Deriving and Modeling Flood Dynamics From GIS-Based Doppler Radar

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Abstract

Doppler radar provides repetitive, short-term atmospheric reflection data, obtained from returns of pulsed radar. When plotted as time-base cells or points, Doppler data can be converted to equivalent rainfall, typically over five-minute intervals. ArcGIS facilitates selection and interpolation of short interval data to create multiple or summarized precipitation grids. This paper presents the compilation and analysis of Doppler data obtained during an intense storm event in Wilson, NC, on August 26, 2001. The storm caused widespread street flooding and resulted in numerous evacuations. Examples of Hydrologic model output that incorporate Doppler rainfall are presented to understand storm dynamics.

Introduction

Flood watch in effect for central North Carolina - *As much as eight inches of heavy rain since Sunday has caused localized flooding in areas north and east of Raleigh, NC. A flood watch remains in effect today for central North Carolina as more rain is expected. As many as 31 counties have been included in the watch.* *FEMA National Situation Update: Tuesday, August 27, 2002*

Early Monday morning August 26, 2002, a large upper-level low-pressure system over the southeast merged with a frontal boundary over the Carolinas to produce areas of locally heavy rainfall. The system moved slowly north producing widespread showers and thunderstorms. Soils baked by a prolonged drought in the Carolinas were unable to infiltrate much of the intense precipitation and rainfall quickly accumulated in drainages and began to flow toward the coast. Wilson County and the Community of Wilson were inundated with flood waters and many areas were evacuated.

"Several hundred thousand dollars of damage was done to the Wilson Fire/Rescue station on Hines Street. Sleeping quarters for the firefighters have been shifted to the four other stations throughout Wilson. However, the Hines Street headquarters is still functioning during the regular day hours. Ed Wyatt, Wilson's city manager, said carpet, wall coverings and sheetrock were all damaged in the station."

"The first floor of City Hall also flooded. Wyatt said most likely the carpet will have to be replaced. There was also some damage to the Toisnot Water Treatment plant. However, Wyatt said damage to it was less than what happened at the fire station. [Stormwater Program Manager Donna] Hendrix said the city got 5.31 inches of rain with four inches of it falling between 8 a.m. and 10 a.m. City crews worked to free street catch basins of debris

washed into them by the water. Some of the items are large, including lawn furniture and buckets." *Wilson Daily Times, August 27, 2002*

Wilson's problem is not just a case of overflowing streams. The water that flooded Fire Station No. 1 last month did not come from overflowing stream banks. It came rushing down streets where catch basins were either improperly placed or were clogged, jumped the curbing and flowed into the fire station. The same problem happens on other streets, notably Glendale Drive near Medical Park Drive and on parts of Nash Street and U.S. 301. Wilson Daily Times, September 25, 2002

Figure 1: Street flooding in Wilson, NC, August 26, 2002. Photo courtesy of Will Aycock, Wilson Fire Department

As flooding subsided, ESRI Public Safety support staff and Natural Hazards consultants were asked to recreate and interpret the extensive rainfall event of August 26, and to prepare to model the consequences. ESRI Business Partner Meteorlogix, Minneapolis, MN retrieved Doppler radar data from recent archives and provided them to Mike Price, ESRI Mining and Earth Science Manager, for modeling. Digital terrain models were acquired from several sources and tested for accuracy and detail. Additional spatial data was acquitted from Wilson City, Wilson County, Wilson Fire Department, and the North Carolina Floodplain Mapping program http://www.ncfloodmaps.com/.

This paper discusses NEXRAD Doppler radar and presents a method for summarizing and gridding time-based Doppler data, recreating the August 26, 2002 North Carolina storm event. A step-by-step tutorial, with actual sample data, will be presented in the Fall 2003 ArcUser magazine, published by ESRI.

