ORAGES

(Observation Radioélectrique et Analyse Goniométrique des Eclairs par Satellite)

A micro-satellite to detect and to locate the lightning VHF emissions from space

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ABSTRACT

Space based sensors enable continuous observations of the convective activity over the whole earth. The ORAGES mission, selected by the French Space Agency (CNES), is designed to locate and detect the VHF emissions of lightning from space with a storm scale resolution. The altitude of the orbit will be at 700-800 km with an inclination of 20-25° which enables to observe the intertropical region where 60% of the storms occur. The instrument is based on a broad band VHF interferometer composed of a 5 antenna network with a center frequency of 120 MHz and a diameter of 3m. The data provided by the mission ORAGES will contribute to estimate the production of Nox by the lightning and to understand the atmospheric water cycle leading to precipitation at the earth's surface which strongly modulates the seasonal and geographical variations of the climate.

INTRODUCTION

ORAGES (Observation Radioélectrique et Analyse Goniométrique des Eclairs par Satellite) is a mission aimed at detecting and locating the VHF radiation of lightnings using an interferometric antennae network aboard a microsatellite platform of the French space agency (CNES). The main characteristics of the mission are presented in this paper.

SCIENTIFIC OBJECTIVES

ORAGES will provide a continuous observation of the lightning activity associated with tropical thunderstorms. Location of the VHF emitting sources through interferometry will enable the analysis of the spatial distribution of lightning discharges. Onboard numerical analyses will provide complementary information : discrimination between intra-cloud and cloud-to-ground flashes, evaluation of the total lightning length, determination of the emission type, …

MISSION SCENARIO

Through a low inclination on the equatorial plane (20-25°), measurements will be made with ORAGES at a relatively high repetitivity. ORAGES will be devoted to the observation of the intertropical zone (≈ 25°S – 25°N) where most convective activity occurs. The altitude of the orbit will be high enough (750-850 km) to allow a wide field of view, while permitting a reasonable horizontal resolution (<15 km). This mission is an experimental mission without plan for immediate operational follow-up. In order to study phenomena ranging from individual convective events to interannual variability, the duration of the mission should be at least 2 years. It is highly desirable that ORAGES be coordinated with meteorological satellites devoted to the observation of precipitating systems and their environments in the tropics. In particular, the French-Indian MEGHA-TROPIQUES [1] planned for a launch in 2006 is an interesting opportunity.

SCIENTIFIC CONTEXT

It is now widely accepted that electrification of thunderstorms depends on the simultaneous presence of supercooled water and rimed graupel particles in the upper part of the updraft. Hence, the rate of total lightning flashes and the ratio of cloud-to-ground discharges are strongly correlated with the updraft intensity [2] and the liquid water content [3] in the thundercloud. Quantitative relationships, derived from observations, have been proposed to relate flash rate to rainfall intensity [4]. Moreover, year-to-year evolution of the global lightning activity may provide a sensitive measure of large-scale temperature variations associated with climate change [5]. Indeed, climate simulations with doubled CO_2 concentration suggest a 25% increase in global lightning frequency [6]. Within the lightning channel, temperature becomes higher than 20 000 K, leading to the breakup of N_2 and O_2 molecules into nitrogen and oxygen atoms. During the cooling process, nitrous oxides NO_X and other trace gases are produced. These nitrous oxides are involved in the production of tropospheric ozone, but the global contribution and the relative efficiency of different types of lightning flashes (intracloud versus cloud-to-ground) to produce NO_X is not well known.

Several systems have been developed to detect and locate lightning flashes at ground level that have shown that relevant information on precipitating systems can be derived from measurements of lightning activity (both intra-cloud and cloud-to-ground flashes) combined with other meteorological data from surface networks, radars, satellites, ...
NASA has recently developed space-based cameras to locate and detect lightning with storm scale resolution (10 to 15 km). The Optical Transient Detector (OTD) was launched in April 1995 aboard the MicroLab-1 satellite at an altitude of 740 km and an inclination of 70° with respect to the equator. The Lightning Imaging System (LIS) is one of the instruments aboard TRMM (Tropical Rainfall Measuring System) satellite launched in November 1997 at an altitude of 350 km and an inclination of 35°, designed to monitor and study tropical rainfall and the associated release of energy. OTD and LIS have provided detailed and comprehensive data on the geographical and seasonal distribution of lightning. One important result from TRMM/LIS points out the strong relationship between lightning activity, cloud dynamics and ice content. Radar measurements show that the electrical activity is always associated with high reflectivity values above freezing level. **Figure 1** shows the correlation between electrical activity (number of flashes / min and km^2) and ice content inferred from microwave brightness temperature.

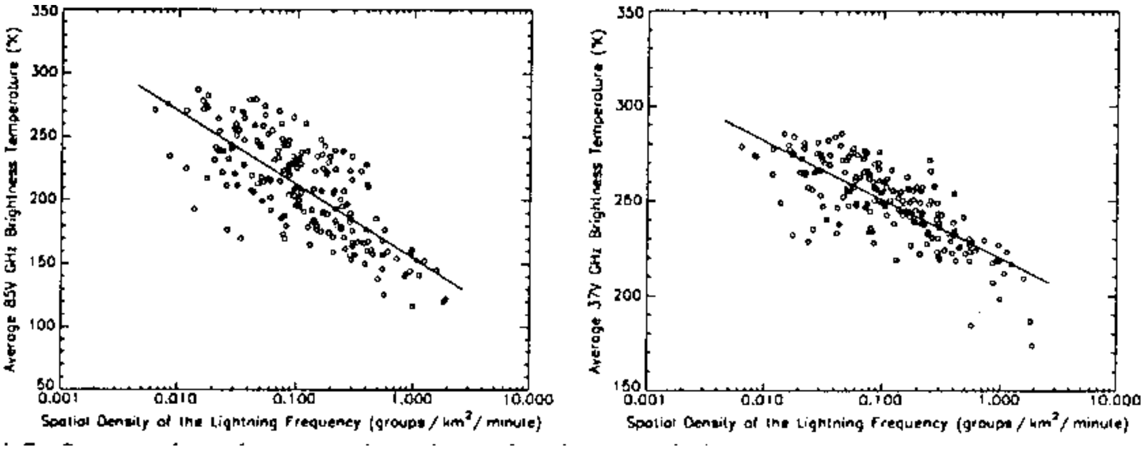

*Figure 1**: correlation between electrical activity (Number of Flashes.min^{-1}.km^{-2}) and ice content inferred from microwave brightness temperaturse (left panel: 85 GHz, right panel: 37 GHz) for 190 convective systems observed by TRMM (NASA-GHCC).***

Recent studies have shown the complementarily between the microwave and electrical measurements [7][8]. Detection of lightning is associated with the presence of supercooled liquid water mixed with graupels. This liquid water can also produce a microwave emission which biases the apparent brightness temperature. Hence, lightning detection could be used to correct for this effect and to improve rainfall estimation from microwave brightness temperature.
Another important conclusion from OTD and LIS data is that the flash frequency observed for the relatively weak oceanic thunderstorms is much smaller than that associated with the generally more intense continental convective systems.
In August 1997, the Los Alamos National Laboratory launched the FORTE satellite (Fast On-Orbit Recording of Transient Events) to detect (no location) the electromagnetic emission in the range of 20 to 330 MHz. One specific point measured by FORTE concerns the Trans-Ionospheric Pulse Pairs [9][10] (TIPPs), which are pairs of intense VHF electromagnetic energy pulses, the second one being the reflection of the first on the Earth's surface. TIPPs are frequently associated with upper atmospheric discharges called "Sprites", "Jets" and "Elves", and with intense X- and gamma-ray energy bursts.

The ORAGES project, selected in 1998 by the French space agency (CNES) for a preliminary phase to validate the design concept of the instrument, is a continuation of these studies. The main difference between OTD, LIS and

ORAGES concerns the method used for lightning detection. OTD and LIS detect and locate the optical flashes associated with lightning at a wavelength of 777.65 nm, while ORAGES – like FORTE – will use the VHF radiation. The main difference with FORTE is that localization of lightnings will be possible using interferometry for ORAGES, whereas geolocation of the events is deduced from an imaging CCD array aboard FORTE. This will improve the detection efficiency (>90%), independently of day/night or ocean/continent background, allow a large field of view (> 1000 km $\times$ 1000 km) with a possibility of detection up to the limb (6400 km $\times$ 6400 km), and permit the extraction of additional information on the lightning sources.

