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Climate control of the global tropical storm days (1965–2008)

Bin Wang,[1,2] Yuxing Yang,[1] Qing-Hua Ding,[2] Hiroyuki Murakami,[3] and Fei Huang[1]

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[1] The tropical storm days have a consistent global record over the past 44 years (1965–2008), which provides an alternative metric for integrated information about genesis, track, and lifespan. Seasonal-reliant singular value decomposition is performed on the fields of the global storm days and sea surface temperature by using the "best track" data. The leading mode, which dominates the variability of the global total number of storm days, displays an east-west contrast between enhanced activity in the North Pacific and reduced activity in the North Atlantic and a north-south contrast in the Southern Hemisphere oceans between active tropics and inactive subtropics, which are coupled with the El Niño and a positive phase of the Pacific Decadal Oscillation (PDO). The second mode reveals a compensating trend pattern coupled with global warming: upward trends over the North Atlantic and the Indo-Pacific warm pool (17.5°S–10°N, 70–140°E) and downward trends over the Pacific, especially the South Pacific. However, the global total number of storm days shows no trend and only an unexpected large amplitude fluctuation driven by El Niño-Southern Oscillation and PDO. The rising temperature of about 0.5°C in the tropics so far has not yet affected the global tropical storm days. **Citation:** Wang, B., Y. Yang, Q.-H. Ding, H. Murakami, and F. Huang (2010), Climate control of the global tropical storm days (1965–2008), *Geophys. Res. Lett.*, *37*, L07704, doi:10.1029/2010GL042487.

1. Introduction

[2] The impact of the rising sea surface temperature (SST) on tropical cyclone (TC) activity is one of the great societal and scientific concerns. With the observed warming of the tropics of around 0.5°C over the past 4 to 5 decades, detecting the observed change in the TC activity may shed light on the impact of the global warming on TC activity. Recent studies of the trends in the existing records of hurricane intensity have resulted in a vigorous debate in academic circles [e.g., *Emanuel*, 2005; *Webster et al.*, 2005; *Chan*, 2006; *Klotzbach*, 2006; *Sriver and Huber*, 2007; *Kossin et al.*, 2007]. Much of the debates centered on uncertainties of the hurricane intensity records [*Landsea et al.*, 2006].

[3] Here we choose the number of tropical storm days as an alternative metric for measuring TC activity, because storm occurrence, which reflects storm population over the full storm life cycle, has a more reliable and longer record (from 1965 to 2008) than intensity, and more suitable for detection of trends. For a given basin, the total number of storm days equals to the TC genesis number multiplied by the basin mean lifespan. The spatial distribution of the storm days can indicate the changes in TC tracks, which has rarely examined over the global domain. The number of storm days provides integrated information about TC genesis, lifespan, and tracks. The lifetime is also, to some extent, related to the peak intensity and thus the power dissipation index [*Emanuel*, 2005], thus, knowledge of the variability of storm days may provide a basis for further understanding changes in the accumulated TC kinetic energy and PDI.

[4] Tropical cyclones occur in nearly all tropical and subtropical ocean basins, including the western North Pacific (WNP), eastern North Pacific (ENP), North Atlantic (NAT), North Indian Ocean (NIO), and South Hemisphere Ocean (SHO). However, the previous studies of TC climate variability have mostly focus on individual ocean basins. The linkage of the TC climate variations among various ocean basins has been examined only in the last decade. *Lander and Guard* [1998] first noticed the extreme "prolific" Atlantic activity concurring with low activity in other basins; hence, the global TC genesis does not show significant relationship with the El Niño-Southern Oscillation (ENSO). Based on a common factor analysis, *Elsner and Kocher* [2000] found the strongest factor of TC activities being correlated with the North Atlantic Oscillation (NAO). However, *Frank and Young* [2007] showed that the ENSO produces the largest effects on interannual variation of global TC activity. *Webster et al.* [2005] has shown that the number of cyclones and cyclone days has decreased in all basins except the NAT during the past decade.

[5] The previous studies of the variability of TC activity have mostly dealt with total numbers in individual basins without resolving the spatial variation within each basin; hence coherent variation across the boundaries of different basins was not revealed. Here we examine cross-basin, spatial-temporal variations of TC storm days. Revealing the coherent global pattern of TC variability is particularly enlightening for understanding primary mechanisms driving the global TC variation. Our primary concerns are: what are the coherent modes of variability of TCs on global scale? What determine the variability? And is there any trend in the global storm days?

