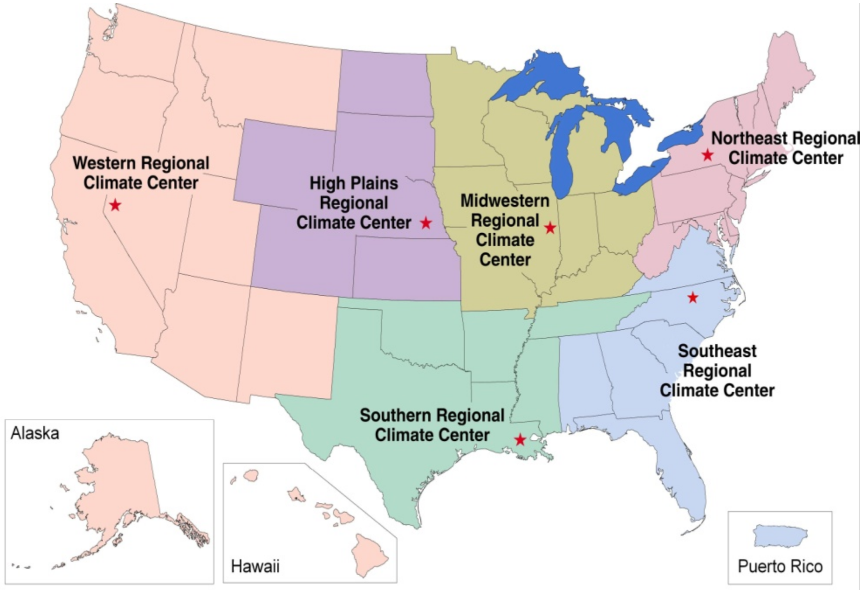
Radar and Multi-sensor Precipitation Estimates in the Midwest

Nancy Westcott
Illinois State Water Survey
Midwestern Regional Climate Center
Institute of Natural Resource Sustainability
University of Illinois

Midwestern Regional Climate Center

Illinois State Water Survey

- One of six NOAA Regional Climate Centers
- Goals
  - Increase value and usage of currently available climatic information
  - Coordinate data from regional and state data networks
  - Develop special and regional climate databases
  - Serve as a clearinghouse for climate information



Climate data, information and applied research

- **Agriculture**
- **Climate change**
- **Energy**
- **Environment**
- **Human health**
- **Risk management**
- **Transportation**
- **Water resources**

Radar Basics

- Transmitter, receiver, antenna, display system (developed just before WWII; deployed US late 50's)
- WSR-88D (NEXRAD radars) 10-cm wavelength radio beams traveling at the speed of light
- Beam spirals upwards in a regular way every 2-5 minutes to get a 3-dimensional view of echoes (storms)
- (1º beam, searchlight conical shape)

  At 60 km, 1º beam = 1 km wide (3000 ft)

  At 120 km, 1º beam = 2 km wide
- Along the beam, sample at 250 m to 1 km intervals.

Reflection from Drops

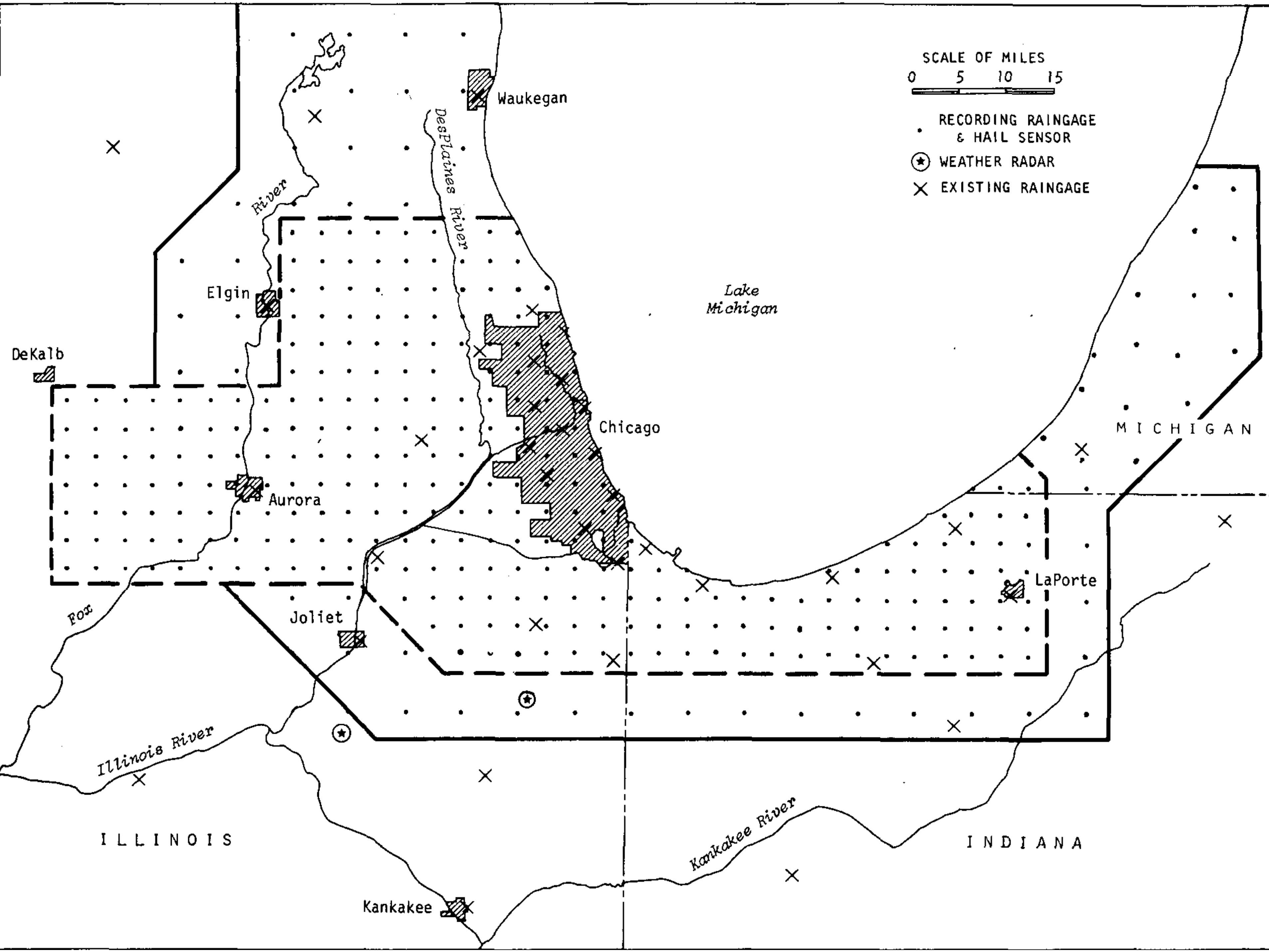
- Reflectivity, Z, measured by radar (signal reflected from the hydrometeors within the beam)
- Backscatter from all hydrometeors in the volume: Reflectivity (power) related to the of the sum of the diameter of the hydrometers to the 6^{th} power, $Z = \sum \mathbf{nD^6}$ **,** for hydrometeors < 10 cm.
- Hydrometeors usually follow a skewed distribution, lots of little ones, fewer big ones.
- Z also elated to characteristics of the radar.

Reflectivity and Precipitation

- $Z = \sum \mathbf{nD^6}$ – empirically derived; originally drop cameras in various regions of country and different seasons. Now digital methods of measuring hydrometeor size and shape.
- To get to rainfall, effective Z/R relationships, use raingage measurement of precipitation (1970s a radar and over 300 gages spaced every 5 miles in Chicago and Cook Co. to develop a relationship):
- $Z_e = A\ R^b$

  $Z_e = 300\ R^{1.4}$, convective rain $Z_e = 600\ R^{2.0}$, snow

  $Z_e = 100\ R^{1.6}$, stratiform rain



SCALE OF MILES
0 5 10 15
RECORDING RAINGAGE & HAIL SENSOR
WEATHER RADAR
EXISTING RAINGAGE
Waukegan
DesPlaines River
River
Elgin
DeKalb
Lake Michigan
Chicago
MICHIGAN
Aurora
Fox
Joliet
LaPorte
Illinois River
ILLINOIS
Kankakee River
INDIANA
Kankakee

Size and Density important

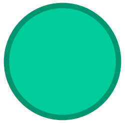
- Size
  - The larger or more plentiful the hydrometeors in the beam, the greater the reflectivity
- Ice vs water
  - water is denser that ice, so gives a larger signal
  - In spring and fall with frozen particles above and melted ones below – messy relationships.
- Up to now, shape has not been critical.

New Polarization Measurements

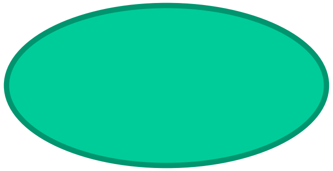
- Shape will be taken into account.

  Usually use only horizontal oriented waves or vertically oriented waves to measure reflectivity
- ZdR, transmitter alternates between both H and V waves and the difference is Z_{dr}.
- Estimated deployment: late 2011-2013

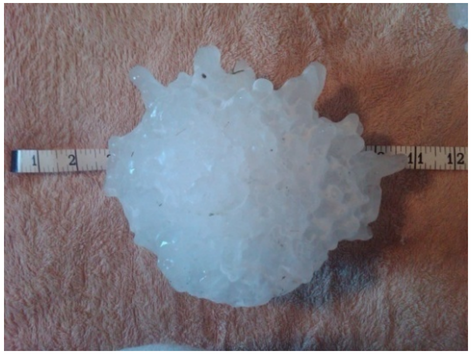
Hydrometeors



Small rain drop
(small Z_{dr})



Large raindrop
(large Z_{dr})



Hail / graupel
If spins
(small Z_{dr});
If melting
(large Z_{dr})

Snow
aggregate
(small Z_{dr})

Snow
crystal
(large Z_{dr})


1
2
11
12

New Precipitation Relationships

- being developed taking into account both reflectivity Z and polarization measurements.
- Polarization being added to WSR-88Ds in the near future (December 2011-2013).
- Regardless because drop spectra change with and between storms, radar parameters varies within storms, over time, by season and region.

MPE

- Multi-sensor Precipitation Estimates = Radar + Gage

NWS Real-Time Coop Daily Gages In Midwest

- ~ 750 gages in 530 of 858 Midwest counties
- ~**0.9 gage** / county (1/1,600 km^2)
- Not ideal

MPE info

- Obtain GIS shape file for daily data or netcdf file (from NWS): 24 hour data – manually QCed.
- Archived data 1,6, 24 hours, from 2002 to present from Codiac Dataset – UCAR.
- MPE Data best 24 hours after valid, when all available gages have been used to adjust radar or MPE

National Weather Service

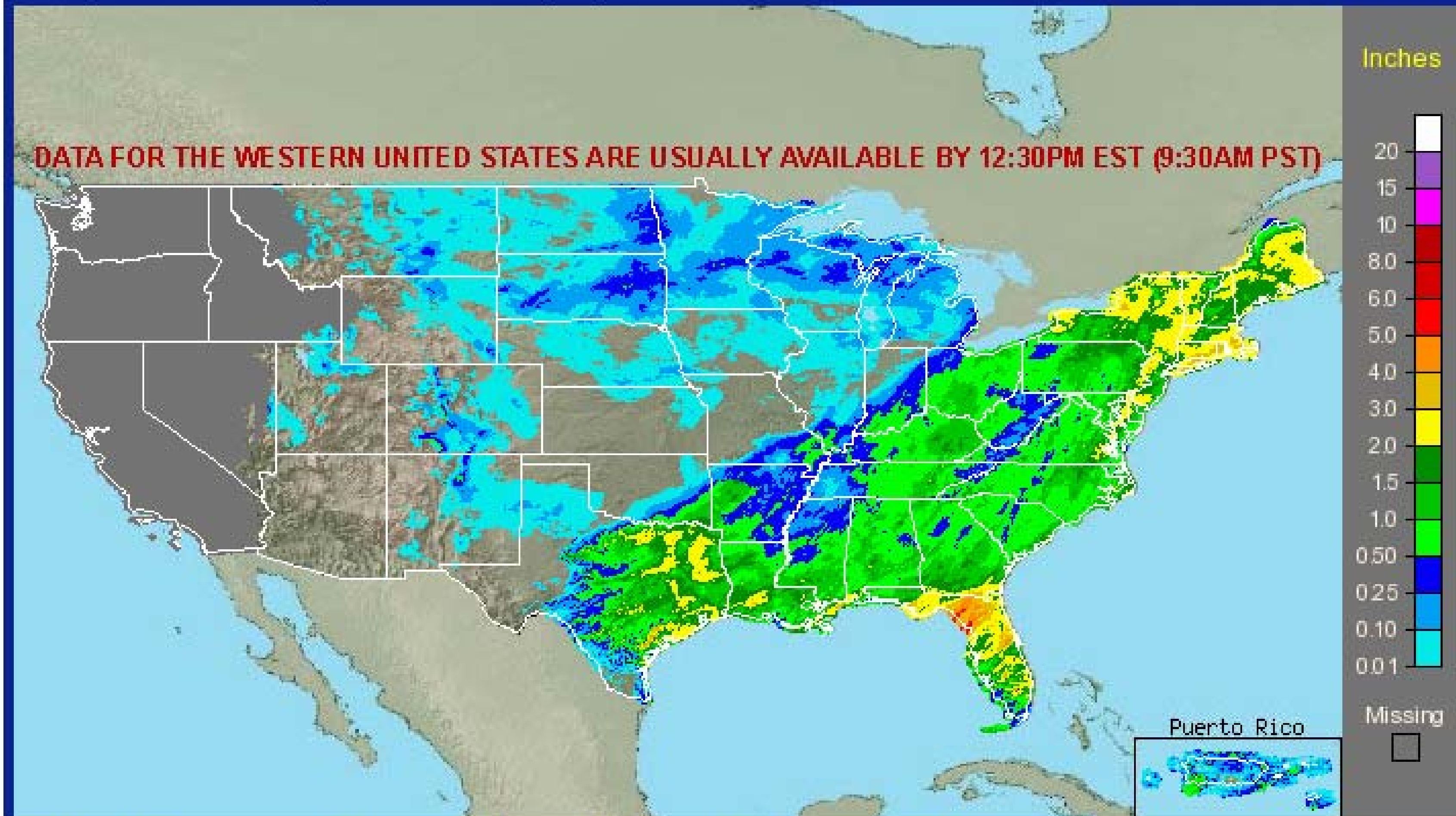
Precipitation Analysis

Local weather forecast by "City, St" or zip code City, St Go

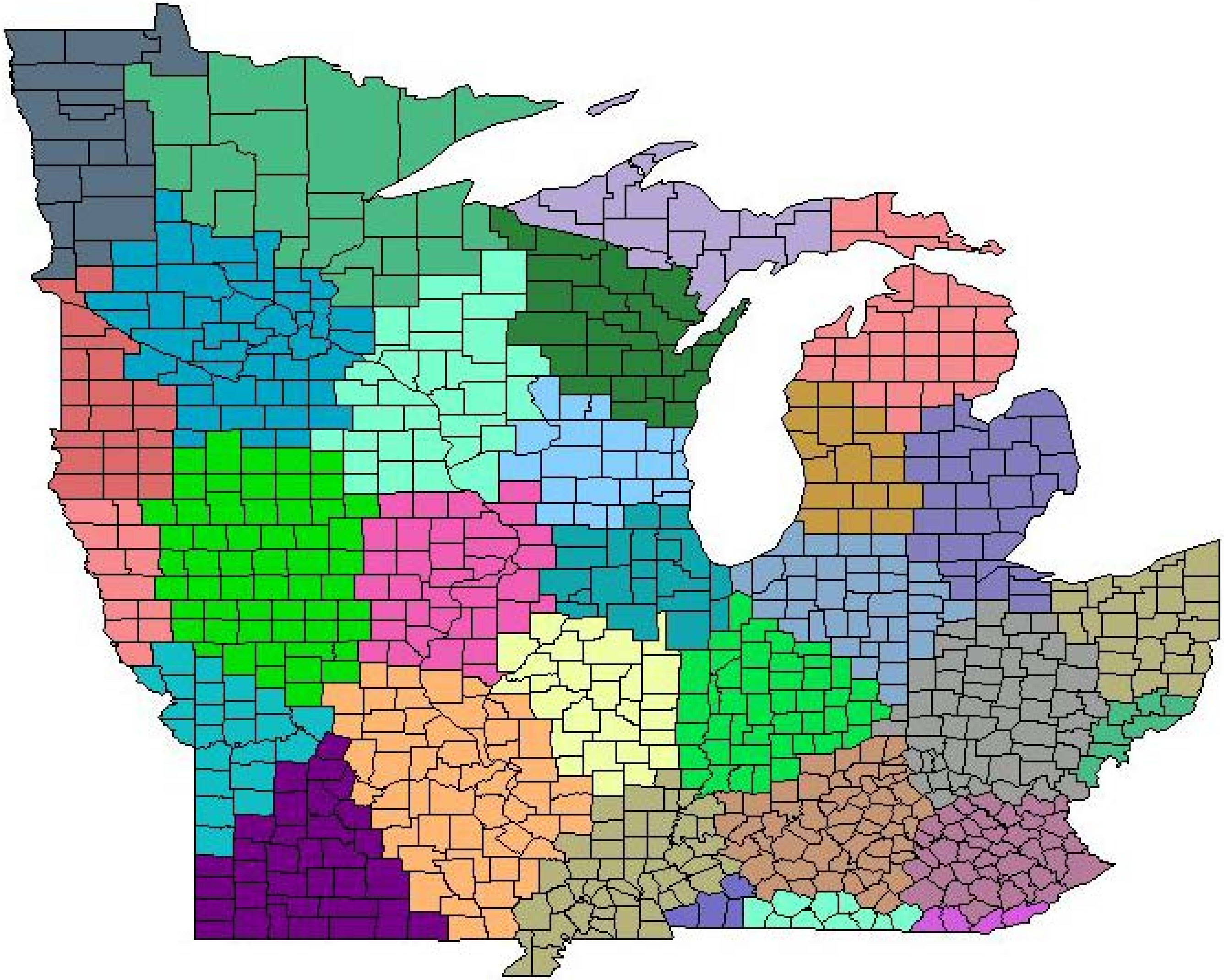
Images | Download | About NWS Precip Analysis | Other Useful Information | Survey & Feedback | Original Precip Analysis

