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Sharp rises in large-scale, long-duration precipitation extremes with higher temperatures over Japan

Daisuke Hatsuzuka¹ , Tomonori Sato¹ and Yoshihito Higuchi²

The intensity of extreme precipitation has been projected to increase with increasing air temperature according to the thermodynamic Clausius–Clapeyron (C–C) relation. Over the last decade, observational studies have succeeded in demonstrating the scaling relationship between extreme precipitation and temperature to understand the projected changes. In mid-latitude coastal regions, intense precipitation is strongly influenced by synoptic patterns and a particular characteristic is the long-lasting heavy precipitation driven by abundant moisture transport. However, the effect of synoptic patterns on the scaling relationship remains unclear. Here we conduct an event-based analysis using long-term historical records in Japan, to distinguish extreme precipitation arising from different synoptic patterns. We find that event peak intensity increases more sharply in persistent precipitation events, which lasted more than 10 h, sustained by atmospheric river-like circulation patterns. The long duration-accumulated precipitation extremes also increase with temperature at a rate considerably above the C–C rate at higher temperatures. Our result suggests that long-lasting precipitation events respond more to warming compared with short-duration events. This greatly increases the risks of future floods and landslides in the mid-latitude coastal regions.

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INTRODUCTION

The moisture-holding capacity of the atmosphere increases with air temperature at a rate of $\sim 7\% \text{ } ^\circ\text{C}^{-1}$, governed by the Clausius–Clapeyron (C–C) relation. This relationship should also hold for the intensity of extreme precipitation, unless there are large-scale circulation changes^{1,2}. However, contrary to expectation, there is widespread observational evidence that short-duration (sub-daily or hourly) extreme precipitation increases with temperature beyond the C–C rate, the so-called super C–C scaling^{3–8}. The rate may increase to almost double the C–C relationship at relatively high temperatures^{3,7}. The strong increase in short-duration precipitation potentially leads to an increase in the magnitude and frequency of flash floods⁸. Hence, attention has focused on elucidating the mechanisms behind the super C–C scaling for short-duration precipitation extremes. To help interpret the mechanisms, one suggestion is to consider the type of precipitation^{9,10}. Earlier studies have attempted to separate convective and large-scale precipitation based on observed cloud types^{7,11,12}, lightning detection¹³, large-scale circulation patterns¹⁴, and event duration¹⁵. The consensus of these studies is that convective precipitation alone produces super C–C scaling in extreme events, emphasizing the primary contribution of local and short-lived precipitation events to super C–C scaling^{7,11–15}.

However, synoptic-scale storms, typically associated with anomalous moisture flux or atmospheric rivers (ARs), also bring extreme precipitation, especially in mid-latitude regions¹⁶. Unlike local thunderstorms, synoptic-scale storms are characterized by persistent and large accumulated precipitation, which can cause widespread floods and landslides over East Asia during summer¹⁷ and over Western Europe and western North America during winter^{18,19}. In the warm season, the interaction between summer monsoon and synoptic systems is a common feature in the extra-tropical regions such as East Asia and South America. In East Asia, such environment is favourable for long-persistent precipitation events, which often

include some burst periods due to convective cells (or mesoscale convective systems) embedded in the stratiform precipitation area²⁰. This type of storm recently led to devastating summer floods and landslides over East Asia, accompanied by the anomalous accumulated precipitation (e.g., in Japan in 2014 and 2018, and in central China and Japan in 2020^{17,21,22}). The scaling rate in this region provides evidence that the extreme values of longer-duration (daily) precipitation have unexpectedly larger scaling rates than shorter-duration precipitation (10 min and hourly)²³. However, despite the significant socioeconomic impacts, the relationship between the scaling and synoptic situations for persistent precipitation events is still poorly understood⁸.

In the empirical scaling approach, daily analysis (i.e., fixed-interval statistics) can skew the results for long-duration events, because a single precipitation event can persist over a number of days, whereas daily precipitation may originate from a short-duration event, especially at higher temperatures¹⁰. In contrast, event statistics enable analysis of the life cycle and background weather patterns of individual storms^{7,15,24,25}. A previous study also emphasized the importance of underlying storm characteristics (such as seasonal changes in dominant storm types and large-scale circulations) in the scaling analysis²⁶. In East Asia, the two types of storms (i.e., AR-like synoptic storms and local convective storms) typically contribute to extreme precipitation during the warm season as mentioned above. As convective precipitation is more dominant at higher temperatures^{7,12}, we would expect that the event statistics can distinguish convective precipitation arising from different storm types or synoptic patterns. Consequently, the classification of storm types in this region potentially leads to deeper insights into future change in convective storms and also different hydrological hazards such as flash floods and widespread floods.

