New WMO Certified Tropical Cyclone Duration Extreme

TC Freddy (04 February to 14 March 2023) Lasting for 36.0 Days

Craig Earl-Spurr,[a] Sébastien Langlade,[b] Daniel Krahenbuhl,[c] Sim D. Aberson,[d] Manola Brunet,[e,f] Johnny Chan,[g,h,i] Chris Fogarty,[j] Christopher W. Landsea,[k] Blair Trewin,[l] Christopher Velden,[m] Robert C. Balling,[c] and Randall S. Cerveny[c]

Many extremes involving tropical cyclone (TC) activity (e.g., intensity, size, duration, rainfall, and mortality) have been part of the World Meteorological Organization (WMO)'s World Weather and Climate Extremes Archive (https://wmo.int/site/world-weather-and-climate-extremes-archive) since its creation in 2007. Most of the TC extremes were accepted into the Archive without formal investigation, having been taken from previous compilations such as that from the Atlantic Oceanographic and Meteorological Laboratory (https://www.aoml.noaa.gov/hrd-faq/).

In the WMO World Weather and Climate Extremes Archive, the record for longest duration of a TC had been accepted as 1994's TC John. John traversed the northeast, central, and northwest basins of the Pacific Ocean for 31 days, from 10 August to 10 September 1994, before it transitioned to become an extratropical system over the ocean. Additionally, TC John traveled the longest distance for a TC with a track length measured at that time of 13,180 km [8,190 mi, 7,115 n mi (1 n mi = 1.852 km)] (Fig. 1). Though John remained far from land areas, there were impacts from coastal flooding due to large waves and rainfall in the Hawai'ian Islands, and significant damage to a U.S. military base on Johnston Atoll.

More recently, during February and March 2023, TC Freddy traversed the Indian Ocean Basin from off the northwest coast of Australia to multiple landfalls in Africa (Fig. 1). It subsequently regenerated back into a tropical storm before dissipating over land. Due to its traversal near and over multiple landmasses, Freddy became the second-costliest TC in the southwest Indian Ocean and led to more than 1,400 fatalities across Madagascar, Malawi, Mauritius, Mozambique, and Zimbabwe, making it the third-deadliest TC in the Southern Hemisphere. Initial estimates suggested that the storm may have had a duration in excess of 31 days, exceeding that of TC John.

Following past procedures of the World Weather and Climate Extremes Archive, the WMO assembled a team of international TC and geospatial analysis experts to evaluate the data and determine if Freddy had achieved the record of longest- duration and longest-track tropical storm. The team consisted of experts from the Tropical Cy-

Though John remained far from land areas, there were impacts from coastal flooding due to large waves and rainfall in the Hawai'ian Islands, and significant damage to a U.S. military base on Johnston Atoll.

AFFILIATIONS: [a] Bureau of Meteorology, Perth, Western Australia, Australia; [b] RSMC La Reunion, Sainte Clotilde Cedex, France; [c] Arizona State University, Tempe, Arizona; [d] NOAA/AOML/Hurricane Research Division, Miami, Florida; [e] University of Rovira i Virgili, Tarragona, Spain; [f] University of East Anglia, Norwich, United Kingdom; [g] Shanghai Typhoon Institute, China Meteorological Administration, Shanghai, China; [h] Asia-Pacific Typhoon Collaborative Research Center, Shanghai, China; [i] School of Energy and Environment, City University of Hong Kong, Hong Kong, China; [j] Canadian Hurricane Centre, Dartmouth, Nova Scotia, Canada; [k] NOAA/NWS/National Hurricane Center, Miami, Florida; [l] Bureau of Meteorology, Melbourne, Victoria, Australia; [m] CIMSS/University of Wisconsin, Madison, Wisconsin

CORRESPONDING AUTHOR: Randall S. Cerveny, cerveny@asu.edu

DOI:10.1175/BAMS-D-24-0071.1

Manuscript received 1 March 2024, in final form 31 May 2024, accepted 6 June 2024

