Utilizing Doppler Radar to Estimate Rainfall Rates for Highway Segments

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Abstract

This paper will present findings and the overall methodology for estimating roadway rain rates. In order to accurately estimate rainfall rates along Interstate highways in Northeast Florida for the Florida Road Weather information System (RWIS) in near real time, the investigators developed and implemented a new methodology to geo-locate Doppler radar rain rates. The intent of this project is to geo-locate the National Weather Service's WSR-88D level-2 Doppler radar to specific mile markers along the roadways of interest, to initiate alerts or warnings to drivers. The geo-located Doppler information can then be analyzed, along with the point-specific shed rate of the road, to determine near real-time conditions of ponding and hydroplaning, and also used for historical analysis of accident statistics to establish causality between accidents that occurred and actual hydroplaning potential.

Introduction

Most drivers would agree that driving during a heavy rain storm is more dangerous than driving on a clear, dry day. The primary risk factors imposed by heavy precipitation include diminished visibility and increased stopping distances caused by the accumulation of moisture on the roadway (ponding) and the subsequent increased risk of hydroplaning, which can cause complete loss of control for drivers.

The development of rainfall monitoring systems is a necessary precursor for the development of real-time, automated driver safety systems. In general, point data is considered the most accurate, since rainfall monitoring sensors (e.g. tipping buckets, etc.) have been developed to a high degree of precision. Unfortunately, it's virtually impossible to deploy sensors close enough to monitor a roadway effectively. Most weather stations in the US are distributed at synoptic scales, with sensors typically separated by 30 – 50 miles. This type of point data collection system is unable to serve as a rainfall monitoring system due to the coarseness of its data. Especially in Florida, many serious downbursts can occur in cells as small as 1 or 2 miles in diameter. Even proposed weather mesonets, based on sensor separations of 6-8 miles, would be incapable of monitoring the smallest storm systems, which, nevertheless, would still remain a threat.

For this reason, the focus of this study is on the utilization of the National Weather Service's WSR-88D (Next Generation Radar) NEXRAD Doppler Radar Network, which consists of 158 operational NEXRAD radar systems deployed throughout the United States and at certain overseas locations [1]. For the scope of this study, the NEXRAD radar located in Jacksonville, Florida (call sign KJAX) was utilized.

NEXRAD Radar Overview

NEXRAD radars obtain precipitation and wind data by reflecting electro-magnetic pulses off objects suspended in the atmosphere such as rain, snow, bugs, birds, etc. The echo intensity (reflectivity) from the suspended object in the atmosphere is highly correlated with precipitation [2].

Figure 1. *Nexrad Radar Radome [1]*

NEXRAD Products and Tools

There are a number of unaltered National Weather Service (NWS) Data Products available from the NEXRAD system, including base reflectivity, composite reflectivity, layer composite reflectivity, echo tops, vertically integrated liquid, one-hour precipitation, three-hour precipitation, storm total precipitation, hourly digital rainfall array, radial velocity, and velocity azimuth display wind [3]. These products have a myriad of potential uses and application domains; however, for precipitation detection and tracking, the Base Reflectivity Products provide the most useful information [4].

NEXRAD Modes, Scan Angles, and Data Values

A slight complication associated with the NEXRAD output is that, depending on atmospheric conditions, the radar data products have different data ranges and temporal frequencies. These variations in data products are called NEXRAD modes. The most sensitive mode of operation is the Clear Air Mode, because in a relatively clear atmosphere, there are few suspended particles to return radar energy, and more time must be spent waiting for data return.

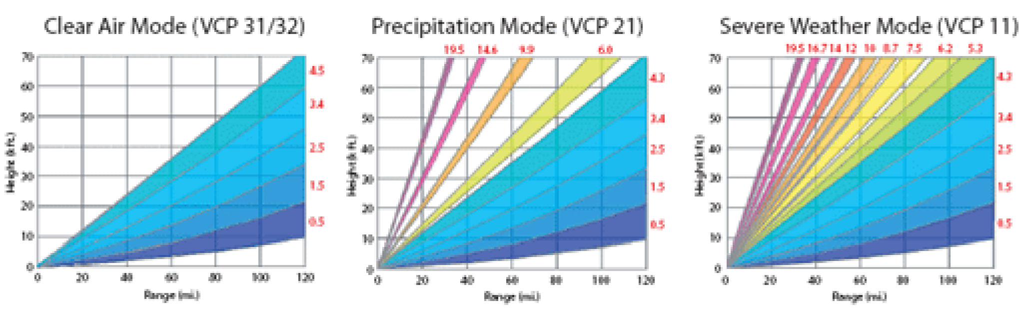


Figure 2. NEXRAD Operational Modes [2]

There are three primary NEXRAD modes: Clear Air Mode (VCP 31/32), in which 5 different elevation scans are completed every 10 minutes, Precipitation Mode (VCP 21), in which nine elevation scans are completed every 6 minutes, and Severe Weather Mode (VCP 11), in which 14 elevation scans are completed every 5 minutes [2].