Here we conducted C–C scaling analysis using an event-based precipitation dataset and compared scaling rates and synoptic

¹Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan. ²Graduate School of Environmental Science, Hokkaido University, Sapporo, Japan.

email: hatsuzuka@ees.hokudai.ac.jp

weather patterns for both short- and long-duration events. In this study, short-duration events are defined as precipitation events whose duration are <5 h and the peak precipitation intensity occurs in the afternoon hours, whereas long-duration events are defined as those lasting longer than 10 h. We used temporally and spatially dense gauge precipitation data from Japan (Supplementary Fig. 1), comprising 646 stations with 10 min temporal resolution over a period of 25 years, with daily mean temperature. This enabled accurate measurement of extreme precipitation in this region, where various weather systems were related to extreme precipitation on different temporal scales²⁷. The associated atmospheric conditions were also calculated from the Japanese 55-year Reanalysis (JRA-55). We only considered the warm season (May–September) to minimize the effect of seasonal changes in dominant weather patterns (i.e., southwesterly dominates in the warm season and northwesterly dominates in the cold season) on the scaling²⁶. For each individual precipitation event, we calculated three event properties as follows: event duration, peak hourly (maximum) intensity, and total precipitation accumulation (Fig. 1).

RESULTS

Synoptic patterns associated with extreme precipitation events

We find that the duration-based classification correctly distinguished precipitation statistics derived from different types of storms. Shorter-duration extreme events (typically <5 h) are more likely to occur around late afternoon, whereas longer-duration extreme events (>10 h) tend to dominate from midnight to early morning (Supplementary Fig. 2), suggesting that these two event types are triggered by different physical mechanisms. Figure 2 shows mean synoptic weather patterns for extreme precipitation events, defined as days where peak event intensity exceeded the 99th percentile at any station for each temperature bin (see

Fig. 1 A schematic illustration for the identification of independent precipitation events. **a** Artificially produced time series of 10 min precipitation. Symbols D , R , and t_d indicate event duration, total precipitation accumulation, and dry (non-precipitation) duration, respectively. **b** Time series of 10 min precipitation (left axis, green bars) and accumulated hourly precipitation calculated every 10 min (right axis, circles) for Event #2. Symbols I_p and t_p indicate event peak hourly precipitation and peak time, respectively. The scale of the x-axis has an interval of 10 min for both panels.

'Methods'). It is obvious that long-duration extreme events were closely related to synoptic-scale large southwesterly moisture fluxes (Fig. 2a), which denoted ARs²⁸. The elongated strong moisture convergence and the mid-level warm temperature anomaly on the leeward side are also indicative of a frontal system along the moisture convergence band. In contrast, in short-duration events with peak intensity in the afternoon, the large-scale moisture convergence is considerably weaker (Fig. 2b). The mid-level cold temperature anomaly and moderate moisture advection are favourable conditions for the development of local deep convection, in conjunction with the daytime heating over the land surface (Supplementary Fig. 2). These contrasting features are also illustrated by the spatial distributions of cloud cover associated with the two event types (see Supplementary Fig. 3 for typical extreme cases). In particular, for the long-duration event under warmer temperature (Supplementary Fig. 3b), the larger area with high cloud tops (i.e., areas below -40°C) suggests a contribution of well-organized or long-lived mesoscale convective systems to the extreme event, as found in the tropics²⁹.

