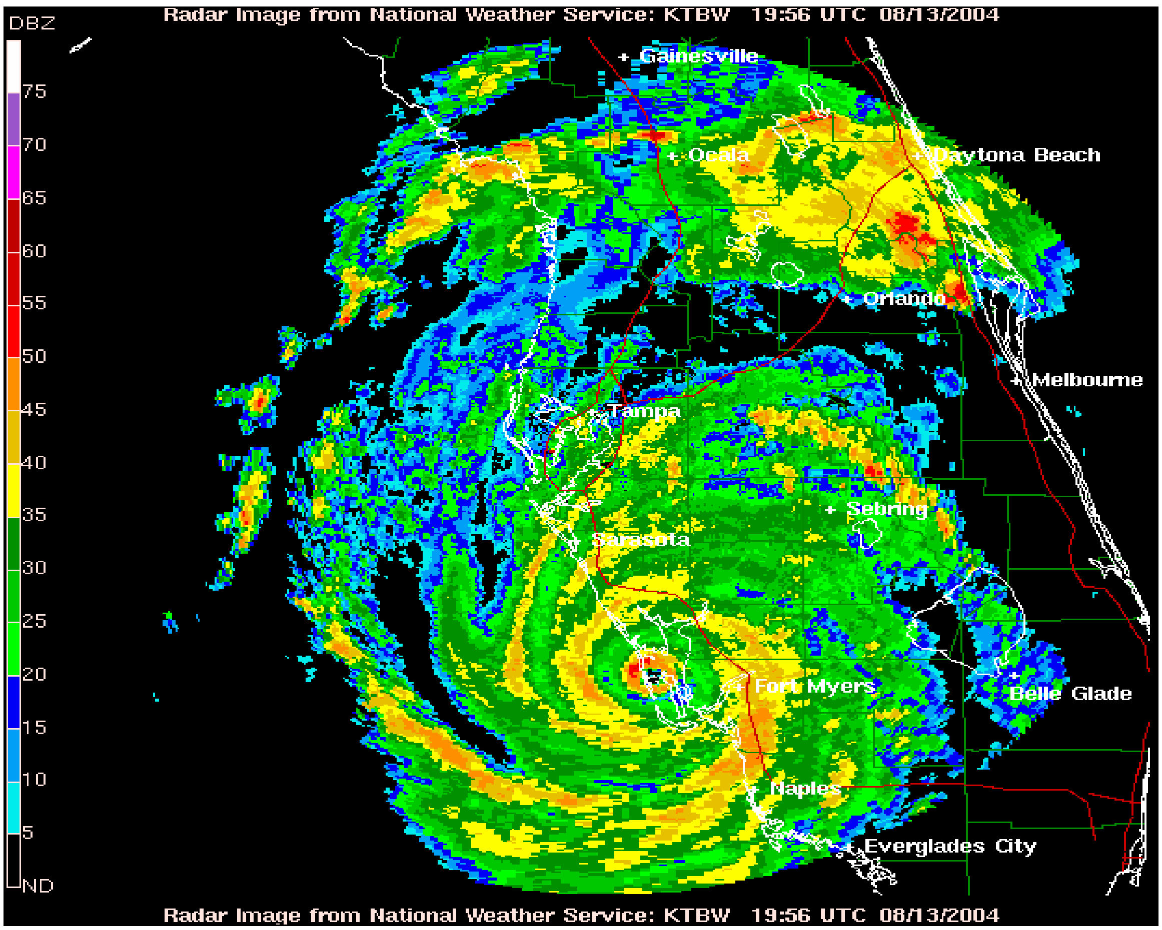
Service Assessment

Hurricane Charley, August 9-15, 2004



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover: Reflectivity image from the WSR-88D located at the Weather Forecast Office in Tampa, FL taken at 1956 UTC, August 13, 2004 as Hurricane Charley made landfall.

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NOAA's National Weather Service
Brigadier General David L. Johnson, USAF (Ret.)
Assistant Administrator for Weather Services

Preface

Hurricane Charley made landfall on the southwest coast of Florida near Cayo Costa, just west of Ft. Myers around 3:45 p.m. EDT on August 13, with maximum sustained surface winds near 150 mph. This made Charley a category 4 storm on the Saffir-Simpson Scale. The maximum storm surge associated with Charley was six to seven feet on Sanibel and Estero Islands. This was less than expected due to a number of factors including an increase in the storm's speed, the eyewall shrinking, and the tide receding. Charley then moved north-northeastward causing significant damage across the Florida peninsula from Punta Gorda, Port Charlotte, Orlando, to Palm Coast (north of Daytona Beach). Charley caused ten direct fatalities in the U.S. and an estimated $14 billion in economic losses. It was a harbinger of things to come, being the first of four hurricanes to affect Florida in August and September of 2004.

This assessment evaluates the service of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) before and during the landfall of Hurricane Charley and provides recommendations to improve services in the future. It takes into consideration the affected audiences in the media and emergency management communities as well as the public.

Service assessments significantly enhance ongoing efforts to improve the quality, timeliness, and value of NWS products and services. Findings of this assessment will further NOAA's goal to serve society's needs for water and weather information.

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Service Assessment Team

An assessment team was activated on August 20, 2004. The team assembled at the Weather Forecast Office (WFO) in Miami, FL on Tuesday, August 24, 2004. During August 25-29, team members visited four Florida WFOs located in Key West, Miami, Melbourne, and the Tampa area; the Tropical Prediction Center (TPC)/National Hurricane Center (NHC); and damage areas. They interviewed Federal, State and County emergency managers, media outlets, and the public in Florida. On September 1, 2004, the Team Leader visited the Southern Regional Headquarters (SRH) Regional Operations Center (ROC) to review their operations. In addition, the Team Leader conducted a review of Hurricane Charley operations at the Southeast River Forecast Center (SERFC) via phone on August 31, 2004.

The team was comprised of the following members:

Jim Weyman	***Team Leader***, Meteorologist in Charge (MIC), WFO Honolulu, Hawaii and Director, Central Pacific Hurricane Center, Honolulu, Hawaii
Frank Marks	Director, Hurricane Research Division Atlantic Oceanographic and Meteorological Laboratory Office of Oceanic and Atmospheric Research Miami, Florida
Jim Duke	MIC, WFO Memphis, Tennessee
Gary Woodall	Warning Coordination Meteorologist (WCM), WFO Fort Worth, Texas
John Cole	WCM, WFO Newport/Morehead City, North Carolina
Reid Hawkins	Science and Operations Officer (SOO), WFO Wilmington, North Carolina
Dan Nietfeld	SOO, WFO Omaha, Nebraska
Ron Trumbla	NOAA Public Affairs, Fort Worth, Texas
Brian LaMarre	Marine and Coastal Services Program Manager, Office of Climate, Water, and Weather (OCWWS), National Weather Service (NWS) Headquarters, Silver Spring, Maryland

Betty Morrow	Social Scientist, Professor Emeritus at Florida International University (Miami) and former Director, Laboratory for Social and Behavior Research at the International Hurricane Research Center

Other valuable contributors include:

Aimee Devaris	Performance Branch Chief, OCWWS, NWS Headquarters, Silver Spring, Maryland
Wayne Presnell	Service Assessment Program Leader, OCWWS, NWS Headquarters, Silver Spring, Maryland
Scott Kiser	Tropical Weather Services Program Manager, OCWWS, NWS Headquarters, Silver Spring, Maryland
Larry Dunn	MIC, WFO Salt Lake City, Utah
Jim Purpura	MIC, WFO San Diego, California
Larry Mooney	MIC, WFO Denver/Boulder Colorado

