EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

Machine Learning Retrieval of Near-Real-Time 3D EarthCARE Scenes from MTG-FCI Observations

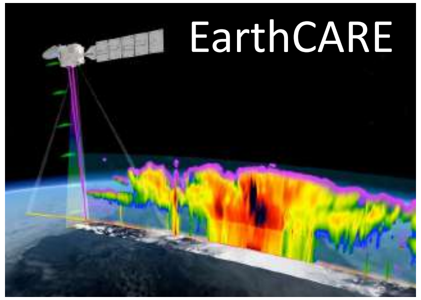
Stella Girtsou, Dimitra Karkani, Aggelos Georgakis, Giorgos Giannopoulos, Charalambos Kontoes, Alexandra Tsekeri

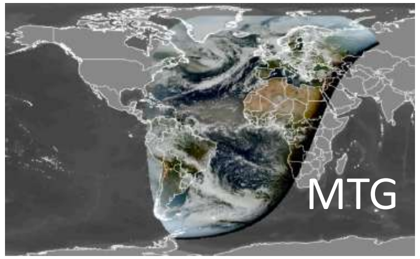
National Observatory of Athens

Obs3Rve Overview

JAXA esa EUROPEAN SPACE AGENCY

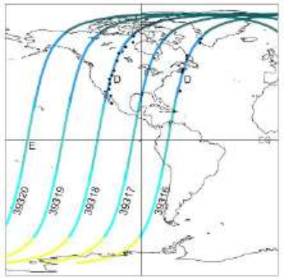
Input

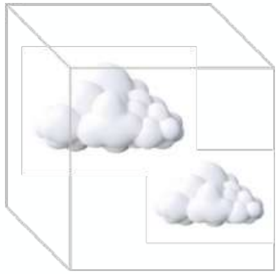




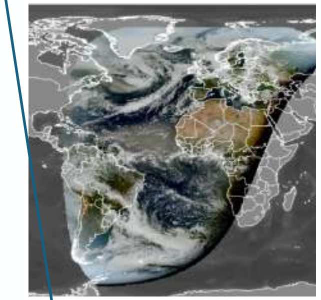
Products

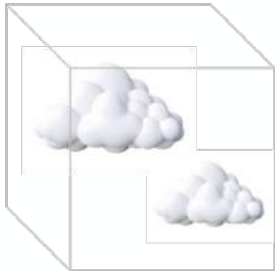
EarthCARE 3D product





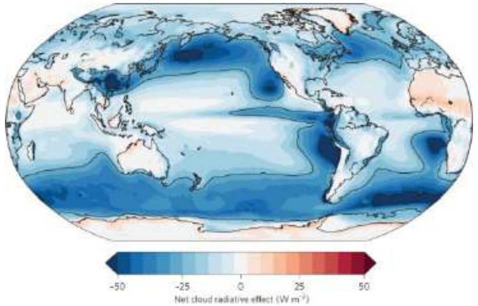
MTG 3D product



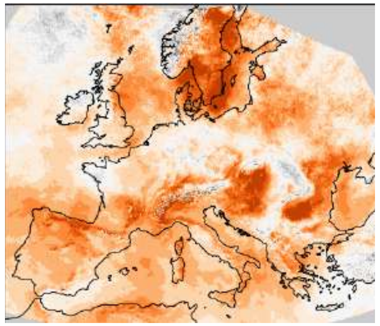


Scientific impact

Cloud radiative effect



Solar radiation/energy



Synergy with ESA/EC projects

CERTAINTY

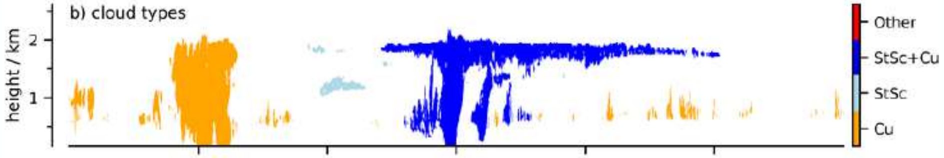
AIRSENSE

EarthCARE DISC
Data, innovation and science cluster

Validation

PERCUSION

ORCESTRA



Obs3RvE

Machine Learning for 3D Cloud Scene Construction

Enhance the 3D RT capabilities of EarthCARE using machine learning and MTG data with the construction of realistic 3D scenes

Real-time Cloud Maps at Europe and the Atlantic Ocean.

Input: FCI/MTG radiances

Output: 3D maps of **cloud types** and cloud **microphysical properties** (i.e. liquid water content, ice water content, effective radius)

Global Cloud Maps

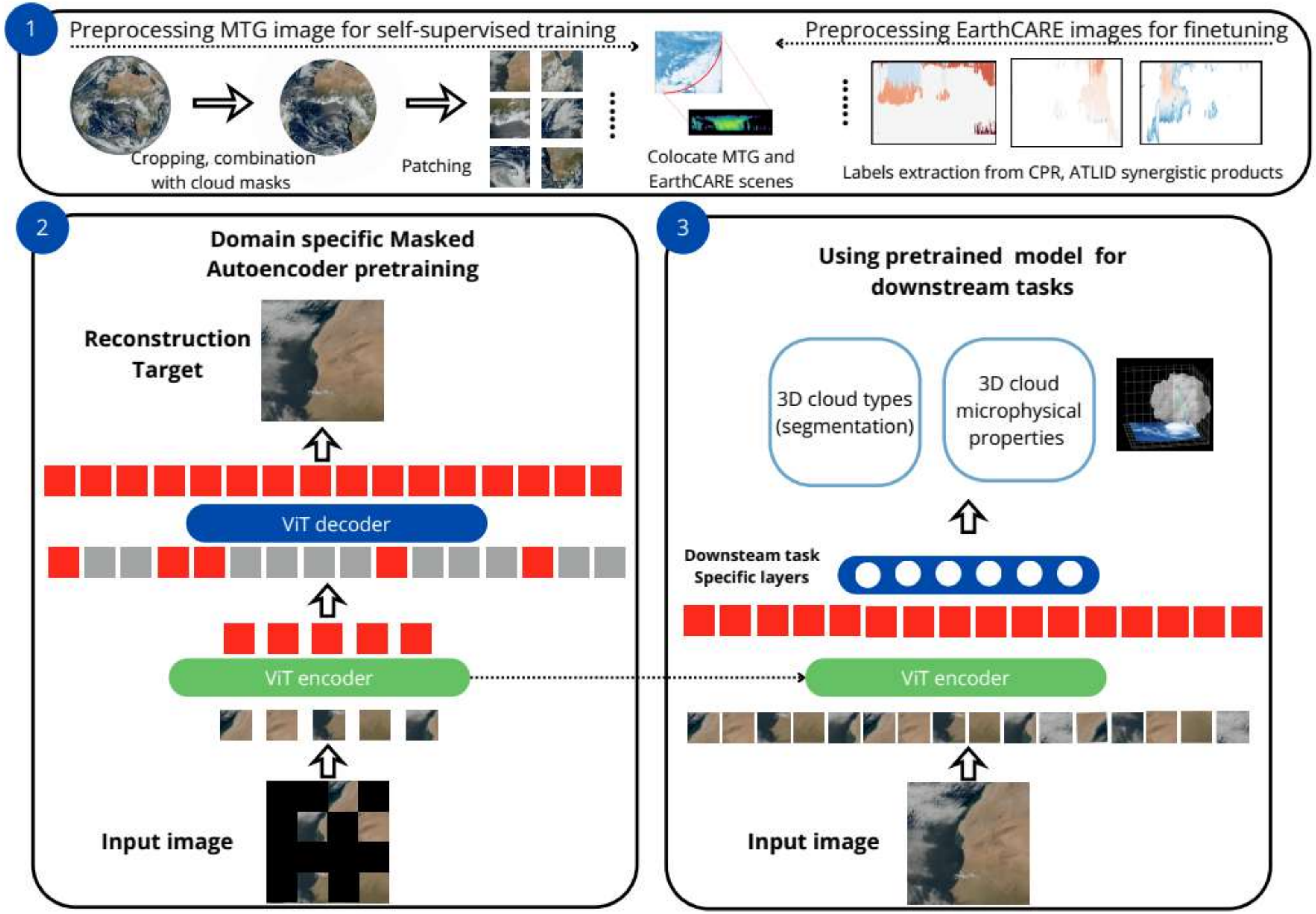
Input: EarthCARE MSI radiances, CPR reflectivity profiles, ATLID backscatter profiles