Continental United States
7-Day Observed Precipitation - Valid 3/13/2008 1200 UTC

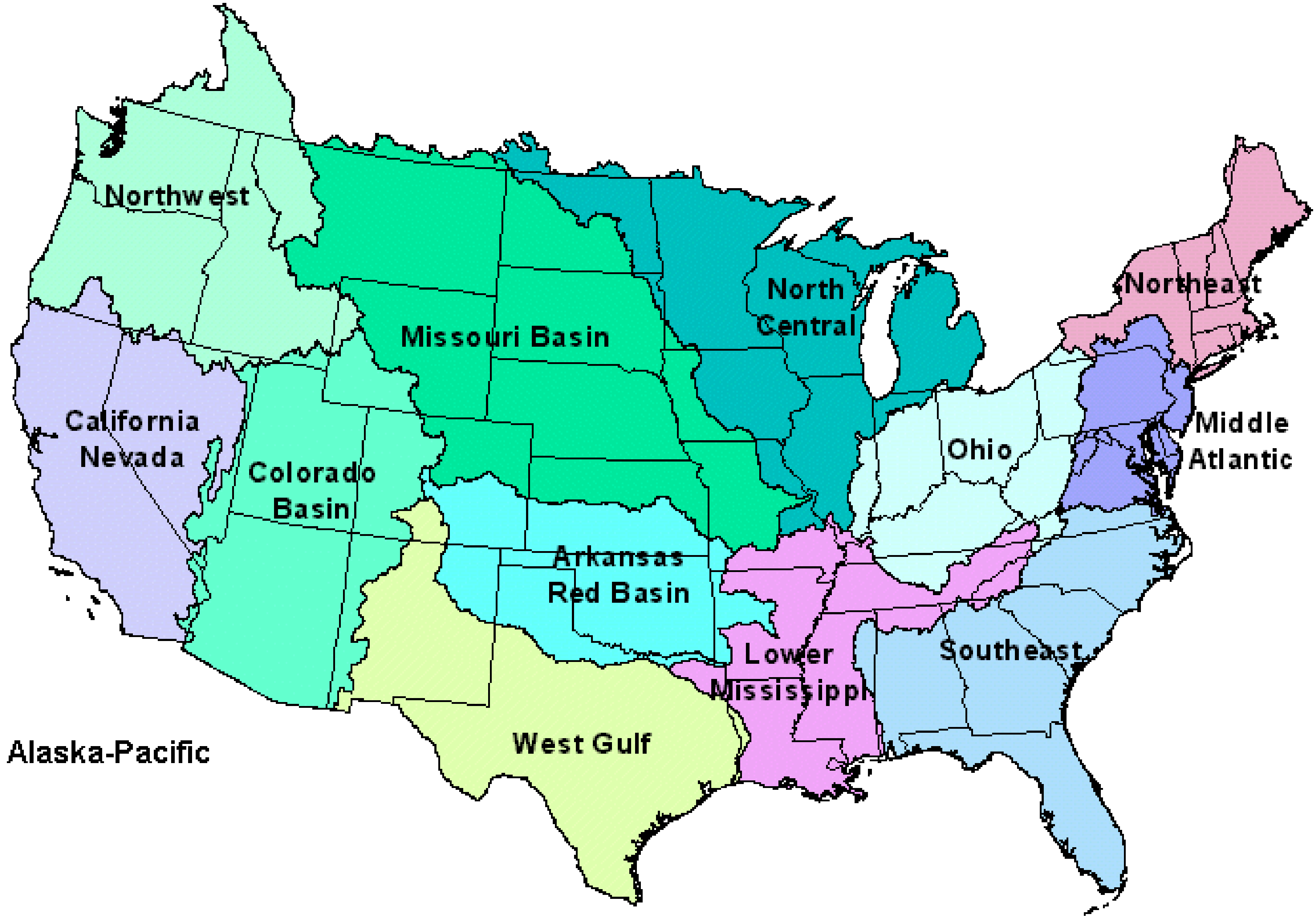
Click on the image to zoom in
Click on "States" to zoom out



Nexrad WSR-88D coverage



WHY USE NCEP / NWS GRIDDED DATA ?


Northwest
Missouri Basin
North Central
Northeast
California Nevada
Colorado Basin
Ohio
Middle Atlantic
Arkansas Red Basin
Lower Mississippi
Southeast
West Gulf
Alaska-Pacific

Feb 2002- Oct 2006
Gridded Precipitation Data

Stage III/IV MPE data

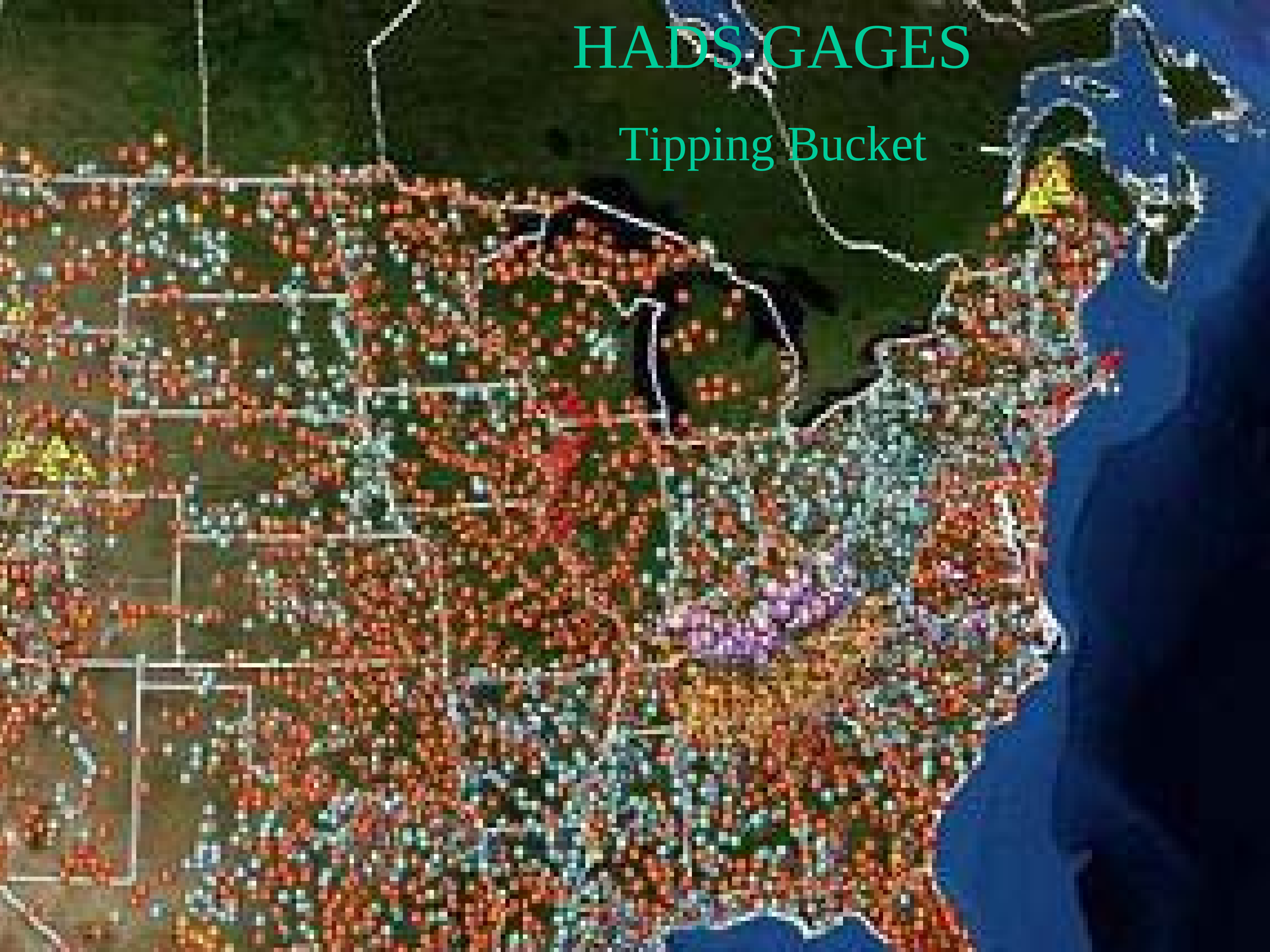
- Daily data valid at 12 GMT (6 CST)
- Mosaicked into National Grid
- 4 x 4 km grid cells
- new MPE algorithm since Feb 2002
- data manually QCed at RFCs

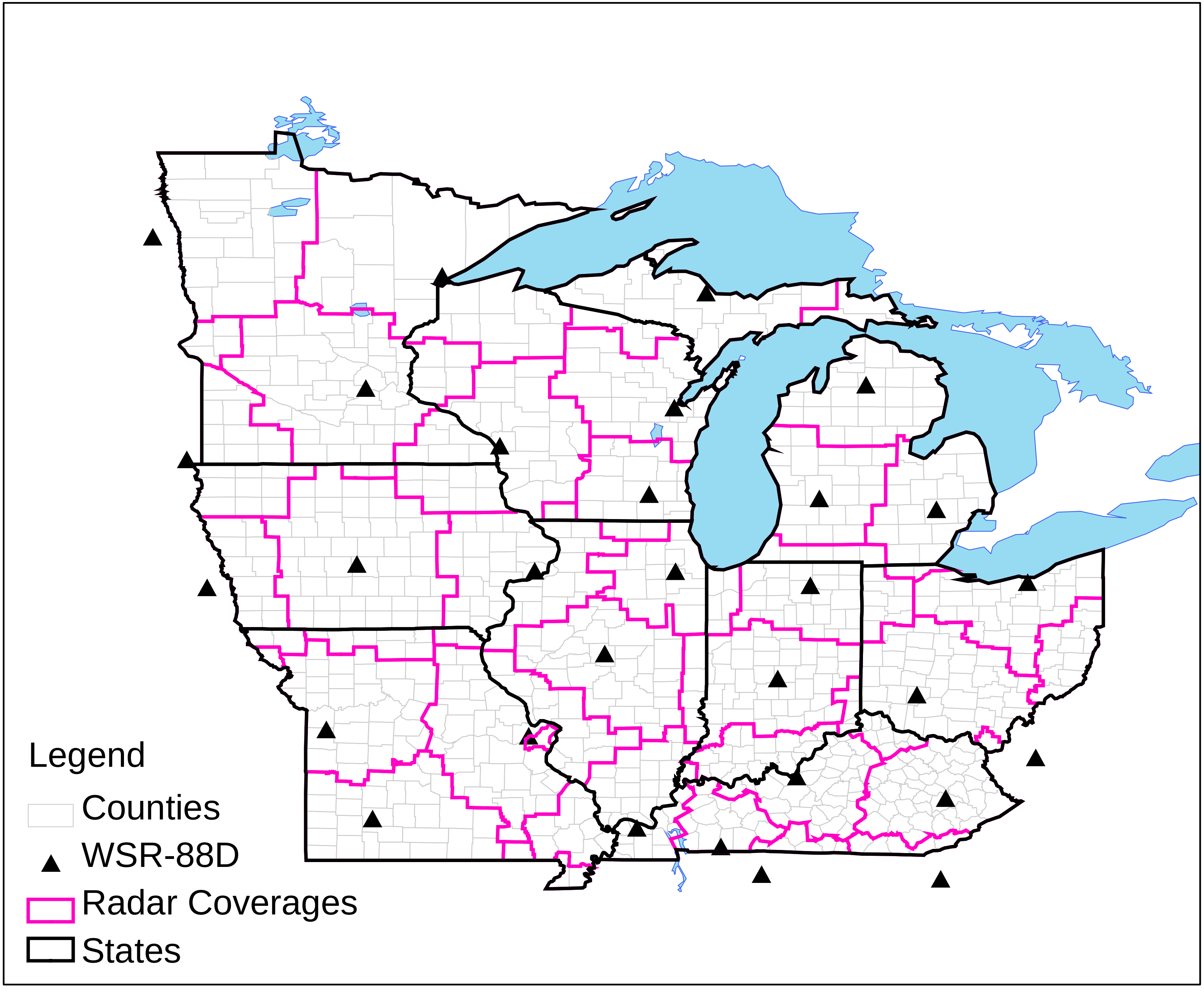
Monthly Time Scale

County Averages, 858 counties

HADS GAGES

Tipping Bucket





Legend
Counties
WSR-88D
Radar Coverages
States

NWS Quality-Controlled Coop Daily Gages in Midwest

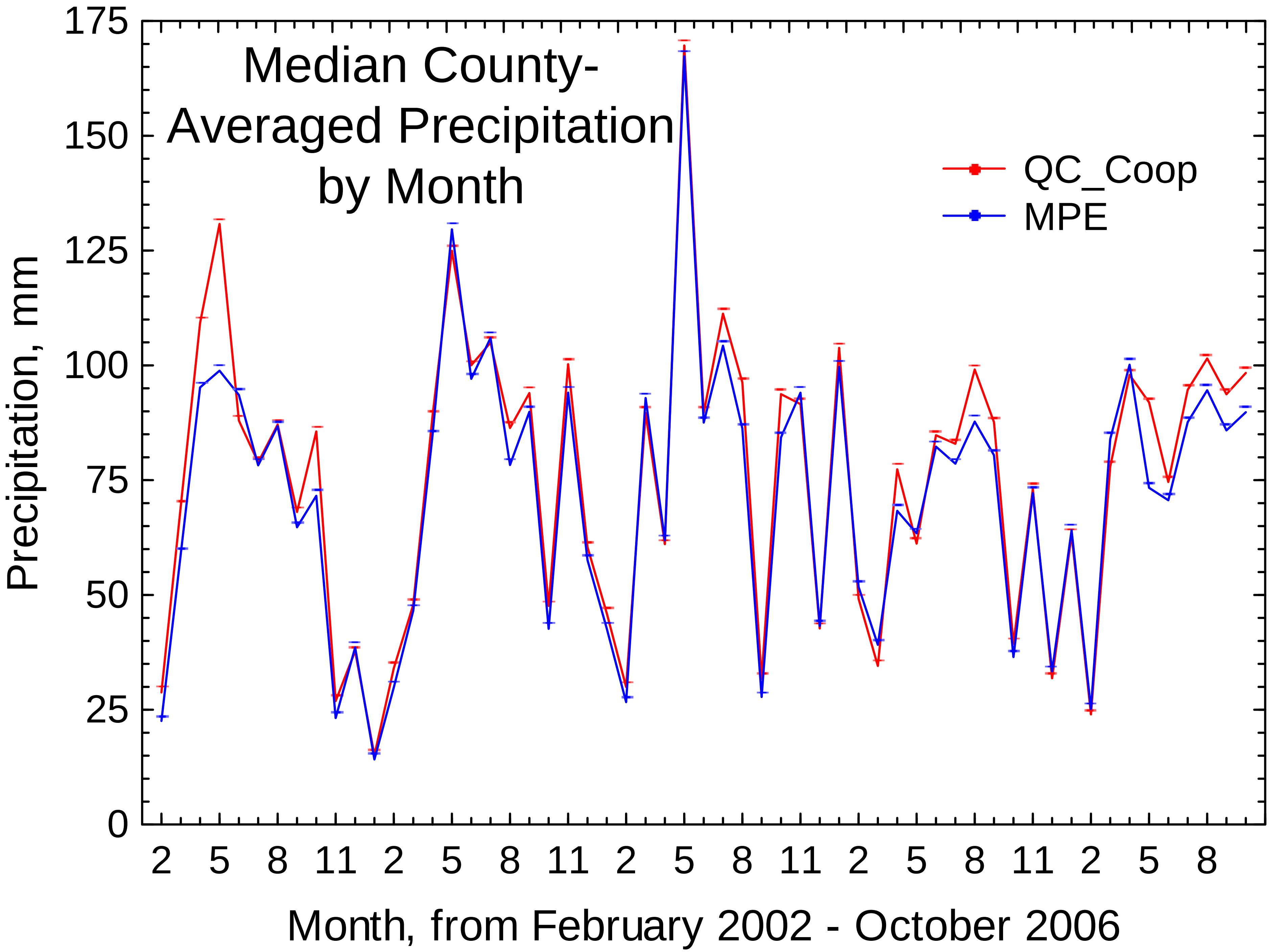
~ 1,500 gages in 775 counties

~ **2.2 gage** / county (1/800 km^2)