Acronyms

AOML	Atlantic Oceanographic and Meteorological Laboratory
ASOS	Automated Surface Observing System
EAS	Emergency Alert System
EDT	Eastern Daylight Time
EM	Emergency Manager
FEMA	Federal Emergency Management Agency
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System (numerical forecast model)
HAZUS	HAZARDS U.S. (FEMA loss estimation model)
HLS	Hurricane Local Statement
HRD	Hurricane Research Division
HURREVAC	Hurricane Evacuation software
mb	Millibar
MIC	Meteorologist in Charge
mph	Miles per hour
NCEP	National Centers for Environmental Prediction
NDFD	National Digital Forecast Database
NHC	National Hurricane Center
nm	Nautical miles
NMAO	NOAA Marine and Aviation Operations
NOAA	National Oceanic and Atmospheric Administration
NOW	Short Term Forecast
NWR	NOAA Weather Radio All Hazards
NWS	National Weather Service
OCWWS	Office of Climate, Water and Weather Services
RMW	Radius of Maximum Winds
ROC	Regional Operations Center
RFC	River Forecast Center
RI	Rapid Intensification Index
SERFC	Southeast River Forecast Center
SFMR	Step Frequency Microwave Radiometer
SOO	Science and Operations Officer
SRH	Southern Region Headquarters
TPC	Tropical Prediction Center
VCP	Volume Coverage Pattern
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WSH	National Weather Service Headquarters
WSR-88D	Weather Service Radar, 1988 Doppler
WWA	Watch, Warning, Advisory [software]

Executive Summary

Hurricane Charley was a small but powerful hurricane. It intensified rapidly just before moving onshore near Cayo Costa, Florida on August 13, 2004 as a category 4 hurricane on the Saffir-Simpson Scale. It is rare for hurricanes to make landfall as a category 4 or 5 and to intensify rapidly just before making landfall. Charley's storm surge (maximum of six to seven feet) was relatively low for a category 4 because the hurricane force winds were confined to a small area and the storm was moving at 25 mph. However, there were ten direct fatalities in the U.S. associated with Charley, and preliminary estimates of the total damage and economic loss were $14 billion. Charley was the third costliest hurricane in the U.S. behind Katrina (August 2005) and Andrew (August 1992).

The National Hurricane Center (NHC) predicted the center of Hurricane Charley to make landfall near Tampa Bay, Florida as a category 3 hurricane throughout most of its lifetime. NHC had placed much of Florida's gulf coast under hurricane watches and warnings approximately 24 to 36 hours before landfall, and they had highlighted the area for possible landfall for four days. However, a slight easterly shift in Charley's track toward the coast south of Tampa less than three hours before landfall caused some coastal residents to feel they had inadequate time to prepare. Media and residents seemed to have focused only on the exact forecasted track of the center of Charley, rather than the cone of uncertainty which NHC had included in these track forecasts.

The NWS uses assessment teams to evaluate NWS' service during significant hydro-meteorological events to highlight best practices and recommend improvements. Overall, the NWS performed well as indicated by the eighteen best practices identified during this assessment. The WFOs used some creative ideas such as Internet hurricane safety videos, new volume coverage patterns for the WSR-88D (which detected tornadoes better), and media interviews in Spanish, and they issued enhanced statements and warnings which provided clearer and concise information on Charley's potential for destruction. NOAA's Atlantic Oceanographic Meteorological Laboratory and Hurricane Research Division (AOML/HRD) provided near real time wind analyses to NHC forecasters, researchers, and the Federal Emergency Management Administration's (FEMA) Hazardous U.S. model specialists to assist these decision makers.

The team also noted some opportunities for improvement. Education on hurricane products needed improving, particularly with regard to the forecast track cone of uncertainty. The flow and content of information updates during the hours just prior to hurricane landfall were critical to users and partners. Due either to equipment failures or interruptions in power or communications, disruptions in the availability of real-time observations impacted forecast and warning operations. Information from Step Frequency Microwave Radiometers (SFMR) may have allowed the NHC forecasters to detect the rapid intensification sooner. Finally, some coordination and software problems at the WFOs impacted gridded wind forecasts and the dissemination of some products. The following report contains ten recommendations for addressing these issues.

Service Assessment Report

Introduction

The mission of the U.S. tropical cyclone weather services program is to save lives, mitigate property loss, and improve economic efficiency. NOAA accomplishes this by issuing accurate watches, warnings, forecasts, and analyses of hazardous tropical weather, and also by increasing public understanding of these hazards. NOAA's NHC partners with WFOs, FEMA, media outlets, and state and local officials to conduct extensive outreach campaigns and promote hurricane preparedness. These entities also work very closely when hurricanes and tropical storms make landfall in the U.S. to provide timely and accurate information on the associated hazards, potential impacts, and public safety.

There were ten direct fatalities in the U.S. associated with Charley and insurance companies' preliminary estimates of the total damage and economic loss was $14 billion. Charley was the third costliest hurricane in the U.S. behind Katrina (August 2005) and Andrew (August 1992). It caused devastating wind damage across Florida from Punta Gorda, to Port Charlotte, to Orlando, and then to Palm Coast.

Hurricane Charley was a relatively small hurricane, but it intensified rapidly to category 4 on the Saffir-Simpson scale (**Appendix A**) just before moving onshore at the barrier islands of Sanibel and Captiva near Cayo Costa, Florida on August 13, 2004. Charley's intensity increased rapidly (a drop of 23 millibars (mb) of pressure in less than five hours) as it approached the southwest coast of Florida. It is unusual for hurricanes to intensify rapidly just before making landfall – they usually weaken – and it is rare for hurricanes to make landfall as a category 4 or 5. Refer to **Appendix B** for details on the observed track of Charley, the NHC forecast track, the rapid pressure drop indicating the strengthening, and a WSR-88D radar image from Weather Forecast Office (WFO) Tampa as Charley made landfall.

Tampa had been highlighted as the potential landfall location based solely on the track forecast. However, NHC had communicated its uncertainty with the track and intensity of the hurricane and the potential for Hurricane Charley to make landfall at locations other than Tampa through several different ways. At the time of landfall, Captiva Island, Punta Gorda, and Fort Myers areas had been:

- in the cone of uncertainty for almost 4 days (the cone of uncertainty is the area in which 70 percent of all past tropical cyclone track forecasts fell based upon the last 10 year average),
- under a hurricane watch for almost 35 hours, and
- under a hurricane warning for almost 23 hours.

Since many southwest Florida residents felt they did not have adequate time to prepare and Charley was such a costly hurricane, NWS sent a service assessment team to evaluate its service during the event. The team identified eighteen best practices which may serve to benefit operations in other NWS offices. The report presents some of the most vital lessons learned during Charley and provides a complete listing of all the best practices on the pages following the report's conclusion.

In addition, the NWS service assessment team found opportunities for improvement. The team captured these in the ten findings and recommendations described throughout this report.

Hurricane Forecast Track and Intensity

In the three to five day range, the NHC forecasted the center of Charley to move onshore near the Tampa area with maximum sustained winds on the high end of category 2 or low end of category 3. In general, NHC maintained this forecast until about three hours before actual landfall. At approximately 1:00 p.m., NHC adjusted its forecast track to show Charley's eye moving onshore near Charlotte Harbor, FL (south of Tampa) and increased the intensity forecast to a category 3. They based this change on information received from the reconnaissance aircraft investigating the hurricane and radar trends. Charley underwent rapid intensification and made landfall near Cayo Costa along the barrier islands of Captiva and Sanibel at approximately 3:45 p.m. August 13, 2004 as a category 4 hurricane.

