

Properties of the Lightning Activity at Storm Scale during HyMeX SOP1 Campaign: Comparison Between an Isolated Storm (05 Sept 2012), a Multi-cellular System (24 Sept 2012) and a Tornadoic Cell (14 Oct 2012)

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ABSTRACT: During the HyMeX (Hydrology cycle in the Mediterranean Experiment) SOP1 (Special Observation Period 1; September-November 2012) campaign, the New Mexico Tech Lightning Mapping Array in conjunction with four European operational lightning detection networks (ATDNET, UKMO; EUCLID; LINET, nowcast; ZEUS, NOAA) recorded the total lightning activity over South-Eastern France. We present here observations collected during three different weather situations: one isolated thunderstorm occurring on the 5th of September, a multi-cellular system on the 24th of September (HyMeX IOP6 case) and the 14 November tornadoic cell. So far the analysis of the lightning data has been focusing on some specific parameters or features like flash density, convection surge or intra-cloud ratio. We first briefly describe the instrumentation operated during the field campaign and the methodology applied to analyze the data. Some properties of the lightning activity (e.g. flash rate, intra-cloud ratio, altitude of flash triggering) are then discussed according to the type and the stage of convective clouds and related to the properties of the parent clouds as derived from concurrent radar and satellite observations. Further investigations on relating the lightning activity to the cloud properties are currently underway and results will be presented during the conference.

INTRODUCTION

The Mediterranean region is regularly affected by heavy precipitation often causing devastating flash floods. Floods and landslides in the Mediterranean basin cost lives and expensive property damages. Improving the knowledge and forecast of these high-impact weather events is a major objective of the HYdrological cycle in the Mediterranean EXperiment (HyMeX) program dedicated to the hydrological cycle in Mediterranean (Ducrocq et al, 2013). Part of this 10-year program, the first Special Observation

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Period (SOP1) HyMeX field campaign was conducted during 2 months (5 September 2012 to 6 November 2012) over Northwestern Mediterranean Sea and its coastal regions in France, Italy, and Spain. The instrumental and observational strategy of the SOP1 campaign was set up to document and improve the knowledge on atmospheric processes leading to heavy precipitation and flash flooding in that specific Mediterranean region. A large battery of atmospheric research instruments were operated during the SOP1 including among others mobile weather Doppler and polarimetric radar, airborne radar, in situ microphysics probes, lidar, rain gauges [Ducrocq et al., 2013; Bousquet et al., 2014a]. Those equipments were deployed at or near super sites. Additionally various operational weather forecasting models were used as detailed in Ducrocq et al. [2013].

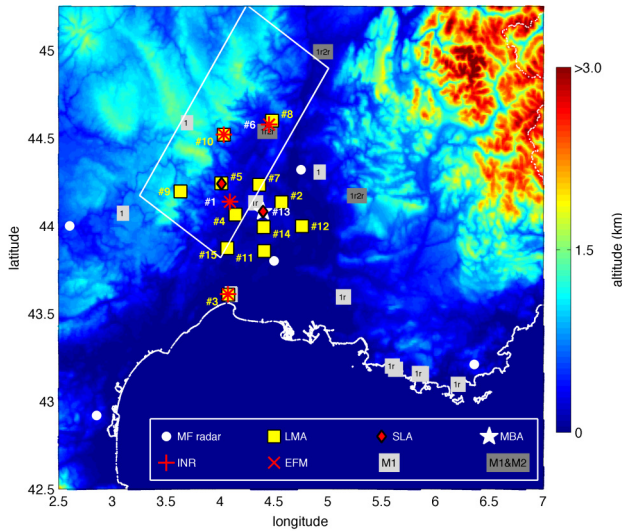


Figure 1. Locations of PEACH instrumental sites, with LMA, SLA, MBA, INR, EFM standing for Lightning Mapping Array stations, Slow Antennas, Micro-barometer Array, Induction Rings and Electric Field Mills respectively. M1 markers indicate VFRS (Video and Field Record System) locations while M2 markers indicate the few locations where additionally a second video camera was operated (at the same site). Locations of the INRs are also indicated. The Cévennes-Vivrais (CV) domain is also delimited by the white polygon.

