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Full Length Research Paper

Re-analysis of tropical cyclone variability from February 1956 to February 2016 over the western North Pacific using the TianGan-DiZhi calendar

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Properly organized data is vital for appropriate statistics and theories. In this study, it was hypothesized that raw tropical cyclone (TC) data labeled with the current Gregorian time system, dampened the dominant signals and order in the data. Therefore, the objective of this study was to explore and reorganize the data, using the TianGan-DiZhi (T-D) calendar. All 6 h TC records in 60 sidereal years over the western North Pacific (WNP) were investigated after the data were transferred from the Gregorian to T-D calendar. TianGan and DiZhi, two collections of elements in the T-D calendar, were then quantified to conduct correlation analyses with different TC parameters. The results showed significant temporal and spatial correlation between 6 h TC records and variables in the T-D calendar over different timescales. Temporally, 6 h TC records in the T-D summer, generally from May 5 to August 6, of the 60 sidereal years were significantly correlated with the strength difference between yearly TianGan and yearly DiZhi for the sidereal years. Spatially, the longitudes and latitudes of 6 h TC records were also significantly correlated with daily variables in the T-D calendar. We conclude that, TC data over the WNP can be better interpreted using the quantified T-D calendar than the Gregorian calendar. Since this ancient time-labeling tool can provide properly organized data, it might be used to modify some inputs in current numerical models to improve forecasting power.

Key words: Tropical cyclone, frequency, temporal, sidereal, Gan-Zhi, calendar.

INTRODUCTION

In general, the variations in tropical cycle (TC) frequency worldwide are related to various factors (Landsea, 2000), including the El Nino-Southern Oscillation (ENSO), Quasi-biennial Oscillation (QBO), and Madden-Julian Oscillation (MJO).

However, recent studies have found a link between solar activity and TC frequency (Elsner and Jagger, 2008; Hodges et al., 2014). Similarly, the number of sunspots are significantly correlated with hurricane frequency on a 22 year cycle (Mendoza and Pazos, 2009; Pazos et al., 2015).

These results indicating a solar influence on TCs naturally suggest the Chinese T-D calendar: the TianGan cycle is 10 sidereal years and DiZhi cycle is 12 sidereal

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years. This means the average value of both, 11 sidereal years, is very close to the solar or sunspot cycle period, which is nearly 11 years according to the Wikipedia. This calendar was widely used historically, and is still used in traditional Chinese medical researches (Tang et al., 2016) and in some climate researches (Tang et al., 2015). Though, there is still no clear and well-distinguished pattern identified for TC variability (Camargo et al., 2010). The current lack of consensus and lack of forecasting naturally lead to the question: Where is the problem?

Could problems exist in current theories? Maybe, but all theories have more or less supporting evidence. Therefore, could the problem lie in the raw data? On initial inspection this appears unlikely, yet suspected raw data labeling cannot be excluded after serious consideration. When the raw data is recorded, the organization method may have influenced and even distorted the data characteristics. This is a possibility, generally ignored yet potentially exciting if true. As a result of such a possibility, it was hypothesized that the current Gregorian time system, in which the raw TC data was organized, dampened some data characteristics. This study explores reorganizing and reanalyzing the data using the T-D calendar.

MATERIALS AND METHODS

Data

About one-third of TCs worldwide and related researches ensued in the western north-Pacific (WNP) (Chen et al., 1998; Chan JCL, 2000; Chen et al., 2006; Yuan et al., 2009); therefore, this basin was chosen for investigating the relationship with the T-D calendar. TC data, the CMA-STI Best Track Dataset for Tropical Cyclones over the western North Pacific, was obtained from www.typhoon.gov.cn. A total of 2008 TCs covering the period from 5 February, 1956 to 3 February, 2016, 60 sidereal years in total, were used in this study. From all 6 h records, 48134 records with intensities labeled "1", Tropical Depression, to "6", Super Typhoon, were used. Records with intensities labeled as "0", weaker than Tropical Depression or unknown intensity, or "9", Extratropical Cyclone stage, were not used.

T-D calendar and its quantification

The TianGan-DiZhi can be separated into TianGan and DiZhi, which are literally translated as heavenly stems and earthly branches, respectively. They can also be abbreviated as Gan-Zhi using the second Chinese character for each phrase.

