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FORECASTING THE IMPACT OF TROPICAL CYCLONES USING GLOBAL NUMERICAL WEATHER PREDICTION ENSEMBLE FORECASTS: A TROPICAL CYCLONE MARCIA (2015) WIND AND RAINFALL CASE STUDY

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ABSTRACT

Wind hazard and rainfall models were coupled to estimate hourly open exposure maximum three-second gust wind speeds and rainfall totals for Tropical Cyclone (TC) Marcia (2015) using Bureau of Meteorology (BoM) best track data. Yeppoon The Esplanade automatic weather station (AWS) was used to perform a verification of the simulated hourly open exposure maximum three-second gust wind speed and rainfall totals with observed estimates. Preliminary verification results reveal that the wind hazard model overestimates the AWS hourly maximum three-second gust wind speed and the rainfall model underestimates the hourly total rainfall. Ensemble prediction system (EPS) forecasts from the European Centre for Medium-Range Forecasts (ECMWF) were examined to determine their utility in simulating TC Marcia's wind and rainfall fields and impacts. The ECMWF EPS fails to capture Marcia's rapid intensification at 72, 48, and 24 hours leading up to the landfall. A time-varying calibration factor is required at each forecast initialization in order to adjust each ensemble forecast member's minimum central pressure to a more realistic estimate of the minimum central pressure to properly simulate impacts to humans and the built environment.

INTRODUCTION

It is well recognized that tropical cyclones (TCs) pose a significant threat to life and property (Pielke and Landsea 1998). There is a continuing need to examine the uncertainty in the location and intensity of landfalling TCs to aid emergency services managers in the decision-making process. In this study, both wind hazard and rainfall models are coupled to simulate hourly maximum three-second gust wind speeds and rainfall totals during the landfall of TC Marcia (2015). Preliminary validation of the simulated gust wind speed and rainfall fields is conducted using Yeppoon The Esplanade automatic weather station (AWS) observations. Once the wind and rainfall models are verified against landfall observations, they are coupled with the European Centre for Medium-Range Forecasts(ECMWF) ensemble prediction system (EPS) forecasts so the variability in forecast hourly open exposure maximum three-second gust wind speed, rainfall and impacts to residential structures and humans can be assessed with respect to forecast time.

DATA AND METHODS

Using best track data from the Bureau of Meteorology (BoM) and empirical relationships developed by Harper and Holland (1999) and Powell et al. (2005) to estimate the Holland B parameter and radius of maximum wind (RMW, when necessary), respectively, a wind hazard model was used to generate Marcia's hourly open exposure near-surface (i.e. 10m) maximum three-second gust wind fields. To obtain these wind fields, first the gradient wind profile was estimated using the model described in Holland (1980). Then, a linear analytic tropical cyclone boundary layer (TCBL) model developed by Kepert (2001) was employed to adjust wind speeds at storm radii ≤ 400 km (Lin and Chavas 2012) to 10 m. Finally, the simulated near-surface wind field was adjusted for surface terrain conditions and averaging time using a gust factor approach. An example of an hourly open exposure near-surface maximum three-second gust wind field for TC Marcia two hours prior to landfall can be seen in Figure 1.

