MEASUREMENT, VALIDATION, ANALYSIS AND DISSEMINATION OF HURRICANE WIND DATA

By

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A REPORT PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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This document is dedicated to my family for their support and prayers.

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The University of Florida, Clemson University, and Florida Institute of Technology comprise the Florida Coastal (FCMP), which was founded in 1998 under sponsorship from the Department of Community Affairs. FCMP team members consisting of faculty members, graduate students and undergraduate students deploy every year during the Atlantic Hurricane Season for any hurricane that threatens the southeastern coast of the United States. One of the main goals is to collect high resolution data of the wind to pursue new research into wind behavior.

Once the data is collected it needs to be post-processed and validated in order to provide a reliable data set to researchers. FCMP purpose is to collect, analyze and disseminate the data. This report presents methods used by author to validate, analyze and disseminate the data. For the validation process, four methods will be presented in this report, which are: 1) self-validating, 2) comparison of data acquired from Tower XP and Tower CBI, 3) comparison of data with wind surface analysis model developed by the NOAA Hurricane Research Division (HRD), and 4) comparison with outside source like, ASOS, METAR, C-MAN or BOUY station that were used to monitor the same

event. The data analysis will present for the first time in the FCMP history a procedure used to compute lateral length scales of the wind gust. Finally the dissemination of the data will present upgrades that have been made by the author to WinDLab software developed in the past by FCMP members at the University of Florida. The packaging and dissemination of it with wind data collected will be available to the public through FCMP web page at http://www.ce.ufl.edu/~fcmp/.

CHAPTER 1
INTRODUCTION

Hurricane History

Hurricanes are migratory tropical cyclones that originate over oceans in certain regions near the equator or the West Indian region, including the Caribbean Sea and the Gulf of Mexico. The term hurricane is probably derived from "Hurukan", the name of the Mayan storm god, and other similar native Caribbean words translated as "evil spirit" or "big wind" [Barnes, Florida's Hurricane History, 1998]. They consist of high-velocity winds blowing circularly around a low-pressure center, known as the *eye* of the storm. The low-pressure center develops when warm, saturated air is underrun and forced upward by denser, cooler air. From the edge of the storm toward its center, the atmospheric pressure drops sharply as the wind velocity rises.

Hurricanes generally move in a path resembling the shape of a parabola. In the northern hemisphere, the storms usually travel first in a northwesterly direction and when in the higher latitudes turn toward the northeast. In the southern hemisphere the usual path of a hurricane is initially to the southwest and subsequently to the southeast. Hurricanes travel at varying rates. In the lower latitudes the rate ranges from 8 to 32 km/h (5 to 20 mph) and in the higher latitudes it may increase to as much as 80 km/h (50 mph). Those areas in which the hurricane winds blow in the same direction as the general movement of the storm are subjected to the maximum destructive violence of the hurricane [*Microsoft Encarta Reference Library,* 2004].

Hurricanes are classified by an intensity rated from one (1) to five (5) using the Saffir-Simpson Scale, which depends upon the wind velocity of the storm. The least destructive category, Category One, has one-minute sustained winds of at least 74 mph (120 km/h). The most destructive, Category 5 has winds that exceed 155 mph (250 km/h). Table 1 summarizes the categories used to classified these atmospheric phenomenon. As seen in the table, the storm intensity may also be classified by barometric pressure or the resultant damage to man made structures. However, sustained wind speed is most commonly associated with the Saffir-Simpson intensity scale.

Table 1-1. Saffir-Simpson Scale

Category	Description	Barometric Pressure		Wind Speed		Storm Surge		Damage Potential
		mb	in	km/hr	mph	m	ft	
5	Devastating	<920	<27	>250	>155	>5.5	>18	Catastrophic damage to structures
4	Very strong	920-944	27.0-27.90	211-249	131-155	4.0-5.5	13-18	Extreme structural damage
3	Strong	945-964	27.91-28.49	179-210	111-130	2.7-3.9	9-12	Extreme structural damage
2	Moderate	965-979	28.50-28.93	154-178	96-110	1.8-2.6	6-8	Moderate damage to houses
1	Weak	980 and over	28.94 and over	120-153	75-95	1.2-1.7	4-5	Minimal damage to vegetation

The Saffir-Simpson scale was developed in the 1970s by Herbert Saffir and National Hurricane Center director Robert Simpson. The scale rates a hurricane's intensity based on wind speed, and helps estimate damage and flooding from a hurricane landfall.

Military aircraft have been flying into hurricanes since 1943 to measure wind velocities, location and size of the eye, pressures within the storm, and their thermal structure. Such data are used for classifying storm intensity and forecasting the storm path and translation speed. Radar, sea-based recording devices, geosynchronous weather satellites, and other devices are now used to supply data to the National Hurricane Center in Florida, which follows each storm virtually from the beginning until its end. This tracking and forecasting has been responsible for great reductions in injury and death.

Improved systems of prediction and communication have been able to help minimize loss of life in hurricanes, thanks to both accurate forecasting and rapid warnings to those in vulnerable areas. However, property damage is still heavy, particularly in coastal regions.

During the last decade the Eastern and Gulf Coasts of US have been struck by several hurricanes. Specifically the State of Florida has been hit by destructive hurricanes including Andrew, a Category 4 hurricane that struck near Homestead in 1992, with nearly $25 billion in damage, more than 50 dead, and thousands left homeless. Opal made landfall near Pensacola Beach, Florida in 1995. Most of the damage attributed to this storm was storm surge, which was responsible for $3 billion in damage.

The vulnerability of property has prompted research toward mitigating damage through retrofits and improved construction procedures. These efforts are dependent upon the development of an improved understanding of the way extreme winds behave as they approach and interact with structures. Several programs have emerged over the past decade to provide the data necessary to guide damage mitigation research. This report documents several important contributions to one such program, addressed in the next section.

Overview of a Full-Scale Hurricane Wind Measurement Project

The Florida Coastal Monitoring Program (FCMP) sponsored by the Florida Department of Community Affairs and FEMA has its origin in 1998. As a joint venture between Clemson University and University of Florida, the purpose is to quantify near-surface hurricane wind behavior using full-scale experiential methods. This project is intended to help in the process of reducing hurricane wind damage to residential structures by providing 'ground-truth' data about the intensity of the wind and the resultant loads on residential structures. This study is of special importance in Florida where a total of 1300 coastline miles are vulnerable to hurricanes during the hurricane season -from June to November- of each year.

The FCMP instrumentation and equipment consists of two separate data collection systems. The first system uses four portable towers designed and built at Clemson University to monitor wind velocity at 5 and 10-meter during a hurricane event. The towers are equipped with instruments to monitor wind velocity, barometric pressure, temperature, rate of rainfall, and relative humidity. For the hurricane season of 2003, two of the four mobile towers were improved with 5 meters portable satellites towers to work simultaneously with the same data acquisition system. This provided the FCMP with the necessary data to computer lateral length size of wind gust, discussed in Chapter 4. The second system collects wind pressure data on the roofs of occupied residential structures. The 30 participating homes are scattered throughout the coastal regions of Florida. Together, the tower and house monitoring systems provide high resolution time histories of both the turbulent wind field over land and the resultant fluctuating pressures on the most vulnerable components of residential homes. Figure 1-1 presents a mobile tower setup near an instrumented house and the satellites towers that were deployed for the first time during the 2003 hurricane season.

Figure 1-1. Mobile tower FCMP deployment for hurricane Michelle during 2001 hurricane season (right). Satellite tower testing at Florida Department of Transportation in Gainesville, FL (right).

The FCMP has been evolving since its inception in 1998. Newer data collection systems and improved hardware and deployment strategies have produced a very reliable system for collecting rare, perishable, and important data. Numerous students have made significant contributions to achieve this reliability.

The contributions made in this study focus on collection, validation, analysis, and dissemination of data. The tasks are to develop software tools to aid in efficient deployment strategies, process the raw collected data, validate the reliability of existing data sets, and develop and distribute a user-friendly interface to analyze the data sets. For the data processing and validation studies, results are provided for tropical storm Isidore[1] and hurricanes Lili[2] and Isabel[3]. Future students will use the tools presented herein to

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[1] Tropical Strom at landfall Isidore Sept/2002

[2] Hurricane Category I at landfall Lili Oct/2002

[3] Hurricane Category II at landfall Isabel Sept/2003

conduct a comprehensive analysis of all existing FCMP data sets. The FCMP web site will be used to disseminate the validated data and the analysis software.

The specific research contributions discussed in this report are delineated below, and presented in detail in the following chapters.

- Train deployment teams and participate in deployments (Chapter 2)
- Develop and construct additional hardware and maintain equipment (Chapter 2)
- Create ArcGIS system to aid in deployments and data validation (Chapter 2)
- Design and program schemes to validate collected data (Chapter 3)
- Conduct analysis of new data sets (since 2002) (Chapter 4)
- Continue the development of WinDLab GUI-based data analysis software for public dissemination and analysis of data sets (Chapter 5)

CHAPTER 2
MEASUREMENT SYSTEMS

Overview

FCMP deployment teams and Clemson University (students and faculty) closely monitor the NHC severe weather bulletins from June 1 to November 30 each year. Teams are ready to deploy to measure any hurricanes that threaten to make landfall along the U.S. coast. During the summer, FCMP personnel provide maintenance to vehicles and tower equipments to make sure everything is ready for deployment.

Once a hurricane threatens to make landfall, teams prepare to deploy two to three days before the expected landfall. UF and Clemson University crews split up into multiple teams depending on how many mobile towers and houses are to be deployed for any particular event. In most cases at least eight people are involved in total. For safety reasons, the goal is to erect the mobile towers and setup the instrumented houses at least 24 hours before landfall, and then move inland to a safe area.

Deployments Techniques

There are three possible configurations to setup a mobile tower:

1. Configuration type one: Isolated Mobile Tower.
2. Configuration type two: Mobile Tower with two Satellites Towers.
3. Configuration type three: Mobile Tower close to an instrumented house.

Working under an ideal situation, in which all instruments function properly and there is only light to moderate rain, the scenario to setup each configuration is presented next. Figure 2-1 presents a deployment configuration type two.

Figure 2-1. Mobile Tower configuration two. (Wilmington, NC - September, 2003 Hurricane Isabel)

At least a two member team will be needed to deploy a single isolated tower (configuration one). The setup time for a team of three trained members deploying a single tower with no satellite towers is 20-25 minutes. The second configuration is a mobile tower with two satellites towers. The satellite tower deployment is labor intensive, requiring a team of four people and a time frame of about 45-60 minutes (see Figure 2-1). Both configurations one and two require additional time to identify an appropriate location and to secure permission to use the land. A scouting team is often used to identify potential deployment locations for some or all of the tower teams. The scouts do not tow any equipment, providing additional mobility and responsiveness. Personnel at the National Weather Service are contacted to get up-to-date storm path predictions. This information is vital to identify the region to consider for deployment. For example, storm path predictions may help teams to decide between targeting Jacksonville, St. Augustine or Daytona Beach, while the scouting teams isolate specific locations within the selected region.

The third configuration is to set up an isolated mobile tower near an instrumented house to capture approach winds. At least two members are needed for the tower and four working on the house. The time frame for the tower is 20-25 minutes and a single house instrumentation requires at least 2 hours. The decision to include house instrumentation in a deployment depends upon the likelihood of landfall near the 30 participating homes along the Florida coast. Once a team has finished their task they contact other teams to check their situation and assist them if necessary. Otherwise they move inland to a safe location and wait for hurricane landfall.

Table 2-1 presents the timeline for tower deployment during hurricane seasons 2002 and 2003. This provides an idea of the time frame required for future deployments.

Table 2-1. Tower setup time differences

Tropical Strom:	**Isidore (2002 - Tropical Storm at landfall)**			
FCMP Mobile Tower	**Configuration Type**	**Location**	**UTC Time Start Collecting Data (Date HH:MM)**	**Time Difference (HH:MM)**
T2	1	Gulf Breeze, FL	9/25/02 20:44	-
T0	1	Mary Esther, FL	9/26/02 0:53	4:09:51
T1	1	Gulf Breeze, FL	9/26/02 19:20	22:36:32
Hurricane:	**Lili (2002 - Category 1 at landfall)**			
FCMP Mobile Tower	**Configuration Type**	**Location**	**UTC Time Start Collecting Data (Date HH:MM)**	**Time Difference (HH:MM)**
T2	1	Donaldsville, LA	10/2/02 23:18	-
T0	1	Lafayette, LA	10/3/02 2:18	2:59:55
T3	1	Lydia, LA	10/3/02 4:25	5:06:45
T1	1	Baton Rouge, LA	10/3/02 6:31	7:12:58
Hurricane:	**Isabel (2003 - Category 2 at landfall)**			
FCMP Mobile Tower	**Configuration Type**	**Location**	**UTC Time Start Collecting Data (Date HH:MM)**	**Time Difference (HH:MM)**
T2	1	Atlantic City, NC	9/16/03 15:45	-
T0	1	Elizabeth City, NC	9/17/03 12:30	20:44:59
T3	2	Frisco, NC	9/18/03 0:09	32:24:52
T1	2	Wilmington, NC	9/18/03 5:05	37:20:03

This table presents FCMP deployments for: (1) Tropical Storm Isidore 2002 landfall just west of Grand Isle, LA. (2) Hurricane Lili 2002 landfall-near Intracoastal City, LA. (3) Hurricane Isabel 2003 landfall at Drum Inlet, NC.

