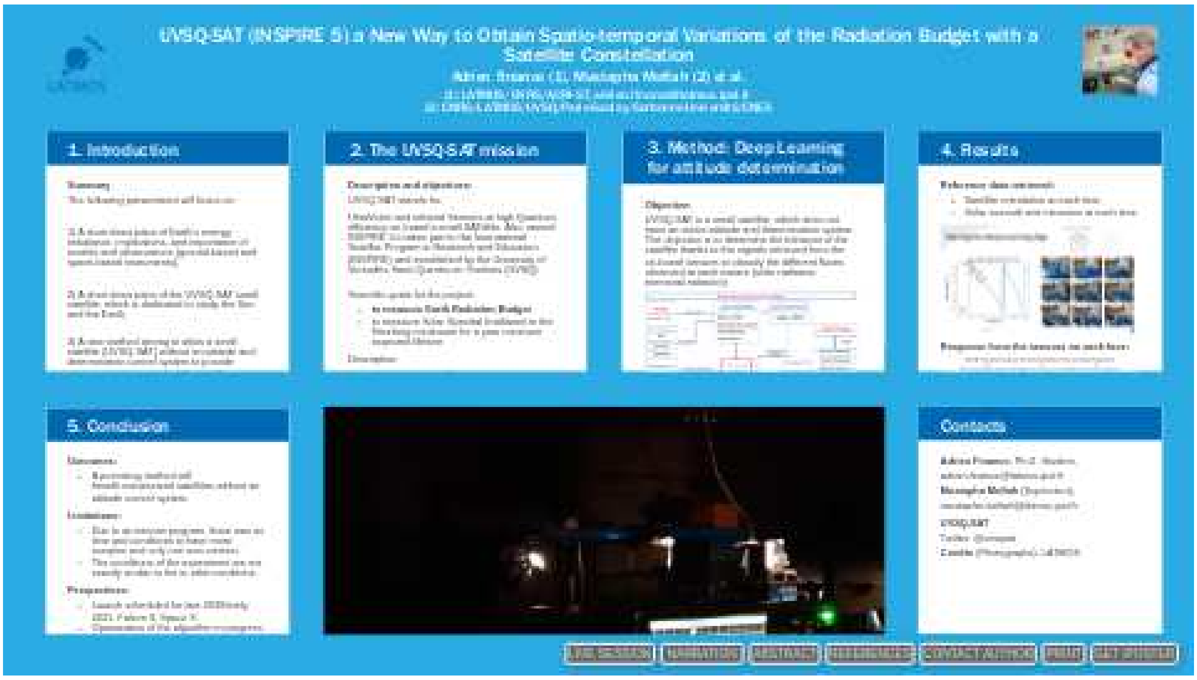
UVSQ-SAT (INSPIRE 5) a New Way to Obtain Spatio-temporal Variations of the Radiation Budget with a Satellite Constellation



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PRESENTED AT:

1. INTRODUCTION

Summary

The following presentation will focus on:

1) A short description of Earth's energy imbalance, implications, and importance of models and observations (ground-based and space-based instruments),

2) A short description of the UVSQ-SAT small satellite, which is dedicated to study the Sun and the Earth,

3) A new method aiming to allow a small satellite (UVSQ-SAT) without an attitude and determination control system to provide accurate measurements of Earth's Energy Imbalance.

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Problematic:

Climate change (GIEC - 2014):

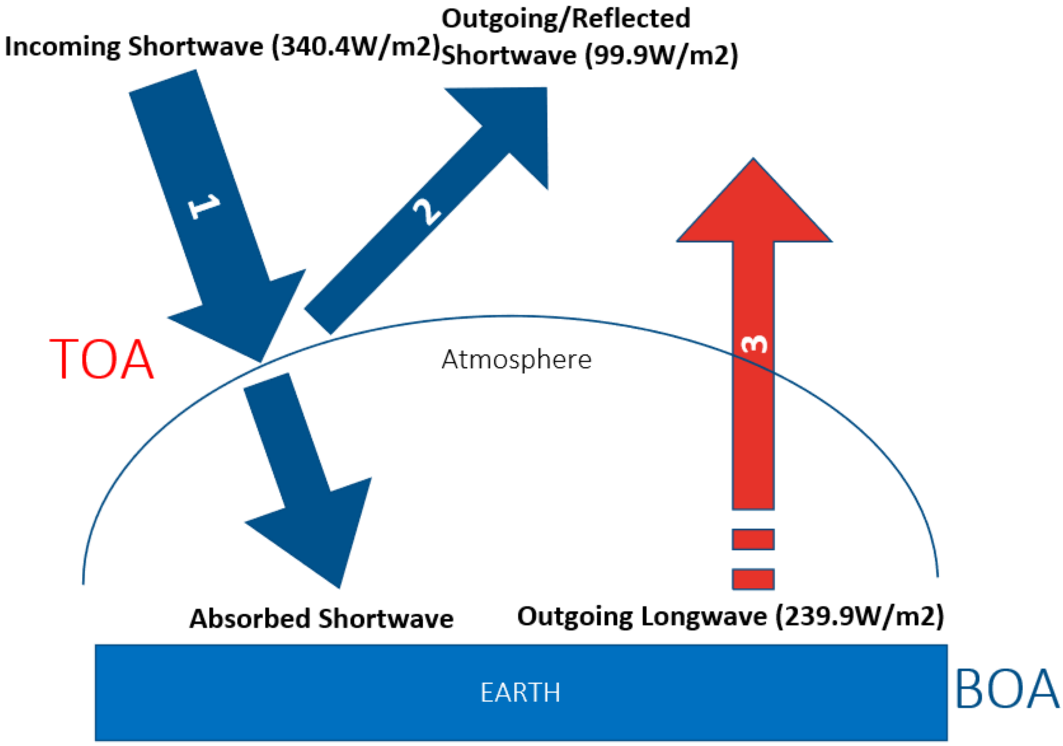
- CO_2 accumulation since 1750 has doubled between 1970 and 2011
- Sea level has increased by 0.19 m between 1901 and 2010
- The surface temperature has increased by about 0.2 K/decade since 1981

Prediction:

- The worst scenario (RCP8,5) predicts a temperature increase of 2.6°C to 4.8°C between 1986-2005 to 2081-2100.

A metric to monitor and understand those changes:

- To understand the evolution of Earth temperatures and climate variability, Earth's Energy Imbalance appears to be the perfect metric [von Schuckmann et al., 2016]. The Earth's Energy Imbalance aims to consider each of the input/output fluxes of the system as they are defined in the figure below. [Trenberth et al, 2010; Hansen et al., 2005]



Actually, the albedo is clearly related to the variation in temperature and 5 % of albedo change is equivalent to a change of 1 K in surface temperature. The Earth Energy Imbalance is one of the Essential Climate Variable (ECV) and is a measure of the amount of energy per unit of surface that will reside on Earth per unit of time.