In the T-D calendar, time is defined in a way quite different from in the Gregorian calendar (for details: https://en.wikipedia.org/wiki/Sexagenary_cycle). TianGan has 10 components or parts, they are referred as T1 to T10, where T stands for TianGan, and the number indicates the order. DiZhi has 12 components or parts, referred to as D1 to D12. One component of TianGan and another component of DiZhi were used in pairs to label time on different time scales; the names of all components of TianGan and DiZhi are presented in Figure 1.

Hours, days, months, seasons, and years are defined differently on the T-D calendar as T-D hours, T-D days and T-D months. For example, the first T-D month, or Zi Yue, generally begins on 7 December. T-D summer is defined as the three T-D months of Si, Wu, and Wei, and generally ranges from 5 May to 6 August. T-D years or sidereal years are generally from 4 February of a year to 3 February of the next year.

Because 60 is a least common multiple (LCM) for TianGan, which has a cycle of 10 time points, and DiZhi, which has a cycle of 12 time points, the 60 different pairs of TianGan and DiZhi constitute a basic cycle, or sexagenary circle. As a result, TianGan and DiZhi cycle over 60 T-D h or 5 T-D days, 60 T-D days or 2 T-D months, and 60 T-D years. Time points in a basic time sequence cycle are heterogeneous, while time points with a gap of 60 are homogeneous.

TianGan and DiZhi have been generally viewed as category notations to record time, and all the previous studies using them followed this tradition. However, this construct does not present the whole story. Different components of TianGan and DiZhi were possibly also related to different strengths of Yang and Yin. Generally, Yang is related to warm and hot climate or conditions, and Yin is related to chilly and cold climate or conditions. Yang and Yin describe the process from birth, growth, prime, and decay to death for everything in the universe (Lu, 2013).

As a result, the T-D calendar can be quantified in the following steps. First, as both the TianGan and DiZhi form a circle, the 10 parts of TianGan divide a cycle evenly into 36° segments (Figure 1A, left), while the 12 parts of DiZhi divide a cycle evenly into 30° segments (Figure 1A, right). Second, the trigonometric function $1-\cos(\theta)$ was used to simulate the aforementioned process from birth, growth, prime, and decay to death.

Therefore, the strength of TianGan can be described with the continuous curve generated from the trigonometric function, and each of the 10 parts of TianGan shares a corresponding range (Figure 1B, left). The DiZhi strength can also be described using this function, and each of the 12 parts of DiZhi shares a corresponding range (Figure 1B, right).

As the angular speed of TianGan, 36° per time unit or 10 time units in a cycle, is faster than that of DiZhi, 30° per time unit or 12 time units in a cycle, 1800° or 60 time units are required for both TianGan and DiZhi to reunite at the initiation point, 0°, at the same time (Figure 1C). Because the angular speeds of TianGan and DiZhi are different, they have different strengths within the basic cycle of 60 time units, either in the form of TianGan minus DiZhi (Figure 1D, left) or DiZhi minus TianGan (Figure 1D, right).

Statistical analysis

Pre-processing of data

All data recorded in the Gregorian calendar were transferred to the Chinese T-D time system for further analysis. The conversion took five steps (Table 1). The first step in the conversion was to identify the names of TianGan and DiZhi corresponding to times in the Gregorian calendar. In the second step, each TianGan or DiZhi component was assigned with its range in degrees (as shown in Figure 1A and 1B). The third to fifth steps completed the conversion accurately, using different formulae. The logic underlying these formulae was to address the bias resulting from elapsed time at lower time scales. For example, consider calculating the specific degree value for different time points in day T1. As day T1 ranges from 0 to 36°, the hours elapsed will influence the final specific degree for day T1. There are 24 h or 12 Shichen in one T-D day; thus the first Shichen corresponds to the half-open interval [0 3), and the sixth Shichen corresponds to the half-open interval [15 18).

