Self-supervised cloud classification using infrared imagery for characterizing extreme precipitation events over the Alps

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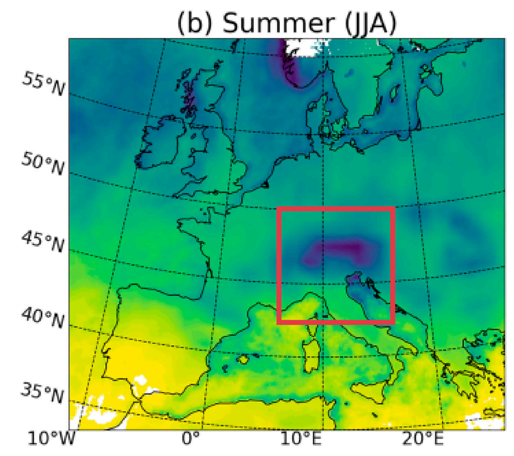
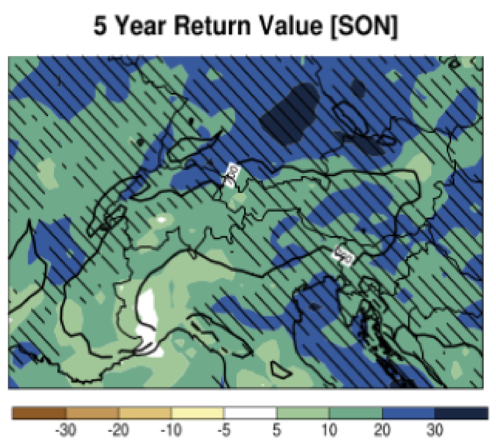
1. MOTIVATION



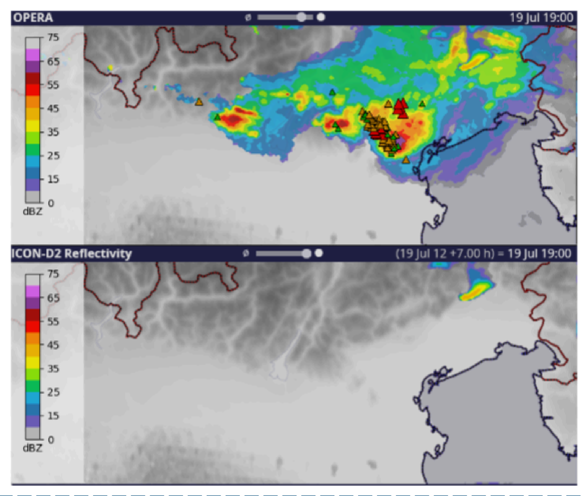
Intense precipitation in the Alpine region, particularly during the summer months

Fig. 1: Seasonal (JJA) precipitation climatology (2011–2020) from IMERG 10-year average data [Lombardo & Bitting, 2024].



Severe **storms** are expected to intensify as **climate change** progresses

Fig. 2: Projected changes (%) in 5-year return value of 1-day precipitation event during fall season (Gobiet et al., 2014).



Models still fail to capture precipitation over **orography**

Fig. 3: Severe hailstorm on 19 July 2023 in Northern Italy: OPERA radar reflectivity vs. ICON-D2 forecast. [Fischer et al., (2024)].

2. GOAL

Investigate the **spatial structure** and **temporal evolution** of cloud states associated with **extreme precipitation** events in the **Alpine region** using a **self-supervised** deep learning (DL) model and **infrared images** from geostationary satellites

3. DATA

Why **10.8 µm Infrared** channel from **Meteosat Second Generation (MSG)**?

- COVERAGE
- SPATIO-TEMPORAL RESOLUTION
- LONG DATASET — from 2013 to 2024 (April to September)
- NIGHT-TIME AVAILABILITY
- HEIGHT PROXY

PROCESSING

The data were **parallax corrected** and interpolated into a **regular grid** (0.04°x0.04°). Data are converted to greyscale images with normalization between 200 and 300 K

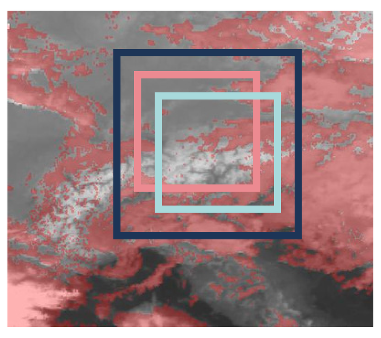


Fig. 4: Left: IR 10.8 channel image with CMSAF cloud mask (red) superimposed. Squares show the 128x128 pixels crops given to the ML model

4. DEEP LEARNING METHOD

Self-supervision is a form of **unsupervised** learning that does not require manually created labels but generates **pseudo-labels** from the data.

