Tropical Cyclone Induced Precipitation over Japan Using Observational Data

Hirotaka Kamahori¹ and Osamu Arakawa²

¹Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan
²University of Tsukuba, Tsukuba, Japan

Abstract

Tropical cyclone (TC) induced precipitation (TCP) over Japan is evaluated with the rain gauge observation based gridded dataset APHRO_JP. The TC–influenced frequency reaches a maximum in the Nansei Islands and decreases monotonically with latitude. On the other hand, the distribution of TCP indicates different characteristics from the one of TC–influenced frequency. The largest annual TCP, 500 mm yr⁻¹ or more, occurs over eastern Kyushu (E-Kyushu), southern Shikoku (S-Shikoku), and the eastern Kii peninsula (E-Kii), where it accounts for 15% or more of the total precipitation. The maximum daily TCP amounts to 200 mm d⁻¹ in those three areas, which are all located on the eastern side of Japan and correspond to eastward or southeastward topographic inclines. A significant relationship is found between the amount of annual TCP and topographic incline, and the large amount of TCP concentrates in the eastward or the southeastward inclines. The extreme daily TCP once every 50 years is also evaluated. The extreme daily TCP is estimated to be 500 mm d⁻¹ comparable to the climatological annual TCP in E-Kyushu, S-Shikoku, and E-Kii. These three areas appear to be the most hazardous part of Japan in terms of TCP.

(Citation: Kamahori, H., and O. Arakawa, 2018: Tropical cyclone induced precipitation over Japan using observational data. SOLA, 14, 165–169, doi:10.2151/sola.2018-029.)

1. Introduction

Tropical cyclones (TCs) are among the most important meteorological phenomena because their heavy precipitation as well as strong winds can cause serious property damage and loss of life. At the same time, TCs are also important as suppliers of water resources. Therefore, estimating the magnitude and predicting the occurrence of TC induced precipitation (TCP) are important for the protection of human lives and property and have been the objectives of numerous studies over many years (Chan and Kepert 2010). One third of global TCs generate and develop in the western North Pacific (Nuemann 1993) and affect East Asian countries, which together have more than 2 billion inhabitants. A study of TCP in this area is therefore especially important. Many studies of TCP have been performed based on observational data. Using meteorological station data, Ren et al. (2006), Dare et al. (2012, 2013), Nguyen-Thi (2012), and Kubota and Wang (2009) have evaluated TCP in China, Australia, Viet-Nam, and tropical islands in the western North Pacific, respectively. Ren et al. (2006) reported that annual TCP is 500 mm d⁻¹ or more in Taiwan, the Hainan Islands, and along the eastern coastline in South China and correspond to eastward or southeastward topographic inclines. A significant relationship is found for the amount of annual TCP and topographic incline, and the large amount of TCP concentrates in the eastward or the southeastward inclines. The extreme TCP once every 50 years is also evaluated. The extreme TCP is estimated to be 500 mm d⁻¹ comparable to the climatological annual TCP in E-Kyushu, S-Shikoku, and E-Kii. These three areas appear to be the most hazardous part of Japan in terms of TCP.

(Citation: Kamahori, H., and O. Arakawa, 2018: Tropical cyclone induced precipitation over Japan using observational data. SOLA, 14, 165–169, doi:10.2151/sola.2018-029.)

2. Data and methodology

We utilize APHRO_JP (Kamiguchi et al. 2010) as a precipitation dataset. APHRO_JP is high resolution (0.05° × 0.05°) gridded dataset derived from rain gauge observations over Japan and was developed under the framework of the project “Asian Precipitation–Highly Resolved Observational Data Integration Towards Evaluation of the Water Resources” (APHRODITE) (Yatagai et al. 2012). APHRO_JPv1207 is the latest version and includes estimated daily precipitation from 1901 to 2011. In this study, APHRO_JPv1207 data for 1981–2010 is utilized to evaluate mean characteristics of TCP over Japan.