The Tampa area was not significantly impacted as originally projected. This was due to the change in track and Charley's eye, the area of strongest winds, was shrinking in size keeping the greatest impacts in a relatively small area. However as noted in the Introduction, NHC had issued hurricane watches and warnings for the landfall area well before the occurrence.

Many people focused on the specific forecast track which indicated the projected path of the center of Hurricane Charley making landfall near Tampa Bay instead of the cone of uncertainty (see **Figure 1**). The cone around the projected track indicated areas of possible landfalls on either side of Tampa. Betty Morrow, Social Scientist, Professor Emeritus at Florida International University (Miami) and an Assessment Team member, interviewed approximately 100 people in the Fort Myers and Punta Gorda areas. She found many did not understand the uncertainty associated with the track forecast. Over 90 percent said they heard the hurricane was going to hit Tampa and not them until it was too late to do something. Steve Jerve, Chief Meteorologist, WFLA-TV, Tampa, echoed this perception, *"What people don't understand is the great amount of error in those tracks. We know that and try to communicate it to the people, but they see the graphic on the air and just focus on that."* Bryan Norcross, Director of Meteorology, WFOR-TV Miami wrote, *"Many Floridians, if not most, have the perception that the forecast was wrong and that the storm bamboozled the experts. But that's not true and the misperception harms the hurricane warning program."*

Finding 1: Many people focused on the specific forecast track which showed the center of Hurricane Charley making landfall near Tampa rather than considering the cone of uncertainty which indicated areas of possible landfalls on either side of the predicted path.

Recommendation 1: The NWS needs to increase their education efforts on hurricane tracks and the uncertainty in tropical cyclone forecasts and to find ways to better communicate the uncertainty and risk.

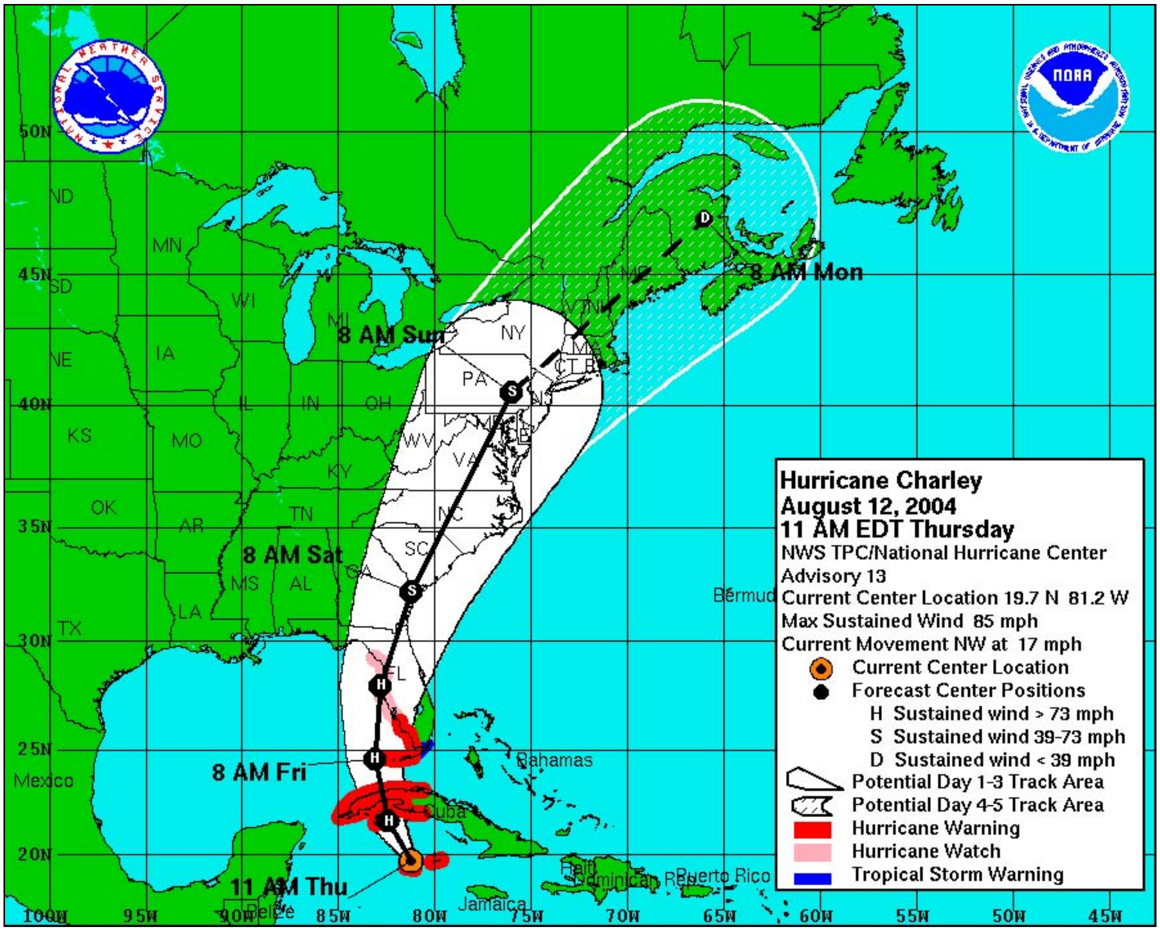


Figure 1. The three-day hurricane forecast, including coastal watches and warnings in effect at 11 am EDT Thursday, August 12 – about 28 hours prior to Charley making landfall. The 1-3 day cone of uncertainty is represented by the white shading. (Note: This is just one example of this graphical product. The product is issued every 6 hours at 11 a.m. and 11 p.m. and 5 a.m. and 5 p.m. Eastern Time.) The graphic consistently showed the ultimate landfall area within the forecast cone of uncertainty.

When Charley was within six hours of landfall, radar and satellite images indicated the eye began to wobble slightly giving the appearance of a possible change in track. Many NWS users perceived these wobbles as changes in the predicted track and became concerned when NHC did not provide information on these possible changes. Some of the TV meteorologists and Emergency Managers (EM) began to adjust the track forecast themselves without official information from NHC. Jim Reif, Chief Meteorologist at WZVN-TV Fort Myers stated, "*Everyone was warned, but in the last 6 hours, something failed. There were a lot of forecasters from Orlando to Tampa to Fort*

Myers who believed they were out on a limb without the NHC during the last couple hours before landfall whether rightfully or not." Alan Winfield, Chief Meteorologist, Bay News 9, Pinellas Park stated, "*They (NHC) just need to communicate a little more often in the last moments."* Dave Roberts from WFTX-TV4 FOX, Cape Coral, echoed this statement, *"The forecast was very good, but the communication was poor. During the last 6 hours, we needed a play by play of events, explanation of wobbles, NHC's thinking or else the public and media are going to arrive at their own conclusions."*

Finding 2a: Many NWS users in the Tampa, Fort Myers, and Orlando areas perceived a change in Hurricane Charley's track due to wobbles indicated by radar and satellite information, and they felt there was a lack of information from NHC concerning this change.

Finding 2b. Local television meteorologists and emergency managers began to make decisions and disseminate information based upon their perceptions of a track change before NHC issued official information.

Recommendation 2: As part of its continuous flow of information prior to landfall, NHC should provide information on possible hurricane track and intensity changes. NHC should continue to emphasize people not in the direct track area of the hurricane need to stay alert for possible rapid changes.

