Trends of Heavy Precipitation Events in Global Observation and Reanalysis Datasets

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Abstract

Trends of heavy-precipitation events represented by available global observations such as the Global Precipitation Climatology Project (GPCP) and four global reanalysis datasets are examined using two indices, OPC (occurrence of rainy days within precipitation class) and NPC (normalized precipitation within precipitation class), mainly over the tropics. These indices are defined by normalization with the total integrated precipitation amount for the analysis period, 1979−2001.

Over land, the observational datasets exhibit larger decreasing trends in the heavier classes. All but one of the reanalysis datasets reproduce these tendencies. Significant correlations for the heaviest class between the GPCP and the other datasets can be found.

Over sea, there was a large discontinuity around 1987 in the two indices for the GPCP pentad data, which was probably caused by the introduction of Special Sensor Microwave Imager (SSM/I) data. Restricted to data after 1988, all of the reanalysis datasets are seen to have positive and more increasing tendencies in the heavier classes, while the observational results show the opposite tendencies, although they are statistically insignificant.

To resolve this discrepancy in order to enable the use of reanalysis data in extreme-event studies, additional improvements will be needed, not only in reanalysis but also in observational datasets.

1. Introduction

Recently, many observational studies on changes in extreme precipitation events have been conducted, based on analyses of historical surface-observation data, mainly over mid-latitude regions (e.g., Karl et al. 1998; Fujibe et al. 2005, hereafter F2005; Groisman et al. 2005). At the same time, many simulation studies also have been conducted (e.g., Meehl et al. 2005; Kimoto et al. 2005). These studies commonly show an increasing tendency of heavy-precipitation events, with some of the observational studies indicating that heavier events tend to have larger increasing tendencies and larger contributions to the precipitation amount. F2005 has clearly shown such a tendency over Japan using a relative precipitation index with respect to the total precipitation.

In these extreme-event studies, there have been problems validating model results with station data, specifically inhomogeneity and coverage limitations in space and time for ground surface-station data. To address these problems, global-observational data based on satellite observation is useful due to its wide coverage and better homogeneity. Reanalysis data is also useful. Furthermore, reanalysis data presents the possibility of providing homogeneous data over a long term, including periods before the advent of satellite observation. For instance, May (2004) has examined extreme-precipitation events during the Indian monsoon using atmospheric general circulation model experiments and precipitation fields from the European Centre for Medium range Weather Forecasts (ECMWF) Reanalysis (ERA-40), and Bengtsson et al. (2004) assessed to use ERA-40 reanalysis as long-term climate data.

The thermodynamic and circulational fields in the models are closely related to atmospheric heating processes through convective parameterization. In that sense, evaluation of precipitation properties in reanalysis datasets is important for using them more effectively.

In this study, we analyze interannual variation and trends of indices based on daily and pentad data from global observation and reanalysis datasets. We also evaluate the usefulness of reanalysis datasets from the view-point of extreme-precipitation event studies. There have been few studies conducted systematically using such global datasets. As extreme precipitation events may be related to convective processes, we focus in this study on the tropics region (30S−30N), where convective rain occurs more frequently.

2. Data

In this study, daily analyzed precipitation data with one-degree resolution from the GPCP (GPCP1D) (Huffman et al. 2001), pentad precipitation data with 2.5-degree (GPCP5D; Xie et al. 2003), and the pentad-mean version of the Climate Prediction Center Merged Analysis of Precipitation standard data (CMAP5D; Xie and Arkin 1996) that does not include reanalysis data, are used as global observational data. The GPCP1D is a unique dataset with a finer spatial and temporal resolution although only field data averaged for the whole period is used in this study due to the short period of just 7 years (1997−2003). The GPCP5D is produced by adjusting CMAP5D so that the adjusted pentad precipitation matches the monthly GPCP value at each grid on every month (Xie et al. 2003).

The following four reanalysis datasets are also examined.

JRA-25 : from the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Industry (CRIEPI) (Onogi et al. 2006)
NCEP-R1: from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (Kalnay et al. 1996)
NCEP-R2: from NCEP and the Department of Energy (DOE) (Kanamitsu et al. 2001)
ERA-40 : from ECMWF (Uppala et al. 2005)

To make a comparison under uniform conditions, the integrated precipitation over the first six-hour forecast at each six-hourly analysis time, i.e., 0, 6, 12, and 18 UTC, is used. In this analysis, the daily and pentad data are computed from the six-hourly data.