Instrumentation improvements for 2003 season

For the 2003 hurricane season, significant improvements were made to the FCMP mobile towers. The first improvement was the addition of real time data acquisition system capabilities to all mobile towers and the second major improvement was the addition of satellites towers to two of the four units.

In order to accomplish the Real Time Data Acquisition goal, FCMP personnel incorporate a second data acquisition system into the mobile towers. The new system configuration consists of a laptop computer equipped with a data acquisition card from *National Instruments Corporation* and a portable cell phone modem that allow FCMP to upload data summaries to an FTP[4] site provided by the University of Florida, so that the data can be accessed in real time. The laptop data collection system is known as Tower XP. It collects data from a shared panel board with the old system. The old system configuration consists of PC computer with a data acquisition system from *ComputerBoard, Inc*. This configuration is known as Tower CBI. Both systems can be seen in Figure 2-2. This configuration provided the FCMP a redundant data set for the same event. In the next chapter a comparison of these two sets of data will be discussed to validate the collected data for Hurricane Isabel (2003). Table 2-2 presents a comparison between these two systems.

Table 2-2. Tower XP and Tower CBI data acquisition system comparison.

Data acquisition system	Hardware and software	Computer Type	Sampling Rate (Hz)	FTP Upload
Tower XP (new)	National Instruments/ Labview 6.0	Laptop (Pentium 4 - 2.5 GHz)	10	Yes
Tower CBI (old)	ComputerBoards, Inc./ Visual C++	PC (Pentium III - 350 Mhz)	100	No

[4] FTP: The File Transfer Protocol for transmitting files between systems on the Internet.

Figure 2-2. Mobile Tower computer box after modification for 2003 hurricane season. Testing at the Castillo de San Marcos (St Augustine, FL) with the cooperation of the National Park Service, an FCMP team from the University of Florida tested the new real-time data acquisition system on July 16, 2003.

Deployments participations and tasks

The author has been active and collaborating with FCMP for the last two hurricane seasons. For the 2002 season, the author was collaborating on tower setups and assisting member of Clemson University on the house instrumentations for Tropical Storm Isidore.

For the 2003 season the author was in charge of training new team members consisting of civil engineers undergrads students from University of Florida. The students were trained to setup the mobile towers and satellites towers, and to setup the computer data acquisition system.

A contribution of the author during the 2003 Isabel deployment was the use of ArcGIS mapping software. This is a very important tool that allows teams to quickly establish appropriate locations to setup the mobile towers. It also allows quick comparison of tower positions relative to the projected and actual storm path provided by the NOAA National Hurricane Center (NHC). This provides key information regarding cell tower locations (used to transmit signal to cellular phones and cell modems) and their proximity to mobile tower deployment positions. This is very important to ensure a good cellular connection signal for successful Real Time Data transmission. In addition, it provides information about all weather stations in the area. The towers were deployed close to those locations in order to use the data for future comparisons and sources to validate FCMP data records. Figure 2-3 presents the final map generated for the FCMP deployment during hurricane Isabel using ArcGIS. During deployment, this map is interactive, using a regularly updated GPS signal to track travel routes and display optimal routes.

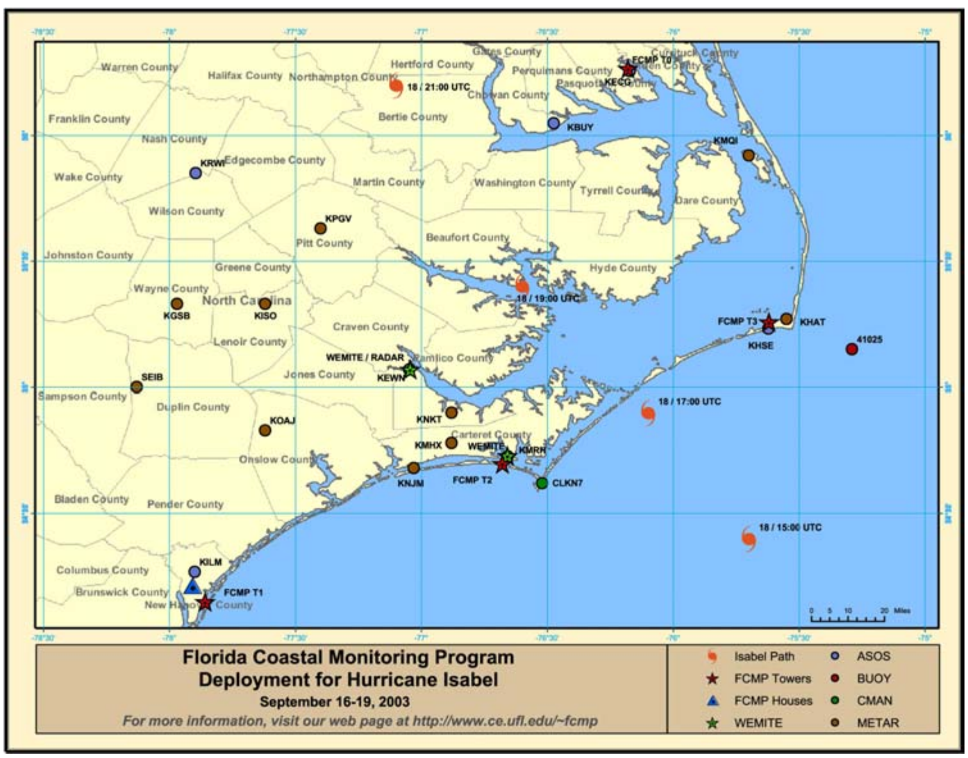

Figure 2-3. FCMP Deployment map for hurricane Isabel 2003.

The product of the data obtained by the FCMP personnel is intended to help engineers quantify hurricanes behavior from a statistical perspective. The data needs to be analyzed and closely scrutinized in order to avoid any suspicious data that may not reflect the actual behavior. The next chapter will focus on the data validation methodology used to verify data sets collected for tropical storm Isidore (2002), hurricanes Lili (2002) and Isabel (2003).

CHAPTER 3
DATA VALIDATION

Introduction

Data collected during deployments must be validated before more extensive analysis can be conducted. Validation is a broad term, and in the current context refers to a verification that the instruments and data collection computers were working as desired. This is accomplished by comparing the collected data by each instrument to other sources of data for the same storm. Average wind speeds, wind direction, and level of turbulence are the primary parameters that are validated. The data sets from the FCMP are to be disseminated to the public via the FCMP dedicated web site. It is critical that the data sets that are made public be as reliable as can reasonably be determined. This chapter addresses the methods used to validate the data and presents examples of validated and invalidated data sets.

Methodology

The validation process will be done using four different sources. The first source is self validation through comparison of the records of the various instruments used in the same FCMP deployment. Time histories of speed and direction recorded from each mobile tower instrument are compared to each other in order to identify equipment that may have malfunctioned. The second validation source is also self validation, but is designed to validate the data collection computers rather than the instruments themselves. The Isabel deployment in 2003 was the first time two computer systems collected and stored data from each tower. The records from these two systems (Tower CBI and Tower

XP) are compared to ensure proper functioning of each computer. The third validation source is any available local wind stations records from ASOS, METAR, CMAN or BUOY stations. These outside sources of collected data can provide peak and mean wind speeds and directions for comparison with FCMP data sets. The fourth validation source is a computer model of wind speeds known as the Surface Wind Analysis Data developed by the NOAA Hurricane Research Division (HRD). This last method of validation will be accomplished using the ArcGIS format, and compares computer model predicted peak wind speeds with those measured from the FCMP hardware. Each validation method will be explained in detail herein.

Self Validation

The first self validation test is designed to identify specific instruments that malfunction over either a portion of a storm or throughout the storm. In some cases a malfunction is obvious to spot with no comparisons needed, for example a speed time history that registers as a constant over a sustained period rather than a fluctuating quantity. An example of this is presented in Figure 3-1 for a tower during Gabrielle.

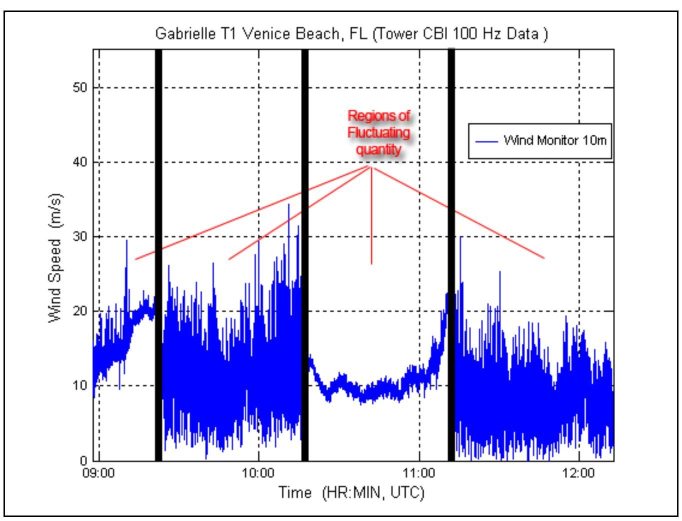

Figure 3-1. Wind Speed time history displaying clear malfunction. (Data collected during hurricane Gabrielle Sept./14/2001)

A malfunction may be more subtle and not easily identified by viewing the record from that instrument alone. Examples include a voltage drop from a wind monitor (vane anemometer) that produces a speed that is low by 10% compared to actual speed, but otherwise looks fine. A malfunction from a single gill anemometer in a three-axis set can produce resultant speeds and directions that are distorted but not obvious. For cases such as these, comparisons are needed to contrast the data from more than one instrument measuring the wind within close proximity of each other.

Fortunately the FCMP mobile tower design includes redundant instruments that can be compared to each other. Recall that a single mobile tower has a wind monitor at 10 meters, a 3-axis fixed gill anemometer set at 10 meters, and another 3-axis gill set at 5 meters. Additionally, up to two satellite towers can be deployed with any mobile tower, providing two more 3-axis sets at the 5 meter elevation within 30.5 meters of the main tower. These five independent sets of instruments are all in close proximity to each other, and the data from each should closely match in terms of speed, direction, and level of turbulence.

The comparisons can be done both graphically and through quantification of differences between instruments. In order to make this a systematic process, the author has developed a set of computer tools in MATLAB that will speed up this process for future data validation. This will establish parameters and procedures required to self validate FCMP collected data. This set of computer tools provides comparison plots of speed and direction time histories and quantifies the mean square error between instruments to compare fluctuations (turbulence).

Figures 3-2 and 3-3 present comparison plots of wind speed and direction time histories for the data collected with Tower CBI during hurricane Isabel at Frisco, NC. The data is presented as an average value every 15 minutes over the 39 hours that data was collected. Several issues can be identified from these graphs. First, note that the 10 meter wind monitor and 5 meter gill anemometer track very close together in both speed and direction. The lower elevation of the 5 meter instrument leads to an expected decrease in its wind speed compared to the 10 meter readings. With an exception at 12:00 to be discussed later, these figures validate the data from these two instruments. However, the comparison of the 10 meter gill anemometer with both the 5 meter gill and wind monitor is poor. In fact, both instruments at 10 meters should lie essentially on top of each other. There is an overall strong indication from these comparisons that the 10 meter gill anemometer set malfunctioned. A follow up closer data inspection then compared the output of each of the three individual gill anemometers from the 5 and 10 meter sets. It was determined that a single fixed axis gill at the 10 meter elevation malfunctioned, resulting in the discrepancy.

The second issue shown in Figures 3-2 and 3-3 is the spike observed for the gill sets between 12:00 and 18:00 UTC of the first 24 hours. Accompanying this spike is a significant gap in the time record where no data was collected. The cause of data spike and gap may be a computer malfunction or electrical failure with the Tower CBI data collection system. This will be discuss in more detail in the next section in this chapter, where a comparison is presented between the two data collection systems on the same tower.