2. Data and Analysis Methods

[6] The positions of TCs in our study were derived from the "best track" data provided by US Navy's Joint Typhoon Warning Center (JTWC) for the WNP, NIO and SHO

[1]Physical Oceanography Laboratory and Ocean-Atmosphere Interaction Laboratory, Department of Marine Meteorology, Ocean University of China, Qingdao, China.

[2]Department of Meteorology and International Pacific Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, USA.

[3]Advanced Earth Science and Technology Organization, Meteorological Research Institute, Tsukuba, Japan.

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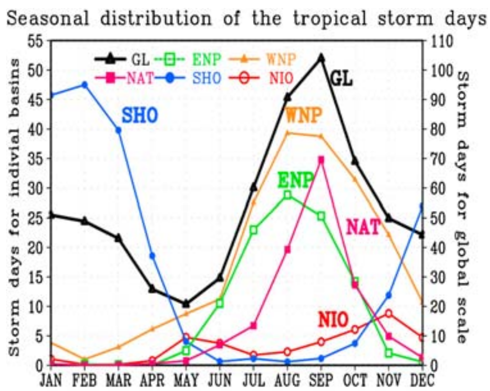

Figure 1. Seasonal distributions of the climatological mean number of tropical storm days as functions of calendar month for the global domain (GL) and five individual basins. The left-hand side tick marks is for the five individual basins and the right hand side is for the global total.

(www.npmoc.navy.mil/jtwc.html) and by the National Oceanographic and Atmospheric Administration's National Hurricane Center (NHC) for the NAT and ENP (www.weather.unisys.com/hurricane/index.html). To diminish the number of missing cyclones, we chose the period of examination starting from 1965 when satellite monitoring of weather events became available. The storm days that are defined in this study include occurrence of all TCs that possess 1-min sustained surface wind of 20 kt or greater. The dataset for such defined storm days is basically homogeneous over the entire analysis period and over the global domain except the NIO, where the storm days show a drastic decrease around 1978 likely owing to the changes in measuring and reporting practice. Since the NIO storm days account for only 5% of the global total, the data inhomogeneity in this region has insignificant impact on our results. To study the spatial-temporal variations of TC storm days, the "best track" data for TC positions reported every 6 hours were transformed into the area-averaged TC frequency occurring at each 2.5×2.5 degree grids. For better spatial continuity, the raw data at each grid were smoothed by a 9-point weighted smoother that conserves the total number of storm days. The SST data were obtained from the National Centers for Environmental Prediction reanalysis data (www.cdc.noaa.gov/cdc/reanalysis).

[7] Use of the calendar year to study year-to-year variation of global TC activity is obviously inadequate. The seasonal distribution of the global storm days (Figure 1) indicates a minimum in May with double peaks occurring in September (due to the Northern Hemisphere (NH) TCs) and January–February (due to the Southern Hemisphere (SH) TCs). For this reason, we define a "tropical cyclone year" as the yearlong period starting from June 1 to the following May 31 which includes a NH TC season from June 1 to November 30 followed by a SH TC season from December 1 to May 31. This definition differs from those used in the previous studies of global TC activity and the differences are important for study of interannual variability.