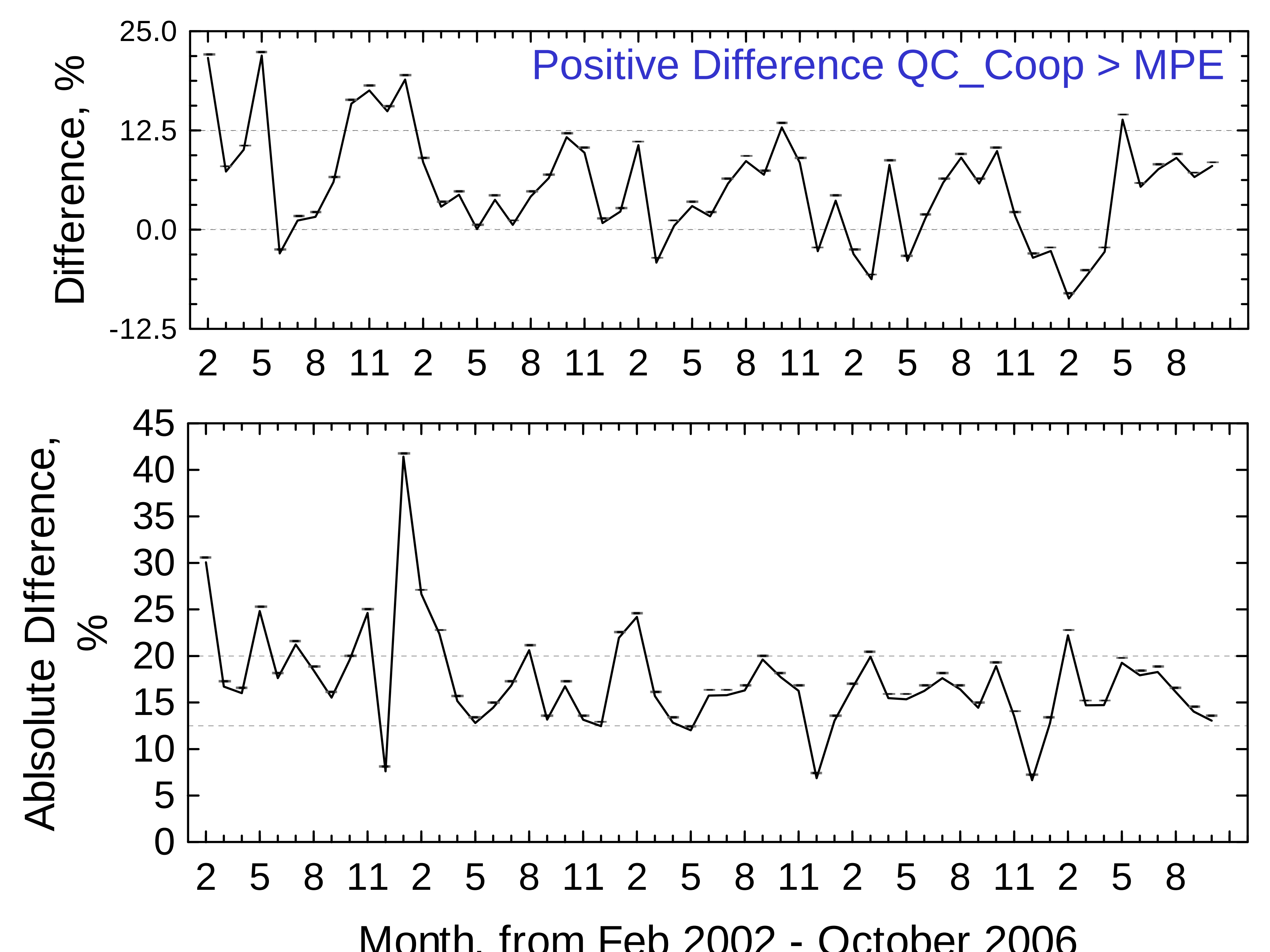
8” non-recording gages

Available ~3-4 months after-the-fact

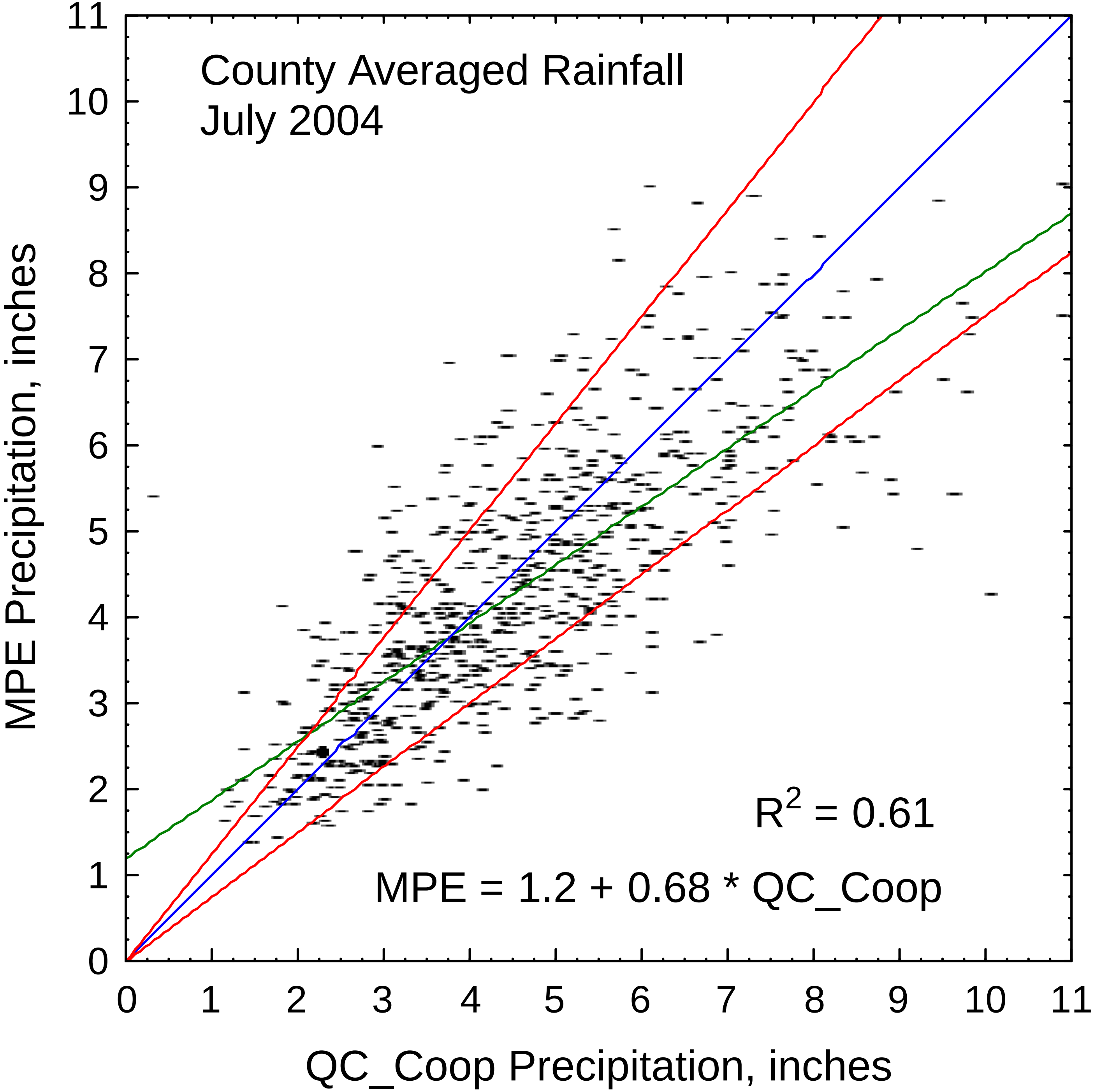
Reference standard



Median County-
Averaged Precipitation
by Month
QC_Coop
MPE
Precipitation, mm
175
150
125
100
75
50
25
0
2
5
8
11
2
5
8
11
2
5
8
11
2
5
8
11
2
5
8
Month, from February 2002 - October 2006



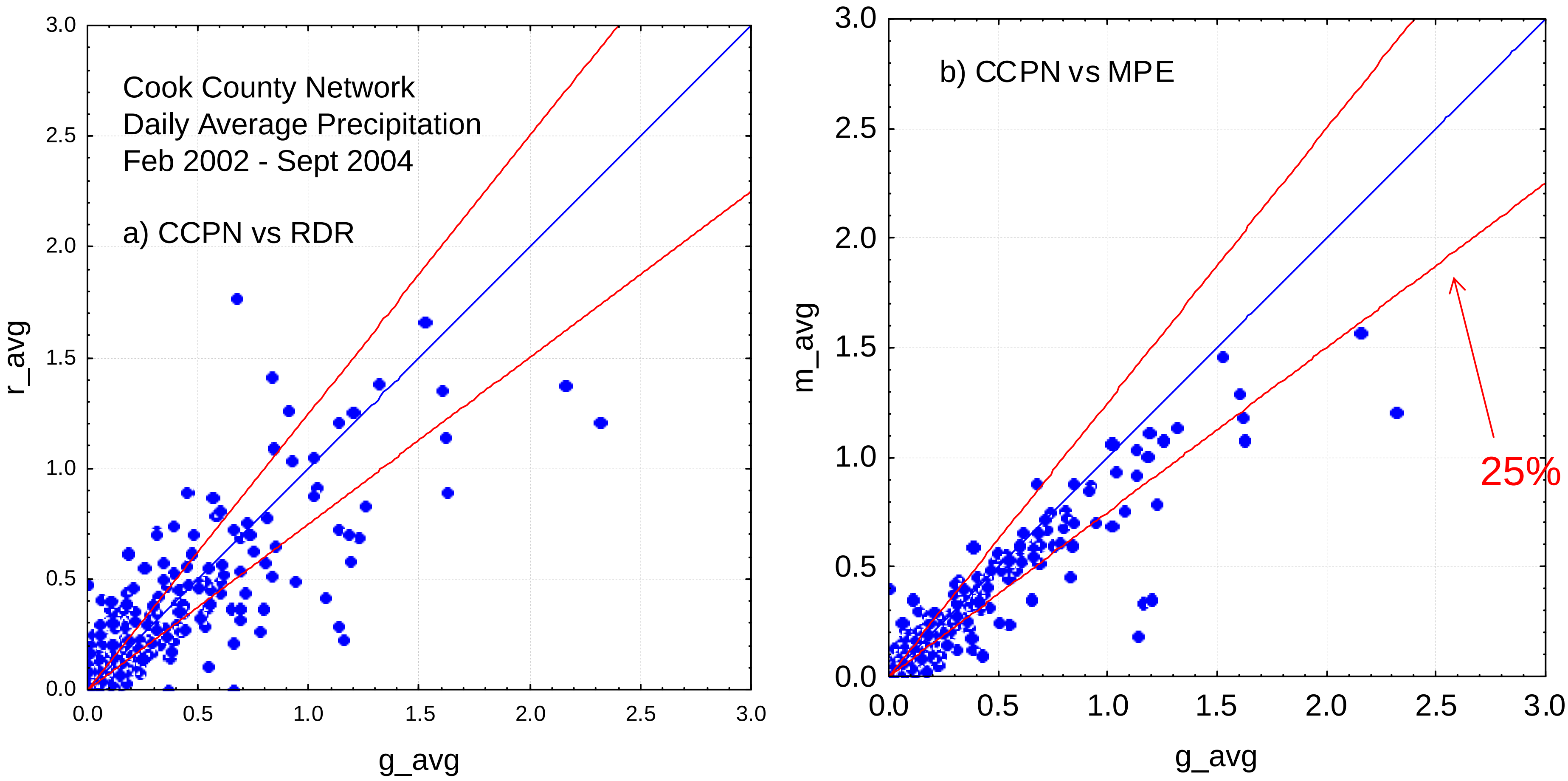
Positive Difference QC_Coop > MPE
Difference, %
25.0
12.5
0.0
-12.5
2 5 8 11 2 5 8 11 2 5 8 11 2 5 8 11 2 5 8
Ablsolute DIfference, %
45
40
35
30
25
20
15
10
5
0
2 5 8 11 2 5 8 11 2 5 8 11 2 5 8 11 2 5 8
Month, from Feb 2002 - October 2006



62 % within

+/- 25 %

Median 6.5%



Cook County Network
Daily Average Precipitation
Feb 2002 - Sept 2004
a) CCPN vs RDR
r_avg
g_avg
0.0
0.5
1.0
1.5
2.0
2.5
3.0
b) CCPN vs MPE
m_avg
25%

For a 3 inch rain

- Factor of 2: 0.01 – 6 inches (WSR-57)
- +/- 50%: 1.5 – 4.5 inches (WSR-88d)
- +/- 25%: 2.25 – 3.75 inches (MPE)

Possible causes of variation in correspondence between MPE and gage

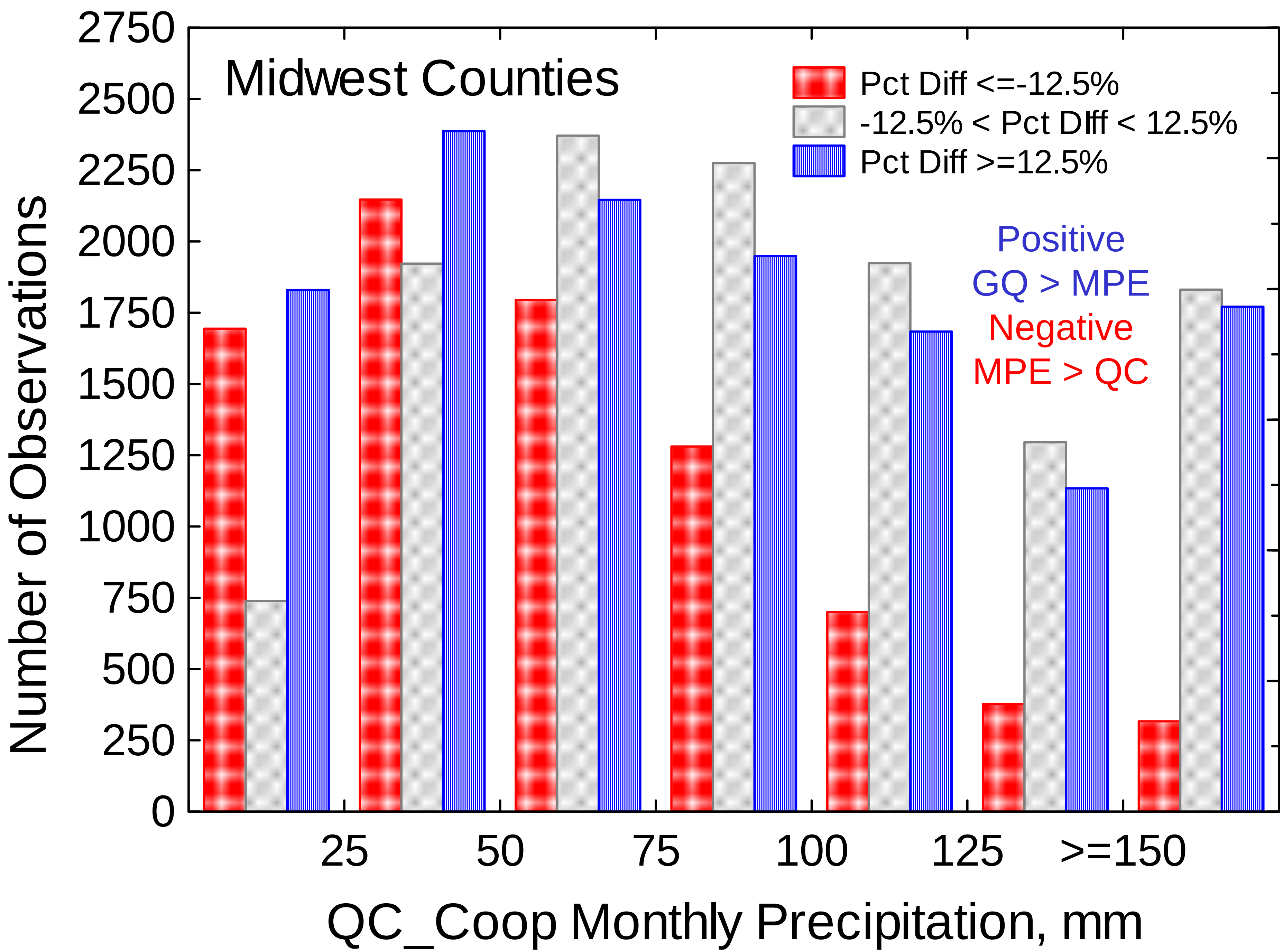
- Precipitation amount
- Number of gages per county or per area
- Distance from Radar
- Convective vs stratiform precipitation
    - Latitude
    - Season
    - Distance from Radar

