An Innovative Approach for Determining Storm Event Rainfall Probabilities

Case Studies Hurricanes Matthew and Joaquin

ASFPM Annual Conference

May 2, 2017 | Kansas City, MO

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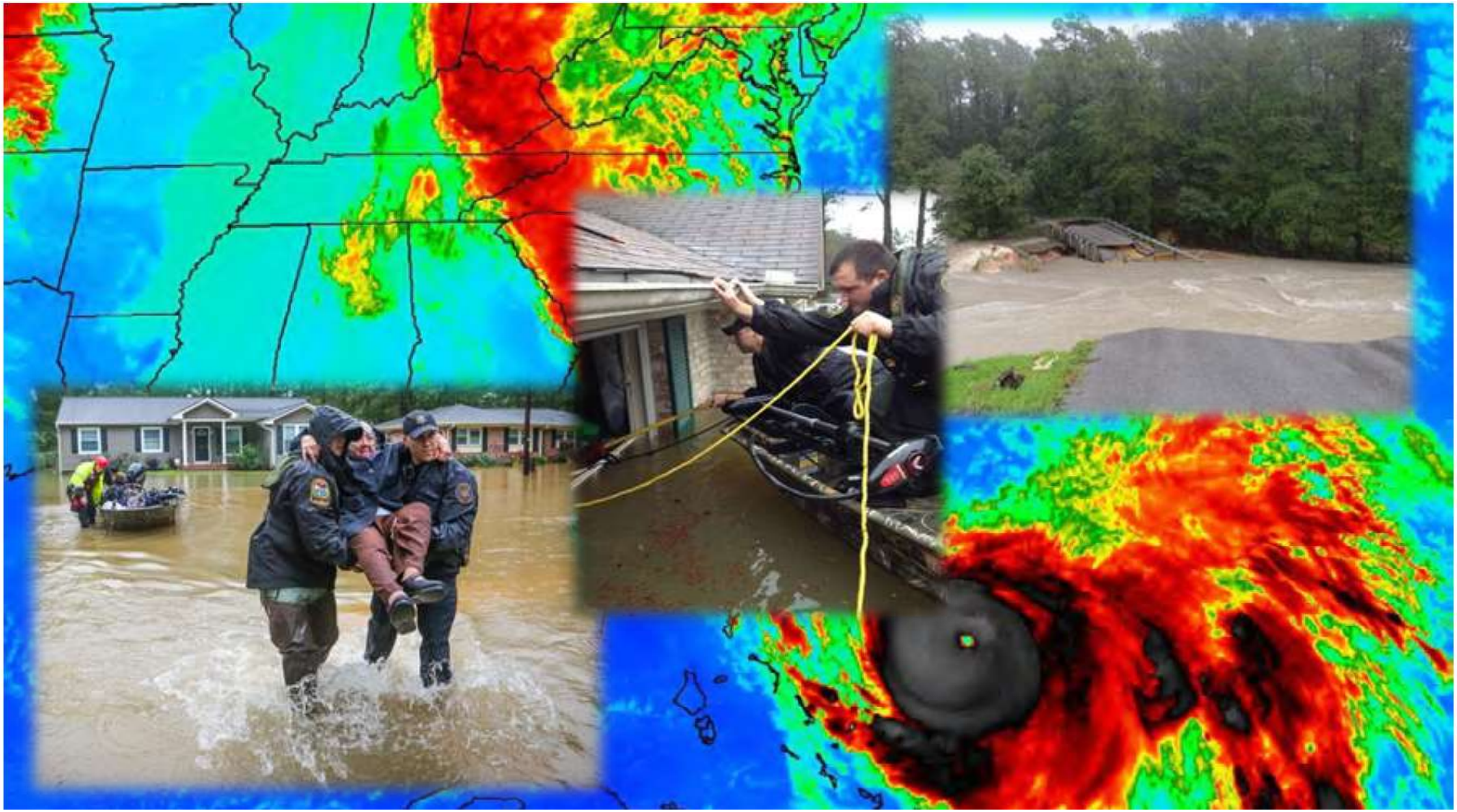
Driving Force – You May Remember This



October 2015 **-** Hurricane Joaquin Storm in the Carolinas

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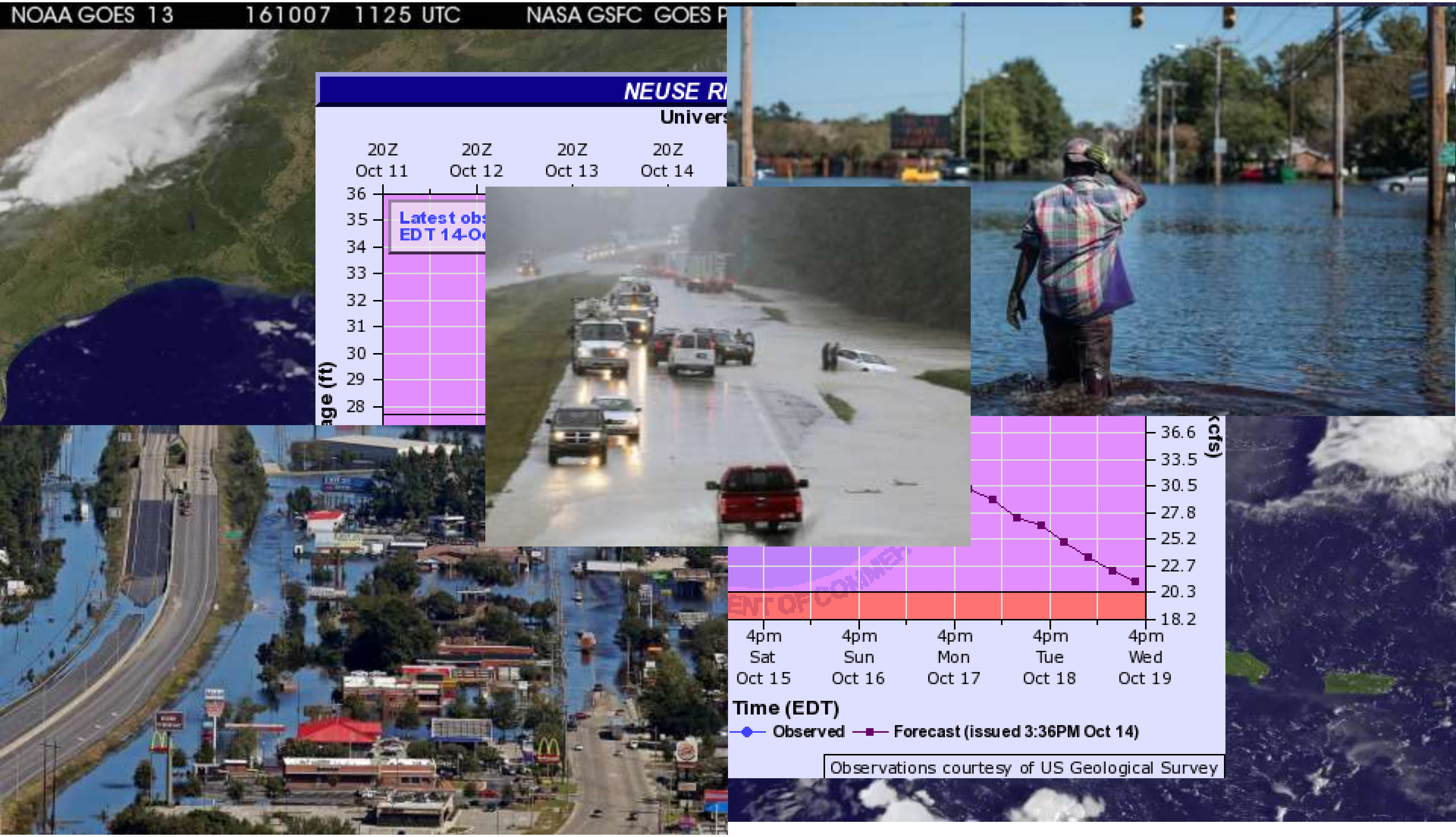
And This …



October 2016 - Hurricane Matthew Storm in the Carolinas

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Presentation Outline

- Background and Context
- Rainfall Probability Concepts
- Storm Event Magnitude Approach
- Case Study Applications
- Summary and Conclusions
- Looking Ahead

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Background and Context

- Rainfall is the most direct and relatable characteristic that defines magnitude of a storm event
- There are a number of resources that report storm event rainfall
- Natural desire to associate large events with recurrence interval

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Problem Statement

- Rainfall generally report as depth totals or animated reflectivity images
- Traditional Reporting Limitations:
  - Duration "lost is translation"
  - Little to no information on storm pattern

Magnitude of storm unknown, misinterpreted, and/or miscommunicated

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The Objective

- Figure out a way to compile rainfall data and compute and visualize storm event magnitudes

Answer the common question:

What magnitude storm event did we (or are we going) to have?

Goals

- Compute for large areas quickly
- Visualize near real-time observed and forecast precipitation probabilities
- Retroactively compute probabilities for historic events
- Integrate wide range of storm magnitudes
  - 2-yr through 500-yr+
- Handle range of storm durations
  - 6-hr, 12-hr, 24-hr, 7-day, etc.

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Rainfall Probability Concepts

Basic Inputs

- When, where, and how much it rained
  - Rainfall amounts distributed over time
  - Spatial location

- Statistical rainfall probability information
  - Depth-Duration-Frequency (DDF)

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Data Sources

- Rainfall Amounts
  - Rain gages
  - Radar-Based:
    - NEXRAD/Radar Products
    - NWS River Forecast Center (RFC) Products
    - NSSL Multiple Radar / Multiple Sensor (MRMS)
- Rainfall Probability
  - NOAA Atlas 14 (successor of TP-40)
  - USGS gage studies
  - Local storm design manuals

Gage-Based Rainfall Data

Pros

- Most accurate
- Near real-time readings

Cons:

- Point-Based Reading
- Incomplete/Inconsistent spatial distribution

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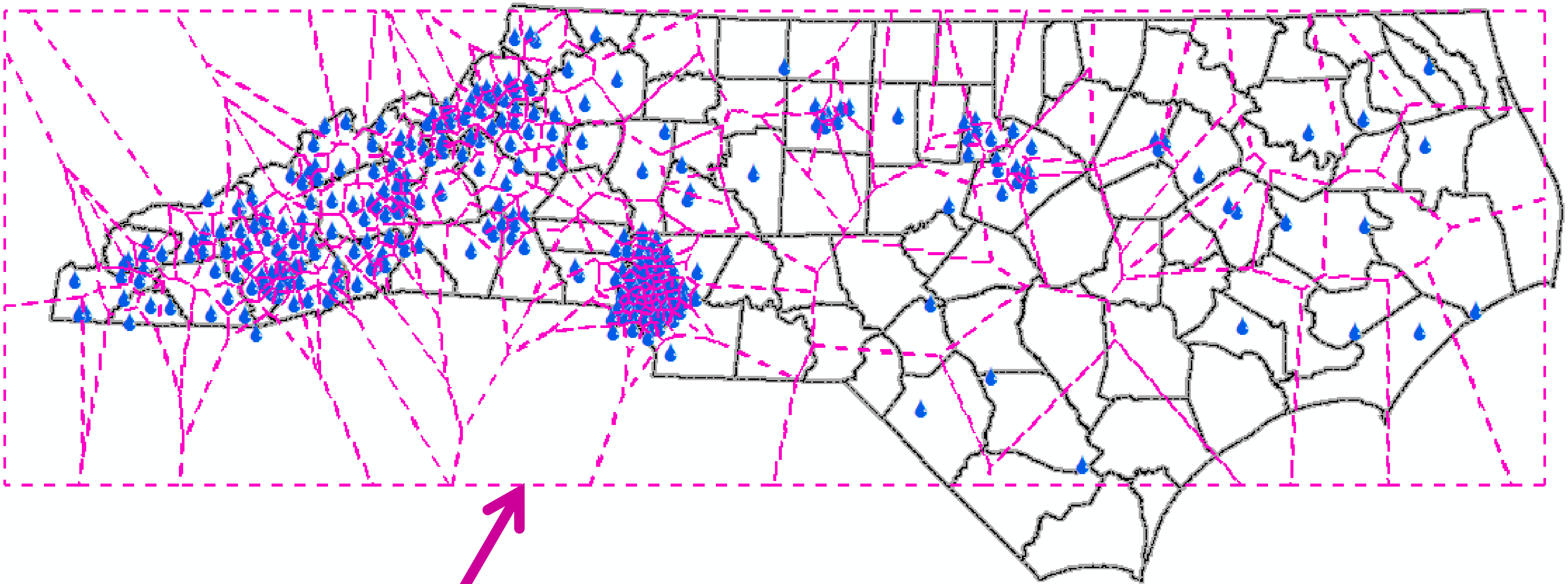
NC Rain Gages