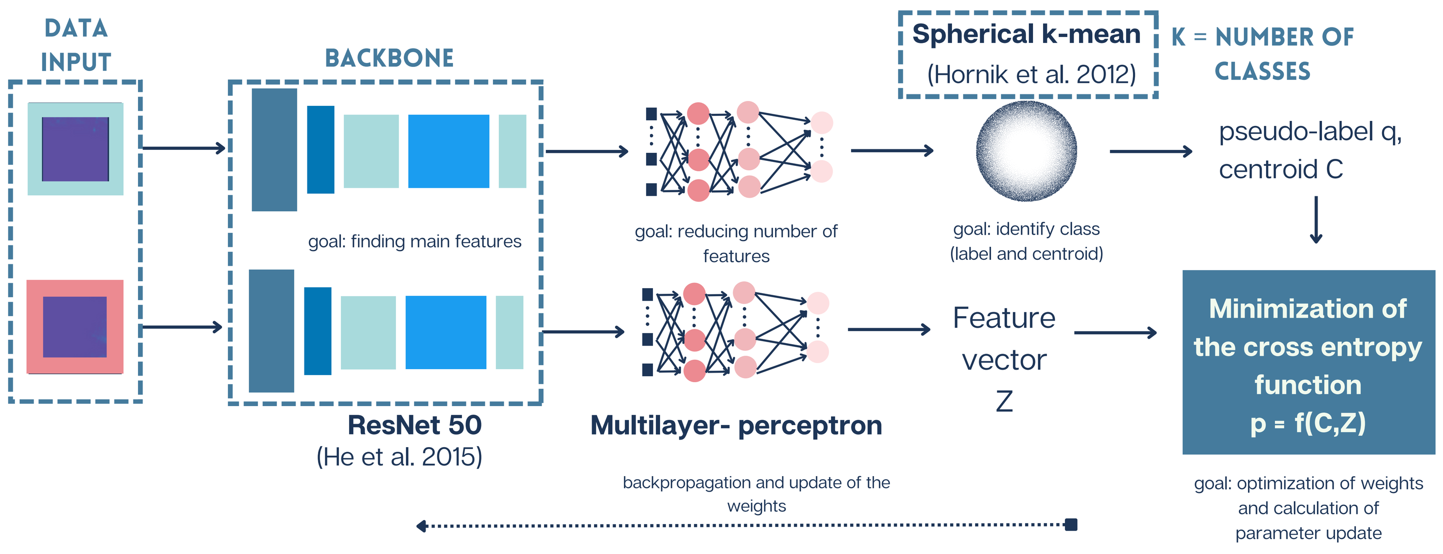


Fig. 5: Architecture of self-supervised ML model adopted in Chatterjee et al., (2023).

5. CLOUD CLUSTERING

The **feature space** consists of multidimensional ensemble of vectors of image semantic properties from multi-year satellite crops. To inspect it, dimensionality must be reduced to 2D.

