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POLICY ISSUES IN HURRICANE PREPAREDNESS  
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**A workshop developed by the  
ATMOSPHERIC POLICY PROGRAM  
AMERICAN METEOROLOGICAL SOCIETY**



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# **FORECAST CONSIDERATIONS**

## **POSITION PAPERS**



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**FORECAST CONSIDERATIONS PANEL**

**Primary Focus Questions**

- 1. What is needed to improve the accuracy of hurricane forecasts?**
  - ?? New platforms (e.g., unmanned aircraft)**
  - ?? New forecast products (e.g., refined statistical approaches)**
  - ?? Improved numerical forecast system (e.g., super-ensemble approach)**
- 2. What are the priorities for improving the forecasts?**
- 3. What policy changes are needed to make improvements available as soon as possible?**

# **Science Support for Improved Hurricane-Landfall Prediction— The U.S. Weather Research Program**

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## **1. USWRP Overview**

The U.S. Weather Research Program (USWRP) is a coordinated research program among four agencies: National Oceanographic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Office of Naval Research (ONR), and National Aeronautical and Space Administration (NASA). One of the two foci of USWRP is the Hurricane Landfall, which was selected after an extensive planning process that matched forecast needs with observational and research opportunities. Hurricane landfall has tremendous impacts on the affected areas that have been well publicized in recent years. Whereas some damage and disruptions of lives and commerce are unavoidable, much can be done to minimize these impacts.

The nation has invested much in an observation system and forecast/warning system in the modernized National Weather Service, which is unparalleled in the globe except for Japan. However, better exploitation of existing (and proposed) observations via advanced data assimilation systems and numerical models would improve the track forecast guidance provided to the National Hurricane Center (NHC) forecasters. In the case of intensity, wind structure, and precipitation associated with hurricane landfall, an aggressive science program is proposed that will provide the understanding necessary to develop effective forecast guidance products. A technology infusion component is integral to this proposed program via seed money for two experimental test beds to demonstrate the viability of advancing the rate at which observational and research advancements are converted to improved operational products.

A research component in social science that is coordinated with the physical science and decision-making communities is also proposed. The objectives would be to understand better the impacts of hurricanes, the costs and benefits of various response strategies, the decision environment of the forecaster, and the process of technology infusion—from basic research to societal benefit. Each of these interrelated factors may contribute to more effective decision making that can reduce the society's vulnerability to hurricanes. Optimizing the partnerships among the emergency management community and the media with the NHC and the local National Weather Service offices offers the best opportunities for improving the hurricane warning system for the United States.

The specific USWRP Hurricane Landfall program goals are to reduce landfall track and intensity forecast errors by 20%, to increase warning lead time to and beyond 24 h with 95% confidence without increasing the present 3:1 overwarning, to make skillful (in comparison with persistence) forecasts of gale- and hurricane-force radii out to 48 h with 95% confidence, and to extend quantitative precipitation forecasts to 3 days and improve skill of day-3 forecasts to improve inland flooding forecasts.

In specific hurricane landfall aspects such as track prediction, augmentation of the existing infrastructure is proposed as the primary investment. In other aspects such as hurricane structure modifications during landfall, a field experiment (observational) program is the prime

requirement. In each aspect, the state of the science, technology, and prediction capability will be indicated, deficiencies vis-à-vis the above goals will be identified, and the proposed research programs will be described.

The nation has already invested heavily in an observations, analysis, forecast, and warning system for hurricane track prediction, and this investment has significantly increased the rate of improvement in NHC track forecasts during the past five years. Predictability estimates indicate that a further 20% improvement over five years may be possible. Near-term advances in track prediction guidance are planned via 1) Geophysical Fluid Dynamics Laboratory (GFDL) model improvement on the new NOAA Class-VIII supercomputer; 2) acceleration of data assimilation advances at the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) to incorporate satellite, radar, and aircraft data that will improve the environmental flow analyses and predictions that are the first-order effects in hurricane motion; and 3) exploitation of a track guidance expert system that will assist the forecaster in selecting which dynamical model tracks to accept or reject. Longer-term research efforts planned to improve track prediction include 1) provision of confidence estimates for track guidance via ensemble prediction systems appropriate for hurricanes, such that the NHC could extend the warning lead time with the same overwarning ratio, and, it is hoped, decrease that overwarning; 2) application of adaptive sampling theory to the hurricane track prediction to specify target areas for special satellite-based or aircraft-based observations that would provide the greatest benefit; and 3) development of the next-generation GFDL hurricane model using the Weather and Research Forecast model framework. Several additional efforts are also expected to lead to moderate improvements in track guidance.

It is emphasized that the absence of an adequate technology infusion infrastructure has inhibited the transfer of hurricane landfall-related research to operations. Consistent with the proposed six “experimental test beds” mentioned in the NWS Strategic Plan, a feasibility demonstration of more rapid and smooth operational implementation of USWRP hurricane landfall research is proposed via two centers: Hurricane Operational Transition (HOT) in Miami and National Test Bed (NTB) for numerical weather prediction at EMC in Washington, DC. Personnel at these centers would work with both the researchers and the operational forecasters to facilitate the transfer of the proposed guidance product and to ensure that it meets operational needs and constraints. A feasibility demonstration of these two technology infusion centers is considered essential for USWRP research to move toward operations, and the Hurricane Research Division (HRD) and EMC have proposed initiatives that complement the proposed USWRP concept. The number of additional personnel needed to accomplish the transition of mature research results or observational technology to operations is indicated throughout the plan. The proposal here is for USWRP to adopt technology infusion as a feasibility demonstration that a smooth and more rapid transfer to operational guidance will be accomplished. The request is for NOAA to include this technology infusion component as part of their USWRP initiatives and then to seek permanent billets and funding to maintain this function in the out years.

Outer-wind-structure analysis and prediction are critical factors in timing of the hurricane warnings, because all disaster-preparedness activities and appropriate evacuations are to be completed before the 35-kt winds cross the coast. Exciting new opportunities are available to make rapid advances in this topic, especially from the NASA QUIKSCAT scatterometer winds, the Advanced Microwave Sounder Unit (AMSU), and high-density and rapid-scan wind observations. Another new platform is autonomous Unattended Aerial Vehicles (UAV) to

supplement staffed reconnaissance. Provision of these new data sources in the GFDL model is expected to lead to reliable forecasts of outer-wind-structure change.

Progress is being made in inner-wind-structure (intensity) analysis using satellite technology. However, its prediction is a challenging scientific problem because of complex, nonlinear processes occurring in the ocean, the hurricane boundary layer, convective structures, and environmental forcing. Thus, investments to advance scientific understanding are proposed to develop the basis for a skillful intensity prediction technique. Fortunately, a cooperative field experiment between the Hurricane Research Division (HRD) and the NASA Convection and Mesoscale Experiment (CAMEX-III) provided a unique data set to advance scientific understanding. Analysis of this 1998 data set will be given a high priority. Whereas numerical models of inner-structure change offer promise, key issues of real-time observations required to provide adequate initial conditions, and improvements in the physical process representation (convection and friction) must first be addressed. Collaboration with an Office of Naval Research initiative to air–sea fluxes in high wind and wave conditions is proposed.

Some innovative observational platforms that have been successfully deployed during 1998 and 1999 on the coast in advance of hurricanes that made landfall have provided exciting new data sets to study structure modifications that occur after landfall. These new observations are from Doppler radar mounted on wheels, portable radar wind profilers, a rapidly deployable automatic surface observing system, and deployable meteorological towers. Highest priority will be given to analysis of these data sets in conjunction with coordinated measurements when the hurricane was just offshore. New conceptual models for explaining localized wind damage streaks are expected. A modeling component to develop forecast guidance for the NHC forecaster is included in this plan.