NC Thiessen Polygons (250 sq mi avg area)

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Radar-Based Rainfall Data

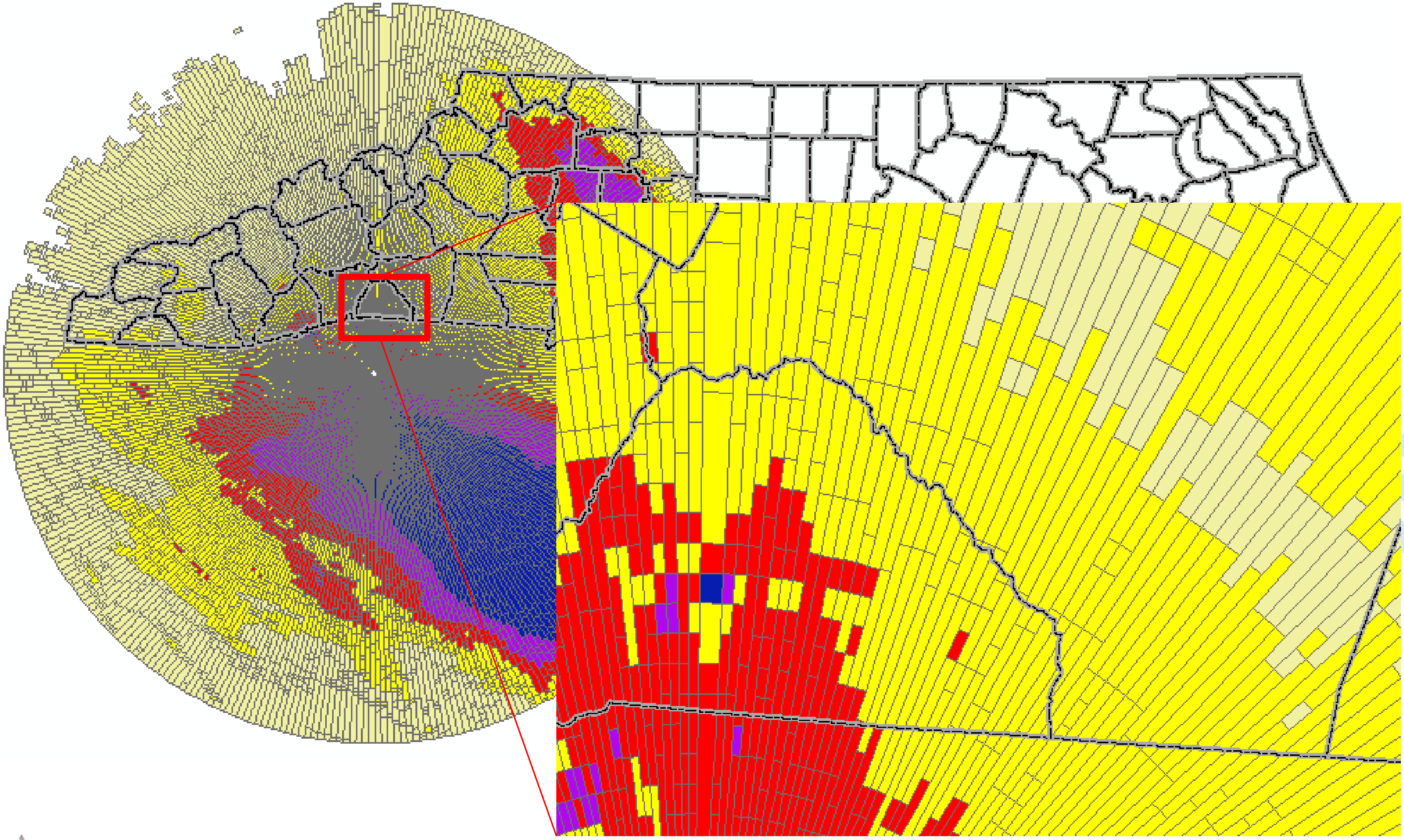
Pros

- Complete coverage
- "Area" based estimates

Cons:

- Less Accuracy
- Ease of use
- Not as "real-time"

NEXRAD Data from Greenville, SC Station



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NWS Precipitation Download

Hourly

Precipitation Shapefile Download

Last Update: 11/18/2015 0847 GMT

(1) Select Download	(2) Select Date Month Day Hour Year	(3) Press the "Download" Button
Precipitation Data Legend File	Nov 18 8 2015	Download Now!

File Name	Files Included	Size
nws_precip_2015111808.tar.gz	nws_precip_2015111808.shp nws_precip_2015111808.shx nws_precip_2015111808.dbf	Approx 0.5 to 7.0 MB

General Information

The precipitation data are quality-controlled, multi-sensor (radar and rain gauge) precipitation estimates obtained from National Weather Service (NWS) River Forecast Centers (RFCs). The original data are in XMRG format and projected in the Hydrologic Rainfall Analysis Project (HRAP) grid coordinate system, a polar stereographic projection true at 60°N / 105°W. Our software reads each participating RFC's XMRG file and grabs the hourly precipitation estimate for each HRAP grid cell.

Use the form above to download these files. Alternatively, you can download a program called wget that mimics ftp capability. Due to increased web security, the anonymous FTP server is no longer available. When using wget, the proper URL to provide is: http://www.srh.noaa.gov/ridge2/Precip/qpehourlyshape/latest or http://www.srh.noaa.gov/ridge2/Precip/qpehourlyshape/YYYY/YYYYMM/YYYYMMDD (where YYYY is the year, MM is the month and DD is the day of month).

We currently only provide a online archive back January 9, 2013. For data prior to that, please contact SR-TUA.Precip@noaa.gov . At this time, the offline archived data goes back to 2010. If you have any questions or problems, please contact SR-TUA.Precip@noaa.gov

Warnings & Forecasts | Graphica

River Observations | River Forecasts

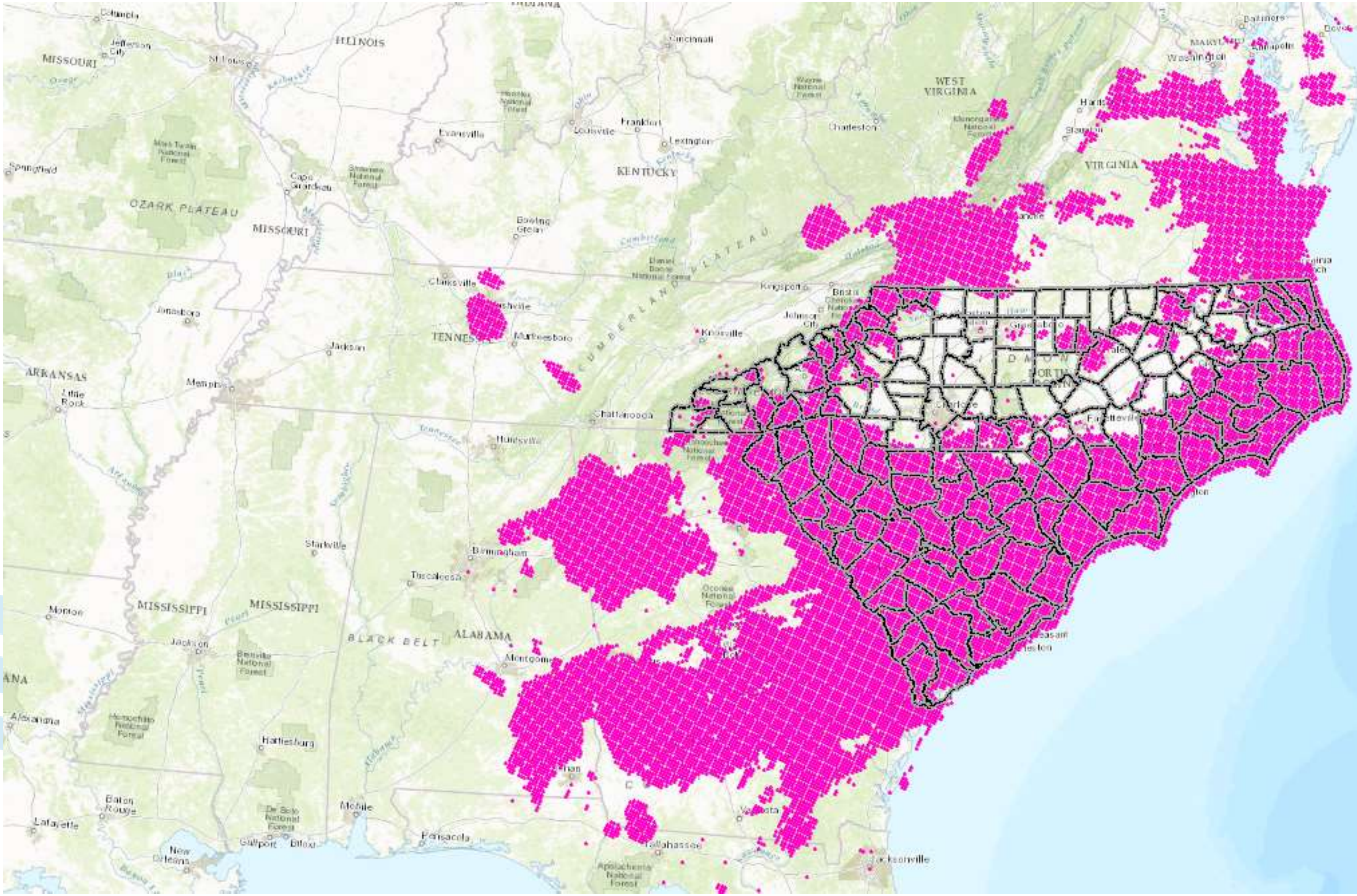
QPE: Quantitative Precipitation Estimates | Dov

(1) Choose Format	(2) Select Time Range	(3) Select Date	(4) Select Download	(5) Select Product	(6) Press the "Download" Button
Shapefile NetCDF Archive Full resolution image for Full Area	Year Month Day	Year 2015 Month November Day 19	1 Day Last 7 Days Last 14 Days Last 30 Days Last 60 Days	Observed Normal Departure from Normal Percent of Normal	Download

File Name	Files Included	Size
nws_precip_1day_observed_shape_20151119	nws_precip_1day_observed_shape_20151119.shp nws_precip_1day_observed_shape_20151119.shx nws_precip_1day_observed_shape_20151119.dbf nws_precip_1day_observed_shape_20151119.prj	15.62 MB

Daily/Monthly/Yearly

NWS Rainfall Download (Point Shapefile)