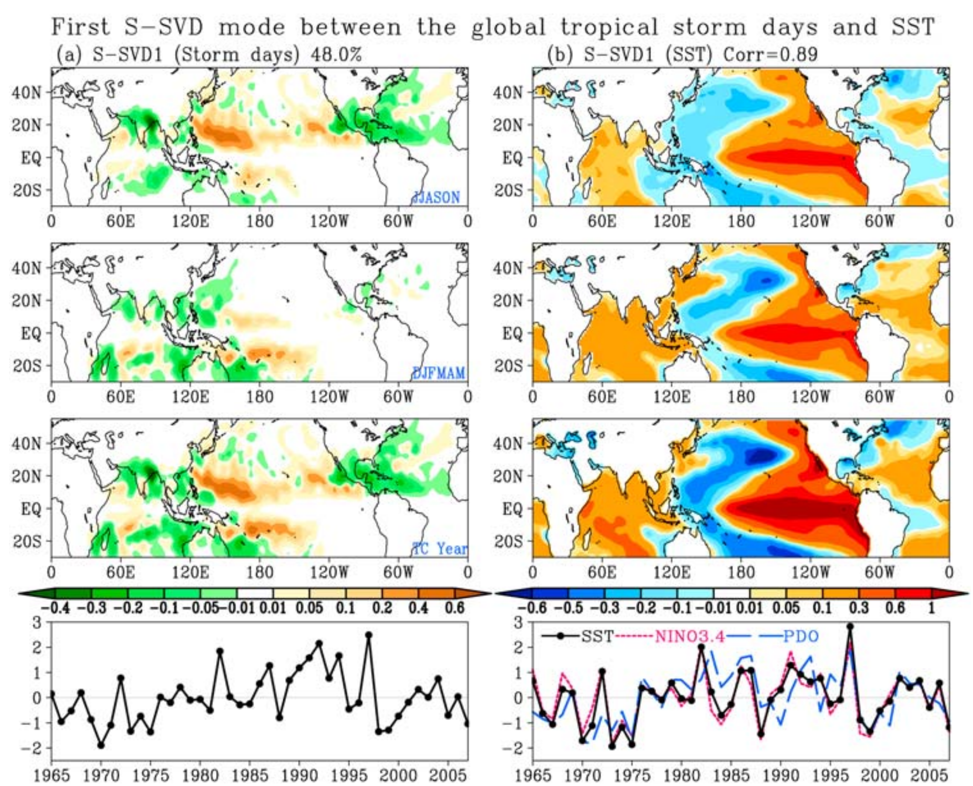

Figure 2. First S-SVD mode between tropical storm days and SST: (a) spatial patterns of for the storm days during (top) the NH TC season (JJASON), (upper middle) the SH TC season (DJFMAM), and (lower middle) the entire TC year, and (bottom) the corresponding time series. (b) Same as Figure 2a except for the SST anomalies. The Nino3.4 index and the PDO index were plotted on Figure 2b for comparison.

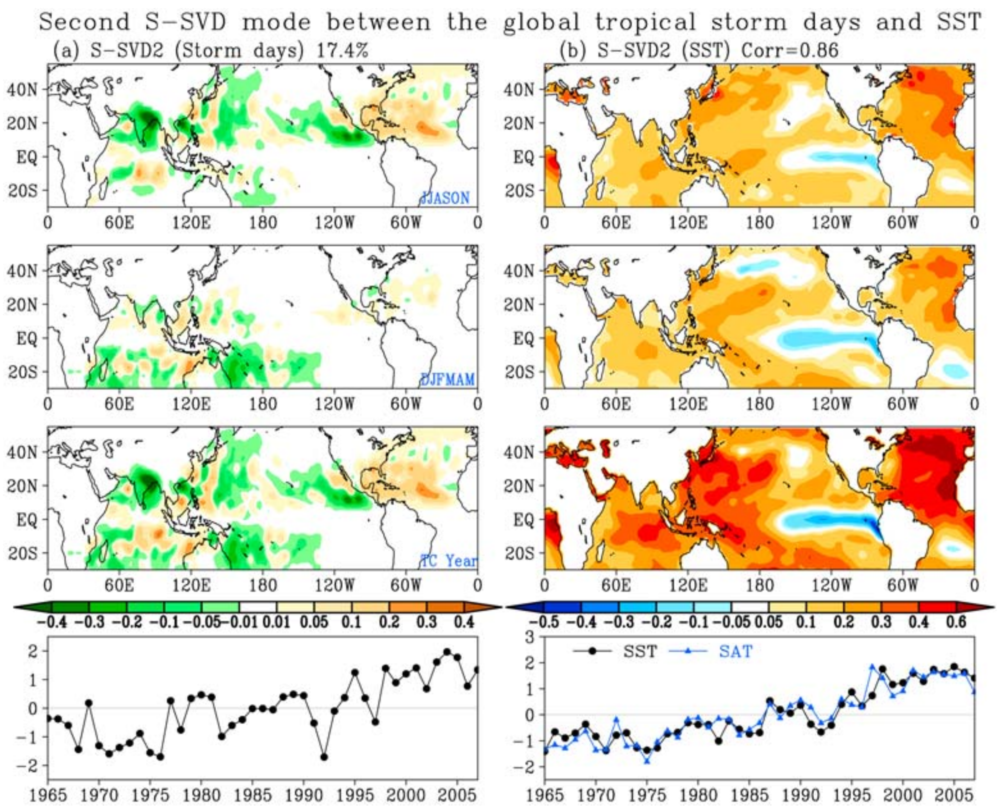

Figure 3. Same as Figure 2 except for the second S-SVD mode between storm days and SST. The global mean surface air temperature (SAT) is also shown in Figure 3b for comparison with the SST trend.

