Using a Reputation System to Produce Trustworthy Rainfall Estimates from Crowdsourced Data:

A Case Study in Durham, North Carolina

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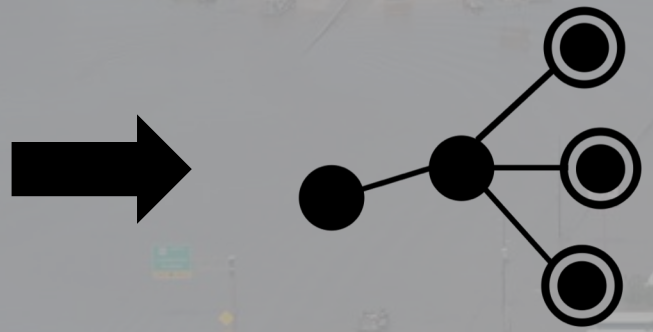
Jonathan L. Goodall

University of Virginia

Engineering Systems and Environment

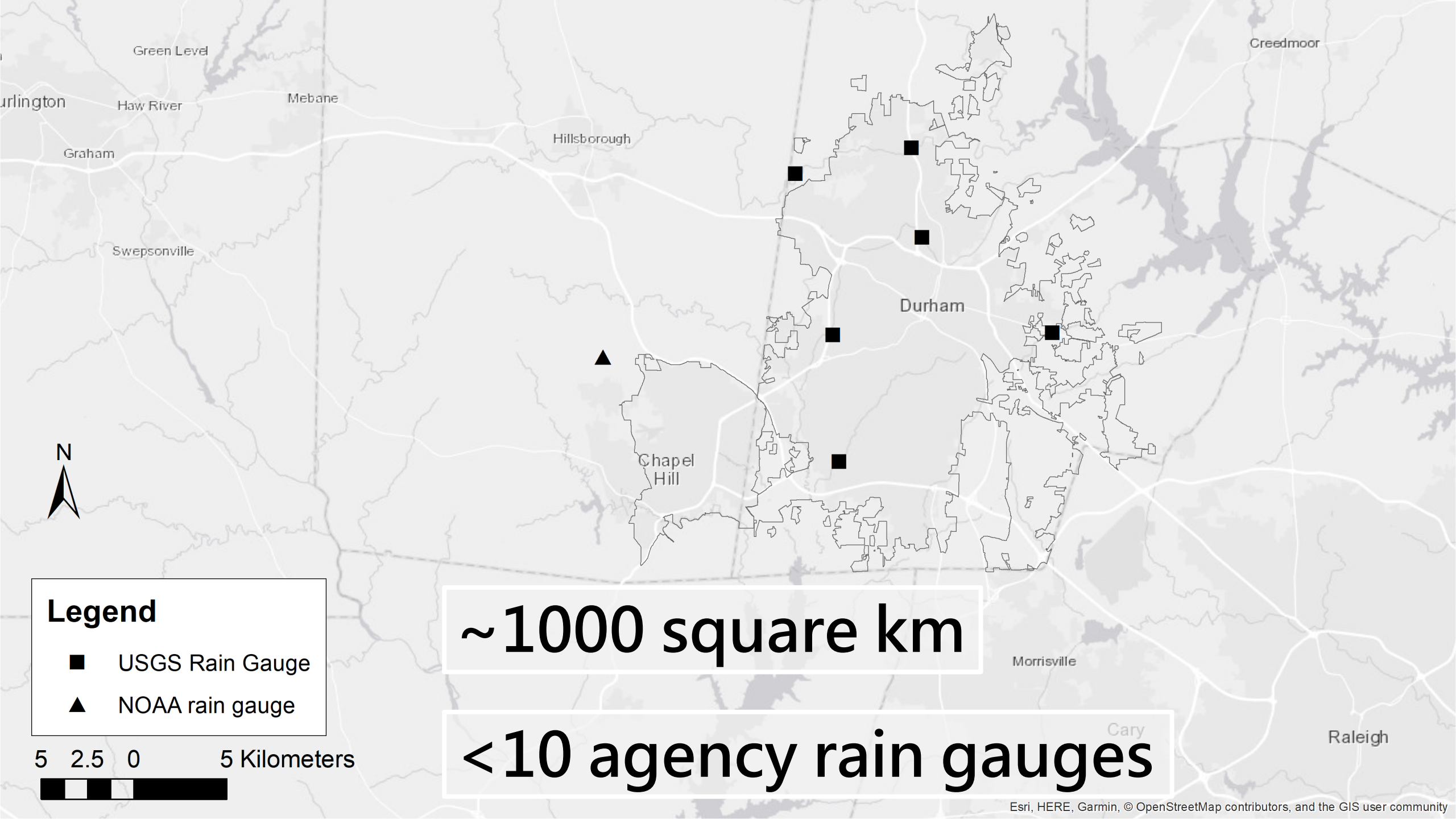
Flooding is becoming commonplace in cities worldwide

Datasets



Models

Decision-making


Green Level
Creedmoor
urlington
Haw River
Mebane
Hillsborough
Graham
Swepsonville
Durham
Chapel Hill
Morrisville
Cary
Raleigh
N
Legend
USGS Rain Gauge
NOAA rain gauge
5 2.5 0 5 Kilometers
~1000 square km
<10 agency rain gauges
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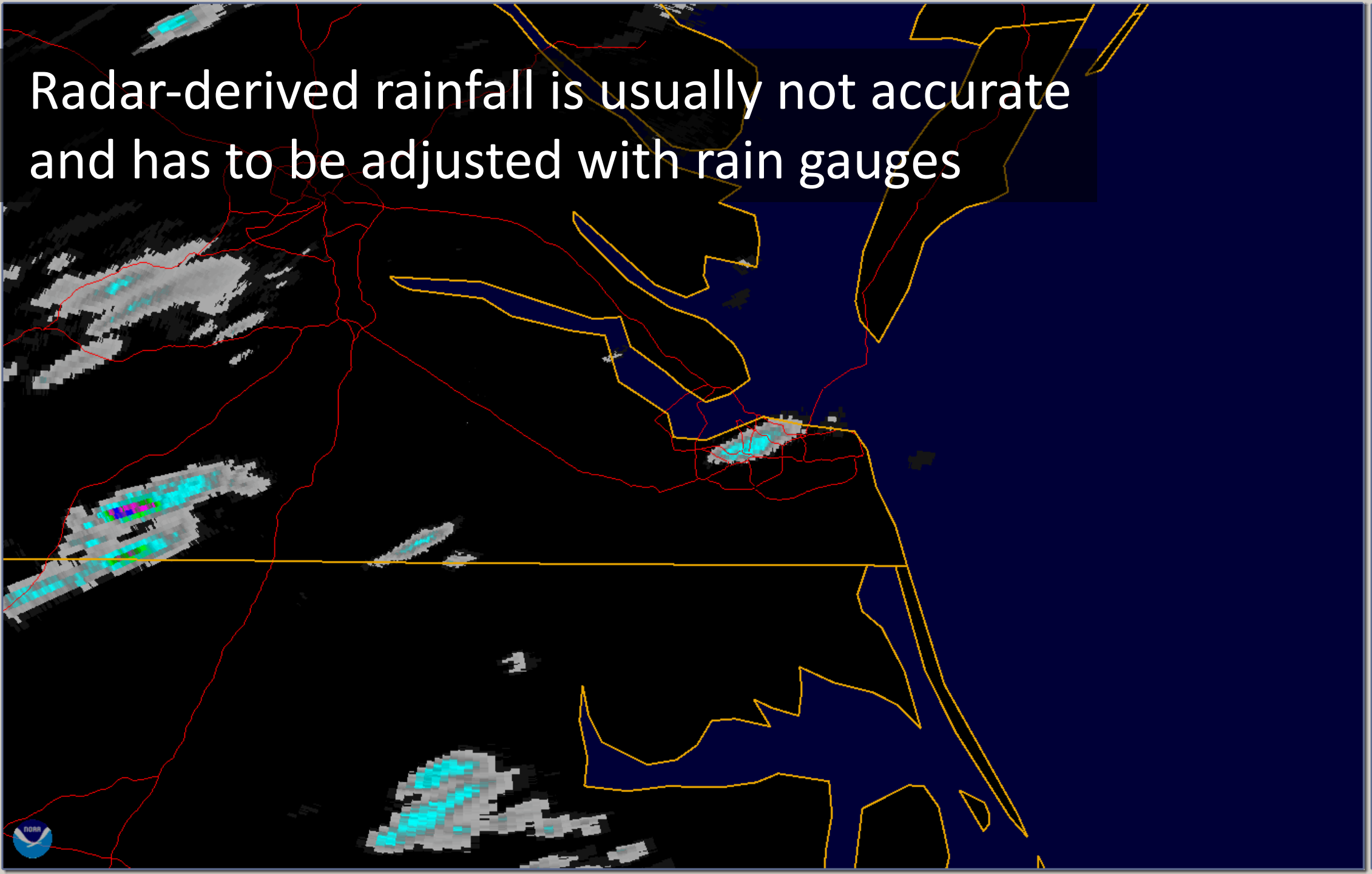
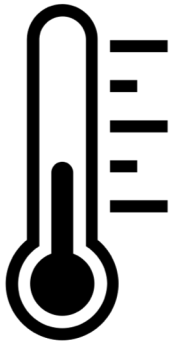
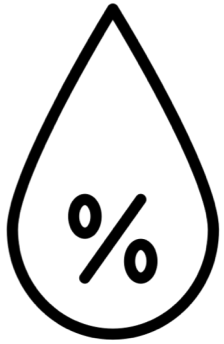

Radar-derived rainfall is usually not accurate and has to be adjusted with rain gauges
NEXRAD LEVEL-III
DIG. ONE HOUR PCP. (D.P.)
KAKQ - NORFOLK RICH, VA
08/11/2018 18:01:18 GMT
LAT: 36/59/02 N
LON: 77/00/28 W
ELEV: 254 FT
MODE/VCP: A / 212
MAX: 2.10 IN
END: 08/11/2018 18:00 GMT
MEAN-FIELD BIAS: 1.00
Legend: IN
8.0
6.0
4.0
3.0
2.5
2.0
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.10
0.01
0.0

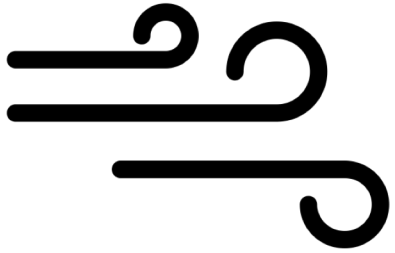
Personal Weather Station (PWS)



