11C.7 **TREATING LANDFALLING HURRICANES AS MESOSCALE CONVECTIVE SYSTEMS - A PARADIGM SHIFT FOR WEATHER FORECAST OPERATIONS**

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1. INTRODUCTION

On July 25, 2006, ten leading hurricane and climate scientists released a Statement on the U.S. Hurricane Problem (Emmanuel et al. 2006). The statement read "…the main hurricane problem facing the United States (is) the ever-growing concentration of population and wealth in vulnerable coastal regions. These demographic trends are setting us up for rapidly increasing human and economic losses from hurricane disasters, especially in this era of heightened activity."

In order to better serve the public as a hurricane landfall becomes imminent, providing accurate and timely weather information at a higher frequency and with greater detail and resolve than is often presently accomplished becomes critical. Short-fused bulletins focusing on the most dangerous localized wind impacts must be issued in such a way as to cut through the information barrage, thereby elevating the urgency of the message and motivating the public to act to protect lives and properties to the fullest extent possible.

Major hurricane landfalls over recent years have afforded some National Weather Service (NWS) Forecast Offices (WFOs) multiple opportunities to utilize advanced technology (e.g. expanding mesonet observations, improved radar scan strategies, storm-based warnings, etc.) along with the need and desire to develop and test improved strategies to keep the public fully and continually apprised of imminent hazards.

WFO Melbourne, Florida, experienced impacts from four significant hurricanes during unprecedented active back-to-back seasons of 2004 and 2005. Several new strategies for providing critical information to the public were devised in-situ by the staff as a series of different and unique situations presented themselves (Spratt et al. 2006). The strategies eventually were refined and evolved into a new and improved forecast/warning approach at the WFO, amounting to an operational "paradigm shift". The concept of the paradigm shift arose from the observed need to provide an increased flow of detailed local weather information when life-threatening conditions became imminent (Sharp et al. 2006).

This paper will explore the rationale for adopting the paradigm shift and its applications to the local (WFO) hurricane forecast and warning process. In particular, the need for an intensified focus on local impacts will be discussed, along with suggested strategies for issuing special local bulletins/warnings for significant/extreme winds. Several past high impact events will be analyzed in the context of applying the paradigm shift to forecast/warning operations. The need for both internal (NWS) and external training and outreach efforts on the new approaches will be briefly addressed. The concluding section will summarize the suggested approach and strategies and illustrate how such an application will lead to more streamlined services, while providing crucial, non-contradictory information to complement NHC products. The authors believe the utility of the approach will become evident as additional life-saving measures are enacted by citizens in the final moments prior to destructive hurricane wind impacts

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2. ADOPTING THE PARADIGM SHIFT

At the local WFO level, the traditional mode of operation for dealing with the tropical cyclone (TC) core has been to treat the system as synoptic in nature. In other words, to ingest synoptic scale forecast/warning information from the responsible NWS National Center (National Hurricane Center, NHC) and apply these parameters directly to the WFO scale with minimal local modifications. While this is a reasonable and necessary approach for extended time scales (> 24 hr before landfall), a much different strategy is warranted as the timeline until onset of significant impacts shrinks. It is at these small time-scales (generally < 12 hr until landfall) when WFO meteorologists actually know the most about the mesoscale structure of the TC core, and possess the ability to assess the distribution and magnitude of imminent gusts associated with identifiable and track-able radar features (Fig. 1).

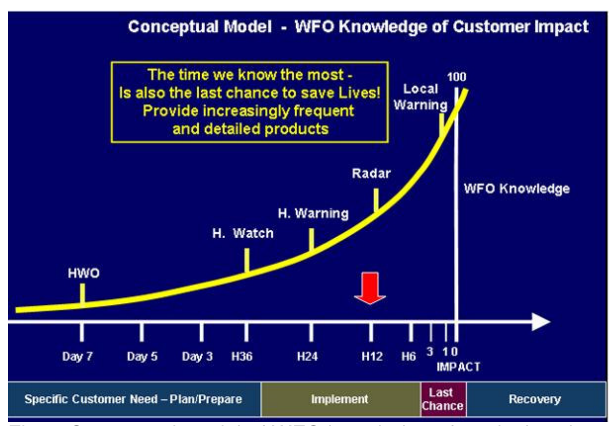

Fig. 1 Conceptual model of WFO knowledge of tropical cyclone impact.