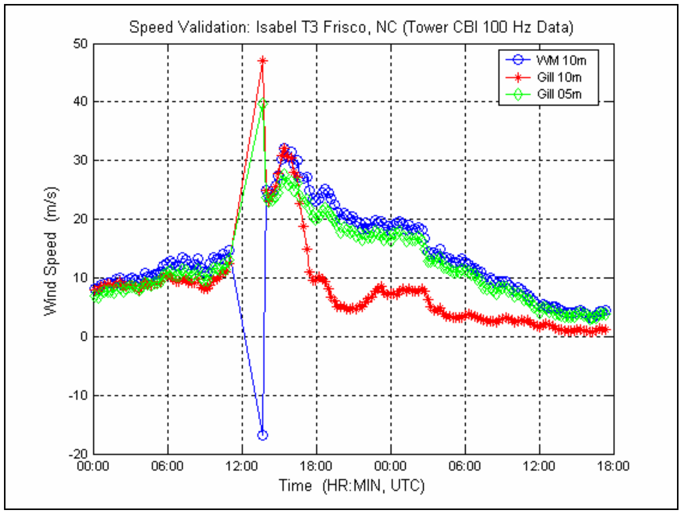

Figure 3-2 Wind Speed comparison plot of 15 minutes average speed for mobile tower T3. A total of 155 15-minute records were collected with Tower CBI for hurricane Isabel at Frisco, NC.

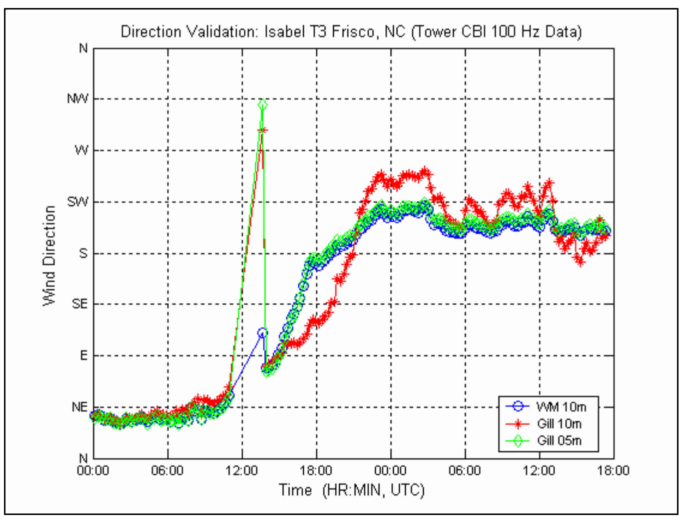

Figure 3-3 Wind Direction comparison plot of 15 minutes average direction for mobile tower T3. A total of 155 15-minute records were collected with Tower CBI for hurricane Isabel at Frisco, NC.

The last portion of this validation test is a quantification of the differences in the fluctuating component of the wind. Figures 3-2 and 3-3 present comparisons of the mean values for speed and direction computed every 15 minutes. This does not provide an evaluation of the fluctuating turbulent component, which occurs over a much shorter time scale than 15 minutes. A sampling rate of 100 Hz is used, producing 90,000 data points per instrument every 15 minutes. The mean square error (or difference), MSE, between all possible pairs of instruments is calculated over 15-minute segments and plotted. These pairs are given in Table 3-1. The acceptable range of MSE depends upon the vertical and horizontal separation between the pair of instruments, and the mean wind speed. For example, the 10 meter gill and wind monitor should produce a relatively low MSE as presented in Figure 3-4, since they are only a few meters apart, while a satellite 5 meter tower and the 10 meter gill will have significantly larger MSE due to large horizontal separation as presented of Figure 3-5.

Table 3-1. Instrument combinations used to compute MSE.

Mean Square Error Combinations
Wind Monitor & 10m Gill Anemometers
Wind Monitor & 5m Gill Anemometers
Wind Monitor & Satellite 1*
Wind Monitor & Satellite 2*
10m Gill Anemometers & 5m Gill Anemometers
10m Gill Anemometer & 5m Satellite 1*
10m Gill Anemometer & 5m Satellite 2*
5m Gill Anemometer & 5m Satellite 1*
5m Gill Anemometer & 5m Satellite 2*
5m Satellite 1 & 5m Satellite 2*

*Combination only possible when satellites towers are deployed.

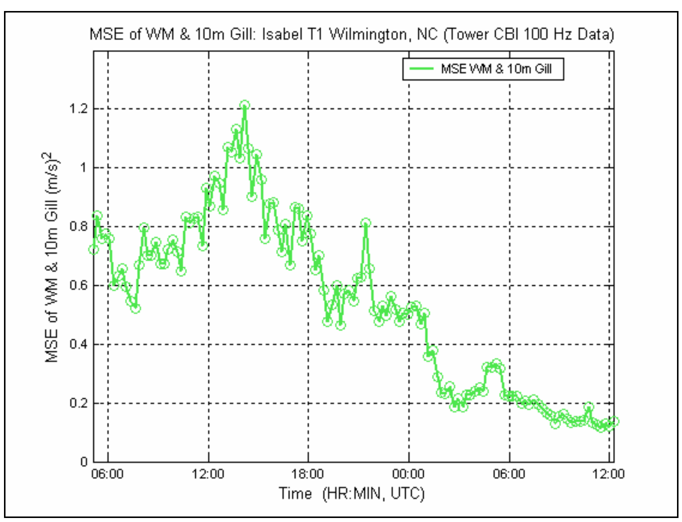

Figure 3-4. MSE time history between wind monitor and 10 meter gill anemometers using 100 Hz data collected with mobile tower T1 during hurricane Isabel at Wilmington, NC

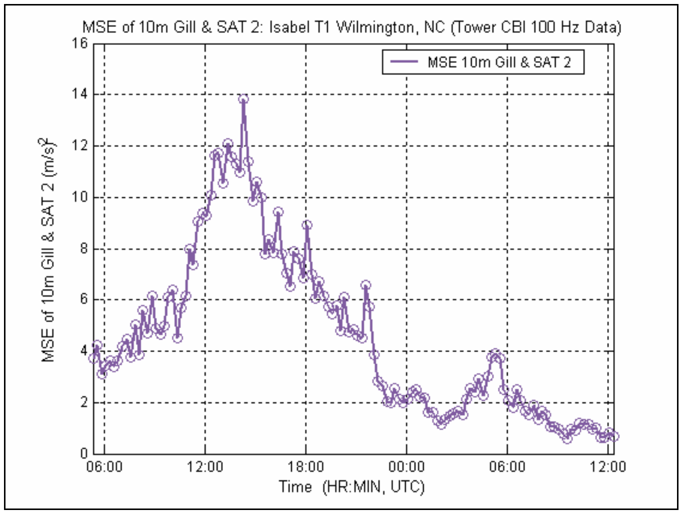

Figure 3-5. MSE time history between 10 meter gill anemometers and satellite 2 using 100 Hz data collected with mobile tower T1 during hurricane Isabel at Wilmington, NC

Data that has been otherwise validated and deemed reliable can be used to generate standardized curves of MSE versus wind speed for the various instrument pairs. Such a curve is shown in Figure 3-6 for the 10 meter anemometer speed versus the 10 meter gill using data collected with mobile tower T1 during hurricane Isabel at Wilmington, NC. Each 15-minute MSE value is associated with the mean wind speed over that time frame. The data is then re-ordered from low to high mean wind speeds to generate the standard curves. These sets of curves are now on file in the data validation database, and will be used as a benchmark for MSE validations for future data collected.

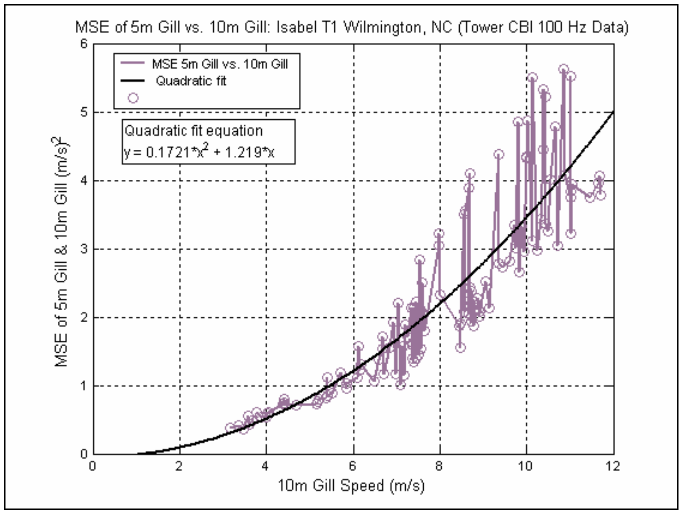

Figure 3-6. Calibration curve for 10 and 5 meter gill anemometers. Generated using T1 Isabel data.

The next step in a validation study is to examine the records with a high MSE. For this study the raw data of the time histories is compared for the particular instruments in question. An example of this is shown in Figure 3-7 using data obtained during hurricane Isabel with the mobile tower T3 on record #45. It is clear from the figure that the instruments or the data collection computer are not functioning properly. The validation procedures were used to quickly identify only those few 15-minute records out of several hundred that required detailed viewing.

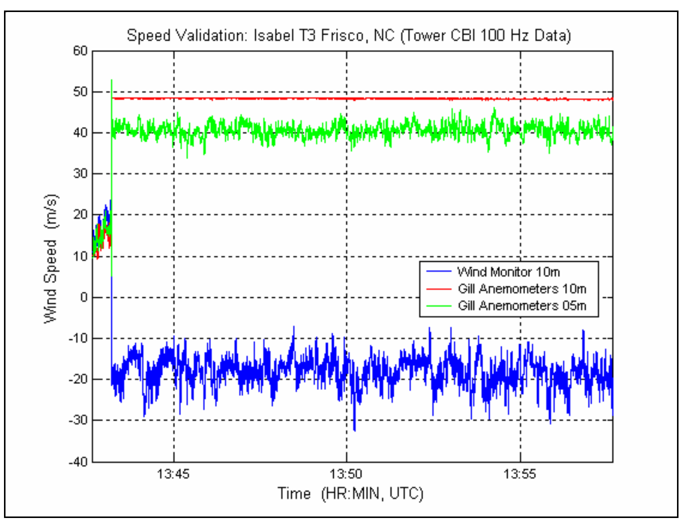

Figure 3-7. Wind speed plot for Tower CBI record #45.(Start at 9/18/2003 13:42:41 UTC Time)

It can be observed from Figure 3-7 that the speed obtained with the wind monitor suddenly decayed from positive to negative value, and the reading for the five and 10 meter gill anemometers jump to higher values. This phenomenon is difficult to precisely explain. The R.M. Young wind monitor is a powered instrument that turns into the wind. It should never produce a negative value, since speed and direction are tracked through separate sensors. The three component fixed gills anemometer does not require a power source, and direction is calculated based on the combined instantaneous speed at each of the fixed anemometers (which can produce positive and negative values). It can be assumed that the problem involves some kind of electrical power problem related to the computer data acquisition system or in the link between the computer and the instruments. For this event we are able to look into the results from the redundant laptop computer data collection system (Tower XP) to further diagnose the problem. This will be explained on the next section.

Tower CBI vs. Tower XP

For the first time in FCMP history, during hurricane Isabel FCMP personnel collected data from each of the mobile towers using redundant computer systems. This was accomplished with the two data acquisition systems previously presented in Chapter 2 (referred to as Tower CBI – the PC and Tower XP – the laptop used to remotely transmit). The redundant data records help to explain problems found with previous data records by isolating whether the problems were instrument or computer related.

Time histories of the data from a given instrument collected by the two systems are plotted. The case that will be used to present this comparison will be for the mobile tower T3 deployed during hurricane Isabel at Frisco, North Carolina, because it was found that the Tower CBI system stopped collecting data for a period of two hours and thirty minutes (ten data records). Tower XP never stop collecting the data, so this leads to the conclusion that the older PC data collection system was not working at its best performance. Figure 3-8 presents a comparison plot of the reading recorded with the wind monitor for the case in concern. Note that in addition to the gap in data collection for the Tower CBI system, a negative mean speed value was not recorded for the Tower XP data set. A detailed time history of the 15 minutes of data associated with the negative wind monitor value can be seen in Figure 3-7 for the Tower CBI system (record 45), and in Figure 3-9 for the Tower XP system (record 49).

Since both systems receive their signals from the same instruments, it can be concluded that the problems with the datasets are related to voltage problems in the data collection system (Tower CBI). It is not a problem with the instrumentation itself or a problem with the wiring from the instruments to the screw terminal where the computers access the voltages. This same electrical problem is likely the cause of the malfunction during the previous 2 ½ hours for Tower CBI. Luckily, the addition of Tower XP just prior to Isabel provided a useable data set.

