Reply

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ABSTRACT

A reexamination of the wind hazard from tropical cyclones for the city of Darwin (Northern Territory), Australia, by Cook and Nicholls concluded that its wind hazard is substantially underestimated by its allocation to region C in the Australian wind code. This conclusion was dismissed by Harper et al. on the basis of interpretation of anemometer records and Dvorak central pressure estimates as well as criticism of the simple technique and data used to interpret historic records. Of the 44 years of historical anemometer records presented by Harper et al. for Darwin, however, only one record was for a direct hit by an intense tropical cyclone. The other records derive from distant and/or weak tropical cyclones, which are not applicable to understanding the wind hazard at long return periods. The Dvorak central pressure estimates from which Harper et al. conclude that Port Hedland (Western Australia), Australia, has a greater wind hazard than Darwin does, when back transformed to Dvorak current-intensity values and gust speeds, indicate the converse. The simple technique used to derive wind hazard from historical cyclone occurrence is defended in detail and shown to produce estimates of wind hazard that are close to those accepted for five locations on the hurricane-affected coastline of the U.S. mainland. Thus the criticisms by Harper et al. of Cook and Nicholl's work are shown to be invalid and the original conclusion that Darwin's wind hazard is substantially underestimated in the current Australian wind code is supported.

1. Introduction

Cook and Nicholls (2009, hereinafter referred to as CN09) analyzed simulated data and historical meteorological data and argued that the allocation of Darwin (Northern Territory), Australia, to the Australian wind code's region C underestimated that town's wind hazard substantially. Harper et al. (2012, hereinafter referred to as H12) present historical anemometer data and Dvorak pressure data of tropical cyclones (TCs) that they use to argue that the conclusions of CN09 are flawed. They dismiss the quality of data that were simulated using the model of Emanuel et al. (2006) and the approach to analyzing the historical data, and they query whether some key TCs in the historical data had not been included in a way that biased the analyses. Here we show that the anemometer record presented by H12 for Darwin is, except for the case of Cyclone Tracy, derived from a different population of data than is represented by the historic hits by extreme TCs and leads to an underestimate of wind hazard. Further, the central pressure data provided by H12, when back transformed to Dvorak current intensity (CI) values, indicate that Darwin has a greater wind hazard than does Port Hedland (Western Australia), Australia, at a 40-yr return period. The simple technique used by CN09 to estimate wind hazard from historical records, and which H12 criticize strongly, is shown to reproduce the wind hazard for five locations on the hurricane-affected coastline of the U.S. mainland remarkably well. We refute H12's allegations that CN09 introduced a bias in the historical data by not including key TCs and maintain our conclusion that Darwin's wind hazard at long return periods is substantially underestimated by its inclusion in region C of the Australian wind code.

2. Reply to specific comments

a. *Historical evidence of the relative tropical cyclone activity at Darwin, Port Hedland, and Townsville*

We agree that Eq. (1) in section 3a of H12 correctly derives return periods from a ranked data series. Use of

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this equation for the temporal probability term in CN09's Eq. (5) decreases the V_{Gust}–R plots in CN09's Fig. 4b by about 2 m s^{-1} for each town. This small adjustment makes no difference to the conclusions of CN09.

Section 3a of H12 presents anemometer data from Port Hedland and Darwin for TCs that have come within an undefined few hundred kilometers of either town over about 45 years (H12's Figs. 1 and 2). These data show that Port Hedland has been affected by more TCs than Darwin has, but we dispute that it thereby can be concluded that the very intense winds associated with events of a 1-in-500-year return period are less for Darwin than for Port Hedland. We discuss this aspect further in section 2b.

Figure 3 of H12 plots Australian Bureau of Meteorology (BoM) database records of the minimum central pressures of TCs coming within 100 and 200 km of Port Hedland, Darwin, and Townsville (Queensland), Australia, dating from 1970 and from 1985 to supposedly provide "further indication of greater intense tropical cyclone activity at Port Hedland than at the other locations." These data were derived by applying the now-superseded wind–pressure relationships (WPRs) of Atkinson and Holliday (1977) for Port Hedland, of Love and Murphy (1985) for Darwin, and of Crane for Townsville (Courtney and Knaff 2009) to mean surface wind speeds derived from the Dvorak CI values (Velden et al. 2006). The equivalent Dvorak CI values and gust speeds of the most intense cyclones for each town in H12's Fig. 3b (i.e., for a return period of ~40 yr) are therefore for Port Hedland CI = 6.5 and gust = 81 m s^{-1}, for Darwin CI = 7 and gust = 90 m s^{-1}, and for Townsville CI ≤ 6.0 and gust ≤ 73 m s^{-1}. Thus Fig. 3b of H12 shows Darwin and not Port Hedland to have the greatest 40-yr return period gust speed within 200 km of the three towns. This is entirely consistent with the conclusion of CN09 that the Australian wind code's 1-in-500-yr gust speed for Darwin of 69 m s^{-1} is a substantial underestimate and that Darwin's wind hazard at long return periods is greater than or equal to that of Port Hedland.

