C³IEL: Cluster for Cloud Evolution, ClimatE and Lightning

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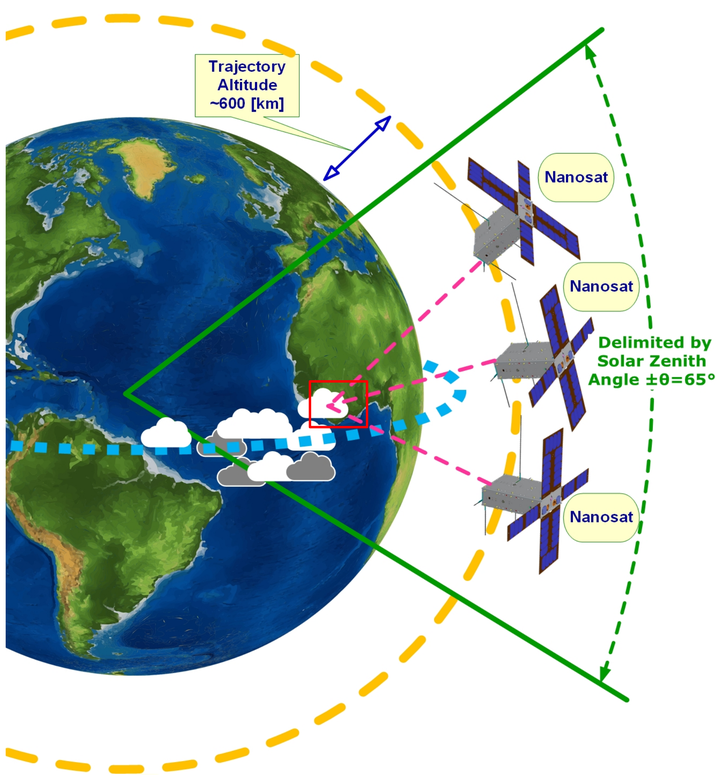
C³IEL (Cluster for Cloud Evolution, Climate and Lightning) is a French-Israeli project of a spatial mission that will provide unprecedented new insights to outstanding climate questions. This demonstration mission, mainly focusing on convective clouds, aims at characterizing dynamically the clouds and their environment at high spatial and temporal resolutions of the scales of the individual convective updrafts. The observations of these space-borne sensors will simultaneously document the vertical cloud development retrieved by a stereoscopic method, the lightning activity and the distribution of water vapor at a high spatial resolution by exploiting a set of ten to twenty multi-angle measurements.

C³IEL: Principle, Instruments, Orbit sampling

Principe: *Documenting the evolution of Earth atmosphere at high temporal and spatial resolution*

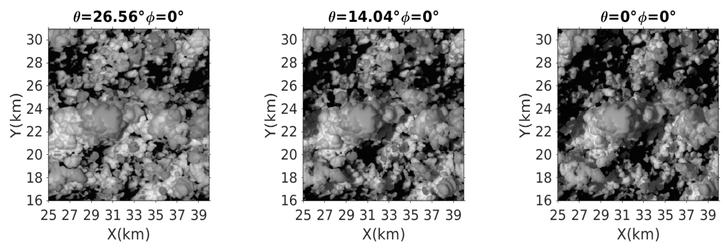


2 to 3 simultaneous observations of the same field of 80 km x 80 km every 20s during 200s => 10 to 20 multi-angular measurements

Instruments on-board the Nanosats

- **High resolution (20m) visible imagers (CLOUD)**

  1 triplet of images every 20s => 11 triplets of images



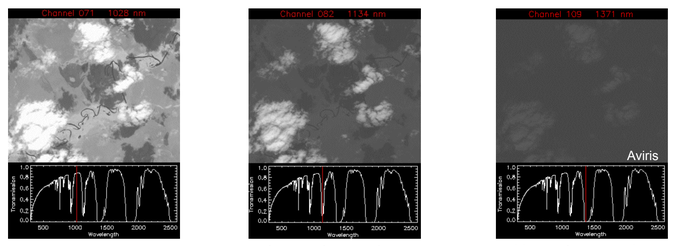
Simulations of deep convective cloud from Méso-NH model (Verrelle et al. 2017) and 3D radiative transfer with 3DMCPOL (Cornet et al. 2010)

