Final Report
for
Phase II - Development of a Road Weather Information System (RWIS) for Florida's Intelligent Transportation System

CONTRACT # BD- 537

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and
Office of Traffic Engineering and Operations
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16. Abstract

The State of Florida needs a RWIS that can provide timely and useful "early warning" weather information to travelers, transportation managers, law enforcement, and emergency managers in order to ensure safe transportation in both normal and evacuation conditions for residents, visitors, and commerce. The University of North Florida, in cooperation with the Florida State University and the National Weather Service, completed Phase II of a research program aimed at developing a RWIS Prototype Research Facility that allows FDOT to evaluate the implementation of a RWIS model that utilizes the existing Motorist Aid System (MAS) microwave tower infrastructure for communications and weather sensor site locations. The research facility provides a method for evaluating alternative designs, configurations, and installation methods for a statewide RWIS. The primary goal of the research program is to develop design recommendations for implementation of a statewide RWIS. The primary objective for Phase II of this project was to further develop and evaluate the proposition that the design of the FDOT RWIS should include the capability to use appropriately located between and near-tower wireless weather sensors. Another major objective was to develop and coordinate cooperative relationships with the National Weather Service (NWS) and other stakeholders. A secondary objective was to continue investigations into the relationships between atmospheric effects and signal fades experienced by the MAS tower system. The research team recommends that the statewide implementation of a RWIS includes the capability for adding wireless weather sensors *between or near* the 20-mile spaced primary weather stations located on the MAS towers. This design feature anticipates the need for specialized stations at fixed locations to address site specific potential hazards such as high wind on high evacuation bridges, locations that are prone to fog, and the deployment of portable units to support wildfire or hazardous material spill response operations. It has become obvious as a result of this research project that a continuing cooperative relationship between the FDOT and the NWS will be mutually beneficial. The Florida Department of Transportation benefits by receiving unbiased recommendations for the best design and operation of a statewide Florida-centric RWIS. The research also contributes to a better understanding of the causes of microwave signal fades and could lead to improved microwave path design parameters. The implementation of an operational statewide RWIS will have a significant and measurable impact on traffic and emergency management operations in the State of Florida. The experience developed through this research project has already been incorporated into the development of a demonstration RWIS for the FHWA-sponsored "iFlorida" project.

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Executive Summary

The State of Florida needs a RWIS that can provide timely and useful “early warning” weather information to travelers, transportation managers, law enforcement, and emergency managers in order to ensure safe transportation in both normal and evacuation conditions for residents, visitors, and commerce. This project specifically addresses two of the FDOT Intelligent Transportation System (ITS) Strategic Plan goals: “to reduce weather related traffic accidents by using road-weather information systems”, and to “improve emergency management communications while providing real-time traveler information systems for evacuation”.

The University of North Florida, in cooperation with the Florida State University and the National Weather Service, has completed Phase II of a research program aimed at developing a RWIS Prototype Research Facility that allows FDOT to evaluate the implementation of a RWIS model that utilizes the existing Motorist Aid System (MAS) microwave tower infrastructure for communications and weather sensor site locations. The research facility provides a method for evaluating alternative designs, configurations, and installation methods for a statewide RWIS.

The primary goal of the research program is to develop design recommendations for implementation of a statewide RWIS. The primary objective for Phase II of this project was to further develop and evaluate the proposition that the design of the FDOT RWIS should include the capability to use appropriately located between and near-tower wireless weather sensors. Another major objective was to develop and coordinate cooperative relationships with the National Weather Service (NWS) and other stakeholders. A secondary objective was to continue investigations into the relationships between atmospheric effects and signal fades experienced by the MAS tower system.

The most significant accomplishment of the research program was the development of the RWIS Research Facility. Through this process, the researchers, FDOT staff, and the ITS contractors involved have all learned a great deal about the specific technical challenges associated with the design and installation of an RWIS. In particular, it is now clear that the MAS tower network provides reliable communications and power infrastructure, and, with adequate lightning protection, a suitable site for the installation of the weather sensors. The research team recommends that the statewide implementation of a RWIS includes the capability for adding wireless weather sensors *between or near* the 20-mile spaced primary weather stations located on the MAS towers. This design feature anticipates the need for specialized stations at fixed locations to address site specific potential hazards such as high wind on high evacuation bridges, locations that are prone to fog, and the deployment of portable units to support wildfire or hazardous material spill response operations.

It has become obvious as a result of this research project that a continuing cooperative relationship between the FDOT and the NWS will be mutually beneficial. A fully implemented Florida RWIS, based on the concept of having a weather station at every MAS tower, would contribute significantly to the establishment of the “Florida Weather Mesonet”. By contributing much needed real-time, relatively high spatial resolution weather data to the NWS forecast models, the RWIS would benefit in turn by receiving more accurate, higher spatial resolution forecasts and advisories. This is especially important when forecasting the road segment locations of hazardous weather phenomena.

In support of this research project, UNF researchers have participated in developing the high-level design requirements for a national RWIS coordination effort, called the "Clarus Initiative", which is being sponsored by the Federal Highway Administration (FHWA). The Florida RWIS Research Team fully supports this initiative and recommends that an FDOT representative become involved in the planning process to ensure that, in the future, the Florida RWIS becomes a fully integrated component of the national system.

It is also recommended that FDOT continue to closely coordinate with FHP and the FDEM in the further development of the Florida RWIS. The RWIS will provide valuable information to traffice and emergency managers that will enable them to react to existing and predicted severe weather events more effectively. Since the RWIS will provide an additional traffic management criterion to be considered, there will be initial and on-going requirements for training and policy development.

There is a continuing need for RWIS-related research in Florida. For instance, a fully implemented version of the RWIS should also include information kiosks at rest areas and other appropriate locations; integration with the 511 system, and, using the FDOT dynamic messaging system, road weather advisories could be posted for in-transit travelers.

The Florida Department of Transportation benefits by receiving unbiased recommendations for the best design and operation of a statewide Florida-centric RWIS. The research also contributes to a better understanding of the causes of microwave signal fades and could lead to improved microwave path design parameters. The implementation of an operational statewide RWIS will have a significant and measurable impact on traffic and emergency management operations in the State of Florida. The traveling public will also be significantly impacted by having additional information for trip planning and from in-transit warnings.

In January 2004, the UNF research team began designing the RWIS component of the FHWA sponsored project called "iFlorida" (see www.iflorida.net). The RWIS design, operational, and maintenance recommendations developed in the research project are being directly applied to the design of the iFlorida RWIS.

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1.0 Introduction

The University of North Florida, in cooperation with the Florida State University and the National Weather Service, has developed a state-of-the art, web-enabled "Road Weather Information System Research Facility" for the Florida Department of Transportation. This report documents both the accomplishments and the challenges/setbacks experienced by the research team during Phase II of the research project.

During Phase II, the multi-disciplinary research team made significant progress, despite significant challenges, toward understanding how to design and implement a Florida-centric RWIS that could *provide timely and useful "early warning" weather information to travelers, transportation managers, law enforcement, and emergency managers, in order to ensure safe transportation in both normal and evacuation conditions for residents, visitors, and commerce.*

1.1 Project Background – Phase I

In the summer of 2001, the University of North Florida (UNF), in cooperation with the Florida State University (FSU) and the National Weather Service (NWS), entered into a contract with the FDOT Office of Research and Development to develop a research program aimed at developing a Road Weather Information System (RWIS) for the State of Florida's Interstate Highway System (FIHS). The project, funded by the FDOT's Office of Research and Development, was envisioned as a 3-phase project. From the beginning, this research has been conducted in close coordination with the former FDOT Office of Intelligent Transportation Systems (FDOT-ITS) and the current Office of Traffic Engineering and Operations (TEO) ITS Program. There has also been considerable technical assistance received from the consulting firms of PB Farradyne, Inc. and RCC Consultants, Inc. who have operated under a separate contract with the FDOT.

The first phase of this research project was completed in July of 2004. In Phase I, the research team's focus was on the design and construction of a full-scale RWIS prototype research facility that would provide the researchers, FDOT, and its contractors with an opportunity to evaluate the potential for using the statewide FDOT Microwave System (which supports the Motorists Aid System (MAS)) as the communications backbone for an Interstate-based RWIS.

Figure 1 illustrates the locations of the 14 MAS microwave towers included in the RWIS prototype research facility and the three specially equipped MAS towers that have supported the FSU microwave signal fading research. The FDOT MAS towers are spaced approximately 20 miles apart—an ideal spacing for the installation of the tower-mounted RWIS weather stations since reliable road weather forecasting requires a relatively high spatial resolution of weather observations.

Figure 2 shows typical configurations for the original data network and acquisition equipment that was installed in each MAS tower. Figure 3 shows the installation of a prototype 'basic weather station' on one of the MAS microwave towers.

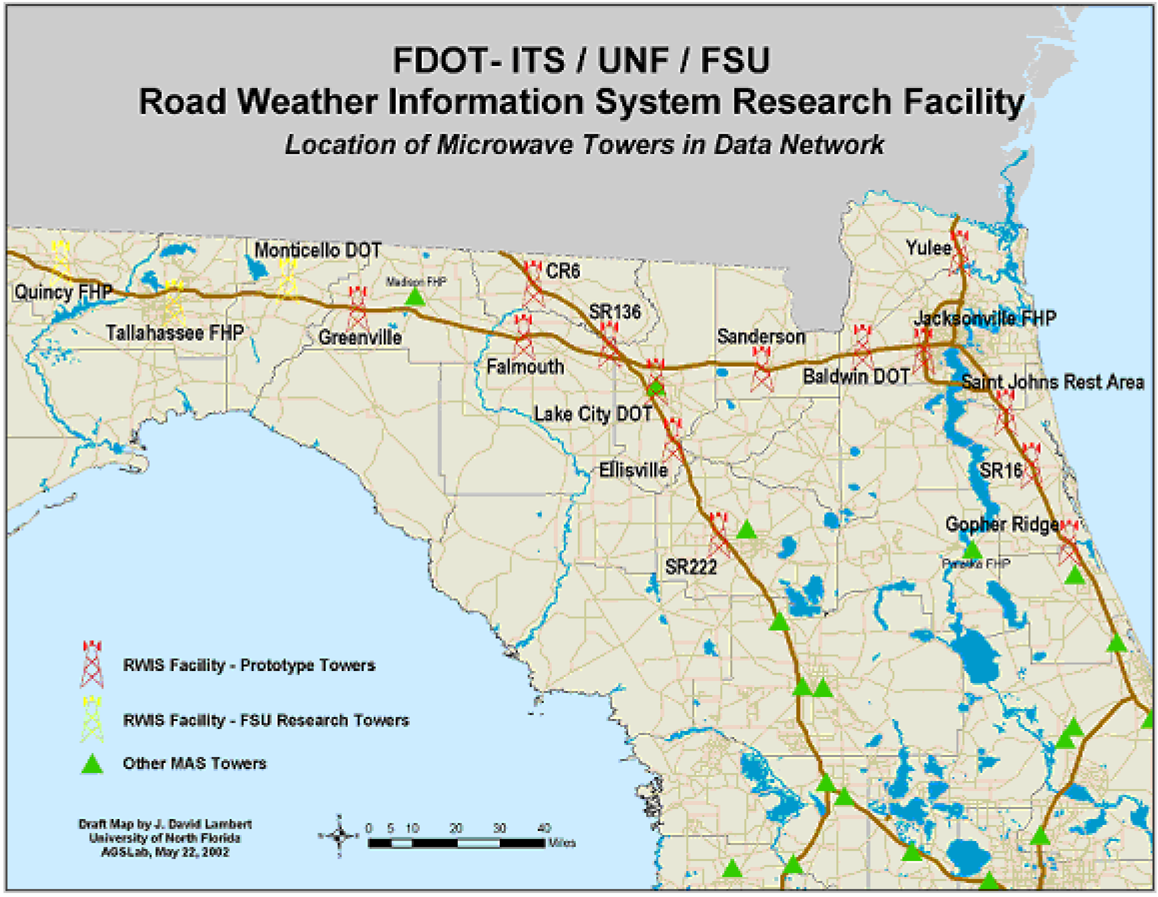

Figure 1: Location of Microwave Towers incorporated into the RWIS Research Facility

Figure 2: Typical installations of the original data network and acquisition equipment for the RWIS Research Facility.

Figure 3: Installation of a 'basic weather station' on a tower in the RWIS Research Facility.

A major feature of the team's original system design concept included the development of the capability for adding wireless weather sensors *between or near* the 20-mile spaced primary weather stations. This design feature anticipates the need for specialized stations at fixed locations to address site specific potential hazards such as high wind on high evacuation bridges or locations that are prone to fog. This feature could also support the deployment of portable units to support wildfire or hazardous material spill response operations that occur between or near the tower locations. The prototyping and evaluation of this design element was a major focus for Phase II of the project.

As an objective of both Phase I and II of the RWIS research project, investigators from the Florida State University Departments of Electrical Engineering, Geography, and Meteorology also conducted research related to atmospheric effects on microwave transmissions and on improving road weather forecasting by using the data provided by the new RWIS.

Many technical lessons were learned during Phase I by both the research team and the staff of the FDOT-ITS/TEO Office (including the ITS contractors working with the researchers) about how to successfully integrate other IT systems with the existing microwave communications system.

Due to stringent technical requirements and various physical limitations imposed upon the integration of the RWIS equipment into the existing microwave network infrastructure, a cooperative design and installation process was necessary. The general process adopted for the project was for the research team to submit a preliminary design document to the FDOT-ITS/TEO Office for each facility component. After FDOT approval, staff working for RCC

Consultants would prepare a Technical Statement of Work (TSW). The TSW formed the basis for approval for the purchase of specialized hardware, equipment, and weather sensors, and dictated the methods of installation to be used to safely integrate the RWIS system into the existing microwave system infrastructure. Lightning and surge protection were major considerations in the design and installation process. The TSW documents that record the detailed design of the research facility components and the installation requirements are included in the appendices associated with the Phase I Final Report.

The research team made significant progress toward the primary goal and objective of the research program in Phase I despite significant technological and budgetary challenges. The completion of Phase I required several "no-cost extensions" for the project as a result of significant delays due to the underestimation (by both the researchers, FDOT, and the ITS Office contractors) of the complications associated with integrating the RWIS network hardware and software into the existing FDOT microwave communication system AND the underestimation of the costs associated with accomplishing that particular task. These challenges are fully documented in the Phase I Final Report.

1.2 Need Statement

The State of Florida needs a RWIS that can provide timely and useful "early warning" weather information to travelers, transportation managers, law enforcement, and emergency managers in order to ensure safe transportation in both normal and evacuation conditions for residents, visitors, and commerce. This project specifically addresses two of the FDOT Intelligent Transportation System (ITS) Strategic Plan goals: "to reduce weather related traffic accidents by using road-weather information systems", and to "improve emergency management communications while providing real-time traveler information systems for evacuation".

The RWIS needs to be particularly focused on weather situations that could be important to traveler safety, including low visibility from fog, smoke, and heavy rain, as well as strong winds, and freezing temperatures. According to the National Weather Service, since the proposed system will significantly increase the number of weather station sites available to weather forecasters, the forecasts and advisories of these weather phenomena will be greatly improved with the statewide deployment of a RWIS. In particular, certain geographic areas, such as North Florida and the Panhandle, have relatively few existing weather stations.

Severe weather can occur in very limited geographic areas in Florida. In particular, heavy rain, fog, and smoke from wildfires can cause reduced visibility for travelers on relatively short segments of the highway. Motorists are often caught by surprise by severely reduced visibility and this has been the cause of several fatal accidents in recent years. High wind speeds on high bridges can also catch motorists off guard; particularly those driving high-profile vehicles such as vans and motor homes. Finally, since road-icing conditions are not common occurrences in Florida, when the roads or bridges do freeze, 'native' motorists, especially, are caught off guard and large numbers of accidents can occur.

Consequently, the design of a RWIS should incorporate the capability to install site-specific (not tower-based) specialized sensors and messaging systems that can provide real-time, in-transit warnings to motorists when low-visibility, high wind, or road/bridge icing conditions may be experienced on the road ahead.

The RWIS needs to provide several methods of access to current, forecasted, *and* historical road weather information. The RWIS should allow travelers to get current *and* forecasted travel weather via the Internet. Using the FDOT dynamic messaging system and other new approaches, such as 511, road weather advisories could also be posted for in-transit travelers. For instance, the fully implemented version of this traveler information system could include touch-screen information kiosks at rest areas and other appropriate locations.

1.3 <u>Similar Efforts</u>

No similar research efforts of this comprehensive scope are known.

1.4 <u>Affected Functional Areas</u>

State Traffic Engineering and Operations Office, State Maintenance Office, District Traffic Operations Offices, District Maintenance Offices; other State and local agencies, particularly the Florida Highway Patrol (FHP), the State Division of Emergency Management (FDEM), local emergency operation centers, and local public works departments.

1.5 <u>Implementation Plan</u>

This research project will lead to recommendations that could be utilized as the basis for constructing a full-scale, statewide operational RWIS.

1.6 <u>Impact to Practice</u>

The implementation of an operational statewide RWIS will have a significant and measurable impact on traffic and emergency management operations in the State of Florida. The RWIS will provide valuable information to managers that will enable them to react to existing and predicted severe weather events more effectively. Since the RWIS will provide an additional traffic management criterion to be considered, there will be initial and on-going requirements for training. The traveling public will also be significantly impacted by having additional information for trip planning and from in-transit warnings.

1.7 Benefits to the Department

As noted previously, the development of a RWIS specifically addresses two of the FDOT Intelligent Transportation System (ITS) Strategic Plan goals: "to reduce weather related traffic accidents by using road-weather information systems", and to "improve emergency management communications while providing real-time traveler information systems for evacuation". This research project will contribute to the realization of these two goals. The Department will also benefit by receiving unbiased recommendations for the best design and operation of a statewide Florida-centric RWIS. The research will also contribute to a better understanding of the causes of microwave signal fades and could lead to improved microwave path design parameters.

In January 2004, the UNF research team began designing the RWIS component of the Federal Highway Administration (FHWA) sponsored project called "Surface Transportation Security and Reliability Information System Model Deployment" (DTFH61-02-X-0089). The objective of the model deployment, commonly called **"iFlorida"**, is to demonstrate the wide variety of operational functions that are enabled or enhanced by a surface transportation security and reliability information system (see www.iflorida.net). This important demonstration project, being implemented in FDOT Districts 5 and 2, benefits greatly from the lessons learned thus far in the RWIS research project. The RWIS design, operational, and maintenance recommendations developed in the research project are being directly applied to the design of the operational iFlorida RWIS.

2.0 Summary of Results

The following summary of results is organized according to the objectives and tasks stated in the original Phase II "Scope of Work". As noted below, certain tasks and objectives have been modified, with FDOT approval, to reflect evolving priorities and to take advantage of interim research findings.

2.1 Between/Near Tower Research and Demonstration Facility

Objective 1) To utilize the prototype RWIS (that was developed in Phase 1) to further develop and evaluate the proposition that the design of the FDOT RWIS should include the capability to use appropriately located between and near-tower wireless weather sensors.

STATUS: Completed.

Notes:

In cooperation with the FDOT TEO Office, using the Telecommunications General Contract (TGC), a Technical Statement of Work (TSW) was completed for the design of the Between/Near Tower Research Facility (attached as Appendix 1). The locations of each of the components associated with this facility are shown in Figures 4 and 5.

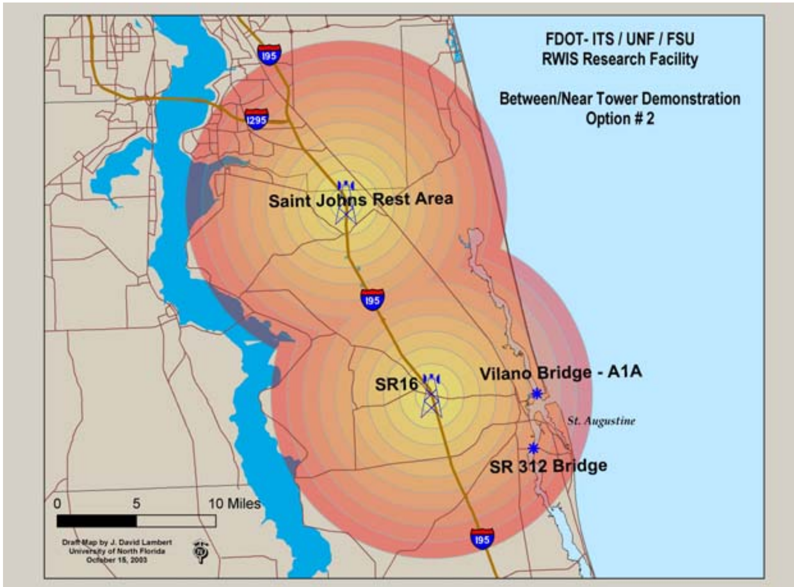

Figure 4: Location of the components of the between/near tower research facility.

Figure 5: The two research facility bridge sites.
Vilano Bridge (A1A) on the left, and SR312 bridge on the right.

The TSW required that the UNF team have a licensed engineer design and ‘seal’ a plan for the bridge mounting pole and brackets that would hold the wind sensors and associated equipment (data logger, radio, antenna, solar panel, etc.). After getting quotes from several firms, UNF selected the engineering firm called Traffic Control Devices, Inc. (TCD) to design a bracket and mounting pole solution. Based on UNF’s conceptual design and technical requirements (see Figure 6), TCD designed and submitted optional bridge mounting solutions, including one that was finally approved by the appropriate FDOT staff in October 2004 (see Figure 8 for final design drawing). For efficiency and cost considerations, installation of the ultrasonic wind sensors on these two bridges (Vilano and SR312) was coordinated with installation on the 4 bridges also outfitted with wind sensors as part of the “iFlorida” demonstration project (see Figure 7). The completed installations of the wind sensor facilities are shown in figure 9.

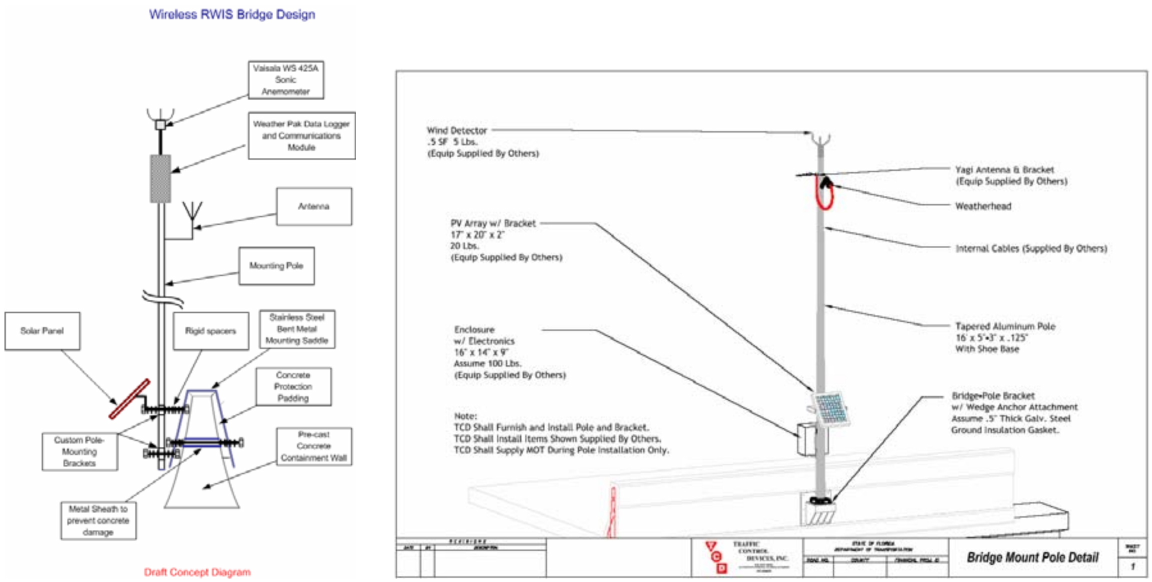

Figure 6: Conceptual and Interim Designs for the Bridge Wind Sensor Facilities

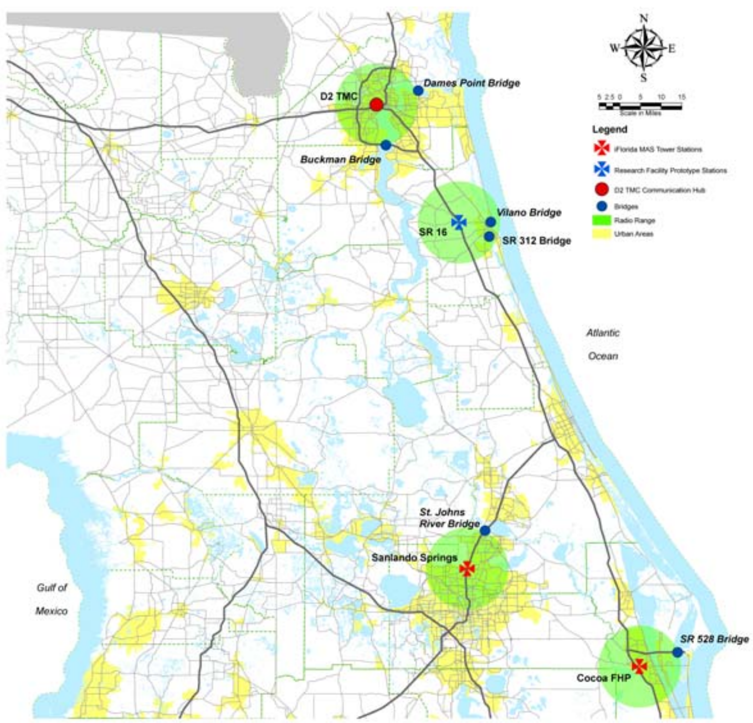

Figure 7: Location of Bridge Wind Sensors installed for both the RWIS Research Facility and the "iFlorida" Demonstration Project.

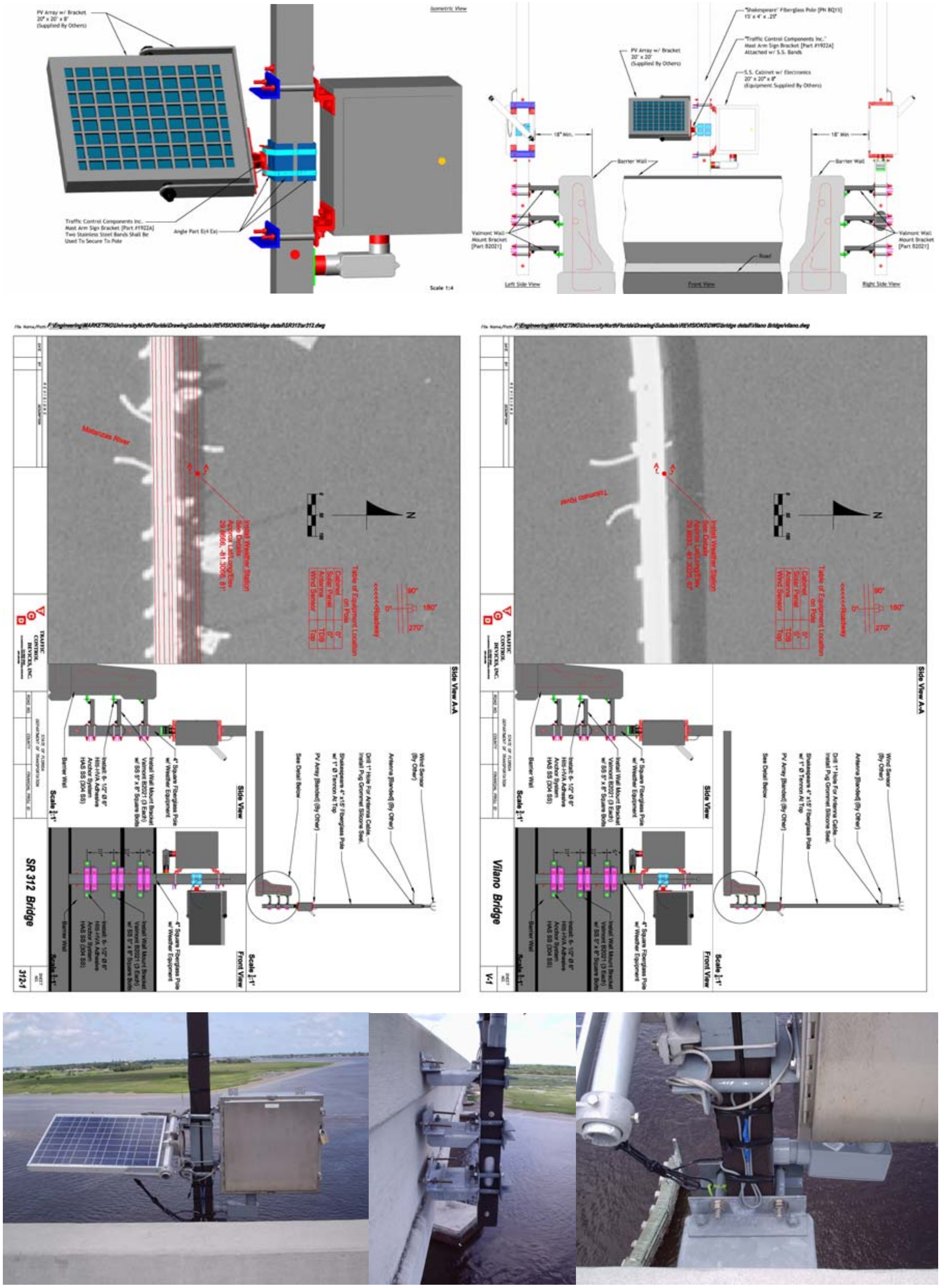

Figure 8: Final FDOT-Approved Design for the Bridge Wind Sensor Facilities. This design uses a fiberglass pole to reduce the potential for lightning damage to electronics and incorporates custom designed brackets.

Figure 9: Completed installation of the wind sensors on the Vilano bridge (upper left) and the SR312 bridge (upper right). TCD, Inc. was contracted to provide installation services (lower left). Closeup of ultrasonic anemometer (lr).

Based on the TSW, the equipment and supplies were also purchased and installed for both of the 900 Mhz antennas and radios on two microwave towers (St. Johns Rest Area and SR16, see Figure 10 below). The prototype 900 Mhz communications system and the associated software have been successfully field-tested. The prototype near (the bridge sensors) and between-tower (such as a portable) communication system provides sufficient signal range to cover the entire road segment between the two antenna-equipped demonstration towers (using an omni-directional antenna mounted at 150-200 feet on the tower and a yagi-type antenna mounted at a lower elevation, such as 10-20 feet on a between-tower roadside portable station) and provides reliable communications with the two bridge sensor systems.

Figure 10: 900 MHz radio installed in SR16 MAS Tower (left) to provide communications with the evacuation bridge wind sensors and portable between-tower stations such as the portable station (shown on the right) that is being used in the iFlorida RWIS demonstration project.

Task 1.1) Develop prototypes and/or evaluate existing sensor technology focused on detecting low visibility conditions due to fog, smoke, or heavy rain.

STATUS: Completed.

Notes:

After investigating both existing sensors and potential new technologies that could be used for an experimental prototype visibility sensor, it was determined that existing commercially available sensor products should be used for the RWIS (patents and standards certification would be major hurdles).

Three different visibility sensor models were identified as meeting the operational needs of the RWIS. At least one of each of these different models has been installed in either the research facility or the iFlorida demonstration facility providing an opportunity for a comparative evaluation between the different models during Phase III. One of the models being deployed for iFlorida is suitable for use as a component of a portable ‘between-tower’ weather station (as shown in Figure 10).

Task 1.2) Further develop the between-tower weather station prototypes to incorporate in-transit warning/messaging capabilities.

STATUS: Completed.

Notes:

The RWIS data analysis subsystem software is currently capable of sending electronic alert messages in several manners, including: email messages to a pre-determined list of email addresses, pager messages to a pre-determined list of phone numbers, and posting of alert data to the RWIS website database for Internet access. All of these methods would provide traffic and/or emergency managers with the basic information needed to determine whether or not to compose an alert message and activate existing or future warning systems, such as dynamic message signs.

It is recommended that this issue be further investigated in Phase III as part of the TMC Pilot project, since it has become obvious that there is a need for the development of criteria, policy and procedures that will require the involvement of representatives from FDOT, FHP, and FDEM.

Task 1.3) Develop a prototype sensor system, or evaluate existing sensors, that can detect high wind conditions on high bridges and/or road icing conditions then activate an in-transit warning/messaging system.

STATUS: Completed.

Notes:

As explained in the case of the visibility sensor evaluation (Task 1.1), the team recommends that existing commercially available sensors should be used since experimental prototypes, while feasible to build in the lab, are not a practical alternative for near-term implementation of the RWIS. Several different types/models of wind sensors were purchased for evaluation. After investigation of alternative types of anemometers, the Vaisala Model WS 425 ultrasonic anemometer (with no moving parts) was selected for installation on high bridges because of the lower maintenance requirements and predicted longevity.

There is an on-going statewide discussion (involving FDOT, FHP, and FDEM officials) about the operational wind speed and gust criteria and the procedures for triggering a wind speed alert for bridges. This technical and policy discussion is focused on determining the specific sustained wind speeds, duration, and gust levels/intervals that would trigger an alert. See the discussion above (Task 1.2) for considerations and issues related to in-transit messaging.

Task 1.4) Conduct prototype demonstration workshops for FDOT staff and other stakeholders to get input and informal evaluations.

STATUS: Needs to be scheduled.

Notes: An on-site demonstration workshop is planned for early Fall 2005. Also, as a result of operational and management experiences related closing bridges during last year's active hurricane season, the research team is actively involved in an on-going statewide discussion (involving FDOT, FHP, and FDEM officials) about the wind speed and gust ***criteria and the operational procedures for triggering a wind speed alert/closure for bridges***. This technical and policy discussion is focused on determining the specific sustained wind speeds, duration, and gust levels/intervals that would trigger an alert/closure situation.

Task 1.5) Conduct technical tests of the prototypes in order to evaluate the effectiveness of the prototype sensor technology for achieving the stated objectives.

STATUS: Completed.

Task 1.6) Develop a GIS model to assist in determining the potential locations of greatest need for between-tower sensors based on a relative risk assessment for fog. The model will be based on parameters such as land cover, soil type, and elevation that might predict fog hazards.

STATUS: Completed.

Notes:

A GIS database covering the spatial extent of I-10 between Jacksonville and Tallahassee was used to model "Fog Propensity based on GeoPhysical Factors". The method used is outlined in Figure 11 below. The results of the intermediate steps in the analysis are shown in Figures 12, 13, and 14. The final result, shown in Figure 14, predicts that factors such as landuse, soil type, and elevation (low areas) may combine to create areas along Interstate 10 that are more prone to fog than other areas. Many of the areas that the model predicts to have a high propensity for fog are known, anecdotally, to be fog-prone segments of I-10. Perhaps the most important conclusion from this study is that there is indeed a need for "between-tower" visibility sensors in specifically identified fog-prone areas, such as the segment of I-10 that crosses the Suwannee River valley.