H12 used 100- and 200-km radii to select the data presented in their Fig. 3 and in their section 3e implied that CN09 chose a 350-km radius to include Tropical Cyclone Monica at peak intensity. Nevertheless, elsewhere Harper (1999) has argued that the radius for sampling "must deliver an adequate sample size without exceeding the regional climatological scale." Harper used a 500-km radius for his study of cyclonic winds in both Queensland (Harper 1999) and Darwin (Harper 2006), and Georgiou (2000) used a 250-km radius for his study of Darwin's cyclonic winds. Rather than using pressure data derived from inconsistent and superseded WPRs, here we derived a larger dataset using the post-1984/85 data on wind speeds coming within 400 km of each town as given by the BoM's Tropical Cyclone Tracks Internet page (http://www.bom.gov.au/cyclone/history/index.shtml). The maximum sample radius for those data was 400 km, and this value delivers an adequate sample size. We used H12's Eq. (1) to produce Fig. 1, in which gust speeds are the maxima nearest to the town and within 400 km of the town. TCs moving toward or parallel to the mainland coast are included but those moving away from the mainland are not. There is no question that many more TCs with gust speeds of less than 80 m s^{-1} come within 400 km of Port Hedland than within 400 km of Darwin, but there is little difference between the two towns for TCs with gust speeds of greater than 85 m s^{-1} (Fig. 1).

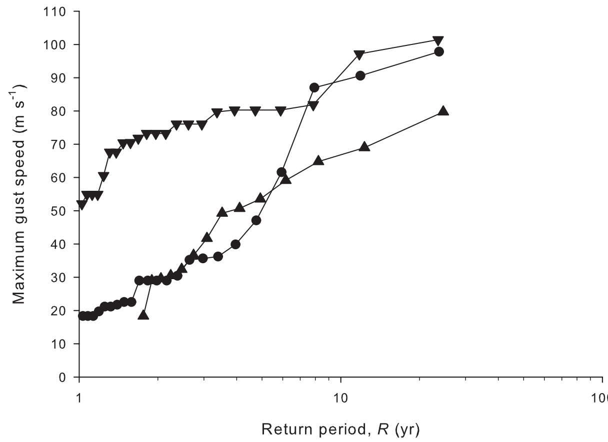

FIG. 1. The V_{Gust}–R curve of TCs coming within 400 km of Port Hedland (filled inverted triangles), Darwin (filled circles), and Townsville (filled triangles) from 1984/85 to 2006/07.

b. *Comparison of anemometer data with CN09's simulation modeling*

In this critique of H12's sections 3a and 3b, we focus on the sampling errors that result from extrapolating short-term records to derive the wind hazard at high return periods. First, we note that the American Society of Consulting Engineers (ASCE) standard ASCE 7-10 "Minimum Design Loads for Buildings and Other Structures" does not permit the "use of regional wind speed data obtained from anemometers…to define the hurricane wind-speed risk" because of the potential for sampling errors associated with short periods of record. Consistent with ASCE 7-10, CN09 discussed the problems in using anemometer data, but those comments apparently were not understood or accepted by H12, and therefore we now provide further details on these problems as they apply specifically to Darwin and H12's Fig. 2.

In H12's Fig. 1a, the most extreme event by far, Cyclone Tracy (1974), is represented as having a gust speed of

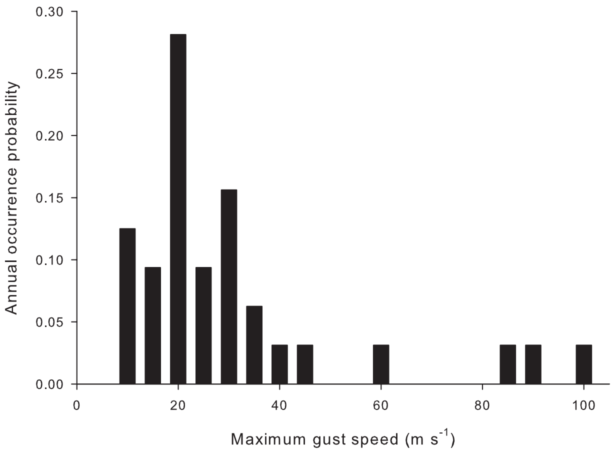

FIG. 2. The pmf of maximum gust speeds of 32 TCs that came within 400 km of Darwin in the 23 years between 1984/85 and 2006/07. The data were taken from the BoM Internet page "Tropical Cyclone Information for the Australian Region."

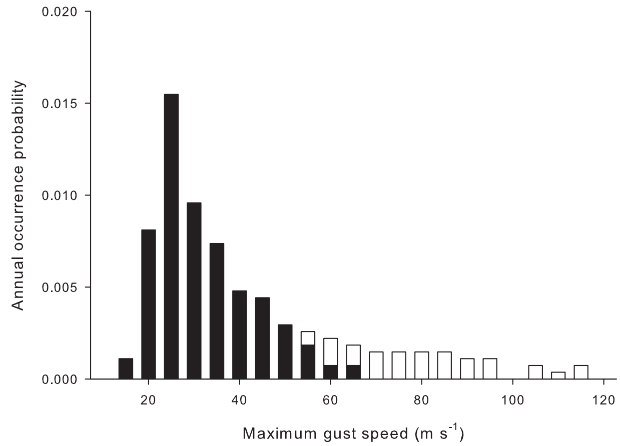

FIG. 3. The pmf of maximum ground-relative gust speeds at a point in Darwin from the WRT-simulated TCs that had maximum gusts > 62.5 m s^{-1} when the TC center was closest to Darwin. White bars are for TC "hits," and black bars are for TC "misses" [TC center more than (R_{MW} + 10) km from the target point].