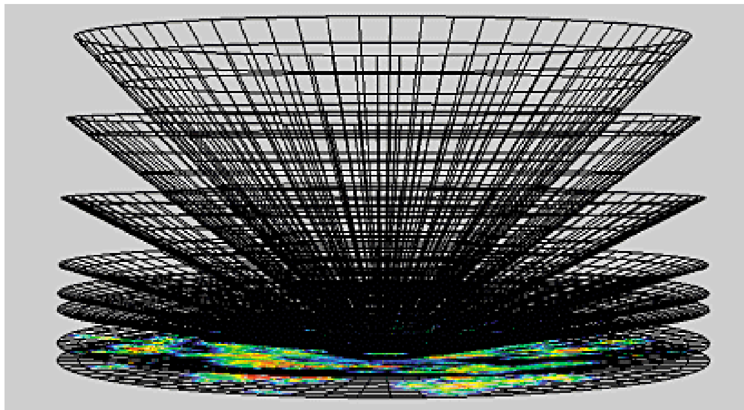
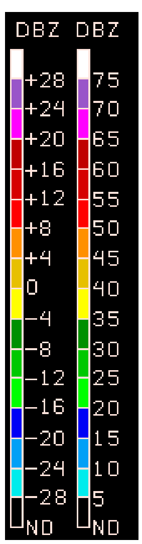


Figure 3. NEXRAD Scan Angles Visualization [5]

Individual NEXRAD Scan Angles are essentially radar slices through the atmosphere, with each slice corresponding to a NOAA/NWS Base Reflectivity data product. The Composite Reflectivity data products contain the maximum reflectivity value of all layers for a given geographic position. For purposes of this study, the primary focus was on rainfall that reached or potentially reached the ground, so the 0.5 Scan Angle Base Reflectivity data product was selected for all operational modes.

Reflectivity values contained in NEXRAD data products are measured in dBZ (decibels of Z) in which Z refers to the amount of energy transmitted [2]. In clear air mode, dBZ values range from 0 to 75 dBZ, whereas in Precipitation or Severe Weather Modes the values range from -28 to +28 dBZ. In either case, each category has the same Rainfall Rate interpretation.



dBZ	Rainrate (in/hr)
65	16+
60	8.00
55	4.00
52	2.50
47	1.25
41	0.50
36	0.25
30	0.10
20	Trace

Figure 4. NEXRAD Mode Dependent Data Values and Meanings [2]

Downloading NEXRAD Data

There are a number of ways in which NEXRAD data can be accessed for various applications. Three of the best include a direct NOAA/NWS FTP download [6], access through the NOAA National Climatic Data Center [7], or automated server downloads via Unidata's Local Data Manager (LDM) Server [8]. For this study, a direct NOAA/NWS FTP download via a Server Daemon Process which checked for file updates every 5 minutes (which is the shortest possible upload frequency) [9]. In the future, this ongoing study will migrate to utilizing the Unidata LDM Server, which has been demonstrated to provide significant levels of redundancy and reliability.

Once the NEXRAD Data Product is downloaded, additional steps must be taken to use the product. The traditional use of this data is graphical visualization. There are many available products which can visualize NEXRAD data, most of which provide a classic 2D view of the data. For example, during the weather portion of the evening news, an image of a Doppler radar scan (not necessarily the WSR-88D) is frequently displayed.

