Day-to-Day Variation of the Angular Distribution of Lightning Activity Calculated from ELF Magnetic Measurements

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Abstract. We study the "local" distribution of lightning activity on the Earth calculated from Extremely Low Frequency (ELF) magnetic field variations. Lightning generates strong electromagnetic impulses recorded in the ELF band as short signal spikes. Using two perpendicular magnetic antennas at our Hylaty station, we calculate the azimuths of the sources of such spikes. These ELF data are compared with selected satellite measurements available on NASA and BADC web centres. For the winter period January 8 to 9, 2006, analysed in detail, a large cyclone was observed over the Mediterranean Sea (MS). The cyclone was created in the western part of the MS and then moved eastwards along the North coast of Africa. The absence of lightning activity nearer our station allowed us to compare the ELF measurements with observations of this cyclone made from the TRMM and Meteosat-7 satellites, using Lightning Imaging Sensor observations and full Earth disk images, respectively. The analysis proves that ELF measurements can be used for on-line monitoring of lightning activity in the vicinity of the measuring ELF station, with the radius of effective observations being more than 2000 km. This inexpensive method can easily be used in areas without other lightning monitoring systems, or it can supplement existing ones.

Keywords: ELF impulses, lightning activity, thunderstorms
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INTRODUCTION

Electromagnetic measurements in the Extremely Low Frequency (ELF) range provide information about both global and more local lightning activity. ELF Schumann Resonances (RS) [1] give information about global activity, and reveal diurnal and seasonal variations of global lightning activity [2, 3]. More local lightning activity is recorded as impulses from individual lightning discharges. In the Earth-ionosphere cavity the damping of waves increases with increasing frequency [4], but for short (~ 1000 km) source-observer distances (or very large discharge currents) higher frequencies result in short perturbations of the magnetic field, leading to spikes in the ELF data. We report on using such ELF measurements to monitor the intensity and angular distribution of such spikes observed at our Hylaty station [5]. We analyzed the two-day period of January 8 and 9, 2006, when a strong cyclone was active over the Mediterranean Sea.

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DATA

The ELF magnetic measurements analyzed were recorded at the "Hylaty" station run by the Astronomical Observatory of the Jagiellonian University in the Bieszczady Mountains in the South East of Poland (49°11'N, 22°33'E). Two horizontal components (NS and EW) are measured by two underground magnetic coil antennas. The antennas are located at a distance of ~100 meters from the electronic acquisition system placed in an underground chamber and using a battery power supply. The measurements are relatively weakly influenced by the 50 Hz signal of the European power supply network. In each analogue channel the signal is sampled at a frequency of 178 Hz using a 16-bit A/D converter. The magnetic recordings are marked with the GPS time, and stored on Flash Memory Cards.

The Lightning Imaging Sensor (LIS) satellite data were imported from the NASA web page http://thunder.msfc.nasa.gov/data/LISbrowse, as were full-disk Infra Red (IR) images from the British Atmospheric Data Centre (BADC) web page http://badc.nerc.ac.uk /browse/badc/meteosat.

METHOD OF ANALYSIS

To calculate the azimuth of an individual spike arrival at the receiver in Poland, we assume that all analyzed lightning are of the –CG type, with the geometry being illustrated in the left panels of Fig. 1. An observer in the figure located on the left side of the discharge will register a negative impulse in his antenna and an observer on the right will register a positive impulse with an identically oriented antenna. This difference, more exactly explained in the right panel of the figure, allows the observer to find the azimuth angle of the discharge position on the Earth's surface.

To make "precise" azimuth measurements of these impulses, we consider only strong impulses, with a minimum amplitude of 50 pT, compared with the measured natural noise level at "Hylaty" of a few pT (in the observed 4-60 Hz frequency range). The amplitudes of the impulses were calculated as

$$|B|_i = \sqrt{B_{i,NS}^2 + B_{i,EW}^2} \quad , \tag{1}$$

where $B_{i,NS}$ and $B_{i,EW}$ are the signal amplitudes in the NS and the EW antennas, respectively. Next, the angle of the B vector perturbation, $B_{i,angle}$, and the azimuth of the discharge, $V_{i,angle}$, are derived as

$$B_{i,angle} = \arctan\left(\frac{B_{i,EW}}{B_{i,NS}}\right) \tag{2}$$

$$V_{i,angle} = B_{i,angle} - 90^{o} \tag{3}$$

The azimuth is calculated as a right-hand angle from North (clockwise, 0-360 degrees). Note that in the case of +CG polarity lightning the same analysis would yield $V_{i,angle}$ increased by 180 degrees.