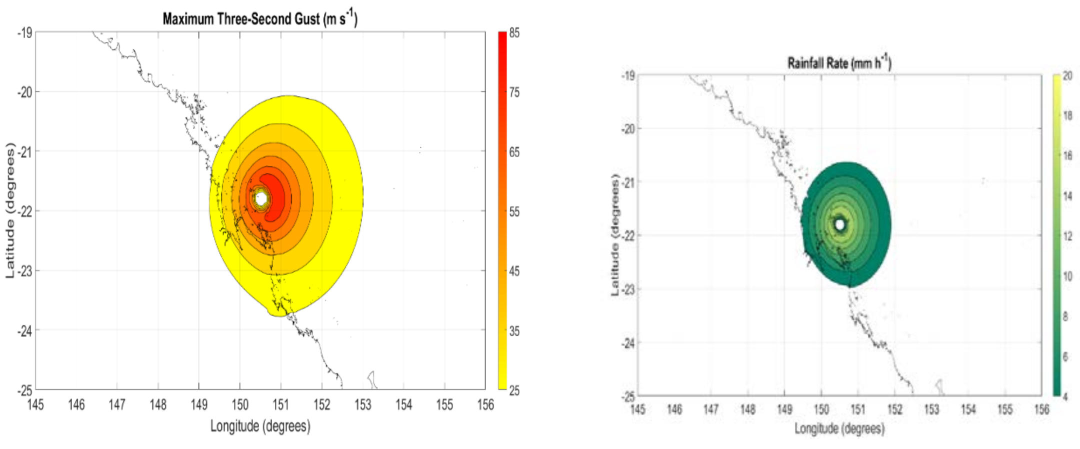
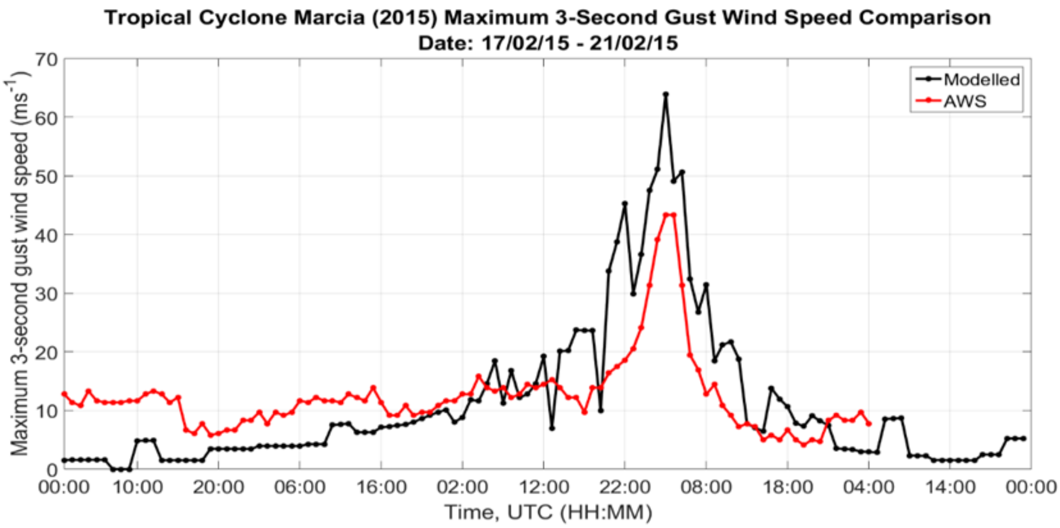


FIGURE. 1. TC MARCIA SIMULATED HOURLY MAXIMUM THREE-SECOND GUST WIND FIELD (LEFT) AND RAINFALL RATE (RIGHT) FIELDS GENERATED AT APPROXIMATELY TWO HOURS BEFORE LANDFALL (19 FEBRUARY 2015 AT 20:00 UTC).

To generate the rainfall rate fields, empirical relationships developed by Tuleya et al. (2007) using a modified (R-CLIPER) model were employed. The model only requires information regarding the maximum near-surface wind speed (i.e. hourly open exposure maximum three-second gust wind speed) and how it varies with respect to storm radius as an input. One caveat to the rainfall model is that the fitting coefficients were calibrated based on US terrain and storms. Future work will involve calibrating these model coefficients for terrain conditions in Australia. An example of rainfall rate field of TC Marcia two hours prior to landfall can also be seen in Figure 1. Using both the wind and rainfall fields, direct comparisons were made with available BoM automatic weather station (AWS) in situ wind and rainfall measurements (Figure 2). The reference AWS selected for comparison with the simulated maximum three-second gust wind speeds and hourly rainfall totals was Yeppoon The Esplanade AWS. Based on the preliminary comparisons shown in Figure 2, the wind hazard model overestimates the hourly open exposure 10 m maximum three-second gust wind speed during the landfall phase and slightly underestimates the inner core rainfall. Furthermore, the rainfall model completely missed the sharp peak in rainfall prior to landfall. This is believed to be a result of the symmetric rainfall model's inability to model rainband rainfall and is an acknowledged limitation of the model.



