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Studies on Possible Changes in Climate and Precipitation Systems in East Asia and Around Japan Associated with Global Warming

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Frequent occurrences of record-breaking floods and snow storms in recent years have alerted our society to an increase of extraordinary precipitation events associated with global warming. The IPCC AR5 (2013) suggested that unlike temperature, which is predicted to increase almost everywhere on Earth, changes in precipitation will occur in a complex pattern. In addition, our scientific understanding of regional changes in precipitation is very limited. The situation regarding weather in Japan and East Asia, in particular, is complex, as they are located between the Pacific Ocean to the east and the Asian continent to the west. Thus precipitation in this region could respond to climate change in complex and sensitive ways (Endo et al., 2018). To enable appropriate disaster preventive actions to be taken, studies are urgently needed that examine future changes in precipitation in this region.

This project aims to obtain accurate information concerning changes in precipitation in East Asia and around Japan associated with global warming. Since precipitation is basically a sub-grid-scale phenomenon even in state-of-the-art climate models, it is difficult to represent its characteristics. Therefore, in this project, we have used various novel observations, especially satellite data, in addition to climate model outputs, to extract the best precise information concerning future changes in the precipitation characteristics, based on a physical understanding of the link between large-scale environmental conditions and precipitation characteristics.

As a result, we could clarify the essential effects of upper tropospheric phenomena such as jet streams (Horinouchi & Hayashi, 2017) and cut-off vortices (Hirota et al., 2016), small-scale sea surface temperature distributions, and large-scale teleconnections (Kubota et al., 2016), in addition to the lower-level atmospheric instabilities usually examined, on precipitation intensity. Moreover, we have found it indispensable to take stratospheric circulation into consideration and include it in numerical models to adequately reproduce storm tracks and associated precipitation (e.g., Gray et al., 2017).

Here we introduce an important result of successfully extracting likely future changes in precipitation characteristics in early summer around Japan, utilizing both satellite radar observations and climate model simulations. Analyzing three-dimensional spaceborne precipitation radar data obtained from the Global Precipitation Measurement (GPM) mission. Yokoyama et al. (2017) classified precipitation systems into three types: mid-latitude, organized and small-sized systems (Fig. 1). Through statistical examination, we confirmed that the maximum observed precipitation in each contiguous rainfall event was significantly more intense in organized systems than in the other two types (Fig. 2). After conducting physical and statistical analyses, we constructed look-up tables for the contributions from each precipitation type, referring to large-scale conditions, using GPM radar observations and meteorological data obtained from Japanese Reanalysis data (JRA55). Then, by referring to large-scale parameters obtained from RCP8.5 scenario runs of CMIP5 multi-model outputs, we extracted changes in contributions of all three different types of precipitation systems toward the end of this century (Yokoyama et al., 2018).

Torrential rainfall events are generally attributed to organized systems rather than small-scale tall convection in unstable environments, as also depicted in Hamada et al. (2015) and Hamada and Takayabu (2018). Such organized systems are effectively suppressed by large-scale subsidence, and rarely found in the Tohoku region or along the Japan Sea side of Japan in summer under the current climate regime (1980-2005; Fig. 3b). However, our future projection (for 2075-2100) shows a large increase of organized systems in these regions (Fig. 3e), which alerts us to a future increase of summertime torrential rainfall where such rainfall is infrequent under current climatic conditions. Small systems, on the other hand, tend to occur according to sea surface temperature (SST) (Fig. 3a). Therefore, precipitation from small systems will increase with higher SSTs under future climate conditions all over Japan (Fig. 3d). Such small systems contain short-duration, intense rainfall which sometimes results in urban flooding. Therefore, communities should also prepare for an increase of such urban-type floods.

In the above study, we showed that an appropriate combination of satellite and climate model data can be used to extract precise information on future precipitation changes. Urgent acquisition and close examination of such information are indispensable to informing policy makers and enabling them to take adequate actions toward disaster prevention.

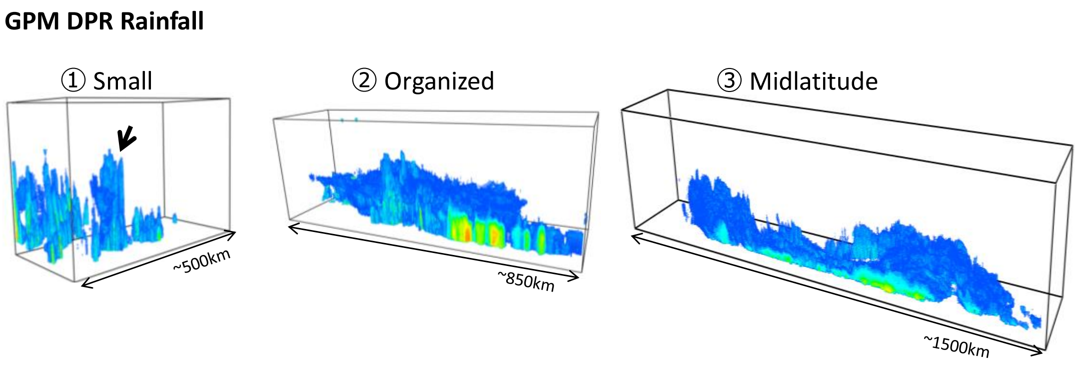

Fig.1. Examples of three classes of rainfall events identified from GPM precipitation radar observations around Japan in early summer (May-July). From Yokoyama et al. (2018).

