Radar and Multi-sensor Precipitation Estimates in the Midwest

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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)
  - (1° beam, searchlight conical shape)
    - At 60 km, 1° beam = 1 km wide (3000 ft)
    - At 120 km, 1° 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, $Z = \sum nD^6$, 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

- $Z = \sum nD^6$ – 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
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 $Z_{dr}$)
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 km²)

• 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
Why use NCEP / NWS gridded data?

Nexrad WSR-88D coverage
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
NWS Quality-Controlled Coop Daily Gages in Midwest

~ 1,500 gages in 775 counties

~ 2.2 gage / county (1/800 km²)

8” non-recording gages

Available ~3-4 months after-the-fact

Reference standard
Median County-Averaged Precipitation by Month

Precipitation, mm

Month, from February 2002 - October 2006

QC_Coop
MPE
Positive Difference QC_Coop > MPE

Absolute Difference,

%}

Month from Feb 2002 - October 2006
County Averaged Rainfall
July 2004

R^2 = 0.61
MPE = 1.2 + 0.68 * QC_Coop

62 % within +/- 25 %
Median 6.5%

MPE Precipitation, inches
QC_Coop Precipitation, inches
Cook County Network
Daily Average Precipitation
Feb 2002 - Sept 2004

a) CCPN vs RDR

b) CCPN vs MPE

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**

**Number of Observations**

- Pct Diff <= -12.5%
- -12.5% < Pct Diff < 12.5%
- Pct Diff >= 12.5%

**Positive**
- GQ > MPE

**Negative**
- MPE > QC

**QC_Coop Monthly Precipitation, mm**

- 25
- 50
- 75
- 100
- 125
- >= 150
Positive
GQ > MPE
Negative
MPE > QC

- Percent Difference <= -12.5 %
- -12.5 % < Percent Difference < 12.5 %
- Percent Difference >= 12.5 %
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:
  - 1° at 60 km = 1 km up;
  - 1° at 120 km = 2 km up
Close to Radar – data hole

Summer

6-18 km cloud tops
~ 1 km cloud base
Positive
GQ > MPE
Negative
MPE > QC

Legend
Counties
PDF\text{may\_aug}
\begin{align*}
-75 &\quad -50 \\
-50 &\quad -25 \\
-25 &\quad -12.5 \\
-12.5 &\quad 0 \\
0 &\quad 12.5 \\
12.5 &\quad 25 \\
25 &\quad 50 \\
50 &\quad 75
\end{align*}
Cook County Precipitation Network

Legend:
- ▲ KLOT radar
- ● CCPN gages
- ○ HADS gages
- △ ASOS gages
- □ MPE grid cells

Individual CCPN Gage
Daily Comparison
25 weighing buckets gages

#15

Kilometers 0 3 6 12
CCPN gages > .25 cm (0.1 inch)
Feb 2002 - Aug 2005
CCPN Gages $\geq 2.54$ cm ($\geq 1$ inch)
Feb 2002 - Aug 2005
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

Vertical slices through storms

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

2.5 km height at 150 km

- Figure 3-12 Fed. Met. Handbook B
- Range-Radar Beam Altitude Nomogram
Warm Season – May - Aug
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
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 CoCoRaHGS
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.

As of July 2010
- 50 states and DC
- More than 5,000 volunteers and growing
- 4,000 precip reports per day

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

Number of Gages within Grid Point

Number of Cases

Percent Frequency

Sample

ng=1
ng=2
ng=3
ng=4
ng>4

Percent MPE within max & min

Percent MPE > max

Percent MPE < min

All pairs with MPE and GAGavg > 0.25 cm
This map was compiled using official National Weather Service data and unofficial observations from the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS).