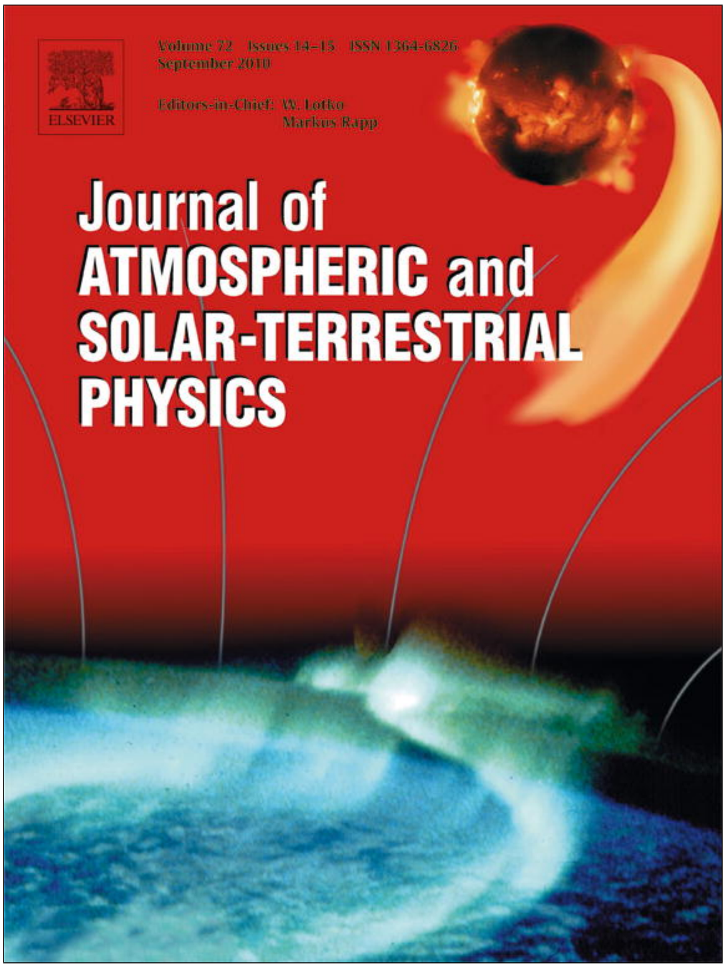
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Correlations between deep convection and lightning activity on a global scale

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ABSTRACT

Satellite observations of cloud top temperature and lightning flash distribution are used to examine the relationship between deep convection and lightning activity over the tropical regions of the northern and southern hemispheres. In agreement with previous work, the analysis of the results shows that, in the summer of both hemispheres, the lightning activity in continental deep convective storms is more intense than that in marine deep convective storms by a factor of between 7 and 10. Furthermore, it was observed that on average the daily lightning rate per $1^\circ \times 1^\circ$ grid cell for the southern hemisphere (SH) is about 20% greater than that of the northern hemisphere (NH), which can be attributed to a larger fractional cover by deep convective clouds in the SH. By using a set of independent indicators, it is shown that deep convection and lightning activity over land are well correlated (with correlation coefficients of 0.8 and 0.6 for NH and SH, respectively). This suggests the capacity for observations to act as a possible method of monitoring continental deep convective clouds, which play a key role in regulating the Earth's climate. Since lightning can be monitored easily from ground networks and satellites, it could be a useful tool for validating the performance of model convective schemes and for monitoring changes in climate parameters.

1. Introduction

Deep convective clouds (DCCs) play a major role in regulating the Earth's climate by transporting heat, water vapor, and momentum from the lower to upper troposphere. Deep convection is the source of water vapor for the upper troposphere in the tropics and it is an effective mechanism to transport aerosols from the planetary boundary layer to the upper troposphere and even to the lower stratosphere (Kulmala et al., 2006). DCC is generally associated with intense updrafts, growth of particles in the solid phase and lightning production. There are many field observations (Lhermitte and Williams, 1985; Carey and Rutledge, 1996; Petersen et al., 1999), which clearly show that lightning production in thunderstorms is associated with the presence of ice particles and strong updrafts in the mixed-phase region, located above the 0 °C isotherm.

Cloud electrification is usually explained by the non-inductive mechanism (Reynolds et al., 1957; Takahashi, 1978; Saunders et al., 1991, 2006; Avila and Caranti, 1994; Pereyra et al., 2000). This mechanism assumes that (1) micrometer ice crystals collide with millimeter graupel particles and bounce off their surface, (2) during the brief time of contact, electric charge is separated between the two particles, (3) electric field is not relevant for charge separation, and (4) the charged ice particles are then carried away to different regions of the cloud due to convective currents and gravitational force.

Laboratory measurements of the interactions between ice crystals and riming ice particles have shown that the charge transfer per rebounding collision could be sufficient to explain thunderstorm electrification. These studies have shown that the magnitude and sign of the charge transferred to riming graupel particles during interactions with ice crystals is sensitive to the cloud microphysical conditions such as the cloud temperature and liquid water content (Takahashi, 1978; Saunders et al., 1991, 1999, 2001; Avila et al., 1995, 1996; Pereyra et al., 2000, 2008), distribution of cloud droplet size (Avila et al., 1998; Avila and Pereyra, 2000), ice crystal size (Keith and Saunders, 1990), and impact velocity (Bürgesser et al., 2006). It was observed that significant charging occurs only when the graupel, ice crystals, supercooled droplets, and water vapor coexist. Furthermore, it was found that the charge transfer per collision increases rapidly with crystal size and impact velocity. These results suggest a strong link between lightning production and the microphysical and dynamical characteristics of the clouds, particularly DCCs.

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The lightning activity in DCC is expected to depend on the intensity of vertical air motion, which is closely related to the storm height. The relationship between flash rate and storm height has been investigated by Williams (1985), who suggested that the flash rate is a function of the fifth power of the storm height on the basis of modification of the scaling law by Vonnegut (1963). Price and Rind (1992) considered the difference in the updraft velocities between the land and the ocean to improve the relationship derived by Williams (1985). They applied their relationships to estimate global lightning distributions. Although the fifth power relationship has been examined through several case studies on the basis of ground and satellite observation, there is no unified view about it from global observations. For instance, Ushio et al. (2001) analyzed the data from the Tropical Rainfall Measuring Mission (TRMM) during 1 month over the land and the ocean, and concluded that the flash rate increases exponentially with the storm height. However, they found that the lightning activity was not necessarily proportional to the fifth power of the storm height but that the relationship depended on the location (land/ocean) and season. Boccippio (2002) revised the scaling relations connecting the lightning flash rate to thunderstorm dynamical and geometrical properties originally derived by Vonnegut (1963). He tested the ocean parameterization used by Price and Rind (1992) and found unrealistic predictions and formal inconsistencies with the Vonnegut's (1963) original theory. Recently, Yoshida et al. (2009) examined the correlation between the number of lightning flashes per second per convective cloud and the cold-cloud depth, which was defined as the difference between the storm height and the melting level (the altitude at 0 °C). They found that the flash rate was proportional to the fifth power of the cold-cloud depth and that the relationship did not have regional dependencies.

Lightning activity on a regional and global scale can be used as a tool for studying changes in the Earth's climate. For instance, Williams (1994) successfully correlated surface wet-bulb temperature anomalies with Schumann resonance amplitudes, which are an indirect measurement of global lightning activity. Kent et al. (1995) studied the influence of the surface air temperature on the amount of upper level tropical clouds. Reeve and Toumi (1999), using satellite data, showed agreement between global temperature and global lightning activity. Price (2000) showed a close link between the variability of upper tropospheric water vapor and the variability of global lightning activity. Williams and Satori (2004) studied the physical origin of the substantial contrast in lightning activity between Africa and South America. Petersen et al. (2005) used satellite data and radar observations to study the fundamental relationship between precipitation ice mass and lightning flash density. Global lightning activity has also been studied on the ENSO (El Niño Southern Oscillation) time scale based on recordings of Schumann resonances and observations from satellites data (Chronis et al., 2008; Sátori et al., 2009a).

In view of the importance attached to knowledge of the distribution of DCC around the globe and the ability of lightning to act as a tracer of vigorous convection, in this work we examine the behavior and the correlations between the average number of flashes per day per $1^\circ \times 1^\circ$ grid cell in each hemisphere and the fraction of each hemisphere covered with DCC in 1 day. The study was performed separately for the continental and oceanic regions of each hemisphere. The land–ocean lightning activity contrast and DCC activity were quantified for the NH and SH. Unlike the comparisons performed in previous work (Ushio et al., 2001; Petersen et al., 2005), the present work uses two sets of observations on different satellites. Since infrared brightness properties were used to detect DCC, no information about the microphysics of the clouds was accessible.

2. Methodology

The lightning data used in this study came from the Lightning Imaging Sensor (LIS) on board the TRMM satellite (http://thunder.msfc.nasa.gov) (Christian et al., 1999) for the period 1998–2008. LIS is a space-based instrument specifically designed to continuously detect the total lightning activity, both intra-cloud (IC) and cloud to ground (CG), for 80 s as any given storm passes through the field of view (600×600 km^2) of its sensor. The orbit of the TRMM satellite has an inclination of 35°. For this reason, the LIS instrument can only detect lightning activity between 35° north latitude and 35° south latitude. The LIS data used in this study included the spatial location of each flash (latitude, longitude) and the total effective observation time during a day. The diagnostic variable employed is the average number of flashes per day (FR) in a $1^\circ \times 1^\circ$ grid cell in each hemisphere, which is obtained by

$$\mathrm{FR} = [\mathrm{SUM}(\mathrm{FNi}/\mathrm{Ti})]/\mathrm{Nc} \quad (1)$$

where for a particular day, FNi is the number of flashes in cell *i*, Ti the effective observation time of cell *i*, and Nc the number of observed cells, and the summation extends only over those cells which are observed on that specific day.