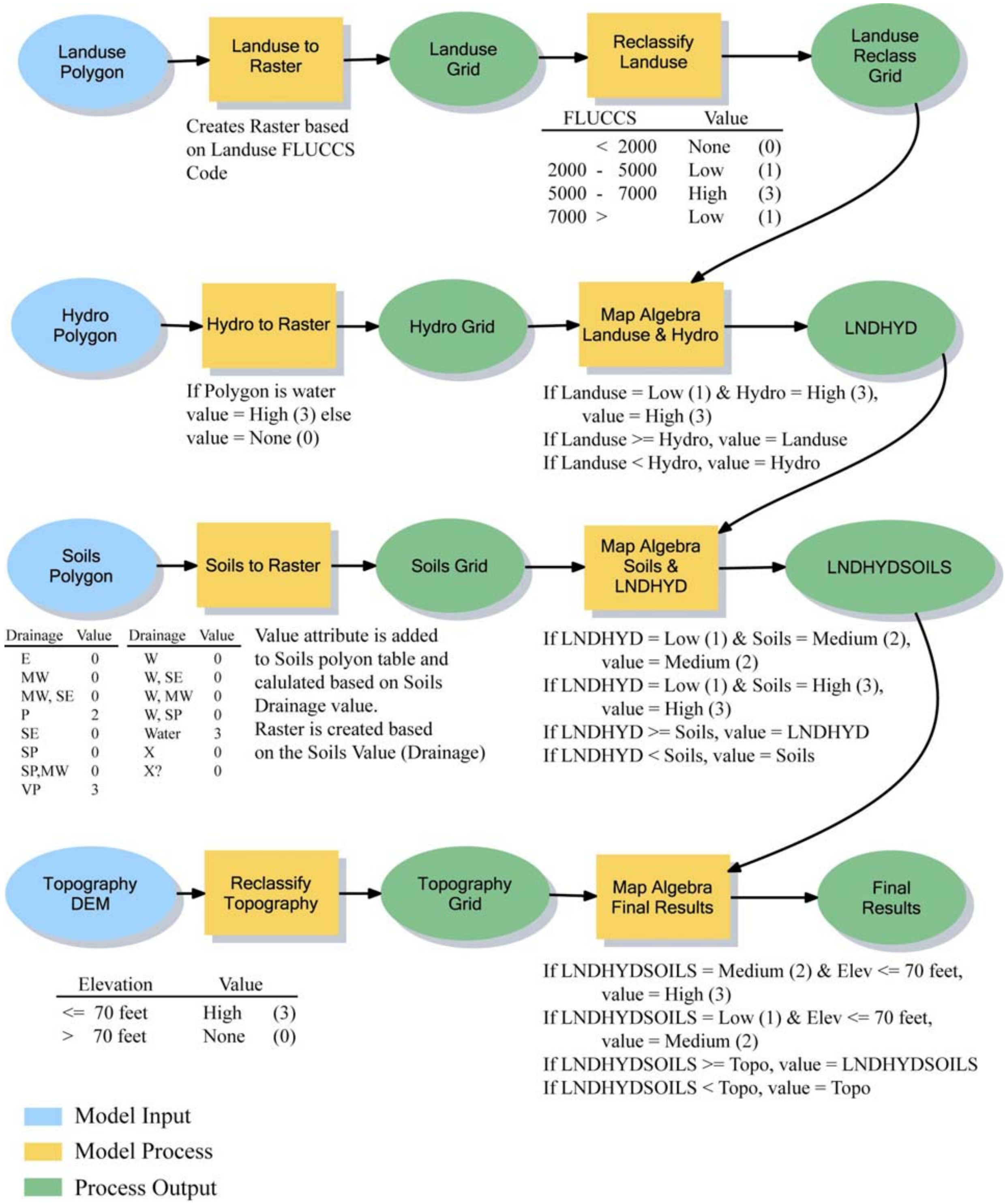

Figure 11: Fog Propensity Based on Geophysical Factors - Model Flow Diagram

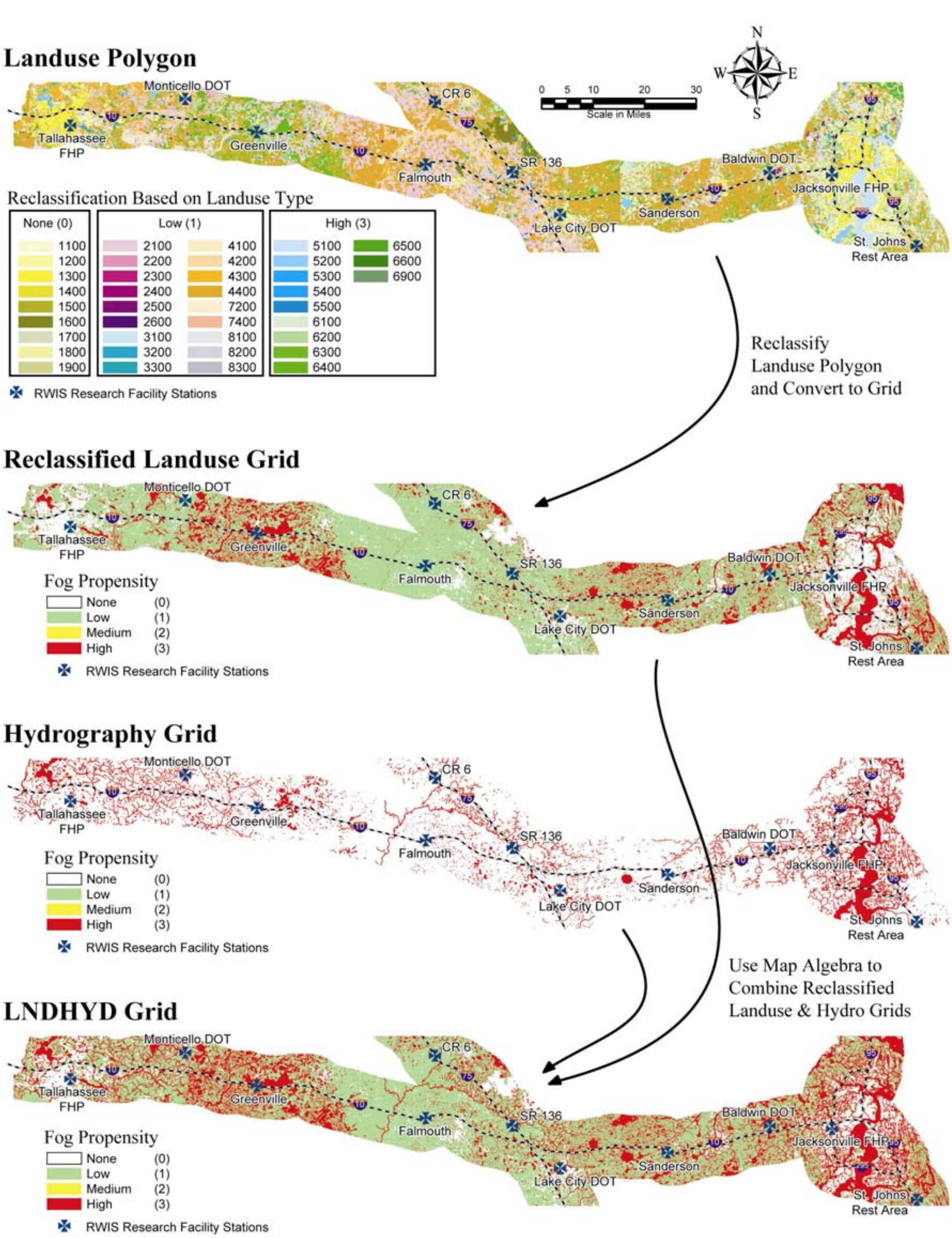

Figure 12: Fog Propensity Based on Geophysical Factors –
Intermediate Analysis Results (Landuse and Hydrography Grids)

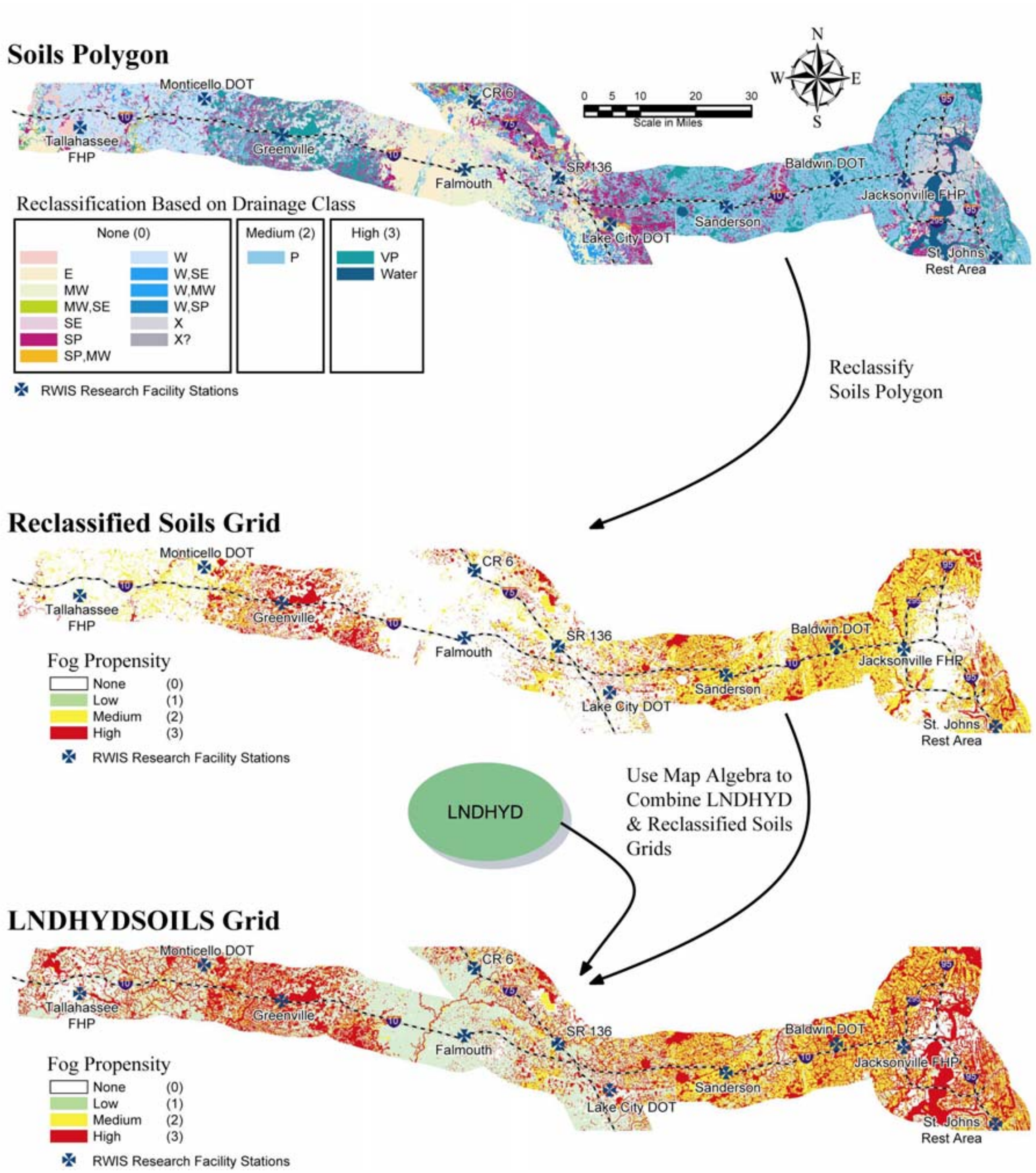

Figure 13: Fog Propensity Based on Geophysical Factors – Intermediate Analysis Results (LNDHYD and Soils Grids)

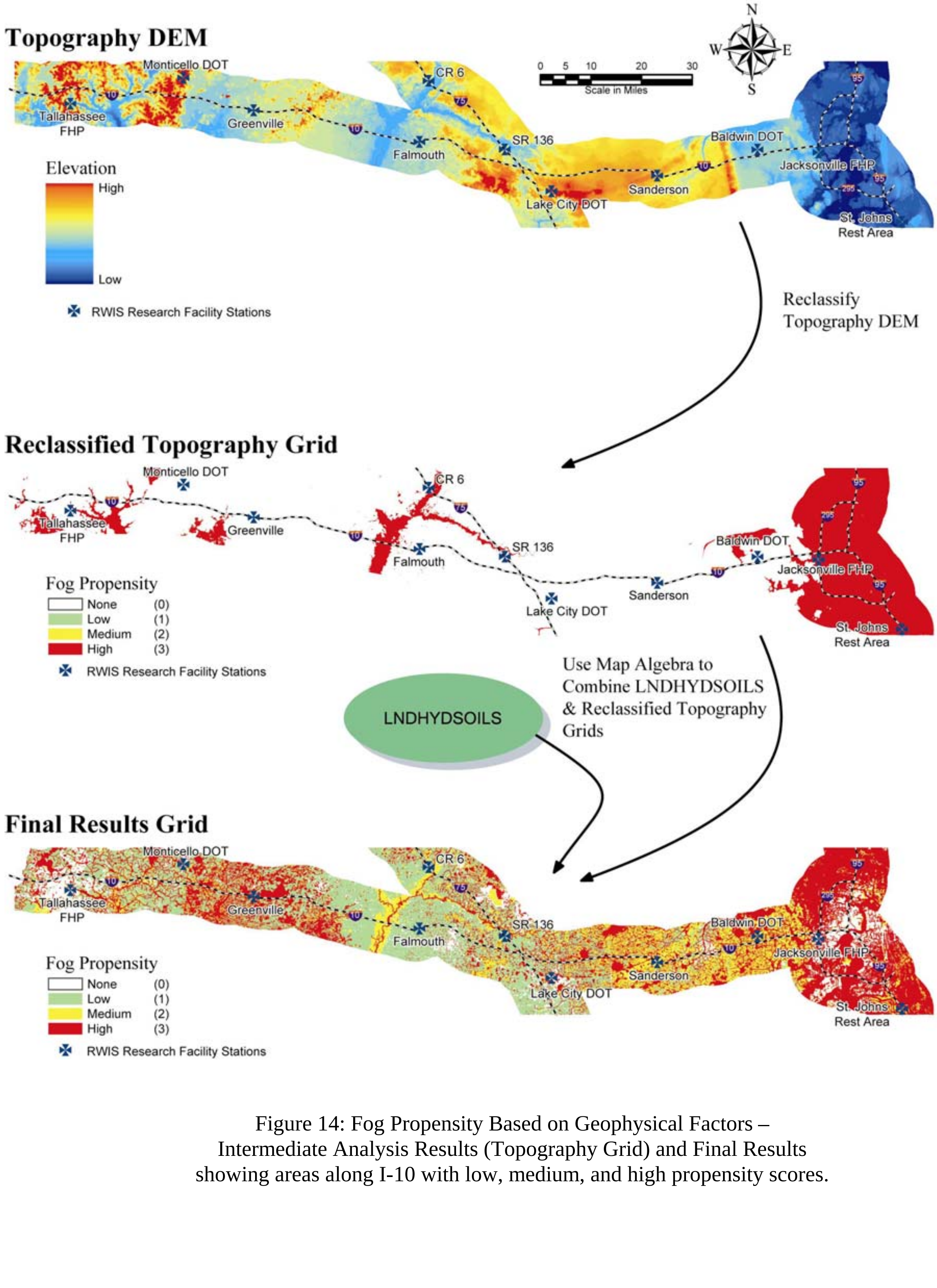

Figure 14: Fog Propensity Based on Geophysical Factors –
Intermediate Analysis Results (Topography Grid) and Final Results
showing areas along I-10 with low, medium, and high propensity scores.

2.2 Coordination with National Weather Service

It has become obvious as a result of this research project that a continuing cooperative relationship between the FDOT and the NWS will be mutually beneficial. By providing the basic RWIS weather data directly to NWS forecasters and others, the potential for higher spatial resolution weather forecasts, to support specific road segment forecasts, is improved. In particular, the RWIS has provided the NWS, and others, with weather data for locations that were previously not covered by any weather stations. The table shown below (in figure 15) lists the official NWS site identifiers given to the weather stations installed as part of the RWIS Research Facility project and the iFlorida demonstration project. Currently, the raw weather data collected at these RWIS stations is automatically sent to the NOAA Forecast System Lab's Meteorological Assimilation Data Ingest System (FSL-MADIS) every five minutes. Through FSL-MADIS, the RWIS data is available to any forecaster (NWS, private, or researcher) that wants to download it (see http://www-sdd.fsl.noaa.gov/MADIS/).

NWS ID	RWIS Site Name	Location Description	Elevation (m)	Latitude	Longitude
BAWF1	BALDWIN	RT301 & I-10 DUVAL CO	25.50	30.3075	-81.9719
ECSF1	ELLISVILE	S.LAKE CITY I-75 COLUMBIA CO	22.50	29.9997	-82.5983
GFRF1	GOPHER RIDGE	I-95 STJOHNS CO	7.30	29.6625	-81.2867
GREF1	GREENVILLE	MADISON CO	28.70	30.4356	-83.6390
GVNF1	SR-222	NEAR GAINESVILLE ALACHUA CO	56.20	29.6878	-82.4461
JHPF1	JAX-FHP	S.I-10 & I-295 W.JAX DUVAL CO	7.30	30.2972	-81.7697
HWJF1	CR6	CR6&I-75 W.JASPER HAMILTON CO	90.00	30.5180	-83.0576
LCYF1	LAKE CITY DOT	COLUMBIA CO	55.50	30.1950	-82.6531
RSTF1	ST.JOHNS REST AREA	I-95 N. ST JOHNS CO	5.90	30.0928	-81.5000
SDRF1	SANDERSON	I-10 & RT-90 BAKER CO	48.60	30.2378	-82.3039
SOMF1	SR-16	NEAR OUTLET MALL ST JOHNS CO	12.00	29.9169	-81.4125
SUCF1	CR136	AT I-75 NE SUWANNEE CO	29.90	30.3192	-82.8081
SUFF1	FALMOUTH	I-10&US90 LIVE OAK SUWANNEE CO	29.80	30.3425	-83.0903
YULF1	YULEE	I-95 & A1A NASSAU CO	6.60	30.6203	-81.6497
DPBF1	DAMES POINT BRIDGE	DUVAL CO	53.30	30.3851	-81.5573
BUCF1	BUCKMAN BRIDGE	DUVAL CO	21.30	30.1898	-81.6673
MLWF1	SR-528 BRIDGE	BREVARD CO	21.30	28.4052	-80.6482
SJBF1	ST JOHNS RIVER BRIDGE	VOLUSIA CO	15.20	28.8346	-81.3197
ORBF1	ORMOND BEACH	US-17 & I-95, VOLUSIA CO	9.40	29.3366	-81.1303
PORF1	PORT ORANGE	SR44 & I-95, VOLUSIA CO	6.30	29.0850	-81.0167
EGWF1	EDGEWATER	I95 & SR442, VOLUSIA CO	7.10	28.9511	-80.9503
MMSF1	MIMS	SR46 & I-95, BREVARD CO	6.20	28.6656	-80.8703
CFHF1	COCOA FHP	SR520 & I-95, BREVARD CO	6.10	28.3569	-80.7827
JUNF1	JUNE PARK	I-95 & US-192, BREVARD CO	5.90	28.0797	-80.7051
SLSF1	SANLANDO SPRINGS	SR424 & I4 SEMINOLE CO	18.60	28.7271	-81.3724
DLDF1	STUART	I95 & SR714, MARTIN CO	5.30	27.1609	-80.3036
IRDF1	INDRIO RD	I95 & INDRIO RD, ST LUCIE CO	6.40	27.5228	-80.4503
BEOF1	SR 520-528	SR 520 & SR 528, BREVARD CO	9.10	28.4525	-80.9786
VILF1	VILANO BRIDGE	VILANO RD & A1A, ST JOHNS CO	20.42	29.9175	-81.3025
SRTF1	SR312 BRIDGE	SR 312 & A1A, ST JOHNS CO	24.69	29.8669	-81.3067

Figure 15: Official National Weather Service Station Identifiers assigned to the RWIS Research Facility and iFlorida weather stations that enable incorporation into weather forecast models.

The FSL MADIS database is available via ftp, by using Unidata's Local Data Manager (LDM) software, or through the use of OPen source project for Network Data Access Protocol (OPeNDAP (formerly DODS)) clients. Users can subscribe to the entire database, or ask for only particular datasets of interest.

Quality Control (QC) of MADIS observations is also provided, since considerable evidence exists that the retention of erroneous data can substantially distort forecast products. Observations in the FSL database are stored with a series of flags indicating the quality of the observation from a variety of perspectives (e.g. temporal consistency and spatial consistency), or more precisely, a series of flags indicating the results of various QC checks. Users of MADIS can then inspect the flags and decide whether or not to ingest the observation.

MADIS also includes an Application Program Interface (API) that provides users with easy access to the data and quality control information. The API allows each user to specify station and observation types, as well as QC choices, and domain and time boundaries. Many of the implementation details that arise in data ingest programs are automatically performed. The current version of the API supports the FSL database, and also the database used in the National Weather Service (NWS) Advanced Weather Interactive Processing System (AWIPS) deployed at NWS weather forecast offices. The API can also be used as an OPeNDAP client to access data directly from the MADIS OPeNDAP server.

MADIS data files are compatible with AWIPS and AWIPS-like display systems and the analysis software provided by the Local Analysis and Prediction System (LAPS) and the Weather Research and Forecasting (WRF) Model 3D-Variational (3DVAR) Data Assimilation System. They have also been used to initialize the Advanced Regional Prediction System (ARPS), MM5, and Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS^{tm}) forecast models.

The FSL MADIS database and API are freely available to interested parties in the meteorological community."

A feature of the FSL-MADIS system is that it provides free long term database archival services to data providers (such as FDOT). Database development and support can be a very expensive endeavor, both in terms of hardware and in terms of management and development personnel. A highly redundant, highly reliable, totally free database service has considerable value.

By transmitting the weather observations from the Florida RWIS weather stations into the FSL-MADIS system, the FDOT will be improving the quality of NWS forecasts. Over time this process will lead inevitably to improved weather information and predictions for use by FDOT traffic managers.

Task 2.1) In coordination with FSU and NWS investigators, evaluate NWS forecast data, advisories, and warnings for incorporation into a RWIS web site.

STATUS: Completed.

Notes:

In cooperation with the NWS and FSU, the UNF research team has developed a prototype application (see Figure 16), based on GIS and Internet Map Server technologies, that uses NEXRAD radar data downloaded every 5 minutes to estimate rainfall rates for specific highway segments. The application is fully described in Appendix 2.

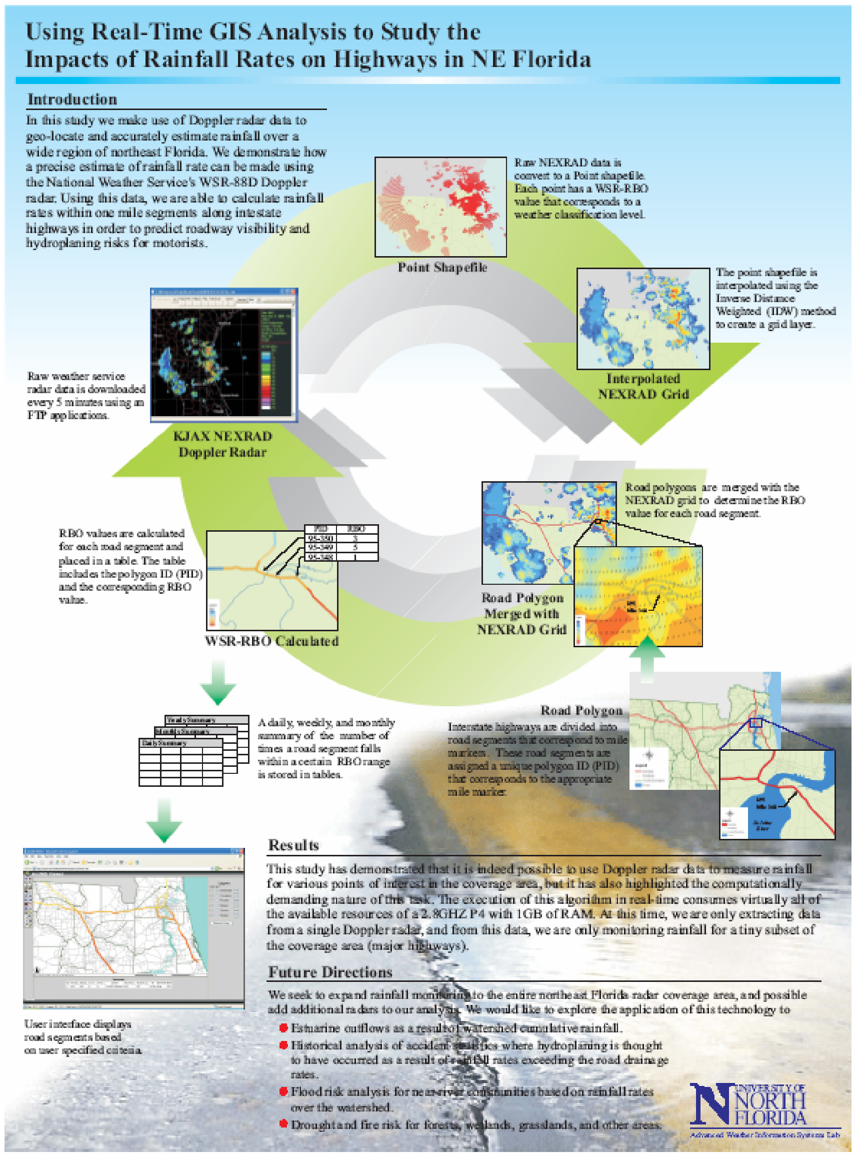

Figure 16: An example of the new capabilities being developed for the RWIS website that have resulted from close cooperation with the National Weather Service and FSU investigators.

As a result of several workshops with FSU and NWS meteorologists, the team decided to evaluate the new NWS forecast products collectively called the National Digital Forecast Database (NDFD). These are grid-type products (examples are shown in Figure 17) with forecast information associated with each grid cell that can be overlaid using GIS methods and technologies onto each of the corresponding road segments. Further evaluation of the usefulness and validity of both the NDFD products and the RWIS post-processing methods will be required since these are new and experimental products.

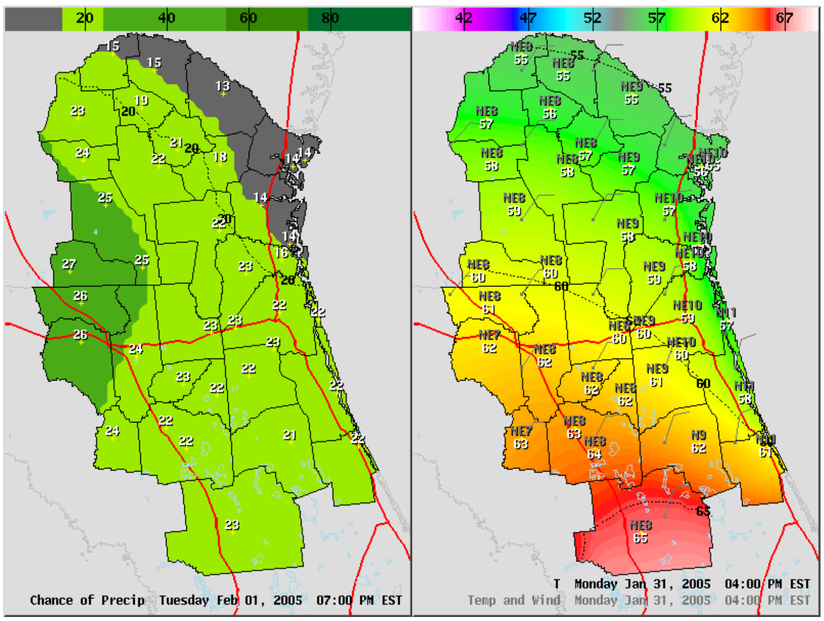

Figure 17: Examples of the new NWS NDFD forecast grid products that could be used as a GIS overlay on road segments to provide road segment forecasts.

Task 2.2) Assist the FSU and NWS investigators in evaluating the accuracy and usefulness of the weather information and advisories to travelers.

STATUS: Completed.

Notes:

The FSU investigators and the NWS cooperators identified several issues associated with the accuracy of some of the weather data that was being collected and those issues have been either resolved or are being worked on. For example, based on an evaluation (conducted by the FSU investigators) of the accuracy of some of the weather data that was being collected, all of the barometers were re-calibrated with the assistance of NWS technical staff.

During the Fall 2004 hurricane events the RWIS research team worked closely with the local NWS Forecast Offices to make sure that the RWIS weather data was available to forecasters and emergency managers. This RWIS weather data was noted by the NWS Forecast Offices as being "invaluable" as bands of severe weather moved across North Florida. It is important to remember that these new weather stations cover several previous 'gaps' in weather data coverage for the region. Most importantly, the need for wind sensors on high coastal evacuation bridges became apparent to law enforcement agencies and emergency managers as they had to make decisions about closing bridges during the high wind events.

2.3 Fog Research Facility

***Original Objective 3*)** To evaluate the potential for incorporating 'traveler kiosk' capabilities into the RWIS.

STATUS: With the approval of FDOT, this task has been delayed until Phase III and the following task was substituted as a higher priority task.

New Objective 3) To design, purchase and install a visibility sensor at the Quincy FHP tower facility, and to update the data collection subsystem to include visibility data in support of FSU fog prediction research activities.

STATUS: Completed within limitations imposed by lightning strike damage.

Notes:

A separate Technical Installation Memorandum was developed in cooperation with the ITS Section Office and the TGC for a fog detection system. A Belfort 6000 visibility sensor was purchased in December 2003, but due to a backorder situation (these same units were also being used for the Air Force weather station upgrade project), there was a significant time delay for receiving the sensor unit. After the unit was installed at the Quincy FHP tower site, it was discovered that the existing power supply unit was not adequate—consequently another power supply was ordered and installed in July 2004. The data collection subsystem software was updated.

Unfortunately, a lightning strike damaged the externally mounted data logger system soon after the system was installed. A repaired data logger was installed and lightning once again destroyed the unit. Since all three of the 'FSU Research Towers' (Quincy, Tallahassee, and Monticello) have been subjected to repeated severe lightning strikes during Phase II that have resulted each time in damaged data loggers, the research team requested approval from FDOT for a modified system design for these three towers that would accommodate moving the data logger subsystem inside the towers.

Since the project budget did not allow for this many major equipment failures, the fog research facility has not been repaired. This has, obviously, prevented the FSU investigators from completing their fog prediction study.

2.4 FloridaRoadWeather.org Web Site

An objective of the project was aimed at the development of a prototype web-based interface to the road-weather data collected by the RWIS research facility (See Figures 18 and 19). An easy-to-remember URL was registered for the project website: **FloridaRoadWeather.ORG** (or .Com, or .Net). The website is currently being updated to include the iFlorida project stations.

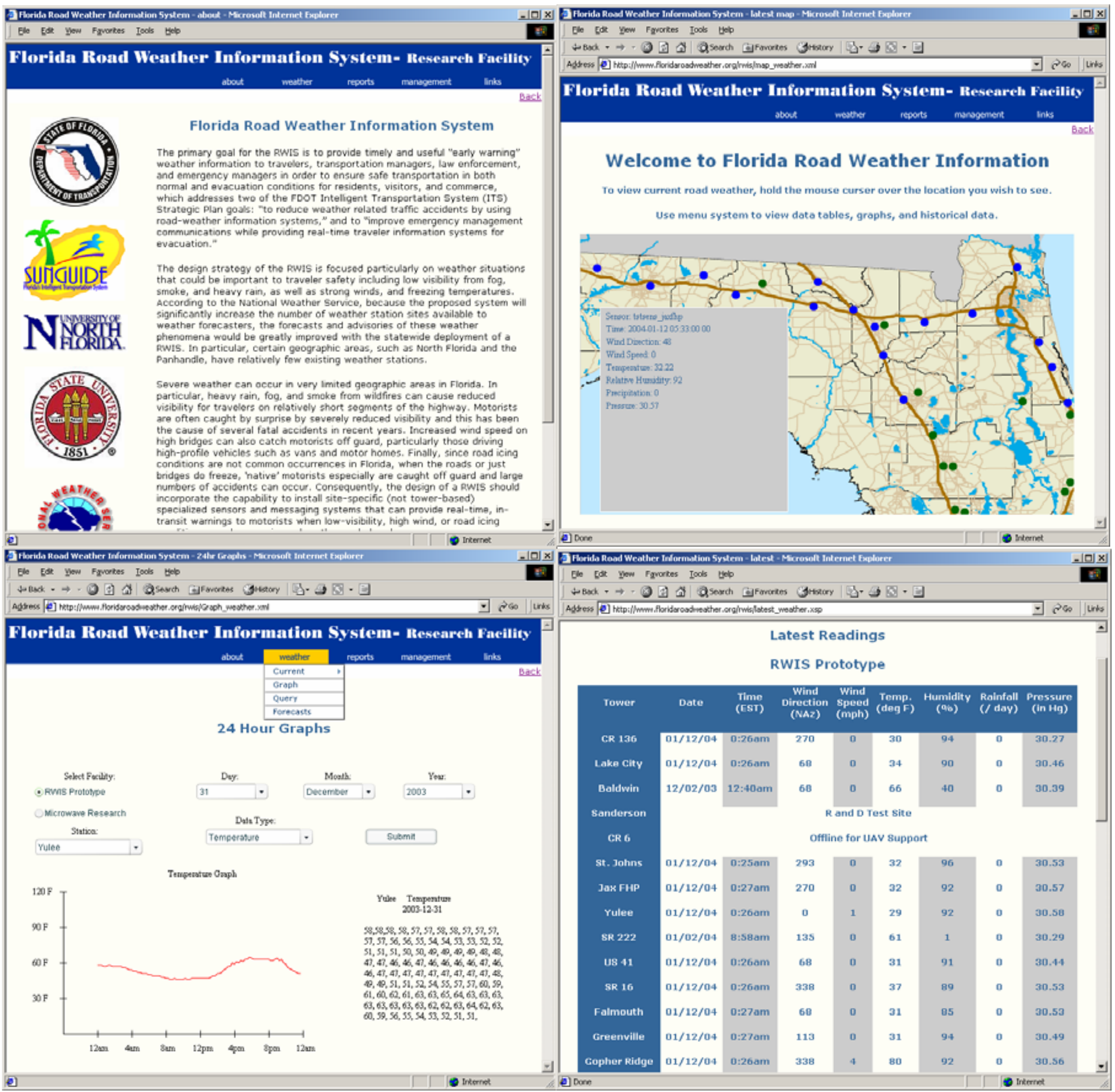

Figure 18: RWIS Research Facility website.