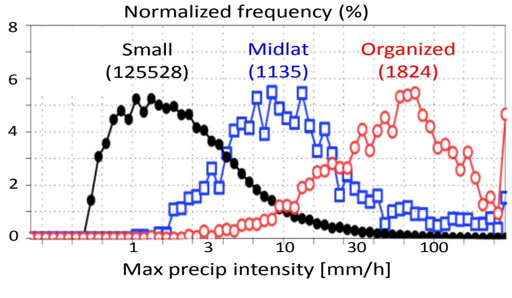

Fig.2. Normalized histograms of maximum precipitation intensity for each of the three types of precipitation events. Parentheses indicate observed numbers. From Yokoyama et al. (2018).

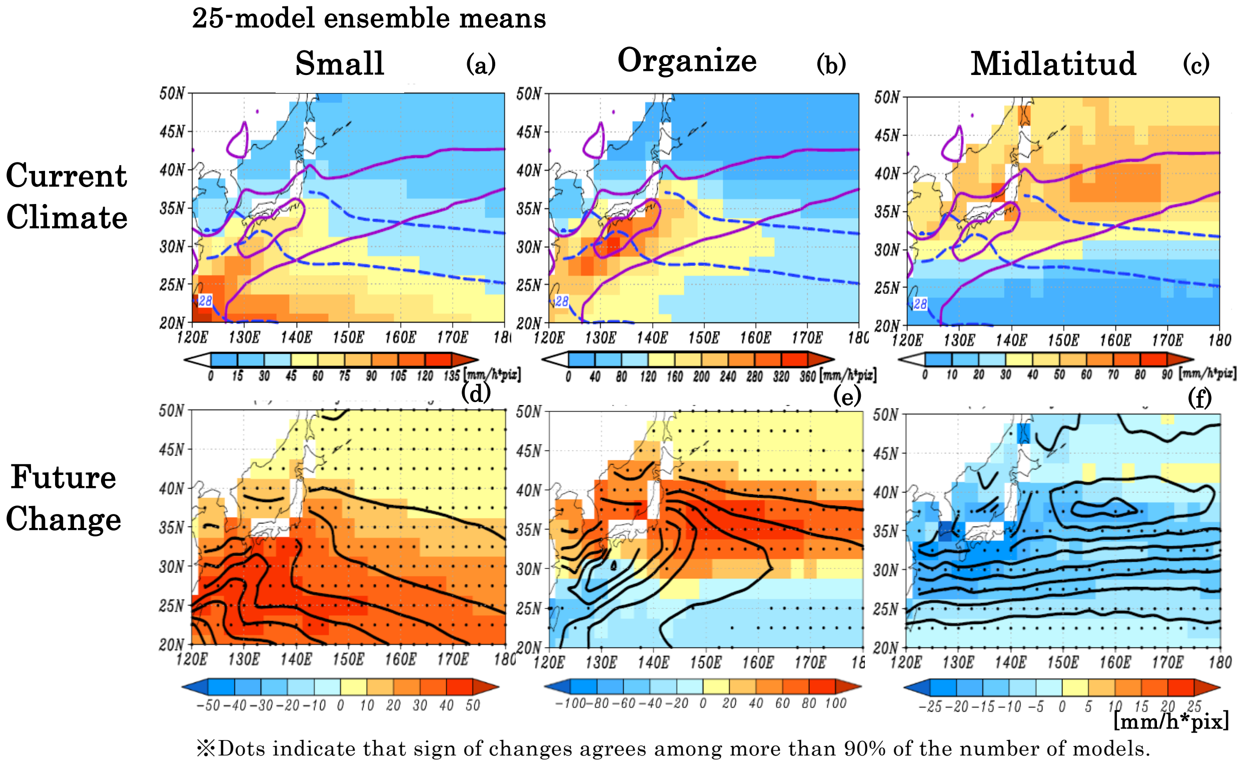

Fig.3. Rainfall contributions reconstructed from GPM and CMIP5 in color for current climate (1980-2005; a-c), and for future change ((2075-2100)-current; d-f). The solid purple lines in the top panels indicate vertical velocity at 500 hPa, and the dashed blue lines indicate SST. The black contours in the bottom panels indicate the rainfall contributions in the current climate. From Yokoyama et al. (2018).

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