Scaling of event peak intensity with surface temperature

The relationship between peak hourly intensity in extreme precipitation, which leads to hydrological hazards such as local flooding, and daily mean temperature is shown in Fig. 3a. The scaling slopes for both event types substantially exceeds the C-C rate. The super C-C scaling for short-duration events agrees with the convective precipitation results from previous studies^{7,8,12}. However, the super C-C rate is also found for long-duration events, in contrast to previous studies that showed long-duration stratiform precipitation associated with synoptic-scale storms does not exceed the C-C rate. In particular, the scaling slope appears to follow a doubled C-C line at a temperature range from 19°C to 24°C . From the quantitative estimation based on exponential regression (see 'Methods'), the scaling rates are $11.1\%^\circ\text{C}^{-1}$ for long-duration events, $9.8\%^\circ\text{C}^{-1}$ for short-duration events, and $9.7\%^\circ\text{C}^{-1}$ for all events, at the overall temperature range. The lower scaling rate for all events is probably due to a more distinct decrease in peak intensity at higher temperatures (discussed in detail later). The super C-C scaling for long-duration events is also robust, regardless of the thresholds of precipitation, whereas for short duration, lower threshold events exhibit a temperature dependence close to the C-C rate as reported in previous studies^{3,12} (Supplementary Fig. 4). These results indicate that peak hourly precipitation originating from large-scale long-duration events responded more sensitively to changes in temperature than that from short-duration events.

The scaling shape for all events has a pronounced peak structure (i.e., decreasing slope above 25°C in Fig. 3a), which has been observed before in mid-latitudes²³. In this region, event duration clearly changes at higher temperatures: short-duration events become more dominant above 20°C (Fig. 3b). This probably reflects the seasonal transition of rainfall characteristics associated with weather patterns, i.e., short-duration events are likely to occur during mid-summer with higher seasonal temperatures (Fig. 3c), and there are more non-precipitation hours or more sunshine in short-duration events, leading to higher daily mean temperatures. According to the transition of event types, peak intensities for all events also reflect those of short-duration events at higher temperatures. As long-duration events are more intense than short-duration events in the extreme hourly intensity (Fig. 3a and Supplementary Fig. 4), the increasing fraction of short-duration events with temperature leads to a suppression of peak intensity growth at higher temperatures when all the events are considered. This indicates that the mixture of diverse event durations (or storm types) can contribute to the negative scaling at the highest temperatures when measuring all events, consistent with previous studies^{23,25,30} and, thus, also to a weaker

Fig. 2 Mean synoptic weather patterns corresponding to extreme precipitation events. The patterns of vertically integrated moisture flux (vector) and its convergence (shading) and temperature anomalies at 500 hPa (contours) for **a** long- and **b** short-duration events. Extreme precipitation events are defined as days above the 99th percentile of event peak intensity at any station for each analysed temperature bin. The number of events is indicated at the lower right of each panel. The temperature anomalies indicate the deviation of temperature in the extreme events from monthly mean climatology (1994–2018). Moisture convergence $>0.2 \times 10^{-4} \text{ kg m}^{-2} \text{ s}^{-1}$ is shaded. The contour interval for temperature anomalies is 0.2°C and the zero line is omitted.

Fig. 3 The relationship between surface air temperature and extreme hourly precipitation. **a** The 99th percentile of event peak hourly precipitation as a function of daily mean surface temperature for long-duration (red), short-duration (blue), and all (black) events. Solid and dashed lines indicate $7\%^\circ\text{C}^{-1}$ and $14\%^\circ\text{C}^{-1}$ rates, respectively. A logarithmic vertical axis is used. Shaded areas denote the 95% confidence intervals estimated using the bootstrap method (see ‘Methods’). The estimated scaling rates are $11.1\%^\circ\text{C}^{-1}$, $9.8\%^\circ\text{C}^{-1}$, and $9.7\%^\circ\text{C}^{-1}$ for long-duration, short-duration, and all events, respectively. **b** Count (solid lines) of long (red)- and short (blue)-duration events and their fraction of all events (dashed lines) in each temperature bin. Note that the total fraction of long- and short-duration events is below 1.0, because all events also include mid-duration (5–10 h) events and short-duration events with morning peak intensity. **c** Monthly count of the two types of events (solid lines). As a reference, the grey dashed line indicates the climatology of the surface temperature over the whole of Japan using data from all 646 stations.