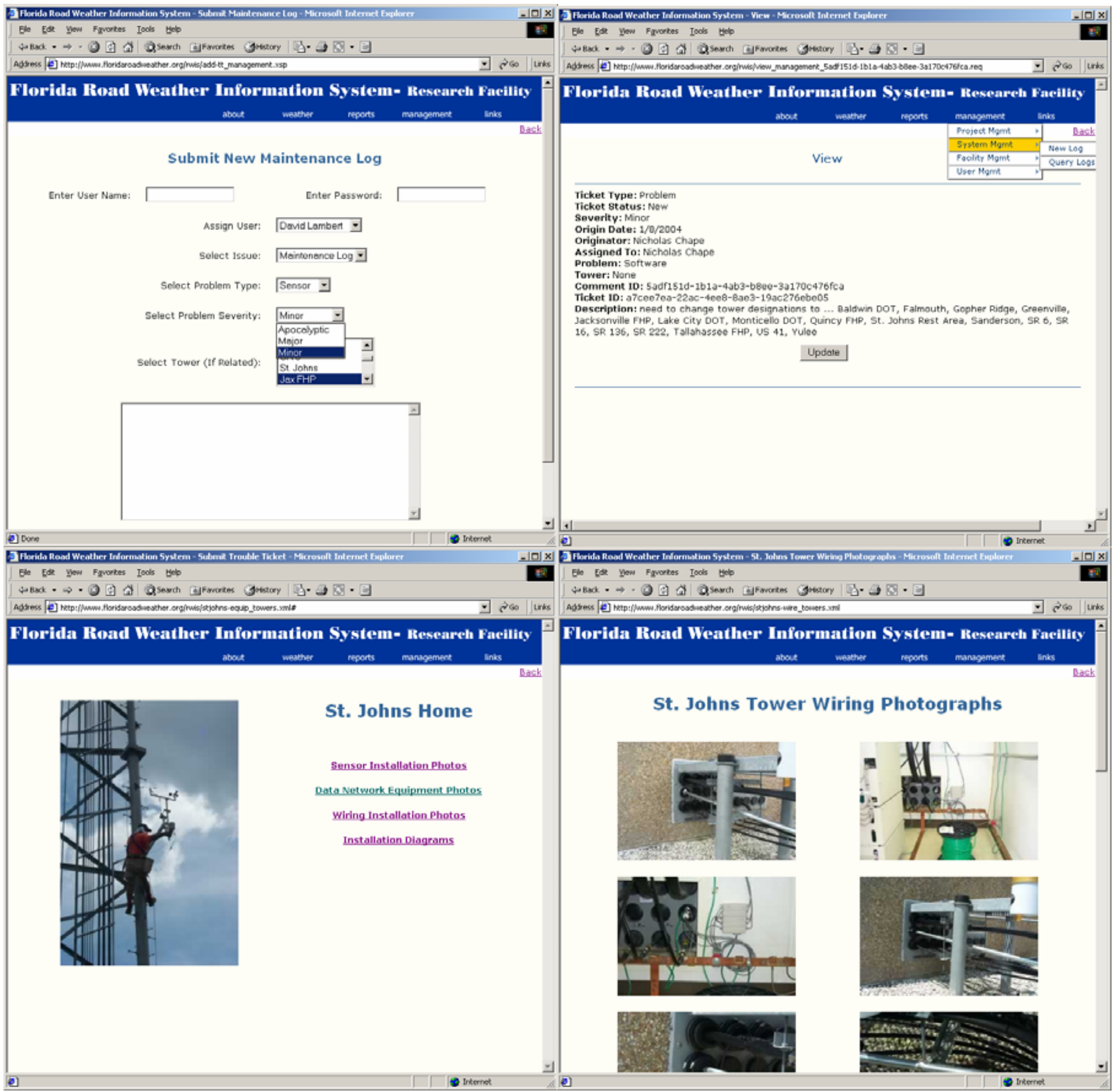

Figure 19: The RWIS Research Facility website includes project and facility management features such as a 'trouble ticket system' and access to installation documents.

Task 4.1) Conduct an evaluation of the functionality of the web site. This will include workshop(s) with stakeholders and potential-user focus groups. Refine the web site as needed based on input and evaluations.

STATUS: Completed.

Notes:

As a result of the workshop input, the following 'easy-to-remember' URL's were registered for the RWIS web site:

FloridaRoadWeather.org
FloridaRoadWeather.com
FloridaRoadWeather.net

Task 4.2) Continue to provide maintenance of, and access to, the web site which will be hosted on a web-server computer housed at UNF.

STATUS: Completed.

Notes:

The RWIS website is currently being updated to include the iFlorida project.

Task 4.3) Continue to maintain and provide web-based access to the historical weather database. Refine access to the system as required.

STATUS: Completed.

Task 4.4) Incorporate input and results from evaluations in order to improve the functionality of the web site.

STATUS: Completed.

Notes:

As a result of evaluation and input, several major revisions and technological updates of the web site were undertaken.

2.5 Research Facility Maintenance and Operations

Objective 5) To operate and maintain the prototype RWIS network and weather stations.

STATUS: Completed.

Task 5.1) Maintain the prototype RWIS communications network and weather stations in operational mode during the period of the contract.

STATUS: Completed.

Notes:

It should be noted that his task required a significant amount of time and effort on behalf of the UNF team. However, by maintaining the system over a substantial period of time, the research team and FDOT have discovered several technical and maintenance issues that were not originally anticipated in the original design concept. Consequently, the experience gained from the research facility had a significant impact on the development of the recommendations for the iFlorida RWIS project design.

Additional Service Not In Scope of Work - Sensor Reconfiguration at Gopher Ridge

Since the MAS tower at Gopher Ridge is being replaced with a taller tower, UNF was required, at FDOT's request, to assist in the removal of the sensors from the original tower, which will be dismantled, and the re-installation of the sensors on a new 30 foot tower located at the communications shelter site (see Figure 20). This necessitated the acquisition of tower climber services for one day (at UNF's cost) and the time for lab personnel to support the climber activities and rewire the sensors.

Figure 20: The "old" and "new" towers at "Gopher Ridge" (left picture), and the 30 foot tall tower installed beside the communications shelter for reinstallation of the weather sensors.

Task 5.2) As required, repair components of the operational prototype RWIS.

STATUS: Completed.

Notes:

Several of the tower sites experienced **several lightning strikes** during the period that resulted in the need to replace several sensors and data loggers. The lightning protection design for the installations was reviewed to determine if there were additional protection measures that could be incorporated into the facilities. As a result of this review, UNF has recommended that the specialized FSU research tower facilities be modified so that the Zeno data loggers will be located inside the tower shelters**.** In the current design the Zeno data loggers are installed in fiberglass NEMA Type 4 boxes that are mounted outside the shelter on the tower structure. Although the Zeno units are equipped with TVSS devices, this level of protection has proved to be insufficient when the towers get direct lightning strikes. The UNF design team is willing to work with RCC Consultants to create a proposed Technical Statement of Work for a new design that will allow the Zeno data loggers to be located inside the shelter. ***Because the projects' repair budget is exhausted, the FSU towers are not currently operational as a result of lightning strikes. Further discussion is needed to determine the future need for repairing the systems installed on these towers.***

Task 5.3) Continue development of the network software as needed to improve the overall reliability and operational characteristics of the RWIS.

<u>STATUS: Completed</u>.

<u>Notes:</u>

Significant effort has been committed to this task during Phase II. As a result, network latency issues experienced during Phase I operations were greatly reduced. The system now meets the level of performance standards needed for the data availability operational requirements.

It is important to point out that the original Phase I proposal did, in fact, anticipate that there could be unknown challenges associated with the networking component of this project since the FDOT microwave system is not a typical off-the-shelf networking solution. For example, in the original Phase I proposal the following two statements were included: *"It is expected that the FDOT-ITS staff and/or contractors will work with UNF to provide industry standard network connections to the microwave communications system hardware that the weather stations can be connected to."*, and *"Although not anticipated, this task may affect the schedule if unanticipated development is required. It is expected that the FDOT-ITS staff and/or their contractors will provide an Internet access point for the microwave communications system to allow the weather data to be transmitted (using TCP/IP) to a server at UNF."*

Although admittedly vague statements, the team's original understanding was that we would be able to connect our equipment to a network router provided by FDOT. When it became clear that this assumption was in error, because the network upgrade for the MAS communications system would not be completed until sometime in 2004 or 2005, the team was forced to reassess their anticipated design with the added challenge of building the system within budget while having to purchase several unanticipated hardware components. The primary components at issue included, but were not limited to, the network routers and CSU/DSU units required to provide network interfacing with the microwave system. Other FDOT-ITS contractors were also required to pre-wire and test each tower to provide the dedicated T1 circuits required for the RWIS system. This single issue was at the core of the project delays associated with Phase I and posed a considerable budgetary challenge for the UNF design team.

Not to be discouraged, the team was eventually able to work with several vendors to obtain substantial discounts on the hardware required (including some refurbished and used equipment) and was able to purchase all of the required equipment within the budget allotted for the project. And, with substantial help from the FDOT-ITS telecommunications contractor RCC Consultants, Inc., the design team was finally able to successfully develop and test a network design that integrated the RWIS system into the *existing* microwave communications system (Figure 21).

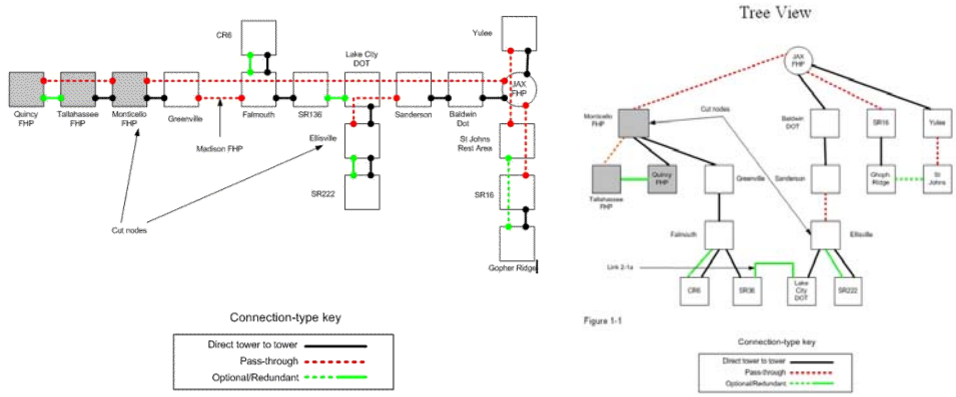

Figure 21: Generalized views of the original RWIS research facility network design.

Additional Services Not Included in the Scope of Work

RWIS Network Reconfiguration Required by MAS Network Upgrade

As stated previously, in the Phase 1 Research Facility, since the MAS Upgrade Project had yet to begin, UNF was required to develop a network using routers and CSU/DSU units. At the completion of the MAS Upgrade Project, UNF was notified that FDOT wished to recapture the bandwidth being utilized by UNF and must migrate to the “Upgraded Network”. Although this work, and the equipment needed to accomplish it, was not in the original Phase II budget, UNF agreed to use equipment funds (originally intended for repairs) to facilitate this transition since the upgraded system would offer higher system reliability. At each MAS tower site, UNF was required to:

- Remove the CSU/DSU units.
- Remove the Cisco Routers.
- Remove the T1 lines and interconnects.
- Install Ethernet TVSS’s.
- Install Ethernet cabling.
- Test and debug the system.

The physical transition to the new network took several weeks of lab personnel time. A bigger challenge, however, was that a significant re-write of middleware computer code needed to occur because the new network didn’t have a default route whereas the existing code base depended on one.

Server Migration to Solid State Devices

UNF has also transitioned the majority of the Research Facility network from a server-based communication infrastructure to a solid state communication infrastructure, specifically using Digi TS-1 (One Port) Serial Terminal Servers. The advantage of this approach is a considerable gain in system reliability, since the solid state Digi's have a low failure rate, low replacement cost, ready acquisition, and easy replacement procedures exist should they fail.

The Crystal Servers that had previously supported network communications for the Research Facility had become quite aged and were experiencing high rates of failure with hard drives, fans, and motherboards. Since legacy hardware for these devices is virtually unavailable, repair of these servers on failure can be quite problematic. However, Crystal Servers that continue to function have been left in place in order to provide backup data storage in the event that a severe weather episode cuts off network functionality but the site itself remains operational. This methodology would allow later acquisition of weather event data.

Figure 22: The original data acquisition and networking configuration (incorporating the required CSU/DSU units and a Cisco Router) is shown in the upper left picture. The upgraded configuration is shown in the upper right photo. This new configuration no longer requires the CSU/DSU units or the router. UNF also upgraded the system to incorporate a Digi TS-1 (One Port) Serial Terminal Server (shown in the lower left photo) connected to the FDOT MAS Ethernet network switch (shown in the lower right photo) to improve reliability of the system..

2.6 Recommendations for Implementation

Objective 6) To develop recommendations for state-wide implementation and maintenance of the RWIS.

STATUS: Completed, See Section 4.0

SUBCONTRACT WITH FSU

Florida State University (FSU) investigators completed the following tasks as a subcontract.

2.7 Weather Research

Objective 7) Design a road-specific weather prediction system (RWPS) as part of the RWIS.

Task 7.1) Evaluate the accuracy and usefulness of the RWIS data for use in the RWPS, focusing on the recently installed tower data.

STATUS: Completed.

Notes:

The FSU meteorologists collaborated with UNF on the installation of the meteorological sensors. During the project, they have continually monitored the quality of the RWIS data, searching for erroneous data, and have reported any instances of 'problematic data' to the UNF team.

The FSU meteorologists have worked with UNF and the National Weather Service to specify an optimum format for the RWIS data so that the data can be used both by the NWS and by FSU researchers. The data format that was adopted, based on these recommendations conforms to the NOAA FSL MADIS format (discussed in Section 3.2 of this report).

Task 7.2) Develop an empirical fog prediction system to be used as part of the RWPS.

STATUS: Completed.

Notes:

The FSU meteorologists worked with the National Weather Service to investigate a recently reported new technique for forecasting fog. This technique has potential for use along Florida highways. The technique was investigated during Phase II of the research project using ordinary surface weather data. Based on this approach, a climate analysis of fog occurrences along the Interstate Highway System in northeastern Florida was developed. This climatologic study showed that the I-10 corridor is especially fog prone.

A report was generated called "*Probability of Fog Along the Interstates of the Southeast United States*" and is attached to this report as Appendix 3. As a result of this preliminary research, their report recommends that future efforts should focus on developing ways to infer the presence of dense fog at tower locations that do not have visibility sensors.

Although the FSU research towers were originally only intended to support the microwave signal fade research component of this project, the team proposed that, with the addition of a visibility sensor at one of these towers, that these facilities could also be used to conduct unique and valuable empirical research on fog prediction. It was also noted that this strategy could leverage the investment in the FSU research towers with only a minimal investment in the purchase and installation of a visibility sensor for one of the towers. Based on this logic, FDOT approved the substitution of the installation of a visibility sensor at the Quincy FHP tower in place of the original 'Objective 3' task that specified the design and evaluation of a 'traveler's kiosk' system.

Consequently, the FSU investigators worked with the NWS to make recommendations for the design requirements for a 'Fog Research Facility' including the selection of the visibility sensor and the data collection subsystem.
Additionally, to take advantage of the new visibility sensor capability of the facility, the FSU team developed and tested specialized analytical software to plot vertical profiles of temperature, humidity, and winds from the research towers so that the evolution of the boundary layer can be related to fog formation.

Unfortunately, as a result of lightning strikes to the Quincy tower, the data logging equipment supporting this system was destroyed and a suitable data set could not be collected that would enable this particular research objective to be realized.

Task 7.3) Investigate spatial analysis schemes for interpolating weather prediction data to highway segments.

STATUS: Completed.

Notes:

Drs. Elsner and Fuelberg held several meetings with other meteorologists to discuss the development and implementation of the Road Weather Prediction System (RWPS). Mr. Irv Watson, a cooperating investigator with the National Weather Service Forecast Office in Tallahassee was active in these discussions. The focus of the meetings was to understand the breadth and limitations of a new NWS product, called the National Digital Forecast Database (NDFD), for use in the RWPS. To further develop an understanding of the potential for incorporating the new NDFD products into the RWPS, Dr. Elsner attended a workshop sponsored by the National Weather Service on using the National Digital Forecast Database (NDFD) that was held in Washington DC in May 2003.

Based on these efforts, the FSU team developed a strategy for using both traditional FDOT surface observations and the new NWS NDFD products that is being evaluated as the basis for a RWPS (see Figure 23). The FSU meteorologists also worked with the UNF investigators to develop methods for incorporating this new approach into future versions of the RWIS website.

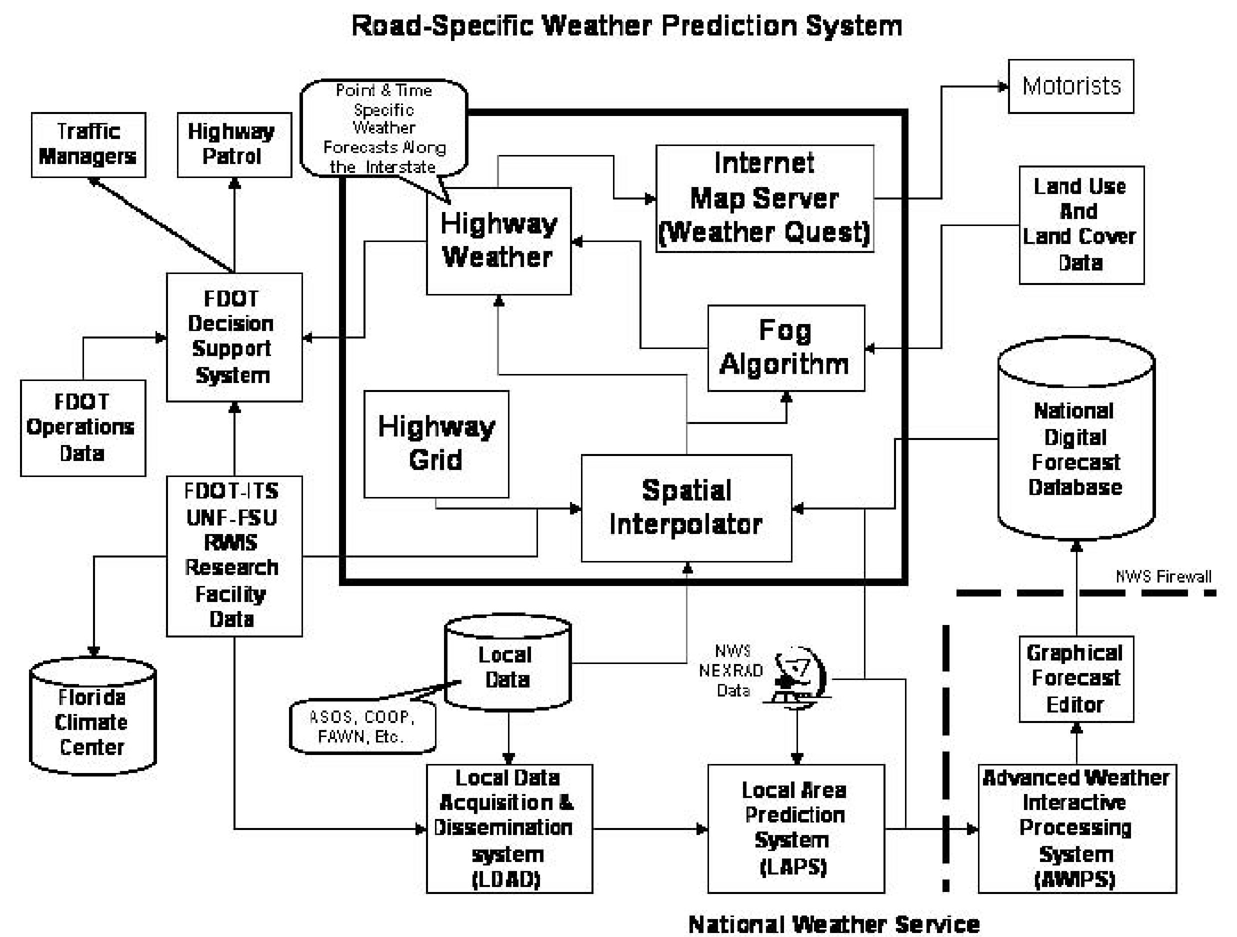

Figure 23: Preliminary design for a Road-specific weather prediction system.

Task 7.4) Seek matching funds for additional development of the RWPS from the National Science Foundation (NSF).

STATUS: Completed.

Notes:

Drs. Elsner and Fuelberg developed and submitted a proposal to the National Science Foundation (NSF). The proposal was not funded; however, valuable comments were received and based on this input, alternative funding sources are being explored.

2.8 Microwave Signal Research

Objective 8) Investigate the relationships between atmospheric effects (humidity, temperature, and pressure) and signal fades experienced by microwave paths (by Drs. Foo and Kwan).

Notes:

As stated previously, lightning strike damage to the specialized facilities developed to support this portion of the research project has severely hindered availability of the data needed to fully complete this task. The UNF team has made suggestions about how the facility could be better protected from lightning damage, however, the project budget has been exhausted at this point and further development of this portion of the project would require a substantial investment by FDOT. Further discussions about this topic will be required to determine the cost vs. the benefits of proceeding with an upgrade to this component of the research facility.

Task 8.1) Study the correlations between atmospheric effects and fades experienced by microwave paths.

STATUS: Completed within limitations caused by lightning damage to system.

Notes:

During Phase I of the RWIS project, three "FSU Research" towers (Quincy FHP, Tallahassee FHP, and Monticello DOT) were instrumented by UNF with meteorological sensors at five pre-determined intervals of height to support this research objective (see Figure 24). A custom Weather/RSL data collection subsystem was also designed and implemented by UNF that archived the weather and RSL data and provided access to these data sets from a secure website using FTP methods. *However, as stated earlier, due to the hardware problems caused by lightning damage at these particular towers, the FSU team was not able to collect enough Weather/RSL data to be able to fully complete this particular task to the level originally envisioned in the proposal.*

Despite the setback caused by the lightning damage to the data collection subsystem, the FSU investigators made significant findings related to this task. For example, based on the detailed study of propagation of radio waves in the troposphere, a Radio Wave Ray Tracing simulator has been developed to construct the different weather parameters' profiles and simulate the propagation of the radio waves from the transmitter to the receiver in different weather conditions. And, using the strip charts of the signal strengths between two DOT communication towers provided by RCC Consultants, computer simulations have been produced to measure the autocorrelation of the signal and the power spectral density. The effect of the weather on the signal has been studied using these simulations.

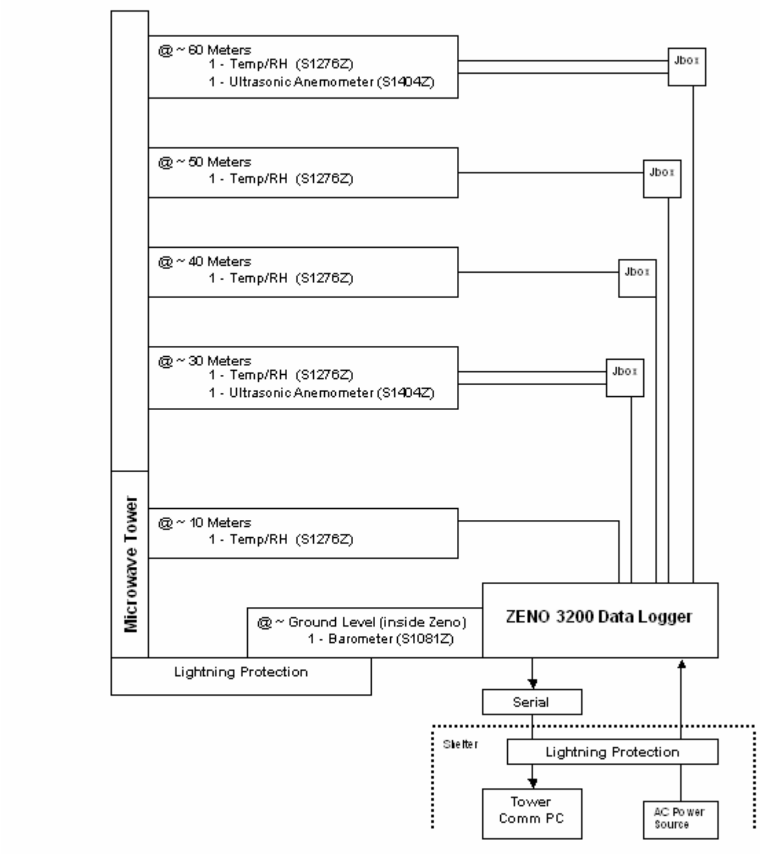

Figure 24: Configuration of Weather Sensors on FSU Research Towers.

Task 8.2) Characterize refractive layers and reflection points.

STATUS: Completed.

Notes:

Computer simulations to compare the refractive index calculated from empirical formulas and different mathematical models have been performed. Using the results of these simulations, the accuracy of different models and their use in the specific weather conditions has been established.

Task 8.3) Develop new microwave link design methodologies to design and maintain microwave paths.

STATUS: Completed.

Notes:

Two technical reports were generated during this reporting period and two presentations were given at a relevant conference (See Appendix 4). Based on this research, the FSU team of Drs. Foo and Kwan plan to develop new guidelines in Phase III to design and maintain microwave paths that can be adopted as national standards.

Publications related to Task 8 completed during Phase II.

1. Technical Report on "Propagation of Radio Waves in Troposphere" by Masood Ejaz.

2. Technical Report on "Modeling of Signal Loss due to the Gaseous Attenuation and Fading in the Atmosphere" by Gilnam Kim.

3. M. Ejaz, S. Foo, B. Kwan, and G. Kim, "*Comparison & Statistical Analysis of the Radio Refractive Index of Air through Empirical Formula and Mathematical Models*," Proceedings of the 7th World Multiconference on Systemics, Cybernetics, and Informatics, Orlando, FL, July 2003

4. G. Kim, B. Kwan, S. Foo, and M. Ejaz, "*Simulation of Received Signal Distribution of Line of Sight Communication in Fixed Wireless Environment*," Proceedings of the 7th World Multiconference on Systemics, Cybernetics, and Informatics, Orlando, FL, July 2003

3.0 Conclusions and Recommendations

The RWIS research project was originally envisioned as a 3 phase project, with the third phase focusing on developing operational procedures and protocols as a result of a Traffic Management Center Pilot Project and a series of stakeholder workshops. Consequently, Phase II of this project has been focused on evaluating infrastructure design-related issues that would eventually be incorporated into the final recommendations for statewide implementation to be developed during Phase III of the research project.

Despite the delays experienced because of several unanticipated design and installation challenges noted earlier, and equipment failures caused by lightning strikes, it is important to emphasize that the RWIS research team is excited about its accomplishments during Phase I and II of the research program. The most significant accomplishment of Phase II is certainly the completion of the operational RWIS research facility. Through this process, the researchers, FDOT staff, and the ITS contractors involved have all learned a great deal about the specific technical challenges associated with the design and installation of an RWIS. In particular, it is now clear that the MAS tower network provides reliable communications and power infrastructure, and, with adequate lightning protection, a suitable site for the installation of the weather sensors.

Another important accomplishment was the establishment of an interdisciplinary, multi-university, multi-agency, private/public team to work on the development of an innovative and successful RWIS for the State of Florida.

The "iFlorida" Demonstration Project

It should be noted that, as a result of Phase I and II budget limitations, the hardware components installed for the prototype research facility represent some compromises that had to be made as a result of this constraint. For instance, UNF was forced (by these budget constraints) to deploy some used and refurbished network hardware, and to select a weather sensor configuration that, while being fully sufficient for our research purposes, is **not the data acquisition, networking, and weather sensor configuration that we would recommend for a permanent, fully operational system.**

However, during the implementation of Phase II of the RWIS Research Project, the UNF research team began designing (beginning in January 2004) the RWIS component of the Federal Highway Administration (FHWA) sponsored project called "Surface Transportation Security and Reliability Information System Model Deployment" (FHWA Contract DTFH61-02-X-0089) . The objective of the model deployment, commonly called **"iFlorida"**, is to demonstrate the wide variety of operational functions that are enabled or enhanced by a surface transportation security and reliability information system (see www.iflorida.net).

This important demonstration project, being implemented in FDOT Districts 5 and 2, has benefited greatly from the "lessons learned" thus far in the RWIS research project. These RWIS design, operational, and maintenance "lessons learned" in the research project have been directly applied to the design of the operational "iFlorida" RWIS. The locations of these new, operational RWIS sites are shown in Figure 25.

Figure 26 shows the general design and the sensors utilized for the iFlorida MAS tower-based weather stations. Complete design documentation for the iFlorida RWIS is available in the final report for that project. During the next two years, UNF will evaluate the iFlorida sensor installations and make recommendations to FDOT based on operational experience.

As part of the iFlorida project, the UNF team installed three weather stations on CCTV camera poles to evaluate these sites as an alternative to the MAS tower installations. Figure 27 shows the design utilized for the camera pole installations. The intention was to evaluate the practicality of utilizing the fiber-optic communications system (where available) instead of the microwave system for the RWIS communications subsystem. The UNF team is currently evaluating this alternative as a component of the iFlorida project.

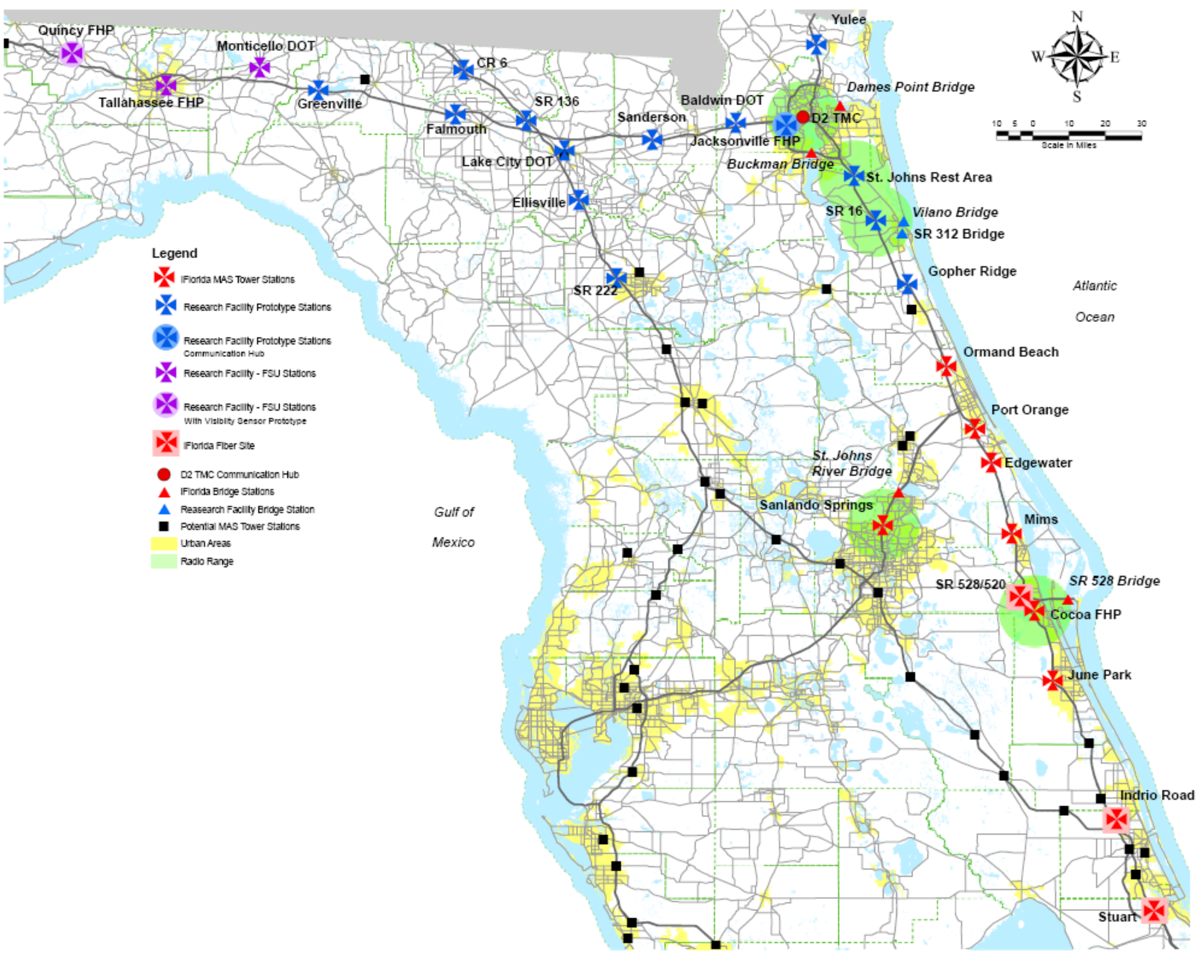

Figure 25: Location of both the RWIS Research Facility weather station sites
and the iFlorida Demonstration Project weather station sites.

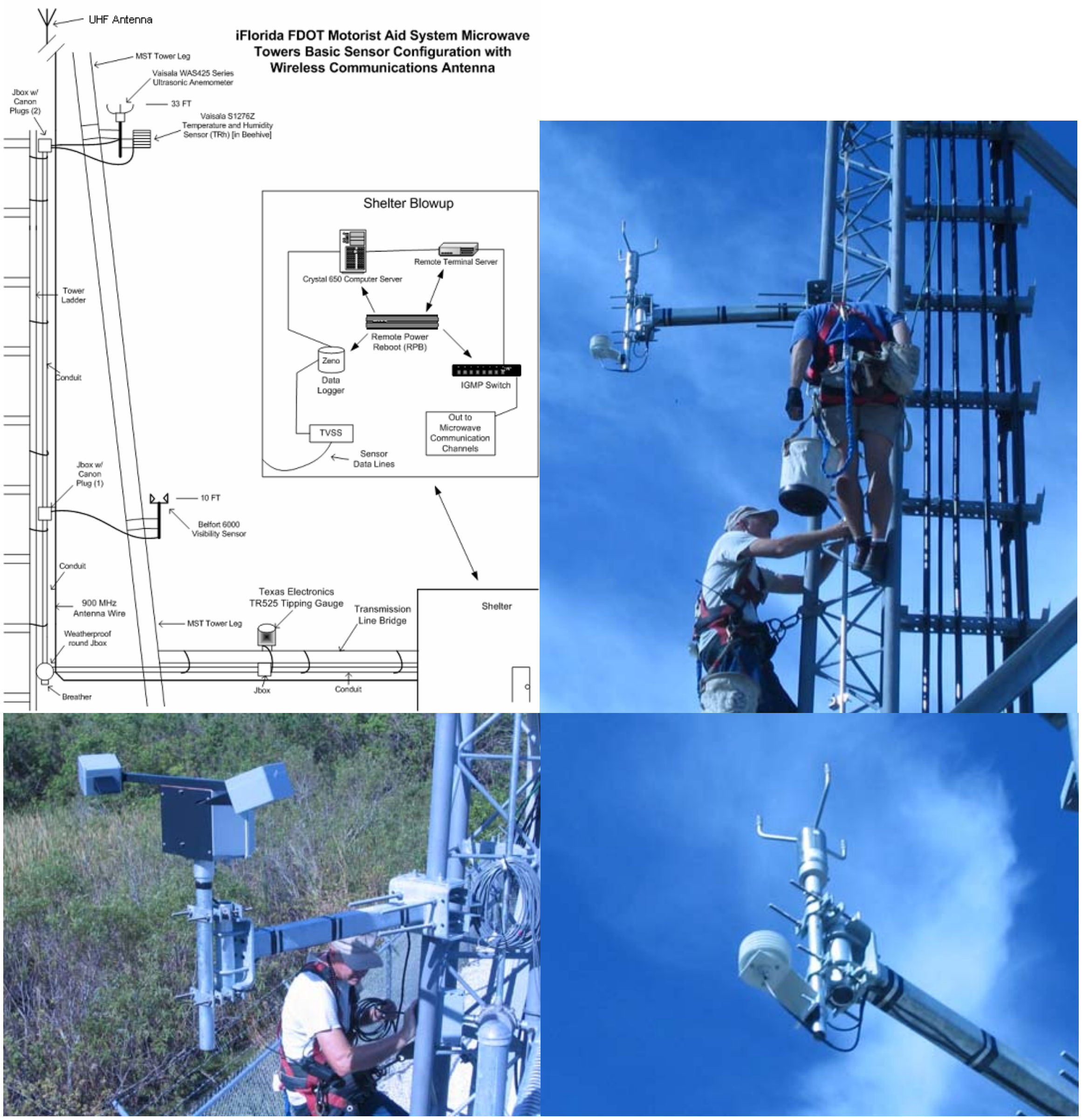

Figure 26: Generalized design diagram (upper left) and pictures of weather sensors installed at iFlorida RWIS Demonstration Project sites.

