The Influence of Tropical Cyclone Size on Its Intensification

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ABSTRACT

This study investigates tropical cyclones of the past two decades (1990–2010) and the connection, if any, between their size and their ability to subsequently undergo rapid intensification (RI). Three different parameters are chosen to define the size of a tropical cyclone: radius of maximum wind (RMW), the average 34-knot (kt; $1\ \mathrm{kt} = 0.51\ \mathrm{m\,s^{-1}}$) radius (AR34), and the radius of the outermost closed isobar (ROCI). The data for this study, coming from the North Atlantic hurricane database second generation (HURDAT2), as well as the extended best-track dataset, are organized into 24-h intervals of either RI or slow intensification/constant intensity periods (non-RI periods). Each interval includes the intensity (maximum sustained surface wind speed), RMW, AR34, and ROCI at the beginning of the period and the change of intensity during the subsequent 24-h period. Results indicate that the ability to undergo RI shows significant sensitivity to initial size. Comparisons between RI and non-RI cyclones confirm that tropical cyclones that undergo RI are more likely to be smaller initially than those that do not. Analyses show that the RMW and AR34 have the strongest negative correlation with the change of intensity. Scatterplots imply there is a general maximum size threshold for RMW and AR34, above which RI is extremely rare. In contrast, the overall size of the tropical cyclones, as measured by ROCI, appears to have little to no relationship with subsequent intensification. The results of this work suggest that intensity forecasts and RI predictions in particular may be aided by the use of the initial size as measured by RMW and AR34.

1. Introduction

The analysis and prediction of tropical cyclones in the Atlantic basin (including the North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea) have evolved significantly over the last few decades (Sheets 1990; Rappaport et al. 2009). Track predictions issued by the National Hurricane Center (NHC) have improved dramatically due to more accurate numerical models and more satellite-based, open-ocean observations. However, in recent years, making improvements to operational tropical cyclone intensity (maximum 1-min, 10-m wind) forecasting have proved to be much more challenging (Gall et al. 2013). The operational prediction of rapid intensification [RI; defined as 30 kt[1] or greater intensity gain over 24 h; Kaplan and DeMaria (2003)] continues to be identified by NHC as their number one priority for improvement (Rappaport et al. 2012).

RI has proved difficult to forecast because of a general lack of understanding of the physical mechanisms that are responsible for these rare events. Previous work has associated the ability of a tropical cyclone to undergo RI with the following: low tropospheric vertical wind shear, a very warm ocean with a deep mixed layer, a moist

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[1] Knots (kt; $1\ \mathrm{kt} = 0.51\ \mathrm{m\,s^{-1}}$) will be the metric of wind speed for the remainder of the paper, as this is what is used for both the tropical cyclone forecasting and database.

troposphere, and inner-core processes (such as concentric eyewall cycles and vortex Rossby waves) (Kaplan et al. 2010). However, little research has been done on whether the size of a tropical cyclone plays a role in its subsequent intensity change. The idea that the initial size of a tropical cyclone can help dictate intensification to follow is a concept that is applied qualitatively by some hurricane forecasters: "Strengthening is forecast [for Tropical Storm Leslie] to begin around the time the shear relaxes, but the rate of intensification could initially be slow due to the large size of the circulation" (T. Kimberlain, NHC Tropical Cyclone Discussion, Tropical Storm Leslie, 0300 UTC 4 September 2012, personal communication). If indeed there exists a robust connection, such knowledge should be better quantified and used objectively to help forecasters better predict RI. Therefore, this study analyzes the sizes of tropical cyclones that underwent RI versus those that are steady state or slowly intensifying over a 24-h period from Atlantic basin tropical cyclones during 1990–2010. The goal of this study is to investigate if there is an association between a tropical cyclone's size and its subsequent intensification.

2. Previous research on size and subsequent intensity change

The effect of tropical cyclone size on subsequent intensity change has been the subject of a few investigations. From a theoretical perspective, Emanuel (1989), building off of the results from Rotunno and Emanuel (1987), concluded that the initial size of the vortex, as measured by the radius of maximum wind (RMW), played a substantial role in its subsequent intensification rate. If the initial vortex was too large, then no subsequent intensification occurred. But as the initial RMW was progressively reduced in size in the model, the intensification rate increased significantly with the smallest vortex having the fastest intensification. It is of note that the small- to medium-sized vortices in his study all eventually reached the same peak intensity, even though their rates of intensification differed.

