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GLOBAL OPTICAL LIGHTNING FLASH RATES DETERMINED WITH THE FORTE SATELLITE

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ABSTRACT: Using FORTE photodiode detector (PDD) observations of lightning, we have determined the geographic distribution of nighttime flash rate density. We estimate the PDD flash detection efficiency to be 62% for total lightning through comparison to lightning observations by the TRMM satellite's Lightning Imaging Sensor (LIS), using cases in which FORTE and TRMM viewed the same storm. We present here both seasonal and total flash rate maps. We examine some characteristics of the optical emissions of lightning in both high and low flash rate environments, and find that while lightning occurs less frequently over ocean, oceanic lightning flashes are somewhat more powerful, on average, than those over land.

INTRODUCTION

The FORTE satellite was launched by Los Alamos and Sandia National Laboratories in 1997 and among its sensors is a non-imaging, optical photodiode detector (PDD). The PDD has detected 2-3 million lightning events worldwide since launch. Using PDD observations of nighttime lightning events, we have determined the geographic distribution of nighttime flash rate density.

FORTE PHOTODIODE DETECTOR

The FORTE Optical Lightning System includes a fast, broadband photometer, the Photodiode Detector, or PDD. The PDD records 2 ms optical waveforms of events with 15 μs resolution, and is sensitive from 0.4 to 1.1 μm. The field-of-view (FOV) of the instrument comprises an 80° cone, or 40° maximum nadir angle. From FORTE's 800 km orbit, this results in a ~1200 km diameter footprint on the ground. The PDD employs a noise-riding threshold and in our database we impose a filter that rejects narrow, high-amplitude events likely to have resulted from energetic particle hits. For greater detail regarding the FORTE PDD, see *Kirkland et al.* [2001] and *Suszcynsky et al.* [2000, 2001].

Particle event filter: The FORTE database of PDD events contains a flag that indicates whether the waveform for a given event is likely to have resulted from an impact on the detector by a high energy particle so that they can be excluded from lightning studies. In an effort to quantify the efficacy of the filter, and to gain confidence in using it, we examined by eye approximately 5,000 individual waveforms that were collected over the South Atlantic Anomaly (SAA) between June-December 1998, plus another 5,000 waveforms gathered over the rest of the globe. In the global set, 0.14% of all events were flagged as particle hits when in fact they were lightning, and no true particle hits were missed by the filter. In the SAA data, 0.02% of all events were flagged as particle hits when in fact they were lightning, and 2.8% of so-called lightning was in fact due to particle hits. Thus we believe our filter to work very well, with the worst miss-rates being less than 3% and only over the SAA.

Detection efficiency: We determined the PDD total lightning flash detection efficiency through comparison with that of the Lightning Imaging Sensor (LIS) on board the NASA/TRMM satellite. (For greater detail of this comparison, see another ICAE 2003 presentation, *W.L. Boeck et al.*, "Multi-satellite observations of oceanic lightning.".) There are a very limited number of coincident TRMM/FORTE overpasses of a given geographic region, due to the large difference in obital inclination between the two satellites. We have nevertheless identified two times when both satellites were in view of the same region, and an active storm was present. Each flash, as reported by LIS, is composed of several (2 - 200) events, with total flash durations of a few milliseconds up to 1-2 seconds. As the FOVs for the two satellites is not precisely coincident, it is possible that some PDD records originate from a flash entirely outside the storm viewed by LIS. To prevent such contamination and consequent over-estimation of our flash-level detection efficiency, we visually inspected both the LIS and PDD data for each flash, and accepted only those PDD events which were within 4 ms of a LIS event. The first storm occurred at −13° latitude and 48° east longitude on April 5, 2001, at 12:30 a.m. local time. LIS was in view of the storm for 86 seconds. The second, more active storm occurred at 26° latitude and 92° west longitude on September 20, 2001, at 12:15 a.m. local time. LIS observed the storm for about 96 seconds. The LIS detection efficiency is estimated to be 88% (*Boccippio et al.* [2000]). The PDD detected 19 of the 27 flashes observed by LIS in these storms, and therefore we estimate the PDD DE to be 62%. The stroke-level detection efficiency

Table 1. Global flash characteristics. Median values from 2 years (1998-1999) of data.

	Flash rate density ($\mathrm{fl/yr\text{-}km^2}$)	Flash peak power ($\mu\mathrm{W/m^2}$)	Total flash energy ($\mu\mathrm{J/m^2}$)	Flash duration (ms)
Over land	**2.2**	321	0.531	261
Over ocean	**1.1**	490	0.620	266

for the FORTE PDD is significantly lower than this number; 62% is a flash-level DE, in which we require only a single event detection for any given flash. We recognize the many limitations of this estimate: it is based on observations of only two storms, for a total of three minutes; both of these storms occurred over ocean; the PDD and LIS DEs may both vary with geography, and as one is a threshold-crossing trigger while the other is an integrating system, they may vary differently.

