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European cloud-to-ground lightning characteristics

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***Abstract*— Cloud-to-ground (CG) lightning data from the European Cooperation for Lightning Detection (EUCLID) network over the period 2006-2012 are explored.**

Lightning detection, lightning climatology, lightning density

I. INTRODUCTION

Electrification has always grasped humans' interest and continuous efforts have been made ever since to improve our understanding in this field. One of the topics receiving great attention has been the temporal and spatial occurrence of lightning on local as well as on global scales. In the past, ground flash densities N_g were assumed to correspond closely to the amount of observed thunderstorm days T_d, resulting in correlations of following form:

$$N_g = a\, T_d^{\,b}\ [\text{km}^{-2}\text{yr}^{-1}], \qquad (1)$$

with *a* and *b* variables depending on, e.g., geographical regions [1]. However, this formula does not take into account the severity of a storm and, moreover, not two thunderstorms are identical in terms of the electrical activity. Hence, the imposed N_g-T_d relation only provides an initial guess for the true amount of occurred cloud-to-ground (CG) flashes. Luckily, over the years the technology by which to observe lightning has advanced tremendously and nowadays regional and global ground-based lightning location systems (LLS) provide a more precise evaluation of the lightning discharges to ground over land and sea. Several studies exist already presenting (sub-) national lightning statistics in Europe, e.g., [2, 3, 4, 5]. In addition, specific instruments on satellites such as the Lightning Imaging Sensor (LIS) and the Optical Transient Detector (OTD) aboard the TRMM Observatory and the MicroLab-1 satellite, respectively, contributed to our understanding of the overall lightning activity, i.e., CG as well as cloud-to-cloud lightning over selected parts of the world [6], without any distinction between the type of lightning.

In this paper, CG lightning characteristics are explored, based on the observations made by the European lightning location system EUCLID. The analysis of the data has been restricted to the area with the highest and nearly uniform performance, as indicated by the dash-dotted line in Fig. 1.

Figure 1: Sensor positions within the EUCLID network for 2012. Note that only data within the polygon (dashed-dotted line) is used for quantitative analysis.