In the frame of the HyMeX program, several international Institutes joined their effort to investigate the lightning activity and the electrical state of thunderstorms through the PEACH (Projet en Electricité Atmosphérique pour la Campagne Hymex) [Defer et al., submitted to ACP]. This topic is part of the HyMeX Working Group WG3 dedicated to the study of heavy precipitation events (HPEs), flash-floods and floods. The research lightning sensors operated during the HyMeX SOP1 were located in the Cévennes-Vivrais (CV) area in Southeastern France (Figure 1). The PEACH observational strategy followed the HyMeX observational strategy with SOP, EOP (Enhanced Observation Period) and LOP (Long Observation Period) activities. The SOP1 PEACH strategy consisted in deploying a relevant instrumentation from September to November 2012 in key locations together with instruments operated by other HyMeX teams with common temporal and spatial coverage. First, Operational Lightning Locating Systems (OLLSs) were easily identified, i.e. ATDnet, EUCLID [Schulz et al., 2014], LINET and ZEUS, as they cover the Mediterranean Basin for already a long time. Then a total-lightning detection system was considered and a portable Lightning Mapping Array (LMA [Rison et al., 1999]) was selected. Electric field mills (EFMs), slow antennas (SLAs) as well as induction rings (INRs) were also listed as key instruments for characterizing the ambient electric field, the change of the electric field induced by the lightning occurrence, and the electrical charges carried by rain drops at ground level, respectively. Finally in order to further support the scientific needs, additional research field instruments were operated like a

mobile optical camera combined with electric field measurement (VFRS, Video and Field Record System), micro-barometer and micro-phone arrays (MBA and MPA respectively) and Transient Luminous Event (TLE) cameras [Fullekrug et al., 2013]. The PEACH project also includes a suite of numerical cloud resolving models (MesoNH, WRF) hosting or not a lightning/electrification scheme [Pinty et al., 2012; Lagouvardos et al., 2013].

DATA AND METHODOLOGY

For the present study, the analysis uses LMA records as well as the reports of EUCLID. Current investigations are underway to evaluate the performances of the different OLLSs in terms of detection efficiency and location accuracy using LMA, VFRS and SLA records as ground truth. In the following, EUCLID reports serve to discriminate intra-cloud flashes to cloud-to-ground flashes. Concerning the LMA data, only VHF sources recorded with at least 7 LMA stations are considered in the analysis of the VHF signal and for merging of VHF sources in flashes.

Lightning properties are related to the cloud structure and dynamics using radar-based products from Météo France operational radar observations [Bousquet et al., 2014a; Bousquet et al., 2014b]. Additionally several studies combining lightning records to ground- and air-based research radar observations are underway. Finally infrared satellite imagery is also used to investigate the cloud development as sensed from space.

CASE STUDIES

1) The 5 September 2012 isolated storm

The 5 September 2012 case was the first storm recorded during HyMeX SOP1 period. Figure 2a presents the spatial distribution of the lightning activity sensed between 16:30 and 18:30. The storm moved to the southeast with broader lightning discharges as the parent thundercloud became mature. The storm exhibited a flash density up to 61 flashes per $0.01^\circ \times 0.01^\circ$ cumulated over the entire storm life cycle (Figure 2c). A flash-by-flash analysis revealed that 11 bolt-from-the-blue flashes over a total of 124 flashes were recorded during the entire storm lifecycle with negative downward stepped leaders propagating from the upper positive charge region ($\sim 8\text{--}10$ km height) to the ground (not shown).

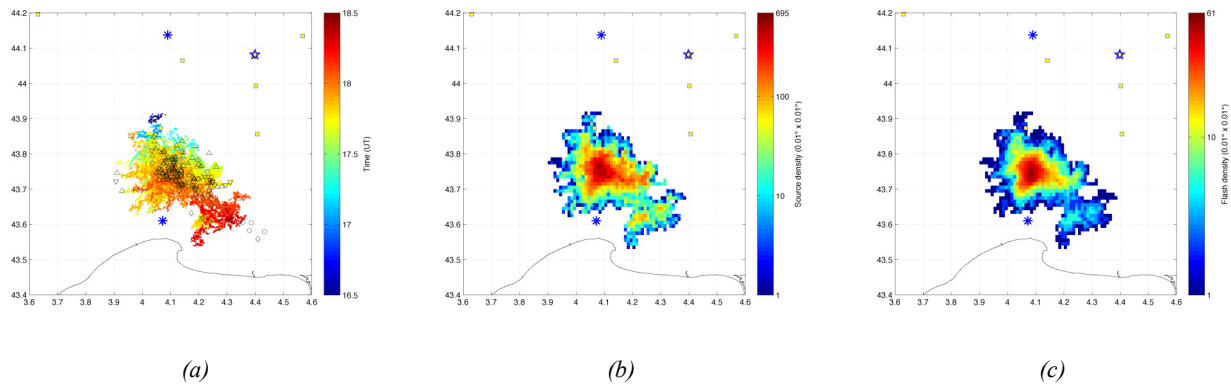


Figure 2. Total lightning activity on the 5 September 2012 with ground projection of (a) the LMA records plotted as a function of time, (b) ground projection of the LMA source density for the entire storm, and (c) flash density deduced from the analysis of the LMA data. Densities are computed per $0.01^\circ \times 0.01^\circ$ bin.

Figure 3 presents the temporal evolution of different parameters deduced from the records of LMA and EUCLID. Each flash was investigated by hand as the flash rate was rather low. Figure 3a shows the time series of total and intra-cloud flash rates as well as the ratio of intra-cloud flashes (multiplied by 20 for plot convenience). Figure 3b shows the time-height of the VHF sources. Due to the scale along the abscissa, flashes are plotted as vertical segments. The dark dots map the altitude of the flash triggering as deduced from the first VHF sources reconstructed. The red (blue) segments plot the vertical extensions between the flash triggering altitude and the upper (lower) VHF source altitude. Note that these two segments do not always map the positive and negative charge regions, as this way of plotting the flashes does not take into account the actual three-dimensional development of the flash. The green (yellow) dots indicated the 10% (90%) percentile of the cumulative distribution of the VHF source altitude. Those two percentiles give an idea on the average altitude of the charge regions where the horizontal branches more or less propagate. In addition Figure 3b shows the EUCLID records for negative (positive) cloud-to-ground events with triangles (diamonds) but also for negative (positive) intra-cloud events with downward triangles (circles) set to an arbitrary altitude of 15 km height. One of the results of HyMeX SOP1 found so far is the ability of operational lightning detection networks like EUCLID to detect some intra-cloud components as discussed in Schulz et al. [2014].

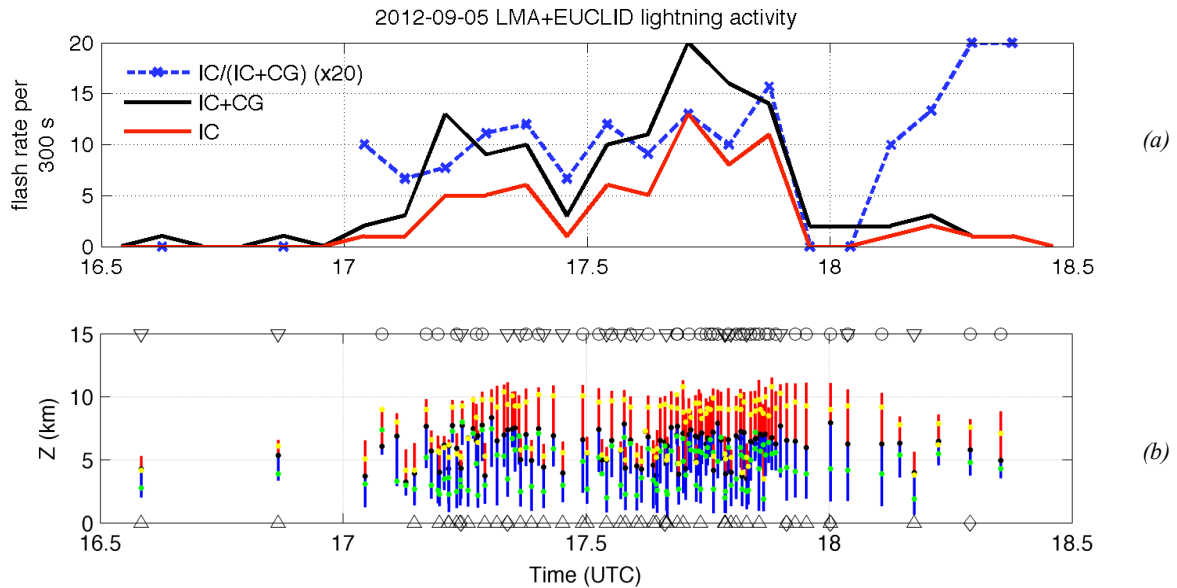


Figure 3. Analysis of the lightning activity during the 5 September 2012 storm with (a) flash rates and intra-cloud ratio, (b) time-height series of the lightning flashes with dark, green and yellow the ignition altitude, the 10% and 90% percentiles of the vertical VHF source distribution.

Figure 3a shows that the storm lived for one hour and half with a maximum flash rate of 20 flashes per 5 min at the period. Two electrical cells were recorded, one during the first 30 minutes, and the second one with the highest flash rate during the following hour. The intra-cloud ratio was on the average of 0.5 but with a slight increase during the life of the storm. Most of the cloud-to-ground flashes were of negative polarity, with an unusual rate of bolt-from-the-blue flashes as already mentioned above. Figure

3b shows that the two first flashes recorded were negative cloud-to-ground flashes, while after 17 UT an intra-cloud lightning activity was first recorded before the cloud-to-ground flash. The triggering of the flashes occurred around 4-5 km height for low altitude flashes and around 7-8 km height for intra-cloud flashes including bolt-from-the-blue flashes. Flashes reached up to 10-km height while the main negative charge region was located at 5-6 km height.

2) *The 14 October 2012 tornadic storm*

Figure 4 shows two hours of LMA and EUCLID lightning records for an electrical cell located in the vicinity of Marseille along the coastline where an EF1 tornado was taped with no injury but with some damages. Figure 4a shows that the storm moved to the North-East with a maximum flash density of 100 flashes per $0.01^\circ \times 0.01^\circ$ cumulated over the 2 hours of the study (Figure 4c).

Figure 5a shows the different flash rates as deduced from the analysis of the LMA sources in combination with the EUCLID reports. A maximum of 43 flashes per 5 min was first recorded just before 14 UT, a second peak of 35 flashes per 5 min was recorded at 14:30 UT. The tornado was reported around 14:30 UT (the actual time of the tornado is currently being investigated). The intra-cloud ratio was evolving during the life of the storm: the storm exhibited periods with only CG flashes (around 13:30 UT) and periods with up to 75% of intra-cloud flashes.

The storm exhibited two convective surges: one, CS1, between 13:50 and 14:00 UT, the second, CS2, more organized as detailed below that ended just after 14:30 UT (Figure 5b). Focusing first on CS2, Figure 5b clearly shows the upward motion of the triggering flash altitude starting at 6 km in the early beginning of the convective surge to reach 10 km at the end of the convective surge. Not only the triggering altitude progressed upward, but also the upper part of the intra-cloud lightning flashes, i.e. the upper positive charge region (yellow dots in Figure 5b). For instance, Figure 6 presents two examples of lightning flashes recorded with the LMA during the early stage and the ending stage of the second convective surge. Figure 6a shows a rather regular intra-cloud flash with a triggering altitude around 6 km and upward negative stepped leaders radiating during 400 ms, while intermittent VHF sources associated with positive discharges are located at lower altitude. Figure 6b shows a totally different vertical evolution of the lightning flash: the flash triggered at 11 km height with a negative stepped leader propagating at constant altitude, while VHF sources associated to positive discharges are located down to 4 km height. Figures 6c and 6d give a schematic of the charge regions as deduced from the LMA records: the convective surge not only transports upward the cloud but also leads to a thinner upper positive charge region and thicker main negative charge region.

Now about CS1, the vertical development of the parent cloud is less dramatically mapped with the lightning observations, probably because of less intense updraft, but flashes still ignited at 9-10 km height. Interestingly Figure 6c shows that flashes composed of a single VHF pulse were identified in that specific convective surge while none were recorded during the second convective surge. We remind here that all VHF sources used in the present study have been located with at least 7 LMA stations, suggesting that those single-source flashes are not noise. An on-going evaluation of those single-source flashes is underway to verify if they emanate from a less organized electrical activity.

Figure 7 shows the longitude-height distribution of the flash triggering for the 2-hour period: the flashes recorded during CS2 triggered rather close to each others and along a well defined path progressing upward while the storm moved to the North-East. Projected into the cloud structure as

retrieved from the operational 15-min radar observations, the flashes triggered in cloud region with reflectivity above 30 dBZ (Figure 8c).

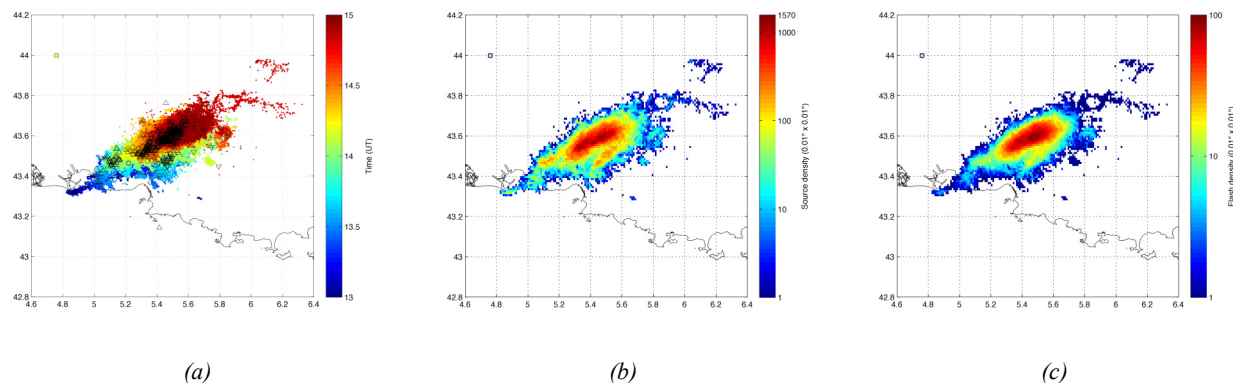


Figure 4. Same as Figure 2 but for the 14 October 2012 tornadic cell between 13 and 15 UT.

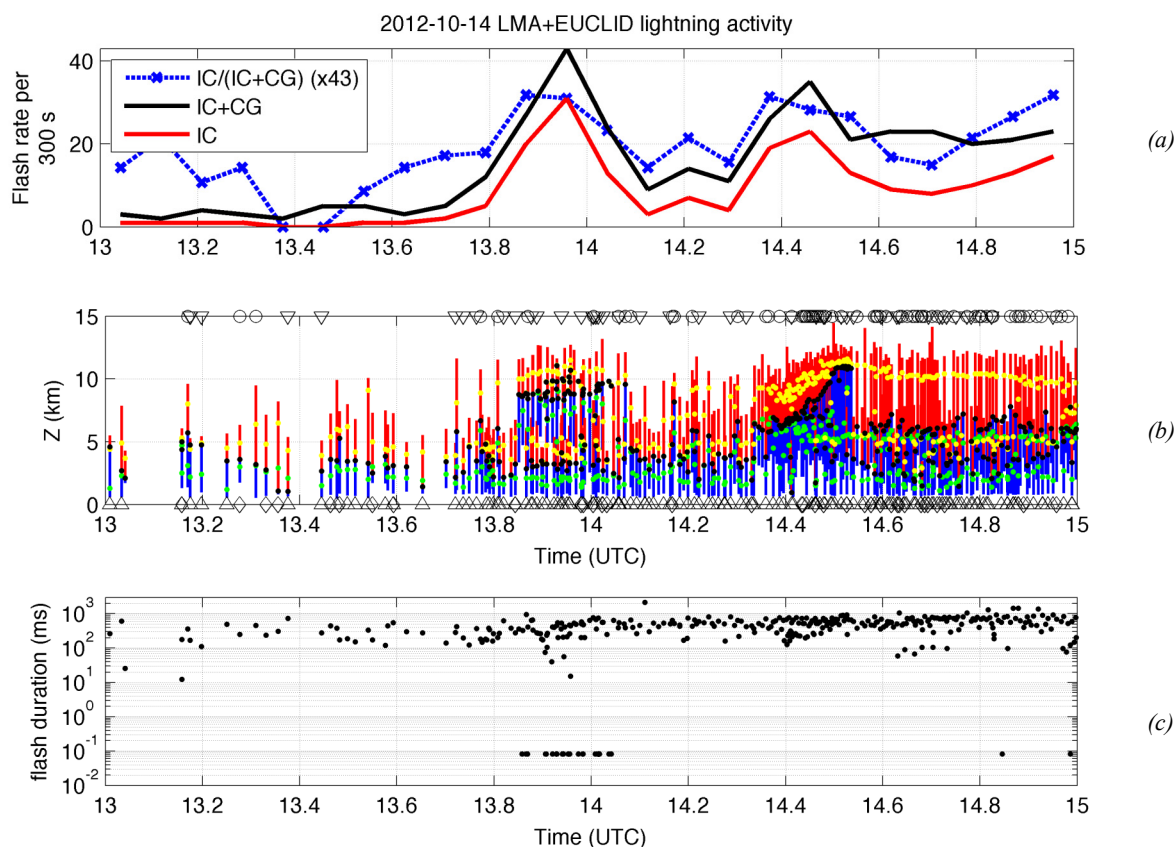


Figure 5. Same as Figure 3 but for the 14 October 2012 tornadic cell, with additionally (c) flash duration as deduced from the LMA data.

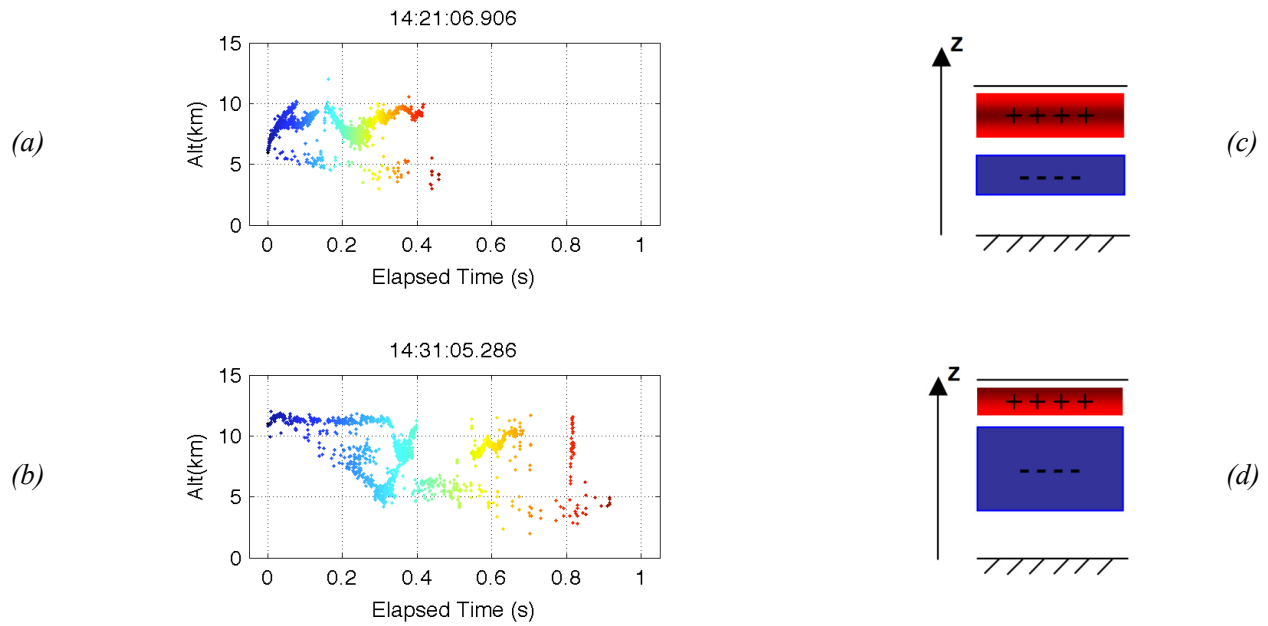


Figure 6. Examples of time-height evolution of two flashes during the second convective surges and vertical description of the charge regions as deduced from the LMA observations.

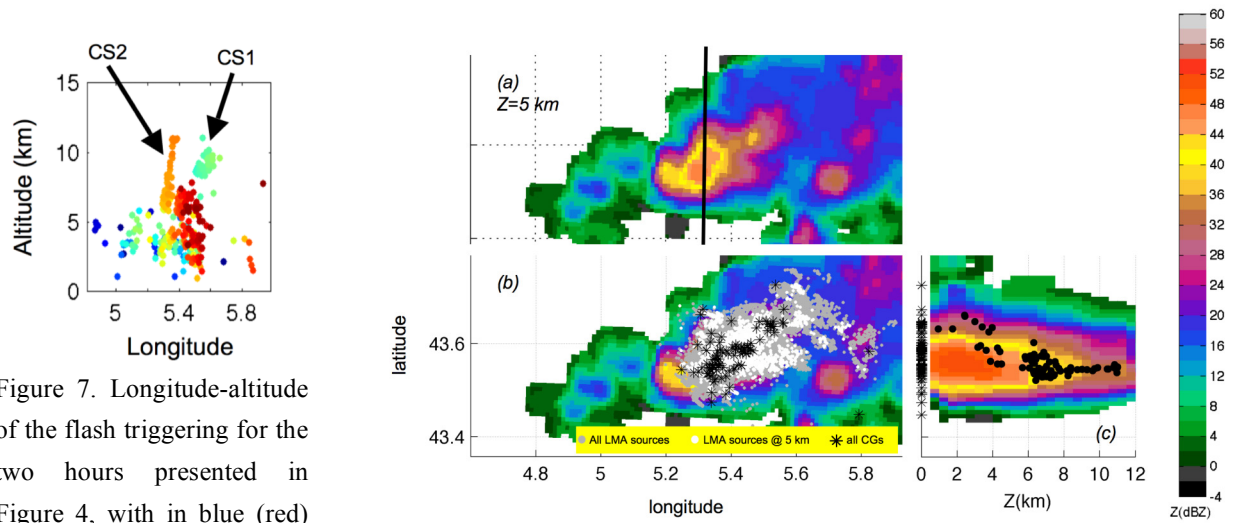


Figure 7. Longitude-altitude of the flash triggering for the two hours presented in Figure 4, with in blue (red) the flashes recorded during the beginning (end) of the studied period.

Figure 8. Horizontal cross section of reflectivity at 5 km height (panel a), with an overlay of the LMA and EUCLID records in gray/white dots and asterisks respectively (panel b), and vertical cross section along the black line in (panel a) with overlay of the flash triggering (panel c).