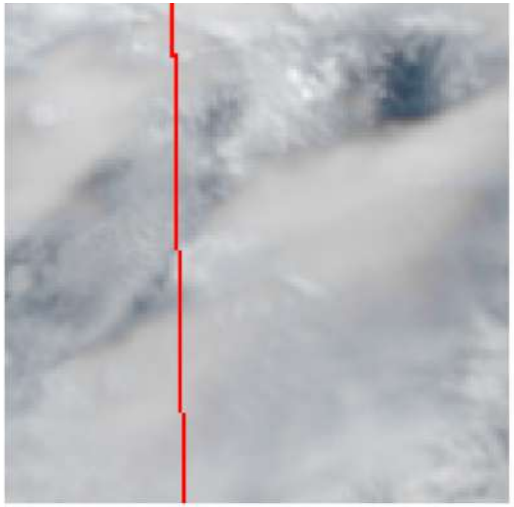
Output: 3D maps of **cloud types** and cloud **microphysical properties** (i.e. liquid water content, ice water content, effective radius)

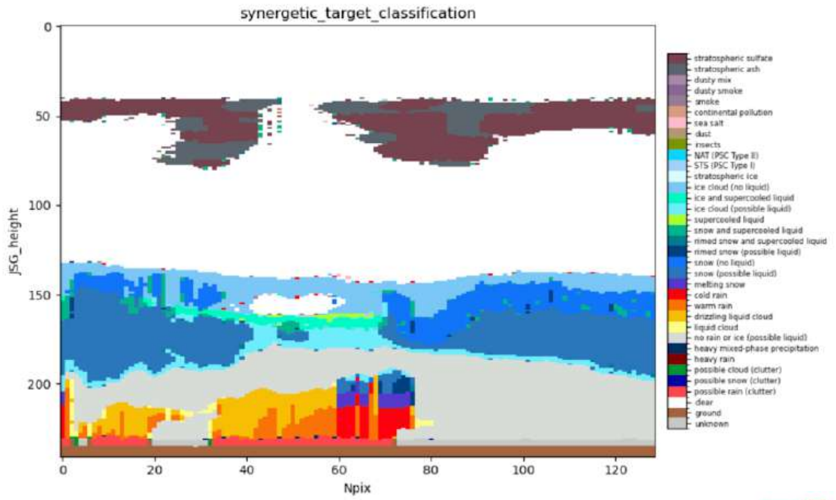
Based on the FDL work

3D Cloud reconstruction through geospatially-aware Masked Autoencoders, Stella Girtsou, Emiliano Diaz Salas-Porras, Lilli Freischem, Joppe Massant, Kyriaki-Margarita Bintsi, Guiseppe Castiglione, William Jones, Michael Eisinger, Emmanuel Johnson, Anna Jungbluth

ML methodology







Pipeline

Data collection

MTG dataset: Collect MTG FCI Level 1c and Cloud Mask
EarthCARE dataset: Collect AC-TC (Cloud Types), ACM-COM (Cloud Microphysical Properties)

Preprocessing

Transformation to **Geolocated Patches** and **Storage optimization** using structures like DataTree and zarr

Pretraining

Pretrain SatMAE on MTG FCI; save checkpoints.