The methods to recognize tropical DCC using infrared measurements are based on thresholds of cloud top temperatures (CTT), which have been defined with different values, for instance, Fu et al. (1990) suggested CTT <215 K, Liu et al. (1995) proposed CTT <230 K, and Hong et al. (2005) and Aumann et al. (2007) suggested CTT <210 K. Different temperature thresholds result in detecting more or less DCCs.

High cirrus clouds are closely connected with DCC and they become a source of uncertainty for the identification of DCC. For this reason, low thresholds of CTT are more convenient. In the current work we have used CTT <210 K to identify DCC.

However, it is important to remark that with this threshold only DCC with top height above 14 km can be detected. This is another important source of uncertainty that results in an underestimation of DCC.

The DCC data in this study were obtained by using CTT and cloud cover fraction per cell data for the period between 2003 and 2008, which are version 5, level 3 products from the Atmospheric Infrared Sounder (AIRS). AIRS is an instrument on board the Aqua satellite, part of the NASA Earth Observing System (http://airs.jpl.nasa.gov/). AIRS measures the infrared brightness of Earth's surface and atmosphere in 2378 spectral channels ranging from 3.7 to 15.4 μm (Chahine et al., 2006). The geophysical parameters have been averaged and binned into $1^\circ \times 1^\circ$ grid cells covering the entire globe, although only grid cells from 0° to $\pm 35^\circ$ latitude were considered. It is important to remark that AIRS observations are neither simultaneous nor synchronous with the LIS observations.

A grid cell with a DCC was identified as an AIRS footprint where the CTT <210 K. For the diagnostic we have defined the fraction of each hemisphere with DCC in 1 day (Fdcc), as

$$\mathrm{Fdcc} = \mathrm{SUM}(\mathrm{Fi})/\mathrm{Nt} \quad (2)$$

where Fi is the cloud cover fraction of grid cell *i*, with CTT <210 K, Nt is the total number of observed grid cells.

The summation extends only over those cells which are observed on a specific day.

It is important to note that the values of the parameters FR and Fdcc are only indicators of the number of flashes per day and the hemisphere fraction covered by convective clouds and that they are not simultaneous indicators on any given day. This is because only a fraction of the global surface is scanned in 1 day and the local time of the satellite observations changes from day to day.

3. Results and discussions

Fig. 1 shows the daily count of FR observed between 0° and 35° northern latitude (Fig. 1a) and between the 0° and 35° southern latitude (Fig. 1b) during the interval from January 1998 to December 2008. The red trace is the result of a running average with a width of 32 days (a 32 day smoothing average), removing the effect of the day-to-day variations from the time series data and creating the equivalent of monthly averages (Aumann et al., 2006, 2007). For a quantitative analysis of peak-to-peak amplitudes and phases we fit the data using the sinusoidal function

$$Y(t) = \mathrm{Yo} + \mathrm{A}\sin[2\mathrm{pi}\ t/B + C] \quad (3)$$

where the parameters Yo, A, B, and C represent the mean value, oscillation amplitude, period, and phase, respectively. These parameters are determined using the least-squares estimation method. Here, for simplicity, it is assumed that the one-harmonic model reproduces fairly well the properties of amplitude and phase of the time series data, which are the relevant ones for the present work. However, in order to evaluate the deviation from the sinusoidal behavior, a more general approach needs to be considered (Sátori et al., 2009b).

Although the plots exhibit a broad scatter in the distribution of data points, it is possible to observe the strong annual variability of the FR in both hemispheres, and the pronounced anti-correlation between the NH and SH. Table 1 displays the values

