The Recent Strengthening of Walker Circulation
Jae-Won Choi, In-Gyum Kim, Jeoung-Yun Kim, and Cheol-Hong Park
National Institute of Meteorological Sciences, Jeju, Korea

Abstract

This study calculated the Walker circulation index and then discovered strengthening of the circulation in recent years. Thus, this study analyzed a difference of averages between 1999−2013 and 1984−1998 to determine the cause of the strengthening of the Walker circulation in recent years. With regard to 850 hPa stream flows, analysis on difference between two periods showed that anomalous easterlies (anomalous trade wind) were dominant due to strengthening of anomalous anticyclonic circulations at the subtropical Pacific of both hemispheres. In order to determine whether upward flows are strengthened at the tropical western Pacific and downward flows are strengthened at the tropical central and eastern Pacific in recent years, a difference in zonal atmospheric circulation averaged over 5°S−5°N between two periods was analyzed. The Walker circulation, in which air ascended at the equatorial western Pacific was descended at the equatorial central and eastern Pacific, was strengthened more in recent years.


1. Introduction

The Walker circulation is one of the most globally distinctive and important atmospheric systems. The circulation has the following characteristics. 1) Trade winds blown from the east to the west, 2) Strengthening of ascending air current in the western Pacific, Southeast Asia, and northern Australia through strengthened convection, 3) strengthening ascending air currents at the western Pacific through trade winds, and 4) strengthening descending air currents at the eastern Pacific (see, e.g., Gill 1982).

Changes in the Walker circulation are related to important changes in rainfall (Allan et al. 1996; Power et al. 1999), river flow (Power et al. 1999), agricultural production (Power et al. 1999; Hammer et al. 2000), ecosystems (Holmgren et al. 2001), severe weather (e.g., Callaghan and Power 2011), and disease (Bouma and Dye 1997). Furthermore, interdecadal changes in the Walker circulation are also related to El Niño-Southern Oscillation (ENSO) that causes important changes in monsoonal circulations and rainfall in neighboring nations (e.g. Krishnamurthy and Goswami 2000; Lu et al. 2004). The intensity of equatorial Pacific zonal wind-stress that is related to the Walker circulation influences equatorial Pacific Ocean circulation crucially (e.g. Vecchi and Soden 2007).

During the 20th century, much attention has been paid to the weakening trend in the Walker circulation (Vecchi et al. 2006; Zhang and Song 2006). The weakening trend is caused by the anthropogenic climate change and can be understood through energy and mass balance of the ascending branch in the circulation (Held and Soden 2006; Vecchi et al. 2006). On the contrary, several studies in recent years explained differently (Sohn and Park 2010; Meng et al. 2012). In particular, Sohn and Park (2010) analyzed the water vapor transport and described strengthened of tropical circulation during the past three decades. Dong and Lu (2013) showed the recent enhancement of Walker circulation since the late 1990s. However, a number of atmospheric and oceanic processes control the intensity of the Walker circulation including a tropical hydrological cycle about radiative forcing that explains partially the opposite result (DiNezio et al. 2010).

The interdecadal shift of climates at the Pacific Ocean in the late 1990s has been confirmed via a number of recent studies (e.g. Chen et al. 2008; Wang and Mehta 2008). Cummins et al. (2005) demonstrated rapid warming in the North Pacific and increases in sea surface height in 1998 in contrast with changes occurred in the climate shift in the mid-1970s, which was accompanied via changes in Interdecadal Pacific Oscillation (IPO; Power et al. 1999) from the negative phase to positive phase. Burgman et al. (2008) and Chen et al. (2008) proved that the interdecadal regime shift of the sea surface temperature (SST) pattern at the late 1990s was an opposite pattern to signals related to well-known climate shift in the mid-1970s. Wang and Mehta (2008) reported rapid warming in the western Pacific warming pool since the late 1990s. However, none of the above studies have focused on interdecadal changes in the tropical zonal circulation.

Thus, this study discussed a climate regime shift in the Walker circulation and analyzes a difference between atmospheric circulations and western North Pacific TC activity according to the above change.