60.3 m s^{-1}. This was the maximum that was recorded prior to the failure of the anemometer at the airport. The 60.3 m s^{-1} gust speed for Tracy is several meters per second faster than any record at Port Hedland but is considerably below the maximum gusts estimated by Harper (2010) for TC Tracy. The wind field required to reproduce Tracy's measured storm surge required gust speeds of 78 m s^{-1} in Darwin's northern suburbs and 92 m s^{-1} for offshore gusts within 12 km of the airport anemometer (Harper 2010).

H12's Fig. 2 misleadingly infers that anemometer data for Port Hedland and Darwin with a maximum return period R of approximately 40–50 yr can be extrapolated to estimate gust speeds of $R = 500$ yr or more. This leads them to conclude that "it is clear that…region-C wind criteria comfortably exceed Darwin's recorded winds." They do concede that "Tracy remains an outlier in this context" but then hasten to add that "this does not preclude the possibility that it potentially represents a 1000-yr return period event." The former is accurate; the latter is baseless speculation as we show below.

The fundamental flaw in H12's Fig. 2 is that it relies on the anemometer data for Darwin given in H12's Table 1, but these data derive from at least two distinct statistical populations. The first major statistical division of the population occurs between intense TCs and the much more numerous nonintense TCs. The plot of the BoM data for Darwin (Fig. 2 herein) indicates that this statistical division occurs at about 40 m s^{-1}. This statistical division is consistent with the rigorous finding by Emanuel (2000, his Fig. 4) that, for TCs of tropical storm strength or greater (gusts > 22 m s^{-1}) in the western North Pacific and North Atlantic Oceans, there were two distinct statistical populations. Emanuel's findings were based on lifetime maximum wind speeds normalized by theoretical potential wind speeds derived from reanalysis datasets. Figure 2 shows untransformed rather than normalized wind speed data because the concurrent potential intensities tend to cluster at about 105 m s^{-1}. The uniformity in the probability mass functions (pmf) of gust speeds from the data simulated using the model of Emanuel et al. (2006) [the WindRiskTech LLC (WRT) data] progressively degrades as the selection criterion shifts from lifetime maximum to maximum at a point at Darwin, but, as shown by Fig. 3, the uniformity nevertheless persists to a marked extent, particularly for the intense TCs. The most significant feature of the pmfs in Figs. 2 and 3 is the long, nearly uniform, tails to the distributions. We have found that none of the commonly used extreme-value distributions will reproduce these long tails for gusts ≥ 70 m s^{-1} if the data for the nonintense TCs are included in the analysis. For example, the formulas for regions C and D in the Australian wind code have been plotted and compared with the pmf for simulated point-based gust speeds ≥ 65 m s^{-1} at Darwin in Fig. 4. These formulas from the Australian wind code, which relate regional wind speeds to return periods, are based on a type-III extreme-value distribution (Holmes et al. 2002). It is clear that both the region-C and region-D distributions underestimate the occurrence probability of the extreme values.

The second major statistical division of the population is between hits from TCs that came close enough to Darwin that the anemometer was either within or just outside the maximum winds in the TC's eyewall and the much more numerous TC misses. Here, we nominally define a hit as occurring if the TC center came within

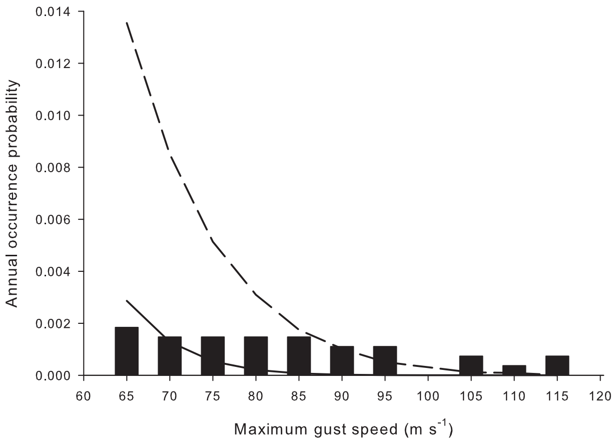

FIG. 4. The pmf for the WRT-simulated TCs that produced gusts ≥ 65 m s^{-1} at a point in Darwin (bars) in comparison with probability distribution functions for region D (dashed line) and region C (solid line) from formulas in the Australian wind code.