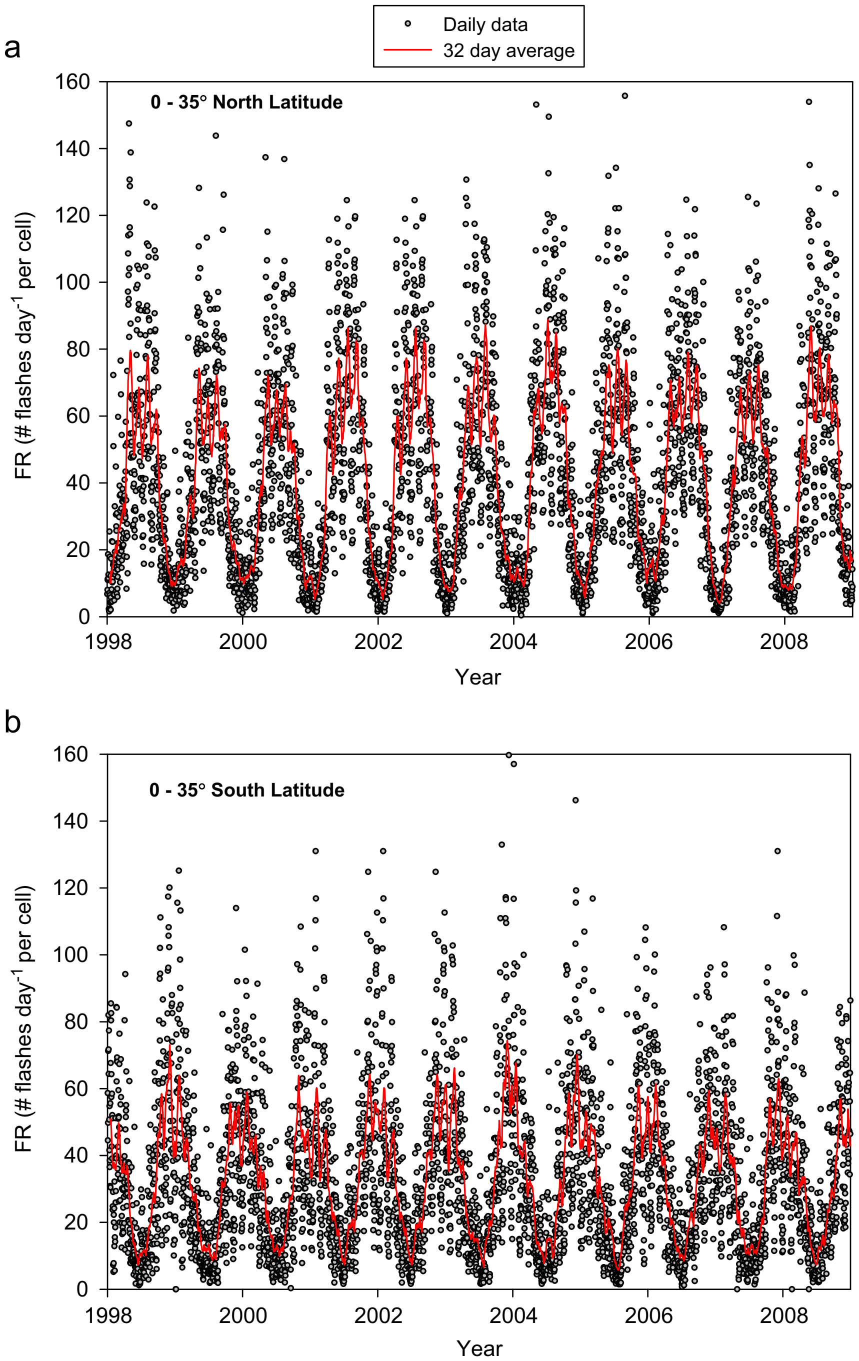

Fig. 1. The daily count of FR for the 0–35° northern latitude (a) and in the 0–35° southern latitude (b) between 1998 and 2008. The red continuous trace is a 32 day smoothing average. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Results of the fitting parameters (*A*, *B*, *C*, and Yo), their standard errors and the coefficient of determination (R^2) obtained for FR data for the northern and southern hemispheres.

	A (flashes/day/cell)	*B* (years)	*C* (radians)	Yo (flashes/day/cell)	R^2
FR–NH	30.5 ± 0.2	1.0001 ± 3e-4	4.58 ± 0.01	41.7 ± 0.1	0.9356
FR–SH	21.2 ± 0.1	1.0022 ± 3e-4	1.70 ± 0.01	33.3 ± 0.1	0.9242

Table 2
Results of the harmonic analysis for both hemispheres.

	Period	Explained variance (%)
NH	Year cycle	56.00
	Semi-annual	0.34
	30–60 days	20.55
SH	Year cycle	41.39
	Semi-annual	0.51
	30–60 days	19.39

and the standard errors of the fitting parameters Yo, *A*, *B*, and *C* obtained for both hemispheres. The estimates indicate that the periods are 1year and the phase difference between the NH and SH is ~165°, which differs by 15° from the expected 180° and it represents about 15 days in time. This departure from the annual behavior could be attributed to the asymmetrical distribution of land surface between NH and SH.

It can be seen in Fig. 1 that in summer lightning activity increases to a high average level with significant fluctuations. The oscillations observed in the peaks of the FR curve are likely related to the Madden–Julian oscillation (MJO) in deep convection. The MJO is an important component of the general circulation: its period spans between 30 and 50 days and prevails between −30° and 30° latitude (Madden and Julian, 1972). By using Schumann resonance intensity, Anyamba et al. (2000) found that the MJO in deep convection can modulate global lightning activity. After the period of high lightning activity, the FR decreases to give a period of low activity that has smaller fluctuations. Mesoscale activity and cirrus feedbacks may also be important sources for the fluctuations observed in the data. Besides, aliasing of a strong diurnal cycle may cause a false intra-seasonal oscillation, as a consequence of poor sampling of single satellite data. The behavior of the lightning activity as a function of time is similar in both hemispheres.

A harmonic analysis of the FR data was made for both hemispheres. This analysis consists of the representation of data fluctuations as summations of sine and cosine functions with frequencies chosen as integer multiples of the fundamental frequency, which is determined by the sample size (i.e. length) of the data (Wilks, 2006). This analysis estimated the contribution to the variance of the relevant frequencies involved in the time series. The results, synthesized in Table 2, shows that the explained variance is representative only for the annual cycle and the 30–60 days band while the explained variance of the semi-annual cycles and the others time bands are insignificant and distributed nearly as white noise.