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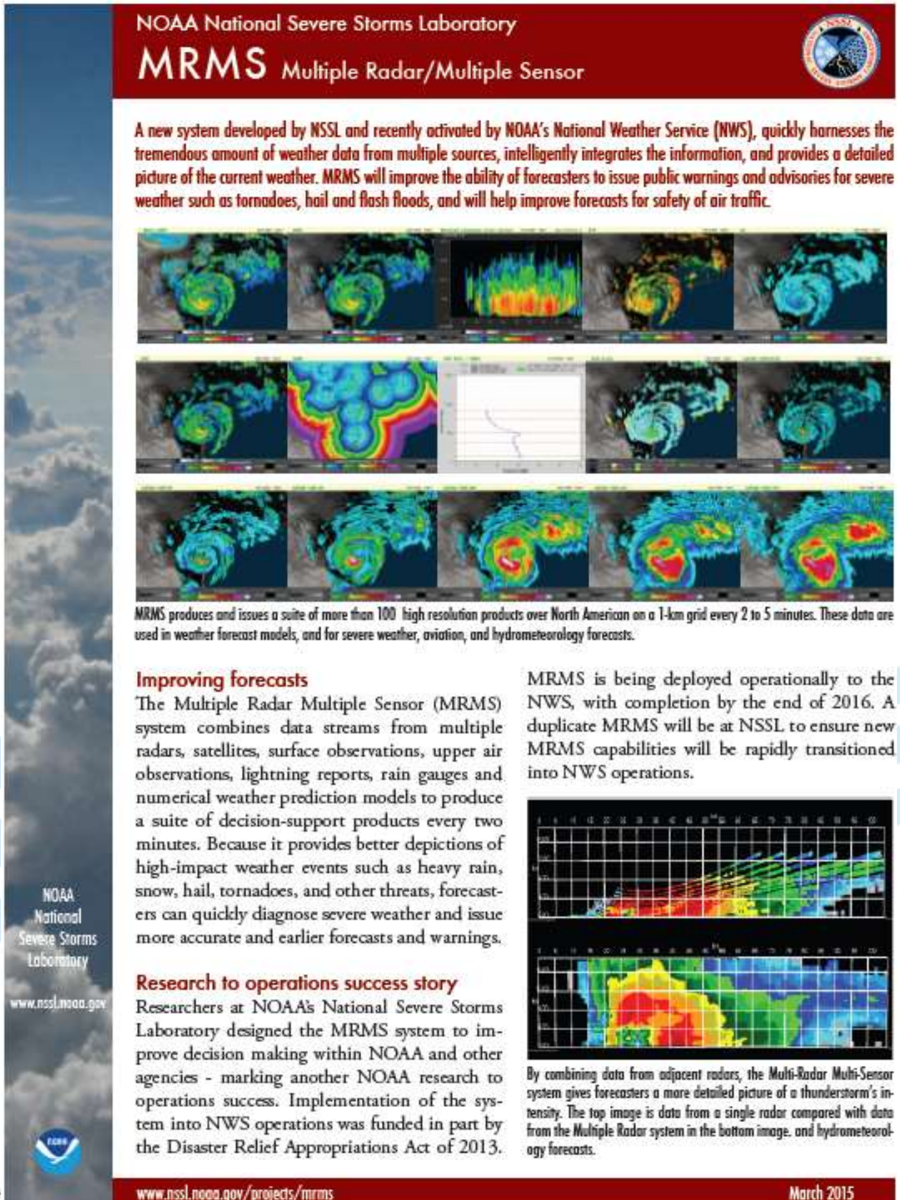
National Severe Storm Laboratory - Multiple Radar/ Multiple Sensor (MRMS)



NOAA National Severe Storms Laboratory

MRMS Multiple Radar/Multiple Sensor

A new system developed by NSSL and recently activated by NOAA's National Weather Service (NWS), quickly harnesses the tremendous amount of weather data from multiple sources, intelligently integrates the information, and provides a detailed picture of the current weather. MRMS will improve the ability of forecasters to issue public warnings and advisories for severe weather such as tornadoes, hail and flash floods, and will help improve forecasts for safety of air traffic.

MRMS produces and issues a suite of more than 100 high resolution products over North American on a 1-km grid every 2 to 5 minutes. These data are used in weather forecast models, and for severe weather, aviation, and hydrometeorology forecasts.

Improving forecasts

The Multiple Radar Multiple Sensor (MRMS) system combines data streams from multiple radars, satellites, surface observations, upper air observations, lightning reports, rain gauges and numerical weather prediction models to produce a suite of decision-support products every two minutes. Because it provides better depictions of high-impact weather events such as heavy rain, snow, hail, tornadoes, and other threats, forecasters can quickly diagnose severe weather and issue more accurate and earlier forecasts and warnings.

Research to operations success story

Researchers at NOAA's National Severe Storms Laboratory designed the MRMS system to improve decision making within NOAA and other agencies - marking another NOAA research to operations success. Implementation of the system into NWS operations was funded in part by the Disaster Relief Appropriations Act of 2013.

MRMS is being deployed operationally to the NWS, with completion by the end of 2016. A duplicate MRMS will be at NSSL to ensure new MRMS capabilities will be rapidly transitioned into NWS operations.

By combining data from adjacent radars, the Multi-Radar Multi-Sensor system gives forecasters a more detailed picture of a thunderstorm's intensity. The top image is data from a single radar compared with data from the Multiple Radar system in the bottom image. and hydrometeorology forecasts.

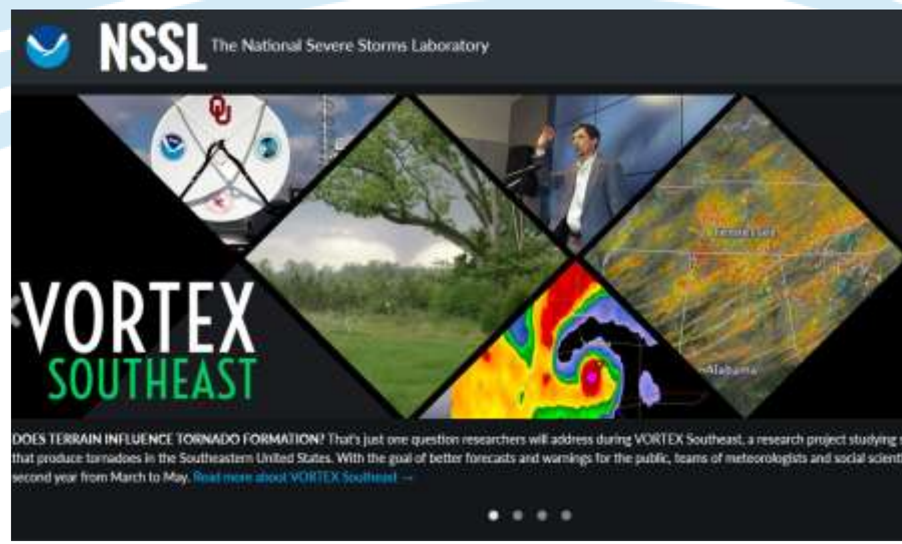
NOAA National Severe Storms Laboratory

www.nssl.noaa.gov

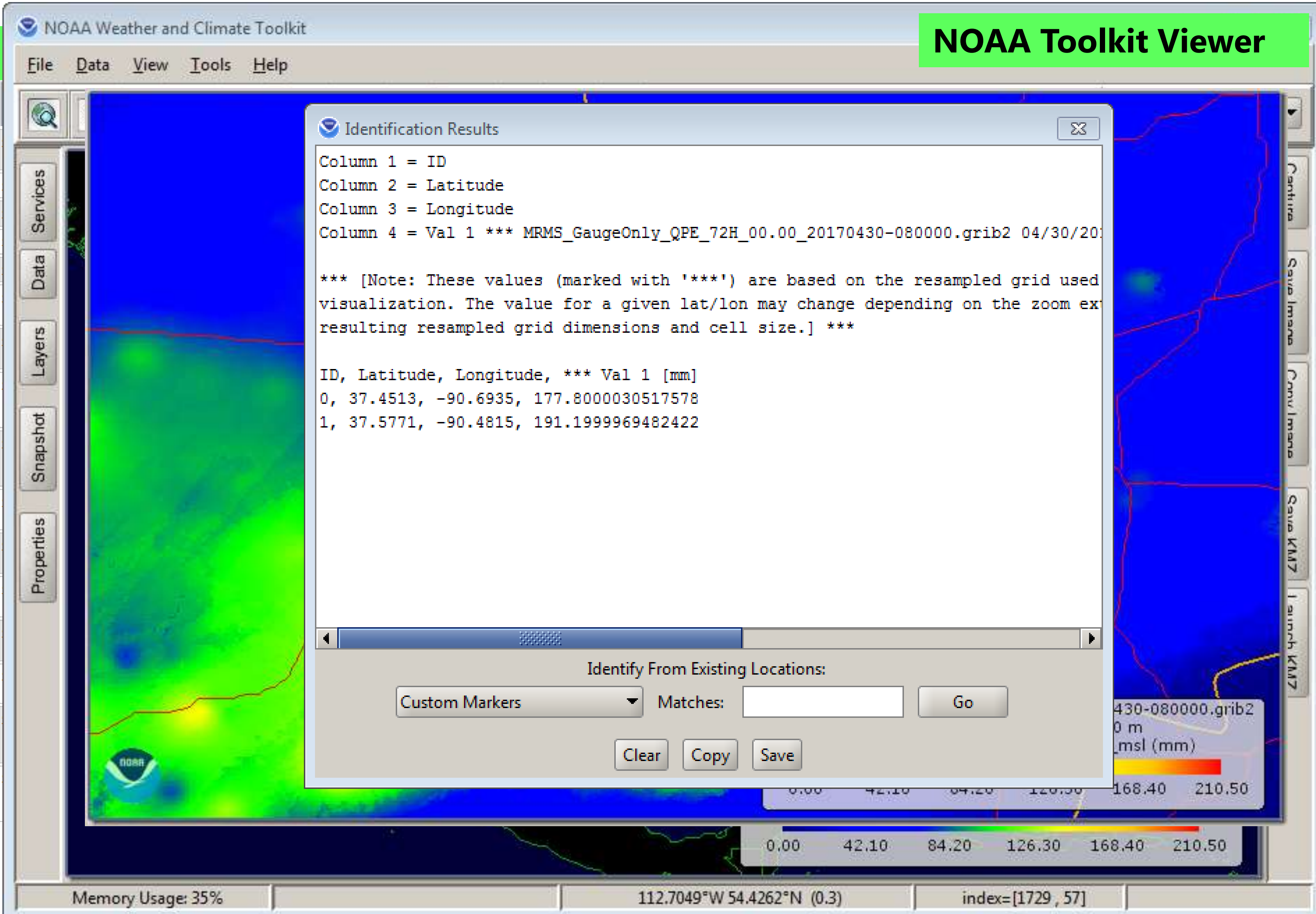
www.nssl.noaa.gov/projects/mrms

March 2015

- Provides integrated technology precipitation estimates
- Evolving technology
- Data retrieval challenges



NOAA Toolkit Viewer



NOAA Atlas 14 Data

- Nationwide coverage (10 volumes)
  - Volume 2 covers Carolinas
- "Static" datasets
- Provides seamless Depth-Duration-Frequency:
  - 5-min to 60-day duration
  - 1-yr to 1000-yr frequency
- Digital access/retrieval through Hydrometeorological Design Study Center (HDSC) website