NEXRAD Doppler

NEXRAD (**Nex**t Generation **Rad**ar) obtains weather information (precipitation and wind) based upon returned energy. The radar emits a burst of energy (green). If the energy strikes an object (rain drop, bug, bird, etc), the energy is scattered in all directions (blue). A small fraction of that scattered energy is directed back toward the radar. In general, the larger the target the more energy returned to the radar. Examples of good returns include large raindrops and hail stones. Examples of poor energy reflectors are snow and drizzle. When one of these large targets is encountered and a large amount of energy is returned to the radar, the energy returned is expressed in units of “Z”, or radar reflectivity.

"Reflectivity" is the amount of transmitted power returned to the radar receiver. Reflectivity (designated by the letter Z) covers a wide range of signals (from very weak to very strong). So, a more convenient number for calculations and comparison, a decibel (or logarithmic) scale (dBZ), is used. The dBZ values increase as the strength of the signal returned to the radar increases. The scale of dBZ values is also related to the intensity of rainfall. Typically, light rain is occurring when the dBZ value reaches 20. The higher the dBZ, the stronger the rainfall rate. Depending on the type of weather occurring and the area of the U.S., forecasters can use a set of rainfall rates, which are associated to the dBZ values. Figure 2 shows a table of representative dBZ values and which type and character of precipitation can be expected. The formula used to calculate these values will be discussed in a later section of this paper.

DBZ Value	Rainfall (in./hr.)	Snowfall (in./hr.)	*Remarks*
05	.00"	Trace-.10"	Cloud/Atmos return/Light snow
10	0 - trace	.10"	Cloud/Atmos return/Light rain
15	.01"	.1 - .2"	Light rain/Light snow
20	.02"	.2 - .3"	Light rain/Light snow
25	.05"	.3 - .5"	Light rain/Light-mdt snow
30	.09"	.5 - .7"	Light-mdt rain/Mdt snow
35	.24"	.7 - 1.0"	Mdt rain/Mdt snow/Sleet
40	.48"	1"+ or sleet	Heavy rain/Heavy snow/Sleet
45	1.25"	1" + or sleet	Heavy rain/Heavy snow/Sleet
50	2.5"	Sleet	Intense rain/Sleet/Hail
55	5.7"	Sleet	Extreme rain/Sleet/Hail
60	12.7"	-----	Extreme rain/Hail
65	-----	-----	Extreme rain/Hail
70	-----	-----	Large hail
75	-----	-----	Large hail

Figure 2: DBZ Values and Expected Precipitation Type and Character, *Table Courtesy of Meteorlogix*

Meteorlogix produces a national Doppler weather radar mosaic every five minutes, with an effective raw data resolution of one kilometer or 0.62 nautical miles (nm). The Meteorlogix 1 km data resolution national mosaic, updated every 5 minutes, is also available via satellite downlink. Services are now also available that allow the national Doppler weather radar mosaic to be converted into Geographical Information Services (GIS) formats. NEXRAD coverage for 142 continental Unites States Doppler stations is shown in Figure 3. A 240 km buffer is shown around each station, representing the approximate maximum coverage for each station.

The Meteorlogix NEXRAD single-site and mosaic radar system represents the most comprehensive real-time Doppler weather radar service available anywhere. Meteorlogix have made an enormous commitment towards quality control and the ability to provide continuous data access. The continuous collection and redistribution of the latest single site radar images, along with a 5-minute full-resolution value-added mosaic, provide unparalleled real-time access to the entire United States NWS NEXRAD Doppler weather radar network.

