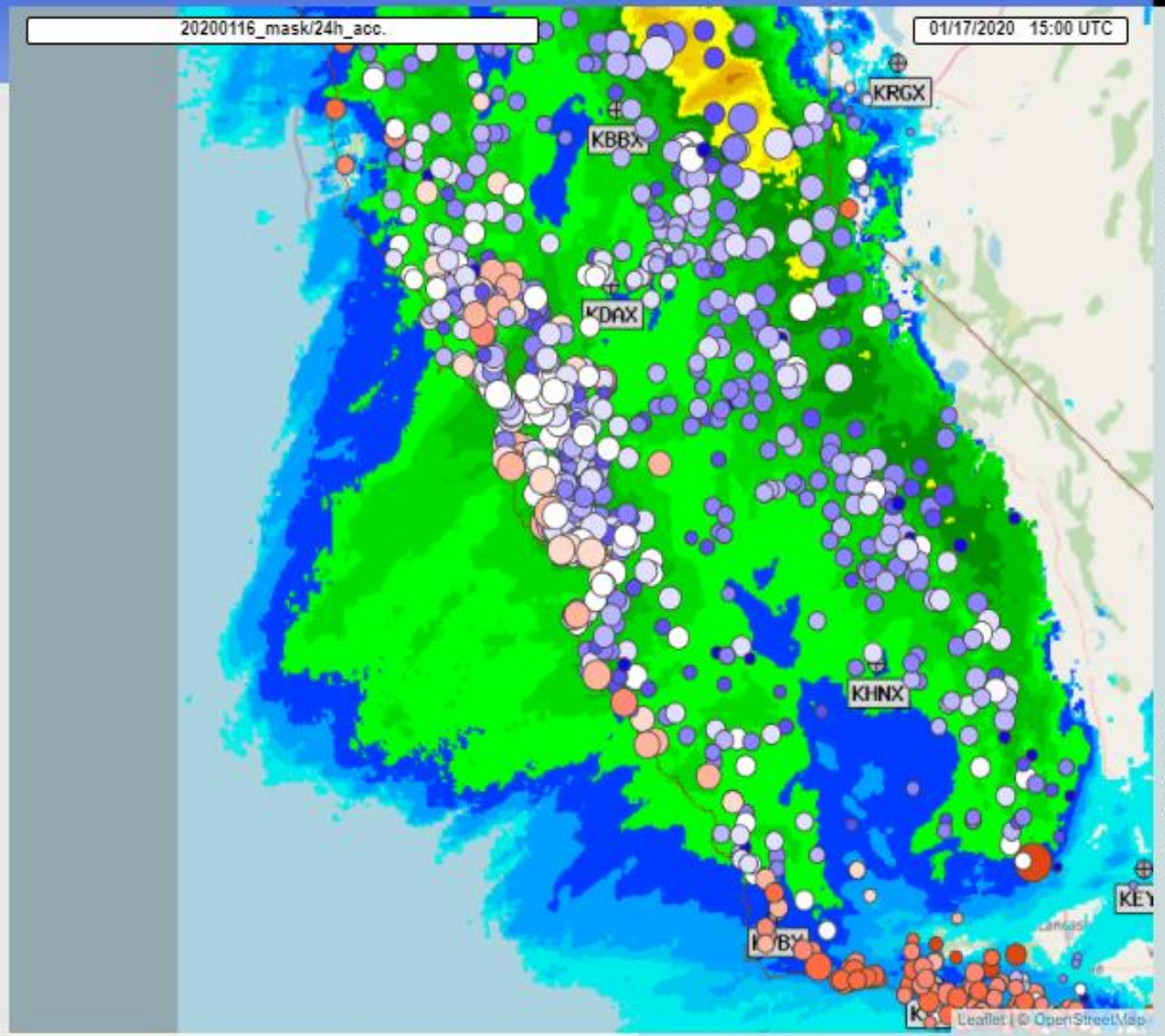


Scatterplot Scale: 2.0 in

	Gauges:	QPE:				
Min	0.01	0.02	Mean Bias(G/R):	0.720	G-R Err Std Dev:	0.337
Avg	0.60	0.83	Add Bias (G-R):	-220.41	Corr Coeff:	0.547
Max	2.91	3.38	Mean Err (G-R)/N:	-0.233	Fract Bias:	-0.389
			Mean Abs Error:	0.337	Fract RMSE:	0.744
			RMSE:	0.446	Fract Std Dev:	0.634

CA 24HR ML



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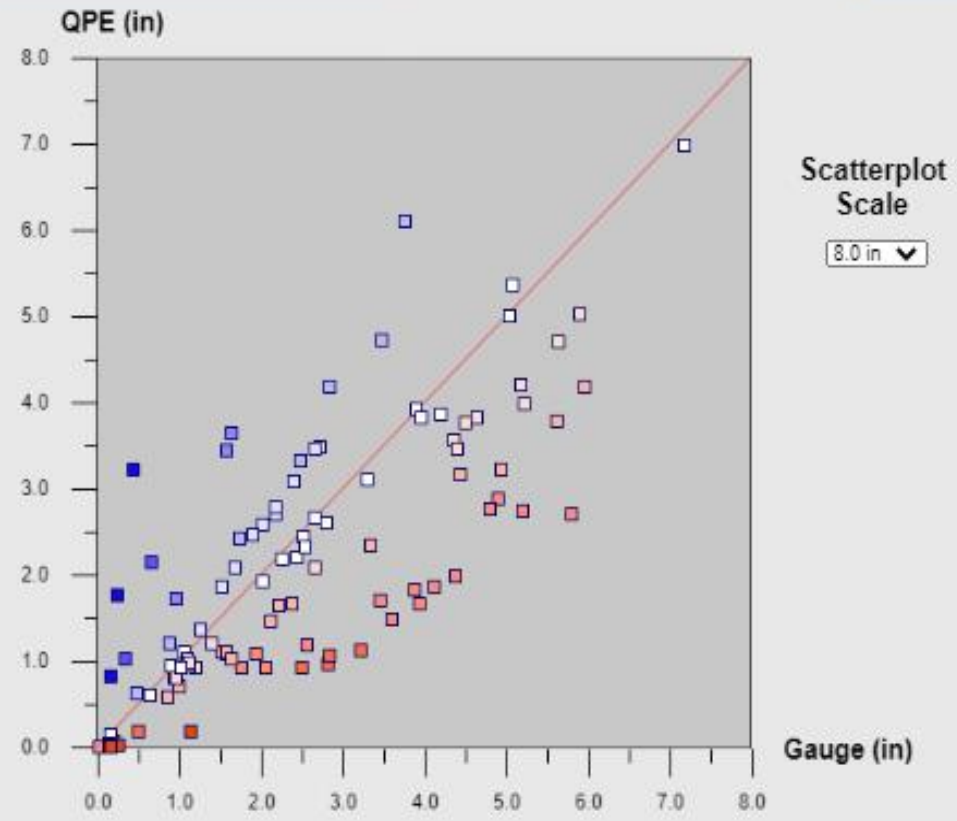
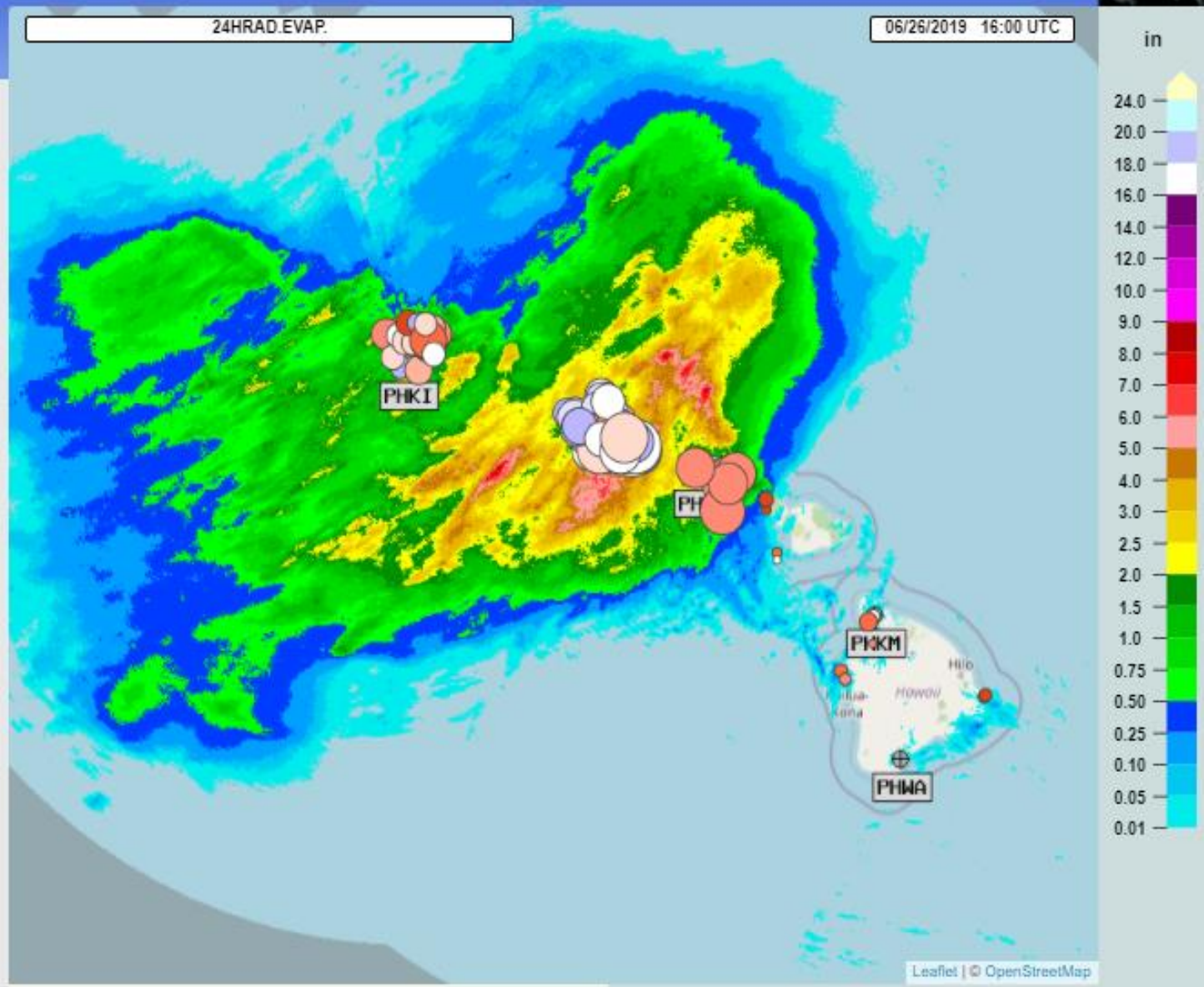


