Global Rainstorm Temporal Variation from 1979 to 2016 Based on the Perspective of Land-Ocean Differentiation

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Abstract. Based on the ERA-Interim precipitation data from 1979 to 2016, this paper uses a variety of statistical methods to diagnose the multi-attribute time series characteristics of global rainstorms and their response to ENSO from the perspective of land-ocean differentiation. The results showed as follows. (1) The global, global land and global ocean rainstorm and their contribution rates showed an increasing trend from 1979 to 2016. The global, global land and global ocean total rainfall showed a decreasing trend. The global land total rainfall showed a distinct sectional change pattern, which first increased from 1979 to 2006 and then decreased from 2007 to 2016. The comparison between the rainstorm and the total rainfall in global land and ocean showed that the rainstorm tended to increase in both ocean and land regions from 1979 to 2016, while the weak intensity rainfall tends to decrease in the globe. (2) The results of MK mutation test showed that the global, global land and global ocean rainstorm changed abruptly in the year of 2006, 1999 and 2008, respectively, without passing the 0.05 significance level test. The global, global land and global ocean total rainfall changed abruptly in the year of 1998, 2014 and 1994, respectively, and passed the test of 0.05 significance level. The rainstorm contribution rates of global, global land and global ocean changed abruptly in the year of 1998, 2014 and 2007, respectively. Only global land rainstorm and global ocean rainstorm passed the 0.05 significance level test. The year of abruptly change of global rainstorm and total rainfall were consistent with the year of ENSO warm event or the year of transition from cold event to warm event. (3) The global land and ocean rainstorm and total rainfall did not change consistently on multiple time scales from 1979 to 2016, but showed inverse phase or forward and lag phase correlation. Fourthly, compared with ENSO, global land (ocean) rainstorm changed earlier (lag) in high energy spectral region. Compared with ENSO changes in low energy spectral region, global land rainstorm changes were consistent or ahead of time, while global ocean rainstorm changes were mainly ahead of time compared with ENSO changes.

1. Introduction

With the rapid development of global warming and urbanization process, rainstorm events occurred frequently all over the world in recent years[1-3], which had caused great harm to regional social economy, life and property, ecosystem and many other aspects. Rainstorm and flood problems were prominent especially for large cities, which had become one of the main challenges for the safe and healthy development of cities[4-5].

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) pointed out that when the probability distribution of climate factors changes, not only the average climate changes, but also the extreme climate changes significantly[2]. The different is that the change of the average climate state may be different from the change of extreme events. Taking precipitation as an example, if the average state shifts to the right, extreme drought events will decrease, while the
frequency of extreme precipitation events will increase significantly. When the fluctuation range of precipitation climate average state increases, the frequency of extreme precipitation events may increase. It is worth noting that not only the rainstorm in the humid area is increasing, but also the rainstorm events in the arid area are increasing[6-8]. For example, there was a sudden rainstorm in a short period of time on July 31, 2018 in Qincheng and Xiaobao Town, Hami, Xinjiang, China. The maximum rainfall intensity reached 110 mm/h, while the maximum annual rainfall in local history was only 52.4 mm, which led to tremendous floods, causing serious economic losses and casualties. A heavy rainstorm occurred in western Japan in July 2018, affecting 16 counties, resulting in 209 deaths and more than 5900 evacuations, resulting in very serious social and economic consequences. The study of global rainstorm and total rainfall is mostly from the land scale, but less attention is paid to the changes of rainstorm and total rainfall in the marine area. At present, there is no consensus on the characteristics of rainstorm and total rainfall in the perspective of land-ocean differentiation.

Based on the perspective of land-ocean differentiation, this research diagnosed the temporal characteristics of global land and ocean rainstorm and its correlation with ENSO, which is not only of great significance to understand the land-ocean difference characteristics of global rainstorm and total rainfall change in the context of climate change, but also helps to reveal the possible impact of large-scale ENSO events on land-ocean rainstorm. In addition, diagnosing the characteristics of global rainstorm from the perspective of land-ocean differentiation is also helpful to support and verify the relevant assessment conclusions of IPCC from the structure and details, and to respond to some concerns of relevant researchers of urban rainstorm.