Statistical analysis

As the time points in the basic time sequence cycle are

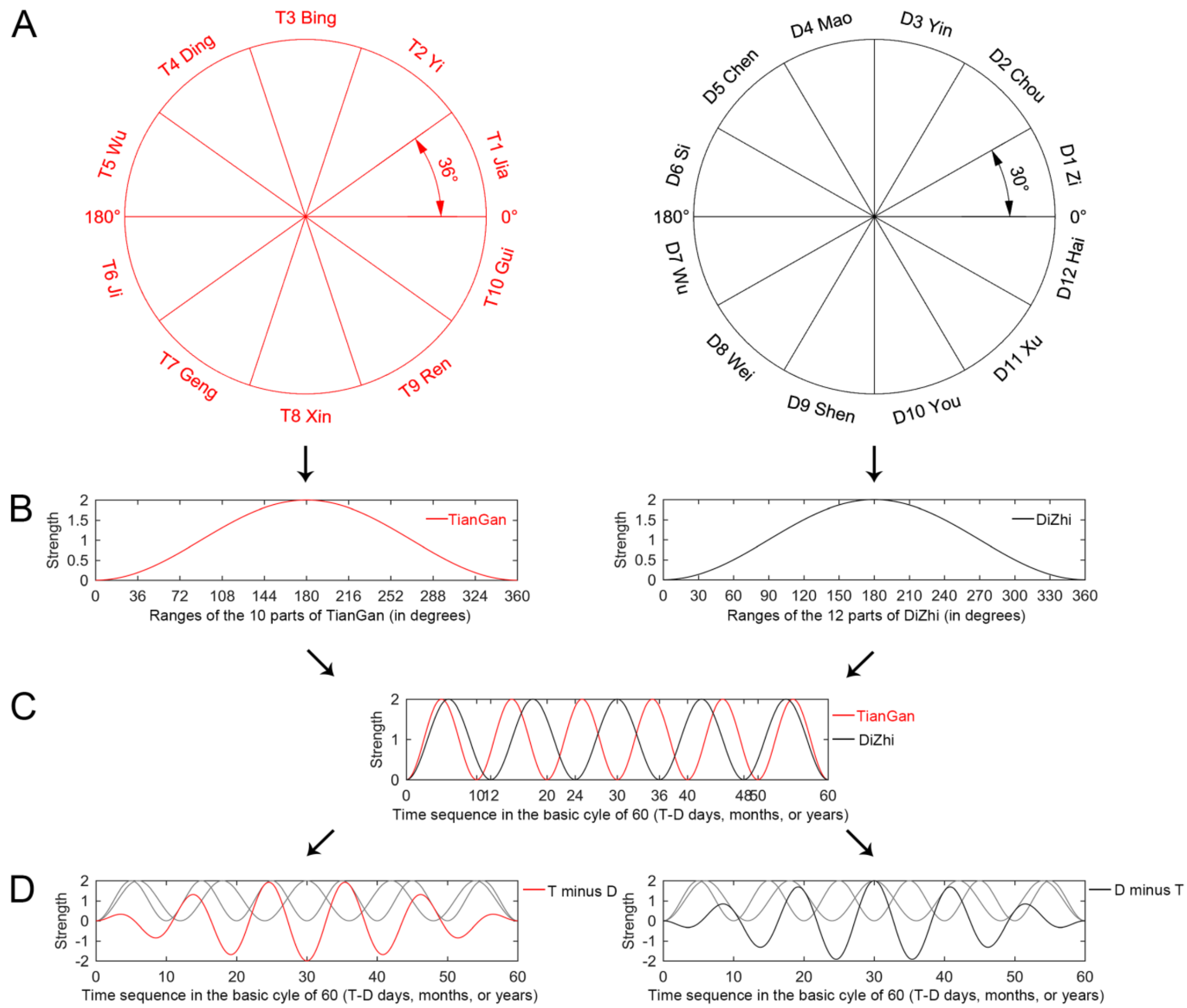

Figure 1. Quantification of TianGan and DiZhi (A) The 10 parts of a TianGan cycle divided evenly into 36° (left), and the 12 parts of a DiZhi cycle divided evenly into 30° (right). The Chinese names for the parts of TianGan and DiZhi go around the respective cycles; (B) The strengths of TianGan and DiZhi are described with a 1-cos(θ) trigonometric function, with different ranges for components of TianGan (left) and DiZhi (right). (C) The least common multiple (60) for TianGan (10) and DiZhi (12); (D) Difference between the strength of TianGan and DiZhi: TianGan minus DiZhi (left) or DiZhi minus TianGan (right), with the gray curves of TianGan and DiZhi as background lines. Here, T represents TianGan and D represents DiZhi.

inhomogeneous, and time points with a gap of 60 are homogeneous, all data were rearranged into the basic time sequence cycle on different time scales. Correlation analyses were conducted in Prism (version 5.0, GraphPad Software Inc.) between major outcome variables (frequencies, intensities, latitudes, longitudes, minimum pressure, and 2-min mean maximum sustained wind speed) and different variables in the T-D time system (TianGan, DiZhi, and their interactions, that is, TianGan minus DiZhi or DiZhi minus TianGan with the opposite sign).