There have been additional papers published on the topic from an observational perspective. DeMaria and Kaplan (1994) developed a statistical model—the Statistical Hurricane Intensity Prediction Scheme (SHIPS)—for predicting intensity changes of Atlantic tropical cyclones at 12, 24, 36, 48, and 72 h. This model used a standard multiple regression technique with climatological, persistence, and synoptic predictors, including one based upon the outer circulation strength (850-mb relative angular momentum measured between 400- and 800-km radii from the center). Their results showed a weak positive association between outer circulation strength and intensification that was statistically significant at 12-, 24-, and 36-h lead times. However, somewhat contradictory to that, DeMaria and Kaplan (1994) also uncovered that the tropical cyclones that most rapidly intensified over a 48-h period tended to have smaller than average outer circulation strength. They ascribed this behavior to the tendency for the outer circulation of tropical cyclones to spin up later in the life cycle, generally after peak intensity has taken place. This finding is consistent with both observational climatological studies in the Atlantic (Merrill 1984) and idealized modeling work (Ooyama 1969). Subsequent SHIPS updates (DeMaria and Kaplan 1999; DeMaria et al. 2005) still employ an outer circulation metric, though this now is represented by the 0–1000-km radii, 850-mb relative vorticity. This large-scale vorticity has a moderately skillful, positive association with intensity change in their 12–120-h prediction scheme. It is noted, however, that DeMaria et al. (2005) consider this metric to be more indicative of the synoptic environment around the tropical cyclone, rather than a direct measure of the storm's size itself.

The rapid intensification index (RII) scheme (Kaplan and DeMaria 2003), a method for probabilistically predicting RI, was tested to see whether 0–1000-km, 850-mb relative vorticity aided these predictions. However, this particular metric was not a skillful predictor of RI and thus was not included within the model, nor is it included in the most recent version of RII (Kaplan et al. 2010).

Kimball and Mulekar (2004) established a climatology of multiple tropical cyclone size parameters for the North Atlantic basin with data from 1988 through 2002. They showed that the RMW decreases from an average of about 55 n mi (1 n mi = 1.852 km) for tropical storms, 40 n mi for category 3 storms, and 30 n mi for category 5 hurricanes. In contrast, the average radii of 34-, 50-, and 64-kt winds, as well as the radius of the outermost closed isobar (ROCI), increase in size with increasing intensity. Kimball and Mulekar (2004) also stratified their dataset by intensifying, steady-state, and weakening tropical cyclones over the next 6 h. This showed a tendency for the radii of 34-, 50-, and 64-kt winds to be smaller in size for intensifiers compared to weakeners, while the RMW and ROCI showed no significant differences.

Chen et al. (2011) compared the 24-h intensification for western North Pacific typhoons that were compact versus those that were incompact. Their "compactness" size parameter is based upon both the RMW and tangential winds at a radius of twice the RMW compared with climatological values. They found that compact tropical cyclones (either small RMW, weak winds at twice the RMW radius, or both) had a substantially higher rate of intensification and more frequent RI relative to incompact systems.

One limitation to these studies is that any possible effects of inner- and outer-core size parameters upon subsequent intensification may be made ambiguous because of the general life cycle tendency for tropical cyclones to reach their largest sizes after their peak intensity is attained (e.g., Ooyama 1969; Merrill 1984; DeMaria and Kaplan 1994). Therefore, this paper will restrict its analysis to only those cyclones that are steady state or intensify in the subsequent 24-h period. It is hoped that this may eliminate, or at least substantially reduce, the impact of the climatological life cycle tendencies upon any relationship between tropical cyclone size and intensification. In doing so, we will also restrict the cases to when the environment would be conducive or at least neutral for intensification, which may allow for a cleaner interpretation of the results obtained.

3. Methodology

a. Data source: HURDAT versus extended best track

The National Hurricane Center (NHC) maintains and annually updates a database of all known Atlantic tropical cyclones since 1851, known as the North Atlantic hurricane database second generation (HURDAT2). This database contains estimates of the latitude; longitude; 1-min maximum sustained surface winds; central pressure; maximum radial extent by quadrant of 34-, 50-, and 64-kt winds; and information regarding whether the cyclone was tropical, subtropical, or extratropical at 6-hourly intervals for each cyclone, as well as asynoptic time information for landfall and peak intensity (Landsea and Franklin 2013).