Scatterplot Scale: 8.0 in

	Gauges:	QPE:				
Min	0.02	0.01	Mean Bias(G/R):	1.152	G-R Err Std Dev:	0.807
Avg	2.44	2.12	Add Bias (G-R):	33.16	Corr Coeff:	0.791
Max	7.17	7.00	Mean Err (G-R)/N:	0.322	Fract Bias:	0.132
			Mean Abs Error:	0.807	Fract RMSE:	0.454
			RMSE:	1.110	Fract Std Dev:	0.435



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HI 24HR OP

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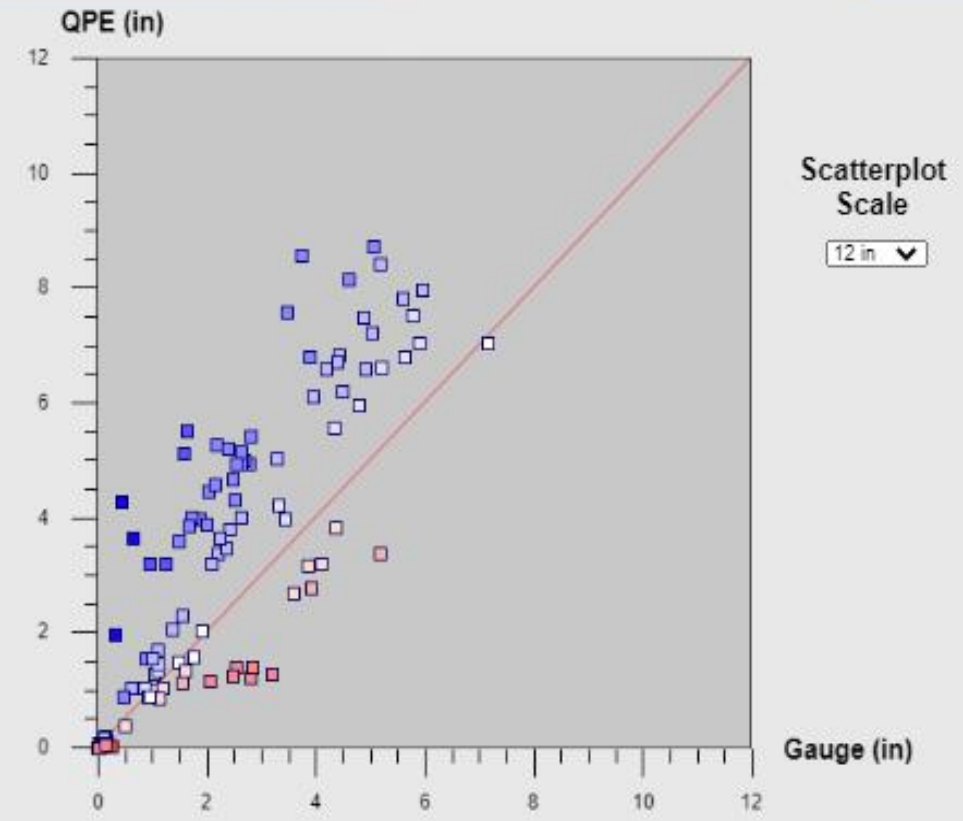
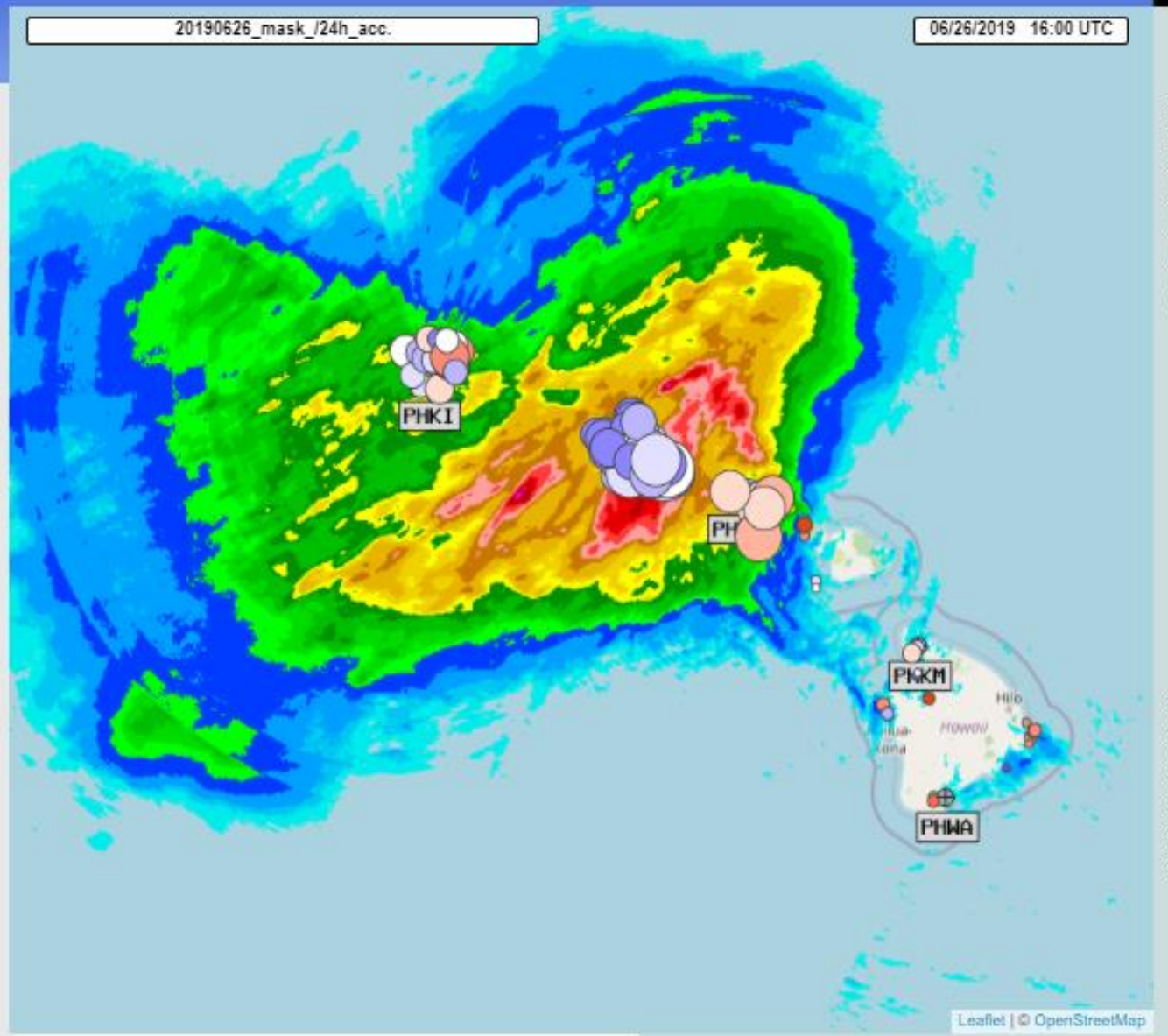