Since the precipitation amount varies depending on the grid size, all data used in this study are converted into the 2.5-degree grid system found in the ERA-40 product, using a box-weighting average procedure on

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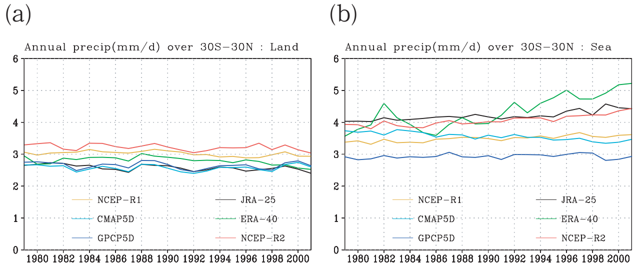

Fig. 1. Trends of annual precipitation (mm/day) averaged over the tropics (30N–30S) over (a) land and (b) sea. Datasets are represented by the following colors: JRA-25 (Black), ERA-40 (Green), NCEP-R1 (Red), NCEP-R2 (Dark yellow), GPCP5D (Blue), CMAP5D (Purple). This coloring is used throughout this paper.

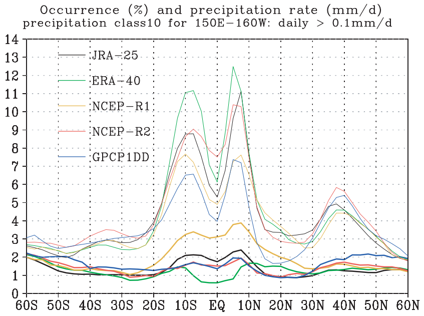

Fig. 2. Latitudinal cross-section of precipitation rate (lower bold lines, mm/d) and OPC10 (upper thin lines, %) between 150E and 160W averaged for 1979–2001.

the gridded values.

An analysis was done for the 23 years from 1979–2001, which is a commonly available data period except for GPCP1D.

3. Methods

Since the climatology of the precipitation amount differs among the datasets used here, it is necessary to look beyond differences in absolute precipitation amount when evaluating the precipitation characteristics in order to permit a comparison of their interannual variations and trends. In this study we apply a method for relatively evaluating precipitation characteristics based on the total amount of precipitation at each grid over the whole analysis period, following F2005.

First we define ten precipitation classes as follows. We consider a daily precipitation-amount time series arranged in ascending order for an analysis period of N years. The amount of precipitation accumulated over the whole analysis period is denoted as TP. We define the precipitation classes by dividing the ordered daily precipitation-amount series with nine thresholds, where the sum of the daily precipitation amounts within each precipitation class is equal to one-tenth of TP. In this way, nine threshold values defining ten precipitation classes are obtained. Each class is numbered with the heaviest (lightest) precipitation class assigned number 10 (1).

Using the thresholds obtained in this way, we define two indices at each grid. One is the occurrence of rainy days within a precipitation class (OPCn: n indicates the class number), defined as the ratio (%) of the number of rainy days in a year within each class to the total number of rainy days in the whole period. Thus, OPC corresponds to the frequency of each class. As OPC is dependent on the definition of rainy day, in this study 0.1 mm/day is used as the threshold to define a rainy day.

The other index is the normalized precipitation within a precipitation class (NPCn), which is defined as the ratio (%) of the total precipitation within a precipitation class in a year to the averaged amount of precipitation in that class for the whole period, TP/10/N. This is the index used in F2005, which represents the relative precipitation amount in a class. Therefore, NPC does not rely on the definition of rainy day.

For analysis using NPC, grids with an annual average precipitation of less than 100 mm are excluded in order to obtain statistically stable results, since NPC tends to become noisy with less precipitation. This condition results in the exclusion from this analysis of dry regions like deserts as well as their adjacent sea area.

For this study, land was defined as any grid with a ratio of land larger than 90%, while grids with land ratios less than 10% were considered as sea. Grids near coastal lines were excluded to avoid the effects of grids that contain both land and sea. Spatially averaged indices are used over both land and sea.