The observed increase in Charley's winds might have been recognized four to six hours sooner if the NHC had received Step Frequency Microwave Radiometer (SFMR) data. NOAA uses their two P3 aircraft for a combination of research and hurricane reconnaissance operations. When Hurricane Charley approached landfall, the NOAA P3 reconnaissance aircraft did not have SFMR instrumentation on board. NWS and NMAO have since coordinated the use of the P3s to ensure SFMR data collection capability is available for all hurricanes approaching the U.S. coastline. Currently, the U.S. Air Force Reserve's weather reconnaissance C-130J aircraft are not instrumented with the SFMR.

Finding 3: Timely SFMR data could have indicated the intensification of Hurricane Charley prior to landfall.

Recommendation 3: NOAA should work with the U.S. Air Force Reserves to put SFMRs on C-130s Js and then obtain certification for reconnaissance missions as soon as possible.[1]

Automated Surface Observing System (ASOS) observations are very important inputs to the NHC forecasts, especially when tropical cyclones are near the U.S. coastline. Class I ASOS systems, located at non-towered airports and other observation sites, have no backup power or communications source and are not designed to withstand hurricane force winds in excess of 125 knots. As a result, ASOS wind measurements during hurricanes rarely record the maximum sustained winds or peak wind gusts due to the lack of a backup power source and/or equipment failure during the period of strongest

[1] This action is in progress.

winds. This has been documented in several articles, and an example can be found in the March 2005 edition of the American Association for Wind Engineering newsletter at: http://www.aawe.org.

Valuable ASOS data during the extreme weather conditions of Hurricane Charley were lost. Yet, during Charley's passage over western Cuba, anemometers remained operational to report 1-minute average winds up to 103 knots with gusts to 130 knots.

Finding 4: Many ASOSs lost valuable data during the extreme weather conditions of Charley. The primary power sources and communication systems (telephones) failed and/or the data measuring instruments were damaged or destroyed. These data losses:

a. prevented forecasters at WFOs and NHC from receiving real-time wind speed and direction data which are crucial to providing life-saving information, products, and services to users at a time when most needed.
b. limited accuracy of decision-makers risk assessment.
c. limited the ability to "ground truth" the radar observed winds.
d. impacted wind forecast accuracy for areas downstream of the hurricane.
e. deprived emergency first responders of important information to aid in their decisions to prioritize response resources.
f. compromised the long-term climate record of extreme weather events.
g. limited structural engineers from determining the correlation between wind speeds and damage which impacts the development of suitable building codes.
h. affected hurricane researchers in improving hurricane forecasting by limiting knowledge on the structure and intensity of specific hurricanes.

Recommendation 4a: NWS Headquarters should assess the installation of backup power sources for ASOS, such as UPSs lasting 12 hours or more, batteries, and solar panels with power storage devices. The highest priority for backup power should be given to ASOSs located in hurricane prone areas (coastal and near-coastal).

Recommendation 4b: ASOS anemometers in hurricane prone areas should be engineered to withstand Category 4-5 hurricane force winds.

WFO Operations and Services

The WFOs most affected during Charley performed well and employed some innovative techniques for getting critical updates to their partners and users; however, there are some opportunities for improvement. The team found the preparation of wind grids for the National Digital Forecast Database (NDFD) increased the workload significantly during already busy hurricane operations. Sometimes the offices were too busy to coordinate, update, and quality control many of the grids. This resulted in some inconsistent wind graphics produced by the NDFD (**Figure 2**).

Finding 5. Images from the NDFD wind grids for Hurricane Charley showed large inconsistencies among Florida WFOs.

Recommendation 5: OCWWS and the Tropical Cyclone Forecast Advisory Wind

Team should explore ways to decrease the workload associated with the preparation of the wind grids and to improve forecasters' capability to produce more consistent gridded forecasts during extreme events such as hurricanes.

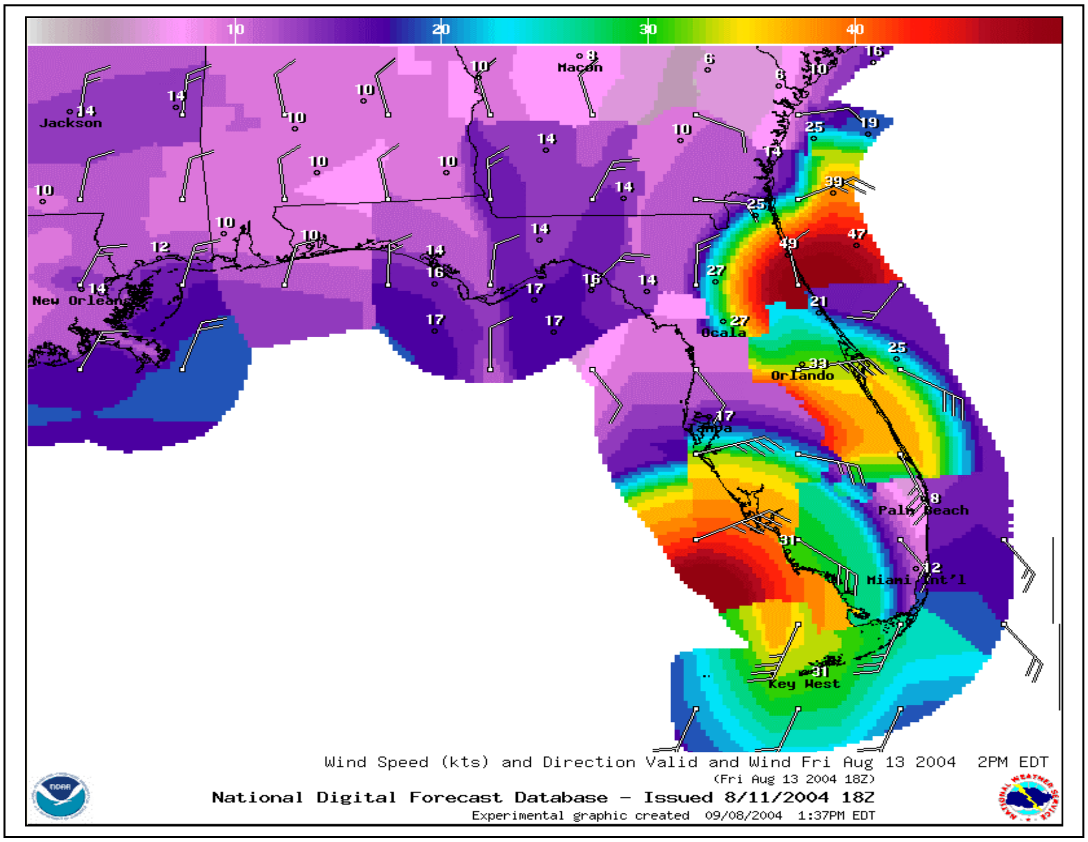


Figure 2. Wind speed and direction grids from NDFD issued on August 11, 2004 at 2 p.m. EDT valid at 2 p.m. EDT August 13, 2004. The WFOs prepared these grids two days before landfall and they were valid approximately 2 hours before landfall near Captiva Island.

The WFOs used a program called WWA (watch, warning, and advisory) software to produce watches, warnings, and advisories. Forecasters identified significant limitations with the use of the WWA editor. The NWS no longer uses WWA in NWS warning operations; however, this finding was important in the context of Hurricane Charley operations. Any software used for production of warnings, watches and advisories should be simple and easy to use.

