17. CONTRIBUTION OF ATMOSPHERIC CIRCULATION CHANGE TO THE 2012 HEAVY RAINFALL IN SOUTHWESTERN JAPAN

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Introduction. From 11 July to 14 July 2012, during the late Japanese "Baiu" rainy season, the southwestern part of Japan experienced an extraordinary heavy rainfall. This event was record breaking at many sites (detailed rainfall analysis is shown in Supplementary Fig. S17.1), and caused devastating damage with 31 deaths, 3 missing persons, floods, mudslides, and damaged homes in the southwestern part of the mainland of Japan.

In a normal rainy season from June to July, a persistent rain band called the "Baiu front" supplies a large amount of water to southwestern Japan and some parts of East Asia (Fig. 17.1a). The Baiu front is associated with the large-scale Asian summer monsoon circulation and a development of the northwestern Pacific subtropical high (PASH). In 2012, water vapor supply to Kyushu, the southernmost part of Japan, was extremely large (Fig. 17.1b). The intense convergence over these areas was forced by the anomalously strong PASH and an anomalous cyclonic circulation over the South China Sea, both inducing southerly convergence flows, which transported a large amount of water vapor into southwestern Japan (Fig. 17.1b).

The stronger PASH during the 2012 rainy season was characterized by a dominant teleconnection pattern over East Asia called the Pacific-Japan (PJ) pattern (Nitta 1987). The PJ pattern consists of a meridional dipole of circulation between the tropical and midlatitude northwestern Pacific (highlighted in Fig. 17.2b by red plus and cross symbols), and is an important teleconnection pattern affecting the East Asian summer climate. Contours in Fig. 17.2a show that convection was more active than normal in the tropics [negative outgoing longwave radiation (OLR)] to the east of the Philippines and Indonesia, associated with a descending high-pressure anomaly over the subtropical area (corresponding to the PASH region) and a low-pressure anomaly to the north of the PASH region. This pressure pattern in 2012 was located to the east of the typical PJ pattern, which tends to intensify heavy rainfall especially in southwestern Japan (Fig. 17.2b, as described hereinafter in detail). In addition, the emergence of another teleconnection pattern called the circumglobal teleconnection (CGT; Ding and Wang 2005; Yasui and Watanabe 2010), which is characterized by a dominant wave train along the Asian Jet located around 30°N–40°N, amplified the PASH in the rainy season of 2012 (the observed wave train can be found in Supplementary Fig. S17.2). These two independent teleconnection patterns both have barotropic structure and affect the PASH activity and Japanese rainfall.

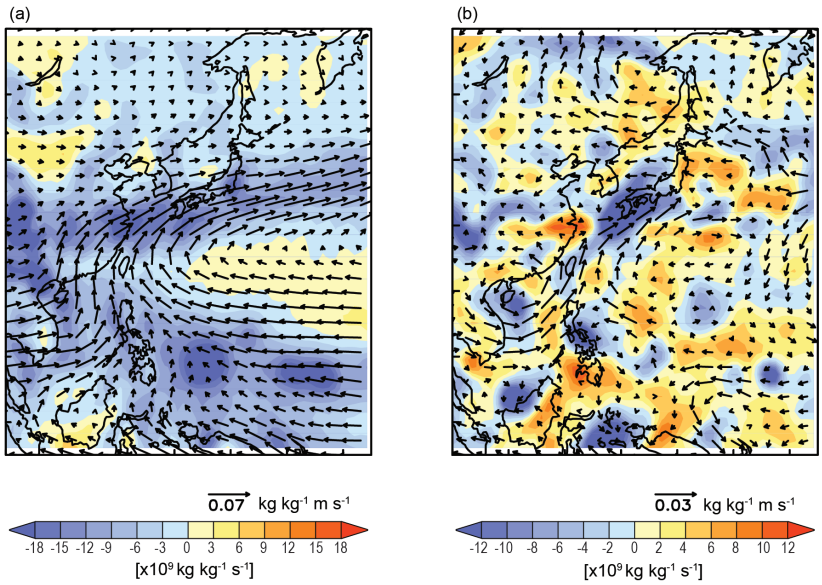

Fig. 17.1. (a) A climatology of the Japanese rainy season (15 Jun–15 Jul) from the JRA-25 reanalysis (1979–2011) column-averaged water vapor flux (kg kg^{-1} m s^{-1}, arrows) and its divergence (×10^{9} kg kg^{-1} s^{-1}, shading). (b) Same as (a) but for anomalies in 2012.