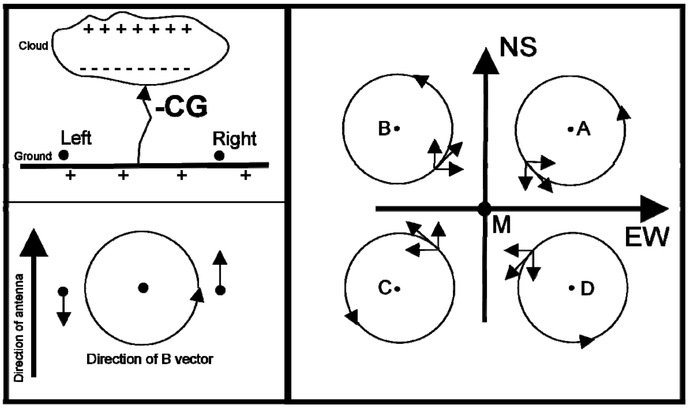

FIGURE 1. The top left panel shows a thunderstorm cloud with separated charges and a -CG discharge from the ground, with two observers on the Left and the Right sides of it. The bottom left panel presents a vertical projection explaining the magnetic measurements made by the observers. The right panel shows different measured signals in two antennas, NS and EW, from lightning discharges (A, B, C, D) situated at different azimuth angles. A circle around each point represents the generated magnetic field perturbation, with the respective vectors representing the signals registered in the antennas.

RESULTS OF ANALYSES

For this study we selected two days in January 2006, in the winter period in the northern hemisphere, with very low lightning activity in Europe. In the analyzed period we registered 28,889 impulses with amplitudes above 50 pT (Fig. 2). For these impulses the average amplitude was 75 pT and the standard deviation was equal to 34 pT. The highest registered amplitude was 904 pT. The average impulse count rate was 0.6/min, with the time distribution presented in Fig. 3.

The azimuthal distribution of the recorded ELF impulses (Fig. 2) shows five local maxima, "small" ones at 0 (360), 60, and 280 degrees, and "big" ones at 190 and 250 degrees. The time variation of the angular distributions within the January 2006 period considered is shown in Fig. 4. In this figure we see two periods, January 2 to 5 and 8 to 9, with increased impulse count rates. Here, we study the data for the period January 8 to 9 in more detail. The variation of the impulse azimuthal distribution during this period is presented in the bottom of Fig. 4, with a large concentration of impulses for azimuths within the range 240° to 190°. Within this range a continuous azimuth variation is registered during the period analyzed, with the average drift rate being about 1.25° per hour.

These ELF results are compared with satellite images of thunderstorm activity on the Earth to a distance of 5000 km from our station. From Meteosat-7 IR images available from the BADC web site we selected thunderstorm cloud regions with azimuths within 190°-240° with the increased concentration of ELF impulses (Fig. 5, panels F and G). At the beginning of the period studied, such a concentration appears at the West of the Mediterranean Sea, and it moves to the East along the African coast on the next day. Then there was no thunderstorm activity over the central MS.

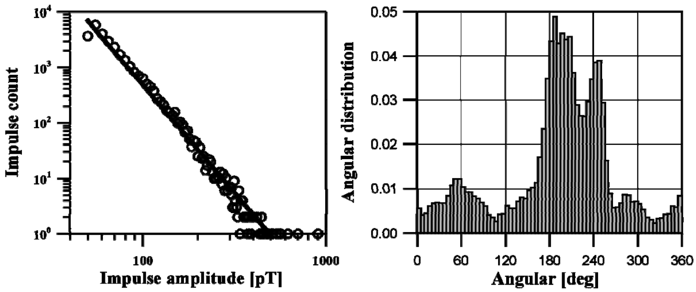

FIGURE 2. Left panel: impulse amplitude distribution (points) with a power-law fit (line). Right panel: the normalized azimuth angle distribution of recorded impulses in 5 degree bins.