Gage Adjustment

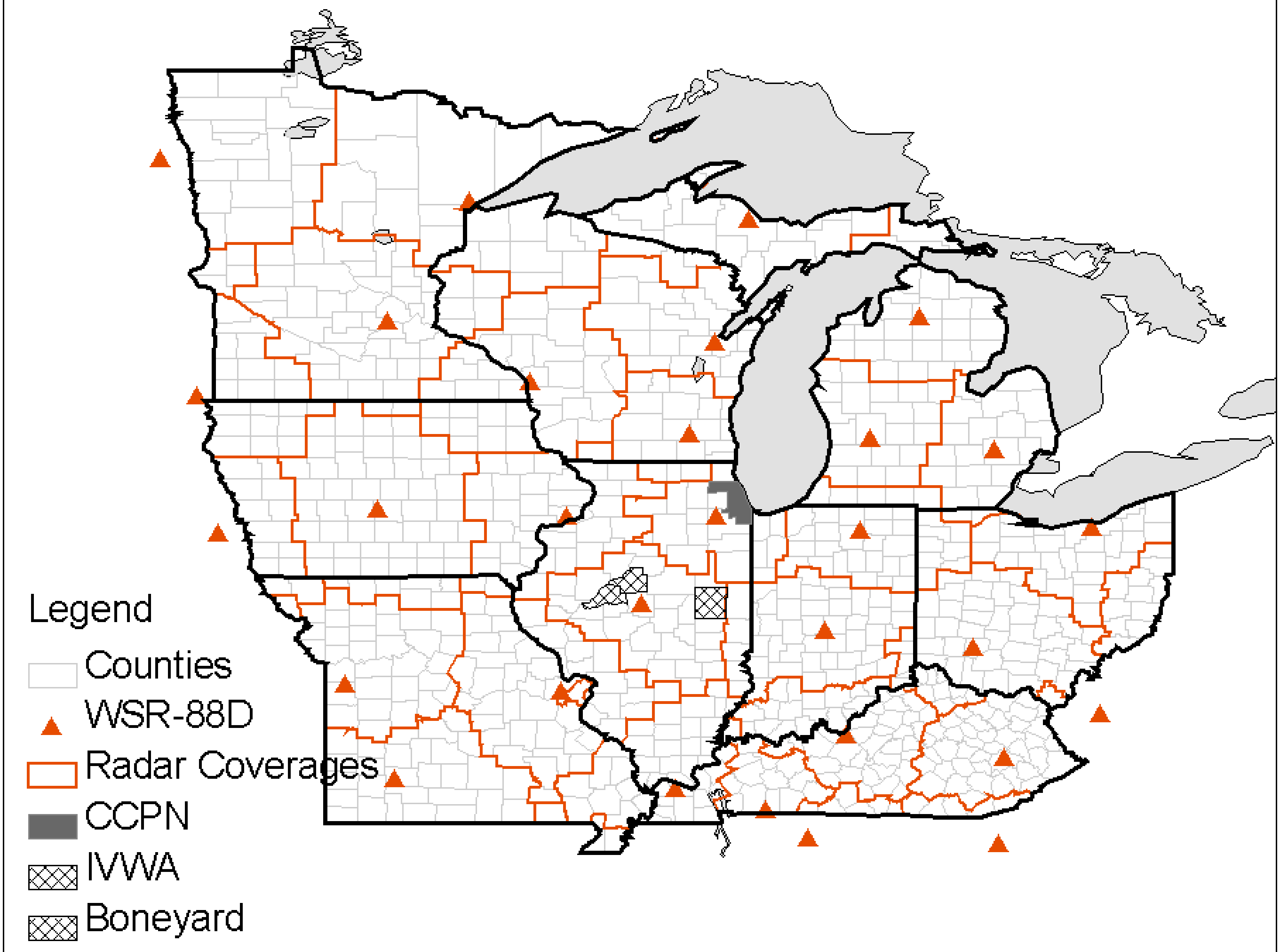
Precipitation Amount

25 mm = 1 inch

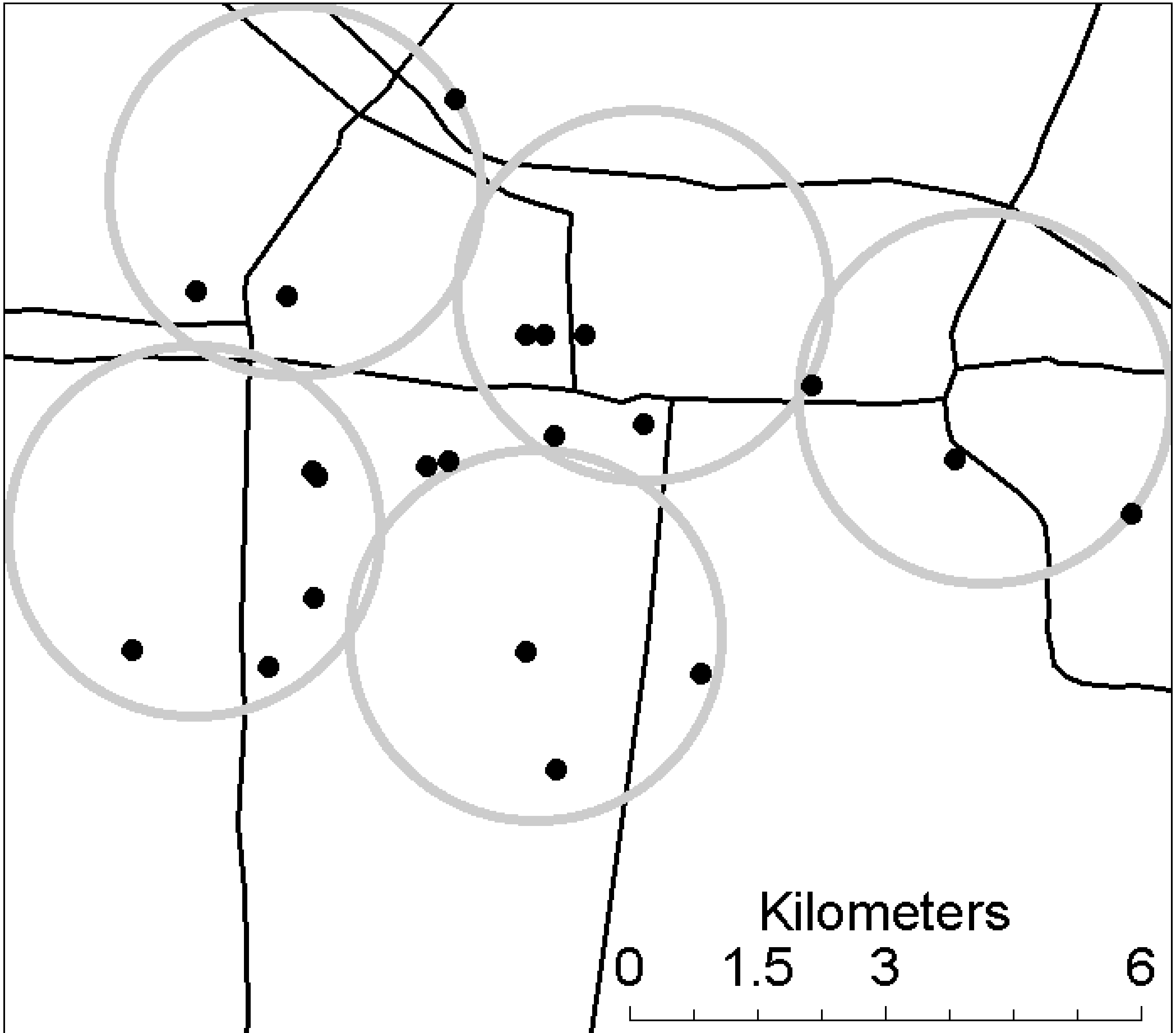
2.5 cm = 1 inch

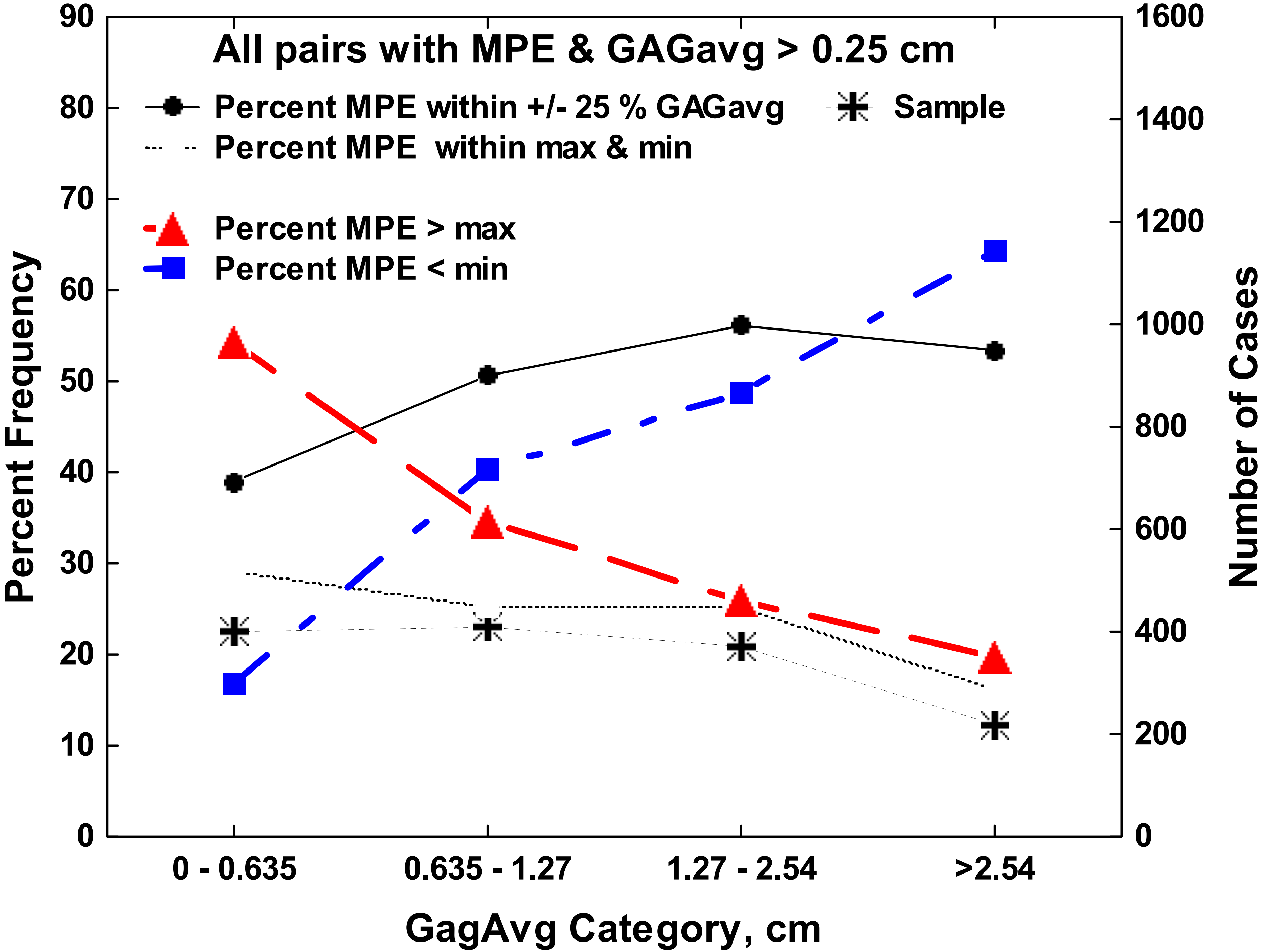


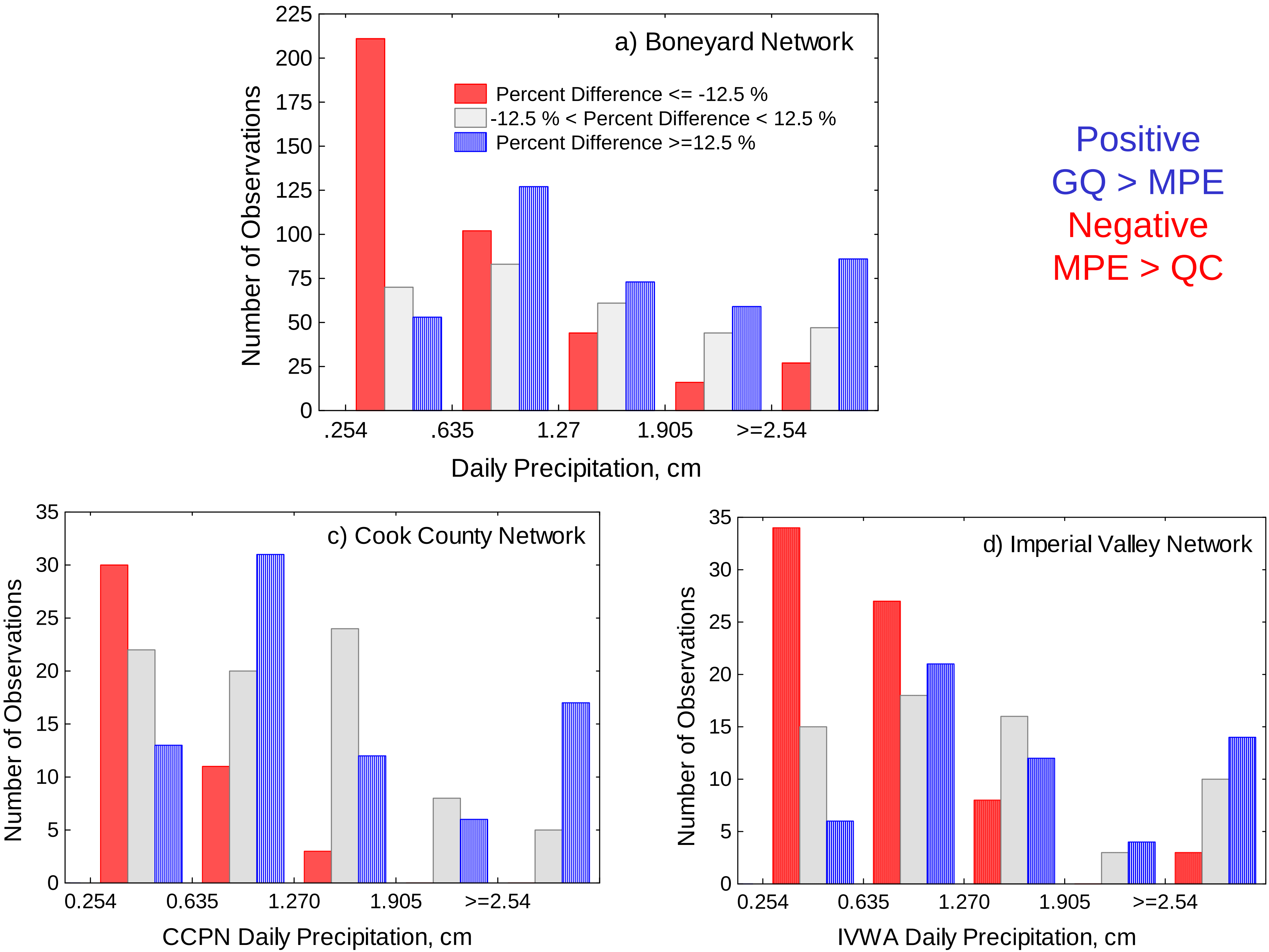
Midwest Counties
Pct Diff <=-12.5%
-12.5% < Pct DIff < 12.5%
Pct Diff >=12.5%
Positive
GQ > MPE
Negative
MPE > QC
Number of Observations
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
25
50
75
100
125
>=150
QC_Coop Monthly Precipitation, mm


Legend
Counties
WSR-88D
Radar Coverages
CCPN
IVWA
Boneyard

d) Boneyard Precipitation Network




All pairs with MPE & GAGavg > 0.25 cm
Percent MPE within +/- 25 % GAGavg
Sample
Percent MPE within max & min
Percent MPE > max
Percent MPE < min
Percent Frequency
Number of Cases
GagAvg Category, cm
0 - 0.635
0.635 - 1.27
1.27 - 2.54
>2.54
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
1400
1600


a) Boneyard Network
Percent Difference <= -12.5 %
-12.5 % < Percent Difference < 12.5 %
Percent Difference >=12.5 %
Number of Observations
0
25
50
75
100
125
150
175
200
225
.254
.635
1.27
1.905
>=2.54
Daily Precipitation, cm
Positive
GQ > MPE
Negative
MPE > QC
c) Cook County Network
Number of Observations
0
5
10
15
20
25
30
35
0.254
0.635
1.270
1.905
>=2.54
CCPN Daily Precipitation, cm
d) Imperial Valley Network
Number of Observations
0
5
10
15
20
25
30
35
0.254
0.635
1.270
1.905
>=2.54
IVWA Daily Precipitation, cm

Number of Gages

- Number of gages / county (monthly)
- Area coverage of gage (monthly)

- Number of gages / grid point (daily)

No effect on agreement between estimates

Distance from Radar

Too Close (within ~30 km):

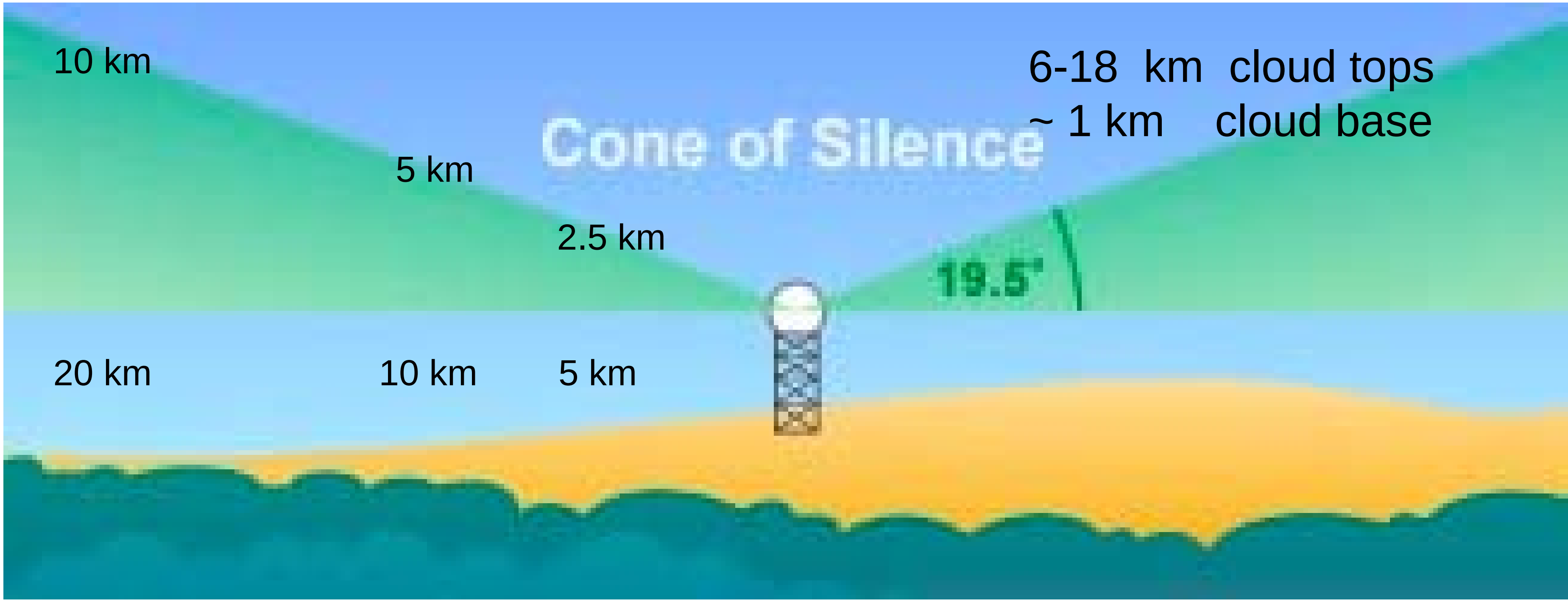
- Ground clutter filtering
- Beam blockage
- Cone of silence

