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Reply to: Limitations of reanalyses for detecting tropical cyclone trends

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Check for updates

Savin S. Chand[1], Kevin J. E. Walsh[2], Suzana J. Camargo[3], James P. Kossin[4,5], Kevin J. Tory[6], Michael F. Wehner[7], Johnny C. L. Chan[8,9], Philip J. Klotzbach[10], Andrew J. Dowdy[2,11], Samuel S. Bell[6], Hamish A. Ramsay[12] & Hiroyuki Murakami[13]

REPLYING TO K. Emanuel *Nature Climate Change* https://doi.org/10.1038/s41558-023-01879-y (2023)

Chand et al.[1] demonstrated that tropical cyclone (TC) frequency in the Twentieth Century Reanalysis (20CR) dataset has declined globally and regionally during the twentieth century. Emanuel[2] has suggested that the decline is artificial, caused by increasing numbers of surface-pressure observations during this time.

Emanuel based this conclusion on a frequency analysis of a parameter that measures flow curvature in the lower troposphere (850-Okubo–Weiss–Zeta (OWZ)) applied to a different, but similar dataset. While we agree this analysis might be sound for TC precursor disturbances, it is not valid for TCs for the following reasons:

- The Emanuel analysis detects too many circulations. It includes other circulations that are too weak, too small, too dry and/or too short-lived to be TCs.
- The Emanuel analysis is not suitable for TC trend analyses, because TCs are a small proportion of the circulations identified.
- It is feasible that the broader class of circulations detected by Emanuel have no strong trend, while real TC numbers decline. This result would be consistent with environmental conditions becoming less favourable for TC formation under enhanced greenhouse warming.
- The argument by Emanuel assumes that models over-predict TC numbers when less constrained by surface-pressure observations. No evidence is provided to support this assumption.
- We also found downwards TC trends, using the same TC detector, in reanalysis datasets that do not assimilate surface-pressure observations.

Emanuel's TC proxy, 850-OWZ, is an instantaneous measure of near-surface flow curvature. In contrast, our TC detector is much more specific to TCs, detecting markedly fewer counts. We require measures of curvature at two levels of the lower troposphere to be present simultaneously in reduced-resolution data (that is, smoothed to reduce small-scale features), and the curvature requirements must be met at two neighbouring grid points[3,4]. This ensures a deep layer of much broader curvature than Emanuel's TC proxy. We also require the curvature region to be very moist, and the wind shear to be moderate or less. If these conditions are maintained consecutively for at least 48 h, only then a TC count is recorded. In contrast, Emanuel's proxy is counted at multiple grid points in every TC at every three-hourly location throughout a TC's lifetime including the spin-up and spin-down periods before it forms and after it decays. It will also be counted for numerous other non-TC circulations.

This assertion that Emanuel's proxy will identify many non-TC circulations is supported by a test reported in Tory et al.[3] (see their Table 1), where a relaxing of the TC detector requirements (to a level still much stricter than Emanuel's proxy) produced a false alarm rate >1,000%. We conclude that Emanuel's trend is probably accurate but represents a broad range of circulations. Our experiments with relaxed detection criteria (removing the time constraint) also revealed a different trend to our TC analysis, that is, an upwards trend between the two climate periods: pre-industrial (1850–1900) and the twentieth century (Fig. 1).

Finally, the number of counts in Fig. 1 of Emanuel shows that many more non-TC circulations are included in Emanuel's analysis. We estimate an annual number of Emanuel's proxy 'hits' of about 280,000. If we assume nine grid points per TC circulation (Typhoon Genevieve in

[1]Institute of Innovation, Science and Sustainability, Federation University, Ballarat, Victoria, Australia. [2]School of Geography, Earth and Atmospheric Sciences, The University of Melbourne, Melbourne, Victoria, Australia. [3]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA. [4]NOAA/National Centers for Environmental Information/Climate Science and Services Division, Madison, WI, USA. [5]The Climate Service, Madison, WI, USA. [6]Research and Development Branch, Bureau of Meteorology, Melbourne, Victoria, Australia. [7]Lawrence Berkeley National Laboratory, Berkeley, CA, USA. [8]Asia-Pacific Typhoon Collaborative Research Center, Shanghai, China. [9]School of Energy and Environment, City University of Hong Kong, Hong Kong, China. [10]Department of Atmospheric Science, Colorado State University, Fort Collins, CO, USA. [11]The ARC Centre of Excellence for Climate Extremes, The University of Melbourne, Melbourne, Victoria, Australia. [12]CSIRO, Environment, Aspendale, Victoria, Australia. [13]National Oceanic and Atmospheric Administration/Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA. e-mail: s.chand@federation.edu.au

