Real-Time WRF Forecasts of Frances, Ivan and Jeanne (2004)

Christopher Davis, Wei Wang and Greg Holland

National Center for Atmospheric Research
Boulder, Colorado, USA

1. Introduction

The 2004 Atlantic hurricane season was noted for the eight tropical cyclones making landfall in the U.S. Among these were the devastating hurricanes Charley, Frances, Ivan and Jeanne. The tracks of all four hurricanes were predicted with relatively high accuracy, helping confirm the overall improvement in hurricane track prediction trumpeted by Elsberry (2005). However, the prediction of storm intensity and structure is still widely recognized as a formidable and largely unsolved challenge. In this article we assess results of real-time, fully explicit forecasts generated by the Weather Research and Forecasting (WRF) model (Michalakes et al. 2001), using the Advanced Research dynamical core (hereafter ARW) for three of the major hurricanes (Frances, Ivan and Jeanne).

The premise of the work is that key structural components of major hurricanes can be predicted only with a model with a horizontal grid spacing of a few kilometers or less, and such simulations can profit by the removal of parameterized convection. Although it cannot be argued that the 4-km grid used here can resolve convection, we will show that key features such as eye-wall asymmetries and inner and outer rainbands can be qualitatively predicted in all cases and accurately predicted in particular instances. Furthermore, we will show that the forecast change of storm intensity during the forecast was better than the intensity change obtained from the official forecast in each case.

2. Model Setup

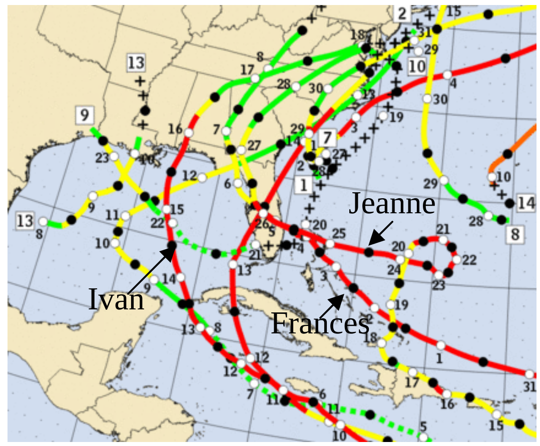

Figure 1. Tracks of landfalling hurricanes in the Atlantic during 2004.

Version 2.0 of the ARW permits interactive nesting, and this was used to run a 4-km domain (450x500 points in the north-south and east-west directions respectively) nested in a 12-km domain. The location of the 4-km domain was dependent on the initial and forecast location of the hurricane, chosen to contain the storm throughout the 48 h forecast period. On the outer domain we used the Kain-Fritsch cumulus parameterization, but the inner domain had no parameterization. Both domains used the NCEP-3 microphysics scheme that predicted only one cloud variable (water for $T > 0^oC$ and ice for $T < 0^oC$) and one hydrometeor variable, either rain water or snow (again thredsholded on 0^oC). The forecasts were integrated on both 12 km and 4 km grids beginning at 00 UTC during the time when each hurricane threatened landfall. Both domains were initialized directly from the National Centers for Environmental Prediction Global Forecast System (GFS) model with no additional data assimilation or balancing. In most cases, even on the 4-

km grid, spin-up required 6-h or less. Although the wind strength adjusted quickly, the radius of maximum winds required much longer to adjust, and did not do so in all cases.

3. Results

a. Frances

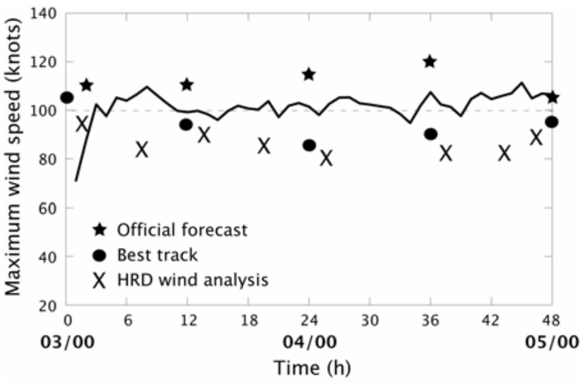

Figure 2. Time series of ARW maximum 10-m wind, official forecast intensity and observations for Frances beginning 00 UTC 3 September.