RESULTS

The data in the two calendars and the resulted difference

TC data in the Gregorian calendar and T-D calendar were compared. First, numbers of TCs were compared. The number of TCs from 1 January, 1956 to 31 December, 2015 labeled using the Gregorian calendar (Figure 2A) were close to that from 5 February, 1956 to 3 February, 2016 rearranged in the T-D calendar (Figure 2B). The difference is provided in Figure 2C. The difference, defined as the difference between the two related values in the two calendars divided by the value in the Gregorian calendar, ranged from -10 to 9.524%, with a standard deviation of 3.293%. Paired *t*-test of the number of TCs in the two calendars failed to detect significant difference. Second, the 6 h TC records were compared. Data in the Gregorian time system (Figure 2D) also appeared similar to the rearranged data in the T-D time system (Figure 2E). The difference ranged from -6.046 to 6.597%, with a standard deviation of 2.715% (Figure 2F). Paired *t*-test of the 6 h TC records in the two

Table 1. The steps of converting the Gregorian calendar to a quantified T-D calendar.

Western year		**Western month**		**Western day**		**Western hour**	
1983		6		23		12	
Step 1: Identifying the corresponding Tian Gan and Di Zhi							
yT	yD	mT	mD	dT	dD	hT	hD
T10-Gui	D12-Hai	T5-Wu	D7-Wu	T9-Ren	D7-Wu	T3-Bing	D7-Wu
Step 2: Identifying of the starting point expressed in angles							
T10	D12	T5	D7	T9	D7	T3	D7
324	330	144	180	288	180	72	180
Step 3: Finding the ranks and totals, respectively							
t3	r3	t2	r2	t1	r1	N/A	N/A
365	140	32	18	12	6	N/A	N/A
Step 4: Conducting the transformation using formulae							
T10+((r3-1+r1/t1)/t3)*36		T5+36*(r2-1+r1/t1)/t2		T9+36*r1/t1		N/A	N/A
D12+((r3-1+r1/t1)/t3)*30		D7+30*(r2-1+r1/t1)/t2		D7+30*r1/t1		N/A	N/A
Step 5: Determining the accurate angles							
yT	yD	mT	mD	dT	dD	hT	hD
337.76	341.47	163.69	196.41	306	195	72	180

T represents TianGan, D represents DiZhi, t represents total, r represents rank, y represents yearly, m represents monthly, d represents daily, and h represents hourly. Thus, yT represents yearly TianGan. t1, t2, and t3 and r1, r2, and r3 are totals and ranks on different scales of time determined as follows. In Chinese tradition, two hours equal one Shichen, and there are 12 Shichen in one day; therefore, t1 or total1 equals 12. Consequently, the Gregorian hour 12:00 ranks sixth, i.e., 12/2 equals 6 or r1, in the total of 12. Similarly, t2 represents the total of all T-D days in the T-D month; r2 represents the rank of the current T-D day in the T-D month; t3 represents the total of all T-D days in the T-D year; and r3 represents the rank of the current T-D day in the T-D year. The fourth and fifth arrows under the Gregorian hour column were unavailable (N/A), as this level was the lowest level of all time scales in the T-D calendar.