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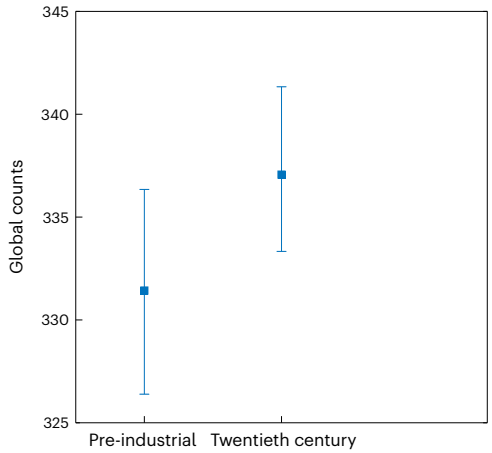

Fig. 1 | Global TC-like circulation counts. Total counts of systems in 20CR with relaxed OWZ detection criteria for the two climate periods: pre-industrial (1850–1900) and twentieth century. Error bars denote the 95% confidence intervals about the mean.

Supplementary Fig. 1b of Emanuel is ~3 × 3 grid points), 8 detections per day (3-hourly data frequency), an average 8-day TC lifetime (assuming a 2-day spin-up[3] plus an average of 6-day mature TC lifetime[5,6]) and 80 TCs per year, one might expect about 46,000 TC-related hits per year, leaving about 234,000 non-TC-related hits. Given that there are many smaller circulations also evident in Supplementary Fig. 1 of Emanuel (some as small as one grid point), some of which will be short-lived, they should comprise far fewer hits than a TC. For example, if the average-size circulation is 4 grid points and the average lifetime is 2 days (8 detections per day), each event will comprise 64 hits, yielding more than 3,600 non-TC events (233,920/64 = 3,655). Thus, for every real TC detected by Emanuel's proxy, there may be about 45 times as many non-TCs present (for example, 3,600/80 = 45).

Emanuel's TC proxy is very different to our detected TCs, and trends should not be assumed to be similar. The flat trend of Emanuel's TC proxy and our downwards TC trend supports the hypothesis that TC numbers are declining in a warming world due to a more hostile formation environment. TCs develop from disturbances with low-level flow curvature, but only a fraction of these disturbances produce TCs. In a more hostile environment, even fewer disturbances will develop into TCs, leading to different trends for these disturbances and TCs, with the latter weaker than the former. Moreover, given that Emanuel's proxy is counted three-hourly throughout, compared with a single TC count, changes in TC longevity will also contribute to different trends between Emanuel's proxy and TCs. For example, if TC lifespans increase in a warming world (which is a plausible hypothesis), then TC trends will again be weaker than trends identified by Emanuel's proxy.

By design, only surface-pressure observations are assimilated in 20CR, which have increased over time, particularly from the mid-twentieth century during a period of rapid global warming[7]. We argue that this increase in surface-pressure observations does not affect the 20CR-detected TCs substantially and that our conclusion of downwards TC trends remain robust. The critique by Emanuel implies that the 20CR-detected TCs were unrealistically high during the pre-industrial period, and as observation densities improved, the assimilation procedure forced TC numbers to be more realistic, hence the downwards trend. However, there is no evidence for a high bias. A low bias is equally plausible, in which case the downwards trend we show would have been underestimated. This uncertainty around potential biases partly inspired our systematic examination of many additional climate datasets and model experiments, in which downwards trends dominated.

A reanalysis dataset that does not assimilate surface-pressure observations, the European Centre for Medium-Range Weather Forecasts (ECMWF) Coupled Reanalysis of the Twentieth Century (CERA-20C)[8], served as an independent verification of TC trends. In addition, data from two high-resolution climate model experiments were used: Database for Policy Decision-Making for Future Climate Change (d4PDF)[9] and International CLIVAR Climate of the Twentieth Century Plus Detection and Attribution project (C20C + D&A)[10]. Both comprised a historical 'reference' period and a non-warming pre-industrial control period, although with different experimental settings. All datasets indicated global and hemispheric downwards trends due to warming, as well as most TC basins individually.

We acknowledge that all climate datasets have limitations. However, as improved reanalysis products and climate models become available, further insights can be drawn not only on TC frequency trends but also on other TC characteristics.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-023-01880-5.

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Data availability

The 20CR dataset used in Fig. 1 is publicly available at https://portal.nersc.gov/archive/home/projects/incite11/www/.

Author contributions

S.S.C. and K.J.T. wrote the initial reply. S.S.C. did the additional analysis. All authors reviewed the reply and provided necessary feedback.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Savin S. Chand.

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