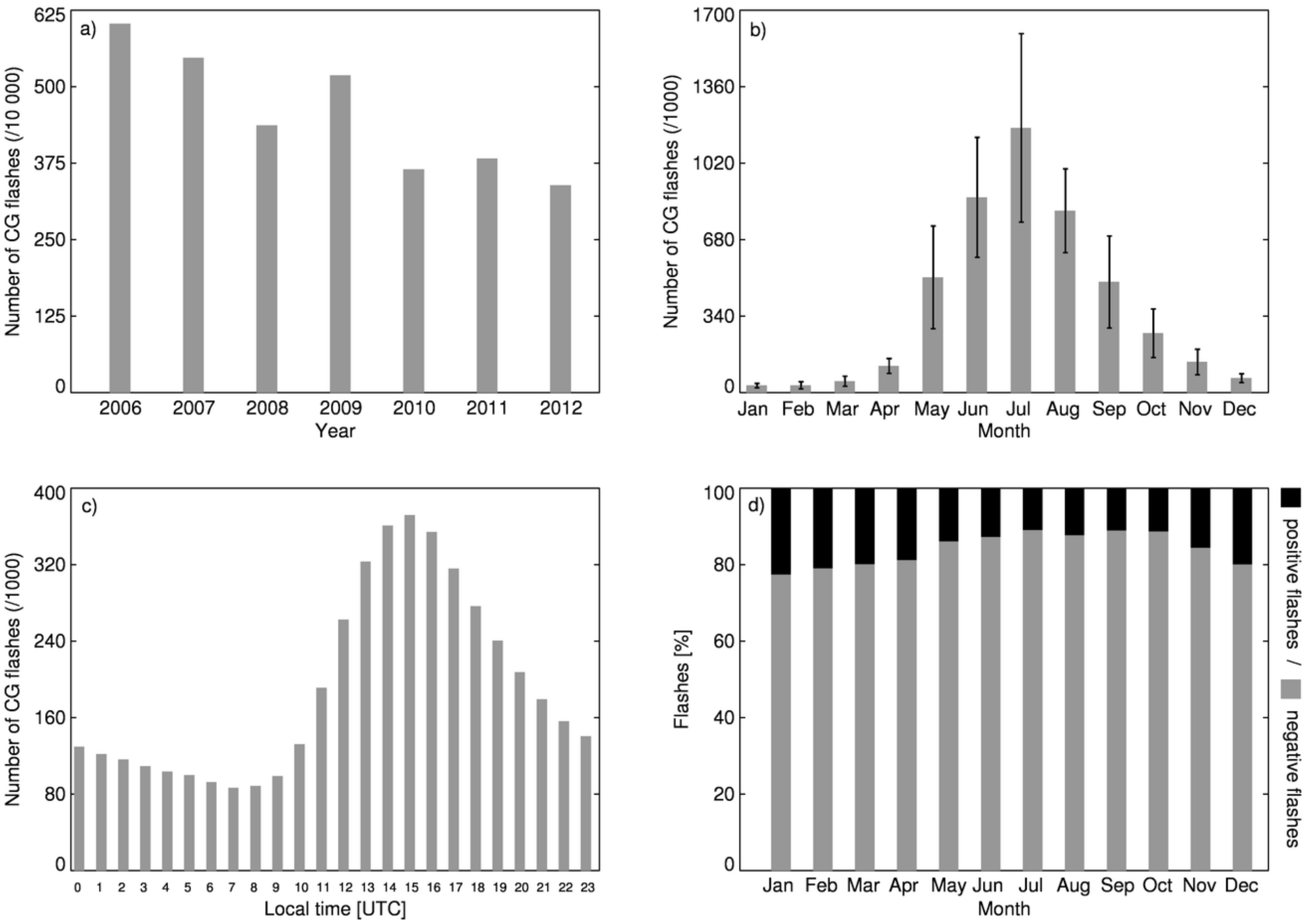

Figure 2: a) Annual CG flash counts, b) mean monthly flash counts with bars representing a ±1 standard deviation, c) mean diurnal flash counts and d) mean monthly polarity distribution, based on 2006-2012 EUCLID data.

II. EUCLID

In 2001, several countries, that is, Austria, France, Germany, Italy, Norway and Slovenia, started a European cooperation for lightning detection (EUCLID), with the goal to provide Europe-wide lightning data with nearly homogeneous quality. Subsequently, Spain, Portugal, Finland and Sweden joined EUCLID as well. EUCLID is special in the sense that the individual partners are highly motivated to run their individual networks with state-of-the-art lightning sensors. As of December 2013 the EUCLID network employs 146 sensors, see Fig. 1, of which there are 8 Lightning Positioning and Tracking System (LPATS), 16 Improved Performance from Combined Technology (IMPACT), 33 IMPACT Enhanced Sensitivity and Performance (ES/ESP), and 89 LS7000 sensors (oldest to newest), all operating over the same frequency range with individually calibrated sensor gains and sensitivities. Data from all these sensors are processed in real-time using a single common central processor, which also produces daily performance analysis for each of the sensors. This ensures that the resulting data are as consistent as possible throughout Europe. In fact, the Europe-wide data produced by EUCLID are frequently of higher quality than the data produced by the individual country networks due to the implicit redundancy produced by shared sensor information.

The performance of EUCLID has been frequently tested over the years in terms of its location accuracy (LA), detection efficiency (DE) and peak current estimation, made possible by comparing to direct lightning measurements at the Gaisberg Tower and to data from E-field and video recordings [7]. Currently, the median LA is in the range of 100 m to 600 m, depending on the region of investigation and amount of ground-truth data available, whereas the DE reaches 95% or more for negative flashes.