Limitations of the data: One fundamental limitation in the present study is that the PDD does not provide geolocation of a detected event. We are limited with this data set to geographic resolution of 1200 km on the ground. Additionally, during daylight observations, the operating trigger thresholds are set high to avoid having the data contaminated by glints off clouds or water. Due to these high trigger thresholds, in addition to the high daytime background light levels, the PDD data taken during daylight are extremely biased and include only the strongest optical lightning events. In this work we therefore exclude the ~10% of data taken during daylight conditions, and consider only nighttime PDD data.

FLASH RATE DETERMINATION

We begin by searching the FORTE state-of-health files to find all the times when the PDD was in the desired configuration. The sub-satellite position at each such second is noted. From each sub-satellite point, we determine the PDD footprint on the ground, and all the 0.5° map cells falling within that footprint receive one second of time. In this way, we create a map of how much time the FORTE/PDD could detect lightning from any given point on the Earth.

The desired configuration for the FORTE PDD is defined to be all times when the sensor was on, event storage was enabled, event detection was enabled, the PDD was triggering autonomously (rather than being slaved to one of the other lightning sensors on FORTE), and the trigger threshold levels were set to 25 engineering units (the lowest setting, typical of nighttime observations).

Once a map of the global observation time is generated, we search the database for all PDD events recorded when the sensor was in the configuration described above, rejecting events deemed to be particle hits (see above). All good events are then grouped into flashes using a sliding 330 ms window. If all events happened rhythmically with a period of less than 330 ms, they would result in a single, infinitely long flash. Because flashes are temporally isolated and finite, however, that does not happen and in fact we see few flashes lasting longer than 1 second. The mean sub-satellite point and time of all events comprising a flash is used to determine the satellite's observational footprint at the time of each flash. Each 0.5° map cell within the footprint is then incremented by one flash. Finally, we divide the event maps by the time maps, coarsen the map to 5° resolution and scale each cell according to the area it covers on the ground and the detection efficiency.

RESULTS

Figure 1 shows the global lightning flash rate density derived from PDD data as described above, for two years' worth of data, 1998-1999. Geographic regions that are poorly sampled appear as white areas on the map (in this case, only the polar caps). In order to highlight the low-flash-density regions of the globe, the color scale is logarithmic in one panel. Despite the 1200 km resolution of the data, we clearly see the continental lightning hot spots along the equator, as well as the marked land-ocean contrast in lightning flash rates. 998,907 PDD events grouped into 253,683 flashes to create this map for 1998-1999. 32% of those flashes occurred over ocean. Land/ocean differences in flash rates and in optical flash characteristics (as sampled by the FORTE/PDD) are shown in Table 1. The flash rates given in Table 1 include all nighttime flashes detected by FORTE, but the flash characteristic values in Table 1 are calculated only for flashes that consist of more than a single event, as detected by FORTE.

Figure 2 shows the global flash rate density for each of four seasons. Each season includes three months, for five years, so that a total of 15 months of PDD data is combined to make each map. As a result the spatial sampling is quite good, except for the southernmost extent of the SAA. We have often shut off FORTE's optical sensors over the SAA to minimize the memory waste caused by very high rates

Table 2. Regional flash characteristics. Median values from 2 years (1998-1999) of data.

Region	**Flash rate density** ($fl/yr\text{-}km^2$)	Flash peak power ($\mu W/m^2$)	Total flash energy ($\mu J/m^2$)	Flash duration (ms)	Lat/ Lon Ranges
			Continental regions		
N. America	**3.4**	391	0.502	255	35→ 50; -120→ -90
S. America	**28.5**	441	0.552	268	-23→ 0; -68→ -45
N. Africa	**5.8**	441	0.557	275	15→ 30; 0→ 30
S/Cent. Africa	**29.4**	363	0.534	263	-25→ 5; 15→ 30
Asia	**2.2**	201	0.396	266	30→ 45; 60→ 105
			Oceanic regions		
N. Pacific	**1.4**	404	0.452	266	15→ 45; -175→ -150
S. Pacific	**3.5**	491	0.584	248	-45→ -15; -170→ -140
E/Equ. Pac.	**2.8**	572	0.647	262	-10→ 10; -120→ -90
N. Atlantic	**2.6**	489	0.678	265	30→ 45; -55→ -25
S. Atlantic	**0.66**	794	0.865	263	-45→ -15; -30→ 0
Indian Ocean	**0.83**	538	0.647	272	-40→ -15; 70→ 100
			Land/ocean regions		
U.S. Gulf Coast	**19.5**	511	0.586	274	23→ 38; -105→ -75
Indonesia	**18.0**	501	0.605	266	-20→ 10; 105→ 135

of energetic particle hits.

In figure 2 the seasonal north-south migration of the lightning is clear. Less obvious is the fact that the highest lightning flash rates are seen over the Amazon in September, when flash rates can exceed 100 flashes per sq. km per year; the second most active region is Central Africa, which keeps a fairly constant rate of ~50-60 flashes per sq. km per year.