Temperature



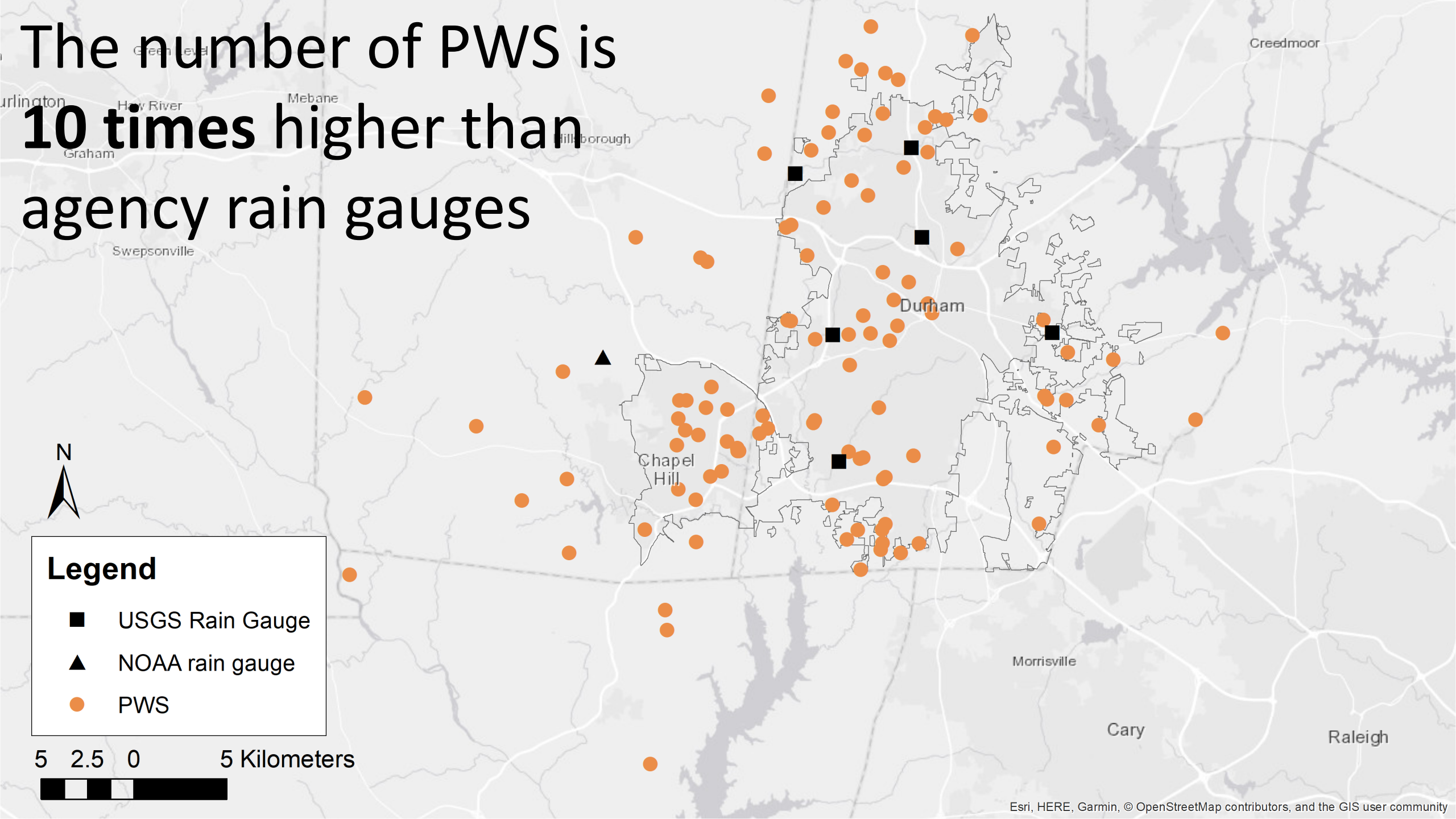
Humidity



Wind speed

Rainfall

The number of PWS is **10 times** higher than agency rain gauges



	Agency Rainfall Networks	PWS Networks
Owner	Trained Personnel	Hobbyists
Siting	Adhere to specific standards	Based on owner’s effort
Sensor Type	Certified sensors	Based on affordability
Calibration	Rigorous	Unknown
Maintenance	Routine	Unknown

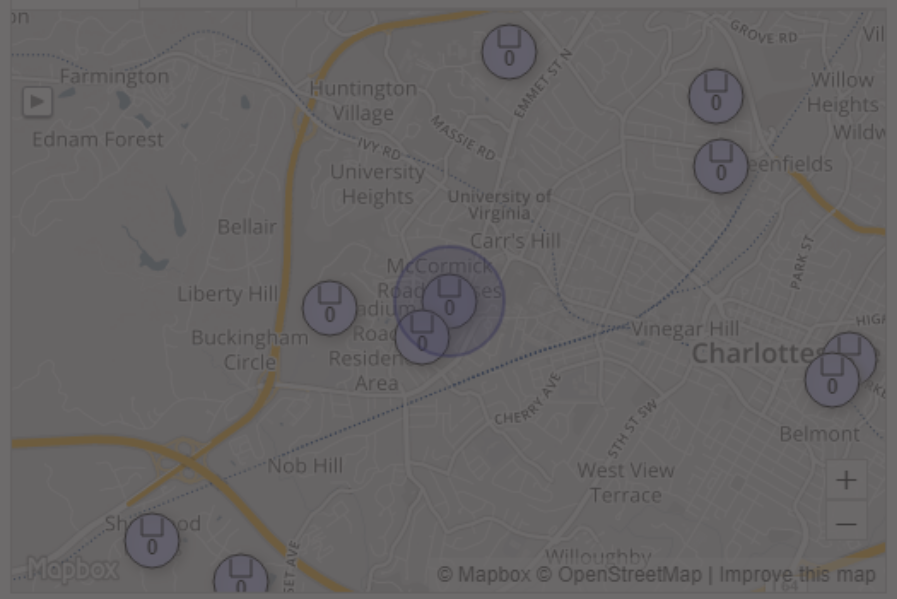
Link Lab, University of Virginia **KVACHARL114** About this PWS | Report | Comments

Forecast for Charlottesville, VA > 38.033 -78.511 > 571 ft

PWS Data | PWS Widgets | WunderStation | My PWS

PWS viewed 79 times since October 1, 2018

Radar | Webcam | Icon



Rain Light Heavy | Mixed Light Heavy | Frozen Light Heavy

View WunderMap

Current Conditions

Station reported 1 minute ago

68.9 °F

Feels Like **68.9** °F

5.0 mph

Wind from **WSW**

Gusts -- mph

Dew Point:	**45** °F	UV:	5
Humidity:	**43**%	Solar:	--
Precip Rate:	**0** in/hr	Soil Moisture:	--
Precip Accum:	in	Soil Temp:	--
Pressure:	**30.05** in	Leaf Wetness:	--

7:30 AM 6:25 PM

Waxing Gibbous | 99% Illuminated

Weather History for Charlottesville, VA [KVACHARL114]

Previous | Daily Mode | October | 28 | 2018 | View | Next

How can we trust personal weather stations?

Link Lab, University of Virginia **KVACHARL114** About this PWS | Report | Comments

Forecast for Charlottesville, VA > 38.033 -78.511 > 571 ft

PWS Data | PWS Widgets | WunderStation | My PWS

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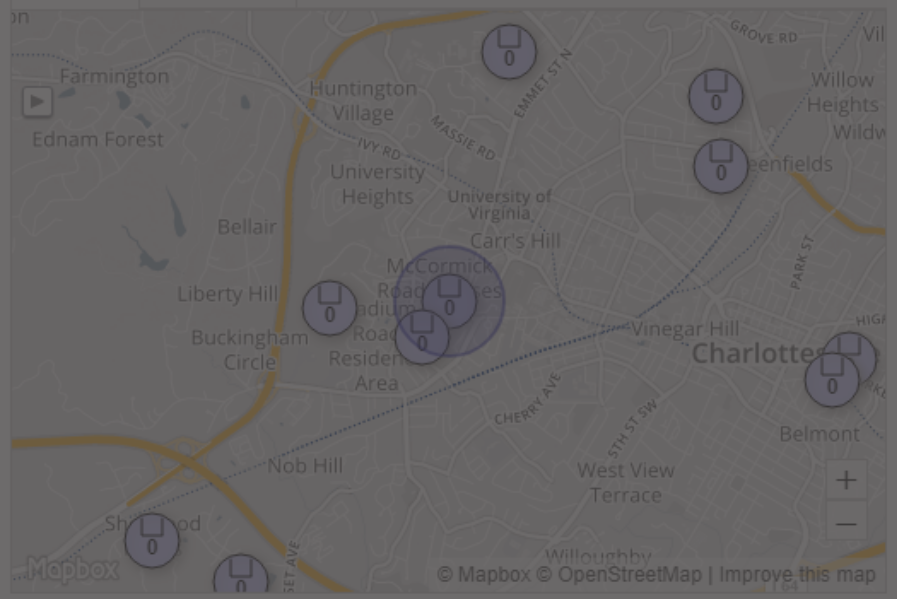


Rain Light Heavy | Mixed Light Heavy | Frozen Light Heavy

View WunderMap

Current Con... eported 1 minute ago

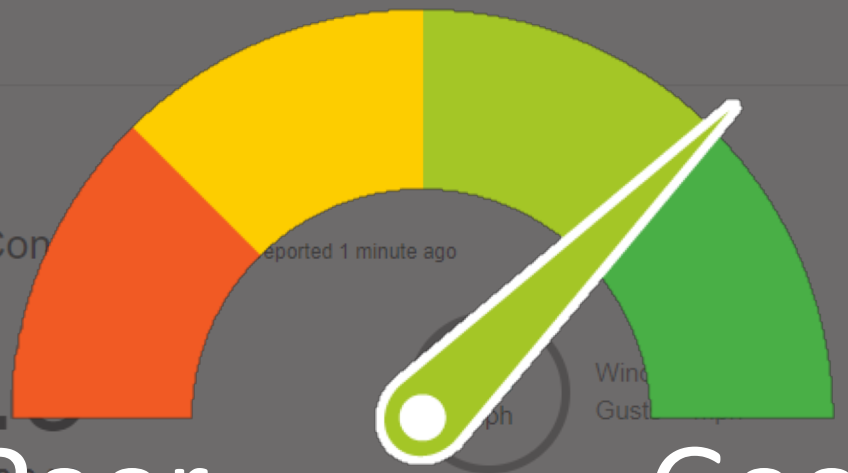
68.