Such a validation study is quite useful, as the focus of corrections to tower T3 will focus on the PC computer Tower CBI, and not the instruments or wiring harnesses.

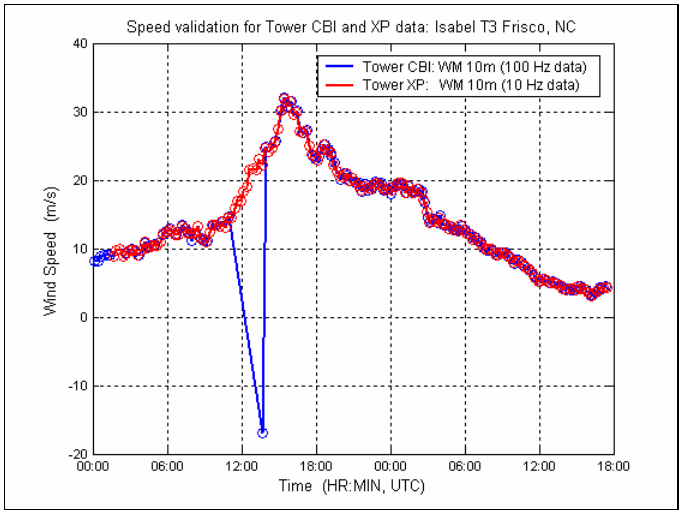

Figure 3-8. Comparison plot of 15 minutes mean winds speed readings collected using the wind monitor with Tower XP and Tower CBI during hurricane Isabel at Frisco, NC.

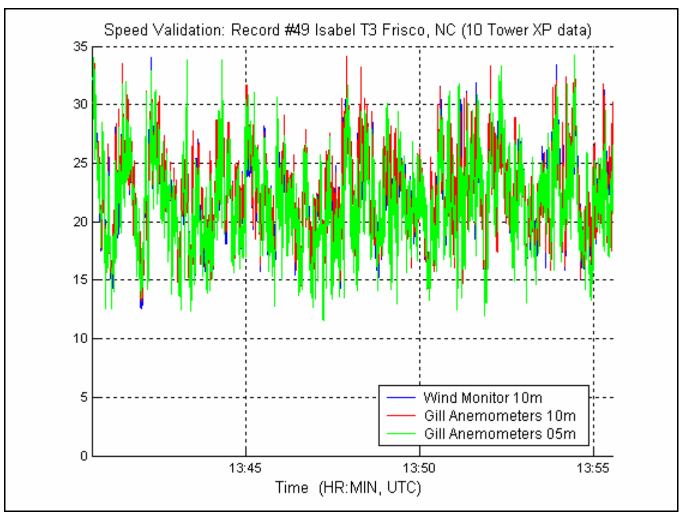

Figure 3-9. Wind speed plot for Tower XP record #49. (Start at 9/18/2003 13:40:35 UTC Time)

Validation - Outside Sources

The available outside sources to compare and validate data are obtained from wind records from various weather stations including, ASOS, METAR, CMAN or BUOY stations, located near any of the four towers. The deployment maps generated with ARCVIEW are used to graphically identify these stations as shown on Figure 3-10. This is a good way to compare and validate the FCMP data, but it depends on the availability of the data. Table 3-4 lists the stations close to FCMP towers for the events studied in this research. At the present time, the data from these stations is being sought.

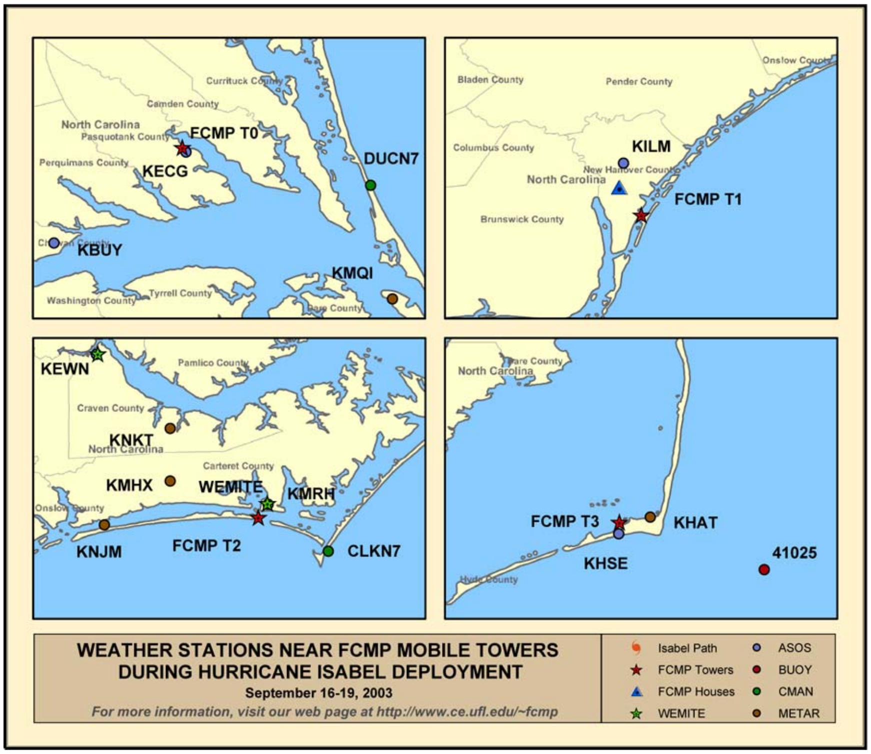

Figure 3-10. Weather Stations near FCMP towers during hurricane Isabel deployment.

Table 3-4. Stations near to FCMP mobile towers during hurricane Isabel (2003)

MP Deployment: Hurricane Isabel			
Mobile Tower: T0			
ASOS	**METAR**	**CMAN**	**BUOY**
KBUY	KMQI	DUCN7	-
KECG	-	-	-
Mobile Tower: T1			
ASOS	**METAR**	**CMAN**	**BUOY**
KILM	-	-	-
Mobile Tower: T2			
ASOS	**METAR**	**CMAN**	**BUOY**
KMRH	KNJM	CLKN7	-
KEWN	KMHX	-	-
-	KNKT	-	-
Mobile Tower: T3			
ASOS	**METAR**	**CMAN**	**BUOY**
KHSE	KHAT	-	41025

Once the data is acquired from the selected source, the next step is to determine the type of data (e.g. Hourly, 1 min maximum, 3 sec gust, etc.). FCMP data is processed and ready to plot and compare with the external data source. Figure 3-11 (left) illustrates a comparison between data acquired from Lafayette Regional Airport (Hourly average) during hurricane Lili (October 3, 2002) and data collected with FCMP mobile tower T0 from the wind monitor. It can be seen that the mean wind speed from both sources follow almost the same trend. The mean direction of the wind is also compared for the same event and presented in Figure 3-11 (right). This outside validation shows that the data acquired from this tower is reliable and can be use for future research and investigations.

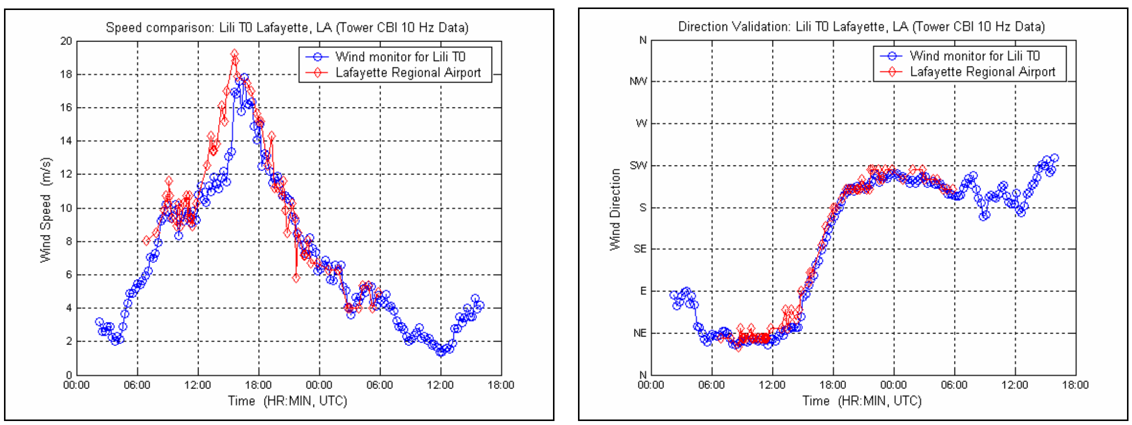

Figure 3-11. Comparison of FMCP data collected during hurricane Lili with mobile tower T0 at Lafayette, LA., with data from Lafayette Regional Airport during October 3, 2002.

NOAA Hurricane Research Division (HRD) Wind Surface Analysis Comparison

The NOAA Hurricane Research Division (HRD) has been developing a numerical model (Wind Surface Analysis) to recreate the overland wind field of hurricanes after a storm has passed. Since 1994, HRD wind analyses have been conducted on an experimental basis to create real time hurricane wind field guidance for forecasters at the National Hurricane Center. During hurricane landfall episodes, HRD scientists work side by side hurricane specialists at National Hurricane Center (NHC) analyzing wind observations on a regular 3 or 6 hour schedule consistent with NHC warning and forecast cycle. An HRD wind analysis requires the input of all available surface weather observations (e.g., ships, buoys, coastal platforms, surface aviation reports, reconnaissance aircraft data adjusted to the surface, etc.). Observational data are downloaded on a regular schedule and then processed to fit the analysis framework. These data are composite relative to the storm over a 4-6 hour period. All data are quality controlled and processed to conform to a common framework for height (10 m or 33 feet), exposure (marine or open terrain over land), and averaging period (maximum sustained 1 minute wind speed) using accepted methods from micrometeorology and wind engineering [NOAA Hurricane Research Division, http://www.aoml.noaa.gov/hrd].

Once the analysis is completed the data is available through the HRD web page. The data (peak wind speeds as predicted by the model) are available in a shape file format, suitable for plotting using ARCVIEW (a GIS software system) along with the FCMP storm deployment map. Figure 3-12 shows one of the maps for Isabel generate by HRD researches, showing the predicted one minute sustained winds at 1630 UTC.

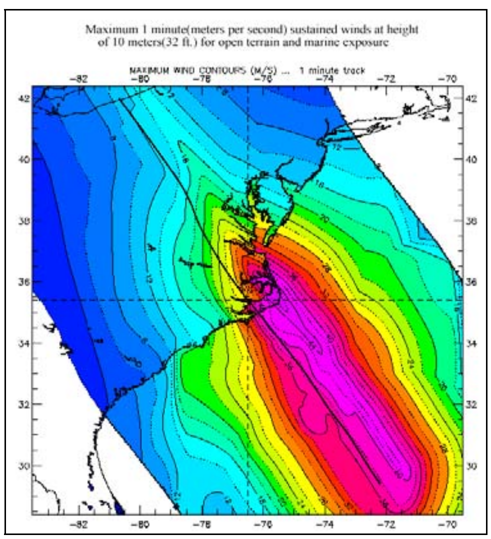

Figure 3-12. HRD Max 1-min sustained surface winds model for hurricane Isabel.

Graphical comparisons can then be made between measurements from the FCMP towers and the HRD predictions within an interval up to six kilometers from the tower (based on the grid size used by the Wind Surface Analysis model). Figure 3-13 presents a comparison plot between FCMP mobile tower T3 data and the HRD model during hurricane Isabel. It can be seen on this graph that the values obtained from the HRD model are higher than the ones computed using T3 data. This is due to the fact the HRD data has been converted to an open marine exposure that will increase the maximum peak values, while the FCMP tower data is as-measured, (i.e. the wind speeds were not converted to an open exposure). On the other hand Figure 3-14 shows the direction comparison between HRD model and wind monitor from T3.

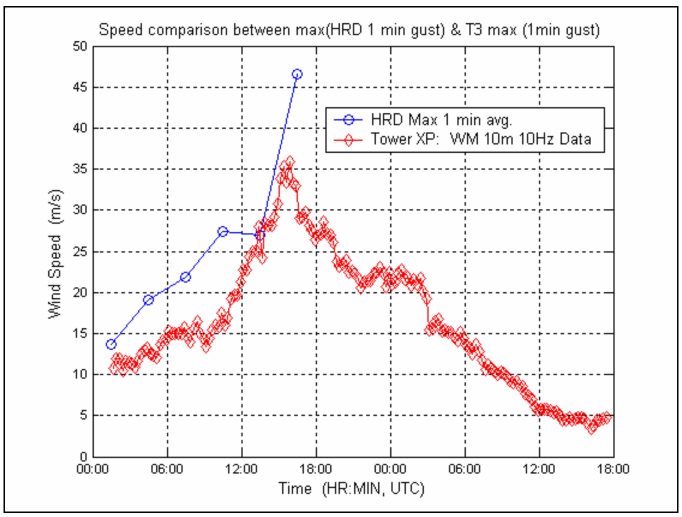

Figure 3-13. Maximum 1 min. comparison between HRD model and mobile tower T3 data from Tower XP during hurricane Isabel at Elizabeth City, NC.

