Dynamics of Atmospheres and Oceans 74 (2016) 1–13

Contents lists available at ScienceDirect

Dynamics of Atmospheres and Oceans

journal homepage: www.elsevier.com/locate/dynatmoce

Development of a diagnosis index of tropical cyclones affecting the Korean Peninsula

Jae-Won Choi [a,*], Yumi Cha [b]

[a] National Institute of Meteorological Sciences, JeJu, South Korea
[b] National Typhoon Center/Korea Meteorological Administration, JeJu, South Korea

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 4 January 2016
Accepted 5 January 2016
Available online 4 February 2016

Keywords:
Tropical cyclone
Western North Pacific subtropical high
Correlation analysis

ABSTRACT

This study has developed the index for diagnosis on possibility that tropical cyclones (TCs) affect Korean Peninsula. This index is closely related to the strength of the western North Pacific subtropical high (WNPSH), which is calculated as a difference in meridional wind between at the highest correlation area (around Korean Peninsula) and at the lowest correlation area (sea southeast of Japan) through a correlation analysis between TC frequency that affects Korean Peninsula and 500 hPa meridional wind. In low frequency years that selected from Korea affecting TC index, anomalous northeasterly is strengthened from Korea to the South China Sea because the center of anomalous anticyclonic circulation is located to northwest of Korean Peninsula. Thus, TCs tend to move westward from the sea east of the Philippines to the mainland China. On the other hand, in high frequency years, anomalous southwesterly serves as steering flow that more TCs move toward Korean Peninsula because the center of anomalous anticyclonic circulation is located to sea east of Japan. Consequently, this study suggests that if this index is calculated using real time 500 hPa meridional winds that forecasted by dynamic models during the movement of TCs, the possibility that TCs approach Korean Peninsula can be diagnosed in real time.

1. Introduction

Many studies have developed indexes and parameters to diagnose and predict tropical cyclone (TC) activities in all seas and each sea. First, regarding indexes applicable in all seas, Emanuel (1986, 1987, 2005) and Bell et al. (2000) quantified TC intensity and developed accumulated cyclone energy, power dissipation index, and maximum potential intensity aimed at finding climate signals in TC activities.

Gray (1977, 1979) discovered climatological parameters about hurricane genesis through combinations of diverse atmospheric factors regarding hurricane activities and predictors in the Atlantic Ocean: (i) low-level relative vorticity, (ii) local or planetary vorticity (Coriolis parameter), (iii) inverse of the vertical shear of the horizontal wind between the lower and upper troposphere, (iv) ocean thermal energy due to temperatures above 26.8 °C to a depth of 60 m, (v) vertical gradient of equivalent potential temperature between the surface and 500 hPa, and (vi) middle troposphere relative humidity. Every year they provided Atlantic hurricane activity data predicted using these parameters and improved parameters (Gray et al., 1992a, 1993, 1994; Klotzbach and Gray, 2004). They also proved that they were very successful in predicting Atlantic hurricane activity using climate factors until December of the previous year. Landsea et al. (1999) analyzed correlation among

* Corresponding author. Tel.: +82 01047569141.
E-mail address: choikiseon@korea.kr (J.-W. Choi).

http://dx.doi.org/10.1016/j.dynatmoce.2016.01.006

atmospheric-oceanic environment factors such as sea level pressure, 200 hPa zonal wind, Quasi-Biennual Oscillation (QBO), and El Nino-Southern Oscillation (ENSO) in the Caribbean, atmospheric-oceanic environment factors like precipitation in the Sahel region west of Africa and Atlantic sea surface temperature, and Atlantic hurricane activities and then verified that all environment factors were closely related to Atlantic hurricane frequency, intensity, and lifetime. More recently, Klotzbach and Gray (2006) developed U.S. landfall parameter index and applied this index to the case of 2004 when Atlantic hurricane activities were most powerful and destructive thus far and proved this index well reflected Atlantic hurricane activities of 2004. Sall et al. (2006) proposed that 925 hPa vertical velocity and 700 hPa potential vorticity were the best atmospheric factors to differentiate intense TC and weak TC. Moreover, many factors and predictors (CLIPER, large-scale atmospheric predictors, and dynamic and thermal predictors) are in use for statistical regression models developed to predict TC intensity and TC track (Neumann, 1972; Neumann and Randrianarison, 1976; Leftwich and Neumann, 1977; Neumann and Mandal, 1978; Xu and Neumann, 1985; Fraedrich and Leslie, 1989; Aberson, 1998; DeMaria and Kaplan, 1999; Morison, 2000).