To supplement this, Demuth et al. (2006) developed an "extended best track" (EBT) dataset with additional operationally estimated parameters like RMW; eye diameter (when available); and pressure and ROCI; as well as the 34-, 50-, and 64-kt wind radii. Similar to HURDAT2, the data in the EBT dataset are arranged in 6-hourly intervals (0000, 0600, 1200, and 1800 UTC) for every cyclone going back to 1988. It should be noted that the radius of maximum wind, eye diameter, pressure, and radius of the outer closed isobar are not "best tracked" (poststorm quality controlled). However, starting in 2004, NHC began to provide poststorm analyses of the 34-, 50-, and 64 kt wind radii (which is why these are included in HURDAT2 beginning in that year). The years between 1990 and 2010 are analyzed for this study, providing just over two decades worth of hurricane seasons. This study considered only utilizing data from 2004 onward, when best-track 34-, 50-, and 64-kt wind radii were available. However, this would significantly reduce the sample size. So while the inclusion of non-best-tracked wind radii from 1990 to 2003 provides data that are noisier and not likely as accurate as the seasons to follow, having a sample size that is over twice as large outweighs these concerns. For RMW, which is an operationally estimated parameter throughout the time period, it is likely that the value is more uncertain farther back in time. While RMW can be directly measured by aircraft reconnaissance, such missions are only available about 30% of the time. Thus, one has to rely upon satellite imagery and data to obtain most RMW estimates. Microwave imagery from polar-orbiting satellites (Hawkins and Velden 2011) can help determine the RMW for high-end tropical storms and minor hurricanes because of their ability to visualize the inner-core convective structure. Additionally, for larger-sized tropical storms and minor hurricanes, Quick Scatterometer (QuikSCAT) and Advanced Scatterometer (ASCAT) data (Brennan et al. 2009) have the ability to directly provide RMW observations. Both the microwave imagery and the scatterometer data were routinely used in NHC operations by the early 2000s, but were unavailable at the start of the extended best-track dataset in 1988. We choose to have the advantage of a larger sample size with the understanding that there are increased uncertainties with this parameter (RMW) as one goes farther back in time. Given that this study focuses on the size of tropical cyclones and their comparison between rapidly and nonrapidly intensifying cyclones, both HURDAT2 and the EBT dataset are the main data sources used in this study.

b. Rapid intensification

Rapid intensification (RI) of a tropical cyclone can be measured by the deepening of the tropical cyclone's pressure or by the increase of the maximum sustained winds over certain period of time, usually over a 24-h period. In Kaplan and DeMaria (2003), RI was defined as the 95th percentile of the 24-h intensity change, at least 30 kt, of all the tropical cyclone cases used in their study. There were a total of 296 RI cases when using this threshold [$\geq 30\,\mathrm{kt}\,(24\,\mathrm{h})^{-1}$] for the period of 1990–2010. (It is noted that such a definition of RI will preclude shorter-period large intensification events, which can be of significant importance as well. The choice of the period for calculating RI is recognized to be somewhat arbitrary).

c. Size parameters

Three measures of tropical cyclone size are analyzed here: RMW, the average radius of the maximum extent of 34-kt winds (AR34), and ROCI. The radii of 50 and 64 kt are not used because this study wishes to include all tropical storms, in which the maximum sustained winds range from 34 to 63 kt. The radius of the eye is also not being used because that describes the size of the inner core of hurricanes primarily and is thus not available in most cases.

The RMW is defined as the distance from the center of a tropical cyclone to the location of the cyclone's maximum winds (azimuthally averaged) in the EBT dataset, typically to the nearest 5 n mi. Again, the RMW values in the EBT dataset are operational estimates and are not best tracked. The maximum extent radius of the 34-kt winds is provided in all four quadrants every 6 h for each cyclone to the nearest 5 n mi in the EBT database and HURDAT2. The four quadrants are averaged in order to have one representative symmetric value like the other two parameters. If one or more of the quadrants has 0 as its value, it is not included in the average. For example, if the values are 50, 30, 0, and 50 n mi (northeast, southeast, northwest, and southwest, respectively), then the AR34 would be 43 instead of 33 n mi.

The ROCI values in the EBT dataset are expressed to the nearest 5 n mi. Occasionally (a few percent of the time), ROCI data are missing from some tropical cyclones for a few time periods. To fill in most of the missing data, the ROCI is calculated using the Unified Surface Analysis maps from the Tropical Analysis & Forecast Branch (TAFB) at NHC (Rappaport et al. 2009). These synoptic maps are created every 6 h and depict important surface features including areas of high and low pressure, frontal systems, troughs, tropical cyclones, African easterly waves, the intertropical convergence zone, and the monsoon trough. The analyses also depict the sea level pressure isobars, usually in increments of 4 hPa. The ROCI is defined as the average of the distances to the north, east, south, and west from the cyclone center to the closed isobar having the highest value (Merrill 1984). Several sample cases of ROCI derived from the Unified Surface Analysis maps were compared versus available ROCI in the EBT database to confirm that this provides a reasonable analysis.

Figures 1a–c show the size distribution for each size parameter (RMW, AR34, and ROCI) for all nonweakening cases (RI and non-RI) during 1990–2010. For example, in Fig. 1a, 35% of all 1312 periods of 24 h have an RMW of 30 n mi. The reason that there are certain peaks in the RMW figure, such as the very distinct maxima at 30 n mi and lesser ones at 20, 40, 50, and 60 n mi for instance, is because all these parameters are operational estimates and the forecasters are rounding to the nearest ½° latitude (30 n mi) and secondarily to the nearest 10 n mi most of the time. The AR34, in contrast, shows in Fig. 1b a much less noisy distribution, likely because of the averaging of quadrants as well as the best tracking employed from 2004 through 2010. The ROCI, like the RMW, also shows an irregular distribution; this is due to forecasters rounding to the nearest 1° or ½° latitude when estimating the ROCI. When the storms are very large in extent, they tend to round to the nearest 50 n mi. Because of this, there are peaks at 120 (2° latitude), 150 (2½° latitude), 180 (3° latitude), 200, 250, and 300 n mi.