In response to the recognition that inland flooding has become over the past three decades the chief cause of deaths associated with hurricane landfall, and at the request of local NWS forecast offices, a program to improve the analysis and prediction of precipitation is planned. Special efforts to exploit the expertise in radar and remote sensing of overocean precipitation will be made to improve quantity-of-precipitation forecasts (QPF) over land following hurricane landfall. Overlap with the QPF focus of the USWRP will add to advances in understanding precipitation processes, improved tools for estimating precipitation and nowcasting, and improvements in modeling. Case studies and model tests of landfall precipitation events will be a high priority. To provide some early forecast guidance, empirical statistical models will be developed, and a conceptual model of the precipitation during the extratropical transition of a tropical cyclone derived by ONR researchers will be provided to NHC.

Social and economic research is an integral part of the Hurricane Landfall focus. Because annual U. S. hurricane losses average about \$5 billion, a cost saving of \$50 million would result from every 1% of those losses that might be prevented. Because the vulnerability to hurricane impacts continues to grow with movement to coastal areas, the assets at stake and the value of an effective response system also rise. Knowledge gained in the social, economic, and decision sciences will lead to implementation of better response strategies, and will help to set priorities as to where increased research would be most beneficial. These studies would focus on each aspect of the hurricane warning service—forecast preparation and communication; dissemination by emergency management, media, and private industry; and sociological aspects of public response to warning content, frequency, consistency, and so on.

Two kinds of field experiments are planned. A number of the required research measurements are achievable during the annual HRD experiments. For example, supplemental targeted observations to test adaptive sampling theory could be made in conjunction with the Gulfstream-IV surveillance flight. An outer-wind-structure measurement program with multiple Aerosondes could demonstrate the feasibility of long-duration flights that would supplement the manned reconnaissance flights in the high wind near the center. Collection of ocean data sets should continue to document potential ocean influences on inner structure changes. Each landfalling hurricane provides an opportunity to collect boundary layer data sets that are critically needed to document the structure modifications at the coast. Another combined field experiment, as during 1998, is planned for the 2001 hurricane season. This experiment will be built around the HRD field experiment, and NASA is again expected to be a major participant. Two central foci will be the dynamics and thermodynamics of inner-structure change and the landfall structure modifications. In addition, provision of the observations for real-time data assimilation and production of validation sets for numerical model testing will be a new focus. Workshops and planning meetings during 2000 will define specific data requirements based on analyses of the successful 1998 experiment.

Key deficiencies have been documented in this plan. Deficiencies in technology infusion are particularly evident in transferring to operations the research and observational technology advances that have been achieved. Further advances to be achieved via this USWRP effort will only add to that gap. Thus, a feasibility demonstration that the HOT and NTB centers will lead to a smooth and more rapid transition is thus considered to be a high priority for a new NOAA initiative. At least five research-transfer positions are needed immediately and this should grow to nine positions over five years. A second deficiency is the infrastructure positions at the HRD and EMC needed to accomplish critical tasks in this plan. Data assimilation tasks at EMC and targeted observations, analysis of the 1998 field experiment data, and application of radar and remote sensing techniques to the inland QPF will not be accomplished at HRD according to this plan without additional funding/personnel from NOAA initiatives. Additional participation by academic researchers must be secured to bring new personnel and new insights that will help to achieve the research goals. New NSF funding for high-quality proposals is required so that the success rate in the grants program can be raised. Multiyear funding is necessary to get academic researchers involved. Last, reaping the benefits of cross-cutting research in data assimilation, optimal observation mix, and QPF between the two USWRP implementation plans will require communication of needs and sharing of research and observing technology advances.

A common perception is that because the United States invested in better observations of hurricanes means that forecasts will necessarily be improved. This perception is not necessarily true. In some cases we have developed the tools to convert better observations to provide improved forecast guidance. This has been true for track forecasts. In the case of outer wind structure, new space-based and aircraft-based observations will likely soon contribute to improved forecasts of the gale-force radius. However, many aspects of the science of inner wind structure are not understood, so the investment in better intensity observations has not paid off in terms of significantly improved intensity forecasts. Similarly, better science understanding is needed to support quantitative precipitation forecasting. Each of these aspects is being addressed in the USWRP Hurricane Landfall plan, which, it is hoped, will receive the necessary funding in the 2002–06 period.

## **2. Research scientist perspectives on the hurricane forecast/warning process**

Past research has led to improved model track forecast accuracies, especially in the last six years. Mark Powell of the NOAA Hurricane Research Division did not find a corresponding decrease in landfall position errors. Furthermore, the trend is for warning longer areas along the coast, rather than smaller areas. Reasons for this inconsistency in warning trends must be explored with an intent to reverse this trend as the USWRP research results in forecast guidance that is improved.

One explanation for increasing warning areas is that an overly conservative warning system has developed in which multiplicative safety factors are introduced in each step. The "no-surprise" theme of the NWS may encourage the NHC forecasters to agree to extend the sizes of warnings beyond what is meteorologically justified. A "no-risk" attitude should be replaced with a situation-specific risk assessment. One science contribution may be to provide the forecaster with confidence-based guidance products that will assist in reducing the warning areas. The emergency management community may also have a "no-surprise" policy in protecting the public in each area, and thus may request a greater safety factor. A basic question is whether the public will only respond if their area is under a warning. The insurance company stipulation that their tourist industry policy will only pay off if the site is within a mandatory evacuation warning area must lead to pressure to extend the area. The media is properly representing that the threat is over an expanding area with time (rather than concentrated at a point along a track). How scientifically based are those spread charts, especially because the forecasts have improved in accuracy and should be situation-dependent?

In a purist scientific world, the NHC forecaster should not issue warnings over any larger area than is meteorologically justified for that specific situation (one warning area fits all situations will necessarily be overly conservative). The level of uncertainty should be an agreed value that is fully understood by the emergency management community and the media. Any further expansion of the area for political or other reasons would then be the considered judgement of those community officials who have a lower "acceptable risk." The science community can help in specifying the uncertainties in each situation, and thus assist the forecasters in working with the user community.

# **Improved Numerical Forecast System for Atlantic Hurricanes using the Superensemble Approach**

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## **1. Introduction**

Improvement of hurricane forecasts is an important prerequisite for “Policy Issues in Hurricane Preparedness and Response.” A suite of hurricane forecast models at the National Hurricane Center in Miami provide guidance on tracks, landfall, and intensity. This suite is made up of statistical, simple (steering) dynamical, and more complex multilevel physical/dynamical models. Above all else, the consensus forecasts, prepared by the experienced duty forecasters (using the above suite of forecasts) at the National Hurricane Center, convey the most important information for hurricane preparedness and response. The role of university research has always been minimal in providing any kind of real-time guidance of catastrophic weather. In recent years, several university groups have experimented with the issues of real-time forecasts, especially related to mesoscale severe weather. Such groups operate out of the universities at Fort Collins, Seattle, University Park (Pennsylvania), and a few others. At The Florida State University (FSU), the notion of a consensus forecast issued by an experienced forecaster was cast into an objective “multimodel superensemble” forecast. That method appears to hold some promise for real-time weather, climate, and hurricane forecasts (Krishnamurti et al. 1999, Science Magazine). Basically that is the theme of this presentation.