EEI = Incoming Solar Radiation - [Outgoing Shortwave Radiation + Outgoing Longwave Radiation]

Here, we have,

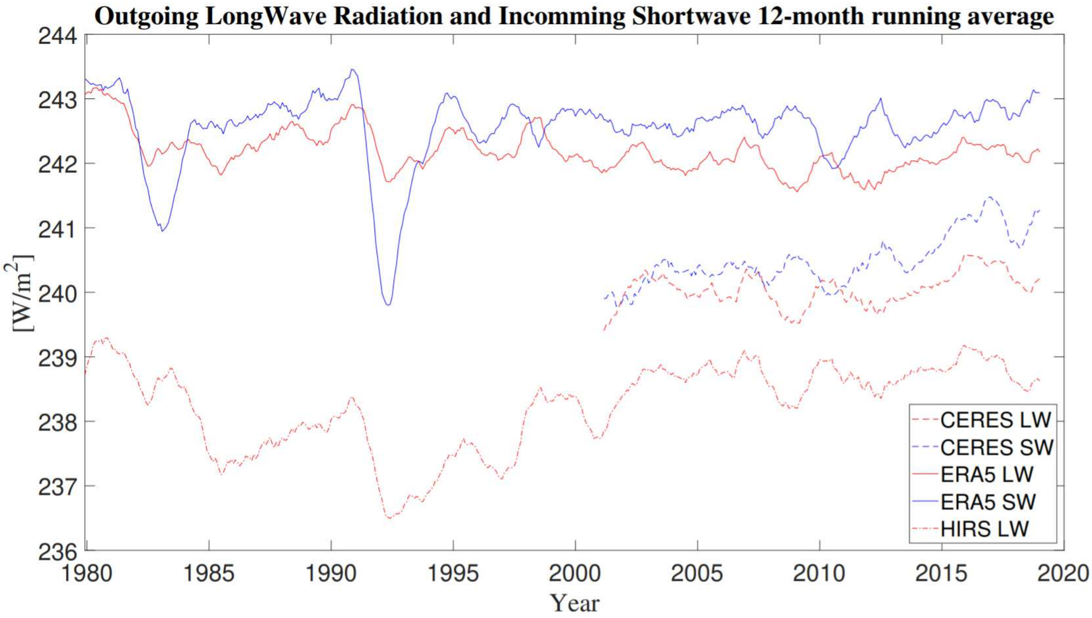
EEI = 340.4-[99.9+239.9]=0.6 W/m^2>0 (Warming)

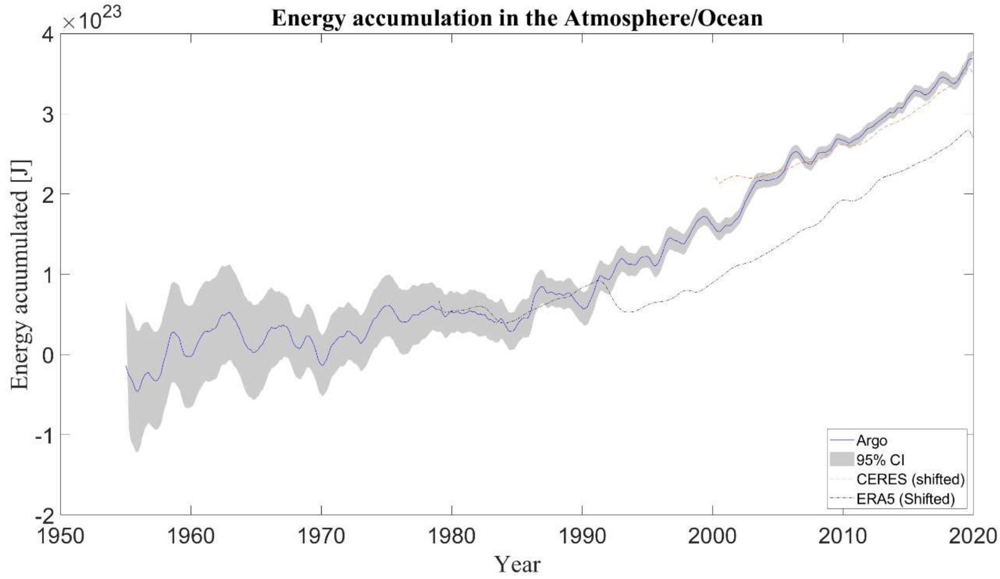
As mentioned before some of that energy is melting ice, warming land, and the atmosphere but the biggest part (93%) is stored in the ocean. To retrieve the EEI it is possible to:

- study the heat content in the ocean as 93 % of the excess energy accumulated by Earth is stored in the oceans [Meyssignac et al., 2019].
- study in and out fluxes at the Top Of the Atmosphere.

Datasets :

- ERA5, a model to retrieve the fluxes at TOA [Hersbach et al., 2020]
- CERES, measurements of fluxes at TOA thanks to Aqua/Terra and geostationary satellites [Loeb et al., 2018]
- ARGO-IAP, measurement of temperatures from 0 to 2000m deep in the ocean (Cheng, the Institute of Atmospheric Physics) [Cheng et al., 2016]





[Finance et al., 2021, manuscript in preparation]

The ocean stores the energy but the inertia of that storage is really important compared to the inertia of the atmosphere.

Therefore, and according to the previous analysis, we suppose that the OHC is a perfect metric to monitor long-term variability whereas the observations at TOA are suitable for High-Frequency dynamics.

A relevant approach is to adapt the measurements at TOA to long term trends from ARGO data. This is what has been done for the EBAF dataset, adapting the trend to OHC.

Long term trend:

- EEI: 0.71±0.10 W/m^2/decade [Johnson et al., 2016]
- Sensitivity: 0.1 W/m^2/decade at 1σ

Short term trend:

- Sensitivity: few W/m^2 to control radiative forcings (aerosols)
- Spatial resolution: few km
- Temporal resolution: 3 hours

[Meftah et al., 2020]

=> Miniaturize instruments into a CubeSat to measure the EEI.

Datasets :

- CERES EBAF Ed4.1

- ERA5 Monthly Averaged Reanalysis

- OHC (Ocean Heat Content) Estimate v3 CZ16 method (EnOI-DE/CMIP5 method)

2. THE UVSQ-SAT MISSION

Description and objectives:

UVSQ-SAT stands for:

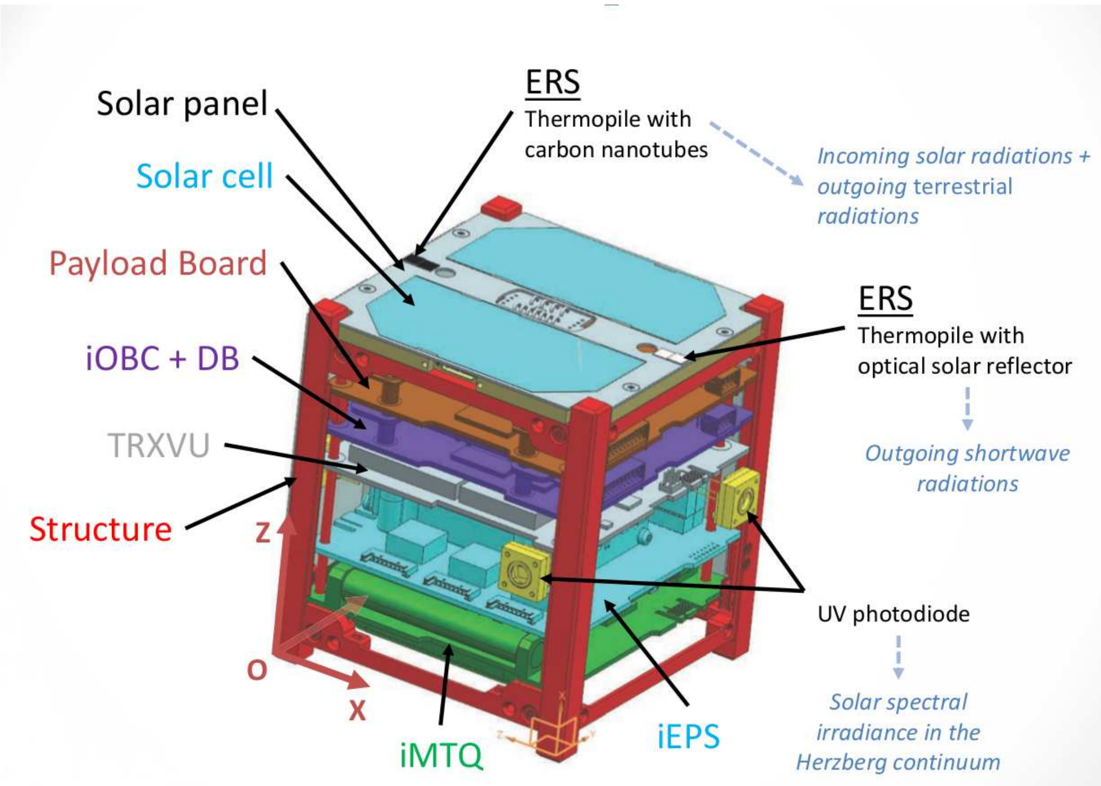
UltraViolet and infrared Sensors at high Quantum efficiency on-board a small SATellite. Also named INSPIRE 5 it takes part in the International Satellite Program in Research and Education (INSPIRE) and established by the University of Versailles Saint-Quentin-en-Yvelines (UVSQ).