HDSC Precipitation DDF Web Access

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.424 (0.386-0.466)	0.501 (0.457-0.552)	0.581 (0.529-0.640)	0.637 (0.579-0.700)	0.700 (0.632-0.768)	0.741 (0.668-0.813)	0.778 (0.698-0.854)	0.810 (0.723-0.889)	0.845 (0.747-0.927)	0.869 (0.762-0.955)
10-min	0.677 (0.617-0.745)	0.801 (0.730-0.883)	0.930 (0.847-1.02)	1.02 (0.926-1.12)	1.11 (1.01-1.22)	1.18 (1.06-1.29)	1.24 (1.11-1.36)	1.28 (1.15-1.41)	1.34 (1.18-1.47)	1.37 (1.20-1.50)
15-min	0.846 (0.772-0.931)	1.01 (0.918-1.11)	1.18 (1.07-1.30)	1.29 (1.17-1.42)	1.41 (1.28-1.55)	1.50 (1.35-1.64)	1.56 (1.40-1.72)	1.62 (1.45-1.78)	1.68 (1.49-1.85)	1.72 (1.51-1.89)
30-min	1.16 (1.06-1.28)	1.39 (1.27-1.53)	1.67 (1.52-1.84)	1.87 (1.70-2.05)	2.09 (1.89-2.30)	2.25 (2.03-2.47)	2.39 (2.15-2.63)	2.52 (2.25-2.77)	2.68 (2.37-2.94)	2.78 (2.44-3.06)
60-min	1.45 (1.32-1.59)	1.75 (1.59-1.92)	2.14 (1.95-2.36)	2.43 (2.21-2.67)	2.79 (2.52-3.06)	3.05 (2.75-3.35)	3.30 (2.96-3.62)	3.54 (3.16-3.88)	3.84 (3.39-4.21)	4.06 (3.56-4.46)
2-hr	1.71 (1.55-1.90)	2.07 (1.88-2.30)	2.57 (2.33-2.85)	2.94 (2.66-3.25)	3.41 (3.07-3.76)	3.76 (3.37-4.15)	4.11 (3.65-4.53)	4.44 (3.92-4.90)	4.87 (4.26-5.38)	5.20 (4.50-5.75)
3-hr	1.82	2.21	2.75	3.16	3.70	4.12	4.53	4.95	5.51	5.95
6-										
12										
24										
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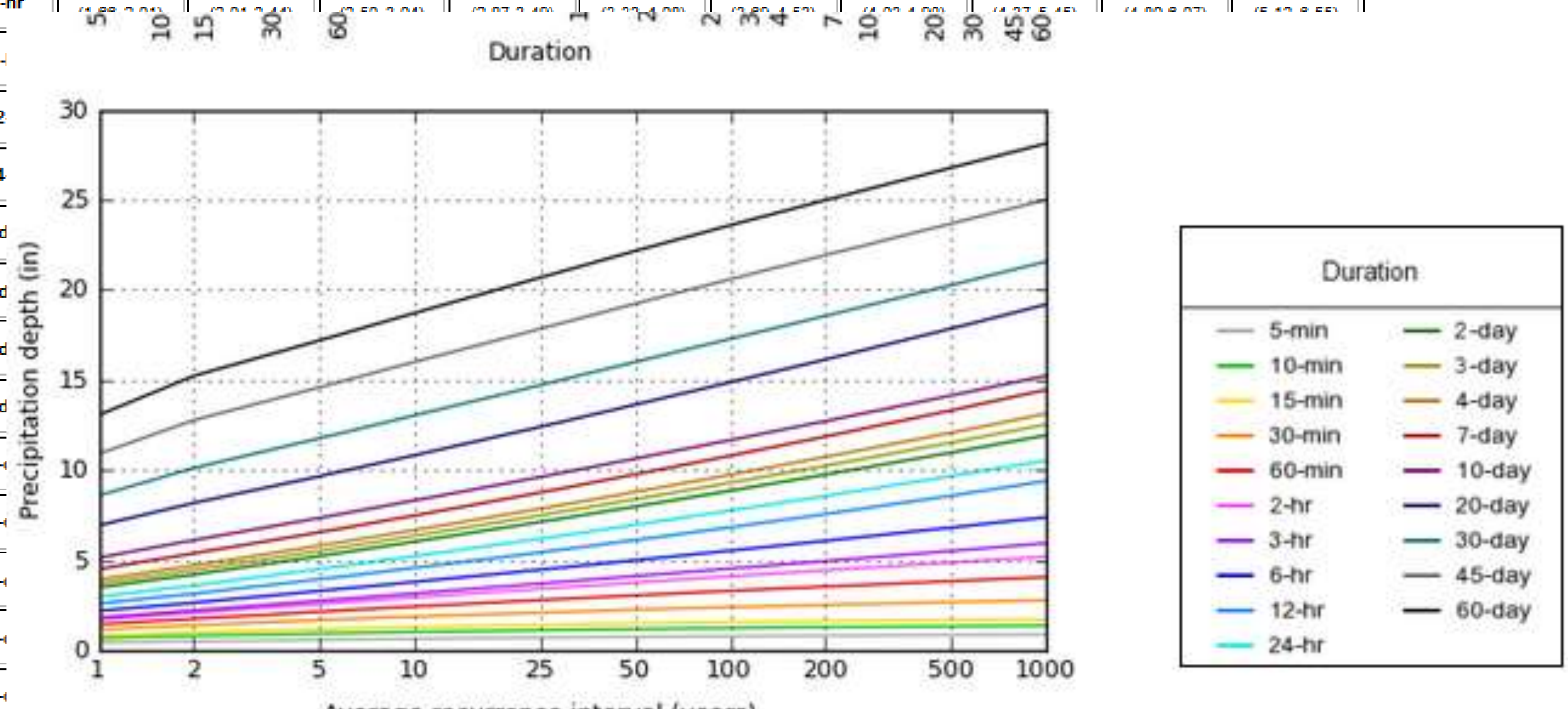
7-d										
10-										
20-										
30-										
45-										
60-										



[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

USGS / Local Data

- Number of local/regional USGS studies that have independent or pseudo-independent DDF (or IDF) information
- Generally focused in more urban areas and generalized at municipal level
- Expected that generally similar to Atlas 14 estimates as often based on(or references) predecessors

Examples of USGS / Local Rainfall Probability Information

USGS
science for a changing world

Prepared in cooperation with the City of Charlotte and Mecklenburg County

Frequency of Annual Maximum Precipitation in the City of Charlotte and Mecklenburg County, North Carolina, through 2004

INTENSITY-DURATION-FREQUENCY TABLE FOR GREENSBORO, NC

Precipitation Intensity Estimates (inches/hour)

Rainfall Duration	Annual Exceedance Probability (1 in __ years)						
	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5 min	4.57	5.44	6.34	6.87	7.55	7.96	8.31
10 min	3.65	4.35	5.08	5.49	6.02	6.33	6.6
15 min	3.05	3.65	4.28	4.63	5.09	5.35	5.56
30 min	2.09	2.52	3.04	3.35	3.77	4.03	4.26
60 min	1.3	1.58	1.95	2.18	2.51	2.73	2.93
2 hr	0.77	0.93	1.16	1.31	1.53	1.68	1.83
3 hr	0.55	0.66	0.83	0.94	1.09	1.21	1.31
6 hr	0.33	0.4	0.5	0.57	0.67	0.75	0.83
12 hr	0.2	0.24	0.30	0.34	0.41	0.46	0.51
24 hr	0.12	0.14	0.18	0.20	0.24	0.27	0.3

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Storm Event Magnitude Approach

Data Sources

- NWS Rainfall Data
- NOAA Atlas 14 Probability Data

General Approach

- Compile pre-staged rainfall reporting and probability data
- Integrate data into single dataset
- Develop calculation algorithms

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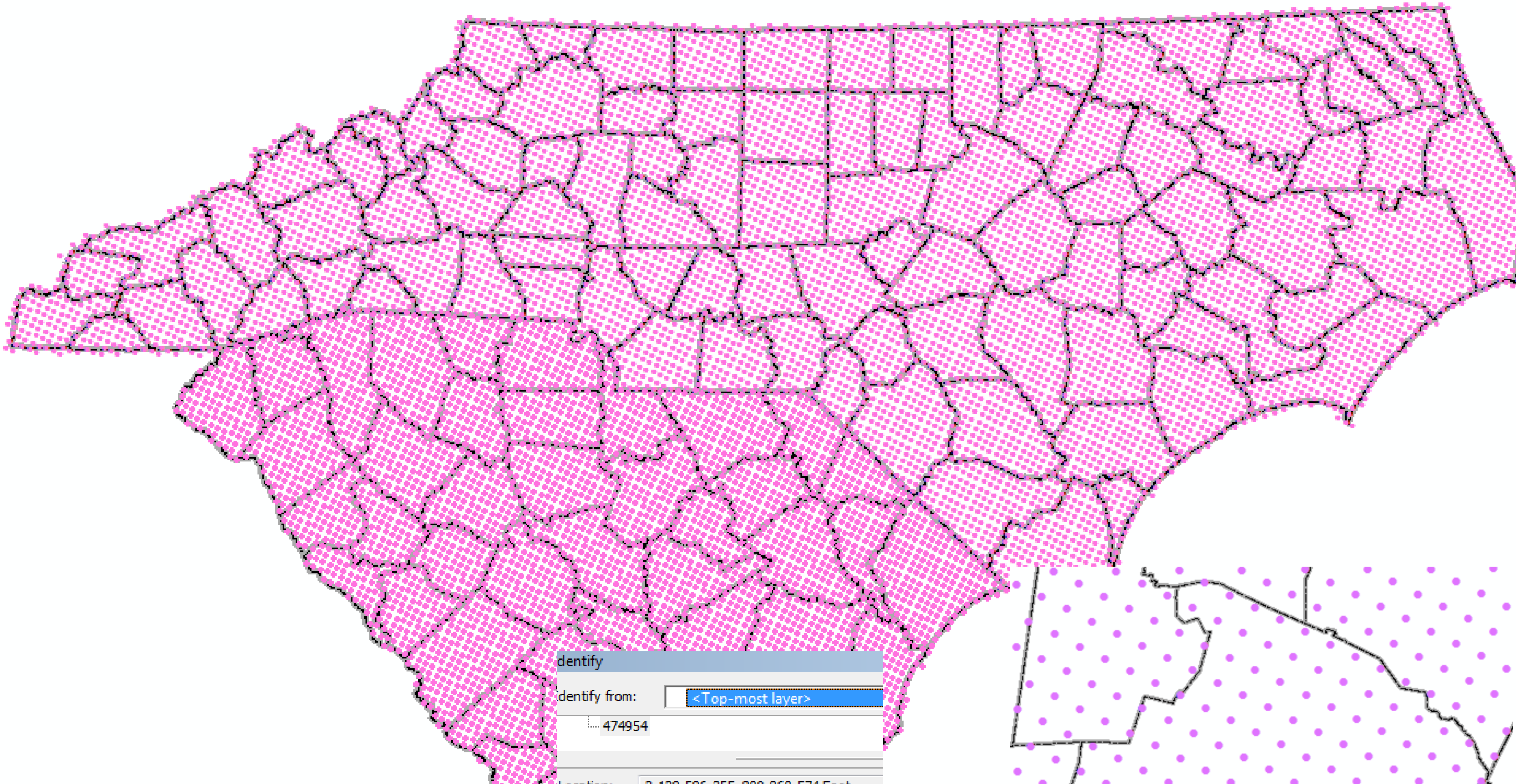
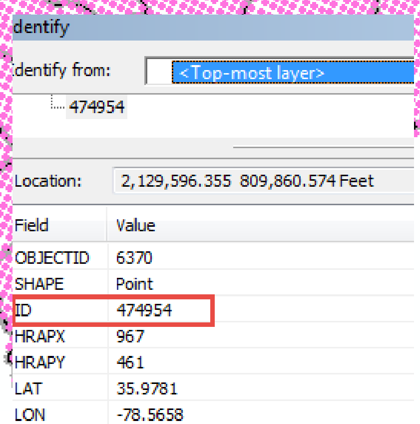
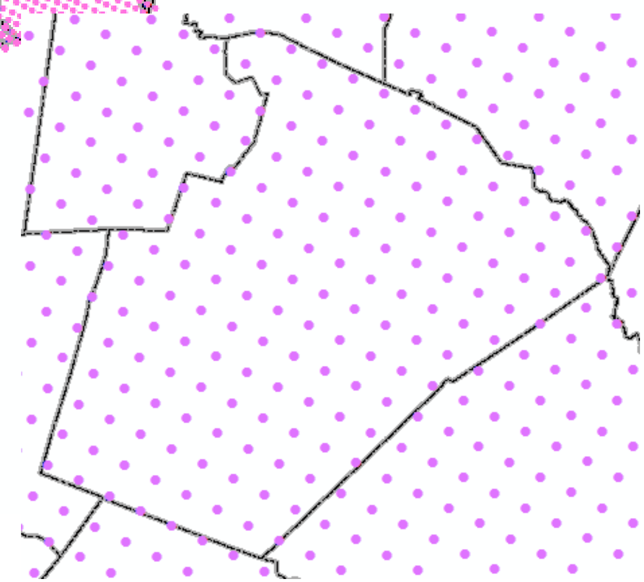
Workflow

