LETTER

Are global tropical cyclones moving slower in a warming climate?

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Abstract

The local tropical-cyclone-related rainfall totals largely depend on the rain rate near the center and the translation speed of a tropical cyclone. Understanding how they respond to a changing climate has been a hot topic. A recent astounding study reported a 10% slowdown in global tropical-cyclone translation speed over the past 68 years (1949–2016) and implicitly related this to the weakening of tropical circulation forced by the anthropogenic warming. It thereby suggested that it might result in more local rainfall totals in a warming climate. However, here this study shows that no robust and significant observational and modeling evidences reveal that they are. The data artefacts introduced by the changes in measurement practices, particularly the introduction of satellite capabilities since the 1970s, are likely the main source of heterogeneities leading to such disagreement. The global slowdown of tropical-cyclone translation speed becomes indeterminate and a significant global speedup trend is even found over land if the records in more reliable satellite sensing era period starting from 1970 are examined, where this period is also the most pronounced warming period in the last half-century. The relationship between the slowdown of tropical cyclones and anthropogenic warming is therefore not apparent and the relevant potential increase in local rainfall totals in the future warming climate is suspicious.

1. Introduction

The amount of local tropical-cyclone-related rainfall is known to be proportional to the rain rate near the center and inversely proportional to the translation speed of tropical cyclone (Lonfat \textit{et al} 2004, Emanuel 2017, Rißer and Wehner 2017, Kossin 2018a, Hall and Kossin 2019). Former highly correlates with tropical-cyclone intensity (Lonfat \textit{et al} 2004), while the latter is largely driven by the environmental steering flow in which the tropical cyclone is embedded (Chan 2005). Given the same rain rates of tropical cyclones, the slow-moving tropical cyclones would result in more local rainfall totals than the fast-moving tropical cyclones do. The projecting increase in atmospheric water-vapor capacity in a warming climate (Held and Soden 2006), thus the increases in global precipitation and extremes (Allan and Soden 2008, Karin \textit{et al} 2013, Hegeral \textit{et al} 2015, Kitoh and Endo 2016, Prein \textit{et al} 2017), and the increase in rain rate near the center of tropical cyclone would be expected and make the situation even worse (Knutson \textit{et al} 2015, Walsh \textit{et al} 2016). Hence, understanding the responses of tropical-cyclone intensity and tropical-cyclone translation speed to the warming climate has become important. This would be particularly insightful to the cities along the coast for better local and contingency planning (Rappaport 2000, Woodruff \textit{et al} 2013, Mori and Takemi 2016).

Recently, Kossin (2018a) reported that the global tropical-cyclone translation speed over the 68 year period 1949–2016 was slowing down by 10% and implicitly related this to the weakening of the tropical circulation forced by the anthropogenic warming (Held and Soden 2006, Vecchi \textit{et al} 2006, Vecchi and Soden 2007, Coumou \textit{et al} 2015, He and Soden 2015, Grise and Polvani 2017, Mann \textit{et al} 2017). He thereby suggested that it might result in more local rainfall totals in the warming climate, particularly over land. Such findings and implications have been widely
interpreted, broadcasted and forwarded by various social media and sectors since then (Guglielmi 2018, Patricola 2018, Shultz et al 2018). Unfortunately, his study was imprecise and questioned. The early work of the present study pointed out two deficits in his calculation of tropical-cyclone translation speed and an author correction had been made after (Kossin 2018b). Although the correction shows no material impact on the key conclusions of the original study on a global scale, it has a number of varying effects on regional scales. Such varying effects are more apparent for tropical cyclones over land. On top of that, this study further suggests that the slowdown of global tropical-cyclone translation speed stated by Kossin (2018a) may not be a real climate signal or it may be exaggerated, which is consistent with what Moon et al (2019) and Lanzante (2019) commented coincidentally.

