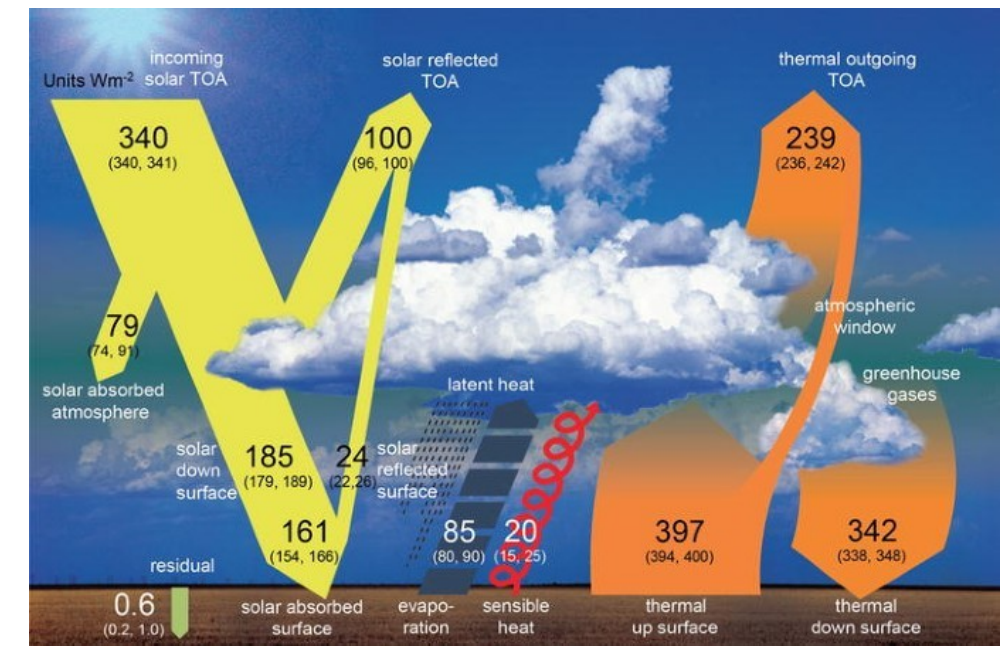


Introduction



Wild et al (2013)²

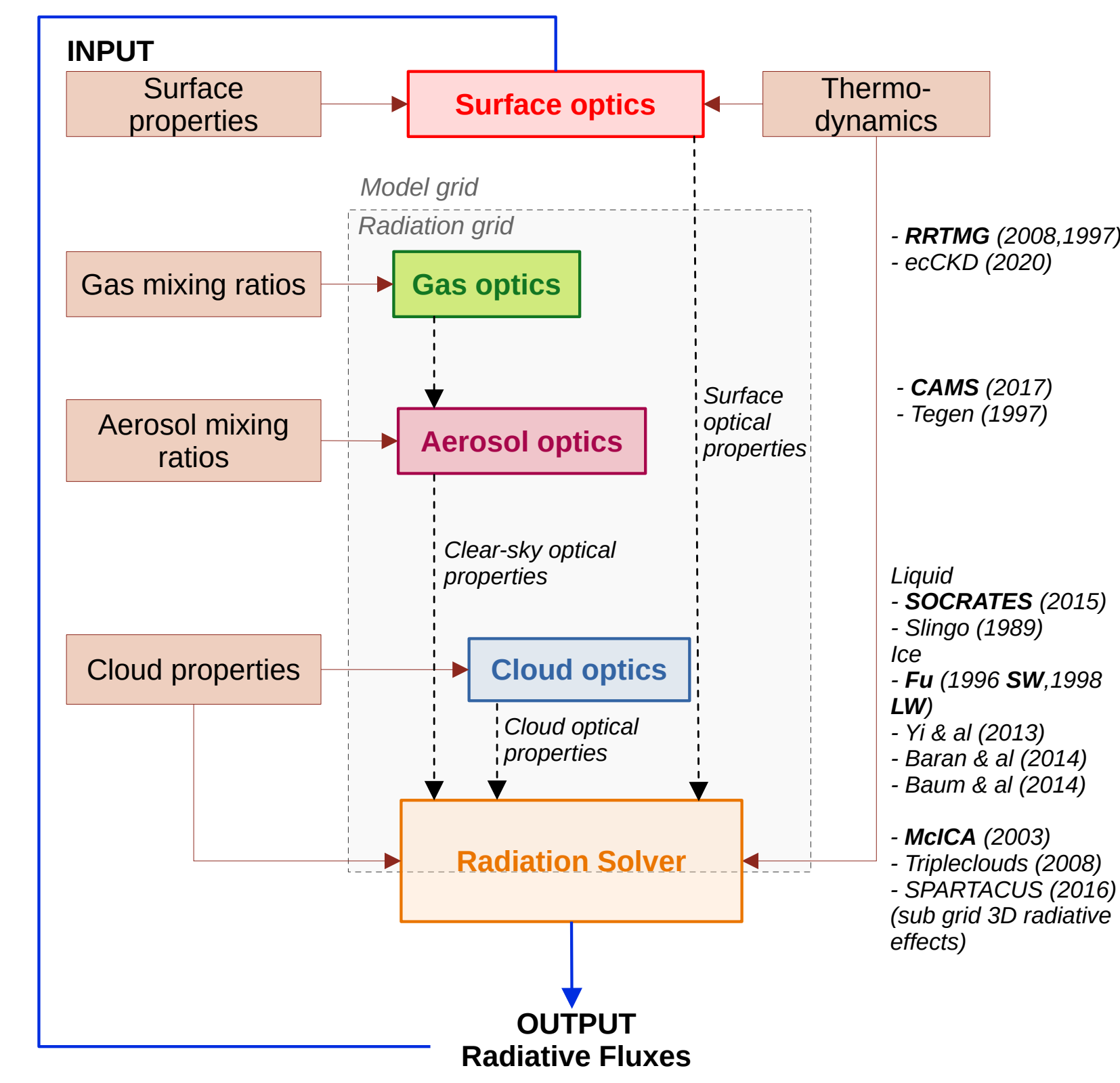
Clouds are a crucial component of the climate system¹, determining atmospheric energy balance and dynamics through processes such as radiation fluxes and transport of energy, moisture and momentum. Tropical deep convective clouds, which mainly drive precipitation and radiation, remain a source of uncertainty in numerical weather prediction models due to observational challenges regarding their properties, such as cloud fraction, vertical distribution, and particle size.

