Wind Speed Analysis of Hurricane Sandy

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The database of the HWind project sponsored by the National Oceanic and Atmospheric Administration (NOAA) for hurricanes between 1994 and 2013 is analysed. Moreover, the wind speed of Hurricane Sandy is studied.

Keywords: wind statistics ; wind field ; tropical cyclone ; air parcel trajectory ; recirculation factor

1. Introduction

Hurricanes are among the most destructive natural hazards, not only in terms of human life, but also on built infrastructure [1]. Since their consequences are devastating, the effects of these winds on structures such as bridges, transmission lines, offshore wind turbines, skyscrapers, or water supplies are the subject of research [2][3][4][5][6]. However, the most common constructions are usually low-rise buildings, where the direct impact perceived by most of the population is on the building roofs [7]. Moreover, coastal economic activities, such as fisheries, are affected [8]. Last but not least, the longest-lasting consequences are observed on human health [9].

Due to their global impact, hurricanes have been studied in numerous analyses, some of which, such as the relationship between pressure or temperature and wind, are experimentally based [10][11]. Other studies consider the vertical wind profile [12], which is extremely useful for evaluating the structural safety of buildings in extreme wind conditions. The hurricane trajectory analysis is one line of research [13], with other studies focus on gauging their size [14]. Theoretical research has also occasionally been conducted [15].

Due to the close link between ocean surface temperatures and hurricanes, Hosseini et al. [16] obtained a high correlation between sea surface temperature, the increase in which was attributed to climate change, and hurricane frequency over the last century. Another consequence of recent atmospheric warming might be the decrease in translation speed and the increase in the rain rate [17]. However, Rojo-Garibaldi et al. [18] reported a decreasing trend in the number of hurricanes in the Gulf of Mexico and the Caribbean over a wider period, 1749–2010, which they correlated with sunspot activity.

2. Wind Speed Analysis of Hurricane Sandy

2.1. Database Analysis

Chavas et al. [19] presented the spatial distribution of hurricane tracks on the Earth in the period 1999–2009 where the lowest number was observed over the Southern Pacific Ocean and Southern Indian Ocean. In the remaining basins, these trajectories were similar for the Atlantic and East Pacific basins. In both regions, hurricanes approached the continent from low latitudes, then veered and moved away from the continent to higher latitudes, with the greatest latitudes being reached in the Atlantic basin. However, hurricanes in the West Pacific basin were confined to low latitudes.

Delgado et al. [20] reanalysed the North Atlantic hurricane database for the period 1954 to 1963. They obtained an average of around 11 storms (tropical storms and hurricanes) per year, with the number varying between 7 and 16. This average was around six for hurricanes each year, ranging between three and nine, and around three per year for major hurricanes, ranging between none and five.

Most hurricanes described in Section 3.1 occur in the second part of the year. This result is in agreement with the study presented by Corporal-Lodangco and Leslie [21], who investigated tropical cyclones in the Philippine region during the period 1945–2011. They reported two seasons: the less active season, from January to May, with a median seasonal frequency of two, and the more active season, from June to December, with a median seasonal frequency of 15. However, although hurricane seasons are usually felt to exist, their start is not fixed since this may be influenced by atmospheric processes. For example, a significant delay in the start of the hurricane season in the western North Pacific was observed after a strong El Niño in the preceding winter [22].

Anomalies in the sea surface are responsible for changes in hurricane frequency. Wang et al. [23] investigated Atlantic hurricanes from 1951 to 2010 and concluded that warm anomalies in the sea surface temperature in wintertime in the main Atlantic development region are frequently followed by unusually active hurricane seasons. Moreover, the hurricane frequency may be affected by certain trends, since analyses of cyclone genesis frequency from October to December over the western North Pacific revealed a decreasing trend with two periods, the first from 1980 to 1995, with about ten hurricanes per year, seven of which could be assigned to the eastern region, and the second from 1996 to 2011, with about six hurricanes per year, where around four may be assigned to the western region [24]. Another factor that may impact on this frequency could be climate change, since analyses of the strength and distribution of hurricanes during the 2016 North Atlantic hurricane season revealed that said year was noticeable for a series of events never before observed, such as the observation site for a high category or the number of high category hurricanes in the same month [25].