Scatterplot Scale: 12 in

	Gauges:	QPE:				
Min	0.01	0.01	Mean Bias(G/R):	0.693	G-R Err Std Dev:	1.327
Avg	2.31	3.33	Add Bias (G-R):	-111.34	Corr Coeff:	0.845
Max	7.17	8.72	Mean Err (G-R)/N:	-1.021	Fract Bias:	-0.443
			Mean Abs Error:	1.327	Fract RMSE:	0.762
			RMSE:	1.757	Fract Std Dev:	0.620

HI 24HR ML



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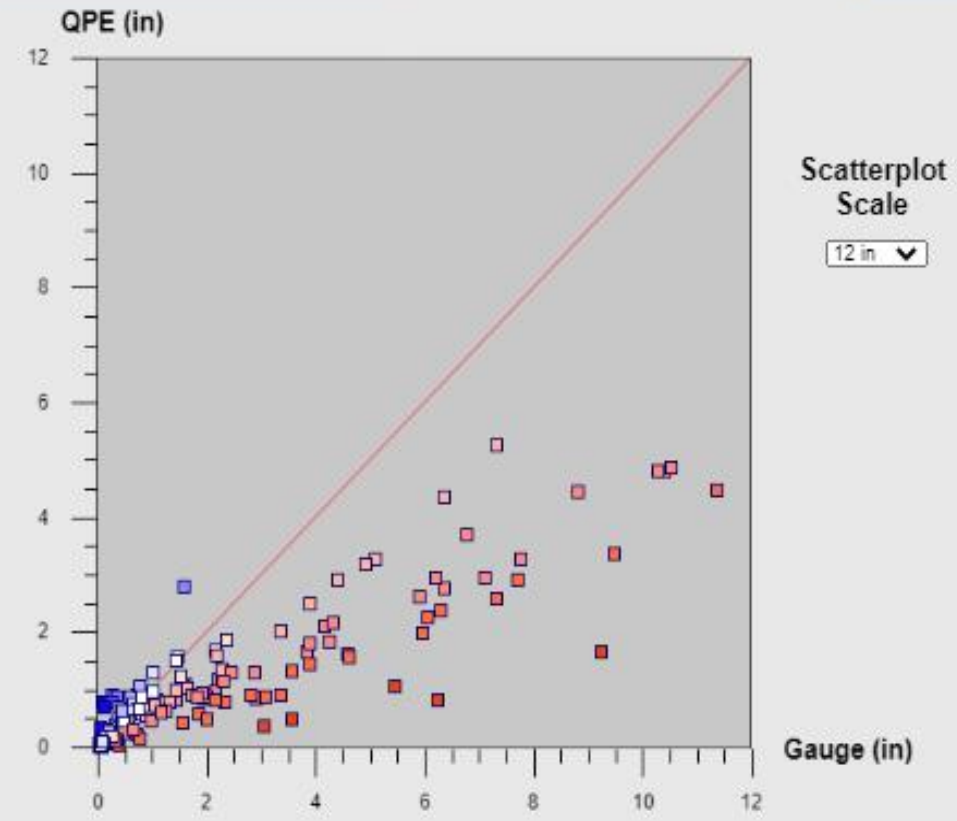
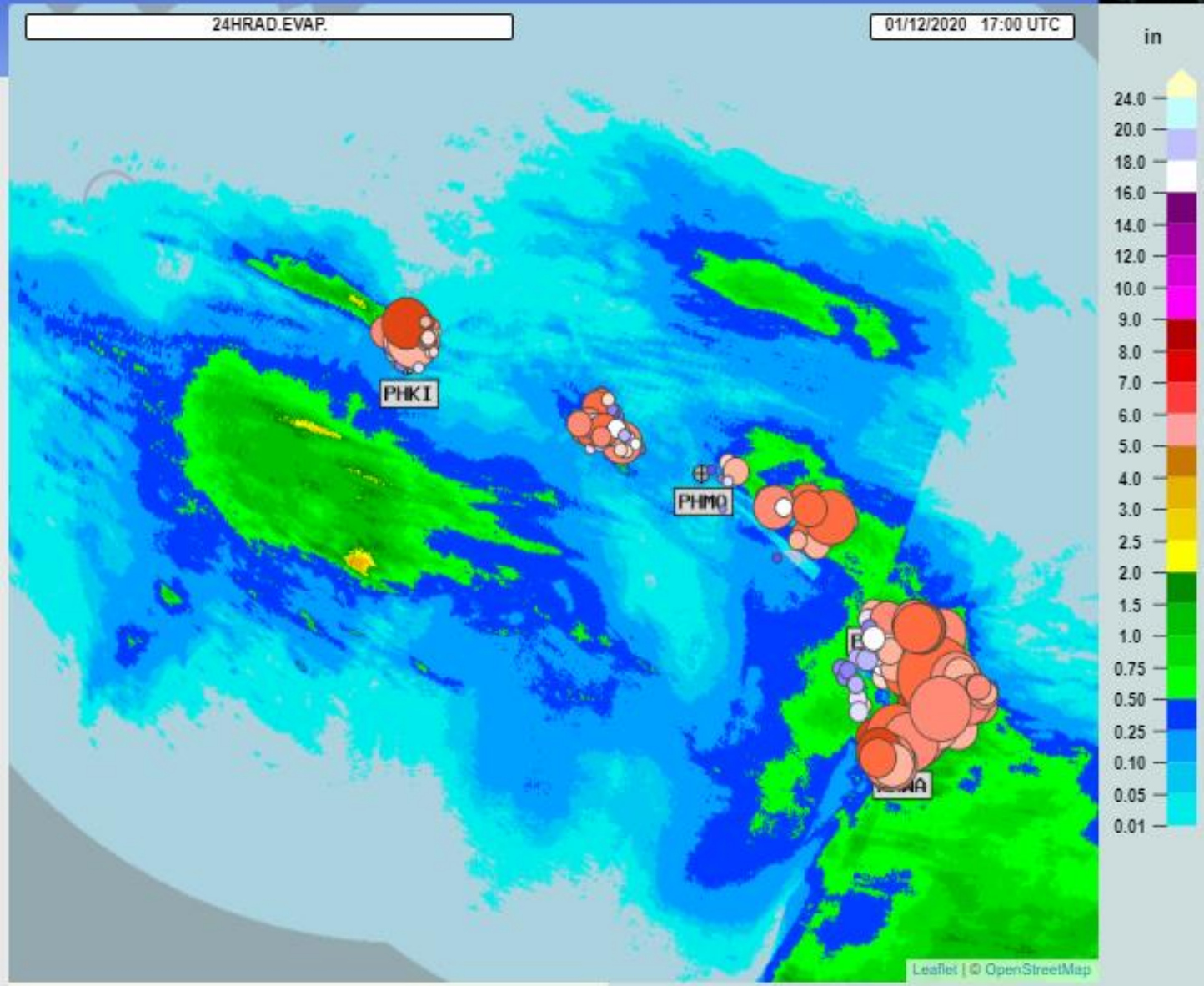


Scatterplot Scale: 12 in

	Gauges:	QPE:				
Min	0.02	0.02	Mean Bias(G/R):	1.973	G-R Err Std Dev:	1.194
Avg	2.19	1.11	Add Bias (G-R):	183.37	Corr Coeff:	0.905
Max	16.81	5.32	Mean Err (G-R)/N:	1.079	Fract Bias:	0.493
			Mean Abs Error:	1.194	Fract RMSE:	0.997
			RMSE:	2.181	Fract Std Dev:	0.866



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HI 24HR OP

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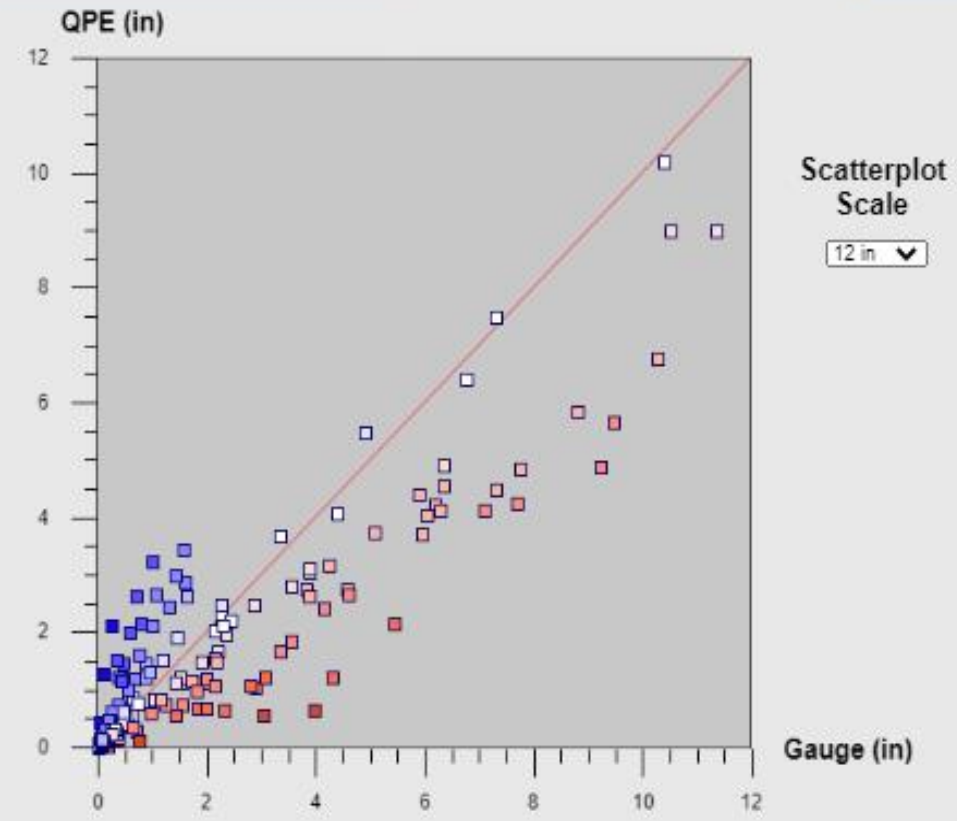