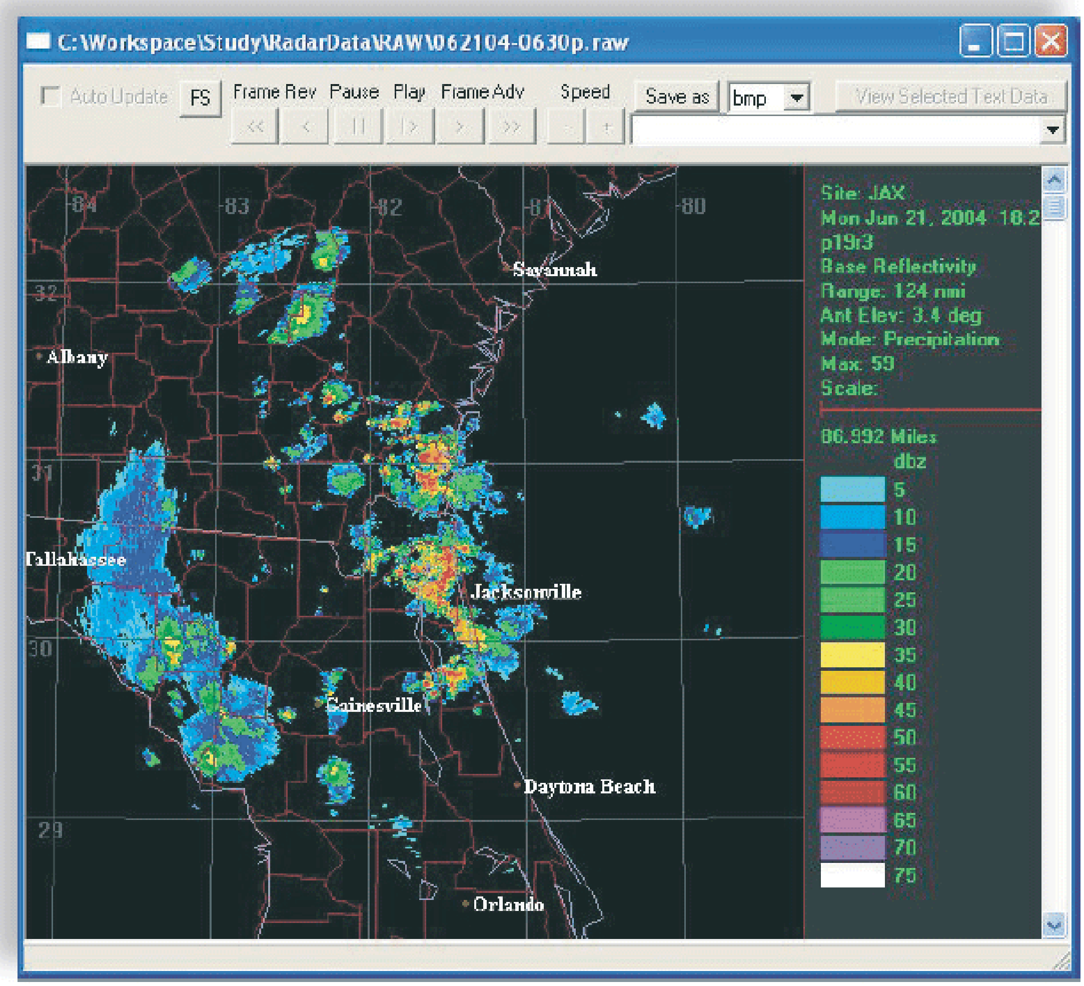


Figure 5. NEXRAD Data Product 2D Visualization Display

The problem with NEXRAD visualization strategies is that these programs only provide anecdotal information to users and require human intervention for interpretation. Since the focus of this study was on automation rainfall detection, human intervention was of course impractical, thus the data downloading was necessarily the first step in our analysis pipeline.

NEXRAD Data Conversion to Shapefile

In order to make the NEXRAD data readable in a GIS environment, the first processing step initiated was the conversion of the NEXRAD data file into a shapefile. A separate server daemon process was created to perform this function whenever a new datafile was downloaded. This daemon, once initiated, fed the data file to the NEX2SHP.exe program created by Dr. Scott Shipley at George Mason University, which functioned to output the data as a point shapefile [10].