Dataset Alignment

Align MTG FCI and EarthCARE scenes to create the **fine-tuning dataset**

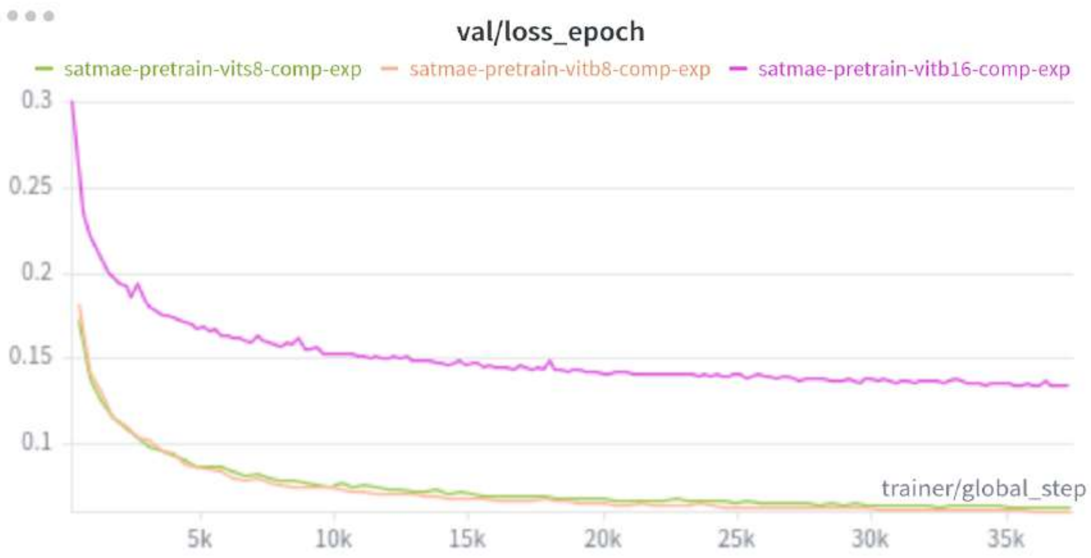
Fine-tuning

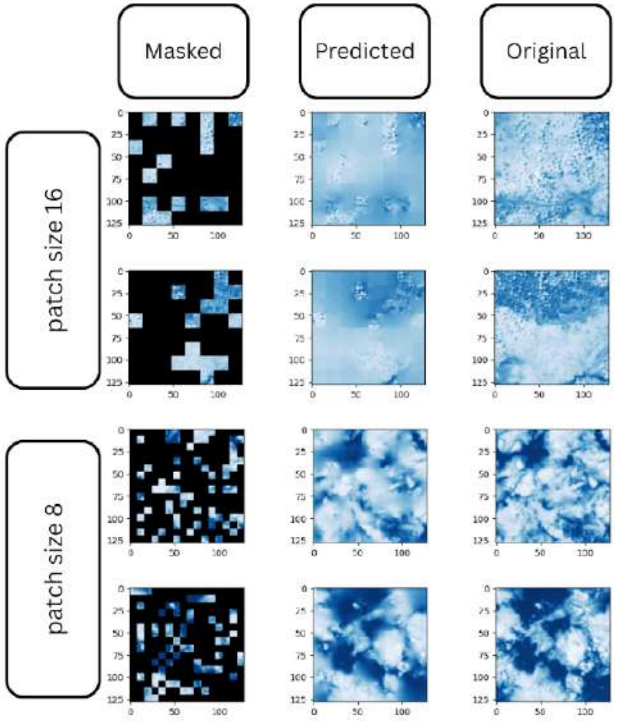
Fine-tune model to produce 3D cloud scenes of cloud types and microphysical properties

Pretraining

Experiments	Architecture	Patch size
1	ViT Base	16
2	ViT Base	8
3	ViT Small	8

Epochs: 200
Learning Rate: 1.5e-4
Masking Ratio: 0.75
Image size: 128
Time encoding





Finetuning

Classes grouping: EarthCARE AC-TC target classifications gives 35 classes - not all relevant to clouds

- Tried 3 different groupings created based on classes imbalance and no precipitation distinction

Architectures: 2 different finetuning architectures, one with only 2 layers and one with more layers and skip connections

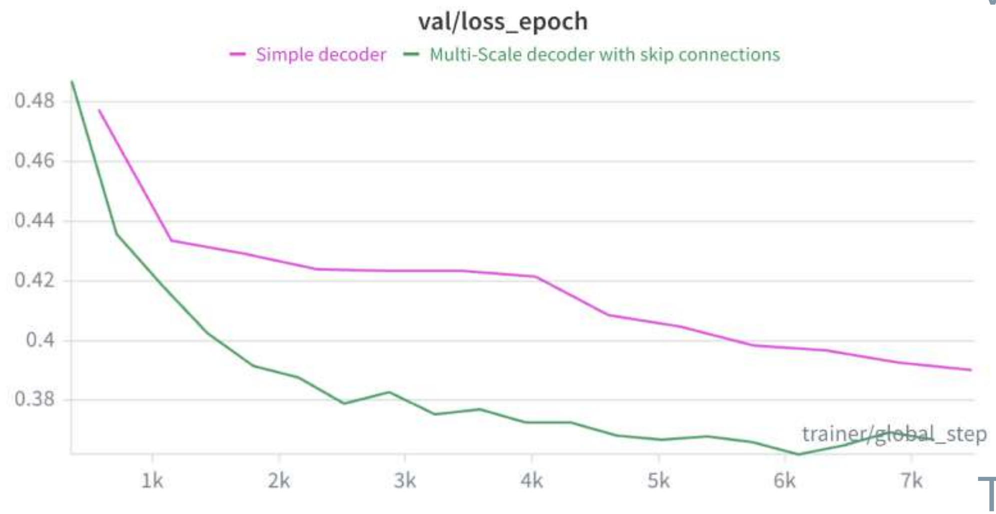
Class weights: Major class imbalance on certain cloud types addressed with various class weights

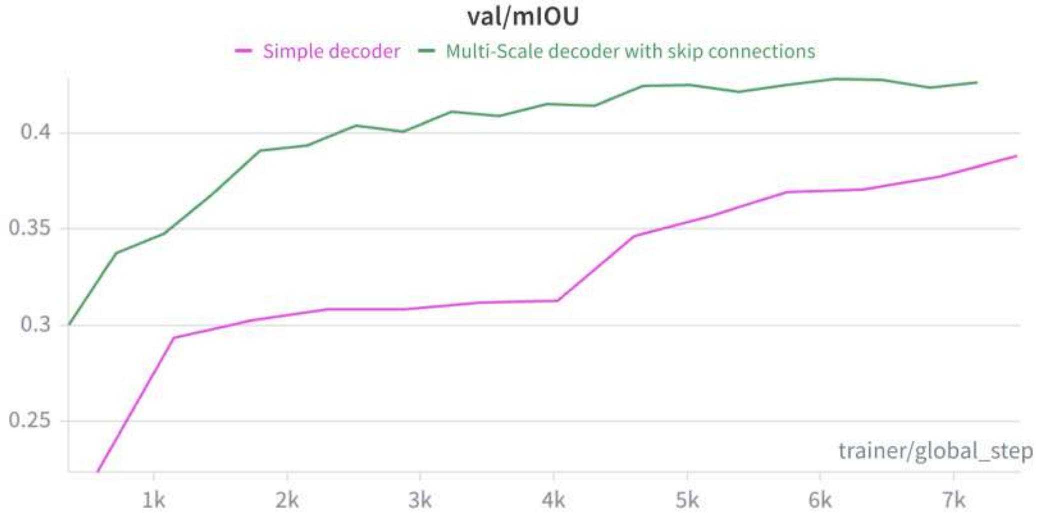
Loss functions: 10 different ways to train our network and make it learn the difficult patterns

- Cross-Entropy Loss: compares predicted **probabilities** with the true class labels.
- Dice Loss: optimizes **overlap** between prediction and ground truth
- Tversky Loss: weights false positives and false negatives differently, making it useful for **imbalanced segmentation** tasks.
- Focal Loss: Focuses training on **hard-to-classify examples** helping improve performance on minority or **difficult classes**.

