C³IEL, the Cluster for Cloud evolution ClimatE and Lightning mission to study convective clouds at high spatial and temporal resolutions

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Clouds and water vapor are key components of the Earth's climate system. Uncertainties remain as to their interactions and evolution in the context of climate change. A better understanding of their exchanges and interactions at high spatial and temporal resolutions is needed to improve their representation in small-scale models such as LES (Large Eddy Simulation), and eventually to make progress in numerical weather and climate forecasts. The French-Israeli space-borne C³IEL (Cluster for Cloud evolution, ClImatE and Lightning) mission is an innovative way, currently under development, to provide new insights on convective clouds, at high spatial and temporal resolutions, close to the scales of the individual convective eddies. The mission aims simultaneously at characterizing dynamically the convective clouds, their interactions with the surrounding water vapor, and their lightning activity.

1. Principle: A train of nanosats

C³IEL is a short baseline (~150 km) **train of 2 synchronized nano-satellites** on a **polar orbit (13:30 LT at the Tropics)** to document the evolution of the **convective clouds** at **high temporal and spatial resolution** with the aim to **improve the representation of convective clouds and associated parametrizations in LES and NWP models.**

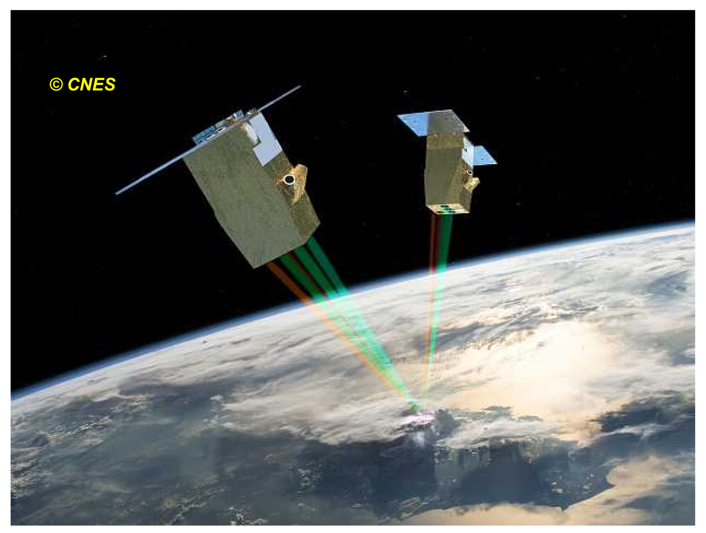

Fig.-1. Artistic view of C³IEL satellites. Launch expected in late 2028.

Instrument	Retrieval principle	Main instrument characteristics		
CLOUD	Imagery and stereoscopy of clouds	*Visible imager at 670nm | nadir resolution = 17 m | one image every 20 seconds during 200 seconds | FOV = 80km x 45km | 3 to 4 sequences*		*day*
WV	Imagery and tomography of water vapor	*SWIR imagers at 1.04, 1.13 et 1.37 µm | nadir resolution = 140 m | one image every 20 seconds during 200 seconds | FOV = 80km x 64km | 3 to 4 sequences*		*day*
LOIP	Imagery and stereoscopy, and photometry of lightning flashes	*Imager at 777.4 nm | nadir resolution = 140 m | 15-ms time resolution | FOV = 360km x 302km*	*Continuous acquisition during 200 seconds | 3 to 4 sequences*	*day*
LOIP	Imagery and stereoscopy, and photometry of lightning flashes	*Photometers at 777.4 and 337 nm | sampling at 20 kHz | FOV = ~300 km diameter*	*Continuous acquisition during 20 minutes*	*night*

Table.-1. List of C³IEL instruments and characteristics.

Reference : Rosenfeld, Cornet, Aviad, Binet, Crebassol, Dandini, Defer, Deschamps, Fenouil, Frid., Holodovky, Kaidar, Peroni, Pierangelo, Price, Ricard, Schechner, and Yair (2022). C3IEL: Cluster for Cloud Evolution, ClImatE and Lightning. arXiv preprint arXiv:2202.03182. [https://arxiv.org/abs/2202.03182]

2. CLOUD: 3D cloud envelope and dynamical development

Target: **Dynamical development of convective cloud envelope**

CLOUD products

L2A : **3D point cloud envelop using stereo-restitution from 2 simultaneous images** (every 20s during 200s)

L2B : **3D dynamical development using stereo-restitution from 2 successive images and L2A 3D coordinates**

Reference : Dandini, Cornet, Binet, Fenouil, Holodovsky, Schechner, Ricard, and Rosenfeld (2022). 3D cloud envelope and cloud development velocity from simulated CLOUD (C3IEL) stereo images. Atmos. Meas. Tech., 15(20), 6221-6242.

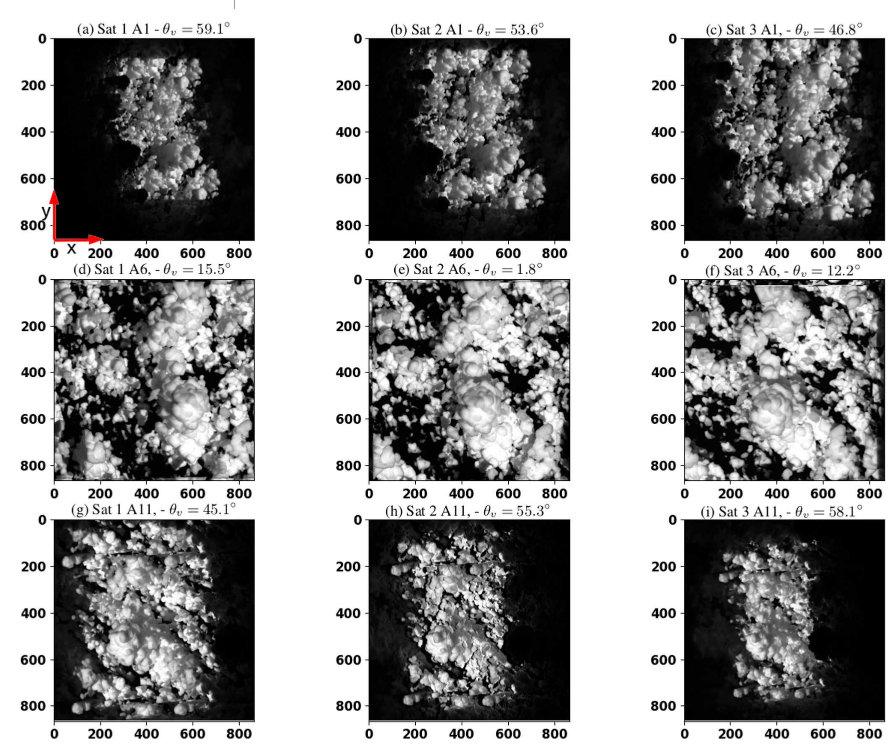

Fig.-2. Synthetic observations simulated with the cloud model Meso-NH, the geometrical model of the cameras and 3DMCPOL.

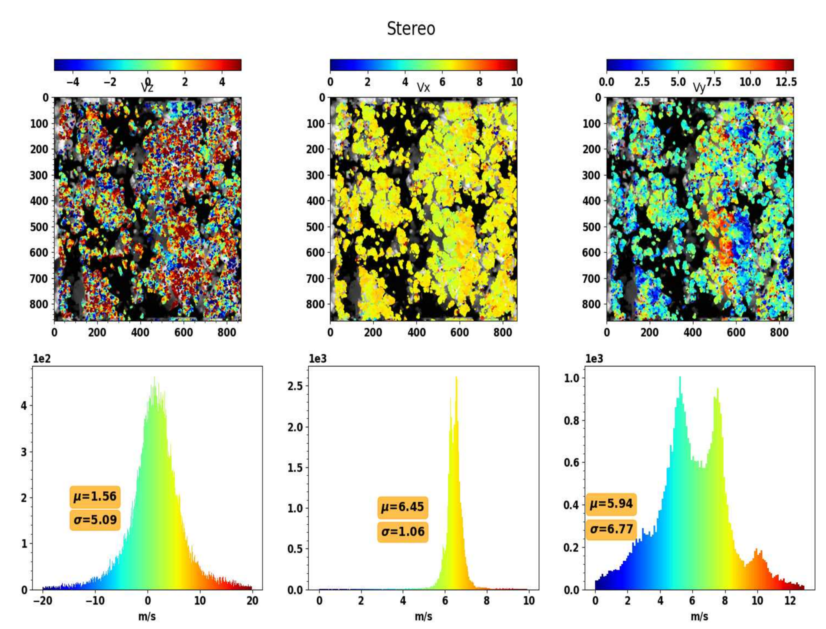

Fig.-3. Components of the 3D retrieved velocity at high spatial resolution.

3. WV: Water vapor around the clouds

Target: **Water vapor (WV) and cloud interactions at high spatial resolution**

VW product

L2: **Integrated water vapor above cloud**

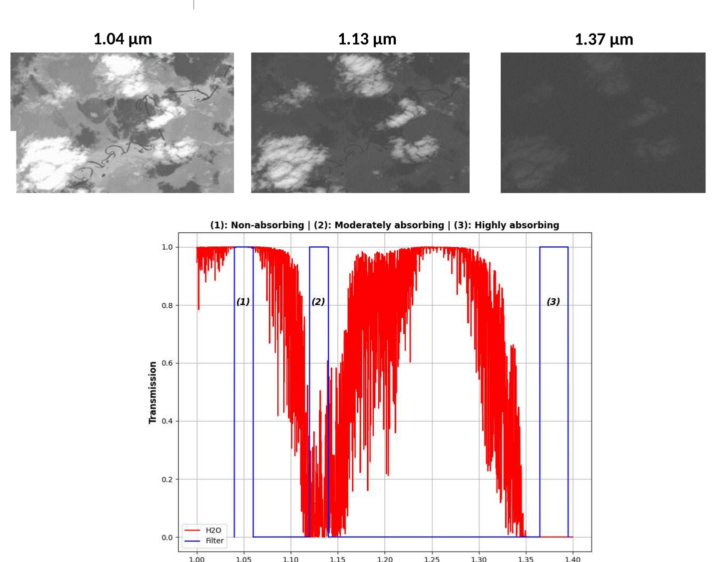

Fig.-4. Atmospheric transmission and WV bands (2nd line), and typical AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) airborne images at 1.04, 1.13 and 1.37 µm (1st line).

Reference: Peroni, R., Penide, G., Cornet, C., Pujol, O., and Pierangelo, C.: Water Vapor Content Retrieval Under Cloudy Sky Conditions from SWIR Satellite Measurements in the Context of C3IEL Space Mission Project, EGUsphere [preprint], 2025. [https://doi.org/10.5194/egusphere-2025-787]

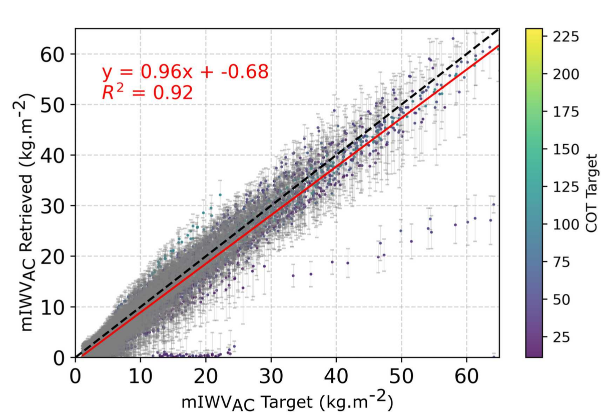

Fig.-5. Relationship between the retrieved and target values of Integrated Water Vapor (IWV) Above Cloud (AC) along the radiation path in the atmosphere (noted $mIWV_{AC}$) for profiles containing low-/mid-level clouds, with linear regression (red line), y = x line (black dashed line),and the uncertainty estimated by the retrieval algorithm (error bars).

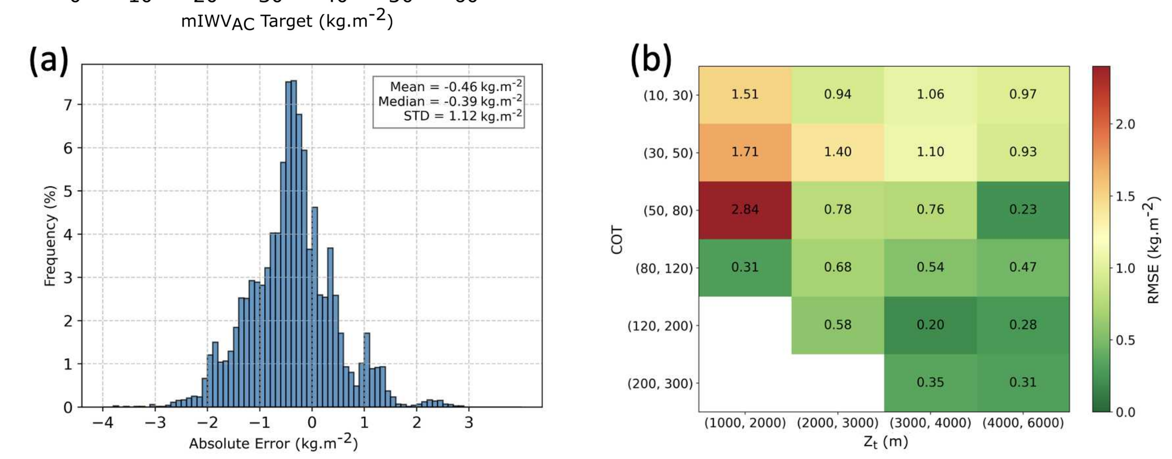

Fig.-6. a) Distribution of the absolute error (retrieved minus target) for the whole dataset, and b) RMSEs calculated according to various cloud top height (Zt) and cloud optical thickness (COT) ranges.

4. LOIP: Lightning physics and lightning activity

Target: **Characterization of the lightning activity in regard to its parent convective cloud development**

LOIP products

L1B: **Calibrated photometric time signals**

L2: **Events, groups, flashes, areas**

L2: Stereoscopic flash reconstruction

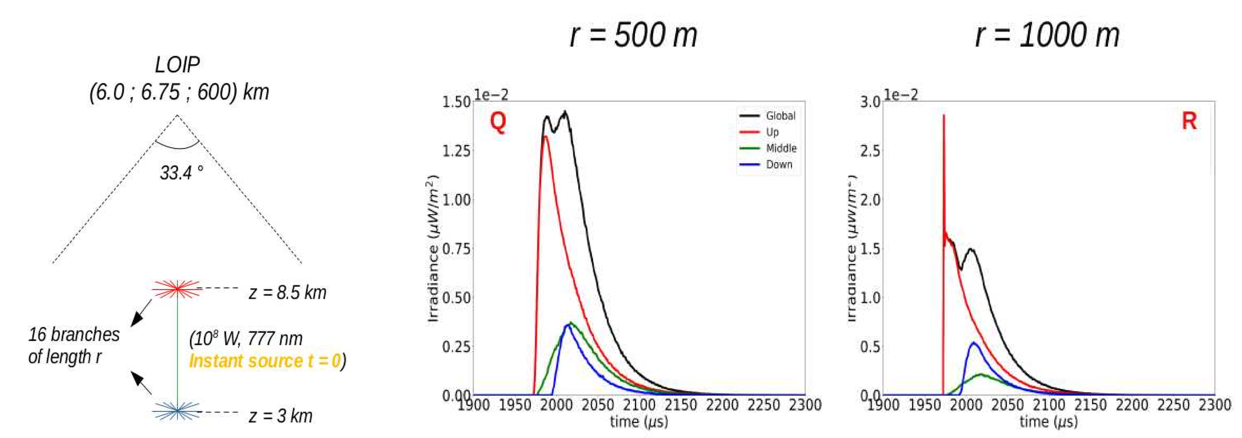

Fig.-7. Simulated photometric waveform (in black) for a lightning composed of a vertical segment with horizontal branches of different lengths and decomposition of the signal, as measured from space, coming from the upper part (red), the lower part (blue) and the middle part (green) of the lightning.

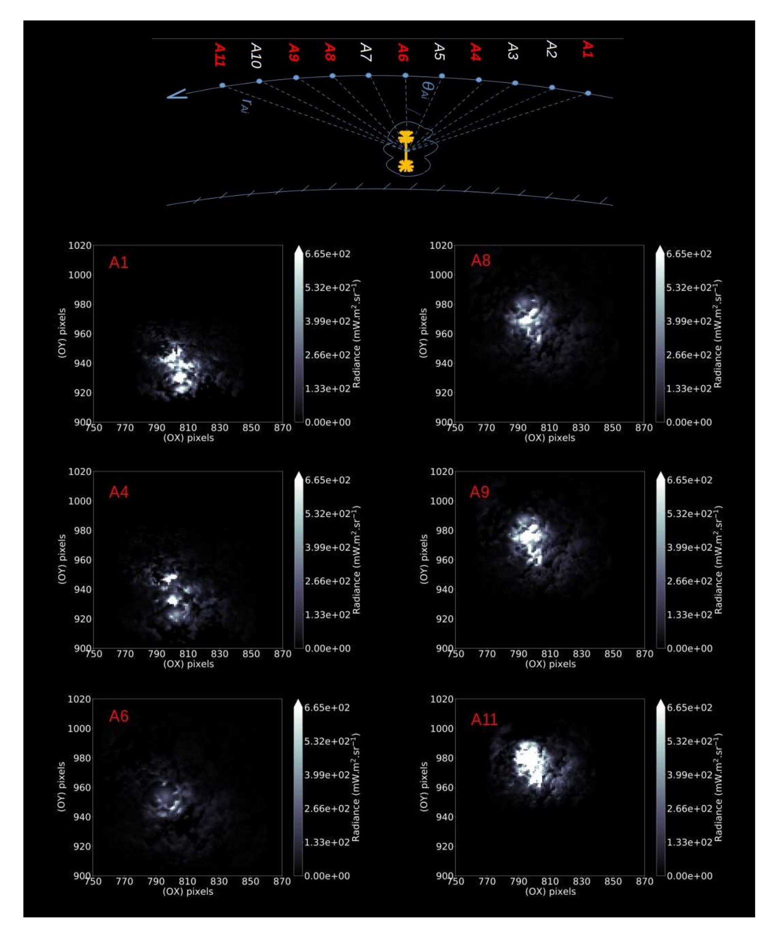

Fig.-8. Synthetic night-time observations simulated with the cloud model Meso-NH, the geometrical model of the cameras and the radiative transfer code 3DMCPOL using a vertical instantaneous lightning source (top panel).