The forecast emphasized here was initialized 00 UTC 3 September, about 54 h prior to landfall. The official forecast issued 03 UTC on the 3rd placed Frances on land near Vero Beach, Florida by 00 UTC 5 September. However, the storm slowed its forward progress and did not make landfall until 6 h later. The ARW forecast captured this reduction of translation speed and placed the storm within 20 km of its observed location at 00 UTC 5 September.

The intensity of Frances was well predicted by the ARW (Fig. 2). The maximum wind speed (reduced to 10 m MSL) from the ARW is relatively constant after the initial spin up, and is closer to observations at all times prior to landfall than the official forecast. Agreement at 00 UTC 5 September between the official forecast and ARW is due to forecast weakening after landfall in the former.

Numerous outer rainbands emanated from Frances during the two days prior to landfall. The ARW displayed remarkable success in forecasting the timing and location of these bands (Fig. 3). The forecast convection cells within the bands are too large, and this appears as a limitation of using a 4-km grid. Note, too, that the basic asymmetry of convection as the storm becomes visible in the radar network, with heavier rainfall to the right (north) of the track, is also captured by ARW.

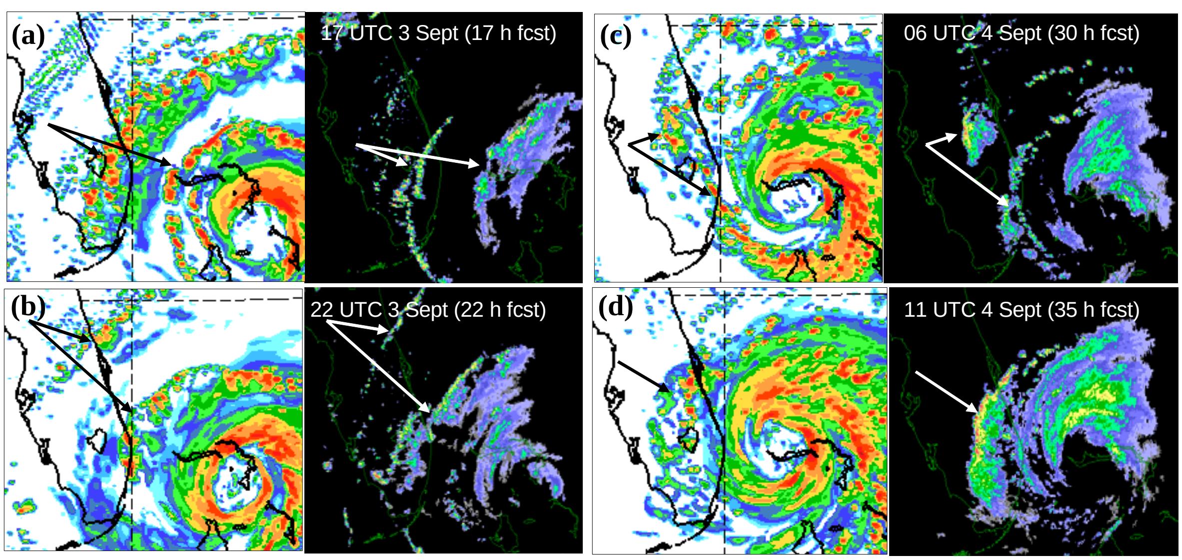

Figure 3. Maximum column reflectivity derived from model (left) and observations (right) for corresponding times in each figure portion. Significant outer rainbands indicated by arrows.

b. Ivan

Ivan was slowly weakening as it made landfall slightly to the east of Mobile Bay around 06 UTC 16 September. The forecast from 00 UTC 15 September produced an excellent forecast of this intensity change, especially when compared to the overestimate of the official forecast (Fig. 4). The predicted track of Ivan placed the storm about 50 km west of its observed landfall location. While this error is significant for estimation of the storm surge in Mobile Bay, it is perhaps beyond reasonable expectations to require smaller errors in a 30 h forecast. More to the point, the entire area of predicted hurricane force winds fell within the warning area issued by the Tropical Prediction Center (TPC).

