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Response of global lightning activity to air temperature variation

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Abstract **It is an issue of great attention but yet not very clear whether lightning activities increase or decrease on a warmer world. Reeve et al. presented that lightning activities in global land and the Northern Hemisphere land have positive response to the increase of wet bulb temperature at 1000hPa. Is this positive response restricted only to wet bulb temperature or in land? What is the response of global lightning activities (in both land and ocean) to the global surface air temperature variation like? This paper, based on the 5-year or 8-year OTD/LIS satellite-based lightning detecting data and the NCEP reanalysis data, makes a reanalysis of the response of the global and regional lightning activities to temperature variations. The results show that on the interannual time scale the global total flash rate has positive response to the variation in global surface air temperature, with the sensitivity of 17±7% K^{-1}. Also, the seasonal mean flash rate of continents all over the world and that of continents in the Northern Hemisphere have sensitive positive response to increase of global surface air temperature and wet bulb temperature, with the sensitivity of about 13±5% K^{-1}, a bit lower than estimation of 40% K^{-1} in Reeve et al. However, the Southern Hemisphere and other areas like the tropics show no significant correlation.**

Keywords: OTD/LIS, response of lightning activity, interannual climate variation.

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For years, the global warming topic has become one of the hot issues in the research of climate change. It naturally follows the question of whether lightning activities increase or decrease on a warmer world, or in other words, whether the global climate change has any effect on lightning activities on different time and space scales, and how. Williams[1], with reference to local measurements at different land stations in the tropics, inferred that lightning activity increases nonlinearly with the increase of surface wet bulb temperature, and the variation curves of Schumann resonance(SR) monthly mean magnetic field and the anomaly of the monthly mean tropical surface air temperature are quite close. With the increase of air temperature, SR magnetic field amplitude is enhanced, and the opposite with the decrease of air temperature. The result shows an approximate 200% of SR amplitude for a 1℃ increase in temperature, from which Williams drew the conclusion of "The Schumann resonance as a globe tropical thermometer". Researches[2,3] indicate an increase in ionospheric potential of 7% or 5% for a 1℃ rise in air temperature, Ionospheric potential is supposed to be a proxy index for global temperature. Reeve et al.[4], using satellite-based Optical Transient Detector (OTD) lightning detecting data during 3 years, analyzed the global and regional land lightning activity. The results predict that a 1 K rise in the average land wet-bulb temperature of the globe would result in an increase in lightning activity of about 40%, and variations in global monthly land lightning activity are well correlated with variations in global monthly land wet bulb temperatures. The correlation is strongest in the Northern Hemisphere and weak in the Southern Hemisphere, however, the tropics show no correlation. Reeve et al.[4] suggested that lightning can be used as a global thermometer, and in a warmer world, and lightning would be more prevalent, lightning activity is an indicator of climate change.

However, with data based on a relatively short period of 3 years, Reeve et al.[4] presented a preliminary revisal of lighting data with its analyzed areas limited in land, and adopted wet bulb temperature at 1000hPa instead of air temperature. In view of the fact that surface air temperature is a basic climatic parameter, it is necessary to give a further analysis of the issue raised in Reeve et al.[4] of "lightning activity as an indicator of climate change", through a more systematic and reliable global lightning observation data of a longer duration. This paper, with 5-year lightning data provided by satellite-based lightning detecting systems (with its observation regions between 75°S—75°N, which almost equals global observation), 8-year lightning data (with the observation regions between 35°S—35°N) and NCEP reanalysis data, gives a reanalysis of the interannual correlation between the lightning activity and wet bulb temperature or air temperature on a global or regional scale, with the reference parameter as seasonal mean lightning flash rate, wet bulb temperature and air temperature of the designated regions.

1 Data source and its processing

Lightning data used in this paper are provided by the Global Hydrology Resource Center (GHRC), which provides the carefully revised lightning database observed by satellites, including lightning data observed by OTD in the area ranging between 75ºS—75ºN from April, 1995 to March, 2000 and that observed by Lightning Imaging Sensor (LIS) in the area ranging between 35ºS—35ºN from December, 1997 to February, 2003, covering altogether 31 seasons from the summer of 1995 to the winter of 2002. Considering that it takes about 50 days for the satellites to complete a full local diurnal cycle, this paper adopts the seasonal mean value instead of the monthly one to ensure the representativeness of lightning data.