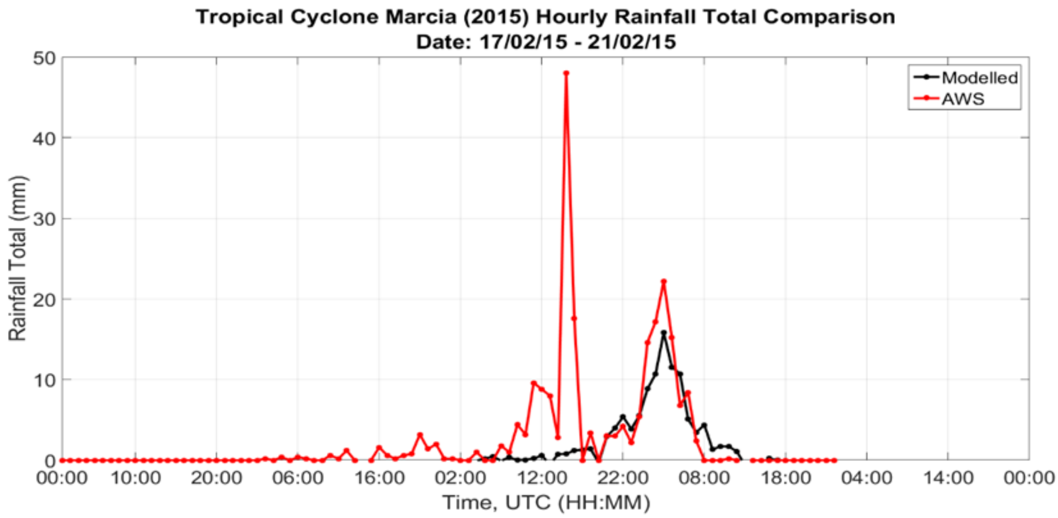


FIG. 2. COMPARISON OF SIMULATED (BLACK) VERSUS OBSERVED (RED) HOURLY MAXIMUM THREE-SECOND GUST WIND SPEEDS (TOP) AND RAINFALL TOTALS (BOTTOM) AT THE YEPPOON THE ESPLANADE AWS.

CASE STUDY: TROPICAL CYCLONE MARCIA (2015)

In an effort to re-create Marcia's landfall hourly open exposure 10 m maximum three-second gust wind field and simulate a range of possible impacts, the wind hazard model described in Section 2 was run with ECMWF EPS latitude, longitude, and minimum central pressure forecast output from each ensemble member at 72-, 48-, and 24-hr leading up to landfall (Figure 3).

