Decadal trends of the annual amplitude of global precipitation

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Abstract

In this study, decadal trends of the annual amplitude of global precipitation are compared in Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP), Global Precipitation Climatology Project (GPCP), and National Centers for Environmental Prediction (NCEP) reanalysis data sets. The analysis reveals decreasing trends in the CMAP and reanalysis data and a flat trend in the GPCP data. The decreasing trends are mainly associated with the increasing trend of low annual minimum precipitation rate in the CMAP data and high annual minimum precipitation rate in the reanalysis data. The trend in the GPCP data is flat because of the balance between decreasing trends along equatorial oceans and increasing trends over subtropical oceans.

Keywords: decadal trends; annual amplitude; global precipitation rate

1. Introduction

Precipitation is important in regulating global hydrological cycles at multiple temporal and spatial scales. There are no precipitation observations over the vast open ocean until the reliable satellite precipitation retrievals were available in late 1970. The rain gauge observations over lands and global satellite precipitation retrievals are merged to form global precipitation data sets with reasonable spatial resolutions for weather and climate studies. The rain gauge-satellite precipitation data were developed based on a series of intercomparison and validation studies (Spencer, 1993; Kondragunta and Gruber, 1997; Ebert and Manton, 1998; Krajewski et al., 2000; Adler et al., 2001). Among the merged rain gauge-satellite precipitation data, the CMAP [Climate Prediction Center (CPC) Merged Analysis of Precipitation] data (e.g. Xie and Arkin, 1997) and the GPCP (Global Precipitation Climatology Project) data (e.g. Adler et al., 2003; Huffman et al., 2009) are the two of the well-recognized precipitation data sets in meteorological research communities. Gruber et al. (2000) carried out a comparison analysis of the two data sets for the period of July 1987–December 1998 and found a good agreement for the average seasonal cycle over both lands and oceans. Yin et al. (2004) compared the GPCP and CMAP Monthly Precipitation Products for the period 1979–2001 and their EOF analysis showed that the first leading modes of the two data sets are identical.

The information from modeling has been added to form a new data set such as the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) (Kalnay et al., 1996). Janowiak et al. (1998) conducted a comparison study between the NCEP/NCAR reanalysis data and the GPCP data for the period of 1988–1995 and found a good agreement on large-scale but substantial difference on regional scales. The precipitation is a good measure for climate studies of the global system because it is associated with dynamic process, water cycle, and cloud microphysics.

Global precipitation variability corresponds to large-scale background circulation changes. The long-term precipitation changes may be caused by both natural and human-induced processes (e.g. Bates and Jackson, 2001) such as the global warming climate (e.g. Jones and Moberg, 2003). Thus, precipitation change may be associated with the warm climate (e.g. Dai and Trenberth, 2004; Liu et al., 2012). The GPCP data show a flat trend of global precipitation (Gu et al., 2007), whereas the CMAP data reveal a decreasing trend (Yin et al., 2004). The decreasing trend of global precipitation in the CMAP data is disputable because of an artifact of input data change and atoll sampling error over the tropical ocean (Yin et al., 2004). The GPCP data show relative bias error estimates of 10–20% over the tropical Pacific (Alder et al., 2012), but they offer the highest correlation and lowest monthly deviations with reference to the rain-gauge atoll station data provided by the Pacific Rainfall Database (PACRAIN) (Pfeifroth et al., 2013). Because global precipitation data only are available for several decades and the global circulation modeling may contain large uncertainties, in particular, in the modeling of cloud and precipitation properties (e.g. Cess et al., 1997), it may be hard to establish coherent long-term trends of global precipitation from available observational and modeling precipitation data sets.

