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NATURAL LIGHTNING FLASHES: FROM OBSERVATION TO MODELING

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Abstract. Different ground-based and space-based sensors are currently used to characterize and locate Earth lightning flashes like VHF mappers, VLF systems with short or long baseline, optical CCD camera and more recently microphone arrays. Concurrent observations with such equipments offer a unique description of the different processes occurring during the life of a lightning flash (triggering phase, leader development and junction phase). While the detection of lightning flashes becomes mature, more challenging investigations are still needed on i) Lightning Nitrogen Oxide (LINOx) production and on ii) the modeling of natural lightning discharges, even if "engineer" lightning schemes combined with electrification schemes are already implemented in numerical cloud resolving models. The PEACH project, the Atmospheric Electricity component of the upcoming field experiment HyMeX, will offer a unique opportunity for the European community to document and characterize the Mediterranean lightning activity with observations and modeling from the lightning scale to the regional scale and to gather the French community in preparation for the validation of future space-based missions like TARANIS and MTG-LI and for the interpretation of their lightning observations.

Keywords: Cloud electrification, lightning flashes, LiNOx, PEACH and HyMeX

1 Introduction

A natural lightning flash is a complex phenomenon composed of successive events, also called flash components, with different physical properties in terms of discharge type and propagation, radio frequency radiation type, current properties, duration. Simultaneous concurrent observations from different techniques sensitive to different properties of the lightning flash are required to characterize and interpret the different processes occurring during a lightning flash and to refine and develop discharge and chemistry modeling schemes. In the following we briefly describe the electrification process and discuss on the types of lightning flashes. Then we describe different techniques to detect and characterize lightning flashes and lightning activity. We then stress out the needs for more investigation on the discharge and chemistry modeling of lightning flashes. Finally we discuss on the Atmospheric Electricity component of the HyMeX project and on the two future space missions offering lightning detection.

2 Electrification processes and lightning occurrence

Optical space-based lightning detection reveals that lightning activity is more often recorded over the continents than over the oceans (Christian & coauthors 2003). Such a feature is explained by stronger updrafts in continental convection inducing a more efficient electrification. Electrical charges are exchanged during non-inductive ice-ice collisions in presence of super-cooled liquid water, the amount and sign of the exchanged charges being dependent on the temperature, the size of the ice particles, the type of hydrometeors and the difference of velocity between the colliding particles. Because the cloud hydrometeors are carrying the electric charges, the transport of the hydrometeors induced by the cloud dynamics leads to the existence of pockets of charges in the

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clouds and to the installation of an ambient electric field. If the electric is locally intense enough to trigger a discharge, a lightning flash can then propagate in the cloud (intra-cloud, IC) or connect to the ground (cloud-to-ground, CG), if the conditions for the lightning discharges to propagate exist. Lightning activity is then a by-product of the dynamics, the cloud microphysics and the electrification. The monitoring of the lightning activity with lightning locating systems (LLSs) provide key information on the occurrence of the convection but also can offer an idea on the developing and dissipating stages of the thunderstorms: an intensification of the convection is accompanied with a sudden increase of the flash rate; the flash rate often reaches its maximum when the cloud ceases to develop vertically; decaying stage of a storm is often associated with a decrease of the flash rate.

3 Sensing lightning flashes

Lightning flashes can be detected and located by different ground-, air- and/or space-based techniques such as optical (Christian & coauthors 2003) and radio frequency (Krehbiel et al. 2000), acoustics detection (Farges & Blanc 2010) as well as by the measurements of the electrostatic field (Soula & Chauzy 1991). According to the technique employed, different flash components are detected. Time-of-Arrival Very High Frequency (VHF) technique can map the three-dimensional structure of both IC and CG flashes inside and outside the clouds by locating pulsed radiation emitted by different flash components. With VHF detection, the development of the flash can be studied down to the microsecond scale and properties of the lightning flashes (e.g. radiation type and velocity of flash components, flash duration, flash structure, flash vertical and horizontal extends) and of the lightning activity (e.g. flash rate, IC/CG ratio) are available for the entire storm life within the coverage area (250-km diameter) of the lightning VHF network.

Lightning flashes can also be located based on the Low Frequency (LF) and Very Low Frequency (VLF) radiation emitted by some flash components. Short-baseline LF/VLF networks like EUCLID (Schulz et al. 2005) or LINET (Betz et al. 2009) covers Europe and locate CG ground connections and some IC activity. Long-range VLF lightning networks take the advantage of the wave guide between the ground and the ionosphere to locate lightning events at thousands of kilometers. Different long-range VLF networks are currently operated like the UK Met Office ATDnet and the WWLLN networks.

Optical detection is also used to detect and study some properties lightning flashes (e.g. duration, continuous current) even if the radiation is scattered by the cloud, ice particles and rain radiative properties between the flash and the sensor. Acoustic technique can provide the 3D location of the thunder sources. Acoustics offers additional information to investigate the physics of lightning discharges (relation between the temperature inside the lightning channel and the induced acoustic signal) and can be used to monitor and track storms (Farges & Blanc 2010).

All these lightning detection techniques in conjunction with space-based (IR, visible, microwave) cloud imagery and ground-based cloud radar can be used to characterize the flashes, the electrical state of the clouds and the cloud microphysical properties from where originate TLEs (Soula et al. 2011).

4 Electrification, lightning flashes and LiNOx in cloud resolving models

The French MESO-NH cloud resolving model operates an electrification scheme combined with a lightning flash scheme that helps to understand the complex processes occurring during a storm (Barthe & Pinty 2007). An electrification scheme based on cloud physics and laboratory studies (Takahashi 1978; Saunders et al. 1991; Tsenova et al. 2010) determines the charges exchanged between the hydrometeors (the charges carried by the hydrometeors are produced by elastic shocks between ice particles in the presence of supercooled water) at each model time step. A simplified physics of the positive and the negative ions is included to simulate the screen charges. The ambient electric field is computed over the entire domain of the model by inverting the Gauss equation and a lightning flash is triggered at the location where the ambient electric field exceeds a height-dependent threshold. The lightning flash then develops as a bi-leader that propagates vertically until the electric field drops below a propagation threshold. A pseudo-fractal scheme is then applied to describe the horizontal extension of the flash as a branching tree that fits with the morphology of the lightning flashes. The electrical charges are then partially neutralized at locations along the flash path, The electric field is updated and the process is iterated until no more flash can be triggering during the time step. In addition a production of nitrogen monoxide (LiNOx) can be computed for application in atmospheric chemistry (Barthe et al. 2007). The electrical scheme has been improved recently (Barthe et al. 2011) to simulate electrified cloud forced by orography over a large computational domain. This was done for the perspective to simulate real meteorological events and to compare with stroke data collected by lightning flash networks.

5 PEACH, the HyMeX Atmospheric Electricity component

The Projet Electricité Atmosphérique pour la Campagne Hymex (PEACH) project of the Hydrology in the Mediterranean Experiment (HyMeX) aims at performing observational-based and modeling-based studies of the electrical activity in maritime and continental Mediterranean storms (Defer & coauthors 2008, available at `http://ozone.obspm.fr/~defer/Hymex/SciencePlanHymex.lightning.pdf`). Different operational lightning detection networks will be used to record, document and analyze the electrical activity at the storm level, at regional or mesoscale, and at the scale of the Mediterranean basin. The lightning networks selected here are complementary not only on their geographical coverage but also on the fact that they sense different flash components. A VHF Lightning Mapping Array (LMA) will also be deployed. Lightning activity will be related to the microphysics and aerosol contents and also to kinematics properties of the continental and maritime Mediterranean storms as measured by ground-based/airborne instruments deployed during the HYMEX experiment (radar, radiometer, lidar, in situ microphysics probes) and space borne operational sensors. An acoustic sensor array will also be deployed to characterize the infrasonic properties of lightning flashes and will provide a unique description of the lightning flashes by merging concurrent electromagnetic and infrasonic observations. In addition, simulations with the non-hydrostatic mesoscale model MesoNH will be performed to evaluate the model capability in simulating cloud and precipitation fields at the resolved convective scale over a large domain but also to test for the first time and in the context of real meteorological situations, the original electrification-lightning scheme which has been developed in MesoNH and which is dedicated to the very high spatial resolution (1 km scale and less). The PEACH multi-scale studies should then offer potential applications of lightning proxy for hazardous weather detection, nowcasting of flash floods, quantitative rainfall estimation over land and sea and for data assimilation in numerical weather prediction models.

6 TARANIS and MTG-LI missions

The PEACH project will help to organize the community to support the TARANIS mission (Blanc et al. 2007). The TARANIS optical instrument includes 2 cameras and 4 photometers. All sensors are equipped with filters for sprite and lightning differentiation. The filters of cameras are designed for sprite and lightning observations at 762 nm and 777 nm respectively with a sampling frequency of 11 frames per second. One of the photometers will measure precisely the lightning radiance and duration in a wide spectral range from 600 to 900 nm with a sampling frequency of 20 kHz. One of the main contribution of TARANIS to the lightning studies will be the possibility to complement, with TARANIS survey mode, the future geostationary satellite lightning imager data and to quantify the efficiency of global lightning networks (as WWLLN or GLD360) in regions without regional networks, as in Africa. The expertise gained during the PEACH project will help investigate the tropospheric processes related to the TLEs. Indeed high-resolution TLE observations will be performed during the HyMeX project (Soula et al. 2011).

The Meteosat program is the primary European source of geostationary observations over Europe and Africa. One of the new missions selected for The Meteosat Third Generation (MTG) program, with a scheduled launch in 2017, is the Lightning Imagery (LI) mission, detecting continuously over almost the full disc the optical signal radiated by both IC and CG discharges at 777 nm with a spatial resolution around 10 km over Europe. The LI mission is intended to provide a real time lightning detection and location capability in support to Nowcasting (NWC) and Very Short Range Forecasting (VSRF) of severe storm hazards and lightning strike warning. Other applications such as proxy for intensive convection related to ice flux, updraft strength and convective rainfall, for assimilation and for LiNOx production are envisaged.

7 Conclusions

The analysis performed by the French community involved in Atmospheric Electricity during the PEACH project will serve to prepare the validation of the TARANIS mission. For instance the methodologies and the expertise gained by the French community on the tropospheric lightning flashes will help answer the scientific questions of the TARANIS mission. However more observational- and modeling-based investigations are still needed. For instance the wide set of detectors operating on different principles requires investigations to really understand what each instrument is sensitive to and to provide a fair assessment on the detection efficiency and location accuracy of the lightning sensors. Such investigations are also important to calibrate instruments and lightning detection networks for a long-term monitoring of the lightning activity as a climate change proxy or to perform studies on the regional, seasonal and diurnal scales. Questions remain on the physical interpretation of the different temporal and spatial multi-scale processes occurring during a lightning flash. The PEACH project with its large battery of sensors will offer a unique description of those processes. The properties of the parent clouds should also be known for both lightning and TLE studies. More work is also required on the modeling. For instance questions remain on the electrification processes as no well-established theory exists yet. In addition multiple parameterizations of the non-inductive process need to be reconciled. The triggering conditions as well as the different multi-scale propagation processes need to be modeled and compared with the typical radiation recorded in radio-frequency, optics and acoustics domains. More works are needed on a good representation of LiNOX with some considerations in plasma kinetic combined with an atmospheric chemistry module.

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