Fig. 4 The relationship between surface air temperature and total-event precipitation amount for long-duration events. **a, b** Total-event precipitation in long-duration events as a function of daily mean surface air temperature (**a**) and their durations (**b**). In **a** and **b**, target events were selected as those showing strong hourly precipitation beyond the 99th percentile for hourly peak intensity at each temperature bin. **c, d** The same as for **a, b** but for the events with total-event precipitation accumulations exceeding the 99th percentile. Red circles show the median values of extreme events and box plots show the 10th (bottom horizontal bar), 25th (box bottom), 75th (box top), and 90th (top horizontal bar) percentiles. In **a** and **c**, solid and dashed lines indicate $7\% \text{ } ^\circ\text{C}^{-1}$ and $14\% \text{ } ^\circ\text{C}^{-1}$ increase, respectively, and a logarithmic vertical axis is used.

scaling rate at the overall temperature range. It is noteworthy that in the individual event types, we still find upper limits for event peak intensity at the highest temperatures, but with a relatively large uncertainty for long-duration events (Fig. 3a). Such a behaviour has been often explained by reduction in relative humidity^{4,5,12,15}. In this region, relative humidity similarly decreases with temperature at higher temperatures (Supplementary Fig. 5), which can be attributed to the land-ocean temperature contrast³¹. This implies that lower relative humidity could become a key factor in the peak-like structures for the individual event types, even under the relatively humid climate associated with the East Asian summer monsoon.

Scaling of event accumulated precipitation with surface temperature

To evaluate the implications for widespread flood risk, we investigate the total precipitation amount for long-duration events. Figure 4 shows the plot for total precipitation

accumulation of long-duration events based on two different thresholds. Figure 4a, b are for long-duration events whose maximum intensity exceeds the 99th percentile (i.e., events with an instantaneous extreme precipitation), but Fig. 4c, d are for long-duration events whose event-total accumulations exceed the 99th percentile. It is noteworthy that even in the same long-duration events, larger event precipitation is observed in events lasting longer than 24 h (Fig. 4c) than in events with instantaneous intense precipitation (Fig. 4a). This means that event-based analysis is a more appropriate measure for long-duration events compared to daily-based statistics. In both cases, the median values of extreme events exhibit a clear super C-C scaling at temperatures between 18°C and 24°C . Quantitatively, the scaling rates are $11.8\% \text{ } ^\circ\text{C}^{-1}$ and $11.4\% \text{ } ^\circ\text{C}^{-1}$ in Fig. 4a, c, respectively, for median values in each temperature bin from 18°C to 24°C . There are no obvious differences in the event durations within this temperature range (Fig. 4b, d), indicating their negligible impact on the scaling relationship. The precipitation characteristics at a storm scale are governed by the relative contribution of

convective and non-convective cells within the storm³². Thus, the super C-C scaling for total-event precipitation is attributable to multiple factors including intensification of convective rain cells, relative increase in convective rain area, and also possibly intensification of non-convective rain cells (e.g., compare Supplementary Fig. 3a, b).

In contrast, in the cold regime (below 18 °C), the extremes of accumulated precipitation (Fig. 4a, c) are not dependent on surface temperature. Their event durations (Fig. 4b, d) are also insensitive to surface temperature. In this regime, the larger areal extent of non-convective precipitation (e.g., Supplementary Fig. 3a) may obscure the contribution of convective precipitation when scaling analysis is attempted for each storm³². In the warm regime (above 24 °C), the accumulated precipitation extremes tend to decrease with temperature, similar to the results for event peak intensity. This is partly explained by the fact that the moisture supply is not sufficient for the development of convection (Supplementary Fig. 5), which also contributes to the decrease in event duration at the highest temperature range (Fig. 4d). It is noteworthy that the warm regime has large uncertainty owing to the limited number of event samples (Fig. 3b). Suggestions for future research include investigating how the spatial structure of storms responds to the increase in temperature.

DISCUSSION

In summary, extreme precipitation associated with long-duration events increased with temperature at rates that exceeded the moisture-holding capacity. This super C-C increase was observed for both event peak intensity and total amount. Extreme precipitation induced by large-scale moisture advection is expected to have a strong connection with the temperature in the moisture-source areas. In such a case, the air temperature in the precipitation region may be very different from the air temperature in the moisture-source region⁶. However, our results demonstrated the considerable sensitivity of precipitation intensity to local temperatures, in particular at higher temperatures. Long-duration extreme precipitation events mostly occurred during the Baiu/Meiyu season (i.e., from May to July) (figure not shown, but the distribution is quite similar to total long-duration events in Fig. 3c). During this season, southwesterly flow associated with the East Asian summer monsoon sustainably supplies abundant moisture in this region (Fig. 2a), which can maintain atmospheric moisture close to the saturation level for the local temperature irrespective of the moisture-source temperature. Moreover, such situations are favourable for the formation and development of mesoscale convective systems near the quasi-stationary Baiu front²⁰. The morning peak of the long-duration events (Supplementary Fig. 2) is also consistent with the behaviour of convective systems associated with the Baiu front³³. Thus, the super C-C scaling of long-duration events could be explained by the response of convection embedded in synoptic-scale storms to warming, especially in the event peak intensity. This involves feedback from cloud dynamics associated with an increase in latent heat release with temperature^{1,8,34}. Although the mechanism of the super C-C scaling is beyond the scope of this study, our results highlight the usefulness of local temperature in diagnosing convective activity within synoptic-scale systems.