2. Data and methods

This study also used the variables of geopotential height, zonal and meridional winds, specific humidity, air temperature, and sea level pressure data from National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis in 1984 to 2013 (Kistler et al. 2001). This NCEP-NCAR reanalysis data comprised spatial resolution such as 2.5° × 2.5° latitude-longitude and 17 vertical levels (specific humidity is 16 vertical levels and sea level pressure is one vertical level). Also, velocity potential consisted of a grid box, including latitude and longitude 192 × 94 and 5 sigma levels.

Further, the National Oceanic and Atmospheric Administration (NOAA) interpolated Outgoing Longwave Radiation (OLR) data retrieved from the NOAA satellite series are available beginning June 1974 from NOAA’s Climate Diagnosis Center (CDC).

The NOAA Extended Reconstructed monthly 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 present day.

In addition, the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) data (Xie and Arkin 1997), the horizontal spatial resolution of which is the same as the NCEP-NCAR reanalysis dataset.

The Niño-3.4 index is derived by Climate Prediction Center (CPC) of NOAA (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). This study uses the Student’s t test to determine significance (Wilks 1995).

This study focuses on the season from July to September; because this period is the season that typhoon is the most active in the western North Pacific although this study does not analyze typhoon activity.
3. Time series analysis

Figure 1 shows the time-series of the Walker circulation index (WCI). This figure shows an increasing trend overall and this increasing trend is statistically significant with 95% confidence level. This figure implies that upward flows are strengthened at the tropical western Pacific and downward flows at the tropical central and eastern Pacific. It also shows that many of the prior years of 1998 had negative values whereas many of the years after 1998 had positive values. A mean value of 1984–1998 was −0.58 whereas a mean value of 1999–2013 was 0.58. A difference in mean values between two periods is significant at the 95% confidence level. Accordingly, a difference in mean values between 1999–2013 and 1984–1998 periods is analyzed in order to determine the cause of the increase in the WCI in recent years.


4.1 Large-scale environments

The present study analyzed OLR to see the difference of convective activity between two periods (Fig. 2a). Positive anomalies are strengthened from the equatorial eastern Pacific to the equatorial central Pacific and negative anomalies are strengthened at the Maritime Continent and the subtropical western North Pacific. This result means that convection was not developed in the former regions whereas convection was developed at the latter regions. As a result, negative anomalies were revealed in the former regions while positive anomalies were revealed in the latter regions with regard to difference in precipitation between two periods (Fig. 2b).

Differences in 850 hPa stream flows between two periods were analyzed to find out the association with the spatial distribution of differences in precipitation between two periods (Fig. 3a). As anomalous anticyclonic circulations were strengthened in the both hemispheres, anomalous easterlies (anomalous trade winds) were strengthened along the equatorial Pacific. This is a typical anomalous atmospheric circulation pattern displayed at La Niña events. Thus, convection can become weak from the equatorial eastern Pacific to the equatorial central Pacific while convection can become strengthened at the Maritime Continent and the subtropical western North Pacific.

Anomalous cyclonic circulations were strengthened at the subtropical Pacific in the both hemispheres in the analysis on differences in 200 hPa stream flows between two periods and anomalous northerlies blown from the anomalous cyclonic circulations in the southern hemisphere were blown into the anomalous cyclonic circulations in the northern hemisphere (Fig. 3b).

A difference in the SST between two periods was analyzed to determine whether the above results of differences between two periods actually revealed the La Niña pattern (Fig. 3c). Cold anomalies were exhibited from the equatorial eastern Pacific to the equatorial central Pacific whereas warm anomalies were exhibited in the other waters. This is a spatial distribution of the typical SST displayed in La Niña events, which implies that La Niña pattern has been strengthened in recent years.