The **EarthCARE mission**, with its unique combination of active and passive sensors, provides unprecedented insights into cloud microphysical properties, vertical structure, and radiative effects. In order to better understand tropical clouds organisation and structure, we first evaluate the **AROME** model's ability to simulate cloud-radiation interactions by comparing its outputs with EarthCARE observations. This analysis establishes a reference baseline for assessing the sensitivity of the model to various configurations of the **EcRAD** radiative transfer scheme, which is include in the AROME model. Then, we conduct sensitivity tests to quantify the model's response according to different type of clouds and/or to variations in critical parameters. These tests aim to identify the parameters that most significantly influence cloud-radiation feedbacks and to improve the model's predictive capability.

Main Questions of my PhD:

- How accurate are clouds (fraction, content, radiation) simulated by AROME ?
- What are the impacts of radiative processes in cloud life cycle ? In spatial organisation of clouds ?

AROME and ecRAD



Inspired from Hogan & Bozzo (2018)

• AROME model :

- small scale numerical weather prediction model of Météo-France
- 2,5 km horizontal resolution
- 64 vertical levels (0-20km)
- hydrostatics mode

• EcRAD :

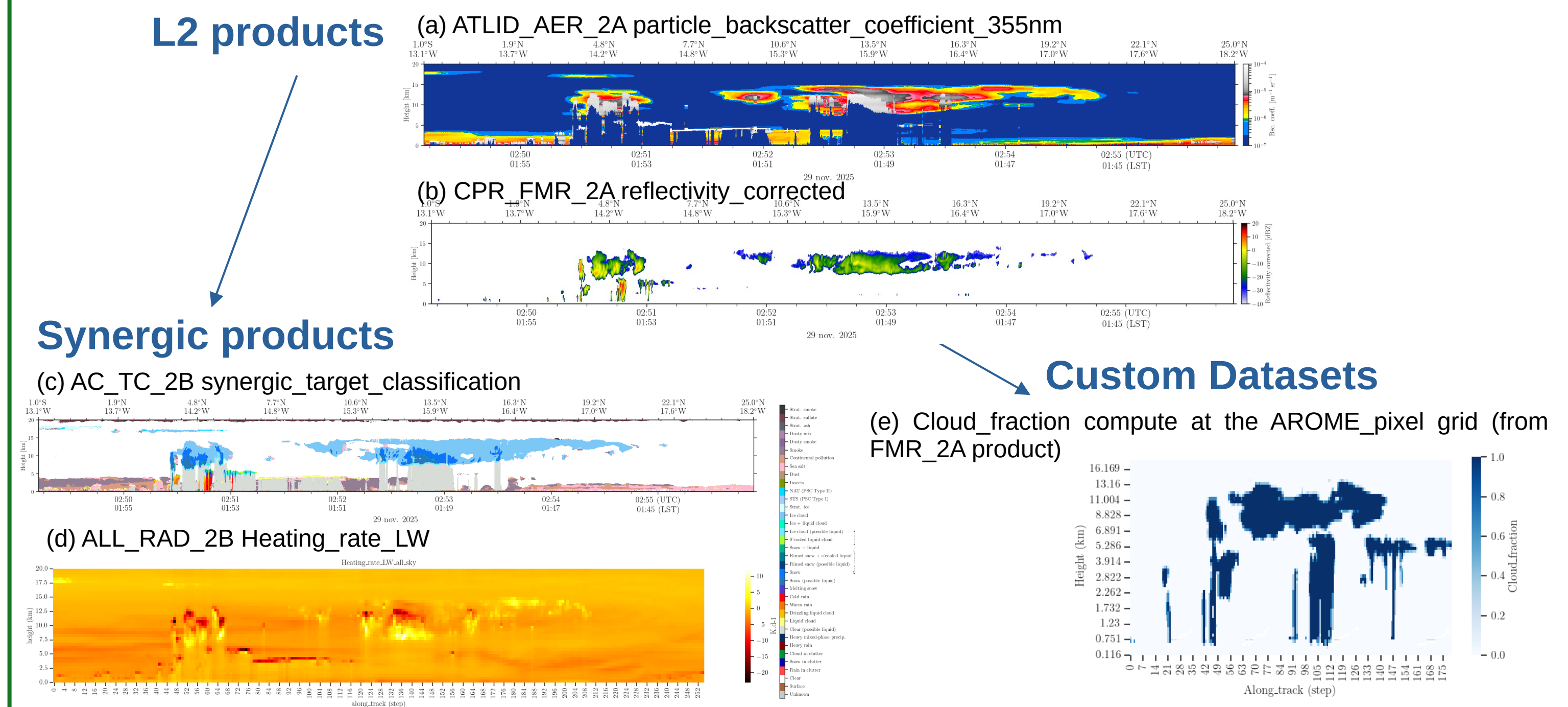
- ECMWF broadband radiation scheme
- Implemented in AROME
- Fast and flexible scheme

EarthCARE and other spaceborne observations

Clouds and the Earth's Radiant Energy System (CERES)

SYN1deg 1-Hourly product : radiative flux observed and calculated (TOA&BOA)
Earth Cloud, Aerosol, and Radiation Explorer

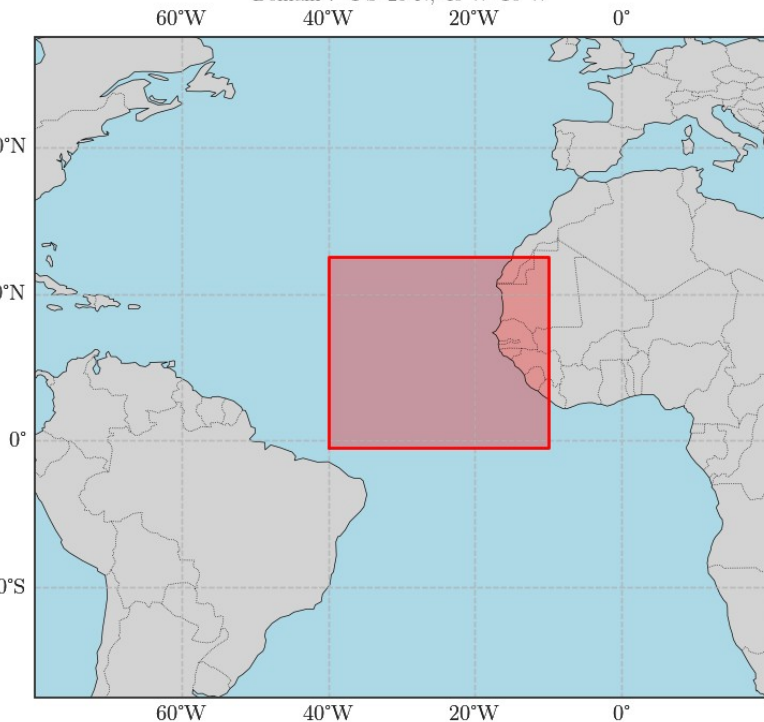
Launched in May 2024, Sun-synchronous, High resolution, combination of 4 instruments active and passive