Scatterplot Scale: 12 in

	Gauges:	QPE:				
Min	0.02	0.01	Mean Bias(G/R):	1.257	G-R Err Std Dev:	0.853
Avg	2.19	1.74	Add Bias (G-R):	75.62	Corr Coeff:	0.920
Max	16.81	10.19	Mean Err (G-R)/N:	0.447	Fract Bias:	0.205
			Mean Abs Error:	0.853	Fract RMSE:	0.634
			RMSE:	1.385	Fract Std Dev:	0.600

HI 24HR ML

Site ID: Lat/Long:

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End Shift: From:

Overlays

Base Map Layer

Inventory History

CONUS LSTM MODEL AND RESULTS

- Trained and simulations over the entire USA
    - Trained in various regions throughout the CONUS
    - Simulation throughout various regions of the CONUS
        - Training, validation, and simulations days were all independent of one another
- 8 variables utilized

Gauge vs QPE Comparison

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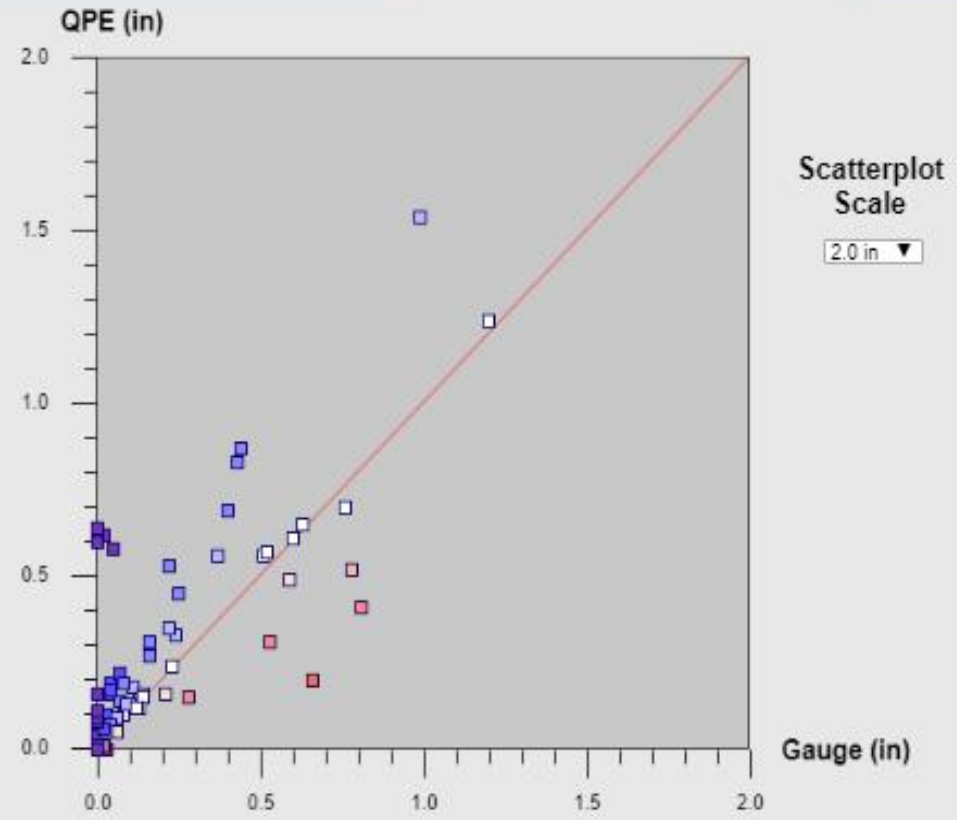
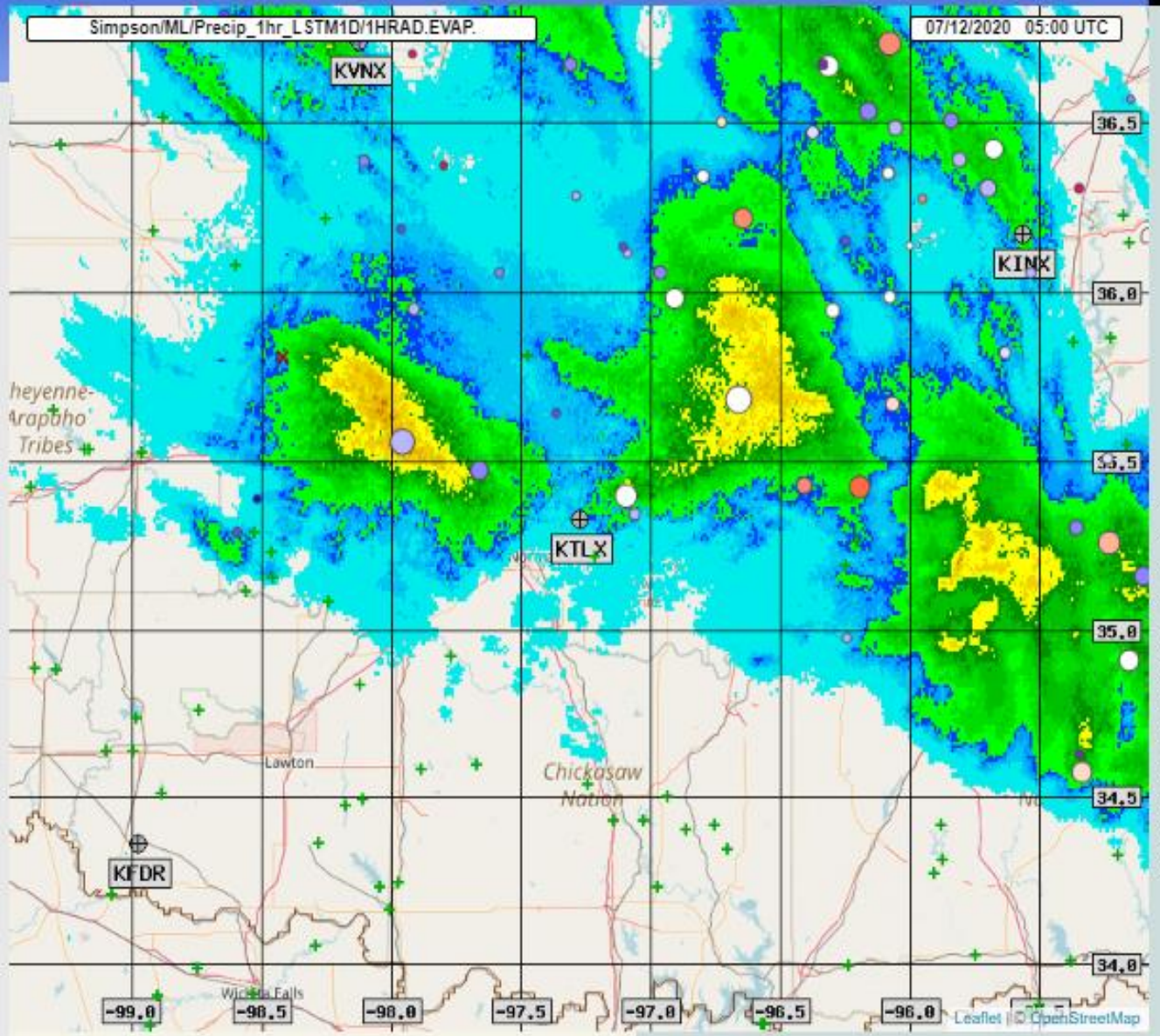


Scatterplot Scale

2.0 in

	Gauges:	QPE:				
Min	0.00	0.00	Mean Bias(G/R):	0.713	G-R Err Std Dev:	0.071
Avg	0.11	0.15	Add Bias (G-R):	-5.66	Corr Coeff:	0.824
Max	1.20	1.54	Mean Err (G-R)/N:	-0.044	Fract Bias:	-0.402
			Mean Abs Error:	0.071	Fract RMSE:	1.419
			RMSE:	0.155	Fract Std Dev:	1.361

KTLX 1HR OP



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

End Shift: From:

Overlays

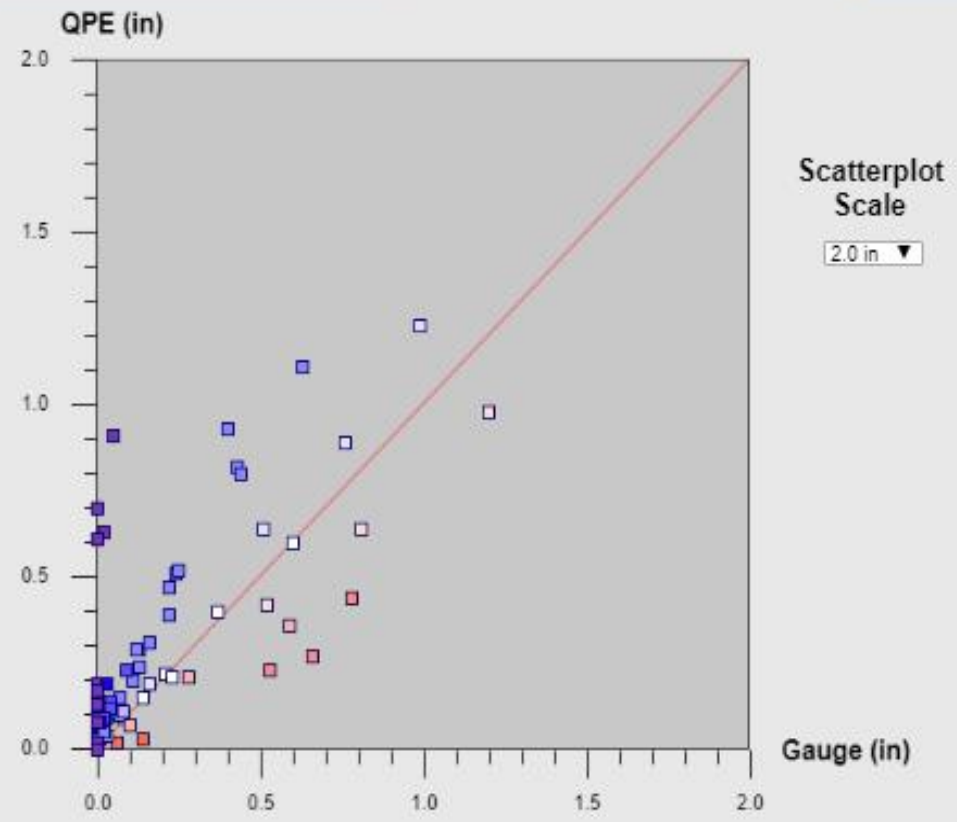
Base Map Layer

Inventory History

Gauge vs QPE Comparison

METOP Analysis Tools

General | Gauge Filtering | Scatterplot & Statistics | Time Series

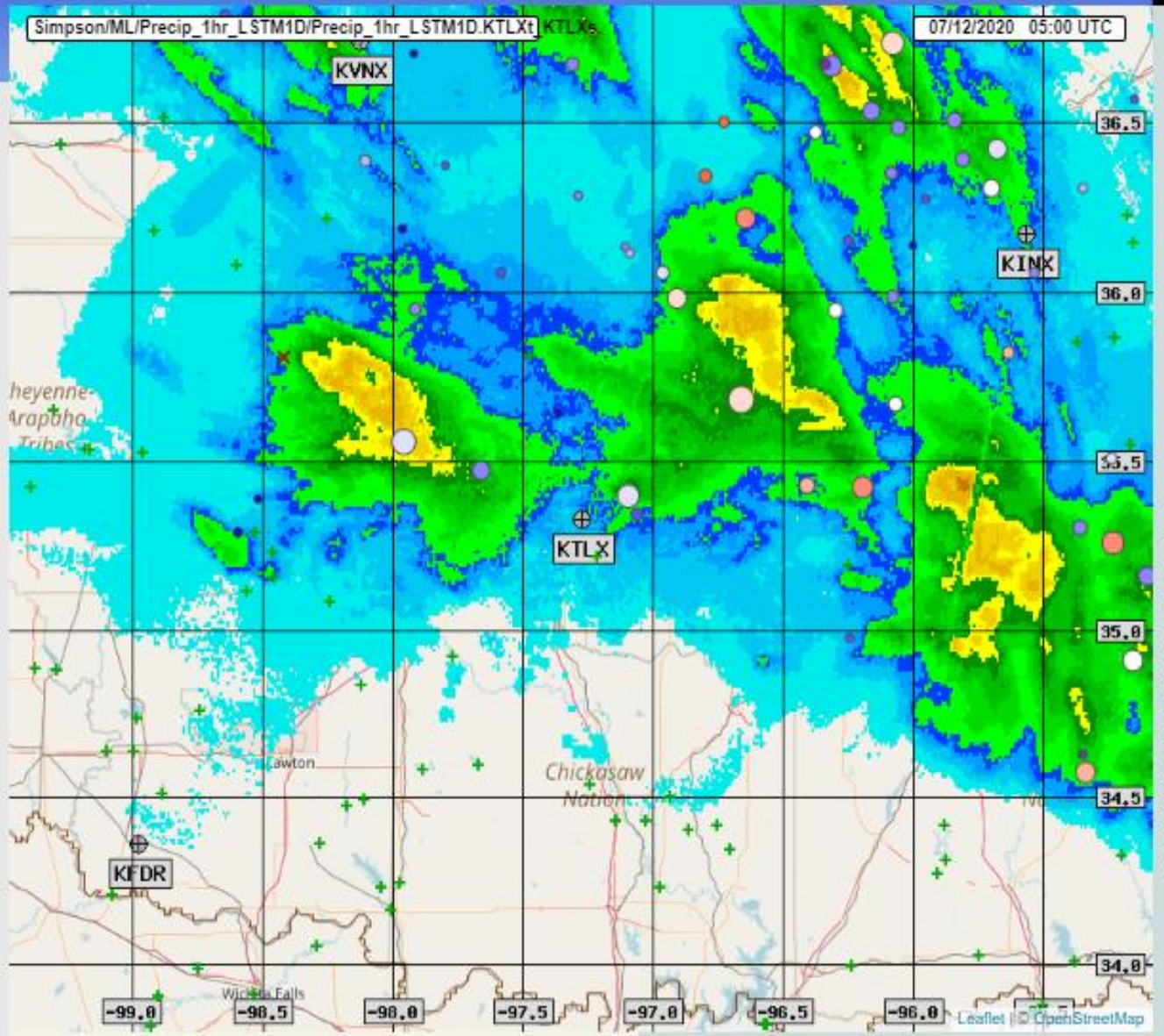


Scatterplot Scale

2.0 in

	Gauges:	QPE:				
Min	0.00	0.00	Mean Bias(G/R):	0.642	G-R Err Std Dev:	0.092
Avg	0.11	0.17	Add Bias (G-R):	-7.84	Corr Coeff:	0.779
Max	1.20	1.23	Mean Err (G-R)/N:	-0.061	Fract Bias:	-0.557
			Mean Abs Error:	0.092	Fract RMSE:	1.619
			RMSE:	0.177	Fract Std Dev:	1.521