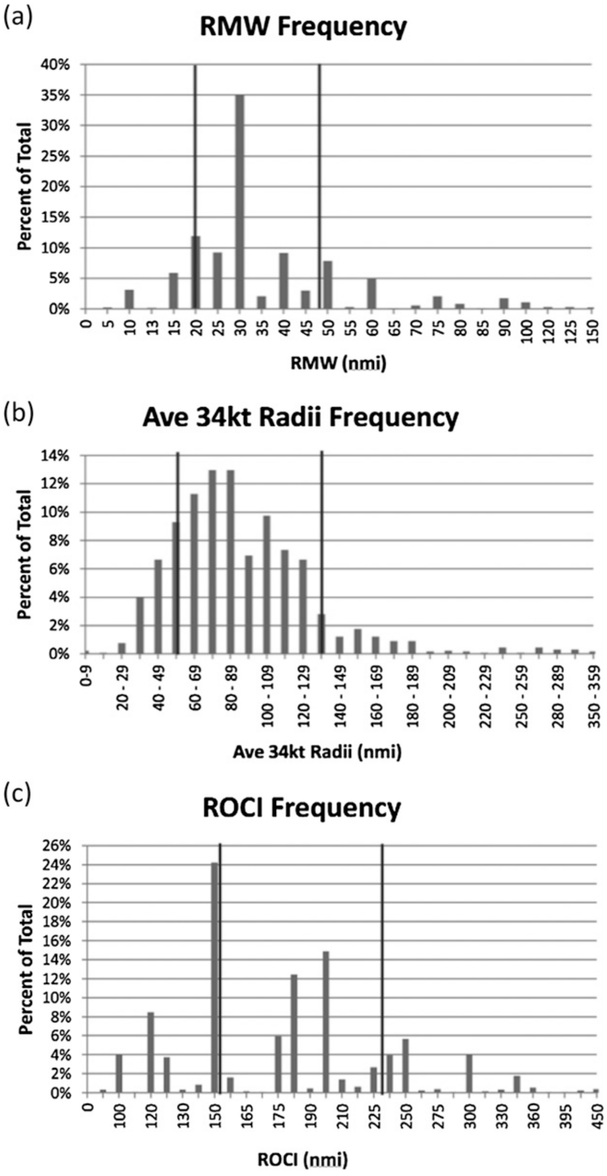

FIG. 1. Size distribution for all nonweakening cases (RI and non-RI) during 1990–2010 of (a) RMW, (b) AR34, and (c) ROCI. Thin lines separate the small, medium, and large boundaries. Note that only nonzero sample size values are plotted along the *x* axis.

To see how independent the three measures of size are, the correlations between the three sizes were calculated. The correlations of AR34–RMW and AR34–ROCI are 0.18 and 0.433, respectively. The correlation of ROCI–RMW is −0.01. Thus, the inner- (RMW) and outer-core (ROCI) size parameters have no association, while the parameter in between (AR34) shares some variability with both.

d. *Data organization*

The analysis was conducted with the nonweakening (both RI and non-RI) 24-h periods for the years 1990–2010. All weakening (at least 5 kt over the subsequent 24-h period) cases are removed. This is done to stratify the dataset by removing systems that, for example, are moving to higher latitudes with strong intensities and small sizes that are likely to subsequently weaken and enlarge (Merrill 1984). Thus, such a preselection may better help determine, given that conditions are either conducive or neutral for intensification, whether initial size plays a role in the rate of intensification or propensity for RI. For the cyclones containing RI periods, only the duration of the cyclone that was within the RI period was retained as an RI case. Some cyclones had intensification periods that lasted more than 24 h. For example, Hurricane Andrew rapidly intensified for 54 h from 1200 UTC 21 August to 1800 UTC 23 August. In these cases, 24 h were counted starting from each 6-h interval that was inside the intensification period and every 24-h period was considered a separate RI period. Therefore, Hurricane Andrew has six RI periods: first (1200 UTC 21 August–1200 UTC 22 August), second (1800 UTC 21 August–1800 UTC 22 August), etc., to sixth (1800 UTC 22 August–1800 UTC 23 August). For the cyclones that did not have any RI periods (non-RI cases), the only 24-h periods included were the ones in which the intensity either increased slowly or remained the same. Hence, any decrease of intensity over a 24-h period was not included within this study.