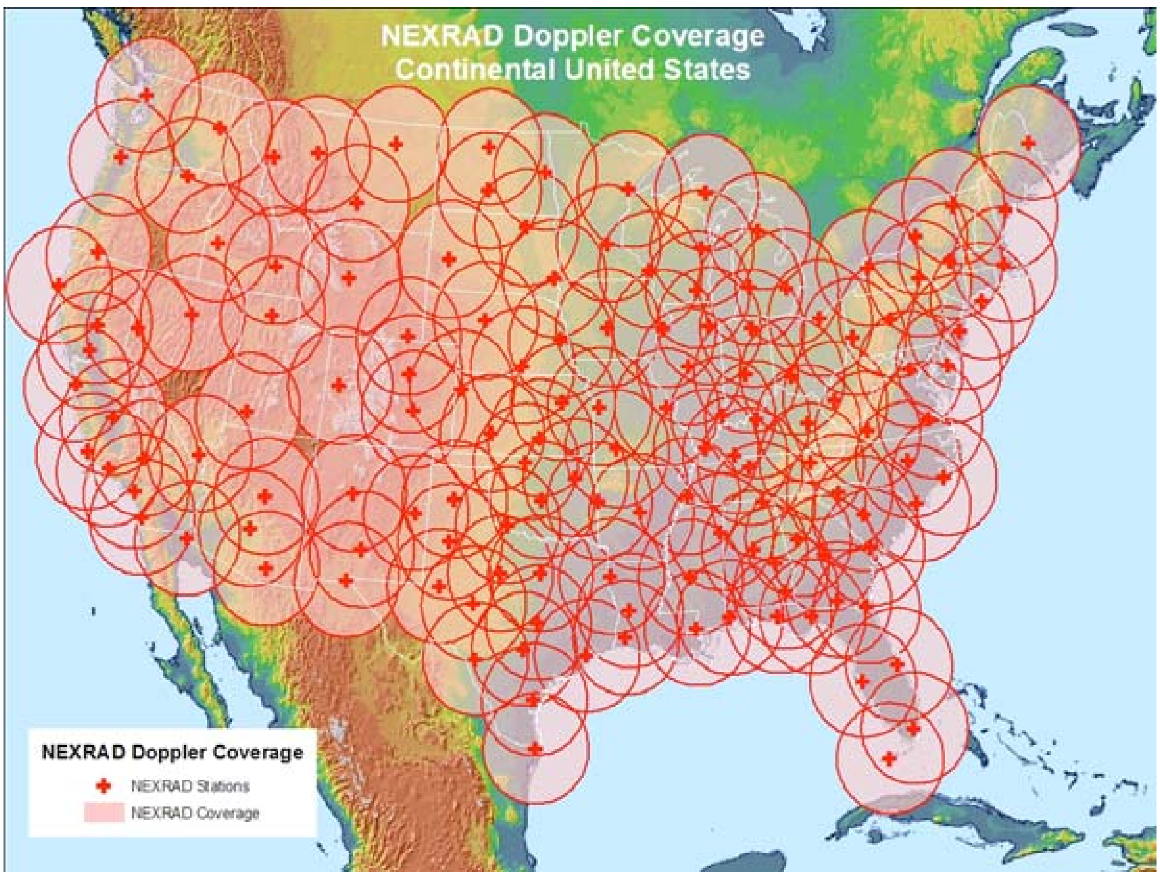

Figure 3: NEXRAD Doppler Coverage for the Continental United States

Wilson, NC Case History August 26, 2002

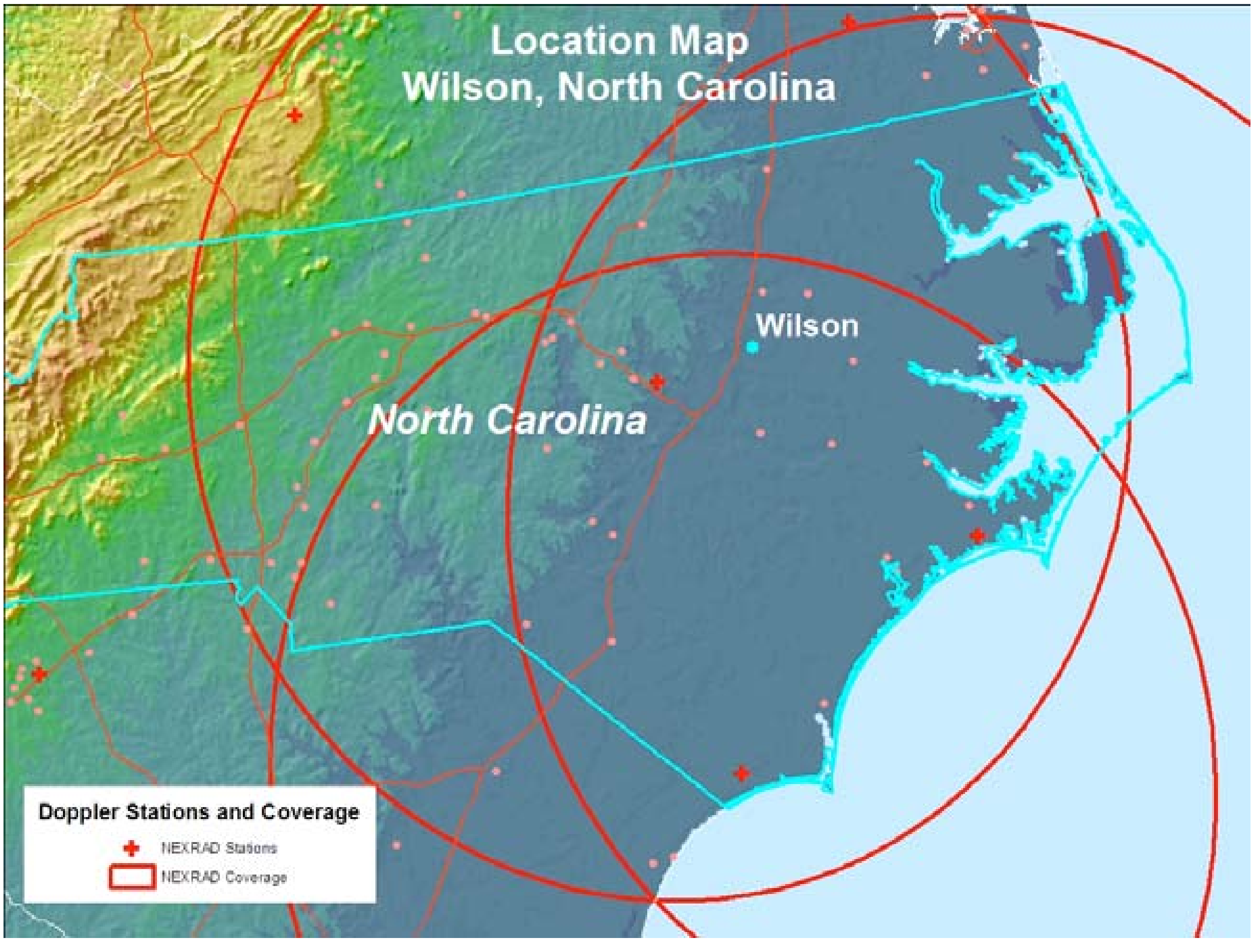

Figure 4: Location Map, Wilson, NC, showing NEXRAD Doppler coverage

The storm that inundated Wilson, NC and surrounding areas began in the early house of Monday, August 26, 2002. A large upper-level low-pressure system over the southeast merged with a frontal boundary over the Carolinas to produce areas of locally heavy rainfall. The system moved slowly north producing widespread showers and thunderstorms. Soils baked by a prolonged drought in the Carolinas were unable to infiltrate much of the intense precipitation and rainfall quickly accumulated in drainages and began to flow toward the coast. Wilson County and the Community of Wilson were inundated with flood waters and many areas were evacuated.