## **2. Improved forecasts from a multimodel superensemble**

This is based on a training and forecast phase from many experiments. Here we take some 120 six-day forecasts made by global modelers. Given roughly 120 such recent past global forecasts and the best estimate of the respective observed fields, a simple linear multiple regression is computed to determine the statistical weights. Some  $10^6$  such weights describe the model biases at each geographical location, each vertical level, each variable, and for each of the participating member models. These statistics are next used to construct the superensemble forecasts. The superensemble invariably performs somewhat better than all multimodels that participate in this exercise. The superensemble has a higher forecast skill in comparison with that of the ensemble mean. That difference arises because the ensemble mean assigns a weight of 1.0 to all participating models and does not correct the bias of the models based on their past behavior. This ends up including some of the poorer models as well, thus the skill of the ensemble mean is degraded. The superensemble is selective in assigning weights, and the past history of performance of models has a major role in comparison with that of current forecasts by the multimodels. The superensemble also performs better than the ensemble mean of “bias-removed” individual models. The superensemble methodology for hurricane forecasts is somewhat different from what is done for global day-to-day weather forecasts and seasonal forecasts. Here we first prepare a database on storm positions, landfall, and intensity from some 120 previous forecasts of the multimodels. The training is done at 12-h intervals along the storm tracks; that is, this is more like a one-dimensional problem.

### 3. Hurricane Track and Intensity Forecasts during 1998 from the Superensemble

First we shall look at the overall statistics of the track and intensity forecasts for the entire year of 1998. Here we show the day-1, day-2, and day-3 skills for these forecasts. The results for the superensemble track forecasts (cross validation) are presented in Fig. 1, and intensity forecasts are shown in Fig. 2.

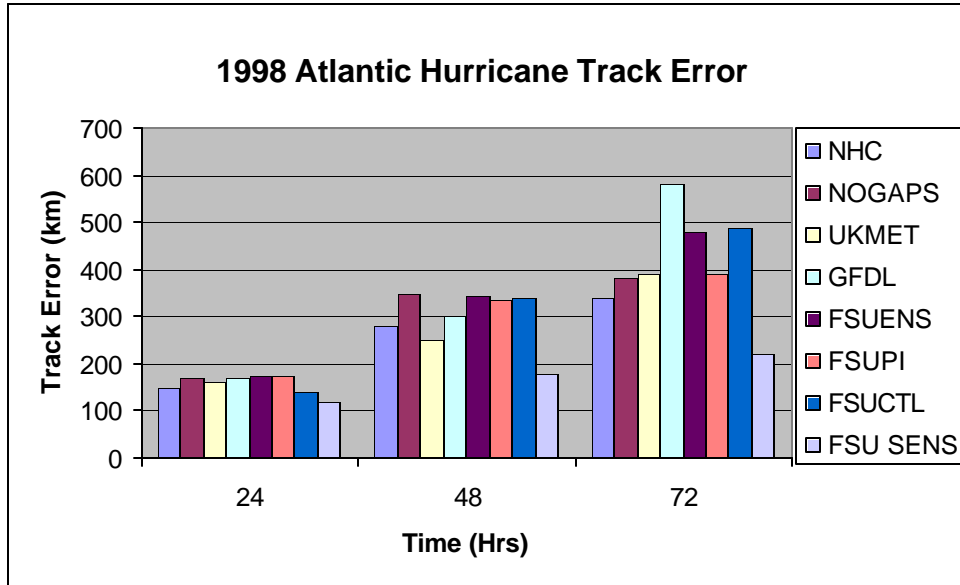


Fig. 1. Superensemble track forecast errors (km) for 1998 Atlantic hurricanes.

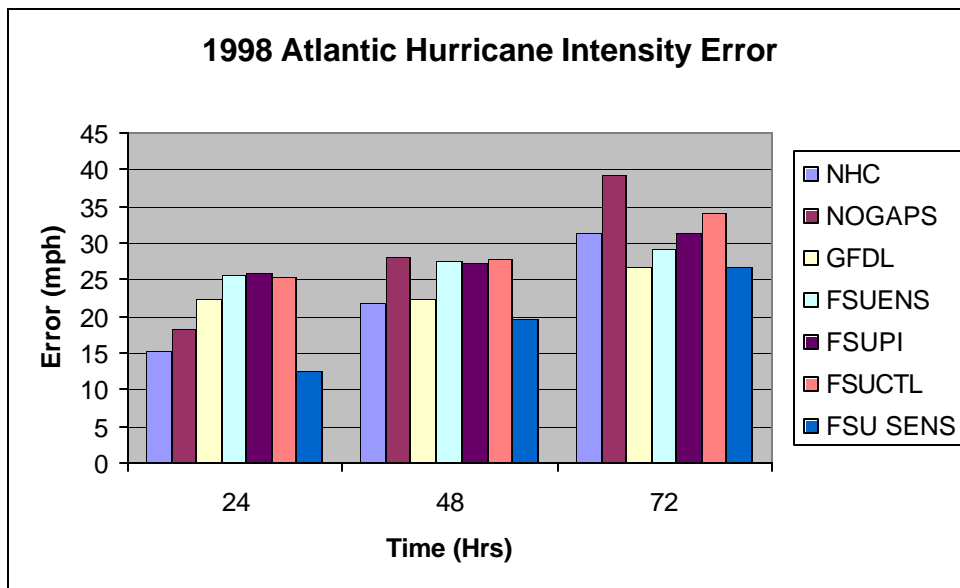


Fig. 2. Superensemble intensity forecast errors (mph) for 1998 Atlantic hurricanes (the model members are arranged in their order from left to right, the last histogram being of the superensemble).

During 1998, the best track forecasts came from the NHC official component. These are in fact subjective forecasts made by the forecasters of the National Hurricane Center in Miami.

They are essentially based on consensus from among the suite of model forecasts available to them. In addition, they also make use of their past experience on subjective hurricane forecasting to arrive at these official forecasts. The superensemble forecasts are superior to those of all other models and official forecasts for each of the three days. The superensemble, in the “control” or the training phase, has position errors on the order of 120, 180, and 200 km for days 1, 2, and 3 of the forecasts, respectively. The corresponding position errors for the superensemble “forecasts” are 120, 180, and 220 km for days 1, 2, and 3 of the forecasts. The same is true for the intensity forecasts as well. The rms forecasts for the control and the test periods from the superensemble are better than those of all other models. Also shown in these diagrams is the skill of the ensemble mean, which is lower than those of the superensemble. These results are based on the use of the cross-validation approach.

#### **4. Overall track forecast errors for all hurricanes of 1999**

The skill of track forecasts for all of the 1999 Atlantic hurricanes from the participating multimodels, the ensemble mean, and the superensemble are summarized in Fig. 3. The following multimodels are included here: NHC1 (the National Hurricane Center's Official Forecast), AVN1 (NCEP's Aviation Model), OHPC, GFDL (the Princeton Model being run at NCEP), VCBI (the equivalent barotropic Vicbar model), UKM1 (the U.K. Meteorological Office Model), NGP1 (the U.S. Navy's NOGAPS model), ENSM (the ensemble mean), and FSU SENS (the FSU superensemble). The ordinate in this diagram illustrates the position error in kilometers and the abscissa denotes forecast time intervals (every 12 h). Here we note that the position errors of the superensemble are below those of the multimodels and of the ensemble mean during the 3-day forecast. The day-3 reductions in position errors in comparison with the NOGAPS and the Aviation model are quite substantial, on the order of 200–300 km. The superensemble reduces the 3-day errors in comparison with the best model (GFDL) by roughly 120 km. Overall, these reductions of errors by the superensemble seem quite encouraging.

#### **5. Intensity forecast errors during 1999**

Our experience with the skill of track forecasts from the multimodel superensemble for 1999 was quite similar to those for 1998. The intensity forecasts have been a difficult issue for numerical weather prediction. In the overall statistics of intensity forecasts, where all the storms of 1999 are included, we did notice a small improvement from the superensemble over all other member models as well as the official best “observed” estimates of intensity. The summary of the 1999 Atlantic hurricane intensity errors is illustrated in Fig. 4. What is apparent here is that the intensity forecasts from the superensemble are only slightly better than the member models in general.