For the pentad data, the two indices can be defined similarly, though with a reduced number of available samples.

4. Results

Before examining the climatological features of heavy-precipitation characteristics and their trends, the tendency of precipitation amount must be checked. Figure 1 plots interannual variations of annually averaged precipitation over sea and land for 30S to 30N. The differences among the datasets are not so especially small. The statistical significance of the trends was tested with the Mann-Kendall rank test at a 1% significance level. No significant trends can be observed over the land except for the decreasing trends of JRA-25 and ERA-40. In contrast, all the reanalysis products exhibit increasing trends over the sea, exceeding the 99% significance level. In particular, ERA-40 has a large increasing tendency, while GPCP5D and CMAP5D have no significant tendencies. A large difference between NCEP-R1 and NCEP-R2 is easily noticed since both were produced using essentially the same assimilation system and data. Minor changes in cumulus parameterization of the forecast models in the NCEP-R2 system, as described in Kanamitsu et al. (2001), might have affected the characteristics of the precipitation.

Figure 2 plots latitudinal-cross sections of OPC10 and the precipitation rate over the western Pacific (150E to 160W). This longitudinal zone is specified because the differences among the datasets are largest there. Latitudinal distributions are reproduced similarly in all the reanalysis datasets except for a large dispersion over the tropical region within 20S to 20N.

The JRA-25 and NCEP-R2 plots show OPC10 to be almost similar to GPCP1D in both the tropics and midlatitudes, while NCEP-R1 is much larger and ERA-40 is much smaller in OPC10 over the tropical region. Among the datasets, ERA-40 displays a somewhat different behavior from the others. Specifically, around the equator the OPC of ERA-40 decreases and reaches the minimum. Unrealistically heavy precipitation in ERA40 over the tropics is pointed out by May (2004) as well. Only the result for OPC is discussed here because the climatological average of NPC is equal to 100% by definition.

Next, we will discuss the interannual variations in the two indices. Figure 3 (a) presents interannual variations of OPC10, based on daily data over the sea for 1979–2001, normalized by the climatological average of OPC for each class. The increasing trends can be seen clearly. These features probably correspond to the in-

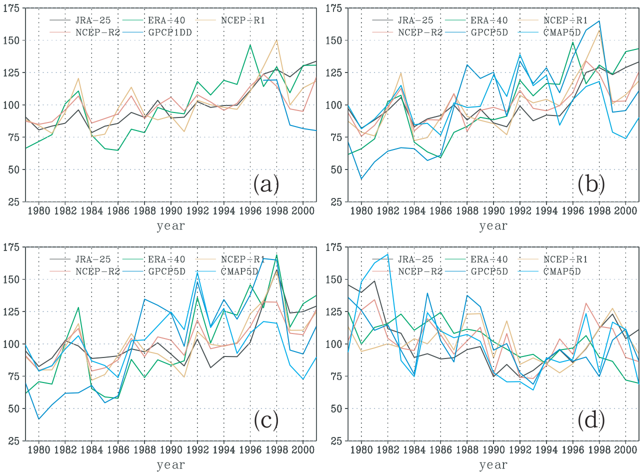

Fig. 3. Interannual variations of OPC10 for 30S–30N over the sea based on (a) daily and (b) pentad precipitation, and NPC10 based on pentad over the (c) sea and (d) land. Both NPC and OPC are normalized by climatological averages in the class.

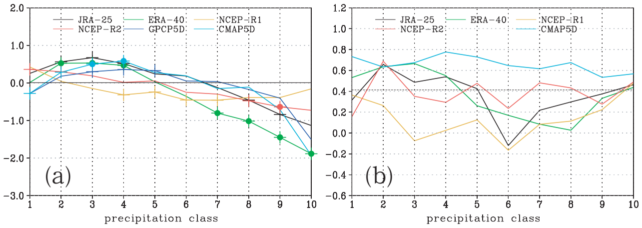

Fig. 4. (a) Trends of NPC for 1979–2001 over 30S–30N based on pentad precipitation in each class over the land. Closed circle (Plus sign) shows statistical significance at 1% (5%) level. (b) Correlation coefficients with GPCP5D for 1979–2001 in each class over the land. Both are based on pentad data.