All extratropical, subtropical, and tropical depression stages were removed from both the RI and non-RI cases. On rare occasions, an RI period began during the tropical depression stage. But the initial AR34 would be zero because by definition, as tropical depressions have maximum sustained wind speeds of 30 kt or less in HURDAT2. For this reason, any cyclone with an intensity 30 kt or less at the initial time was removed (it is recognized that this restriction will on occasion eliminate cases of RI that occur with a very weak initial intensity, such as Hurricane Humberto in 2007, which intensified from a 25-kt low to an 80-kt hurricane in 24 h). Other RI cases were also deleted because of a lack of data (expressed as a −99 in the EBT database) at the beginning of the RI periods.

Tropical cyclones that made landfall within 24 h of the initial point being considered were also removed. However, if the tropical cyclone made landfall and then continued its course eventually going over water again, it was included in the analysis if it survived without weakening for at least another 24 h over water. Several tropical cyclones were found to survive without weakening after making landfall and subsequently going over water again, and all such cases were included.

TABLE 1. Size climatology based on each size parameter.

Size parameter	TC size category	Size (n mi)
RMW	Small	≤20
	Medium	20 < medium < 48
	Large	≥48
AR34	Small	≤59
	Medium	59 < medium < 135
	Large	≥135
ROCI	Small	≤151
	Medium	151 < medium < 235
	Large	≥235

After these considerations, out of the 280 tropical cyclones of tropical storm intensity or greater that occurred from 1990 to 2010, a total of 205 tropical cyclones were used in this study (120 non-RI and 85 RI). The 24-h dataset contains 1312 periods of 24 h: 1016 non-RI cases and 296 RI cases. The sample sizes as presented do not represent independent RI events, because of allowing for overlapping non-RI and RI periods to be counted. Approximately 18% of the 85 tropical cyclones had a single RI period (exactly 24 h in duration), 19% had two overlapping RI periods, 18% had three overlapping RI periods, 20% had four overlapping RI periods, and 25% had five or more overlapping RI periods. For the statistical significance tests to follow, the significance levels are performed by conservatively assuming that each TC is one sample, even if it is included in the database multiple times. Such a conservative approach in counting the sample size is used for both the non-RI and RI cases.

e. *Size climatology*

To accurately assess the different sizes of the tropical cyclones being used, a size climatology is calculated from the 1990 to 2010 seasons. The data used in the size classification contain the entire duration that these systems were tropical cyclones. The data consists of 5132, 5264, and 5239 6-hourly intervals of RMW, AR34, and ROCI, respectively. For each size parameter (RMW, AR34, and ROCI) the small and large sizes are categorized using the 25th and 75th percentile of the size distribution as shown in Table 1. It is of note that these size distributions are similar to those arrived at by Merrill (1984) and Kimball and Mulekar (2004).

4. Analysis and results

a. *Size comparison for RI versus non-RI*

An average of the RMW, AR34, and ROCI was compared for the RI and non-RI cases (Figs. 2a–c). The