Results

Validation





Test

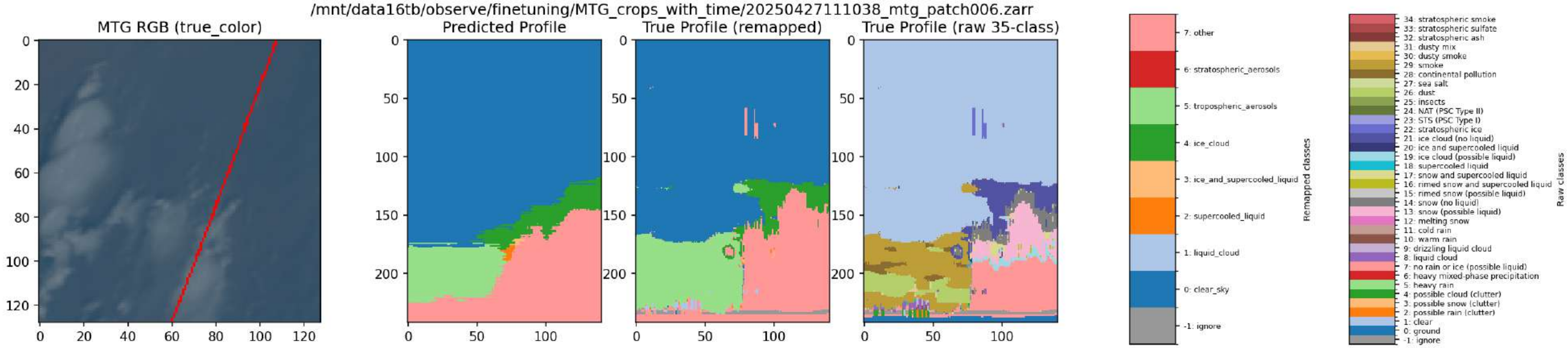
F1

Class	Simple	Multi-Scale
0 — clear sky	0.928	0.926
1 — liquid cloud	0.241	0.261
2 — supercooled liquid	0.182	0.187
3 — ice + supercooled	0.180	0.205
4 — ice cloud	0.545	0.520
5 — tropospheric aerosols	0.728	0.715
6 — stratospheric aerosols	0.672	0.656
7 — other	0.851	0.852

IOU

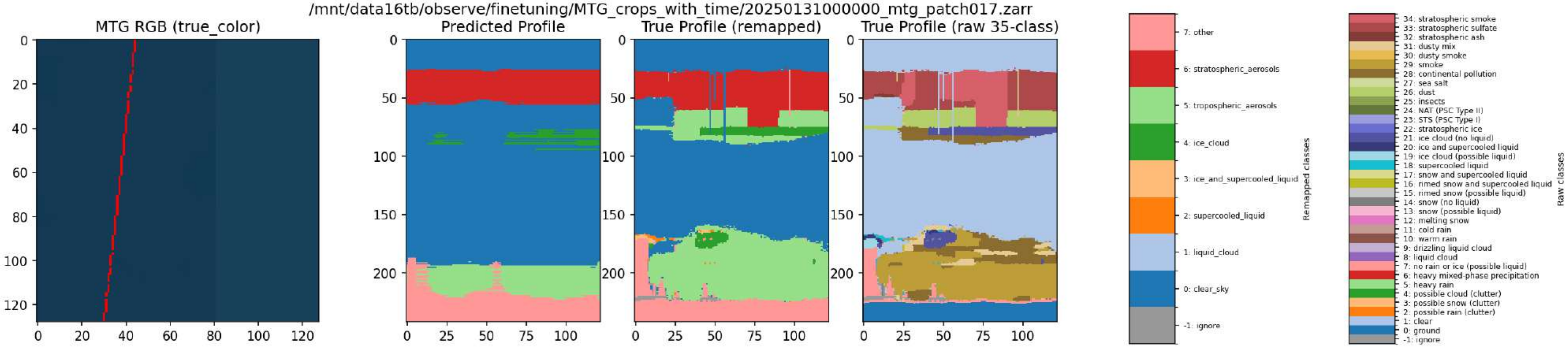
Class	Simple	Multi-Scale
0 — clear sky	0.866	0.863
1 — liquid cloud	0.137	0.150
2 — supercooled liquid	0.100	0.103
3 — ice + supercooled	0.099	0.114
4 — ice cloud	0.374	0.352
5 — tropospheric aerosols	0.573	0.556
6 — stratospheric aerosols	0.506	0.488
7 — other	0.741	0.742

Results



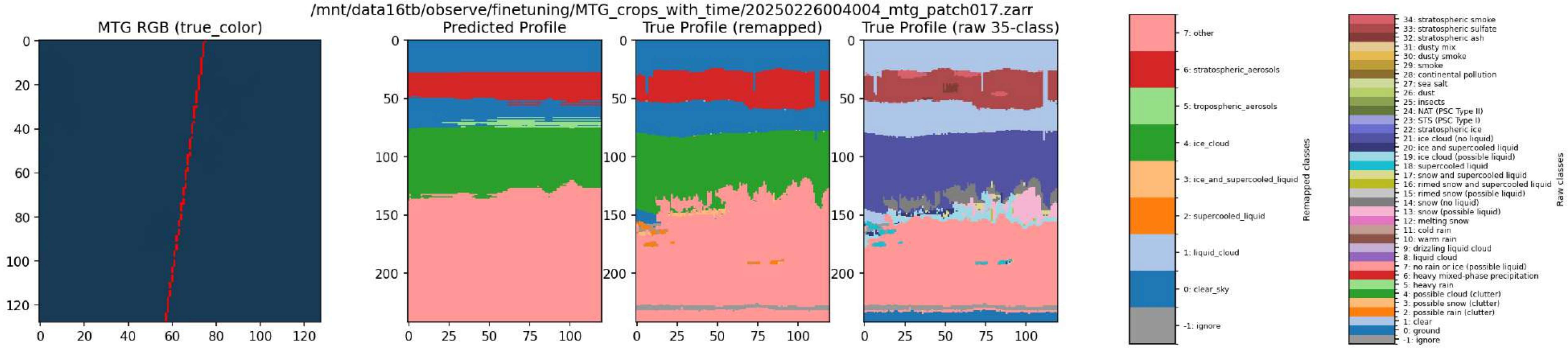
/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250427111038_mtg_patch006.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