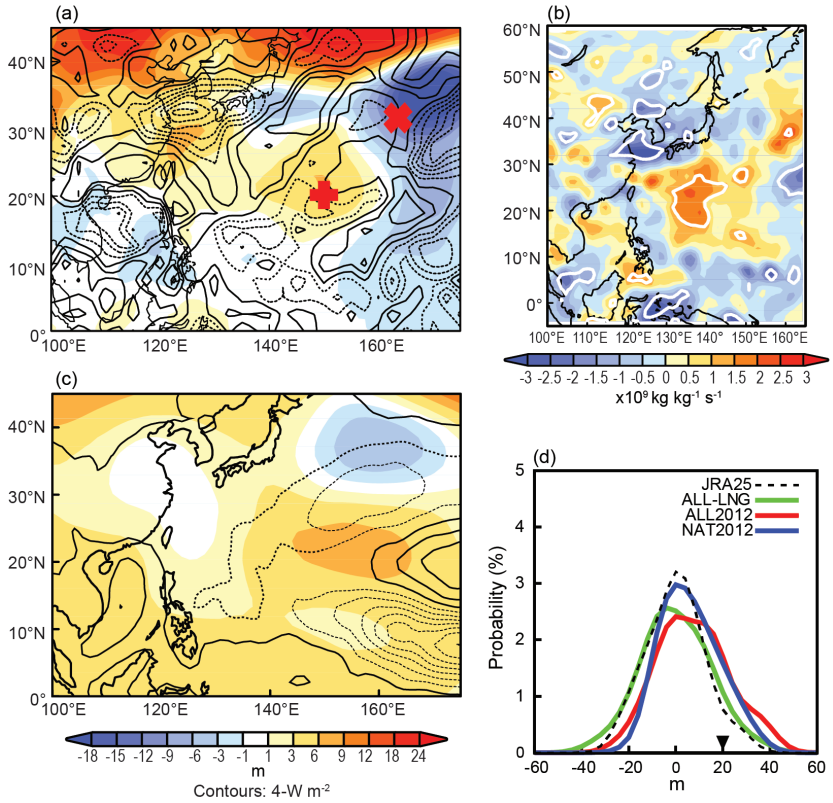

Fig. 17.2. (a) Same as Fig. 17.1b but for Z500 (m, shading) and OLR (contour, 4-W m^{-2} interval). (b) Regression coefficient of column-averaged water vapor divergence onto the observed PJ index from 1979 to 2012 (×10^{9} kg kg^{-1} s^{-1}). White lines denote a 90% significance level. (c) Same as (a) but for a 100-member ensemble-mean of ALL run for the 2012 rainy season. (d) Histogram (bars) and PDF (curve) estimated by the kernel method (Silverman 1986; Kimoto and Ghil 1993) of the PJ index; 1979–2011 climatology based on the JRA-25 (dashed) and 10-member ensemble of ALL-LNG (green), 100-member ALL (red), and NAT (blue) runs for 2012. Triangle indicates an observed anomaly in the 2012 rainy season.

The importance of evaluating the extent to which anthropogenic global warming affects specific extreme weather events has been increasing. In this context, Pall et al. (2011) conducted huge ensemble experiments with an atmospheric general circulation model (AGCM) under two specific boundary conditions corresponding to the period of an extreme event, the observed forcing and a counterfactual forcing without anthropogenic climate change, and evaluated the probabilistic difference in event occurrence rates as the contribution of anthropogenic effect by analyzing the huge pool of AGCM ensemble experiments.

We basically adopted the methodology of Pall et al. (2011). In the case of rainfall events over Japan, most AGCMs do not have the ability to reproduce such regional phenomena but may possibly represent large-scale circulations such as the PJ pattern and the CGT. In general, CGT is said to be atmospheric internal variability that cannot be attributed to SST forcing (Kosaka et al. 2009). On the other hand, the PJ pattern is a teleconnection from the tropics and has the potential to respond to SST variability, although the PJ pattern is also affected by the stochastic CGT. In terms of global warming, Kusunoki et al. (2006) demonstrated an increase in Baiu rainfall due to the El Niño-like tropical SST changes associated with the intensification of the PASH using time-slice experiments of future projections with a high-resolution AGCM. Therefore, in this study, we focused on the extent to which the anthropogenic SST change raises the level of the PJ occurrence in 2012 relative to natural variability.