Feels Like 68 °F

Dew Point:	45 °F	UV:	5
Humidity:	43%	Solar:	--
Precip Rate:	0 in/h	Soil Moisture:	--
Precip Accum:	in	Soil Temp:	--
Pressure:	30.05 in	Leaf Wetness:	--

7:30 AM 6:25 PM

Waxing Gibbous | 99% Illuminated



Trust score

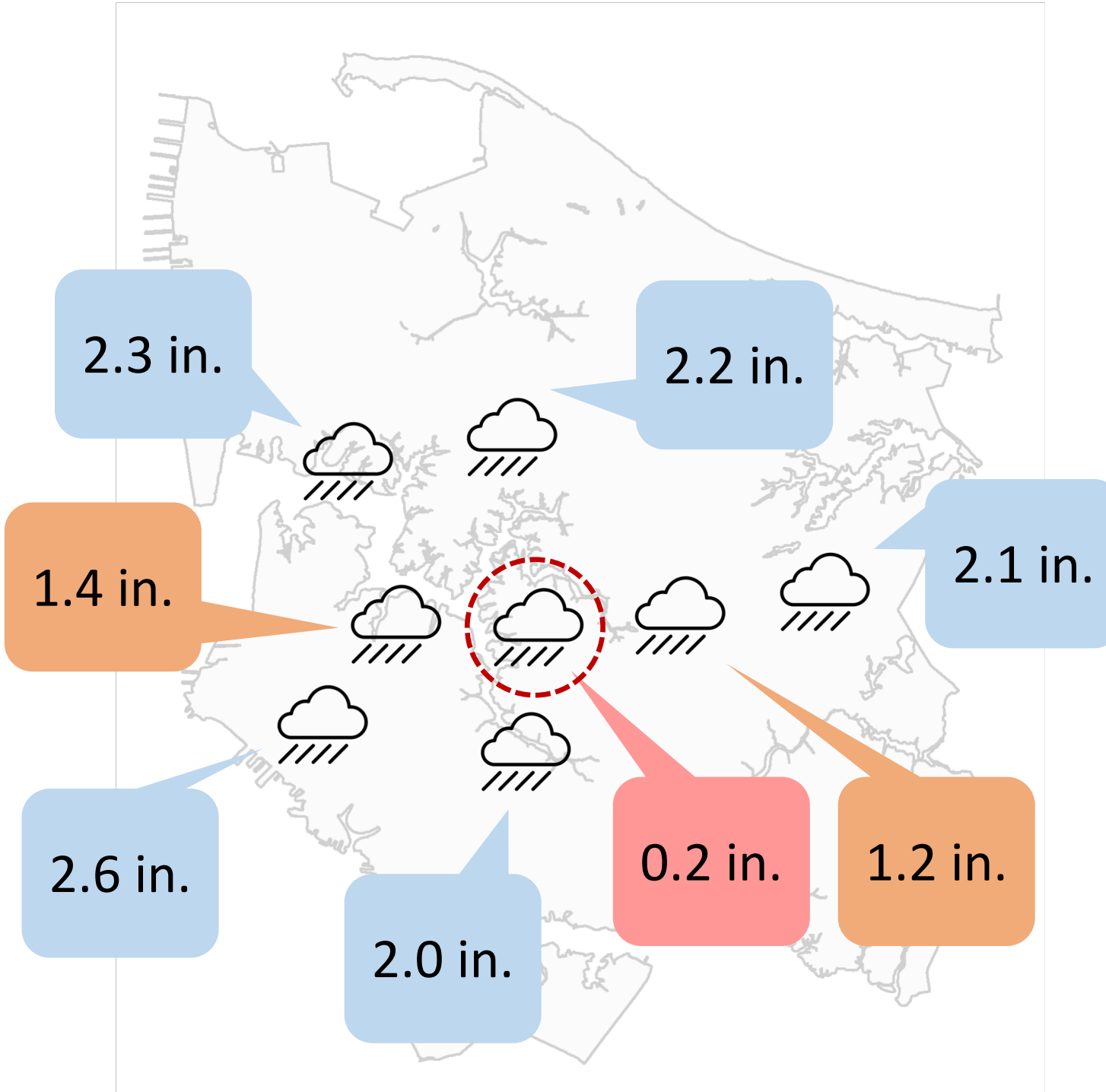
Weather History for Charlottesville, VA [KVACHARL114]

Previous | Daily Mode | October | 23 | 2018 | View | Next

Summary
Oct 23, 2018

Trust:

Collective opinion of neighboring PWSs about the behavior of a subject PWS



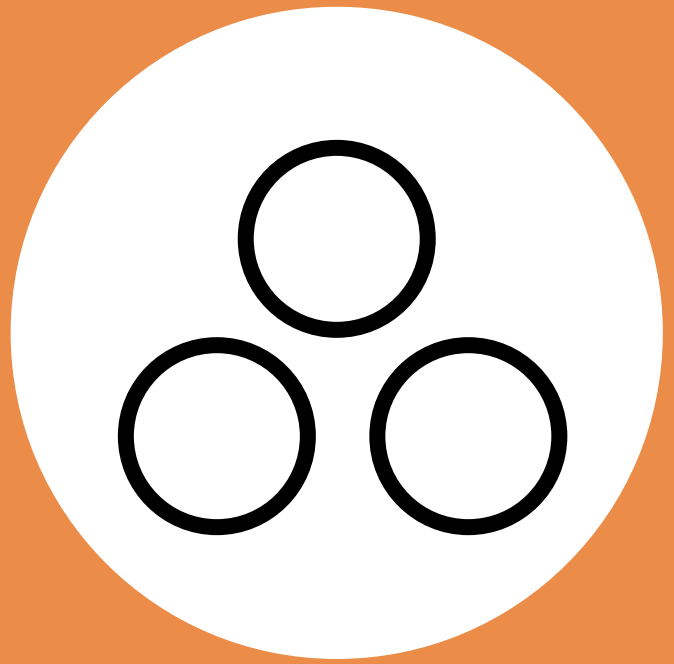
Crowdsourced Personal Weather Station

+

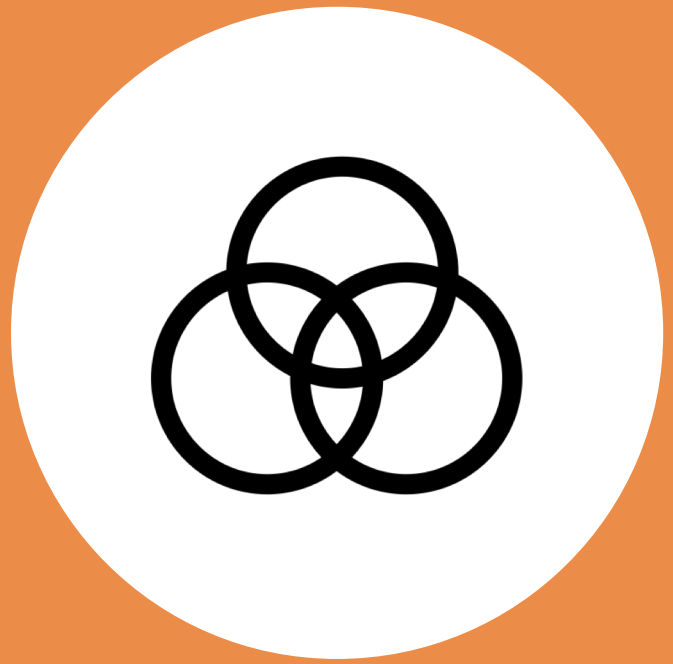
Areal Rainfall Estimation Method

Trustworthy Rainfall Estimate

Reputation **S**ystem for **C**rowdsourced **R**ainfall **N**etworks

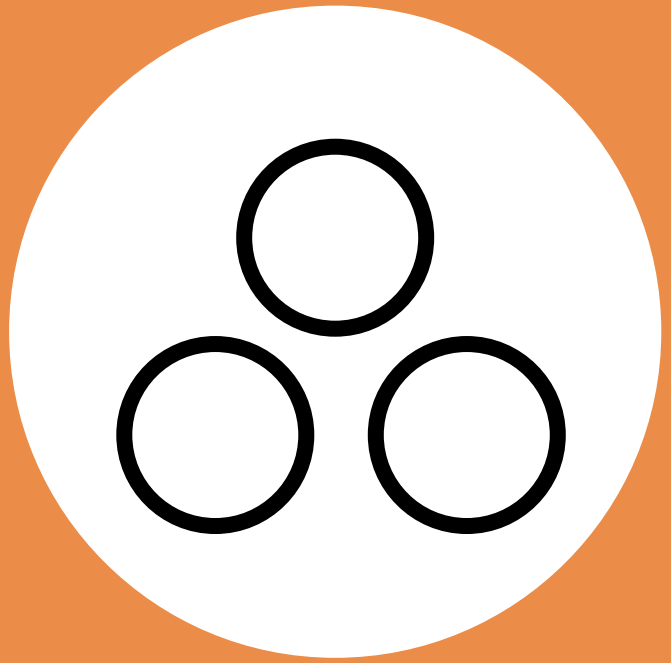


Cluster



Consensus

Score



Cluster

Consensus

Score

Cluster

Partition PWSs into groups that report similar data

Method: *k-Means*

Input:

- Latitude
- Longitude
- Elevation

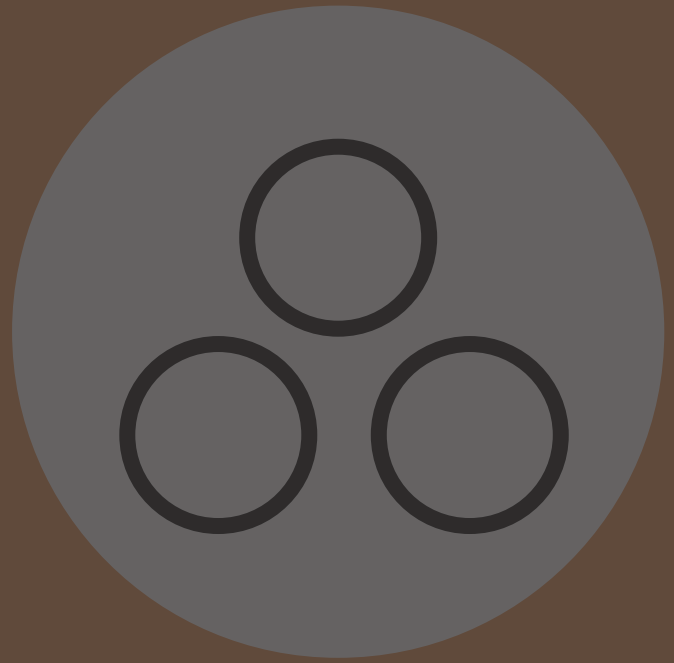
Cluster

Partition PWSs into groups that report similar data

Method: *k-Means*

Input:

- Latitude
- Longitude
- Elevation



Cluster

Consensus

Score

Consensus

Find the consensus and the deviation from the consensus within the cluster

Method: *Robust Averaging*

Simple Average (t) = 35.9

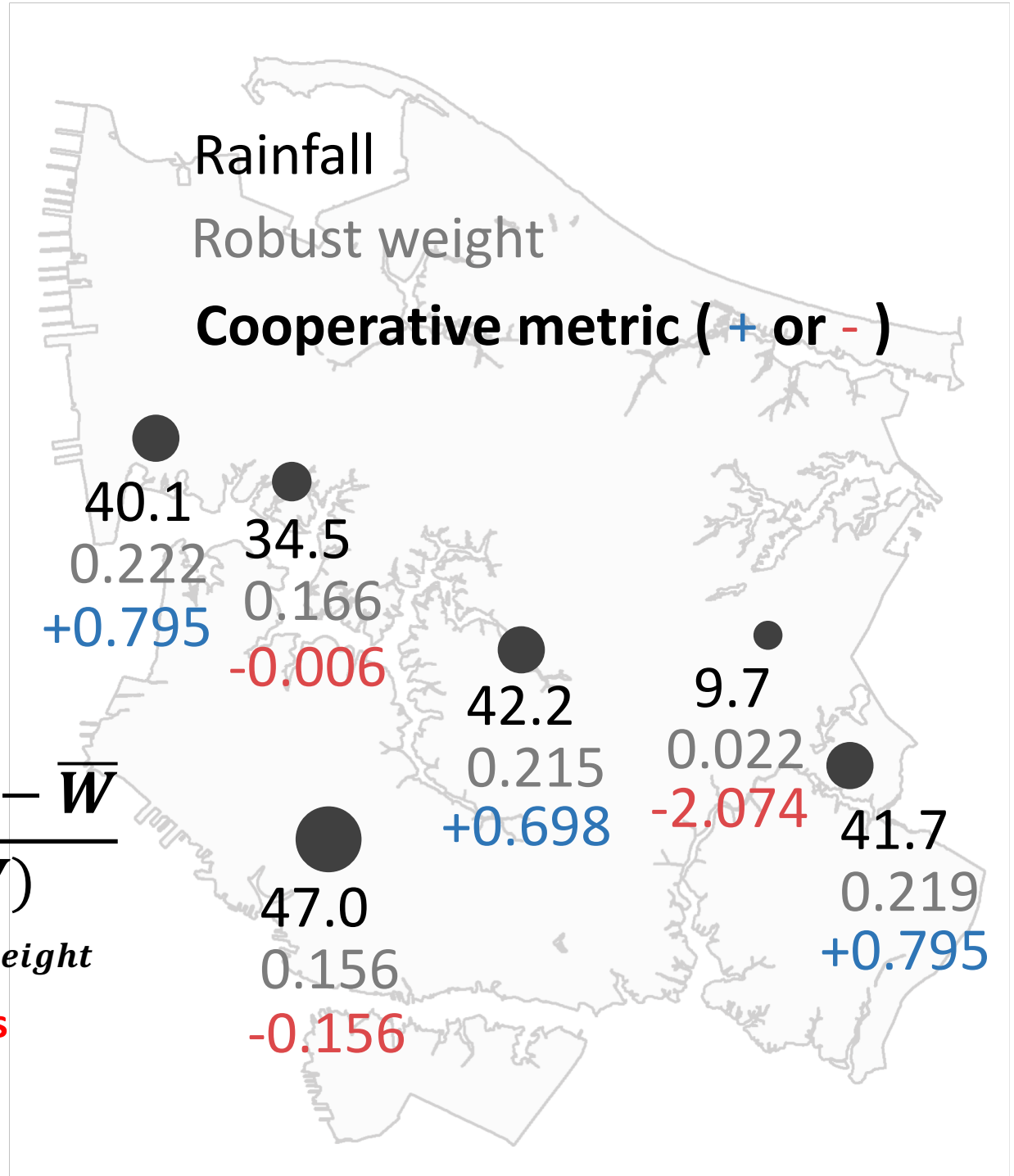
Robust Average (t) = 40.4

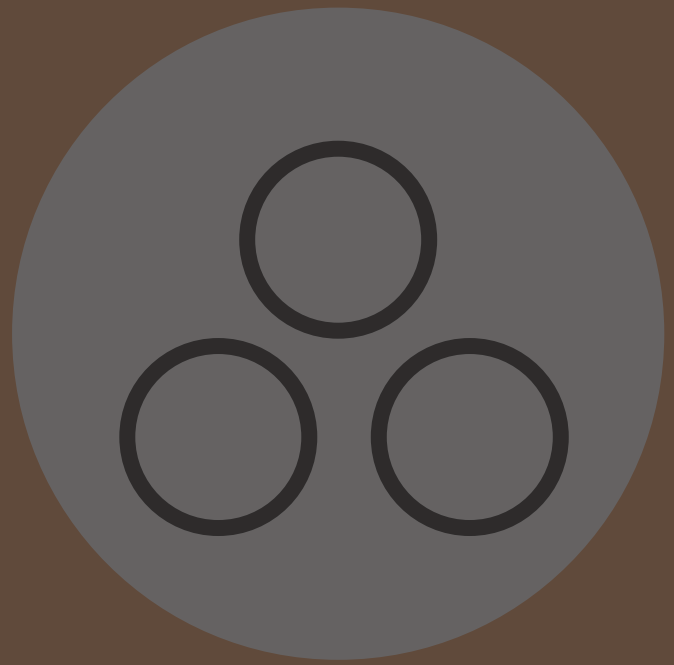
Cooperative metric $C_i(t) = \dfrac{W_i(t) - \overline{W}}{\sigma(W)}$

$W_i(t)$: *robust weight* $\overline{W}$: *average weight* $\sigma(W)$: *std weight*

Cooperative behaviors $C_i(t) > 0$

Non-cooperative behaviors $C_i(t) < 0$





Cluster

Consensus

Score

Score:

Manages and represents reputation information

Method: *Beta Reputation System*

$$f(p|\alpha,\beta)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}p^{\alpha-1}(1-p)^{\beta-1}$$

$$\text{TS(Trust Score)}\sim \text{E}(p|\alpha,\beta)=\frac{\alpha}{\alpha+\beta}$$

Initial neutral trust score

$$TS_{t=0}=10\times\text{E}(\text{p}|1,1)=5.0$$

Input: Cooperative metric

$If\ C_t>0$

$$\alpha_{t+1}=\alpha_t\times ff+C_t\ ,\qquad \beta_{t+1}=\beta_t\times ff$$

$If\ C_t<0$

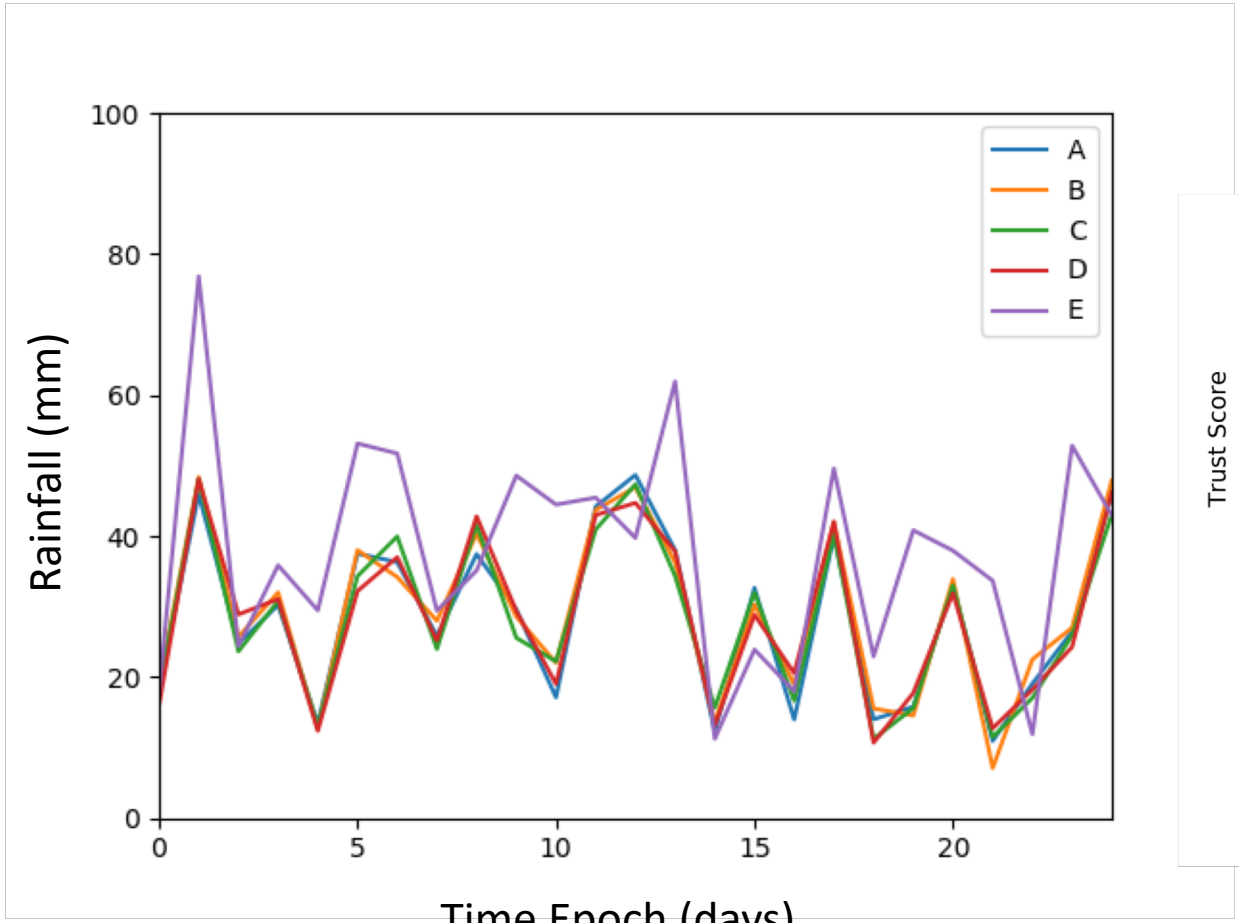
$$\alpha_{t+1}=\alpha_t\times ff\ ,\qquad \beta_{t+1}=\beta_t\times ff+|C_t|$$

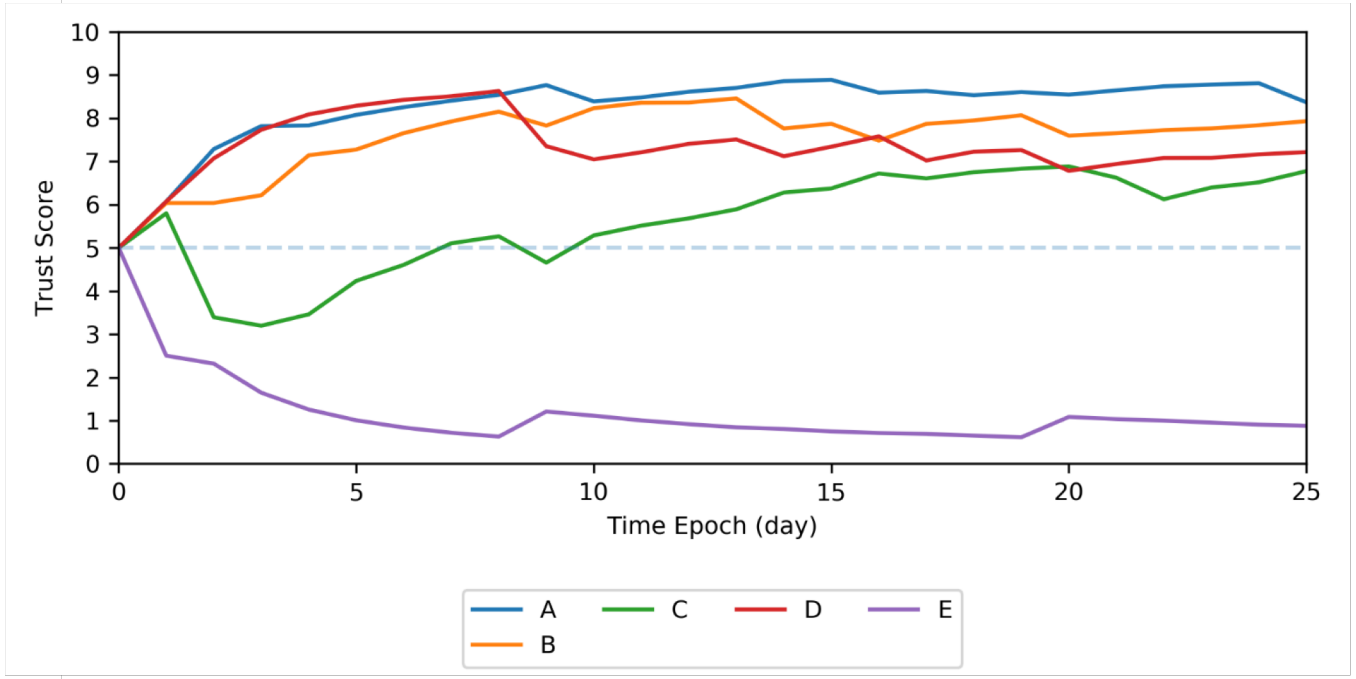
$$Forgetting\ Factor(ff):\ 0\le ff\le 1$$