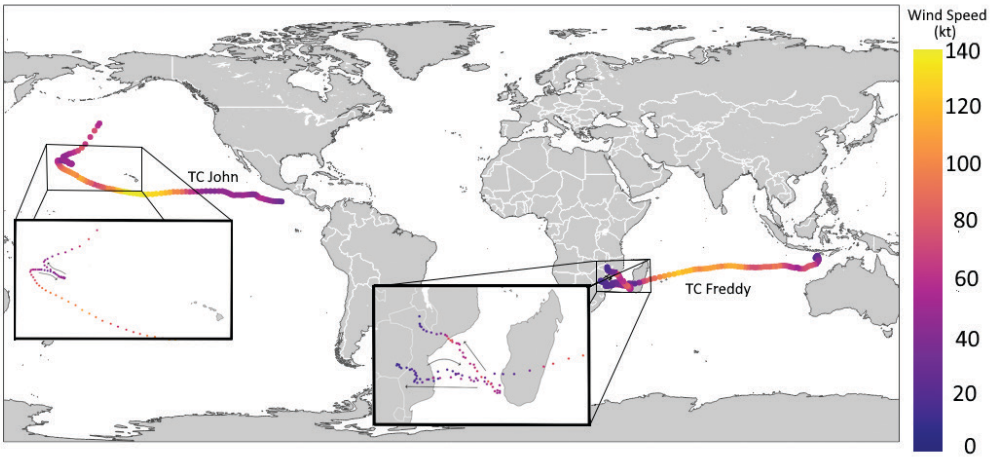

Fig. 1. Best tracks of TC John (1994) and TC Freddy (2023), with wind speed in color. Inset maps show the retrogression motion occurring in both TCs.

clone Warning Centre (TCWC) Melbourne (Bureau of Meteorology, Australia) and the Regional Specialized Meteorological Centre (RSMC) La Réunion (Météo France, France La Réunion) that forecasted TC Freddy, as well as scientists from Spain, Canada, Hong Kong China, and the United States.

The panel was immediately faced with several decisions regarding not only the data of TC Freddy but also with the accepted extremes recorded for TC John. Unfortunately, information on the methods used to compute the precise numbers (duration and distance) listed for TC John have been lost. Consequently, the team reconstructed the duration and distance numbers for TC John based on the best track data in the U.S. National Hurricane Center (NHC) HURDAT database, which comprises data from NHC and the Central Pacific Hurricane Center in the Western Hemisphere and (as best determined by the committee) by the Joint Typhoon Warning Center (JTWC) in the Eastern Hemisphere. An additional source of data for the Eastern Hemisphere component of the track (only) was a best track supplied by the Japan Meteorological Agency (JMA), the responsible agency for tropical cyclone data in that region. Tropical cyclone track data are maintained by a number of different WMO RSMCs, with each having responsibility for a different region; JTWC separately produces track data for tropical cyclones globally.

First, recalculation of TC John's distance and duration indicated that they were likely based on consideration of the entire best track from the initial observation to the last observation regardless of classification. Using the HURDAT best track data with all observations, the committee recomputed TC John as having 121 6-h observation periods for a duration of 732 h, or 30.50 days. Following past research, each observation is considered representative of a 6-h interval. It is likely that value of 30.5 days was rounded to 31 days when TC John's duration extreme was first recognized.

There are several methods that could be used to compute distances, all of which assume direct movement between each pair of observation points.

There are several methods that could be used to compute distances, all of which assume direct movement between each pair of observation points. The method most likely used in the early determination of TC distance was a linear Mercator-distance calculation based on distance between latitude–longitude observation points. The distance achieved by TC John using that method was 13,180 km (8,190 mi, 7,115 n mi). However, recommendations from the committee's geospatial analysts suggested that a set of spherically based calculations (assuming a perfectly spherical Earth) would be most accurate. Although the differences between linear Mercator and trig-

onometric spherical calculations are small, the spherical calculations using current methods are considered to be more precise. The method is based on the spherical law of cosines:

$$s_{AB} = arcos(\sin(\lambda_A) + \sin(\lambda_B) + \cos(\lambda_A)\cos(\lambda_B)\cos(\mu_A - \mu_B)) * r$$
$$= 2\, arsin\left[\sqrt{sin^2\left(\frac{\lambda_B - \lambda_A}{2}\right) + \cos(\lambda_A) + \cos(\lambda_B) sin^2\left(\frac{\mu_B - \mu_A}{2}\right)}\right] \quad (1)$$