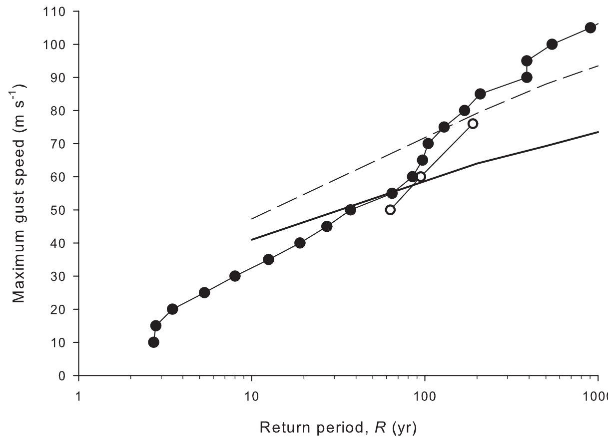

FIG. 5. The V_{Gust}–R curve at a point derived for Darwin from the 1897, 1937, and 1974 cyclones (open circles) in comparison with the region-D (dashed line) and region-C (solid line) curves from the Australian wind code and with the Darwin plot in Fig. 3 of CN09 (filled circles).

a distance (R_{MW} + 10) km of the anemometer, where R_{MW} is radius of maximum winds. As is apparent from Fig. 3, no TC misses in the simulated data caused point-based gust speeds that were greater than 65 m s^{-1}.

From the above discussion, it is clear that the non-intense TCs and those intense TCs that miss will not inform the occurrence probability of gusts that are greater than 65 m s^{-1}. The only group that needs to be examined is the intense TCs that hit. Although in H12's data for Darwin, this group comprises just the one record—that for TC Tracy, it can be expanded by reference to Darwin's historic record. Good barometric and wind direction records were kept at Charles Point and at Darwin for the cyclone that severely damaged Darwin in 1897 (Murphy 1984). At its closest approach, when the center was approximately 26 km southeast of the old Darwin airport at Parap, Northern Territory, the gusts produced there by the 1897 TC would have been about 60 m s^{-1}. For the 1937 cyclone, wind speeds were recorded by a Dynes anemometer and good barometric records were kept (Murphy 1984: Nicholls 2007). When corrected for terrain category, the 1937 TC's recorded maximum gusts at the old Darwin airport were 50 m s^{-1} when the TC center was 40 km to the southeast, and the R_{MW} is estimated to have been 30 km (Nicholls 2007).

If we adopt Harper's (2010) estimate of Tracy's maximum gusts as 76 m s^{-1} at Parap near Darwin, then over the 142 years since European settlement a functioning anemometer at the old Darwin airport would have recorded gusts, corrected for terrain category, of 60, 50, and 76 m s^{-1} for the TCs of 1897, 1937, and 1974, respectively. Applying H12's Eq. (1) to these three records produces the plot shown in Fig. 5 herein. It is noted that, for the range covered, this plot of gust speed against return period (V_{Gust}–R) is in reasonably close agreement with that for Darwin in CN09's Fig. 3 (included in Fig. 5 herein) and with CN09's Fig. 4b. Bubb (1984) also raised concerns that the historic cyclones of 1897 and 1937 were not accounted for adequately in one of the papers that informed the allocation of Darwin to region C of the Australian wind code, that of Dorman (1984b). These concerns were dismissed on the faulty argument that there were insufficient historic data to apply that approach elsewhere (Dorman 1984a).

The commentary on the Australian wind code (Holmes et al. 2002) states that the regional wind speeds were determined from an analysis of long-term records of daily maximum gust speeds from the Australian Bureau of Meteorology, but apart from Dorman's (1984b) study no details of the method or assumptions as applied to Darwin have ever been published in peer-reviewed literature. H12 in their section 3b list four references that provide ‘‘methods of processing extreme wind speeds to make unbiased future estimates of wind speeds over long return periods.'' Here we applied the most recent of those methods, that of Holmes and Moriarty (1999), to H12's records of Darwin's daily maximum gust speed data (H12's Table 1). Holmes and Moriarty's method states that if the largest observation is larger than the next two by three or more threshold units then using a median of the upper three values will reduce excessive dependence on the one large observation. For Darwin's data, this required the gust speed of Cyclone Tracy to be replaced by a median of the highest three gust speeds. The resulting fit of the generalized Pareto distribution (GPD) using a threshold of 20 m s^{-1} (Fig. 6) gave a 1-in-500-yr gust speed of 41 m s^{-1} and an upper limit of extreme winds of 49 m s^{-1}. This

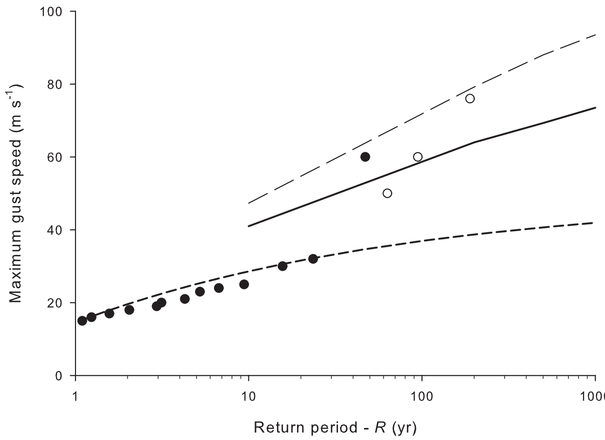

FIG. 6. GPD (short-dashed line) fitted to 44 yr of Darwin's anemometer data (filled circles) from H12's Table 1 and Fig. 2 using the method of excesses over high threshold of Holmes and Moriarty (1999). This is compared with the region-D (long-dashed line) and region-C (solid line) curves from the Australian wind code and with data from the 1987, 1937, and 1974 cyclones over 142 years of records as given in Fig. 5 (open circles).