Scientific goals for the project:

- **to measure Earth Radiation Budget**
- to measure Solar Spectral Irradiance in the Herzberg continuum for a year minimum expected lifetime

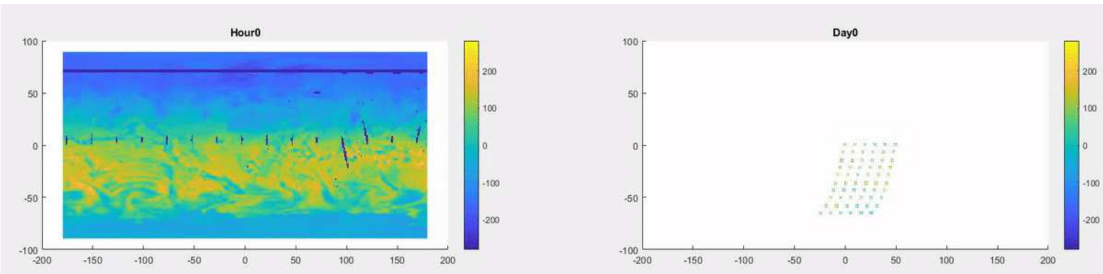
Description:

It uses high quantum efficiency ultraviolet and infrared sensors. It is composed of twelve miniaturized Earth Radiative Sensors distributed on the six faces.



credits: LATMOS, [Meftah et al., 2020]

Part of a future constellation:



Calibration:

Due to sanitary conditions, the calibrations could not be carried out in the laboratories specialized for this purpose (PTB in Germany, LASP in the US). Therefore the team effectively set up custom-made calibration benches in order to calibrate the various sensors as best as possible.

Each of those calibration benches corresponded to each type of sensor.

Sensors:

ERS (Earth Radiation Sensor with Wide Field Of View):

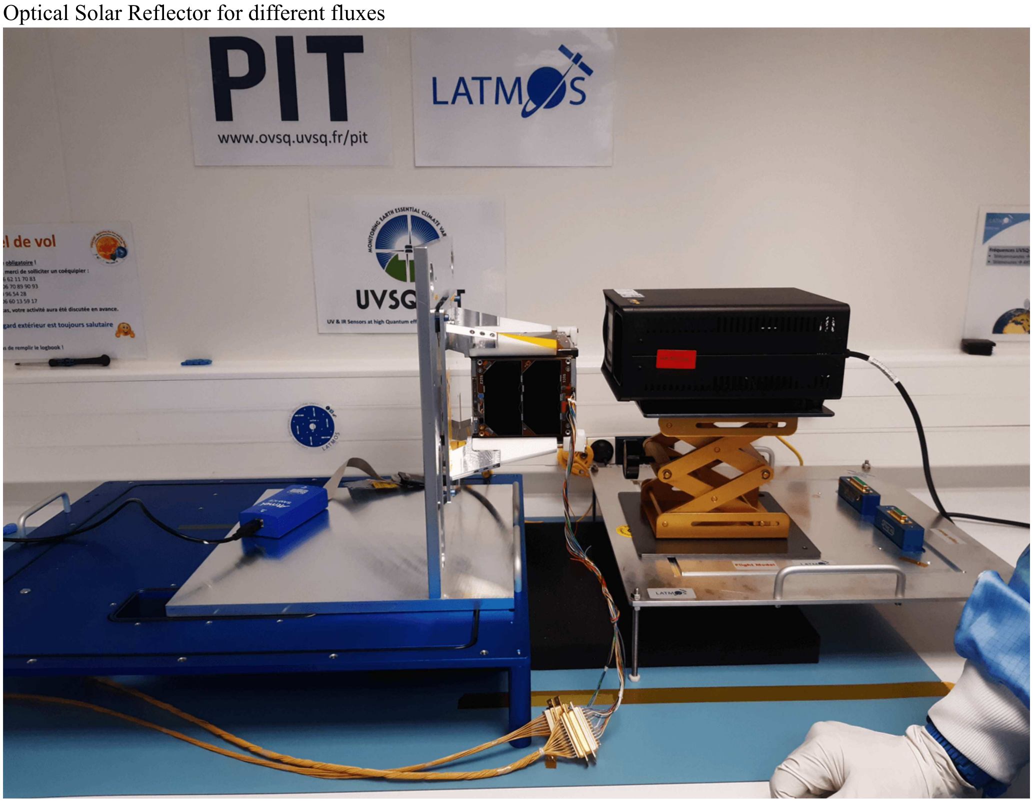
- 6 x Carbon NanoTubes: Total Solar Irradiance (TSI) + Outgoing Shortwave Radiation (OSR) + Outgoing Longwave Radiation (OLR), 0.2 - 100 µm
- 6 x Optical Solar Reflector: OLR, 0.2 - 3 µm (absorptivity=0.06), 3 - 100 µm (absorptivity=0.84)

UVS (Ultra Violet Sensor with Narrow Field Of View):

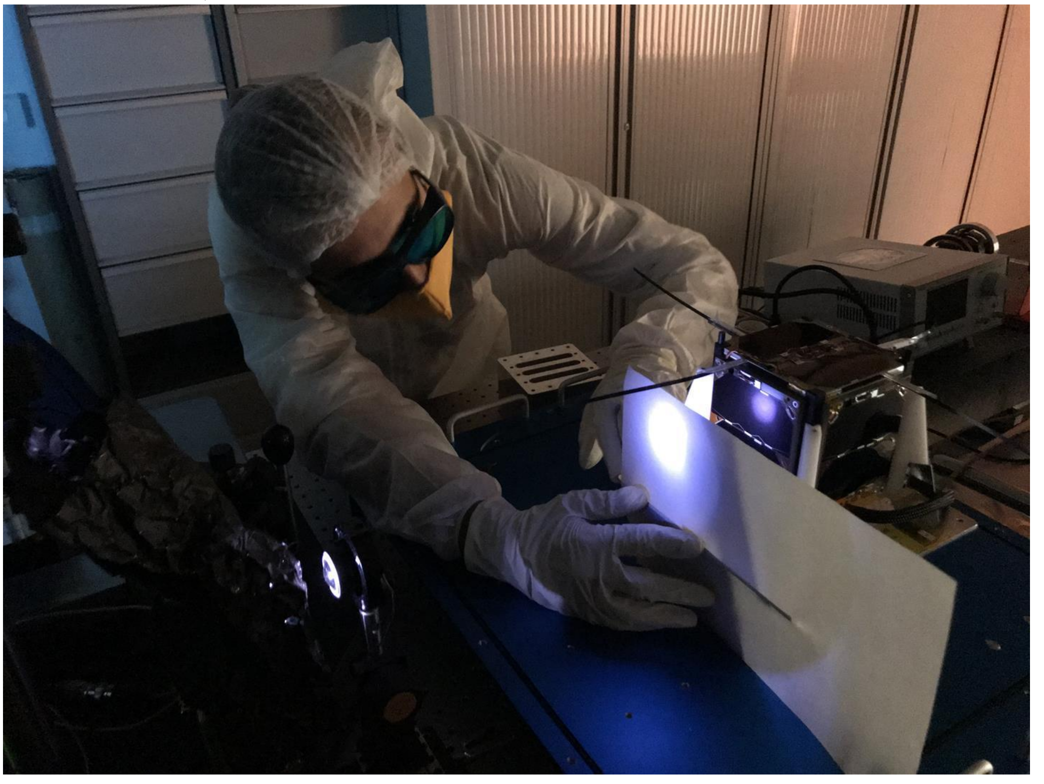
- 3 x UVS UV: 200 - 1100 nm
- 1 x UVS TSI: 220 nm, FWHM = 10.14 nm at 50 %, FWHM = 17.41 nm at 90 %