The objective of this study is to analyse similarities and differences in decadal trends of the annual amplitude of global precipitation and associated precipitation
statistics between the data sets of CMAP and GPCP and NCEP reanalysis. The annual amplitude of global precipitation rate is defined as the difference between the annual maximum and minimum monthly mean precipitation rate. We conduct such comparison study in the annual amplitude for the following reasons. First, climate changes such as global warming may have important impacts on precipitation extremes (e.g. Emori and Brown, 2005; Kharin and Zwiers, 2005), which may lead to certain decadal trends of precipitation extremes such as the annual amplitude at annual time scale. Second, Li et al. (2015) used this data set to analyse the decadal trends of global precipitation and associated precipitation statistics and found that divergent decadal trends are associated with the differences in precipitation statistics. The decadal trends of the annual amplitude are important aspect of decadal trends of global precipitation. Third, the precipitation statistics associated with the annual amplitude may be different from that related to annual mean global precipitation, which have different sensitivity to data quality. The organization of this study is as follows. The data are briefly discussed in Section 2. The results are presented in Section 3. A summary is given in Section 4.

2. Data

The observational precipitation data used in this study include the CMAP (Xie and Arkin, 1997) and GPCP (Huffman et al., 2009) data. The GPCP data is one of Global Energy and Water Exchanges (GEWEX) global analyses of the water and energy cycle organized by the GEWEX Radiation Panel. Both CMAP and GPCP data were constructed by merging gauge and satellite estimates and have the horizontal resolution of 2.5° latitude by 2.5° longitude. The satellite retrievals in the CMAP data include Geostationary Operational Environmental Satellite (GOES) Precipitation Index (GPI), Outgoing Longwave Radiation (OLR) Precipitation Index (OPI), Special Sensor Microwave/Imager (SSM/I) scattering and SSM/I emission and Microwave Sounding Unit (MSU). The satellite retrievals in the GPCP data include the SSM/I retrievals, merged geosynchronous-and low-Earth-orbit infrared data, the OPI data, and the estimate from Television Infrared Observation Satellite Operational Vertical Sounder (TOVS) and Advanced Infrared Sounders (AIRS).

The modeling data is the reanalysis data (R-1) developed by a joint project between the NCEP and the NCAR, which involves the recovery of land surface, ship, rawinsonde, pibal, aircraft, satellite, and other data (Kalnay et al., 1996; Kistler et al., 2001). The updated version R2 (Kanamitsu et al., 2002) is used in this study. The updates include new physics and observed soil moisture forcing and collection of previous errors. The precipitation in the reanalysis data is from the model integration forward for 6 h after the model is initialized with other observational variables such as winds, temperature, and moisture. The horizontal resolution is 1.905° latitude by 1.875° longitude.

Adler et al. (2012) showed an estimated error bar of ±7% for GPCP long-term global precipitation. Although the reanalysis data were processed with the same assimilation system, the data may include possible artificial trends from increasing input data (e.g. increasing aircraft data) and data quality improvement (e.g. increasing vertical resolution of radiosonde).

3. Results

To study precipitation statistics for the annual amplitude of global precipitation, monthly mean grid-scale precipitation data during 1979–2008 are used to accumulate precipitation amount and to divide by total precipitation amount at the precipitation-rate interval of 0.3 mm d⁻¹ for the annual maximum and minimum monthly mean precipitation rate, respectively (Figure 1). For both maximum and minimum monthly mean precipitation rates, high precipitation rates (e.g. 10 mm h⁻¹) have more contributions to total precipitation in the reanalysis data than in the two observational data, which is consistent to that found in Li et al. (2015) in their analysis of decadal trends of annual and global

![Figure 1](https://example.com/figure1.jpg)

**Figure 1.** Contribution (%) to total precipitation from grid-scale data of annual (a) maximum and (b) minimum precipitation rate at the precipitation-rate bin of 0.3 mm d⁻¹ from 1979 to 2008 as function of precipitation rate in the CMAP (red), GPCP (green), and NCEP reanalysis (blue) data.