where S_{AB} is the distance between observational endpoints A and B, r is the Earth's radius, and λ_A and λ_B and μ_A and μ_B are the respective latitudes and longitudes of points A and B. The necessity of inverting the cosine (top version) or sine (bottom version) magnifies rounding errors when the angles are small (e.g., between individual 6-h observations). Many of the problems and limitations of spherical distance calculations are avoided if the normal vector to the Earth ellipsoid (called an *n*-vector) is used to represent the positions. The *n* vector is a three-dimensional extension of the angle between a pair of two-dimensional vectors. The right side of Eq. (1) can be replaced by the *n*-vector equivalent, which produces a more computationally efficient computation than simple spherical calculations and avoids possible asymptotic inaccuracies.

Consequently, the committee employed that more complex approach. Given that positions are given in the best track data to the nearest 0.1° latitude/longitude, the committee recommended measurements rounded to the nearest 5 km with an uncertainty of 10 km. This accounts for rounding uncertainty only and not any other sources of uncertainty in determining the central location of the tropical cyclone. Using this spherical computation method, TC John's distance from first to last observation is 13,410 km, rather than the previously accepted 13,180 km.

An additional problem uncovered and addressed by the WMO committee with regard to the previously published TC John extremes was a lack of explicit acknowledgment of the TC status for those duration and distance values. In the middle of the HURDAT track (between 1800 UTC 2 September 1994 and 0600 UTC 3 September 1994), TC John's maximum sustained wind speed fell below 34 kt (1 kt ≈ 0.51 m s^{-1}), leading to its classification as a tropical depression, although the weakening is less in the available JMA dataset, which maintained tropical storm status throughout. For this WMO extremes evaluation, a merged HURDAT–JMA dataset was used with tropical storm intensity maintained throughout John's lifetime.

The committee was faced with addressing the question of whether the duration and distance values of a storm below tropical storm status should be considered in the calculations. The committee used the phrase "tropical cyclone" as a warm-core, nonfrontal synoptic-scale cyclone with organized deep convection and a closed surface circulation about a well-defined center. "Tropical storm" as used by the committee refers to a specific level of development of a tropical cyclone in some basins that is defined slightly differently by different agencies (Table 1). For TC John, the committee decided to accept only observations of at least tropical storm status (U.S. definition, 1-min average, or equivalent, see below) in WMO extremes decisions.

Based on that decision, TC John's duration and distance were computed for only the periods when it was of at least tropical-storm intensity. Using a merged HURDAT–JMA dataset, TC John had 119 6-h periods with maximum sustained 1-min wind speed above 34 kt for a combined du-

The committee used the phrase "tropical cyclone" as a warm-core, nonfrontal synoptic-scale cyclone with organized deep convection and a closed surface circulation about a well-defined center.

Agency	Tropical storm or "Named Storm" definition	Source
Bureau of Meteorology (Australia), SE Indian Ocean	A TC with a (10-min mean) wind speed of at least 34 kt or 63 kph, extending more than halfway around near the center and persisting for at least 6 h.	http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/understanding/tc-info/
Météo France (Reunion), SW Indian Ocean	A TC in which the estimated maximum 10-min wind speeds over a significant portion of the circulation is estimated to be between 34 and 63 kt. Significant portion of the circulation is more than 1 quadrant.	Langlade (2024, personal communication)
United States/Canada (Atlantic/E. Pacific basins)	A TC in which the maximum sustained surface wind speed (using the U.S. 1-min average) ranges from 34 kt (39 mph or 63 kph) to 63 kt (73 mph or 118 kph).	https://www.nhc.noaa.gov/aboutgloss.shtml#t
Philippines (W. Pacific basin)	A TC with the maximum wind speed of 62–88 kph or 34–47 kt.	https://www.pagasa.dost.gov.ph/information/about-tropical-cyclone
Japan (W. Pacific basin)	A TC with 17 ms^{-1} (34 kt) ≤ maximum wind speed < 25 ms^{-1} (48 kt).	https://www.data.jma.go.jp/multi/cyclone/cyclone_caplink.html?lang=en

Table 1. "Tropical storm" definitions based on selected global monitoring agencies.

ration of 714 h, or 29.75 days, and a distance of 13,160 km (HURDAT only values, which does not include the three observations it has below 34 kt: 29.0 days and 13,105 km).