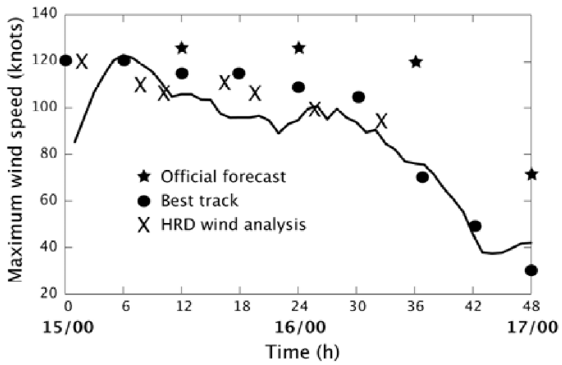

Figure 4. As in Fig. 2, but for Ivan, beginning 00 UTC 15 September.

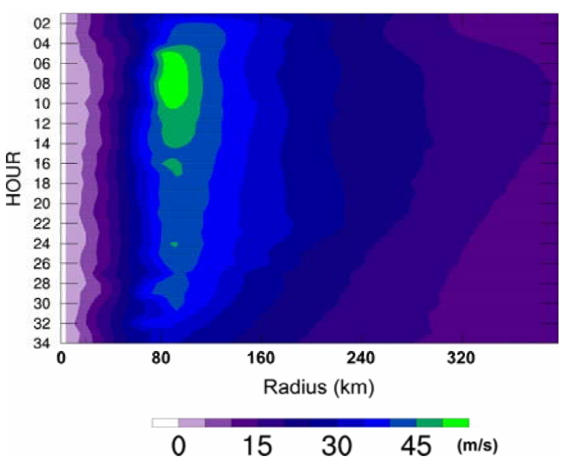

Figure 5. Time-radius diagram of azimuthal mean tangential 10-m wind beginning 00 UTC 15 September. Landfall occurs at 30 h.

Perhaps the most significant error in the prediction of Ivan was the radius of maximum wind (RMW), forecast near 80 km, but observed near 25 km. As suggested in Fig. 5, a time-radius diagram of azimuthal mean tangential wind, the initial RMW derived from the GFS is maintained through much of the forecast. Thus, while the strength of the wind spun up quickly, the contraction of the core did not. This error implies a corresponding error in total circulation, radius of hurricane force winds and a potentially large error in storm surge prediction.

c. Jeanne

The forecast of maximum wind in Jeanne was the poorest forecast of the three storms considered herein (Fig. 6). As was the case with Ivan, the GFS initial condition produces a storm that is too large and does not contract with time. Apparent from Fig. 6, however, is the intensification of Jeanne by an amount close to what was observed.

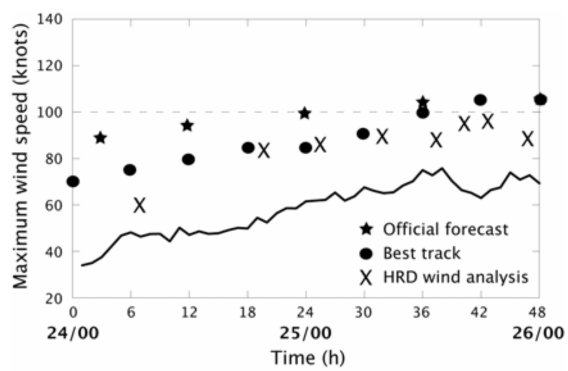

Figure 6. As in Figure 2, but for Jeanne, beginning 00 UTC 24 September.

Thus, in all three cases, the intensity change of the tropical cyclone approaching landfall was well predicted.

4. Conclusions

We have investigated real-time forecasts of Frances, Ivan and Jeanne from 2004 using the ARW model with a grid spacing of 4 km. Overall, the results suggest that the ARW model has considerable potential for hurricane applications, both as a research tool and for improving forecasts of structural features. We consider that fundamental problems of under-resolved core structure may be solved by foregoing convective parameterization in favor of explicit cloud schemes. We are particularly hopeful for significant improvements in the landfall forecasts, especially if additional, underutilized, information, such as radar data and the HRD surface wind analyses can be explicitly included at the assimilation stage.

References

Elsberry, R. L., 2005: Achievement of USWRP hurricane landfall research goal. *Bull. Amer. Meteor. Soc.*, **86**, 642-645.

Michalakes, J., S. Chen, J. Dudhia, L. Hart, J. Klemp, J. Middlecoff, and W. Skamarock, 2001: Developments in Teracomputing: Proceedings of the Ninth ECMWF Workshop on the Use of High Performance Computing in Meteorology. Eds, W. Zwieflhofer and N. Kreitz. World Scientific, Singapore. pp. 269-276.