Output: Trust score

$$TS_t=10\times E(p)=\frac{\alpha_t}{\alpha_t+\beta_t}$$

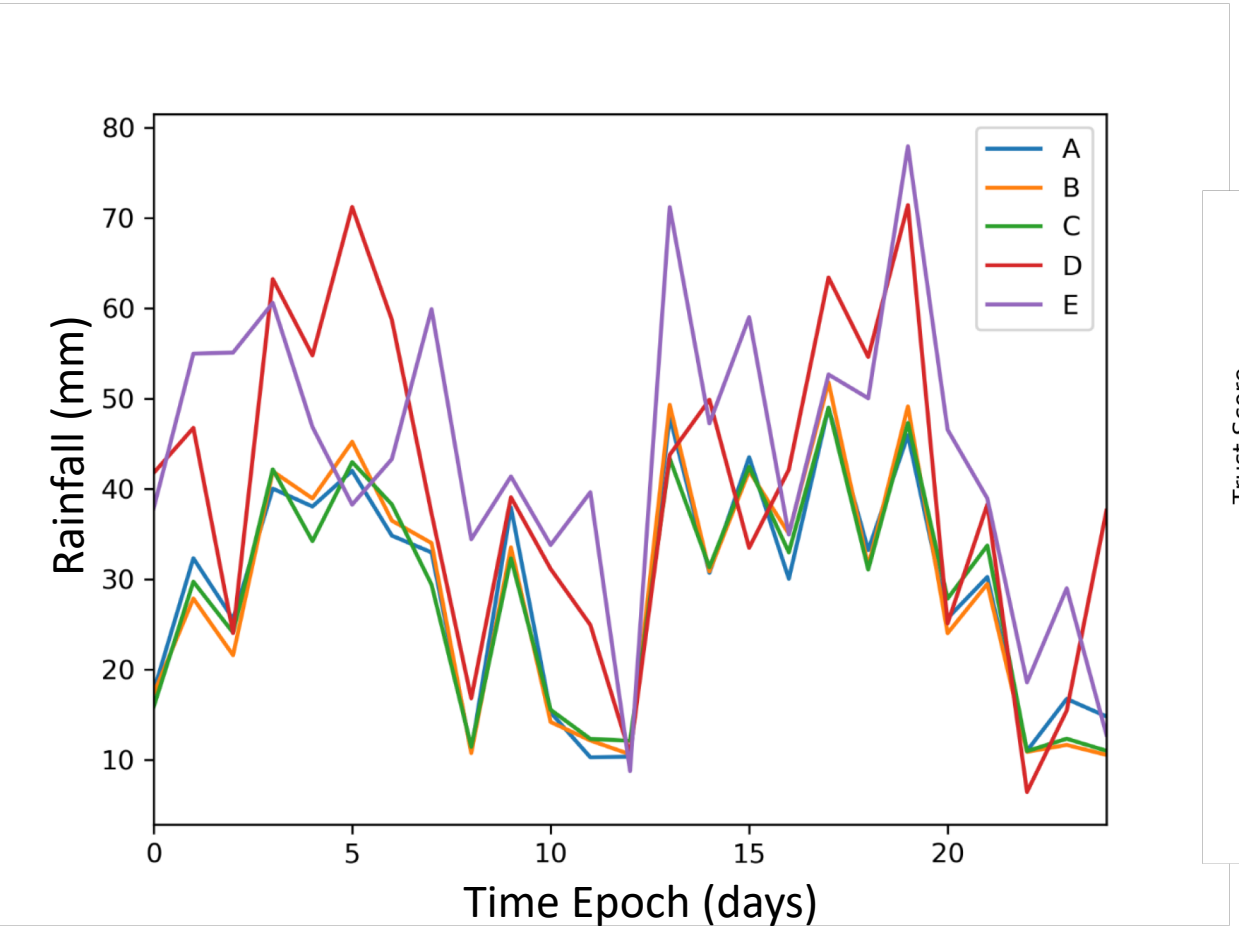
$$TS_{t+1}=10\times E(p)=\frac{\alpha_{t+1}}{\alpha_{t+1}+\beta_{t+1}}$$