- Extract storm precipitation data for desired time/duration from NWS site
- Associated with Pre-Stage/Loaded Data
- Calculate probability based on depth and duration
- Create probability rasters
- Summarize at watershed (HUC12) or desired AOI level
- Map results

NWS Reporting Point Grid

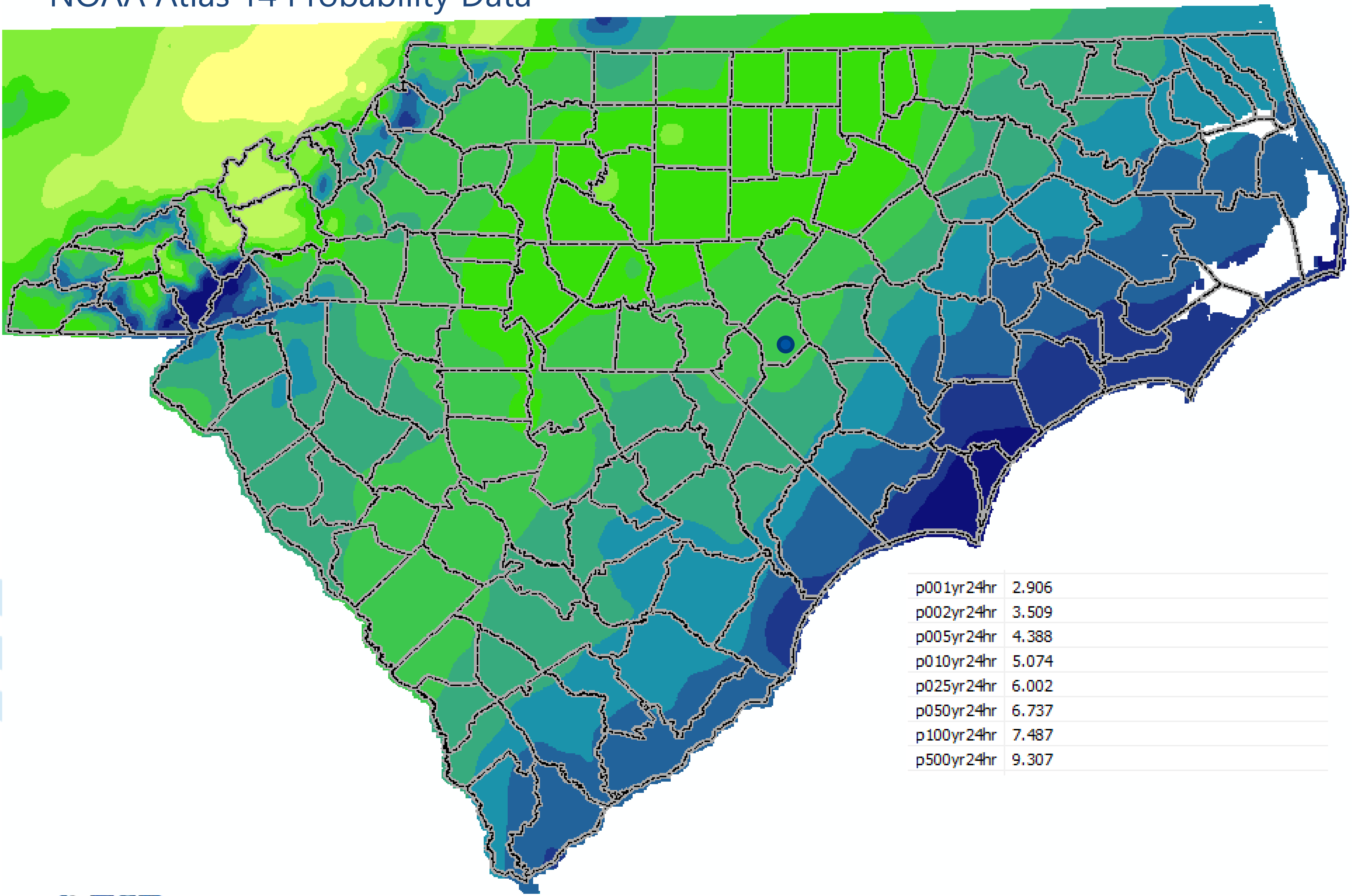






- 2.5 mi grid spacing
- Static ID to link to storm observed/forecast readings

NOAA Atlas 14 Probability Data



p001yr24hr	2.906
p002yr24hr	3.509
p005yr24hr	4.388
p010yr24hr	5.074
p025yr24hr	6.002
p050yr24hr	6.737
p100yr24hr	7.487
p500yr24hr	9.307

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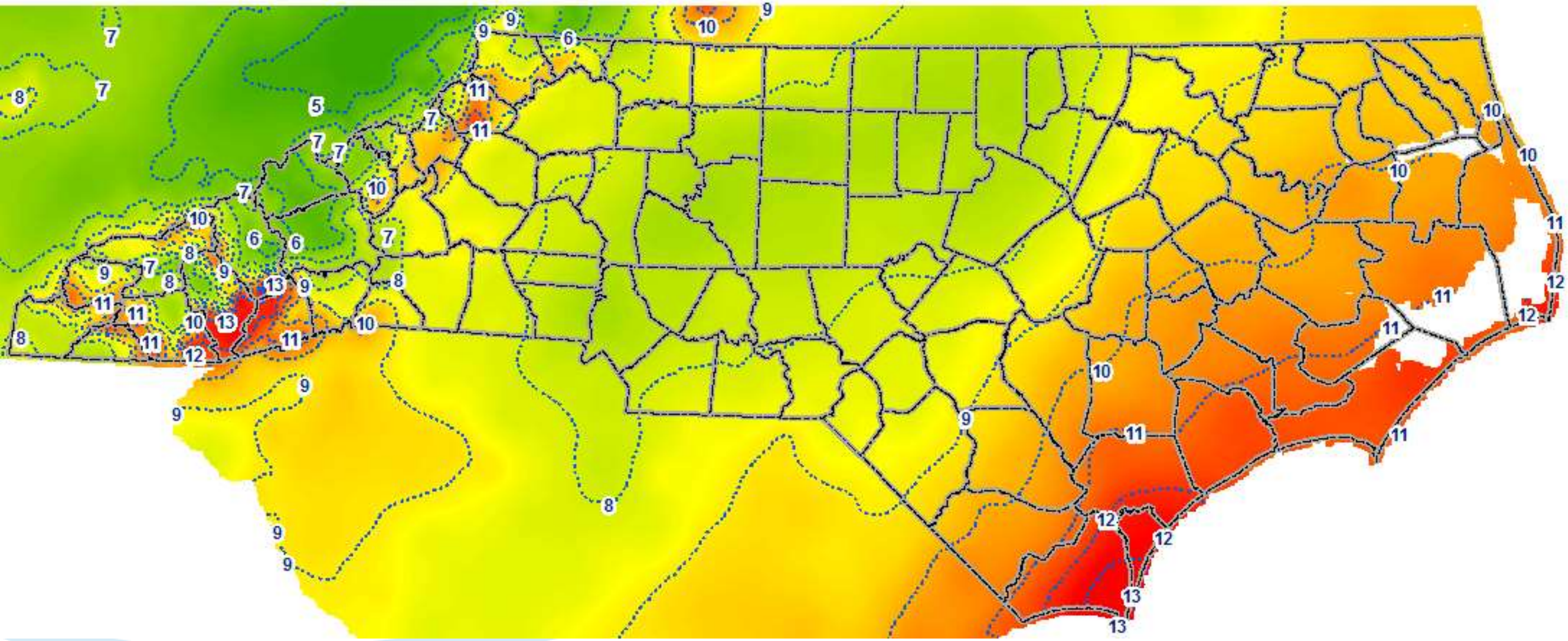
NC 24-hr 100-yr Rainfall Depth Raster



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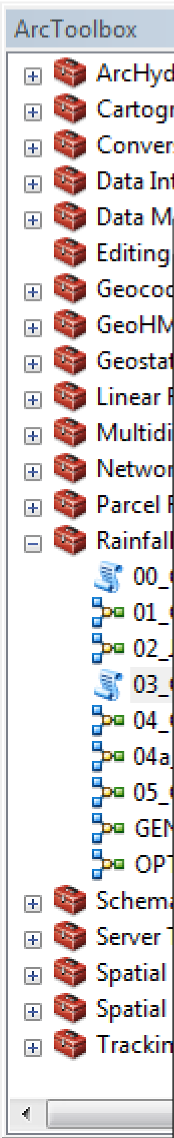
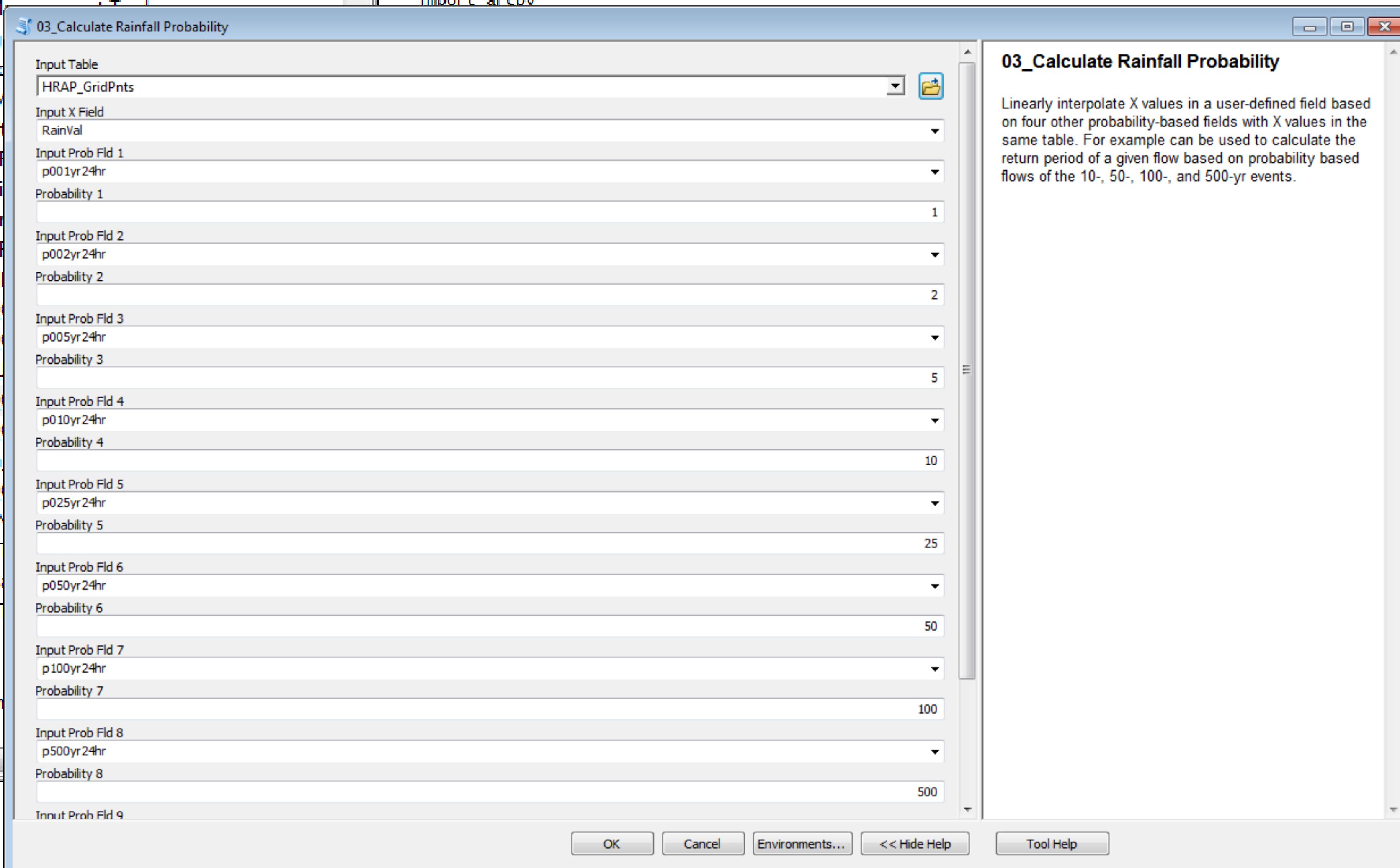
Rainfall Processing Tools

```
# ---------------------------------------------------------------------------
# Name:     GetLatestQPE_ScriptTool.py
# Type:     Python Script Tool for ArcGIS
# Purpose:  Download and upzip latest qualitative precipitation estimate point shapefiles from
#           NOAA Southeast Region Headquarters (SRH) website.
#
# Author:   Neal Banerjee, PE, CFM
# Date:     September 2016
# ArcGIS Version:    10.0 and Higher
# Python Version:    2.7.5
#
# Usage: GetLatestQPE <WorkDirectory>
#
# ---------------------------------------------------------------------------

# Import necessary Python modules
import arcpy
```