Yet, as the TC moves into radar range and knowledge of individual features quickly rises, WFO meteorologists may not fully utilize available data and their extensive local forecast expertise to produce value-added enhancements to NHC bulletins. Applying the paradigm shift described below should help WFOs concentrate resources for issuance of frequently updated weather messages describing imminent local impacts, targeted to areas of greatest risk.

The central theme of the paradigm shift is to treat the hurricane inner core as a mesoscale convective system (MCS) – rather than part of the synoptic scale hurricane circulation. Interestingly, while the AMS Glossary of Meteorology defines a MCS as "…round or linear in shape, and include systems such as tropical cyclones…", WFO operational practices typically have not made such a distinction. By treating the inner core as an MCS, WFO forecasters can then turn their greatest attention to the most dangerous portion of the hurricane and operate in much the same way as they would during a severe local storm (SLS) outbreak. With maximum focus on the mesoscale impacts of the inner convection bands, forecasters can then analyze, react, advise and warn on associated local destructive wind features, rather than continuing to evaluate the entire synoptic scale circulation, which can prove taxing and can inadvertently reduce attention on the inner core features.

Application of the paradigm shift results in working a TC landfall in a way similar to extra-tropical severe local storm outbreaks (e.g., severe squall lines, derechos, discrete supercells, etc.). In these situations, the national center (Storm Prediction Center, SPC) collaborates with affected WFOs and a long-fused severe weather watch is issued. Watch lead-times are typically 2-6 hours ahead of severe storm development. Meanwhile, WFOs continually assess the mesoscale environment and maintain a minute-by-minute radar watch. Short-fused warnings are issued as warranted when confidence becomes high that defined wind criteria will be met. The warnings are issued when the conditions become imminent (typically well under an hour until impact) and are effective for as small of an area as possible (sub-county scale). Statements precede and follow warnings with additional threat, impact, location, and movement details and may contain increasingly emphatic language as probable impacts become more critical. Warnings receive near-universal dissemination via the Emergency Alert System (EAS) and local media.

Transition to a similar model for hurricane landfalls is encouraged. After NHC issues long-fused hurricane watches and warnings, WFOs should fill the information/warning void at the local scale as landfall is approached with increasingly detailed short-fused statements and warnings. Highly descriptive and emphatic language should be used when necessary to urge last-minute protective actions (Goldsmith 2006). Dissemination of information should be via highly-visible products to ensure EAS activation and immediate receipt by those in the warned areas.

A new short-fused warning product (Extreme Wind Warning, EWW) became available for use by WFO's in 2007. The product is extremely valuable and provides a previously unavailable means for WFO's to trigger EAS activation and to urge immediate and final protective sheltering prior to the onset of life-threatening wind conditions.

EWW aside, the most highly-visible product issued by WFOs during TC situations is the Hurricane Local Statement (HLS). Policies concerning the issuance of the HLS have been revised over recent years to allow greater flexibility (NWS Instruction 10-601, 2007). These allowances, when utilized, increase the effectiveness of the HLS by creating a short, detailed product stressing the most high-impact weather approaching a specific area (e.g. 85 kt winds impinging upon a large coastal city or an inland city where many evacuees have relocated). Relatively lower impacts can be omitted temporarily (e.g. within 6-hr of landfall) for small, specific areas to concentrate on the imminent high-impact event and to ensure the information is received as intended.

3. FOCUSING ON IMPACTS

NWS policy is for WFOs to issue short-fused warnings for severe convective wind *gusts* ($\geq$ 50 kt) and tornadoes, due to the threat to life and property (e.g. see severe squall line in Fig 2). In fact, providing this service is the paramount responsibility of the WFO in fulfilling requirements to protect life and property. Extensive resources are dedicated to this task and verification warning lead-times averaged 16 and 13 minutes for severe thunderstorms and tornadoes respectively during 2006 across the NWS Southern Region (NWS Performance Management, 2006). However, when dealing specifically with TC situations, NWS Instruction 10-601 (2007) states short-fused wind warnings (severe thunderstorm warnings) "…should be confined to peripheral events, such as outer rain-bands, prior to sustained tropical storm or hurricane strength winds."