2. Data and methods

2.1. Data Sources

The data used in this research are from ERA Interim 6h precipitation data of 1979-2016 from the European Centre for Medium-Range Weather Forecasts, with spatial resolution of 0.75°×0.75°, and spatial coverage of 90°S-90°N and 180°E-180°W. Firstly, the 6h precipitation data was processed into daily precipitation data, then the rainstorm and total rainfall of 1979-2016 were calculated according to the year, and then the rainstorm and total rainfall of the global land and global ocean are calculated respectively. In this research, the event with a daily rainfall of more than 50 mm was called a rainstorm event, and the event with a daily rainfall of more than 0 mm was called a rainfall event. Annual rainstorm and total rainfall is the sum of rainstorm and rainfall events in a year.

2.2. Calculation method

Time series diagnosis methods mainly include trend test, Mann-Kendall (MK) mutation test, similarity analysis based on continuous wavelet transform, Cross Wavelet Transform and Wavelet Coherence. Similarity analysis based on continuous wavelet transform: we can describe the correlation between two time series as a number only in a very simple case. However, the correlation between two time series usually changes with time and wavelength. Due to the existence of noise in time series, the two datasets may be uncorrelated on the short time scale of smaller wavelength, but have strong correlation on the larger wavelength scale (such as 10a or 30a). The correlation between two time series can be calculated based on continuous wavelet transform, which can reveal the correlation characteristics of the two time series at multiple time scales. Moreover, this method can also effectively reveal the similarity between two data sets of different measurement units. The calculation methods of trend test and MK mutation test are detailed in literature [4]; the calculation methods of Cross Wavelet Transform and wavelet coherence are detailed in literature [8]. The year of 1981-1990, 1991-2000, 2001-2010 and 2011-2016 are called 1980s, 1990s, 2000s and 2010 respectively in this research.

3. Results and analysis

3.1. Trend of global interannual rainstorm over land and ocean
From the perspective of the change of rainstorm sequence, in terms of the interannual variation, the global land rainstorm and global ocean rainstorm showed an increasing trend in the fluctuation from 1979 to 2016, and the increasing trend passed the 0.05 significance level test (Figure 1). The increasing trend was significant especially after 1995. In terms of decade variation, both the global land annual rainstorm and global ocean annual rainstorm were the least in the 1990s, the most in 2010s, and the both annual rainstorm in 2000s were more than that in 1980s. In all the decades, the annual rainstorm growth in 2010s was the largest reaching 19.84% compared with that in 2000s. From the perspective of global land, in terms of interannual variation, the global land rainstorm also showed an increasing trend in fluctuation from 1979 to 2016, its increasing trend also passed the 0.05 significance level test. In terms of decade variation, the annual change of global land rainstorm was consistent with that of global rainstorm. Of all the decades, the global land rainstorm growth in 2000s was the largest reaching 29.61% compared with that in 1990s. From the perspective of global ocean, in terms of interannual variation, the global ocean rainstorm also showed an increasing trend in the fluctuation from 1979 to 2016, its increasing trend passed the 0.05 significance level test. In terms of decade variation, the annual change of global ocean rainstorm was consistent with that of global rainstorm and global land rainstorm. In all the decades, the global ocean rainstorm growth in 2010s was the largest reaching 29.64% compared with that in 2000s. The fluctuation diagnosis based on the variation coefficient showed that the annual fluctuation of the global ocean rainstorm was the largest from 1979 to 2016, followed by the global land rainstorm, and the global rainstorm was the smallest. The variation coefficient of the three were 0.20, 0.18 and 0.17, respectively, indicating that the annual variation of the global rainstorm was the most stable, followed by the global land rainstorm, and the global ocean rainstorm was the most unstable.

