12B.5 PREDICTABILITY AND DYNAMICS OF HURRICANE JOAQUIN (2015) EXPLORED THROUGH CONVECTION-PERMITTING ENSEMBLE SENSITIVITY EXPERIMENTS

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1. INTRODCTION AND METHODOLOGY

Hurricane Joaquin (2015) presents an unusual case in which current numerical weather prediction models and forecasters struggled to confidently and accurately forecast the track and intensity. The 72 to 120-h track errors were more than double the mean track errors over the previous 5 years (Berg 2016). The intensity forecasts for Joaquin were also poor. Official NHC intensity forecast errors between 72 and 96 h were ~70% larger than intensity errors over the previous 5 years (Berg 2016).

Output from the real-time Pennsylvania State University Weather Research and Forecast model coupled with an ensemble Kalman filter (PSU WRF-EnKF) for Joaquin is utilized for this study (Weng and Zhang 2016; Zhang and Weng 2015). The 60-member ensemble from 1200 UTC 29 September 2015 contained large ensemble track and intensity spread. The purpose of this study is to understand the reasons for the large track and intensity spread in the ensemble forecasts of Joaquin and identify potential regions of IC errors that contributed to the track bifurcation and large intensity spread.

2. RESULTS AND DISCUSSION

2.1. Examination of Real-time Ensembles

While the official forecast track and intensity errors of Hurricane Joaquin were larger than average, the PSU WRF-EnKF deterministic forecast from 1200 UTC 29 September correctly forecasted Joaquin turning out to sea and undergoing rapid intensification, despite the track forecast having errors in the initial motion and the intensity forecast having errors in the timing of rapid intensification (Fig. 1).

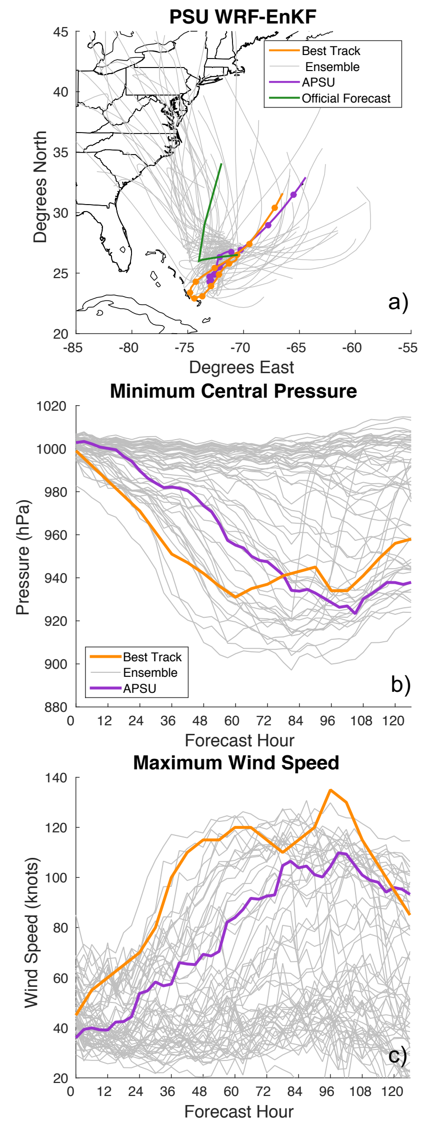

FIG. 1. Real-time PSU WRF-EnKF ensemble and deterministic 126 h (a) track, (b) minimum central pressure, and (c) maximum wind speed forecasts from 1200 UTC 29 September. Best track during this period is also shown and markers on deterministic track forecast and best track denote location every 12 h.

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While the deterministic forecast performed quite well, the associated ensemble members contained very large spread in the track and intensity. The ensemble track forecasts were nearly split with half of the members tracking Joaquin toward the U.S. East Coast and the rest away from the U.S. (Fig. 1a). The ensemble also produced large intensity spread with many members developing into major hurricanes and others not intensifying at all (Fig. 1b,c).

2.2. Explaining Joaquin's Large Track and Intensity Spread

The initial position spread in the real-time (CNTL) ensemble is ~60 km and increases to nearly 500 km by 84 h (Fig. 2a). The initial intensity spread of CNTL is ~5 hPa (~10 knots) and increases to ~35 hPa (~30 knots) by 84 h into the forecast and appears to asymptote at these values (Fig. 2b,c). To understand the regions of IC uncertainty impacting the forecasts, forecasts are run with IC differences in specific regions (within 300 km and outside 600 km of the initial vortex center) removed.