The plotted values are on top of each other. Thus is it can been conclude the FCMP tower instrumentation was recording reliable directional data for this event, while wind speed studies require further investigation to account for the peak one minute discrepancies.

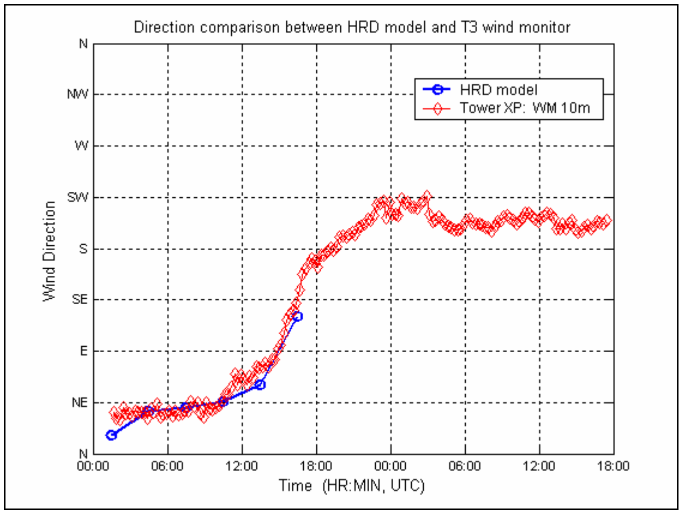

Figure 3-14. Direction comparison plot between HRD model and wind monitor for T3 during hurricane Isabel.

Also it is important to mention that HRD researchers used FCMP data for the first time as a source from among others to generate these models during hurricane Isabel landfall. They were able to access the data real-time using the FCMP website to create these models.

Conclusion

The final goal after all four validation methods have been run is to identify reliable data sets from the FCMP data base. Once the data has been self validated and compared with others sources it is ready to be analyzed and disseminated. These sets of data will be then used to perform advanced research to better comprehend the behavior of the wind during hurricanes events. The next chapter will present the procedures used to compute the lateral length scale of the wind gust with the data obtained during hurricane Isabel, collected with mobile towers T1 and T3. From this validation process it was determined that T1 data is trustworthy and all records of data seems to be excellent. On the other hand, it was determined that some data records for T3 need to be truncated. For this particular case, the 10 meter gill anemometers and the records of satellite one need to be removed from the data set. These validation methods provide the FCMP personnel with the necessary tools to avoid analyzing and disseminating bad data records.

CHAPTER 4
DATA PROCESSING AND ANALYSIS

Introduction

FCMP personnel efforts to collect high resolution hurricane wind speed and direction time histories do not end once a hurricane strike has occurred. The next task is to process and analyze the data in order to provide engineers, meteorologist and researchers with better tools to help them understand this phenomenon. For example, engineers will be able to improve design codes and guidelines, leading to better designs to strengthen construction of houses, buildings and other man made structures in order to improve lifestyles and to provide better commodities. The data analysis is conducted with MATLAB (MATrix LABoratory), for the convenience that it provides powerful analysis tools to perform statistical analysis, and graphical user interface (GUI) programming capabilities that allow dissemination of datasets. For this purpose, a stand alone GUI software (WinDLab) has been developed by FCMP personnel to provide a user-friendly application to perform analysis on the collected data [Cuenca 2002].

This chapter presents new contributions to the data post-processing procedures. This includes the addition of information to the data files and production of summary graphs and tables to guide users loading data and provide a frame of reference. This also includes the development of a new statistical analysis tool to quantify the lateral size of turbulent gusts.

Methodology

The data processing procedures that will be outlined in this chapter describe the step by step tasks required to convert the collected data into a MATLAB workspace format. In order to speed up this procedure a series of programs and functions have been developed to provide future FCMP personnel with tools to perform these tasks.

The data collected from each of the four portable towers are stored continuously throughout a storm in 15 minute increments. The first post-processing task is to export the collected data to ASCII text format from the Tower CBI acquisition software. The exported data includes the four channels of environmental variables (temperature, humidity, pressure, and rainfall), the speed and direction channels from the 10-meter wind monitor, and the six channels from the pair of three-axis fixed gill anemometer arrays in their original non-orthogonal components (the two arrays are at 5 and 10 meter elevations). After conversion to ASCII format, the second task is to convert the non-orthogonal components into orthogonal components (two horizontal and one vertical), and then save all 12 channels in a MATLAB workspace file format [Cuenca 2002]. At this stage the 15-minute data files are in a convenient and compact format for analysis within MATLAB.

The next two procedures are the author's contributions to data post-processing. The third task is to generate a database in Microsoft Excel which contains miscellaneous information for each record for any particular storm event. The development of WinDLab [Cuenca 2002 and Weaver 2003] software as a user friendly format for analysis of FCMP data necessitated the inclusion of additional information within each of the 15-minute data records. This additional information provides users with adequate data for a proper frame of reference for the data set. Table 4-1 lists the information added to each data file.

Table 4-1. Miscellaneous information added to data records.

Information added to each data records
Date and time stamp
File source used create MATLAB file
Storm name
City and State
Analyst name
GPS coordinates
Terrain description
Tower used to collect data
Trailer angle orientation
Notes related to deployment

In order to perform the fourth and final task a program was written by the author in order to read the Microsoft Excel database into MATLAB and store its content as new variables into each file. Complete data sets are created for each storm and are ready to work within WinDLab. In order to reduce the size of each of the 15-minute data files (8-12 MB depending on whether satellites towers were deployed), a down-sampled version of 10Hz is created from the 100Hz original data. This provides users easy access to the files through the FMCP web page and reduces the processing time required to load the data into WinDLab. This can result in a substantial savings in time when several hours of data are loaded for analysis. In fact, computers with limited processing speeds and memory can only load a few of the 100 Hz files, while using the down sampled files greatly increases their capacity to load, view and analyze complete storms (upwards of 30 hours). The additional capabilities of WinDLab that were added to access this new data will be discussed in Chapter 5.

Storm deployments overview and data summaries

In order to document each deployment, the author and other FCMP personnel developed a series of maps, aerial images, and summary tables for each tower deployed for a particular event. These are used to disseminate the data through WinDLab and the FCMP web page, to be discussed in Chapter 5. ArcView mapping software is used to generate maps with tower locations and the storm path. The U.S. Geological Survey (USGS) provides the Microsoft® TerraServer web site with high resolution aerial images of the United States [TerraServer-USA; http://www.terraserver-usa.com]. The images are in the public domain and are freely available to use and re-distribute. The aerial pictures are collected from TerraServer using the global position system (GPS) coordinates recorded during tower deployments.

Figure 4-1 presents a deployment overview map for hurricane Isabel and an aerial image for mobile tower T2 (2003 hurricane season). These images help users access the data sets by providing a frame of reference. For example, the left image in Figure 4-1 helps the user to determine which towers will provide higher speed winds coming off of the ocean (north of the storm path: T0 and T3), and which towers will see lower speed (and more turbulent) winds coming from over land out to sea (south of the storm path: T1 and T2). The aerial view of a specific tower location (Figure 4-1: right) gives further details about the exposure on all sides of the tower location, which is critical for detailed analysis of turbulence characteristics.

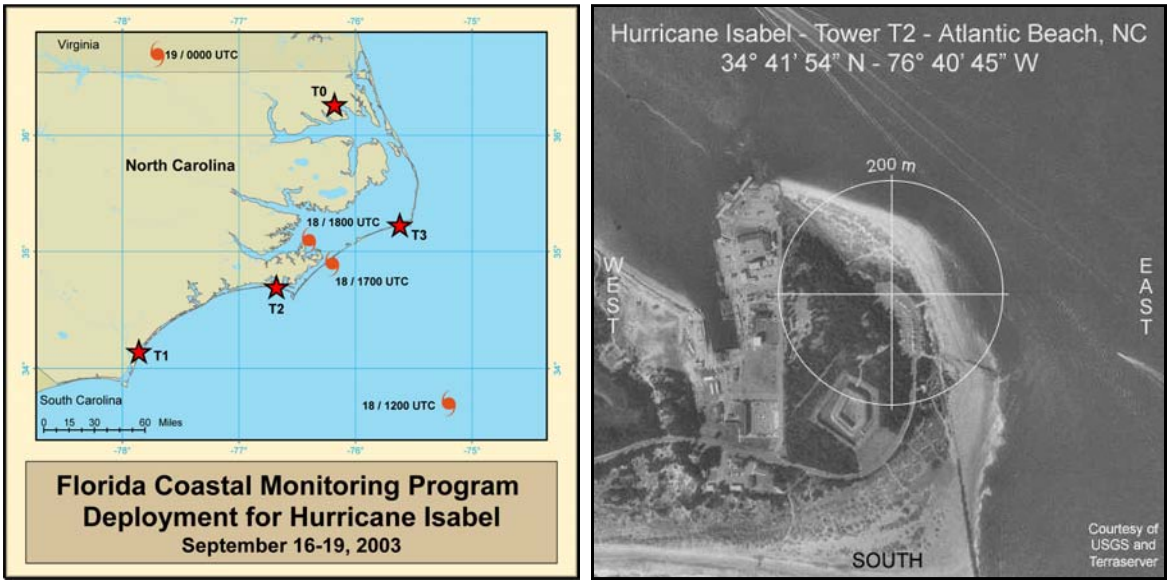

Figure 4-1. FCMP deployment map for hurricane Isabel during 2003 season (left) and aerial view of mobile tower T2 (right).

In addition to the map and aerial views, summary graphs and tables are created for each storm and each tower to provide information on wind speeds over different averaging times (10 Hz, 3-second and 15-minute), wind directions, and peak wind speeds with respective direction, time and record number. In an effort to make this an automated process, the author has written a MATLAB program that uses the processed data to generate summary graphs and save them as image file and an output text file with the winds speed peaks. Table 4-2 presents a summary of the maximum wind speeds recorded by the FCMP towers during the deployment for hurricane Isabel, including the record number where the maximum wind speeds occurs and the respective direction and time. Figure 4-2 presents the output graph obtained from this code, showing wind speed and direction time histories and the maximum three second-gust recorded during hurricane Isabel with tower T0. The maximum wind speed peaks were computed using a moving average for 15 minutes segments of data. Graphs such as these are now provided to users of WinDLab in the data loading interface, allowing selection of the appropriate data records for further analysis as the user sees fit. More discussion is provided in Chapter 5.

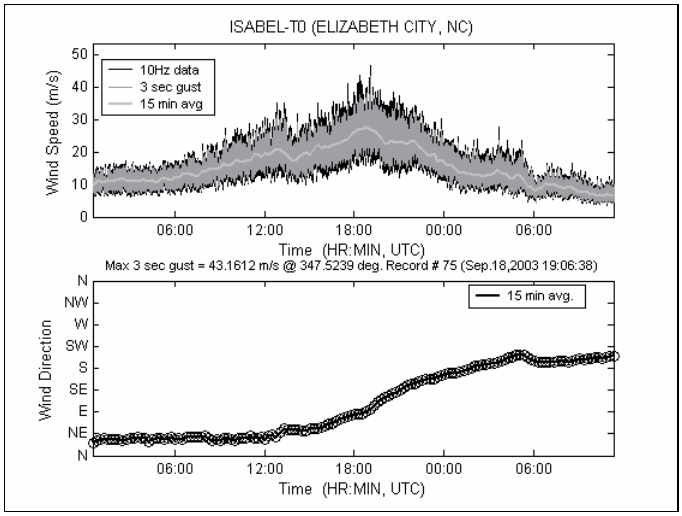

Figure 4-2. Summary graph of wind speed and direction for Tower T0 during Isabel

Table 4-2. Maximums peak wind speed observed during hurricane Isabel.