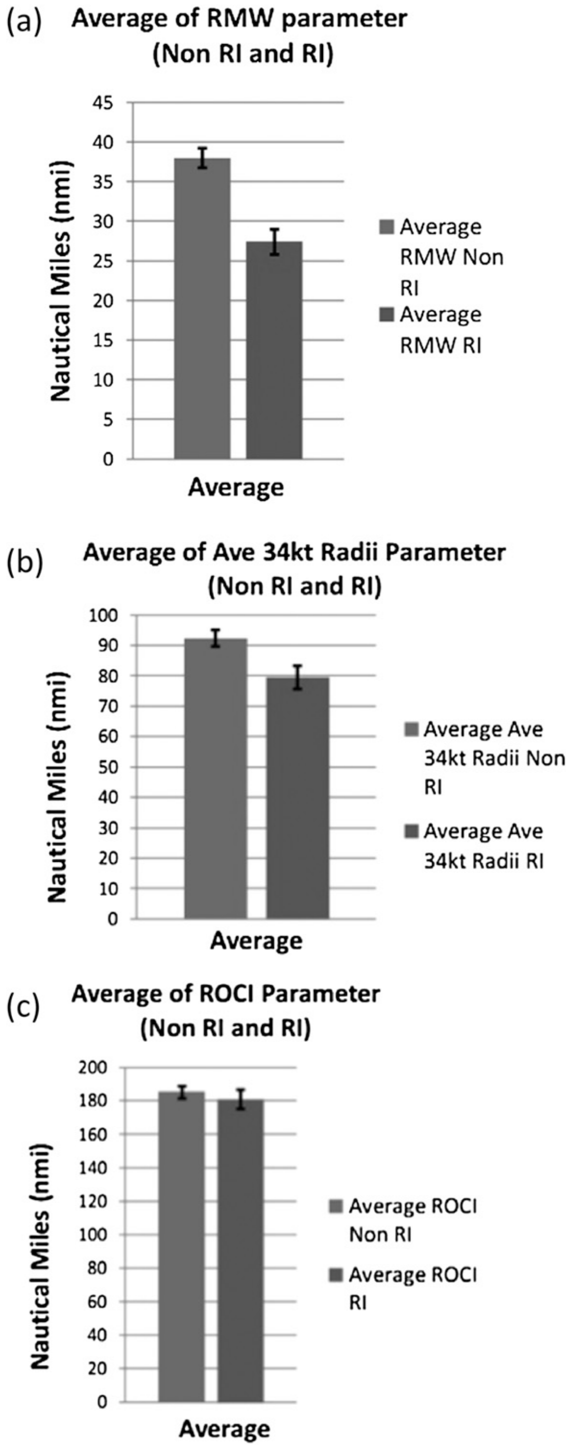

FIG. 2. Average sizes for RI and non-RI stratification of (a) RMW, (b) AR34, and (c) ROCI. The 95% confidence intervals are shown.

non-RI cyclones have a tendency to be larger than the RI cyclones. The comparison between the RMW (Fig. 2a) RI cases (27 n mi) and the RMW non-RI cases (38 n mi) results in a Student's t test P value of <0.01. A similar statistical significance (0.02) is seen with the AR34 (Fig. 2b; 79 n mi for RI and 92 n mi for non-RI). However, Fig. 2c shows that there is only a slight difference of about 2 n mi between the RI and non-RI cases for the ROCI parameter, which is not statistically significant.

b. *Size parameters versus change of intensity*

Using the climatology that was developed, each size parameter was divided into small, medium, and large sizes for all cases (RI and non-RI) in Table 1. Scatterplots were created for the overall distribution of each individual size of every parameter (RMW, AR34, and ROCI) and the 24-h subsequent change of intensity (Figs. 3a–c). These plots contain all nonweakening cases (all 1312 periods of 24 h) and the vertical lines show the boundaries of small, medium, and large sizes for each size parameter. It is evident that the greatest change of intensity can occur within the smaller cyclones when using RMW as a size parameter (Fig. 3a). This figure shows that there is a negative correlation between the RMW and subsequent change of intensity. This negative correlation of -0.23 (significant beyond 0.01) suggests that as the RMW increases, the subsequent intensity increase diminishes for these cases within neutral to conducive environmental conditions. As most of the data points reside in the small and medium categories for the case of RI, this also gives the impression that there is a general size threshold for RI. It can be seen that once the RMW is larger than about 50 n mi, it is very unlikely for a tropical cyclone to undergo RI. Figure 3b illustrates a somewhat weaker negative correlation (-0.13, significant at 0.07) between the change of intensity and the average 34-kt radius. Similar to Fig. 3a, Fig. 3b also illustrates that the majority of the RI data points are located within the small- and medium-size categories, suggesting that it is difficult but not impossible for RI to occur after reaching 140 n mi for AR34. Conversely, Fig. 3c shows basically no connection between the change of intensity and the ROCI size parameter. All RI data points are much more scattered than those in Figs. 3a and 3b and are nearly equally distributed across the small, medium, and large bins.

c. *Frequency and distribution of size parameters in RI cases*

Finally, Figs. 4a–c display the probability of RI for each size stratification (small, medium, and large) for the RMW, AR34, and ROCI parameters. Figure 4a illustrates that in the past two decades, a small nonweakening tropical cyclone is 4–5 times more likely to go through RI than a large, nonweakening tropical cyclone, when using the RMW parameter. Figure 4b shows that when using AR34, it is 3 times more likely for a small tropical cyclone to have an RI period than a large tropical cyclone.