The Wilson Fire Department actively supports GIS testing and development through sharing of real-world data sets for training and experimentation. As floodwaters were just beginning to recede, ESRI was contacted to assist with follow-up modeling to support future planning preparedness, and modeling. In July 1999, ESRI participated in modeling and analysis of an intense Summer thunderstorm event on Mount San Gorgonio, just east of ESRI's Redlands, CA office. That study strengthened the alliance between ESRI and data weather provider

Meteorlogix. It also initiated development of protocol for modeling five minute Doppler intervals to compile, summarize, and model calculated Doppler rainfall over time.

Nine hours of regional data were obtained from Meteorlogix for the period 0900Z (4:00 a.m. EDT) to 1755Z (12:55 p.m. EDT). This adapt included a total of 108 shapefiles, one for each five minute interval over the nine hours. Raw data points were arranged in a 1 km array and registered in Geographic NAD83 coordinates. Attributes for each point included an Index, the dBZ value, a type field (Always Rain) and Time, expressed in Greenwich Mean Time (Z).

To perform a summary of five minute interval rainfall for each point, a Spatial Index was created by truncating and concatenating the decimal X and Y values for each point. The extensive data set will be summarized against this index field. The Equivalent Rainfall in millimeters is next calculated, using a formula developed by NOAA staff http://www.roc.noaa.gov/ops/z2r_osf5.asp. The formula is summarized below:

***Rainfall** (R, mm/hr) = (Z/A)^(1/B), where Z = 10^(dBZ/10)*

For this study, values of A=300 / B=1.4 and A=250 / B=1.2 are applied. See Belville, James D., *Recommended Parameter Changes to Improve WSR-88D Rainfall Estimates During Cool Season Stratford Rain Events*, for additional information regarding parameter selection for various storm events. Tables showing calculated values for both parameter sets are shown in Figure

DBZ	MM/HR	IN/HR	IN/5MIN
5	0.039	0.0015	0.00013
10	0.088	0.0035	0.00029
15	0.200	0.0079	0.00066
20	0.456	0.0180	0.00150
25	1.038	0.0409	0.00341
30	2.363	0.0930	0.00775
35	5.378	0.2117	0.01764
40	12.240	0.4819	0.04016
45	27.856	1.0967	0.09139
50	63.395	2.4959	0.20799
55	144.278	5.6802	0.47335
60	328.354	12.9273	1.07728
65	747.283	29.4206	2.45171
70	1700.700	66.9567	5.57972
75	3870.531	152.3831	12.69859

Normal "WSR88-D convection - A=300 / B=1.4

DBZ	MM/HR	IN/HR	IN/5MIN
5	0.026	0.0010	0.00009
10	0.068	0.0027	0.00022
15	0.179	0.0070	0.00059
20	0.466	0.0183	0.00153
25	1.216	0.0479	0.00399
30	3.175	0.1250	0.01042
35	8.287	0.3262	0.02719
40	21.630	0.8516	0.07096
45	56.457	2.2227	0.18523
50	147.361	5.8016	0.48347
55	384.636	15.1432	1.26193
60	1003.961	39.5260	3.29383
65	2620.495	103.1691	8.59742
70	6839.904	269.2876	22.44063
75	17853.224	702.8828	58.57357

Rosenfeld Z tropical convection - A=250 / B=1.2

Figure 5: Equivalent Rainfall calculated in mm/hr, in/hr, in/5 min

To simplify calculation in ArcGIS, each of the above tables were separately joined to the appended Doppler data before summarizing. Next, each set was summarized, using the Spatial Index as a key. Fields included in the summary are Decimal Longitude (mean), Decimal Longitude (mean) and In5Min (sum). During the first pass, the entire nine hour time range was summarized.

Following summary, the resulting tables were each posted as X-Y points, in the local North Carolina State Plane NAD83 US Feet coordinate system. Summary points were then gridded to create equivalent rainfall maps for both A/B variable pairs. The resulting grids, built in NC State Plane, were contoured. Finally, vector data and an elevation hillshade were added to the model for presentation and discussion.