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Case Study Applications

- SC/NC Hurricane Joaquin – October 2015
- SC/NC Hurricane Matthew – October 2016
- Mecklenburg County – August 2011

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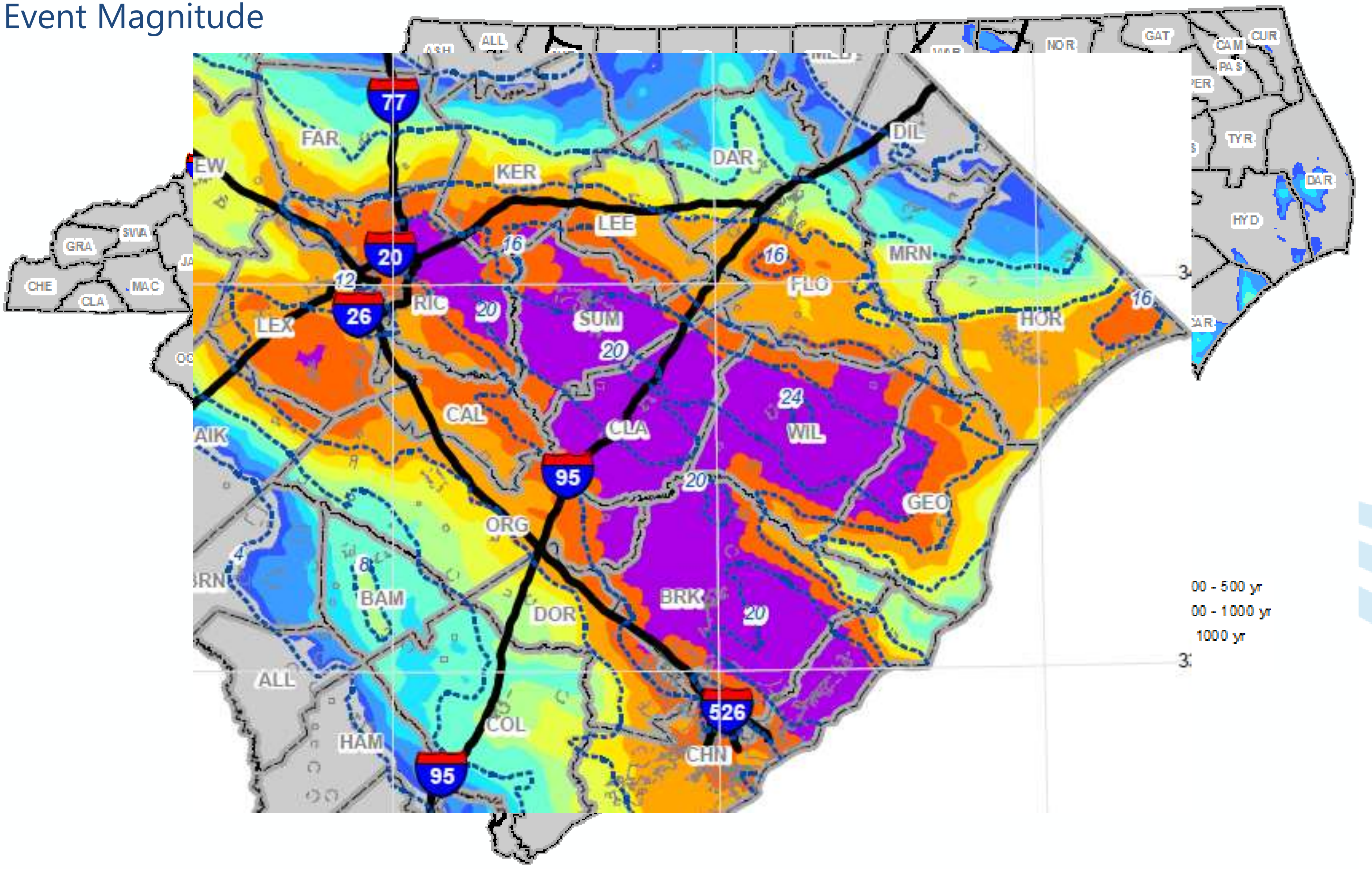
Hurricane Joaquin

- October 3 – 5, 2015
- Hurricane and stalled low pressure system
- 3″ – 20″+ of rainfall
- 20 fatalities
- Billions in losses and damage
- South-Central SC hit hardest

3-Day Probability Storm Event Magnitude



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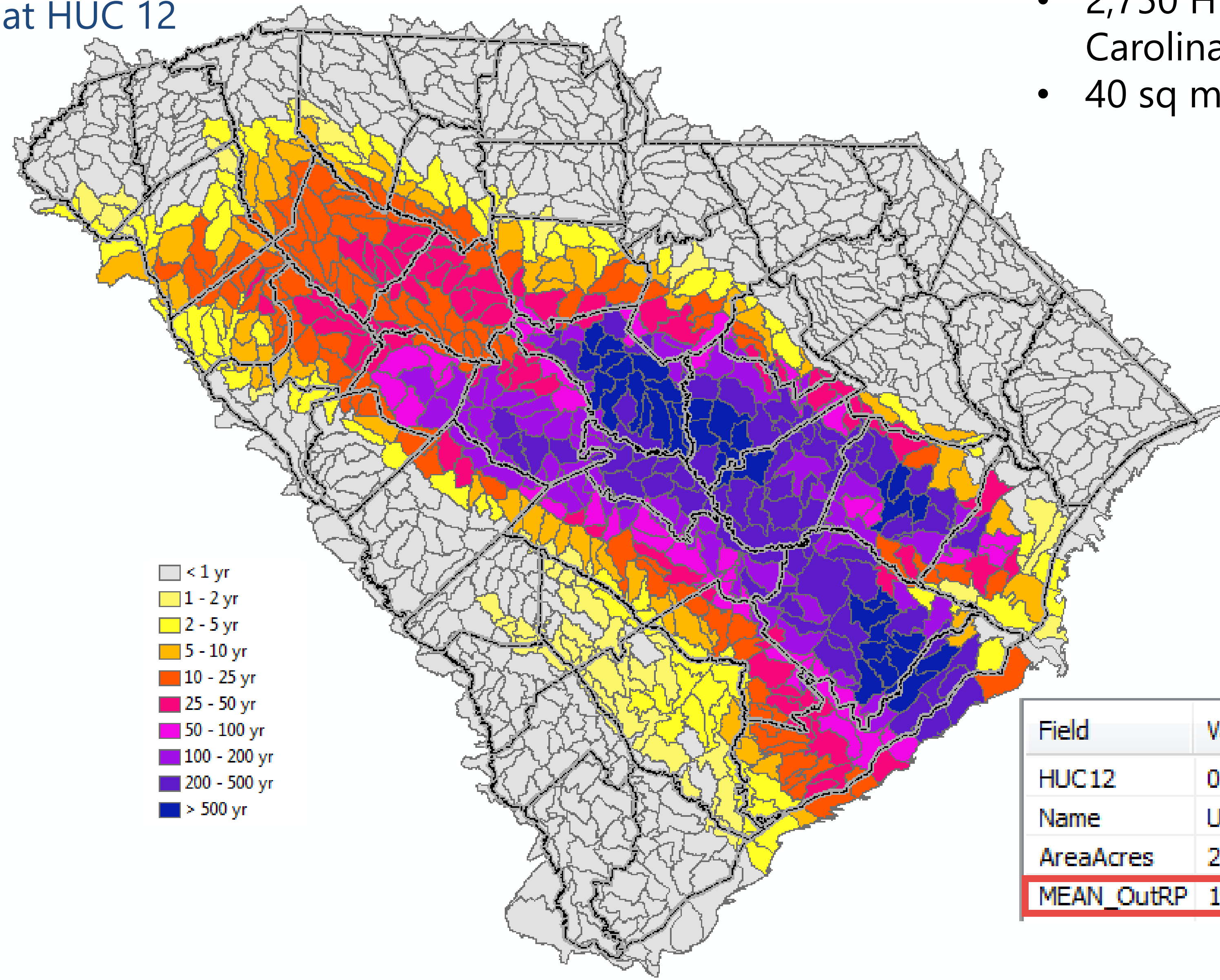
Probability Summarized at HUC 12

- 2,750 HUC12s in Carolinas
- 40 sq mi average area ±



Field	Value
HUC12	030501100102
Name	Upper Congaree Creek
AreaAcres	23613
MEAN_OutRP	195.627026