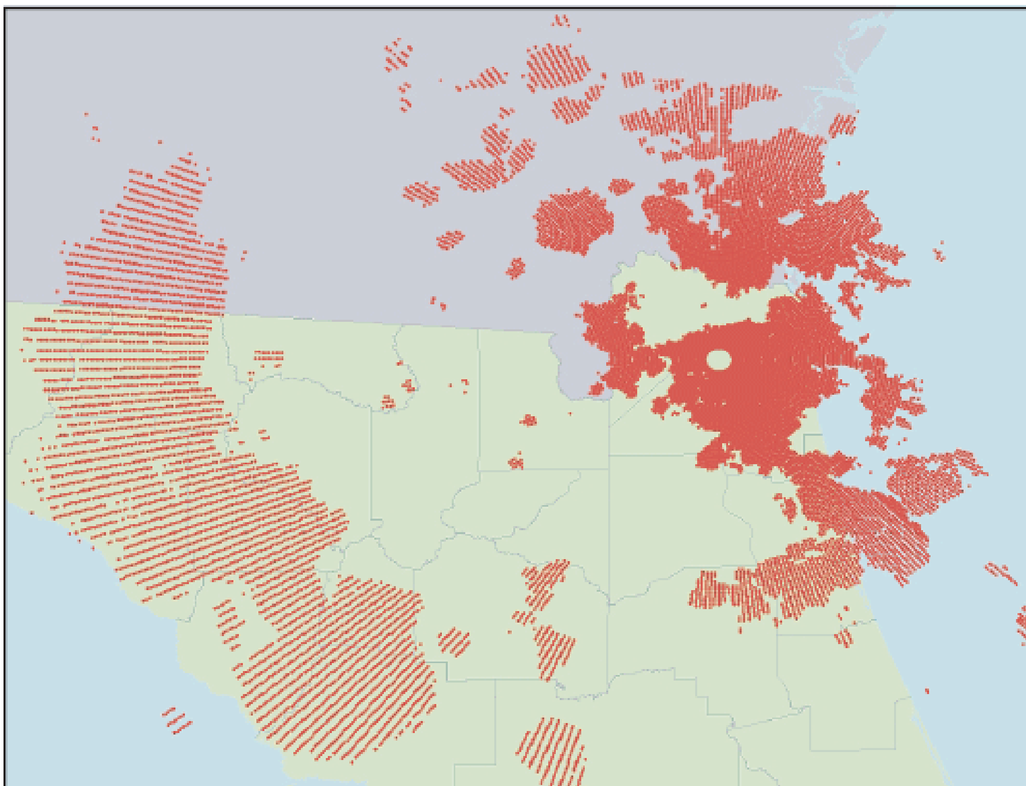


Figure 6. Point Shapefile Output Displayed over Basemap

Road Polygon Layer Development

In order find rainfall rates for specific roadway segments, it was necessary to create road polygons for the roadways of interest. The first consideration for these polygons was what size to make them. After consideration of the issue, 1 mile segments centered on mile marker locations was considered optimal, since smaller sections would be hard to classify and larger sections would be too coarse.

The Road Polygon Layer consisted of all the interstate highways in northeast Florida divided into polygon segments that represented Interstate miles. To create this polygon layer a number of different steps where taken. First, the Interstate center lines where downloaded from Florida Department of Transportation website. Next, a random number of mile marker coordinates along the interstates where taken using GPS measurement. The mile marker coordinates where then used to determine the rest of the mile markers by measuring one mile from the known markers along the interstate center line and then drawing a line that was perpendicular to the center line. The interstate center lines were then buffered by 250 feet creating polygon features. The mile marker lines where trimmed at the polygon. The mile marker lines where then overlaid with the interstate polygons creating a new road polygon layer which corresponds to the interstate mile markers.