2.2. Wind Speed

These measurements have occasionally been taken if the experimental device is near the hurricane route [26]. In these situations, the wind speed gradually increases to the maximum, and then decreases once the hurricane centre moves away from the experimental site. Although measurements are taken at a single point, they may be considered similar at sites that are an equal distance from the centre, since radial symmetry is assumed. Moreover, studies normally present the horizontal wind speed profile, where one maximum is reached at a certain distance [27], and this wind speed shape has occasionally been modelled [28][29].

Although analyses of wind speed distribution are not common, the current study considers the Laplace distribution of the wind speed due to the shape of the wind speed histogram. However, Cui and Caracoglia [30] used the Weibull distribution for annual wind speed maxima.

2.3. Radius

For US tropical cyclone forecast centres, estimating the maximum extent of the 17.5, 25.7, and 32.9 m s^{-1} (34, 50 and 64 kt, respectively) winds in compass quadrants (northeast, southeast, southwest, and northwest) surrounding the hurricane centre is critical [31][32]. These wind thresholds are known as gale-force, destructive, and hurricane-force, and the corresponding distances are called the “wind radii”. The average 17.5 m s^{-1} wind radius calculated in 2014–2015 in the western North Pacific basin was around 248 km, larger than those for the Atlantic and eastern North Pacific basins, which were around 176 and 152 km, respectively [33].

Chavas and Emanuel [34] analysed the azimuthally-averaged radius of 12 m s^{-1} wind, r_{12}, and the radius of vanishing winds, r_0, for a dataset covering the period 1999–2008. Their global median values were 197 and 423 km, respectively. Moreover, they presented these values in each basin. The largest radii were reached in the West Pacific basin, around 250 and 500 km, whereas the smallest values were observed in the East Pacific basin, slightly below 150 and 350 km.

2.4. Air Parcel Trajectories

Wind speed vertical profiles in the boundary layer modelled by Snaiki and Wu [35] revealed the noticeable influence of the surface below 300 m, where the change is around 5 m s^{-1}. Shu et al. [36] presented the wind speed profile in the troposphere, with the maxima being reached at nearly 1000 m height and close to 35 m s^{-1}.

Myers and Malkin [37] presented the spiral trajectory of air parcels in a hurricane and Niu et al. [38] considered its mathematical form by a logarithmic spiral. Spirals observed in trajectories at low altitudes may be attributed to friction with the surface, whereas loops in the mid troposphere may be due to a composition of the wind rotation and the hurricane displacement.

References

1. Depietri, Y.; McPhearson, T. Changing urban risk: 140 years of climatic hazards in New York City. Clim. Chang. 2018, 148, 95–108.
2. Crowley, R.; Robeck, C.; Dompe, P. A three-dimensional computational analysis of bridges subjected to monochromatic wave attack. J. Fluids Struct. 2018, 79, 76–93.
3. Gallucci, M. Rebuilding Puerto Rico’s Grid: Eight months after Hurricane Maria, electricity is nearly restored—But that’s just the beginning. IEEE Spectr. 2018, 55, 30–38.
4. Hallowell, S.T.; Myers, A.T.; Arwade, S.R.; Pang, W.; Rawal, P.; Hines, E.M.; Hajjar, J.F.; Qiao, C.; Valamanesh, V.; Wei, K.; et al. Hurricane risk assessment of offshore wind turbines. Renew. Energy 2018, 125, 234–249.
5. He, Y.; Han, X.; Li, Q.; Zhu, H.; He, Y. Monitoring of wind effects on 600 m high Ping-An Finance Center during Typhoon Haima. Eng. Struct. 2018, 167, 308–326.
6. Murià-Vila, D.; Jaimes, M.A.; Pozos-Estrada, A.; López, A.; Reinoso, E.; Chávez, M.M.; Peña, F.; Sánchez-Sesma, J.; Lopez, O. Effects of hurricane Odile on the infrastructure of Baja California Sur, Mexico. Nat. Hazards 2018, 91, 963–981.
7. Huang, P.; Tao, L.; Gu, M.; Quan, Y. Experimental study of wind loads on gable roofs of low-rise buildings with overhangs. Front. Struct. Civ. Eng. 2018, 12, 300–317.
8. Monteclaro, H.; Quinitio, G.; Moscoso, A.D.; Napata, R.; Liberty, E.; Anraku, K.; Watanabe, K.; Ishikawa, S. Impacts of Typhoon Haiyan on Philippine capture fisheries and implications to fisheries management. Ocean Coast. Manag. 2018,