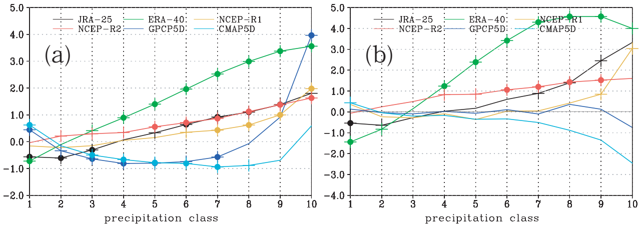

Fig. 5. Same as Fig. 4 but (a) over the sea, (b) over the sea for 1988–2001.

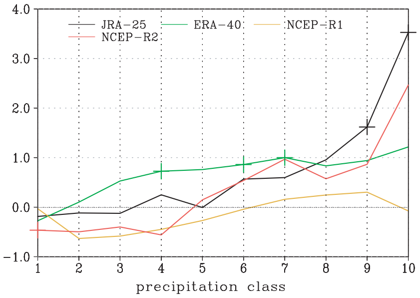

Fig. 6. Trends of NPC for 1979–2001 over the Yangtze river basin (105E–120E, 25N–35N), based on daily data.

creasing trends in reanalysis precipitation amounts over the sea (Fig. 1). Peaks are observed around 1983, 1987, 1992, and 1998, which correspond to years of the mature phase of El Niño.

As GPCP1D is not available over a long term, we applied the same procedures to pentad data since the GPCP5D and CMAP5D data, produced without using any model products, are available on a pentad basis (Fig. 3 (b)). Comparison of the two figures shows that results similar to those with the daily data were obtained by the pentad data as well.

Figure 3 (c) is the same figure as Fig. 3 (b) but with NPC10. The result indicates that OPC and NPC behave almost similarly; therefore we will discuss only NPC hereafter.

In Fig.3 (c), CMAP5D exhibits no increasing trends, but GPCP5D has a clear increasing trend with a large discontinuity around 1987. Since SSM/I data began to be used in the GPCP5D and CMAP5D data in that year, this discontinuity is probably caused by the use of SSM/I data. In particular, SSM/I emission-based precipitation estimates are used only over the sea, while scattering-based estimates cover both the land and the sea. Over the land, conversely, decreasing trends can be seen in Fig. 3 (d). There is no gap as was seen over the sea around 1987.

The linear trends of NPC over the land in each class are plotted in Fig. 4 (a). The statistical significance for each trend is indicated by a plus mark for 5% and a filled circle for a 1% significance level by the Mann-Kendall rank test. This is a result computed for 1979–2001. The observational data has decreasing tendencies in the heaviest class and larger decreasing trends in the heavier classes. All the reanalysis datasets except NCEP-R1 reproduce these tendencies, although they are not significant in all cases. This result indicates that the reanalysis datasets are consistent with the observational datasets (GPCP5D and CMAP5D) in short-term precipitation characteristics. Furthermore, we examined the correlations of NPC time series between GPCP5D and other datasets for 1979–2001 over land (Fig. 4 (b)). In the case of class 10, correlations trends were computed among the time series plotted in Fig. 3 (d). The horizontal dashed line in Fig. 4 (b) indicates a 95% confidence level. Correlation coefficients for all products are significant for the heaviest class (class 10). This demonstrates that not only do the signs of trends in the reanalysis data agree with that of the GPCP5D, but the interannual variations of the reanalysis data also resemble those in the GPCP5D for the heaviest class.

In contrast, over the sea all the reanalysis datasets exhibit increasing tendencies in almost all classes in Fig. 5 (a). The NCEP-R1 and R2 also show increasing trends although they do not incorporate SSM/I data. ERA-40 has large increasing trends except for the lighter- precipitation classes. Conversely, GPCP5D and CMAP5D have decreasing trends in the middle classes, and GPCP5D has an especially large increasing trend in the heaviest class. The figure reveals a discrepancy between the trends in the GPCP5D/CMAP5D datasets and those in the reanalysis data. However, careful inspection of the time series for NPC10 (Fig. 3 (c)) of GPCP5D and for NPC6 (not shown) of CMAP5D reveals that there are large discontinuities among them in 1987, resulting in erroneous trends of GPCP5D in Fig. 5 (a).

