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RESEARCH ARTICLE

STUDY ON CLIMATOLOGICAL CHARACTERISTICS OF RAINFALL INDUCED BY TROPICAL CYCLONES USING THE SATELLITE OBSERVATIONS

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ABSTRACT

The climatological characteristics of rainfall induced by tropical cyclone over the western North Pacific are examined using the satellite observation. The Tropical Rainfall Measuring Mission (TRMM) 3B42 provides invaluable rainfall data for tropical cyclone (TC) research since 1998. Based on TRMM 3B42 data, rainfall properties of TCs are statistically quantified for different sea surface temperature (SST) levels and TC intensities. As TCs are stronger, the TC-induce rainfalls increase about 15% per 20 knot of TC's wind speed. The rainfall induced by TC also increases as the SST warming. The increase rate is about 8-10 % per 1 □of SST. The rate is comparable to the idealized environmental water vapor content changes obtained by multiplying the average SST change by 7% per 1 °C. The changes in TC-induced rainfall related to both TC intensity and SST also show consistent results, suggesting that both TC intensity and SST are main factors for the changes in TC-induced rainfall.

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INTRODUCTION

A tropical cyclone (TC) is a devastating natural system accompanying strong wind gust, heavy rainfall. Every year, TCs cause a great amount of social and economic damage in TC-prone countries. In particular, heavy rain induced by TCs pours down relatively short period, resulting in flood over the broad area. Thus, it is worthy to examine the characteristics of the TC-induced rainfall to prepare the possible damages from TC. Because TCs spend most of their life in the ocean, satellite observation sareindispensable for examining TC-induced rainfalls. The satellite data is indirect estimates of rainfall using the characteristics of the cloud top observed by infrared channels or hydrometeor contents observed by microwave channels (Wilheit, 1986; Janowiak *et al*. 2001; Huffman *et al*. 2007). The rainfalls retrieved by infrared channels cover wide area with relatively short time interval but have relatively large error. Meanwhile, the microwave-retrieved rainfalls have high accuracy but their spatial coverage is narrow and time interval of observation is relatively long. The TRMM 3B42 rainfall dataset overcomes the disadvantages by combining multiple independent rainfall estimates from various infrared and microwave satellite observations such as TRMM TMI, AMSR-E, SSMI/S, AMSU, MHS, GOES-E, GOES-W, Meteosat-7, and Meteosat-5, providing invaluable rainfall information for tropical cyclone (TC) research. The increase in thermodynamic energy and environmental water vapor content associated with global warming has led to considerable impacts on TC rainfalls. Previous studies (Kim *et al*. 2006; Lau and Zhou 2012) suggest an increasing trend in TC rainfall in various regions. Also, Knutson *et al.* (2010) suggest that TC rainfall may increase with global warming using a global numerical model. The increase of the increasing thermodynamic energy induced by the sea surface temperature (SST) warming strengthens the TC intensity and related rainfalls. The SST warming also leads the increase in environmental water vapor content which can affect the change in TC-induced rainfall. Thus, it is worthy to evaluate the quantitative analysis on the variation in TC rainfall related to the SST changes. In this study, we analyze the mean features of the rainfall fields around TCs over the western North Pacific related the changes in SST and TC intensity using daily TRMM 3B42 rainfall data. In section 2, the utilized datasets are introduced. The TC rainfalls are evaluated in section 3 and a discussion and conclusions are presented in section 4. Data to evaluate the rainfall induced by TCs, we utilize the TRMM 3B42 rainfall data (Huffman *et al*. 2007). The TRMM 3B42 provides global 3-hourly rainfalls on 0.25-degree spacing grid since 1998. For TC position data, we utilize the best track data from the Joint Typhoon Warning Center (JTWC). The best track data provides TC information including location, wind speed and central pressure in 6-hour interval. The SST

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RESULTS

Figure 1 illustrate the composite of TRMM 3B42 rainfall near the TC centers for 1998-2013. The TC-induced rainfalls show larger rainfalls over than 100 mm day^{-1} near the TC center. The maximum value of the rainfall exceeds 140 mm day^{-1}. The TC rainfalls decrease as further away from the TC center. The spatial distribution of rainfall show a pattern of concentric circles and mean rainfall more than 20 mm day^{-1}is located within 3-degree from the TC center. Thus, in this study, the mean TC rainfall is defined as the rainfall averaged within 3-degree of the TC center.