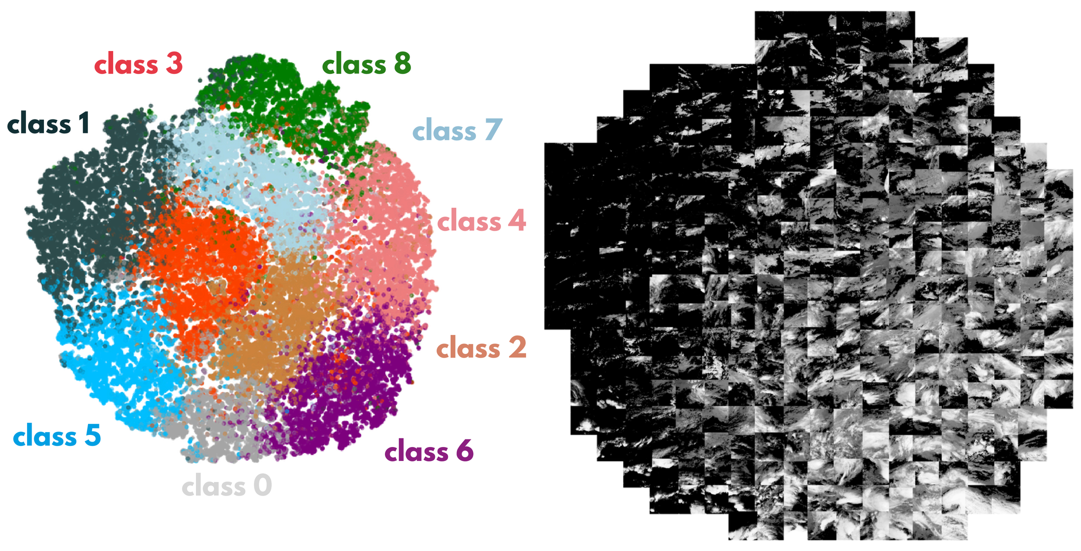


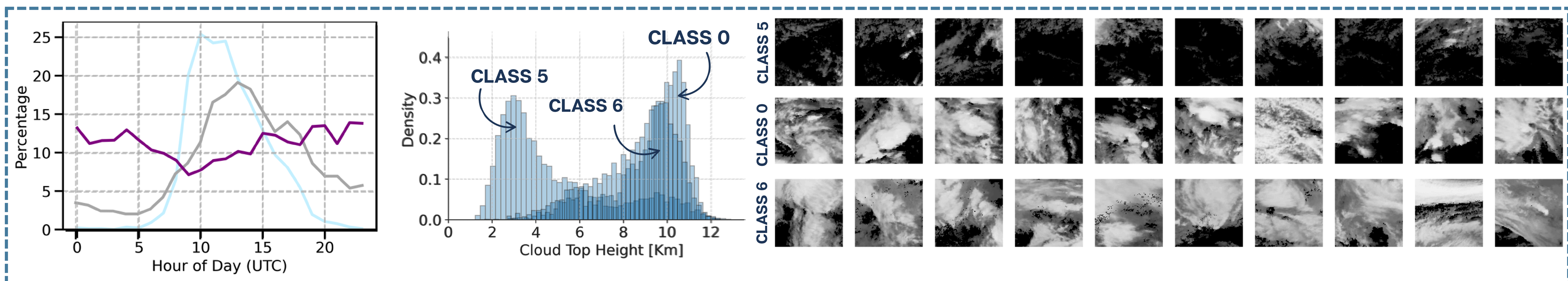
Fig. 6: 2D feature space visualization using t-SNE, based on the DL model trained with IR 10.8 image crops (including cloud masks) across 9 classes. Left: Feature representation with color-coded points for each class. Right: Feature space overlaid with sample image crops.

Classes need to be characterized by analyzing their diurnal occurrences and incorporating cloud physical properties from CMSAF and other ancillary datasets.

- Cloud top height (CTH) and optical thickness (COT) from **CMSAF**
- Rain rate from satellite (**IMERG**) and ground radar (**OPERA**)
- Lightning data from **EUCLID**

6. EXEMPLE OF CLASSES CHARACTERIZATION

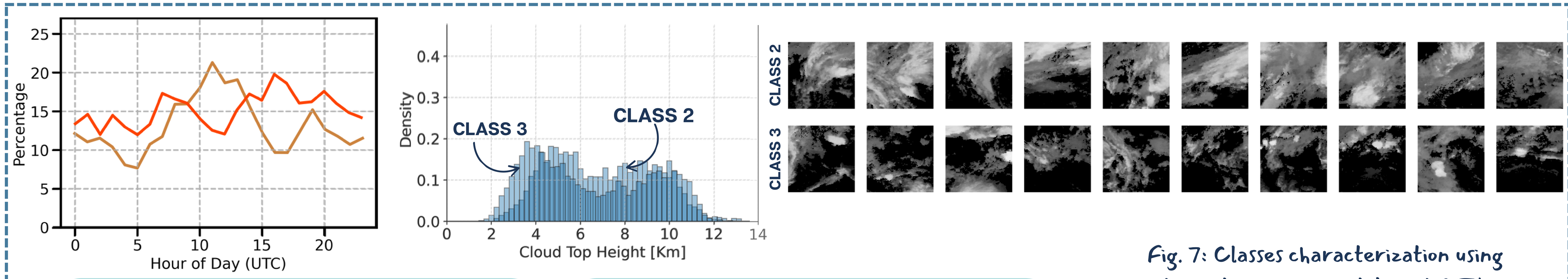
Which classes contain convection and precipitation?