As TC position information, we utilize the best track data of the Japan Meteorological Agency (JMA). The JMA best track data are available after 1951, and include location of the TC center, central surface pressure (Pc), maximum wind speed (Vmax), gale wind radius, and storm wind radius. In this study, TCs with intensities of tropical storms or higher (Vmax ≥ 34 kt) are targeted. In general, the best track provides TC information including position data in 6-hour interval. On the other hand, APHRO_JP is daily data. To provide daily TC position, we assume that the TC position at 12UTC in the best track represents daily mean position. To examine the relationship between TCP and topography, we utilize Global 30 Arc-Second Elevation Data (GTOPO30, Gesch et al. 1999). We interpolate the GTOPO30 data to a resolution of 0.25 degrees to evaluate that relationship.

The definition of a TC–affected area is important for evaluating TCP. Ying et al. (2012) have considered that the regions affected by individual TC were subjectively identified by inspecting weather maps and observation data to study the climate trend of SVAP in China. However, objective determination of regions affected by TCs is preferable for scientific discussion. Kubota and Wang (2009) have defined TCP as daily precipitation observed at the stations within 1000 km of the TC center. Ren et al. (2006) defined a variable TC–affecting radius that varies from 500 km to 1000 km, depending on the size of the TC. Nguyen-Thi et al. (2012) assumed the TC–affecting radius to be 600 km. Prat and Nelson (2013) considered precipitation within 500 km of a TC center to be TCP.

In all previous studies, any precipitation within some definite distance from the TC center was assumed to have been induced by the TC. However, precipitation around a TC includes precipitation

©The Author(s) 2018. This is an open access article published by the Meteorological Society of Japan under a Creative Commons Attribution 4.0 International (CC BY 4.0) license (http://creativecommons.org/license/by/4.0).
affected by other disturbances as well as by the TC. To identify precipitation caused by the TC, it is necessary to decompose the precipitation field around TCs into precipitation directly affected by the TC and by other disturbances. Kamahori (2012) examined the mean feature of precipitation fields around the TC center using precipitation anomalies defined as the differences between daily and monthly precipitations. The methodology of Kamahori (2012) yields an approximate decomposition of total precipitation into precipitation directly affected by TCs and by other disturbances. In this study, we utilize the methodology of Kamahori (2012) to evaluate TCP over Japan.

Figure 1a shows a composite of the daily total precipitation relative to the TC center derived from HIRAS-JP, which includes precipitation directly affected by TCs and precipitation by other disturbances, and Fig. 1b is the daily precipitation anomaly, which is presumed to include only precipitation directly affected by TCs. The elongated northeast–southwest structure and the negative anomaly in the northwest quadrant in Figure 1b are consistent with results from Kamahori (2012). Figure 1c shows the radial distribution of the azimuthally averaged total and the anomalous precipitation. The anomalous precipitation tends to zero at a radius of 8° of latitude, but the total precipitation remained positive at greater radial distance because of the contribution from other disturbances. In this study, we define TCP as the difference between daily and monthly mean precipitation in unit of mm d\(^{-1}\) observed at the grid point within 8° of latitude from the TC center. We also define the number of TC–influenced days (TCN) as the number of days per year that each grid point is located within 8° of latitude from the TC center.

### 3. Results

Figure 2 shows the geographical distribution of annual TCN, annual TCP, the contribution of annual TCP to the total precipitation (TCPF), and annual maximum of daily TCP. TCN decreases monotonically with latitude and equals 20 days yr\(^{-1}\) or more in Okinawa, 10–12 days yr\(^{-1}\) in Kyushu, 4–10 days yr\(^{-1}\) in other parts of western Japan, and less than 2 days yr\(^{-1}\) in Hokkaido (in terms of location names, please refer to Fig. S1.). Distribution of TCN shows no significant difference between the eastern side and the western side of Japan (Fig. 2a).