First evaluation with CERES

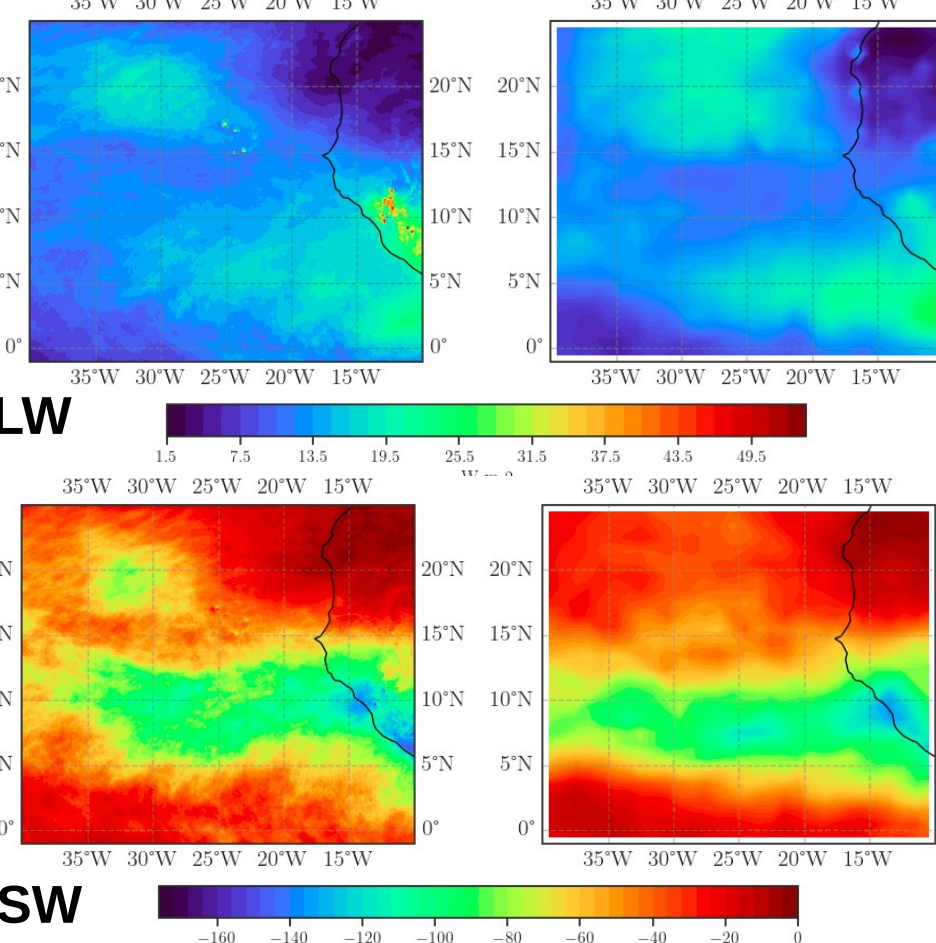
Simulation Setup :

- MAESTRO domain
- 10/08/24 to 09/09/24
- Initialisation at 09/08/24 18UTC
- 6h forcing
- Interactive Ocean mixed layer