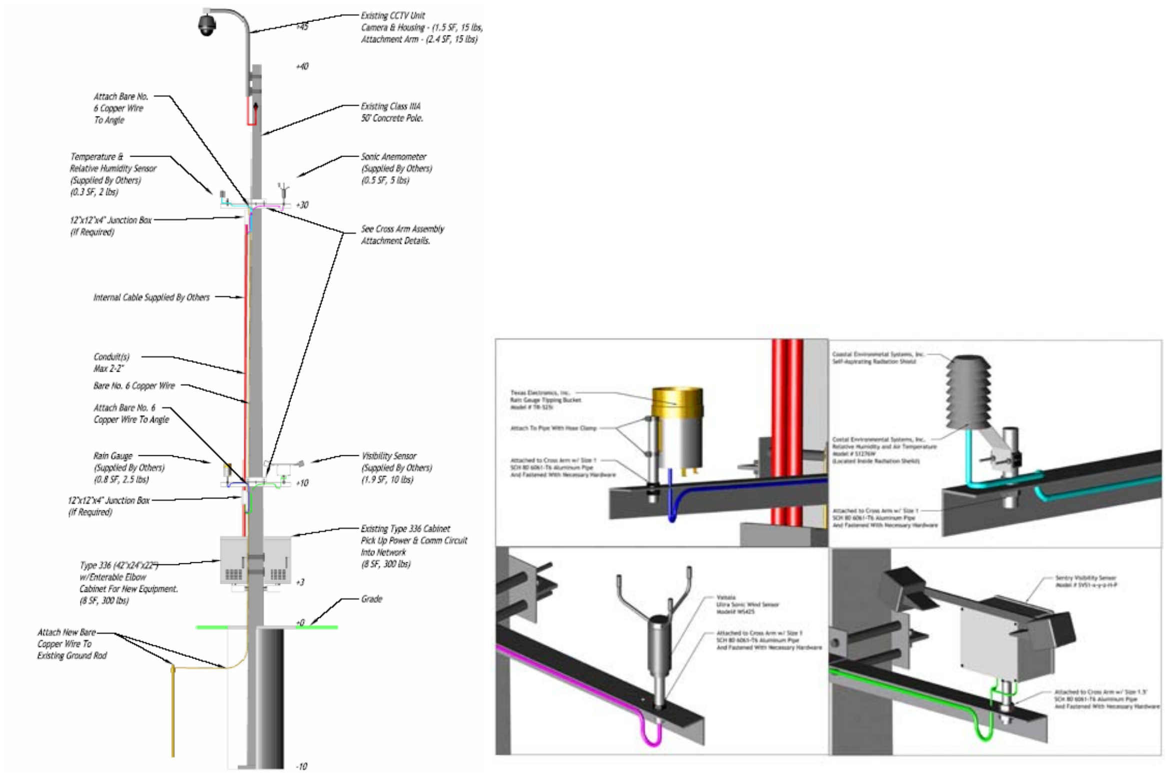

Figure 27: Design for utilizing the District 5 fiber-optic camera sites as an alternative to locating the RWIS weather stations at the MAS towers.

<u>The Florida Weather Mesonet Initiative</u>

A challenge associated with generating accurate road-segment-specific weather forecasts is presented by the relatively coarse spacing of current existing weather stations in Florida. It became evident early in the design process that the proposed state-wide deployment of a RWIS could significantly increase the number of weather station sites available to both public (NWS) and private weather forecasters which could significantly contribute to the development of higher spatial resolution forecast models (called ‘Mesoscale’ forecasting) for Florida.

By contributing much needed real-time, relatively high spatial resolution weather data to the NWS mesoscale models, the RWIS could benefit in turn by receiving more accurate, higher spatial resolution forecasts and advisories. This is especially important when forecasting the road segment locations of hazardous weather phenomena. Essentially, the concept is that the RWIS contributes data to the NWS forecast models which lead to better quality NWS forecast products that are subsequently incorporated into the more reliable RWIS—a mutually beneficial partnership.

A fully implemented Florida FIHS RWIS, based on the concept of having a weather station at every MAS tower, would contribute significantly to the establishment of a “Florida Weather Mesonet”. The University of North Florida Advanced Weather Information Systems Lab

(AWISLab) is leading a multi-agency initiative, with funding from NOAA, to develop a plan for the development of the Florida Weather Mesonet. Much like the Clarus Initiative, described below, the Florida Mesonet is a mechanism to collect and disseminate locally accurate meteorological data for the benefit of the state and its citizens.

The Mesonet is a "network of networks of weather stations" supported by participating institutions and agencies. The FDOT, as a cooperating agency, already shares its basic weather data with others as a result of transmission of the RWIS data to the FSL-MADIS. A major goal is to develop a "one-stop-shop" website that will have metadata for all identified Mesonet sites and that classifies these sites as to the level and quality of the weather data that the sites provide. The primary strategy to further develop the Mesonet involves an effort to enlist all of the various local, state, and federal agencies that have existing weather stations in the data-sharing effort. The goal is to have a reliable weather station spaced no less than every 20 miles across the state. Participation in the Mesonet Initiative only requires each cooperating agency to transmit their weather data to the FSL-MADIS. The Florida Mesonet Initiative is being coordinated with the National Weather Service (NWS) efforts to establish a comprehensive National Mesonet.

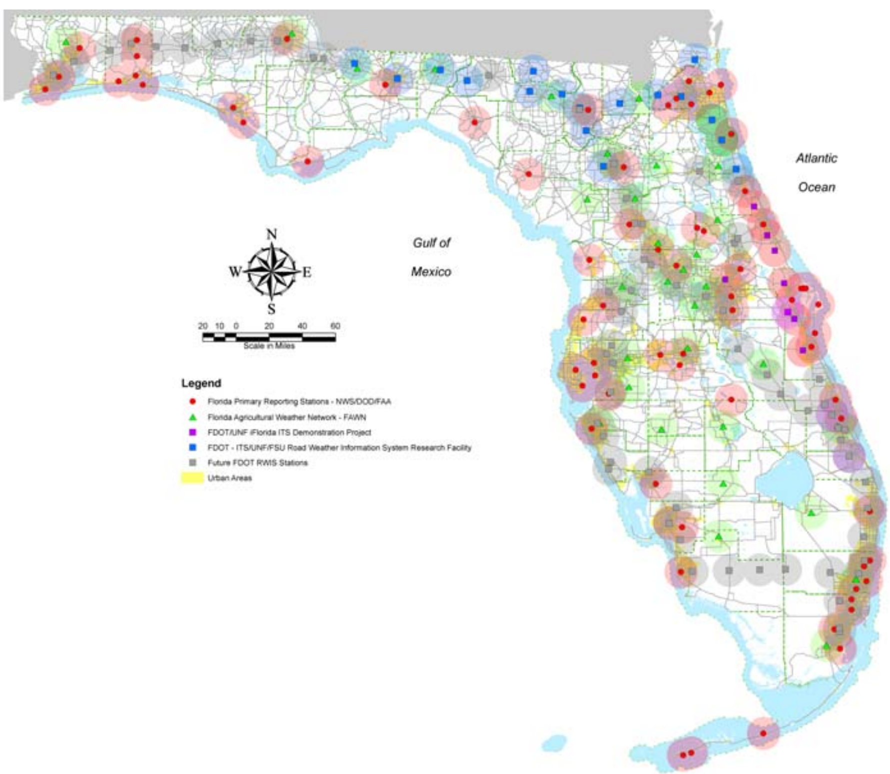

Figure 28: Current cooperating weather stations included in the Florida Mesonet Initiative. The map shows how the current and future MAS-tower-based RWIS weather stations could make a significant contribution to the system, especially by providing reliable (i.e., power and communications) stations in rural locations.

The "Clarus Initiative"

In support of this research project, UNF researchers have participated in developing the high-level design requirements for a national RWIS coordination effort, called the "Clarus Initiative", which is being sponsored by the Federal Highway Administration (FHWA). The Florida RWIS Research Team fully supports this initiative and recommends that an FDOT representative become involved in the planning process to ensure that, in the future, the Florida RWIS becomes a fully integrated component of the national system.

The Clarus Initiative is described below in an excerpt from the recently published report "*Clarus Weather System Design – High Level System Requirements Specification" (prepared by* Mixon/Hill, Inc. under FHWA Contract No. DTFH61-05-C-00022, July 2005).

> *"The Clarus project is essentially a plan to create a "network of networks" —much like the Internet — for surface transportation environmental data. While the Internet is an interconnection of computer networks, Clarus will be an interconnection of environmental (weather, pavement, and water level condition) data collection networks. Each of the weather networks will function autonomously; they will collect information and disseminate it internally without direction or dependence on Clarus. Each participating weather network's connection to Clarus will add two new possible modes of functionality. First, the participant will be able to share collected environmental data with Clarus. Second, participants will be able to receive environmental data collected by Clarus. The primary recipients of this data will be weather service providers, but any Clarus participants would be able to receive data if they so chose. This concept of autonomous data sharing is comparable to the World Wide Web layer of the Internet, where organizations can publish information on web pages, or browse and download information published by other organizations on the web. Ownership of the data is retained by the organization that provided the data to Clarus, and the provider organization can restrict the dissemination of the data through data sharing agreements with the Clarus program. The Clarus system will add a third mode of functionality, which might be called "meta-librarian." The Clarus system will collect, organize, and qualify the environmental data to be published by the system. The data will be collected from the participants, organized by location and type of data, and quality flags will be added. When this is done, the data will be published to the Service Providers and other participant/consumers in Clarus. The intent of the Clarus Initiative is to demonstrate how an open and integrated approach to observational data management can be used to collect, control the quality of, and consolidate surface transportation environmental data. The Clarus Initiative will address the necessary infrastructure to consolidate the data from a multitude of independent data collection systems. This process offers the prospect of enhancing data coverage, improving the performance of meteorological support services, and providing guidance to owners of these data sources regarding the quality of their data and performance of their data collection systems. Clarus represents the next step in bringing together surface transportation best practices and the greater weather community."*

Many of the basic concepts proposed previously by the Florida RWIS Research Team are reflected in the Clarus initiative objectives and design approach. In particular, the Clarus initiative supports the concept of a system where observation data that is collected by RWIS stations is transmitted to a central location and then freely shared with everyone in a non-proprietary format. Currently, the Florida RWIS implements this concept by transmitting data to the FSL-MADIS system (described previously). The research team recommends that, when the Clarus system is implemented, the Florida RWIS should transmit data to *both* the Clarus database and FSL-MADIS.

As noted earlier, RWIS weather data can be an important enhancement to the existing weather data sources that support general purpose weather forecasting—in other words, more weather stations means the potential of better weather forecasting. The Florida RWIS is an important contributor to the Florida Mesonet Initiative, and, by default to the national Mesonet. The national Mesonet will in turn further the realization of the Clarus Initiative's goals and objectives. In other words, for FDOT to realize the full potential of a RWIS, the agency should adopt a policy of cooperation with, and support of these two important initiatives.

Some MAS Tower Locations Are Not Suitable for Tower-Mounted Weather Stations

A few MAS towers in the system are really not suited to having weather sensors directly mounted on the tower because of the proximity of planted or natural trees (see Figure 29). *"Ideally"*, a tower should have a grassed area of about 1 acre surrounding the tower (e.g., approximately 100 feet radius of cleared area around the tower). Most of the "unsuitable" locations are found along Interstate 10 in North Florida. This situation does not necessarily preclude the utilization of the reliable power and communications systems provided by the MAS tower system.

Figure 29: Photo on left illustrates how some MAS tower locations do not provide a desirable location for a weather station because of surrounding trees. Photo on right illustrates a more ideal location for a weather station.

In every case known to be unsuitable for direct tower-mounting of the sensors, there is a suitable area for installation of a remote 30-foot tower-mounted weather station within a distance that would allow, in many cases, for power and communications lines to be installed through an underground conduit. In the cases where "hard-wired" connections to tower-based power and communications is not possible, a remote, station could be installed with a solar power system and communications with the tower-based network could be easily accomplished using radios mounted on both the MAS tower and the remote weather station tower. It has been estimated that a typical remote station will add about $5000 to the cost for installation at these sites.

Need for Between and Near-Tower Weather Sensors

A major feature of the team's system design concept includes the capability for adding wireless weather sensors *between or near* the 20-mile spaced primary weather stations. These secondary stations are not equipped with a complete weather sensor array; rather they may just include a wind or visibility sensor. This system design feature anticipates the need for specialized stations at fixed locations to address site specific potential hazards such as high wind on high evacuation bridges or locations that are prone to fog. This feature could also support the deployment of portable units to support wildfire or hazardous material spill response operations that occur between or near the tower locations.

The research facility and installations associated with the iFlorida project provide FDOT with a chance to evaluate the relative benefit of this element of the RWIS design concept, and, in an operational context, to develop policies and procedures for utilizing the wind speed data provided by the prototype system in cooperation with other stakeholders such as law enforcement and emergency management agencies.

This concept also highlights a "value-added" aspect of maintaining the MAS tower network into the future--the potential value of having 200 foot towers that provide a base for antennas supporting wireless communications with various ITS devices located within radio range of the towers. For instance, a preliminary evaluation of the locations of high evacuation bridges in the state has shown that by installing an antenna on adjacent MAS towers that wireless communication with wind sensors mounted on these high evacuation bridges could easily be accomplished. This would provide a single, standard solution for the entire state rather than many district or local custom solutions that may, or may not, provide this valuable data to everyone needing the information during an evacuation event.

As a result of interviews conducted after the 2004 hurricane season with traffic managers, law enforcement, and emergency managers, it has become evident that there is a widely held perception that there is a **high priority** need for wind sensor stations located on high coastal evacuation bridges. Managers have expressed the need for reliable information about wind speeds at bridges in order to know when to close the bridges to high profile vehicle traffic during a hurricane evacuation. The "fog propensity" study conducted as part of this research project illustrates a potential need for between-tower visibility sensors in fog-prone highway segments along I-10 in North Florida.

Cooperation with other Agencies

It is important to point out that the research team has received enthusiastic cooperation, comments, and recommendations from other State and Federal agencies and private industry (e.g., Florida Highway Patrol (FHP), Florida Division of Emergency Management (FDEM), National Weather Service NWS), several manufacturers of relevant equipment, etc.). These "adjunct research team members" are representative of the stakeholders in the future system, and have played an important role as advisors on the design and operation of the system. In particular, the Science and Operations Officers at the Florida NWS Forecast Offices in Jacksonville, Tallahassee, and Melbourne have been playing a major role as advisors and cooperators. It is recommended that FDOT continue to closely coordinate with FHP, FDEM, and NWS in the further development of the Florida RWIS.

Maintenance

As a result of experience with the operation of the research facility, the team has been able to identify a few important long-term maintenance issues that should be considered when planning for statewide implementation. First, the prototype system has had some maintenance problems associated with some of the budget-related compromises. Consequently, the team has learned that it is not economical in the long run to cut corners on the quality of the weather sensors installed because these components are relatively more difficult to maintain since they require a certified tower climber be employed for replacement or maintenance activities.

Second, the research team now has a deep appreciation for the need for robust lightning protection—several of the equipment failures experienced thus far have been associated with lightning strikes which, despite the design team's best efforts at providing protection, found weak spots in the design. Future design recommendations for lightning protection will certainly incorporate these lessons learned by both the researchers and the FDOT contractors.

The research team recommends that, in a statewide implementation, maintenance of the tower-mounted and bridge stations could be accomplished by contracting two groups of specially-trained technicians. Field maintenance of the RWIS sensors and tower-based data acquisition and communications hardware could become an additional task added to the on-going maintenance contract for the microwave towers. In addition to the field-based maintenance requirements, there will also be a need for technical contractors that have special skills related to maintaining the operational system software and web servers. Specialized training could be provided by UNF for both the field maintenance and system software technicians.

In the short term, UNF has developed a proposal to maintain the existing RWIS for the next two years to enable continuing evaluation and further development of recommendations for eventual statewide implementation.

Future Research Needs

There is a continuing need for RWIS-related research in Florida. For instance, a fully implemented version of the RWIS *could* also include information kiosks at rest areas and other appropriate locations, integration with the 511 system, and, using the FDOT dynamic messaging system, road weather advisories could be posted for in-transit travelers.

The UNF AWISLab will be continuing the development of a system for estimating current rainfall rates on specific highway segments using Doppler radar. The preliminary study, conducted as an element of Phase II, is described in Appendix 2. Future research in this area will include the extension of the model to include parameters such as pavement and road design in order to predict relative risk to motorists in real-time.

References

The Florida RWIS research team recommends the following documents to FDOT for guidance in the future development of the Florida RWIS.

Clarus – The Nationwide Surface Transportation Weather Observing and Forecast System; Pisano, Pol, Stern, and Goodwin; TRB 2005.

Clarus Initiative Coordinating Committee (ICC) Management Plan(Revision 1); James Pol, U.S. DOT; September 2004.

Clarus Weather System Design – High Level System Requirements Specification; Mixon/Hill, Inc. (FHWA Contract No. DTFH61-05-C-00022); July 2005.

Weather Information in the National ITS Architecture Version 5.0; Meridian Environmental Technology, Inc.; August 2004.

Weather Information for Surface Transportation: National Needs Assessment Report; Office of the Federal Coordinator for Meteorology; FCM-R18-2002; December 2002.

Weather and Environmental Content on 511 Services; 511 Deployment Coalition; June 2003.

NTCIP 1204:1998 NTCIP Object Definitions for Environmental Sensor Stations; National Electrical Manufacturers' Association, American Association of State Highway and Transportation Officials, and Institute of Transportation Engineers; 1998.

Where the Weather Meets the Road: A Research Agenda for Improving Road Weather; The National Academies; BASC-U-02-06-A; 2004.

Draft Report: Joint TMC/TOC System Integration Study for Emergency Transportation Operations and Weather: Baseline Conditions; Battelle; 2004.

Road Weather Information System Environmental Sensor Station Siting Guidelines; FHWA, Pub. #FHWA-HOP-05-026; April 2005. (http://www.ops.fhwa.dot.gov/publications/ess05/index.htm)

Appendix 1

Technical Statement of Work
for Near/Between Tower Demonstration Project

CONTRACT BD-537

DEVELOPMENT OF A ROAD WEATHER INFORMATION SYSTEM (RWIS)

FOR

FLORIDA'S INTELLIGENT TRANSPORTATION SYSTEM - PHASE II

FLORIDA DEPARTMENT OF TRANSPORTATION

SCOPE OF SERVICES

FOR

BETWEEN/NEAR TOWER RWIS COMMUNICATIONS INFRASTRUCTURE

INSTALLATION REQUIREMENTS

February 13, 2004

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Tallahassee, Florida 32303
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\\TLITSSERVER\PERSONNEL\KN962WA\PROJECTS\RWIS\PHASE2\BETWEEN-NEARTOWER\BETWEEN-NEARTOWERRWISINSTALLATIONSOS20040213.DOC

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1. GENERAL

This Statement of Work provides technical specifications for the installation of antenna systems at two of the Florida Department of Transportation (FDOT) Motorist Aid System (MAS) communications sites, and an optional third site. The work specified herein consists of installation tasks that are required by the University of North Florida (UNF), hereafter known as the Contractor, to implement a between/near tower Road Weather Information System (RWIS). This work is delineated in the Development of a Road Weather Information System for Florida's Intelligent Transportation System - Phase II contract. See Contract #BD-537. The project's weather information will be carried over the FDOT digital microwave system via the RWIS network system that was installed in Phase I of the RWIS contract. The intent of this project is to provide a wireless infrastructure that will communicate with field deployed weather sensors to provide an 'in-transit severe weather messaging/warning system' for travelers, transportation managers, law enforcement, and emergency managers.

The installation of the antenna systems, and all associated hardware, on the towers must be neat, secure, and free of sharp bends. The installation must also be in accordance with good engineering practice.

The installation work shall be of high quality and of the type and quantity prescribed by this specification. In all cases, the routing of the wiring and its dressing shall be neat, secure, and free of sharp bends. All cables and wiring shall be cut to appropriate lengths without being too taut or too slack. The Contractor is responsible for the removal of any surplus materials and all other debris from the site at the conclusion of the work activities.

The Contractor shall provide all materials necessary to complete the installation including, but not limited to, new antennas, mounting brackets, transmission lines, connectors, transmission line holders, ground kits, lightning surge protection equipment, and all associated hardware. All equipment installations shall be performed in a professional manner utilizing the appropriate hardware and applying good engineering principles.

2. TERMS

Department:	The Purchaser (or Owner) State of Florida Florida Department of Transportation (FDOT) Contact Person is the FDOT Project Manager (see below) in Tallahassee, Florida
Contractor:	University of North Florida Division of Engineering 4567 St. Johns Bluff Rd., South Jacksonville, FL 32224-2645 Contact: J. David Lambert, Ph.D. Telephone: (904) 620-3881
FDOT Project Manager:	J. Nick Adams, C.P.M., ITS Office, 605 Suwannee Street, MS 90 Tallahassee, Florida 32399-0450 V: (850) 410-5608. F: (850) 410-5501 nick.adams@dot.state.fl.us
Project Consultant:	Russell Allen RCC Consultants, Inc., ITS Office, 605 Suwannee Street, MS 90 Tallahassee, Florida 32399-0450 V: (850) 410-5626 F: (850) 410-5501 russell.allen@dot.state.fl.us

3. APPLICABLE PUBLICATIONS AND STANDARDS

The latest issues of the following publications and standards, unless otherwise specified, shall be part of this installation Statement of Work. In the event of inconsistencies between this Statement of Work and these publications and standards, the requirements of this specification shall take precedence.

A. ASCE-7: South Florida Building Code (Applicable in some Florida counties).

B. ASTM A123: Standard Specification for: Zinc (Hot Galvanized) coatings on products fabricated from rolled, pressed, and forged steel shapes, plates, bars, and strip.

C. ASTM A153: Standard Specification for: Zinc coating (hot-dip) on iron or steel hardware.

D. National Electric Code (NEC) (NFPA 70).

E. Applicable Manufacturer's Instructions and Standard Practices.

F. Applicable Occupational Safety and Health Administration

4. CONTRACTOR'S RESPONSIBILITIES AND QUALIFICATIONS

The Contractor is required to carefully examine the specifications contained herein and inform themselves thoroughly regarding any and all site conditions and requirements that may, in any manner, affect the work to be performed under this Statement of Work.

The Contractor is solely responsible for all equipment, materials, and services delineated in this Statement of Work. Notwithstanding the details presented in this Statement of Work, the Contractor is responsible for verifying the completeness of the materials required and suitability of devices to meet these specifications. The Contractor shall provide and install, without claim, any additional equipment required for operation in accordance with this Statement of Work.

The Contractor shall possess the qualifications, skills, and experience necessary to accomplish the work required by this Statement of Work. The Contractor shall possess experience and competency in the proper installation of lightning protection systems. These requirements are in addition to the normal contractor licensing requirements of the State of Florida.

5. SITES OF WORK

The installation materials shall be delivered and installed as outlined in these specifications at the following FDOT communications sites:

1. St. Johns Rest Area
   SW Corner of Southbound Rest Area on I-95
   Durbin, FL
   Lat: 30-05-34.0N Lon: 81-30-00.0W NAD83

2. SR16
   SW Quadrant of SR16 & I-95 Intersection (Old Exit 95 / New Exit 318)
   St. Augustine, FL
   Lat: 29-55-01.0N Lon: 81-24-45.0W NAD83

3. Gopher Ridge (OPTIONAL)
   SE Quadrant of US1/SR5 & I-95 Intersection (Old Exit 92 / New Exit 298)
   Marineville, FL
   Lat: 29-39-45.0N Lon: 81-17-12.0W NAD83

6. INSTALLATION, GROUNDING, AND GENERAL FACILITY REQUIREMENTS

6.1 Installation

6.1.1 General

This section establishes the minimum installation requirements for the towers, antenna systems, and communications equipment as specified by this Statement of Work, to be located at the aforementioned MAS communications sites.

The Contractor shall provide all communications equipment, and associated installation hardware for the between/near tower RWIS communications systems.

The Contractor shall be responsible for furnishing all of the necessary equipment, hardware, labor, and procedures to securely attach these antenna systems.

IN ADDITION, THE APPENDICES MAY CONTAIN SPECIFICATIONS THAT ADD TO OR DIFFER FROM THE MAIN DOCUMENT. THE SPECIFICATIONS OF THE APPENDICES SHALL TAKE PRECEDENCE OVER THE MAIN DOCUMENT.

The equipment installations required by these specifications include, but are not limited to, all of the described equipment and materials, services, and associated ancillary hardware. All installations shall be accomplished in accordance with good engineering practice. The end result shall be a completely integrated and operating 900 MHz between/near tower component of the road weather information system.

The Contractor shall install the equipment and wiring in accordance with this Statement of Work.

The Contractor is required to adhere to FCC Rules, NEC, all local codes, and building regulations. Additionally, the Contractor must perform all work in a manner consistent with good engineering practice. The Contractor is required to coordinate with the FDOT ITS Office and the microwave maintenance contractor prior to the commencement of any installation work at any FDOT microwave communications site.

The Contractor shall be responsible for determining local facilities for delivering, storing, and legally disposing of post-installation materials. The Contractor is also responsible for location and protection of any existing underground utilities at the work site. **Any damage to any existing installation shall be repaired by the Contractor at no additional cost to the Department.**

6.1.2 Antenna Systems

The 900 MHz omni-directional antennas furnished by the Contractor shall be Radio Frequency Systems Model AO9009-3, or approved equivalents. The antennas shall be attached to the towers through the use of 3-foot side arm mounting brackets. The Contractor shall submit to the Department a side arm design for pre-approval. If the side arm is prefabricated, then all specifications sheets shall be submitted to the Department for pre-approval.

All antennas shall use manufacturer recommended/approved mounting hardware and be verified to be plumb. Antennas shall not follow the slope of the tower.

6.1.3 Transmission Lines

All transmission lines shall be installed in one continuous piece. Splicing of transmission lines is not permitted. Transmission lines shall be 5/8" diameter Times Microwave LMR-900, or approved equivalent. The Contractor shall follow manufacturer's specifications for minimum bend radius when installing the transmission lines. The transmission lines shall be installed in accordance with the appendices.

All transmission lines shall be labeled with color-coded tape, and a brief description of the antenna type and location (e.g., "AO9009-3 at 180 ft"). The color-coded tape shall be wrapped around all transmission lines in three locations: inside the transmission line entrance panel, outside the transmission line entrance panel, and at the top where the antennas are connected.

6.1.3.1 Transmission Line Support

6.1.3.1.1 Vertical Transmission Line Support

Vertical transmission lines shall be supported in accordance with the transmission line manufacturer's instructions for basic wind speed; however, the transmission lines shall not be supported at intervals greater than 36 inches on center. The transmission lines shall be secured to the tower members or transmission line ladder with stainless steel hanger kits. The transmission lines shall not be tied directly to tower members with plastic, wire, or stainless steel ties.

6.1.3.1.2 Horizontal Transmission Line Support

Horizontal transmission lines shall be supported by the cable bridge between the tower and the equipment building. The transmission lines shall be supported per the manufacturer's instructions; however, the transmission lines shall not be supported at intervals greater than 36 inches on center

6.1.3.2 Transmission Line Hangers

Transmission line hangers shall be Wireless Solutions Model BH-58 stainless steel hangers, or approved equivalent.

6.1.3.3 Lightning Protection

The transmission lines shall be provided with ground kits and lightning protectors suitable for bulkhead mounting. Surge protectors shall be Atlantic Scientific Model 51034B, or approved equivalent. Ground kits shall be Times Microwave Model GK-S900T, or approved equivalent. See Section 6.2 for installation details.

6.1.4 Entry Port Installation

All transmission lines shall enter the shelter through entry ports, in accordance with the site-specific requirements, as shown in the appendices. All entry ports shall be sealed with entry port boot assemblies and roof entry boot sealer, in accordance with the site-specific requirements, as shown in the appendices.

6.1.5 Communications Equipment

The Contractor provided 900 MHz transceivers shall be Freewave Model DGR09TFS, or approved equivalents. The Contractor shall be responsible for verifying proper installation of the transceivers.

All communications equipment, and associated hardware, shall be installed in the existing equipment racks as specified in the appendices. All equipment and data and power cabling must be secured to the equipment racks. All cabling shall be directed to the existing RWIS data network equipment, and shall be positioned such that no empty rack units that may be used in the future are blocked. Positioning of the equipment is shown in the appendices.

6.1.6 Corrosion Protection

All hardware and other attachments shall be galvanized per ASTM A153.

6.2 Grounding and Surge Suppression

6.2.1 General

The purpose for installing a grounding system is to provide personnel and equipment lightning protection, and to minimize the induced noise and static in the system. The following specifications must be used in conjunction with the National Electrical Code (NFPA-70) and all local grounding-related building codes.

Lightning damage to equipment and structures and its prevention is a major consideration in the design of communication facilities in Florida. The Contractor must construct all communication facilities in accordance with the design requirements delineated herein to ensure that adequate lightning protection is constructed at each site. ANY VARIANCE FROM THE DEPARTMENT DESIGN SHALL BE SUBMITTED IN WRITING AND MUST BE PRE-APPROVED IN WRITING BY THE PROJECT MANAGER OR IT WILL NOT BE ACCEPTED.

Installation practices for Department sites must meet the requirements herein to ensure compliance with Department construction practices.

ANY VARIANCE FROM THE DEPARTMENT'S PRACTICES SHALL BE SUBMITTED IN WRITING AND MUST BE PRE-APPROVED IN WRITING BY THE PROJECT MANAGER OR IT WILL NOT BE ACCEPTED.

Grounding and surge suppression are designed as a complimenting system. NO VARIANCE FROM THE DEPARTMENT DESIGN OR MATERIALS WILL BE ACCEPTED UNLESS DESIGN DRAWINGS AND CALCULATIONS HAVE BEEN SUBMITTED TO AND APPROVED IN WRITING BY THE PROJECT MANAGER.

All grounds for the transmission lines shall be installed on the side of the shelter that the transmission lines enter.

The Contractor shall install grounding for the surge protection devices per the manufacturer's instructions and connect to the existing grounding system with no less than the minimum wire size specified herein, or the manufacturer's recommended wire size, whichever is larger.

Lead lengths from each TVSS device, between the circuit to be protected and to ground, shall be minimized in accordance with the installation specifications for all devices. TVSS power device lead lengths shall not exceed ten inches. ANY VARIANCE FROM THE DEPARTMENT'S PRACTICES SHALL BE SUBMITTED IN WRITING AND MUST BE PRE-APPROVED IN WRITING BY THE PROJECT MANAGER OR IT WILL NOT BE ACCEPTED.

6.2.2 Connections

The Contractor shall use lugs or clamps, appropriate to the size and the type of wire and provisions/requirements of the equipment being grounded, to connect the ground conductors to the equipment. To ensure good electrical connections, the Contractor shall crimp and then solder the wires connected to the lugs or clamps.

The Contractor shall remove all non-conducting surface coatings before each connection is made. The Contractor shall apply an anti-oxidant compound ("No-OX", or approved equivalent) to all connections. The Contractor shall install star or lock washers, or some other means appropriate to the fastener used, to ensure a continued good electrical connection. The objective is to provide a good, low maintenance electrical and mechanical connection that will not deteriorate.

6.2.3 Conductor Bending

Ground conductors (wires) shall be downward coursing and vertical, as much as possible, and be as short and straight as practical. Sharp bends and multiple bends in conductors shall be avoided in all cases. Any deviation must be submitted in writing and pre-approved in writing by the Project Manager.

6.2.4 Transmission Line Grounding and Lightning Protection

Each transmission line shall be routed into the equipment building through the transmission line entrance panel, and into a surge protection device for each line. The surge protectors must be grounded to the communications shelter's interior perimeter ground halo. The transmission lines shall also be grounded on the exterior of the transmission line entrance panel. See Figure 6.2.4-1 (Typical Entrance Panel Grounding Detail - Side View).

In addition to grounding at the entrance point, all transmission lines shall be grounded and bonded, at a minimum, at both the top and bottom of the tower using the appropriate grounding kits as specified in this Statement of Work. The cut in the plastic jacket of the transmission lines made for grounding shall be carefully wrapped with rubber installing tape. The rubber tape shall then be covered with "Scotch" brand #88 all weather vinyl electrical tape or approved equivalent, per Andrew Corporation's instructions. Use of other grades of "Scotch" tape or their equivalents is not acceptable. The entire spliced area shall then be painted with "Scotchkote" brand electrical coating. Alternatively, Decibel Products, Inc. "Vapor Wrap" may be used to weatherproof the cuts in the plastic jackets of the transmission lines.

At the top of the tower, a mechanical connection between the transmission line ground and the tower is acceptable. The grounding strap may be attached to a tower member by bolting or clamping. Each ground strap shall be separately attached.

At the bottom of the tower, the grounding kit(s) shall be attached to the bus bar using both double-lug connections and lock washers.