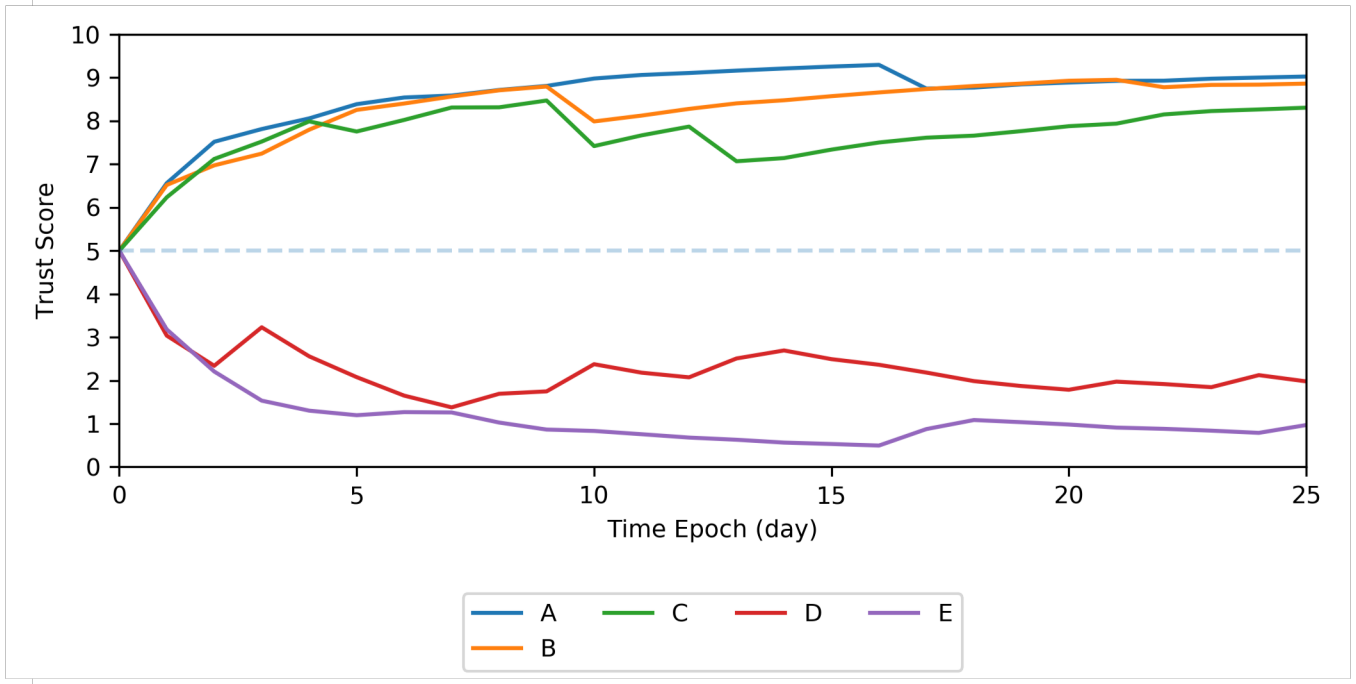




4 trustworthy vs.
1 untrustworthy PWS

Trust score evolution



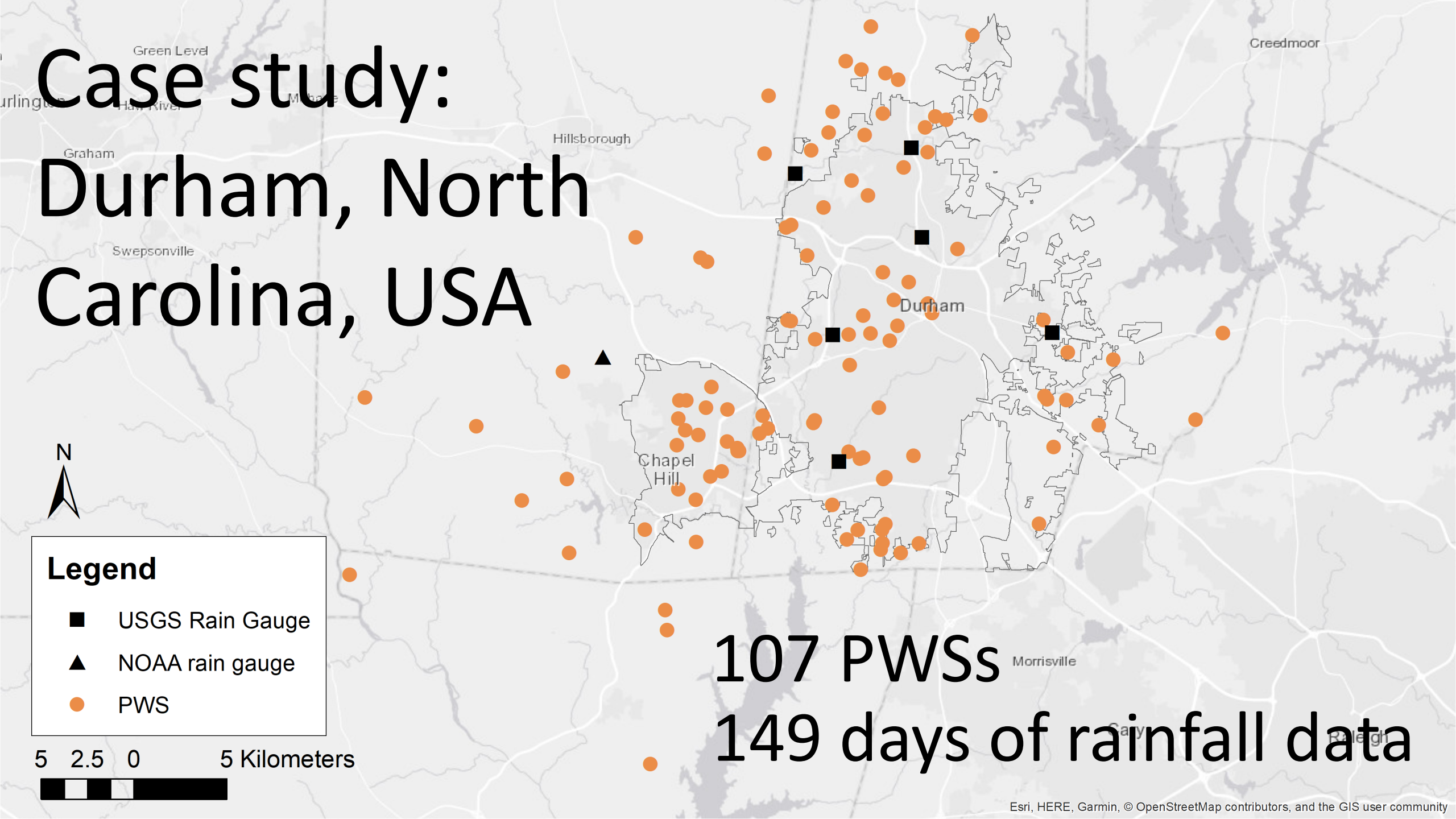


3 trustworthy vs.
2 untrustworthy PWSs

Trust scores evolution

Reputation System Results

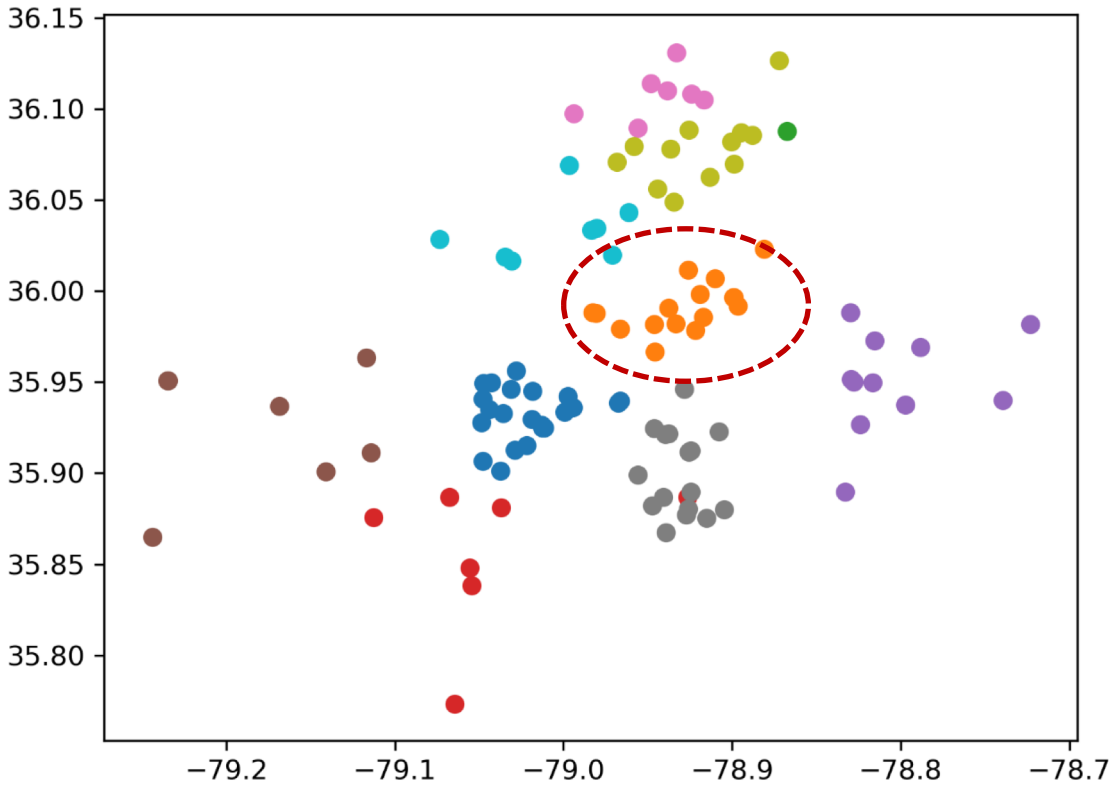
Case study: Durham, North Carolina, USA

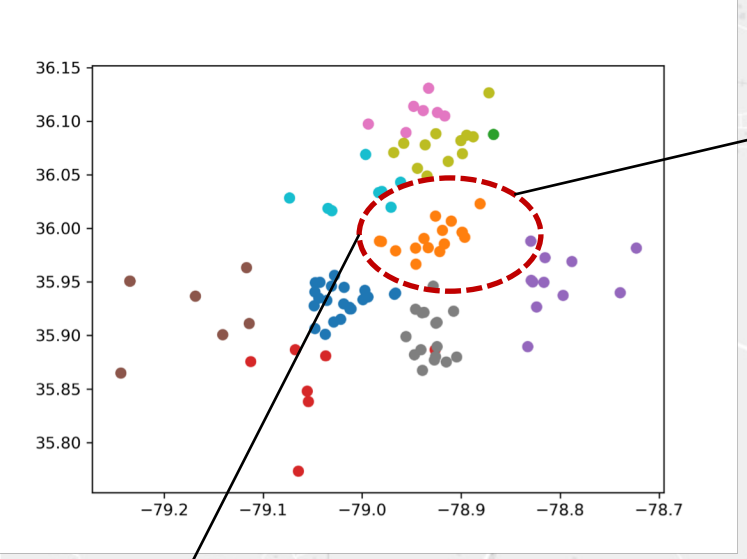


107 PWSs

149 days of rainfall data

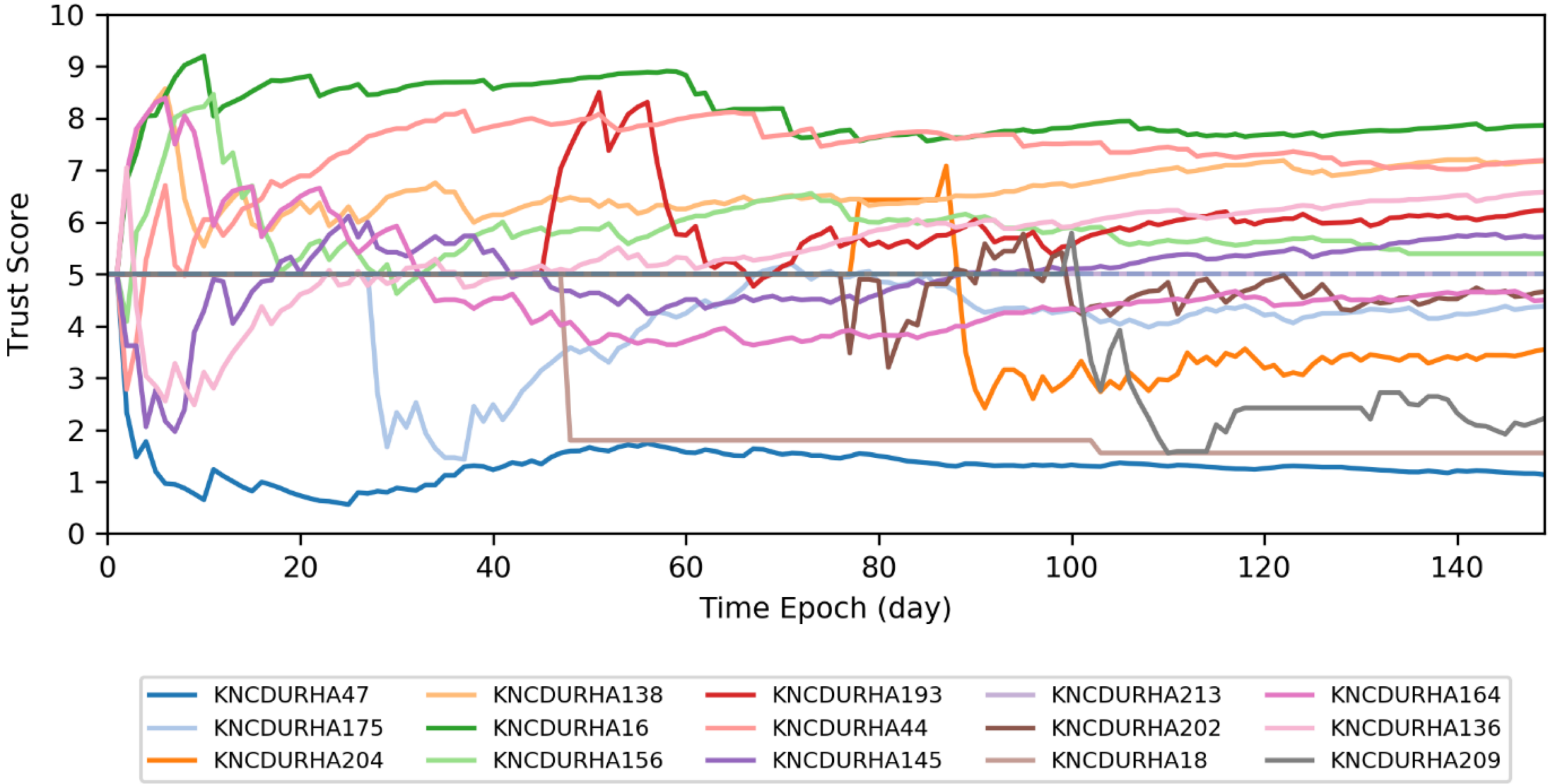
K-Means cluster using **longitude, latitude, and elevation**





KNCDURHA156
KNCDURHA202
KNCDURHA44
KNCDURHA209
KNCDURHA18
KNCDURHA213
KNCDURHA138
KNCDURHA175
KNCDURHA204
KNCDURHA136
KNCDURHA164
KNCDURHA16
KNCDURHA47
KNCDURHA145
KNCDURHA193