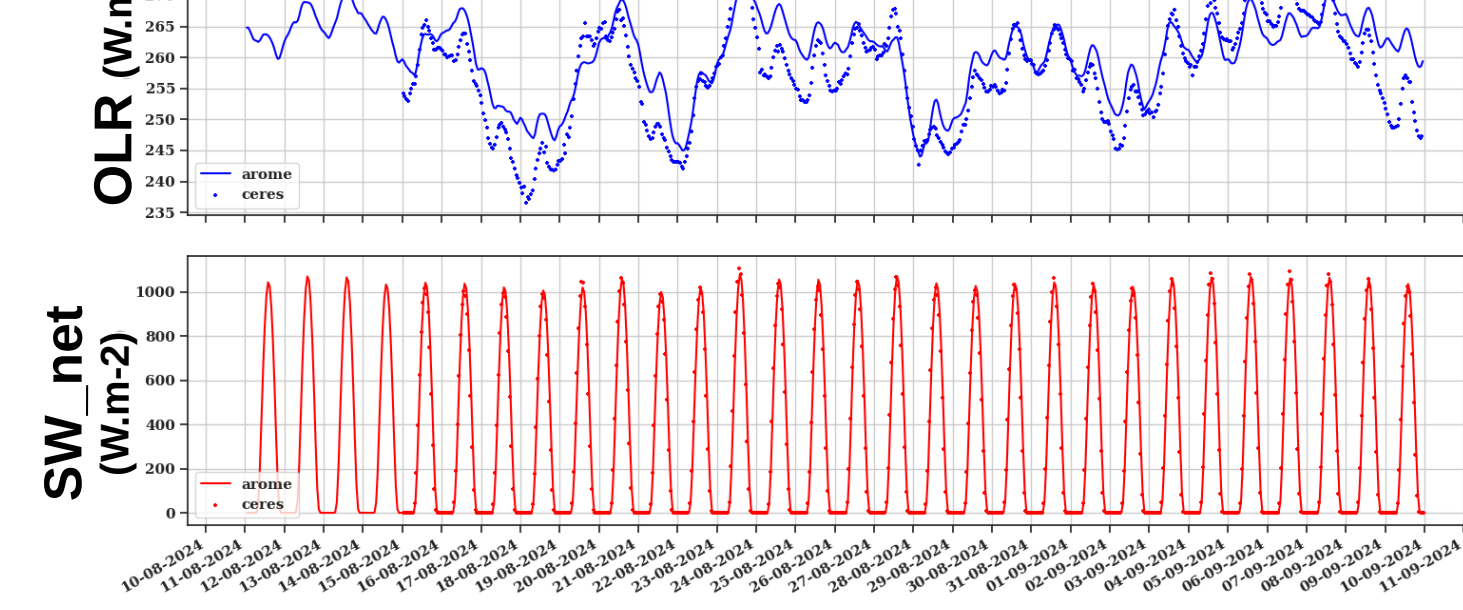
Cloud Radiative Effect (W.m-2)

Mean value on MAESTRO period



Time series over the MAESTRO period, At TOA

Mean value on MAESTRO domain, Each Hour