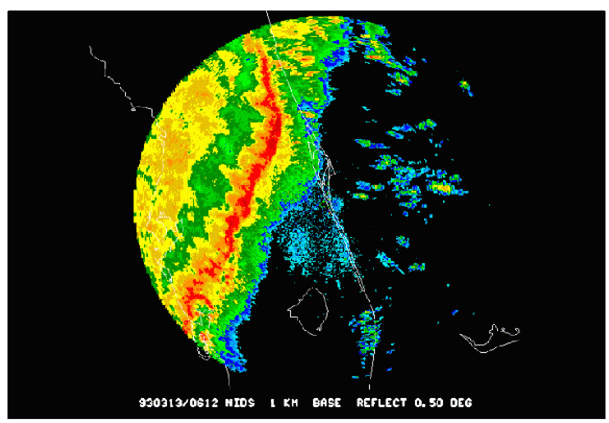

Fig. 2 Squall line over central Florida associated with the Superstorm of 1993. The bow echo produced severe wind gusts and tornadoes.

In an effort to compensate for the lack of short-fused warning requirements associated with destructive TC winds, the EWW was devised and approved for WFO issuance (Spratt et al., 2006). Since 2007, WFOs have been tasked to issue EWWs for situations when *sustained* winds of 100 kt or greater become imminent (i.e. Saffir-Simpson Category 3 or greater; this is also equivalent to 122 kt (140 mph) or greater gusts using a typical 1.2 gust factor). Subsequent debate has taken place on whether a more appropriate wind threshold might be justified. Most agree that setting the EWW threshold too low (e.g. 50 or 75 kt) would result in too frequent warning issuances for each landfall, lessening the rarity of the warning and likely reducing public response over time. However, setting the EWW threshold too high hinders the ability of the WFO to provide short-fused, EAS-activated bulletins to the public to warn of imminent, high impact and potentially life-threatening winds (Fig. 3). This is especially important when considering landfall scenarios associated with: major hurricanes; under-forecast rapid intensification; impacts to areas where hurricanes are rare and changes to track. Certainly, a threat for life-threatening wind impact exists below the current 100 kt sustained threshold.

Fig. 3 Hurricane Charley (2004) moving rapidly inland across central Florida. The hurricane was weakening to Category 2 on the Saffir-Simpson scale at about this time.

While it can be argued that the public should already be fully prepared for the high-impacts due to prior issuance of hurricane watch/warnings, consider that these long-fused products typically are issued 1-2 days prior to the event (i.e. lacking immediacy) and for very large areas (i.e. lacking specificity). Analogous to extra-tropical situations, the long-fused products provide a synoptic scale watch/warning, whereas short-fused warnings urge immediate protective action on the mesoscale or storm scale for a small and specific location and for a limited duration.

Recent trends of surging population along hurricane prone coastlines and increasing NHC hurricane watch/warning lead-times suggest the need for a new approach. Consider that average 2000-2006 NHC hurricane watch and warning lead-times and coastal lengths have increased to 50 hours (425 nm) and 34 hours (362 nm) respectively (DeMaria and Franklin, 2007). While such an improvement in lead-time is certainly welcomed by emergency managers and the general public for planning and evacuation needs, the extensive lead-time and large warning zone also opens a problematic warning void in the shorter temporal and geographic scales when the most significant impacts are becoming imminent.