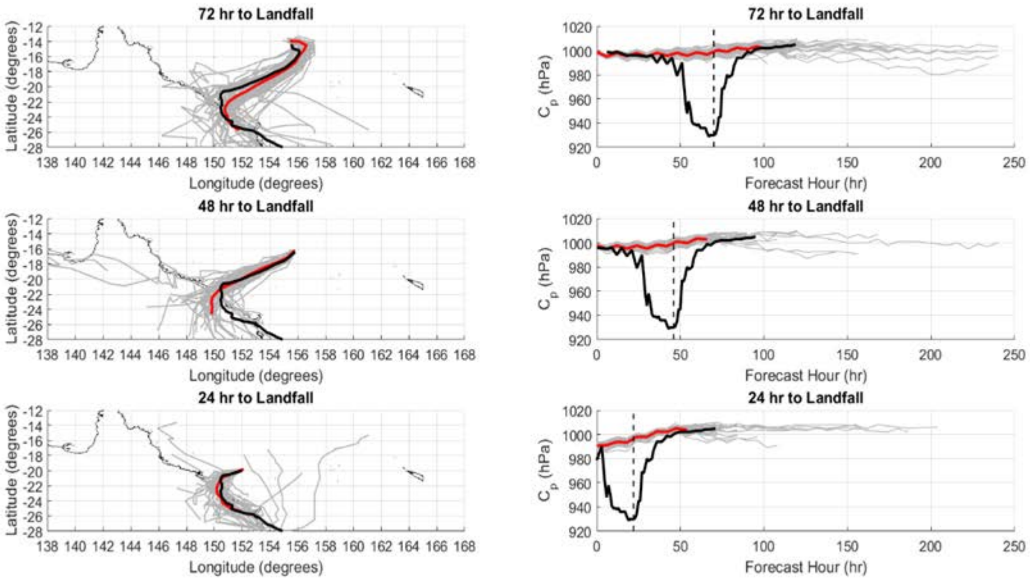


FIG. 3. ECMWF EPS FORECAST MEMBER (GRAY LINES) AND ENSEMBLE MEAN (RED LINE) TRACK AND MINIMUM CENTRAL PRESSURE FORECASTS 72-, 48-, AND 24-HR LEADING UP TO THE LANDFALL OF TC MARCIA. THE BLACK LINE REPRESENTS THE BOM BEST TRACK POSITION AND MINIMUM CENTRAL PRESSURE.

The same empirical relationships that were used to estimate the Holland B parameter and RMW for the verification analysis in Section 2 were used again here to generate ECMWF EPS estimates of the Holland B parameter and RMW. At 72-hr leading up to landfall, the ECMWF ensemble mean landfall location lies east of the BoM best track landfall position and the rapid intensification is completely missed by the EPS. In fact, at each forecast hour, the rapid drop in pressure is never resolved in the ECMWF EPS. As for the position at 48-hr and 24-hr leading up to landfall, the ECMWF ensemble mean track forecast shifts west of the BoM best track but lies within 50–100 km of the actual landfall location. As the forecast landfall time decreases, the spread in ensemble guidance narrows, indicating a higher degree of confidence in the EPS forecast of the mean position of Marcia with decreasing forecast time. Given that the ECMWF EPS does not fully capture the rapid intensification phase of Marcia, it was difficult to realistically simulate TC Marcia's wind and rainfall fields, as well as, wind-related damage to residential structures or the total number of people displaced from their homes, as initially planned.

CONCLUSIONS AND FUTURE WORK

A wind and rainfall hazard model was coupled with BoM best track data to reproduce the hourly maximum three-second gust wind speed and rainfall fields during the landfall of TC Marcia. Simulated hourly gust wind speeds and rainfall totals were verified against observations collected at the Yeppoon The Esplande AWS prior to and during landfall. Preliminary comparisons between the simulated and observed hourly gust wind speed and rainfall measurements suggest that the wind hazard model underestimates TC Marcia's peak landfall intensity and slightly underestimates the inner core rainfall. Outer rainband rainfall totals were grossly underestimated by the model, as expected, given the rainfall model cannot properly model rainband features.

ECMWF EPS forecasts were retrieved and both storm position and intensity (i.e. minimum central pressure) information was extracted to simulate the hourly maximum three-second gust wind speed and rainfall fields for all ensemble members. Based on a general assessment of the ECMWF EPS forecasts, ensemble mean, and BoM best track for position and intensity at 72-, 48-, and 24-hr leading up to the landfall, the model track envelope spread narrows with decreasing forecast time as expected and the ensemble mean position gets closer to the actual landfall location. However, the ECMWF EPS fails at every forecast hour to accurately capture and forecast the rapid intensification of TC Marcia prior to landfall, resulting in an inability to properly simulate impacts to the built environment and humans.

Future work will consist of further calibration of both the wind hazard and rainfall models using more storms (e.g. TCs Larry 2006, Yasi 2011, Ita 2014, and Nathan 2015). Once these models are fine-tuned, more EPS forecast output from the TIGGE archive and BoM will be retrieved to further assess how well other EPSs perform relative to the ECMWF EPS for TC Marcia and the above-mentioned historical landfall events.

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