- **Water vapor (WV) imagers at 1km resolution with**

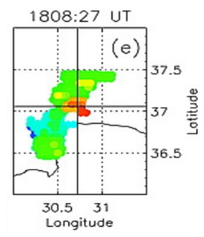
1.0 µm small WV absorption — Background

1.1 µm moderate WV absorption — Lower Atmosphere

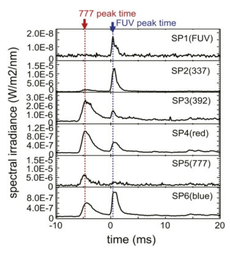
1.35 µm strong WV absorption — Upper trosposphere



- **Lightning imagers and photometers (ZEUS)**



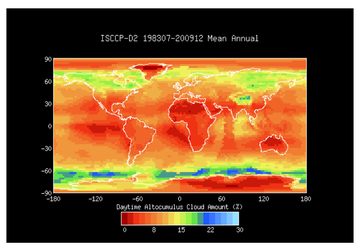
(Defer et al., 2005)



(Adachi et al., 2016)

Sampling strategy: *snapshot of 80kmx80km every 300s during 2 years at 13:30 LT*

ISCCP climatology mean cloud amount (%) gives an indication of number of sampling cloudy scenes :



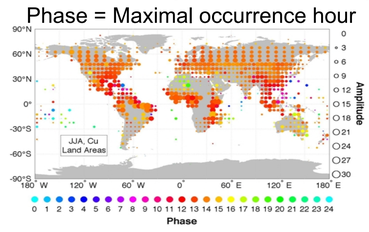
According to the sampling strategy a total of 99000 observed scenes will be measured including
8.6% => **8500 Cumulus**
+11.5% => **11400 Altocumulus**
+ 2.9% => **2900 Deep convective clouds**

=> about 22800 convective cloud scenes

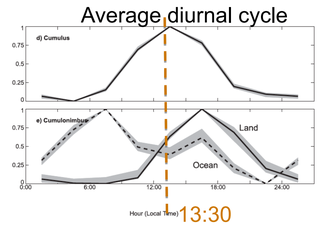
Statistical cloud occurrence at 13:30 LT

From ground observation (Eastman et Warren, 2014)

Phase = Maximal occurrence hour



Average diurnal cycle

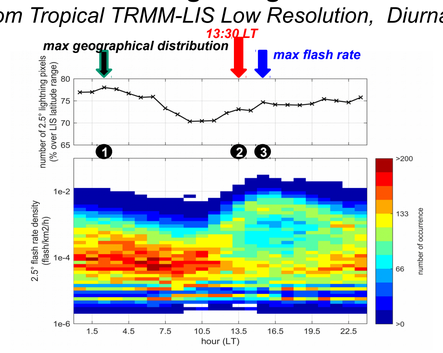


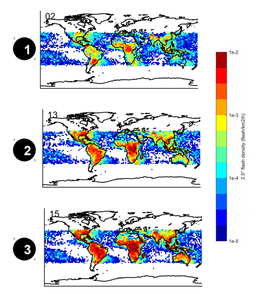
13:30

=> Numerous convective clouds and possibility to use JPSS coincidence

Lightning occurrence at 13:30 LT

From Tropical TRMM-LIS Low Resolution, Diurnal Climatology (period 1998-2005)





=> 13:30 LT = expected strong electrical activity but not the strongest
=> Night overpass should document numerous medium electrical activity

C³IEL Mission: Scientific Observations and Objectives

2 to 3 CLOUD imagers at high spatial resolution 20m

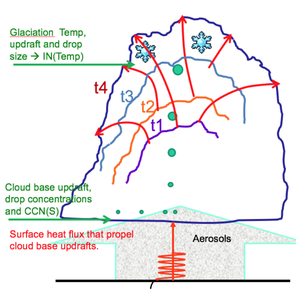
Stereo-views at high resolution (20m) => convective cloud development retrieval

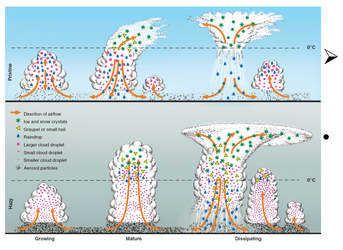
Expected products:

- 3D cloud reconstruction => cloud vertical extension
- Cloud development velocity at the scale at which the processes occur
- Convective cloud repartition including small clouds

Science benefits:

- ***C³IEL measurements will help to improve parameterization of convective clouds in LES or NWP models with direct or statistical comparisons of:***
  - Development of convective cells (size, height…)
  - Horizontal and vertical growth of cloud, divergence at cloud top
  - Development of convective towers and large turbulent structures at cloud top
  - Estimates of vertical velocity inside the clouds, relationships with cloud top velocity