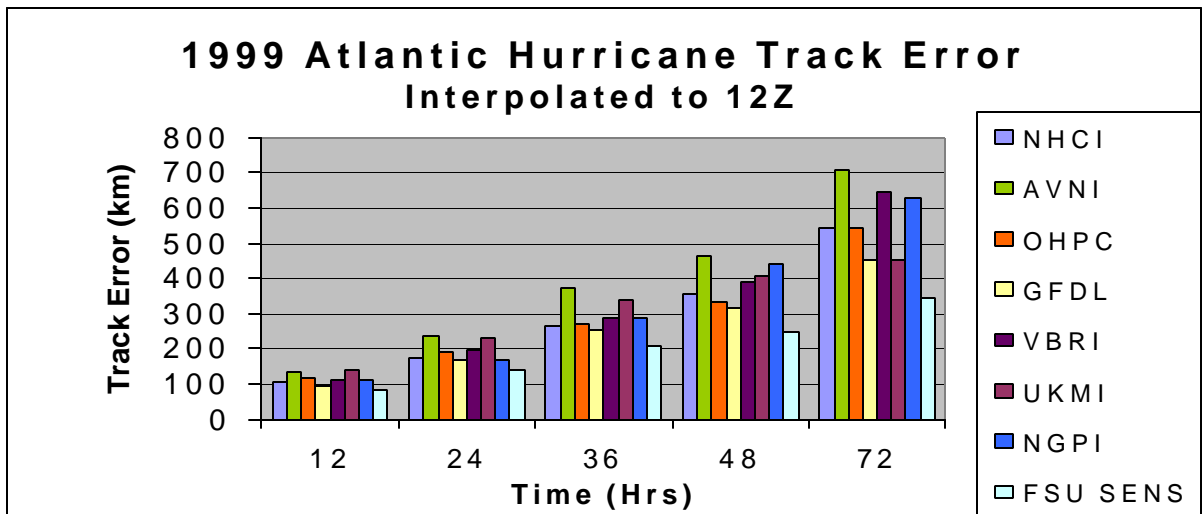


Fig. 3. Superensemble track forecast errors (km) for 1999 Atlantic hurricanes.

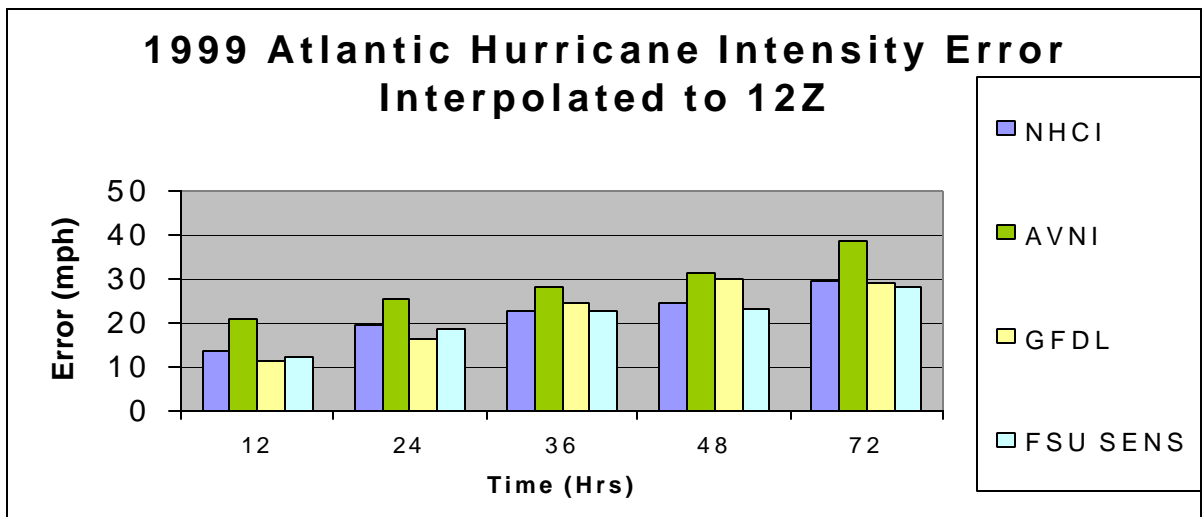


Fig. 4. Superensemble intensity forecast errors (km) for 1999 Atlantic hurricanes (the model members are arranged in their order from left to right, the last histogram being of the superensemble).

The intensity issue needs to be addressed from mesoscale higher-resolution models and a superensemble. That work will require planning and careful implementation of multimodels and the training phase.

## 6. Response to the Focus Questions

### a). What is needed to improve the accuracy of hurricane forecasts?

?? **New platforms (e.g., unmanned aircraft):** An Unattended Aerial Vehicle (UAV) flying over the tops of deep convection near 15 km above sea level with an array of remote sensing equipment such as GPS-based surface winds and passive microwave radiometers can provide information on hydrometeors, rain rates, and surface winds; furthermore, advanced microwave sounding units can be extremely helpful in future surveillance of

hurricanes. UAVs of the future can follow the storm over several days and provide data sets toward the understanding of storm intensity. Further exploitation of coastal and airborne radars and satellite data sets at high resolution, especially from geostationary platforms, could provide useful data sets at frequent time intervals and spatial resolutions.

?? **New forecast products (e.g., refined statistical approaches):** Possibly neural network techniques could be advanced to improve track and intensity forecasts. Further research is needed in these areas.

?? **Improved numerical forecast system (e.g., superensemble approach):** This is worth exploring further in the coming years with improved higher-resolution multimodels. For the immediate future this would be most desirable.

#### **b). What are the priorities for improving the forecasts?**

Mounting a UAV program or a new geostationary satellite-based remote sensing program would take several years. In the immediate future the operational research aircraft programs of NOAA and NASA (CAMEX 3 and 4) need to be augmented. Currently there are three NOAA aircraft (two P3s, a Gulf Stream, a USAF C130, and possibly a NASA DC8). There is great need for the data sets from these aircraft to be available fully on GTS for numerical modeling in real time; only a small fraction of these data sets are seen on GTS. Better coordination of aircraft and deployment of observations is needed, especially in the context of adaptive strategies.

#### **c). What policy changes are needed to make improvements available as soon as possible?**

This is difficult to address without knowing what the current status of policy issues is. AMS policy statement is an overall umbrella. We need to go beyond that to address coordinated observational and modeling issues.

# Hurricane Forecasting Considerations

Steven W. Lyons

The Weather Channel

## 1. Overview

We are all aware of the modest but steady improvements in tropical cyclone track forecast skill the NHC has reported over the past 30 yr. I believe it amounts to about 1% per year. Largest improvements have been realized at extended forecast times and have been at least partly attributed to numerical model improvements. I believe we also realize that the rate of forecast improvements has not kept up with the rate of coastal population growth. Of course, population increase has absolutely no direct physical effect on forecast skill or on the breadth of watches and warnings. In other words, how many people that could be affected by a hurricane at landfall has no direct link to how large watch or warning areas should be. Ideally, the meteorological situation and its uncertainty “should” dictate the size of watches and warnings.

In his recent research at the HRD, Dr. Mark Powell has brought one very interesting aspect of hurricane track forecasting to light. Verifying track forecasts revealed that hurricane landfall forecasts *have not improved* appreciably since 1976 at any time scale. Obviously, we should be more interested in making accurate landfall forecasts than we are in making accurate high-seas forecasts. If our landfall forecasts have not improved, that can only mean that high-seas forecasts have improved at a rate of more than 1% per year, although keep in mind the number of landfall forecasts is a small percentage of the total number of forecasts. It is disappointing to see the lack of forecast improvement at landfall, but what is the cause? It turns out that, historically, landfall forecasts tend to be a little more accurate than their high-seas counterparts. One reason given is that because there are more data available along the coast and inland and forecasts are already more accurate there, it is more difficult to improve upon coastal forecasts. Another possible reason could be the “forecast of least regret,” namely, the forecast track is subjectively modified to cover “risks” associated with high population, long evacuation times, very vulnerable coasts, and political demands. The result is degraded forecast skill.