Both the Bureau of Meteorology and Météo France, the responsible RSMCs for the south Indian Ocean, created best tracks for Freddy over their areas of jurisdiction. The committee merged the two datasets into a single best track (Fig. 1). However, before calculation of the distance and duration values could be addressed, the committee realized that another potential problem existed. The wind speed entries for TC John employed 1-min averaging, whereas those for Freddy employed a 10-min average. To properly adjudicate differences between basins, the committee considered upward adjustments to the TC Freddy intensity by 10%. Thus, a 34 kt 1-min average wind would be comparable to (34 kt − 3.4 kt), or 30.6 kt for a 10-min average. Given that best track data are rounded to the nearest 5 kt, observations of 35 kt for TC John are similar to about 30 kt for TC Freddy. For the purposes of providing a common basis for comparison, the minimum threshold for tropical storm status in this assessment was therefore set at 34 kt for a 1-min average and 30 kt for a 10-min average, recognizing that operational definitions of tropical cyclones vary between RSMCs and that this threshold may not correspond exactly with the operational thresholds used by warning agencies in particular basins. Therefore, the TC Freddy wind speed observations of 30 kt or greater were used for comparison with the TC John observations of 35 kt or greater. As with the TC John distances, given that positions are given in the best track data to the nearest 0.1° latitude/longitude, the committee recommended measurements rounded to the nearest 5 km with an uncertainty of 10 km.

Application of that decision yields a distance of 12,785 km between observations, meeting the threshold of 30-kt sustained wind speed for TC Freddy.

Consequently, the committee recommended, and the WMO Rapporteur of Weather and Climate Extremes accepted, the following records:

- The longest WMO-recognized duration for a TC is TC Freddy, determined using a 10-min sustained wind speed threshold of 30 kt, resulting in 144 6-h periods, 864 h, or 36.0 days. TC John is the second longest-lived TC (using 1-min maximum sustained wind speed threshold of 34 kt), with 119 6-h periods for a combined duration of 714 h, or 29.75 days, and a distance of 13,160 km.
- The WMO-recognized longest distance achieved for a TC remains TC John, with a distance of at least 13,160 ± 10 km (8,175 mi, 7,105 n mi) (and considering 1-min maximum sustained wind speed observations at or above 34 kt using the HURDAT dataset). To put that number in perspective, that distance is nearly 33% of the Earth's circumference. TC Freddy's distance is a close second with 12,785 ± 10 km (7,945 mi, 6,905 n mi) using a 10-min sustained wind speed threshold of 30 kt.

The decisions made in this WMO evaluation will aid in future comparison studies between TCs in differing oceanic basins or with TCs crossing forecasting jurisdictions. This study also demonstrates that significant improvements in technology (e.g., Geographical Information Science, or GIS, Analysis) now allow for a more precise determination of TC characteristics—such as distance traveled—than has previously been achieved. ●

The decisions made in this WMO evaluation will aid in future comparison studies between TCs in differing oceanic basins or with TCs crossing forecasting jurisdictions.

FOR FURTHER READING

Cerveny, R., 2024: *Judging Extreme Weather: Climate Science in Action*. Routledge, 208 pp.

Gade, K., 2010: A non-singular horizontal position representation. *J. Navig.*, **63**, 395–417, https://doi.org/10.1017/S0373463309990415.

Harper, B. A., J. D. Kepert, and J. D. Ginger, 2010: Guidelines for converting between various wind averaging periods in tropical cyclone conditions. TCP Sub-Project Rep., WMO/TD-1555, 64 pp., https://library.wmo.int/idurl/4/48652.

Kells, L. M., W. F. Kern, and J. R. Bland, 1940: *Plane and Spherical Trigonometry*. McGraw Hill, 290 pp.

Landsea, C. W., 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.*, **121**, 1703–1713, https://doi.org/10.1175/1520-0493(1993)121<1703:ACOIMA>2.0.CO;2.

Peterson, M. J., and Coauthors, 2023: New WMO certified megaflash lightning extremes for flash distance and duration recorded from space. *Bull. Amer. Meteor. Soc.*, **103**, 257–261, https://doi.org/10.1175/BAMS-D-21-0254.1.