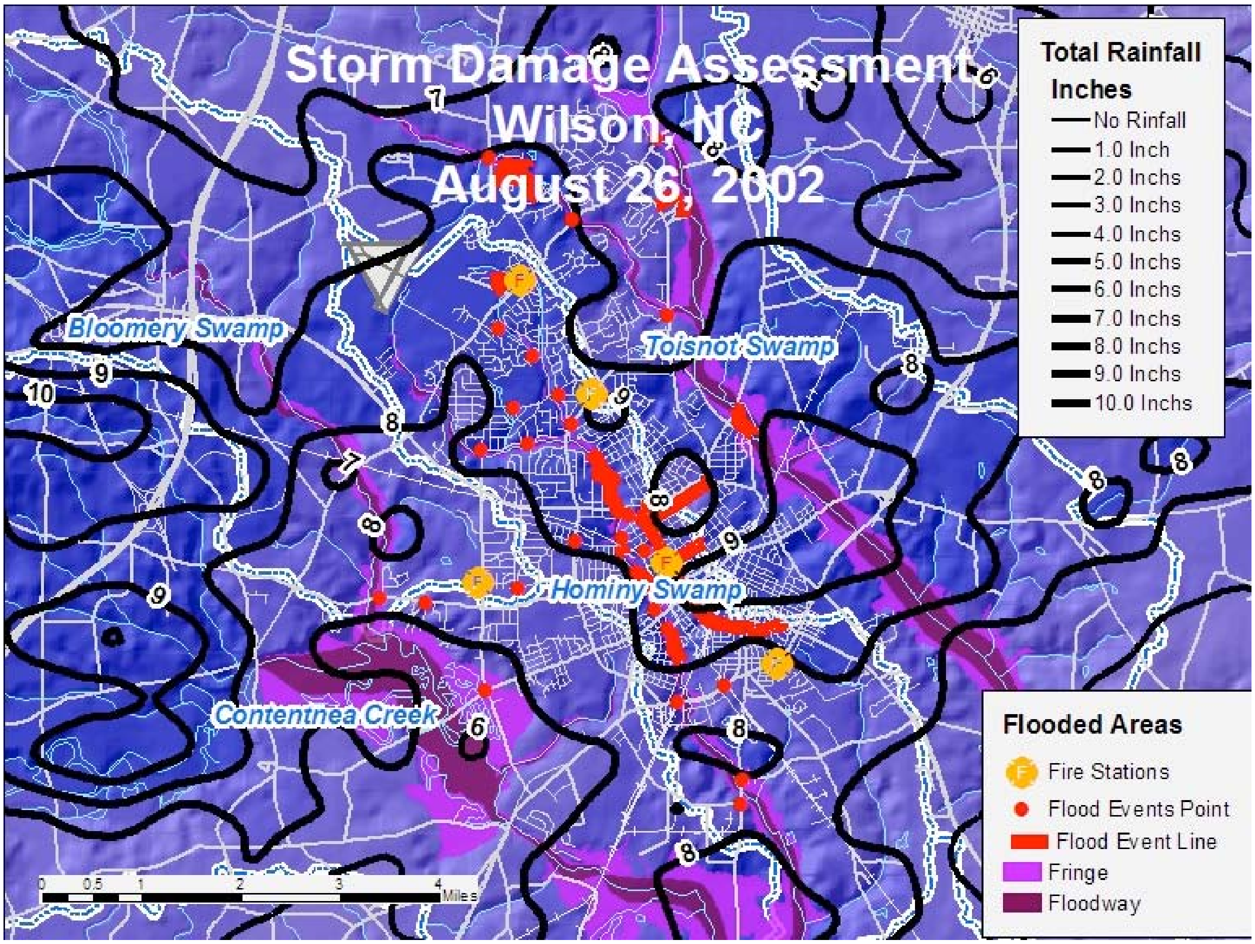

Figure 6: Storm Damage Assessment, Wilson, NC

Figure 6 shows Wilson, NC and its surrounding area, with actual storm damage areas shown in red. Total rainfall calculated for the nine hour period, and applying the more conservative A/B variable pair totaled nearly ten inches in some areas! Notice that most of the inundation occurred in a very small drainage basin named Hominy Swamp, and that most damage occurred outside of traditional flood channels, mapped in purple. You can imagine that the City of Wilson is moving quickly to plan for and to mitigate future damage in this small, populated drainage!