Results

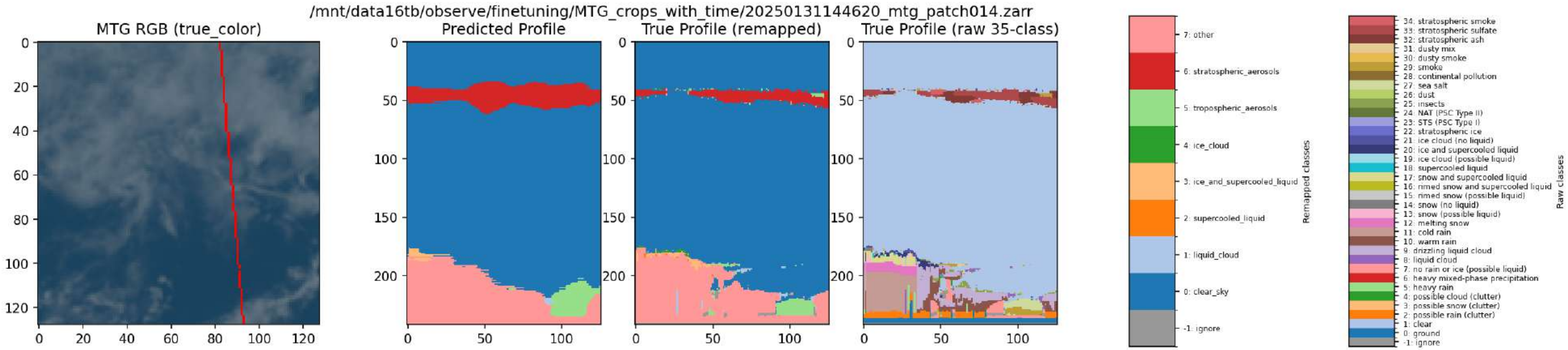


/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250131000000_mtg_patch017.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

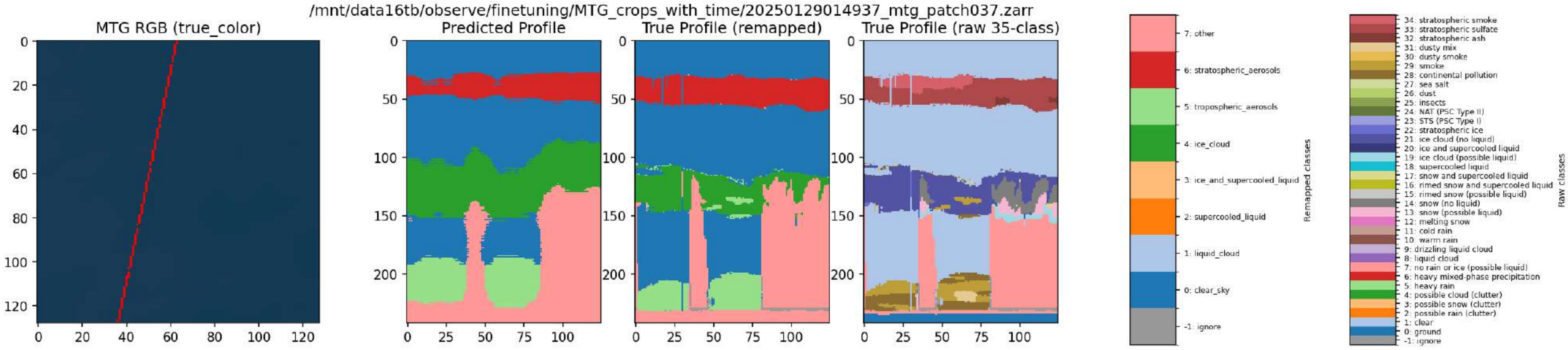
Results


/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250226004004_mtg_patch017.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

Results

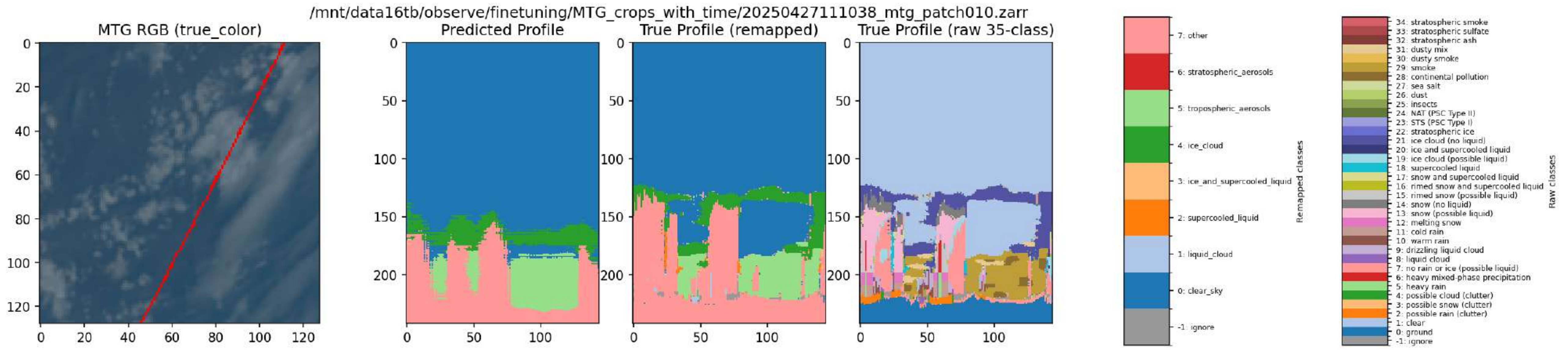

/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250131144620_mtg_patch014.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