On average

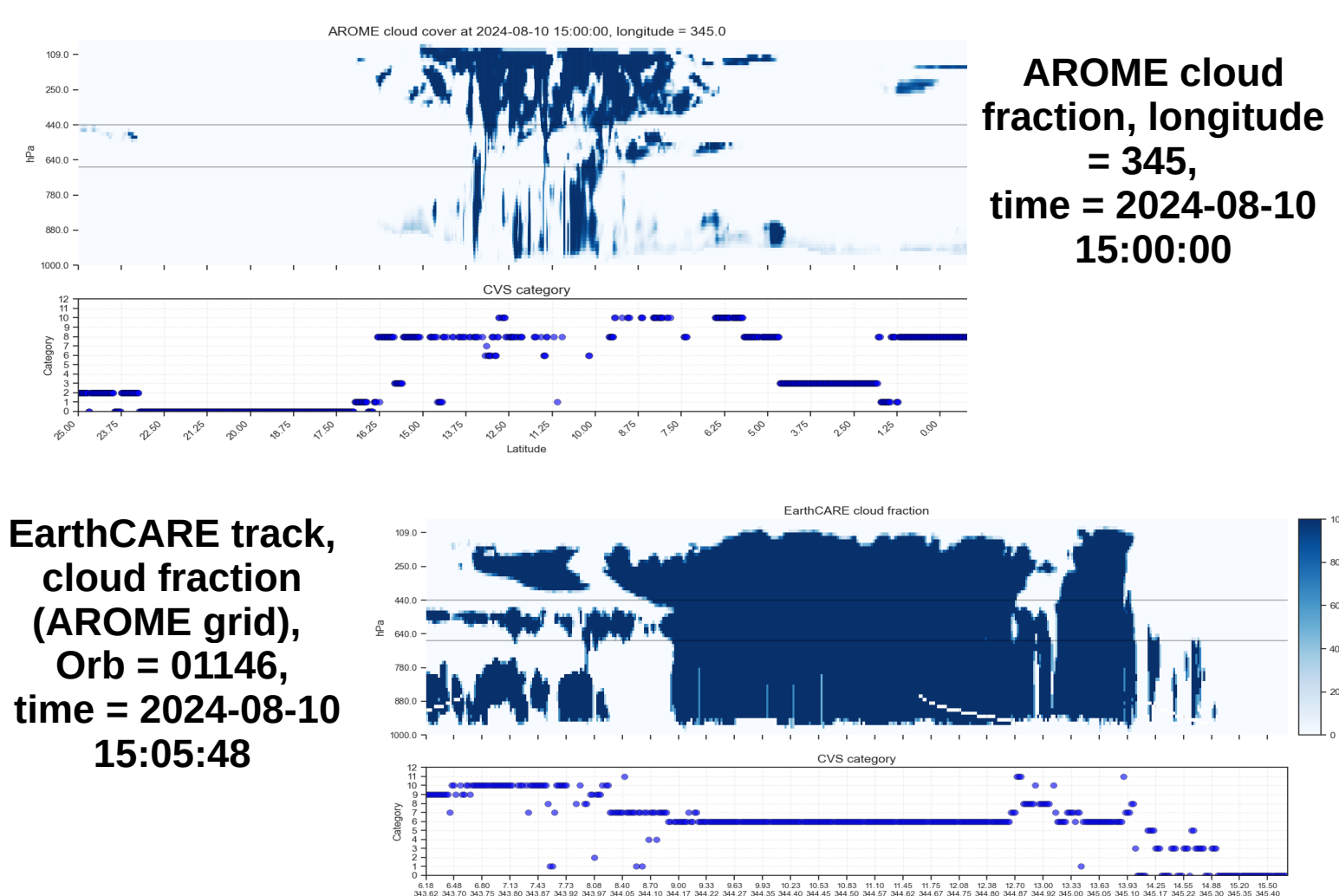
- Right order of magnitude for Cloud Radiative Effect
- At TOA, right behaviour of the model regarding CERES observations