Finally let’s look at the big picture. Figure 7 shows the same rainfall grid and contour data loaded into our North American Albers Index Map. Notice how the bull’s eye of the nine hour rainfall pattern centers just of Wilson! It appears that the remainder of eastern North Carolina escaped the worst of this storm.

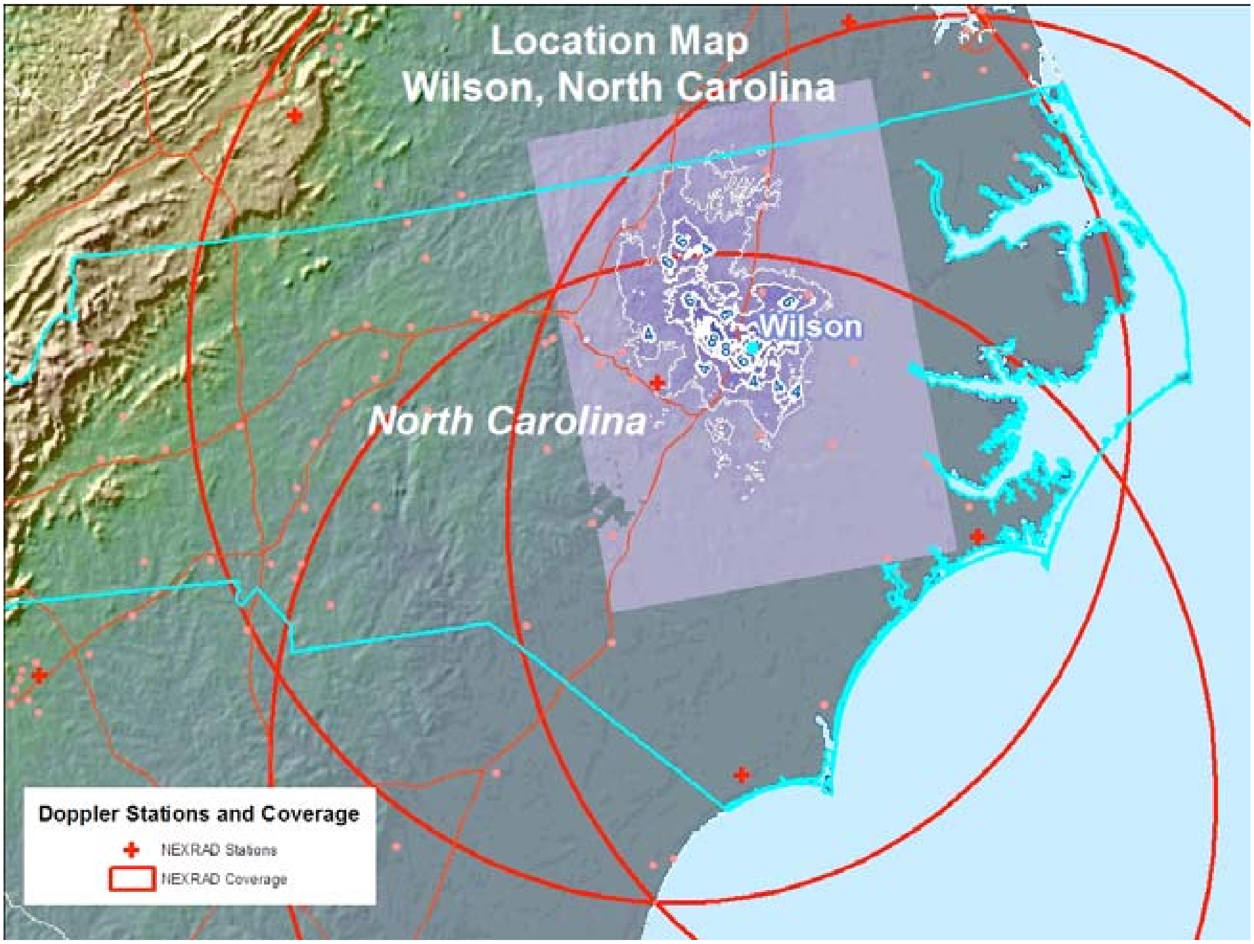

Figure 7: The Big Picture, Wilson, NC August 26, 2002

Step by Step Summary, to be expanded in Fall 2003 ArcUser Magazine

Following is a summary of key issues and steps developed to model NEXRAD Doppler data and to calculate the equivalent rainfall during the Wilson event. These steps will be presented in a Technical Session at the ESRI 2003 User Conference and will be described in detail in the Fall 2003 ESRI ArcUser technical publication. This process was originally developed using ArcView 3.x and is now adapted for ArcGIS. ArcGIS' ability to project on-the-fly, create enhanced legends, perform complex editing, and more are being incorporated to improve and streamline the total process.

Key Doppler radar data development and modeling issues include:

Accurate definition of study area extent and temporal range
Careful data management, including confirmation of time
Development of a Spatial Index, unique for each geographic location
Application of the proper formula to calculate Equivalent Rainfall in appropriate units
Statistical summarizing of Rainfall across critical time ranges
Calibration of calculated Rainfall over time using actual field measurements

Steps to perform the entire modeling process include:

- Acquire and download Doppler point data
- Unzip, store Doppler points; Rename Doppler points if desired
- Load Doppler points into ArcGIS
- Verify data completeness; Edit Attribute Tables: Add Time derived from file name if necessary, Add field for Index
- Merge points into single set for entire time span