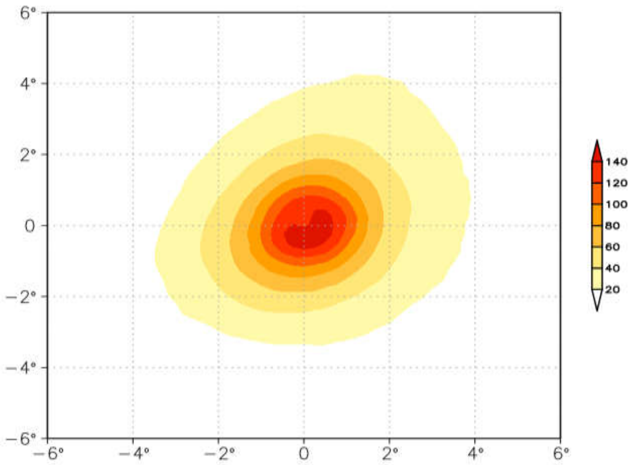

Fig.1. Mean rainfall around TC center. Unit is mm day^{-1}

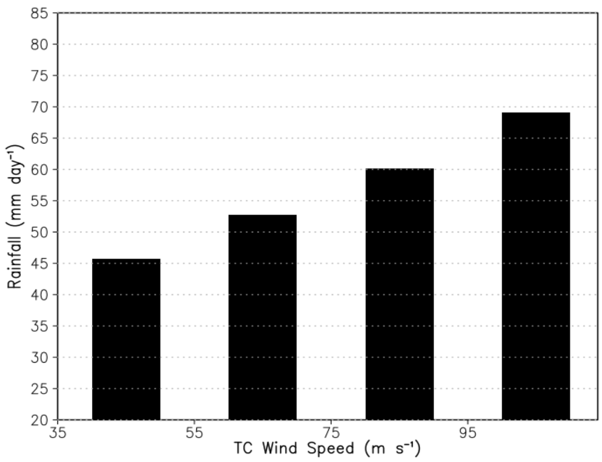

Fig. 2. Variation of mean rainfall within 3 degree from TC center dependent on TC intensity

Figure 2 show the changes in the mean TC rainfall dependent on TC intensity. The TC intensity are categorized as 20 knot interval from 35 knot. As the TC intensity increases, the moisture convergence for a given amount of mass convergence is enhanced. Thus stronger TC should increase rainfalls where moisture convergence is an important component of the water vapor budget. The mean TC rainfalls are 45.8 mm day^{-1} for 35-55 knot, 52.8 mm day^{-1} for 55-75 knot, 60.1 mm day^{-1} for 75-95 knot and 69.1 mm day^{-1} for over than 95 knot. On average, the rainfalls increase about 15% per 20 knot of TC wind speed (e.g., 15 %from 35-55 knot to 55-75 knot of TC wind speed, 14% from 55-75 knot to 75-95 knot and, 15% from 75-95 knot to over than 95 knot). The results suggest that the TC rainfall may be exponentially changed as TC wind speed with the rate of 0.7% knot^{-1}.