Based on these results my first recommendation is that we make every effort possible to leave the NHC forecaster alone to make the best “meteorological” forecast possible, without worry of coastal population, coastal vulnerability, money or political consequences. Nonmeteorological issues are fundamentally the job of emergency managers, politicians, and the private sector, not meteorologists at NHC. When the forecaster includes nonmeteorological elements in his forecast, they are considered at least twice (the second time is by emergency management). The meteorologist should stick strictly to the meteorological forecast and assessment of its uncertainty out in time without worry of ramifications of a poor forecast. The NHC forecaster’s role with emergency managers, media, and other disciplines should be to educate them about how forecasts are made and about forecast uncertainties.

## 2. Tropical cyclone nowcasts

One huge improvement in the meteorology of tropical cyclones is the nowcast capabilities we have today as compared with yesteryear. The Galveston hurricane of 1900 and the great northeastern U.S. hurricane of 1938 are examples of tropical cyclones that caught people very much by surprise. That can no longer happen, thanks to satellite meteorology that

allows us to monitor continuously the location and intensity of tropical cyclones around the world. Most visual media outlets have the capability of displaying these wonderful images for all to see. Would it not be wonderful to have satellite images of the 1900 and 1938 hurricanes in our archives? We should continue our efforts to improve and to develop more satellite-based techniques to monitor various aspects of tropical cyclones, including techniques that estimate impact elements at sea, along the coast, and inland.

### 3. Track forecasts

Numerical prediction of tropical cyclone tracks has improved tremendously since the early models of the 1950s and 1960s. Ironically, today's reliance on model guidance has possibly led to the decline in skill of subjective tropical cyclone forecasts. It is hard to imagine that landfall forecasts in the 1970s were about as good as they are today and watch/warning areas were *smaller*. Back then forecasters relied very much on subjective forecast techniques. Today they rely heavily on model forecasts. Revitalizing and improving subjective analysis and forecast skills without inhibiting numerical model advances could provide significant improvements in track forecasts.

Through computer advances, model forecasts very likely will continue to improve, assuming we remember one fundamental problem with tropical cyclone forecasting: maximizing observations. We must continue to improve the initial conditions we provide models, because even the world's best track forecast models fall short of very simple models when they are incorrectly initialized. We have seen this happen with the GFDL model. In this vein, we must make sure our modeling efforts address getting "real observations" into models at the expense of the model first guess, *not* the other way around. The NOAA jet objective is to do exactly this. Has anyone examined the extent to which jet data are contributing to model initial conditions?

Reconnaissance data from the Hurricane Hunters and NOAA have been invaluable for determining tropical cyclone strength and are much appreciated by all users of this information. Ultimately, though, I see by far the biggest spatial and temporal coverage of 4D "observations" coming not from aircraft, ships or rawinsondes, but from satellite remote-sensing technology. Eventually that technology will provide a vast arsenal of remotely sensed data. We *must* find better assimilation techniques that allow models to accept and to digest satellite information. I find that satellite "information" is my single best source for diagnosing tropical cyclones and their surrounding environments and therefore validating or invalidating numerical guidance. This is true because satellite data are underutilized in models. Verification of satellite wind accuracy should be based on other observations, not on verification against model first-guess fields or model analyses.

There are three additional aspects of tropical cyclone track forecasting that I would like to mention, 1) ensemble forecast techniques, 2) measures of "track confidence," and 3) track model boundary conditions. 1) As computers get faster, a multitude of ensemble forecast possibilities will grow quickly. I am sure Dr. Krishnamurti will discuss ensembles and superensembles in some detail, so I will be brief and say that any ensemble techniques that provide a more robust forecast that leads to an improved track and/or higher confidence in the forecast should be highly encouraged. Very simple ensembles such as repeat numerical forecasts varied by small changes in tropical cyclone initial position and/or initial speed could be powerful tools to estimate general predictability and forecast track confidence. These kinds of runs that use identical boundary conditions require very simple model changes.

2) I strongly believe the research community should be working hard to develop techniques that give us forecast track confidence levels or certainty. Such confidence estimates would help not only emergency managers with their critical decisions, but would help the media to provide the public with forecast confidence levels so they can best assess their risks. Forecast uncertainty should be kept quantitative and scientifically repeatable rather than subjectively derived.

3) Each year, NHC evaluates the skill of various tropical cyclone models, regional models, global models, climatological models, and their “official forecast.” This verification indicates that, over a large sample, the GFDL triple-nest tropical cyclone model and the UKMET global model outperform other operational models (the official forecast remains the best over all). The GFDL model (and nearly all other U.S. tropical cyclone models) uses lateral boundary conditions from the NCEP global spectral model. It turns out that the NCEP model does not verify as well as the Navy model or the UKMET model. I know it may not be politically correct, but I say, “let us all swallow our pride” and run various combinations of these models to maximize skill. We are trying to save lives and property, and that should be our highest priority. Through international cooperation we can all benefit from sharing resources. Currently, I believe the GFDL model initialized by the UKMET or Navy NOGAPS model will provide better track forecasts than it does using the NCEP global model. As I recall, GFDL showed this for a few cases when NCEP computers were unavailable and they initialized their model with UKMET or Navy model forecasts. That does *not* mean the relative skill of various models will remain unchanged through time. We should continue our *strong support* of each modeling center so they may continue to improve their models independently of each other. If we do not, we may all eventually find ourselves at the same dead-end street!

#### **4. Intensity forecasts**

There has been little appreciable improvement in tropical cyclone intensity forecast skill over the past 30 yr over the high seas and at landfall. Also, tropical cyclone intensity nowcasts have remained nearly unchanged during the period of aircraft monitoring. However, the need for accurate intensity forecasts is highly situation-dependent. This is true because of the nonlinear growth of wind, wave, and surge damage as a function of tropical cyclone strength. We know that major hurricane landfall events, although far rarer than those of lesser strength, cause most hurricane damage.

Ideally, we want to make accurate intensity forecasts at all times, but by far the most important intensity forecasts are those within 36 h of landfall. Landfall intensity not only controls the magnitude of coastal impact, but also controls how, who, and how many people emergency managers attempt to evacuate from a coastline. We have known this for years, but in 1999 hurricane Floyd displayed this very clearly. So, I think we must concentrate on intensity forecast accuracy for tropical cyclones at landfall, and I do not mean to infer that intensity change mechanisms at and near landfall are necessarily different from tropical cyclone intensity changes in the high seas.

If we search forecast records, we find the largest intensity forecast errors are associated with tropical cyclones that develop rapidly or weaken rapidly. Intensity forecasts tend to be far more conservative for these events than what nature deals out. Part of the reason for this is that statistical satellite guidance techniques, through averaging, provide intensity trends that are more

conservative than extreme events. Better understanding of mechanisms for rapid intensification and rapid weakening is very important.

Today we remain in a debate over what the controlling influence is on intensity change: sea surface temperatures or the environment in which the tropical cyclone is embedded. Unfortunately, the atmosphere is not linear and there is no way to separate these effects from each other, except through simplified linear models. After 25 years of watching tropical cyclones I am convinced both are important depending on the circumstances, but from the side of a forecaster, environmental aspects by far outweigh sea temperature considerations. Sea temperature appears to have a fundamental control on “potential” strength, but full potential is rarely realized. Inspection of current research suggests that sea surface temperatures are being examined more than are environmental influences. Even in the spirit of sea surface temperatures, is anyone looking at all those tropical cyclones with which forecasters routinely deal that weaken as they move over warmer water? We need to maintain a practical side and examine intensity changes that routinely give forecasters big problems and have large impact on our coastal populations.