Results



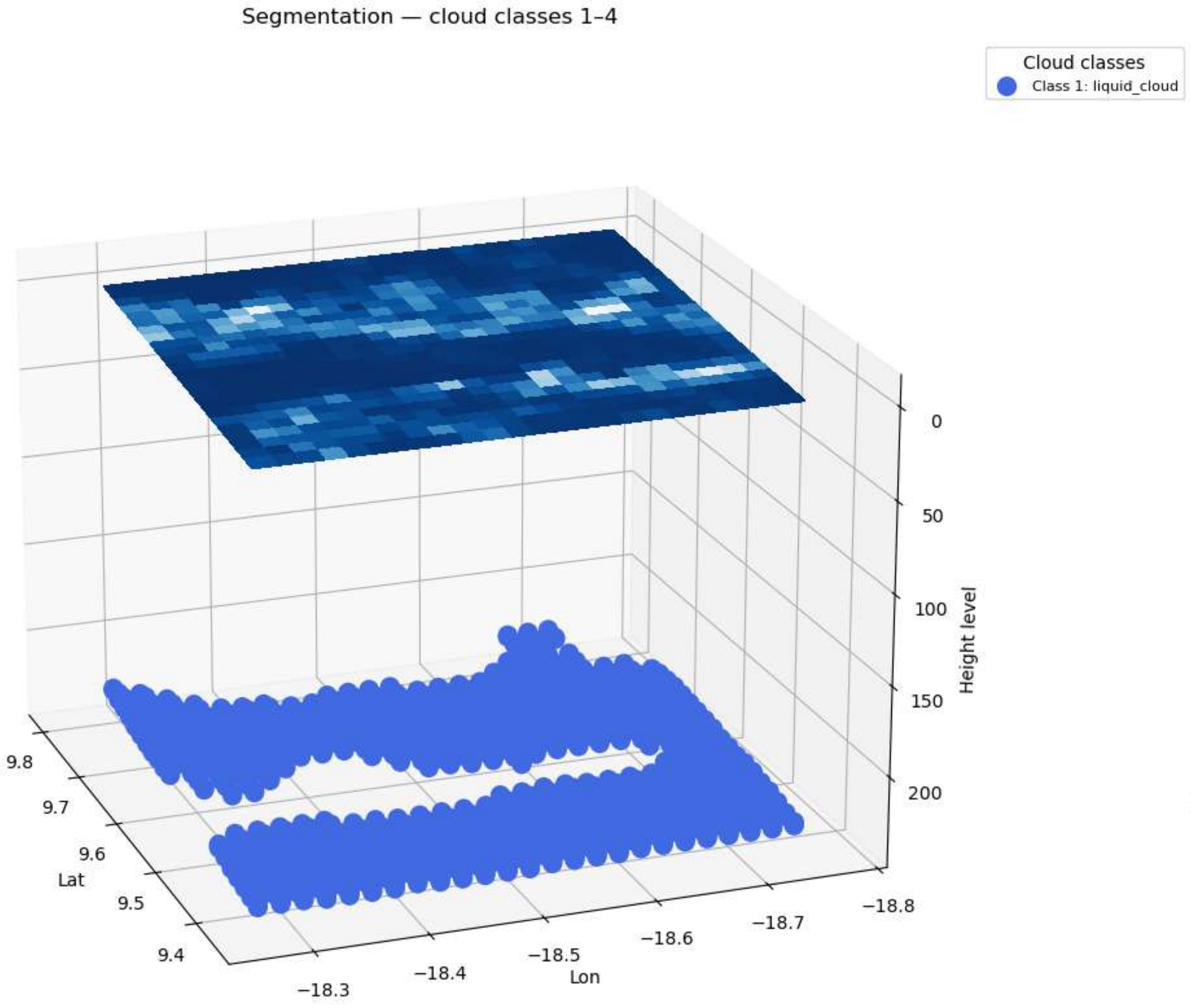
/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250129014937_mtg_patch037.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