But are we associated the right radiation to right clouds ?

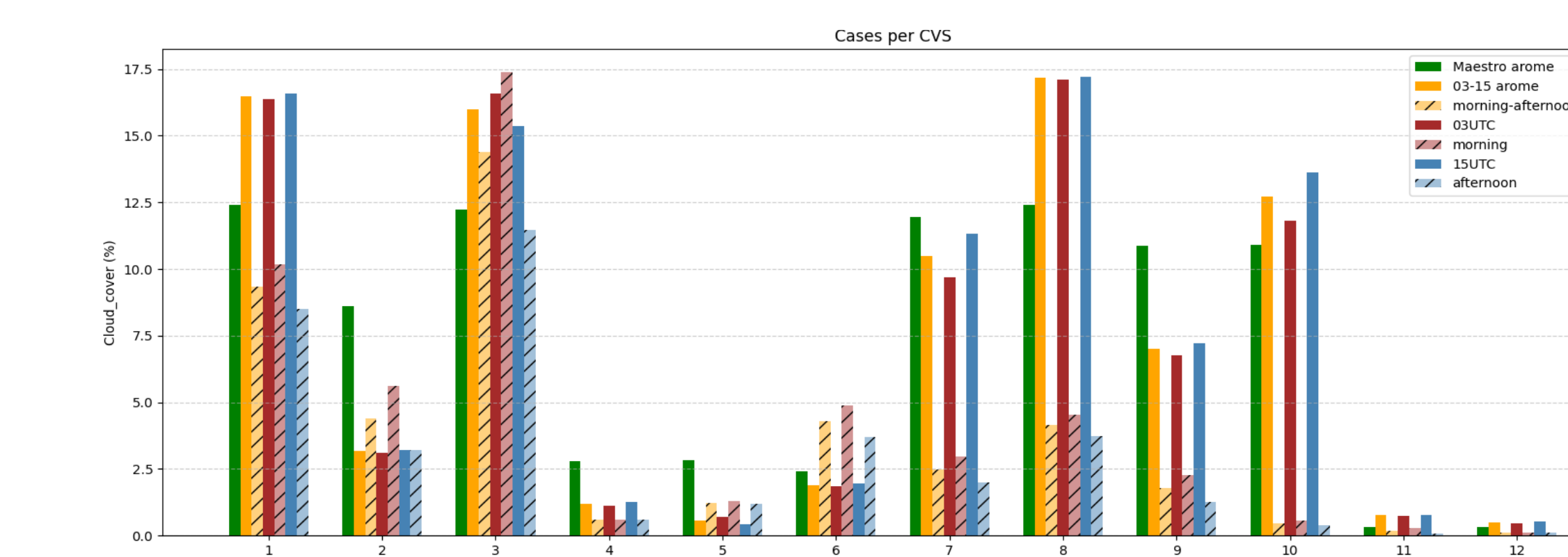
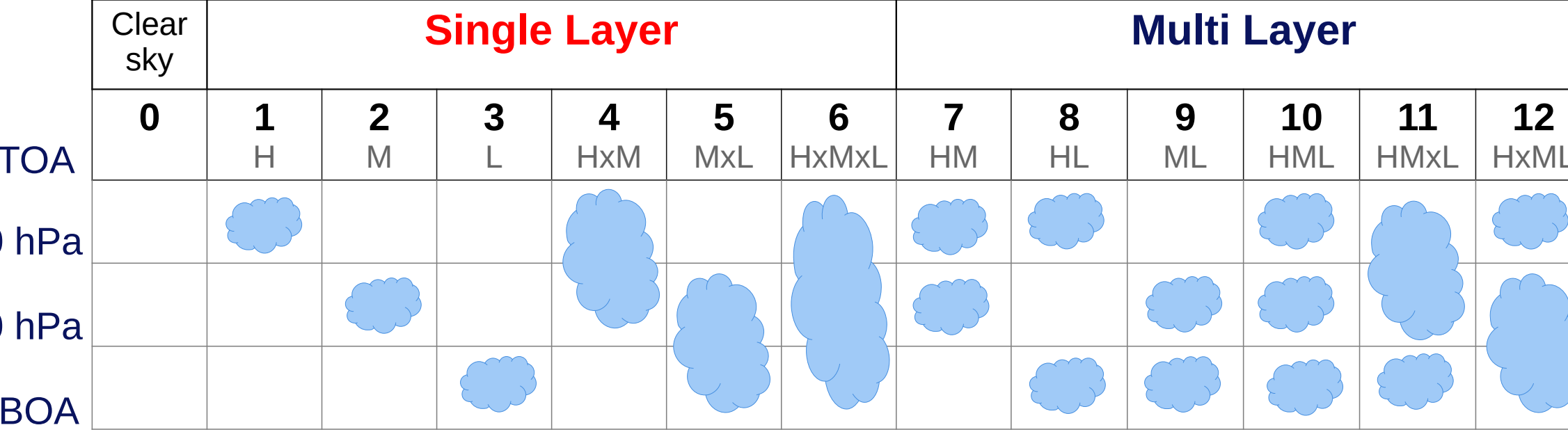
Sorting Clouds by their Vertical Structure to study their radiative effects