A spectral analysis of the FR data using the Blackman–Tukey method was also made. The spectral densities were smoothed with a Parzen lag window with a length of 1000 days and a 90% of confidence interval (Chatfield, 1989). For both hemispheres, the analysis shows two remarkable peaks, one connected with the annual cycle and other one between 40 and 60 days, which is associated to the Madden–Julian oscillation. For the SH the spectral density also shows a peak around 23 days, which is not present for the NH. The spectral density of the NH is higher than the SH for the annual and the 40–60 day cycles. It is noticeable that the semi-annual wave, which is significant for other climatic variables, is absent in the FR data.

To assess how variations in lightning activity are related to deep convective activity we have used AIRS data to analyze the seasonal variability and phase relationships between DCC and the lightning flash rate. Analyses of the lightning and convective activity have been performed separately for continental and oceanic regions. The variables FR and Fdcc had to be redefined considering the continental and oceanic areas of each hemisphere. To achieve this the summations in (1) and (2) were confined to land and ocean cells, respectively.

Fig. 2 shows the averaged FR data (Fig. 2a and b) and the 32 day smoothed average of the daily count of Fdcc data (Fig. 2c and d) as a function of time, observed in continental and oceanic regions of the 0–35° SH between January 2003 and December 2008. Also a sinusoidal fit (3) is overlaid as a dotted line. The values of the fitting parameters and their standard errors are listed in Table 3. An important phase difference (~41 days) between FR over land and ocean is noted in Fig. 2a, b and Table 3, it could be a consequence of the sparse data in the ocean region, which produces a poor sinusoidal fit (R^2=0.488). Instead, a good phase correlation (~7 days difference) between Fdcc over land and ocean can be seen in Table 3.

The results from the sinusoidal fit show that the average FR in the continental region of the SH oscillates annually between 30 and 208 flashes per day per cell, while over the ocean FR varies from 5 to 10 flashes per day per cell. This indicates that in summer the lightning activity is about 20 times more intense over the land than over the ocean. Fig. 2(c) and (d) also shows greater deep convective activity over the land than over the ocean. However, the difference is not as pronounced as with the lightning activity. In fact, the continental fraction covered by DCC with CTT <210 K reaches 0.0097 in summer, while the ocean fraction is only 0.0051. One can see that there is approximately a factor of 2 between deep convective activity over the land and ocean. Hence, this suggests that the lightning activity in continental deep convective storms is more intense than lightning activity in marine deep convective storms by a factor of 10 in the SH. These results reinforce the findings of earlier researchers who have reported the land–ocean lightning activity contrast (Orville and Henderson, 1986; Zipser, 1994; Boccippio, 2002; Christian et al., 2003; Ushio et al., 2001; Yoshida et al., 2009). For instance, Orville and Henderson (1986) reported the distribution of global midnight lightning between 60° north latitude and 60° south latitude for 365 consecutive days. They found that the global land–ocean lightning ratios range from 5.3 to 10. Also, Yoshida et al. (2009) found that convective clouds on land have about 10 times as many flashes as those over the ocean.

It has been hypothesized that most oceanic convective storms have updrafts below a threshold value, at which the large ice particles, supercooled water droplets and ice–ice collisions are not present in the mixed-phase region in sufficient concentrations for electrification leading to lightning (Zipser, 1994). A number of recent publications have addressed the possibility that tropospheric aerosols could affect cloud electrification through the impact of aerosols on cloud microphysical properties (Lyons et al., 1998; Williams and Stanfill, 2002).