Finding 6: Some of the WFOs found the WWA software difficult and time-consuming to use and stated WWA contributed to a number of errors in their products. Because it was easier to edit previous products rather than use WWA, the offices experienced problems with headers, expiration times, and other entries. These formatting problems, especially errors in the product valid time, led to product dissemination errors in some cases and caused some users to not receive or to not process the products properly.

Recommendation 6: Software used for production of warnings, watches, and advisories should be easy and efficient to use and require minimal manual quality control.

WFO Key West enhanced their Hurricane Local Statements (HLS) by identifying information changed since the previous issuance by beginning each section with the following bullet:

…*NEW INFORMATION SINCE LAST UPDATE*…

Bryan Norcross stated, *"WFO Key West's HLSs were the best ones I have seen."* (**Best Practice 6**)

Not all HLS users across Florida shared this sentiment. Some found the HLSs to be of little use because they contained too much information given in other products, covered too wide of an area, were too long, and often repeated the same information contained in previously issued HLSs.

Finding 7: Some users considered the variety of NWS tropical cyclone weather products excessive and overlapping without a single place to go for a concise summary. They found the HLS did not fulfill this need.

Recommendation 7: NWS should improve the HLS issuance time, format, structure, and content to meet the needs of the users.

The NOAA Weather Radio All Hazards (NWR) broadcast cycle was excessively long on several transmitters as Charley approached the Florida coast. WFO Tampa's broadcast cycles reached 33 minutes at times during Charley, and the staff tried to mitigate this by changing the periodicity of some of their products to play only once or twice an hour. There were user complaints about broadcast cycle length, including one in writing. WFO Melbourne's broadcast cycles exceeded 20 minutes, and they took action to monitor the cycle length and combine products for broadcast purposes to keep the cycle length under eight minutes. WFO Key West used scripts to reduce the length of their NWR broadcast (**Best Practice 7**).

Finding 8: NWR broadcast cycles were too long at some WFOs. NWS Instruction 10-1710, "NOAA Weather Radio Dissemination" provides guidance for NWR programming during hazardous weather events. The policy contains explicit instructions for hurricane situations: "During hurricane and tropical storm warnings, limit the programming to: separate warning message with the advisory, service area forecast, short term forecast, tracking, conditions in the weather roundup, safety rules, or any HLS."

Recommendation 8: To minimize the NWR broadcast cycle length, WFOs should make use of the capability for assigning priority to weather products and for transitioning the broadcast into high or exclusive product suites to follow the guidelines in 10-1710.

WFO Key West used the new Volume Coverage Pattern (VCP) 121 for their radar to better detect tornadoes. Using VCP 121 eliminates range folding, increases the frequency of data, and increases the maximum Doppler range for better detection of significant radar velocity and reflectivity imagery. (**Best Practice 4**).

WFOs Miami and Tampa conducted media interviews in Spanish, helping to reach the large Spanish-speaking population in Florida. The Science and Operations Officer (SOO) at WFO Miami is fluent in Spanish, and he provided Spanish language translations of the HLSs to local users. He also provided six live interviews in Spanish for local and national Spanish media, including markets covering Tampa, Melbourne, and San Juan, Puerto Rico. The WFO Tampa Meteorologist-in-Charge (MIC) conducted numerous interviews in Spanish for the media as well (**Best Practice 8**).

Due to the small radius of maximum winds and the intensity of the hurricane winds over land, WFO Melbourne issued a Tornado Warning approximately one hour prior to the extreme winds of the eye-wall entered their area of responsibility. The warning emphasized the destructive winds over 100 mph and possible tornadoes (**Best Practice 10**). Following the Tornado Warning, WFO Melbourne issued 12 Severe Weather Statements about every 20 minutes for 5 ½ hours to give the latest location of the eye-wall and areas to be impacted. The warning activated all EAS outlets and was broadcasted on 69 radio stations and numerous television stations simultaneously. This approach worked well in this extraordinary circumstance.

Cheryl Grabowski, Osceola County Emergency Management Director, viewed the use of a Tornado Warning with Severe Weather Statements updates to heighten awareness of the devastating winds as *"Fantastic. They gave me almost to the minute locations, and were really helpful."* Grabowski went on to say, *"We could use the products to track the power outages in Osceola County."* Dean O'Neal said the Tornado Warning was a, *"Stroke of genius for getting onto EAS."* O'Neal commented on the follow up Severe Weather Statements saying, "*…they were incredibly helpful and contained new data that we did not have.*"

The Office of Climate, Water, and Weather Services (OCWWS) at NWS headquarters (WSH) has created a team to work on science issues, warning criteria, nomenclature, distribution issues, and public response for possible "Hurricane Eye-Wall Warnings" or other possible short-term and long-term solutions to the issues of inland affects from very intense eye-walls.

Other NOAA Offices Assisting NWS Operations and Services

During the lifecycle of Hurricane Charley, NOAA's AOML/HRD ran two versions of the rapid intensification (RI) forecast index in real time. The RI may help estimate the probability of rapid intensification of a hurricane. AOML/HRD personnel provided the output to the hurricane specialists at NHC. The RI showed potential as a forecast tool as it performed 8-13% better than hurricane climatology during Charley **(Best Practice 15)**.

NWS Southern Region Headquarters (SRH) detailed two meteorologists (from WFOs Austin/San Antonio and Birmingham) to WFOs Tallahassee and Tampa to supplement their operational staffs. WFO Tampa believed the additional forecaster was very helpful. In addition, the Regional Operations Center (ROC) responded to a radar outage in Tampa effectively and efficiently. They coordinated with WFO Tampa, the Radar Operations Center staff, the National Logistics Supply Center, and a contractor and ensured prompt delivery of required parts to get Tampa's WSR-88D fixed fourteen hours before the hurricane struck.

During the event, limited Internet bandwidth caused problems with access to NWS Florida websites. SRH performed the necessary steps to bring on-line two additional web servers. SRH completed this operation several hours prior to landfall. This provided the SRH with ample access capability to accommodate the multitude of data requests, especially for radar imagery. All of the Florida WFOs stated the SRH ROC was very proactive and provided valuable support to the WFOs in Florida during Hurricane Charley (**Best Practice 16**).

The Southeast River Forecast center (SERFC) took a number of actions to enhance information flow to support decision makers and users of hydrologic information. They used a variety of means to communicate with partners, including "pushing" graphics to a web site, resulting in a combined audio/video briefing. The SERFC sent "SERFC Flood Alert" email messages to key partners to provide a heads up on anticipated conditions (**Best Practice 17**).

The SERFC for the first time provided daily guidance to WFO Miami on anticipated Lake Okeechobee elevations. SERFC hydrologists issued basin-specific Hydrologist Forecast Discussions, and improved the 24-hour Graphical Hydro-meteorological Discussion to depict conditions expected during the near term. The SERFC also produced the Significant River Flood Outlook to identify and communicate areas of concern throughout the event.

Ben Nelson, Florida State Meteorologist, wrote, *"The SERFC nailed this one. They had been saying for a week that the St. Johns and Tampa area Rivers would be hit…and they were."*

Hurricane Evacuation software (HURREVAC) is used by government EMs as an aid in evacuation decision-making. HURREVAC uses NHC information to track hurricanes and estimates when evacuation decisions should be made based on a number of inputs. Several EM officials in inland counties expressed the need for HURREVAC to indicate the location of Inland Hurricane and Tropical Storm Wind Watches and Warnings. In August 2004, shortly after Charley, the Director of TPC/NHC asked the software developer about the feasibility of this enhancement. The developer stated the requested enhancement would be a very difficult task unless there was a single product, issued in a computer friendly format, that contained all of these warnings. Currently no such product exists; the individual WFOs issue their warnings individually.