NCEP/NCAR reanalysis data[5] were provided by NOAA-CIRES Climate Diagnostics Center (CDC), with observation from June, 1995 to February, 2003, through which we calculated the seasonal mean wet bulb temperature at 1000hPa, surface wet bulb temperature, surface air temperature of the designated areas, taking into consideration different influences of grid areas at different latitudes when calculating the mean values.

In the calculation of ocean and land parameters, this paper adopts the land-sea mask provided by NCEP. According to this paper, the seasons are divided as follows, spring from March to May, summer from June to August, autumn from September to November, and winter from December to the next February.

2 The reanalysis of the correlation between global and regional lightning activity and wet bulb temperature

Fig. 1(a) shows the seasonal mean lightning flash rate and surface wet bulb temperature, which were calculated from those of 19 seasons in global land, with the correlation coefficient of 90% defined as the obvious correlation. In view of observing the correlation between interannual variations of lightning flash rate and those of temperature, we calculated the anomaly of the seasonal mean parameter of each corresponding season, with the anomaly of spring calculated by the mean value of 4 years and that of the remaining 3 seasons calculated by the mean value of 5 years, to remove the influences of seasonal cycle. Fig. 1(b) shows the linear fit of the anomaly percent of lightning flash rate and anomaly of wet bulb temperature, with correlation coefficient (for simplicity, named R) being 0.57 (with obvious correlation at the confidence level of 95%) and the sensitivity(the slope and standard error of fit lines) being 13±5% K^{-1}. The following regards R and sensitivity similar to those shown in Fig. 1(b) as the response index of lightning flash rate to temperature variation.

To make a comparison with the corresponding analysis in Reeve et al.[4], we calculated in our analysis not only the seasonal mean wet bulb temperature at 1000hPa but also the seasonal mean surface wet bulb temperature and air temperature. Table 1 shows the response of lightning flash rate to the variations in temperature through the analysis of the OTD/LIS lightning data under the following observation scopes as the global land, the northern or Southern Hemisphere land, and tropical land. Firstly, the response of lightning activity to the variations in wet bulb temperature at 1000 hPa during 3 years is generally in accordance with that analyzed in Reeve et al.[4]. That is to say, the lightning flash rate of the global land and the Northern Hemisphere land seems to have a positive response to the variations in wet bulb temperature at 1000 hPa, with the sensitivity of 10±7% K^{-1} and 16±6% K^{-1}, a bit lower than the estimation in Reeve et al.[4]. However, there is no obvious correlation between lightning activity and the variation of wet bulb temperature at 1000hPa in the Southern Hemisphere land and tropical areas. Secondly, the response of lightning activity to the variations in wet bulb temperature at 1000Pa and in surface wet bulb temperature, which are both based on the OTD/LIS revised data of 3 or 5 years, is almost the same. Lightning variations in the global land and the Northern Hemisphere land have a response to variations in wet bulb temperature, with the sensitivity around 13% K^{-1}.

Table 2 further provides the sensitivity of response of lightning activity in the global ocean (and the globe) to wet bulb temperature during 5 years, which proves that the seasonal mean anomaly of the total lightning flash rates in the global ocean (and the globe) on interannual scale has no correlation (and no obvious correlation) to variations of corresponding wet bulb temperature.

Response of lightning activity in different regions to surface wet bulb temperature variation is analyzed here through the 8-year lightning data, covering the regions