KTLX 1HR ML



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

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Overlays

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Gauge vs QPE Comparison

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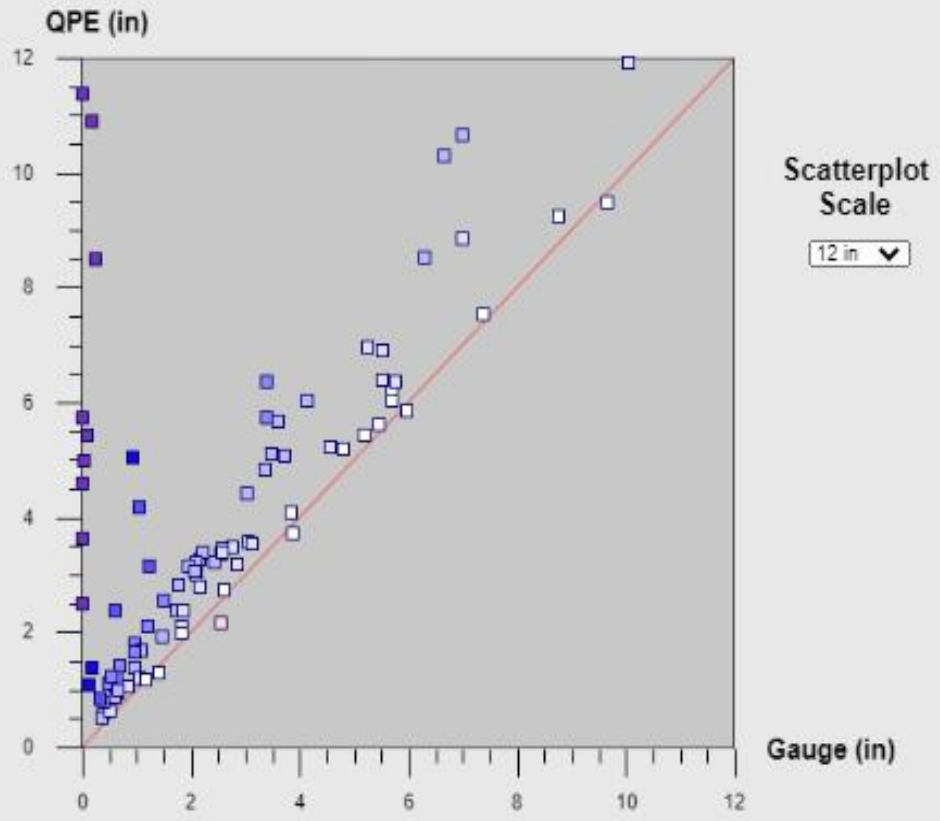
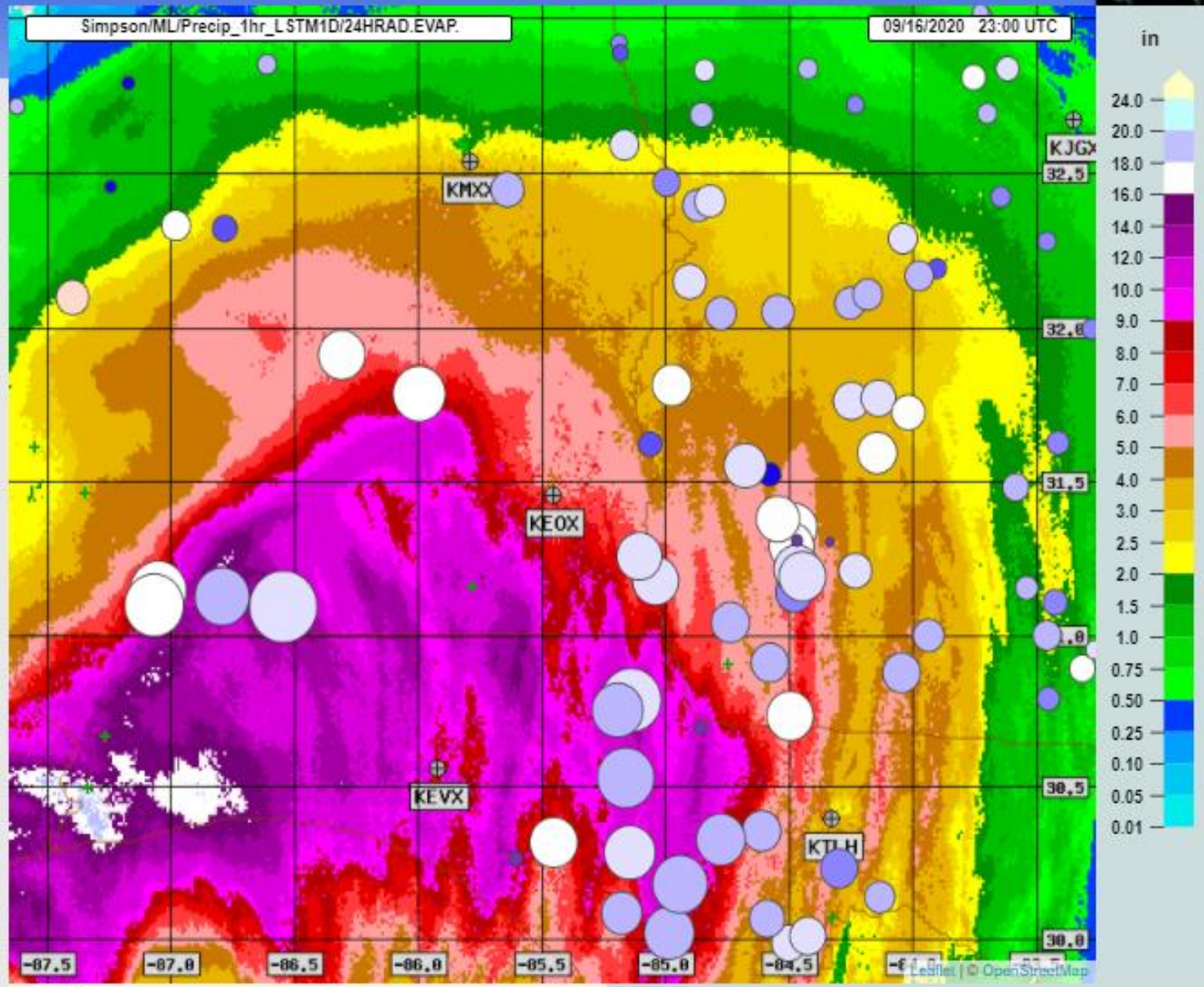


Scatterplot Scale: 12 in

	Gauges:	QPE:				
Min	0.00	0.54	Mean Bias(G/R):	0.605	G-R Err Std Dev:	1.865
Avg	2.83	4.67	Add Bias (G-R):	-177.40	Corr Coeff:	0.625
Max	13.05	16.89	Mean Err (G-R)/N:	-1.848	Fract Bias:	-0.654
			Mean Abs Error:	1.865	Fract RMSE:	1.201
			RMSE:	3.394	Fract Std Dev:	1.007



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

End Shift: From:

Overlays

Base Map Layer

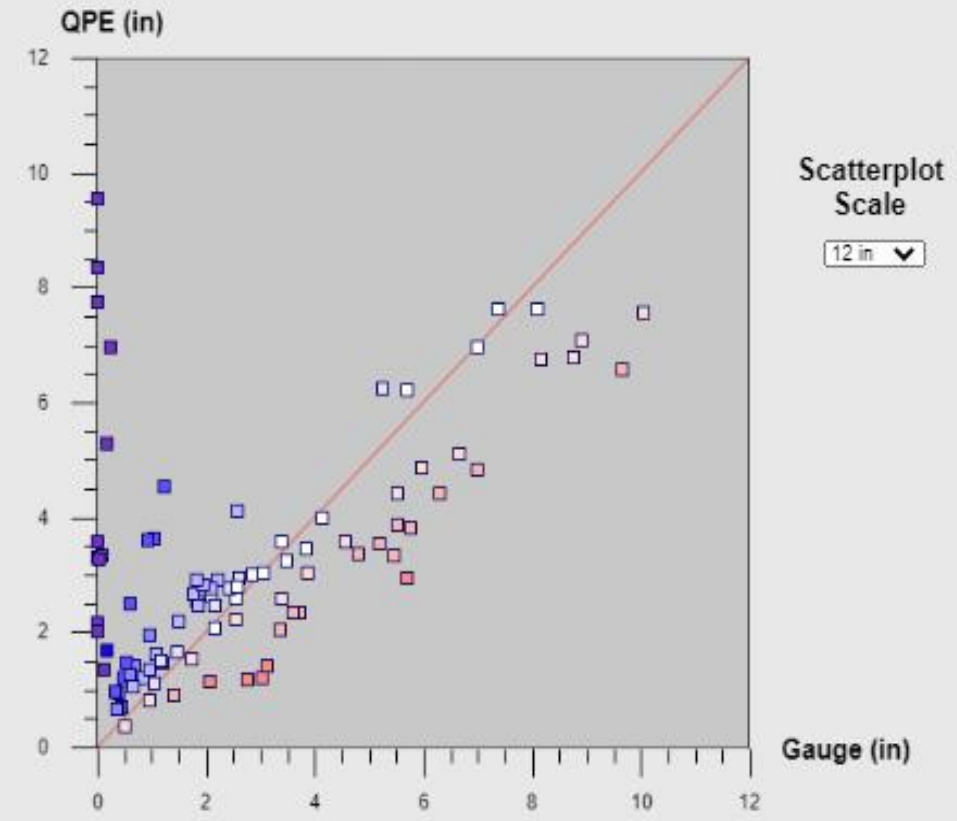
Inventory History

KEOX 24HR OP

Gauge vs QPE Comparison

METOP Analysis Tools

General | Gauge Filtering | Scatterplot & Statistics | Time Series

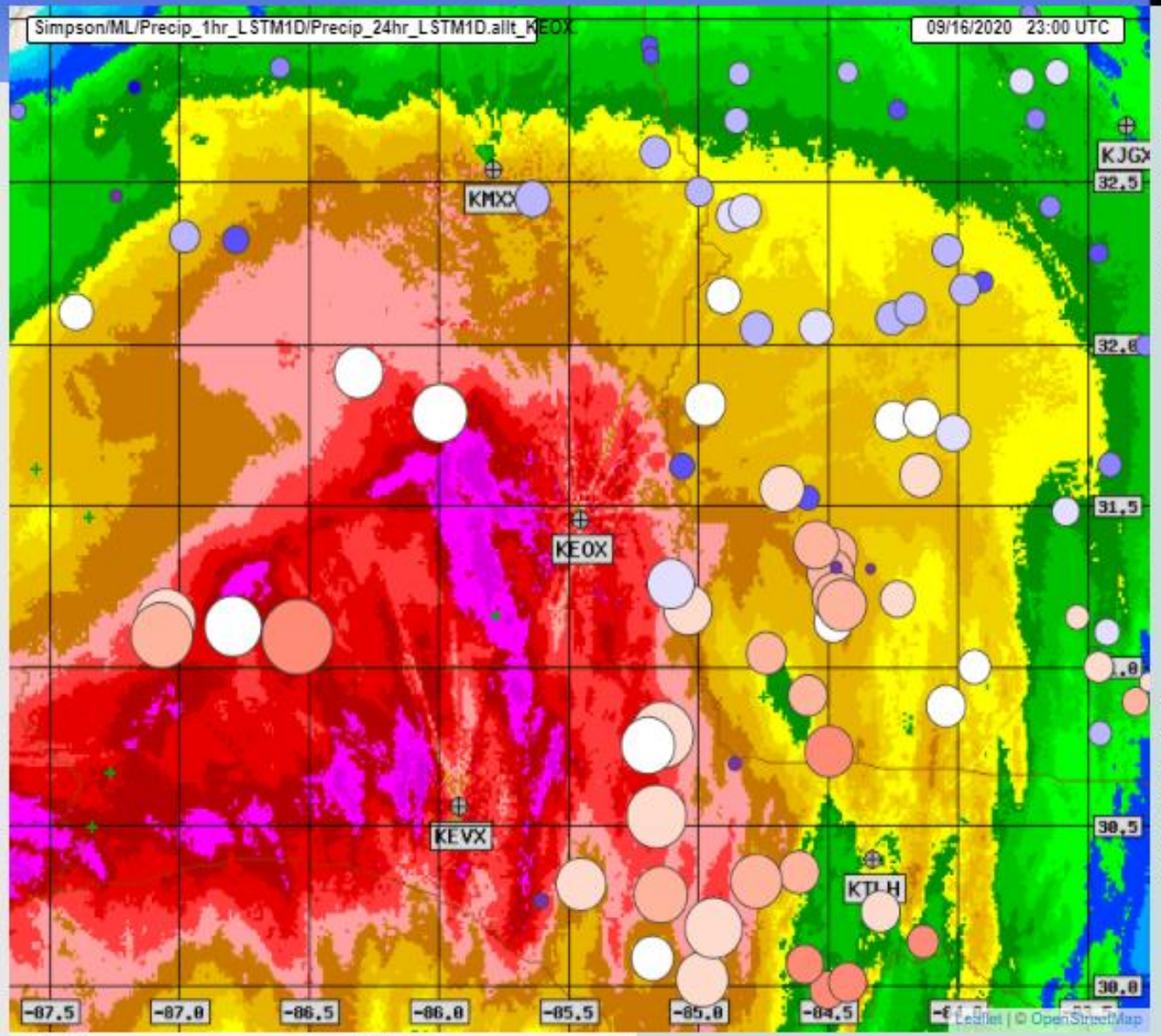


Scatterplot Scale

12 in

	Gauges:	QPE:				
Min	0.00	0.39	Mean Bias(G/R):	0.868	G-R Err Std Dev:	1.468
Avg	2.83	3.25	Add Bias (G-R):	-41.18	Corr Coeff:	0.596
Max	13.05	9.56	Mean Err (G-R)/N:	-0.429	Fract Bias:	-0.152
			Mean Abs Error:	1.468	Fract RMSE:	0.809
			RMSE:	2.286	Fract Std Dev:	0.795

KEOX 24HR ML



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

End Shift: From:

Overlays

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Gauge vs QPE Comparison

METOP Analysis Tools

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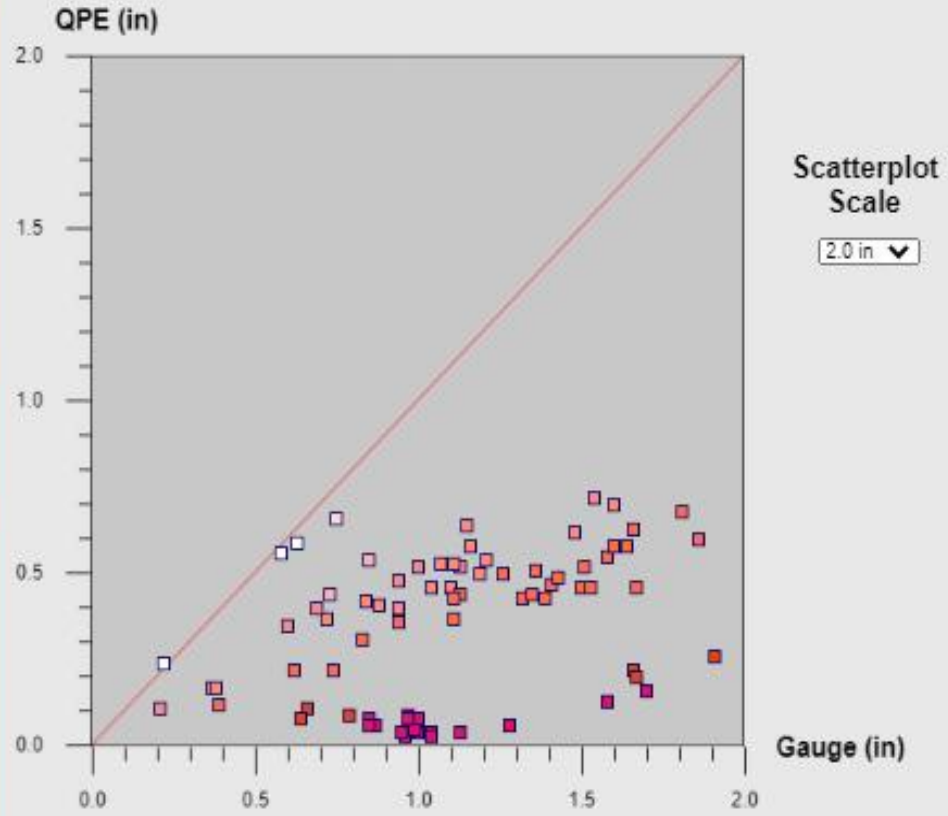
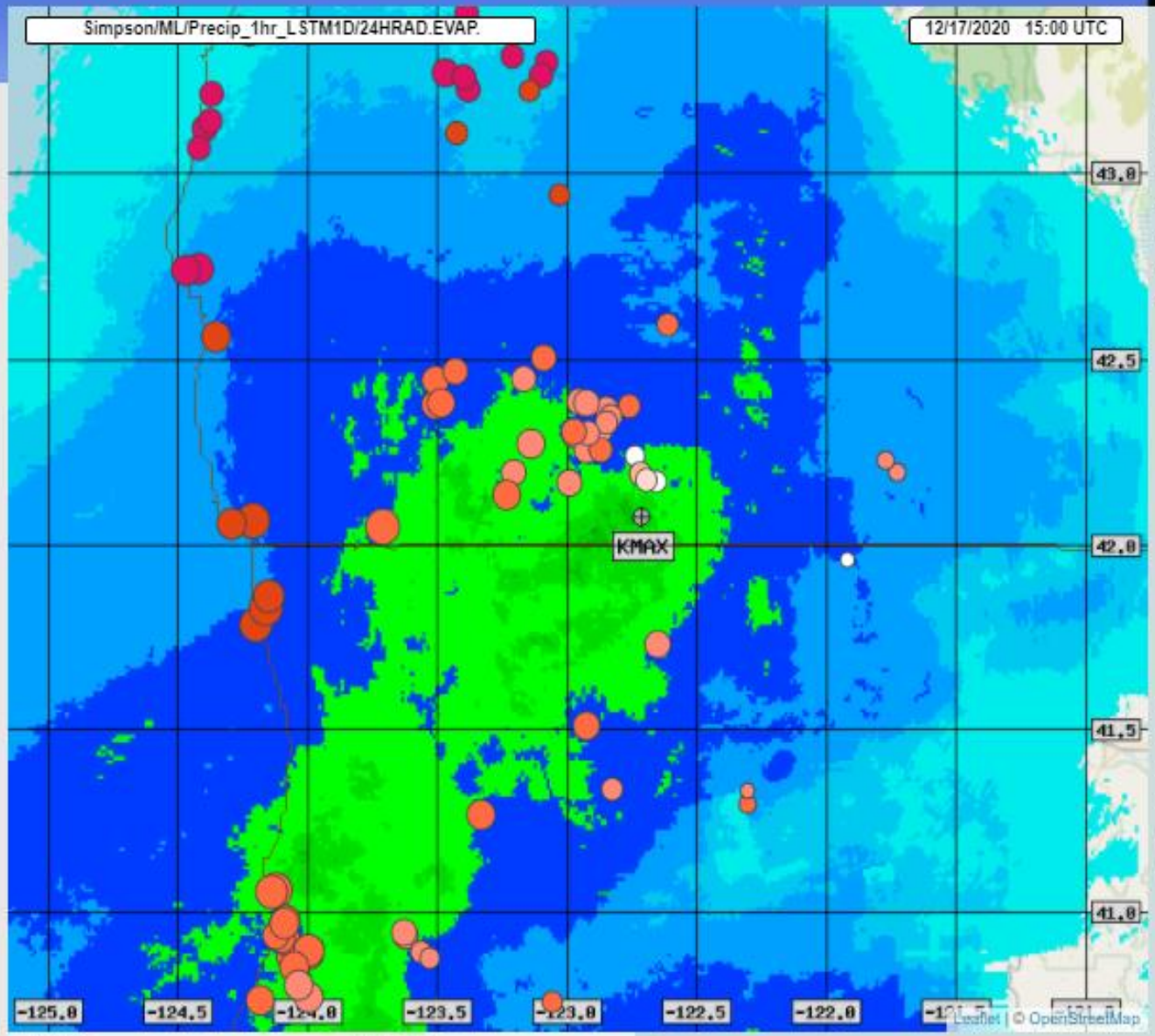