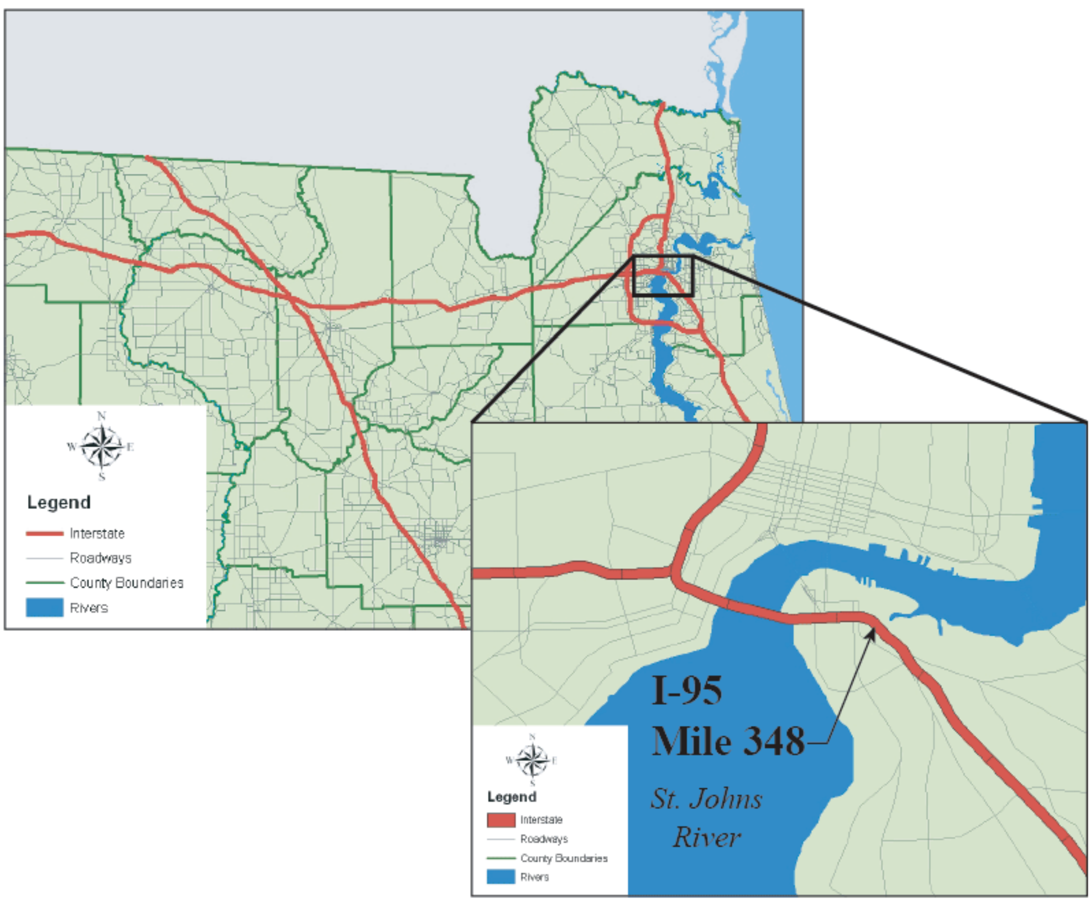


Figure 7. Road Polygon Layer Visualization over Basemap

NEXRAD Point Data to Grid Conversion

Since the objective of this project was to overlay road polygons over the NEXRAD data, the decision was made to convert the NEXRAD point data into a gridded raster. Rasterizing the data converts the point data into a continuous 2D field. When overlaying polygons over a 2D field it is relatively easy, from a programmatic standpoint, to determine which raster values are present in a given polygon.

One of the major decisions to make, however, when creating the raster, was which interpolation strategy to use. Interpolation is the procedure used to predict cell values for locations that lack sample points [11]. There are a number of trade-offs to consider when interpolating, mainly based on computational difficulty of the interpolation algorithm and the type of data to be interpolated. The interpolation strategy selected for this project was Inverse Distance Weighting (IDW) because of the algorithmic simplicity and general applicability of the function. With IDW, greater weight is applied to near cells than far cells, which is basically the interpolation strategy required. One potential difficulty that may arise with the use of IDW is that, in very sparse datasets, clear days, for example, improper interpolations can result. Further analysis of interpolation strategies will be conducted for this application in the future.

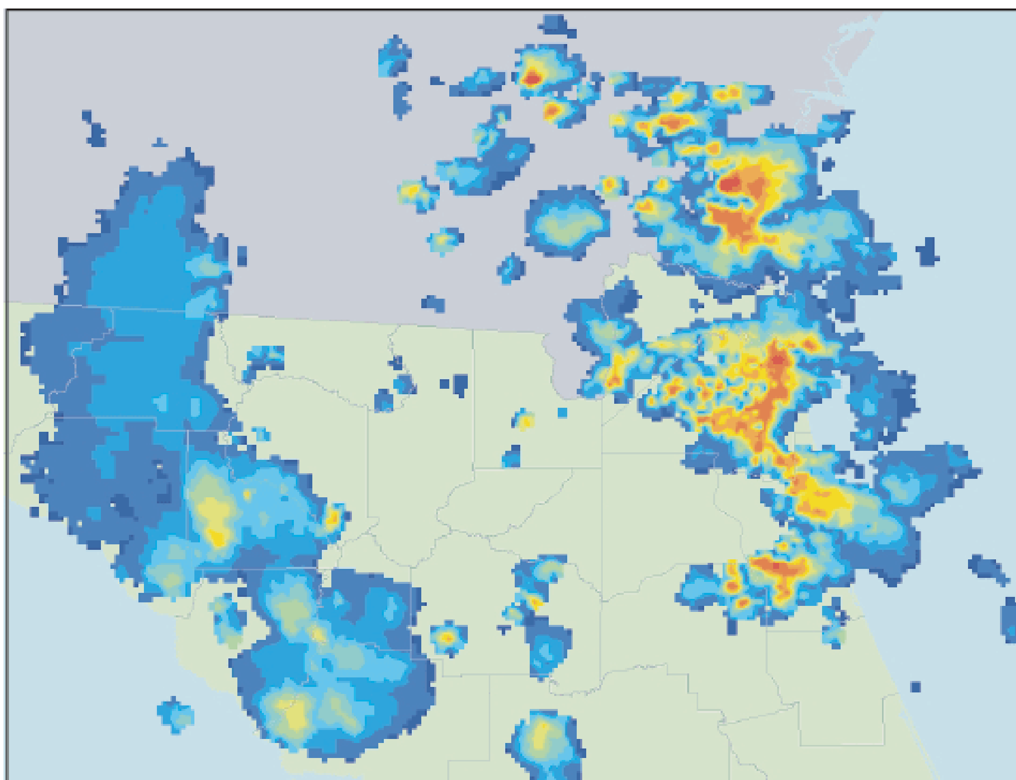


Figure 8. Interpolated NEXRAD Grid

Merging Road Polygons with NEXRAD Grid

Once the raster grid is generated, it is overlaid with the road polygons to determine the rainfall rate for each road segment. The first step was to convert the interpolated grid into a polygon dataset where each polygon contains the corresponding cell value. To do this, it was necessary to multiply each cell value in the grid by a factor of 10, and then convert the value from a floating point grid to an integer grid. The new integer grid was then converted to a polygon dataset and intersected with the road polygon creating a new polygon dataset of rainfall rates associated with each road segment.