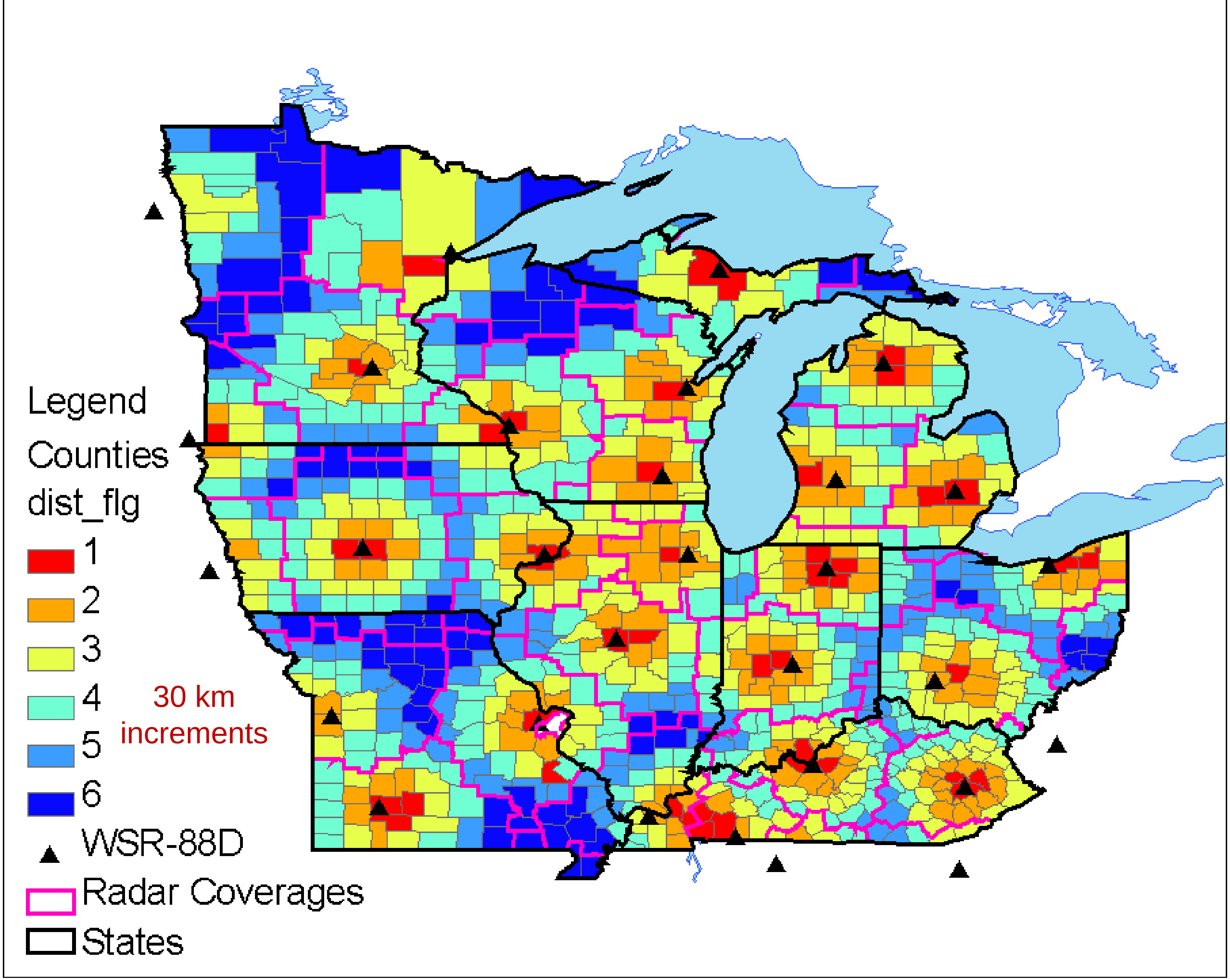
Too Far:

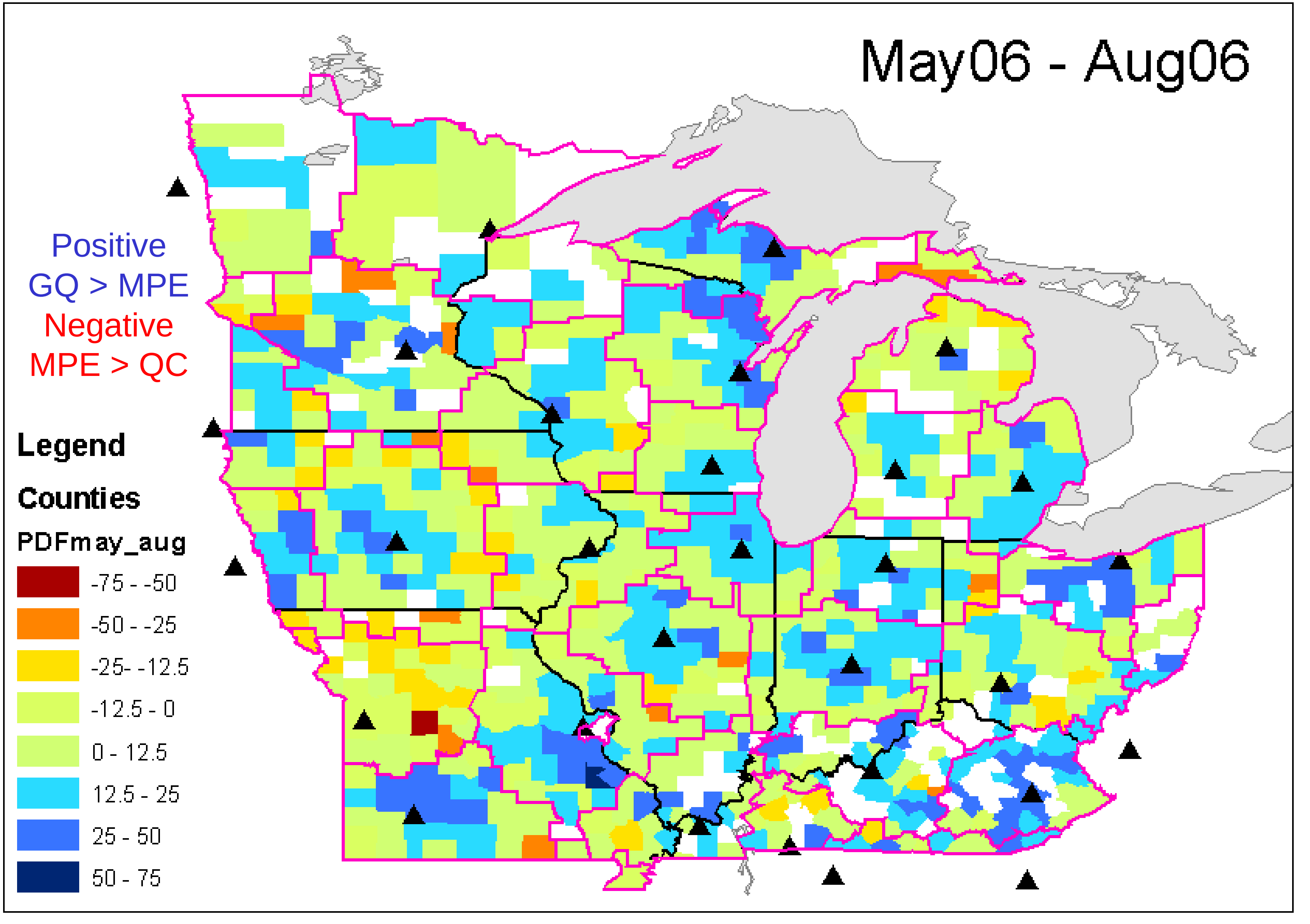
- Beam wider, higher:
- 1º at 60 km = 1 km up;
- 1º at 120 km = 2 km up

Close to Radar – data hole

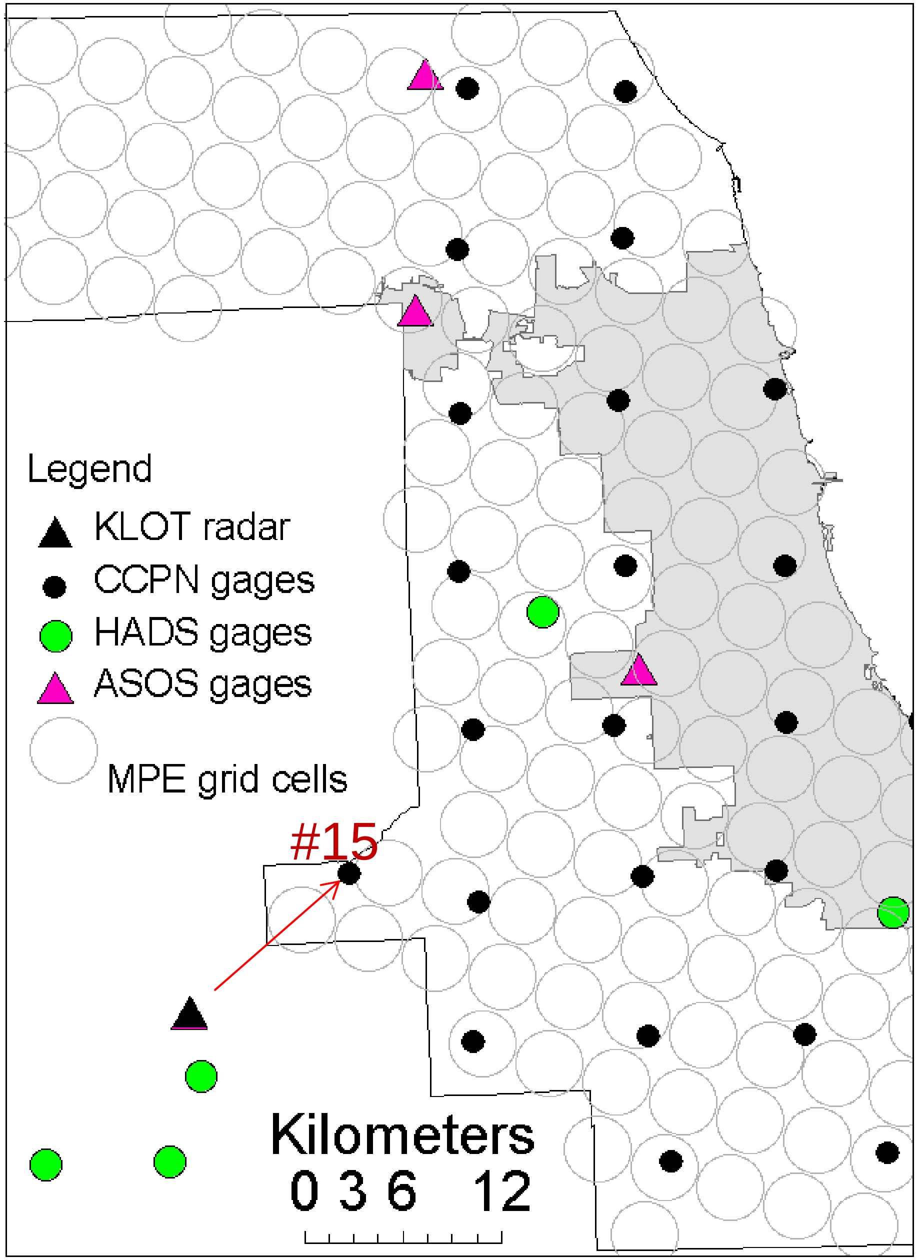
Summer




Legend
Counties
dist_flg
1
2
3
4
5
6
WSR-88D
Radar Coverages
States
30 km
increments


May06 - Aug06
Positive
GQ > MPE
Negative
MPE > QC
Legend
Counties
PDFmay_aug
-75 - -50
-50 - -25
-25- -12.5
-12.5 - 0
0 - 12.5
12.5 - 25
25 - 50
50 - 75

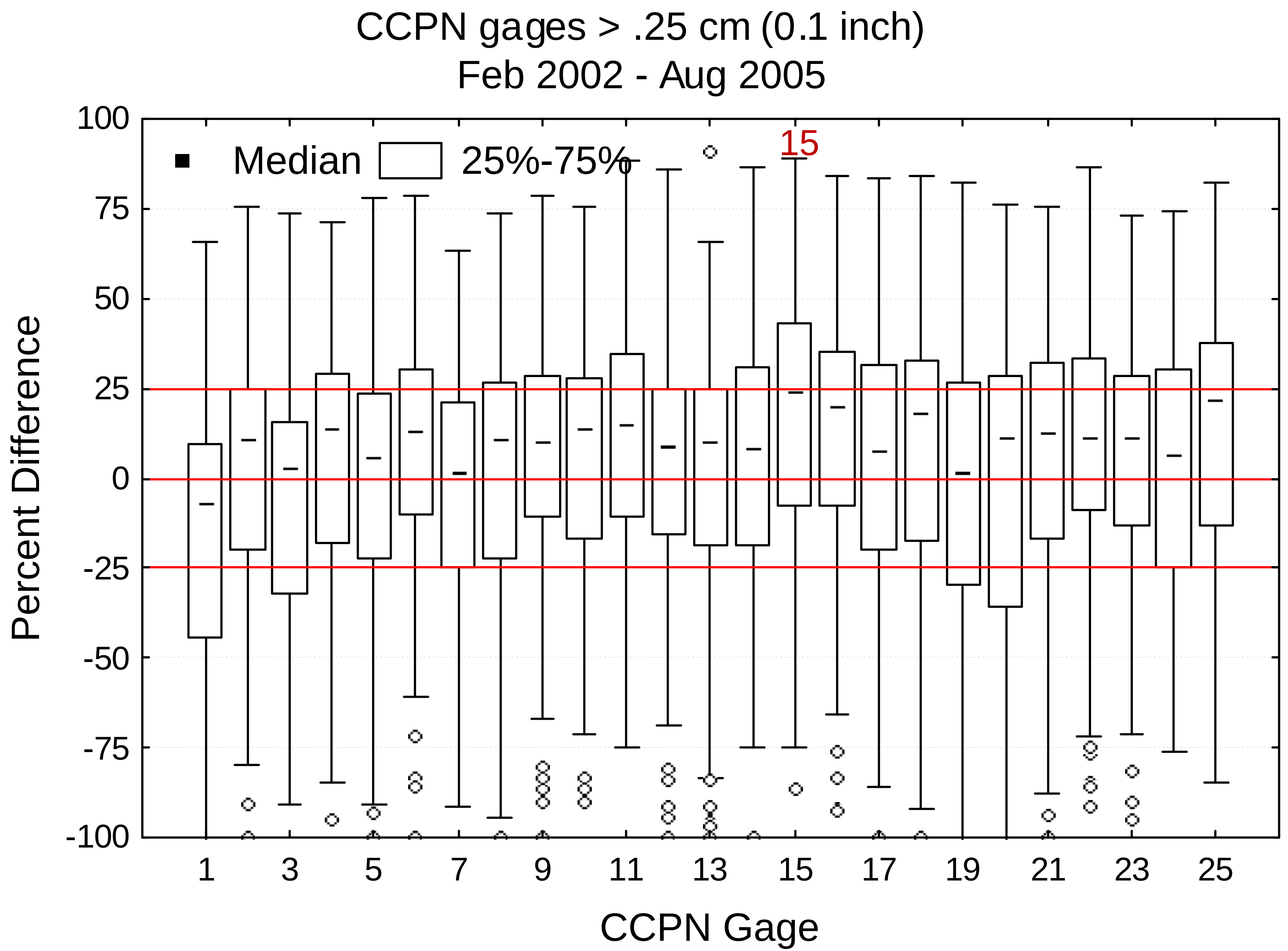
Cook County Precipitation Network

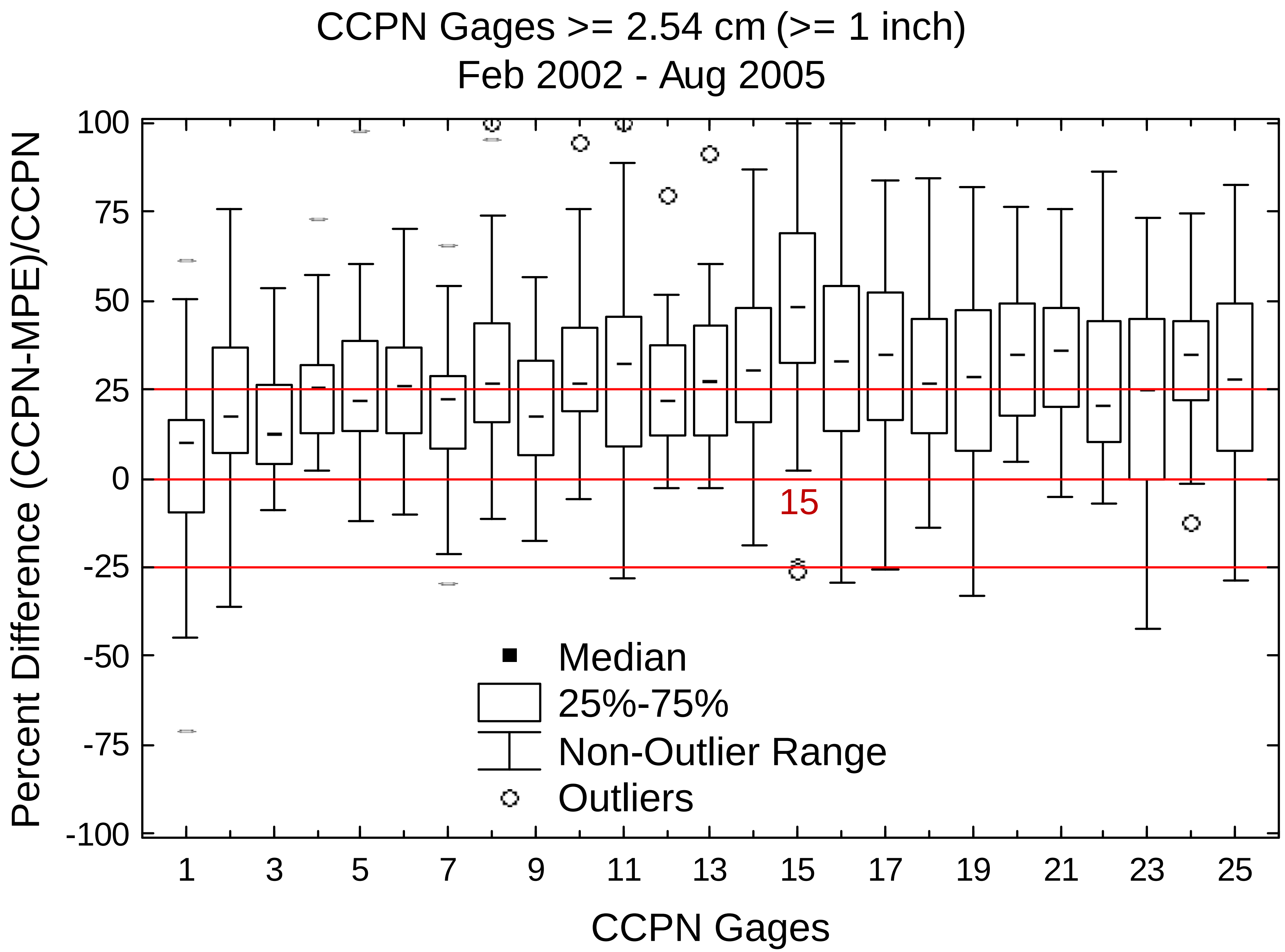


Individual CCPN Gage

Daily Comparison

25 weighing buckets gages


CCPN gages > .25 cm (0.1 inch)
Feb 2002 - Aug 2005
Median
25%-75%
15
100
75
50
25
0
-25
-50
-75
-100
Percent Difference
1
3
5
7
9
11
13
15
17
19
21
23
25
CCPN Gage