[8] The singular value decomposition (SVD) analysis was used to effectively isolate important coupled modes of variability between two fields [*Bretherton et al.*, 1992]. In order to unravel seasonally evolving variability of TC activity from year to year coupled to the lower boundary forcing, mainly the SST, we apply Season-reliant SVD (S-SVD) analysis, in which a covariance matrix is constructed by using two consecutive (the NH and SH) seasonal mean anomalies for each TC year as a "yearly block." After the SVD is performed, the yearly block is then decomposed into two consecutive seasonal anomalies so that seasonally evolving patterns of storm day anomalies can be obtained for each eigenvector. The detailed method is described by *Wang et al.* [2003] and *Wang and An* [2005].

3. Leading Coupled Mode of Climate Variation of the Global TC Activity and SST

[9] Figure 2 shows the singular vectors of the leading S-SVD mode (S-SVD1), which explains 48% of the total square covariance between storm days and SST. In the NH TC season (Figure 2a), a striking east–west see-saw pattern is seen with opposing polarities between the North Pacific and NAT. During the SH TC season, storm occurrence increases in the tropics (equatorward 20°S) and decreases in the subtropics (poleward 20°S) in the SHO. For the annual TC activity, the leading mode is characterized by 1) an east–west contrast between enhanced activity in the North Pacific and reduced activity in the NAT, and 2) a north–south contrast in the SHO between active tropics and inactive subtropics. The corresponding SST pattern (Figure 2b) shows a combined structure of the ENSO and Pacific decadal oscillation (PDO) [*Mantua et al.*, 1997]. The temporal evolution of the *annual storm days* associated with the S-SVD1 is highly correlated with the Nino3.4 SST anomaly (r = 0.83) and PDO index (r = 0.58), but insignificantly correlated with the NAO index [*Li and Wang*, 2003] (r = 0.06). Therefore, the modes-SVD1 is primarily regulated by the ENSO and to a less degree by the PDO, but not by the NAO.

[10] ENSO enhances TC activity over the Indo-Pacific Ocean primarily by shifting TC genesis positions equatorward, thus increasing TCs' lifespan. In the WNP, during El Niño the locations of TC genesis move southeastward [*Chan*, 1985] and TCs' mean life span increases form 4 days during strong La Niña events to 7 days during strong El Nino events [*Wang and Chan*, 2002]; likewise in the ENP the number of intense hurricanes, thus the mean lifespan increases [*Gray and Sheaffer*, 1991]. In the SHO more TCs develop in its northern part [*Camargo et al.*, 2007], thereby increasing the storm days equatorward of 20°S. The decrease of tropical storm days over the NAT is mainly due to El Niño-enhanced vertical shear that suppresses TC genesis; and the reduction of TC activity over the subtropical SHO is primarily due to El Niño-induced subsidence in the subtropics.

4. Trend Pattern of Storm Days Coupled With the Global Warming

[11] The second S-SVD mode (S-SVD2), accounting for 17.4% of the total covariance between storm days and SST,

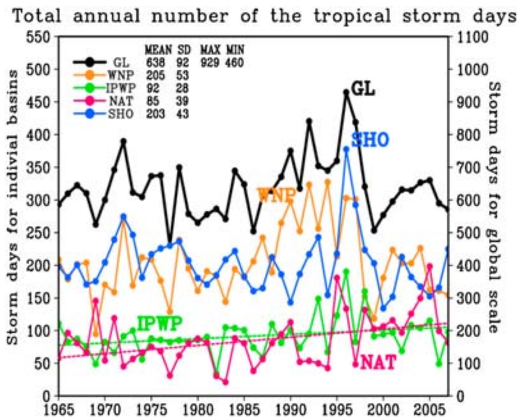

Figure 4. Time series of the total annual number of tropical storm days during each TC year for the global domain (GL), western North Pacific (WNP), North Atlantic (NAT), and SH ocean (SHO), and Indo-Pacific Warm Pool (IPWP, 17.5°S–10°N, 70°E –140°E). The left-hand side tick marks are for individual basins (region) and the right hand side are for the global total. The mean numbers and standard deviations, maximum, and minimum are shown in the legend.

reveals an upward trend pattern in storm days (Figure 3a) coupled with an evident upswing in the global SST (Figure 3b) that highly correlates with the rising global mean surface air temperature (r = 0.93). The SST trend pattern shows a global scale uniform warming except in the equatorial eastern Pacific where weak cooling occurs. This pattern bears some resemblance to the linear trend pattern of global surface air temperature (figure not shown) but with large differences in the equatorial eastern Pacific and the NH storm track regions. The spatial pattern of the storm days (Figure 3a) features an increasing trend in the NAT and in the Indo-Pacific warm pool ocean (IPWP; 17.5°S–10°N, 70°E–140°E), but a decreasing trend in the tropical Pacific (20°S–20°N, 140°E–100°W), especially over the South Pacific.