2. Data and methods

Data and methods are mostly based on those of (Kossin’s 2018a, 2018b), but a subset of data over period 1970–2016 was mainly investigated. The best-track data from the International Best Track Archive for Climate Stewardship (IBTrACS) (Knapp et al 2010, Schreck et al 2014) and the 2 min gridded global relief for both ocean and land areas data (ETOPO2v2) from the NOAA’s National Centers for Environmental Information were examined. The best-track data from the Joint Typhoon Warning Center and the US National Hurricane Center (NHC) were combined to provide global coverage. To avoid counting the spurious tracks while retaining the physical cases, the duration threshold of a minimum of 3 d is set because it is unlikely that a spurious track would exceed 2–3 d. It is noted that the best-track data starting from 1970 is intentionally chosen here, rather than 1949 as in Kossin (2018a) or any other years, because the IBTrACS has clearly stated that ‘due to the disparity between tropical-cyclone positions prior to 1970, some tracks during that period may not be properly merged’. Such disparity is likely due to the limited observations in the pre-satellite era. Inclusion of data before 1970 may therefore introduce un-necessary and unmeasurable uncertainties that could weaken the robustness of the study and even lead to misleading climate implications. To be in line with the IBTrACS, the periods before and after 1970 are defined as the pre-satellite era and satellite era, respectively, in this study. Similar partition can be also found in Moon et al (2019) and Lanzante (2019). Notes that period 1970–2016 is indeed the longest time period that we can retrieve from the best-track position data with high confidence. Although the first early 21 years’ data (1949–1969) are sacrificed, according to the classical period of climate defined by the World Meteorological Organization (Arguez and Vose 2011) (i.e. period over 30 years long), the later 47 year period is long and representative enough for giving climatic signals. The global land-ocean temperature index from the NASA’s Goddard Institute for Space Studies was used as a proxy of anthropogenic warming. The annual-mean global temperature anomaly is the difference between global surface temperature relative to 1951–1980 average temperatures. To a first approximation, though global-mean temperature accounts both natural and anthropogenic forcings, it can be treated as a proxy of anthropogenic warming because anthropogenic forcings highly dominate the warming climate in twentieth-century (Meehl et al 2004).

Translation speed is calculated by six-hourly synoptic time positions along each tropical-cyclone track. Great circle arc is used to calculate the distance between positions. Linear regression is applied to estimate the trend. The percentage change is calculated by the difference between the last and first points of the best-fit trend line over the first point. Over-land positions are determined by where the topographic elevation is greater than 0 m. If either one or both of the two positions used to calculate the translation speed are over land, the speed is classified to be an over-land speed, else it is over-water. Statistical significance of trends is based on the two-sided 95% confidence intervals.

3. Results

The time series and trends of annual-mean global and hemispheric tropical-cyclone translation speed are shown in figure 1. The global and hemispheric translation speeds of tropical cyclones were significantly decreasing over the full 68 year period of record 1949–2016 (table 1). The tropical cyclones in tropics (within ±30° of the equator) and high latitudes (30° away from the equator) were significantly slowing down, in which the slowdown rate of the latter is much evident than the former (figure 2). However, it is noteworthy that the global and Northern Hemisphere slowdown trends are almost gone (−0.00 and −0.01 km h⁻¹ yr⁻¹, respectively) and the slowdown in tropics becomes insignificant (−0.01 km h⁻¹ yr⁻¹) over the subset 47 year period of record 1970–2016 (figures 1, 2 and table 1). Although the slowdown trend in the Southern Hemisphere retains and the tropical cyclones at high latitudes tend to speed up (but insignificant), they account for only a small portion, 30% and 10%, of total records, respectively. Thus, the big signal, that is no significant global trend in translation speed of tropical cyclones in the satellite era, is largely promising. Remarkably, even 1970–2016 is the most pronounced warming phase in the last half-century, the corresponding relationship between global tropical-cyclone translation speed and global-mean temperature anomaly is very weak and insignificant (r = −0.10), although there is less expectation for
a one-to-one relationship (Kossin 2019). Such inconspicuous trends and weak correlation suggest that the warming climate and its indirect consequences associated, like the weakening of the tropical circulation, do unapparent effect on the tropical-cyclone translation speed. Notes that the linkage between global-mean temperature anomaly and tropical-cyclone translation speed discussed here does not constitute a detection and attribution analysis, but shows as a brief disproof or another view to (Kossin’s 2018a, 2019). More works are needed to achieve this.

Figure 2 shows that the translation speed of tropical cyclones at high latitudes is about twice that at low latitudes. In addition, the translation speed of tropical cyclones at high latitudes is shown to be sharply decreasing in the pre-satellite era, but mildly reversed after, though both are statistically insignificant. These indicate that the signal of the global slowdown of tropical-cyclone translation speed in 1949–2016 is largely dominated by the fast-moving tropical cyclones at high latitudes in the pre-satellite era. Nevertheless, it is noted that the records at latitudes higher than 30° account for only about 13% of the total records on average in the pre-satellite era. Second, the estimations of translation speeds of tropical cyclones at the high-latitude open oceans in the pre-satellite era could be in low confidence because the available observations (e.g. ship reports, rawinsondes, meteorological stations, etc) at high latitudes were much sparser than those at low latitudes at that time (Frank and Gray 1980). In
other words, using such a very small portion of low-confidence data in the pre-satellite era to conclude the sign of trend and interpret the climate implication could be arbitrary.