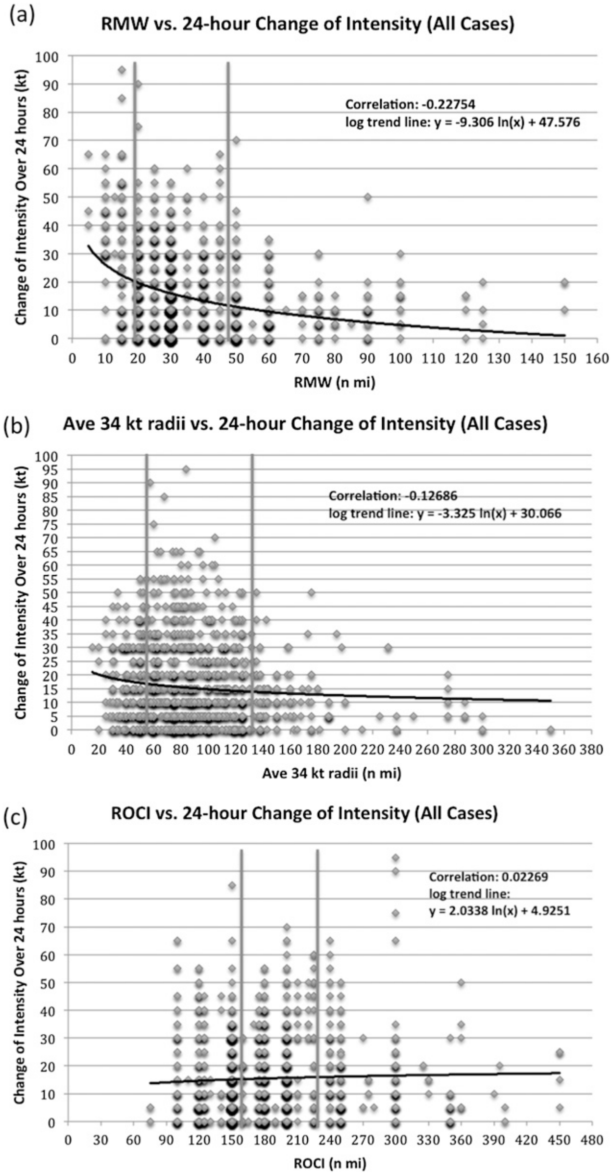

FIG. 3. Changes in intensity over 24 h of all cases for (a) RMW, (b) AR34, and (c) ROCI. The two vertical lines separate the small, medium, and large boundaries. The horizontal lines represent the logarithmic trend line.

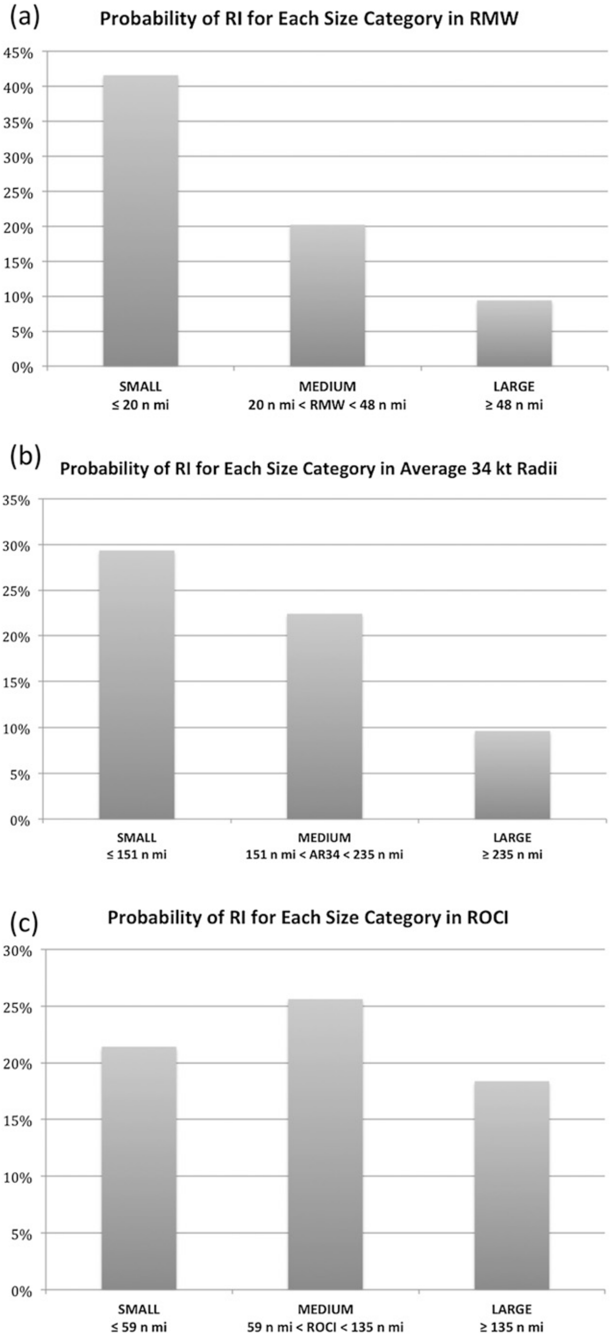

FIG. 4. Probabilities of RI for each size stratification for (a) RMW, (b) AR34, and (c) ROCI.

Finally, in the case of the ROCI parameter, the probability of a tropical cyclone undergoing RI is essentially the same for small, medium, and large cyclones. There is less than a 10% difference between each size category, thus showing that ROCI is not useful as a discriminator for potential RI cases.