Climate models in the fifth phase of the Coupled Model Intercomparison Project commonly project increases in the frequency of ARs in the northern mid-latitudes, under the Representative Concentration Pathway 4.5 and 8.5 scenarios³⁵. Therefore, the results presented in this study have important implications for future changes in extreme precipitation associated with ARs. In particular, the sharp increase with temperature in total-event precipitation for long-duration events (Fig. 4a, c), whose synoptic patterns resemble AR events (Fig. 2a), suggests a

potential increase in the risk of widespread floods and landslides because of climate change over the mid-latitude coastal regions where ARs make a large contribution to extreme precipitation and flood events^{16,36}. In contrast, as shown in the present and many previous studies^{4,5,12,15,30}, the peak-shaped scaling relationship raises doubts about future increase of precipitation extremes²⁶. Recently, climate models projected increases in both the peak of extreme precipitation and the peak-point temperature in a warmer climate³¹. This means that the current peak-like structures (Fig. 3a) may not reflect the potential upper limit for future precipitation extremes. Continuous monitoring of precipitation and atmospheric moisture will be essential to identify any modulation of C-C scaling in the present climate³⁷ and thus provide more accurate insights into the future. Besides the C-C scaling studies, we also identified the need for convection-permitting climate models to produce reliable projections of large-scale, long-duration precipitation extremes, as often proposed for short-duration precipitation^{8,26}.

METHODS

Data

We used surface observations of 10 min precipitation and daily mean surface air temperature from 646 stations located uniformly over Japan (Supplementary Fig. 1a). We considered the period 1994–2018 (25 years) when 10 min precipitation was available. The data were corrected through the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency and precipitation was recorded by tipping-bucket rain gauges with a resolution of 0.5 mm. We chose AMeDAS stations with <1% missing or uncertain values during the analysis period for 10 min precipitation data. As the selected stations were mostly located at an elevation of below 500 m (586 out of 646 stations), all data from 646 stations were pooled in one dataset with no consideration for their elevations. In this study, only the warm season (May–September) was considered, when the East Asian summer monsoon commonly influenced the climate in this region.

The data set used for the analysis of synoptic-scale atmospheric conditions related to extreme precipitation events was the JRA-55³⁸, which globally provides 6 hourly atmospheric fields at 1.25° × 1.25° spatial resolution.

Event-based analysis

We created a database of precipitation events for each station using the 10 min precipitation series. Precipitation events have been detected by specifying a minimum inter-event time^{13,15,24,25}. Following these studies, we defined an individual event as the period separated by a dry interval (i.e., continuous non-precipitation spell) of 3 h or longer. A sensitivity test was also performed using 1 and 6 h dry intervals, but these thresholds had no significant impacts on the scaling results. We considered precipitation events with a total amount >1.0 mm. Tropical cyclones also bring heavy precipitation in this region. However, extreme precipitation associated with tropical cyclones is also influenced by their intensity and such a dynamic effect could lead to a deviation from pure thermodynamic scaling³⁹. Hence, we excluded days under the influence of tropical cyclones based on the best track data of the Japan Meteorological Agency, which were defined as days when a tropical cyclone was centred within a 1000 km radius from a station of interest. Applying this methodology, we detected 790,554 events in total over 25 warm seasons. For each event, we determined three event properties: event duration, peak hourly intensity, and event precipitation accumulation. The peak hourly intensity was defined as the maximum value of 60 min precipitation calculated for each 10 min interval within an event (see Fig. 1). Based on these event properties, 18%, 21%, 32%, and 29% of the events were associated with long-duration, mid-duration, afternoon-peak short-duration (defined as 'short' in this study), and morning-peak short-duration events, respectively (see below for each event definition).

In this study, we focused on two typical storms that cause extreme precipitation in this region: one was local thunderstorms and the other was synoptic-scale storms accompanied by anomalous moisture flux (e.g., ARs). Event duration was a critical factor to distinguish these storm types^{15,30}. Supplementary Fig. 2 shows the diurnal variation in the relative frequency of peak hourly precipitation summarized for different event durations.