3.2. Trend of global interannual total rainfall over land and ocean

From the change of total rainfall sequence, the global total rainfall showed a decreasing trend in the fluctuation from 1979 to 2016, the decreasing trend passed the 0.05 significance level test (Figure 2). The global land total rainfall first increased and then decreased from 1979 to 2016, but it showed a decreasing trend in the whole study period. In terms of decade variation, the annual change of the global total rainfall of land and ocean gradually decreased with the development of decade. It was found that the global rainstorm was increasing, while the global total rainfall tended to decrease, indicating that global weak intensity rainfall tended to decrease as a whole. As the rainstorm events were highly sudden and occur at a relatively concentrated time, the global rainfall tended to develop in an extreme direction under the background of global total rainfall decreasing and rainstorm increasing, which resulting in the existing arid areas becoming drier, the humid areas becoming wetter, and the regional flood and drought events increasing[29]. From the perspective of global land, the global land total rainfall tended to decrease as a whole from 1979 to 2016, and the decreasing trend fails to pass the 0.05 significance level test, and there was an obvious phenomenon of increasing first and then decreasing, as shown in Fig.2(b). Among them, the increasing trend was obvious from 1979 to 1990, the slight decreasing trend from 1991 to 2006, and the obvious decreasing trend from 2007 to 2016. In terms of decade variation, the global land total rainfall was the most in 1980s, the least in 2010s. It was found that the global land rainstorm tended to increase from 2007 to 2016, and the total rainfall tended to decrease, indicating that weak intensity rainfall tended to decrease. From the perspective of global ocean, the global ocean total rainfall tended to decrease in fluctuation from 1979 to 2016, and the decreasing trend passed the 0.05
significance level test, but there was an increasing trend from 2007 to 2016 compared with the previous period. In terms of decade variation, the global ocean total rainfall was most in the 1980s and least in the 2000s, and more in the 1990s than in the 2010s. It was found that the global ocean rainstorm tended to increase and the total rainfall tended to decrease. This side showed the weak intensity rainfall tended to decrease. The fluctuation diagnosis based on the variation coefficient showed that the global ocean total rainfall interannual fluctuation was the largest from 1979 to 2016, followed by the global total rainfall, and the global land rainfall was the smallest. The variation coefficients of the three were 0.023, 0.018 and 0.017, respectively. The coefficients of variation of the above three were relatively small, and the difference was not large, indicating that the interannual variation of the global total rainfall over land and ocean was small.

Figure 2: Global land and ocean total rainfall interannual variation

3.3. Trend of global interannual rainstorm contribution rate over land and ocean

On the basis of the absolute change of the global land and ocean rainstorm, this research uses the proportion of the rainstorm to the total rainfall as the rainstorm contribution rate to diagnose the relative change characteristics of the global land and ocean rainstorm (Figure 3). The global rainstorms contribution rate showed an increasing trend in the fluctuation from 1979 to 2016, the increasing trend passed the 0.05 significance level test, and the contribution rate increased from 2.06% in 1979 to 4.39% in 2016, with the growth rate more than doubled. The global rainstorm contribution rate showed an increasing trend in 1979-1990 and 1996-2016, while that in 1991-1995 showed a decreasing trend. From the perspective of decade variation, the global rainstorm contribution rate growth was the largest in 2010s reaching 20.60% compared with that in 2000s. From the perspective of global land, global land rainstorm contribution rate showed an increasing trend in the fluctuation from 1979 to 2016, the increasing trend passed the 0.05 significance level test. The global land rainstorm contribution rate in 2006-2016 was significantly higher than that in 1979-2005. From the perspective of decade variation, the global land rainstorm contribution rate was the highest in 2010s, the lowest in 1990s, and higher in 2000s than in 1980s. Among them, the global land rainstorm contribution rate growth in 2000s was the largest reaching 30.15% compared with that in 1990s. From the perspective of global ocean, the global ocean rainstorm contribution rate showed an increasing trend in the fluctuation from 1979 to 2016, the increasing trend passed the 0.05 significance level test. The global ocean rainstorm contribution rate increased in 1979-1990 and 2001-2016, but decreased in 1991-2000. From the perspective of decade variation, the global ocean rainstorm contribution rate showed an increasing trend with the development of the decade. Among them, global land rainstorm contribution rate growth in 2010s was the largest reaching 29.58% compared with that in 2000s. Based on the fluctuation diagnosis of variation coefficient, it was shown that the annual variation of the global ocean rainstorm contribution rate was the largest, followed by the global land, and the global total was the smallest. The variation coefficients of the three were 0.20, 0.19 and 0.18, respectively, which showed that the annual variation of the global ocean and land rainstorm contribution rate were relatively small and stable. It can be seen that the contribution rate of global land and sea torrential rain is increasing, that is to say, the contribution rate of global weaker rainfall is decreasing. The absolute and relative changes of the global land and ocean rainstorm indicated that the global rainstorm was developing towards the extreme direction.
3.4. Abruptly changes of global interannual rainstorm over land and ocean