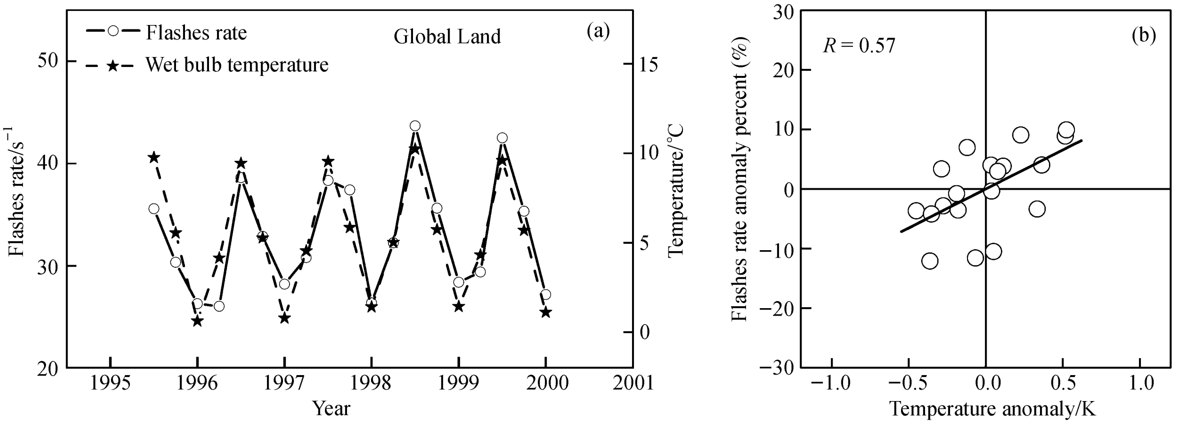

Fig. 1. Correlation between global land lightning activity and surface wet bulb temperature. (a) Interannual variations in the seasonal mean values; (b) correlation between the anomalies of seasonal mean values.

Table 1 Response of global and regional land lightning activity to temperature variation

	Global land		Northern Hemisphere land		Southern Hemisphere land		Tropical land	
	R	sensitivity/% K^{-1}	R	sensitivity/% K^{-1}	R	sensitivity/% K^{-1}	R	sensitivity/% K^{-1}
Reeve et al.[4]	0.548	49±25	0.566	65±32	0	−2±24	0	−1±20
3-year wet bulb temperature at 1000 hPa	0.444	10±7	0.633 correlative	16±6	0.001	0±13	0.174	4±7
3-year surface wet bulb temperature	0.466	11±7	0.644 correlative	17±6	−0.013	−1±12	0.174	4±7
3-year surface air temperature	0.456	11±7	0.603 correlative	16±7	−0.019	−1±12	0.243	5±7
5-year wet bulb temperature at 1000 hPa	0.560 correlative	12±4	0.578 correlative	14±5	0.007	0±8	−0.030	−1±6
5-year surface wet bulb temperature	0.568 correlative	13±5	0.575 correlative	14±5	−0.018	−1±8	−0.021	0±6
5-year surface air temperature	0.603 correlative	14±4	0.574 correlative	13±4	−0.049	−1±7	0.036	1±5

Table 2 Response of lightning activity in the global ocean (and the globe) to temperature variation during 5 years

	Wet bulb temperature at 1000 hPa	Surface wet bulb temperature	Surface air temperature
Global oceanic R and sensitivity/% K^{-1}	0.02	0.05	0.227
	1±16	3±16	14±14
Globe R and sensitivity/% K^{-1}	0.370	0.393	0.488 correlative
	14±8	14±8	17±7

between 35°S—35°N as shown in Table 3. It shows that only the anomaly of lightning activity in the Northern Hemisphere (EQ—35°N) and the anomaly of its surface wet bulb temperature have a relatively high correlation coefficient (R = 0.25, but with no correlation at the confidence level of 95%), with the sensitivity of 11±8% K^{-1}. Moreover, the lightning variations of each region between 35°S—35°N have no obvious correlation with variations of surface wet bulb temperature, or in other words with no response.

3 Analysis of correlation between the global and regional lightning activity and surface air temperature

With surface air temperature as a basic climatic parameter, it is necessary to have a direct understanding of the responses of the global and regional lightning activity to the variations in surface air temperature. Besides the analysis of the relationship between lightning activity and wet bulb temperature, we also analyze the correlation between the interannual variation of lightning activity and that of surface air temperature, as is shown in Table 1 and Table 2. Obviously, 1) according to the analysis based on the 3-year and 5-year OTD/LIS lightning data, in the global land the sensitivities of the seasonal mean lightning flash rate to the variation of surface air temperature are 11±7% K^{-1} and 14±4% K^{-1} respectively, and the correspondingseasonal mean sensitivities of the Northern Hemisphere land are 16±7% K^{-1} and 13±4% K^{-1} respectively, with no obvious correlation between the lightning flash rate of other regions as the Southern Hemisphere land and tropical land and the interannual variation of surface air temperature. All the results are generally in accordance with the analysis of the response of lightning activity to wet bulb temperature, with slight difference of the sensitivity in the former; 2) in the global ocean, lightning activity has no obvious correlation to either variation of air temperature or variation of wet bulb temperature; 3) different from wet bulb temperature, the global total flash rate (the number of flashes per second on the earth) has a positive response to the variation of surface air temperature, with the sensitivity of 17±7% K^{-1}. Fig. 2 illustrates the correlation between variation of the global total flash rate and variation of surface air temperature during 5 years.

