Global rainstorm multi-attribute variation and its multiscale correlation with ENSO

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Abstract. This research uses a variety of statistical methods to diagnose the multi-attribute time series characteristics of global rainstorms and its response to ENSO from the perspective of land-ocean differentiation. The results showed that: (1) The global, global land and global ocean rainstorm and their contribution rates showed an increasing trend from 1979 to 2016. While, 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 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]. What’s different is that the change of the average climate state may be different from the change of extreme events[6]. 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[7-9]. 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.

On the global scale, the global average precipitation had increased slightly, and the precipitation in the northern hemisphere had decreased significantly in recent decades, but it had increased in the middle and high latitudes, and the trend of precipitation change in the tropics and the southern hemisphere was not obvious[10]. The understanding of the law of global precipitation change trend in the past 100 years was mainly limited to land precipitation, and it can only be determined that the change trend is slightly
increased. There was a very obvious uncertainty in the understanding of the real global precipitation change[11-14]. From the perspective of global rainstorm, in terms of observation and research, the change of global precipitation extreme value in recent 100 years lacked spatial consistency, however, extreme heavy rainfall did have significant change from the beginning to the end of the 20th century, especially the increase of extreme precipitation in the middle and high latitudes. Precipitation tended to be extreme in most areas, and rainstorm events seem to increase. The trend of extreme precipitation in most countries was greater than that of total precipitation. The observational evidence since 1950 showed that in the past 60 years, the rainstorm in many regions of the world has increased. The rainstorm frequency had changed significantly in some regions, and the regions with significant increase in frequency may be more than the regions with significant decrease, but there were strong regional and sub regional changes in trend. Moreover, the rainstorm event change trend in many regions was not statistically significant. Generally, the frequency and intensity of extreme heavy rainfall in most land areas were likely to increase, and more areas had heavy rainfall, and some areas had observed the increase of frequency and intensity of extreme heavy rainfall, but due to the lack of consensus in the existing scientific research, only a conclusion of medium reliability was given. IPCC AR5 pointed out that when the greenhouse gas doubles, the extreme heavy rainfall increases significantly, and its range is far greater than the average intensity of precipitation. Both observation and simulation showed that the emission of greenhouse gases increases the intensity of rainstorm in two thirds of the land area of the northern hemisphere. In terms of model simulation, the results of global climate model show that anthropogenic climate forcing has led to the enhancement of global extreme precipitation (high reliability), and the increase in temperate regions is consistent, while the interannual variation in tropical regions is large. With regard to the prediction of heavy rainfall changes, IPCC SREX believed that the frequency of heavy rainfall or the ratio of heavy rainfall to total rainfall in many regions of the world in the 21st century may increase (probability: 66%-100%)[1]. The conclusion of IPCC AR5 was that, the frequency and intensity of future global rainstorm events will change to varying degrees, and it is likely that heavy rainfall events (probability: > 90%) will increase in most parts of the world in the 21st century in the context of global climate change[2]. To sum up, 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
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. ERA-Interim because of its high spatial resolution, precipitation data has been highly concerned in the field of climate change, and previous studies have shown that the quality of the data is high, which plays an important role in global weather and climate diagnosis. Time series diagnosis methods mainly include trend test, Cross Wavelet
Transform and Wavelet Coherence. 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. Interannual trend of global rainstorm and total rainfall over land and ocean

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. 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.

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. 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. 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. 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.

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. 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 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.

3.2. Multi time scale correlation analysis of global rainstorm and total rainfall over land and ocean

XWT and WTC were used to analyze the correlation between ENSO and rainstorm (total rainfall). Fig.10 showed the correlation between global land rainstorm (total rainfall) and ENSO based on XWT. In the high energy spectral region, on the scale of 2-3a, the global land rainstorm changed about 0.50-0.75a ahead of ENSO in 1998-2000, as shown in Fig.1(a). On the scale of 2a, the global land rainstorm lagged behind ENSO about 0.5a in 1996-2000. In terms of global land total rainfall, on the scale of 2-4a, the global land total rainfall had the same phase change relationship with ENSO in 1996-2000, as shown in Fig.1(b). In the low energy spectral region, on the scale of 1-3a, the global land rainstorm changed about 0.25-0.75a ahead of ENSO in 1998-2000, as shown in Fig.1(c). On the scale of 2a, the global land rainstorm changed about 0.5a ahead of ENSO around 2008. For the global land total rainfall, on the scale of 1-4a, the global land total rainfall had the same phase change relationship with ENSO around 1996-2000, as shown in Fig.1(d). The correlation between the global land rainstorm (total rainfall) and ENSO in high energy and low energy spectral regions passed the test of 0.05 significance level.

In the high energy spectral region, on the scale of 2a, the global ocean rainstorm changed about 0.5a behind ENSO in 1998-2000. In terms of global ocean total rainfall, on the 4a scale, the global ocean total rainfall and ENSO had the same phase change relationship around 1986-1993. On the 2a scale, the global ocean total rainfall lagged behind ENSO about 0.5a around 1988-1990. On the 4a scale, the global ocean total rainfall and ENSO variation were consistent. In the low energy spectral region, on the 10-year scale, the global ocean rainstorm changed about 2.5a ahead of ENSO around 1994-2000. In terms
of global ocean total rainfall, the change of ENSO in global ocean total rainfall in 2005-2010 was mainly in reverse phase on the scale of 1-4a. On the scale of 6a, the change of ENSO in global ocean total rainfall in 1996-2008 was mainly in reverse phase. The correlation between the global ocean rainstorm (total rainfall) and ENSO in high energy and low energy spectral areas passed the test of 0.05 significance level.

![Figure 1](image1.png)

**Figure 1** Correlation of global land rainstorm (total rainfall) and ENSO based on XWT and WTC

### 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 correlation analysis of global rainstorm and total rainfall with ENSO showed that in the high energy spectral region, the global land rainstorm changed earlier than ENSO, while the global ocean rainstorm changed later than ENSO. In the low energy spectral region, the global land rainstorm was consistent or ahead of ENSO, while the global ocean rainstorm was mainly ahead of ENSO. The variation of global land total rainfall and ENSO was mainly consistent in the high and low energy
spectral regions. Compared with ENSO in high energy spectrum, global ocean total rainfall mainly changed in consistency or in advance, while in low energy spectrum, it mainly changed in reverse phase.

4.2. Discussion
This research holds that the multi-scale study of global climate change should be carried out at the first place from the scale of land and ocean differentiation, which is of scientific significance for a comprehensive understanding of climate change, and can also play a supporting role in the IPCC Assessment Report. 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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