Annual TCP is relatively large in southern Japan and tends to decrease toward the north (Fig. 2b). However, the decrease with latitude is not monotonic and there are large regional contrasts. Annual TCP over eastern Kyushu (E-Kyushu), southern Shikoku (S-Shikoku), and the eastern Kii Peninsula (E-Kii) is around 500 mm yr\(^{-1}\) or more, but only about 300 mm yr\(^{-1}\) over Okinawa (Fig. 2c). This regional pattern is consistent with the distribution of topographic altitude. Figure 2d shows the geographical distribution of TCPF. The geographical distribution of TCPF also shows the largest amount in E-Kyushu, S-Shikoku, and E-Kii, and qualitatively same contrast between the western side and the eastern side of Japan as that of annual TCP (Fig. 2a). The maximum TCPF are 18% in E-Kyushu, 15% in S-Shikoku, and 14% in E-Kii, respectively (Fig. S4). But TCPF in Okinawa is 11% and is less than the three areas. The annual maximum of daily TCP is also large in the three areas, and shows qualitatively same east–west contrast as that of annual TCP or TCPF (Fig. 2d). Maximum daily TCP is 260 mm d\(^{-1}\) over E-Kii, 230 mm d\(^{-1}\) over S-Shikoku, 200 mm d\(^{-1}\) over E-Kyushu, 180 mm d\(^{-1}\) over the southern Japan Alps area, and 160 mm d\(^{-1}\) over Okinawa (Fig. S5). In Japan, the potential for a flood disaster due to TCs is therefore greatest in E-Kii, S-Shikoku, and E-Kyushu. The potential is also large in the southern Japan Alps area.

In general, larger precipitation is expected on a windward incline because of topographic effects. Figure 3a shows TC tracks around Japan from 1981 to 2010. Most TCs approach Japan from the south or southwest direction. Therefore, in most areas of Japan, it is expected that easterly or southeasterly winds are dominant when TCs approach. Figure 3b shows the relationship between annual TCP and the direction of the topographic incline. Here, the topographic incline is evaluated on the original resolution of GTOPO30 by the centered difference method and interpolated on a grid with 0.25° spacing, and the annual TCP is also interpolated on 0.25° grid, to avoid local effects and show only overall topography. Most higher TCP occurs on an eastward incline, and annual TCP greater than 400 mm yr\(^{-1}\) occurs only in the southeast quadrant except for 1 case. The correlation coefficients between annual TCP and topographic altitude is only 0.06 and is not significant. Figure 3c shows the geographical distribution of the zonal direction of the topographic incline. Most eastward inclines are distributed on the eastern side of Japan, and
Fig. 2. (a) Annual TCN (days yr$^{-1}$), (b) annual TCP (mm yr$^{-1}$), (c) annual TCPF (%), and (d) annual maximum of daily TCP (mm d$^{-1}$).

Fig. 3. (a) TC tracks around Japan. (b) Relationships between annual TCP and direction of topographic incline. Radial distance from the center is annual TCP in mm yr$^{-1}$ and azimuthal angle is direction of the topographic incline. (c) Geographical distribution of topographic incline along the east–west direction.
most westward inclines are on the western side. It is logical to expect that large amounts of TCP would occur on the eastward inclines such as E-Kyushu, S-Shikoku, or E-Kii, because easterly water vapor fluxes would be advected around the approaching TCs and forced upward by the incline. On the other hand, the contribution from TCs after passage is minor. In Okinawa, there is no high mountain nor steep incline (Fig. S1). Therefore, we can understand that annual TCP in Okinawa is less than that in E-Kyushu, S-Shikoku, or E-Kii due to less topographic effect.

Figure 4 shows the probability daily TCP with a return period of 50 years. Here, Gumbel distribution (Gumbel 1958) is applied to the annual maximum of daily TCP to evaluate the probability TCP. Large areas with a probability TCP of 500 mm d\(^{-1}\) or more are found in E-Kyushu, S-Shikoku, and E-Kii. Even in the eastern Hokkaido, the probability TCP is 250 mm d\(^{-1}\) or more. These values are roughly comparable to the mean annual TCP in unit of mm yr\(^{-1}\). We infer, therefore, that once every 50 years on average the annual maximum of the daily TCP will be comparable to the mean annual TCP in unit of mm yr\(^{-1}\). Such information is important for disaster prevention management.