Summary for hurricane Isabel (Tower CBI 100Hz Data)				
T0 - Elizabeth City, NC				
Measure	**Record No.**	**Date & Time UTC**	**Speed (m/s)**	**Direction (Deg)**
15 min avg	74	9/18/2003 19:00:02	27.7712	352.81
1 min avg	75	9/18/2003 19:06:59	32.7184	352.58
3 sec gust	75	9/18/2003 19:06:38	43.1612	347.52
T1 - Wilmington, NC				
Measure	**Record No.**	**Date & Time UTC**	**Speed (m/s)**	**Direction (Deg)**
15 min avg	47	9/18/2003 16:53:23	11.8141	295.15
1 min avg	44	9/18/2003 16:08:11	15.6516	304.63
3 sec gust	50	9/18/2003 17:56:36	22.0363	284.59
T2 - Atlantic Beach, NC (Forth Macon)				
Measure	**Record No.**	**Date & Time UTC**	**Speed (m/s)**	**Direction (Deg)**
15 min avg	194	9/18/2003 16:25:35	25.1609	211.04
1 min avg	194	9/18/2003 16:15:35	28.9638	214.32
3 sec gust	194	9/18/2003 16:14:47	35.5607	219.30
T3 - Frisco, NC (Cape Hatteras)				
Measure	**Record No.**	**Date & Time UTC**	**Speed (m/s)**	**Direction (Deg)**
15 min avg	52	9/18/2003 15:43:12	31.7642	326.81
1 min avg	54	9/18/2003 16:02:20	34.8363	341.27
3 sec gust	53	9/18/2003 15:54:04	44.1412	340.74

Lateral length scales analysis

The analysis of hurricane wind records consists of many statistical tools, each designed to quantify an aspect of the complicated phenomenon of turbulent wind behavior. Many aspects of analysis have been addressed by previous FCMP personnel, and are already included within the WinDLab GUI being distributed on the FCMP web site. These include visualization, spectral and probabilistic analysis, gust factor and turbulence intensity calculations, and longitudinal length scale quantification [Cuenca 2002, Weaver 2003].

This section focuses on an analysis tool that was not applicable to the FCMP data sets previous to the 2003 hurricane season. The calculation of lateral length scales requires the simultaneous measurement of turbulent wind at several spatially separate locations. The needed spatial separation is now provided by the 5-meter satellite towers that are deployed along with the main towers starting in 2003.

Integral scales of turbulence quantify the average size of the turbulent eddies[5] in unsteady winds. There are nine integral scales of turbulence and each corresponds to a projection of the longitudinal (u), transverse (v) or vertical (w) fluctuations in the along wind, across wind, or vertical directions (x, y, z). The two integral scales of most interest to the FCMP are the longitudinal length scale L_u^x, which quantifies the average physical size of along wind eddies (u) parallel to the along wind direction (x), and the lateral length scale L_u^y, which quantifies the lateral size (y) of along wind fluctuations (u). Physically the longitudinal length scale L_u^x represents the time it takes (duration) for a

[5] A current, as of water or air, moving contrary to the direction of the main current, especially in a circular motion.

gust to pass over a structure, while the lateral length scale L_u^y represents how wide a gust is as it approaches a structure. This is significant in terms of the way the structure 'feels' the wind gust. Small L_u^y indicates only a portion of the structure will feel the average gust, large L_u^y indicates that an average gust may envelope and entire home. The longitudinal length scale L_u^x indicates duration of the average gust. With previous data sets FCMP personnel were restricted to computing L_u^x, as it only requires data from a single anemometer.

The lateral length scale is computed by quantifying the statistical correlation of the wind speed between pairs of towers. This statistical correlation is plotted as a function of projected lateral separation, which changes with the mean direction of the wind. Equation 4-1 defines the lateral length scale L_u^y as the area under the cross-covariance function between the fluctuating along wind components of spatially separated instruments, normalized by the standard deviation of the fluctuations (resulting in a correlation coefficient).

$$L_u^y = \int \frac{E[u_1 u_2]}{\sigma_{u_1} \sigma_{u_2}} dr \qquad (4\text{-}1)$$

Where u_1 and u_2 are the zero mean fluctuating along wind components of wind measured at locations separated by a distance *r*, and σ_{u_1} and σ_{u_2} are their standard deviations. *E*[ ] is the expectation operator (averaging operator). The numerator is the spatial covariance function, and the ratio is the spatial correlation function, which is bounded between zero and one.

This equation assumes that the gusts are impinging upon a line of instruments orthogonal to the mean wind direction. That is, Eq. 4-1 can be quantified by spreading out a line of many anemometers perpendicular to the wind and within several feet of each other. The correlation coefficient is then computed between pairs of these instruments and plotted as a function of the distance between the pairs. The area under the resulting curve is the lateral length scale L_u^y. This idealized measurement is illustrated in Figure 4-3

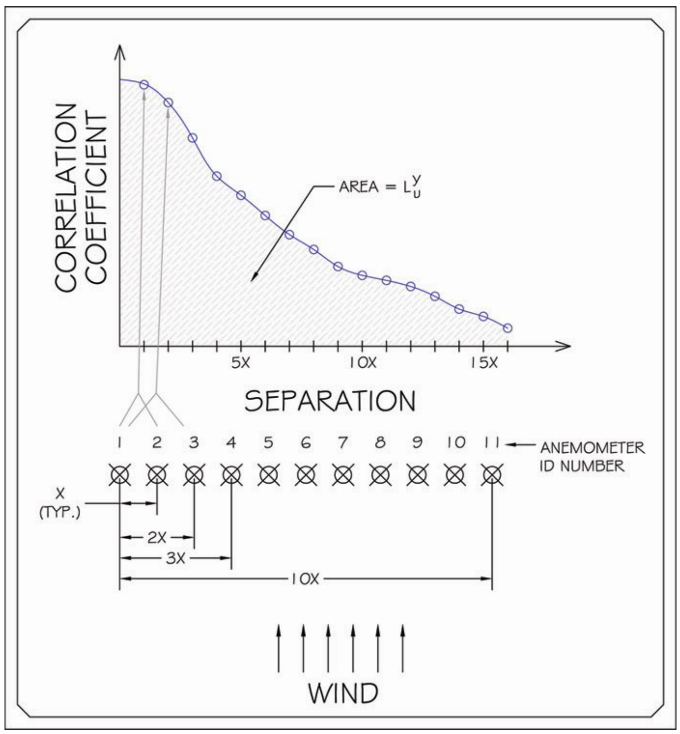

Figure 4-3 Illustration of idealized measurement of L_u^y

Of course the idealization in Figure 4-3 cannot be achieved using the FCMP equipment and deployment strategies. Not enough instrumentation is available to lay out closely spaced anemometers, and the changing wind direction of a passing hurricane renders the orthogonal alignment between the instruments and wind impossible to sustain. In an effort to measure lateral length scales L_u^y, FCMP personnel developed satellites towers to be deployed in conjunction with the main mobile towers for the first time in 2003. This was a very important achievement for the program, providing the necessary of data to compute gust lateral size of the wind as it flows through the tower array. Two satellites towers (five meter in height) are deployed up to 30.5 meters (100 ft) from two of the four main mobile towers and wired into the Tower CBI data acquisition system. The data from multiple main portable towers are not useful for lateral length scale calculations, since they are typically spread miles apart, and their individual data collection computers are not synchronized.

As illustrated in Figure 4-3, the calculation of L_u^y requires the correlation between many different separation distances. This is effectively achieved by the changing wind direction, which alters the perceived (projected lateral) distance between the three-tower array. Thus, the correlation between pairs of the three towers provides a variety of lateral separations as the wind direction changes, and the spatial correlation function in Eq. 4-1 is built over the course of the storm from the three-tower array.

The longitudinal separation between towers not orthogonal to the wind will produce a time lag between towers feeling the same gust. This lag is removed by calculating the temporal cross-covariance function between instrument pairs, and taking only the peak value as the data point to add to the spatial correlation in Eq. 4-1. Figure 4-4 presents an actual cross-covariance computed for record # 125 using hurricane Isabel data collected with mobile tower T1. Figure 4-5 presents a plan view of the configuration used during hurricane Isabel (2003) for mobile towers T1 and T3. The tower tongue angle is measured from the north to the mobile tower tongue orientation and the tower line angle is measured from the line created by connecting the satellites and main towers to the tongue angle.

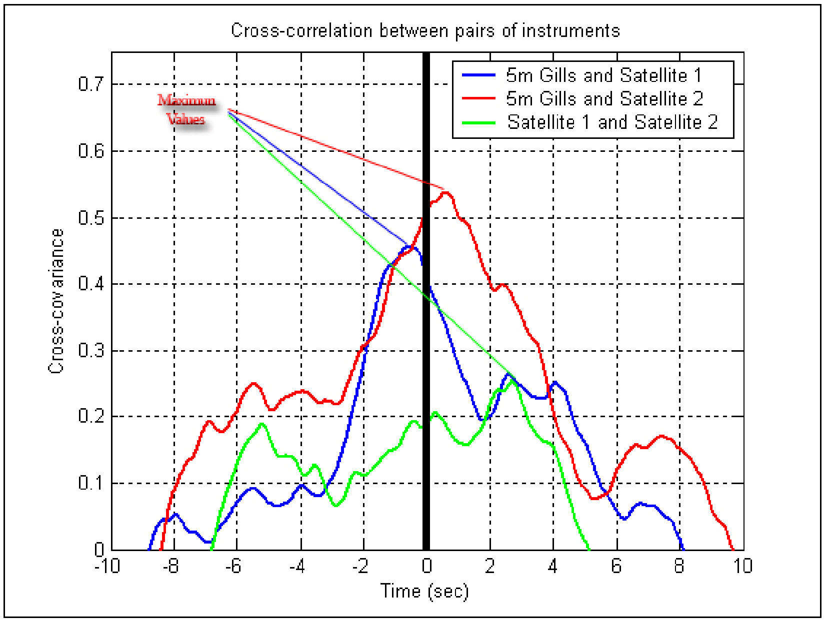

Figure 4-4. Cross-covariance between pairs of instruments to get peak values.

The beta angle shown in Figure 4-6 represents the relative difference between the approach wind direction and the orientation of the three towers relative to north, and is computed by adding the tongue angle and the tower line angle and then subtracting the average mean wind speed direction for every 15 minutes of data. This beta angle is used to compute the projected lateral separation between pairs of towers, with the projection being perpendicular to the wind direction.

The procedure for calculating L_u^y is now outlined. The first task is to compute the horizontal mean wind direction for every 15 minutes of data from the main mobile tower 5 meter three component gills anemometers. The second task is to decompose the velocity fluctuation on each instrument into instantaneous mean-removed fluctuating components parallel to mean direction (along wind), called *u*, and perpendicular to mean wind direction (across wind), called *v*.

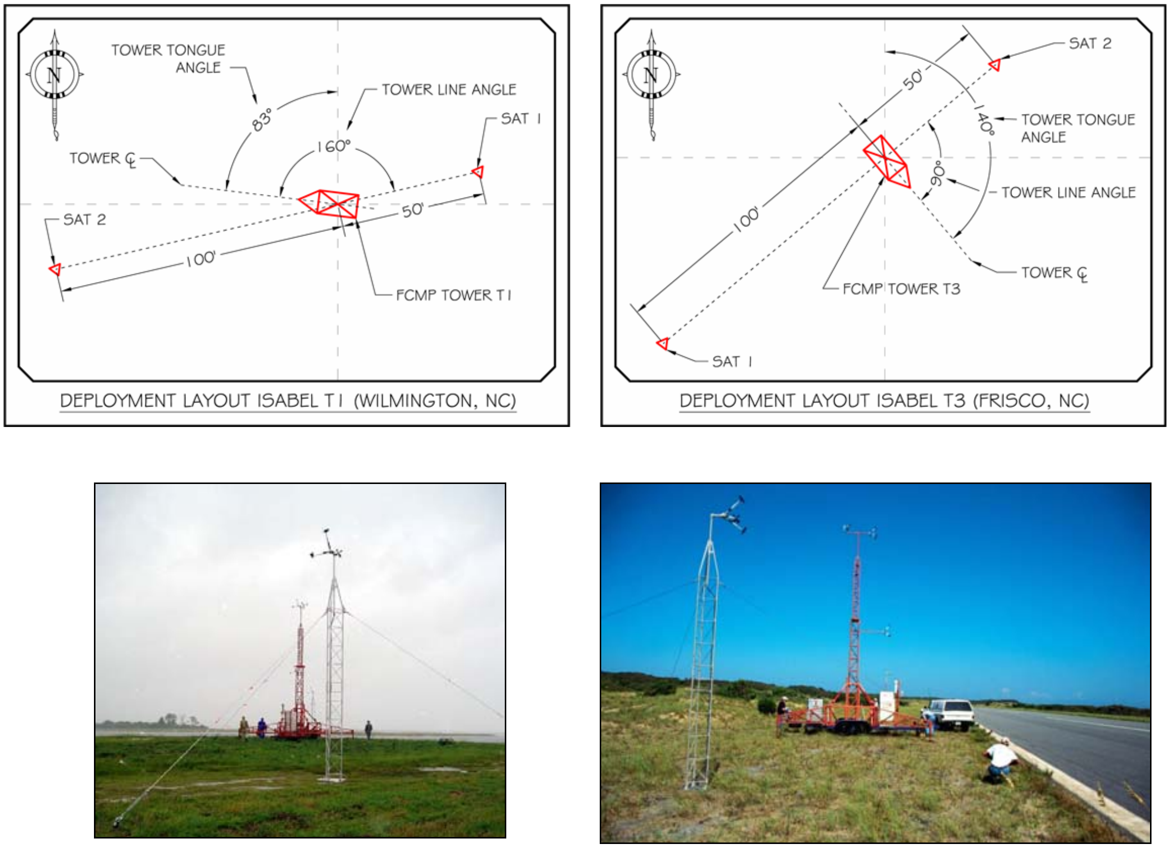

Figure 4-5. Satellite tower deployment configuration for hurricane Isabel (top), and pictures of the actual deployments (below).