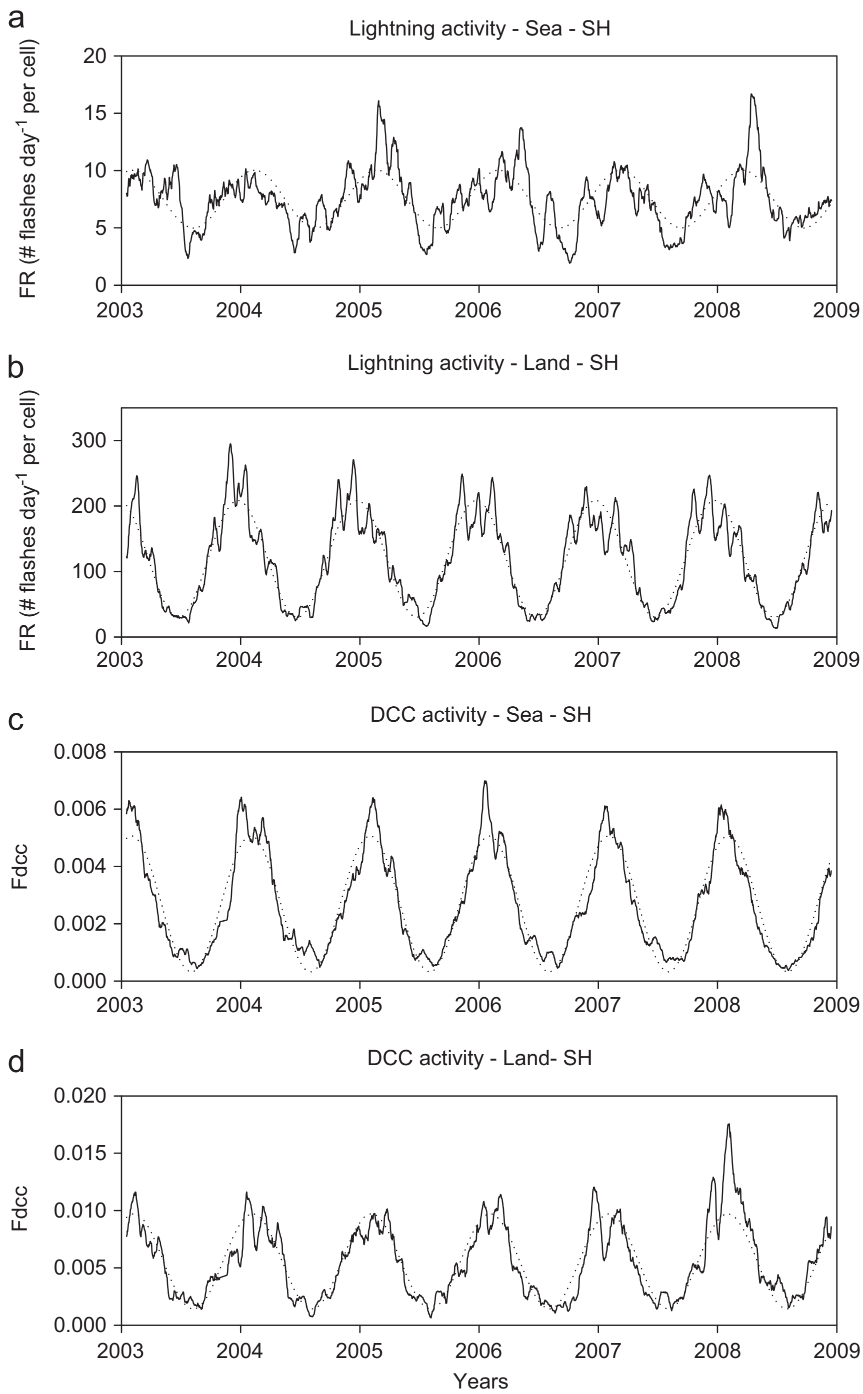

Fig. 2. The averaged FR data for the 0–35° southern hemisphere observed in oceanic (a) and continental (b) regions as a function of time. The averaged Fdcc data for the same regions are shown in (c) and (d). The dotted line represents the sinusoidal fit for each set of data.

Table 3
Results of the fitting parameters (*A*, *B*, *C*, and Yo), their standard errors and the coefficient of determination (R^2) obtained for FR and Fdcc data for oceanic and continental regions over the SH.

SH	*A* (#/day/cell)	*B* (years)	*C* (radians)	Yo (#/day/cell)	R^2
FR-Sea	2.52 ± 0.06	1.023 ± 0.002	1.00 ± 0.05	7.51 ± 0.05	0.4880
FR-Land	89.0 ± 0.8	1.0001 ± 0.0008	1.71 ± 0.02	119.2 ± 0.5	0.8640
Fdcc-Sea	$(2.37 \pm 0.01)e-3$	1.0000 ± 0.0006	1.03 ± 0.01	$(2.69 \pm 0.01)e-3$	0.9055
Fdcc-Land	$(4.14 \pm 0.04)e-3$	0.9961 ± 0.0009	0.91 ± 0.02	$(5.56 \pm 0.03)e-3$	0.8072

Aerosols are produced and introduced into the atmosphere by industry and transport emissions, soil erosion, and the oceans. Some of them can act as cloud condensation nuclei (CCN), which can form clouds and can then be removed by precipitation. An increment in the production of aerosols leads to an increase in available CCN, and for a constant liquid water content, more CCN lead to more and smaller cloud droplets (Twomey, 1974).

Thus, the aerosol hypothesis is based on the assumption that larger CCN concentration leads to smaller cloud droplets. An increment in the number of CCN would produce the following effects: greater number of smaller cloud droplets which will not collide as efficiently, reduce the formation of drizzle drops, decrease precipitation formation, enhance the liquid water content attaining the mixed phase region of moist convection, which invigorates the ice phase microphysics. According to this hypothesis the lightning activity should increase with CCN concentration. It is worth noting that the boundary layer CCN concentration over land is found to be at least one order of magnitude higher than over the oceans (Pruppacher and Klett, 1997). Thus, it is expected on the basis of aerosol variations alone that land regions will have more intense lightning activity than oceanic regions. Unfortunately, in this work we cannot make any progress regarding this hypothesis, because we do not know the vertical structure and the microphysical properties of the DCC producing lightning. In this regard, studies that use radar reflectivity through the mixed phase region are best suited to provide information for testing the aerosol hypothesis (Ushio et al., 2001; Yoshida et al., 2009)

Fig. 3 shows the 32 day smoothed average of FR (Fig. 3a and b) and Fdcc (Fig. 3c and d) as a function of time, observed over continental and oceanic regions of the 0–35° NH between January 2003 and December 2008. The sinusoidal fit is overlaid as a dotted line and the values of the fitting parameters and their standard errors are listed in Table 4. A reasonably good phase correlation between FR over land and ocean (~12 days difference) can be observed in Fig. 3a and b and Table 4. While a substantial phase difference between Fdcc over land and ocean (~58 days) is noted in Table 4, it is likely that this is a result of the low annual variability and consequently poor sinusoidal fit ($R^2=0.5957$) of Fdcc over the ocean.

