Re-examination of Trends Related to Tropical Cyclone Activity over the Western North Pacific Basin

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ABSTRACT

In order to re-examine some trends related to tropical cyclones (TCs) over the western North Pacific since 1949, the unreliable maximum sustained wind ($V_{\text{max}}$) recorded in the 1949–1978 TC best-track data from the Shanghai Typhoon Institute was modified based on the wind–pressure relationships (WPRs) in this study. Compared to the WPR scheme based on the cyclostrophic balance, the WPR scheme based on the gradient balance could give a better fit to TCs under higher wind speeds and could introduce smaller estimated errors for TCs locating at higher latitudes as well as TCs landing on the continent. After the $V_{\text{max}}$ modification based on minimum sea-level pressure and TC center latitude, the revised annual number of category 4–5 typhoons shows no long-term trend, while the potential destructiveness measured by power-dissipation index decreases slightly, and this trend is not significant in the period 1949–2008.

Key words: tropical cyclone, wind–pressure relationship, gradient balance, power-dissipation index


1. Introduction

Tropical cyclones (TCs) are considered to be the most violent natural disasters in the world. Among all the ocean basins, the western North Pacific (WNP) is the most remarkable one, where the average number of TCs per year is the highest (~28) and exceeds 30% of the global total (Chan, 2004). Because of its importance, many TC warning centers are organized over the WNP basin, including the Joint Typhoon Warning Center (JTWC, USA), the Regional Specialized Meteorological Center-Tokyo Typhoon Center (RSMC, Japan), the Shanghai Typhoon Institute (STI, China), and others. The task of these organizations is to observe and forecast some characteristics of TCs, such as their tracks, their intensities, and so on. In recent years, these TC best-track data, mostly from JTWC and other organizations, in some basins, have been used by many meteorologists to investigate the TC-related climatological trends (Landsea, 2005; Emanuel, 2005; Anthes et al., 2006; Pielke, 2005; Pielke et al., 2006; Klotzbach, 2006). A rigorous discussion continues as to whether these trends are caused by global warming or are just natural multidecadal oscillations.

One of the crucial reasons for the divergence of opinions among climatologists is that, compared with the data that are gathered now, the quality of the best-track data was poor in the 1970s and even poorer before that time (Curry et al., 2006). Before the 1970s, the TC data over the WNP basin were obtained using aircraft reconnaissance as well as observations at surface stations. In these common procedures, the surface pressure of the TC center was observed directly…
or was transferred from the geopotential height which was measured at the flight-level near the eye, and then the maximum surface wind was estimated using some empirical relationships (Fletcher, 1955; Jordan, 1958; Fletcher and Johannessen, 1965). Since then, many observational techniques have been developed to detect TCs and to compute their intensities. These improvements include the Dvorak technique, in which the intensity is estimated by identifying the satellite imagery (Dvorak, 1975; Dvorak, 1984), mobile Doppler radar, and GPS dropsondes, which measure the wind speed directly (Hock and Franklin, 1999). Since the maximum sustained wind speed (V_max) was not directly measured but was converted before the 1970s, these data were sometimes unreliable in nearly all of the best-track datasets, and in some they were even overestimated (Chen, 1997; Emanuel, 2000). Using V_max as an index of the intensity, TC-related long-term trends from the best-track dataset are therefore uncertain.

One way to overcome this difficulty is to revise the best-track data statistically and/or dynamically where a huge dataset of samples is available. For example, Emanuel (2006) introduced V_max-dependent corrections on the former V_max estimations recorded in the JTWC best-track dataset before 1973 in order to obtain newly modified best-track data. However, the V_max correction made by Emanuel (2006) did not consider any possible dynamic constraint (e.g., from a wind–pressure relationship) on his purely statistical fitting of V_max from JTWC. Notably, the data record of minimum sea-level pressure (MSLP) is quite short for JTWC (beginning in 2000), though the record of V_max extends back to 1945. On the other hand, for RSMC of Japan, V_max data have been recorded only since 1977.

This study aimed to find a suitable wind–pressure relationship (WPR) underlying the STI best-track data. Only the best-track data from the STI of China Meteorological Administration is considered here because it includes both V_max and MSLP data continuously recorded from 1949 to the present, unlike any other TC warning centers covering the WNP basin. In terms of statistical accuracy, this dataset therefore provides an advantage for fitting the V_max and MSLP data in terms of WPR. Furthermore, the V_max correction proposed is indeed dependent on the MSLP, since the measurements of TC minimum central pressure are less erroneous (Murnane, 2004). Moreover, based on this dynamical and statistical correction, the STI best-track dataset should be reorganized, and particularly, the STI best-track data before 1979 should be corrected. This investigation of the TC-related climatological trends according to this newly formatted data is also necessary.

This paper is organized in the following way: Data and methodology are given in section 2, including a brief description of WPRs. The data-quality problem is briefly reviewed in section 3. Then the evolution of coefficients in WPRs from 1949 to 2008 is described in section 4, which also includes some comparisons among different WPRs. The trends of TC annual number and potential destructiveness derived from the newly modified STI best-track data are obtained in section 5, followed by a discussion of the validity of WPRs in another best-track datasets. A summary is given in the last section.

2. Data and methodology

The TC best-track data from 1949 to 2008 used in this study were provided by the Shanghai Typhoon Institute (STI) of China Meteorological Administration (CMA). Compared with best-track datasets compiled by other organizations (e.g., JTWC and RSMC) in the WNP basin, the STI data that recorded both V_max and MSLP is a complete dataset. However, the data before the 1970s was not based on real-time observations but was based on reviews made after the TC events, and therefore it was less reliable. Only the best-track data from 1979 to 2008 from STI was used to develop the empirical parameters in the following four WPR schemes:

Scheme 1 : \( V_{\text{max}} = K_1 (p_0 - p_c)^{0.5} \),

Scheme 2 : \( V_{\text{max}} = (K_2 - \theta/a_2) (p_0 - p_c)^{0.5} \),

Scheme 3 : \( V_{\text{max}} = K_3 (p_0 - p_c)^{0.5} \),

Scheme 4 : \( V_{\text{max}}^2 + b_4 (2\Omega \sin \theta) V_{\text{max}} = K_4 (p_0 - p_c) \),

where \( p_c \) is MSLP, \( p_0 \) is the environmental pressure that is chosen to be 1010 hPa according to some previous works (Takahashi, 1939, 1952; Mcknown et al., 1952; Fletcher, 1955; Fortner, 1958; Seay, 1964; Atkinson and Holliday, 1977; Subbaramayya and Fujiwhara, 1979; Lubeck and Shewchuk, 1980; Shewchuk and Weir, 1980; Guard and Lander, 1996), \( \Omega \) is the self-rotating angular velocity of Earth, \( \theta \) is the latitude of the TC center. The seven empirical parameters \( (K_1, K_2, K_3, K_4, a_2, n_3, \text{ and } b_4) \) were estimated using the multiple linear regression method.

Unlike some other wind–pressure models applicable at any radius inside a TC (Holland, 1980; DeMaria et al., 1992), Eqs. (1)–(4) are only derived at the radius of maximum wind (RMW). Eqs. (1)–(4) are based on three assumptions: (1) The pressure gradient force could be estimated by the difference between the inconstant MSLP and the constant environmental