upper limit was less than that of the southern Australian cities of Perth (Western Australia), Adelaide (South Australia), Melbourne (Victoria), and Sydney (New South Wales), which are outside the cyclone zone (Holmes et al. 2002). It is also only 81% of the maximum gust speed of Cyclone Tracy as recorded at the time of instrument failure. This GPD clearly does not provide an unbiased or realistic description of the extreme events, but it does demonstrate that TC Tracy is indeed an outlier and representative of a different population of data from the rest of the anemometer records. A comparison of the GPD with the three intense cyclones that affected Darwin in 1897, 1937, and 1974 (Fig. 6) clearly indicates that the anemometer data presented by H12 cannot provide a reliable indication of either the upper limit to cyclonic winds affecting Darwin or of the long-return-period winds relevant to limit-state design rules as are now used for engineering.

c. *Lack of validation and inaccuracy of the simulation modeling*

H12 allege that CN09 used the WRT simulation "without first validating the model results." In fact the validation process was extensive and led to two revisions of the WRT datasets for Darwin and Townsville and three revisions of the datasets for Port Hedland. The impact of various assumptions in the modeling is described in Table 1 of CN09.

Before giving details of the validations that were carried out, we describe our rationale for not validating three of the parameters recommended by H12. First, central pressures were not validated because our investigations concerned wind speeds only. Central pressures were provided by WRT, but they are calculated deterministically in the model and are not based on any parametric relationship to wind speed. Second, the skill of the wind field model in reproducing observed wind speeds given central pressure and radius of maximum winds was also deemed irrelevant to our investigations and was not validated. The WRT data include only the maximum wind speed at each 2-h interval so that CN09 did have to use a wind field model to determine wind speeds at a point in the town when that point was outside the RMW. The accuracy or otherwise of that wind field is unimportant, however, because, as indicated in Fig. 3 herein, such misses are not important in determining the hazard from gusts >65 m s^{-1}. Last, the distance of closest approach was irrelevant because the WRT storms have already been restricted to just those coming within 100 km of each town.

Our validations of the track shapes and directions showed that they were realistic and relate to those obtained in the historic record for all three towns except that, as shown in CN09's Table 3, Darwin had a higher percentage of TCs with an easterly component of track direction than is indicated by the historic record over the past three decades. Our interest here is for intense TCs, and, as pointed out by CN09, all five of the intense TCs that came within 50 km of Darwin since its settlement in 1869 had an easterly component in their track direction at their nearest approach to Darwin.

The translation speeds and monthly occurrences were found to be within reasonable agreement with the historic records for each town. It is made clear in the text and in Table 1 of CN09 that decay after landfall was examined for both Darwin and Townsville. The only measure of storm size that is of interest in CN09 is the R_{MW}; CN09's Eq. (1) relates storm size to intensity and latitude, and its derivation and validation are detailed in CN09 (p. 2335). The statistical distribution of the WRT gust speeds rather than of the central pressures was validated by plotting the pmfs of the 1000 maximum gusts within 100 km of each town and comparing the plots with those derived from the analysis of BoM data for the period from 1984/85 to 2006/07. It was found that for all three towns there was a good match between the WRT and BoM data pmfs for the maximum gust speeds relating to long return periods. Note also that CN09 validated the WRT data pmfs for extreme gusts by use of the historical records with the simple technique as shown by CN09's Figs. 3 and 4.

H12 claim that the number of events simulated to produce the records for Port Hedland, Darwin, and Townsville are well above the average annual frequency of TCs per annum for the entire Australian region, which they give as 12. They do not, however, define the longitudinal boundaries of "the *entire Australian region*," nor do they quote the source of their information. It is stated in CN09 (p. 2333) that WRT's TC generation is "based on post-1970 genesis data from the Joint Typhoon Warning Center." These data are for the entire Southern Hemisphere. The mean annual TC frequency for the South Pacific and southern Indian Oceans from 1981 to 2009 was 27.6 (Cooper and Falvey 2009, their Table 3-2). This compares very favorably to the average number of TCs generated annually in the study of each location by WRT being 27.4. Of these cyclones, only those that came within 100 km of each town were further analyzed. For Darwin and Port Hedland the simulation produced about one every 3 yr within 100 km, roughly consistent with the records for the past century from the Australian Bureau of Meteorology.