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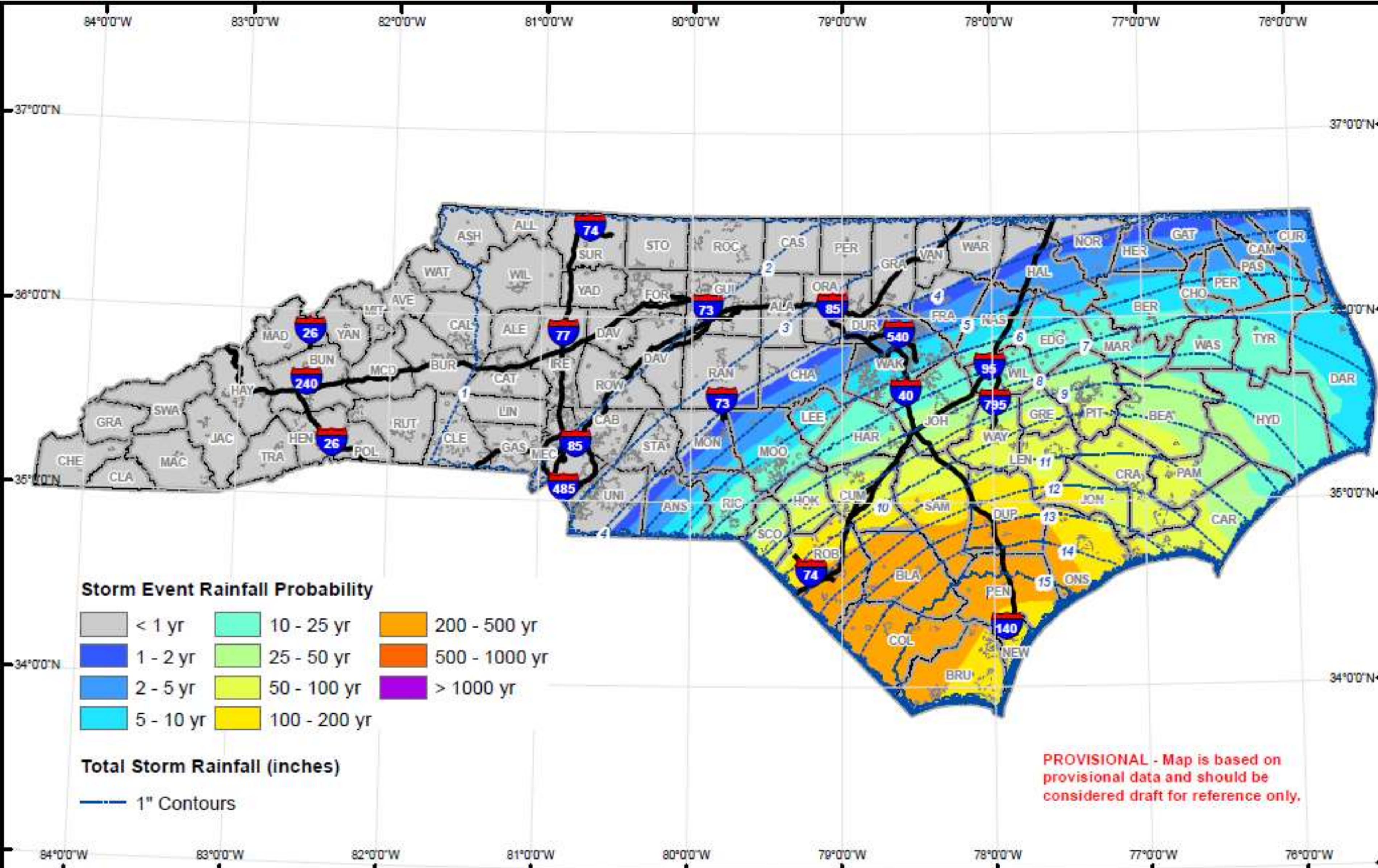
Hurricane Matthew

- October 7 – 8, 2016
- 3″ – 20″+ of rainfall
- 26 fatalities in Carolinas
- New records at 8 gages
- Billions in losses and damage
- Extended flooding for weeks



0 12.5 25 50 Miles

NLB 10/7/16

Legend

Interstates

Counties

Municipalities

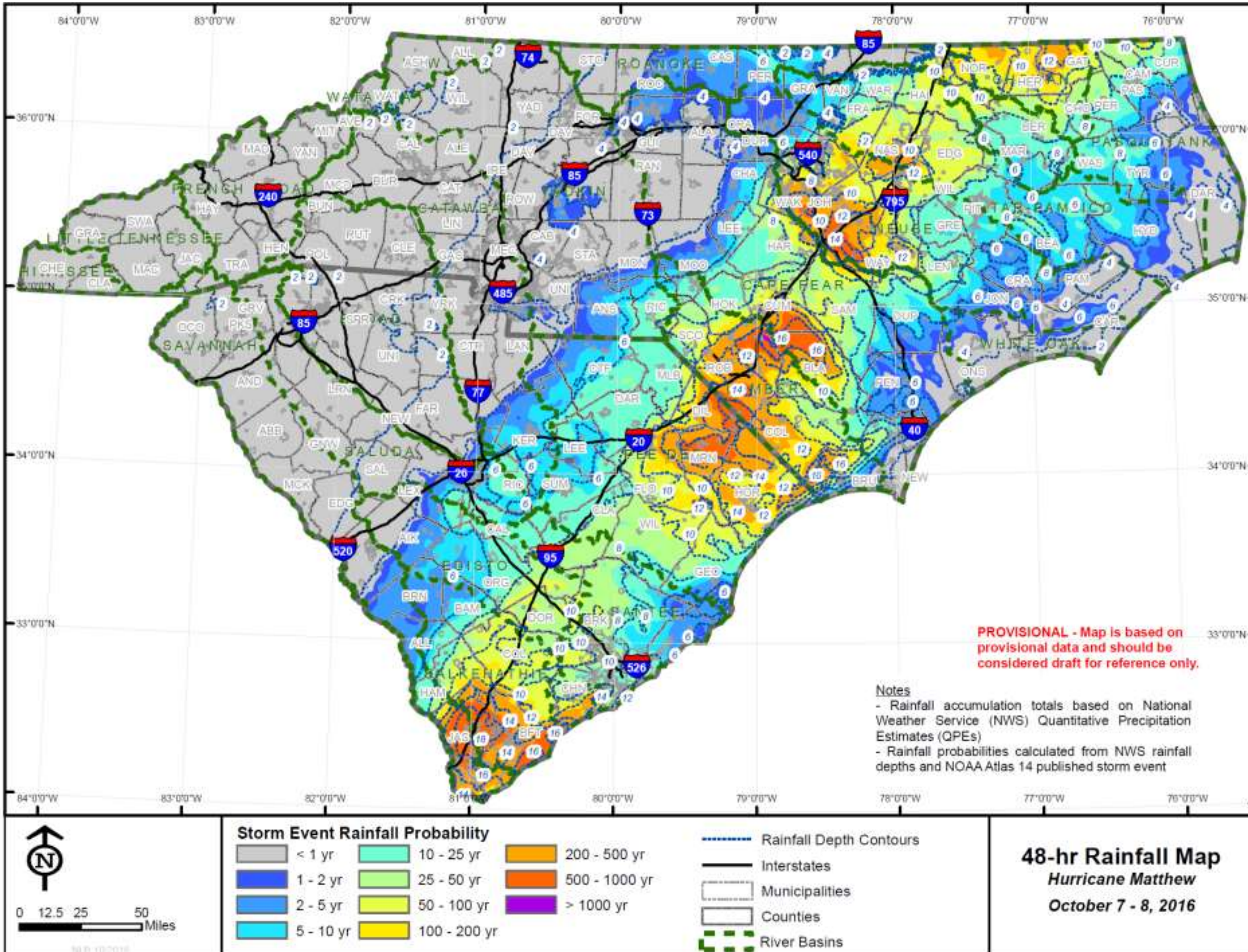
Notes

- Rainfall forecast totals based on Weather Prediction Center (WPC) estimates
- Rainfall probabilities calculated from NWS rainfall depths and NOAA Atlas 14 published storm event probabilities

Max. 48-hr Forecast Rainfall Map

Hurricane Matthew

8PM 10/7/16 - 8PM 10/9/16


48-hr Rainfall Map
Hurricane Matthew
October 7 - 8, 2016
PROVISIONAL - Map is based on provisional data and should be considered draft for reference only.
Notes
- Rainfall accumulation totals based on National Weather Service (NWS) Quantitative Precipitation Estimates (QPEs)
- Rainfall probabilities calculated from NWS rainfall depths and NOAA Atlas 14 published storm event
Storm Event Rainfall Probability
< 1 yr
1 - 2 yr
2 - 5 yr
5 - 10 yr
10 - 25 yr
25 - 50 yr
50 - 100 yr
100 - 200 yr
200 - 500 yr
500 - 1000 yr
> 1000 yr
Rainfall Depth Contours
Interstates
Municipalities
Counties
River Basins
0 12.5 25 50 Miles
N
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
79°0'0"W
78°0'0"W
77°0'0"W
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34°0'0"N
33°0'0"N
ROANOKE
WATAUGA
FRENCH BROAD
CATAWBA
LITTLE TENNESSEE
HIWASSEE
SAVANNAH
SALUDA
EDISTO
SANTEE
CAPE FEAR
NEUSE
TAR-PAMLICO
PASQUOTANK
CHOWAN
WHITE OAK
LUMBER
PEE DEE
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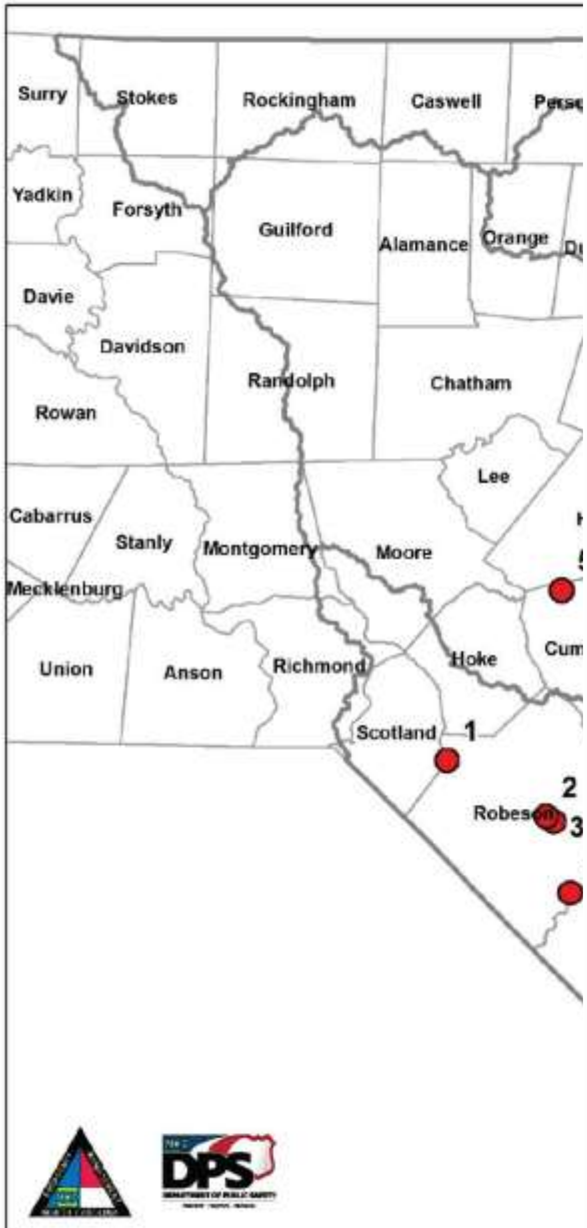
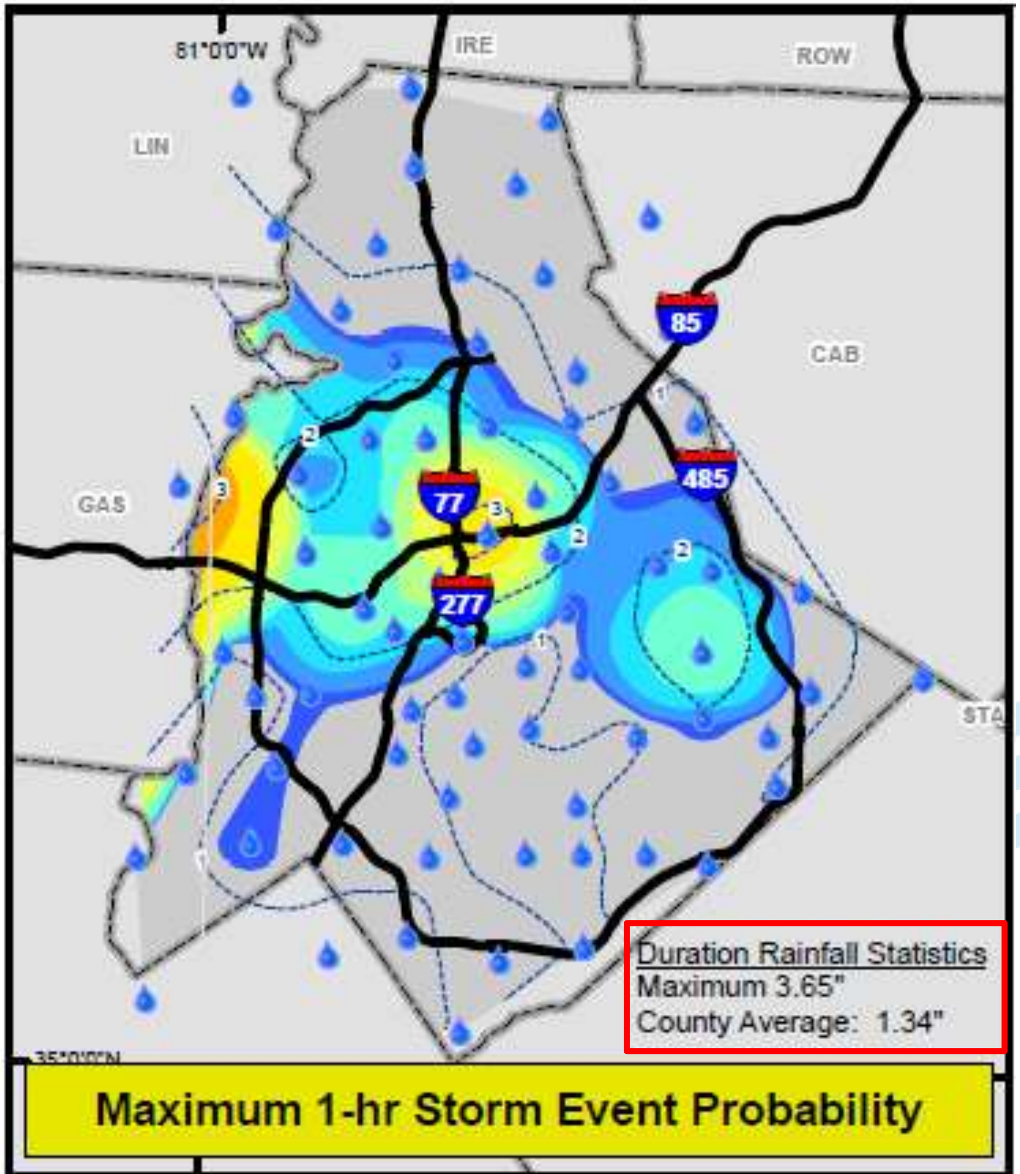