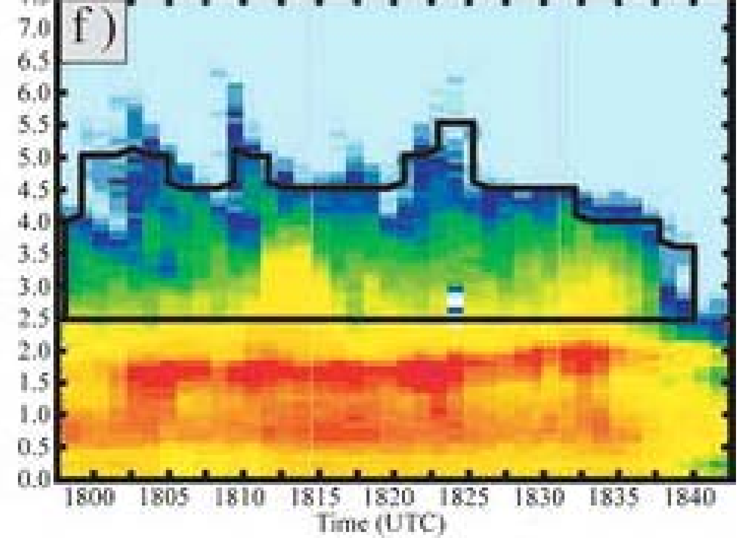


CCPN Gages >= 2.54 cm (>= 1 inch)
Feb 2002 - Aug 2005
Percent Difference (CCPN-MPE)/CCPN
100
75
50
25
0
-25
-50
-75
-100
15
Median
25%-75%
Non-Outlier Range
Outliers
1
3
5
7
9
11
13
15
17
19
21
23
25
CCPN Gages

Convective vs Stratiform

- Convective
  - Taller; summertime; extended season in the south

- Stratiform
  - Widespread, not at tall; wintertime; extended season in the north; more snow in northern latitudes



Winter precipitation band;

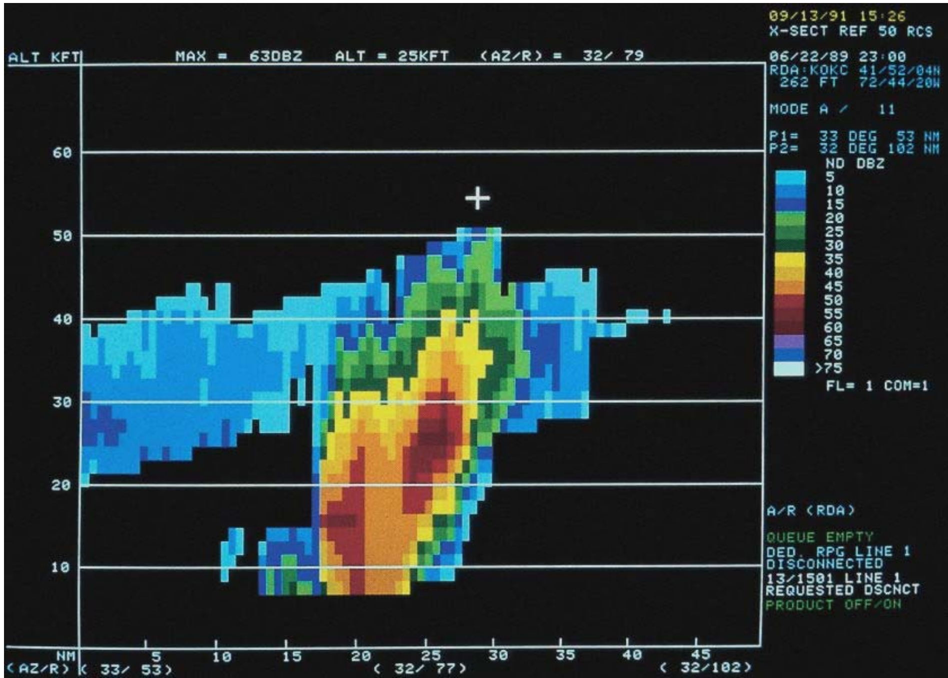
Max precip < 2.5 km

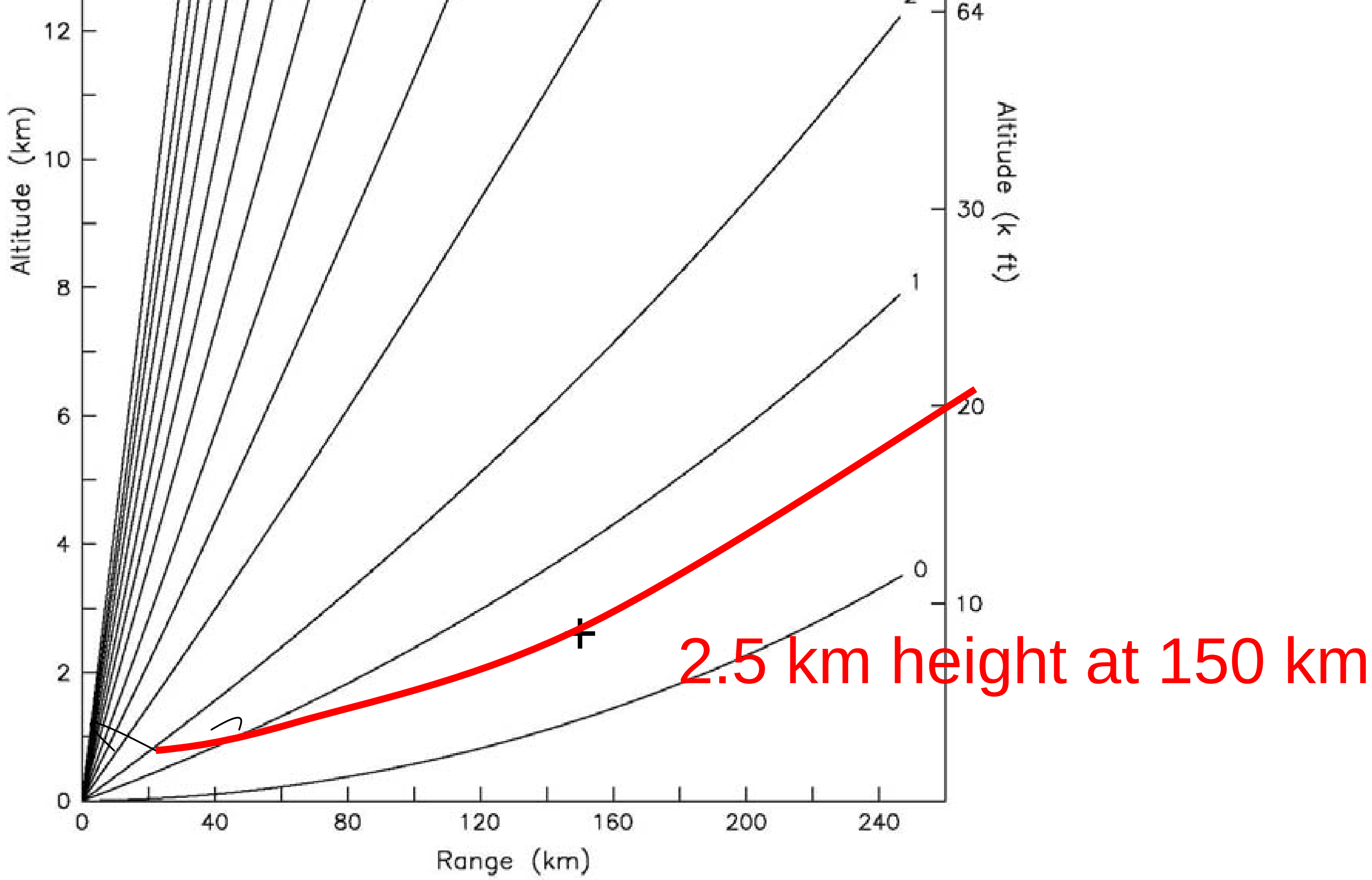
After: Cronce, Rauber, Knupp, Jewett, Walters and Phillips, 2007. Vertical Motion in Precipitation Bands in 3 Winter Storms, JAMC. Snow band: Fiona, IL January 2004

Vertical slices through storms

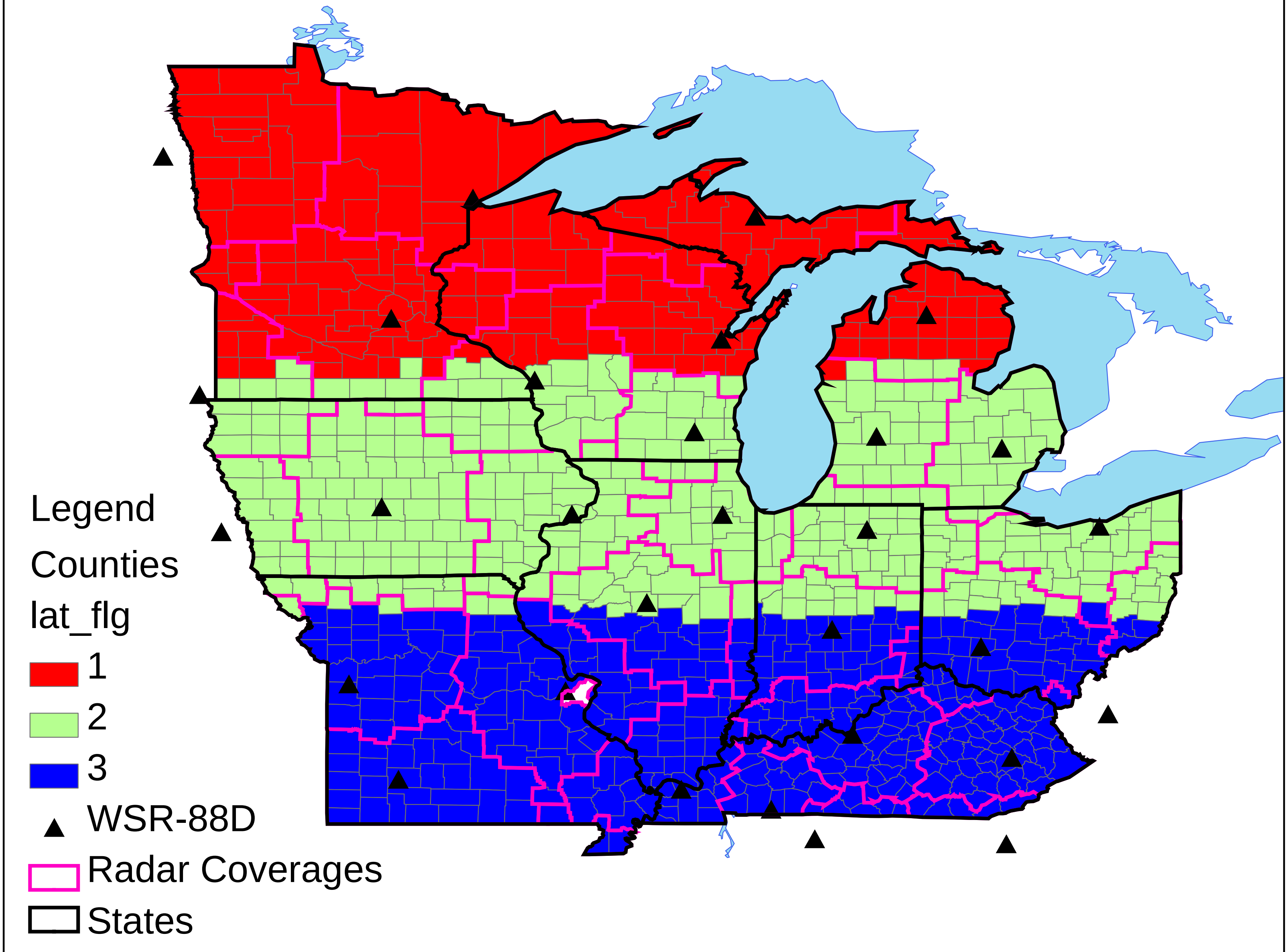
Multi-celled Convective Storm:
Max Precip > 6-8 km altitude.

After: Fed. Met Handbook C., 2005.

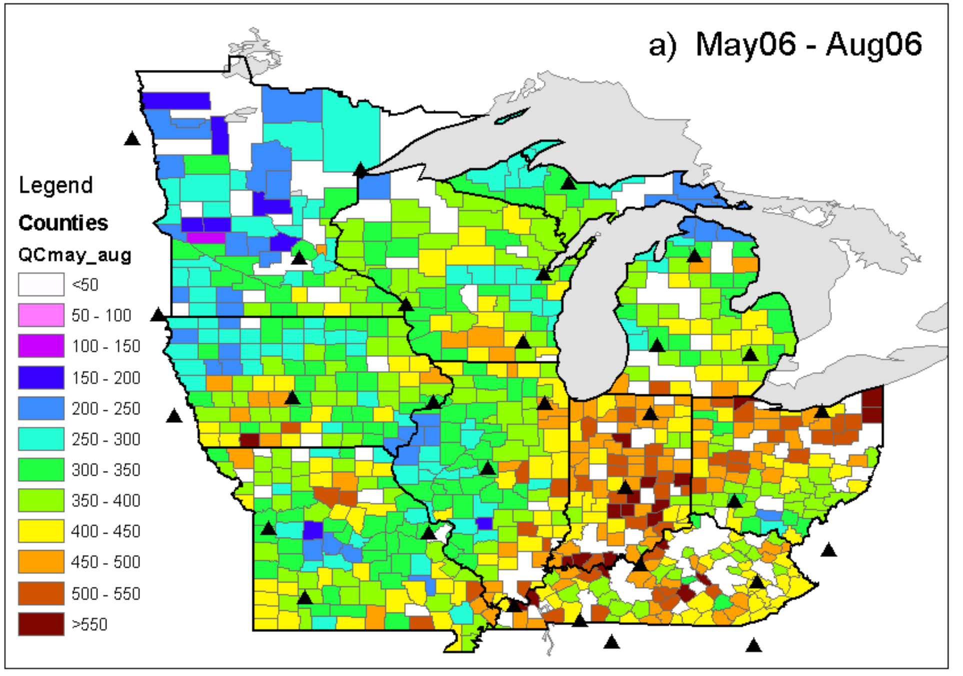




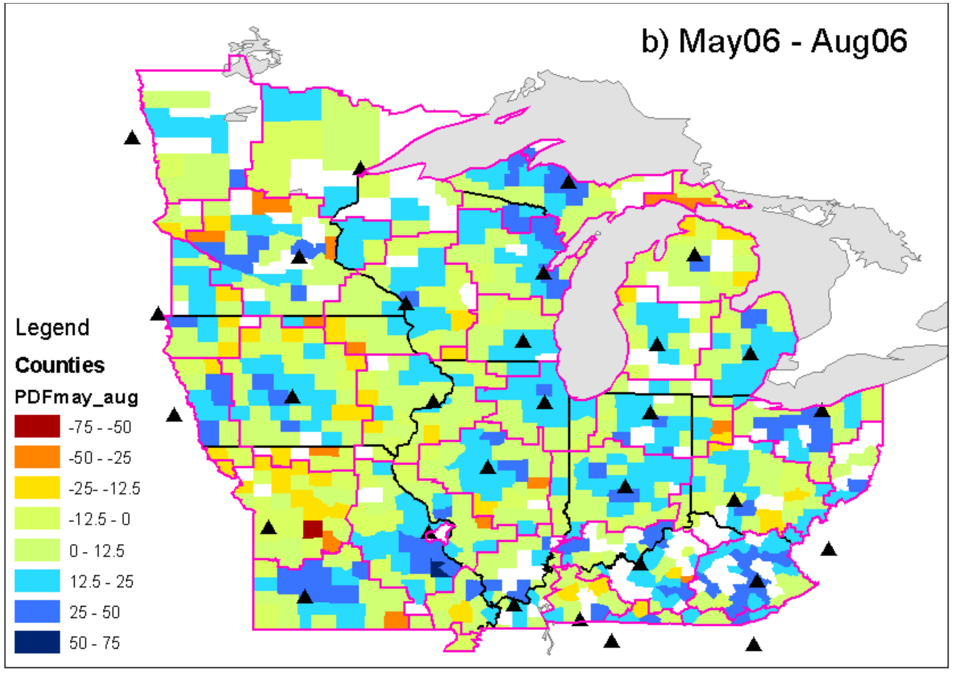
- **Figure 3-12 Fed. Met. Handbook B**
- **Range-Radar Beam Altitude Nomogram**