Finding 9: HURREVAC software did not identify the areas of Inland Hurricane and Tropical Storm Wind Watches and Warnings.

Recommendation 9: NWS should encourage the developers of HURREVAC to enhance the software to identify areas of inland hurricane wind watches and warnings and offer to collaborate on the most efficient way to accomplish this.

Dissemination Services

The Internet was a popular dissemination tool for NWS products during Charley. From August 12 through 15, the total number of hits (i.e., the retrieval of an image or other content from a server) received by NWS websites was approximately 412 million. In comparison, during the five-day hurricane Isabel event, the same NWS websites collectively received about 255 million hits.

At the approach of tropical storm Bonnie, two days before hurricane Charley, NWS established a number of protocols to facilitate communications among NWS webmasters for manual load balancing of radar pages. NWS did this to mitigate the anticipated high web traffic from the Southern Region by shifting some demands to the Central, Eastern, and WSH web servers. In addition, NOAA, NWS, and NHC coordinated to better support the NHC website.

Despite these efforts, severe server loads taxed commodity bandwidth at mirror sites and occasional mirror site outages occurred. Some EMs said they were unable to get updated radar information, and other users reported being unable to get updated forecasts and warnings from local WFO Internet sites and the NHC Internet site. The NWS contracted with a commercial web provider to host the TPC/NHC web site for the remainder of the 2004 hurricane season. However, the switch over to the commercial provider did not occur until the afternoon of August 13, at approximately the same time of Charley's landfall.

The NWR transmitters in Orlando and Daytona Beach lost electrical power as the hurricane force winds swept through and failed because no backup power was available. The NWR transmitter at Sugarloaf (Key West area) lost power due to a transmission line being struck by a sailboat that broke loose. This particular transmitter does have a backup generator, but it also failed. NWR is a primary entry point for warning messages to the Emergency Alert System (EAS), so these failures disabled a primary dissemination channel for NWS to send warnings to commercial television and radio outlets. WFO Key West issued a Tornado Warning for the Lower Keys in Monroe County, including Key West, during the period the NWR transmitter was non-operational.

Finding 10a: Some NWR transmitters lost electrical power during Charley. Previous assessment reports documented this problem; however currently, there is no funding available to provide backup power to all NWS NWR sites.

Finding 10b: Since the NWR transmitter was not operational, the EAS was not activated when the Key West tornado warning was sent. WFO Key West was unaware of the NWR outage and did not notify the EAS primary and secondary stations of the Tornado Warning until 17 minutes after it was issued.

Recommendation 10a: The NWS should acquire emergency power generators for all NWR transmitters in hurricane prone areas and eventually for all of the remaining sites as funding permits.

Recommendation 10b: WFO Key West should work with EAS stations to establish backup EAS entry points and timely backup notification for tornado warnings. These procedures should be documented in their Station Duty Manual and local EAS Plan.

Conclusion

Although Hurricane Charley's behavior was unusual with its change in track and rapid intensification just before landfall, all NOAA offices worked well as a team and provided valuable information to its partners and users. NHC had proper watches and warnings in effect for southwest Florida well before Charley made landfall, and they forecasted the possibility of a major hurricane (i.e., category 3, 4, or 5) affecting Florida. The WFOs met performance standards for products and services and used creative methods for statements, warnings, and product dissemination. They also provided excellent public service by delivering media interviews in both Spanish and English. The SR ROC and SERFC provided valuable resources and information to the NHC and WFOs. NOAA's HRD provided real time hurricane wind analyses. Michael Lowder, Director of Operations, Response Division, FEMA, Department of Homeland Security, stated,

> *"Outstanding – 10 out of 10! The White House was totally amazed we had this process in place that brought [everyone] together... and then the hurricane specialist on duty personally participated, so they got information straight from the expert. The key part of the success with Hurricane Charley was the participation and coordination of all agencies in NWS and EM communities."*

The team also discovered some opportunities for improvement in NWS services. The NWS needs to provide additional education and outreach efforts and to improve communication methods on the uncertainty in hurricane track forecasts. NHC's issuance of additional information on possible track or intensity changes during the last few hours before landfall would have assisted the media, the public, and decision-makers. In addition, NWS needs to improve the HLS issuance times, format, structure, and content to meet the users' requirements.

In addition, the team identified some technical problems. ASOSs were unable to transmit due to power and/or communications failures or damage to the instruments during the time of the strongest winds, and therefore critical wind and pressure data were unavailable. SFMR data for Charley were not available, and this could have hindered NHC's forecasters from recognizing the rapid intensification sooner. The preparation of forecasted wind grids for the NDFD was inefficient, and the final product was of low quality. WWA software was difficult to use and produced some product errors.

The recommendations in this report will improve these areas and create more valuable products and services from the NWS during future hurricanes affecting the U.S.

Best Practices

1. Because of NHC's extensive coordination before the hurricane season, TPC, WFOs, RFC, SRH, WSH, NCEP, EMs, FEMA Headquarters, FEMA Region IV, military, media, and many other government and non-government agencies worked well together to protect the American public.

2. NOAA Public Affairs ensured PA representatives were on standby to help NHC with the media during hurricane events.

3. To ensure smooth and efficient operations, WFO Key West staff had easy access to an Intranet-based hurricane operations plan, which had a decision-assistance flow chart and worksheet.

4. WFO Key West used the new Volume Coverage Pattern (VCP) 121 to eliminate range folding, increase frequency of data, and increase in maximum Doppler range for better detection of significant radar velocity and reflectivity imagery. VCP 121 is designed to aid in the detection of tornadoes.

5. WFO Key West prepared two videos for the Internet on hurricane safety and HLSs. A local county government access channel and two local tourism channels aired these, prior to and during the hurricane season, reaching thousands of Florida Keys residents and non-residents.

6. WFO Key West made the HLS easier to use by identifying information changed since the previous issuance. The section began with the following bullet:
   …NEW INFORMATION SINCE LAST UPDATE…

7. WFO Key West used local scripting to reduce the NWR cycle time during critical weather operations. This produced a short, concise broadcast of the tropical cyclone suite of products. The office reduced broadcast cycle times to less than ten minutes with some as low as seven minutes.

8. The WFO Tampa MIC and WFO Miami SOO conducted numerous interviews for the Spanish media in Spanish. They provided Spanish language translations of the HLSs to local users. They also provided live interviews in Spanish for local and national media including markets covering Tampa, Melbourne, and San Juan, Puerto Rico.

9. WFO Miami provided a constant flow of information to their users through issuing Severe Weather Statements, Local Storm Reports, and Short Term Forecasts (NOW). They issued NOWs nearly hourly from August 12 at 6 a.m. EDT through 8 p.m. EDT on August 13 containing updates on local conditions. The media and the EMs praised the usefulness of these products in providing information.

10. Because of the small radius of the most intense winds, WFO Melbourne issued a Tornado Warning, valid for one hour, emphasizing the destructive winds over 100 mph and tornadoes associated with the eye-wall of Charley before the destructive winds entered their area of responsibility.

11. WFO Melbourne assigned each Hydro-meteorological Technician the responsibility to recruit storm spotters in two counties. This increased the pool of storm spotters, particularly in sparsely populated areas.