H12 note that the simulation periods given in CN09 for 1000 TCs coming within 100 km of Port Hedland and Darwin give annual frequencies λ that are markedly different from those indicated by the anemometer records shown in their Fig. 1, but H12 do not state the distance of each cyclone from the towns. It is clear from the proliferation of gust speeds of less than 25 m s^{-1} that most TCs in their data passed at a large distance and so cannot be compared with data for TCs within 100 km. The frequency of the TCs simulated by WRT in CN09 as having gusts > 85 m s^{-1} within 100 km was consistent with the historical data for all three towns.

d. Return-period calculations from the historical record

Section 3d of H12 dismisses both the data and the simple technique used for the analysis of historical data. In the appendix, we provide a detailed defense of the simple technique and of the data we used. In summary, we reject H12's criticism of the technique but do acknowledge several minor errors in our analyses. Nevertheless, correcting these minor errors produced negligible differences in our conclusions—in particular, the values of V_{Gust} for $R \geq 500$ yr for Darwin will still be over 20 m s^{-1} more than the region-C values required by current building regulations. We provide the data that we used and reject the accusation that we omitted the intense TCs Orson and Larry, respectively, from the analyses of Port Hedland and Townsville.

To demonstrate further the validity of the simple technique, we applied it to obtain V_{Gust}–R plots for five locations around the hurricane-exposed coastline of the U.S. mainland using 1909–2008 data obtained from the National Oceanic and Atmospheric Administration (NOAA) Historical Hurricane Tracks Internet page (www.csc.noaa.gov/hurricanes/#) and compared the results with those given by the wind-load rules of the current ASCE standard, ASCE 7-10. Results for the five chosen locations for $R = 500$ yr are shown in Table 1. The ASCE 7-10 values were obtained by linear interpolation between the values given for mean recurrence interval = 300 and 700 yr in Fig. 26.5–1 of that document. The simple technique used the same methods and weakening rules as were used to derive Fig. 4b of CN09 except that the sample radius used was 200 n mi (370 km) instead of 350 km and the "Exposure C" gust speeds were obtained by multiplying NOAA's 1-min sustained wind speeds over water by 76.4/69 as indicated by values in Table C26.5–2 of ASCE 7-10. The results indicate that the simple technique yielded gust speeds that are equivalent to or slightly less than the values given by ASCE 7-10.

TABLE 1. Surface (10 m) gust speeds in Exposure C for a return period of $R = 500$ yr for five sites on the hurricane-exposed coastline of the U.S. mainland.

Location	V_{Gust} for $R = 500$ yr (m s^{-1}) From ASCE 7-10	V_{Gust} for $R = 500$ yr (m s^{-1}) Using simple technique
Galveston, Texas	66	67
Biloxi, Mississippi	70	69
Key West, Florida	78	73
Miami Beach, Florida	74	74
Folly Beach, South Carolina	64	58

3. Conclusions

There was one record of an intense cyclone crossing at or near Darwin in the 44 years of anemometer data presented by H12, and this was for Cyclone Tracy in 1974. Despite the greater number of tropical cyclones affecting Port Hedland and the fact that the gust speed for Cyclone Tracy given by H12, 60.3 m s^{-1}, was that at the moment when the instrument failed, the gust speed for Tracy was greater than any recorded gust speed at Port Hedland. When considered in the context of the intense tropical cyclones affecting Darwin in 1897 and 1937, the historical record gives good reason to expect a very high gust speed for a 500-yr return period. The anemometer records of tropical cyclones that passed Darwin as nonintense storms or at large distances provide no reliable basis for estimating long-return-period gust speeds because they represent a different population of events.

The central pressure data presented in H12's Fig. 3b for tropical cyclones within 200 km of Port Hedland, Darwin, and Townsville, when back transformed to the Dvorak CI values and gust speeds, show that Darwin had a more intense 1-in-40-yr event than Port Hedland. H12's opposite conclusion is an artifact of their use of data derived from the application of superseded wind–pressure relationships that were different for each town to determine central pressure from the wind speed values resulting from Dvorak analyses.

The simple technique used by CN09 to estimate wind hazard from historical data has been defended as have the historical data analyzed. There were no omissions of key tropical cyclones, but some minor errors have been addressed. Reanalysis of a slightly modified dataset produced no significant variation to the conclusions. H12 see the match between the results of the simple technique and the accepted wind hazard for Port Hedland and Townsville as a chance outcome of compounded errors in the technique and the data, but when the simple technique was applied to estimate wind hazard in five locations on the hurricane-affected coastline of the mainland United States, the results closely matched the accepted wind hazard in ASCE 7-10.

We conclude that H12's critique of the methods and data of CN09 has no validity and that Darwin's wind hazard has been substantially underestimated by the Australian wind code.

APPENDIX

Return-Period Calculations from the Historical Record

In their abstract, H12 allege that CN09 make two flaws (notated 1 and 3) in their application of the simple technique to analyze the historical data:

"1) invalid assumptions in their analysis method, including that cyclones are assumed to be at the maximum intensity along their entire path across the sampling circle even after they have crossed extensive land areas" and

"3) the omission of key cyclones when comparing the risk at Darwin with two other locations."

The first part of alleged flaw 1 contradicts H12's acknowledgment that CN09 state that "[a]llowance was made for the weakening from the maximum wind speed values to landfall values." The values obtained for the weakening of TCs from the maximum values within the sampling circles for each of the three locations are detailed in Table A1, which shows that alleged flaw 3 is also groundless—there was no "omission of key cyclones."