[12] Since the S-SVD2 accounts for only 4.2% of the total variance of the global storm days, whether the trends seen in the S-SVD2 can be detected in the total variability remains elusive. Figure 4 presents the total numbers of storm days averaged over the NAT and IPWP, which show statistically significant upward trends (at 95% confidence level) in the storm days in the NAT and IPWP over the past 44 years. Note also that these upswings are primarily attributed to the recent trends after the early 1980s during which the data are more reliable. The trend over the warm pool has not been reported previously and is likely due to significant local sea surface warming.

[13] The results presented in Figure 3 provide a global trend pattern of the storm days coupled with global SST warming, which are largely consistent with the results derived from regional studies. Over the NAT, the hurricane genesis frequency and the number of intense hurricanes have increased significantly over the past few decades [*Webster et al.*, 2005]. Over the WNP, the TC number and intensity have not shown any increasing trend [*Chan*, 2006], but the prevailing tracks have shifted westward due to interdecadal changes in the large scale steering flows [*Wu and Wang*, 2004; *Wu et al.*, 2005]. In the vicinity of Australia, the number of storm days increases to the northwest of Australia and decreases to the east over the South Pacific Convergence Zone [*Hassim and Walsh*, 2008].

5. Variability and Trend of the Global Total Number of Storm Days

[14] Figure 4 presents the time series of the total annual numbers of storm days. The time evolution of the global storm days resembles closely the counterpart of the storm days in the S-SVD1 (Figure 2a), suggesting that the S-SVD1 predominates the variability of the global total storm days, and thereby the variability of the global total storm days is primarily driven by the ENSO and PDO. Note that the global total has a large amplitude variation with a minimum of 460 days in 1977 TC year and a maximum of 929 days in 1996 TC year. Strong TC activity is seen in 1990s (1990–1997), which is mainly attributed to the changes in the WNP and SHO TC activity (Figure 4). This decade-long highly active period concurs with the unprecedented prolonged ENSO event of 1990–1994 and the strongest El Nino episode of 1997 during the last century. The large fluctuation in global storms days is a surprise because the annual number of TC genesis has been thought to be stable owing to the storm-induced feedback that tends to limit the global number of cyclones that can form each year [e.g., *Henderson-Sellers et al.*, 1998]. However, the variation of the storm days is strongly affected by the mean lifetime of TCs. In the western Pacific, when the genesis locations shift eastward toward the open oceans, the TCs' lifespans increase substantially due to their prolonged tracks over the open oceans. The ENSO and PDO may change the mean lifetime considerably through coordinated impacts on genesis locations over the entire Pacific, thus, cause the large fluctuation in the global storm days.

[15] Note also that the global storm days do not show any trend over the past 44 years. The WNP and SHO TC activities, which dominate the global TC activity, have no trend. Lack of trend in the global domain is expected from compensation of TC activity over each basin except the NAT (Figure 3a). Significant upward trends are found only over the Atlantic and the Indo-Pacific warm pool (Figure 4), which is consistent with the results of the S-SVD2 (Figure 3).

[16] In summary, the annual number of storm days during a tropical cyclone year is a meaningful and reliable measure of the global TC activity. Based on more reliable data from 1981 to 2007, on average, about 86 TCs (with maximum wind speed of 20 kt or above) are generated annually and the total number of storm days is about 650, thus the mean life span of TCs is about 7.5 days. Over the period of 1965–2008, the global TC activity, as measured by storm days, shows a large amplitude fluctuation regulated by the ENSO and PDO, but has no trend, suggesting that the rising temperature so far has not yet an impact on the global total number of storm days. An important implication is that the spatial variation of SST, rather than the global mean temperature, may be more relevant to understanding the change of the global storm days.

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Q.-H. Ding and B. Wang, Department of Meteorology, University of Hawaii at Manoa, 1680 East West Rd., POST Bldg. 401, Honolulu, HI 96825, USA. (wangbin@hawaii.edu)

F. Huang and Y. Yang, Physical Oceanography Laboratory, Department of Marine Meteorology, Ocean University of China, Qingdao 266100, China.

H. Murakami, Advanced Earth Science and Technology Organization, Meteorological Research Institute, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052, Japan.