The third task is to compute, for each mobile and satellite tower configuration, the separation of the instruments perpendicular to the mean wind direction. This projected separation will vary as a function of time and mean wind direction. Figure 4-6 presents the angle between the mean wind direction for every 15 minutes record and the tower line which is called as Beta angle and resulting instrument projected separation as a function of time for the T1 tower in Isabel (see Figure 4-5, left).

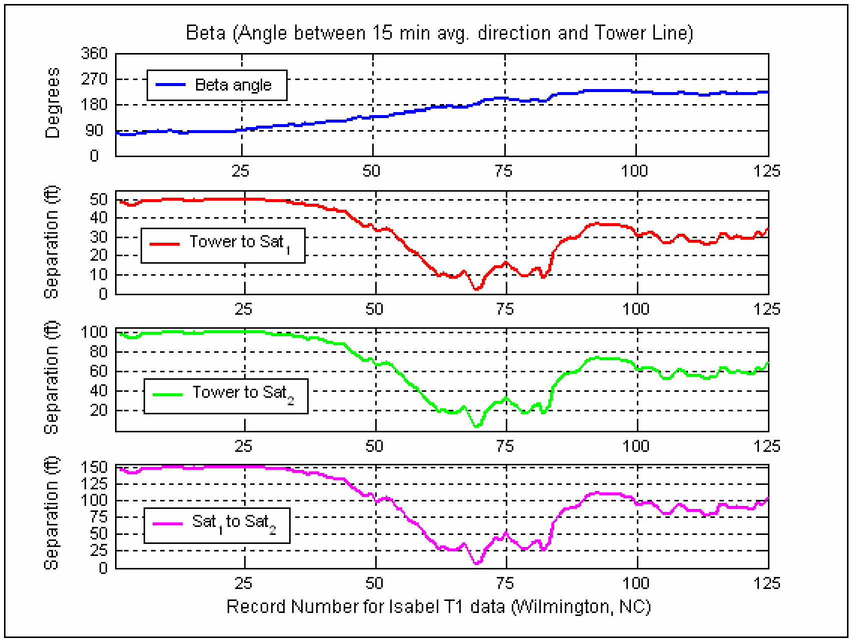

Figure 4-6. Instruments perpendicular to mean wind direction projection for mobile tower T1 during hurricane Isabel. Each record number on the x-axis corresponds to 15 minutes of data.

The fourth step is to compute the temporal cross-covariance between *u* components on pairs of instruments every 15 minutes, normalized by their standard deviations. This produces a plot of the correlation function (bounded between zero and one) as a function of time. The peak is pulled off in order to remove the time lag induced from longitudinal separation between instruments, and added as a point to the plot of spatial correlation as a function of separation. As the wind sweeps through different directions over the duration of the storm, the spatial correlation function is populated with points from many separation distances.

To compute the lateral length scale a linear model is fit through all points obtained from this procedure. The area under this curve represents the lateral length scale of the wind gusts. Figure 4-7 presents the normalized cross-covariance vs. separation generated from the data collected with mobile tower T1 during hurricane Isabel (Wilmington, N.C.). The area under the curve represents the lateral length scale.

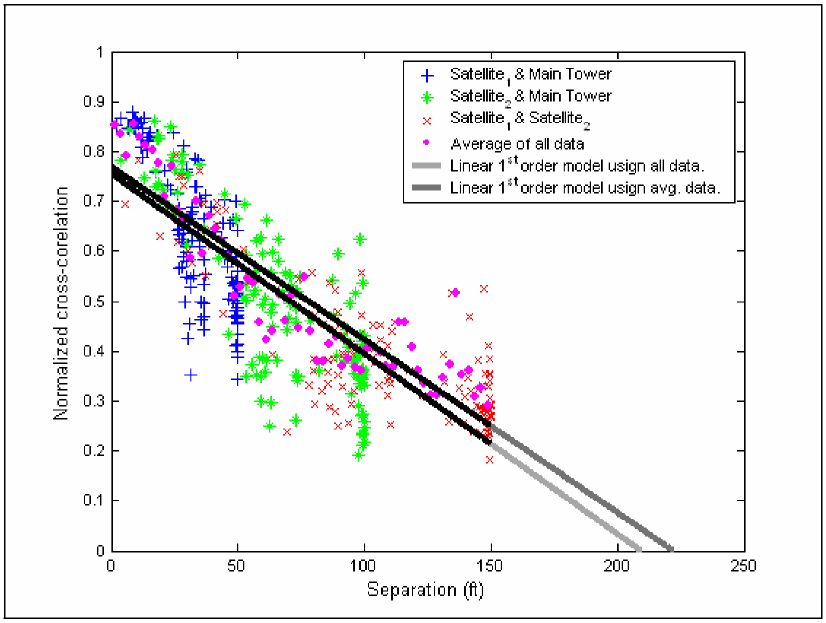

Figure 4-7. Normalized cross-correlation vs. separation using mobile tower T1 hurricane Isabel data.

Various scenarios were considered for integration. The first scenario was to compute the area under all normalized cross-covariance points from the combination of all instruments: (satellite one & main tower), (satellite two & main tower) and (satellite one & satellite two). The second scenario was to average every 5 feet the normalized cross-covariance from all instruments. The third scenario was to fit a linear model to all points. The fourth scenario was to fit a linear model to the average of all points. The integration was performed on these four scenarios up to 150 feet, representing the largest physical distance between instruments. Figure 4-7 shows that the correlation at 150 feet was still significant, and will prompt FCMP teams to deploy the satellite towers further from the main tower in future storms. Two more scenarios were obtained by extrapolating the data from the linear fit models to the x axis. Table 4-3 summaries the values obtained from these scenarios and the integration limits used to compute the lateral length scales. The lateral length scales fall in the 70 feet-plus range, indicating that the wind field measured at this particular location consisted of gusts large enough to envelope a typical residential structure. Thus the entire house will feel coordinated wind gusts.

Table 4-3. Lateral length scale summary for mobile tower T1 during hurricane Isabel

Lateral length scales summary for Isabel T1 10Hz data		
Scenario	Area = Lateral Length Scale (ft)	Integration Limits (ft)
1. All points	73.7611	0 - 150
2. Average from all points	75.3058	0 - 150
3. Linear Model for All points	72.9829	0 - 150
4. Linear Model for Average points	76.7361	0 - 150
5. Linear Model for All points	79.4441	0 - 209.8
6. Linear Model for Average points	85.8736	0 - 222.6

As a rule of thumb some researchers [e.g. Simiu and Scanlan 1996] suggest that the lateral length scale may be approximated as one third of the longitudinal length scale L_u^x, though this relation was not developed using hurricane data. For comparison purposes the longitudinal length scale was computed, and the ratio between the lateral length scale and average longitudinal length scale ranged from 0.45 – 0.49. This comparison is very rough since the longitudinal and lateral length scales depend significantly on the length and degree of the stationary of the record being analyzed, and stationary is not maintained in hurricanes over a time frame more than 30 minutes (typically). As more deployments yield additional data sets, more conclusions can be drawn regarding the range of lateral length scales typical of hurricanes. This information, when combined with the results of other statistical analyses, helps to provide a clearer picture of how hurricane winds interact with structures.

Conclusions

The purpose of this chapter is to outline procedures and methodology developed by the researcher for data processing and analysis, which is important to pass and future members of the FCMP program. The focus is to standardize data processing procedures and to implement new data analysis concepts to compute lateral length scales. In order to accomplish this, the researcher has developed a computer tool package that contains step by step procedures to generate a storm information database using Microsoft Excel and enhance FCMP MATLAB programs. Functions were developed to find maximum wind peaks values, summary pictures were generated and saved, and advanced analysis was performed to compute lateral length scales.

CHAPTER 5
DISSEMINATION

Introduction

Researchers and engineers will have access to the collected hurricane data to conduct analyses and investigations of wind behavior. The data files are to be accessible online through the FCMP web site in the post-processed MATLAB format detailed in Chapter 4. In addition to the data files, GUI-based software has been developed by FCMP personnel specifically for visualization and analysis of the FCMP data, and will also be accessible by the public at the FCMP web site.

This Wind Data Laboratory (WinDLab) software was originally developed in MATLAB by Cuenca [2002], and has since been revised by Weaver [2003]. WinDLab provides users with a graphically based format to perform advanced statistical analysis on high resolution hurricane data. The most recent WinDLab version [Weaver 2003] has been upgraded by the author in several significant ways, including a data loading interface that provides users with details of each storm and tower deployment, additional analysis tools designed for the new satellite towers, a more convenient architecture for the addition of new information from future storms. An installation wizard for easy downloading and use over the web has also been added. This chapter provides a brief overview of WindLab, and discusses the new additions made for ease of use and distribution.

Summary of previous WinDLab version

The left side of Figure 5-1 shows the first tool that is accessed when a user initiates WinDLab. The user must first select the data files desired for analysis, where each data file is 15 minutes from a single tower in a single storm. Once the data is loaded, the user is given many options for both visualization and analysis of the data, as seen by the available buttons in the main window.

During the defense of the Weaver thesis [2003], the committee noted two specific aspects of WinDLab that needed improvement. The first was the data loading (Select Data Files) section that was the required starting point. There was no information provided to guide the user in selecting files for loading. For example, if the user were interested in peak winds, they would need to know in advance that the peak winds for tower T3 during hurricane Isabel occurred 18 hours (72 records) after data collection was initiated. It was suggested that some guidance be provided to users within the graphical display as a frame of reference. The second suggestion was to enter data such as storm names and tower deployment details into an ascii-type input file to be accessed by WinDLab. In this manner, pull down lists of storm names and towers are not hard-coded into the program, and the input list is easily updatable for future additions.

The author's primary objectives were to make changes to address these concerns, and to add another analysis tool to calculate lateral length scales from the new satellite towers. Other improvements include the automation of all WinDLab tools to identify whether 100Hz or 10 Hz data has been loaded, visualization tools for the satellite tower data, additional tower information (GPS, etc.) displayed at the top of every analysis window, and a time axis on all graphs that corresponds to date and UTC time of collection.

WinDLab modifications

Since the previous version of WinDLab did not offer users the ability to browse data files to be loaded in a user-friendly interface, this capability was added to the software. This was the first contribution of the author to the software, in addition to a new summary data window that provides information on FCMP collected data and a lateral length scale window that works for hurricane Isabel data collected with mobile tower T1 and T3. Figure 5-1 shows a screen shot comparison of the previous WinDLab main control and the new version with additional buttons to load the new windows. Each new tool is discussed next.