5. Conclusions and discussion

The likelihood for tropical cyclones to undergo RI displays a significant sensitivity to their initial size. On average for the years between 1990 and 2010, tropical cyclones experiencing RI start with a significantly smaller size than those not undergoing RI. Cyclones not experiencing RI are approximately 10 n mi larger than cyclones undergoing RI when using RMW and AR34 as the initial size parameters. In contrast, when using ROCI as the size parameter, there is only a negligible difference in size between the non-RI and RI cases.

When comparing the three size parameters with the subsequent change of intensity, it is shown that the initial RMW and the initial AR34 have a significant negative correlation with the change of intensity. When using RMW as a size parameter, there is a tendency for smaller tropical cyclones to have a higher subsequent change of intensity. This is also seen when using AR34 as a size parameter, but it is not as distinct. Again, no consistent relationship is uncovered with ROCI.

Scatterplots depicting the RMW and AR34 versus the change of intensity for RI cases demonstrate that most of the RI cases fall within the small- and medium-size categories. Figures 3a and 3b indicate that it is difficult for RI to occur after about 50 n mi for RMW and 140 n mi for AR34. For both size parameters, these thresholds lie near the boundary separating the medium and large cyclones, suggesting that once the tropical cyclone has a large RMW and/or AR34, it is rare for it to undergo RI.

The frequency charts demonstrate that the highest percentage of RI occurrences come from the medium and small tropical cyclones. This, along with the other results, appears to demonstrate a pattern that RMW and AR34 are the best size parameters to determine if the tropical cyclones will undergo RI and if the synoptic environment is neutral or conducive for overall intensification. Overall, there is a consistent signal that smaller cyclones have a larger change in intensity. Finally, when examining all of the RI cyclones in the past two decades, a tropical cyclone is 3–5 times (when using AR34 and RMW as parameters, respectively) more likely to undergo RI if it is small rather than large.

These analyses suggest that while the outer-core size of tropical cyclones (as represented by the ROCI) is essentially independent of subsequent intensity change, the inner-core size (as represented by the RMW) has a moderate negative association with intensity changes over the next 24 h. An intermediate size measure between the inner and outer core (as represented by AR34) has some correlation with intensity changes, but is weaker than that obtained from the inner-core size data. Such a conclusion about the significant relationship between inner-core size and subsequent intensity change was not found by Kimball and Mulekar (2004). Their previous study may have been limited by including all tropical cyclone data and computing a 6-h intensity change. The current study removes all weakening tropical cyclones to partially eliminate the climatological life cycle impacts as well as to focus on a perhaps less noisy 24-h intensity change period.

It is acknowledged, however, that the removal of subsequent 24-h weakening cases many not completely remove the effects of the climatological life cycle in the results. A hypothesis that large tropical cyclones may be further into their life cycle, more intense, and closer to their maximum potential intensity due to being over cooler sea surface temperatures was tested. It turns out that the average intensities for small, medium, and large RMW tropical cyclones are 65.3, 51.8, and 44.2 kt, respectively. Thus, this hypothesis does not appear valid and is not likely to explain the results obtained in this study.

The physical basis for the reduction in intensification rate as inner-core size (primarily RMW) increases may be related to the role of inertial stability. As the inner-core storm size becomes larger, inertial stability also increases, which inhibits inflow from transporting higher angular momentum air inward within the boundary layer (Smith et al. 2011; Chan and Chan 2013). Further study of this is needed to confirm whether inertial stability changes are indeed the mechanism for size modulation of the intensification rate.

The lack of a relationship between outer-core size (primarily ROCI) and intensification rate is also of interest in finding a physical explanation. Past work from both observations and axisymmetric modeling (Merrill 1984; Weatherford and Gray 1988; Chavas and Emanuel 2010; Chan and Chan 2012; Rotunno and Bryan 2012) indicates that the inner and outer wind fields vary nearly independently from one another. Moreover, outer-core size is only weakly correlated with intensity and thus intensity can change rapidly without accompanying changes in size.

The negative correlation between inner-core size and subsequent intensity change demonstrated here has the potential to assist hurricane forecasters in their challenging task to predict tropical cyclone intensity. With the results presented here, only subjective adjustments to intensity forecasting can be made based upon the inner-core size of the tropical cyclone because this component must be placed into the context of the existing environmental factors. A possible next step with this work is to examine whether inner-core size could be incorporated into statistical intensity forecasting [SHIPS, DeMaria et al. (2005); Logistic Growth Equation Model (LGEM), DeMaria (2009); and RII, Kaplan et al. (2010)] techniques. Inclusion of inner-core size parameters within the statistical models might then provide some improvements to intensity forecasting. If it is incorporated within these statistical techniques, then that would help to confirm that inner-core size provides some fundamental information for subsequent intensity change that is independent of other factors. However, the current study does not address the effect, if any, of tropical cyclone size and subsequent rates of weakening for systems embedded within a hostile synoptic environment. Further research into the effects of size on intensity change in general is warranted.

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