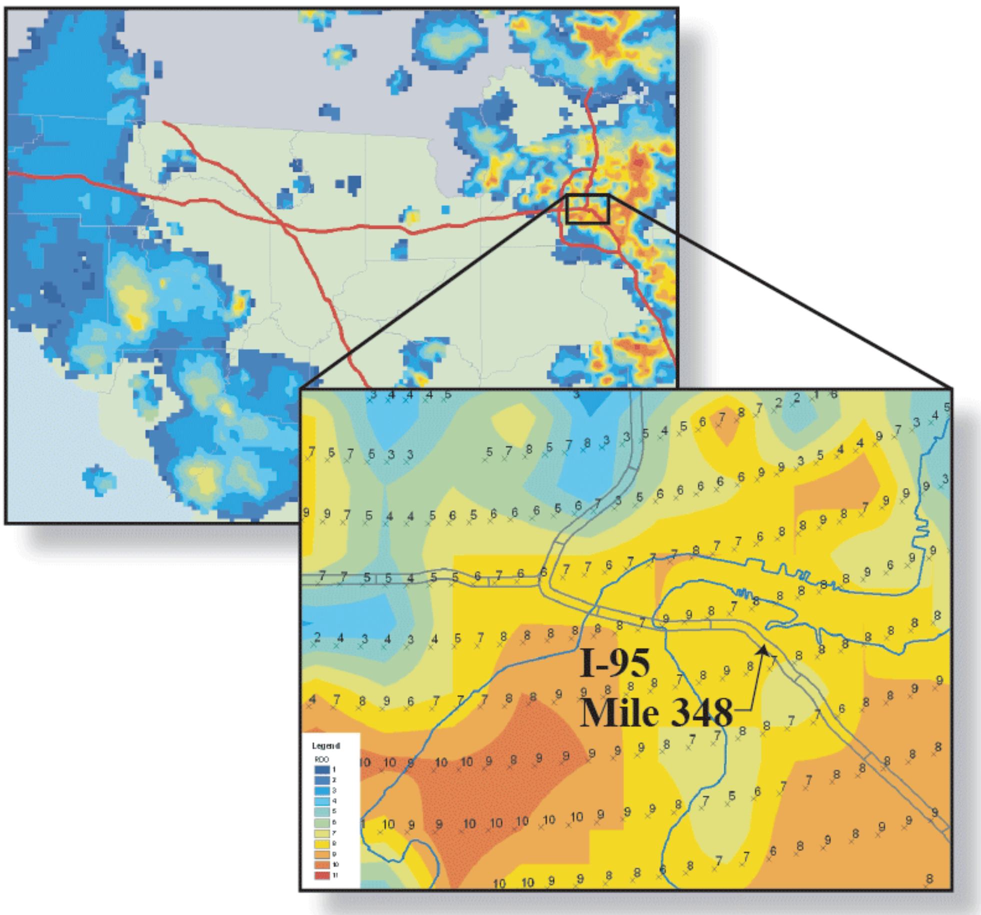


Figure 9. Road segments overlaid on the NEXRAD polygons

Determining Estimated Roadway Rainfall Rate

Determining the estimated rainfall rates for each road segment involve analysis of the RBO value, which is an interpretive measure developed by the National Weather Service. Table 1 describes the relationship between RBO, dBZ, and VIP levels (an older classification system that may still have uses with visualization strategies).

Table 1. National Weather Service VIP/DBZ Conversion Table [12]

NWS VIP	**WSR-RBO Level**	**dBZ (Precip Mode)**	**Rainfall**
0	0	< 5	
	1	5 to 9	
	2	9 to 14	
1 (Very Light)	3	15 to 19	.01 in/hr
	4	20 to 24	.02 in/hr
	5	25 to 29	.04 in/hr
2 (Light to Moderate)	6	30 to 34	.09 in/hr
	7	35 to 39	.21 in/hr
3 (Strong)	8	40 to 44	.48 in/hr
4 (Very Strong)	9	45 to 49	1.10 in/hr
5 (Intense)	10	50 to 54	2.49 in/hr
6 (Extreme)	11	55 to 59	> 5.67 in/hr
	12	60 to 64	> 5.67 in/hr
	13	65 to 69	> 5.67 in/hr
	14	70 to 74	> 5.67 in/hr
	15	>75	> 5.67 in/hr

Each road segment can have multiple RBO values. A number of aggregate values such as maximum, minimum, sum, average, and the number of RBO's for each road segment are stored in the database. For the purposes of this study, the maximum RBO represents the worst case, and is the value used in estimating the rainfall rate for each road segment.