1 0.5 0 1 Kilometers


Trust Score
Time Epoch (day)
0
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
KNCDURHA47
KNCDURHA175
KNCDURHA204
KNCDURHA138
KNCDURHA16
KNCDURHA156
KNCDURHA193
KNCDURHA44
KNCDURHA145
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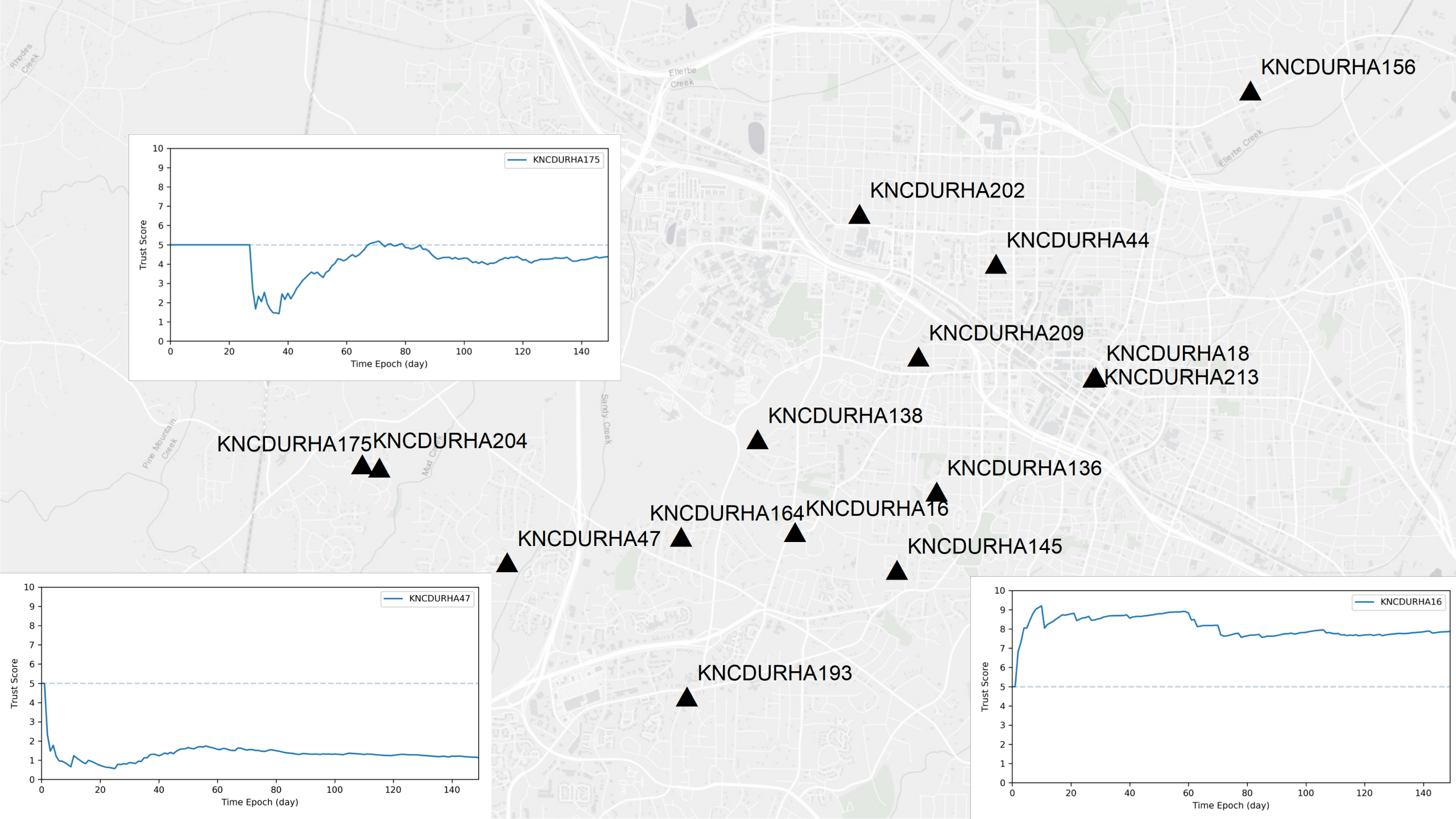
KNCDURHA156
KNCDURHA202
KNCDURHA44
KNCDURHA209
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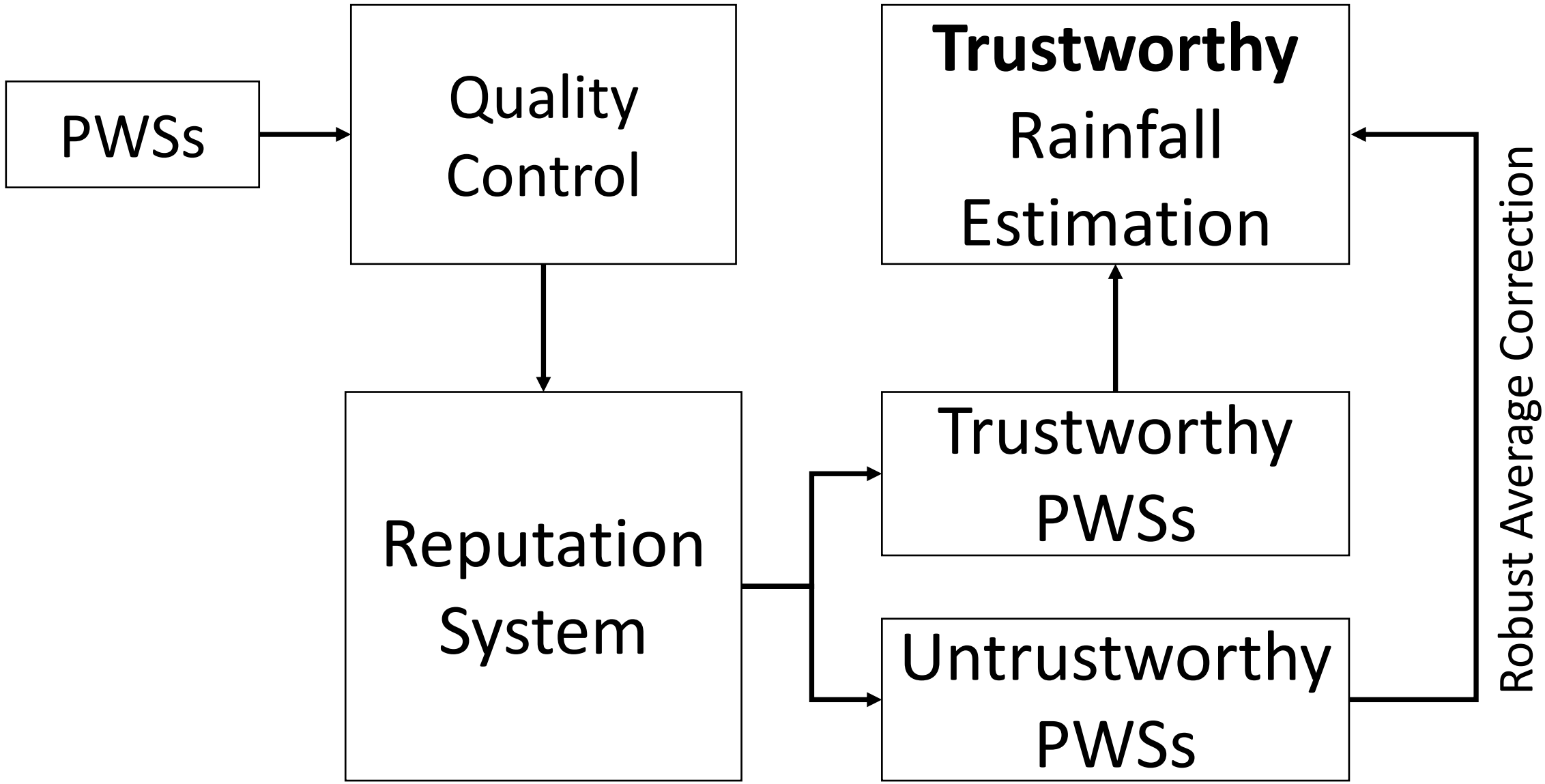
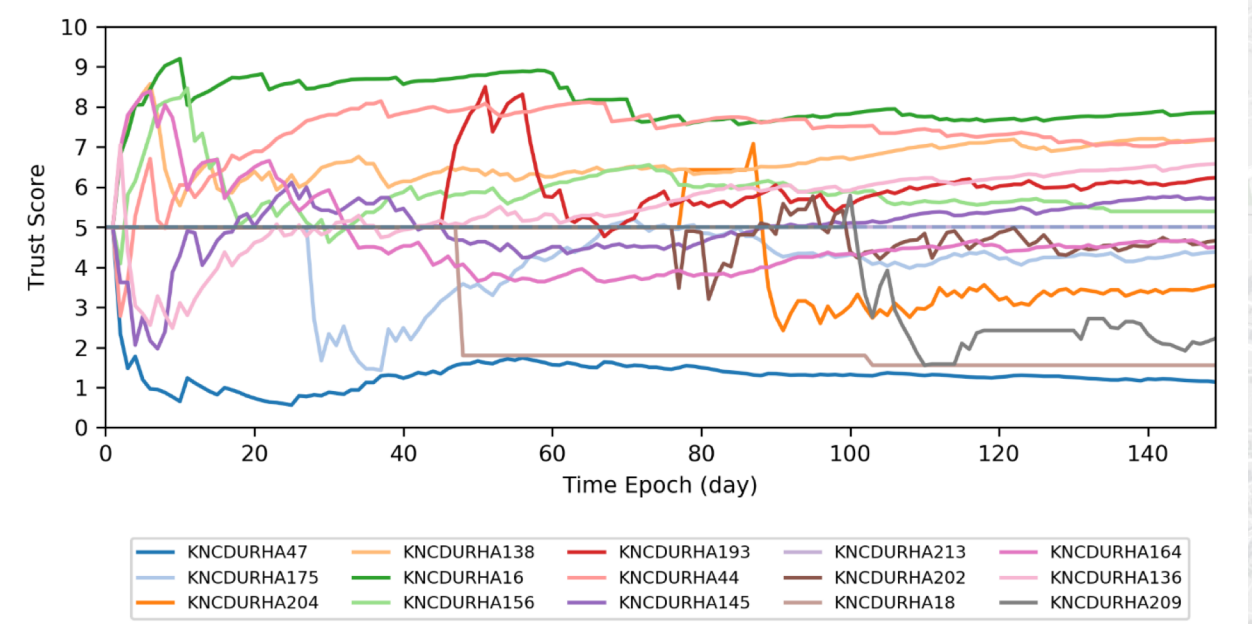
KNCDURHA204
KNCDURHA136
KNCDURHA164
KNCDURHA16
KNCDURHA47
KNCDURHA145
KNCDURHA193
KNCDURHA175
Trust Score
Time Epoch (day)
KNCDURHA47
Trust Score
Time Epoch (day)
KNCDURHA16
Trust Score
Time Epoch (day)

Trustworthy Rainfall Estimates


PWSs
Quality Control
Trustworthy Rainfall Estimation
Reputation System
Trustworthy PWSs
Untrustworthy PWSs
Robust Average Correction