Short-duration events (typically <5 h) were more likely to occur around late afternoon, which was more prominent for extreme hourly intensity. In contrast, longer-duration events (>10 h) tended to be dominant from midnight to early morning. Such a diurnal contrast between different event durations was also identified in previous studies^{40,41}. The afternoon peak of short-duration events is probably due to the diurnal variation of surface solar heating, whereas for long-duration events the morning peak may be explained by the atmospheric condition before the maximum precipitation occurs (e.g., moisture accumulation and convection growth in the evening)⁴¹.

Based on these results, we classified precipitation events into two types based on their durations: short- and long-duration events. Short-duration events referred to precipitation events lasting <5 h with peak precipitation intensity in the afternoon hours (from 1200 to 0000 local time), based on the characteristics of local thunderstorms in the study region. On the other hand, long-duration events referred to those lasting longer than 10 h. To minimize the effects of different storm types on the scaling, mid-duration (i.e., 5–10 h) events and short-duration events with morning peak intensity were classified as neither short- nor long-duration events. However, as these events account for approximately half of all events, we also show the results of these excluded events similarly to the analysis for short- and long-duration events in Fig. 3 (Supplementary Fig. 6).

To analyse the synoptic-scale atmospheric conditions for extreme precipitation events, we composited JRA-55 reanalyses across all days above the 99th percentile of peak intensity at any station, i.e., extreme events occurring at multiple stations on the same day were considered as one event. We confirmed that the event duration-based classification distinguished two storm types in the large-scale atmospheric conditions, i.e., that short- and long-duration events corresponded to local thunderstorms and synoptic-scale storms, respectively (see Fig. 2 and main text for details).

Scaling of extreme precipitation

The relationship between extreme precipitation and temperature was investigated using a binning technique. Here we used an equal-distance method, following previous studies^{4,7,11}. First, we assigned daily mean temperature on the day of each precipitation event to the corresponding event. If the event extended over multiple days, the average temperature of those days was used. The pairs of precipitation properties for each event (i.e., peak hourly intensity or precipitation accumulation) and daily mean temperature obtained from each station were pooled in one large data set, then placed in bins of 2 °C with steps of 1 °C (i.e., overlapping bins). In addition, to ensure a robust scaling relationship, the calculation was performed only within a temperature range from 11 °C to 27 °C, so that >80% of all stations were used for each bin (Supplementary Fig. 1b). For the binned data, we mainly computed the 99th percentiles of precipitation properties as a threshold for extremeness. To estimate the uncertainty, we also calculated the 95% confidence intervals of the percentiles using a bootstrap method. For a given temperature bin, 1000 samples of percentile values were estimated from randomly sub-sampled datasets of precipitation properties. Then 95% confidence intervals were determined based on the assumption that 1000 estimated values follow a normal distribution. The number of sub-samples was set to half the sample of the original data for a given temperature bin.

Finally, to identify the scaling of precipitation with temperature, we applied an exponential regression, which is widely used in scaling studies^{5,6,23}. We fitted a least-squared linear regression to the logarithm of precipitation extremes as follows (Supplementary Fig. 7):

$$\log(P) = \beta_0 + \beta_1 T \quad (1)$$

where P is precipitation and T is the corresponding temperature. The median temperatures of each bin were used to calculate the regression equation. Then scaling ($\Delta P\% \text{ } ^\circ\text{C}^{-1}$) was estimated using the exponential transformation of the regression coefficient β_1 :

$$\Delta P = 100 \times (e^{\beta_1} - 1) \quad (2)$$

DATA AVAILABILITY

The AMeDAS station data are available at <https://www.data.jma.go.jp/obd/stats/etrn/>. The JRA-55 reanalysis is available at https://jra.kishou.go.jp/JRA-55/index_en.html#download. The geostationary satellite data were downloaded from Kochi University at <http://weather.is.kochi-u.ac.jp/>.

CODE AVAILABILITY

The computer code used in the present study is available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

D.H. designed the study, performed the analysis, and wrote the manuscript. T.S. advised on the analysis and interpretation of the results, and helped revise the manuscript. Y.H. conducted pre-processing analysis.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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Correspondence and requests for materials should be addressed to D.H.

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