Method. We conducted a 100-member AGCM ensemble experiment (factual run, called the ALL run) by an atmospheric component model of the Model for Interdisciplinary Research on Climate version 5 (MIROC5, T85L40, Watanabe et al. 2010). The model was integrated over the recent four years (2009–12), with observed SST and sea ice under the anthropogenic external conditions during the period. In order to assess the influence of possible anthropogenic effects, another 100-member ensemble was generated under anthropogenic forcing fixed at conditions from the year 1850, with modified boundary conditions (SST and sea ice) in which possible human-induced components were removed (counterfactual run under the natural external conditions, called the NAT run, see Shiogama et al. 2013 for details). The difference in the SST boundary conditions between the ALL and NAT runs is characterized by the El Niño-like warming trend pattern in the tropical Pacific, as is the case for most 20th century experiments with coupled GCMs. To validate the model reproducibility of the

interannual variability, the ALL run for 1946–2011 was replicated with a reduced ensemble size of 10 (ALL-LNG run).

Validation. Most AGCMs generally have difficulty in reproducing local rainfall variability associated with the Baiu front but have the potential to represent the background circulation. Anomaly correlation maps of rainfall and pressure patterns (500-hPa geopotential height; Z500) between the ALL-LNG and observed anomalies are shown in Supplementary Fig. S17.3a, b, respectively, and they indicate that high correlation is distributed only over a limited area in the equatorial oceans for precipitation, while a significant correlation for Z500 extends to midlatitudes. Therefore, we focused on the specific PJ pattern in 2012. Figure 17.2c shows simulated anomalies of OLR and Z500 in an ensemble mean of the ALL run as in Fig. 17.2a. The ensemble captured the observed PJ pattern responding to active convection in the tropics. We defined a PJ index as the difference of Z500 anomalies between 20°N, 150°E and 32°N, 163°E (plus and cross symbols, respectively, in Fig. 17.2a; the index is defined as the former minus the latter and a positive value corresponds stronger PASH). This index represents the 2012 extreme rainfall well because an observed water vapor supply regressed onto the PJ index shows an enhanced Baiu rainfall over southwestern Japan (Fig. 17.2b). The PJ index for 2012 is the third highest since 1979 (the time series can be found in Supplementary Fig. S17.3c), where the other two extreme cases (1995 and 2006) also involved disastrous heavy Baiu rainfall. The model ensemble average of this index from the ALL-LNG run is positively correlated with the index calculated from observations ($r = 0.35$, exceeding the 90% significant level), indicating that the "PJ pattern responds to the SST forcing to a degree through a convection change in the tropical western Pacific and that there is a potential to detect human influences through our method using the AGCM. The smallness of the correlation suggests that atmospheric natural variability that is independent from the SST variability also plays an important role in this region. Because the top/bottom 15 cases of the ALL-LNG run diagnosed by the PJ index clearly show the CGT pattern, which intensifies/depresses the PJ pattern (the pattern for the top 15 cases can be seen in Supplementary Fig. S17.2b), our AGCM also has the ability to capture this stochastic atmospheric internal variability. The shape of the probability density function (PDF) of the PJ index based on the model (green curve in Fig. 17.2d) and that derived from observations (dashed curve) are sufficiently similar that we consider our model suitable for the purpose of this study.

Results. We showed the PDFs for the PJ index from ALL and NAT runs with red and blue curves, respectively, in Fig. 17.2d to evaluate the anthropogenic effect to an occurrence rate of the 2012 circulation pattern. The PDFs of both ALL and NAT runs are shifted to the positive PJ pattern relative to the climatological distribution (green). On the other hand, the difference between the ALL and NAT runs is subtle and an ensemble mean of the ALL run is slightly larger than that of the NAT run; it implies that human-induced El Niño-like SST change slightly intensifies the "PJ pattern through the enhanced PASH. These results suggest that our results support the indication of Kusunoki et al. (2006), but in the case of the 2012 event, the effect of anthropogenic global warming is too small to be detected compared with the variability due to the natural variability of the SST.

Conclusions. The extremeness of the Japanese heavy rainfall of 2012 was mainly caused by the oceanic natural variability and probabilistic atmospheric natural variability rather than by anthropogenic climate change.