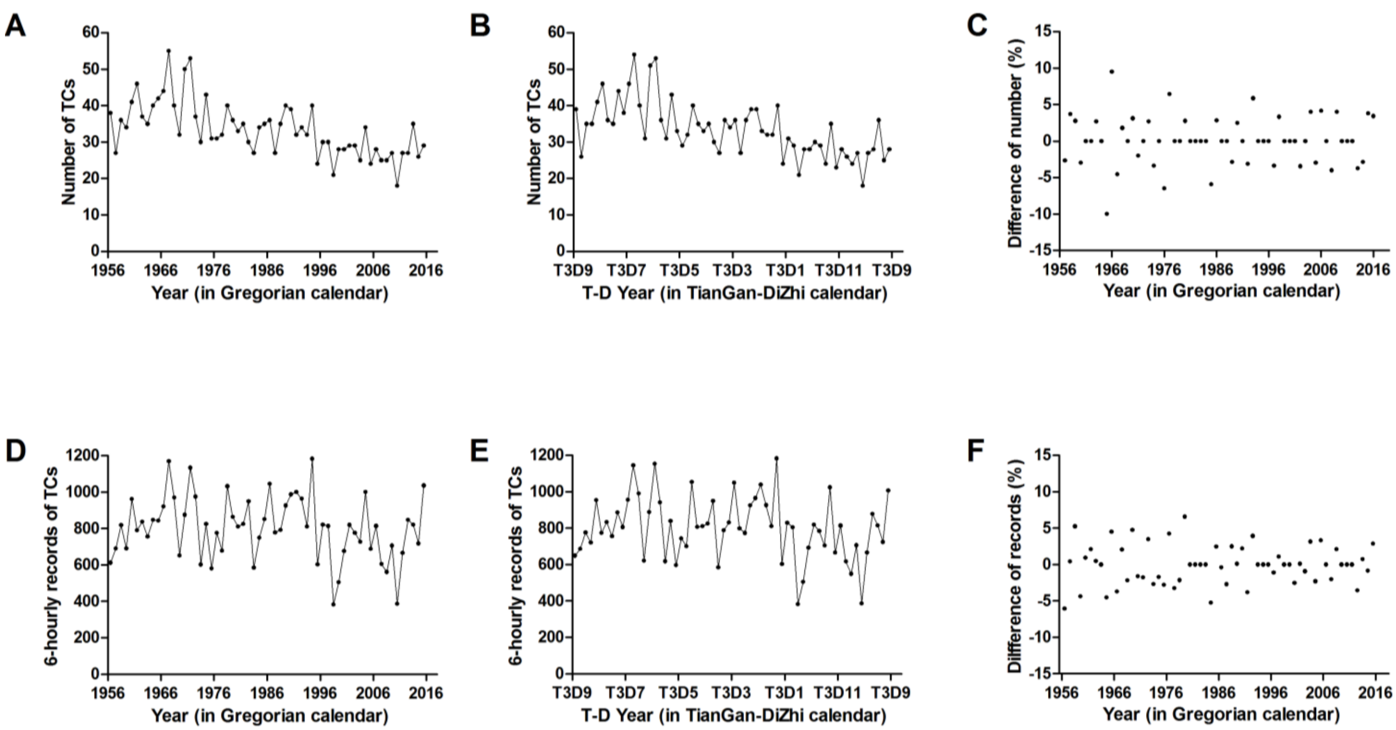

Figure 2. The difference in data between the Gregorian and TianGan-DiZhi calendars (A) The number of TCs from January 1956 to December 2015 presented in the Gregorian calendar; (B) The number of TCs from February 1956 to February 2016 presented in the TianGan-DiZhi calendar; (C) The difference between TC records in the two calendars. The 6 h TC records presented in Gregorian calendar (D) or TianGan-DiZhi calendar (E). The difference between the TC records is also presented in (F).