Figure 5 shows the seasonal march of monthly TCN, TCP, and TCPF. The season with TCN greater than 1.0 mon\(^{-1}\) lasts from June to October at 26°N, which corresponds to Okinawa, and from July to September at 36°N, which corresponds to Tokyo. There are no areas with TCN greater than 1.0 mon\(^{-1}\) north of 40°N. The TC season is longer in southern areas and decreases monotonically with increasing latitude. The peak season of TCN is August at all latitudes. In contrast to TCN, both monthly TCP and TCPF reach a maximum in September, when the TCN is relatively small compared with that in August, at most latitudes north of 25°N. We should consider that individual TCs bring heavier rainfall in September than during other seasons. Therefore, September is the most hazardous season for TC rainfall–related disasters, and is the most contributed season to water resources at a same time. We can understand that the TCP difference between August and September results from the difference between the TC tracks of both months. In August, most TCs approach Japan from the south direction, but most TCs from the southwest direction in September (Fig. S2). Therefore, in Japan where TCs approach, it is expected that the dominant wind is easterly in August and southeasterly in September. So that, it is suggested that approaching TCs in September have larger southerly wind component and more water vapor advection, and result more TCP than in August.

4. Summary

TC–induced precipitation (TCP) over Japan is evaluated using the rain gauge observation based gridded dataset APHRO JP. We found that we could properly evaluate TCP by accumulating differences between daily precipitation and the corresponding monthly means within a distance of 8° of latitude from the TC center. Annual TCP is relatively large in southern Japan area and decreases with increasing latitude. However, the decrease is not monotonic; there are localized areas of large annual TCP. The largest annual TCP, 500 mm yr\(^{-1}\) or more, occurs in E-Kyushu, S-Shikoku, and E-Kii, where annual TCP accounts for 18%, 15%, and 14% of the total precipitation, respectively. These percentages indicate that TCP is important for water resources in these areas. The annual maxima of daily TCP are 200, 230, and 260 mm d\(^{-1}\) in E–Kyushu, S–Shikoku, and E–Kii, respectively, and are distributed in a pattern that is consistent with the distribution of annual TCP. Therefore, there is a definite possibility of flash flooding due to TCs in these areas.

Based on the fact that most areas with large annual TCP correspond to eastward or southeastward topographic inclines, we can expect that large amounts of TCP result from topographic effects associated with easterly or southeasterly wind by TC circulation. In contrast to E-Kyushu, S-Shikoku, and E-Kii, annual TCP over Okinawa, which has the largest TCN, is only around 300 mm yr\(^{-1}\), lower than the annual TCP over those three areas, because Okinawa has no steep inclines. This comparison suggests the importance of topographic effects on TCP.

To assess potential hazards due to TCP, the probability daily TCP is evaluated. The probability daily TCP is 500 mm d\(^{-1}\) with a return period of 50 years in E-Kyushu, S-Shikoku, and E-Kii. These three areas appear to be the most hazardous part of Japan in terms of TCP. Even in the eastern Hokkaido, the probability daily TCP is lower than 300 mm d\(^{-1}\).
TCP is 250 mm d\(^{-1}\) or more. These values are roughly comparable to the climatological annual TCP.

Future change of TCP is an important and interesting problem. Increasing in TC intensity is discussed in future climate (Ying et al. 2012; Christensen et al. 2013). Even in the past climate, it is important to study changes in TC intensity from the observation. In general, however, the gridded dataset may include apparent or artificial climate signals due to changes of input observing systems. For example, Kamiguchi et al. (2010) found a false trend in the annual maximum of daily precipitation in APHRO_JP dataset due to a large change in the number of observations around 1978. In a trend study, we should utilize station data rather than gridded data. For example, Ying et al. (2011) found an increasing trend in the TC–induced rainfall in China by using station data from 1955 to 2007. Investigation of TCP trends using the station data over Japan will be the focus of our next study.

Acknowledgements

We thank two anonymous reviewers for their valuable comments to improve the manuscript.

Edited by: T. Nasuno

Supplements

Supplementary materials include 5 figures.

Fig. S1 Surface altitude over Japan, and location names referred in this study.

Fig. S2 Monthly TC tracks around Japan from July to October.

Fig. S3 Distribution of annual TCP (mm yr\(^{-1}\)) in (a) the Sakishima Islands, (b) Okinawa and Amami, (c) Kyushu, (d) Shikoku, (e) Kii peninsula, and (f) the southern Japan Alps area.

Fig. S4 Same as Fig. S3, but for annual TCPF (%).

Fig. S5 Same as Fig. S3, but for the annual maximum of daily TCP (mm d\(^{-1}\)).