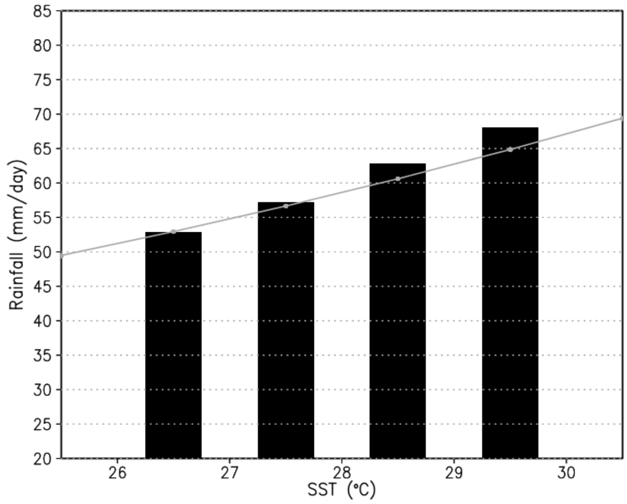

Fig. 3. Variation of mean rainfall within 3 degree from TC center dependent on SST levels. The line illustrates idealized water vapor content scaling, obtained by multiplying the average SST change by 7% °C^{-1}.

Figure 3 show the changes in the mean TC rainfall dependent on SST levels. The SST levels are categorized as 1°C interval from 26 °C. As the SST increases, the environmental atmospheric water vapor content increases. If we assume that the moisture budget within the TC rainfall region is dominated by moisture convergence from the larger environment, the increases in the atmospheric moisture content should lead to increases in TC rainfalls. The mean TC rainfall 52.9mm day^{-1}for 26-27 °C, 57.2 mm day^{-1}for 27-28 °C, 62.9 mm day^{-1}for 28-29 °C, and 68.1mm day^{-1}for over than 29 °C. On average, the rainfalls increase at the rate of 8.5% °C^{-1}(e.g., 8.1 % from26-27 °Cto 27-28 °C, 9.8% from 27-28 °Cto 28-29 °Cand, 8.2% from28-29 °C to over than 29°C).

If we assume that the moisture convergence from the larger-scale environments dominates the moisture budget near the TC, the mean increase in rainfalls follows roughly the changes expected based on increases in the environmental water holding capacity of the atmosphere which increases at about 7% per 1 °C SST warming (Knutson *et al.* 2013).The average rate of mean TC rainfall on SST change (8.5% °C^{-1}) is slightly larger than the increase of the idealized changes in TC rainfalls induced by increases in environmental water holding capacity (7% °C^{-1}). Because the TCs make the moisture convergence from wider environments and exhaust the moisture by rainfall in relatively small region, the increase rate of mean TC rainfall on SST change can become larger the environmental water holding capacity.

Figure 4 show the changes in the mean TC rainfall dependent on SST levels for each TC intensity category. Because the SST warming induces the increases in TC intensity, it is worth to examine the changes in TC rainfalls dependent on SST for each TC intensity category. The mean TC rainfall increase as SST warming for each TC intensity category. The average increase rate of 11% □$^{-1}$for 35-55 knot, 7% □$^{-1}$for 55-75 knot, 7% □$^{-1}$for 75-95 knot, and 10%. □$^{-1}$for overt than 95 knot of TC wind speed. The increase rate of the mean TC rainfall on SST is larger in weak and strong TCs while relatively small in moderate TCs.