III. Data and Methodology

Even though EUCLID is an evolving network expanding gradually its boundaries and the amount of sensors participating over the years, it can be assumed that from 2006 onwards the network has been stable. As such, we opt for

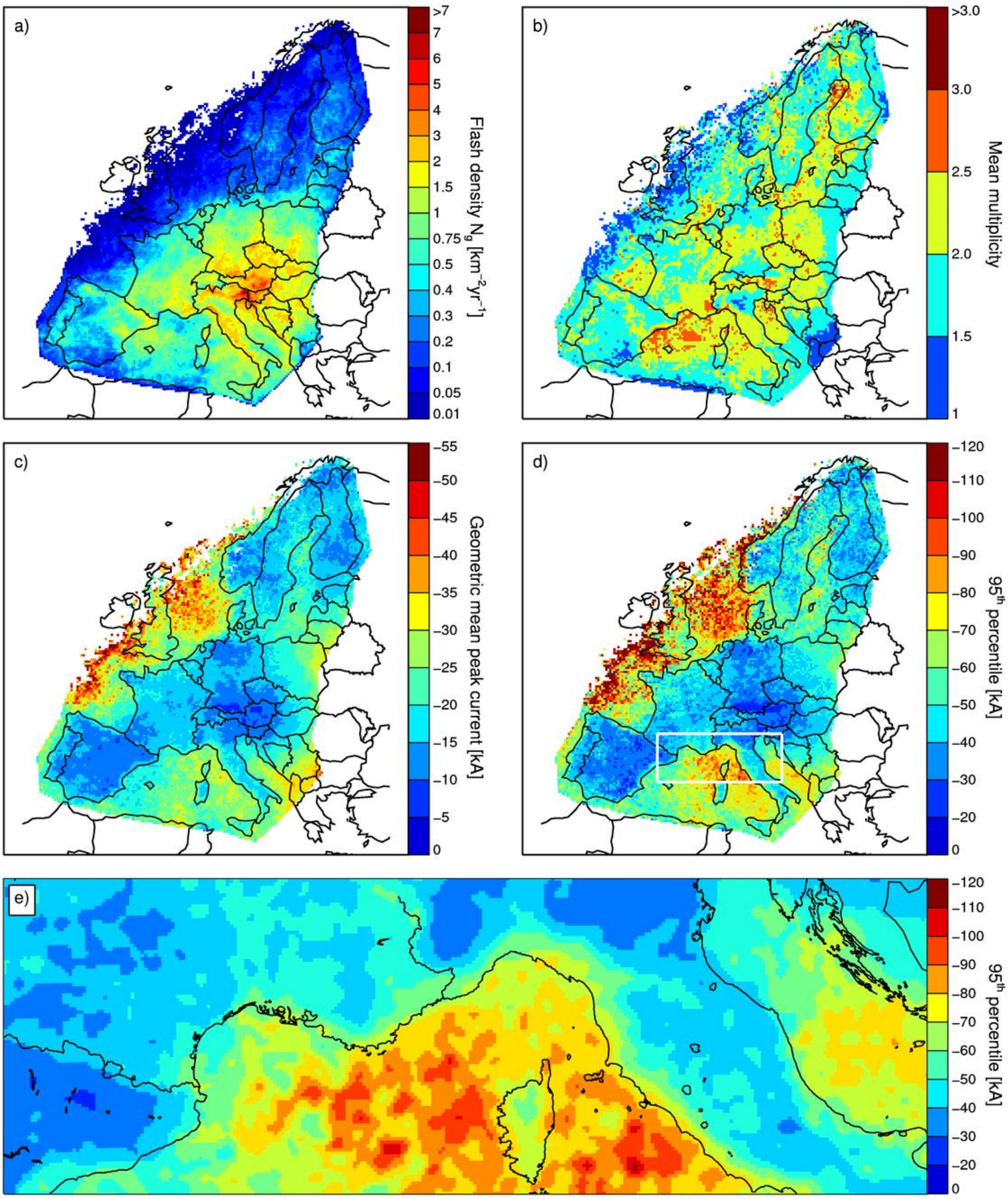

Figure 3: a) Mean annual flash density [$km^{-2}yr^{-1}$], b) multiplicity distribution of negative flashes, c) geometric mean, and d) 95th percentile of the peak current magnitude [kA] from first strokes in negative flashes, based on 2006-2012 EUCLID data and adopting a spatial resolution of 20 x 20 km^2. Note that only the data within the polygon, as indicated in Fig. 1, is plotted. (e) Zoom-in as outlined by the white box in Fig. 3d, smoothed by a Gaussian filter for clarity.

using flash data from 2006 until 2012 in this study. In addition to CG detections, EUCLID is able to detect part of the strongest cloud-to-cloud discharges as well, using the capability of the LS7000 sensors. However, in the remainder of this study, solely CG data are used.