ORAGES will bring new scientific data to investigate the perturbations of the tropical atmosphere and will be strongly complementary to MEGHA-TROPIQUES. This mission from CNES and ISRO (French-Indian cooperation) is planned for a launch in 2006, and is designed to obtain reliable statistics on the water and energy budget of the tropical atmosphere and to describe the evolution of convective systems at appropriate time scales, using a microwave imager, a microwave sounder and an infrared radiometer. If the two missions were to fly together, precise observations on humidity, cloud and precipitation, as well as radiative budget elements, obtained by MEGHA-TROPIQUES could certainly help in the interpretation of the ORAGES products. Reciprocally, information on the presence or the absence of electrical activity could help to more correctly analyze the microwave brightness temperatures observed by MEGHA-TROPIQUES.

The development of a database concerning lightning activity in the intertropical zone, in relation with data from meteorological satellites, will allow to investigate the following themes :

- Classification of electrical activity as a function of cloud type (continental or oceanic, convective or stratiform, mesoscale organization, evolution, duration, …) ;
- Relationships between electrical activity and rainfall intensity (deduced from direct – raingauges – or indirect – radars, radiometers, … – measurements).
- Characteristics of lightning activity associated with perturbations of the tropical atmosphere (cyclogenesis, tropical and equatorial waves, intra-seasonal oscillation, monsoons, …).
- Relation between lightning activity and surface temperature (e.g. in relation with interannual perturbations over the tropical oceans such as ENSO, …).
- Production of NO_X by lightning, role of the intra-cloud vs. cloud-to-ground flashes.

Correlation between TIPPs and VHF emissions.

GEOPHYSICAL PARAMETERS TO BE RETRIEVED

The data provided by ORAGES will be:

- Detection, localization and time sampling of the VHF lightning emission, within a field of view of 1000 km $\times$ 1000 km, with a horizontal resolution is 15 km $\times$ 15 km;
- Outside this region, the most intense emissions will be located up to the limb (3200 km horizontally from the nadir) with a horizontal resolution less than 150 km $\times$ 150 km;
- From spatial and temporal criteria, lightning channels will be reconstructed from the series of detected lightning sources;
- Evaluation of the total lightning length;
- Discrimination between intra-cloud and cloud-to-ground flashes;
- Determination of the type of emission (lightning leader development, recoil streamers, TIPPs, …).

PREPARATION OF ORAGES

For the scientific preparation of ORAGES, the relationships between rainfall and electrical activity have been investigated following two directions. The first one consists in analyzing available data from radar, satellite and lightning detection systems. To that purpose, observations from the operational networks in France (ARAMIS for radars, METEORAGE for cloud-to-ground flashes and SAFIR for total lightning activity) and from field campaigns (MAP in the Alps in 1999) have been analyzed and compared [11]. Further studies will be devoted to radar and lightning data collected in the tropical environment of French Guyana. The second item concerns the development of a specific module in the French non-hydrostatic model for atmospheric simulation MésoNH [12], in order to simulate the electrification of the thundercloud and the development of lightning when the electric field inside the cloud reaches critical value. The “electrified” version of Méso-NH model has been tested for the ideal case of a supercellular storm [13] and will be applied to tropical continental and oceanic storms.

For the preparation of the scientific payload, a prototype of ORAGES has been designed and developed in 2001. It is based on a broad band VHF interferometer composed of a 5 antenna network with a center frequency of 120 MHz and a diameter of 3. m, an analog receiver and a numerical unit for real-time signal analysis which characteristics are listed in Table 1. In October 2001, an experiment has validated the main performance of the instrument by using a nacelle balloon (**Figure 2**).

	Weight	Volume	Power
5-antenna network	<6.5kg		-
Analog receiver	2.5 kg	6.25 l dm^3	15 W
Numerical unit	4 kg	4.2 l dm^3	28W

Table 1 : *Characteristics of the ORAGES prototype.*

Figure 2 : *The balloon nacelle of ORAGES with the 5-antenna network.*

CONCLUSION

The information provide by the mission ORAGES on the intra-cloud and cloud-to-ground lightning activity within tropical convective systems will be combined with that from ground based and spaceborne meteorological observing devices, to investigate the processes involved in the evolution of convective systems through the characterization of the regions where dynamic and microphysical processes can sustain electric activity. These results will contribute to understand the atmospheric water cycle leading to precipitation at the earth's surface which strongly modulates the seasonal and geographical variations of the climate.

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