Phases:

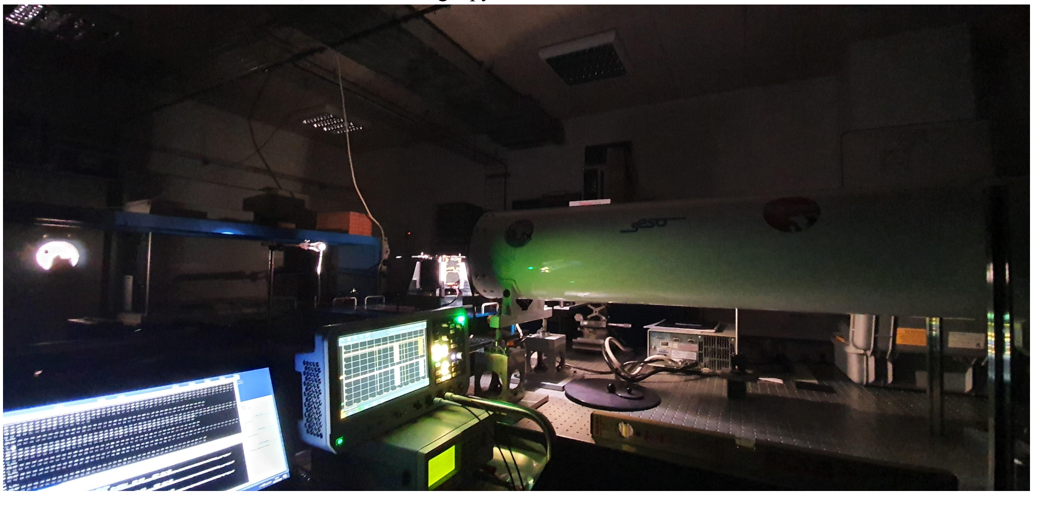
- Black body: ERS - Carbon NanoTubes / Optical Solar Reflector, Goal: Longwave Radiation to calibrate ERS - Optical Solar Reflector for different fluxes



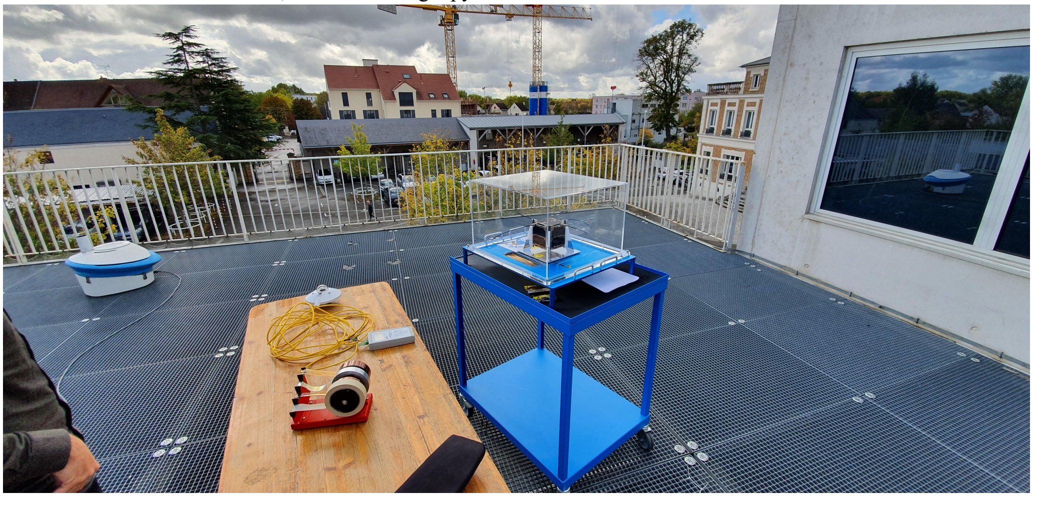
- Deuterium: UVS - UV, Goal: UV Radiation to calibrate the UVS sensors



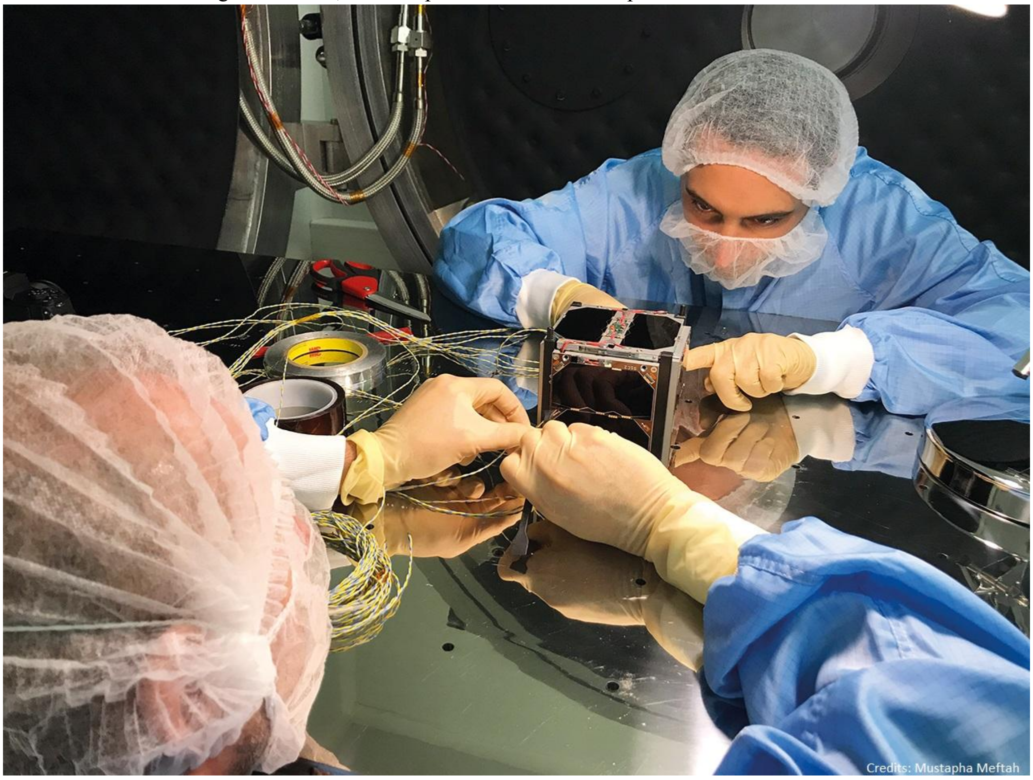
- Xenon: ERS - CNT + UVS - TSI, reference using a pyranometer