Tables 2 and 3 suggest that the global slowdown of tropical-cyclone translation speed in 1949–2016 could be a result of data artefacts, including tracking uncertainties, measurement limitations, and changes in measurement practices, particularly the introduction of satellite remote sensing since the 1970s (Knapp et al 2010, Schreck et al 2014). Dramatic increases of best-track records are found after the pre-satellite era in most regions, especially at low latitudes. The annual mean of global tropical-cyclone position records increases abruptly by 37% (from 1898 to 2594), in which those in the eastern North Pacific, western North Pacific and Southern Hemisphere <100° E increase by +196% (from 151 to 447), +40% (from 617 to 866) and +34% (from 289 to 386), respectively (table 2). The increases of tropical-cyclone position records at low latitudes in various regions ranging from +9% to +238% (table 3). The change in the annual mean of global tropical-cyclone position records at low latitudes to the total records increases from 87% in the pre-satellite era to 90% after. Furthermore, it is interesting that there is no record in the eastern North Pacific at 0–10° N latitude band before 1970. Such large changes are far beyond any known climate variability (both internal and external). The data artefacts introduced by the introduction of satellite data after the 1970s are therefore undoubtedly an
Table 2. Annual-mean numbers and percentage changes of tropical-cyclone position records by period and region (NH, Northern Hemisphere; SH, Southern Hemisphere; NA, North Atlantic; WNP, western North Pacific; ENP, eastern North Pacific; NI, Northern Indian). Significant changes, based on the one-sided 95% confidence interval, are shown in bold.

| Period                  | Number of Tropical Cyclones | Change (%) |
|-------------------------|----------------------------|------------|
| 1949–1969 (Pre-satellite) | 1898                       | +37        |
| 1970–2016 (Satellite)    | 2394                       | +43        |
| NH (water)              | 1111                       | +50        |
| NH (land)               | 162                        | –9         |
| SH (water)              | 557                        | +30        |
| SH (land)               | 68                         | –20        |
| NA (water)              | 343                        | +10        |
| NA (land)               | 299                        | +12        |
| WNP (water)             | 617                        | +40        |
| WNP (land)              | 563                        | +41        |
| ENP (water)             | 151                        | +196       |
| ENP (land)              | 146                        | +201       |
| NI (water)              | 4                          | +75        |
| NI (land)               | 163                        | –23        |
| SH (<10°E, water)       | 289                        | +34        |
| SH (<10°E, land)        | 271                        | +37        |
| SH (>10°E, water)       | 18                         | –17        |
| SH (>10°E, land)        | 336                        | +16        |
| SH (>40°E, water)       | 286                        | +23        |
| SH (>40°E, land)        | 50                         | –20        |

apt explanation for the above. The substantial change in number of global best-track records over water (from 1668 to 2391; 43% increase) and the slight change over land (from 230 to 203; 12% decrease) suggest that more tropical cyclones were not well-tracked and undercounted in the pre-satellite era over water than those over land such that some should have been missed, especially those in the open oceans where the observations were very limited.

Let us take an example which is most likely the case in the pre-satellite era: data undercount. If a slow-moving tropical cyclone has been missed or some valid position points before the first track record have not been detected, where the first track record is tracked somewhere in the middle of tropical-cyclone lifetime, this would likely lead to overestimation of the tropical-cyclone translation speed. It is because tropical cyclone generally forms at tropical open water and staggers at first, particularly at the genesis stage where the structure of tropical cyclone is not well-organized and the steering flow is comparatively not prevailing at low latitudes in general (e.g. figure 2). Counting less slow-moving samples would increase the mean of tropical-cyclone translation speed, but vice versa if more slow-moving samples are counted which is more likely happening in the satellite era. This explains why even there is a mild global speedup of tropical-cyclone translation speed at high latitudes in the satellite era (figure 2), it does not contribute and modify the overall trend much (figure 1).

On finer regional scales, the inter-basin variability in tropical-cyclone translation speed is observed. It is worth noting that the findings and interpretations deduced from period 1970–2016 do also not largely ‘inherit’ or retain those deduced from 1949 to 2016. In 1970–2016, slowdowns are found in the western North Pacific, eastern North Pacific, and Southern Hemisphere, while speedups are found in the North Atlantic and Northern Indian regions (figure 3 and table 1). Although significant slowdowns in the eastern North Pacific and the region around Australia are recorded, the significant slowdown trend of tropical cyclones over the western North Pacific no longer persists and is even vanished when the study period is changed from 1949–2016 (−0.05 km h⁻¹ yr⁻¹) to 1970–2016 (−0.00 km h⁻¹ yr⁻¹). As the tropical-cyclone activity in the western North Pacific dominates in the globe and Northern Hemisphere (table 2), the corresponding significant slowdown trends of tropical-cyclone translation speed are also gone (figure 1 and table 1).