The relaxed-to-APSU-inner-core ICs ensemble (Rcore) is the only experiment whose track spread approaches that of CNTL (Fig. 2a). The 84-h position spread of Rcore is ~80% of that of CNTL. These results suggest that Joaquin's large track forecast spread likely occurs regardless of perturbations to the initial storm's inner core region. While the track divergence is still evident when the storm's initial inner-core perturbations are removed, the intensity spread is greatly reduced compared to CNTL (Figs. 2b,c). While the intensity spread has increased substantially by 84 h, the intensity spread is ~20% less than CNTL. Additionally, the intensity spread is roughly constant over the first 12 h. This result suggests that the IC differences in the environment can have a significant effect on the intensity forecast of Joaquin, but do not account for the full range of the intensity forecast spread within the first 84 h, consistent with Emanuel and Zhang (2016) who found that initial intensity errors dominate within the first 48 h but environmental IC difference errors dominate thereafter.

The relaxed-to-GFS-environment ICs (Renv), despite having the same initial position spread as CNTL, have 84-h position spread less than 30% of CNTL (Fig 2a). This result suggests that IC differences in the environment are necessary for the track divergence. While the IC differences in the storm's inner-core region does not significantly impact the track of Joaquin, the intensity spread of Renv almost exactly matches the spread of CNTL (Fig 2b,c), demonstrating that IC differences to the storm's inner core region alone were able to replicate the intensity spread of the CNTL ensemble.

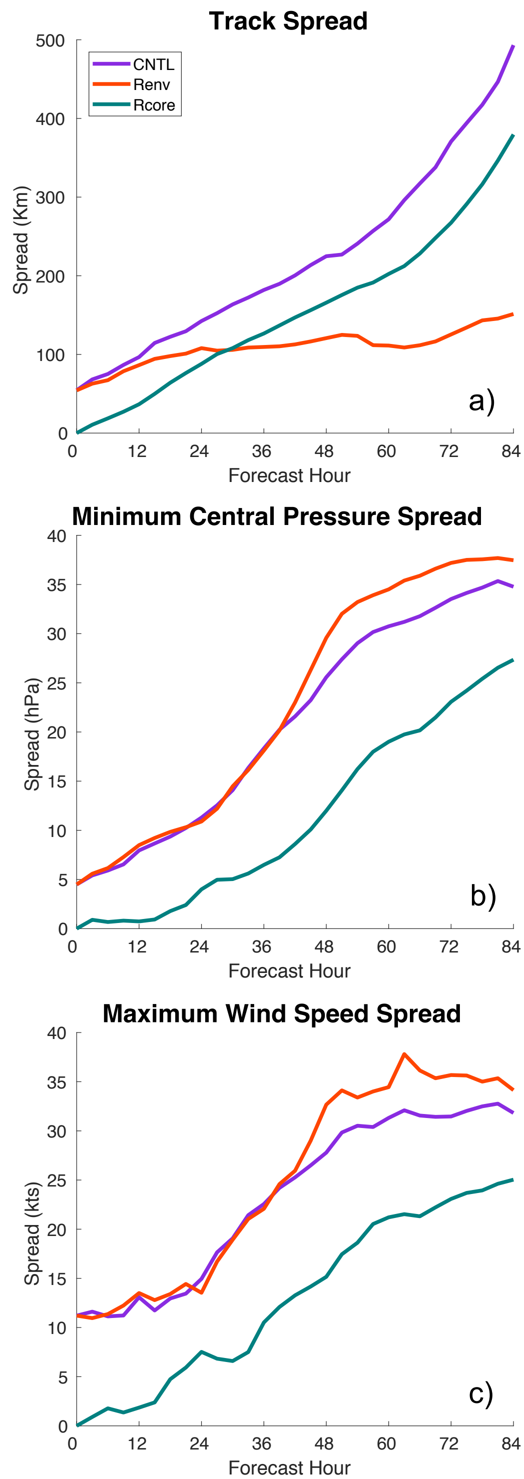

FIG. 2. Ensemble (a) track, (b) minimum central pressure, and (c) maximum wind speed spread comparison of CNTL, Renv, and Rcore ensembles.