12. WFO Melbourne used the weekly NWR Tone Alarm test conducted on Wednesday, August 11, as an opportunity to conduct a live briefing to alert people Tropical Storm Charley would intensify into a hurricane over the northwest Caribbean that afternoon and be a threat to central Florida later in the week.

13. The WFO Tampa webmasters combined documentation from the damage surveys with over 250 damage photographs, radar loops, and electronic versions of all hurricane-related products into a comprehensive page on their website.

14. WFO Tampa, SRH and, a contractor, corrected a back up power problem with the WFO Tampa WSR-88D. The radar was restarted and manually transferred to generator power. The system was returned to service at approximately 2 a.m. EDT, on August 13, about 14 hours before landfall.

15. NOAA's AOML/HRD ran two versions of the RI forecast index. Performance of the RI index during Charley showed it had skill ranging from 8-13 percent better than climatology.

16. All of the Florida WFOs stated the SRH ROC was very proactive and provided valuable support to the WFOs in Florida during Hurricane Charley.

17. The SERFC took a number of actions to enhance information flow to users. They used a variety of means to communicate with their partners, including "pushing" graphics to a web site, resulting in a combined audio/video briefing. The SERFC sent "SERFC Flood Alert" email messages to key partners to provide a heads up on anticipated conditions.

Appendix A

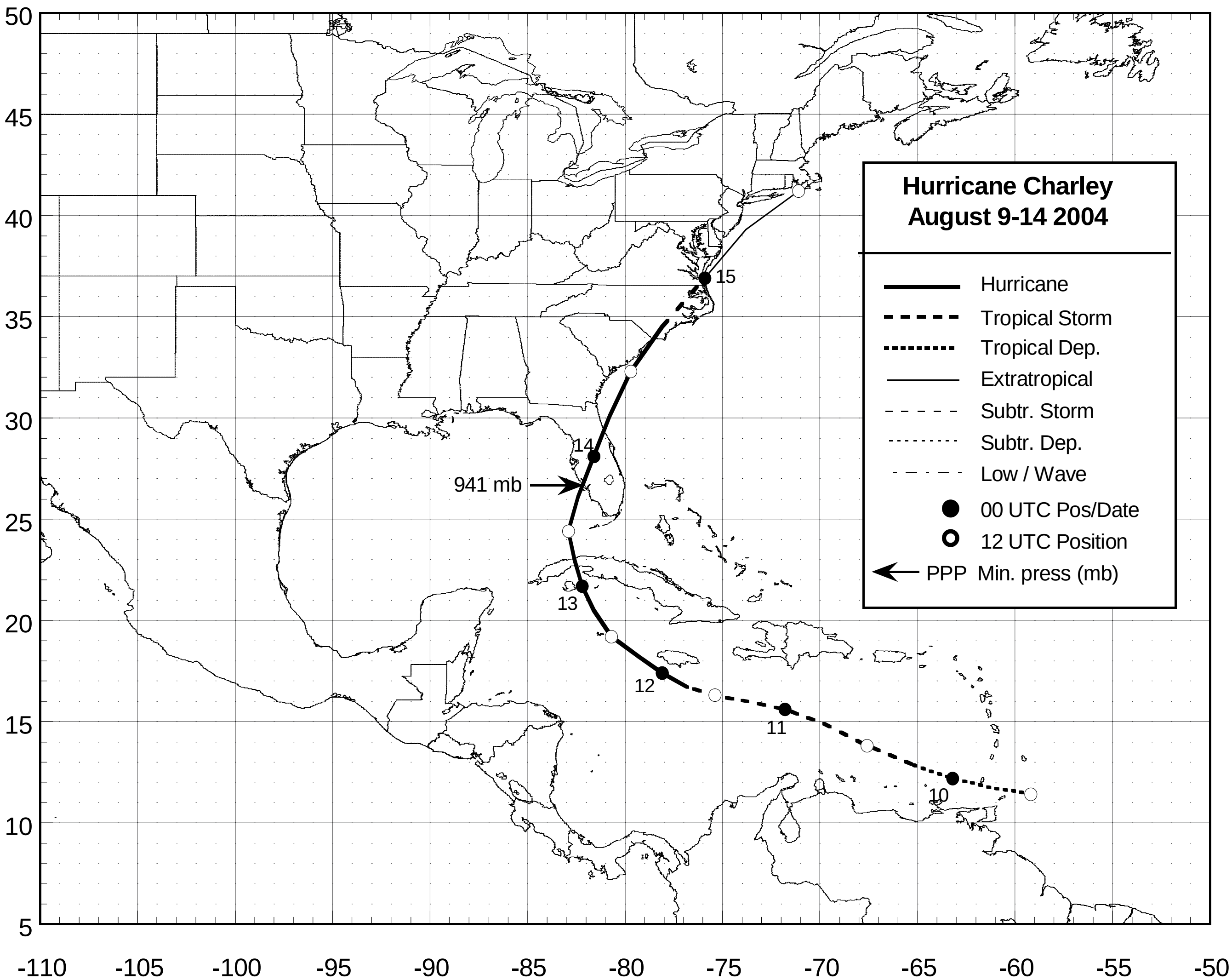
The Saffir-Simpson Hurricane Scale

The Saffir-Simpson Hurricane Scale is a 1-5 rating scale based upon the hurricane's intensity. The National Weather Service and others use this to estimate the potential property damage and storm surge expected along the coast from a hurricane landfall for the continental United States. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. All winds speeds are the US standard 1-minute mean wind speeds in mph.

Category	Sustained Wind in mph	Barometric Pressure in millibars	Storm Surge in feet above normal	Damage
1	74-95	>980	4-5	Minimal
2	96-110	965-979	6-8	Moderate
3	111-130	945-964	9-12	Extensive
4	131-155	920-944	13-18	Extreme
5	>155	<920	>18	Catastrophic

Appendix B
Track, Intensity, Verification, and Landfall Data for Hurricane Charley

Map of the Best Track positions for Hurricane Charley, August 9-14, 2004



Hurricane Charley preliminary verification data for track in nm and intensity forecast in knots. Numbers of cases are shown in parentheses.

Forecast period	Charley average official track error	10 year average official track error	Charley intensity forecast error	10 year average intensity forecast error
24 hrs (1 day)	71 (18)	78 (2894)	9 (18)	10
48 hrs (2 days)	83 (14)	146 (2368)	19 (14)	15
72 hrs (3 days)	176 (10)	217 (1929)	25 (10)	19
96 hrs (4 days)	459 (6)	248 (421)[1]	23 (6)	20[1]
120 hrs (5 days)	777 (2)	319 (341)[1]	8 (2)	21[1]

[1]Errors given for the 96 and 120 hr periods are averages over the three-year period 2001-2003

Preliminary forecast track errors (in nm) for Charley for the official forecast (OFCL), Clipper (CLP5), Geophysical Fluid Dynamics Laboratory (GFDL), Global Forecast System (GFS), and Florida State University Super ensemble (FSSE) with the number of cases in parentheses.

12 h	24 h	36 h	48 h	72 h	96 h	120 h	
OFCL	37 (20)	71 (18)	89 (16)	83 (14)	176 (10)	459 (6)	777 (2)
CLP5	53 (20)	130 (18)	201 (16)	258 (14)	394 (10)	587 (6)	969 (2)
GFDL	36(19)	66(17)	89(15)	119(13)	128(9)	276(5)	629(1)
GFSO	35(19)	54(17)	74(14)	103(12)	167(8)	362(4)	
FSSE	36(16)	59(14)	79(12)	96(10)	187(7)	572(3)	

Comparison of Hurricane Charley's Forecast Track and Observed Radar Track

Blue Line: Radar Track from 8:00 a.m. to 8:00 p.m., August 13, 2004
Red Dashed Line: Forecast Track. The 5:00 a.m. and 11:00 a.m. forecast track showed Hurricane Charley making landfall in the Tampa area. The 2:00 p.m. Special Advisory showed landfall near Captiva Island and then in the Punta Gorda/Port Charlotte area.