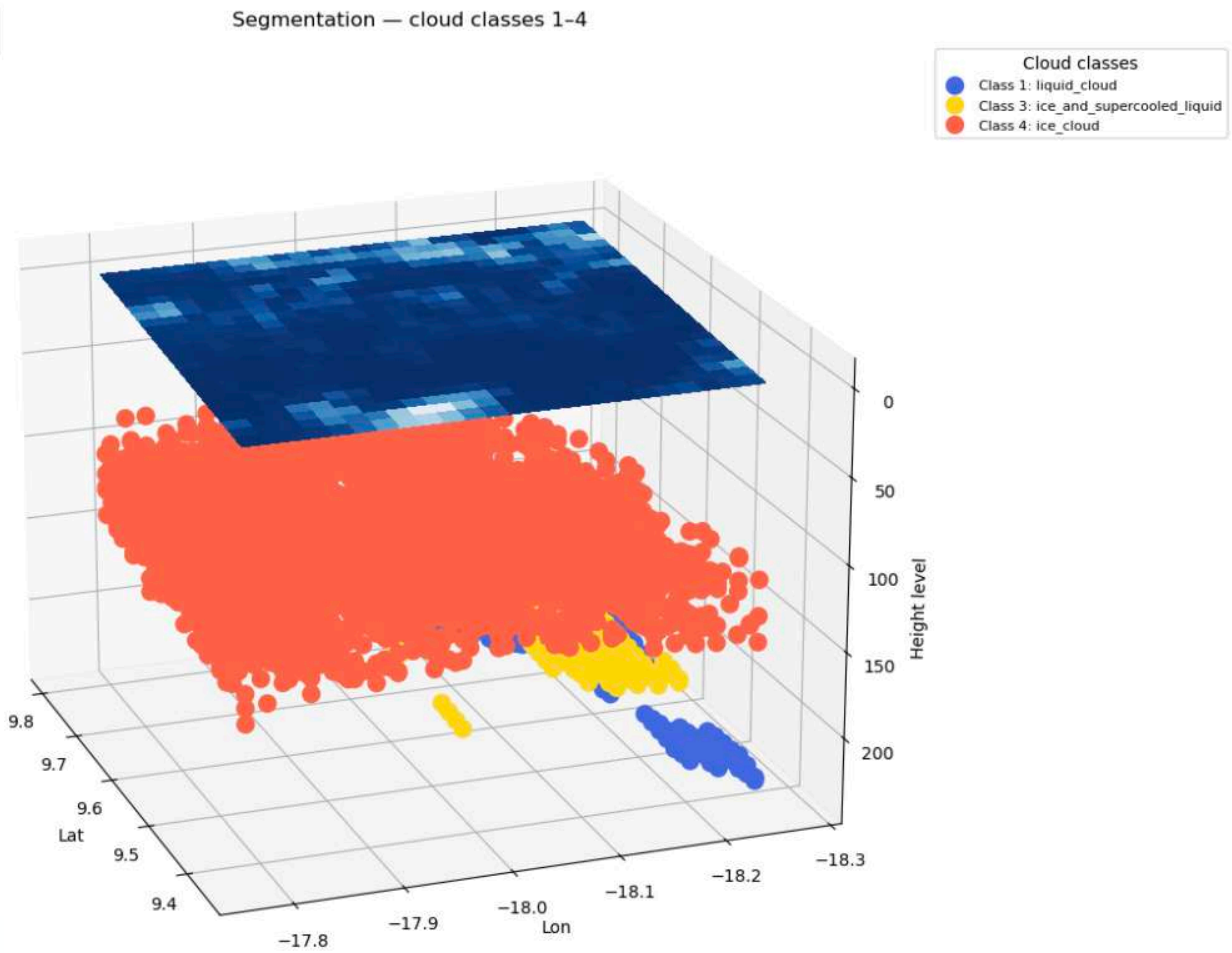
Results



/mnt/data16tb/observe/finetuning/MTG_crops_with_time/20250427111038_mtg_patch010.zarr
MTG RGB (true_color)
Predicted Profile
True Profile (remapped)
True Profile (raw 35-class)
7: other
6: stratospheric_aerosols
5: tropospheric_aerosols
4: ice_cloud
3: ice_and_supercooled_liquid
2: supercooled_liquid
1: liquid_cloud
0: clear_sky
-1: ignore
Remapped classes
34: stratospheric smoke
33: stratospheric sulfate
32: stratospheric ash
31: dusty mix
30: dusty smoke
29: smoke
28: continental pollution
27: sea salt
26: dust
25: insects
24: NAT (PSC Type II)
23: STS (PSC Type I)
22: stratospheric ice
21: ice cloud (no liquid)
20: ice and supercooled liquid
19: ice cloud (possible liquid)
18: supercooled liquid
17: snow and supercooled liquid
16: rimed snow and supercooled liquid
15: rimed snow (possible liquid)
14: snow (no liquid)
13: snow (possible liquid)
12: melting snow
11: cold rain
10: warm rain
9: drizzling liquid cloud
8: liquid cloud
7: no rain or ice (possible liquid)
6: heavy mixed-phase precipitation
5: heavy rain
4: possible cloud (clutter)
3: possible snow (clutter)
2: possible rain (clutter)
1: clear
0: ground
-1: ignore
Raw classes

Results - 3D


Segmentation — cloud classes 1–4
Cloud classes
Class 1: liquid_cloud
Lat
9.8
9.7
9.6
9.5
9.4
Lon
−18.3
−18.4
−18.5
−18.6
−18.7
−18.8
Height level
0
50
100
150
200


Segmentation — cloud classes 1–4
Cloud classes
Class 1: liquid_cloud
Class 3: ice_and_supercooled_liquid
Class 4: ice_cloud
Lat
9.8
9.7
9.6
9.5
9.4
Lon
−17.8
−17.9
−18.0
−18.1
−18.2
−18.3
Height level
0
50
100
150
200

Key insights

Remarkable results given the input (only MTG)

Strong detection of ice clouds, as well as tropospheric and stratospheric aerosols

Accurate prediction of cloud and aerosol vertical structure

As we continue gathering data from EarthCARE we will explore multimodal schemas

Colocation quality is sensitive to temporal offset: 10 min → poor overlap; 3 min → improved

Minority classes (ice, liquid cloud, supercooled liquid) are underrepresented → standard training fails; addressed via custom metrics, loss functions, and class weights.

Next steps

Work on 3D microphysical properties from 2D **MTG** observations

3D **EarthCARE** products

Having input from MSI, ATLID and CPR will boost the predictions

Evaluate our predictions with how well each scene reproduce the **radiation** in the TOA

Evaluate our predictions with **ground based** cloudnet and aircraft percussion data

Next presentations

Day 3: Wednesday 10 June 2026

T313	11:54	12	Quantifying 3D radiative transfer effects of clouds using ML-generated 3D cloud scenes for EarthCARE, and airborne observations from ORCESTRA/PERCUSION campaign	Dimitra Kouklaki

Posters

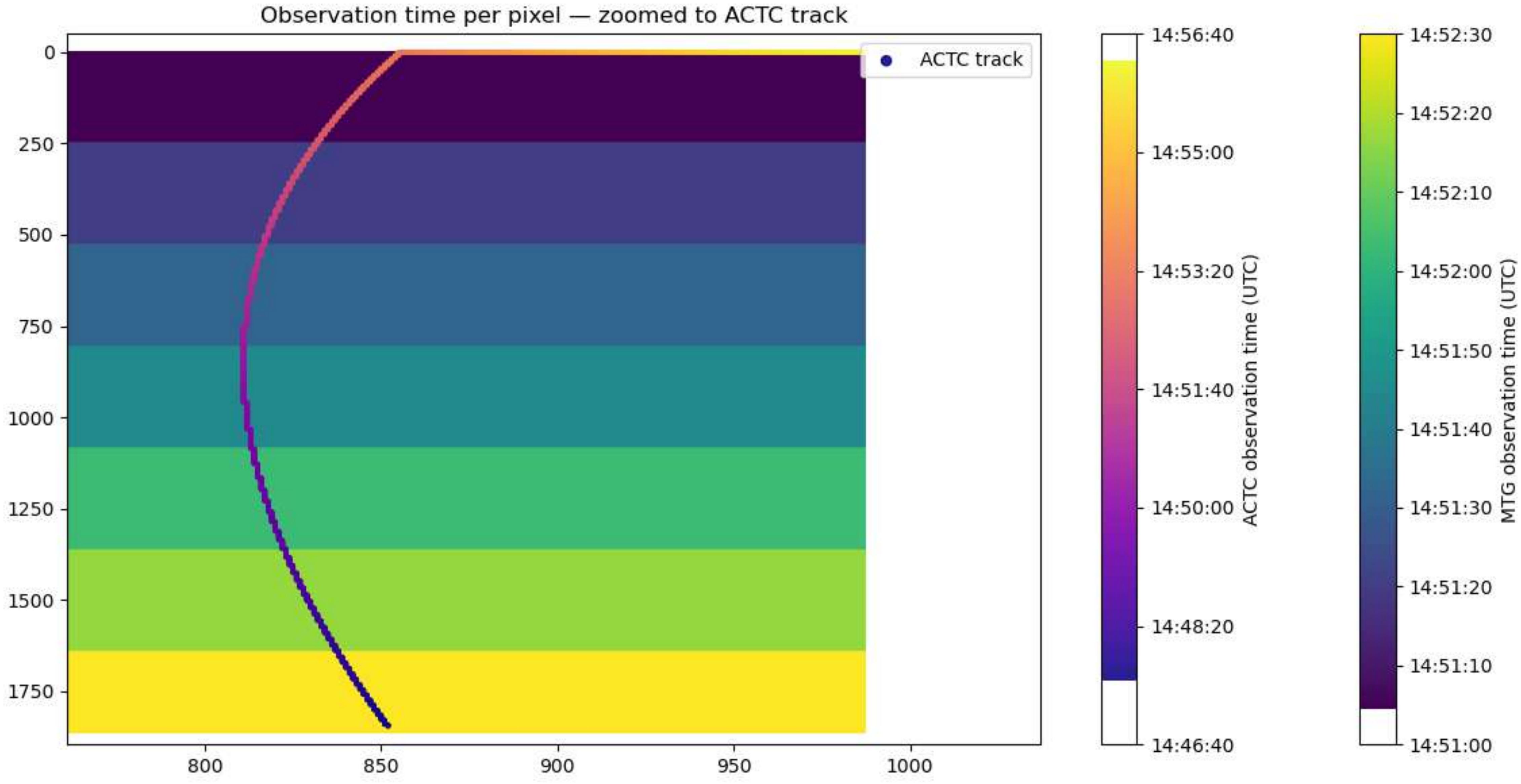
P098	Reconstructing the “unknown” features in AC-TC, utilizing an ML-based approach	Dimitra Karkani