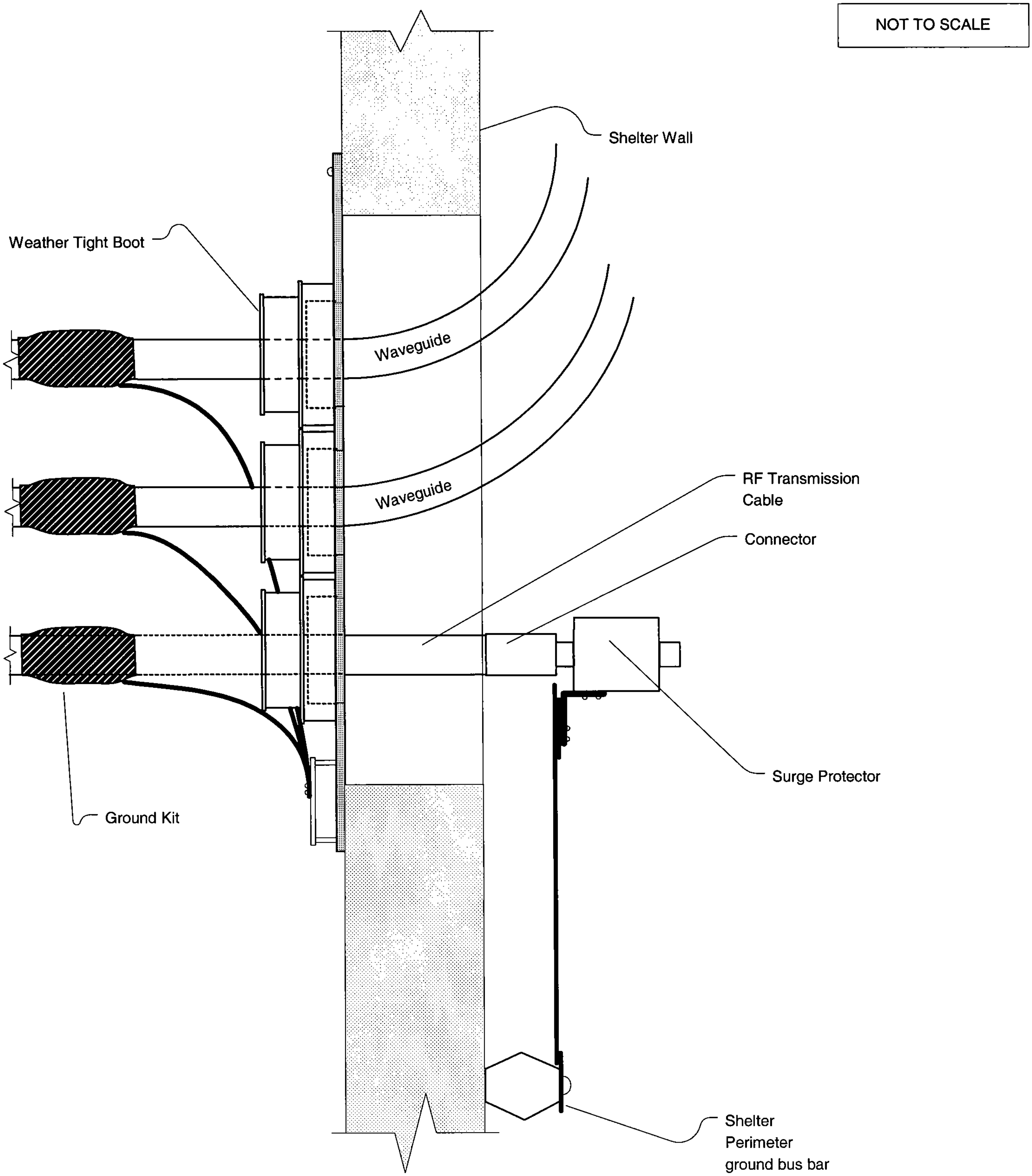


Figure 6.2.4-1
Typical Entry Port Grounding Detail
(Side View)

\\Tlitsserver\personnel\KN962WA\Projects\RWIS\Phase2\Between-NearTower\Figure6.2.4-1_TypicalEntryPortGroundingDetail-SideView.vsd
11/26/03

6.3 General Facility Requirements

6.3.1 Site Preparation

The Department will provide site space for the equipment installations. The Contractor shall install all necessary equipment in the provided space, and make all necessary electrical and mechanical connections. Routing of wires and cables shall be neat and orderly. Electrical connectors shall be the responsibility of the Contractor. All environmental protection requirements shall be complied with. The Contractor must contact the local FDOT district contact person and FDOT Project Manager for specific information regarding site preparation.

6.3.2 Debris Removal

At the completion of the installations specified herein, the Contractor shall remove all debris and return the grounds to their original condition.

7. SUBMITTAL DATA AND NOTIFICATION REQUIREMENTS

7.1 Design Documentation Submittal

All design documentation submittals shall be delivered to:

Mr. J. Nick Adams, C.P.M.
605 Suwannee Street, MS 90
Tallahassee, Florida 32399-0450
Telephone: (850) 410-5608
Fax: (850) 410-5501

Construction shall not begin until the Department has approved all submitted plans.

7.2 Construction Plan - Schedule of Events

The Contractor shall submit a detailed construction plan for approval by the Department. The plan shall include a schedule of events detailing each phase of construction including a projected timeline. The time of deliveries to the site shall be highlighted on the schedule.

CONSTRUCTION SHALL NOT BEGIN UNTIL THE CONSTRUCTION PLAN HAS BEEN APPROVED BY THE PROJECT MANAGER, OR DESIGNATED REPRESENTATIVE.

8. INSPECTION AND VERIFICATION

8.1 General

The inspection shall be performed by the Contractor and witnessed by the Project Manager, or designated representative.

The Contractor shall notify the Project Manager and the Department's local personnel at least ten days prior to completion of the installation. Following the antenna system installations, the Contractor, in conjunction with the Department's Project Manager, or designated representative, shall verify that all equipment is correctly installed and functional.

The Contractor shall remedy all deficiencies at no additional cost to the Department.

8.2 Grounding Inspection

The grounding system will be inspected for proper connection types, tightness, workmanship, and conformance with the approved design. Any mechanical bonds that are deemed unsatisfactory shall be repaired with new bonds.

8.3 Site Inspection

The site shall be inspected to be free of debris. Any unique site requirements are delineated in the Appendices.

APPENDIX A – SAINT JOHNS REST AREA SITE REQUIREMENTS

Appendix A – Table of Contents - Saint Johns Rest Area

SAINT JOHNS REST AREA

In general, the Contractor shall furnish and install a 900 MHz antenna system. The Contractor is responsible for the installation of a new antenna system, transmission lines, and all associated lightning protection equipment and hardware.

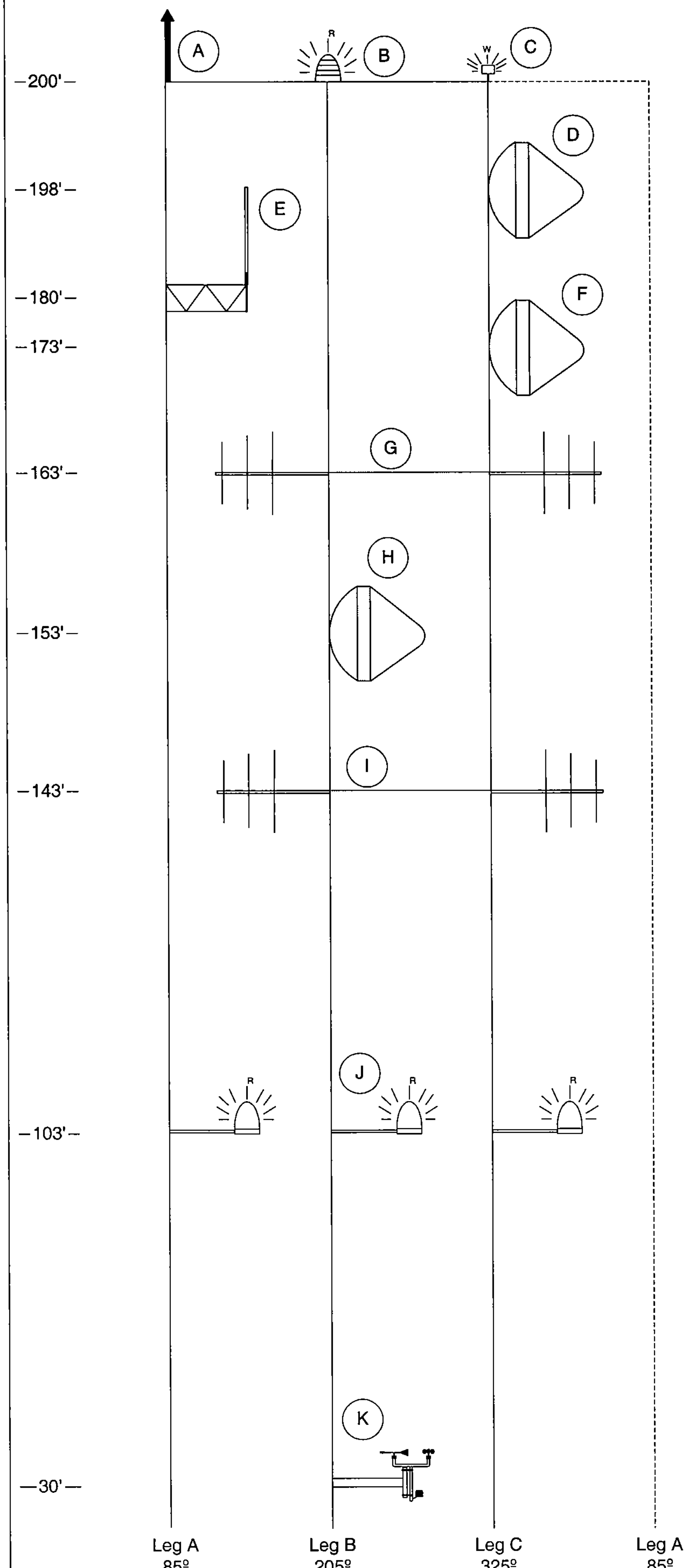
The Contractor shall submit to the Engineer for approval a detailed construction plan and schedule for all installation work.

The following items shall be furnished and installed at the Saint Johns Rest Area MAS site:

A. One (1) RFS AO9009-3 antenna (or approved equivalent) mounted to a 3-foot side arm, associated transmission line, lightning protection, and installation hardware, installed per Section 6 and Figures A-1 through A-3 in this appendix.

B. One (1) Freewave DGR09TFS transceiver (or approved equivalent), Atlantic Scientific Model 51034B surge protector (or approved equivalent), and grounding and installation hardware, installed per Section 6 and Figure A-4 in this appendix.

NOT TO SCALE



ID	Type	Leg	Elev.	Deg.	FPE	Tx. Line	Note
A	Lightning Rod	A	200' (Base)	-	-	-	
B	Beacon	B	200' (Base)	-	-	-	
C	Strobe	C	200' (Base)	-	-	-	
D	PA8-65	C	198' (C.L.)	320	-	WE-65	
E	AO9009-3	A	180' (Base)	-	-	5/8"	2
F	PA8-65	C	173' (C.L.)	320	-	WE-65	
G	DB-230-2	B, C	163' (C.L.)	160/ 325	2.72	1-1/4"	1
H	PA8-65	B	153' (C.L.)	155	-	WE-65	
I	DB-230-2	B, C	143' (C.L.)	160/ 325	2.72	1-1/4"	1
J	Side Beacons	A, B, C	103' (Base)	-	-	-	
K	Weather Sensors	B	30' (Base)	-	-	RS-232	

FCC Tower Registration	1060069
Tower Manufacturer	N/A
Tower Model Number	N/A
Tower Light Controllers	N/A

Notes:
1) This antenna is comprised of two (2) DB-230 antennas connected via a phasing harness to make the antenna array. The antennas are mounted on separate legs. One (1) 1-1/4" transmission line feeds this antenna array. The given F.P.E. is 2.72 for both antennas as a system.
2) **TO BE INSTALLED AS PART OF THIS PROJECT**.

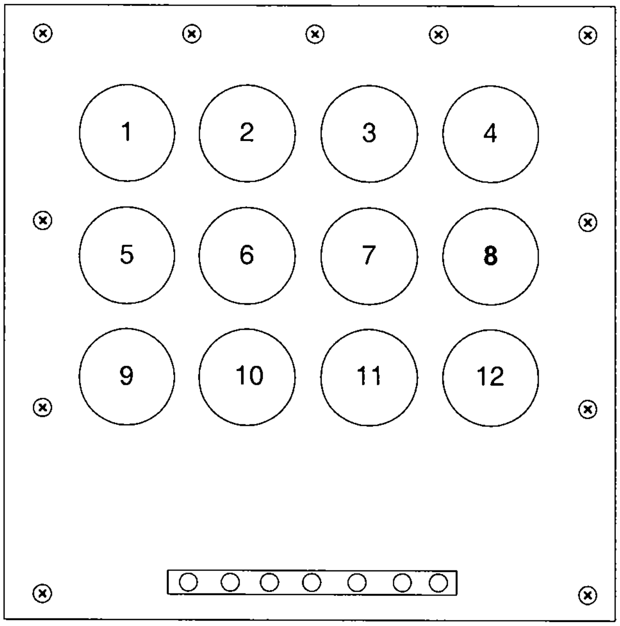
C.L.	Center Line of Antenna
WE-65	RFS Cablewave Systems Elliptical Waveguide
1-1/4"	Andrew Corporation Foam Dielectric Transmission Line, LDF Series
PA8-65	RFS Cablewave Systems Microwave Antenna
DB-XXX	Decibel Products Antenna

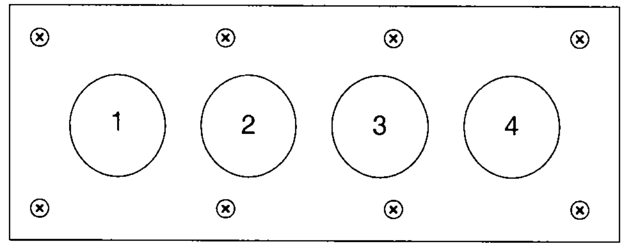
Figure A-1
St. Johns Rest Area
Antenna Loading Diagram

St. Johns Rest Area
July 24, 2002
Verified: Yes

State of Florida
Department of Transportation

RCC Consultants, Inc.





1. Andrew Heliax 1.25" LDF6-50 coaxial
2.-4. Empty

1. RFS Cablewave Systems WE65 Flexwell Elliptical Waveguide
2. RFS Cablewave Systems WE65 Flexwell Elliptical Waveguide
3. RFS Cablewave Systems WE65 Flexwell Elliptical Waveguide
4. Empty
5. RWIS SERIAL CABLES
6.-7. Empty
8. RWIS 900 MHz System (To be installed as part of this project)
9.-12. RFS Cablewave Systems S-FLC 12-50J Flexwell coaxial

Figure A-2
Saint Johns Rest Area
Entry Port Diagram
Exterior View

Scale: 3/4" = 1'-0"

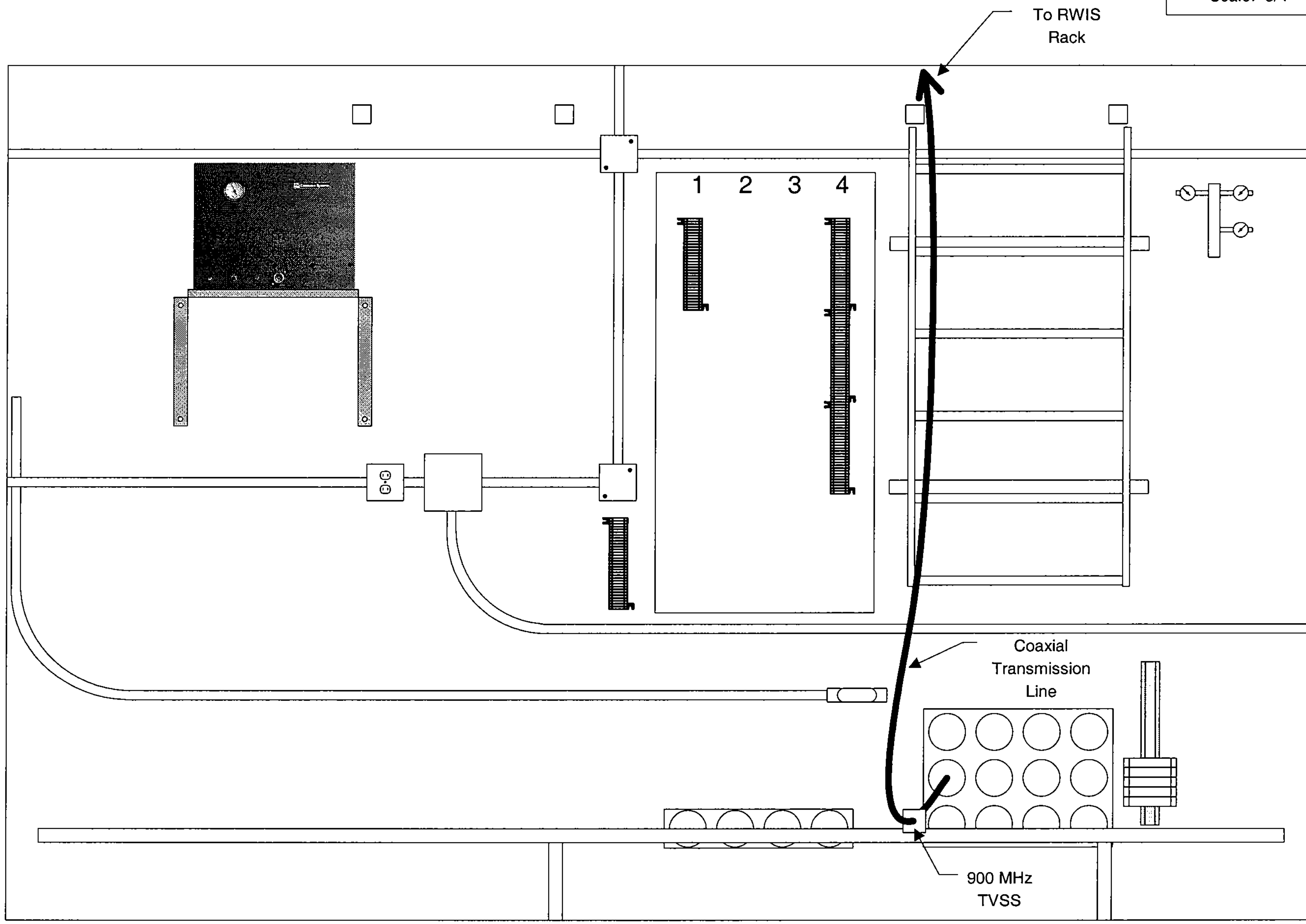


Figure A-3
Saint Johns Rest Area
Interior East Wall

TLITSSERVER:\\Personnel\KN962WA\Projects\MicMaint\RWISTowerSensorInstallation\FigureA3_StJohnsRestArea_InteriorEastWall.vsd
11/25/2003

Scale: 1 1/4" = 1'-0"

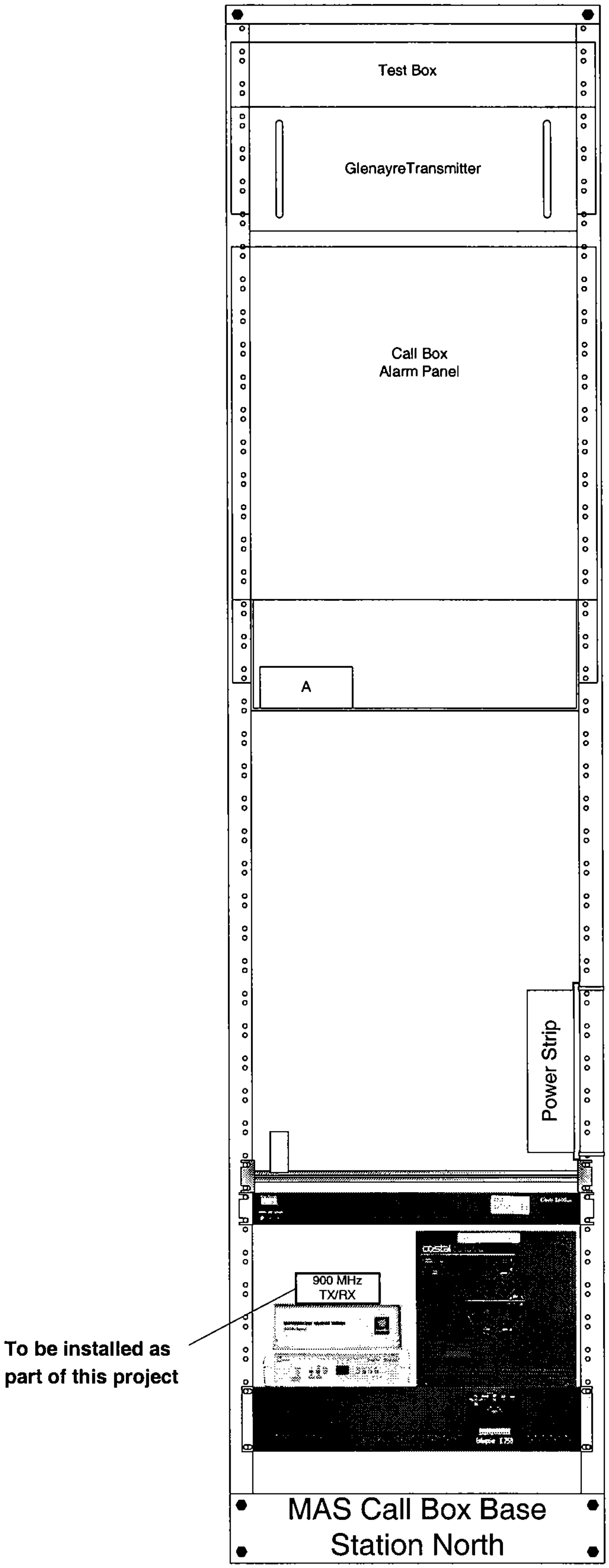


Figure A-4
Saint Johns Rest Area
MAS Call Box Base Station North Rack Detail - Front View

APPENDIX B – SR16 SITE REQUIREMENTS

Appendix B – Table of Contents - SR16

SR16

In general, the Contractor shall furnish and install a 900 MHz antenna system. The Contractor is responsible for the installation of a new antenna system, transmission lines, and all associated lightning protection equipment and hardware.

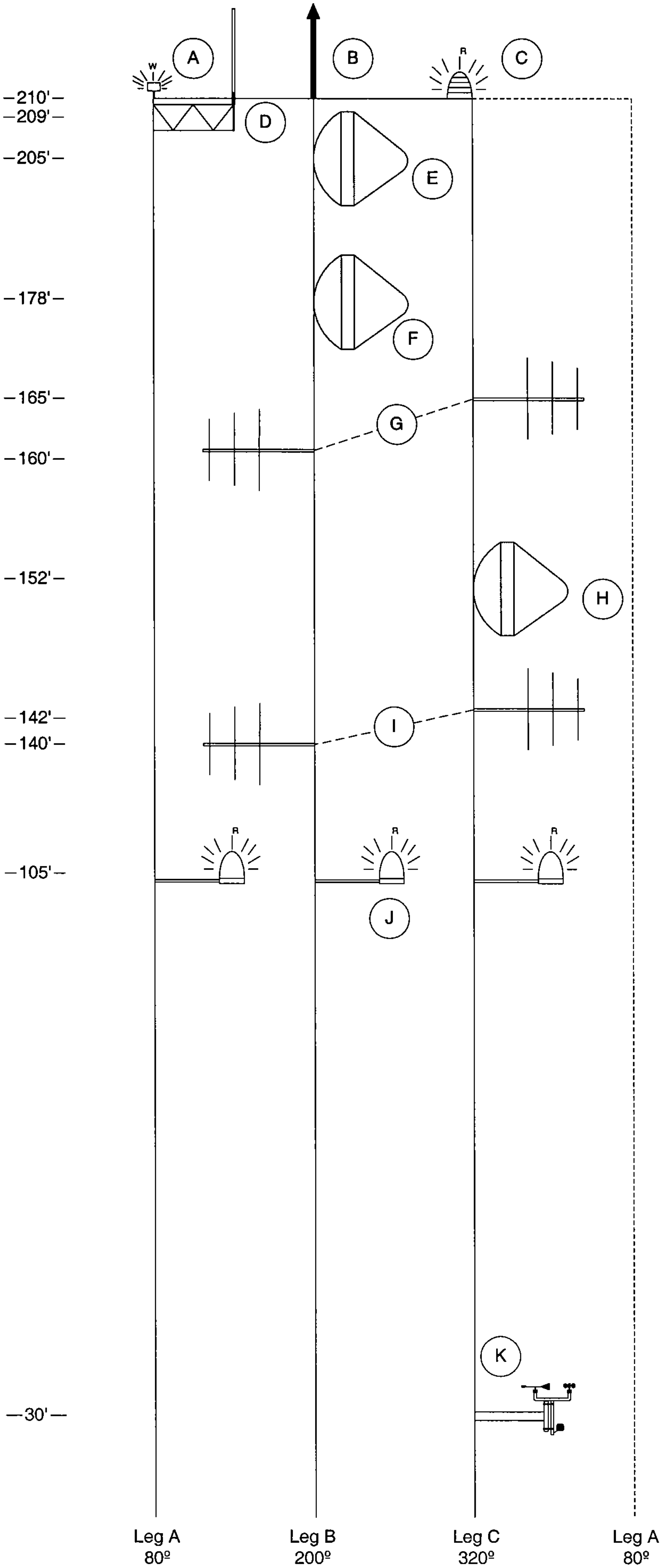
The Contractor shall submit to the Engineer for approval a detailed construction plan and schedule for all installation work.

The following items shall be furnished and installed at the SR16 MAS site:

A. One (1) RFS AO9009-3 antenna (or approved equivalent) mounted to a 3-foot side arm, associated transmission line, lightning protection, and installation hardware, installed per Section 6 and Figures B-1 through B-3 in this appendix.

B. One (1) Freewave DGR09TFS transceiver (or approved equivalent), Atlantic Scientific Model 51034B surge protector (or approved equivalent), and grounding and installation hardware, installed per Section 6 and Figure B-4 in this appendix.

NOT TO SCALE



ID	Type	Leg	Elev.	Deg.	FPE	Tx. Line	Note
A	Strobe	A	210' (Base)	-	-	-	
B	Lightning Rod	B	210' (Base)	-	-	-	
C	Beacon	C	210' (Base)	-	-	-	
D	AO9009-3	A	209' (Base)	-	-	5/8"	2
E	PA8-65	B	205' (C.L.)	156.6	-	WE-65	
F	PA8-65	B	178' (C.L.)	156.6	-	WE-65	
G	DB-230-2	C	165' 160'	-	2.72	-	1
H	PA8-65	C	152' (C.L.)	336.6	-	WE-65	
I	DB-230-2	C, B	142' 140'	-	2.72	-	1
J	Side Beacons	A, B, C	105' (Base)	-	-	-	
K	Weather Sensors	C	30' (Base)	-	-	RS-232	

FCC Tower Registration	1061377
Tower Manufacturer	ROHN
Tower Model Number	SSVMW
Tower Serial Number	N/A
Tower Light Controllers	Dual Lighting

Notes:

1) This antenna is comprised of two (2) DB-230 antennas connected via a phasing harness to make the antenna array. The antennas are mounted on separate legs. One (1) 1/2" transmission line feeds this antenna array. The given F.P.E. is 2.72 for both antennas as a system.
2) **TO BE INSTALLED AS PART OF THIS PROJECT.**

C.L.	Center Line of Antenna
WE-65	RFS Cablewave Systems Elliptical Waveguide
7/8" ,1/2"	Andrew Corporation Foam Dielectric Transmission Line, LDF Series
PA8-65	RFS Cablewave Systems Microwave Antenna
DB-XXX	Decibel Products Antenna

Figure B-1
SR16
Antenna Loading Diagram

SR 16
October 30, 2002
Verified: Yes

State of Florida
Department of Transportation

RCC Consultants, Inc.

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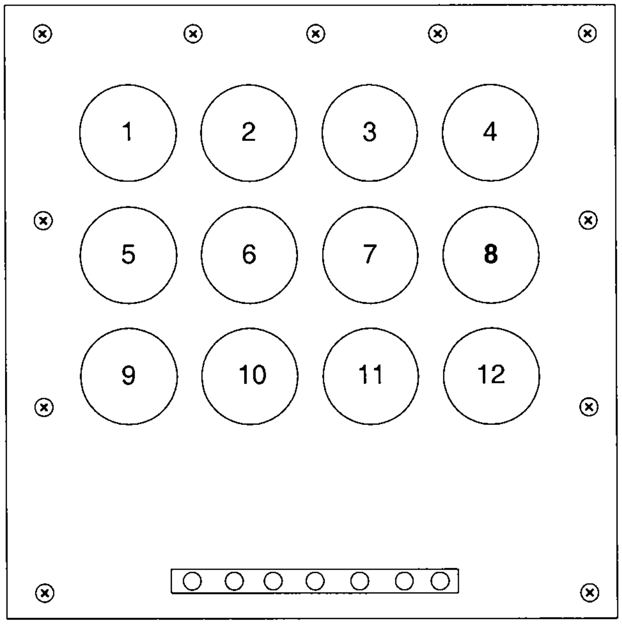
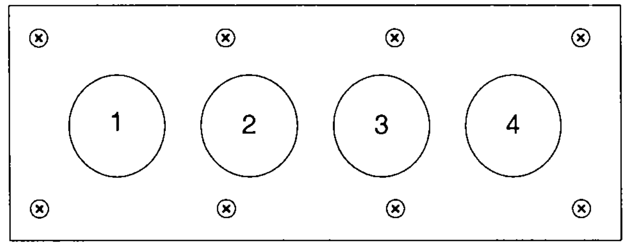
2/13/2004

Scale: 1 1/2" = 1'-0"





1.-4. Empty

1.-3. RFS Cablewave Systems WE65 Flexwell Elliptical Waveguide
4. Empty
5. RWIS SERIAL CABLES
6.-7. Empty
8. RWIS 900 MHz System (To be installed as part of this project)
9.-10. RFS Cablewave Systems S-FLC 12-50J Flexwell coaxial
11.-12. Empty

Figure B-2
SR16
Entry Port Diagram
Exterior View

Scale: 3/4" : 1'

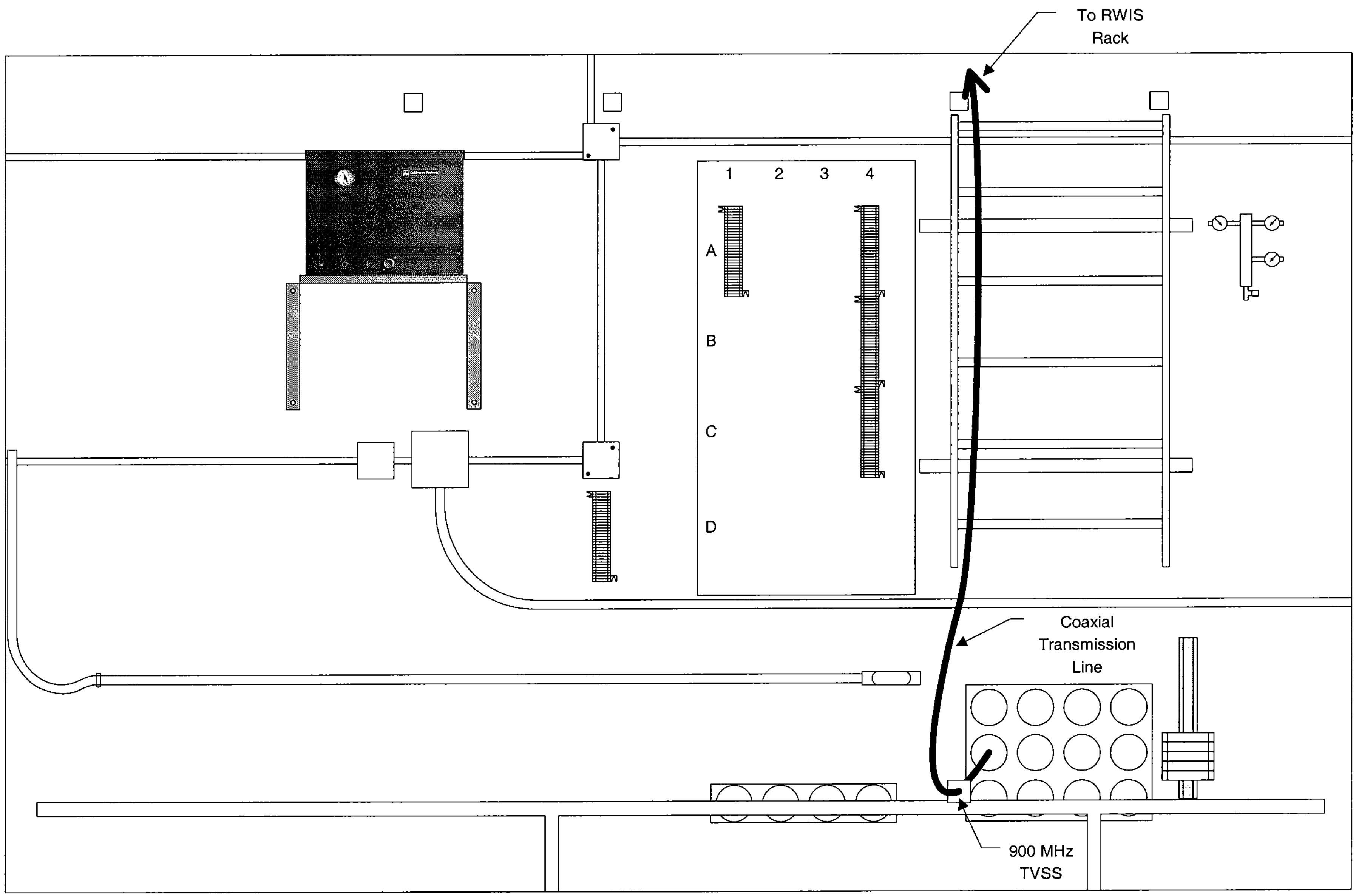


Figure B-3
SR16
Interior South Wall

Scale: 1 1/4" = 1'-0"

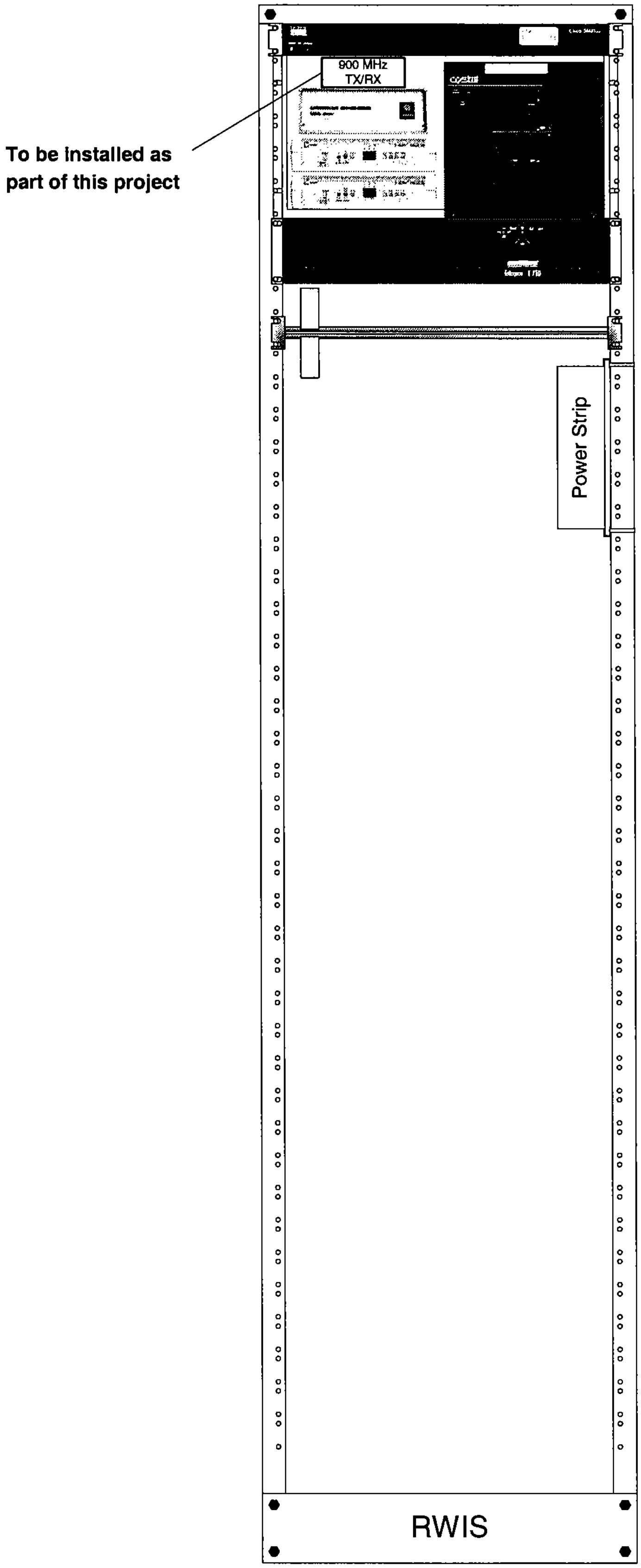


Figure B-4
SR16
RWIS Rack Detail - Front View

APPENDIX C – GOPHER RIDGE SITE REQUIREMENTS (OPTIONAL)

Appendix C – Table of Contents - Gopher Ridge

GOPHER RIDGE

In general, the Contractr shall furnish and install a 900 MHz antenna system. The Contractor is responsible for the installation of a new antenna system, transmission lines, and all associated lightning protection equipment and hardware.