The results from the sinusoidal fit show that the average FR in the continental region of the NH fluctuates annually between 16 and 167 flashes per day per cell, while in the oceanic region it varies from 9 to 24 flashes per day per cell. The difference between the lightning activity over land and ocean regions in the NH is less significant than that found for the SH. In fact, during summer, FR over land is only about 7 times greater than that over the oceans.

Although the plots exhibit a broad scatter in the distribution of data points, mainly from the ocean region, the results show a similar deep convective activity over land and ocean. The continental fraction covered by DCC with CTT <210 K reaches 0.0056 in summer, while the ocean fraction is 0.0059. Similar to the SH, the current results support the idea that lightning activity in continental deep convective storms is more intense than lightning activity in oceanic deep convective storms.

In the land regions of the SH and NH a positive correlation exists between FR and Fdcc. The Pearson correlation coefficients are 0.60 ($p<10^{-4}$) and 0.86 ($p<10^{-4}$) for SH and NH, respectively, suggesting that the lightning activity might be modulated by deep convective activity. By extending the data analysis, we found that the correlation between FR and Fdcc may be enhanced if CTTs warmer than 210 K are considered. For instance, the correlation coefficient between FR and Fdcc with CTT <230 K (-43 °C) is 0.70 and 0.92 for SH and NH, respectively.

These correlation coefficients indicate that lightning activity is a good indicator of the deep convective activity over the continents. The significant correlation between lightning activity and DCC on a global scale lends further validity to the use of lightning measurements as a diagnostic for deep convective activity. Since lightning can be monitored easily and continuously, from space and ground networks, lightning may become a useful tool for monitoring changes in important climate parameters in the future.

By comparing quantitatively the Fdcc between hemispheres, it is worth noting that the ratio between the Fdcc over NH land and SH land is 0.6. On the other hand, by comparing the FR over land between hemispheres it is observed that the ratio between the FR over NH land and SH land is 0.8 (20% difference). These values were obtained by taking the maximum values of Fdcc and FR in both hemispheres. The distribution of ocean and land areas is likely to induce a disparity between the solar radiation absorption between hemispheres. Sunlight reaching the Earth's surface plays an important role in influencing surface temperatures (land and ocean), in controlling surface evapotranspiration, and in destabilizing the atmosphere to produce local convection. Thus the surface properties, thermodynamic conditions and instabilities that drive vertical air motion could be the cause of the larger lightning activity over land in SH. Williams (1994) investigated the response of the DC and AC global electrical circuit to seasonal variations in surface air temperature. He suggested that the annual global temperature signal appears to be dominated by an imbalance in landmass between the NH and SH and that the global lightning activity responded to surface air temperature on semi-annual and annual timescales.

There is an apparent discrepancy between the results reported in Table 1 and Tables 2 and 3. In fact, the results in Table 1 show that the maximum number of flashes per day is larger in the NH than in the SH; however, the results in Tables 2 and 3 indicate that the maximum FR values over the land region of the SH is higher than those of the NH. The reasons for this apparent controversy are the following: while the lightning activity over land of the NH is higher than those in the SH, the continental area of the SH is smaller than those of the NH, then FR over the land region of the SH exceed those of the NH.

4. Summary and conclusions

A dataset of cloud top temperature from the Atmospheric Infrared Sounder and lightning data from the Lightning Imaging Sensor was used to investigate the relationship between deep convection and lightning activity. The correlations between the average number of flashes per day per grid cell in each hemisphere and the fraction of each hemisphere covered with DCC in 1 day were examined. According to early works (Orville and Henderson, 1986; Christian et al., 2003; Ushio et al., 2001, Yoshida et al., 2009), it was found that lightning activity in deep convective storms of the SH and NH is between 7 and 10 times higher over the continents than over the oceans. The physical origin for the land–ocean lightning activity contrast is likely related to the cloud microstructure and precipitation-forming processes, which are known to be influenced by updraft and aerosols (Michalon et al., 1999; McCollum et al., 2000).

The ratio between the maximum Fdcc (summer season) over NH and SH land is 0.6 and the ratio of the maximum FR over NH and SH land is 0.8. These results suggest that the surface properties, thermodynamic conditions and instabilities that drive vertical air motion and the production of deep convection might be the cause of the larger lightning activity in the SH than in the NH.