In reexamining the data, we have identified a minor error in the text of CN09 and several minor errors in the data used to describe the post-1984 record. The error in the text is that the Darwin data were for TCs with maximum gusts of >57 m s^{-1} and not of >69 m s^{-1} as stated in the last paragraph on page 2334 of CN09. The errors in the data are presented in Table A1 herein. Tropical Cyclone Amy (1979/80) was mistakenly included with the data for Port Hedland, and TC Steve (1999/2000) was mistakenly omitted from the data for Townsville. The data for Port Hedland that were used in CN09 were derived from the BoM database central pressures and the Atkinson and Holliday (1977) wind–pressure relationship. This was an inadvertent inclusion from an earlier analysis covering tropical TCs extending back to 1970. It is noted that the statement in CN09 that it was not necessary to convert pressure data to wind speeds (first sentence of first full paragraph on p. 2337) was thereby partly in error. In Table A1, all entries are based directly on the BoM wind speed estimates except those for Port Hedland as used in CN09.

The low gust speed of 67 m s^{-1} for TC Larry in CN09 was estimated before entries for it appeared in the BoM database and was based partly on the published opinions of both Harper and Holmes that TC Larry's peak gusts at landfall were likely to have been less than 65 m s^{-1} (Davidson 2006). Note that the landfall wind speed for Larry remains blank in the BoM database and that the 73 m s^{-1} value given in the corrected column of Table A1 may be higher than BoM would intend—we have simply linearly interpolated from the adjacent records 1 h either side of landfall.

Table 2 of H12 lists just the five TCs shown in Table A1 herein for Darwin. We agree with H12 that the small number of TCs for Darwin suggests that the threshold should have been lower—but dropping that threshold from 57 to 43 m s^{-1} and so adding TC Debbie to the list makes no difference to the V_{Gust}–R plot for the higher wind speeds.

Table 3 of H12 lists 29 TCs for Port Hedland as compared with only 9 in Table A1 herein. The 20 omissions are not "key cyclones" as alleged by H12 but are TCs having gust speeds less than the chosen threshold level of 69 m s^{-1}. Eleven of them had maxima below the threshold, and the other nine weakened as defined below the threshold. Note that the two very different values for TC Orson in Table A1 indicate an apparent error in the BoM database whereby TC Orson at landfall is allocated a central pressure of 923 hPa and a 10-min wind speed of 61 m s^{-1} whereas the Atkinson and Holliday (1977) wind–pressure relationship for that pressure indicates a 10-min wind speed of only 54 m s^{-1}.

Table 4 of H12 lists almost the same TCs for Townsville as in Table A1 but includes TC Tessi, which weakened below the chosen 36 m s^{-1} threshold, and omits Katrina and Justin, which did not so weaken.

Although the corrections in Table A1 appear to be extensive, the corrected data produce V_{Gust}–R plots that are little different from those in Fig. 4b of CN09. For instance, for a return period of 500 yr, the corrections lead to V_{Gust} increasing from 83 to 86 m s^{-1} for Port Hedland, remaining the same at 93 m s^{-1} for Darwin,

TABLE A1. The data for the V_{Gust}–R plots in Fig. 4b of CN09 and as corrected herein. All values relate to TCs coming within 350 km of each town at the time of attaining their maximum values over the 24-yr period from 1 Jan 1985 to 31 Dec 2008.

				Weakened V_{Gust} (m s^{-1})	
Town	TC name	Season	Weakening rule used*	Used in CN09	Corrected
Port Hedland	Orson	1988/89	(ii)	76	86
	George	2006/07	(ii)	83	80
	Amy	1979/80	(ii)	79	Not included
	Chris	2001/02	(ii)	76	79
	Glenda	2005/06	(i)	77	76
	Olivia	1995/96	(ii)	72	74
	Annette	1994/95	(ii)	69	71
	Kirsty	1995/96	(ii)	69	71
	Sam	2000/01	(ii)	69	71
Darwin	Monica	2005/06	(ii)	98	98
	Thelma	1998/99	(i)	87	87
	Ingrid	2004/05	(i)	65	65
	Neville	1991/92	(i)	58	58
	Debbie	2003/04	(ii)	Not included	44
Townsville	Larry	2005/06	(ii)	67	73
	Joy	1990/91	(i)	62	62
	Aivu	1988/89	(i)	57	60
	Rona	1998/99	(ii)	51	51
	Winifred	1985/86	(ii)	49	49
	Steve	1999/2000	(ii)	Not included	44
	Celeste	1995/96	(i)	39	40
	Katrina	1997/98	(i)	37	37
	Justin	1996/97	(ii)	37	37

* Here, (i) indicates the wind speed in the BoM database 12 h after the recorded time for the maximum wind speed within 350 km of the target town or when the TC was nearest to the town if there are several equal maxima and (ii) indicates the actual or interpolated wind speed at landfall if this occurs at some time less than 12 h from the time for the maximum value.

and increasing from 68 to 74 m s^{-1} (extrapolated) for Townsville. The only significant change in these is the 6 m s^{-1} increase for Townsville, which is entirely due to the increase from 67 to 73 m s^{-1} in the weakened gust speed for TC Larry. This case illustrates the need for high-quality data. It also demonstrates the danger in using short-period records—if TC Hamish (2008/09 season) and TC Yasi (2010/11) with weakened V_{Gust} values of 74 and 79 m s^{-1}, respectively, are included in an updated, 26-yr-long record for Townsville then Eq. (5) of CN09 gives the 500-yr return period V_{Gust} = 79 m s^{-1}. It is of interest that it also produces a V_{Gust}–R plot for Townsville that is very similar to the one derived from the simulated data shown in Fig. 3 of CN09.