- Create Unique Index based on truncated concatenated X, Y coordinates
- Reproject points to local coordinate system
- Perform local point shift, if necessary
- Calculate Doppler Rainfall with formula *Rainfall (R, mm/hr) = (Z/A)^(1/B), where Z = 10^(dBZ/10, A=300, or other, B=1.4 or other, see Belville, James D., Recommended Parameter Changes to Improve WSR-88D Rainfall Estimates During Cool Season Stratford Rain Events, http://www.roc.noaa.gov/ops/z2r_osf5.asp)*
- Or, join calculated Doppler rainfall to table using common dBZ field
- Summarize table based on concatenated X, Y Spatial Index
- Summarize 5 Minute Doppler points based on time interval(s)
- Post Summary points, create legend, review results
- Interpolate Summary points to create grid: Use spline first, then IDS, then Kriging, if necessary
- Create legend for Total Precipitation grid, contour grid
- Add hillshade, basins, and other vector data; Make a cool, yet soggy map!

Summary

The Wilson, NC NEXRAD Doppler study presented in this paper continues to expand and improve. Methods for gathering and modeling periodic Doppler-derived rainfall are being tested in many natural resource fields, including Mining and Earth Science, Watershed and Ecosystem Management, Construction and Civil Engineering, and Public Safety. Stay tuned for further developments in these fields! Also, watch for the Fall 2003 ArcUser for a detailed explanation of the steps that we developed and enhanced to model the Wilson event.

Acknowledgments

The authors wish to acknowledge the staff of the Wilson, NC Fire Department for their heroic efforts to mitigate the impacts of the August 2002 flooding. We also commend their continued dedication to apply GIS and spatial technology to protect their citizens from natural and manmade hazards. Special thanks to Fire Chief Don Oliver and to GIS Specialist Will Aycock.

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