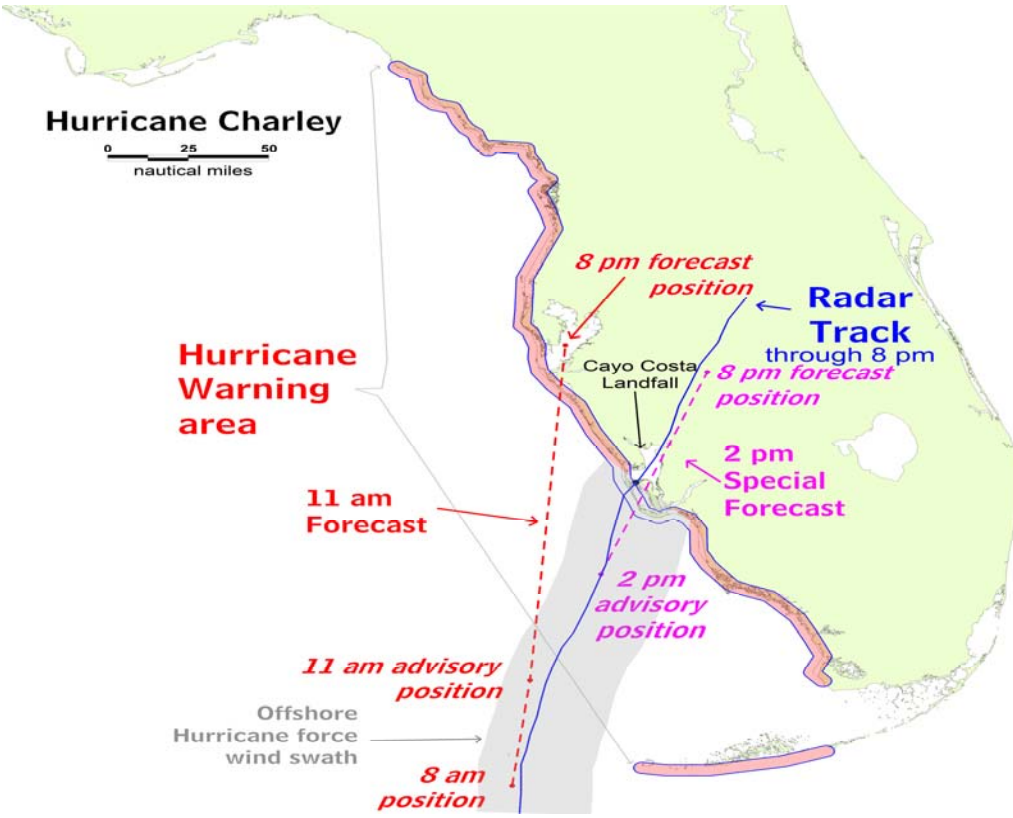
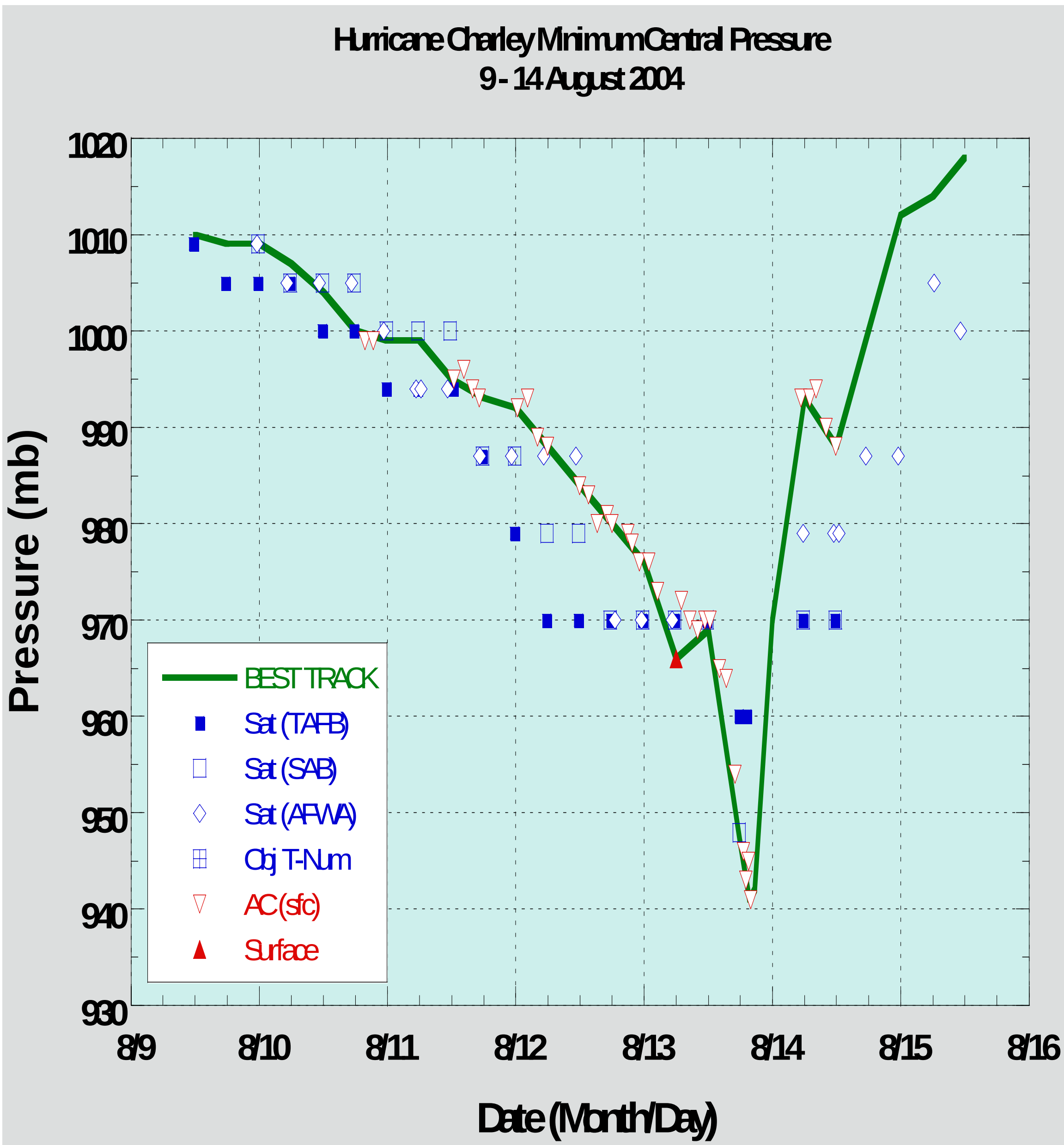


Chart of Hurricane Charley's Minimum Central Pressure
From August 9 through August 14, 2004.

Note: Minimum central pressure fell 23 mb from 964 mb at 9:22 a.m. to 941 mb at 1:57 p.m. prior to landfall at 3:45 p.m.



WFO Tampa's WSR-88D Reflectivity Image on August 13, 2004 at 3:56 p.m.