P065	Evaluating EarthCARE Cloud Typing and Microphysics with Cloudnet data (online)	Ioanna Tsikoudi

Thank you!

Stella Girtsou, sgirtsou@noa.gr
Dimitra Karkani, dkarkani@noa.gr
Aggelos Georgakis, ageorgakis@noa.gr
Giorgos Giannopoulos, giannopoulos@noa.gr
Alexandra Tsekeri, atsekeri@noa.gr

Colocation


Observation time per pixel — zoomed to ACTC track
ACTC track
0
250
500
750
1000
1250
1500
1750
800
850
900
950
1000
14:56:40
14:55:00
14:53:20
14:51:40
14:50:00
14:48:20
14:46:40
ACTC observation time (UTC)
14:52:30
14:52:20
14:52:10
14:52:00
14:51:50
14:51:40
14:51:30
14:51:20
14:51:10
14:51:00
MTG observation time (UTC)

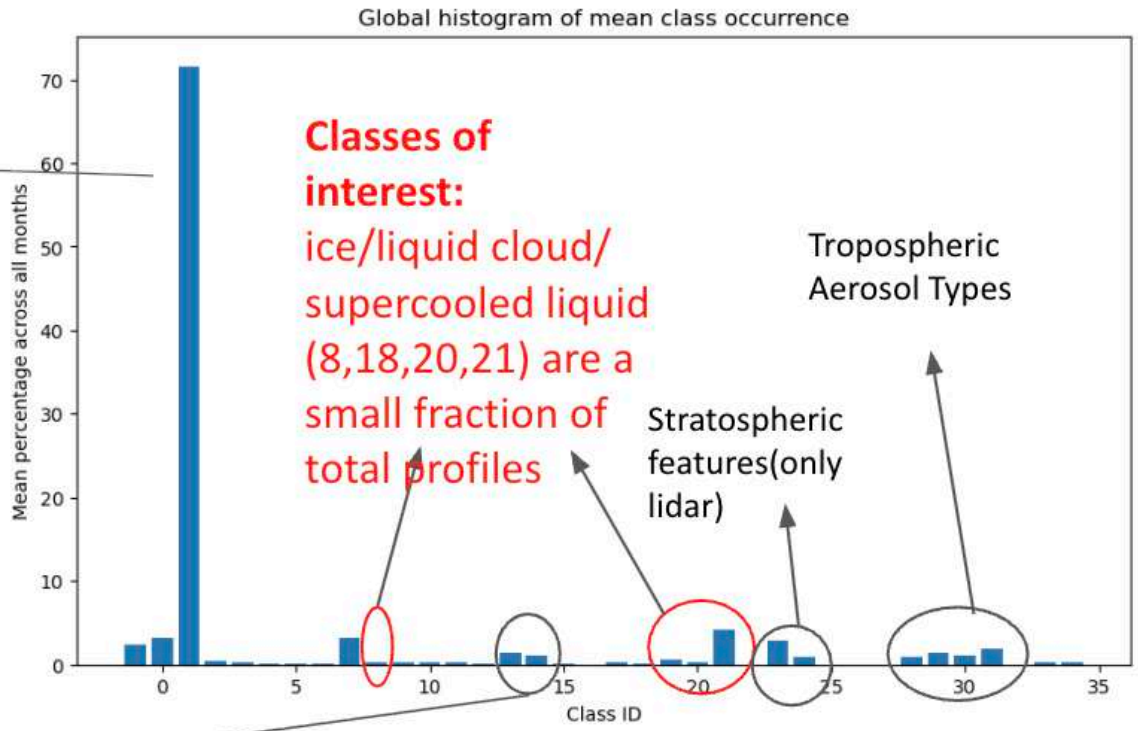
Imbalance

Segmentation Task: Highly Imbalanced dataset

```
synergistic_target_classification = {
    -1: "unknown",
    0: "ground",
    1: "clear",
    2: "possible rain (clutter)",
    3: "possible snow (clutter)",
    4: "possible cloud (clutter)",
    5: "heavy rain",
    6: "heavy mixed-phase precipitation",
    7: "no rain or ice (possible liquid)",
    8: "liquid cloud",
    9: "drizzling liquid cloud",
    10: "warm rain",
    11: "cold rain",
    12: "melting snow",
    13: "snow (possible liquid)",
    14: "snow (no liquid)",
    15: "rimed snow (possible liquid)",
    16: "rimed snow and supercooled liquid",
    17: "snow and supercooled liquid",
    18: "supercooled liquid",
    19: "ice cloud (possible liquid)",
    20: "ice and supercooled liquid",
    21: "ice cloud (no liquid)",
    22: "stratospheric ice",
    23: "STS (PSC type I)",
    24: "NAT (PSC type II)",
    25: "insects",
    26: "tropospheric aerosol types",
    27: "tropospheric aerosol types",
    28: "tropospheric aerosol types",
    29: "tropospheric aerosol types",
    30: "tropospheric aerosol types",
    31: "tropospheric aerosol types",
    32: "stratospheric aerosol types",
    33: "stratospheric aerosol types",
    34: "stratospheric aerosol types",
}
```

Clear sky pixels dominate:

i.e. When lidar sees clear sky or if the lidar is extinguished and when radar indicates clear sky



Classes of interest:
ice/liquid cloud/ supercooled liquid (8,18,20,21) are a small fraction of total profiles

Stratospheric features(only lidar)

Tropospheric Aerosol Types

Snow, possible liquid/no liquid

i.e. Radar takes over lidar,(missing data or extinguished)/Radar class indicates snow, and lidar does not indicate liquid