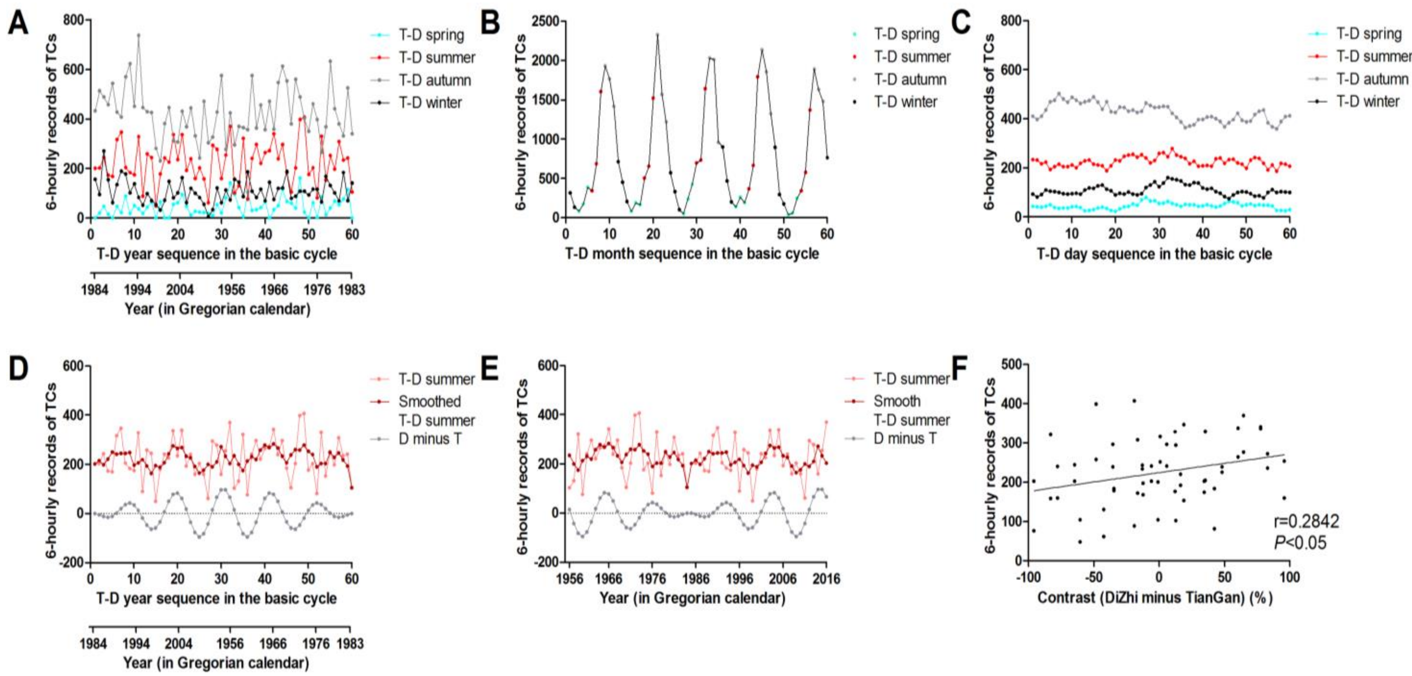

Figure 3. The 6 h TC records rearranged using the T-D calendar to show the irregular variation. The data were presented on the timescales for the T-D year (A), T-D month (B), and T-D day (C). The shapes of the original and smoothed curves for the 6 h TC records in T-D summer were similar to those of the DiZhi minus TianGan curves, shown in the gray line and multiplied by 100 for better comparison, in the basic cycle of years in the T-D calendar (D) or Gregorian calendar (E). Correlation analysis showed that the DiZhi minus TianGan curve strength was significantly correlated with the 6 h TC records in the T-D summer (*P*<0.05) (F).

calendars also found no significant difference.

The correlation between data rearranged within the basic cycle and variables in the T-D time system

The basic cycle in the T-D time system consists of 60 T-D time points on each time scale, in which time point T1D1 is the first and time point T10D12 is the last. All data were rearranged into the basic cycle, with T1D1, on the time scale of year, month, and day, in the first place of the basic cycle, and T10D12 in the last place.

Correlations between TC frequencies and variables in the T-D calendar were calculated first. Results indicated that the number of TCs or their intensities in the T-D time system were not significantly correlated with any variable in the T-D time system. Similarly, the frequencies in the 6 h TC records or their intensities in 60 T-D years in the T-D time system were not significantly correlated with any variable in the T-D time system. Subsequently, the 6 h TC records were deconstructed into four parts using the T-D seasons and rearranged again in the following manner for further examination. On an annual time scale, 6 h TC records in each T-D year were rearranged into the basic cycle, with the year T1D1 (February 1984 to February 1985) in the first place of the basic cycle, and the year T10D12 (February 1983 to February 1984) in the last place. In Figure 3A, note that a horizontal ordinate of Gregorian calendar was presented below that of the T-D calendar for clarity. Similarly, the 6 TC records for each T-D year were rearranged using the T-D months (Figure 3B) and T-D days (Figure 3C), with T1D1 months or days in the first place and T10D12 months or days in the last place.

Results indicated that the shape of the curve for the 6 h TC records in the T-D summer, either in the original or smoothed form, was similar to the DiZhi minus TianGan curve. The latter was multiplied by 100 for better visual comparison in the T-D calendar in Figure 3D and in the more familiar Gregorian calendar in Figure 3E. The correlation tests showed that the 6 h TC records in the T-D summer were significantly (*P*<0.05) correlated with the DiZhi minus TianGan curve (Figure 3F). However, the 6 h TC records rearranged in T-D months (Figure 3B) or days (Figure 3C) were not significantly correlated with any variable in the T-D calendar.

The correlation of other TC attributes and different variables in the T-D time system were also conducted on the daily timescale. The latitudes (Figure 4A), longitudes (Figure 4B), minimum pressure near the TC center (Figure 4C), and 2-min mean maximum sustained wind speed (Figure 4D) of the 6 h records in the four T-D seasons are presented in the basic cycle of 60 T-D days.