In order to determine whether upward flows are strengthened at the tropical western Pacific and downward flows are strengthened at the tropical central and eastern Pacific in recent years, a difference in zonal atmospheric circulation averaged over 5°S–5°N between two periods was analyzed (Fig. 4). The result showed that anomalous upward flows were strengthened in western regions of 170°E whereas anomalous downward flows were strengthened in eastern regions of 170°E. That is, the Walker circulation, in which air ascended at the equatorial western Pacific was descended at the equatorial central and eastern Pacific, was strengthened more in recent years.

We also investigated whether other indices (Niño-3.4 index, 850 hPa zonal wind index, 200 hPa zonal wind index) related to the WCI revealed interdecadal variation (Fig. 5). For the Niño-3.4 index, a mean value during 1984–1998 was 0.12 whereas that of 1999–2013 was −0.12. Here, a difference of the mean values between two periods is statistically significant at the 85% confidence level (Fig. 5a). The 850 hPa zonal wind index averaged over the Niño-4 region during 1984–1998 was 0.35 whereas that of 1999–2013 was −0.35. A difference of the mean values between two periods was statistically significant at a 90% confidence level (Fig. 5b). The 200 hPa zonal wind index averaged over the Niño-4 region during 1984–1998 was −0.38 whereas that of 1999–2013 was 0.38. A difference of the mean values between two periods was statistically significant at the 90% confidence level (Fig. 5c). Thus, all three indices related to the WCI showed interdecadal variation from the late 1990s.

Differences in 850 hPa velocity potential and 200 hPa velocity potential between two periods were analyzed to find out the characteristics of the differences in global-scale atmospheric circulation between two periods (Fig. 6). Positive anomalies of 850 hPa velocity potential were revealed at the western region of 150°E while negative anomalies were revealed at the eastern region (Fig. 6a). The center of the positive anomalies was located at the
Maritime Continent and the center of the negative anomalies was located at the equatorial central Pacific. 200 hPa velocity potential showed an opposite pattern of spatial distribution compared to that of 850 hPa velocity potential (Fig. 6b). The center of the negative anomalies was located at the western coast in the Maritime Continent and the center of the positive anomalies was located at the equatorial central Pacific. The spatial distribution anomalies of velocity potential at the upper and lower tropospheres mean that the Walker circulation in which air rises over the Maritime Continent and moves to the east and then descends down at the equatorial central Pacific, has been more strengthened than before in recent years.
5. Summary and conclusion

This study calculated the Walker circulation index and then discovered strengthening of the circulation in recent years. Thus, this study analyzed a difference of averages between 1999–2013 period and 1994–1998 period to determine the cause of the strengthening of the Walker circulation in recent years.

The spatial distribution of differences in precipitation between two periods showed that negative anomalies were revealed in the equatorial central and eastern Pacific while positive anomalies were revealed in the Maritime Continent and subtropical western North Pacific. This is a typical La Niña pattern. Differences in 850 hPa stream flows between two periods were analyzed to find out the reason for the spatial distribution of differences in precipitation between two periods. Due to strengthening of the anomalous anticyclonic circulations in the subtropical Pacific in the both hemispheres, anomalous easterlies (anomalous trade winds) were strengthened in the equatorial Pacific. Differences in 200 hPa stream flows between two periods showed that anomalous cyclonic circulations were strengthened at the subtropical Pacific in the both hemispheres.

In order to determine whether upward flows are strengthened at the tropical western Pacific and downward flows are strengthened at the tropical central and eastern Pacific in recent years, a difference in zonal atmospheric circulation averaged over 5°S–5°N between two periods was analyzed. The Walker circulation, in which air ascended at the equatorial western Pacific was descended at the equatorial central and eastern Pacific, was strengthened in recent years.

We also investigated whether other indices (Niño-3.4 index, 850 hPa zonal wind index, 200 hPa zonal wind index) related to strengthened in recent years.

Acknowledgements

This work was supported by the R&D Project of the Korea Meteorological Administration “Development and application of technology for weather forecast” (grant no.: NIMR-2013-B-1).

Edited by: S.-K. Park

References


Manuscript received 12 January 2016, accepted 14 March 2016 SOLA: https://www.jstage.jst.go.jp/browse/sola/