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mean precipitation rate. The reanalysis data produce much stronger decadal signals than the two other observational data do, in particular, over the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) and surrounding tropical oceanic areas. Strong precipitation could be a common problem in numerical modeling (e.g. Sui et al., 1998) in the reanalysis data where the recycling of moisture is too large in most models and the lifetime of moisture is too short (Trenberth et al., 2011). On the other hand, the CMAP and GPCP data may underestimate oceanic mean precipitation compared with the merged precipitation estimate from the CloudSat, Tropical Rainfall Measuring Mission (TRMM) and Aqua during 2007–2009 (Behrangi et al., 2014). The CMAP data also reveal larger contributions to total precipitation than the GPCP data do, which may be due to the fact that the two observational data sets use different satellite measurements and different retrieval algorithms.

The analysis of the annual amplitude of globally averaged precipitation rate reveals decreasing trends for the CMAP and reanalysis data and a flat trend for the GPCP data (Figure 2). The linear trends of the annual amplitude of globally averaged precipitation rate and associated linear correlation coefficients are $-0.0088$ and $0.74$ mm d$^{-1}$ year$^{-1}$ for the CMAP data, $0.0010$ and $0.06$ mm d$^{-1}$ year$^{-1}$ for the GPCP data, and $-0.0054$ and $0.72$ mm d$^{-1}$ year$^{-1}$ for the reanalysis data. Thus, the decreasing trends of the annual amplitude of globally averaged precipitation rate in the CMAP and reanalysis data are statistically significant. The annual amplitude is larger in the CMAP data than in the GPCP data, whereas it is smaller in the CMAP data than in the reanalysis data.

To examine the spatial contribution to linear trend of the annual amplitude of global mean precipitation rate, the spatial distribution of linear trend of the annual
amplitude of precipitation rate is shown in Figure 3. The negative linear trends of the annual amplitude along equatorial Indian and Pacific Oceans mainly contribute to the decreasing trends of global mean annual amplitude in the CMAP data (Figure 3(a)). Compared with those in the CMAP data, the negative linear trends of the annual amplitude along equatorial Indian and Pacific Oceans are weaker in the GPCP data (Figure 3(b)). The positive linear trends occur over subtropical oceanic areas. As a result, the negative linear trends are balanced by the positive linear trends in global mean calculations, which causes the flat trend for global mean annual amplitude in the GPCP data. The positive linear trends of the annual amplitude appear along the central and eastern branches of ITCZ and SPCZ and the Indian Ocean off the equator whereas the negative linear trends occur along the equator (Figure 3(c)). Thus, the decreasing trends of global mean annual amplitude is because of the fact that the negative linear trends are stronger than the positive linear trends.

Because the annual amplitude of global mean precipitation rate is defined as difference between annual maximum and minimum global mean precipitation rate, the decadal trends of annual maximum and minimum global mean precipitation rate are examined separately. Because the annual mean precipitation rate shows a weak decreasing trend, the decreasing trend of the annual amplitude in the CMAP data is associated with the increasing trend of annual minimum mean precipitation rate (Figure 4(a)). Both annual maximum and minimum mean precipitation rates show flat trends in the GPCP data (Figure 4(b)), which lead to the flat trend of the annual amplitude of global mean precipitation rate. Both annual maximum and minimum mean precipitation rates reveal increasing trends in the reanalysis data, but increasing trend of annual maximum mean precipitation rate is smaller than that of annual minimum mean precipitation rate (Figure 4(c)). Thus, the decreasing trend of the annual amplitude corresponds to the increasing trend of annual minimum mean precipitation rate.