However, by treating the hurricane core convection as a MCS and employing a paradigm shift to operationally handle the event as a severe local storm, it can be argued that wind warning (EWW) criteria should be based on wind gusts and not sustained wind, as is the case with extra-tropical convective and gradient wind warnings as well as tornado warnings. Consider that Fujita (1978, 1992) surmised that convective scale downdrafts were responsible for the most severe wind damage in hurricanes. Other research is now being done to understand the structure and behavior of the hurricane boundary layer, some noting the implications of small-scale rolls (as sampled by radar) which exhibit vertical and horizontal coherency and are approximately aligned with the mean wind direction (Lorsolo and Schroeder 2006, Wurman and Winslow 1998). These results, and others, collectively support the presence of mesoscale irregularities in the surface wind field which may locally enhance damage (i.e. Fig. 4). Such local, often transient features in the inner TC wind field likely are not representative of the synoptic scale hurricane circulation and therefore may not be accounted for by NHC, but certainly can have a profound impact upon a local community. In fact, Powell et al. 2003 suggested that in hurricanes, convective 3-sec gusts may approach values twice that of the sustained wind. Also, Franklin et al. 2000 examined eye-wall wind profiles from GPS dropsondes and documented the mean velocity variation with height. Results suggested that winds at the top of a 30-story building typically average 17 kt (about 20 mph or one Saffir-Simpson category) higher than at the surface. With post-landfall turbulent mixing in the boundary layer, downward momentum transfer of Category 3 winds from a Category 2 hurricane certainly appear quite plausible.

In addition, previous studies have found the spread of structural damage and tree damage to be more strongly affected by gust speeds than by maximum wind speeds (Kitamura et al., 2004; Francis and Gillespie, 1993). The Enhanced Fujita (EF) scale (Enhanced Fujita Scale, 2006) for tornadoes likewise correlates structural damage to estimates of 3-sec gusts. For example, the EF-scale damage indicator for Jr./Sr. High Schools, which often serve as hurricane shelters in many communities, documents that the collapse of tall masonry walls of a school gym, cafeteria or auditorium can be expected from 3-sec gusts of 99 kt, whereas the uplift of a light steel roof structure correlates with gusts of 94 kt using a lower bound estimate. Collectively, these factors suggest to the authors that a EWW threshold of 100 kt *gusts* provides a more reasonable and representative criteria for destructive wind damage (and high threat for casualties) than a *sustained* wind of 100 kt. Refining the EWW criteria to this threshold would also correspond to an exact doubling of the non-tropical convective wind warning criteria of 50 kt gusts, establishing a systematic and hierarchical link between the two warnings. In addition, given the tornado-like damage patterns often observed along the track of TC inner rain-bands, using the EF scale to evaluate such enhanced convective wind damage may be a viable option.

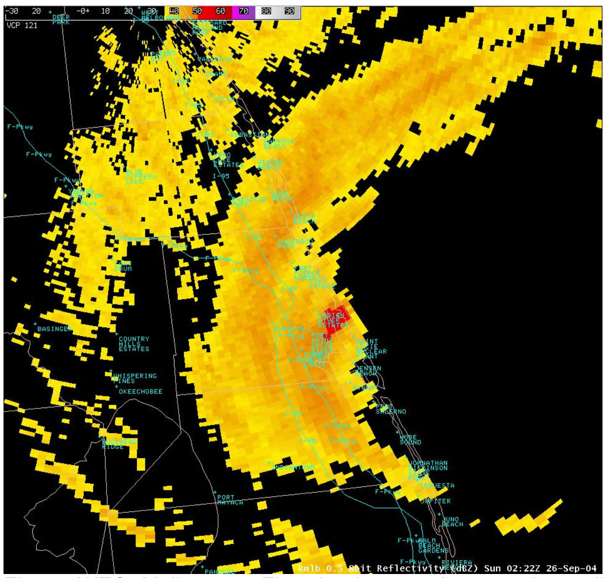

Fig. 4 WFO Melbourne, Fl radar image of convective cell containing enhanced reflectivity observed along the inside edge of Hurricane Jeanne (2004) eye-wall at landfall. A damage survey noted several areas of enhanced wind damage along the track of the cell.

4. RAPID INTENSIFICATION SCENARIO

"Forecasting rapid intensification (and decay) cycles are the greatest problem" facing NHC according to Max Mayfield, former Director of the NHC (Holland et al., 2006). Several working groups have been convened over recent years to address how to approach and improve this issue. The NOAA Hurricane Improvement Forecast Project (HFIP, 2007) identified the number one priority for the next 10 years: "Guidance for tropical cyclone intensity change, with highest priority on the onset, duration, and magnitude of rapid intensification events". The Hurricane Intensity Forecast Improvements and Impacts Projections (HiFi) science strategy workshop concluded that "in addition to improving maximum wind intensity forecasts, this goal requires a capacity to predict a range of phenomena that are currently poorly predicted, including: small-scale vortices and wind streaks that bring extreme winds/gusts to offshore and coastal structures".