Map Location	River Name and Location	County	Peak Matthew Elevation (ft)	Previous Record (ft)	Approximate Return Event	Duration above flood stage
Lumber River Basin						
1	Lumber River at Maxton	Robeson	186.5	184.5	100-year	N/A
2	Lumber River at Lumberton, Above I-95	Robeson	124.3	120.5	200-year	Currently above NWS flood stage
3	Lumber River at Lumberton, 5 Ave.	Robeson	119.3	115.8	75-year	15 days *(ongoing)*
4	Lumber River at Boardman	Columbus	85.5	81[illegible]	>500-year	N/A
Cape Fear River Basin						
5	Little River at Manchester	Cumberland	155.0	151.8	>500-year	4.5 days
6	Cape Fear at Lillington	Harnett	123.2	137.0	<10-year	1 day
7	Cape Fear River at Fayetteville	Cumberland	78.6	88.6	100-year	5 days
8	Cape Fear River at Lock #1 near Kelly	Bladen	24.8	26.0	100-year	6 days
9	NE Cape Fear River near Chinquapin	Duplin	36.3	39.8	500-year	7 days
Neuse River Basin						
10	Crabtree Creek at Crabtree Valley Mall	Wake	225.5	230.5	35-year	1 day
11	Crabtree Creek at Old Wake Forest Rd	Wake	205.8	N/A	100-year	1 day
12	Neuse River near Clayton	Johnston	148.0	149.6	45-year	2 days
13	Neuse River at Smithfield	Johnston	127.4	125.7	200-year	4.5 days
14	Neuse River near Goldsboro	Wayne	71.6	70.8	90-year	10.25 days
15	Neuse River at Kinston	Lenoir	38.1	37.5	75-year	11 days (ongoing)
16	Hominy Swamp at Forest Hill Rd	Wilson	122.8	N/A	>500-year	1 day
17	Contentnea Creek at Hookerton	Greene	37.9	42.0	>500-year	9.75 days

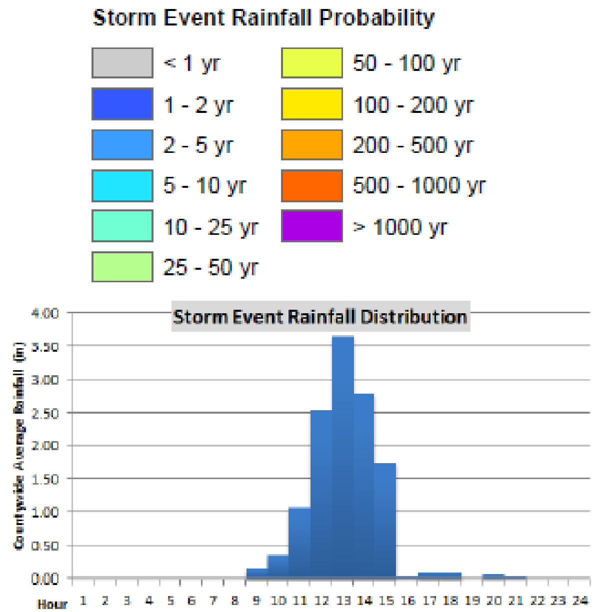
August 2011 Storm

- August 5, 2011
- Stalled low pressure system western-central Charlotte
- Major "flash flood"
- 7"+/- rain in short period
- 2 fatalities, 160 buildings flooded
- $2M in damage

Multi-Duration Storm Event Magnitude



- Intense 6-hr storm concentrated over 3-4 hours
- Dense gage network
- Example of multi-duration probability



Notes
- Rainfall accumulation totals based on Mecklenburg County / USGS Rain Gage Network (72 gages)
- Rainfall probabilities calculated from gage rainfall depths and NOAA Atlas 14 published storm event probabilities

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Performance/Scalability

- Algorithms work very fast at large are levels (e.g. statewide)
  - Probability calculations: seconds
  - Mapping and AOI Summary: seconds to minutes
- Scalable nationwide
- Can use similar logic for rainfall forecast
  - 3-day advance in 6-hr increment
- Can automate retrieval and processing every hour

Summary and Conclusions

- Traditional rainfall reporting can lead to misinterpretation of storm event magnitude
- Combining readily available rainfall data, can estimate storm event magnitudes for multiple durations over large areas
- Same logic can be applied to historic storms or forecasted rainfall
- Data and algorithms are scalable and can be batched for automated processing

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Looking Ahead

- Relate rainfall probability estimates with flood impacts
  - Flood Warning / Gages (where exists)
  - Existing models (e.g. RiskMAP) in ungaged areas

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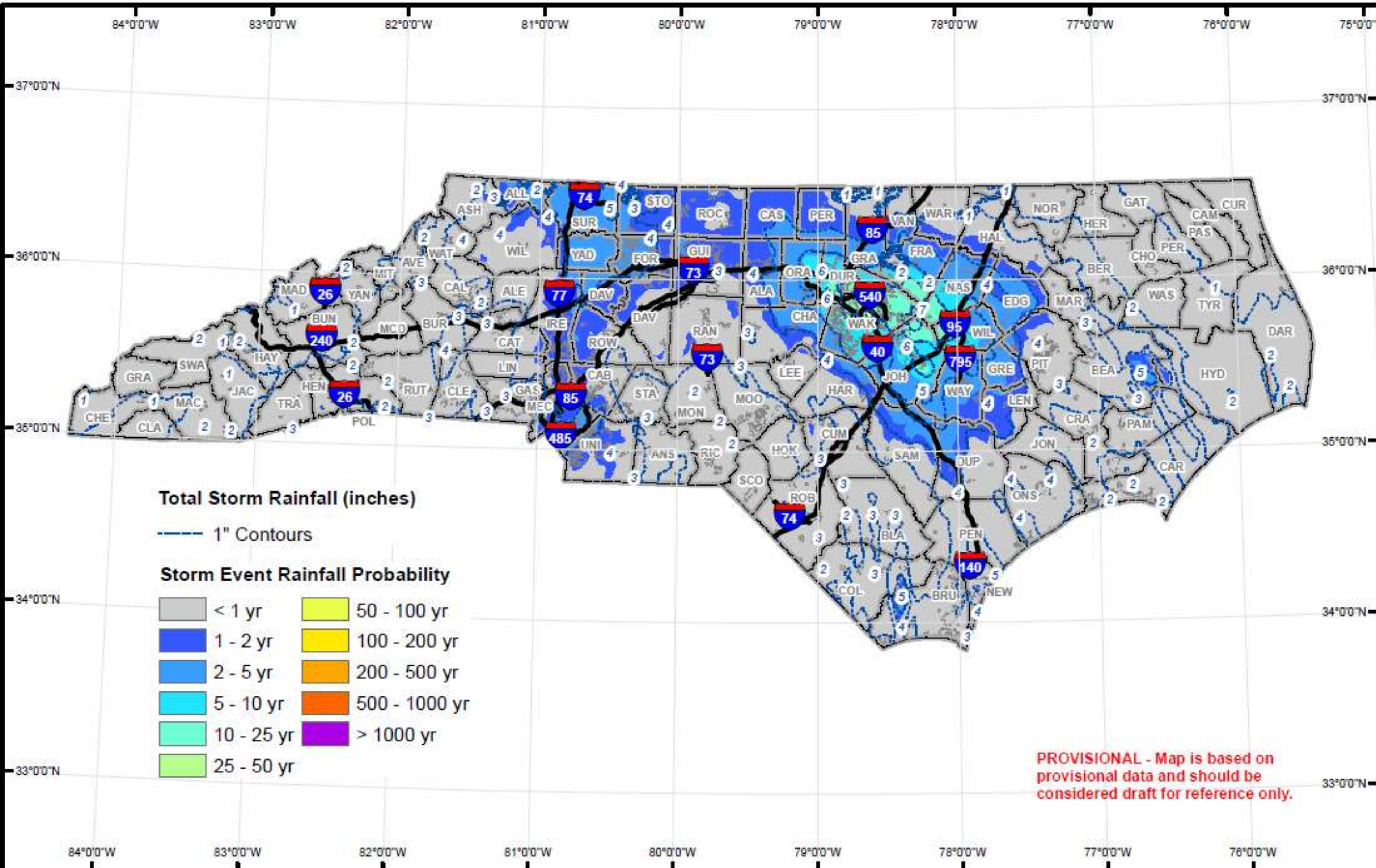
NC FIMAN in EOC During Hurricane Matthew

NC National Guard @NCNationalGuard · 4h
Our #AlwaysReady team is working closely with our State Emergency Response partners coordinating support efforts for Hurricane #MatthewNC
NC Emergency Managem, NC Public Safety and NC Governor's Office

10 8



N

0 12.5 25 50 Miles

Legend

- Interstates
- Counties
- Municipalities

Notes

- Rainfall accumulation totals based on NOAA Southeast Region Headquarters (SRH) estimates
- Rainfall probabilities calculated from NWS rainfall depths and NOAA Atlas 14 published storm event probabilities

Last 48-hr Rainfall Map

North Carolina

4/25/2017