Simulations with MesoNH of the electrical features of two precipitating events observed during HyMeX (2012) in South-Eastern France

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ABSTRACT: CELLS, the explicit electrical scheme of MesoNH is used to simulate the temporal evolution of the electrical charges, to compute the ambient electric field and to trigger lightning flashes, ultimately. The scheme is highly coupled to the current ICE3 microphysical scheme to generate locally the electrical charges by non-inductive processes and to disseminate these charges by various microphysical processes in order to build positive-negative regions of charges at cloud scale.

Simulations were performed with the grid-nesting facility at 4 km and 1 km resolution to reach the km scale at which simulated flashes could be resolved. The electrical scheme was run for several hours on a large domain of nearly 400x400x50 grid points using the Meteo-France Arome analyses that encompass the HyMeX (HYdrological cycle in the Mediterranean EXperiment) SOP1 (Special Observation Period 1 in 2012) field experiment area. Results are analyzed and compared to records of two lightning detection networks: EUCLID (2D accurate counts) and HyLMA (3D mapping of the flashes). LMA data are especially useful to observe intra-cloud flashes and to document the polarity of the cloud layers where flashes propagate, thus giving a precious indication for comparing the polarity of the simulated cloud regions, as well as the triggering altitude and horizontal extent of all the flashes. First promising results of two contrasting precipitating cases, isolated convection and 8 hour precipitating event of HyMeX-SOP1, are discussed.

INTRODUCTION

During the first Special Observing Period (SOP1) of the HYdrological cycle in Mediterranean EXperiment (HyMeX, see *Ducrocq* [2013]) a network of 12 LMA stations were deployed and operated in the South East flank of the Massif Central, a mountaneous region in France. The purpose was to investigate the electrical properties of heavily precipitating orographic clouds that result from the lifting of moist warm air flowing from the next Mediterranean sea. A unique dataset of lightning flashes generated by orograhic clouds was produced for the first time in Europe and for the purpose here to evaluate an explicit electrical scheme in a mesoscale model running under real meteorological conditions.

The electrical scheme (CELLS, see *Barthe et al.* [2012]) of the cloud-resolving model MesoNH was developed 1/ to simulate the temporal evolution of the charges carried by the hydrometeors and by the ions, 2/ to compute the ambient electric field and ultimately, 3/ to trigger the lightning flashes, to close the electrical charge budget. The scheme is tightly coupled to the current 1-moment microphysical scheme (ICE3) of MesoNH to separate locally the electrical charges by non-inductive and inductive processes and also to disseminate these charges among the drop/ice particles by the various microphysical mechanisms of ICE3 in order to build positive-negative regions of charges at cloud scale.

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The simulation of several electrified clouds observed during the HyMeX SOP1 was performed with the MesoNH model grid-nesting facility at 4 km and 1 km resolution to reach the km scale at which simulated flashes could be resolved. The electrical scheme CELLS could be run for several hours on a domain as large as 400x400x50 grid points using the Meteo-France Arome analyses encompassing the HyMeX field experiment area [*Pinty et al.*, 2013].

Results are analyzed and compared to records of two lightning detection networks: EUCLID (2D accurate impact counts) and HyLMA (3D mapping of the flashes). LMA data are especially useful to observe intra-cloud flashes and to document the polarity of the cloud layers where flashes propagate, thus giving a precious indication for comparing the polarity of the simulated cloud regions, as well as the triggering altitude and horizontal extent of all the flashes.

A SHORT SUMMARY OF THE ELECTRICAL SCHEME

The electrical scheme CELLS is highly embedded into the 1-moment microphysical scheme of MesoNH. The charges are carried by each type of particule present in ICE3 (droplets, raindrops, ice crystals (i), snow-aggregates (s) and graupels (g)) and by the positive and the negative ions [*Helsdon and Farley*, 1987; *Mansell et al.*, 2005]. The charges are size-distributed according to the empirical law $q = eD^f$ where exponent f depends on the particle type of dimension D. The physics and the initialization of the ions is standard. The important non-inductive charging process is computed analytically for i-s, i-g and s-g interactions but with look-up tables for the charge separation diagram taken from *Takahashi* [1991]; *Saunders et al.* [1991]; *Saunders and Peck* [1998], etc. and which depends on the local temperature and available supercooled water content. Electrical charge transfers accompany the (water) mass transfers computed in ICE3. The charges are transported by the resolved and turbulent flow and by the hydrometeores at their fall speed. The charges are feeding the corresponding category of ions in case of evaporation or sublimation of the hydrometeores.

The electric field E is updated at the end of the time step and also after occurrence of a flash as several flashes can be triggered, and so charges rearranged, in a single time step. The Gauss equation $\nabla.E = Q/\epsilon$, where Q is the total charge density and $\epsilon = 8.85\ 10^{-12}$ Fm^{-1}, is inverted with appropriate boundary conditions (conductive ground surface and fair weather conditions elsewhere). Practically the algorithm computes the electrical potential $V = -\nabla^{-1}(E)$ with $V_{surf} = 0$, leading to a Laplace equation to solve iteratively in generalized terrain-following coordinates. The three components of E are then easily derived.

A lightning flash is triggered when E reaches the breakdown value $E_{trig} = \pm 201.74 exp(-z/8.4)$, here in kVm^{-1}, that decreases with altitude z in km, as observed by *Marshall et al.* [1987]. A vertical bi-directional leader propagates upwards and downwards until the ambient vertical electric field (E_z) at the tips of the last segments falls below 15 kVm^{-1} or when the sign of the vertical component of the electric field reverses. When the lowest end of the leader reaches the bottom of the cell which altitude is below 2 km above ground level (AGL), the flash is categorized as a "cloud-to-ground" (CG) flash and is artificially prolonged to the ground [*MacGorman et al.*, 2001]. The flashes propagate horizontally in regions with charge densities in excess of ± 0.2 nCm^{-3}. In these regions and despite the poor horizontal resolution, the scheme keeps the idea of charge density criterion to build a 3-D branched discharge which is monitored by the fractal nature of the flashes. As suggested by *Petrov and Petrova* [1987], the number of branches N_{br} at distance r from the triggering point is assumed to follow $N_{br} = (L_\chi/L_{mean)} i^{\chi-1}$ where L_{mean} is the mean 3D mesh size, L_χ, a characteristic length scale, and χ the fractal dimension $(2 < \chi < 3)$. The running integer i is computed as $i = NINT(r/L_{mean})$, where the NINT function returns the nearest integer of a real number. The total charge in excess of $q_{neut} = 0.1$ nCm^{-3} along the lightning channels, i.e. the grid points reached by a flash, is neutralized by adding ions of opposite sign. For intracloud (IC) flashes, a charge correction is applied to all grid points belonging to the flash to ensure the electroneutrality of the total charge removal [*MacGorman et al.*, 2001]. The charge neutrality constraint does not apply for CG discharges.

An important aspect to put forward in the CELLS scheme, is the necessary and efficient parallelization of the code, in particular the computation of E and of parts concerning the complex flash scheme. We refer to Barthe et al. (2012) for additional details.

CASE OF ISOLATED STORMS OF 5$^{\rm th}$ SEPTEMBER 2012

The case describes the evolution of two moderate storms of short-duration (1-2 hours) with a well-depicted flash signature. The model MesoNH was configured to run in one-way grid-nesting with 50 levels and domains of 192x192 and 384x384 grid points at 4 km and 1 km, respectively. MesoNH used Arome analyses (Meteo-France product) at 06Z for initialization and to feed the open lateral boundaries at 4 km. These are updated each 3 hours. MesoNH was run for 9 hours without electricity and then was restarted for 6 additional hours but with activation of the electrical scheme in the inner domain at 1 km resolution.

Figure 1 shows the flow and the wet potential temperature at 950 hPa. In the model convection starts to develop in the South West of the Alps at 15Z and then in the South East flank of the Massif Central when the first convective system dissipates as confirmed by radar observations (not shown). Both systems are moderately active for cloud electicity and for this first numerical experiment done with the TAKAH scheme. Figure 2 displays the location of all LMA sources (color) and EUCLID impacts (black) between 15Z and 19Z. The picture is to be compared to the map produced by MesoNH outputs (on the right) where extensions of IC (color) and CG (black isocontours) flashes are shown. While the location of the two convective centers are well reproduced, the figure reveals also spurious convection and an excess of cloud electrification over the Alps. This complicates a careful comparison of the flash rate detected by the LMA and simulated by the model.

Figure 3 shows a closer view of the 2$^{\rm nd}$ storm developing between 17Z and 18:30Z South to the LMA network. The surface area covered by the simulated flashes is in very good agreement with the LMA sources. The location of flash triggering is aligned in the same direction of the EUCLID data. The upper panel of the LMA reveals IC and CG flashes which are triggered at two different altitudes. Inspection of the ”high and low” LMA flashes suggests three altitudes at which flashes propagate horizontally. Thus the storm possesses a direct tripole structure (+,-,+). This feature is checked on an East-West vertical cross-section of the simulation. In Fig. 4, the total electrical charges show a tripole structure which results from the positive charging of the upper pristine crystals and lower graupel while the negative charges are carried by the snow/aggregate category at mid level. Below the freezing level, rain is positive where graupel particles melt and negative when rain issues from snow/aggregate on the edge of the cloud. The isocontours of the electric field reach 100 kV^{-1}, so close to the breakdown value, at the slant interface of the two lower regions of oppposite polarity. On the last figure 5, the vertical component of the electric field, $E_z < \pm 15$ kV^{-1}, is plotted at ground level with contours of the instantaneous precipitation rate. Because the majority of the raindrops are charged positively and close to the ground, E_z is pointing downward. Elsewhere, E_z is positive showing the influence of negative snow and space charges.

CASE OF THE PRECIPITATING EVENT OF 26$^{\rm th}$ SEPTEMBER 2012

The case is a moderately precipitating event (up to 89 mm/18 hours) which is in contrast with the previous case. The metorological situation displayed in Fig. 6 shows a South warm and wet flow impinging on a ridge in the South East of the Massif Central. This is a typically expected situation for the HyMeX project which focuses on heavy and localized precipitation over moderate orography.

The MesoNH simulation is initialized with the 00Z analysis of 26 Sept. 2012. Its duration is 12 hours. Only the last 8 hours are run with the electrical scheme on and with TAKAH charge separation diagram.

The simulation produces 6000 lightning flashes in the whole domain. This is comparable to the 3890 flashes deduced from the LMA records for the same period of time. Figure 7 shows EUCLID data (CG and

IC) plotted on the domain of interest at kilometer scale resolution. The colored dots are coding the estimated peak current, $I < \pm$ 50 kA, of each flash. The location of the triggering (IC) and impact (CG) coordinates of the simulated flashes are also shown in Fig. 7. Here the color counts the number of flashes (less than 8) per grid point. The location of the flashes compares quite well for the 8 hours of simulation even if the extension of the simulated "lightning field" is reduced in the South West of the main precipitating band.

The LMA data are displayed in Fig. 8, showing all the recorded sources to compare to the simulated total flash count map on the right of the same figure. As in Fig. 3, this plot is obtained by accumulating the horizontal projection of the area reached by each flash, i.e. all the model grid points along the vertical that belong to the same flash, and counting one unit per flash. Up to 800 flashes per "model pixel" (red area) were simulated. Comparing the rightmost plots in Figs 7 and 8, reveals that the flashes have a significant horizontal extension around the triggering grid points.

The temporal evolution of the flashes (averaged over 1 min., excepted for E_{trig} and Z_{trig}) is reproduced in Figure 9. One can observe that the period of lightning activity is highly variable (from 0 up to 40 flashes/min. and 15 CG/min.). No positive CG are found. The flash triggering altitude oscillates between 3 and 7 km height for the CG and the IC, respectively. The huge quantity of charge which is neutralized after 270 min. is due to CG with a large horizontal extension (see the plot "nber of segments"). The analysis of LMA data is underway to confirm these general features.

CONCLUSION

The ensemble of LMA flash observations combined to EUCLID and other data (radar and aircraft flights not used here) taken during HyMeX-SOP1 represents a unique dataset to study small-scale dynamical, microphysical and electrical interactions at mesoscale over orography. From the modeling point of view, the explicit resolution of convection at 1 km scale in the multiple nested mesoscale model MesoNH shows encouraging results partially explained by the quality of Arome analyses which include additional assimilated data of operational radar and surface networks. At km scale resolution and for real-case simulations, the explicit electrical CELLS scheme provides a realistic picture of the lightning activity, that depends first on an accurate representation of the convection, but which is fully consistent with the 1-moment cloud microphysics ICE3 scheme for cloud charging and charge dynamics details.

This study needs a deeper analysis indeed and should explore other well-documented cases of HyMeX, to demonstrate that an explicit electrical scheme is able to simulate realistically some electrical features of the clouds (charge stratification, flash rate) but at a reasonnable cost thanks to technical efforts to optimize the parallelized code. For this purpose, the HyLMA dataset is essential to assess the quality of the (real case) simulations in many respects. Other simulations with Saunders-like charge separation diagrams and CELLS tuning variants are underway and will be reported.

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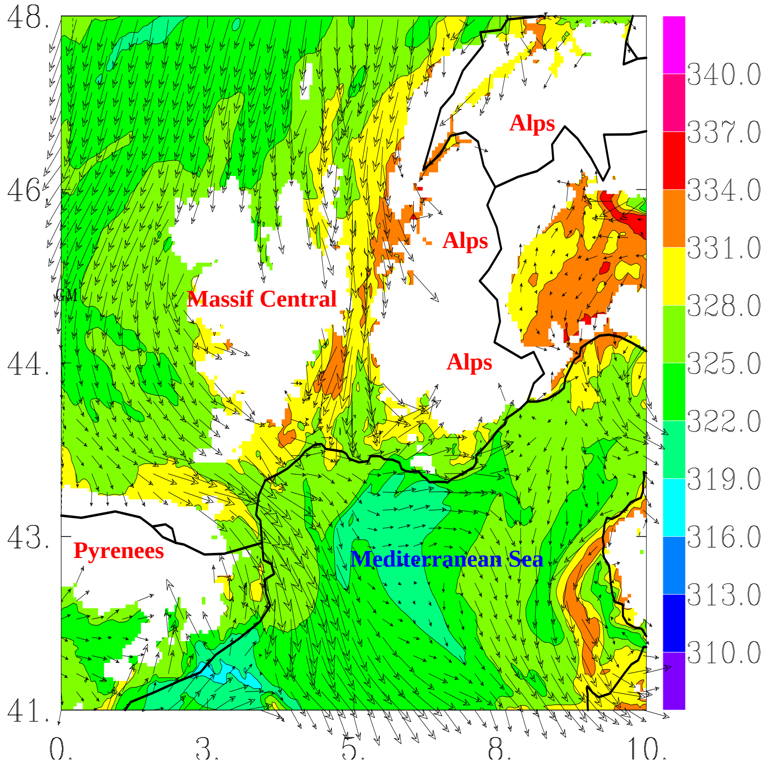

Figure 1: Map of the domain at 4 km resolution showing the 950 hPa wind and the wet potential temperature fields at 06Z of 5 Sept 2012.

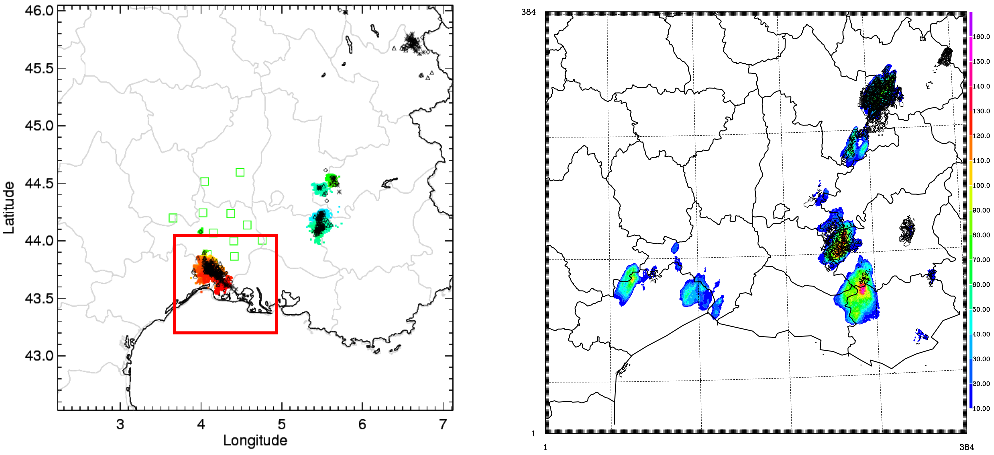

Figure 2: Left: Time-colored LMA data showing the location of the flashes between 17Z and 19Z of 5 Sept 2012. The black stars are marking the impact data of the NLDN EUCLID network. The red square is the domain of interest of the 2nd electrified storm shown in Fig. 3. Right: 2D map of the extension of the simulated IC flash count (color codes the number of flashes) and of the simulated CG flash (isocontours in black).

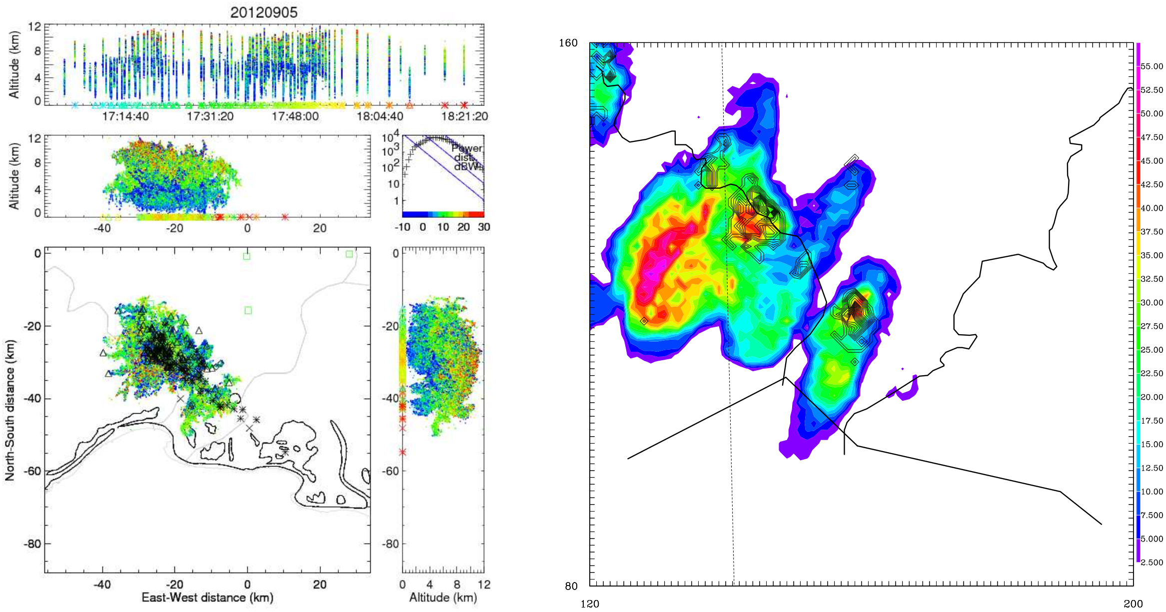

Figure 3: Left: LMA data showing the location of the flashes between 17Z and 18:30Z of the HyMeX case of 5 Sept 2012. Data of the NLDN EUCLID network are superimposed in black. Right: 2D map of the simulated flash extension (at the same scale approx. and in color) with isocontours depicting the triggering areas. The color coding counts the number of flashes.

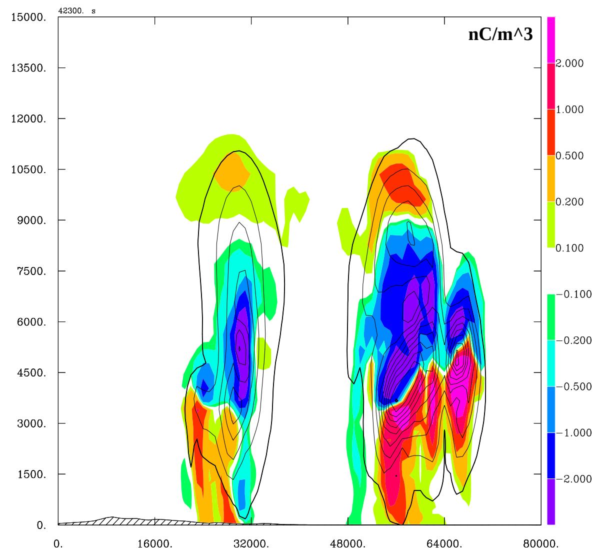

Figure 4: Vertical cross-section of the total charges (colored) and electric field (contours of 10 kVm^{-1} increments).

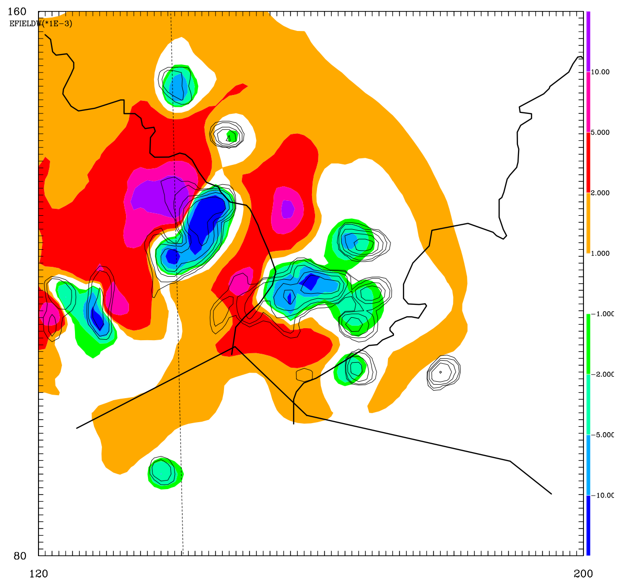

Figure 5: Instantaneous surface electric field (colored) and precipitation rate (contours at 1, 2, 5, 10, 20 mmh^{-1}).

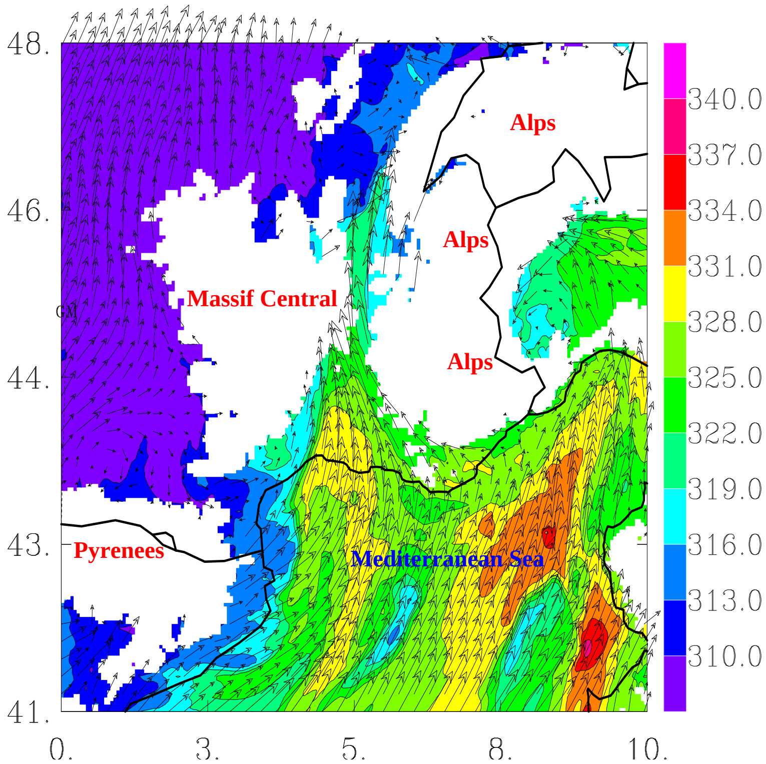

Figure 6: Same as in Fig. 1 but for the HyMeX case of 26 Sept 2012 at 04Z.

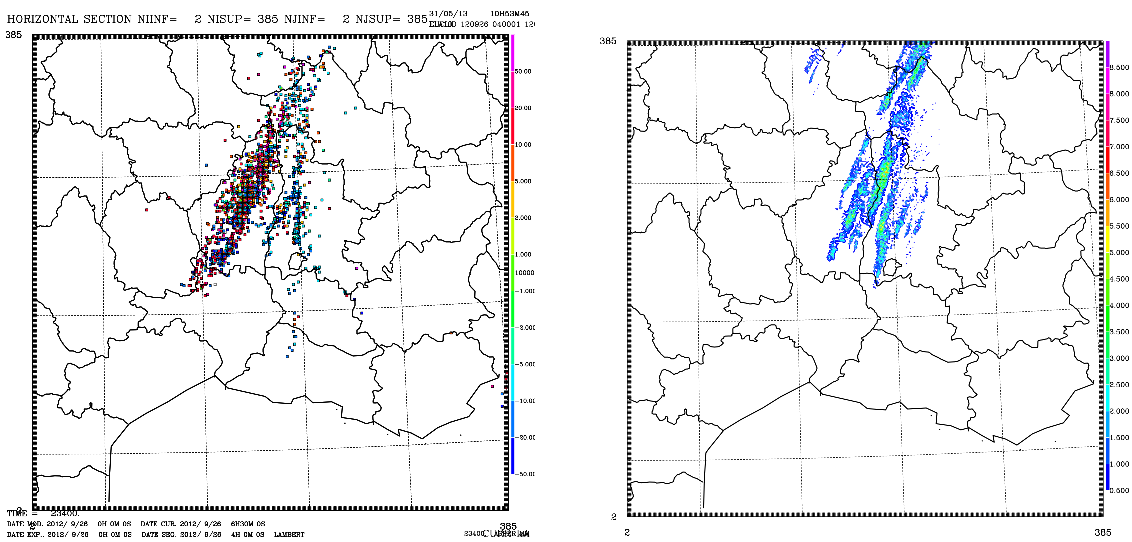

Figure 7: Left: Data of the NLDN EUCLID network with color coding the flash peak current, between 04Z and 12Z of the HyMeX case of 26 Sept 2012. Right: 2D map showing the triggering (IC) and impact (CG) location of the simulated flashes for the same period of time.

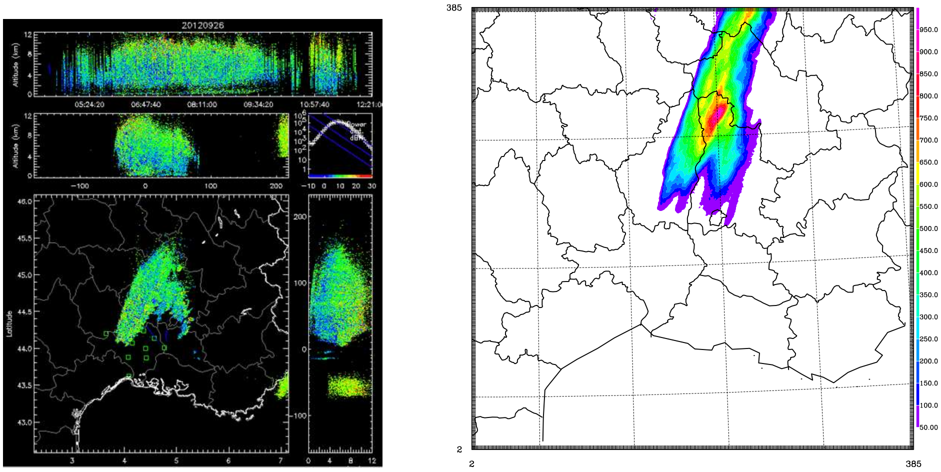

Figure 8: Left: LMA data showing the location of the flash sources between 04Z and 12Z of the HyMeX case of 26 Sept 2012. Right: 2D map of the extension of the simulated flashes. Color is coding the number of flashes.

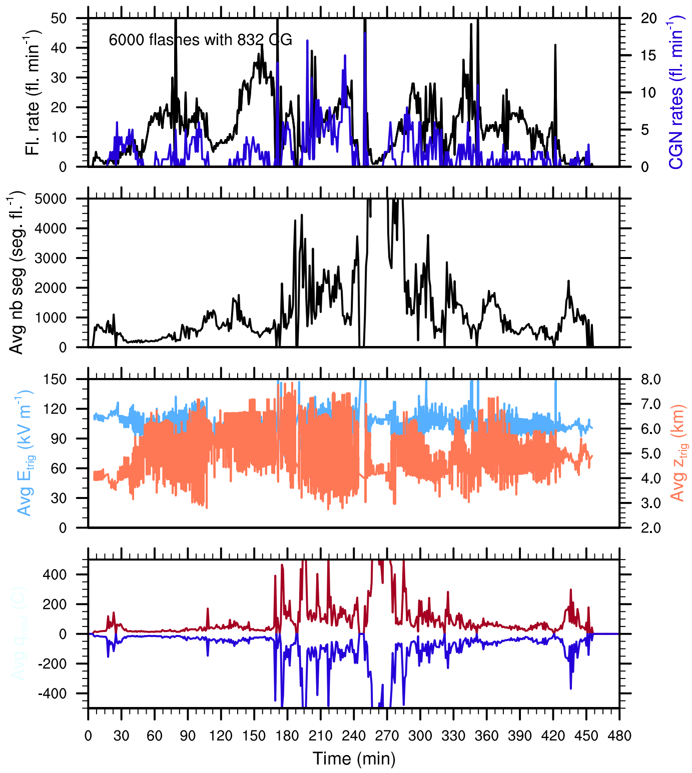

Figure 9: Time series of the "1 min averaged" simulated flashes of 26 Sept 2012 between 04Z and 12Z (480 min. duration). Top: total flash count (black) and CG count (blue), 2$^{\text{nd}}$ plot: proxy of the horizontal extension of the flashes, 3$^{\text{rd}}$ plot: E_{trig} (light blue) and triggering height Z_{trig} (light red), bottom: quantity of neutralized charges (red and blue).