While forecasting TC intensification is solely the responsibility of NHC, the real-time analysis of intensity, track and structural changes and reacting to them are responsibilities shared by NHC and WFOs. In times of rapid, un-forecast or under-forecast intensity changes near the time of landfall, NHC issues a "Tropical Cyclone Update" (TCU) product which briefly details the unanticipated change, yet the message does not activate the EAS and may not be immediately visible to those directly in the path of the change through the substantial volume of other weather products and media coverage. Here is an example of a TCU from Hurricane Charley (2004) as landfall was approaching:

AT 115 PM EDT...1715Z...A U.S. AIR FORCE RESERVE UNIT RECONNAISSANCE AIRCRAFT MEASURED 10000 FT FLIGHT LEVEL WINDS OF 162 MPH AT A DISTANCE OF 8 MILES FROM THE CENTER OF THE HURRICANE. THIS GIVES AN ESTIMATED SURFACE WIND OF 145 MPH...CATEGORY FOUR ON THE SAFFIR SIMPSON HURRICANE SCALE. A SPECIAL ADVISORY WILL FOLLOW SHORTLY.

The Special Advisory was then issued approximately 45 minutes later (Pasch et al. 2004).

In these situations, WFOs are in a better position to react immediately to observed changes by targeting highly specific (time and location) critical informational messages directly to the public within seconds. High-priority Warnings (i.e. EWW) can be EAS-activated to ensure universal receipt and more emphatic language can be used to urge protective actions. Close collaboration between NHC and the WFO is essential and the flow of critical products should be seamless and complimentary. Information needs to flow to those in the path of destructive winds at nearly the same rate at which the data are being analyzed.

Another recent example of unanticipated rapid intensification toward landfall involved Hurricane Humberto (2007). Humberto strengthened from a tropical depression to a hurricane (45 kt increase) in 18 hours, immediately prior to landfall. While only a Category 1 hurricane at landfall (Fig. 5), wind impacts spread onshore overnight and contributed to many residents feeling unwarned (Miami Herald, April 1 2008). The landfall WFO performed with a mesoscale focus during this event and weather messages were updated frequently, although often were issued as "Short-Term Forecasts", which can be considered a low-priority product which typically do not receive large (media) attention or distribution. The "Hurricane Local Statement" product receives higher media attention, especially if written in a concise, detailed manner and is focused only on the most immediate and high-impact weather.

Consider a scenario based on Humberto (2007), but with a hypothetical under-forecast rapid intensification from a minimal Category 1 hurricane to a borderline Category 4 (45 kt increase). Long-fused hurricane watches and warnings have been in place for over 24 hours. Frequent collaboration is occurring between NHC and the local WFOs as the hurricane continues to deepen rapidly. Based on velocity data on radar imagery, the WFO issues a single-item Hurricane Local Statement to detail expected wind impacts for several specific coastal counties, indicating gusts possibly reaching Category 2 to 3 levels in a few hours. Hurricane Local Statements continue to be updated frequently with information based on radar imagery and expected impacts to specific cities, towns and counties. One hour prior to the expected arrival of an inner rain-band with 100-115 kt gusts (based on radar velocities), an EAS-activated EWW is issued for two coastal counties. Another EWW is issued an hour later as the rain-band spreads inland to affect the next tier of counties. The EWWs and single impact Hurricane Local Statements are treated with the highest priority by local media and the public. The critical information emphatically urges those within the direct path of the destructive winds to take immediate action to protect their lives, in the same way as if a tornado was about to strike. Coastal residents who unwisely chose not to heed mandatory evacuation orders, public safety officials within the evacuation zone and thousands of people at inland shelters move immediately from scattered locations within their buildings to the most hardened interior location within their shelter to protect themselves from tornado-like winds. Lives are saved in the final moments before extreme wind onset due to WFO high-impact statements and warnings.