The 8-year OTD/LIS lightning data are available at present, with the observation regions between 35°S—35°N. As the global lightning activities mostly occur in the tropical or subtropical zones, is it possible to replace the

Table 3 Response of lightning activity in different regions to surface wet bulb temperature variation during 8 years

	35°S—35°N			35°S—35°N Land					
	Ocean	Land	Globe	35°S—EQ	EQ—35°N	Tropic	Africa	Asia/Oceania	America
R	−0.15	0.10	0.04	−0.01	0.25	−0.18	0.11	−0.05	−0.05
Sensitivity/% K^{-1}	−8±10	3±6	1±7	−1±7	11±8	−6±6	4±9	−2±7	−1±5

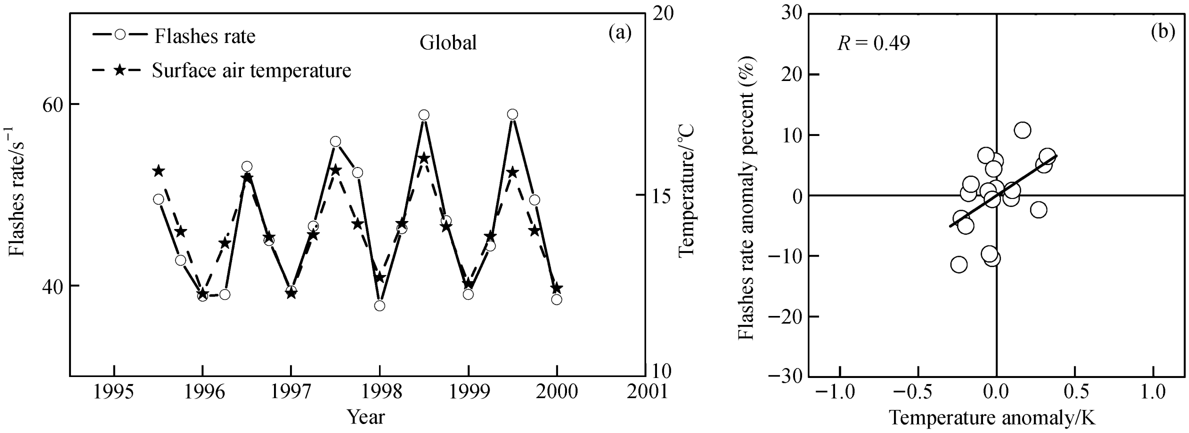

Fig. 2. Correlation between global lightning activity and surface air temperature. (a) Interannual variations in the seasonal mean value; (b) correlation between the anomalies of seasonal mean values.

Table 4 Response of lightning activity in different regions to surface air temperature variation during 8 years

	35°S—35°N			35°S—35°N Land					
	Ocean	Land	Globe	35°S—EQ	EQ—35°N	Tropic	Africa	Asia/Oceania	America
R	−0.02	0.10	0.11	−0.14	0.08	−0.15	0.26	−0.04	−0.06
Sensitivity /% K^{-1}	−1±10	3±5	4±7	−5±6	3±7	−4±5	8±6	−1±8	−2±5

global lightning flash rate with that of the tropical or subtropical zones? We calculated the sensitivity of the seasonal mean land lightning flash rate between 35°S—35°N to the interannual variation of the seasonal mean global land surface air temperature (wet bulb temperature) as 5±5% K^{-1} (5±5% K^{-1}), with the correlation coefficient of 0.19(0.17), not obviously correlated. It seems that the lightning activity between 35°S—35°N can not fully reflect the global lightning activities. The following is the analysis through the data provided above to determine whether the regional seasonal mean lightning flash rate is correlated to the seasonal mean surface air temperature.