Numerical models have shown only poor skill with intensity forecasts in real time although there have been numerous studies that have verified a measured trend after the event is over. Are these studies getting the correct answer for the wrong reason because they are working backward from the answer? My guess for getting models to forecast intensity change better is to provide a more accurate initial 3D divergence field and horizontal and vertical latent heating distributions. These are two tough tasks, but I believe that if they can be met they will dramatically improve model intensity forecasts. At least the horizontal distribution of deep convection can be obtained from satellite information. Alternatives include improving subjective and statistical recognition and measurement of these elements.

Currently, intensity forecasts are “marred” by the way we portray tropical cyclone intensity. Let me forget for a moment the 10-m elevation of the wind forecast (which has its origin from a standard wind height used to generate ocean waves). Let me put it this way, if you found 1 out of 1000 nonmeteorologists that could tell you what the NHC’s definition of “maximum sustained wind” in a tropical cyclone is I would be surprised! We need to change the way we describe tropical cyclone winds to the public. Tagging a tropical cyclone by a single maximum wind speed “somewhere” in the circulation is inconsistent with the impacts that winds can generate; thus it exaggerates impacts at landfall. It fits the Saffir–Simpson classification nicely, but should we not be basing that scale on a more robust and spatially dominant wind speed? We have heard wind engineers complain for years how wind damage from “most” hurricanes is well below what should have occurred from the forecast/nowcast maximum sustained wind. I have had difficulty explaining to The Weather Channel viewers that a specific maximum sustained wind cannot be seen at any buoy or coastal observation site and that impacts from winds that strong would likely not be realized at the coast. Obviously, this aspect is important for asymmetric tropical cyclones, but this variety makes up the majority of tropical cyclones. I strongly suggest we redefine our definition of maximum sustained wind so that it better represents observed wind measurements. This problem is exacerbated by the “maximum envelope of water,” or MEOW, used by emergency managers to make evacuation decisions. MEOW provides worst-case surge scenarios along a coastline based on a single maximum 10-m wind estimate somewhere in a tropical cyclone. In most cases, maximum sustained wind is localized within a small area on one side of a tropical cyclone. The result of applying that

maximum to the entire tropical cyclone and then applying the MEOW leads to overwarning, even for the case of a perfect track and intensity forecast.

## **5. Tropical cyclone impacts**

NHC currently provides tropical cyclone track and intensity forecasts. Based on these two parameters it is possible to estimate/forecast the *potential impact* to U.S. residents at and beyond landfall. Impacts include surge flooding; wave erosion, wave damage, and wave flooding; wind damage; and rainfall-induced flooding. The private sector needs to move away from simple transmission of meteorological information and become the “interpreter” that adds value to those “meteorological” forecasts and transforms them into coastal and inland impact forecasts that the public understands and can use to make sound life-saving decisions. We need more scientific research that addresses impact, not just track and intensity forecasts. These studies should benefit disseminators and potential victims, not just meteorologists. It is no longer sufficient simply to tell people where a tropical cyclone is going and how fast the winds are. People and commerce take action based on expected impacts; they do not take action based directly on meteorological parameters.

Along this line of impact thinking, we need to change the way we depict ocean wave information in tropical cyclone advisories. Collocation of 12-ft seas with 34-kt winds is rarely valid. Rather than provide 12-ft sea information, I suggest that we change the advisory to include estimates of wave height at the radius of 34-kt winds. Radii of 12-ft seas can extend many hundreds of miles away from the tropical cyclone, distracting from the advisory information.

Last, both Hurricane Irene and Hurricane Floyd showed me the failure in how the National Weather Service disseminates its information. They have too many products and too many places for people to have to look to find them. Inland impacts from Irene (via the Miami WFO) and Floyd (via eastern WFOs) were well covered yet people were caught by surprise, because once the NHC stops its advisories or fails to mention the extent of inland impacts most people and media disregard those impacts. I propose HPC (that already makes advisories behind NHC) take over the NHC advisory as the tropical cyclone moves inland. Advisory format should remain identical to the NHC ocean advisory, but discussion should be shifted to inland wind and flood potential. The *only* difference in the product after this seamless transfer of responsibility should be the NCEP name change from TPC/NHC to HPC within the advisory.

## **6. Summary**

I have touched upon a few areas where I think we can realize large improvements in tropical cyclone forecasts at a very low cost that really amounts to not much more than policy changes in some cases. These changes are logical, and how we got away from doing them is a mystery to me. If someone were to come into our business cold and see what we are currently doing, they would likely ask why we are doing it that way. I think they would expect us to be doing it in ways very similar to what I have proposed. I will close by saying to everyone dealing with the tropical cyclone threat: visit the people you are trying to protect. They may open your eyes to better ways of doing business.

**Forecast Considerations**  
**Max Mayfield**  
**Director, National Hurricane Center**

Working with the Tropical Prediction Center, the hurricane landfall component of the U.S. Weather Research Program (USWRP) has identified several primary forecast goals to be attained after an intensive 5-year research and development program. These are 1) to reduce landfall track forecast errors by 20%; 2) to increase warning lead time with 95% confidence to beyond 24 h without increasing the current level of overwarning; 3) to reduce landfall intensity forecast errors by 20%; 4) to make skillful forecasts of tropical storm and hurricane force wind radii out to 48 h; and 5) to improve forecasts of inland flooding by extending and improving the skill of quantitative precipitation forecasts out to three days. As in real estate, for which the three most important factors are “location, location, location,” in hurricane forecasting the three most important factors are “track, track, and track.” Obviously, goal 2 cannot be attained without a significant improvement in track forecast accuracy, but, in addition, progress in items 3-5 are of limited use in the absence of an accurate track forecast.

Given that overall track forecast accuracy has been improving at a rate of 2% per year or less, and that landfall forecasts appear to have been improving at an even slower rate, the 20% track improvement goal over 5 years is clearly quite ambitious. However, research technologies that have made or are making the transition to operations may be major contributors to reaching this goal. Preliminary results from the first flights of the NOAA Gulfstream IV (G-IV) jet aircraft, which flies in the environment of hurricanes that threaten to make landfall, show mean improvements in track forecasts of 10%–15%. Improvements resulting from the G-IV, however, have been inconsistent and point to the need for significant advances in data assimilation techniques.

During the decade of the 1980s, statistical techniques provided the primary operational track forecast guidance. During the 1990s, however, dynamical models improved considerably and surpassed the skill of the statistical techniques. As we enter a new decade, there are indications that the next significant increment of track forecast accuracy will come from a second wave of statistical analysis that extracts the best information from the dynamical models. Ensembles, whether they are simply an average of the best of the dynamical models or are an elaborate “training” system such as The Florida State University superensemble, are showing great promise. Ultimately, however, improvements to numerical weather prediction are required, through increased computer power, better physical parameterizations, and improved observations and data assimilation algorithms.

The USWRP goal of a 20% improvement in intensity forecasts is even more daunting than the 20% track improvement goal. In recent years, intensity forecasts have been improving at a slower rate than track forecasts, and there is no technology currently at hand to assist us with intensity forecasts analogous to those of the G-IV jet for track. In fact, in the near term, it is possible that intensity forecasts *will appear to become less accurate than before*. New technologies, such as the GPS dropwindsondes and the Stepped-Frequency Microwave Radiometer (SFMR), are allowing us for the first time to *measure*, rather than to infer, the maximum surface winds in a tropical cyclone, and we are learning that the hurricane’s wind structure is more complicated than was previously thought. The ability to diagnose this increased variability in intensity is well ahead of our ability to forecast it. As a result, intensity

verification statistics are likely to worsen over the next several years as we improve our estimates of current intensity.