3) The 24 September 2012 IOP06 storm system

On the 24th of September 2012, an intense and fast moving convective line crossed the CV domain during the early morning (Figure 9), Liguria-Tuscany by mid-day and Northeastern Italy in the evening with an amount of rainfall observed of $\sim 100\text{mm}/24\text{hr}$ over South-Eastern France, with rainfall intensity of 50 to 60 mm/hr and wind gusts up to 90 to 100km/h. The storm activity started in the evening of the 23 September on the west side of the LMA coverage area and moved to the east where successive electrical cells developed and merged (Figure 10).

Between 02 and 03 UT, the lightning activity was more or less distributed along a north-south direction and extended further north to the LMA network (Figure 11). Focusing on the electrical cells located in the vicinity of the LMA network, the lightning activity was located east of the significant updrafts as retrieved from the radar data (Figure 11b,c) with the deepest convective cell recorded south of the system with lightning flashes reaching up to 13 km height. In this thunderstorm, preliminary analysis of the lightning data suggests that the intra-cloud ratio was 110:14 for the period 02:25-02:30, where 64% of CG flashes were of negative polarity. For the studied core, electrical discharges were recorded mainly in cloud regions with reflectivity above 20 dBZ (Figure 11d,e).

The different PEACH instruments documented the lightning activity of that stormy day as shown and investigations are underway to characterize the lightning flashes. Some of the electrical cells were also documented with the airborne 95-GHz radar RASTA and in situ microphysics probes on board the Falcon 20, and by different precipitation research radars located in the Northern part of the HyLMA coverage area. In addition cloud simulations have also been performed for that storm, among others, as detailed in Pinty et al. [2014, this conference].

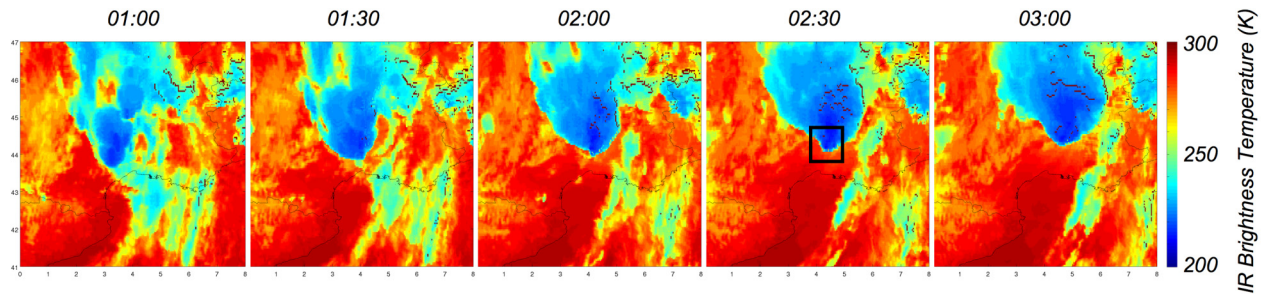


Figure 9. Brightness temperatures reported from geostationary infrared sounder on 30-min basis.

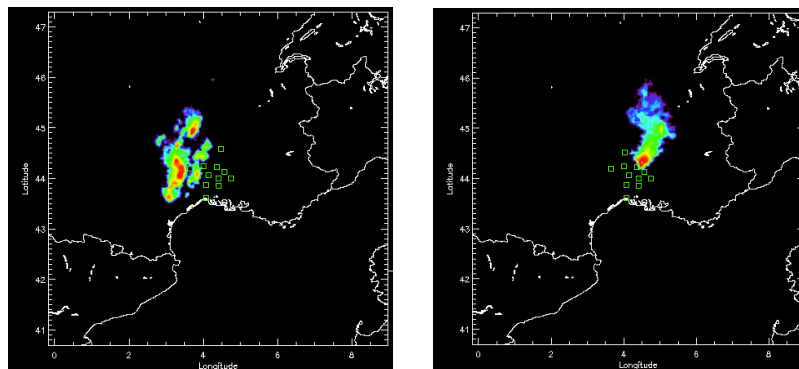


Figure 10. VHF sources density recorded by the LMA between 01:00 and 01:10 (left) and between 03:00 and 03:10 (right) during the 24 September 2012 IOP6 case.