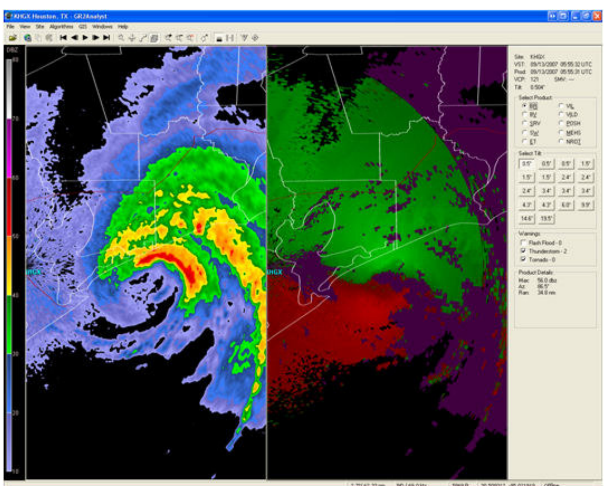

Fig. 5 WFO Lake Charles, LA radar reflectivity image of Hurricane Humberto (2007) nearing landfall, following an unanticipated and unprecedented rate of intensification from a tropical depression to hurricane in only 18 hours.

5. MAJOR NORTHEAST HURRICANE SCENARIO

The return period for a Category 2 hurricane in the Boston area is 48 years and 85 years for a Category 3 (Neumann 1987). For the New York City (NYC) area, the return periods are 39 and 68 years, respectively. While such statistics reveal the rarity of significant hurricanes for the northeast states, resultant impacts can prove enormous. High population and density corridors, residents inexperienced with hurricane affects, exposed coastlines and bays, and reduced preparation time due to typically fast approaches all portend a future event of major consequences and potentially disastrous dimensions.

The only significant hurricane to impact the Northeast United States during the past 20 years was Hurricane Bob (1991). Bob made landfall as a Category 2 hurricane, then quickly weakened to Category 1 status as the center approached near Boston (Fig. 6). The highest sustained wind recorded was 85 kt with gusts to 109 kt over a small region of extreme eastern Massachusetts (Vallee and Dion 1997). While Bob was a relatively weak hurricane with most significant impacts (mainly associated with storm surge flooding) limited to a small region, six fatalities resulted and damage was estimated at three billion dollars when adjusted for inflation, wealth and population updated to 2005 (Pielke et al., 2008). The track and intensity for Hurricane Bob were well forecast by NHC and except for along the immediate coast, hurricane impacts were of Category 1 intensity. Given the vulnerabilities of the northeast, how would a major landfall be dealt with today?

In addition to increasing coastal populations and the exposure of a greater number of residents to weather impacts they have no personal familiarity with, communication systems have changed dramatically over the past decade. The need for and expectation of immediate and constant information continues to grow. Twenty-four hour news cycles and technology allowing real-time access to graphical and textual data via portable devices is becoming increasingly common. With such data readily available, targeted high-impact weather messages can play a major role to keep the public safe, but only if produced and released effectively.

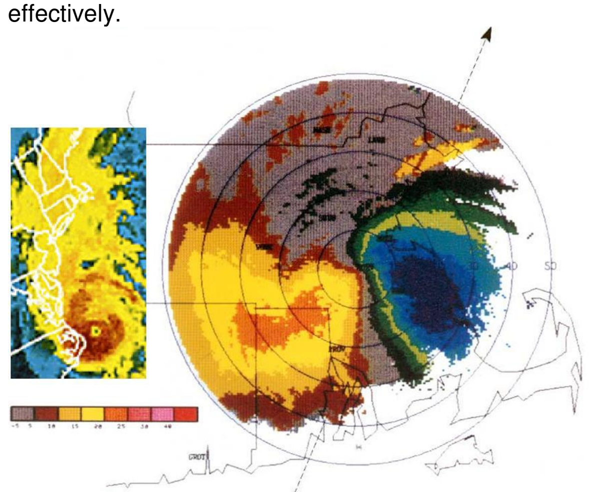

Fig. 6 Color enhanced satellite image of Category 3 Hurricane Bob (1991) offshore North Carolina and accelerating north toward New England at 20 kt (left). Base velocity image from an experimental Doppler radar near Boston as the weakening Category 1 hurricane passed nearby (right).