Legend
Counties
lat_flg
1
2
3
WSR-88D
Radar Coverages
States

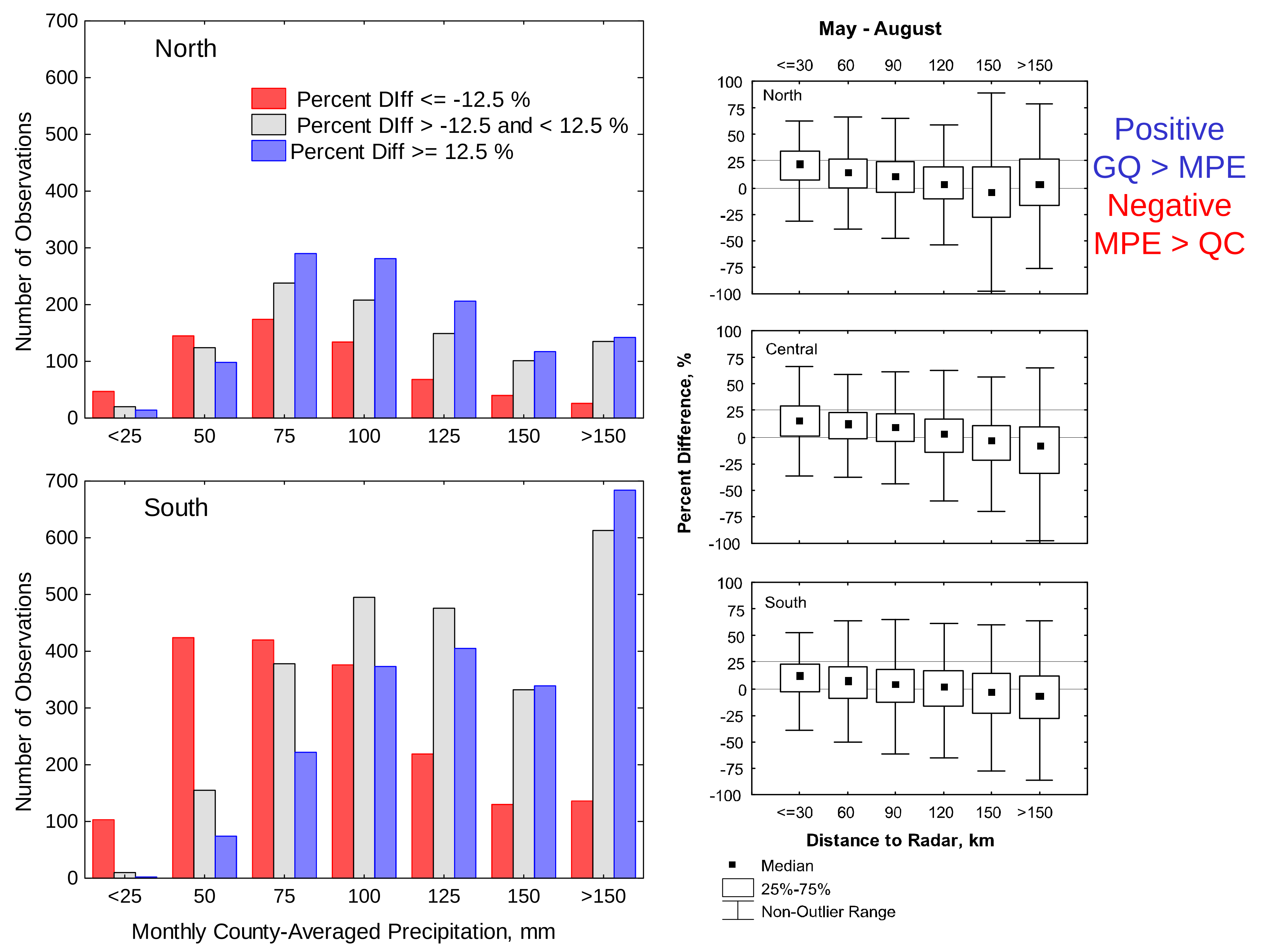
Warm Season – May - Aug



a) May06 - Aug06
Legend
Counties
QCmay_aug
<50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
350 - 400
400 - 450
450 - 500
500 - 550
>550



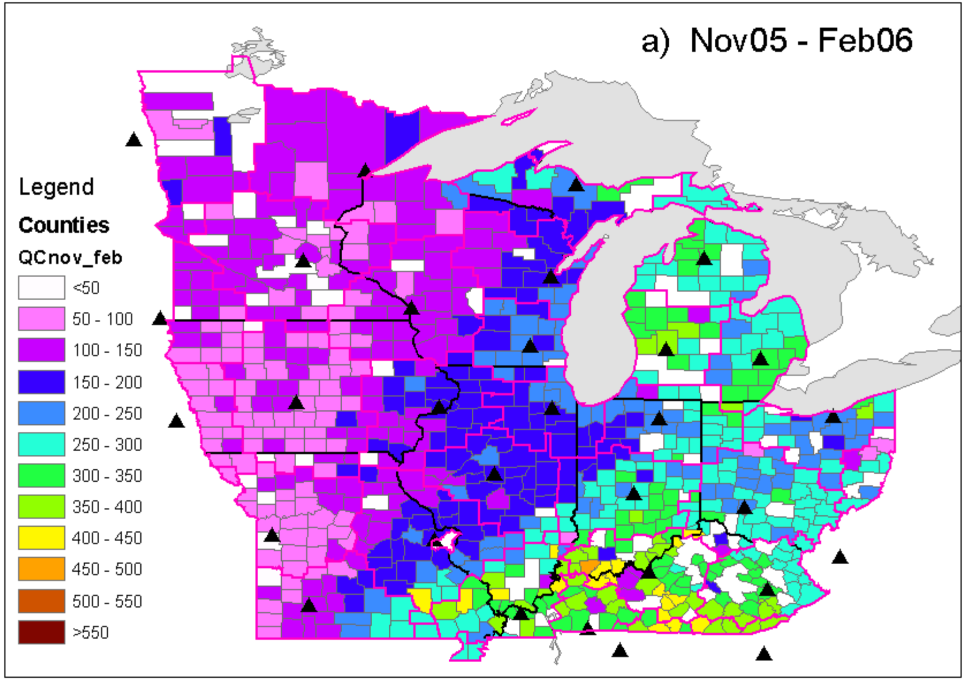
b) May06 - Aug06
Legend
Counties
PDFmay_aug
-75 - -50
-50 - -25
-25- -12.5
-12.5 - 0
0 - 12.5
12.5 - 25
25 - 50
50 - 75


North
Percent DIff <= -12.5 %
Percent DIff > -12.5 and < 12.5 %
Percent Diff >= 12.5 %
Number of Observations
South
Monthly County-Averaged Precipitation, mm
<25
50
75
100
125
150
>150
May - August
<=30
60
90
120
150
>150
North
Central
South
Percent Difference, %
Distance to Radar, km
Median
25%-75%
Non-Outlier Range
Positive
GQ > MPE
Negative
MPE > QC

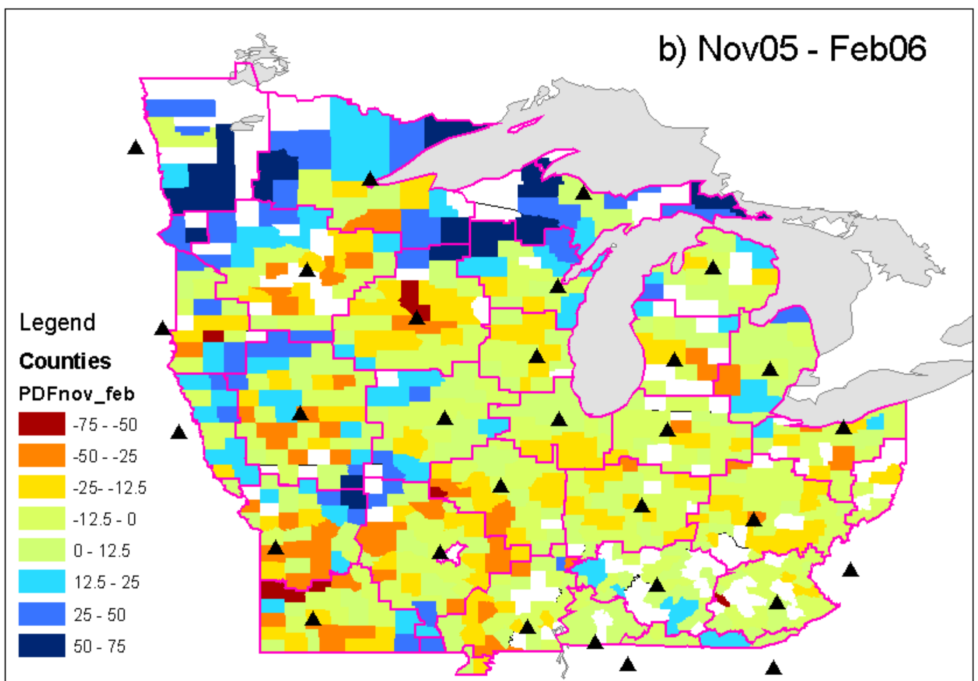
May - August

- Convective Precipitation
- Poorest very close to radar, perhaps due to beam blockage or ground clutter filtering or the cone of silence
- Best at distance, wider beam sampling more area – better areal precipitation estimate
- Similar results at all latitudes.

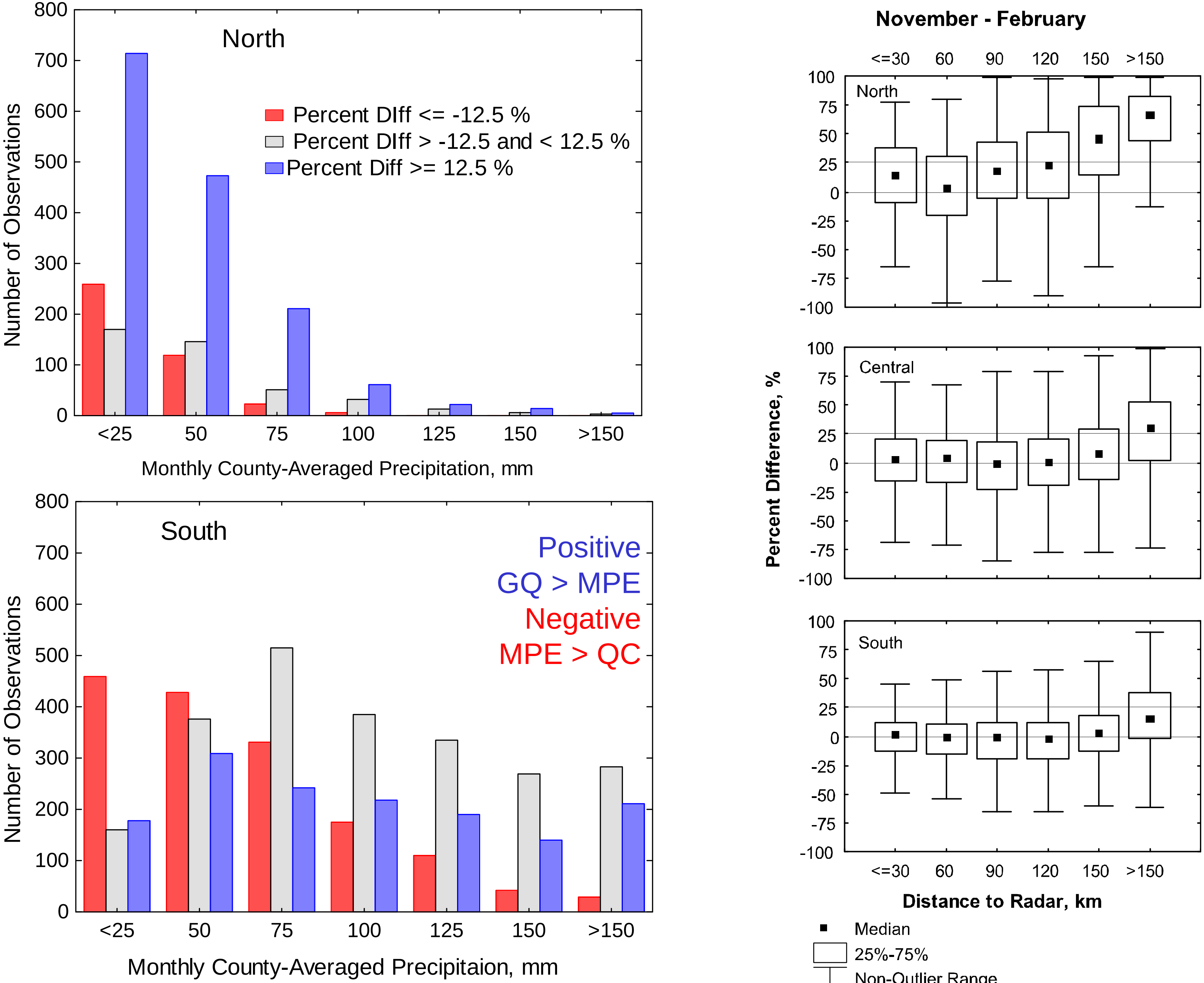
Cold Season Nov-Feb



a) Nov05 - Feb06
Legend
Counties
QCnov_feb
<50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
350 - 400
400 - 450
450 - 500
500 - 550
>550



b) Nov05 - Feb06
Legend
Counties
PDFnov_feb
-75 - -50
-50 - -25
-25- -12.5
-12.5 - 0
0 - 12.5
12.5 - 25
25 - 50
50 - 75


North
Percent DIff <= -12.5 %
Percent DIff > -12.5 and < 12.5 %
Percent Diff >= 12.5 %
Number of Observations
0
100
200
300
400
500
600
700
800
<25
50
75
100
125
150
>150
Monthly County-Averaged Precipitation, mm
South
Positive
GQ > MPE
Negative
MPE > QC
Number of Observations
<25
50
75
100
125
150
>150
Monthly County-Averaged Precipitaion, mm
November - February
<=30
60
90
120
150
>150
North
Central
South
100
75
50
25
0
-25
-50
-75
-100
Percent Difference, %
Distance to Radar, km
Median
25%-75%
Non-Outlier Range

November - February

- North – snow more common – low stratiform clouds
- Close in - lower elevations better sampled, as antenna not have to sample tall cumulus clouds
- Poorer agreement with range – beam rise above the top of the heaviest precipitation in stratiform layer.
- HADS gages used to adjust radar - typically tipping bucket gage tip mechanism underestimate snow especially under windy conditions; HADS missing data
- South – more apt to include convective precipitation; less snow

Conclusions

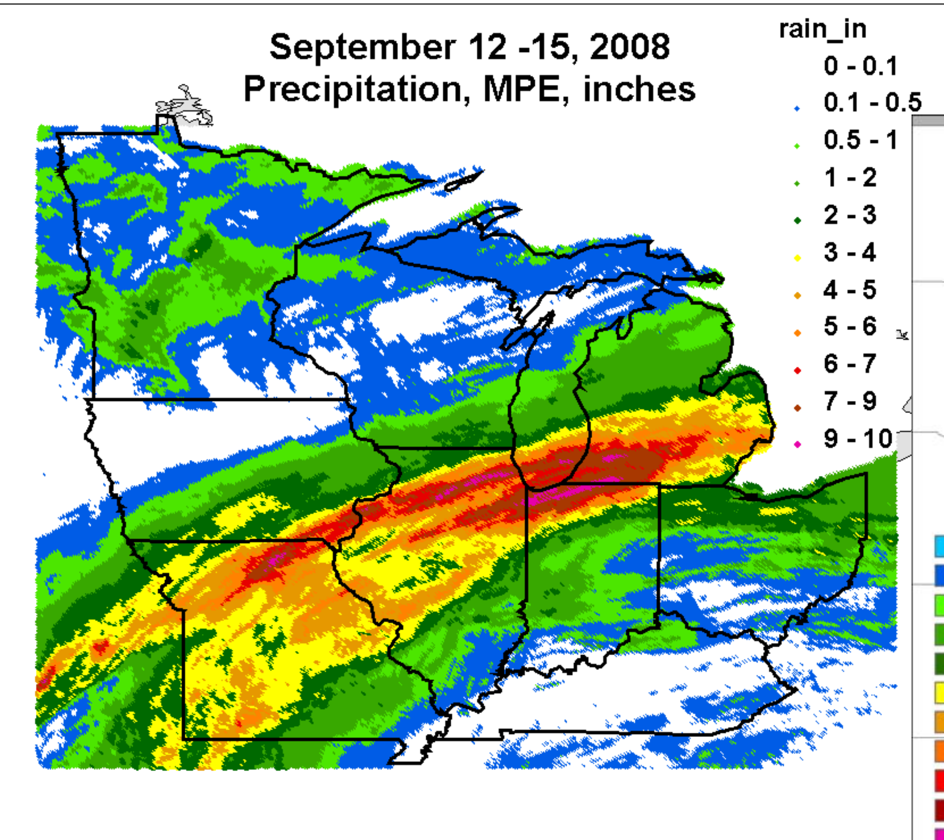
- MPE agreement varies across Midwest
- At higher precipitation rates, MPE underestimates precipitation;
- At lower precipitation rates, MPE overestimates precipitation
- North >44 N latitude, MPE greatly underestimates in winter
- Best estimates everywhere in summer and/or for convective events (except very close to radar)
- County distance from radar in stratiform precipitation and use of HADS gages (typically tipping bucket) in winter results in MPE underestimation

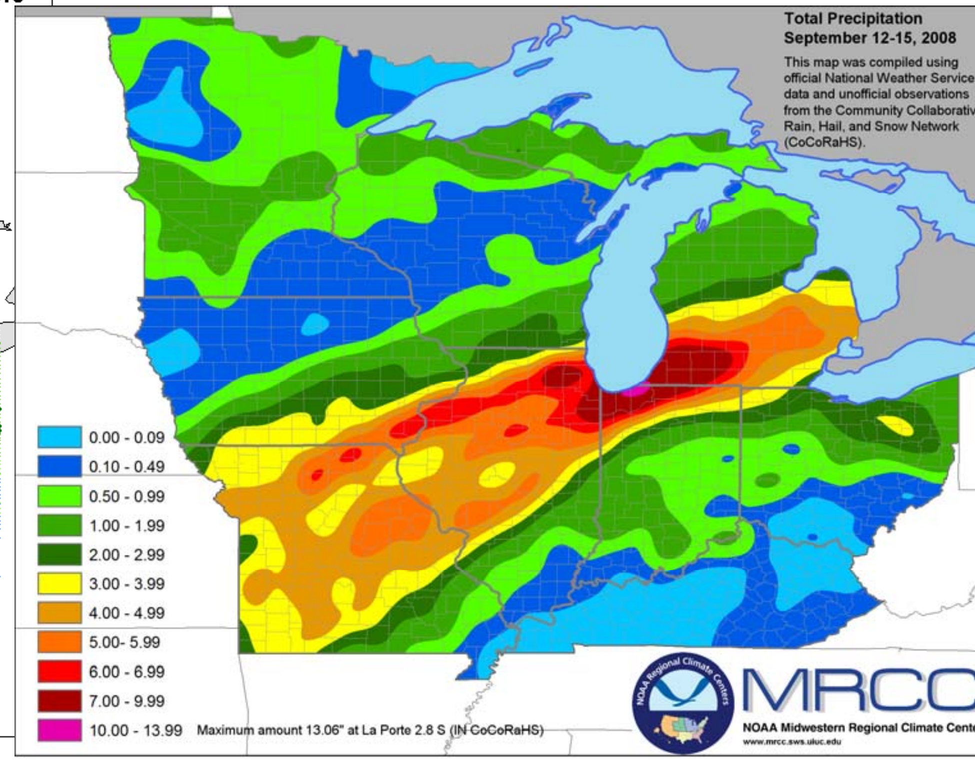
Future

- Polarization will be added to radars in next few years. Information about the shape of drops and sometimes whether frozen or not.