Because TianGan and DiZhi were rivals and interacted, correlation analyses between TC parameters and their interaction were conducted first. Results showed that the

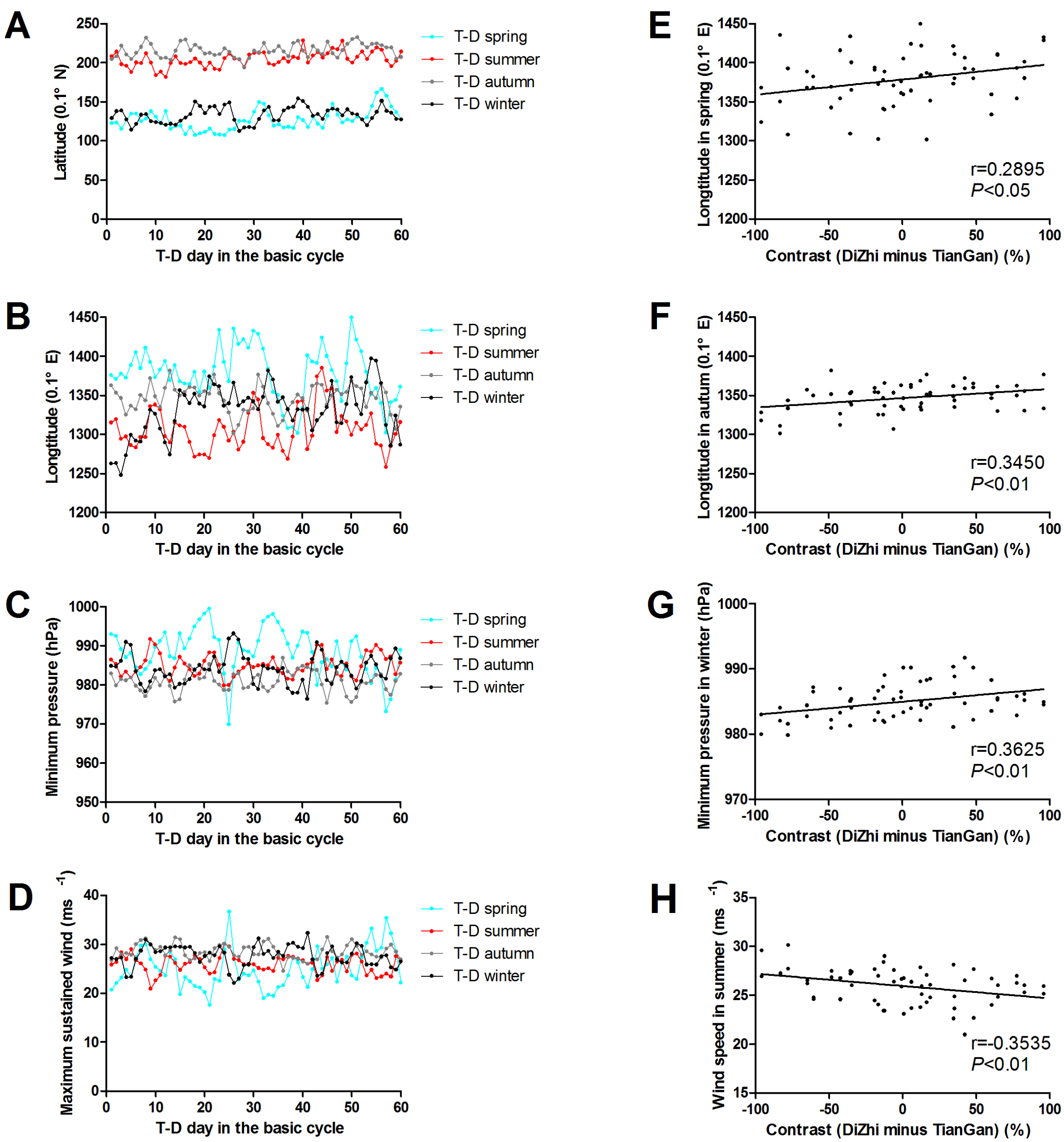

Figure 4. The correlation of TC attributes and different variables in the T-D time system. On the time scale of days, the latitude (A), longitude (B), minimum pressure (C) and wind speed (D) of the 6 h records in the four T-D seasons were present in the basic 60 T-D day cycle. Significant correlations were found between the DiZhi minus TianGan curve and longitudes of the 6 h TC records in T-D spring (*P*<0.05) (E) and T-D autumn (*P*<0.01) (F), minimum pressure in T-D winter (*P*<0.01) (G), and wind speed in T-D summer (*P*<0.01) (H).