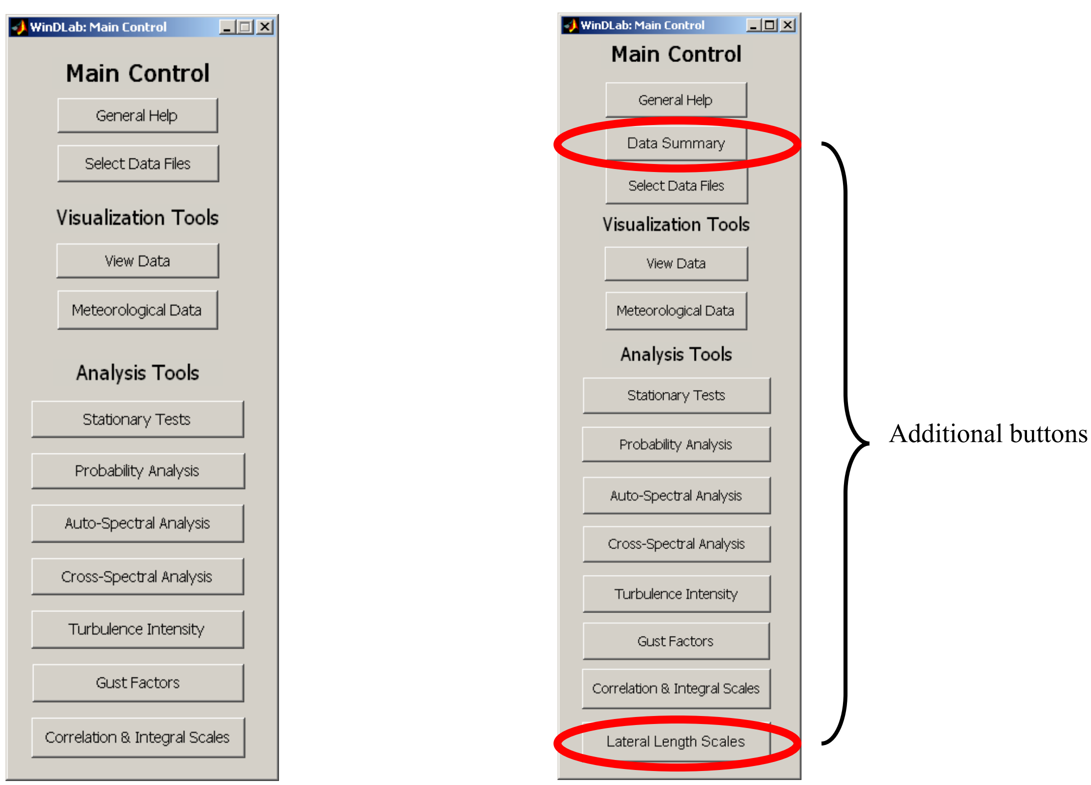

Figure 5-1. Main control for previous version of WinDLab (left) and new version with additional buttons (right)

The Data Summary window provides the user with a frame of reference for all the existing FCMP data. This window allows users to select the storm and FCMP mobile tower (T0 – T3) from a dropdown menu list. When a storm is selected, a deployment map for that storm is provided to show the user where the FCMP towers were deployed relative to the storm path (Figure 5-2). The user can then select a specific tower deployed during that storm, and view an aerial map of the location of deployment (provided by USGS). A summary graph of the data collected by that storm is then displayed to provide a broad overview of the peak and sustained wind speeds (Figure 5-3). Finally, the table at the top of the window provides the following detailed information:

- Storm name
- Year
- Satellites towers present
- Location of selected tower (town)
- GPS coordinates and type of source for selected tower.
- Number of records collected
- Start time of collected data
- End time of collected data

The data displayed in this window is accessed from a MATLAB workspace file that contains the summary information for each particular event. This was done in order to provide an easy way to upgrade the summary information database. This will allow users to download the latest summary files from the FCMP web page once the new data have been collected and processed. The database is created using MS Excel and then is converted to a MATLAB format using a program created by the author. This is setup in such a way that future FCMP towers and storm can be added to the list taking into consideration the possibility that the FCMP will get new mobile towers for the 2004 hurricane season.

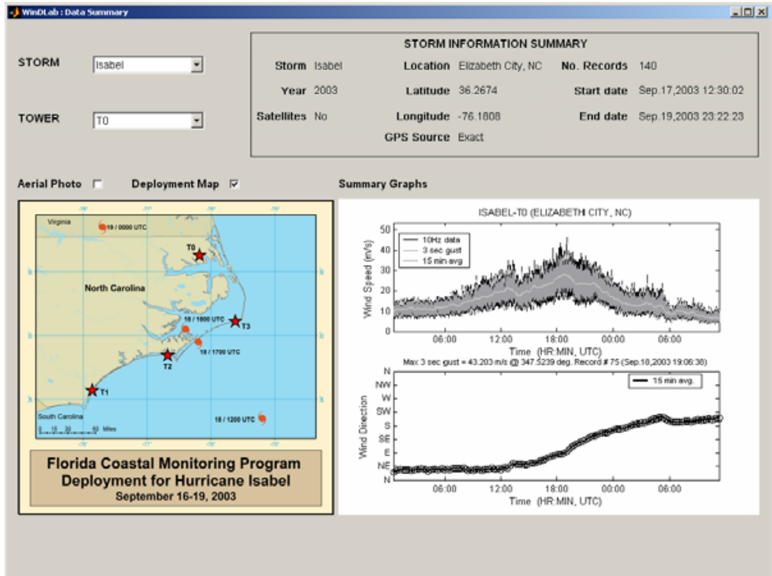

Figure 5-2. New WinDLab Data Summary window showing Deployment Map for Hurricane Isabel.

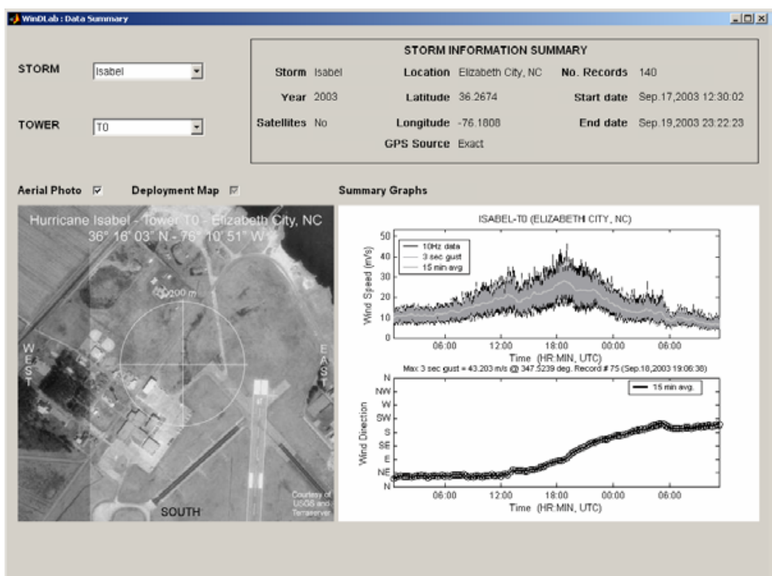

Figure 5-3. New WinDLab Data Summary window showing aerial picture of tower T0 location (Elizabeth City, NC) during Hurricane Isabel.

Referring back to Figure 5-1, the Select Data Files window has been updated to provides users with the ability to browse and access data files through any media storage or network location. This provides a better interface than the previous version. Figure 5-4 presents a screen shot of the new data loading window interface incorporated into WinDLab.

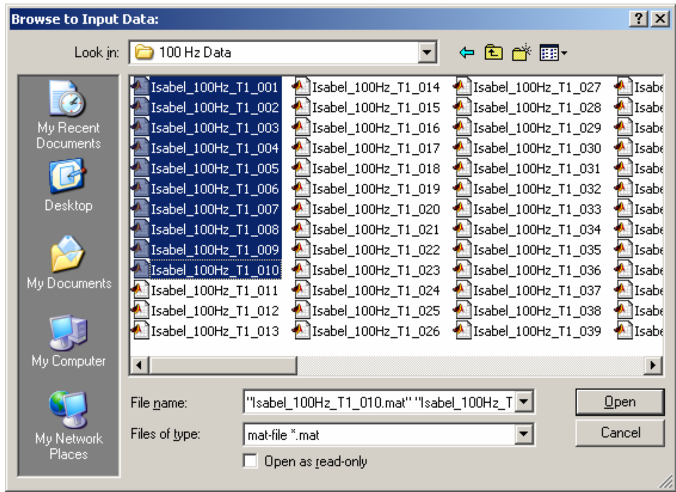

Figure 5-4. Select Data Files window to browse and load FCMP hurricane data into WinDLab.

The new Lateral Length Scales windows show the results obtained from the analysis performed on data records from hurricane Isabel collected with mobile towers T1 and T3. The information provided in this window includes the arrangement used to deploy the main and satellites towers, a 3-D plot that represent the coherence (linear correlation) between 5 meters gill anemometers as a function of separation and frequency, 2-D plots of the spatial correlation vs. separation, and the projected separation perpendicular to mean wind direction. A summary file that shows the computed lateral length scale values for hurricane Isabel mobile tower T1 and T3 is also accessible from this window. Figure 5-5 presents two of the graphs that can be accessed from the Lateral Length Scales window (tower layout and spatial correlation).

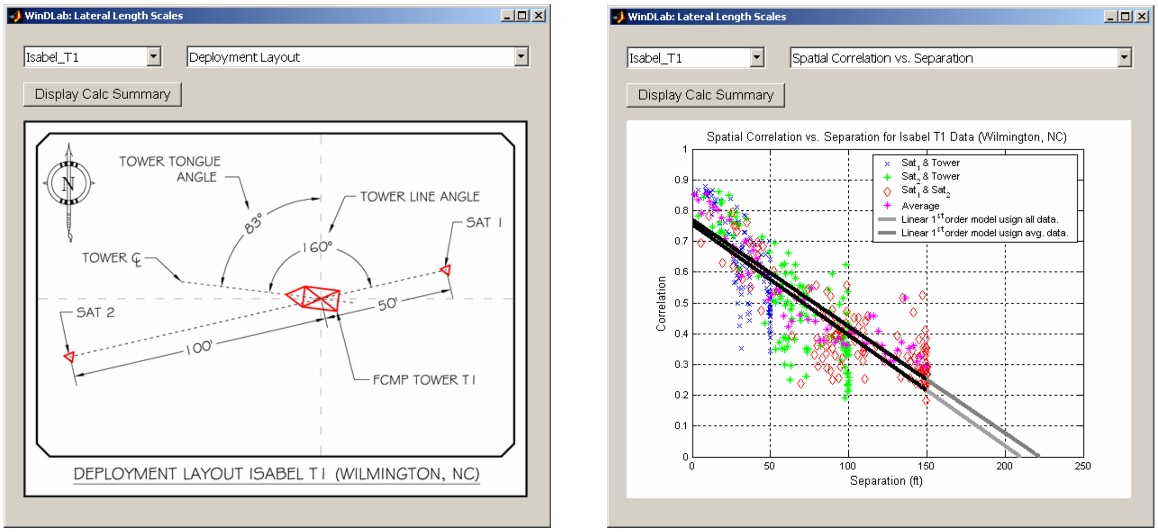

Figure 5-5. New WinDLab lateral length scale windows. Left: Satellite tower layout for T1 during hurricane Isabel. Right: The spatial correlation plot from T1 used to calculate lateral length scale

WinDLab package and distribution

The FCMP web page is used to distribute WinDLab analysis software and the data files desired by the user. A stand-alone version of WinDLab is built using the MATLAB compiler (version 3.0.1). Stand-alone applications run without a MATLAB interpreter, and do not require a MATLAB license. The only required files to run stand-alone applications are the MATLAB run-time libraries, which are distributed with the WinDLab software. Once the stand alone version is compiled, all WinDLab and MATLAB run-time libraries files are compressed into one installation package. This process is prepared using two different programs in order to generate a single file installation package. The first program used is *InstallShield for Microsoft Visual C++ 6*, which compresses WinDLab files and the MATLAB library required to execute the stand-alone application. It provides an executable program that will transfer all required files to execute WinDLab on any computer, and provides the user the option of selecting the destination path to install the software. The second program used to complete the package process is *PackageForTheWeb*, this program wraps the setup files previously create into an internet ready package, and then the final product is ready to be distributed through the FCMP web page (http://www.ce.ufl.edu/~fcmp). The assistance of Mark Williams is gratefully acknowledged for this portion of the work.

Conclusions

The most significant updates to the WinDLab software package are discussed in this chapter. The data selection process was greatly enhanced to provide users with sufficient information to select appropriate storms, towers and specific files. A lateral length scale tool was added for satellite tower analysis. A self-installing, executable version of WinDLab was created for ease of distribution, without the need for MATLAB by the end user. Upon completion of the data validation (discussed in Chapter 3), data files will be made available on the web as well as WinDLab software. Distribution of this data to researchers and the general public is a major overall objective of the FCMP. The author's contributions have put the program in position to fulfill this objective.

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BIOGRAPHICAL SKETCH

Luis D. Aponte-Bermúdez was born on October 25, 1977, in Bayamón, Puerto Rico, to Benjamín Aponte-Ayala and Griselle M. Bermúdez-García. After graduating with honors from the Disciples of Christ Academy in 1995 at Bayamón, Puerto Rico, Luis moved Mayagüez, Puerto Rico to attend the University of Puerto Rico, Mayagüez campus, where he was accepted on the Civil Engineering Department, he graduate with the highest honors after completing 5 year engineering curriculum, and receive his bachelor’s degree in Spring 2002. Luis then move the United States to start working with and engineering consulting firm in Silver Spring, Maryland. On Fall 2001 Luis and his wife moved to Gainesville, Florida where she was accepted into the Department of Architecture and Interior Design to pursuit her master, Luis then start attend University of Florida during the spring 2002 to pursuit his masters and doctoral degrees. Upon graduation, from University of Florida in April 2004, Luis will continue graduates studies for his doctoral degree expected to be completed on December 2005, after that Luis will join University of Puerto Rico as a faculty member in the Department of Civil Engineering and Surveying.