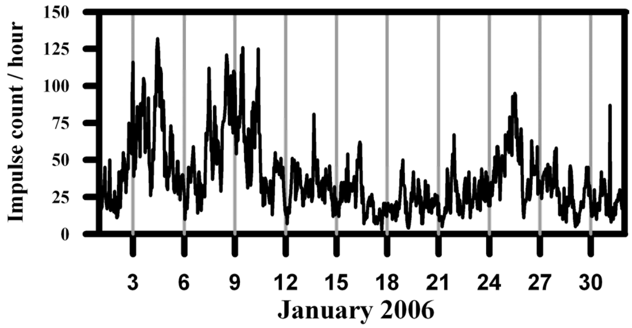

FIGURE 3. The high impulse rate of "big" ELF impulses observed during January 2006.

The satellite LIS instrument is in a polar orbit with an inclination of 35 degrees, so the areas of interest can be observed only twice per day (Fig. 5A). Nevertheless, its lightning activity observations confirm this activity relation to the cloud complex under study, with the lightning activity centres following the clouds as they drift to the East. In Fig. 4 (see arrow at the bottom) there is a new concentration of ELF impulses in the morning of January 10. This thunderstorm was active for only a few hours over the South of Spain, as confirmed by both satellite observations (not presented here).

When analyzing the data of Fig. 4, "a reflected component" of weaker concentrations of observed impulses is noted, which exist for the azimuths of the main concentrations plus 180°. We interpret these features as being created by +CG lightning discharges in the same thunderstorms in which the main concentrations are due to –CG discharges.

SUMMARY

Magnetic measurements from a single ELF observation station have been used to analyze both the azimuth and the amplitude distributions of natural ELF magnetic impulse signals. Using satellite-tracked thunderstorm cells has proved that the large amplitude spikes in the ELF data are mostly generated by negative cloud-to-ground (-CG) discharges, with the smaller number of +GC signals also present appearing in the data as the "reflected component".

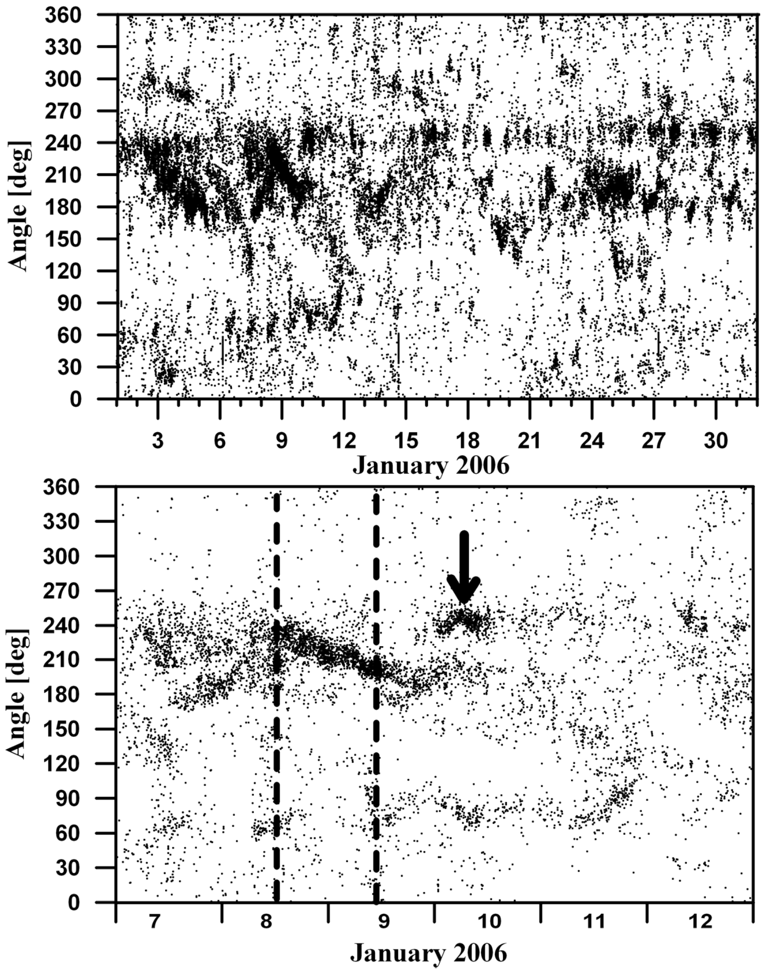

FIGURE 4. Time variation of the derived angular distribution of impulses registered in the full month of January 2006 (top) and in the period January 7 to 12 (bottom). The vertical lines indicate the times of satellite IR images presented in Fig. 5. The arrow indicates an event of new impulses observed on January 10.