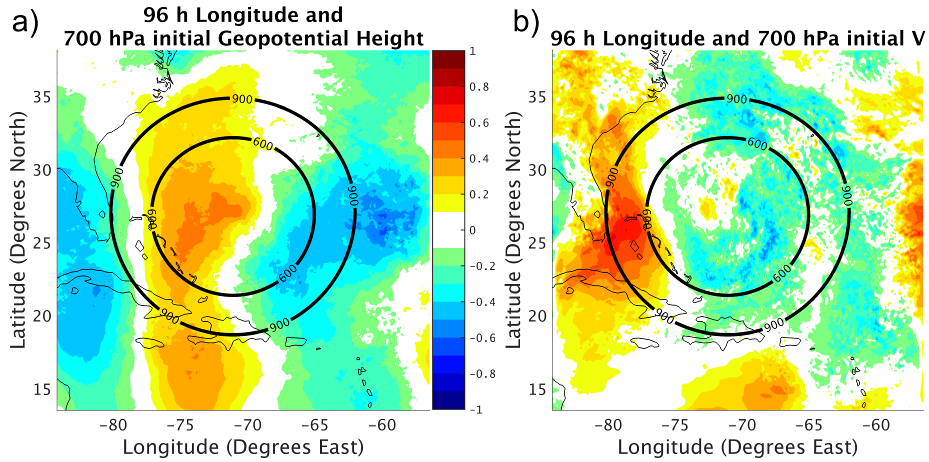

FIG. 3. Ensemble correlations of (a) initial 700 hPa geopotential height and (b) 700 hPa meridional wind component (V) with storm center longitude at 96 h.

The track uncertainty of Joaquin is shown to predominantly result from IC errors in the near storm environment, with ensemble members steered out to sea generally steered initially farther south and associated with higher 700 hPa geopotential heights and stronger positive meridional winds east of the initial position (Fig. 3).

The importance of IC differences between 600 and 900 km from the initial storm center in the track bifurcation is shown by gradually increasing the size of the vortex that is identical to APSU, from the mean IC of ensemble members that track out to sea (Fig. 4).

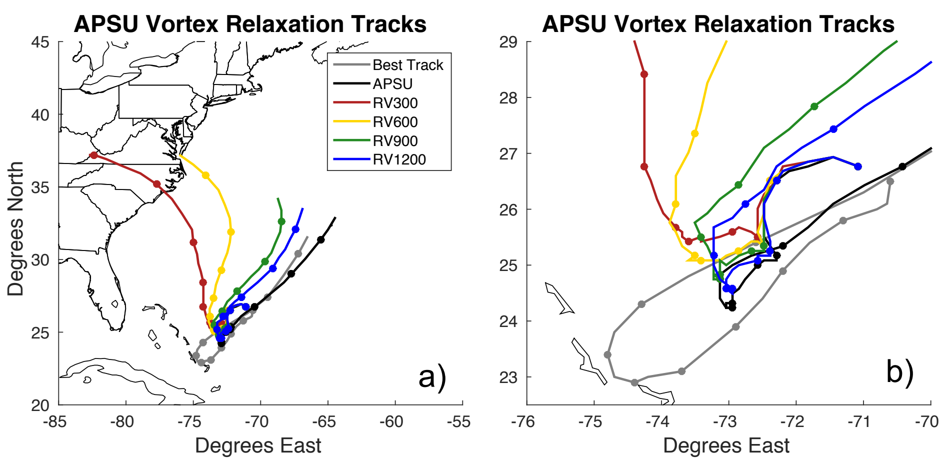

FIG. 4. Forecasts for APSU vortex relaxation experiments from LMIC for (a) track and (b) zoomed in view of track divergence.

3. SUMMARY AND CONCLUSIONS

While the PSU WRF-EnKF deterministic forecast for Hurricane Joaquin from 1200 UTC 29 September was somewhat successful, in terms of both track and intensity, the associated ensemble forecast revealed large uncertainty. Using a series of sensitivity experiments, we demonstrated that the early intensity spread was largely dominated by IC differences within 300 km from the vortex center. More specifically, the intensity spread was strongly controlled by initial intensity differences with the stronger initial members generally intensifying most.

Even if all IC error to the environment is removed (Renv), the intensity forecast spread is nearly identical to that when IC error exists everywhere (CNTL), demonstrating that without improvement to the ICs within the inner-core region this intensity forecast will not improve. These results strongly indicate the need for better observations and data assimilation methods to reduce inner-core IC uncertainty if we want to see significant intensity forecast improvements.

The track spread, was largely dominated by IC differences outside of 300 km from the vortex position, specifically between 600 and 900 km. The results of this study, and others (e.g. Majumdar et al. 2006; Harnish and Weissman 2010; Munsell and Zhang 2014; Torn et al. 2015), demonstrate that large ensemble track spread can result from IC differences to the near-storm environment and do not require differences in the ICs of midlatitude troughs, although they can also be important.

4. REFERENCES

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