Rosenfeld et al., Science, 2008

- ***With VIIRS/JPSS, studies of cloud-aerosol interaction studies:***
  - Vertical updraft from CLOUD/C3IEL + Effective radius from VIIRS/JPSS
    => Separation of aerosol-cloud interactions from dynamics processes

- **With JPPS instruments:**
  - Impact of Lightning on NOx and O3 Concentration with **CrIS**
  - Study of overshooting using **VIIRS IR** (stratosphere humidification, CO large scale transport)

Monospectral water vapor cameras at 1km resolution

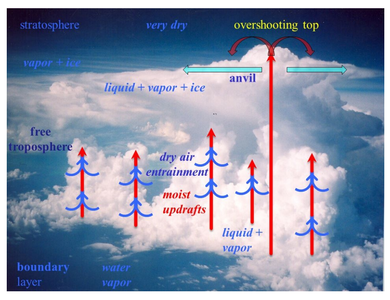
Multi-angular water vapor absorption measurements (1km resolution)

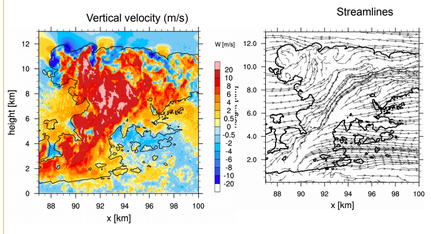
Expected products:

- Integrated water vapor column amount at 1km around the convective clouds
- With multi-angular measurements, coarse vertical water vapor profiles including water vapor amount in the lower atmospheric layers amounts

Science benefits:

- ***Comparison with simulated clouds for evaluation of mixing:***
  - Water vapor and cloud interactions
  - Entrainment/detrainment processes between clouds and their environment
  - Water vapor redistribution in the atmosphere





LES of cumulonimbus (Δx=50m) (*Verrelle et al, 2017*)

- ***Evaluation and improvement of parameterizations:***
  - Turbulence scheme (eddy diffusivity) for Cloud Resolving models: partition between resolved motion (vertical velocity) and subgrid transport (turbulent mixing)
  - Shallow convection scheme (eddy diffusivity and mass flux) for Cloud Resolving Models
  - Convection scheme (mass flux) for global models

- **With JPPS instruments:**
  - Convective cloud organization and humidity profile modification with **ATMS**
  - Relation between CTH and Rain with **ATMS**

Lightning imagers and photometers

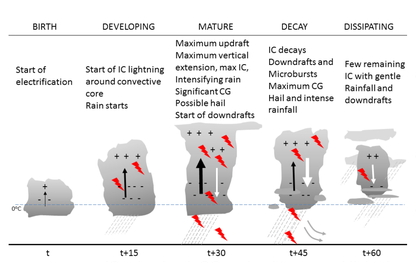
Detection and characterization of the lightning activity in regard to its parent convective cloud development

Expected products:

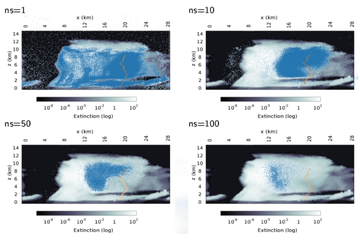
- Lightning detection and flash activity during day and night
- Temporal and spectral Characterization of lightning flash
- Lightning characterization at high latitudes

Science benefits:

- ***Lightning physics at multiple temporal and spatial scales:***
  - Link between lightning activity and convection characteristics (cloud height, cloud growth…)
  - Links between lightning activity and upper tropospheric water vapor
  - Scattering of the optical lightning signal by ice and liquid hydrometeors



IC = in-cloud; CG = cloud-to-ground lightning



Photons propagation trough a LES CLOUD, Simonne Guilbert, Master report

- ***Characterization of lightning source:***
  - Lightning stereo and cloud shape retrieval with radiative transfer process to characterize the lightning source in terms of position and energy level

- ***Improvement/Validation of lightning and electrification parameterizations in Cloud Resolving Models***

- **With geo-satellite observations:**
  - Statistical studies of cloud life cycle
  - Lightning as a proxy of strong vertical wind => study with C³IEL for extension to geostationary satellite
  - Impact of aerosol concentration (AOT), size (Angstrom Exponent) and types (e.g., fine non-absorbing, absorbing, dust, maritime) on cloud formation and development