These results are in agreement with previous studies which confirm that electrical activity is associated with DCC and can be a

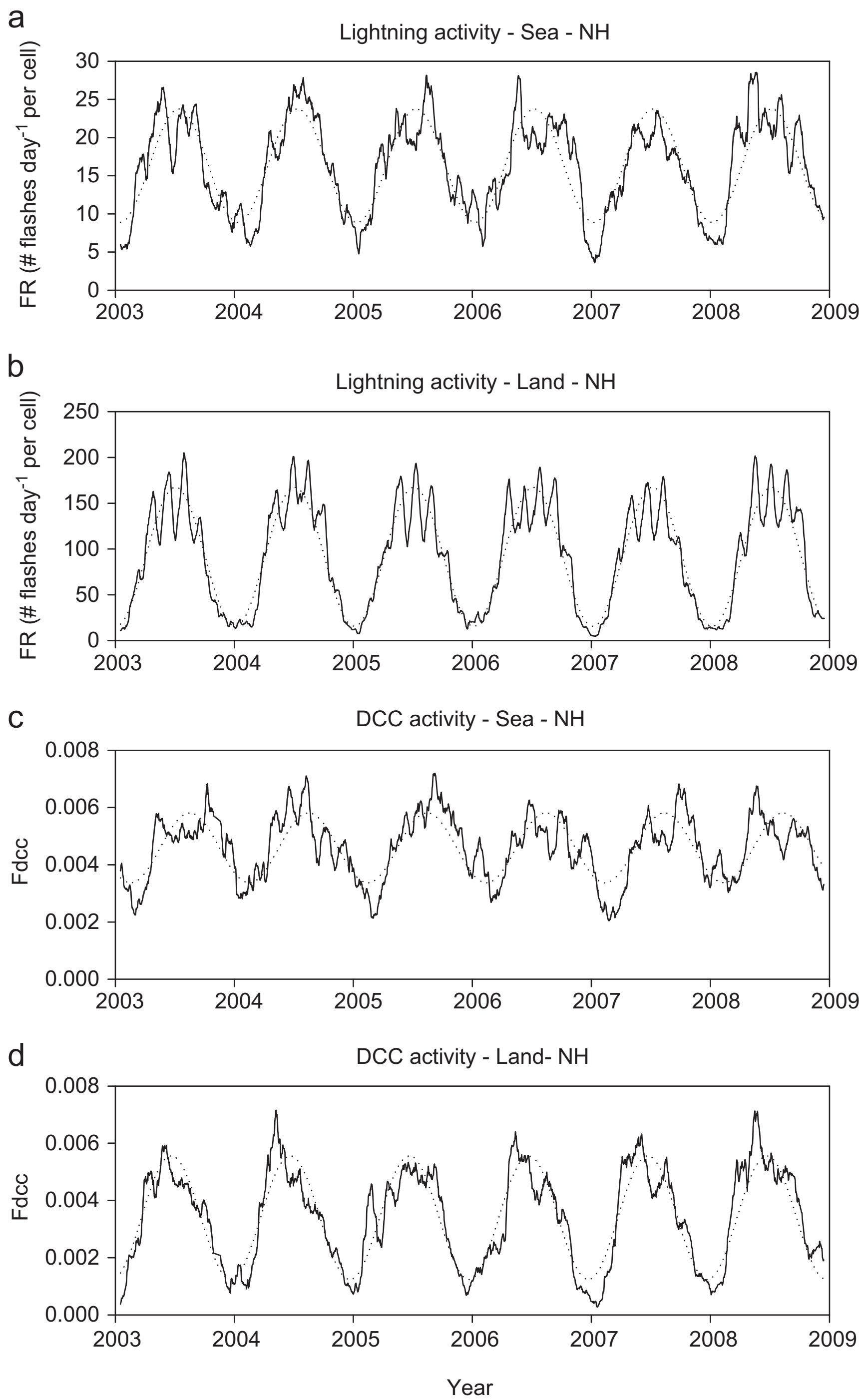

Fig. 3. The averaged FR data for the 0–35° northern hemisphere observed in oceanic (a) and continental (b) regions as a function of time. The averaged Fdcc data for the same regions are shown in (c) and (d). The dotted line represents the sinusoidal fit for each set of data.

Table 4
Results of the fitting parameters (*A*, *B*, *C*, and Yo), their standard errors and the coefficient of determination (R^2) obtained for FR and Fdcc data for oceanic and continental regions over the NH.

NH	*A* (#/day/cell)	*B* (years)	*C* (radians)	Yo (#/day/cell)	R^2
FR-Sea	7.4 ± 0.1	0.996 ± 0.001	4.48 ± 0.02	16.3 ± 0.1	0.7518
FR-Land	75.9 ± 0.6	1.0018 ± 0.0008	4.68 ± 0.02	91.5 ± 0.5	0.8696
Fdcc-Sea	$(1.29 \pm 0.02)e-3$	0.997 ± 0.002	3.90 ± 0.04	$(4.59 \pm 0.02)e-3$	0.5957
Fdcc-Land	$(2.16 \pm 0.02)e-3$	1.001 ± 0.001	4.90 ± 0.02	$(3.40 \pm 0.01)e-3$	0.8214

good indicator of deep convective activity. In fact, knowledge of the distribution of lightning around the globe is important in many fields. This confirms the ability of lightning observations as a possible method of monitoring continental DCCs, which play a key role in regulating the Earth's climate.

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