→ Cloud Vertical Structure classification algorithm

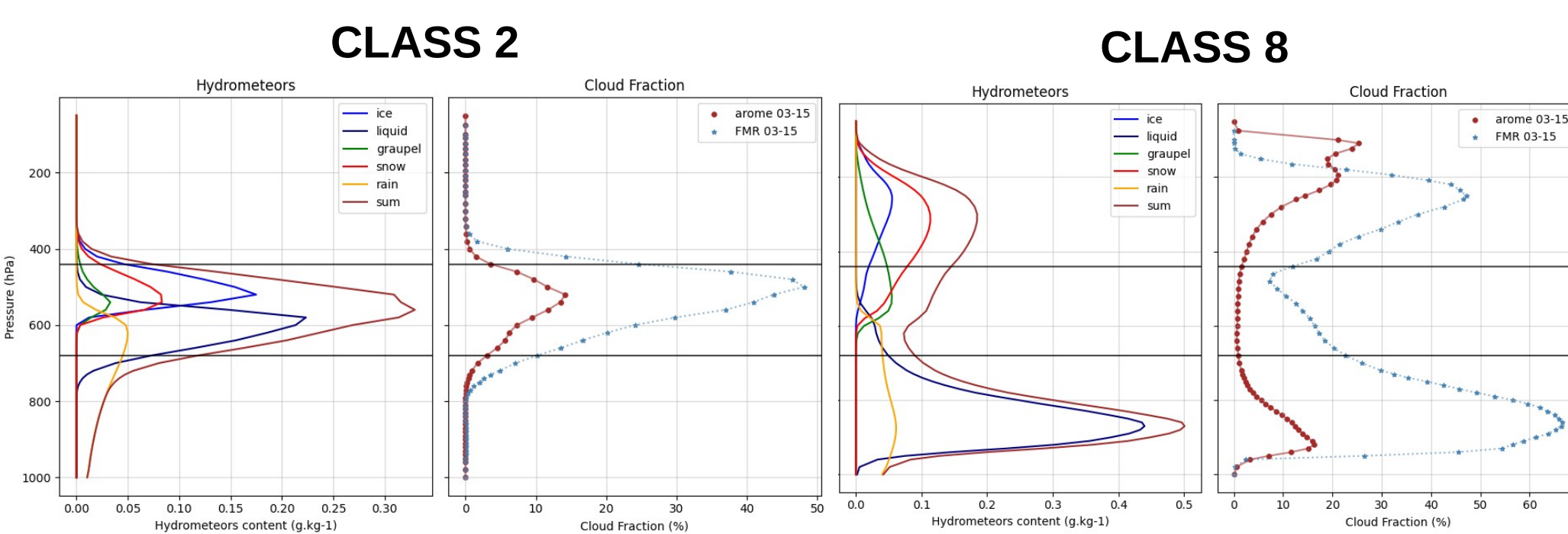
- One profile is associated to a category
- We consider a cloud when cloud fraction > 0, no minimum thickness
- We consider only clouds from 1 to 3 layers