References

Arakawa, O., and A. Kitoh, 2011: Intercomparison of the relationship between precipitation and elevation among gridded precipitation datasets over the Asian summer monsoon region. Global Environ. Res., 15, 109–118.

Chan, J. C. L., and J. D. Kepert, 2010: Global Perspectives on Tropical Cyclones. World Scientific, Singapore, 436 pp.

Christensen, J. H., and co-authors, 2013: Climate Phenomena and their Relevance for Future Regional Climate Change. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dare, R. A., N. E. Davidson, and J. L. McBride, 2012: Tropical cyclone contribution to rainfall over Australia. Mon. Wea. Rev., 140, 3606–3619, doi:10.1175/MWR-D-11-00340.1.

Dare, R. A., 2013: Seasonal tropical cyclone rain volumes over Australia. J. Climate, 26, 5958–5964, doi:10.1175/JCLI-D-12-00778.1.

Gesch, D. B., K. L. Verdin, and S. K. Greenlee, 1999: New land surface digital elevation model covers the Earth. Eos Trans. AGU, 80, 69–70, doi:10.1029/99EO00050.

Gumbel, E. J., 1958: Statistics of Extremes. Echo Point Books & Media, 375pp.

Kamahori, H., 2012: Mean features of tropical cyclone precipitation from TRMM/3B42. SOLA, 8, 17–20, doi:10.2151/sola.2012-005.

Kamiguchi, K., O. Arakawa, A. Kitoh, A. Yatagai, A. Hamada, and N. Yasutomi, 2010: Development of APHRO JP, the first Japanese high-resolution daily precipitation product for more than 100 years. Hydro. Res. Lett., 4, 60–64, doi:10.3178/HRL.4.60.

Kubota, H., and B. Wang, 2009: How much do tropical cyclones affect seasonal and interannual rainfall variability over the western North Pacific? J. Climate, 22, 5495–5510, doi:10.1175/2009JCLI2646.1.

Nguyen-Thi, H. A., J. Matsumoto, T. Ngo-Duc, and N. Endo, 2012: A climatological study of tropical cyclone rainfall in Vietnam. SOLA, 8, 41–44, doi:10.2151/sola.2012-011.

Nuemann, C. J., 1993: Global overview. Global guide to tropical cyclone forecasting, World Meteorological Organization, Rep. TCP-31, WMO/TD-560. Geneva, Switzerland.

Prat, O. P., and B. R. Nelson, 2013: Mapping the world’s tropical cyclone rainfall contribution over land using the TRMM multi-satellite precipitation analysis. Water Resour. Res., 49, 7236–7254, doi:10.1002/wrcr.20527.

Ren, F., G. Wu, W. Dong, X. Wang, Y. Wang, W. Ai, and W. Li, 2006: Changes in tropical cyclone precipitation on China. Geophys. Res. Lett., 33, L20702, doi:10.1029/2006GL027951.

Rodgers, E. B., R. F. Adler, and H. F. Pierce, 2000: Contribution of tropical cyclones to the North Pacific climatological rainfall as observed from satellites. J. Appl. Meteor., 39, 1658–1678, doi:10.1175/1520-0450(2000)039<1658:COFTNC>2.0.CO;2.

Yatagai, A., K. Kamiguchi, O. Arakawa, A. Hamada, N. Yasutomi, and A. Kitoh, 2012: APHRODITE: Constructing a long-term daily gridded precipitation dataset for Asia based on a dense network of rain gauges. Bull. Amer. Meteor. Soc., 93, 1401–1415, doi:10.1175/BAMS-D-11-00122.1.

Ying, M., B. Chen, and G. Wu, 2011: Climate trends in tropical cyclone-induced wind and precipitation over mainland China. Geophys. Res. Lett., 38, L01702, doi:10.1029/2010GL045729.

Ying, M., T. R. Knutson, H. Kamahori, and T.-C. Lee, 2012: Impacts of climate change on tropical cyclones in the western North Pacific basin. Part II: Late twenty-first century projections. Tropical Cyclone Res. Review, 1, 231–241, doi:10.6057/2012TCRR02.09.

Manuscript received 27 June 2018, accepted 1 October 2018 SOLA: https://www.jstage.jst.go.jp/browse/sola/