Tropical cyclone intensity forecasting is at least a decade behind track forecasting, in the sense that the best available tool for forecasting intensity is still a statistical–dynamical model (SHIPS). We have a limited physical understanding of tropical cyclone intensity change, especially rapid deepening. The rapid deepening of Hurricane Opal, a 1995 hurricane close to the land-based observational network, illustrates a research community literally miles apart—split between those who attribute the strengthening to a subsurface oceanic heat source and those who blame potential-vorticity interactions in the upper troposphere.

Whereas hurricane tracks are determined almost exclusively by their large-scale atmospheric environment, hurricane intensity is influenced to a greater degree by smaller-scale features in both the atmosphere and ocean. This means that a much finer observational network will be required to bring forecasts of intensity by dynamical models to the same level as track forecasts. Moreover, operational dynamical models, such as the Geophysical Fluid Dynamics Laboratory hurricane model, have inadequate resolution for an accurate simulation of the inner core region of a hurricane. Also, improvements to physical parameterizations used in the models will likely be required. The problem goes far deeper than merely collecting new data or increasing model resolution, however. A host of new technologies and platforms have been proposed to address observational needs, each with its own set of characteristics, accuracy, and sampling limitations. We will probably find that the next generation of mesoscale hurricane models is enormously sensitive to these characteristics. New technologies that rely on the presence of scatterers, for example, may leave important parts of the hurricane vortex unsampled. It is unclear how well these technologies will fit together to produce improvements in intensity prediction. There is an urgent need for data simulation experiments before an intelligent observational system can be designed to address the intensity problem.

Customer demand for new products, as well as misapplication of existing products, dictates new forecast products. Five-day track forecasts appear to be in the near future, although these are likely to be useful only to a small customer subset because of the associated uncertainties. Perhaps the most misunderstood forecast parameters are the hurricane and tropical storm force wind radii. Although mathematicians have done wonders in the field of data compression, any attempt to depict the very complicated two-dimensional wind field of a tropical cyclone using only four numbers is a problematic enterprise. Emergency managers need to know how an approaching hurricane’s wind field will affect their operations; however we do not yet have the capability to tell them what they need to know. Observations from SFMR, coupled with analysis techniques that are making the transition to operations, may allow us to provide a detailed graphical depiction of the hurricane’s current wind field within a few years. Useful *forecasts* of a hurricane’s wind field, unfortunately, are many years away, and, because of the importance of uncertainties, may come from probabilistic rather than deterministic approaches.

Last year’s Hurricane Irene has reminded us that it is not always enough to have the correct warnings in place. Many were shocked at the impact of Irene’s rains in south Florida, despite accurate and timely flood watches and warnings issued by the Miami Weather Forecast Office. Hurricane Floyd killed 56 people in the United States; most of these deaths were due to drowning in freshwater. The warning process cannot be considered successful unless the impacts of a hurricane’s hazards are effectively communicated to government officials and the general public. We have done a good job communicating the potentially deadly and devastating

impacts of storm surge and wind; now more emphasis needs to be placed on freshwater flooding, which has become the leading cause of hurricane-related deaths in recent years. It is important, however, that we make it clear that the greatest potential for loss of life remains from storm-surge flooding.

Support for hurricane research, both basic and applied, has declined to critical levels. Resources allocated for hurricane research over the past 20 yr have not even been permitted to keep up with inflation. NOAA's Hurricane Research Division, whose experiments led directly to the purchase of the Gulfstream jet and whose pioneering efforts in data analysis are taking us into the graphical era, can no longer afford to go into the field each summer. Although the path to improved hurricane forecasts faces a number of obstacles, both conceptual and technical, there are none that cannot be overcome with determined effort. However, without a revitalized, well-funded program of hurricane research, progress on these issues will remain agonizingly slow.

## Comments

Robert C. Sheets

Former Director, National Hurricane Center

I have some very strong opinions about what should or should not be done with respect to most items up for discussion. Some of those opinions are given below as revised on 18 May 2000 to reflect some recent actions by Broward County (Fort Lauderdale), Florida, and the Florida Windstorm Underwriters Association (forced “wind pool”):

1. **Do not mess with the Saffir–Simpson scale for hurricanes and the associated warning process!** After several years of public awareness programs, this scale is now an integral part of how coastal and near-coastal residents respond to hurricanes. That process has been quite effective in reducing loss of life along and near the coast and probably inland with respect to response for winds.

2. **Do not add some new scale for inland flooding from hurricanes!** As others have said, we already have such a scale - it is called “inches.” If some new scale is added, it will likely confuse more than help. For years, the West Pacific region experimented with an “International” scale of 1 to 10 for hurricanes/typhoons. It has not caught on for public use and now various countries in the region are using the Saffir–Simpson scale or its equivalent. Any scale for flooding, damage potential from winds, and so on that is more complex than the Saffir–Simpson scale would likely have little public use. It is possible that such a scale might be useful for some public officials, but that is questionable.

With respect to flooding, it should be recognized that the degree of flooding is not directly related to the strength of the hurricane as determined by the maximum wind speed or lowest central pressure. There are many factors such as ground saturation, interactions with some baroclinic system, upslope flow, and so on, with wide variations of rainfall and associated flooding over short distances. Also, heavy rains and associated inland flooding can take place with weak tropical systems or systems not associated with tropical systems at all. The great Midwest flooding of a few years ago is an example of major flooding that had nothing to do with hurricanes. Many other such cases could be cited, even in the hurricane-prone inland and/or coastal regions.

Because similar flooding conditions for a given area can be created by the remnants of hurricanes or other weather systems, to avoid confusion, these events should generally be treated the same way. Use of key descriptive words would likely be more effective in communicating the danger to the public than some new scale. Three such descriptive words could be “**moderate,**” “**severe,**” and “**catastrophic**” combined with “**localized**” and “**widespread.**” For example, the rainfall section of the **National Hurricane Center’s Tropical Cyclone Public Advisories** could contain phrases such as “**rainfall of 6 to 10 inches is expected along the path of the hurricane that will likely create widespread moderate flooding and localized severe flooding** over portions of eastern North Carolina during the next day or two.” Some qualitative definitions of what “moderate,” “severe,” and “catastrophic” mean with respect to flooding would be needed. Of course, these definitions could be different for different communities.

With respect to evacuations, I believe that **we are evacuating too many people** for hurricane threats. Part of this situation is due to the fact that we use “MEOWS” to describe the potential storm surge because of the uncertainty in the forecast track and intensity. Also, nearly all of the storm-surge and associated evacuation maps published in phone books, newspapers, and hurricane preparedness tabloids for various categories of hurricanes are for worst-case scenarios with storms moving onshore normal to the coast. Situations such as Hurricane Floyd traveling nearly parallel to the coast (slightly inland, along the coast, or slightly offshore) produce much less coastal inundation. Also, it has been common practice to attempt to evacuate any area that could potentially get flooded, even if that flooding might not be life threatening, with only a few inches of water surrounding the houses. Arguments presented for this approach to evacuation are that people could be isolated from emergency services, and thus it is better to get all potentially threatened residents out of harm’s way. All of this means massive evacuations which after the fact may show that 90% or more of those evacuating did not need to do so. Also, after Hurricane Andrew, many inland residents away from the threat of the storm surge are not confident that their homes are built well enough to provide a safe place of refuge during a severe hurricane. Of course, mobile home and manufactured home communities should be evacuated in any case. With this as a background, I recommend that public officials use the following guidelines when recommending or ordering evacuations.