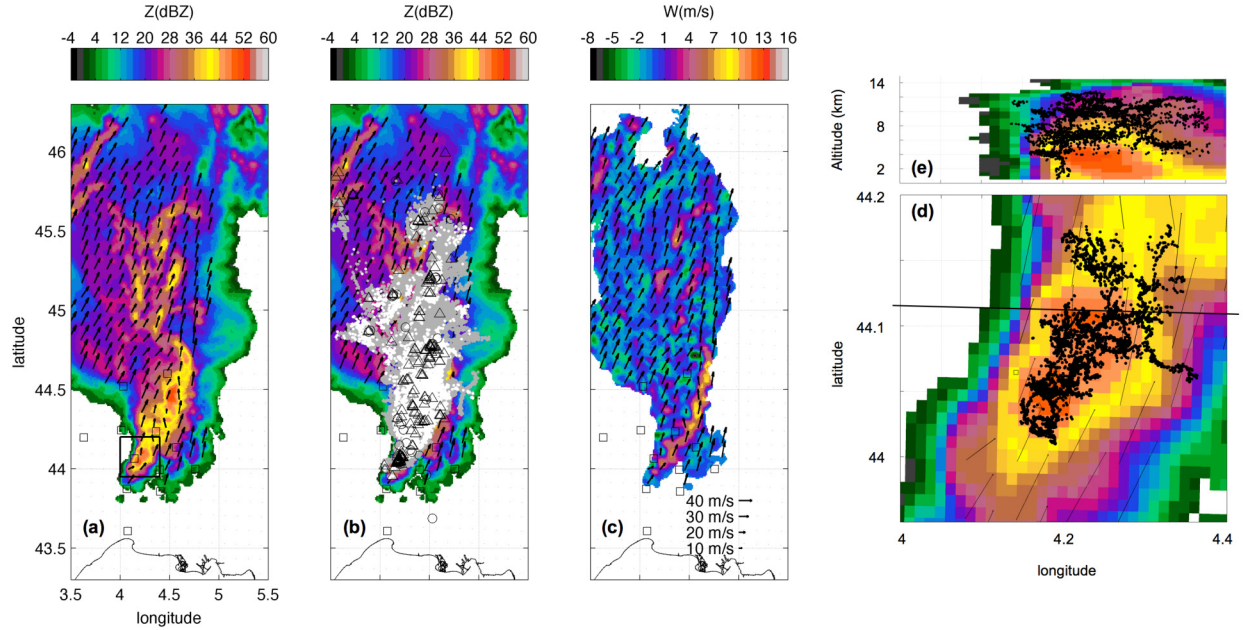


Figure 11. (a) reflectivity and horizontal wind at 5 km amsl from 3D Multiple-Doppler wind and reflectivity analysis from 0215-0230 UTC on 24 Sep 2012, (b) overlay of lightning activity as recorded by LMA (in grey along the depth of the reflectivity layer (of 500 m); in white over the entire atmospheric column) and EUCLID (-CG strokes as triangles; +CG strokes as circles) during 15 minutes, (c) vertical velocity, (d) zoom in the domain drawn in (a) with lightning observations collected at 02:29:06-02:29:16 where 7 flashes were recorded by the LMA including one -CG flash in the considered domain, and (e) vertical distribution of the VHF sources along the plan delimited by the segment in (d).

CONCLUSIONS

In the present article a very small number of examples of observations collected with the different PEACH instruments during the HyMeX SOP1 has been discussed. The rather unique and comprehensive lightning dataset collected during the SOP1 period will serve to investigate the properties of the lightning flashes but also to access objectively and for the first time the performances of European OLLSs in the South-Eastern France and along its shoreline. This task will help refine our current knowledge on what European OLLSs actually record and more specifically which intra-cloud processes are detected and located. The investigation should eventually provide new insights on the potential of IC detection from European OLLSs for operational storm tracking and monitoring over the entire Mediterranean Basin.

Several analyses are already underway to investigate the properties of the lightning activity from the flash scale to the regional scale in relation with cloud and atmospheric properties as derived from satellite imagery, operational/research ground-based and airborne radars, rain gauges and in situ microphysical probes. The analyses focus not only on HyMeX SOP1 priority cases (Ducrocq et al., 2013) but also on non-SOP1 cases as LMA records are available from June 2012 to end of November 2012. The analysis will eventually provide the key lightning-related parameters, which describe the electrical nature of the thunderstorm in Southeastern France. The case studies will not be only observational-based but will also

make use of cloud simulations. Indeed realistic simulations will be performed and the comparison with the observations collected during the cases of interest should help verifying not only the microphysical schemes but also the electrical and lightning schemes. Cloud Resolving Models should provide not only insights on the links between dynamics, microphysics, rain and lightning activity based on case and sensitivity studies but also provide some guidance to determine suitable lightning-based proxies for better characterization and monitoring of the thunderstorms.

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