Inspired from Oreopoulos & al (2017)



Cloud Cover (%) for the 12 CVS classes. In green, all hours over the MAESTRO period with AROME. In orange, AROME 03-15UTC and EarthCARE tracks during MAESTRO period (transposed to 2025). In red (resp blue) morning (resp afternoon) data. Clear Sky : AROME 03-15 : 12,1 %, 03 : 13,6 %, 15 : 10,5 %, Maestro : 12,1 % / FMR : 56,6 %, Morning : 49,3 %, Night : 63,7 %



- Too much multi-layer clouds in AROME
 - Weak diurnal cycle
 - Cloud_fraction FMR > Cloud_fraction AROME
 - Need to compute a cloud fraction with other products including LIDAR in order to document ice and liquid water contents over the region
- Perspectives :
- Take snow into the computation of cloud fraction in AROME
 - Compute radiation impact (TOA&BOA) for each class

Key Points and Perspectives

- EarthCARE is used to evaluate and improve the cloud-radiation interaction in AROME, which implemented ecRAD.
 - First evaluation of AROME with CERES show right order of magnitude
- Make possible the comparison between EarthCARE and AROME by studying the **Cloud Vertical Structure (CVS)**
 - Too much multi-layer clouds with AROME
 - EarthCARE (FMR) undersampling works well and the diurnal cycle is weak in the region
- Move to other products (ACM_COM/AC_TC/ALL_RAD) to improve detection of thin clouds, document ice/liquid water content with EarthCARE over the region and compute radiation impact for each class
- What are the impacts of radiative processes in cloud life cycle and cloud spatial organisation ?
 - Sensitivity tests with EcRAD to different parameters & different domains

References :

- [1] Zelinka & al, 2020, Causes of Higher Climate Sensitivity in CMIP6 Models
- [2] Wild et al, 2013, The global energy balance from a surface perspective
- [3] Hogan & Bozzo 2018, A flexible and efficient radiation scheme for the ECMWF model
- [4] Hogan & al, 2020, Evaluating and improving the treatment of gases in radiation schemes: the Correlated K-Distribution Model Intercomparison Project (CKDMIP)
- [5] Hogan & al, 2000, Deriving cloud overlap statistics from radar
- [6] Oreopoulos & al, 2017, New insights about cloud vertical structure from CloudSat and CALIPSO observations
- [7] Luo & al, 2016, Examining cloud vertical structure and radiative effects from satellite retrievals and evaluation of CMIP6 scenarios
- [8] Coddington & al, 2016, A solar irradiance climate data record
- [9] Baran & al, 2014, A coupled cloud physics-radiation parameterization of the bulk optical properties of cirrus and its impact on the Met Office unified model global atmosphere 5.0 configuration
- [10] Baum & al, 2014, Ice cloud bulk single-scattering property models with the full phase matrix at wavelengths from 0.3 to 100 um
- [11] Lacono & al, 2008, Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models
- [12] Fu & al, 1996, An accurate parameterization of the solar radiative properties of cirrus clouds
- [13] Fu & al, 1998, An accurate parameterization of the infrared radiative properties of cirrus clouds of climate models