To avoid these discontinuities, we applied the same analysis procedure to a shortened period, 1988–2001, since the use of the SSM/I data starts in 1987. Figure 5 (b) plots class dependencies of the linear trends of NPC for each precipitation class, based on pentad data for 1988–2001 over the sea. It should be noted that decadal variation may greatly affect the results, as the analysis period is shortened in Fig. 5 (b), resulting in no statistically significant discrepancy between obser- vations and reanalyses in the middle and lower classes.

Comparing Fig. 5 (b) with Fig. 5 (a), the reanalysis data shows positive and increasing trends, even for 1988–2001, that are similar to those for 1979–2001, while GPCP5D and CMAP5D present negative and decreasing tendencies in heavier precipitation classes, although they are not statistically significant.

Over land in the tropics, the decreasing trends seen in Fig.4 (a) seem to contradict the increasing tendency of daily heavy precipitation events reported in the recent analyses using station data (e.g., Karl et al. 1998). It should be noted that such increasing tendencies are analyzed mainly in the mid-latitude region, and therefore the analysis region differs from that in this study. In response to this, we examined the tendency of NPC in the Yangtze river basin. Increasing trends of NPC based on daily products of reanalyses in Fig. 6 become larger in the heavier precipitation classes for all the datasets but NCEP-R1, although they are not significant. These increasing trends are qualitatively similar to the observational results (Endo et al. 2005), although the analysis period here is shorter than theirs. This also shows the possibility of using reanalysis datasets in addition to observational data.

5. Discussions and conclusions

In this study we examined the trends of daily and pentad precipitation in four reanalysis and two global-observation precipitation datasets (GPCP and CMAP), with two types of indices, OPC and NPC, mainly over the tropics. The use of these indices makes possible an effective comparison of precipitation characteristics even if the precipitation amounts are quite different from each other.

Climatological horizontal distributions of OPC10 show that JRA-25 and NCEP-R2 have a fundamental feature similar to GPCP1D in daily precipitation over the tropical western Pacific. However, the ERA-40 (NCEP-R1) dataset exhibits a much smaller (larger) OPC10 than GPCP1D.

Over the sea, examination of the interannual variations of the indices revealed that there is a large discontinuity in 1987 in the two indices of GPCP5D. A similar discontinuity can be seen in CMAP5D. These discontinuities are probably caused by use of SSM/I data, considering that its use started in 1987. Therefore GPCP5D and CMAP5D data taken over the sea should be used with caution when studying long-term variations in heavy-precipitation events.

Examination with the period restricted to 1988–2001 revealed that the reanalysis datasets still have positive and more increasing trends in heavier classes. In contrast, GPCP5D and CMAP5D over the sea have negative trends in the heaviest class. These opposite tendencies might occur due to several causes, such as the limited analysis period and quality changes in the reanalysis and observational data. Therefore, quality improvement in both reanalysis and global observational data is needed for their utilization in the study of extreme events.

Over the land, we found that all of the observational and reanalysis datasets display decreasing tendencies in the heaviest precipitation class, although not all of them are significant. The dependency of NPC trends on precipitation class exhibits more decreasing trends in the heavier classes. These observational features over the tropical land contrast with the increasing tendency in the mid-latitudes identified by past studies, as reviewed in the introduction. Besides, significant correlations between the GPCP and other datasets can be found.

In this study, the analysis is limited mainly to the tropics. Many studies using surface observation data have been conducted with a focus on mid-latitude regions, due to the availability of surface-observation data. To examine the case of the mid-latitudes, we applied our analysis procedures to the Yangtze river basin using daily reanalysis data. The result reveals a larger increasing tendency in the heavier precipitation classes except for NCEP-R1, although they are not significant (Fig. 6). Further study is needed to clarify regional differences in trends in heavy precipitation.

The rise of the global sea-surface temperature is considered to have an impact on the long-term variation of precipitation. Its impact on reanalysis data should be investigated in association with the increase of precipitation over the sea to provide a better understanding of precipitation characteristics in reanalysis datasets.

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