latitudes of the 6 h TC records were not significantly correlated with the DiZhi minus TianGan curve. Significant correlation was found between the DiZhi minus TianGan curve and the longitudes for the 6 h TC records in T-D spring (*P*<0.05) (Figure 4E) and T-D autumn (*P*<0.01) (Figure 4F), minimum pressure in T-D winter (*P*<0.01) (Figure 4G), and maximum sustained wind speed in T-D summer (*P*<0.01) (Figure 4H). These indicated attributes were also correlated with TianGan or DiZhi alone. The strength of TianGan of the T-D days in the basic cycle was significantly correlated with longitudes in T-D autumn (r= -0.3044, *P*<0.05), minimum pressure near the TC center in T-D spring (r=-0.3570, *P*<0.01), 2-min mean maximum sustained wind speed near the TC center in T-D spring (r=0.3152, *P*<0.05), and T-D winter (r=-0.2987, *P*<0.05). The strength of DiZhi was significantly correlated with latitudes in T-D spring (r=0.2954, *P*<0.05), minimum pressure in T-D summer (r=0.3931, P<0.01), and maximum sustained wind speed in T-D summer (r=-0.3636, P<0.01).

DISCUSSION

The T-D calendar was quantified for the first time in this study. Using this quantified time system, the seemly irregular variations in TCs over the WNP showed some previously unrecognized order. Notably, there were several significant correlations in T-D summer. The results showed that the 6 h records (Figure 3F) were positively correlated with DiZhi minus TianGan, and wind speeds in T-D summer were negatively correlated with DiZhi minus TianGan (Figure 4H) or DiZhi alone. Two questions were gotten from these observations:

1. What is the nature of such difference induced by DiZhi minus TianGan?
2. What are the underlying mechanisms for these correlations?

First, the nature of such difference between TianGan and DiZhi arises from their interactions. As discussed previously, in materials and methods, TianGan is related to Yang, while DiZhi is related to Yin. Because Yang and Yin are rivals in Chinese philosophy, they can be subtracted from each other and the difference equals their interaction, in modern terms.

Therefore, the value of DiZhi minus TianGan is the net value of DiZhi. Consequently, a positive net value indicates that DiZhi or Yin is stronger than TianGan or Yang; and a negative net value indicates that DiZhi or Yin is weaker than TianGan or Yang. Yang is related to warm and hot climates or conditions, while Yin is related to chilly and cold climate or conditions. Because on the one hand the TCs generally formed over warm sea areas (Gray, 1998), where Yin is much weaker than Yang; on the other hand, the larger the subtracted value (DiZhi minus TianGan) was the more records of TCs occurred," it is logical to infer that a high net value of Yin is required to reach a balance of Yang and Yin.

The negative correlation between wind speed in T-D summer and DiZhi minus TianGan (Figure 4H) or DiZhi alone suggests that most of these 6 h records belonged to low-intensity TCs. For other significant correlation, explanations are not as readily available, as only some seasons showed some order, which indicated there might be some other unknown mechanisms. More related researches using the quantified T-D calendar are required.

These correlations alone might be useful for limited prediction. For example, because the number of 6 h TC records in T-D summer was significantly correlated with variables in the T-D time system on an annual timescale (Figure 3D, E, and F), it would be useful to predict TC frequencies in T-D summer across different T-D years. These observations might be also helpful for forecasting models. Currently, five numerical models (Halperin et al., 2013) have been used with various inputs. It is possible that better results will be achieved with inputs modified in advance using the correlations provided in this work. For example, the significant correlation between spatial parameters, that is, latitudes and longitudes, and variables in the T-D time system will assist numerical models in predicting the location of genesis, and even tracks, of TCs.

Conclusion

The T-D calendar has been primarily viewed as a tool to record time. However, in this study, the T-D calendar was used for the first time as a quantifiable tool in TC analysis. The raw TC data was appropriately organized in the quantified T-D calendar, which provided a proper statistical analysis and helpful discovery. Therefore, we suggest that the quantified T-D calendar might also be useful for analyzing events in more disciplines.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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