158, 128–133.

9. Schwartz, R.M.; Tuminello, S.; Kerath, S.M.; Rios, J.; Lieberman-Cribbin, W.; Taioli, E. Preliminary Assessment of Hurricane Harvey Exposures and Mental Health Impact. Int. J. Environ. Res. Public Health 2018, 15, 974.
10. Holland, G. A Revised Hurricane Pressure–Wind Model. Mon. Weather Rev. 2008, 136, 3432–3445.
11. Lin, L.; Weng, F. Estimation of Hurricane Maximum Wind Speed Using Temperature Anomaly Derived From Advanced Technology Microwave Sounder. IEEE Geosci. Remote Sens. Lett. 2018, 15, 639–643.
12. Liu, Y.; Chen, D.; Li, S.; Chan, P. Revised power-law model to estimate the vertical variations of extreme wind speeds in China coastal regions. J. Wind. Eng. Ind. Aerodyn. 2018, 173, 227–240.
13. Kendall, W.S. Barycentres and hurricane trajectories. In Geometry Driven Statistics; Dryden, I.L., Kent, J.T., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2015; pp. 146–160.
14. Mok, D.K.H.; Chan, J.C.L.; Chan, K.T.F. A 31-year climatology of tropical cyclone size from the NCEP Climate Forecast System Reanalysis. Int. J. Clim. 2018, 38, e796–e806.
15. Meyer, G.; Vitiello, G. On the molecular dynamics in the hurricane interactions with its environment. Phys. Lett. A 2018, 382, 1441–1448.
16. Hosseini, S.R.; Scaioni, M.; Marani, M. On the influence of global warming on atlantic hurricane frequency. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. ISPRS Arch. 2018, 42, 527–532.
17. Kossin, J.P. A global slowdown of tropical-cyclone translation speed. Nature 2018, 558, 104–107.
18. Rojo-Garibaldi, B.; Salas-De-León, D.A.; Sánchez, N.L.; Gómez, M.A.M. Hurricanes in the Gulf of Mexico and the Caribbean Sea and their relationship with sunspots. J. Atmos. Sol. Terr. Phys. 2016, 148, 48–52.
19. Chavas, D.R.; Lin, N.; Dong, W.; Lin, Y. Observed Tropical Cyclone Size Revisited. J. Clim. 2016, 29, 2923–2939.
20. Delgado, S.; Landsea, C.W.; Willoughby, H. Reanalysis of the 1954–63 Atlantic Hurricane Seasons. J. Clim. 2018, 31, 4177–4192.
21. Corporal-Lodangco, I.L.; Leslie, L.M. Climatology of Philippine tropical cyclone activity: 1945-2011. Int. J. Clim. 2016, 37, 3525–3539.
22. Kim, D.; Kim, H.-S.; Park, D.-S.R.; Park, M.-S. Variation of the Tropical Cyclone Season Start in the Western North Pacific. J. Clim. 2017, 30, 3297–3302.
23. Wang, X.; Liu, H.; Foltz, G.R. Persistent influence of tropical North Atlantic wintertime sea surface temperature on the subsequent Atlantic hurricane season. Geophys. Res. Lett. 2017, 44, 7927–7935.
24. Choi, J.; Cha, Y.; Kim, T.; Kim, H. Interdecadal variation of tropical cyclone genesis frequency in late season over the western North Pacific. Int. J. Clim. 2017, 37, 4335–4346.