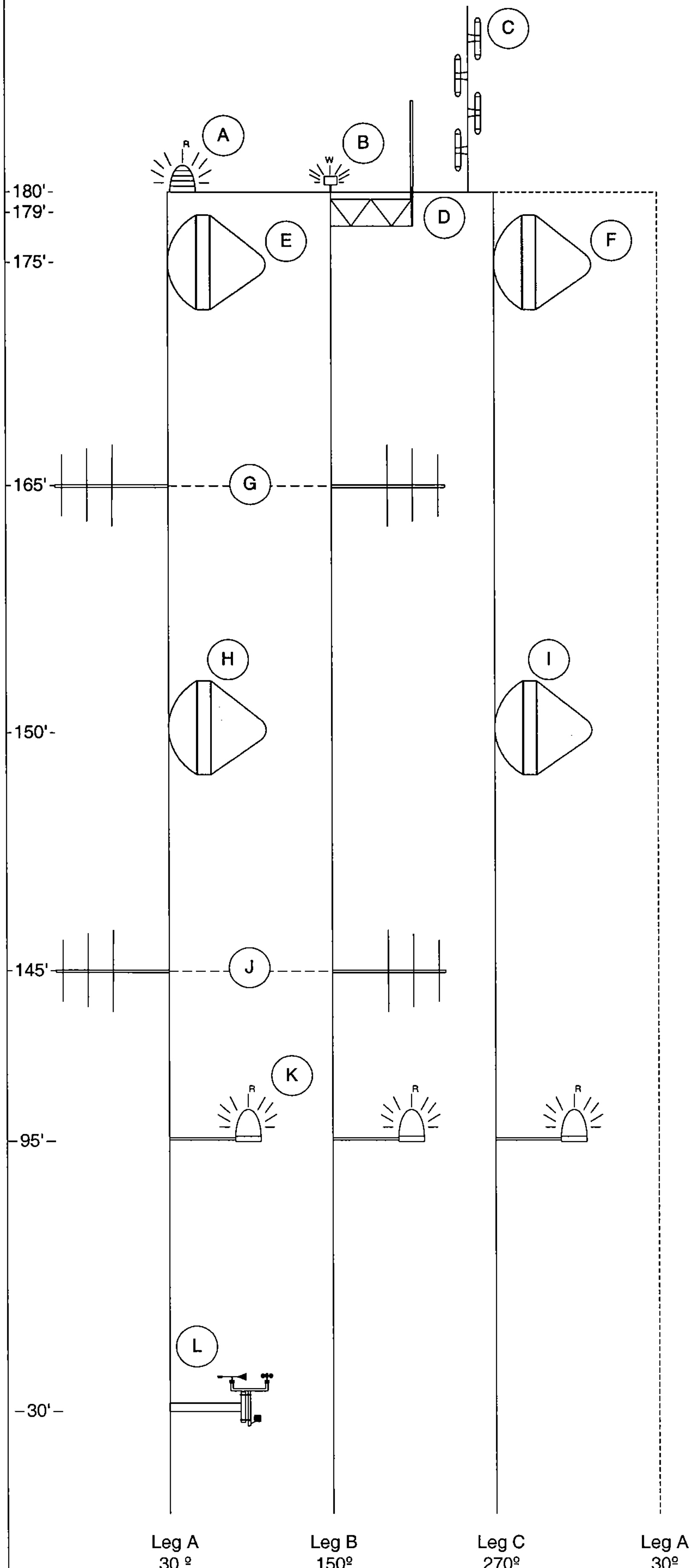
The Contractor shall submit to the Engineer for approval a detailed construction plan and schedule for all installation work.

The following items shall be furnished and installed at the Gopher Ridge MAS site:

A. One (1) RFS AO9009-3 antenna (or approved equivalent) mounted to a 3-foot side arm, associated transmission line, lightning protection, and installation hardware, installed per Section 6 and Figures C-1 through C-3 in this appendix.

B. One (1) Freewave DGR09TFS transceiver (or approved equivalent), Atlantic Scientific Model 51034B surge protector (or approved equivalent), and grounding and installation hardware, installed per Section 6 and Figure C-4 in this appendix.

NOT TO SCALE



ID	Type	Leg	Elev.	Deg.	FPE	Tx. Line	Note
A	Beacon	A	180' (Base)	-	-	-	
B	Strobe	B	180' (Base)	-	-	-	
C	DB-224	C	180' (Base)	-	3.15	7/8"	
D	AO9009-3	B	179' (Base)	-	-	5/8"	2
E	PA8-65	A	175' (C.L.)	338	-	WE-65	
F	PA8-65	C	175' (C.L.)	270	-	WE-65	
G	DB-230-2	A, B	145' (C.L.)	350/ 135	2.72	1/2"	1
H	PA8-65	A	150' (C.L.)	338	-	WE-65	
I	PA8-65	C	150' (C.L.)	270	-	WE-65	
J	DB-230-2	A, B	145' (C.L.)	350/ 150	2.72	1/2"	1
K	Side Beacons	A, B, C	95' (C.L.)	-	-	-	
L	Weather Sensor	A	30' (Base)	-	-	-	

FCC Tower Registration	1061378
Tower Manufacturer	ROHN
Tower Model Number	SSV
Tower Serial Number	31249AE
Tower Light Controllers	N/A

Notes:

1) This antenna is comprised of two (2) DB-230 antennas connected via a phasing harness to make the antenna array. The antennas are mounted on separate legs. One (1) 1/2" transmission line feeds this antenna array. The given F.P.E. is 2.72 for both antennas as a system.
2) **TO BE INSTALLED AS PART OF THIS PROJECT.**

C.L.	Center Line of Antenna
DB-XXX	Decibel Products Antenna
PA8-65	RFS Cablewave Systems Microwave Antenna
WE-65	RFS Cablewave Systems Elliptical Waveguide
7/8", 1/2"	Andrew Corporation Foam Dielectric Transmission Line, LDF Series

Figure C-1
Gopher Ridge
Antenna Loading Diagram

Gopher Ridge
June 6, 2002
Verified: No

State of Florida
Department of Transportation

RCC Consultants, Inc.

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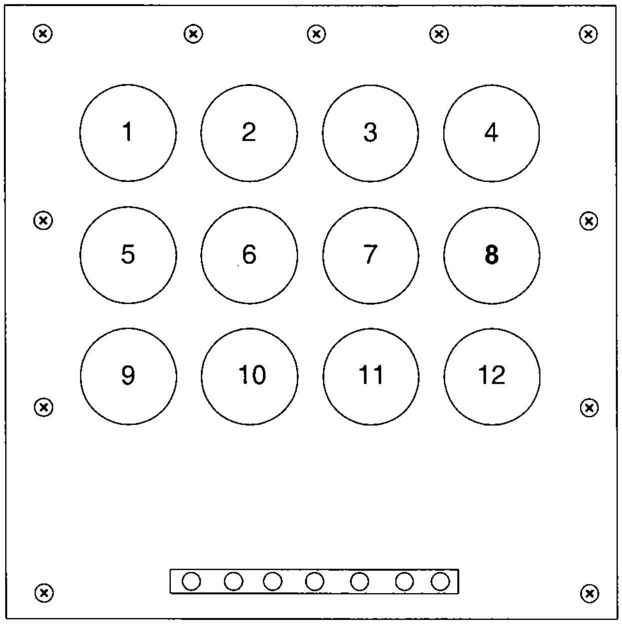
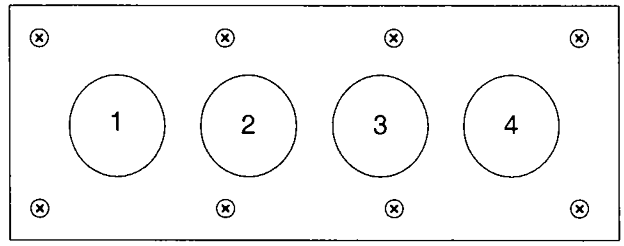
2/13/2004





1.-4. Empty

1.-5. RFS Cablewave Systems WE65 Flexwell Elliptical Waveguide
6.-7. Empty
8. RWIS 900 MHz System (To be installed as part of this project)
9. RWIS SERIAL CABLES
10.-12. RFS Cablewave Systems FLC 12-50J Flexwell coaxial

Figure C-2
Gopher Ridge
Entry Port Diagram
Exterior View

Scale: 3/4" = 1'-0"

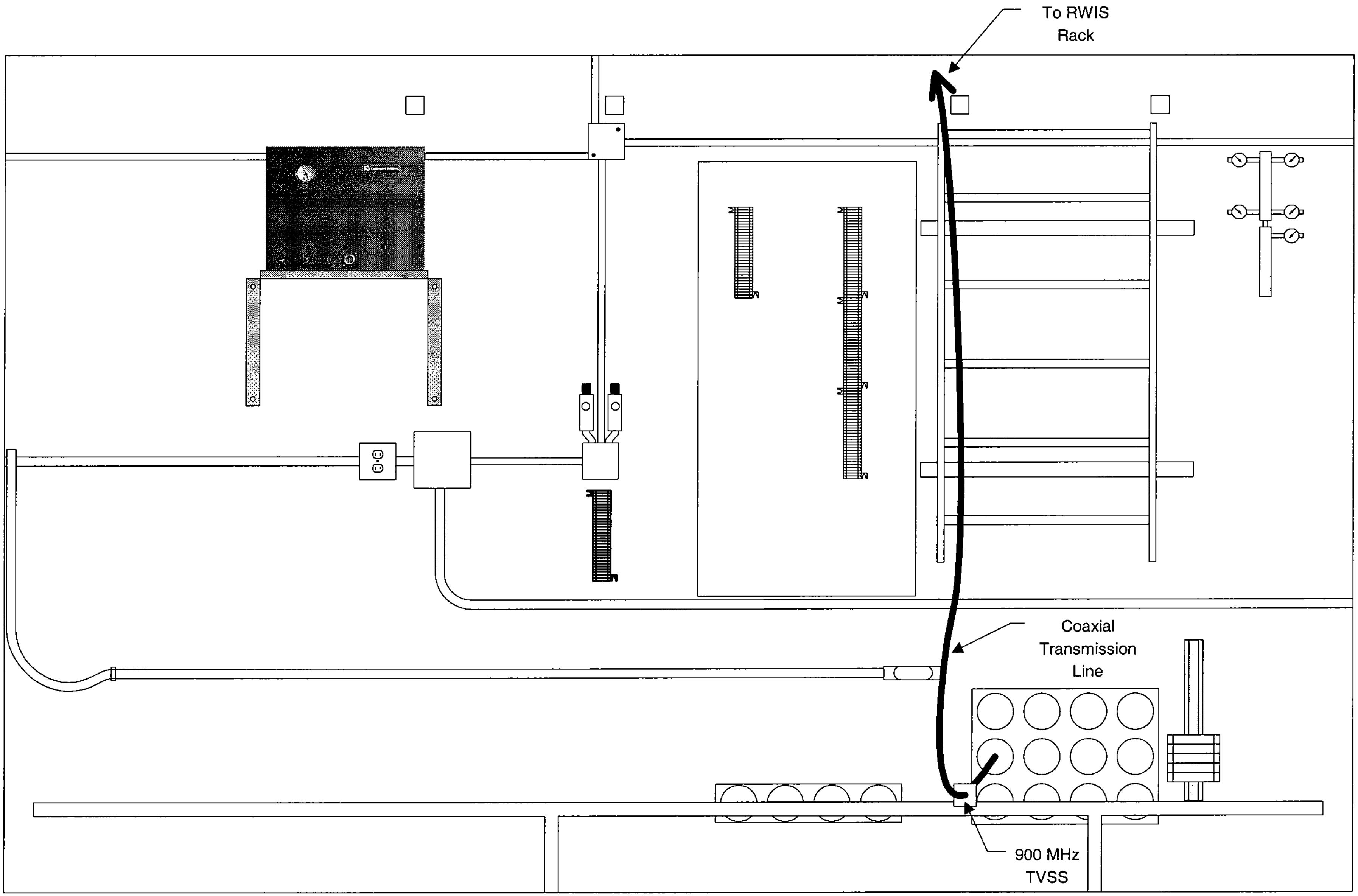


Figure C-3
Gopher Ridge
Interior West Wall

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11/25/2003

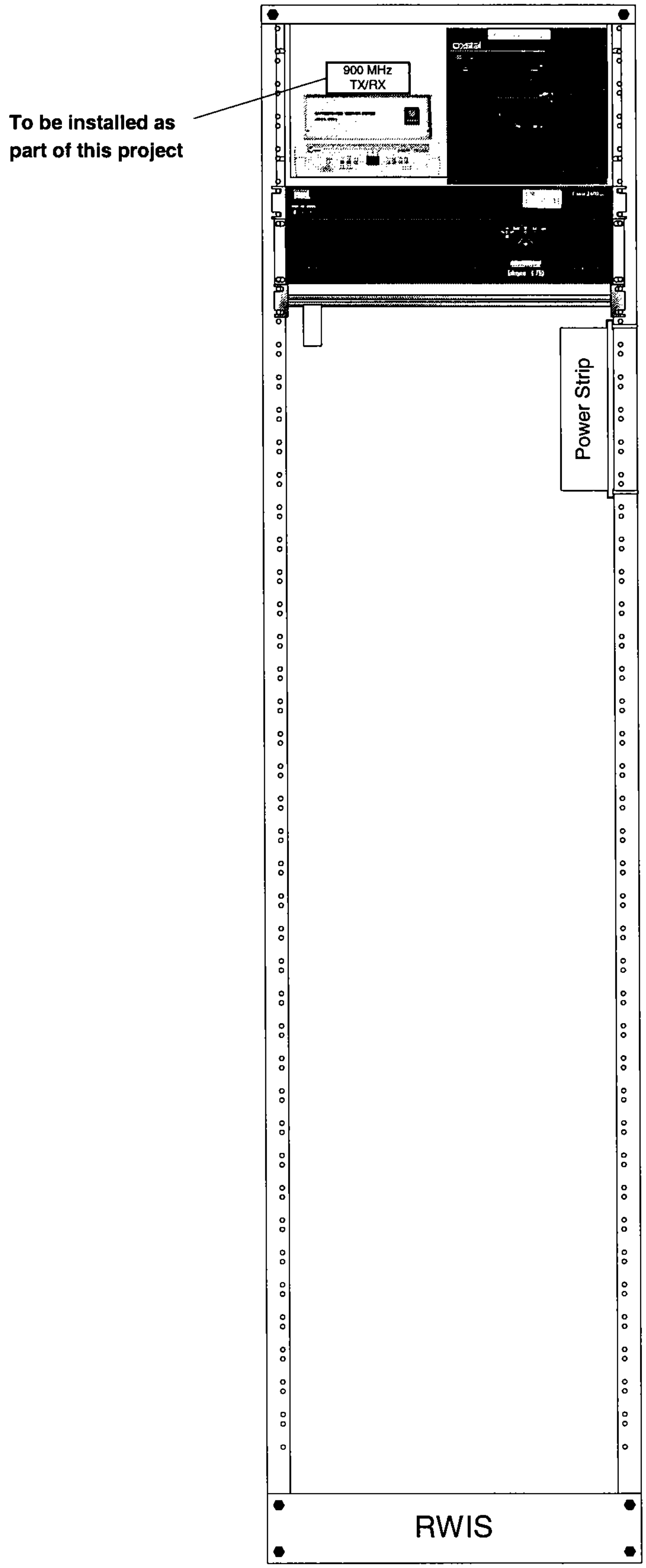


Figure C-4
Gopher Ridge
RWIS Rack Detail - Front View

Appendix 2

Research Report:

"Utilizing Doppler Radar to Estimate Rainfall Rates for Highway Segments"

Utilizing Doppler Radar to Estimate Rainfall Rates for Highway Segments

Nick Chape, Research Coordinator, AWISLab
Robert Richardson, GIS Specialist, AWISLab
J. David Lambert PhD, Director, AWISLab
Patrick Welsh PhD, Executive Director, AWISLab

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 (<u>Nex</u>t Generation <u>Rad</u>ar) 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.

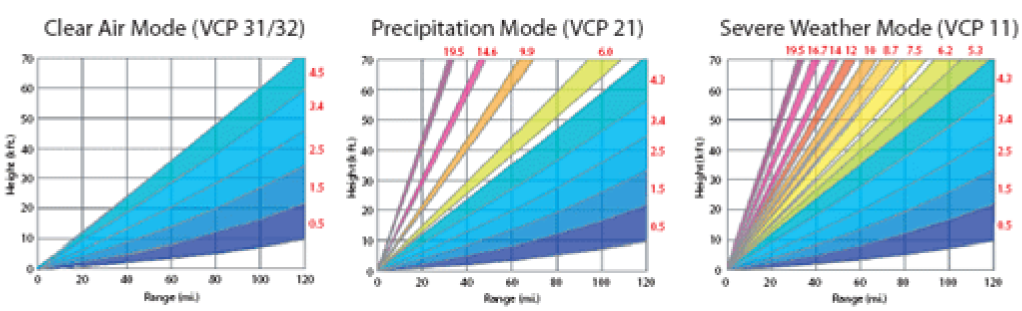


Figure 2. NEXRAD Operational Modes [2]

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].

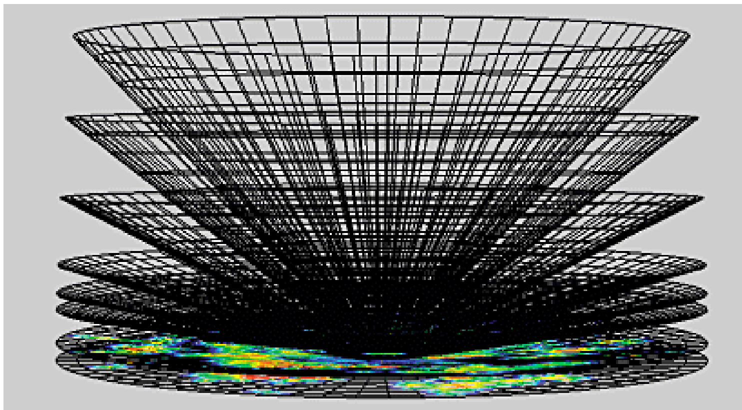
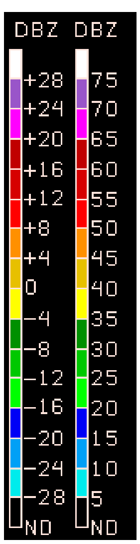


Figure 3. NEXRAD Scan Angles Visualization [5]

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.

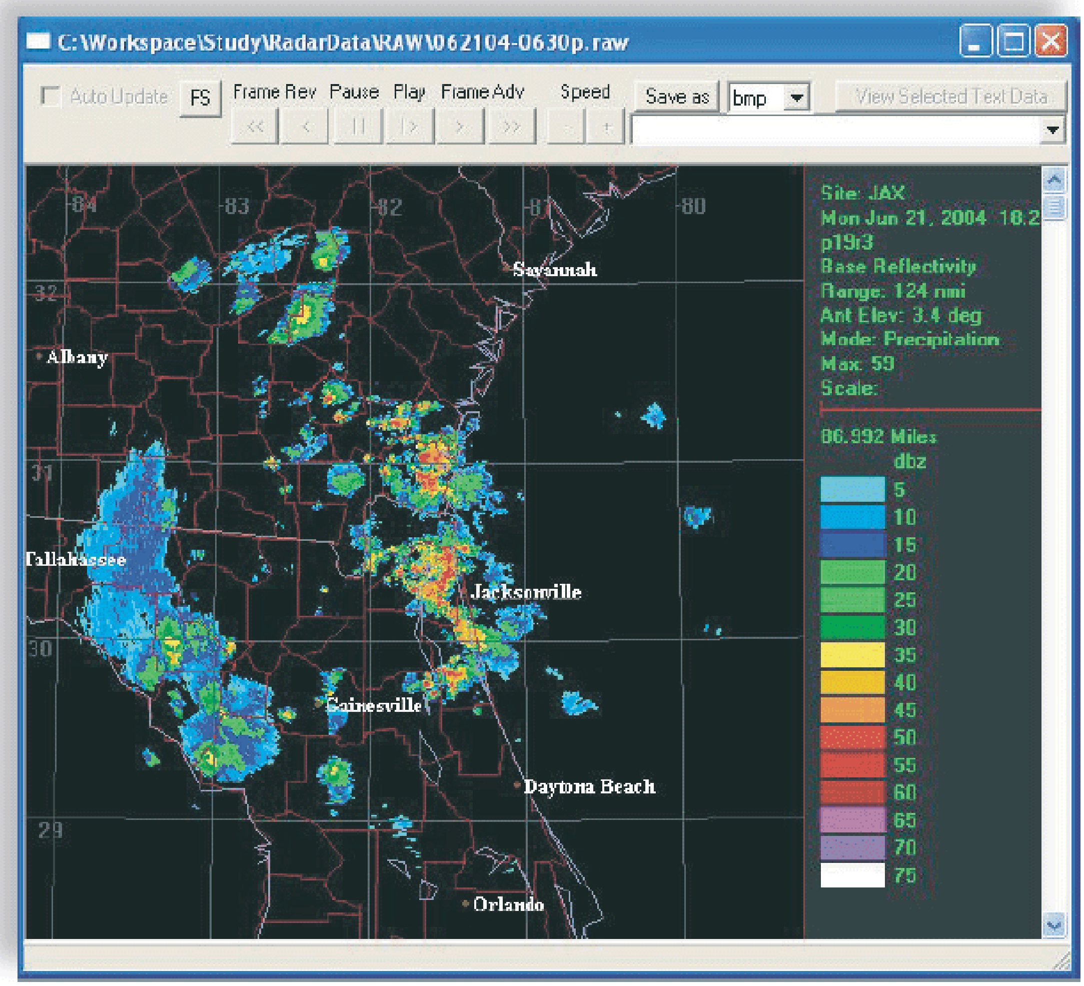


Figure 5. NEXRAD Data Product 2D Visualization Display

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].

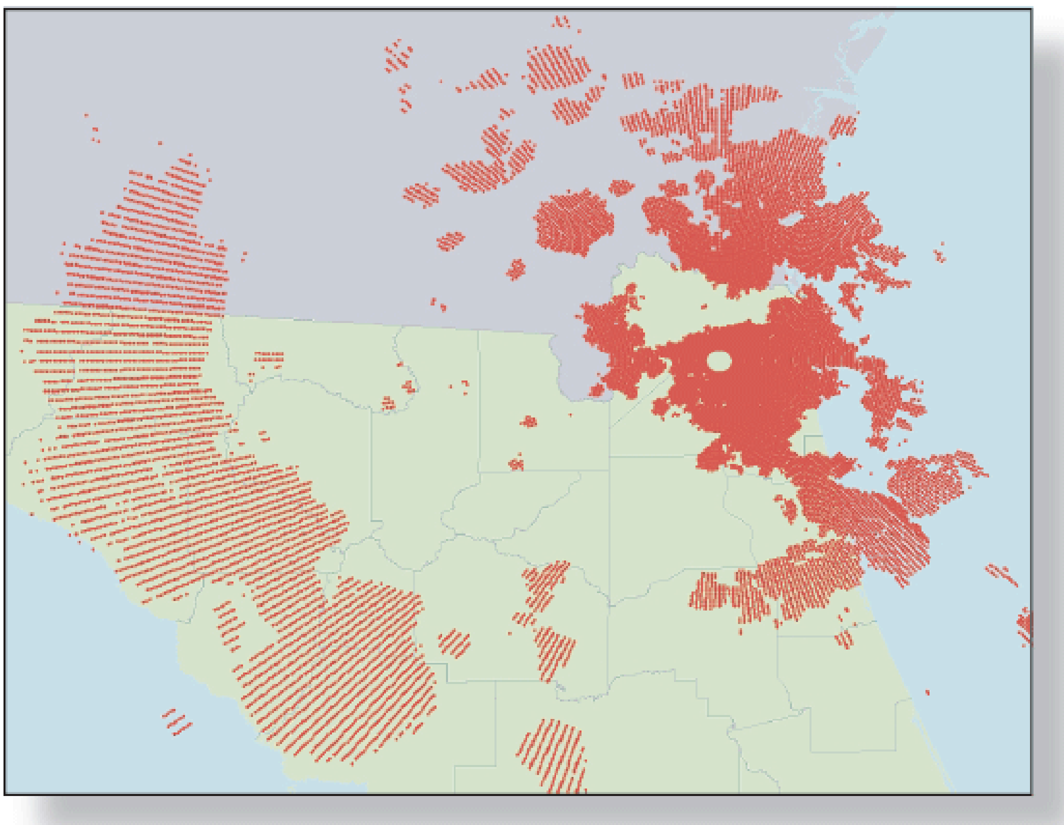


Figure 6. Point Shapefile Output Displayed over Basemap

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.

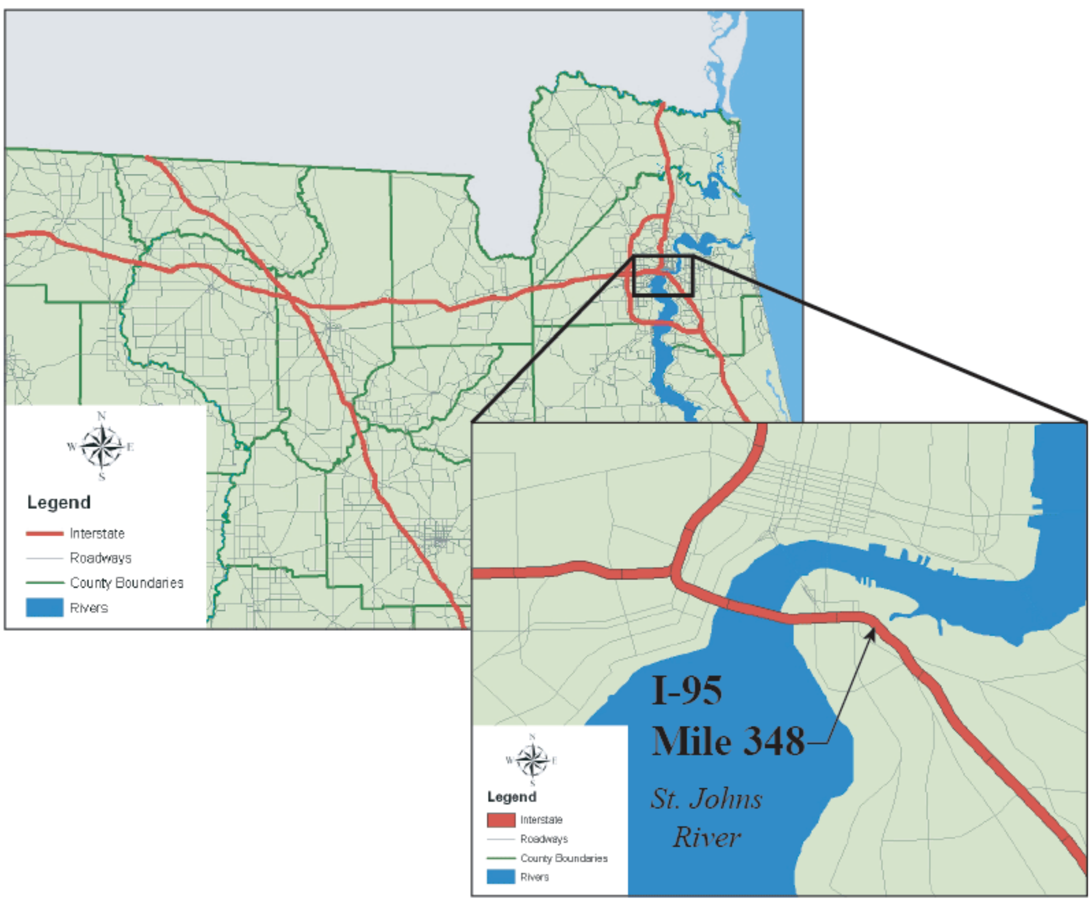


Figure 7. Road Polygon Layer Visualization over Basemap

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.

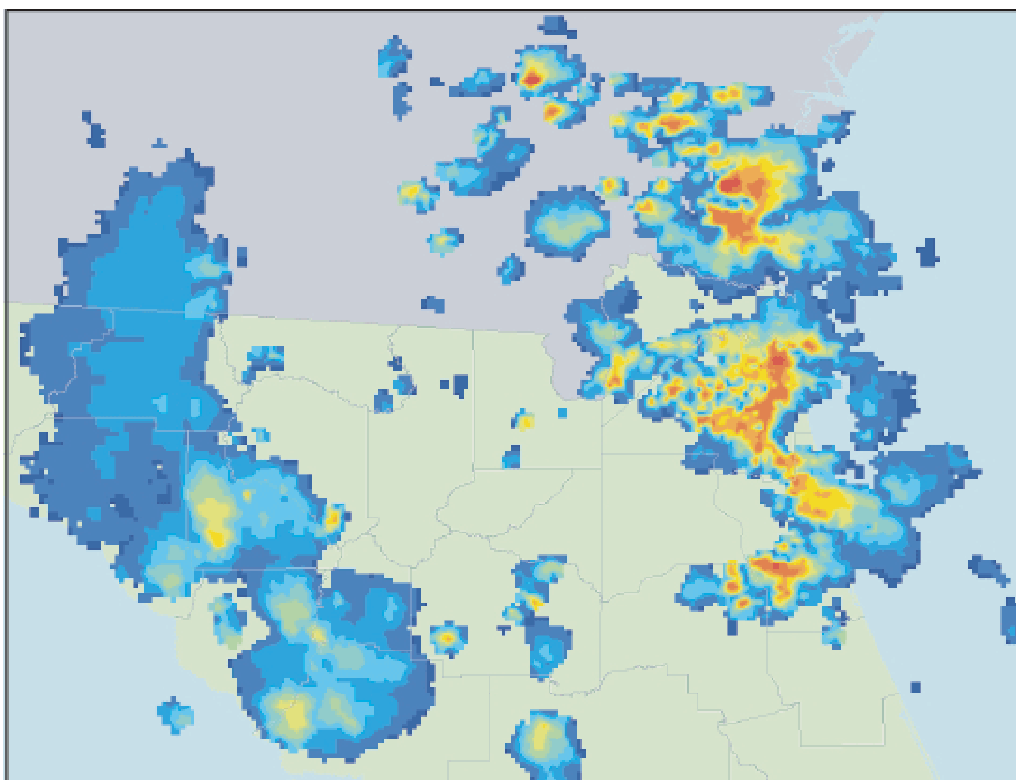


Figure 8. Interpolated NEXRAD Grid

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.

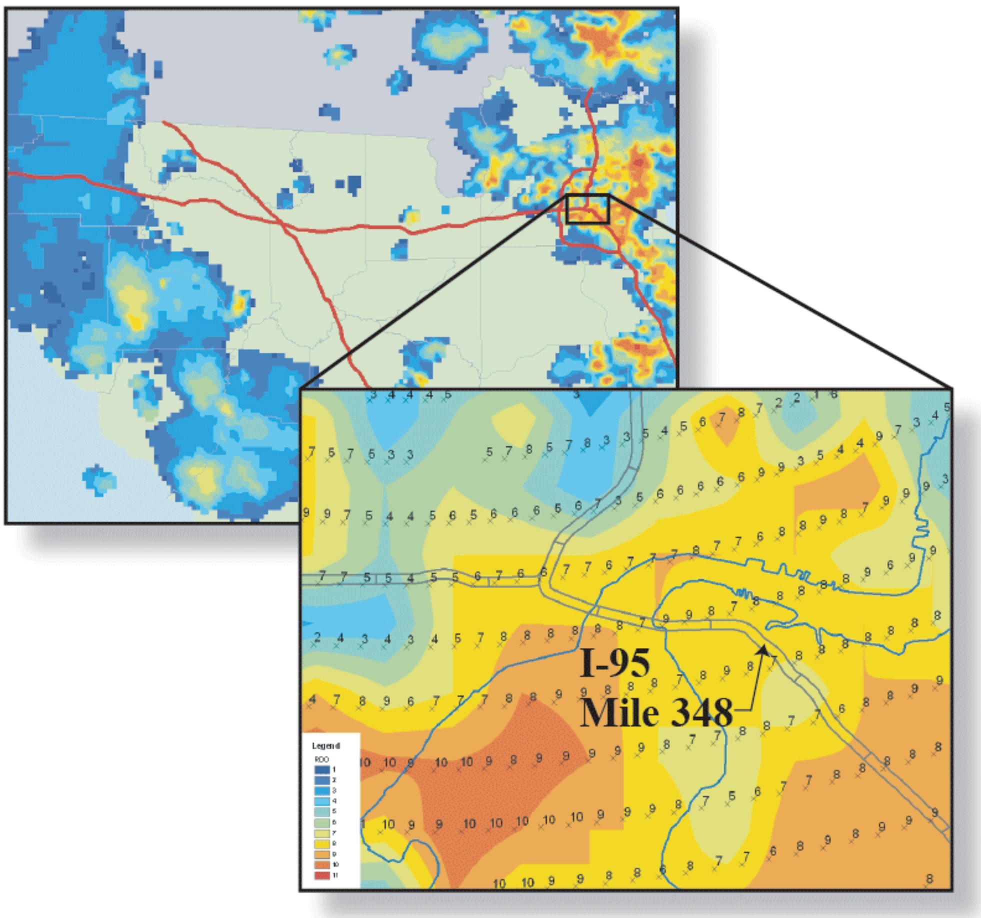


Figure 9. Road segments overlaid on the NEXRAD polygons

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.