- Sun: ERS - CNT + UVS - TSI, reference using a pyranometer



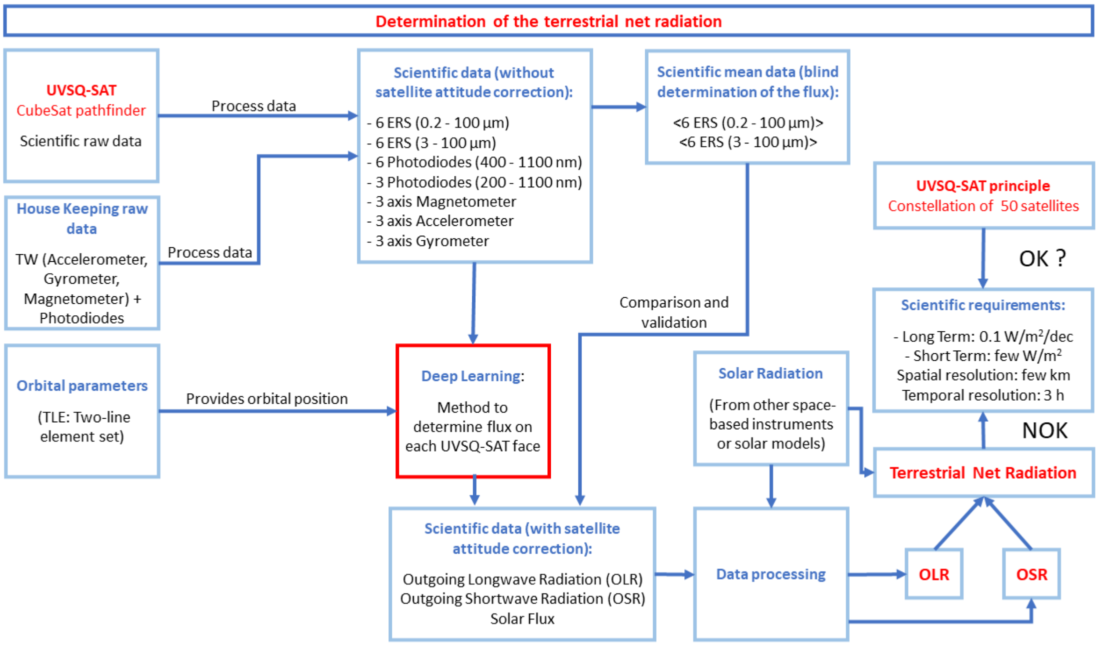
- Thermal Vacuum Testing: Dark UVS, linear dependence with the temperature



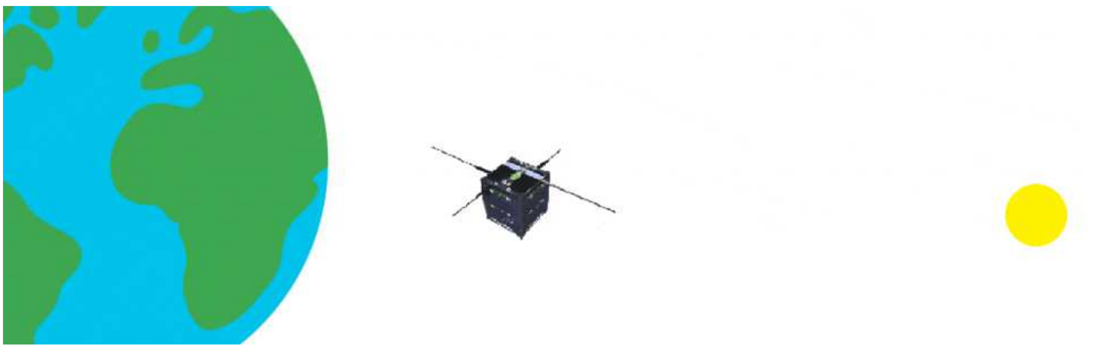
3. METHOD: DEEP LEARNING FOR ATTITUDE DETERMINATION

Objective:

UVSQ-SAT is a small satellite, which does not have an active attitude and determination system. The objective is to determine the behavior of the satellite thanks to the signals retrieved from the on-board sensors to classify the different fluxes observed at each instant (solar radiation, terrestrial radiation)



Methods:



1st step: Earth (In-orbit training)

Determine the position of the satellite in the plane normal to nadir

- Using the ERS (3 - 100 µm) sensors
- Regression algorithm

2nd step: Sun (Training below)

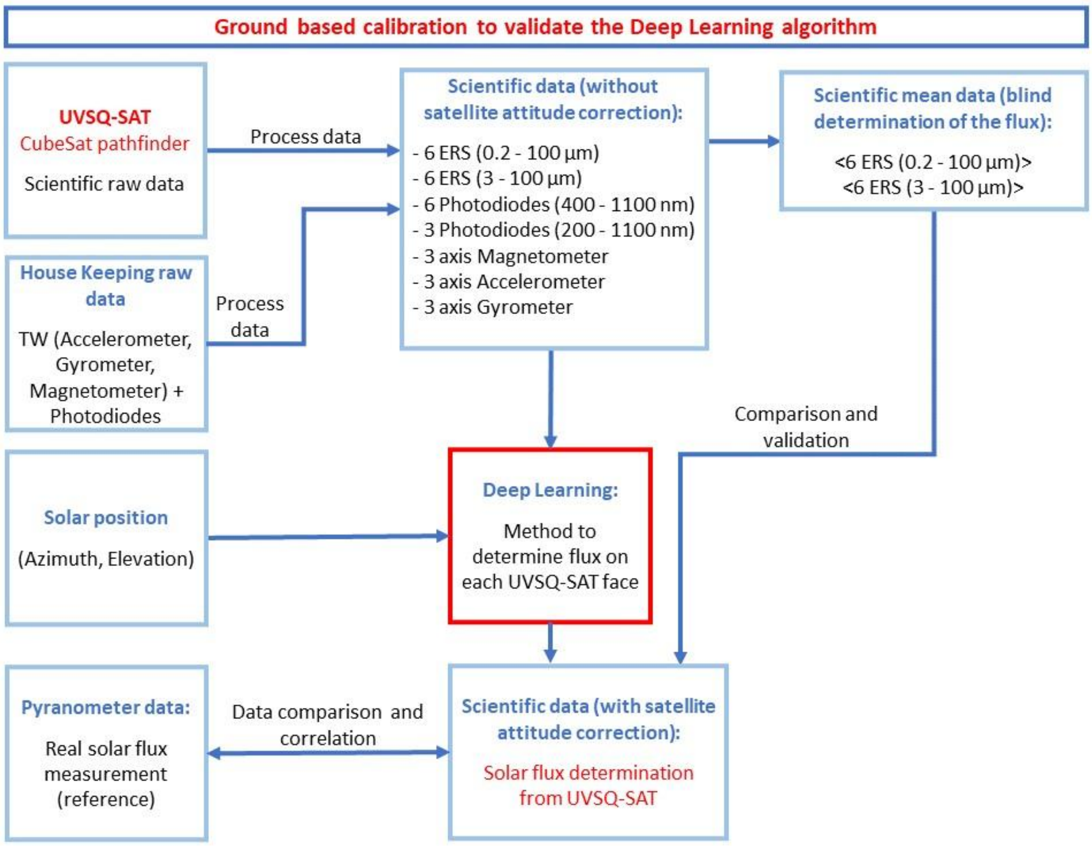
Determine the azimuth of the sun

- Using ERS (0.2 - 100 µm) sensors Wide Field Of View (WFOV)
- Regression algorithm

OR

- Using UVS sensors, Narrow Field Of View (NFOV)
- Classification algorithm (facing the sun or not)

Training for Sun azimuth and elevation determination:

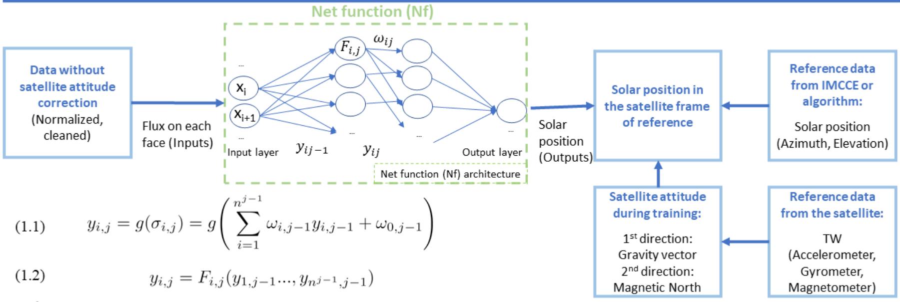


- Rotation of the CubeSat into different known positions

- Retrieve the signals from the satellite sensors, the Cubesat's orientations (its Euler angles), and the Solar position

Theoretical architecture:

Deep Neural Network training theory for attitude determination



(1.1) $$y_{i,j} = g(\sigma_{i,j}) = g\left(\sum_{i=1}^{n^{j-1}} \omega_{i,j-1} y_{i,j-1} + \omega_{0,j-1}\right)$$

(1.2) $$y_{i,j} = F_{i,j}(y_{1,j-1} \dots, y_{n^{j-1},j-1})$$

where,

- $y_{i,j}$ are the output of the node (i,j) and $y_{i,0} = x_i$ are the inputs, $\forall i \in [1, n^0]$ and $\forall j \in [1, l]$
- l is the total number of layer
- $\sigma_{i,j}$ is the cache output before going through the activation function
- n^j is the number of neuron at layer j
- g is the activation function
- $\omega_{i,j}$ are the weights, $\omega_{0,j}$ is called the bias

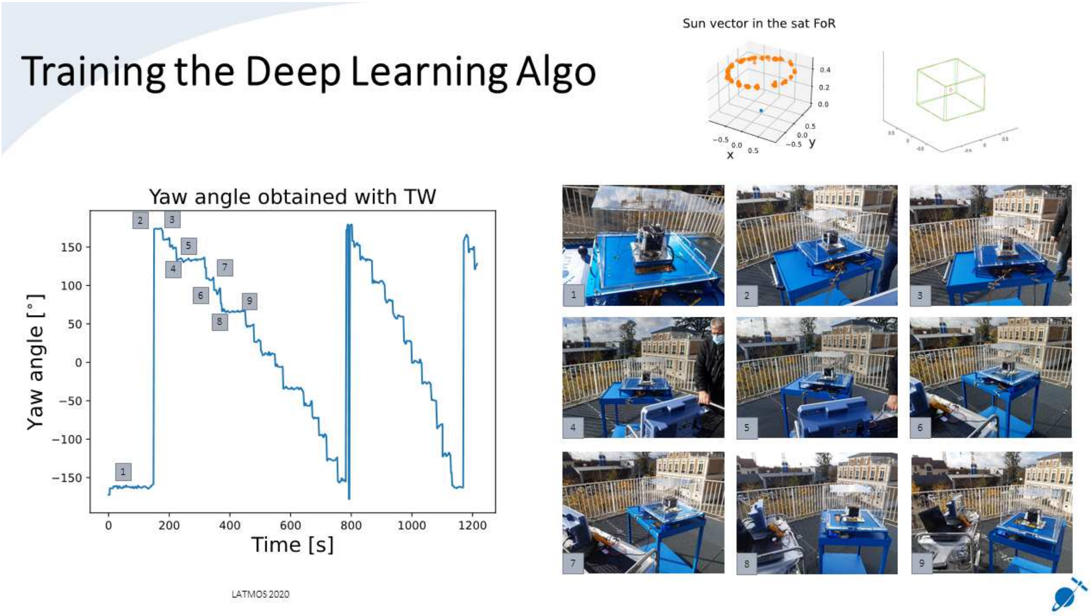
For UVSQ-SAT, we choose to use ReLU activation function such as:

$$g(x) = \begin{cases} 0 & \text{for} \quad x < 0 \\ x & \text{for} \quad x \geq 0 \end{cases}$$

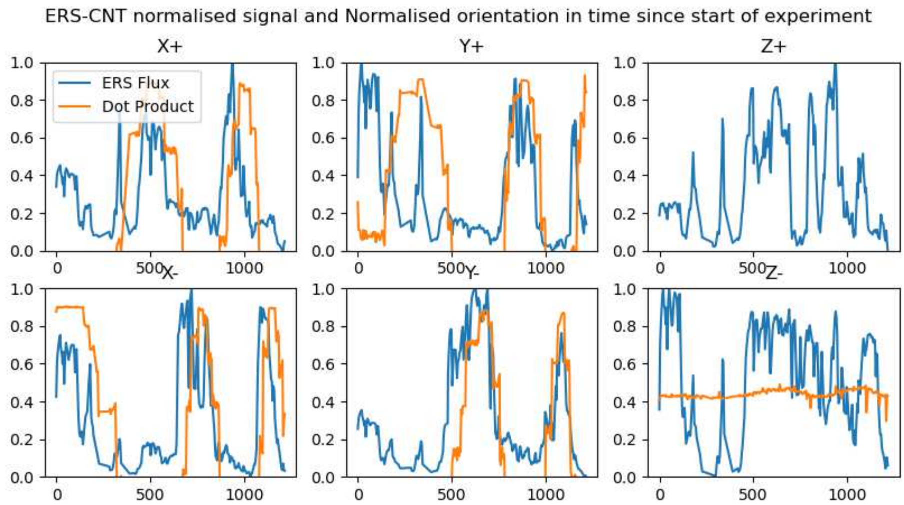
4. RESULTS

Reference data retrieved:

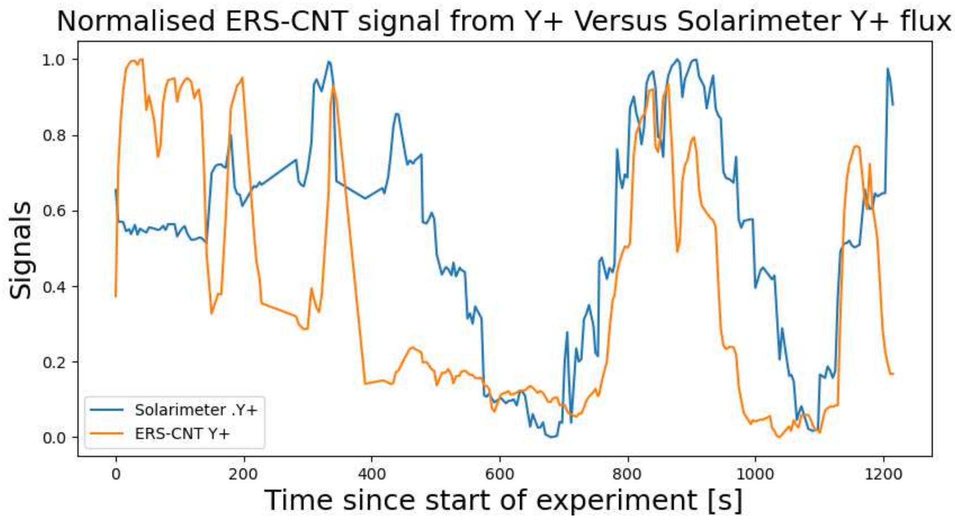
- Satellite orientation at each time
- Solar azimuth and elevation at each time



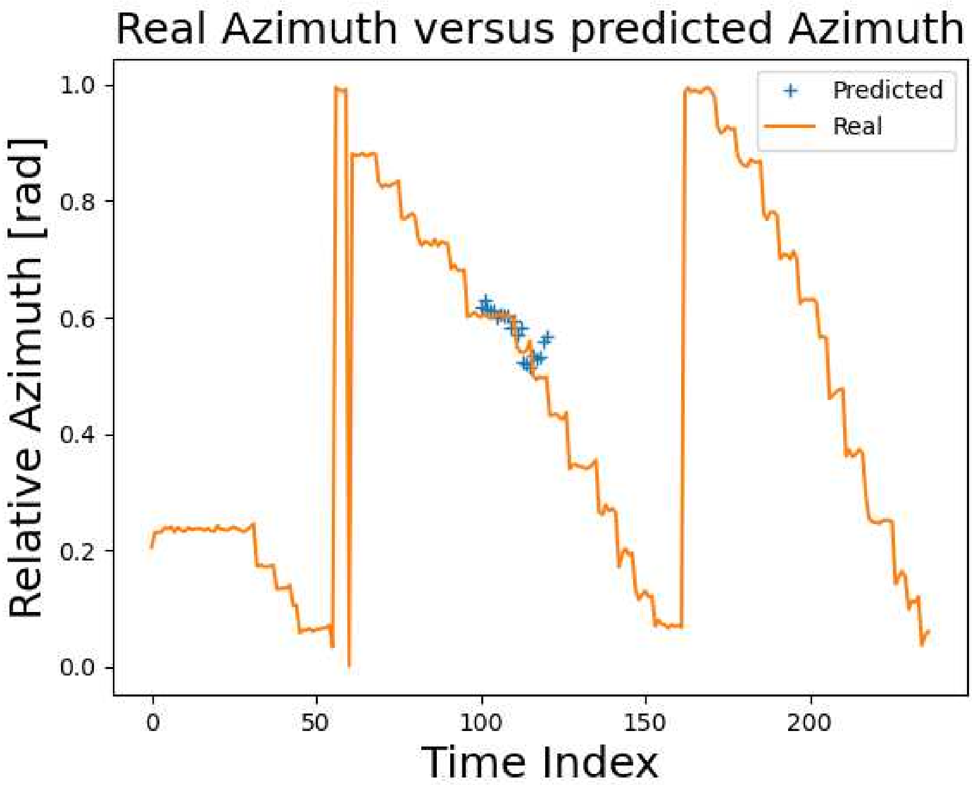
Response from the sensors on each face:



Flux normalization on face Y+ using the angular correction reference pyranometer:



Predict the azimuth with 4 fully connected layers:



5. CONCLUSION

Outcomes:

- A promising method will benefit miniaturized satellites without an attitude control system.

Limitations:

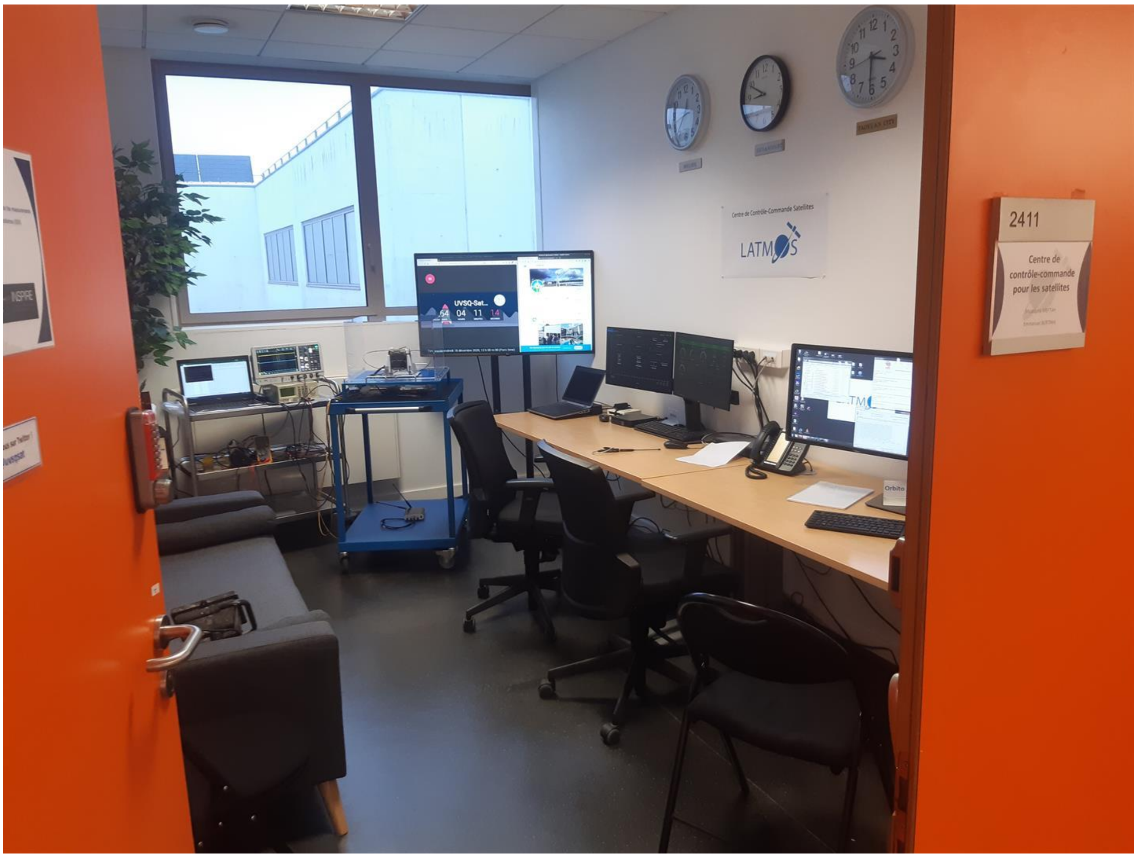
- Due to an intense program, there was no time and conditions to have more samples and only one axis rotation.
- The conditions of the experiment are not exactly similar to the in-orbit conditions.

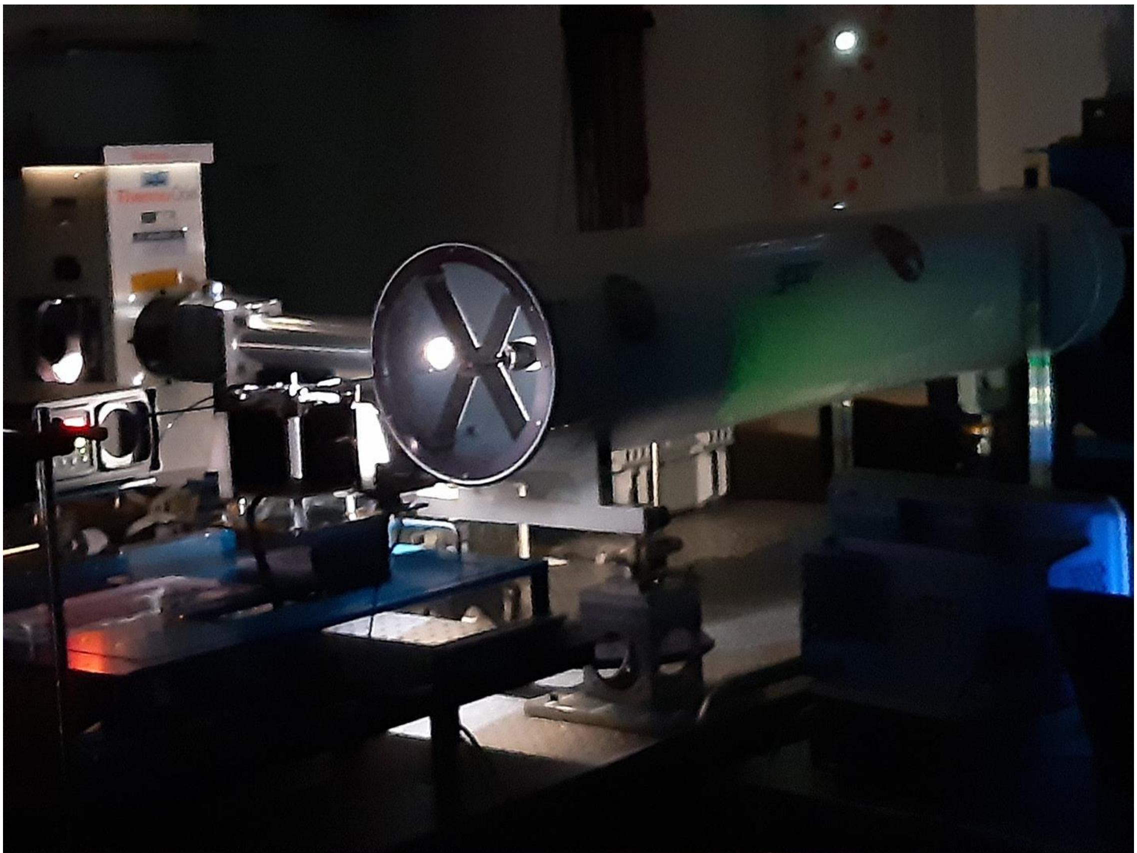
Perspectives:

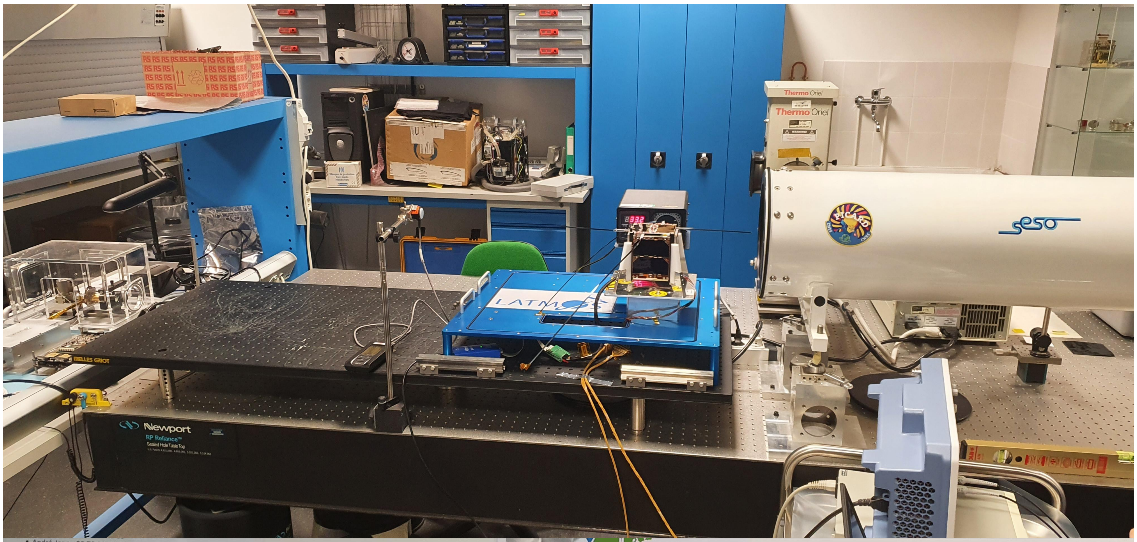
- Launch scheduled for early 2021, Falcon 9, Space X.
- Optimization of the algorithm in progress (layers hyperparameters, activation functions, use convolution network instead)
- Train the deep learning algorithm in-orbit (Magnetometer, Accelerometer, Gyrometer)

Future:

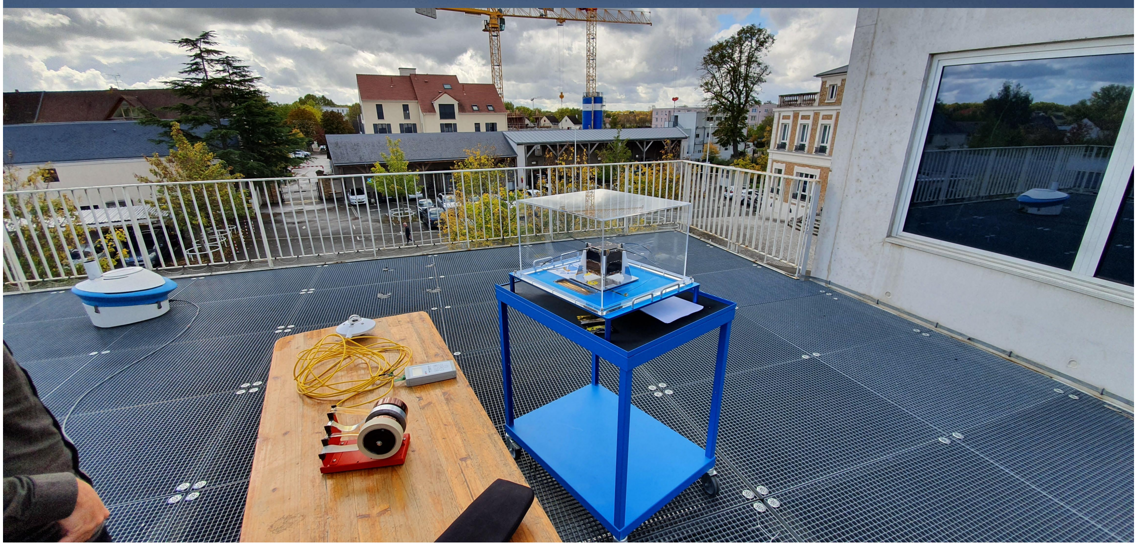
- UVSQ-SAT+ to be launched in June 2022
- The algorithm for satellite attitude knowledge will be implemented in the future constellation
- A future constellation of small satellites to improve spatiotemporal resolution






Newport
Thermo Oriel


UVSQSAT
Dans tous les cas, votre activité aura été discutée en avance.
Un regard extérieur est toujours salutaire



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UVSQ-SAT

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ABSTRACT

Monitoring Earth Energy Imbalance (EEI) is absolutely fundamental to understand and prevent climate change as it corresponds to the Earth's excess heat. In particular, measuring radiative forcing in an environment with a wide range of conditions entails a better understanding of its impact on the climate.
The UltraViolet and infrared Sensors at high Quantum efficiency on-board a small SATellite (UVSQ-SAT) aims to improve measurements of the radiation at Top Of the Atmosphere (TOA). It becomes a pathfinder for Radiation Budget measurements on-board a CubeSat demonstrating a disruptive technology, implementing miniaturized sensors on a small satellite (twelve miniaturized thermopiles sensors and four photodiodes). This project is promoted by the University of Saint-Quentin-en-Yvelines with the support of the International Satellite Program in Research and Education (INSPIRE). The satellite will be launched and in-orbit in December 2020.
One of the main purposes of the mission is to measure the Essential Climate Variables (ECV) more precisely using multi-point observation, in an effort to improve spatiotemporal coverage through future constellation. The scientific goals of the mission are first to observe incoming solar radiation and outgoing terrestrial radiation at Top Of the Atmosphere. The second purpose is to measure solar spectral irradiance in the Herzberg continuum. Finally, the third objective is to improve the technological readiness of a sensor.
This session will focus on the ability to define the spatiotemporal accuracy required to monitor the variability of those Essential Climate Variables. Therefore, it will allow us to determine the number of satellites and characteristics of the future constellation meeting these specifications.

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