H12 list four assumptions that they allege are inherent in CN09's simple technique. The first part of assumption 1 of H12 has been dispelled by the discussion above relating to alleged flaw 1 in the abstract of H12. The second part of assumption 1 that ''cyclones are at the maximum intensity. . .including after they have crossed extensive land areas'' is incorrect. The simple technique only uses data from those intense TCs that will hit the target town at or near landfall. Cyclones that cross extensive land areas on their approach to the target town are excluded by the method in deriving values for the relationship between V_{Gust} and return period—they simply form part of the large majority of TCs that will miss the target town.

With regard to assumption 2 of H12, we do not assume straight-line tracks but do assume that the tracks ''may occur at any location within the sampling radius with equal probability.'' Equation (4) of CN09 will obviously not apply to those rare TCs that recurve and make two hits on a town, but it most certainly will still apply to TCs with the curved tracks that normally occur.

Assumption 3 of H12 is correct except that ''+ 1 km'' should be inserted after ''radius of maximum winds.'' We agree that Eq. (5) will underestimate return periods at lower wind speeds—that is why the method is only intended to apply to intense TCs and the threshold value of V_{Gust} used in the data was kept as high as was reasonably possible. CN09 were not concerned with lower wind speeds—the abstract to CN09 states that the concerns lay with the ''wind hazard at the long return periods relevant to engineering requirements'' and Fig. 2 on page 2333 of CN09 makes it clear that gust speeds at those return periods range from 65 to 100 m s^{-1}.

Assumption 4 of H12 is stated as "no account is taken of the forward motion of the cyclone on the predicted wind speeds." This was because, in the long term, such motion was found to have negligible effect on the point-based gust speed distribution. Although the assumption is only specifically mentioned in relation to the simulation modeling on pages 2333 and 2334 of CN09, it is correct that the assumption also applies for the simple technique. Note that assumption 4 is not further discussed in the rebuttal, which implies that the reasons given on page 2334 of CN09 to support this significant simplification of our analyses were accepted.

After listing the four alleged assumptions, H12 use their Fig. 4 to show that assumptions 1 and 2 are false. Consideration of the tracks for TCs Thelma, Ingrid, and Monica (the "TIM" cyclones) in H12's Fig. 4 may help to explain the principles behind CN09's simple technique. If the tracks are displaced 3.0° eastward for Thelma, 2.0°eastward and 0.3° southward for Ingrid, and 2.5° westward for Monica then it can be shown that each of the TCs would make landfall at or near Darwin. By also rotating the tracks differing amounts, other combinations of displacements would also provide landfall hits. The chance of a landfall hit is small, but it is the aim of Eq. (4) of CN09 to quantify that chance as follows: The three TCs have an average "weakened" $V_{\mathrm{Gust}} = 83$ m s^{-1}, and for that speed CN09's Eq. (1) gives the average $R_{\mathrm{MW}} = 13.7$ km; so Eq. (4) gives the chance of a landfall "hit" from a cyclone of this strength as equal to 14.7/350 (4%). The actual tracks in Fig. 4 of the H12 can be regarded as examples of the 96% of tracks by TIM-type cyclones that do not make a landfall hit on Darwin. (Note that the phrase "landfall hit on Darwin" can include instances of intense TCs that have crossed peninsulas or islands prior to making the hit.)

H12 present several pages of critique of the simple technique of CN09. In response, we rebut their main points. CN09 derived the simple technique from the "ballpark" approach of Nicholls (2007) by making an allowance for weakening and for calculating the radii of maximum winds R_{MW} as a function of V_{Gust} and latitude instead of assuming a single constant value. We advise that both R_{MW} and the 1 in ($R_{\mathrm{MW}} + 1$) have units of kilometers. H12 state that CN09's Eq. (2) should be in the form $R = (\lambda P_t P_s)^{-1}$. We dispute this and note that such an equation would have the implausible units of years squared.

The data for the post-1984 record were obtained from the BoM "Newcyclonedatabase-08repair.xls" file, which only extends to mid-2007. Given that the paper was being published in late 2009, we decided to extend the cutoff date for data to 31 December 2008. A check of BoM records revealed that there were no TCs that complied with the selection criteria in those extra 1.5 yr, but the check enabled us to extend the period of record to 24 yr.

We reject the assertion in H12 that the description given as to how the data were obtained for the written record on page 2334 of CN09 was "too imprecise" to enable a check to be made. We admit that it would take some time for someone to assemble the data but regard this form of analysis as an important adjunct to using short-period, more-accurate data to facilitate checks. Note that only the data for Port Hedland were drawn entirely from the BoM database, which begins in 1906. The periods of record for Darwin and Townsville commenced in 1869 and 1858, respectively, and most of the data for those towns were drawn from the references given on page 2334 of CN09 (i.e., Callaghan 2005; Murphy 1984; Nicholls 2007) rather than from the BoM database.

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