25. Collins, J.M.; Roache, D.R. The 2016 North Atlantic hurricane season: A season of extremes. Geophys. Res. Lett. 2017, 44, 5071–5077.
26. Wang, X.; Huang, C.; Huang, P.; Yu, X. Study on wind characteristics of a strong typhoon in near-ground boundary layer. Struct. Des. Tall Spéc. Build. 2016, 26, e1338.
27. Zhang, G.; Perrie, W.; Li, X.; Zhang, J. A Hurricane Morphology and Sea Surface Wind Vector Estimation Model Based on C-Band Cross-Polarization SAR Imagery. IEEE Trans. Geosci. Remote Sens. 2016, 55, 1743–1751.
28. Chavas, D.R.; Lin, N. A Model for the Complete Radial Structure of the Tropical Cyclone Wind Field. Part II: Wind Field Variability. J. Atmos. Sci. 2016, 73, 3093–3113.
29. Wijnands, J.S.; Qian, G.; Kuleshov, Y. Spline-Based modelling of near-surface wind speeds in tropical cyclones. Appl. Math. Model. 2016, 40, 8685–8707.
30. Cui, W.; Caracoglia, L. Exploring hurricane wind speed along US Atlantic coast in warming climate and effects on predictions of structural damage and intervention costs. Eng. Struct. 2016, 122, 209–225.
31. Knaff, J.A.; Sampson, C.R.; Chirokova, G. A Global Statistical–Dynamical Tropical Cyclone Wind Radii Forecast Scheme. Weather Forecast. 2017, 32, 629–644.
32. Reul, N.; Chapron, B.; Zabolotskikh, E.; Donlon, C.; Mouche, A.; Tenerelli, J.; Collard, F.; Piolle, J.-F.; Fore, A.; Yueh, S.; et al. A New Generation of Tropical Cyclone Size Measurements from Space. Bull. Am. Meteorol. Soc. 2017, 98, 2367–2385.
33. Sampson, C.R.; Fukada, E.M.; Knaff, J.; Strahl, B.R.; Brennan, M.J.; Marchok, T. Tropical Cyclone Gale Wind Radii Estimates for the Western North Pacific. Weather Forecast. 2017, 32, 1029–1040.
34. Chavas, D.R.; Emanuel, K.A. A QuikSCAT climatology of tropical cyclone size. Geophys. Res. Lett. 2010, 37.
35. Snaiki, R.; Wu, T. Modeling tropical cyclone boundary layer: Height-resolving pressure and wind fields. J. Wind Eng. Ind. Aerodyn. 2017, 170, 18–27.
36. Shu, Z.; Li, Q.; He, Y.; Chan, P. Vertical wind profiles for typhoon, monsoon and thunderstorm winds. J. Wind Eng. Ind. Aerodyn. 2017, 168, 190–199.

37. Myers, V.A.; Malkin, W. Some Properties of Hurricane Wind Fields as Deduced from Trajectories; US Department of Commerce: Washington, DC, USA, 1961. Available online: ftp://ftp.library.noaa.gov/noaa_documents.lib/NOAA_historic_documents/WB/National_Hurricane_Research_Project_Report/NHRP_49_19 (accessed on 1 June 2018).

38. Niu, H.; Dong, G.; Ma, X.; Ma, Y. An analytical model of a typhoon wind field based on spiral trajectory. Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ. 2016, 231, 818–827.