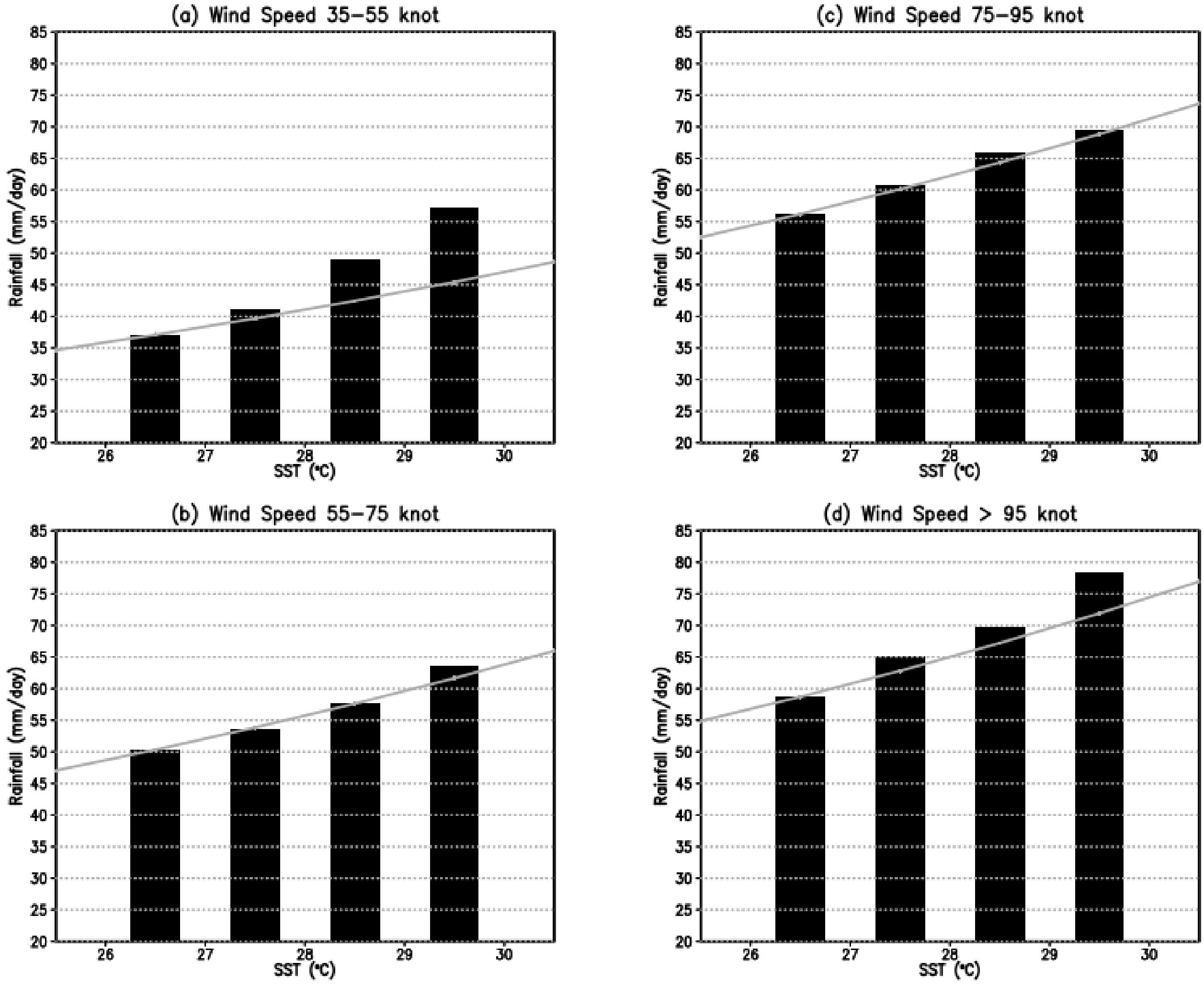

Fig. 4. Variation of mean rainfall within 3 degree from TC center dependent on SST levels for each TC intensity (a) 35-55 knot, (b) 55-75 knot, (c) 75-95 knot, and (d) greater than 95 knot.. The line illustrates idealized water vapor content scaling, obtained by multiplying the average SST change by 7% °C^{-1}

Also the increase of TC rainfall dependent on SST for each TC intensity category is comparable to the increase of the idealized changes in TC rainfalls induced by increases in environmental water holding capacity.

Conclusion

In this study, the rainfall properties of TCs are statistically quantified for different sea surface temperature (SST) levels and TC intensities based on TRMM 3B42 data. As TCs are stronger, the TC-induce rainfalls increase about 15% per 20 knot of TC's wind speed. The rainfall induced by TC also increases as the SST warming. The increase rate is about 8-10 % per 1 ℃ of SST. The rate is comparable to the idealized environmental water vapor content changes obtained by multiplying the average SST change by 7% per 1 °C. The changes in TC-induced rainfall related to both TC intensity and SST also show consistent results, suggesting that both TC intensity and SST are main factors for the changes in TC-induced rainfall.

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