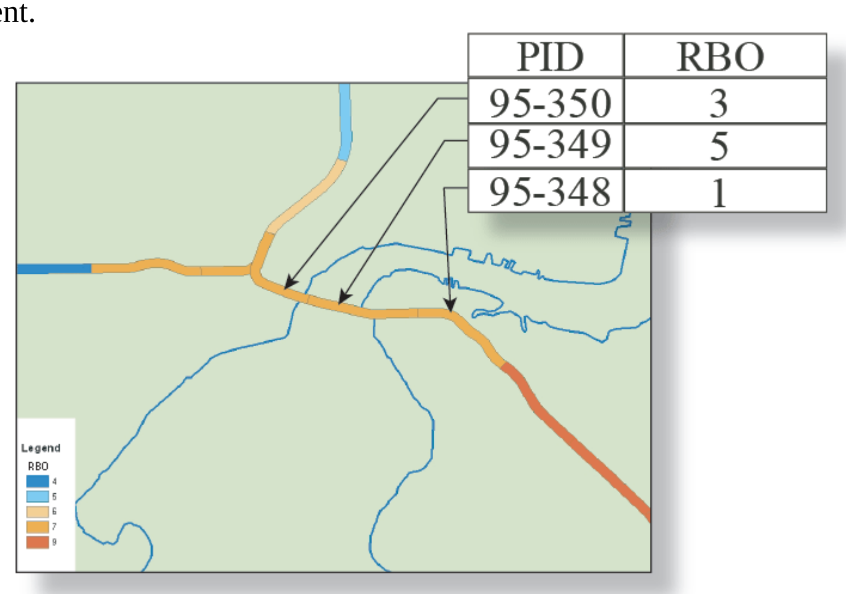


Figure 10. Roadway Rain Rate (RBO) Determination

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.

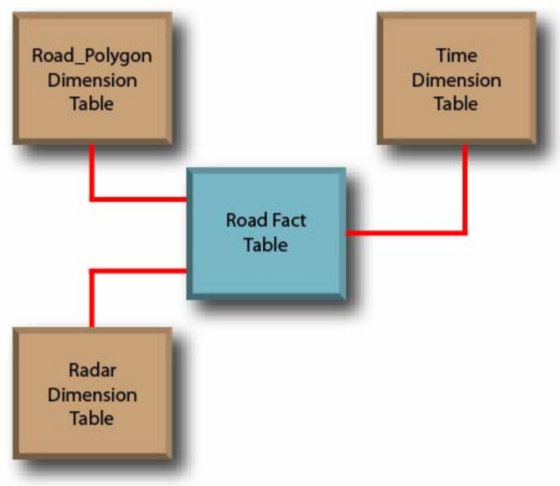


Figure 11. Data Warehouse

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.

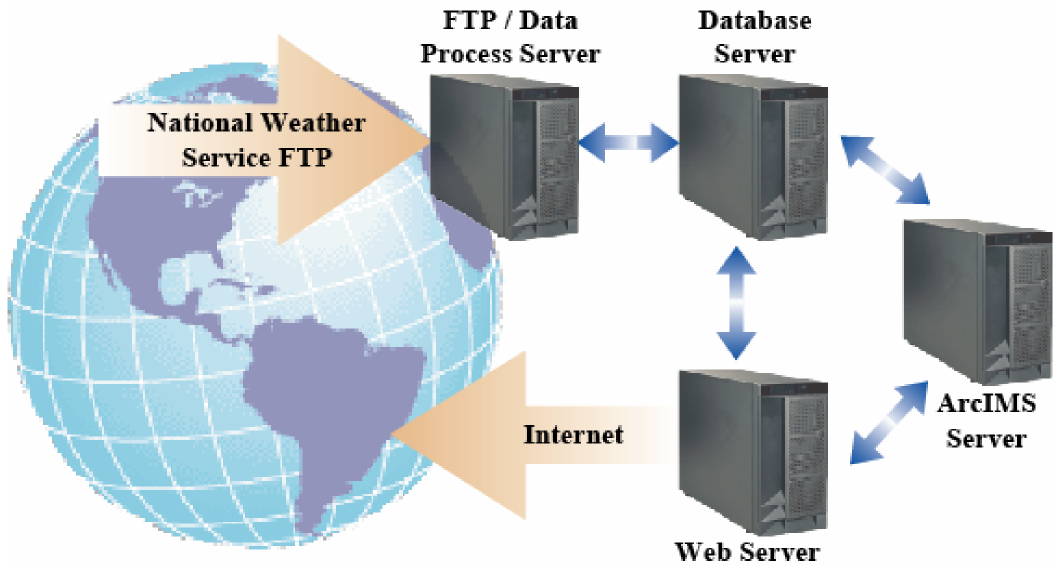


Figure 12. System Architecture Layout

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.

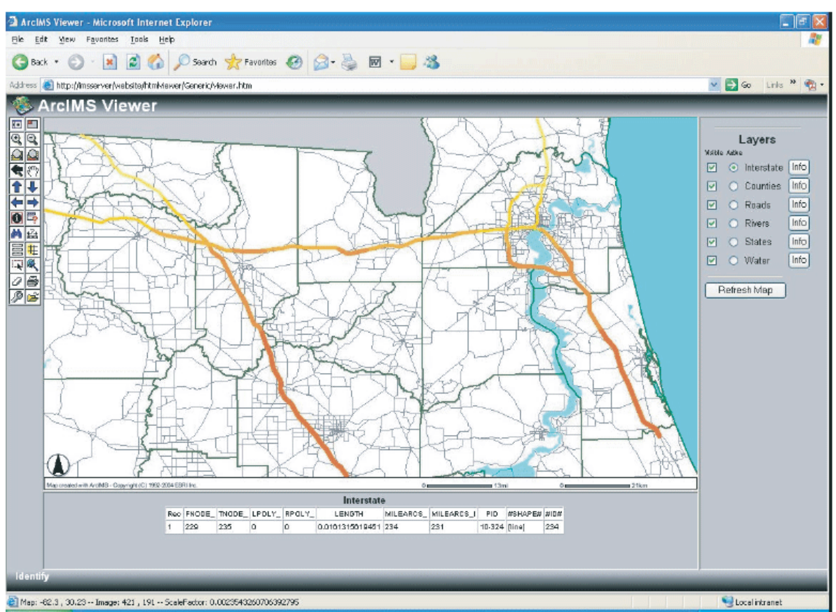


Figure 13. ArcIMS Display of Near Real Time Precipitation Volume

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 Office of Research and Development called "**Phase II Development of a Road Weather Information System (RWIS) for Florida's Intelligent Transportation System, CONTRACT # BD- 537".**

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Appendix 3

Research Report:

"Probability of Fog Along the Interstates of the Southeast United States"

Probability of Fog Along the Interstates of the Southeast United States

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April 30, 2004

Synopsis

The data used to develop the road-specific visibility climatology are taken from the Solar and Meteorological Surface Observational Network (SAMSON) 3-volume CD-ROM set. The set is divided geographically into regions: Eastern, Central, and Western U.S. It contains hourly solar radiation data along with selected meteorological elements for the period 1961–1990. It encompasses 237 National Weather Service stations in the United States, plus offices in Guam and Puerto Rico. The data includes both observational and modeled data. The meteorological elements are: Total and opaque sky cover, temperature and dew point, relative humidity, pressure, wind direction (true north) and speed, visibility, ceiling height, present weather, precipitable water, aerosol optical depth, snow depth, days since last snowfall, and hourly precipitation.

Our interest is the visibility recorded in tenths of a kilometer at stations over the southeast U.S. The available stations include Tallahassee, Daytona Beach, Jacksonville and Tampa in Florida, Macon, Augusta, Savannah, Athens, Columbus, and Atlanta in Georgia, Huntsville, Montgomery, Mobile, and Birmingham in Alabama, and Charleston and Columbus in South Carolina (Fig. 1). We assume that dense fog is the cause of visibility reduction below 1 mile. We separate cases into fog (visibility less than 1 mile) and dense fog (visibility less than 1/4 mile). We consider the relative frequency of fog and dense fog in 3-hour intervals. Figure 2 shows the relative frequency of dense fog in Tallahassee by time of day. Relative frequency is based on approximately (depending on season) 8,220 hourly observations from each of the 16 stations over the period 1961–1990.

Figures 3 and 4 show the probability (relative frequency) of fog during winter and spring, respectively in 4 different 3-hour periods. The relative frequencies at the individual stations are spatially analyzed using kriging. Figures 5 and 6 show the probability of dense fog. Figure 7 shows the correlation between the probability of dense fog and elevation based on the 16 stations over the southeast United States conditioned by season and time of day.

Acknowledgements. The data were supplied by Irv Watson. The maps were produced by Chris Lesser. Partial support for this study was provided by the The Florida Department of Transportation as a Subcontract from the University of North Florida.

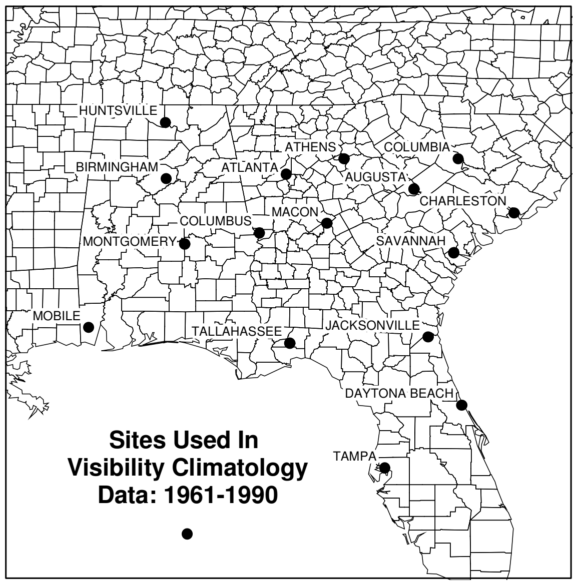


Figure 1: Locations of stations used in developing the fog climatology.

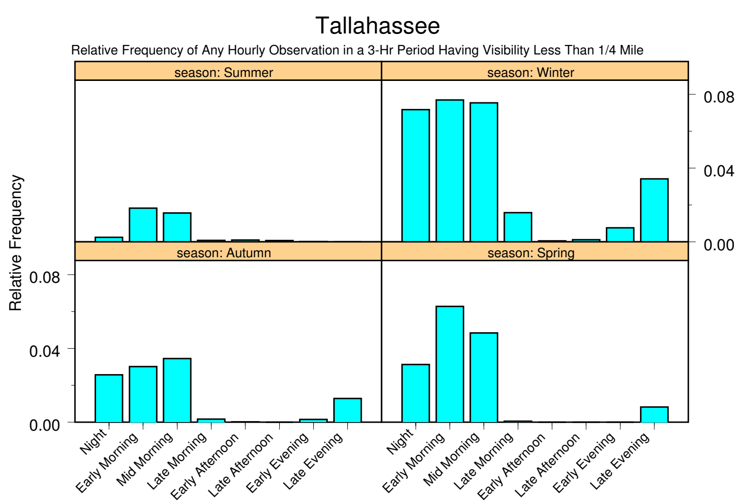
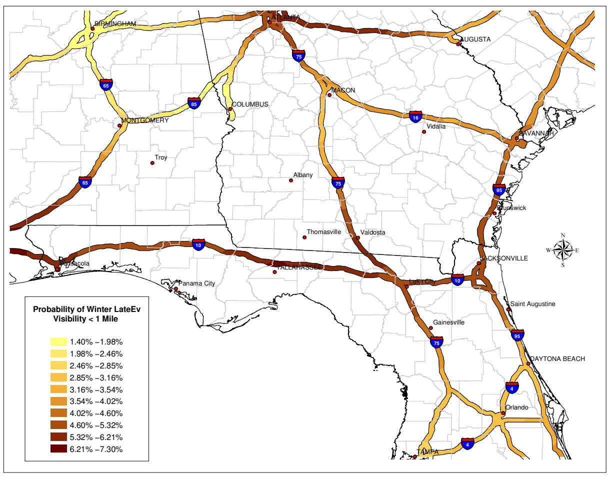
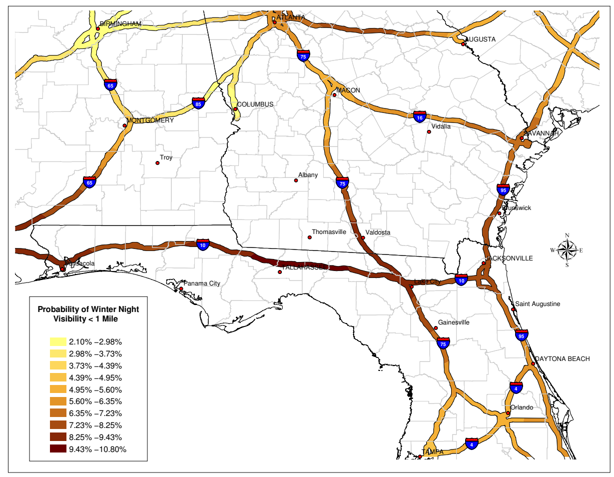


Figure 2: Relative frequency of dense fog in Tallahassee by time of day.

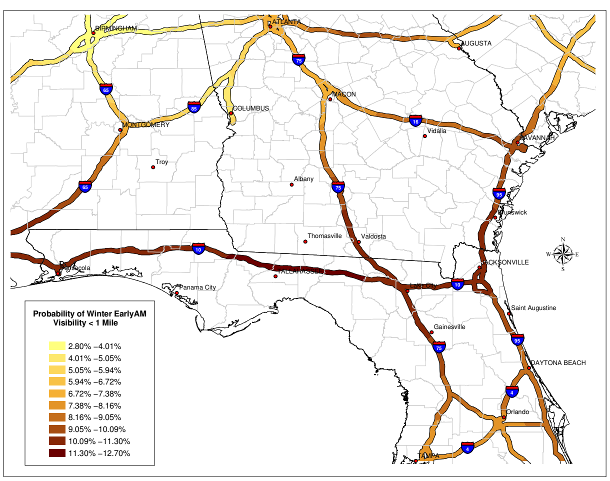
(a) Late Evening (10 pm – 12 midnight)



(b) Night (1 am – 3 am)



(c) Early Morning (4 am – 6 am)



(d) Mid Morning (7 am – 9 am)

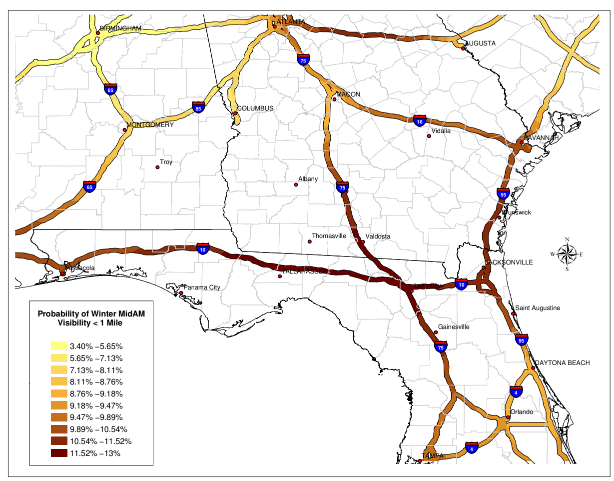
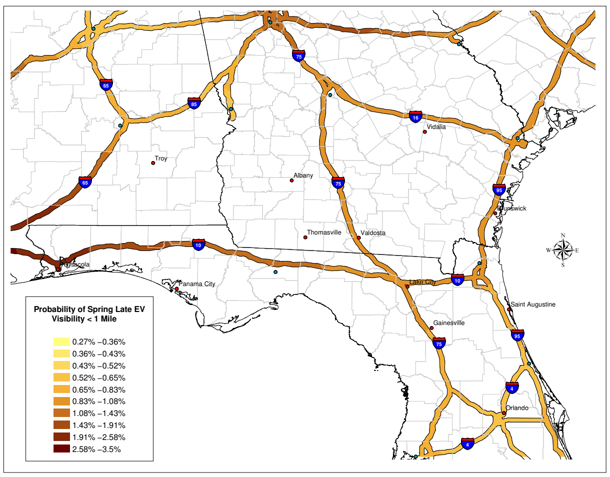


Figure 3: Probability of fog (driver-level visibility less than one mile) during winter (December, January, February).

(a) Late Evening (10 pm – 12 midnight)



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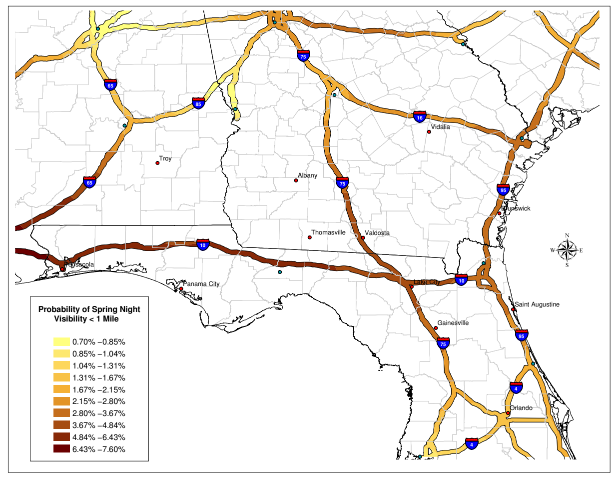

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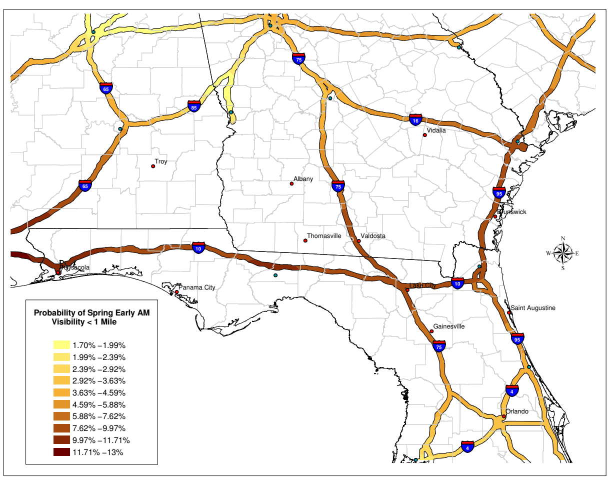


(d) Mid Morning (7 am – 9 am)

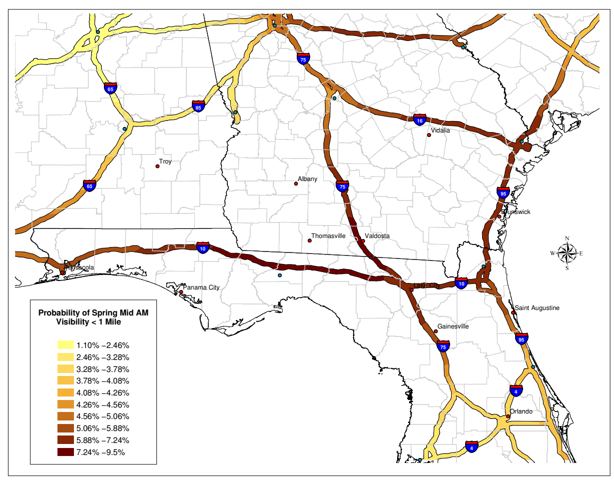
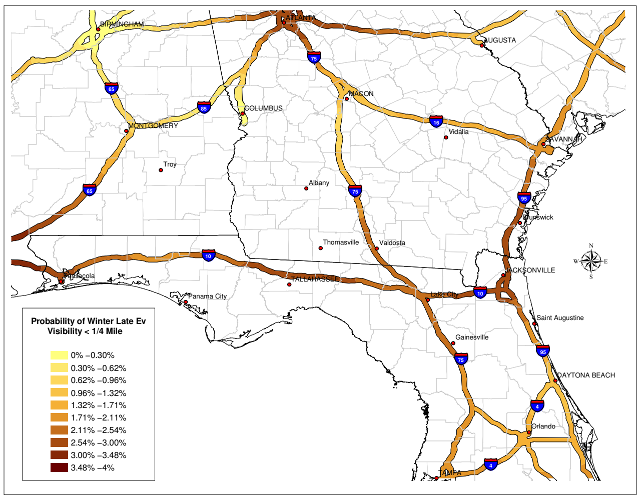
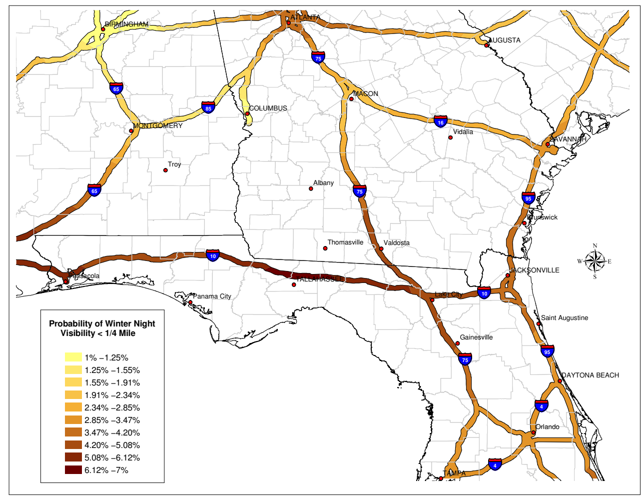


Figure 4: Probability of fog (driver-level visibility less than one mile) during spring (March, April, May).

(a) Late Evening (10 pm – 12 midnight)



(b) Night (1 am – 3 am)



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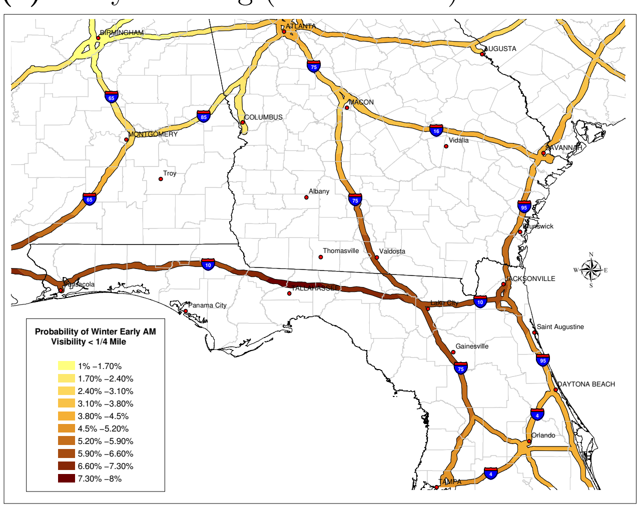

(d) Mid Morning (7 am – 9 am)

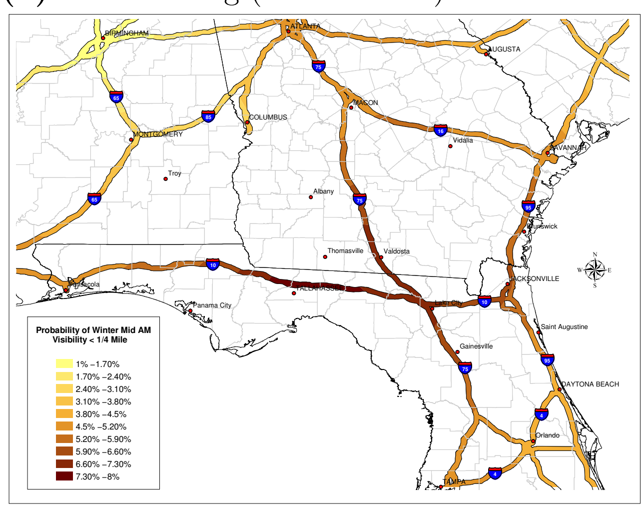

Figure 5: Probability of dense fog (eye-level visibility less than one quarter mile) during winter (December, January, February).

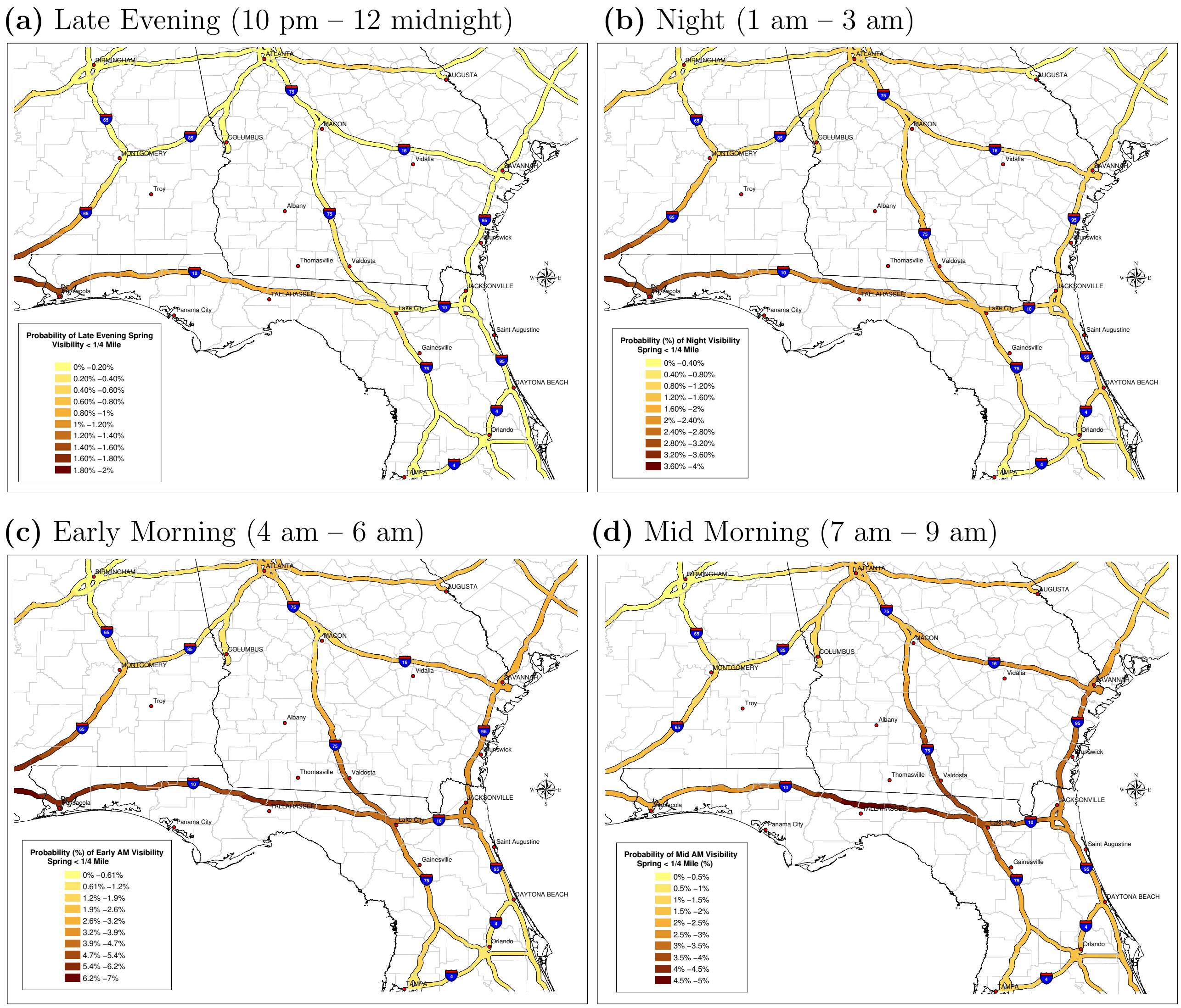

Figure 6: Probability of dense fog (eye-level visibility less than one quarter mile) during spring (March, April, May).

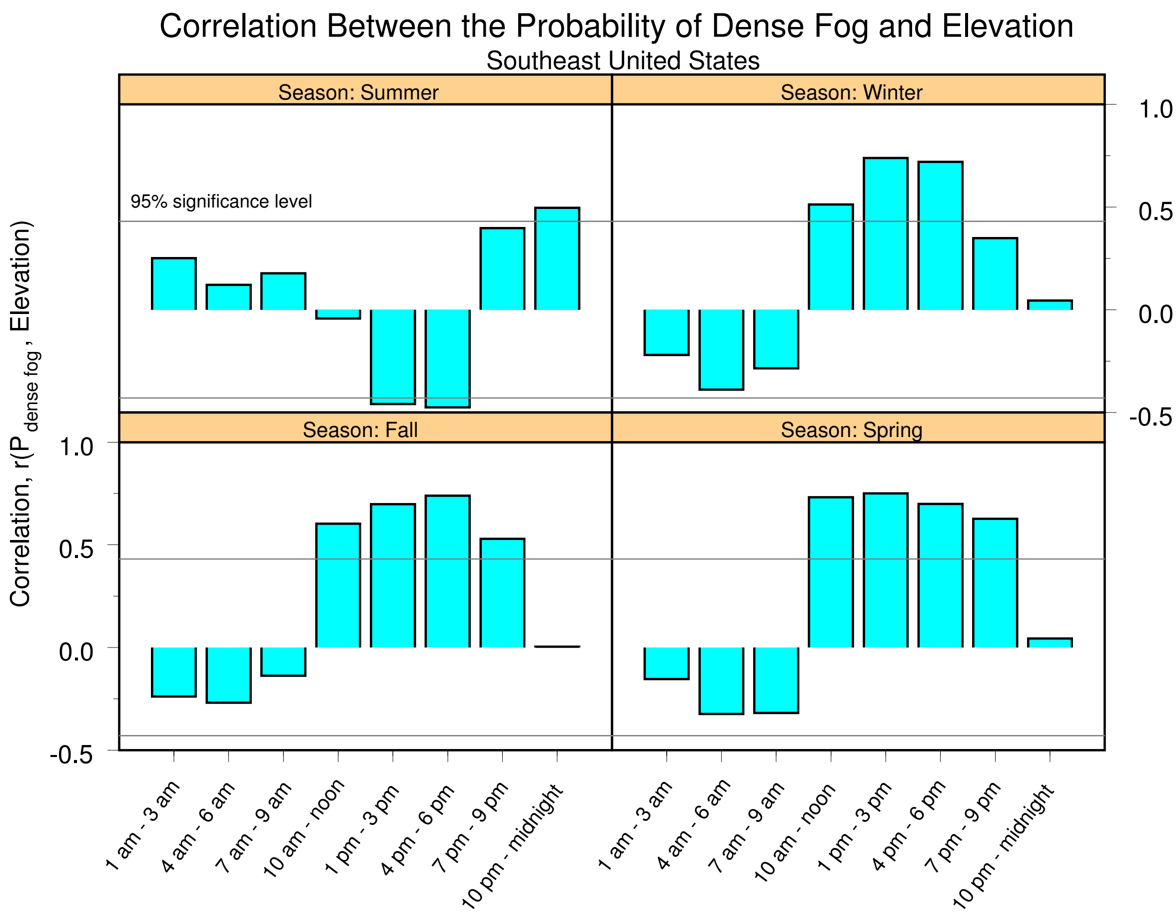

Figure 7: Correlation between the probability of dense fog and elevation conditioned by season and time of day.

Appendix 4

Research Report:

"Simulation of Received Signal Distribution of Line of Sight Communication in Fixed Wireless Environment"

Simulation of Received Signal Distribution of Line of Sight Communication in Fixed Wireless Environment

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ABSTRACT

Modeling the radio channel has historically been one of the most difficult parts of mobile radio system design, and is typically done in a statistical fashion, based on measurements made specifically for an intended communication system or spectrum allocation. Many propagation models have focused on the prediction of the average received signal strength at a given distance from the transmitter. One of the major challenges in achieving such predictions is to accurately characterize the radio propagation channels in the complex environment where various multipaths exist between the transmitter and the receiver. This paper focuses on the channel modeling of the scattering effect on a wireless channel in the case when both transmitter and receiver are at fixed locations. An alternative scattering model is presented without making the probabilistic assumptions as in the conventional approaches, such as the Clarke's scattering model. The model is physics-based, involving an arbitrary number of randomly moving objects in the wireless communication channel. This paper describes the calculation of the average received signal power. The computer simulation results of two representative scenarios are presented.

Keywords: Scattering, Bistatic Radar, Radar Cross Section, Doppler shift

1. INTRODUCTION

In wireless communications, scattering occurs when objects are smaller than the wavelength of the propagating wave. In a physical environment, objects such as trees and trucks tend to scatter the incoming energy in all directions, thereby providing destructive or constructive signal power at the receiver.

The statistical characteristics of the electromagnetic fields of the received signal at the mobile receiver can be studied by applying scattering theory. Several scattering models have been suggested to explain the observed statistical nature of a wireless channel. Clarke's model is commonly used to estimate the received signal at the mobile receiver. This model assumed each wave having equal average amplitude, uniformly distributed phases, and uniformly distributed angles of arrival. Different from Clarke's analysis, this paper relaxes these assumptions in order to simulate a more realistic scattering environment. In reality, the amplitude of each arriving wave bounced off a scatterer is different because each scatterer has unique electromagnetic characteristics. Further, it is more appropriate to consider that different moving object reradiates different signal power. To incorporate these basic mechanisms into a scattering model, the concepts of bistatic radar and radar cross section (RCS) are exploited. A radar system that employs separate antennas for transmitting and receiving is called bistatic radar.

The following sections briefly describe the mathematical models pertaining to scattering, Doppler shift, RCS, and channel modeling. The comparison of Clarke's model and the proposed scattering model is presented with respect to the computer simulation results.

2. EFFECTS OF A SCATTERING OBJECT IN THE CHANNEL

The concept of free-space is an ideal propagation medium for wireless communication. Assume an isotropic point source that radiates P_t Watts. The radiated power from the source is uniformly spread out over any arbitrary point that has the same distance r from the source.

From the Friis free space equation [1], the received power at a receiver antenna that is separated from a radiating transmitter antenna by a distance r is given by [1]

$$\mathrm{Pr} = \frac{P_t G_t G_r l^2}{(4p)^2 r^2 L} \ (Watts) \tag{1}$$

Where P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, *?* is the wavelength (m), *and L* is the system loss factor (L=1).

The power flux density, S (W/m^2) at distance r (m) from a radiation source is given by

$$Sr = \frac{P_t G_t}{4pr^2} = \frac{E^2}{h} = \frac{|E|^2}{377\Omega} \ (W/m^2) \tag{2}$$

Where *?* is the intrinsic impedance of free space that is given by 120p(377O) and |E| represents the magnitude of the E-field in far field region. Then the power received at the receiver antenna, P_r, can be thought as a multiplication of the power density and the effective aperture of the receiver antenna, $A_e(m^2)$. From equation (2),

Now, consider the case of the receiver is not antenna with gain but an object that has arbitrary geometric shape. All types of antenna design are aimed at the efficiency of capturing desired signal in the channel. One dominant factor in an antenna design is the gain of the antenna which is related to its effective aperture, A_e. The gain of an antenna is given by

$$G = \frac{4p \cdot A_e}{l^2} \tag{3}$$

However, when an arbitrary object receives the transmitted signal, the amount of the received signal will be limited by its geometric configuration. By introducing the Radar Cross Section (RCS) concept to the object, the received power at the object can be calculated.

Radar Cross-Section (RCS)

Radar coss-section (RCS) measures the target's reflection of signals in the direction of the receiving antenna [2]. In this paper, one moving object (scatterer) with arbitrary forward-moving direction (the scatterer can not move backwards) with arbitrary velocity (the scatterer can change its velocity continuously every given time segment) is assumed. By reminding the concept of the bistatic radar, moving object in the radio channel can be captured with its own specific RCS and can reradiate signals as a scattered beam toward receiver antenna.
However, the RCS of a specific object is difficult to specify concisely. Slight changes in viewing aspect or frequency result in large fluctuations in cross section. There is no standard, agreed-upon method for specifying the single-valued cross section of an object. The average value or the median might be taken. *Table 1* shows the approximate average RCS values of various object at microwave band.