1. Only recommend or order evacuations for those people whose lives are at risk from drowning or building collapse caused by substandard construction (mobile homes, manufactured homes). Do not order or even recommend evacuations for areas where potential flooding would be only a few inches. Broward County (Fort Lauderdale), Florida, has now initiated such a program. That program has reduced their potential evacuations by about 200,000 people, or about 40 percent of designated evacuees under their previous plan. Miami Dade County, Florida, has indicated they will use a similar plan on a case-by-case basis.

2. Use phased evacuations whenever possible, getting out the highest-risk people first.

3. Use realistic potential storm surge inundation for the particular storm situation. Take into consideration areas of probable offshore flow as compared with onshore flow. With today's communications capabilities, more-realistic storm-surge potential maps could be presented to local emergency management officials as well as to the general public than those based on the more prevalent worst-case “MEOW” approach with storms moving normal to the coast.

4. Do not use the “all of my area” or “none of my area” approach to warnings and associated evacuation, but realistically assess risk. A line must always be drawn somewhere, giving a warning on one side of the line and not on the other. A hurricane warning should nearly always have a tropical storm warning on its edge to help convey the transition in the degree of threat.

5. Try to evacuate people tens of miles or less, not hundreds of miles. There are some recommended actions listed below that should help this approach to become a reality.

On the longer term, the following actions should be undertaken.

The U.S. Congress should implement a **National Hurricane Hazard Reduction Act** similar to the very successful **National Earthquake Hazard Reduction Act** created several years ago. Such an equivalent act and funding would provide long-term continuous funding for research to improve short-term and long-term forecasts of hurricanes and their effects and to develop and/or to promote cost-effective mitigation programs. Efforts are presently under way at the International Hurricane Center at Florida International University to build a coalition of university scientists and others from around the nation to get such an act passed by the U.S. Congress.

The second is for the U.S. Congress, state legislators, and local governments to pass hurricane loss-mitigation legislation that would not only reduce the ever-rising disaster assistance outlays, but would actually promote the safety and economic well being of residents and businesses subject to hurricane-generated damage. Some examples of such legislation are as follows.

### **U.S. Congress**

1. **Reduce Federally subsidized coastal development.** The Barrier Islands Act of a few years ago was a good start in this direction, but federally subsidized water and sewage treatment plants, roadway systems, and so on have encouraged rapid coastal development. That is not to say that such programs should not take place, but that those programs should be strongly tied to community planning that requires restrictions on population density, strong building codes, community shelters, and so on that would reduce evacuation times and minimize damage from hurricanes. The **National Flood Insurance Program** should be amended along the lines suggested by the current FEMA Director, **James Lee Witt**; to restrict multiple pay-outs greatly and to phase toward true risk-based premiums rather than being subsidized by those in lower risk areas. A recent study by the St. Petersburg Times in the Tampa Bay area indicated that these subsidies were now as much as 70% or more in some areas and generally 50% or more for most of that coastal zone. Also, new construction should be required to obtain risk-based private-sector flood insurance at market rates. Such requirements would reduce development in very high risk areas and/or would result in properly built structures with low risk to flooding or storm surge and wave action in those areas.

2. **Change Federal tax laws** to allow private insurance companies to set aside funds for infrequent but catastrophic losses such as hurricanes or earthquakes. Current tax laws basically operate on a year-to-year profit/loss tax basis that is unrealistic for such events as catastrophic losses from a major hurricane or earthquake that might occur once in a 10-year period. These characteristics of the tax laws have driven the reinsurance market offshore or overseas. The first-line insurer then has to buy reinsurance from these companies, thus taking funds away from the economy of the United States and almost assuredly increasing insurance rates for individual homeowners. The state of Florida instituted a Hurricane CAT Fund after hurricane Andrew to accumulate such "reinsurance" funds tax free. These funds are accumulated by a "tax" upon

every hurricane policy in the state. In essence, this means that other states are subsidizing insurance for Florida residents.

### **State legislatures and/or local governments**

1. **Implement and enforce strong, hurricane-resistant building codes.** This is not complex science. We know how to build hurricane-resistant structures. Contrary to the arguments of builders' associations who generally oppose improved codes on the erroneous grounds that the increased cost of construction will price many people out of the home-buyer market, major improvements are available at minimal cost increases (studies show the additional cost ranges from 2% to 5% of the total cost of the home). Southeast Florida, which has such codes in effect, has shown no signs of slowing in growth rates since codes were strengthened after Hurricane Andrew. When the cost of such improvements is spread over the typical 30-year mortgage, it is infinitesimal. Also, most insurance companies now provide some reduced rates for home owners who have doors and windows protected. Having homes, outside of the potential life-threatening flood zone, in which you can live before, during, and after a hurricane greatly reduces evacuation and recovery times and costs for communities.

2. **Change insurance legislation** to encourage competition for well constructed and protected homes. Contrary to the common misconception that "...[i]nsurance against wind damage costs is done on a **VOLUNTEER** basis through private insurance underwriters" (quote from a recent book on Atlantic hurricanes), that insurance is **anything but VOLUNTARY** in many high-risk coastal areas. That is, many such high-risk coastal area properties are in a forced "wind pool." Generally, all private insurance companies operating in the state must take a portion of that risk, based upon their percentage of coverage in the rest of the state. Because these companies are not going to lose money, they must charge higher rates elsewhere in the state to make up for potential losses in the high-risk areas where rates may not be actuarially sound. Frequently, homes side by side in the "wind pool" exist for which one homeowner who has built properly and provides protection for windows and doors pays the same premium as his neighbor who has done nothing to reduce possible damage. That situation may be changing. In a very recent proposal/action by the Florida Windstorm Pool, they recognized that wind is frequently highly correlated to the "style" of the structure. They are now planning to charge substantially more for structures with gabled ends, large porch or carport overhangs, garage doors not properly braced, and so on and to give reductions for "hipped" roof styles. It is expected that other insurers will follow that lead. These actions could have a profound impact upon the style of homes in the future, once the public realizes that there are substantial financial penalties for the wrong kind of structure and benefits for those built to resist damage from wind. To aid in this process **legislation should be passed that allows insurance companies to compete for the good risk in the "pool" by offering lower rates and then counting that policy against their assigned portion in the high-risk "pool"**. Such action should encourage individual homeowners and developers to build more-hurricane resistant structures. If they do not, let insurance premiums increase to actuarially sound rates for those who choose not to build to the higher standard.

3. **Require all new homes to have a “safe room.”** “Safe rooms” can be easily and inexpensively designed into new homes. This could be a walk-in closet in the master bedroom or an interior bathroom. Such rooms would protect occupants from such short warning events as tornadoes and would also provide a place of refuge in a severe hurricane, thus reducing the number of evacuees and evacuation times.

4. **Require all manufactured home communities and mobile home parks to have a community building on site to be used as a hurricane shelter.** This building would be built to engineered standards to protect residents from hurricanes or tornadoes. New developments should be required to have such structures as part of the permitting process [Lee County, Florida (Fort Myers) now has such an ordinance]; existing parks and communities would be given some period in which to bring their existing community buildings up to hurricane-resistant standards (most such communities already have recreation/community buildings).

5. **Require public buildings such as schools to be built so that they can be safely used as hurricane shelters.** The state of Florida now has such legislation for all new schools. Also, offer tax incentives or other financial help to prepare private-sector buildings for use as shelters. Such a practice will reduce evacuation times, so that people can evacuate tens of miles, not hundreds of miles. If shorter lead times result, then “overwarning” can be greatly reduced.

If such actions are taken, the threat to life and property from hurricanes will be greatly reduced.