We summarize median flash rates and characteristics from several regions of interest in Table 2. The flash rates given in Table 2 include all nighttime flashes detected by FORTE, but the flash characteristic values in Table 2 are calculated only for flashes that consist of more than a single event, as detected by FORTE.

SUMMARY

We have examined lightning flash rates and characteristics globally and within several regions of interest using data collected by the FORTE photodiode detector under nighttime conditions. We estimate the flash detection efficiency for these observations to be 62%. Flash rates are generally lower over ocean by a factor of two, although general oceanic rates are a factor of 15-25 lower than the rates over the four well-known lightning hotspots. The peak power recorded by FORTE for flashes over ocean is 50% greater than that for flashes detected over land. The integrated flash energy recorded for flashes over ocean is 17% greater than that for flashes detected over land. The durations of flashes detected over land and ocean were the same.

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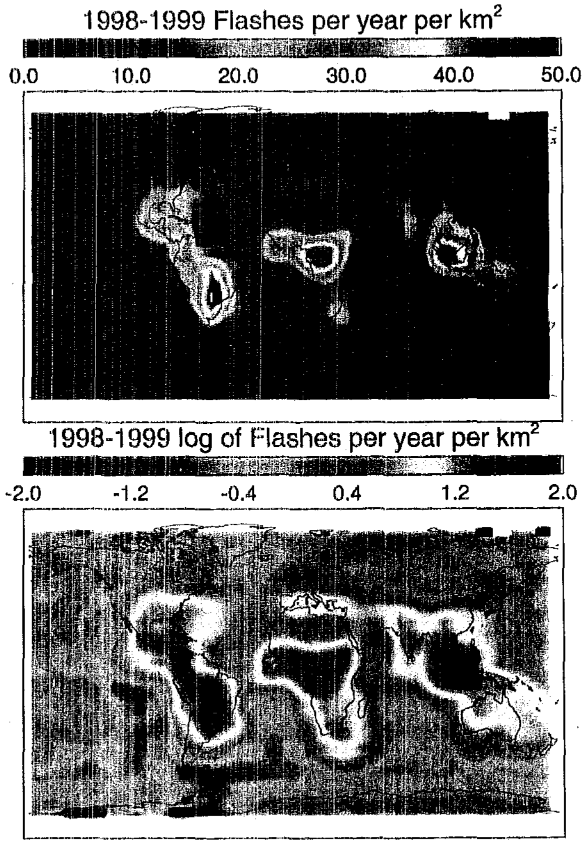

Figure 1: Lightning flash rate density in flashes per year per square kilometer, for 1998-1999. In the lower panel, the color scale is logarithmic to bring out the full range of features.

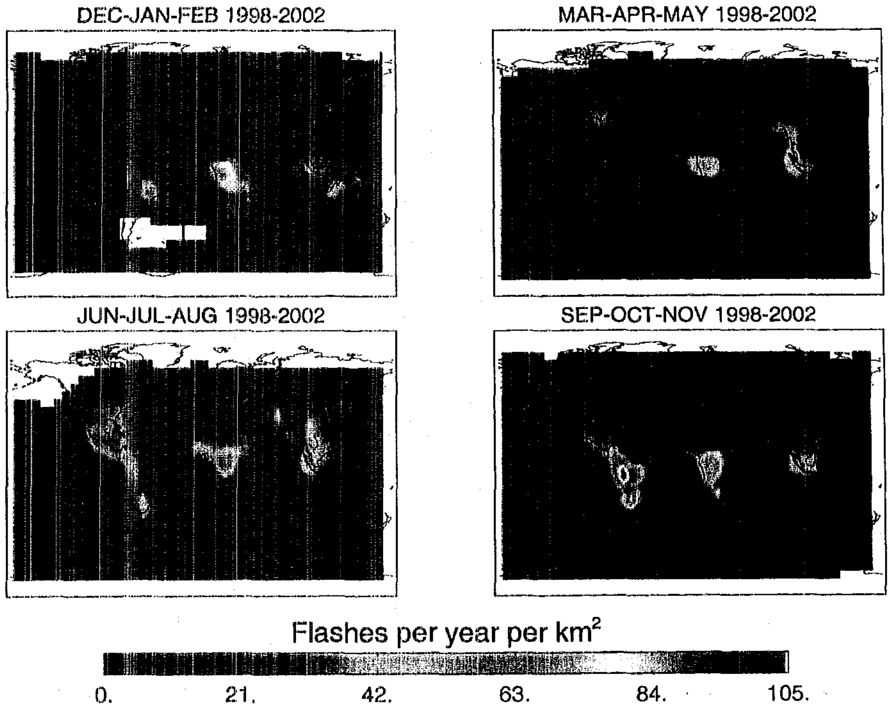

Figure 2: Lightning flash rate density in flashes per year per square kilometer, for each of four seasons. The data span five years, so that each map includes data from 15 months, as noted above each map.