2018/07/29 Trust Score



5.56

4.53

7.34

2.94

5.00

1.56

6.90

6.15

4.12

3.10

7.95

4.42

5.19

1.35

5.83

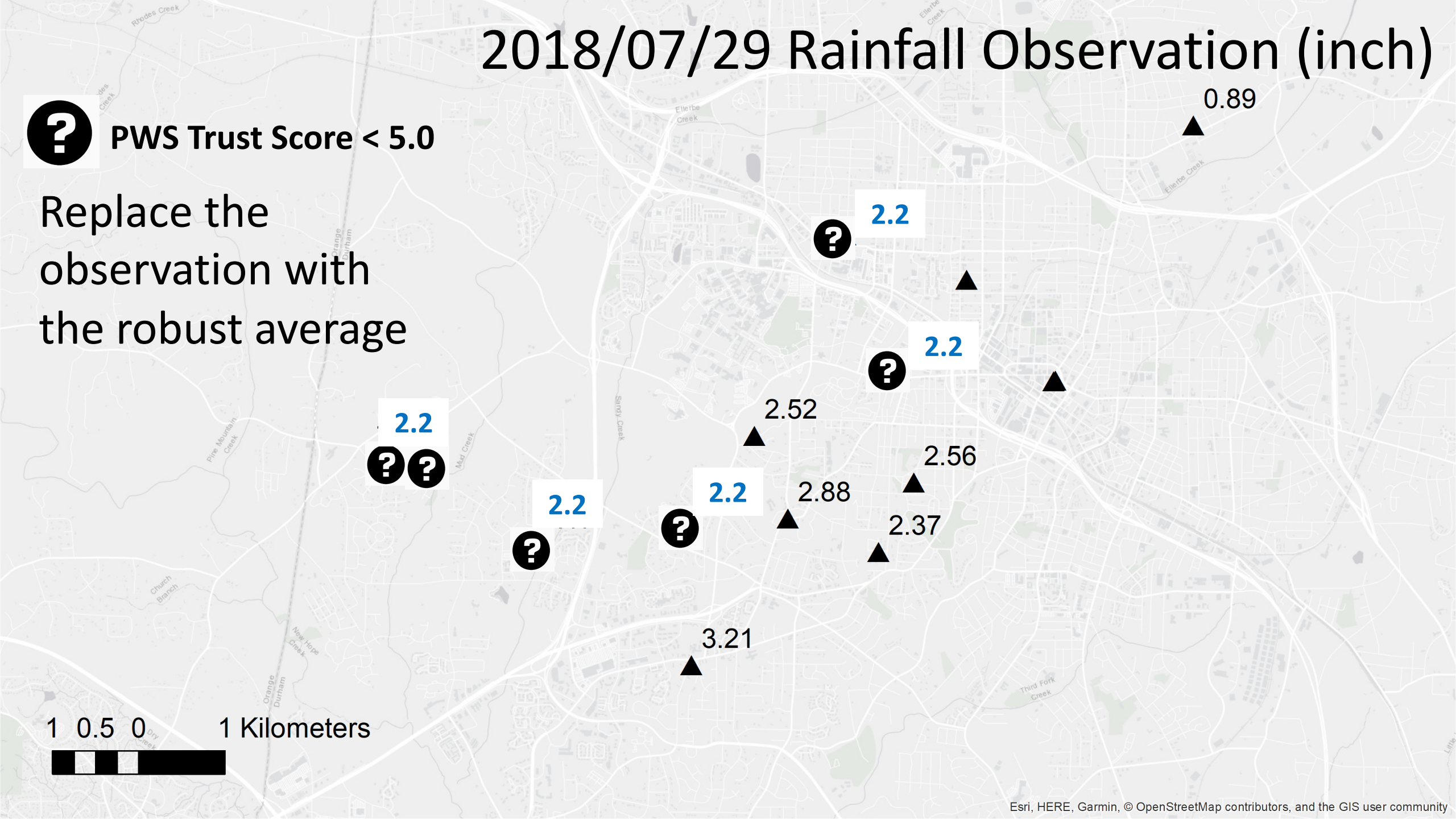
1 0.5 0 1 Kilometers

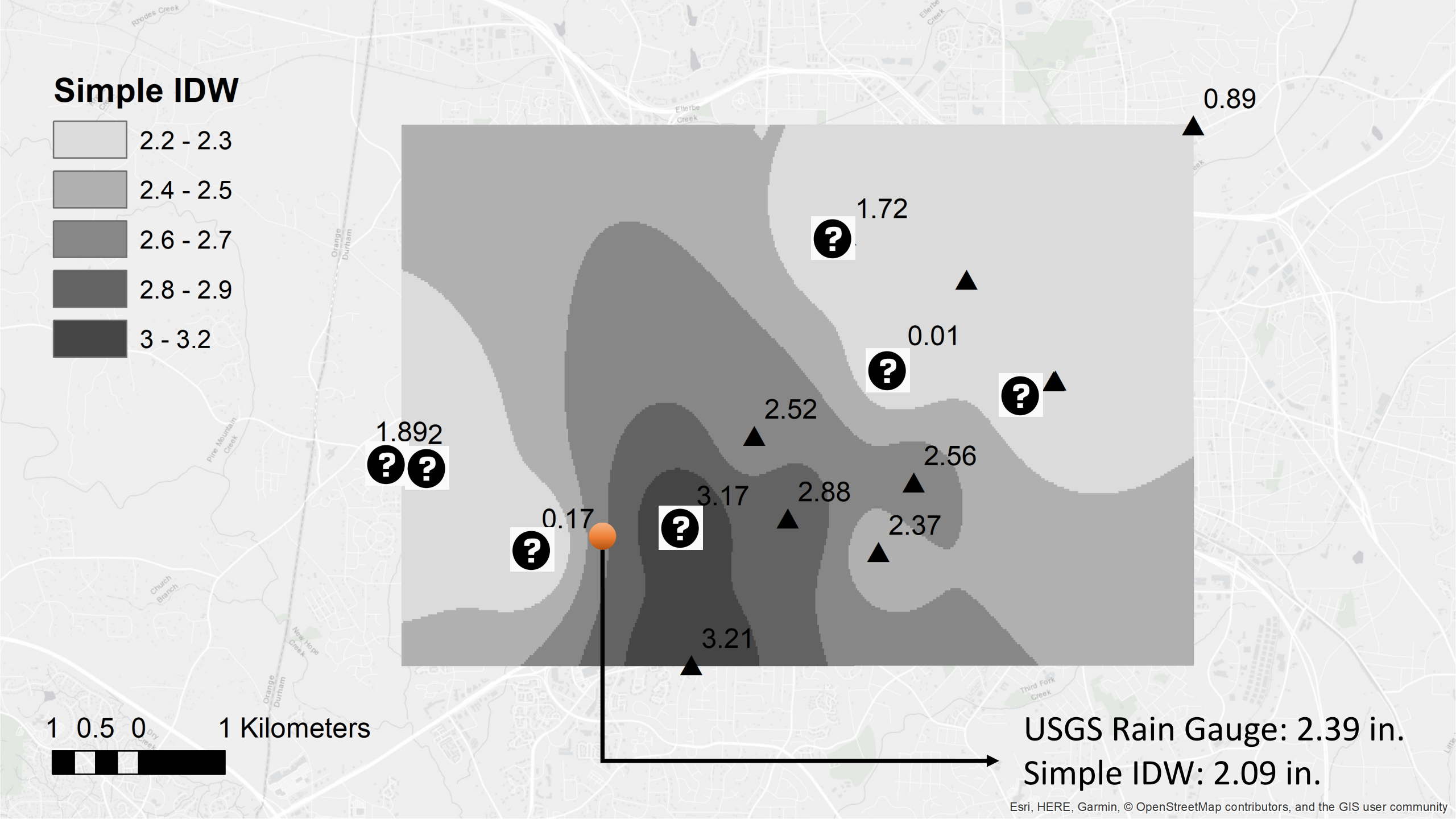
PWS Trust Score < 5.0

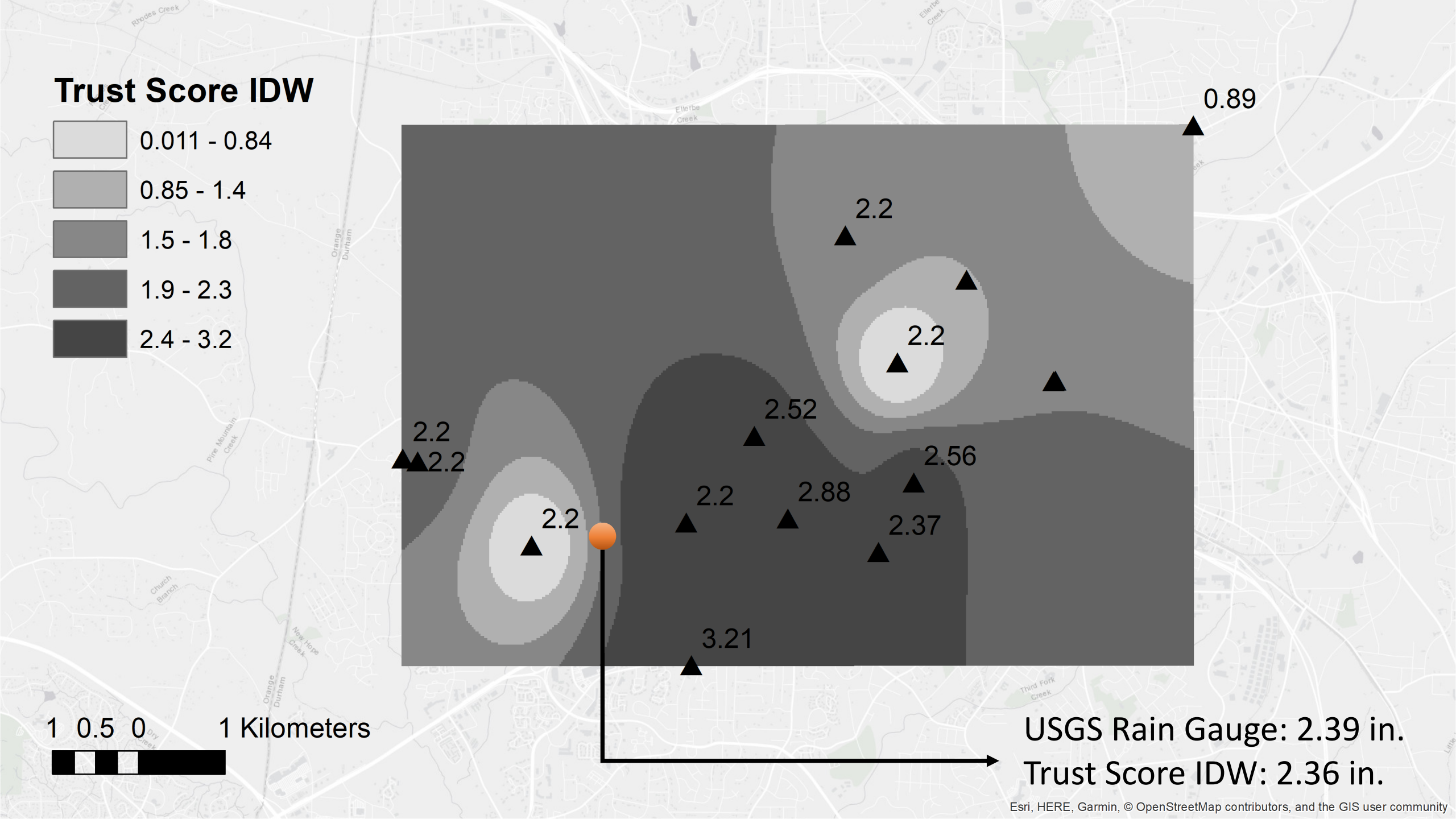
2018/07/29 Rainfall Observation (inch)

PWS Trust Score < 5.0

Replace the observation with the robust average




Simple IDW
2.2 - 2.3
2.4 - 2.5
2.6 - 2.7
2.8 - 2.9
3 - 3.2
0.89
1.72
0.01
2.52
1.892
2.56
3.17
2.88
0.17
2.37
3.21
1 0.5 0
1 Kilometers
USGS Rain Gauge: 2.39 in.
Simple IDW: 2.09 in.
Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community


Trust Score IDW
0.011 - 0.84
0.85 - 1.4
1.5 - 1.8
1.9 - 2.3
2.4 - 3.2
0.89
2.2
2.2
2.52
2.2
2.2
2.56
2.2
2.88
2.2
2.37
3.21
1 0.5 0 1 Kilometers
USGS Rain Gauge: 2.39 in.
Trust Score IDW: 2.36 in.
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All 149 Days

Method	RMSE(in)
Simple IDW	0.313
Trust Score IDW	0.225

Days with rainfall > 1 in

Method	RMSE(in)
Simple IDW	0.611
Trust Score IDW	0.361

Conclusion

- Crowdsourced PWSs are filling in data gaps of agencies data but introduce trust gap for utilizing them
- A reputation system method can effectively bridge this trust gap by evaluating the trustworthiness of the crowdsourced PWSs
- Using trustworthy rainfall estimate method can improve the knowledge of rainfall patterns in areas with dense PWSs

Questions?

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UVA Hydroinformatics Group
https://uvahydroinformatics.org

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