In addition, comparing to the findings inferred from period 1949 to 2016, the slowdown of tropical cyclones over water is no longer significant in 1970–2016, which is comparable to the global statistics, while the speedup of global tropical-cyclone translation speed over land becomes significant in 1970–2016 (+0.05 km h⁻¹ yr⁻¹; 13% increase; table 1). The relevant local rainfall totals over land are therefore expected to decrease rather than an increase in general, which contradicts what Kossin (2018a) and Hall and Kossin (2019) suggested. This forms another important dispute that we should keep an eye on. Figure 4 shows that except those in the eastern North Pacific and east of Australian regions, positive trends are observed in the North Atlantic, western North Pacific, northern Indian, Madagascar and the east coast of Africa regions, although none is significant (table 1).

Inspiringly, the chief result and implication of this observational study agree well with the comprehensive climate modeling study conducted by Knutson et al. (2013). Their climate models, which simulated the future Atlantic tropical cyclones in the twenty-first century, do not project tropical cyclones will slow down, even if those atmospheric tropical circulation patterns are modeled to weaken in the warming climate. Such a positive cross-validation between their model simulations and observations of this study indeed consolidates the robustness of both works, suggesting that the global slowdown of tropical-cyclone translation speed proposed by Kossin (2018a) may not be a real climate signal or it may be exaggerated.
4. Conclusions and discussion

Are global tropical cyclones moving slower in a warming climate? No rigorous and significant observational and modeling evidences show that it is. The relationship between the slowdown of tropical-cyclone translation speed and anthropogenic warming is not apparent. The potential increase in local rainfall totals over land by the tropical cyclones in the future warming climate is suspicious. In contrary, the local
tropical-cyclone-related rainfall totals over land are more likely to decrease. Notes that this is not a detection and attribution study, but the one raising other views and concerns to (Kossin’s 2018a, 2019). The data artefacts introduced by the changes in measurement practices, particularly the introduction of satellite remote sensing capabilities since the 1970s, are likely the main source of heterogeneities leading to such disagreement. Thousands of cares must be taken when dealing with the tropical-cyclone best-track data in the pre-satellite era.

Perceptibly, there is a change point of tropical-cyclone translation speed in the Southern Hemisphere at 1981 (see figure 1), however, the reason for this is
not clear. As the satellites in the early satellite era (1970–1980) were mainly polar-orbiting which covered the globe, the relevant data heterogeneities in this period should be more likely in a global sense, but not regional. Nonetheless, changing the study period from 1970–2016 to 1981–2016 in the Southern Hemisphere would substantiate the conclusion of the present study further. The trend of tropical-cyclone translation speed in the Southern Hemisphere becomes insignificant and indeterminate over period 1981–2016 (+0.02 km h⁻¹ yr⁻¹). This speedup trend is dominated by the tropical cyclones west of 100° E (+0.05 km h⁻¹ yr⁻¹). Apart from these, no other significant material changes are found between 1970–2016 and 1981–2016 (not shown).

It is declared that this study is not the follow-up of Moon et al (2019) and Lanzante (2019). We worked independently and doubted the global slowdown of tropical-cyclone translation speed suggested by Kossin (2018a) coincidentally, though Kossin (2019) still insists. We share the same concern that the data quality prior to the satellite era may be incomplete and unreliable and we dispute that the trends in Kossin (2018a) do not decrease monotonically over the full period of record but rather are due to step changes. Lanzante (2019) suggested it is likely due to a combination of natural internal climate variability and an abrupt increase of satellite observations after the 1970s. The multidecadal variability of atmosphere or ocean (Sun et al 2017, Lanzante 2019), which directly or indirectly modulates the atmospheric circulation and thus modifies the steering flow of tropical cyclone, could be another possibility resulting in the change points of tropical-cyclone translation speed. Yet it is noteworthy that, the significant regional increases in annual-mean number of records from the pre-satellite era to satellite era found in this study (ranging from +9% to +238%; see table 3) are much more prominent than those in Lanzante (2019) (ranging from +0% to +20%). This therefore further justifies the possible heterogeneities of best-track data and reinforces the robustness of the study.

More works, for example, further analyses with stratification of tropical-cyclone intensity, examination of local rainfall totals and attribution studies, are needed to determine the expected change in tropical-cyclone translation speed and its relevant consequences as a function of warming forcing. Besides, we should stay tuned for the significant speedup of global tropical-cyclone translation speed over land in the last half-century. The work on the multidecadal atmospheric or oceanic variability on tropical-cyclone translation speed is also indispensable.

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Data availability statement

The IBTrACS best-track data file ‘Allstorms.ibtracs_all_v03r10.nc’ was taken from https://ncdc.noaa.gov/ibtracs/. The ETOP02 data were downloaded from https://ngdc.noaa.gov/mgg/global/etopo2.html. The global land-ocean temperature index was retrieved from https://climate.nasa.gov/vital-signs/global-temperature/.

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