- Polarization will affect should improve radar measurements but unclear by how much.

- Range / height effects will still be present.





MPE, 4x4 cells

Interpolated, COOP and CoCoRahGages

The Community Collaborative Rain Hail and Snow Network (CoCoRaHS)

www.cocorahs.org

- Grassroots - volunteer observers measuring rain, snow, and hail in their communities
- A climatological network with a near real-time component

GOAL – To provide accurate high-quality precipitation data to observers, decision makers and other end-users on a timely basis.

In Illinois during July 2010:
Average of 376 reports per day.
Total of 499 observers submitting 11,950 reports.

<u>As of July 2010</u>

- 50 states and DC
- More than 5,000 volunteers and growing
- 4,000 precip reports per day

Placement of your gauge

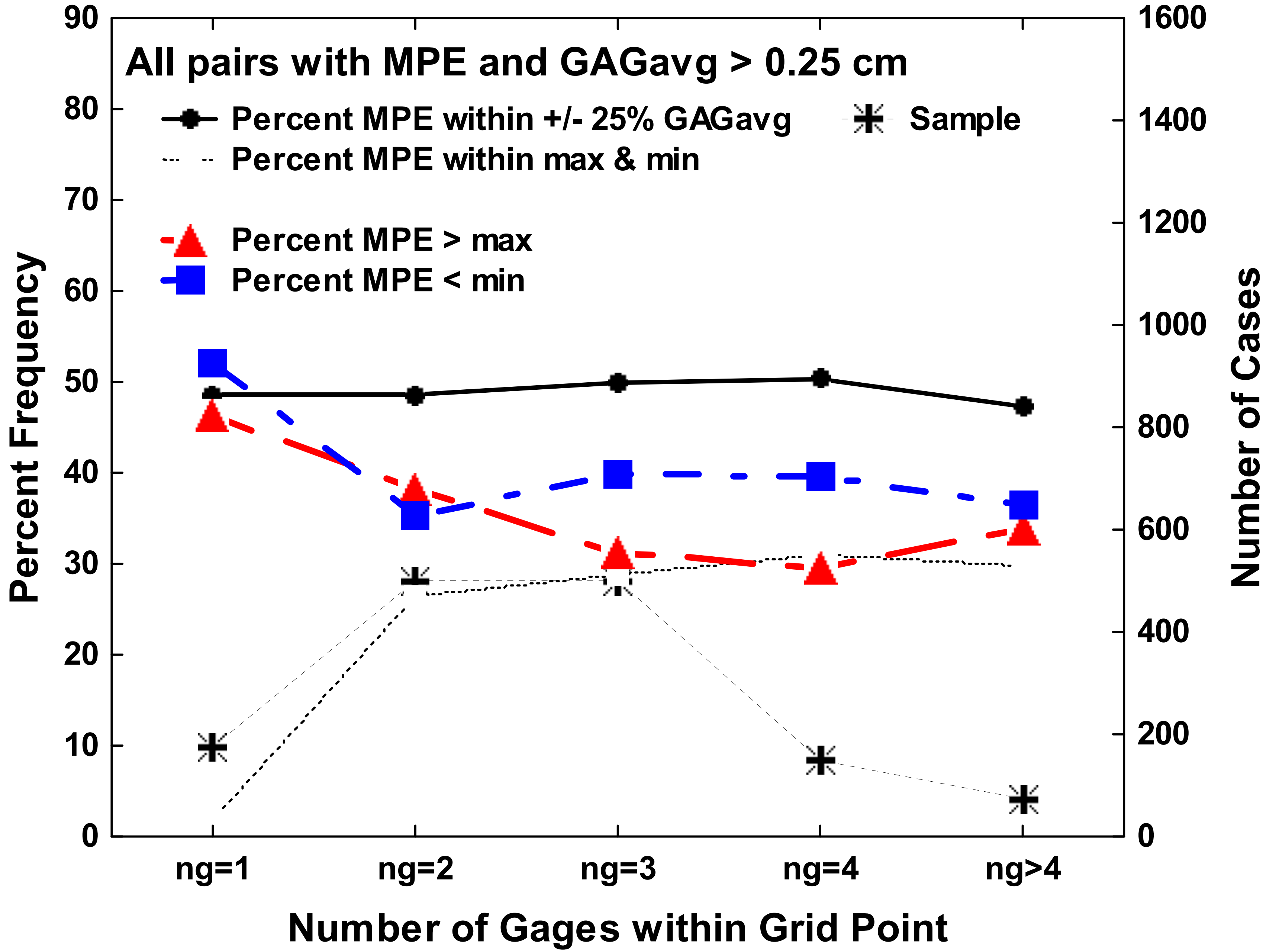
"Location is the key to good data"

Distance from Radar

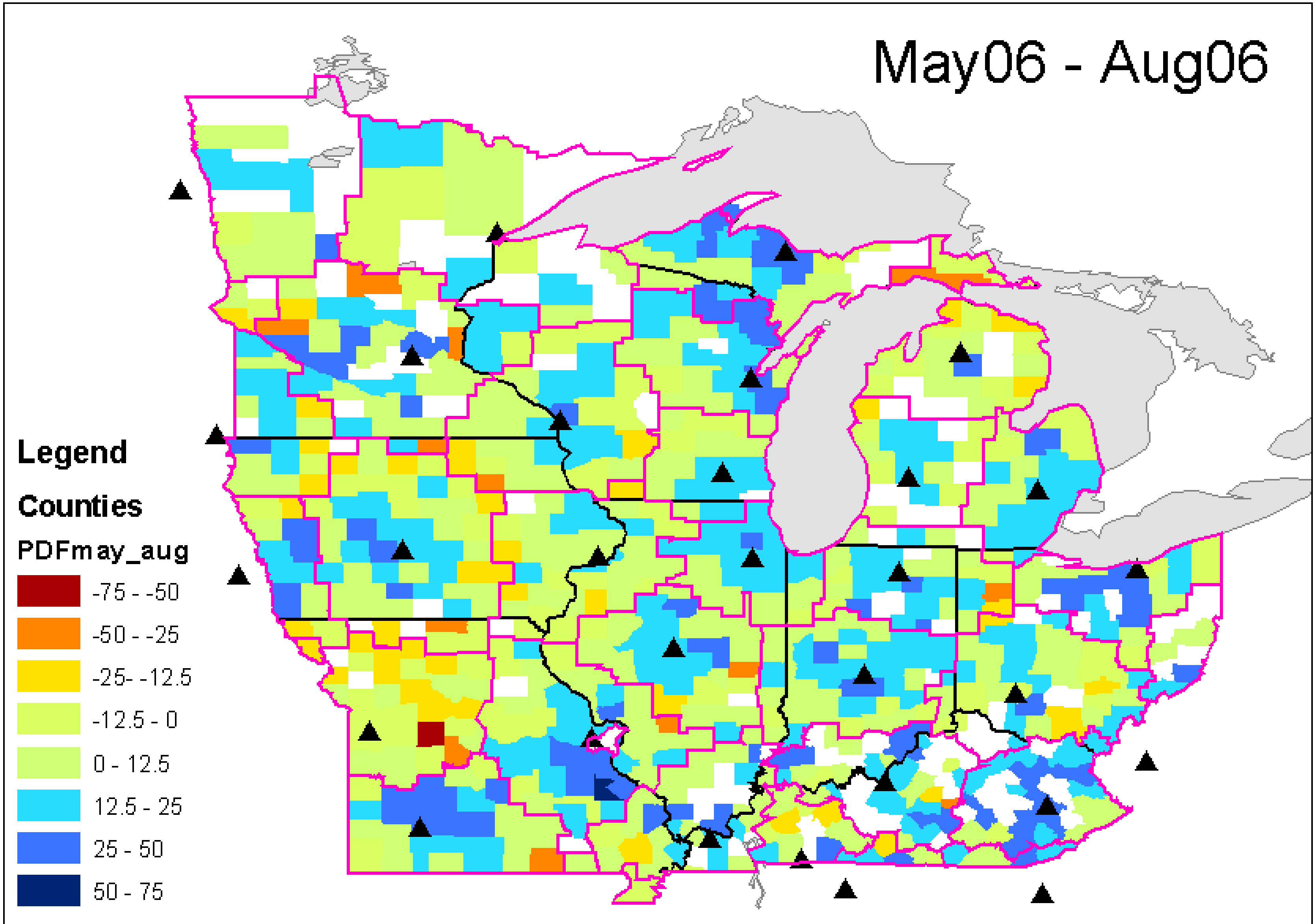
- Cone of silence (impact within ~20 km)
- Ground clutter within 26 mi (42 km)
- Measure most precip within 92 mi (150 km)

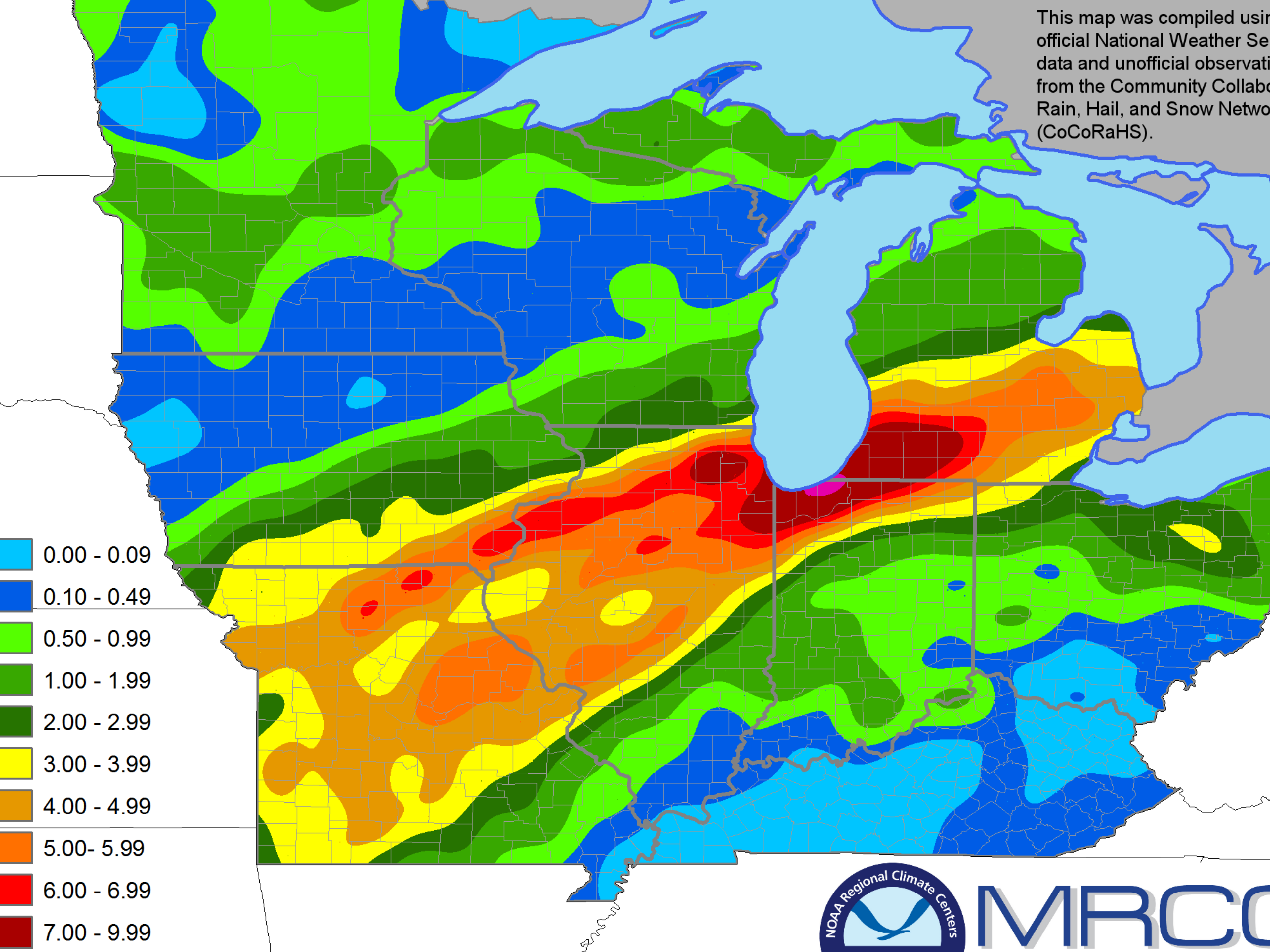
CHECK:

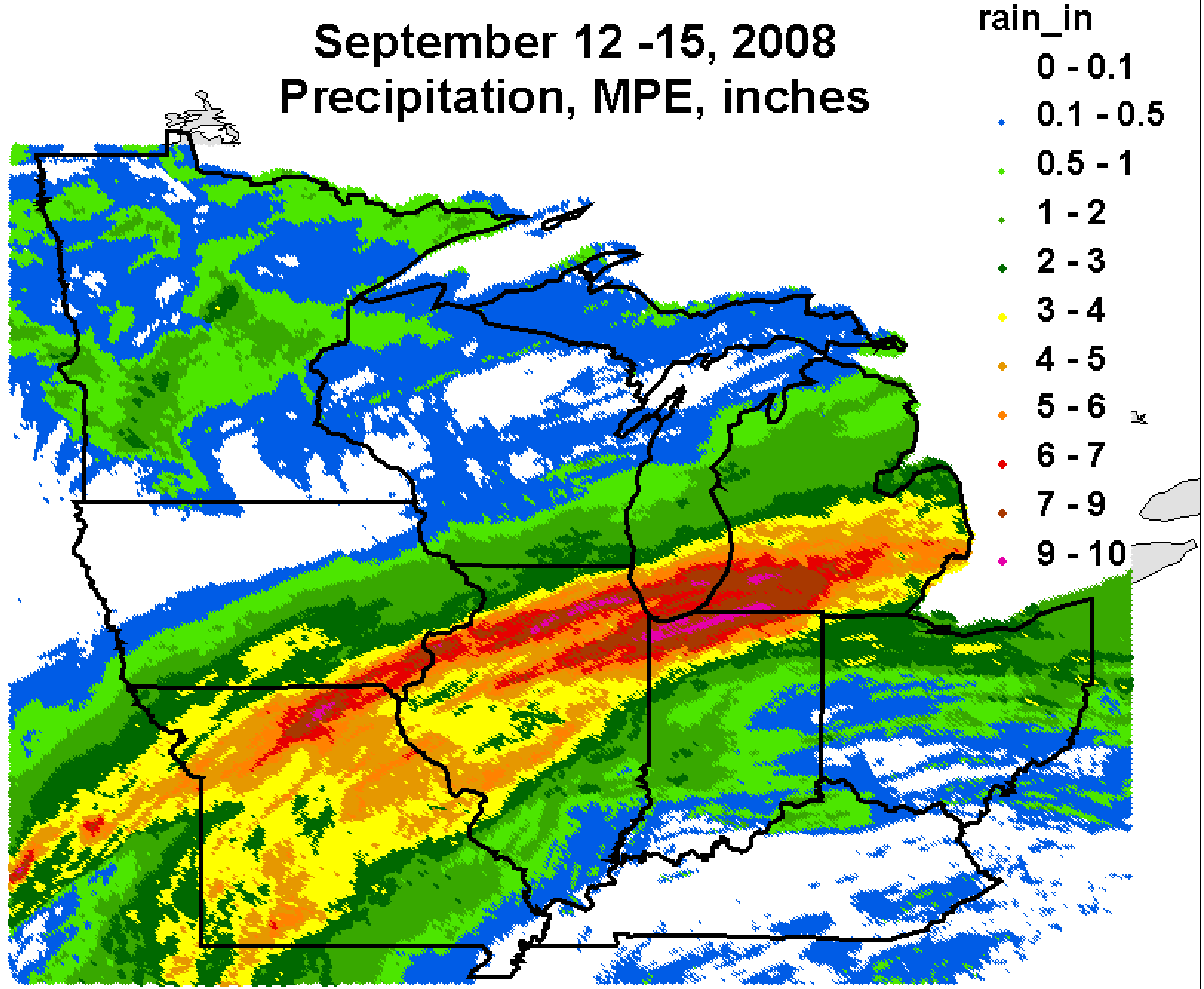
- Look at light rain vs distance from radar.
- If MPE sees more precipitation than gage – will see less with range because will be from shallower clouds



All pairs with MPE and GAGavg > 0.25 cm
Percent MPE within +/- 25% GAGavg
Sample
Percent MPE within max & min
Percent MPE > max
Percent MPE < min
Percent Frequency
Number of Cases
Number of Gages within Grid Point
ng=1
ng=2
ng=3
ng=4
ng>4
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
1400
1600


May06 - Aug06
Legend
Counties
PDFmay_aug
-75 - -50
-50 - -25
-25- -12.5
-12.5 - 0
0 - 12.5
12.5 - 25
25 - 50
50 - 75


This map was compiled usi
official National Weather Se
data and unofficial observati
from the Community Collab
Rain, Hail, and Snow Netwo
(CoCoRaHS).
0.00 - 0.09
0.10 - 0.49
0.50 - 0.99
1.00 - 1.99
2.00 - 2.99
3.00 - 3.99
4.00 - 4.99
5.00- 5.99
6.00 - 6.99
7.00 - 9.99
NOAA Regional Climate Centers
MRCC


September 12 -15, 2008
Precipitation, MPE, inches
rain_in
0 - 0.1
0.1 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 9
9 - 10