Imagine the scenario of an imminent hurricane landfall across the northeast U.S. Inner core rain-bands containing radar-detected velocities of 100-120 kt are poised to rapidly spread across NYC. Millions of residents have remained in their homes and public shelters. Hurricane warnings have been in effect for nearly 20 hours and the most recent NHC bulletin indicates landfall within a few hours across central or eastern Long Island with a significant threat to NYC. Just before landfall, the hurricane center wobbles northwest. Considering the synoptic scale track, the wobble is subtle and persists for only an hour, but for residents of western Long Island and NYC it means the difference between Category 1 and Category 3 impacts. While residents knew such an outcome was possible, a steady hurricane motion over the past 6 hours caused a gradual relaxation of readiness.

In such a situation, local WFOs must have tools to deliver high priority messages which can immediately supersede the multitude of other media information. These messages can provide a final opportunity to those in the direct path of the destructive impacts to return to a maximum level of readiness and also know how long the extreme winds will last before the worst is over.

6. INLAND IMPACTS

Tropical Storm Erin (2007) proves a very interesting case when examined within context of the ideas expressed throughout this paper, e.g. WFO initiating a mesoscale focus on the inner rain-bands and working the event in a mode similar to an extra-tropical severe weather outbreak.

Shortly after making landfall along the southeast Texas coast as a minimal tropical storm, NHC downgraded the system to a tropical depression and transferred future synoptic scale responsibilities to the NWS Hydrometeorological Prediction Center (HPC). HPC subsequently issued 6-hourly updates summarizing past, present and future impacts. Several days after landfall, the radar presentation of tropical depression Erin suddenly regained tropical-storm-like structure well inland over Oklahoma and even briefly possessed an eye-like feature. While the main impact from the system was flooding rains, WFO radars and experimental Phased Array Radars (PAR, Fig. 7) revealed the organized structure and indicated peak velocities just outside the eye-like feature near 70 kt. Sustained tropical storm force winds with gusts to hurricane force were recorded in isolated areas along the track. Radar data also indicated several velocity couplets and multiple tornado warnings were issued. Two tornadoes were reported but little if any associated damage was sustained.

With the Erin event occurring so far inland, NHC was not involved with monitoring the event, although HPC followed the event from the synoptic scale and issued 6-hourly advisories. This allowed the local WFO to work the event independently and to exclusively control the release of informational and warning products. Due to the far inland location and lack of synoptic scale (tropical) watches/warnings, the default mode of operation was to treat Erin as a decaying tropical MCS and engage the system as a severe local storm outbreak (with flooding, tornado and convective wind threats) as the circulation spin-up ensued. During the 6-hour period that the system sustained maximum intensity, the local WFO issued over 20 severe thunderstorm warnings, 4 tornado warnings and over 25 informational/update statements (in addition to high impact flood warnings and statements).

While the authors are certainly not advocating the issuance of 50 kt convective wind warnings for TC landfall situations, analyzing inner core features and issuing information in a similar severe local storm manner is recommended. Small scale, transient wind features occur within both extra-tropical and tropical MCS and often produce high-impact events.

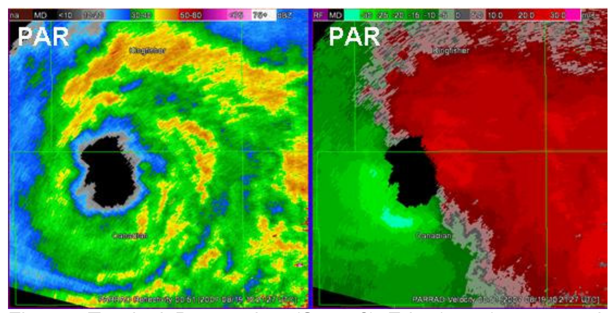

Fig. 7 Tropical Depression (Storm?) Erin (2007) near peak inland intensity over Oklahoma as seen by an experimental Phased Array Radar (PAR). Base reflectivity is displayed on the left and base velocity on the right.

7. EDUCATIONAL REQUIREMENTS

Multiple training initiatives must be developed to take advantage of the ideas expressed above associated with the paradigm shift. The training is envisioned to be of minimal cost in terms of time investment, but the benefits would be large.