Meanwhile, TC genesis frequency in the tropical and subtropical western North Pacific accounts for 30% of TCs which globally occur annually. A minimum of three TCs to a maximum of 10 TCs among TCs which occur annually affect the middle latitude regions of East Asia (e.g., Chia and Ropelewski, 2002). However, the number of indexes and factors to predict and diagnose western North Pacific TC activities is relatively smaller compared to those for the Atlantic Ocean. Harr and Elsberry (1991) first conducted group classification of the pattern of TC track and used climatological factors by each form and parameters such as 700 hPa zonal wind in order to predict TC track. Fogarty et al. (2006) developed China landfalling index of TCs reflecting the pattern of TC activity landing on China every year through analysis of correlation between TC landfall frequency and climate factors.

In consideration of all such situations about TC activities in the western North Pacific, developing indexes and factors to predict and diagnose TC activity in each region of East Asia is essential. Therefore, this study will develop a real time index which can diagnose the possibility of influencing the Korean Peninsula during the movement of TC. Regarding TC which landed on and affected the Korean Peninsula, Choi et al. (2010a) verified that the frequency of TC which landed on and affected the Korean Peninsula was divided into three periods (1951–1965, 1966–1985, 1986–2004) and landfall track had the trend of moving eastward recently. Choi et al. (2009b) discovered that upper-level Tibetan high near India during the previous summer well reflected the characteristics of TCs which landed on the Korean Peninsula and affected it and at the same time had positive correlation with TC frequency during summer and developed a statistical model using this factor. In addition, Choi et al. (2009b) and Choi and Kim (2010b) proved that there was positive correlation between the frequency of TC which landed on the Korean Peninsula and Arctic Oscillation (AO). Besides, relationship between diverse elements such as ENSO and TCs which landed on and affected the Korean Peninsula was studied (Choi and Kim, 2007a; Choi et al., 2009a). However, the above factors may be applied to seasonal prediction about TCs which landed on and affected the Korean Peninsula.

Section 2 introduces data and analysis methods. Section 3 analyzes correlation between the frequency of TCs affecting the Korean Peninsula and 500 hPa meridional wind. Section 4 defines the diagnosis index of TCs which affect the Korean Peninsula and Section 5 analyzes differences between years with high indexes and years with low indexes. Section 6 analyzes cases and proposes indexes which diagnose the effects of real time TC. Section 7 summarizes the result of this study.

2. Data and methods

The TC data in this study was obtained from the best-track of TC provided by Regional Specialized Meteorological Center (RSMC)-Tokyo Typhoon Center. This data consist of TC name, latitude and longitude location of TC, TC central pressure, and TC Maximum Sustained Wind Speed (MSWS), which were observed in every 6 h. TC is generally classified into four classes by the criteria of MSWS as follows: Tropical Depression (TD, MSWS < 17 m s^{-1}), Tropical Storm (TS, 17 m s^{-1} ≤ MSWS ≤ 24 m s^{-1}), Severe Tropical Storm (STS, 25 m s^{-1} ≤ MSWS ≤ 32 m s^{-1}), Typhoon (TY, MSWS ≥ 33 m s^{-1}). Along with the four classes of TC above, this study included extratropical cyclone, which was transformed from TC for analysis. This was because such extratropical cyclone also incurred great damage on property and human in the mid-latitude regions in East Asia.

Moreover, this study also used the variables of geopotential height (gpm), zonal and meridional winds (m s^{-1}) data from National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis (Kalnay et al., 1996; Kistler et al., 2001). This NCEP-NCAR reanalysis data consisted of spatial resolution such as latitude and longitude 2.5° × 2.5° and 17 vertical levels. The NOAA Extended Reconstructured monthly Sea Surface Temperature (SST) (Reynolds et al., 2002), available from the same organization, was also used. The data have a horizontal resolution of 2.0° × 2.0° latitude-longitude and are available for the period of 1854 to the present day.

About 60% of TCs which occur in the western North Pacific are distributed between July and September (e.g., Chia and Ropelewski, 2002) and therefore the present study defines these three months as summer time.

In order to calculate TC passage frequencies, each TC was calculated after being relocated within a 5° × 5° grid. Even if a TC passed over the same grid multiple times, it was regarded as a single passage.

TCs which affect the Korean Peninsula in the present study are defined as TCs of July, August, and September which passed the domains of 32°–40°N and 120°–138°E, as described in Fig. 4a (KMA, 1996).