Table 4 provides the analysis of the response of the lightning flash rate of different regions between 35°S—35°N during 8 years to the interannual variation of the corresponding seasonal mean surface air temperature. It is shown that there is no obvious correlation between these two, between 35°S—35°N, no matter in the land or ocean, the Africa, Asia/Oceania or America, or other regions in Northern and Southern Hemisphere and the tropical zones.

4 Conclusions and discussions

Based on the satellite-based OTD/LIS lightning detecting data provided by GHRC and the NCEP reanalysis data, this paper analyzes the response of the global lightning activities to the global temperature variations. The results are as follows.

(1) The analysis of the 5-year data shows : limited in land, as to the global or the Northern Hemisphere land, the seasonal mean lightning flash rates all have sensitive positive response to the interannual variations of the seasonal mean surface wet bulb temperature and the seasonal mean surface air temperature. The global land lightning flash rate increases by about 13±5%, with the corresponding wet bulb temperature or air temperature increasing by 1K. The corresponding sensitivities of the Northern Hemisphere land are 14±5% K^{-1} and 13±4% K^{-1} respectively. In other regions as the Southern Hemisphere and the tropical zones, there is no obvious correlation between the anomalies of land lightning flash rate and the interannual variations of surface wet bulb temperature or the surface air temperature. This result is generally in accordance with the analysis in ref. [4] of the correlation between lightning activities and wet bulb temperature at 1000 hPa, whereas our estimation of the sensitivity is a bit lower.

(2) The analysis of the 5-year data shows that the global total flash rate has a positive response to the surface air temperature variation, with the sensitivity of 17±7% K^{-1}, but has no obvious response to wet bulb temperature. The global ocean lightning activity also has no obvious response to the temperature variation.

(3) The analysis of the 8-year data shows that having analyzed the correlation between the lightning flash rate anomalies of different regions between 35°S—35°N and the interannual variation of the corresponding seasonal mean surface air temperature, we find that in all the regions except the Northern Hemisphere land there is no obvious correlation between the seasonal mean lighting activities and variations of the seasonal mean temperatures in the corresponding region.

In summary, our reanalysis further testifies the conclusion that lightning activities are the indicator of climate change. Nevertheless, it deserves greater emphasis that global lightning activities have sensitive positive response to the interannual variations of the seasonal mean surface air temperature (not surface wet bulb temperature) on the globe and global land, with the sensitivity of response a bit lower than estimation of 40% K^{-1} in ref. [4], but it is larger than the 6% K^{-1} sensitivity using general circulation model by Price[6]. Based on the analysis of the 5-year or 8-year OTD/LIS lightning detecting data, which have been carefully revised[7,8] after 2000, these conclusions have better statistic reliability than those based on the 3-year OTD lightning data only. However, in view of the short time span and uncertainty of the detecting data, even better global lightning detecting data and further testing are required. Moreover, why don't the global ocean lightning activities have the same response to the ocean temperature variation as that on the global land? Is it because the enormous ocean thermal inertia leads to the fact that there is exactly no correlation between the two mentioned above; or is it because the sample sizes of the current lightning data statistics are insufficient? All these hypotheses require further study in the future.

Moreover, we also analyzed the response of the global and regional lightning activities to the variation of precipitation (Figures are omitted for lack of space). The result shows that the variation of lightning activities on global land and the Northern Hemisphere land responds to the variation of precipitation, with the sensitivity of about $0.9\pm0.3\%$ mm^{-1}. However, in the Southern Hemisphere and the equator, there is no correlation between the two mentioned above, which is similar to the response of lightning activities to temperature. On a global scale, R of the total flash rate to precipitation and convective precipitation are -0.09, -0.28 respectively, with no correlation at all. It is generally believed that the relationship between lightning activities and convective precipitation is much closer than that between lightning activities and precipitation. Conversely, the correlation coefficient of lightning activities to the variation of convective precipitation provided by the NCEP reanalysis data is lower than that to precipitation, which is an interesting issue and deserves further research.

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