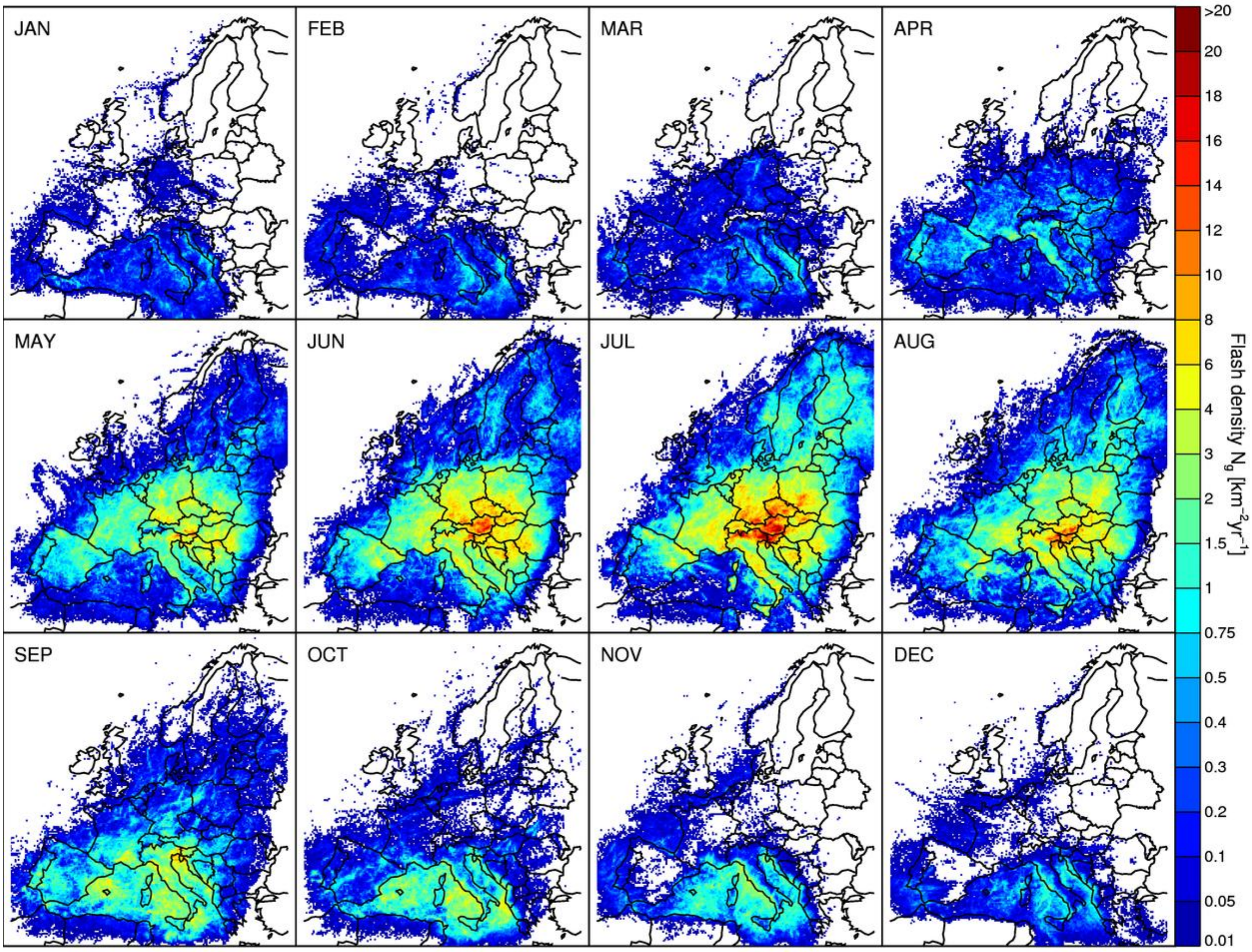

Figure 4: Monthly variability of flash density, N_g [$km^{-2}yr^{-1}$], based on 2006-2012 EUCLID data and adopting a spatial resolution of 20 x 20 km^2.

Initial stroke data has been grouped into flashes, with individual strokes belonging to a particular flash if $\Delta t < 1.5$s and $\Delta r < 10$ km. In addition, a temporal interstroke criterion, Δtinterstroke, of 0.5 s is used as well. The position and peak current of the first return stroke are chosen as the position and peak current of the CG flash, respectively.

In the following, the spatial analysis is presented adopting a grid size of 20 x 20 km^2, or stated explicitly otherwise.

IV. Results and Analysis

A. Temporal statistics

Fig 2a displays the temporal distribution of the CG flash count as a function of year. As expected, the number of CG flashes experiences a natural variability over the years, with an observed minimum of ~ 34×10^5 flashes in 2012 and increasing up to ~60×10^5 flashes in 2006.

The distribution of the mean monthly flash count is shown in Fig. 2b. Eighty-five percent of all the detected flashes occurred during the period from May through September, with a peak in July and a minimum in January.

In Fig. 2c the diurnal flash count as a function of local time shows the typical lightning frequency variations. There is an increase from 0700 local time to a maximum in the afternoon at about 1500 local time, followed by a slow decrease. Hence, as expected the diurnal flash count follows the diurnal temperature cycle.

Fig. 2.d shows the mean polarity distribution in Europe for the individual months. A moderate rise in the percentage of negative flashes in the summer months is observed, similar to the reports based on NLDN data [8, 9] in the United States.

B. Flash density

Fig. 3a plots the seven-year mean annual ground flash density derived from roughly 32 million CG flashes. The