Our study of the period January 8 to 9, 2006, revealed a systematic drift in the azimuth angle of the impulse source, which we identify as an eastward drifting of the thunderstorm clouds observed by satellite LIS lightning observations and IR satellite images. The source was observed to move from the South coast of Spain to the East, along the North coast of Africa. The lifetime of this system and its movement agree well with the directions obtained using the ELF magnetic field analysis.

We observed significant variations in the statistics of -CG and +CG counts identified by our method. The difference changes with time; it suggests that the ratio of +CG to -CG discharges increases during the day.

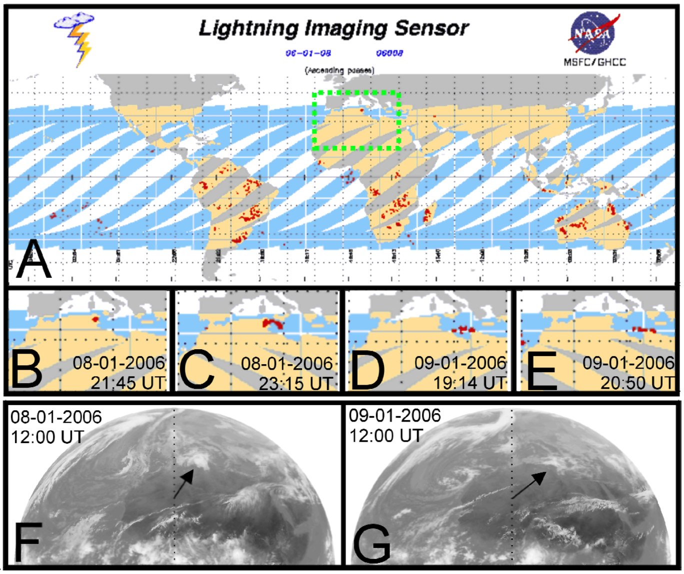

FIGURE 5. Panel A: the satellite observations of lightning activity (red spots) recorded by the LIS instrument on January 8, 2006. The green rectangle indicates the area of our "local" study. Panels B, C, D and E show the results of similar LIS observations at successive times. Panels F and G present Meteosat-7 Infra Red images of the northern hemisphere at 12:00 UT on January 8 and 9. In each panel an arrow points to the drifting thunderstorm cloud complex.

The angular analysis presented in this paper shows that a cheap online measurement of lightning activity can be obtained from the ELF impulses. The effective radius of such observations is estimated to be more than 2000 km.

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REFERENCES

1. W.O. Schumann, On the radiation free self-oscillations of a conducting sphere, which is surrounded by an air layer and an ionospheric shell (in German), *Zeitschrift Naturforschung*, 7a, 149, 1956.
2. A.P. Nickolaenko, G. Sátori, B. Zieger, L.M. Rabinowicz and I.G. Kudintseva, Parameters of Global Thunderstorm Activity Deduced from the Long-term Schumann Resonance Records, *Journal of Atmospheric and Solar-Terrestrial Physics*, 60, No 3, 387-399, 1998.
3. G. Sátori, Monitoring Schumann resonances - II. Daily and seasonal frequency variation, *Journal of Atmospheric and Terrestrial Physics*, Vol. 58, No. 13, 1483-1488, 1996.
4. E.T. Pierce, The thunderstorm as a source of atmospheric noise at frequencies between 1 and 100 kHz. *Stanford Research Institute Technical Report*, Project 7045, DASA 2299, 1969.
5. A. Kułak, J. Kubisz, A. Michalec, S. Zięba and Z. Nieckarz, Solar variation in extremely low frequency propagation parameters: 2. Observation of Schumann resonances and computation of the ELF attenuation parameter, *Journal of Geophysical Research*, 108(A7), 1271, 2003.