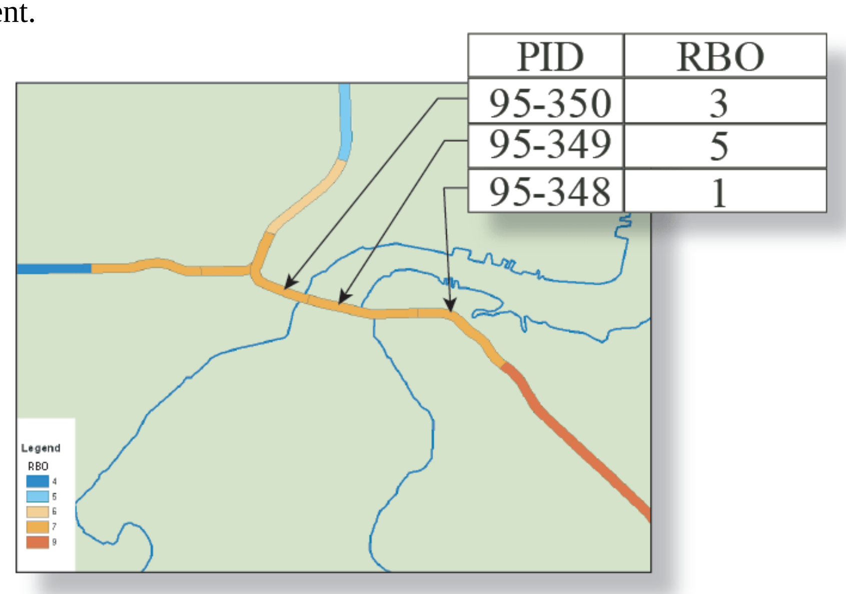


Figure 10. Roadway Rain Rate (RBO) Determination

Database Architecture

A data warehouse star schema approach was designed to store the rainfall data. This approach involved three dimension tables and one fact table. The first dimension table was the Road_Polygon table and is used to store all information about each polygon including a unique key for each polygon that relates it back to the shapefile. The Road_Polygon table corresponds to the road shapefile where one record in the table relates to one polygon feature in the shapefile. Presently the table is loaded using a script that reads the shapefile and insert the records into the table. In the future, the road shapefile will be stored in the database using ArcSDE technology eliminating the need for the script.

The second dimension table is the Time table. The Time table stores the date and time for each time step. The National Weather Service places the NEXRAD data file on the FTP site approximately every five minutes depending on the mode of the radar. Each file has a creation time which corresponds to Zulu Time, also known as Greenwich Mean Time (GMT) and Universal Time Coordinated (UTC). Zulu time is the time zone or time on the Zero or Greenwich Meridian [2]. The Zulu Time and the converted local time is store in the database. Each record in the Time table is given a unique key that is derived from the Zulu time.

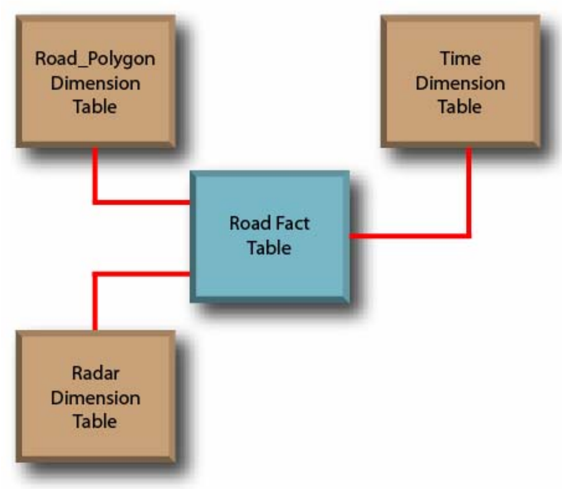


Figure 11. Data Warehouse

The Radar table is the last dimension table and is used to store all the information about the radars. The table contains the location information such as city, state, latitude, longitude, height of radar, and ground elevation.

All the dimension tables are link together by a fact table. The fact table contains the primary keys from all dimension tables. Each record in the fact table relates to one road segment at s specific time step for a particular radar. The record also contains the aggregated information the road segment.

System Architecture

For this study, a server was dedicated for NEXRAD data download and GIS processing.