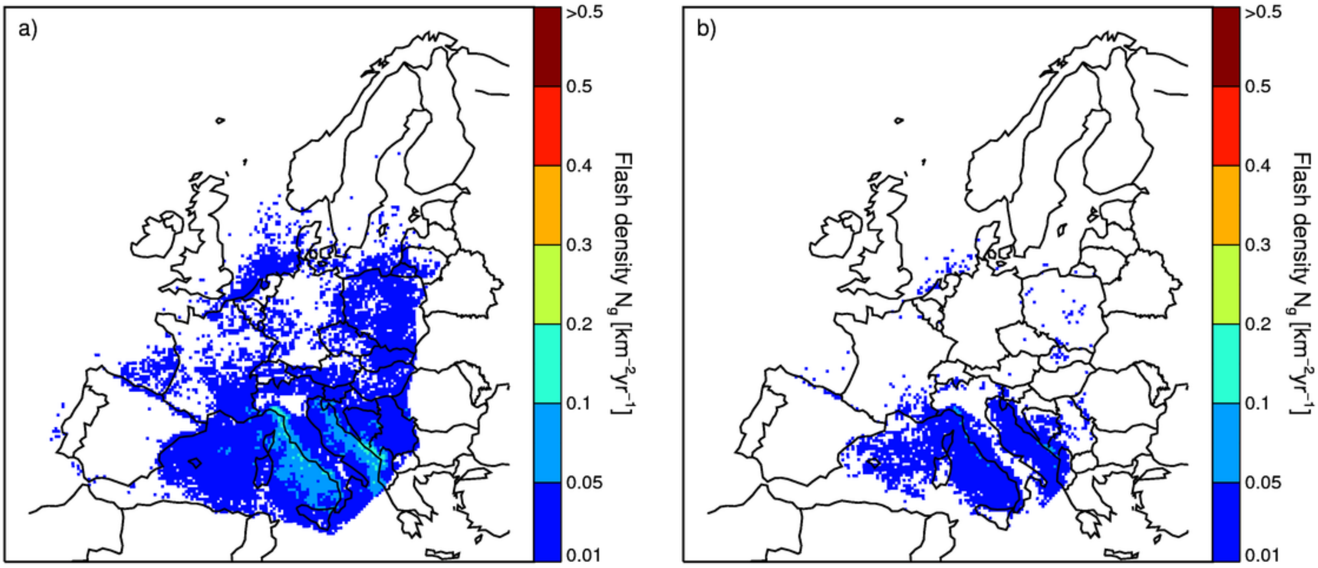

Figure 5: Mean annual flash density [km^{-2}yr^{-1}] of negative flashes with detected peak current magnitude above (a) 75 kA and (b) 100 kA.

highest densities are found to be located over land, with the densest lightning detected at the triple point between Austria, Italy and Slovenia; experiencing a flash density of ~7 flashes km^{-2} yr^{-1}.

Fig. 4 shows the monthly flash density distribution. Note that the densities are extrapolated to whole years to attain km^{-2} yr^{-1} units. One notices that the main lightning activity over the Mediterranean and coastal sea occurs during the months 1-3 and 9-12, whereas over land the majority of the activity kicks in during the summer months starting around May and ending in September.

C. Multiplicity

The term 'multiplicity' is used here to indicate the total number of strokes per flash and depends strongly on the stroke DE and adopted algorithm to group strokes into flashes. Fig. 3b shows the spatial distribution of the multiplicity of negative flashes. The minimum is found at the limits of EUCLID's boundary and is a consequence of a drop in detection efficiency where only the strongest strokes within a flash tend to be detected. We find that the spatial distribution of multiplicities lie within 1.5 and 3 strokes per flash, with a mean multiplicity of 2.1 and 1.3 for negative and positive flashes, respectively. This spatial variance can be attributed to orography, cloud altitude and latent heat of the surface, intrinsic to specific areas. Note that a negative CG flash with a maximum multiplicity of 49 has been recorded. The latter was a flash to a tall radio and TV tower in the south of Austria, at the border of Italy and Slovenia. The overall highest multiplicities are found over the Northern part of the Bay of Biscay, the Adriatic Sea and the Mediterranean Sea.

D. Lightning peak current

Of all recorded flashes, 19% are positive. Mean/median peak currents are -19/-14 kA and +23/+13 kA for negative and positive flashes, respectively.

Fig. 3c and 3d display the geometric mean and 95th percentile of estimated peak current magnitudes in negative flashes. A clear transition between land and sea alongside the Italian and Sardinian coast and the Adriatic Sea is noticed when looking at the 95th percentile. Fig. 3e is a zoom-in of Fig. 3d indicated by the white box to highlight the sharp increase of the 95th percentile values between land and sea. This in accordance with the findings of [10, 11], using the global GLD360 and WWLLN observations, respectively. Furthermore, the contrast between land and sea lightning becomes evident when looking at the flash density of negative flashes with estimated peak currents larger than 75 kA and 100 kA, as plotted in Fig. 5a and 5b, respectively. It is seen that flashes with higher peak currents primarily occur in greater numbers over sea then to over land.

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