As opportunities arise, cross-training of NHC and WFO forecasters should be considered. Each group has their own forecast requirements and responsibilities, however understanding each others role in the forecast, warning and communication process would help solidify a seamless information suite for the benefit of all users.

Internal training is needed to further address how WFOs can provide more frequent, high-impact, detailed yet concise weather messages to the public during landfall situations (to include the notion of a mesoscale focus on warning operations). This education should encompass proper strategies for issuing Hurricane Local Statements as well as Extreme Wind Warnings. The timeline for adopting such a shift should be near-term, before more advanced radar technology is fielded (i.e. PAR).

Pre-season external training and outreach sessions (for Emergency Managers, public safety officials, the media and the general public) conducted by both NHC and WFOs should include information and examples pertaining to Extreme Wind Warnings. Educating users before the storm will limit opportunities for misunderstanding, confusion or surprise near the time of landfall.

Additional research is needed on the impacts of inner rain-band winds at and post landfall. This research should concentrate on the mesoscale and even storm scale features and what impacts they can produce for those present along the path of the eye-wall. Such studies should not be the exclusive work of tropical meteorologists, but should be broadened to include severe storm scientists as well. The recent Erin (2007) event hopefully will act to spark such cross-discipline studies naturally.

8. CONCLUSIONS

Given the early and wide placement of accurate hurricane watches and warnings issued by NHC over recent years, there are few scenarios where citizens should be ill-prepared or caught off guard by subsequent storm impacts. NHC continually stresses that everyone present within a watch/warning area should prepare for possible/probable hurricane conditions. In reality however, this is not always the case. There are many situations where for one reason or another (mostly beyond the capacity of NHC and WFOs to alleviate) citizens do not take proper measures to protect life and property ahead of significant impacts.

Some recent events where ill-advised personal planning placed lives at risk due to insufficient sheltering include the following hurricanes: Charley (2004; Pasch et al. 2004), Jeanne (2004; B. Hagemeyer, personal communication, September 25, 2004), Katrina (2005; Blackwell 2008), Wilma (2005) and Humberto (2007). Not only are residents within coastal locations along the direct path of the TC core at risk, but so are some living or displaced inland. Large shelters containing hundreds or even thousands of evacuees possess a particular vulnerability should the building become compromised by destructive winds. It is during situations such as these where WFOs must provide detailed local information to protect those remaining in the danger zone. Providing a seamless flow of information from both NHC and WFOs to address short-term changes from the hurricane-to-local scale has never been more critical to keep the public informed and ultimately to protect lives.

It is recommended that WFOs treat the central TC core as a MCS rather than part of a synoptic scale system. After applying such a paradigm shift, WFO analysis and warning strategies can be transitioned to employ protocols similar to those used during significant extra-tropical convective wind events (e.g., severe squall lines, derechos, discrete supercells, etc.). WFO forecasters should take a proactive and aggressive local stance as landfall is approached. A last minute urgent bulletin (statement) or (extreme wind) warning issued for a very specific area can advise destructive winds are imminent and urge immediate and final protective actions. Such a strategy has saved countless lives during non-tropical severe weather events and should be employed to do the same during tropical events. This operational shift should be concomitant with balanced adjustments to hurricane preparedness and mitigation strategies. Close collaboration between NHC and landfall WFOs is paramount during such situations. Proactive informational bulletins should flow more frequently as landfall approaches, while becoming increasingly concise, specific and direct, using language consistent with the severity of imminent impacts. Together, these strategies will likely help improve final hurricane preparations and lower the risk of casualties.

9. ACKNOWLEDGEMENTS

The authors wish to express their appreciation of the NOAA Hurricane Conference participants for debating the merits of the Extreme Wind Warning. Thanks to the subsequent efforts of a special wind team, the concept was advanced into a new official warning. Discussions with several staff of the National Hurricane Center (NHC) and the Hurricane Research Division (HRD) helped to hone the suggested operational approaches and ensured the concepts remained consistent with and complementary to NHC products.

10. DISCLAIMER

The views expressed are those of the authors and do not necessarily represent those of the National Weather Service or its parent agency (NOAA).

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