The MK mutation test method was used to diagnose the temporal mutation characteristics of global land and ocean rainstorm, total rainfall and rainstorm contribution rate. In Fig. 4, UF and UB were the statistical curve of rainstorm. According to the principle of MK mutation test, ±1.96 and ±2.56 were taken as the MK test values of critical curve, i.e. the confidence interval of significance level of 0.05 and 0.1. If the curve of UF and UB intersects and falls between the critical curve of ±1.96 or ±2.56, it means that the rainstorm has an abruptly change and passed the test of significance level of 0.05 or 0.1. It can be seen that the global rainstorm, global land rainstorm and global ocean rainstorm abruptly changed in 2006, 1999 and 2008 respectively, which only passed the 0.1 significance level test, but failed to pass the 0.05 significance level test. It was worth noting that there were many intersections of the UF and UB curves of the global land rainstorm and global ocean rainstorm, but considering that they were not continuous and stable intersections, this research considered that they fluctuated greatly in this period of time, rather than the mutation point. Similarly, the global total rainfall, global land total rainfall and global ocean total rainfall changed abruptly in 1998, 2014 and 1994 respectively, and all passed the test of 0.05 significance level. The global rainstorm contribution rate, global land rainstorm contribution rate and global ocean rainstorm contribution rate and global ocean rainstorm contribution rate changed abruptly in 2006, 2003 and 2007 respectively, among which the mutation of the global land rainstorm contribution rate and global ocean rainstorm contribution rate passed the test of 0.05 significance level, while the global rainstorm contribution rate failed to pass the test of 0.1 significance level. ENSO is the product of the Pacific SST anomaly. ENSO is the strongest interannual variation signal in the air-sea system, and also the most important factor affecting the global climate interannual change. Based on the sea surface temperature index of monthly Niño3.4 published by the National Oceanic and Atmospheric Administration (NOAA) climate prediction center, it was found that the abruptly change of global land and ocean rainstorm and total rainfall occurred in the year of warm event or from cold event to warm event, indicating that the change of global land and ocean rainstorm and total rainfall may be related to ENSO event. The dynamics of occurrence and development was closely related to the thermodynamic process.

4. Conclusion and discussion

4.1. Conclusion

(1) The global land and global ocean rainstorm and its contribution rate showed an increasing trend in the fluctuation, and all of the above trends passed the test of 0.05 significance level from 1979 to 2016. The global total rainfall, global land and global ocean total rainfall showed a decreasing trend in the fluctuation from 1979 to 2016, among which the global total rainfall and global ocean total rainfall passed the test of 0.05 significance level. However, the global land total rainfall changes obvious in different stages, which showed that it tended to increase from 1979 to 2006 and decreased from 2007 to 2016. The comparative analysis of the rainstorm and total rainfall over global land and ocean showed that the rainstorm tended to increase in both global land and global ocean, while the weak intensity rainfall tended to decrease.

(2) The rainstorms over the global, global land and global ocean abruptly changed in 2006, 1999 and 2008, which only passed the test of 0.1 significance level, but failed to pass the test of 0.05 significance.
level from 1979 to 2016. The total rainfall over the global, global land and global ocean abruptly changed in 1998, 2014 and 1994 respectively, all passing the test of 0.05 significance level. The rainstorm contribution rate over the global, global land and global ocean abruptly changed in 2006, 2003 and 2007 respectively. Only the mutation of total rainfall over global land and global ocean passed the test of 0.05 significance level. The year of abruptly change of rainstorm and total rainfall over global land and ocean was consistent with the year of warm event of ENSO or the year of transition from cold event to warm event.

4.2. Discussion
The key point of the study on the global land and ocean difference of rainstorm is that on the one hand, it can diagnose the dynamic change characteristics of the global land with intensive human activities and the global ocean rainstorm with relatively less attention. Through the comparison of the global land and ocean rainstorm changes, it can reveal the potential impact of human activities on the global land rainstorm characterized by rapid urbanization. On the other hand, the division of IPCC is mostly distributed on land, and there are few ocean areas, and the problem of global rainstorm is often explored from the global land scale. However, about 90% of the global rainfall is in the ocean. The study of global rainstorm only from the land scale may lead to one-sided and unscientific understanding of global rainstorm. The multi-attribute change characteristics of global rainstorm are diagnosed based on ERA Interim data from 1979 to 2016. This data has the characteristics of high spatial resolution but short time span. Limited by the current level of scientific cognition, ERA Interim data may have some uncertainty. Therefore, the conclusion of this data in the land and ocean still needs to be verified by other different source data from 50a, 100a or even longer time scales.

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