Object	RCS(m^2)
Pickup truck	200
Automobile	100
Bicycle	2
Man	1
Bird	0.01
Insect	10^{-5}

Table1: Example RCS at microwave frequencies

In the microwave channel, the power received to a small moving object is reradiated (or scattered) to the receiver. The RCS of an object dominates the amplitude of reradiating power. Therefore the scattering power at an object is

$$\text{RCS} \times \text{power density} = P_s = s \cdot S = s\,\frac{P_t G_t}{4pD_t^2}\ (Watts) \tag{4}$$

In the bistatic radar case, mostly the actual RCS (forward-scatter) reduces when compared to backscatter RCS. Therefore when it applied to the scatter modeling, gain factor of 0.1 to 1.0 of backscatter RCS is considered.

Doppler Shift

When a scatterer (or receiver) moves at a constant velocity ?, it receives signals from the transmitter Tx. The difference of path length *?l* traveled by the signal from Tx to mobile receiver is *?l=d·cos?* where *?* is assumed to be the same in point of A and B if we assume that the distance between the transmitter and the mobile receiver is relatively far enough.
Due to the path difference *?l*, the phase also will be changed in the scatter. The phase change *?F* is given by

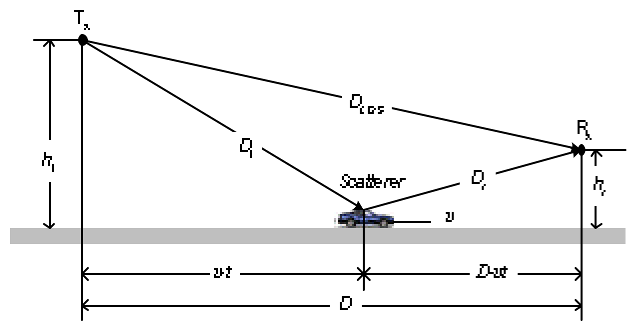
$$\Delta\Phi = \frac{2p \cdot \Delta l}{l} = \frac{2p \cdot v \cdot \Delta t \cdot \cos q}{l} \tag{5}$$

Therefore the Doppler shift is given by

$$f_d = \frac{1}{2p}\frac{\Delta\Phi}{\Delta t} = \frac{v}{l}\cos q \tag{6}$$

Geometry of 2-Dimensional Scattering Model

Consider a scatter moving with a constant ?, from the transmitter toward receiver. Both transmitter and receiver are fixed in one position on the ground with different height h_t and h_r respectively. The scatter model shown in *figure 1* considers possible 2-dimensional geometric layout of the transmitter/receiver and the scatterer. Referring to *figure 1*, ht is the height of the transmitter and hr is the height of the receiver. D_t and D_r are the distance between the transmitter antenna and the scatterer, the distance between the scatterer and the receiver antenna respectively.



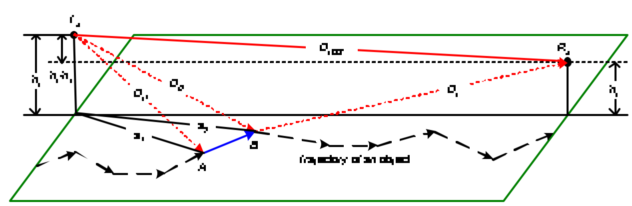
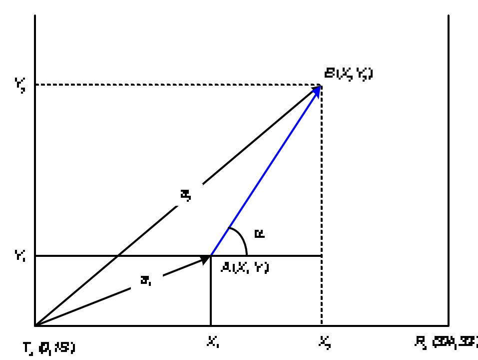


Figure 2: Layout of 3-Dimensional scattering model



directivities of the transmitter and receiver antenna. To analyze the effect of moving object at one specific time instant, geometry of motion on the X-Y plane is considered as *figure 3*. Initial position is given by an arbitrary position in X-Y plane, A=(x_1,y_1). Then from the *figure 3*, The distance between the transmitter and A is given by

$$D_{t_1} = \sqrt{h_t^2 + a_1^2} \quad \text{where} \quad a_1 = \sqrt{x_1^2 + y_1^2} \tag{7}$$

And the second position B=(x_2,y_2) after traveling time *?t* is given by

$$x_2 = x_1 + v \cdot \Delta t \cdot \cos a, \qquad y_2 = y_1 + v \cdot \Delta t \cdot \sin a \tag{8}$$

where $a = \tan^{-1}(\frac{y_2 - y_1}{x_2 - x_1})$

Thus the distance between the transmitter and B is

$$D_{t_2} = \sqrt{h_t^2 + a_2^2} \quad \text{where} \quad a_2 = \sqrt{x_2^2 + y_2^2} \tag{9}$$

As like in the case of 2-D Doppler shift case, *?* is assumed to be the same at point A and B since the transmitter is assumed to be located very far away from the moving scatterer. And also, in the far-field region, the height of microwave antenna is relatively very small when compared to the distance from the moving object. Therefore *?* is assumed to be the same with a in the X-Y plane. The far-field region is considered in the simulation as 200 meters.

the directly received power, P_{direct} is given by $P_{direct} = \frac{P_t G_t}{4pD_{LOS}^2} A_e = \frac{E_0^2}{2h}$

then the E-field and its amplitude at the receiver is

$$E_0 = \sqrt{\frac{P_t G_t A_e h}{2pD_{LOS}^2}} \tag{10}$$

$$E_{direct} = \sqrt{\frac{P_t G_t A_e h}{2pD_{LOS}^2}} \cos\left\{w_c(t - \frac{D_{LOS}}{C})\right\} \tag{11}$$

$$= E_0 \cos\left\{w_c(t - \frac{D_{LOS}}{C})\right\}$$

the incident power of the object at a point with distance D_t from the transmitter is

$$P_{si} = \frac{P_t G_t}{4pD_t^2} RCS = \frac{E_{si0}^2}{2h} \tag{12}$$

and the E-field and its amplitude at the object are given by

$$E_{si0} = \sqrt{\frac{P_t G_t \cdot RCS \cdot h}{2pD_t^2}} \tag{13}$$

$$E_{si} = \sqrt{\frac{P_t G_t \cdot RCS \cdot h}{2pD_t^2}} \cos\left\{w_c(t - \frac{D_t}{C})\right\} \tag{14}$$

$$= E_{si0} \cos\left\{w_c(t - \frac{D_t}{C})\right\}$$

Again like in 2-dimensional model, a forward-scattering RCS and backscattering RCS have related with factor G (0.1 < G < 1). Thus the output power at the object is

$$P_{so} = Psi \cdot \Gamma = \frac{P_t G_t}{4pD_t^2} RCS \cdot \Gamma = \frac{E_{so0}^2}{2h} \tag{15}$$

In the last propagation sequence, the moving object will experience Doppler shift in its frequency. Therefore based on the analysis in 'Determination of Scattered and Doppler shifted E-field' part, the received E-field at receiver via scattering object can be expressed as

$$E_{rr} = E_{rr0} \cos\left\{w_c\left(t - \frac{Dt}{C} - \left(1 + \frac{w_d}{w_c}\right)\frac{D_r}{C}\right)\right\} \tag{16}$$

where $E_{rr0} = \sqrt{\frac{P_{so} h}{2pD_r^2}}$ and Doppler shift frequency $w_d = 2pf_d$

Due to different scattering position of each object, each arriving signal at the receiver antenna will experience path difference. Equation (3.8.8) can be expressed as

$$E_{rr} = E_{rr0} \cos\{w_c(t - t_d)\} \tag{17}$$

where $t_d = \frac{D_t}{C} + \left(1 + \frac{w_d}{w_c}\right)\frac{D_r}{C}$

If a time t_d is taken for the first portion of a signal to arrive at the receiver, the arrived signal should be started to be received after t_d. To consider this time delay element, unit step function is deployed to equation (18). Therefore the signal with time delay t_d due to the indirect path is expressed as

$$E_{rr} = E_{rr0} \cos\{w_c(t - t_d)\} u(t - t_d) \tag{18}$$

where $u(t - t_d) = \frac{1}{2}\left(1 + \frac{t - t_d + e^{-40}}{|t - t_d| + e^{-40}}\right)$

If we assume N moving object in the channel, the overall E-field at the receiver due to n object is

$$E_{rr\_total} = \sum_{n=1}^{N} E_{rrn} = \sum_{n=1}^{N} E_{rr0n} \cos\{w_c(t - t_{dn})\} u(t - t_{dn}) \tag{19}$$

where $t_{dn} = \frac{D_{tn}}{C} + \left(1 + \frac{w_{dn}}{w_c}\right)\frac{D_{rn}}{C}$

This can be expressed as an in-phase and quadrature form given by

$$E_{rr}\_total = T_c \cos(w_c t) u(t - t_d) + T_s \sin(w_c t) u(t - t_d) \tag{20}$$

where $T_c = \sum_{n=1}^{N} E_{rr0n} \cos(w_c t_{dn})$, $T_s = \sum_{n=1}^{N} E_{rr0n} \sin(w_c t_{dn})$

Then the envelope of the received E-field |E|, is given by

$$|E| = \sqrt{T_c^2 + T_s^2} \tag{21}$$

And the reflected signal $E_{reflect}$ is

$$E_{reflect} = -E_0 \cos\left\{w_c(t - \frac{D_{reflect}}{C})\right\} \tag{22}$$

Therefore the total signal at the receiver due to scattering, reflection, and direct signal is sum of all paths.

$$E_{total} = E_{direct} + E_{reflect} + E_{rr\_total} \tag{23}$$

$$= E_0 \cos\left\{w_c(t - \frac{D_{LOS}}{C})\right\} - E_0 \cos\left\{w_c(t - \frac{D_{reflect}}{C})\right\}$$

$$+ \sum_{n=1}^{N} E_{rr0n} \cos\left\{w_c\left(t - \frac{Dtn}{C} - \left(1 + \frac{w_{dn}}{w_c}\right)\frac{D_{rn}}{C}\right)\right\}$$

3. SIMULATION RESULTS

Clarke's model is 2-dimensional. It is intended to characterize the scattering effects that take place between a fixed transmitter to a mobile receiver on a plane. More specifically, the model accounts for the spectral spreading due to the Doppler effect. *Figure 4* shows the simulation results of scattering objects in a wireless channel predicted by the Clarke's model.

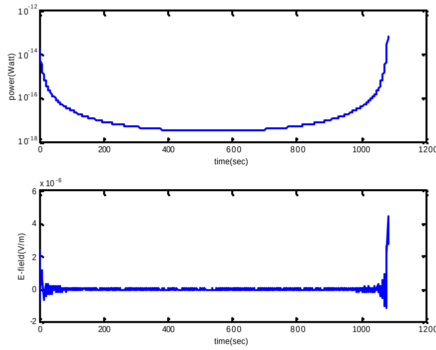


Figure 4: Scatter plots of Clarke's model

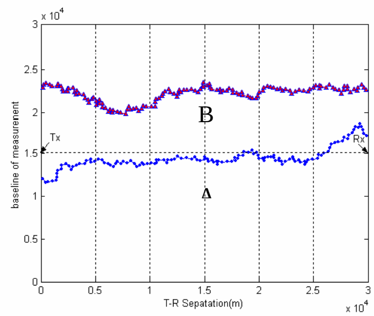
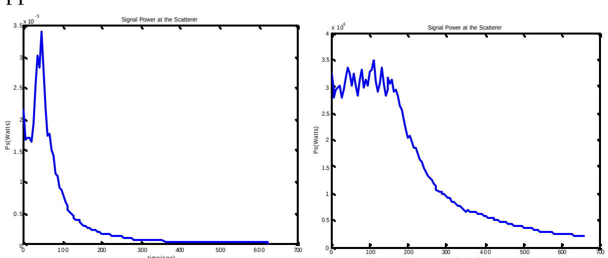


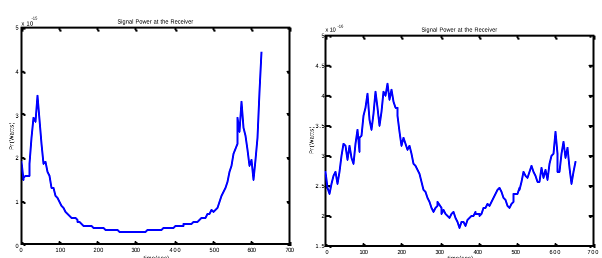
Figure 5: Two different trajectories of vehicles

The proposed model deals with scattering due to moving objects in the channel of a fixed link. *Figure 5* shows two different trajectories of moving objects with the same RCS on the X-Y plane. Each trajectory is generated by an object moving randomly in a forward direction with velocity in the range 50~100 km/hr. The transmitter and the receiver have heights h_t,= 100m and h_r = 50m, respectively. *Figure 6* shows the signal power intercepted by a scatterer gradually decreases as it approaches the receiver side.



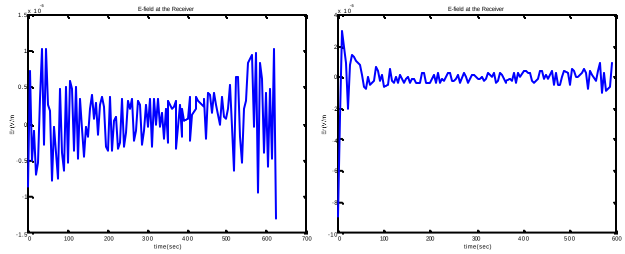
(a) Trajectory A (b) Trajectory B

Figure 6: Plot of received power at the scatterer with two different trajectories



(a) Trajectory A (b) Trajectory B

Figure 7: Plot of received power at the receiver with two different trajectories



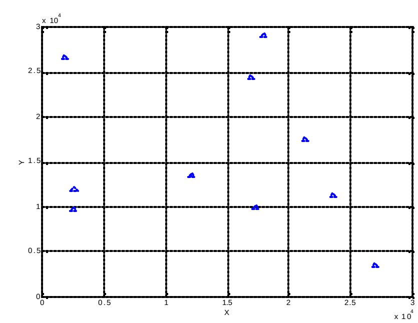
(a) Trajectory A (b) Trajectory B

Figure 8: Plot of received E-field at the receiver with two different trajectories.

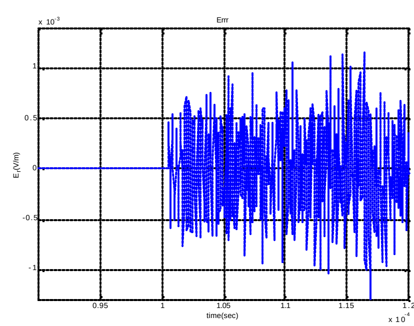
Figures 7 and *8* depict the effect of Doppler shift due to a moving object in the wireless channel. When the trajectory (A) is close to the direct path, the signal-power and E-field plots show an agreement with the Clarke's scattering model. When the trajectory (B) is farther away from the direct path, the signal-power and E-field plots tend to indicate dissimilar distortion characteristics.

Random object motion with 3-dimensional model

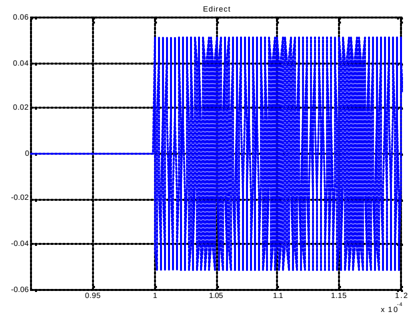
In this scenario, each object is assumed to have different direction and velocity in the channel in order to maximize the random nature of scattering. *Figure 9*(*a*) shows the trajectories of randomly moving objects in the x-y plane. The corresponding direct signal, the ground reflected signal, and the scattered signal are generated. According to equation (23) all the signal components are summed together at the receiver antenna. *Figures 9*(*b*) – *9*(*e*) show each received signals from different propagation paths. As expected, the histogram plot of received signal due to scattering shows Rayleigh distributions in all the scenarios simulated.



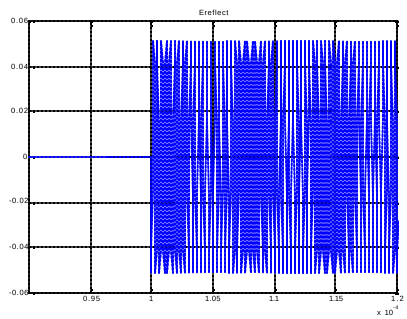
(a) trajectories of moving objects



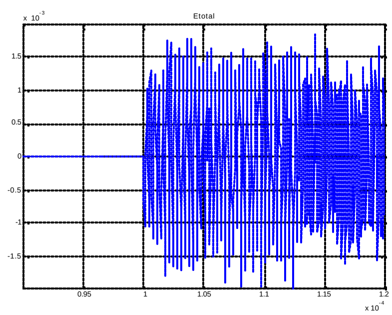
(b) received E-field at receiver



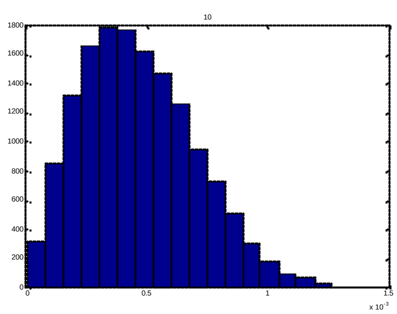
(c) direct E-field at receiver



(d) reflected E-field at receiver



(e) total received E-field



(f) histogram of the envelope

Figure 9: simulation results of total received signal with short slot time $5*10^{-4}$ (sec) in random direction and random velocity model.

4. CONCLUSION

The performance of a wireless system is dependent upon accurate knowledge of the wireless channel characteristics. To reduce signal distortion in a fixed line-of-sight (LOS) wireless communication system, the study of scattering is essential. An alternative method of modeling the effects of scattering by randomly moving objects has been proposed. This model utilizes the notion of RCS associated with bistatic radar and incorporates the Doppler shift in frequency in calculating the strength of the received signal. This research effort has demonstrated the effects of moving objects in a fixed LOS wireless communication channel. The computer simulations clearly indicate the effect of scattering on the direct signal. The envelope of the composite signals follows the Rayleigh distribution.

This model is suited for modeling various scenarios, including (1) when the channel has dynamically time-varying characteristics due to moving object in the channel, and (2) the channel has huge topographical obstacles in the channel. Future research will be focused on the identification of indirect path for reliable transmission. This will provide an insight for the design of MIMO (Multi-Input Multi-Output) systems, which can extend the conventional wireless communication capacity as well as efficiency.

5. REFERENCES

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Appendix 5

Research Report:

"Comparison & Statistical Analysis of the Radio Refractive Index of Air through Empirical Formula and Mathematical Models"

Comparison & Statistical Analysis of the Radio Refractive Index of Air through Empirical Formula and Mathematical Models

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ABSTRACT

Radio refractive index of air plays an important role in the propagation of RF waves in free air. If the values of atmospheric pressure, temperature and vapor pressure are known for several heights, refractive index can be calculated using empirical formula otherwise mathematical models are used to estimate the values of refractive index for different heights above the surface. In this paper several mathematical models including Effective Earth Radius, Modified Effective Earth Radius, and Exponential model to calculate the radio refractive index are discussed and compared with the empirical formula. The accuracy and reliability of these models are then presented for a number of different weather conditions. The paper also discusses the average values of modified refractive indices at the surface for a number of stations all around the USA.

Keywords: Radio Refractive Index, RF Waves, Refractive Index Empirical Formula, and Refractive Index Mathematical Models

1. INTRODUCTION

Radio refractive index of air plays an important role in the bending of radio frequency waves in free air, especially in the lower atmosphere, most notably the troposphere. The atmosphere above the surface of the earth is divided into several layers, each with a refractive index value. When radio waves pass through these layers they tend to deviate from their straight path due to the difference in the refractive index values of different atmospheric layers. Refractive index value depends on several weather parameters such as total air pressure, air temperature, and water vapor pressure. The refractive index of air has values slightly greater than unity near the earth's surface and approaches unity with increasing heights. Since values of refractive index are very close to unity at all the heights, modified refractive index is used instead of real refractive index for practicality.

Values of weather parameters are not always available for different heights, hence it is hard to evaluate the refractive index of air using empirical formula. In this case, mathematical models are used to estimate values of radio refractive index. The use of mathematical models to estimate the radio refractive index is limited, as they cannot predict abrupt change in the refractive index due to the weather anomalies, for example in case of the weather ducts.

The following section explains the empirical formula and different mathematical models including effective earth radius, modified effective earth radius, and exponential model. Next, simulative comparison of different models with the empirical formula is presented using weather data from different stations around the US having different weather properties. Average refractive index values at the surface height for several stations are then presented using the empirical formula.

2. CALCULATION OF RADIO REFRACTIVE INDEX

Empirical Formula

The empirical formula to calculate modified refractive index value is given by [1]

$$N = (n-1)x10^{6} = \frac{77.6}{T}\left(P + \frac{4810\,e}{T}\right) \tag{1}$$

where N is the modified refractive index, n is the real refractive index, T is the atmospheric temperature in Celsius, P is the total atmospheric pressure in millibar (or hPa), and e is the partial pressure of water vapor pressure in millibar (or hPa). This expression gives the value of N within 0.02% of error for T = -40 to 50 ^{o}C

Mathematical Models

Since values of pressure, temperature, and water vapor pressure are not always available for different heights hence mathematical models are developed to calculate the value of modified refractive index. Three of these models are explained as follows.

Linear or Effective Earth's Radius Model: This method assumes a fictitious earth larger than the actual earth with effective radius a_e. The curvature of this earth absorbs the curvature of radio rays and hence the relative curvature of the two remains the same and radio rays can be drawn as straight lines over this earth rather than curved rays over the true earth. This method of accounting for atmospheric refraction permits a tremendous simplification in many practical problems of radio propagation engineering although the height distribution of refractive index implied by this model is not a very realistic representation of the average refractive index structure of the atmosphere. This model estimates closer values of refractive index in the first few kilometers above the surface of the earth but deviates tremendously as the height increases. This model is also commonly known as 4/3 Earth Model. The expression to calculate the modified refractive index as suggested by this model is

$$N = N_s - \frac{h - h_s}{4a} x10^{6} \tag{2}$$

where N_s is the refractive index value at the surface, h is the total height of refractive layer, h_s is the elevation of the station above sea-level, and a is the radius of the earth. These terms can more clearly be defined by the geometry of ray propagation from one layer to the next as shown in *figure1*.

Modified Effective Earth's Radius Model: Effective earth's radius model gives good estimate of the refractive index at lower heights but as the height increases the error in refractive index as calculated by this model increases. This is due to the fact that the observed refractivity is an exponential function of height rather than linear. Modified effective earth's radius model overcomes this problem by dividing the atmosphere into three layers and suggesting three models as follows.

First model of atmospheric refractivity based upon the effective earth's radius concept in the first kilometer. N is assumed to decay linearly with height from the earth's surface h_s to 1 km above the surface h_s+1

$$N(h) = N_s + (h - h_s)DN \tag{3}$$

where $-\Delta N = 7.32e^{0.005577N_s} = N_s - N(1\ km)$

N decreases exponentially from h_s+1 to a constant value of 105 at 9 km above sea level i.e. for $h_s + 1 \le h \le 9km$

$$N = N_1 e^{-c(h-h_s-1)} \tag{4}$$

where $N_1 = N$ @ 1 km; $c = \dfrac{1}{8-h_s}\ln\dfrac{N_1}{105}$

Less than 10% of the total bending occurs above h = 9 km

$$N = 105e^{-0.1424(h-9)} \tag{5}$$

At h = infinity, N = 0.

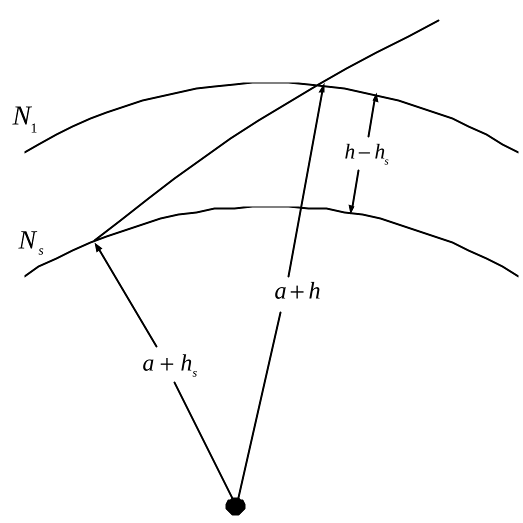

Figure 1: *Ray Propagation*

Exponential Model: The next model to be considered may be specified by assuming a single exponential distribution of N:

$$N = N_s e^{-c_e(h-h_s)} \tag{6}$$

where $c_e = \ln\dfrac{N_s}{N(1km)} = \ln\dfrac{N_s}{N_s+\Delta N}$

This model of atmospheric refractivity is a close representation of the average refractivity structure within the first 3 km. Further the single exponential model has the advantage of being an entire function, and therefore is easily used in theoretical studies

3. COMPARISON OF THE REFRACTIVE MODELS

The three models are compared against empirical formula using the weather data obtained from University of Wyoming [2] and surface elevation data obtained from MIT [3]. Two stations are chosen: Tallahassee, FL and Chatham, MA. These stations are chosen as Tallahassee has a moderate weather throughout the year and Chatham has extreme weather. Two sets of weather data are used: 1st August 2002 (around 12:00PM) and 1st January 2003 (around 12:00PM). The comparison is shown in *figure 2* to *figure 5*.

From the plots it is quite evident that modified effective earth's model and exponential model follow the empirical values of refractive index closely while the effective earth's model is closer in the first few kilometers (under some weather conditions) but departs from the true values as the height keeps on increasing. Also, none of the model can predict the abrupt changes in the refractive index as calculated from empirical formula due to the anomalous change in the weather parameters. In the first plot (*figure 2*) the difference between the empirical formula and 4/3 model up to 1.5 km is around 5%. As the distance increases this difference also increases and at 3 km it's around 16%. The difference between exponential model and the empirical formula is around 5% at 1.5 km, around 10% at 4 km and around 16% at 8 km. The difference between modified effective earth's radius and empirical formula is around 3% at 1.5 km, around 4% error at 4 km and they almost overlap around 8 km. After 9 km the modified model almost overlaps with the exponential model and both yield almost the same error comparing with the empirical formula. This data corresponds to a cold weather with low dew point temperatures (near zero ^oC) i.e. low vapor pressures.

Weather corresponding to *figure 3* produced refractive index profile that is not very smooth. However in this figure 4/3 model seems to predict closer values up to 4 km with a maximum error of 8%. After 4 km the error keeps on increasing. Modified effective earth's radius and exponential model follow the empirical formula up to 5 km with a maximum error of around 7.6% and from 5 to 8 km with a maximum error of 5% and 15% respectively. This weather corresponds to high temperatures and high vapor pressure.

Figure 4 corresponds to weather condition with moderate temperatures and high vapor pressures. As it can be seen 4/3 model follows the empirical formula up to 3 km with reasonable error, then the error start getting bigger. Up to 3 km both the modified and exponential models follow the empirical formula with low error, between 3 km to 5 km exponential model is closer to the empirical formula while from 5 km to 7 km modified model is closer.

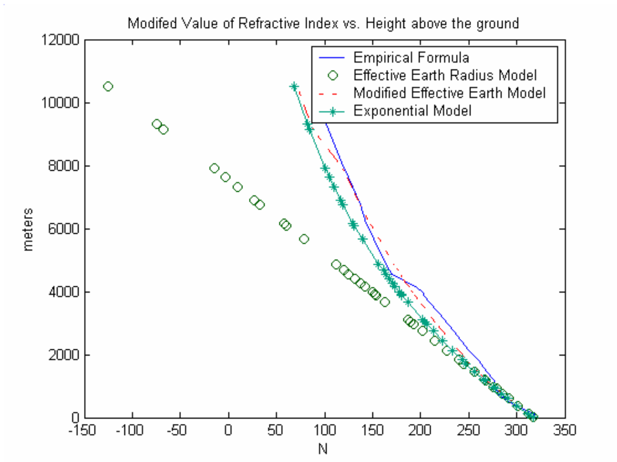

Figure 2: *Chatham, MA - 1st Jan 2003 – 12PM*

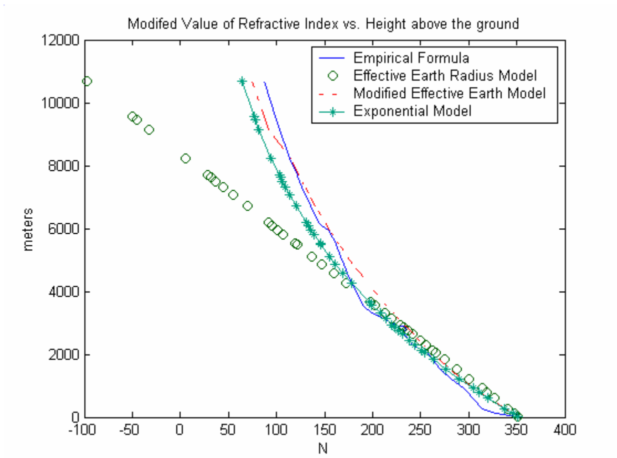

Figure 3: *Chatham, MA - 1st Aug 2002 – 12PM*

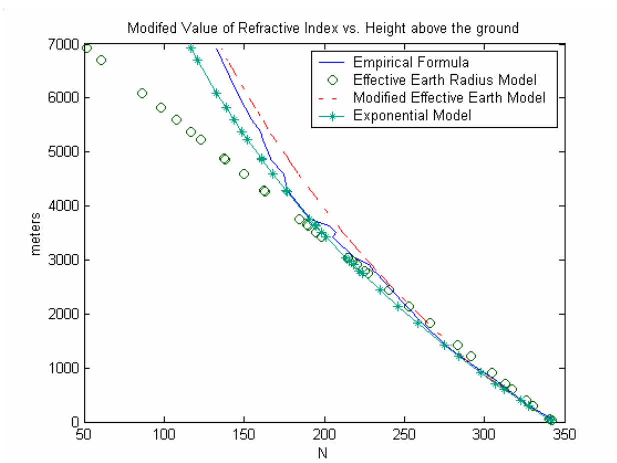

Figure 4: *Tallahassee, FL - 1st Jan 2003 – 12PM*

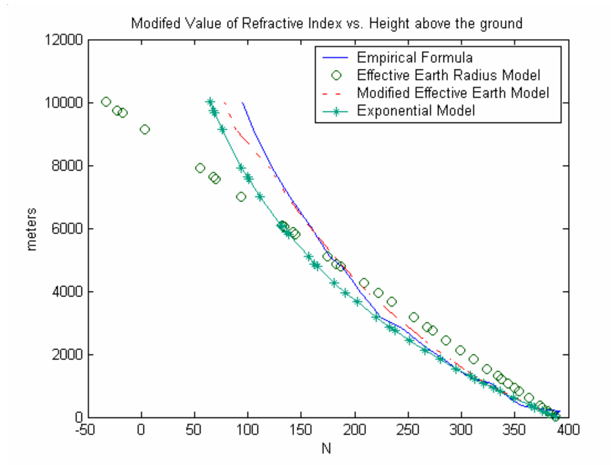

Figure 5: *Tallahassee, FL - 1st Aug 2002 – 12PM*

Figure 5 corresponds to weather condition with high temperatures and high vapor pressures. 4/3 model is quite off from the empirical formula for almost all the heights. Up to 3 km both the modified and exponential models follow the empirical formula closely. From 3 km to 8 km modified model is very close to the empirical formula than the exponential model.

All the weather conditions discussed so far have almost the same values of total air pressure for all the heights. Only difference is in the values of temperatures and dew point temperatures. *Figure 2* corresponds to cold temperature condition with low dew point temperatures (low vapor pressures), rest of the figures correspond to moderate or high temperatures with high vapor pressures. Refractive indices calculated from the empirical formula and mathematical models for Tallahassee weather in January with low dew point temperatures (low vapor pressures) is shown in *figure 6*. As can be seen from this figure, which is quite closer to *figure 2* (since condition of dew point temperatures are almost the same in two), the 4/3 model works fine for the first 1.5 km, modified model works good for all the heights and exponential model is the closest after modified model for all the heights.

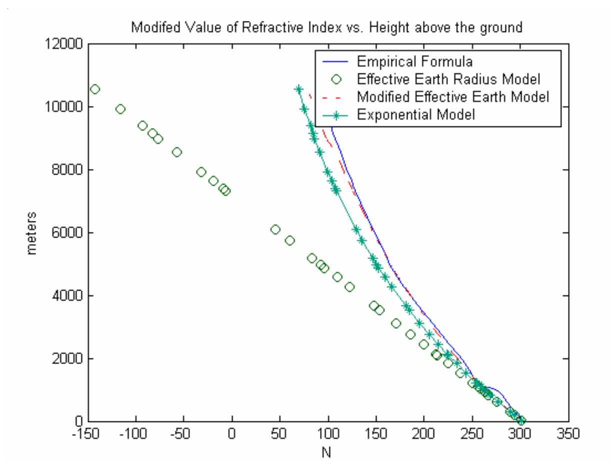

Figure 6: *Tallahassee, FL – 15th Jan 2003 – 12AM*

Table 1 shows the approximate average values of modified refractive indices at the surface level for a number of different stations all around The USA for the months of January and August along with the average elevation above the sea level.

Table 1: *Values of 'N_s' and 'h_s'*

Station	N_s *(Jan)*	N_s *(Aug)*	h_s *(feet)*
Chatham, MA	321	351	46
Tallahassee, FL	345	393	160
Key West, FL	375	393	7
Jacksonville, FL	347	370	8
Newport, NC	351	378	21
Lake Charles, LA	320	386	20
Oakland, CA	330	340	42

4. CONCLUSION

Radio refractive index of air plays an important role in the propagation of radio waves. Refractive indices for different layers of air above the surface can be calculated with the use of empirical formula if total atmospheric pressure, temperature, and vapor pressure (or dew point temperature) are known for all the heights. Refractive index can also be estimated with the help of mathematical models. The best mathematical model under almost all weather conditions and for all heights is the Modified Effective Earth's Radius model. The problem with this model is that it consists of three expressions for three different height ranges and also it requires the knowledge of elevation of the station above sea level. The Exponential model works well within 3 km above the surface for a weather condition with low temperatures and low vapor pressures and up to 4 to 4.5 km for weather conditions with high temperatures and high vapor pressures. It consists of a single expression that makes it attractive to use and it doesn't require the knowledge of elevation above the sea level either. Effective Earth's Radius model estimates the value of refractive index using a linear expression. It works fine within 1.5 km above the surface for low temperatures and low vapor pressure conditions and up to 3 km for high or moderate temperatures, high vapor pressure conditions.

5. REFERENCES

[1] B. R. Bean and E. J. Dutton, **Radio Meteorology**, New York: Dover Publications, Inc., 1968.

[2] **http://weather.uwyo.edu/upperair/sounding.html**

[3] **http://www.mit.edu: 8001/geo**