Scatterplot Scale: 2.0 in

	Gauges:	QPE:				
Min	0.21	0.03	Mean Bias(G/R):	3.281	G-R Err Std Dev:	0.818
Avg	1.18	0.36	Add Bias (G-R):	67.88	Corr Coeff:	0.386
Max	2.39	0.77	Mean Err (G-R)/N:	0.818	Fract Bias:	0.695
			Mean Abs Error:	0.818	Fract RMSE:	0.791
			RMSE:	0.930	Fract Std Dev:	0.377

KMAX 24HR OP



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

End Shift: From:

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Gauge vs QPE Comparison

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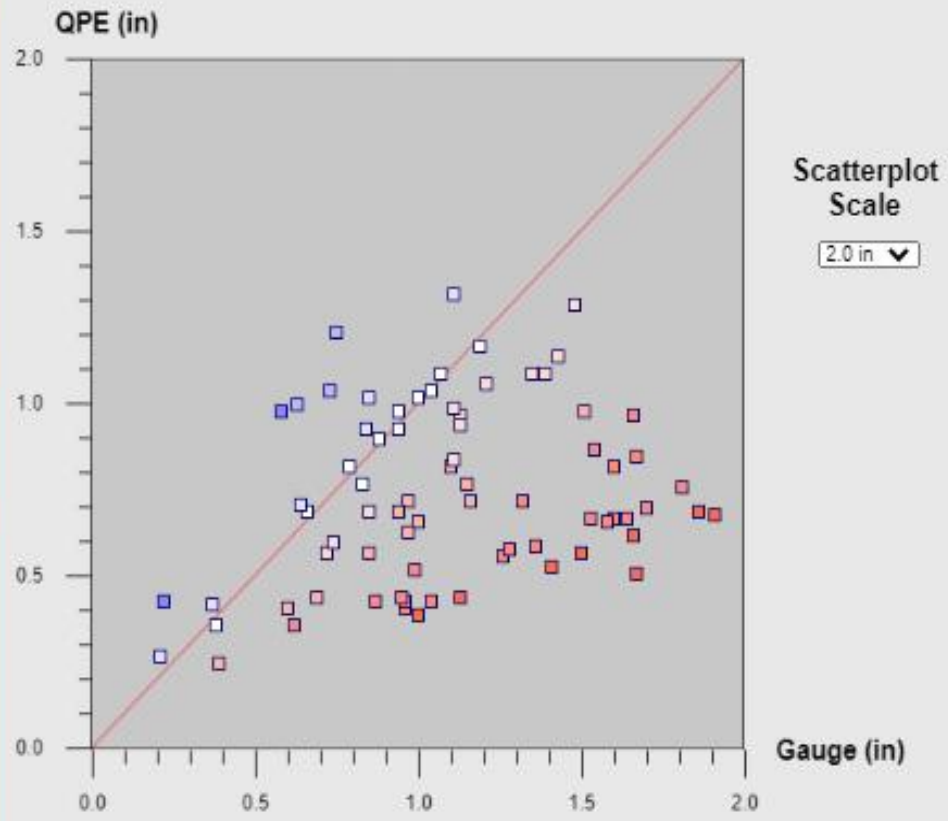
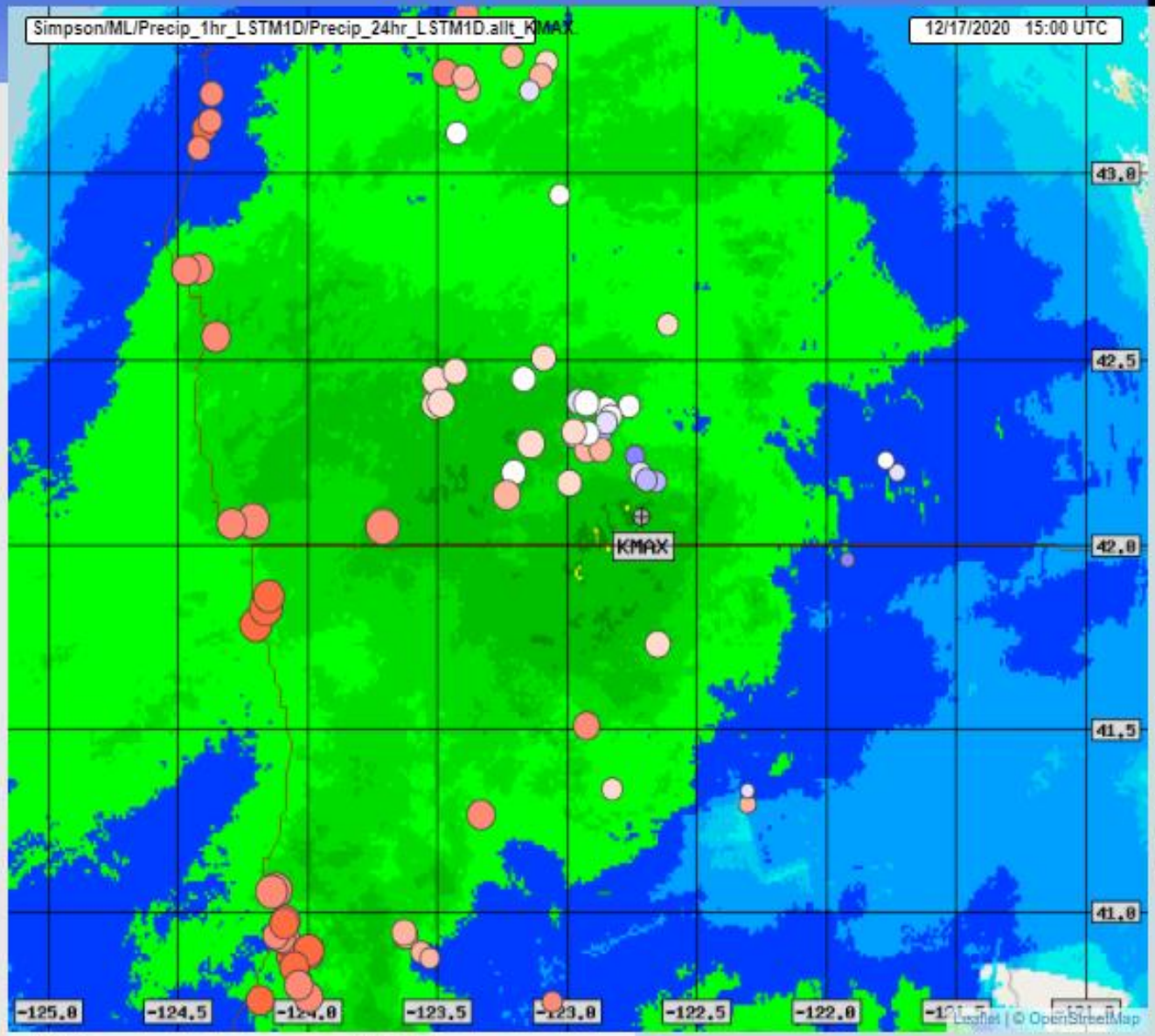


Scatterplot Scale

2.0 in

	Gauges:	QPE:				
Min	0.21	0.25	Mean Bias(G/R):	1.574	G-R Err Std Dev:	0.491
Avg	1.18	0.75	Add Bias (G-R):	35.61	Corr Coeff:	0.309
Max	2.39	1.32	Mean Err (G-R)/N:	0.429	Fract Bias:	0.365
			Mean Abs Error:	0.491	Fract RMSE:	0.540
			RMSE:	0.635	Fract Std Dev:	0.398

KMAX 24HR ML



Site ID: Lat/Long:

Gauge: Bad QC: Range:

QPE: No Report: Azm:

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DISCUSSION

- Good results from both CNN and LSTM
- With an abundance of information, more simulations are possible
- Need upgrade to hardware → RAM and storage
  - 18 days training for Taiwan (few cool season events, typhoons, etc.)
  - Hours / Days for CONUS
- Cloud?

CONCLUSIONS

- Two different types of ML models have been shown to produce promising results from a variety of regions.
  - High quality controlled data
  - Large amounts of data available
- More ML models to be developed: ConvLSTM; Unet, GAN's, etc.
- Real-time ML model being implemented in Taiwan

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