The annual minimum precipitation rate can be further analysed by the low- and high-precipitation rates from grid-scale data. Following Li et al. (2015), the grid-scale monthly mean precipitation-rate data for the decadal analysis can be divided by 2.1 mm day$^{-1}$ for the CMAP data, 5.0 mm day$^{-1}$ for the GPCP data, and 3.3 mm h$^{-1}$ for the reanalysis data. In the CMAP data, the annual minimum mean precipitation rate of lower than 2.1 mm day$^{-1}$ reveals the increasing trend, in particular, during the period of 1986–2008, whereas that of higher than 2.1 mm day$^{-1}$ has the flat
trend (Figure 5(a)). To examine the spatial distribution of the decadal trend, we take spatial distribution of difference in annual minimum monthly mean precipitation rate between temporal averages from the periods 1994–2008 and 1979–1993. The increasing trend of the annual minimum mean precipitation rate of lower than 2.1 mm day\(^{-1}\) is primarily associated with the positive difference over mid-latitude oceans (Figure 6(a)), whereas the flat trend of higher than 2.1 mm day\(^{-1}\) corresponds mainly to the balance between the positive and negative difference along the equator (Figure 7(a)). Thus, the decreasing trend of the annual amplitude results from the increasing trend of annual minimum global-mean precipitation rate of lower than 2.1 mm day\(^{-1}\). In the GPCP data, the annual minimum mean precipitation rates of lower and higher than 5.0 mm day\(^{-1}\) have flat trends after 1989. The decreasing trend from 1979–1993 to 1994–2008 for lower than 5.0 mm day\(^{-1}\) is primarily related to the negative difference (Figure 6(b)), whereas that for higher than 5.0 mm day\(^{-1}\) corresponds mainly to the positive difference over the ITCZ and SPCZ (Figure 7(b)). As a result, the annual minimum mean precipitation rate has the flat trend. Because the annual minimum mean precipitation rate of lower than 3.3 mm day\(^{-1}\) has a flat trend, the decreasing of the annual amplitude is related to the increasing trend of annual minimum mean precipitation rate of higher than 3.3 mm day\(^{-1}\) (Figure 5(c)). The flat trend of annual minimum mean precipitation rate of lower than 3.3 mm day\(^{-1}\) is mainly associated with the balance between the negative difference over the oceans and positive difference over the land in the mid-latitudes (Figure 6(c)). The increasing trends of annual minimum mean precipitation rate of higher than 3.3 mm day\(^{-1}\) is because of the fact that the positive differences over the off-equatorial areas are stronger than the negative differences along the equator (Figure 7(c)).

4. Summary and discussions

In this study, monthly mean precipitation rates from the CMAP, GPCP, and NCEP reanalysis data from 1979 to 2008 are compared for decadal trends of annual maximum difference (AMD) of global precipitation. The annual amplitude is defined as the difference between annual maximum and minimum monthly mean precipitation rate. The analysis of the annual amplitude of globally averaged precipitation rate shows decreasing trends for the CMAP and reanalysis data but they are different. First, the annual amplitude is larger in the reanalysis data than in the CMAP data. Second, the decreasing trend of the annual amplitude is related to the increasing trend of weak annual minimum mean precipitation rate in the CMAP data, whereas it corresponds to the increasing trend of strong annual minimum mean precipitation rate. The trend of the annual amplitude in the GPCP data is flat because the decreasing linear trends along equatorial Indian and Pacific Oceans are balanced by the increasing linear trends occur over subtropical oceanic areas.

As an artifact of input data change and atoll sampling error over the tropical oceans may lead to the decreasing trend of global precipitation in the CMAP data (Yin et al., 2004), it may have impacts on the decadal trend of AMD. Unlike the CMAP and reanalysis data, the GPCP data has the flat trend of AMD. The difference may be due to the fact that the decadal trend of annual minimum mean precipitation rate in the GPCP data is flat but they show increasing trends in both the CMAP and reanalysis data. Because to the lack of rain gauge measurement over the vast ocean, the oceanic precipitation over the ITCZ and SPCZ, the major contributor to global precipitation, relies on satellite retrievals. The satellite precipitation retrievals cannot be properly validated with the observational data, in particular, at the decadal timescale. The decadal trend of global precipitation may be checked with the analysis of possible physical processes. The process study may provide
the theoretical guidance of decadal trend of global precipitation in a united physical framework. Therefore, the coherent decadal trend of global precipitation from the modeling and observational data requires the improvement of both numerical modeling and satellite retrievals.

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