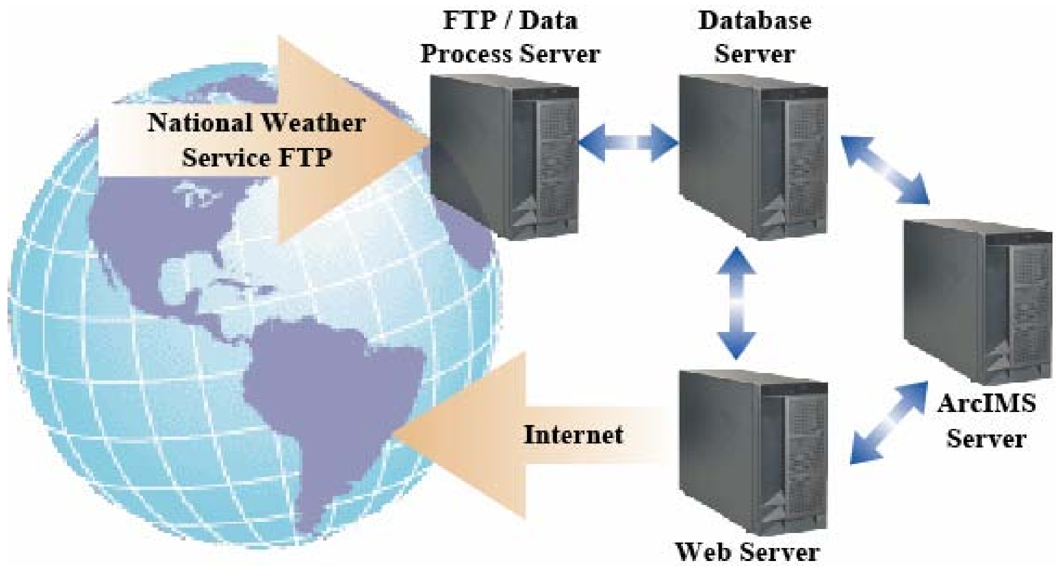


Figure 12. System Architecture Layout

Additional servers had been previously allocated for Web server, IMS server, and database server roles.

Results Visualization and proposed Applications Development

A prototype IMS application was developed for preliminary display. The color selections were based on RBO values. Additional work is required in this area in terms of usability analysis for the data.

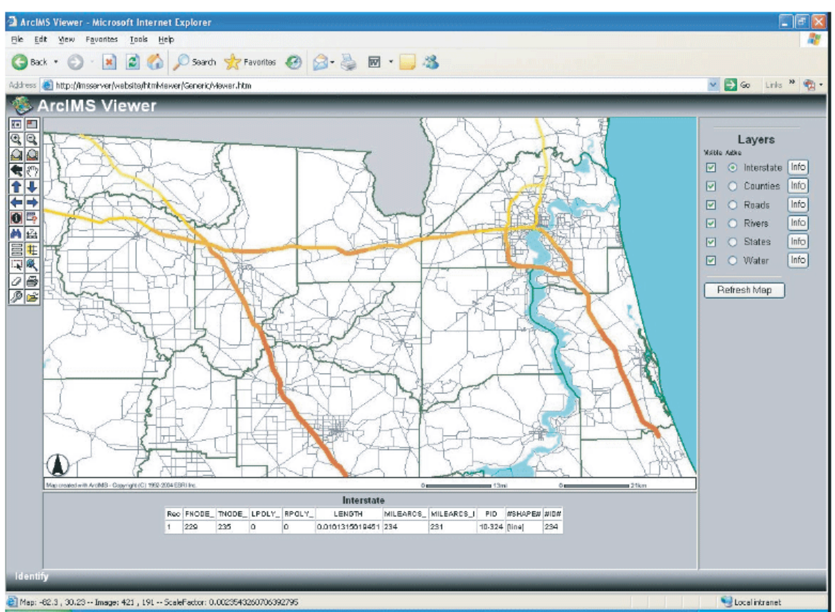


Figure 13. ArcIMS Display of Near Real Time Precipitation Volume

Future proposed applications include the correlation of extreme rates of rainfall with accident statistics over a long period of time and development of a system for generating real-time warnings for traffic managers and in-transit travelers.

NEXRAD Rainfall Estimation Sources of Error

A number of potential sources of error exist when estimating surface rainfall from NEXRAD data. One of the largest data inconsistencies with NEXRAD data is that the elevation slice increases in altitude as the radar beam propagates away from the source. This property is characteristic of the physics of radars, and thus cannot be removed.

Another complication of the NEXRAD data is that one cannot be certain that suspended droplets are actually reaching the surface, even though the lowest elevation (0.5 degree) slice is being evaluated. Anecdotally, more extreme rainfall rates seem more likely to actually reach the surface than lighter rain rates. This property should be further evaluated.

Also, rainfall does not fall in a perfectly vertical fashion. Depending on the prevailing winds, rain falls in a slight to significant angle. Thus, rainfall estimation directly beneath droplets at elevation may be an erroneous assumption.

Finally, NEXRAD Radars are unable to detect rain directly over the radar source. This phenomenon is called the "Cone of Silence." Other NEXRAD sites can provide data for these regions, but the range is extreme, thus the data is at significant elevation and the data is more likely to be inaccurate.

Conclusion

This project has demonstrated the general value and applicability for this application of NEXRAD data. Significant research still remains in the development of this system into practical applications and the removal of errors.

Acknowledgements

This study was conducted as a component of a research project funded by the Florida Department of Transportation Research Center called "The Development of the Florida Road Weather Information System Research Facility."

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