CLASS 5
early stage of convection:
- low CTH and COT (not shown)
- mixed cloud scenes, small convective cells
- mostly noon (local time)

CLASS 6
convection embedded:
- high cloud tops and rain rates (not shown)
- extended cloud systems
- large convective cells embedded in larger cloud patterns

CLASS 0
mature convection:
- highest cloud tops and rain rates (not shown)
- afternoon convection peak
- large convective cells with complex cloud scenes



CLASS 2
bimodal cloud scene:
- bimodal cloud top distribution
- low rain rates (not shown)
- large convective cells with complex cloud scenes

CLASS 3
bimodal cloud scene
- lower COT and CTH compared to class 2
- low rain rates (not shown)
- small convective cells with complex cloud scenes

Fig. 7: Classes characterization using diurnal occurrence plots and CTH distributions, along with the 10 image crops closest to the class centroids. Only classes exhibiting convective activity are shown.

7. OUTLOOK

Extreme events analysis

The feature space can be used to characterize selected case studies of intense rainfall and hailstorms in test mode. The DL model is currently being enhanced to improve its performance.

DATA INPUT
- Model now supports **NetCDF input**.
- Additional channels can be added, e.g.: **6.2–10.8 µm** difference (proxy for overshooting tops).

BACKBONE
- Switched from ResNet to **Vision Transformer** (*Vaswani et al., 2017*).
- More powerful for capturing **non-local features**, especially with **large datasets**.

K OPTIMIZATION
- k needs adaptation to the new configuration.
- The one yielding better feature space **clustering** and lower inter-class **correlation** will be selected.

Model Evaluation

Extreme event case studies can be compared with ICON simulations to assess their performance in capturing cloud structures and evolution.

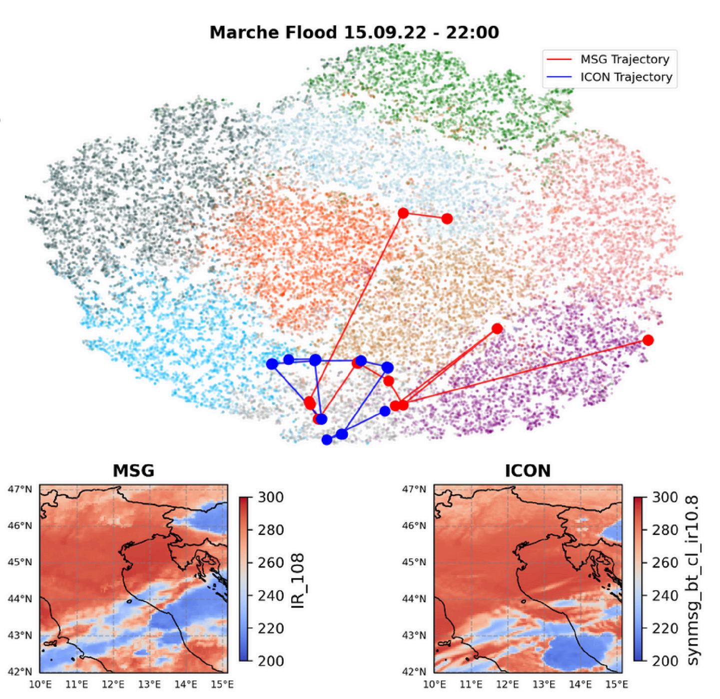


Fig. 8: Feature space example showing the trajectory of observed and simulated 10.8 µm MSG data during the Marche (Italy) flood (09.2022)

8. REFERENCES

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