# Quantifying the Cloud Radiative Effects through Airborne and Satellite Observations and 3D Radiative Transfer Modeling

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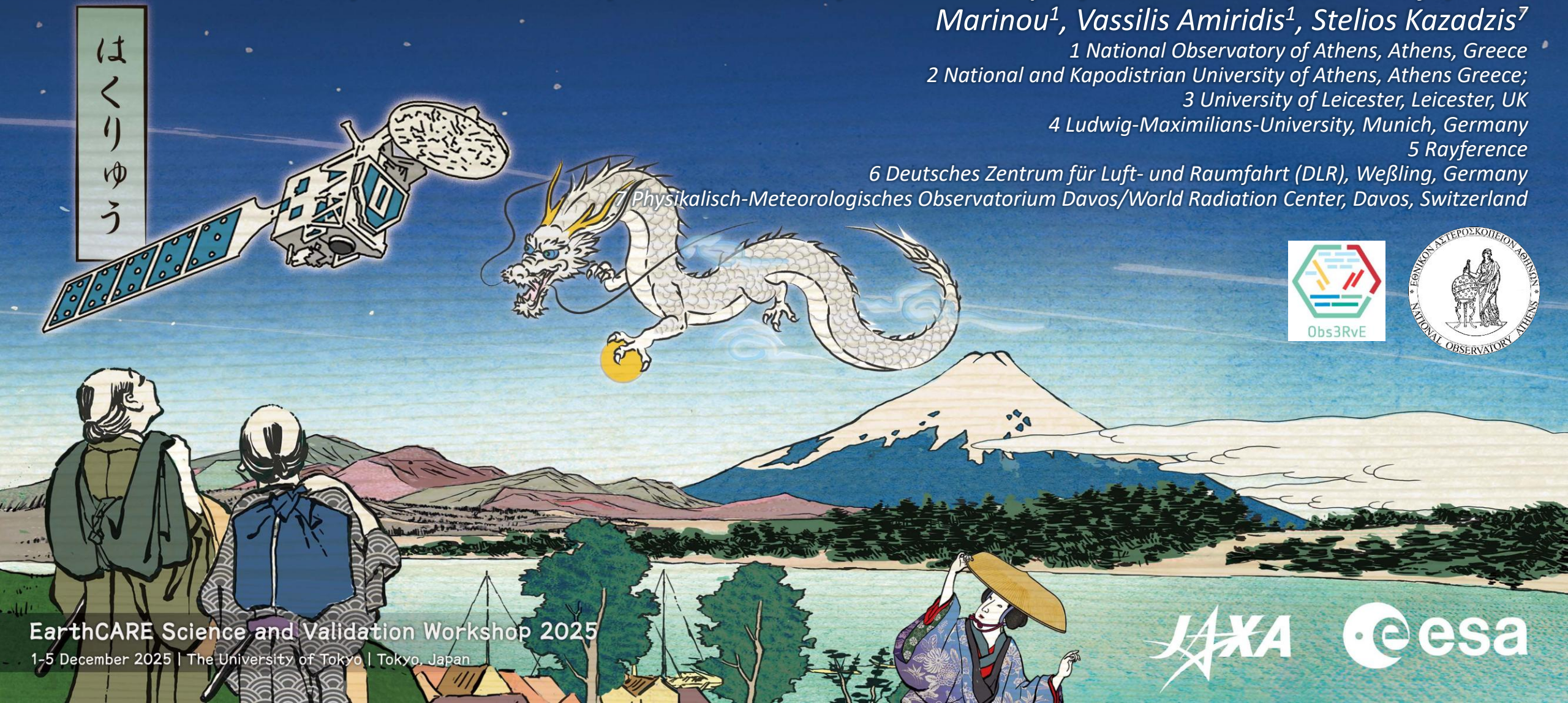
*3 University of Leicester, Leicester, UK*
*4 Ludwig-Maximilians-University, Munich, Germany*
*5 Rayference*
*6 Deutsches Zentrum für Luft- und Raumfahrt (DLR), Weßling, Germany*
*7 Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center, Davos, Switzerland*




Obs3RvE

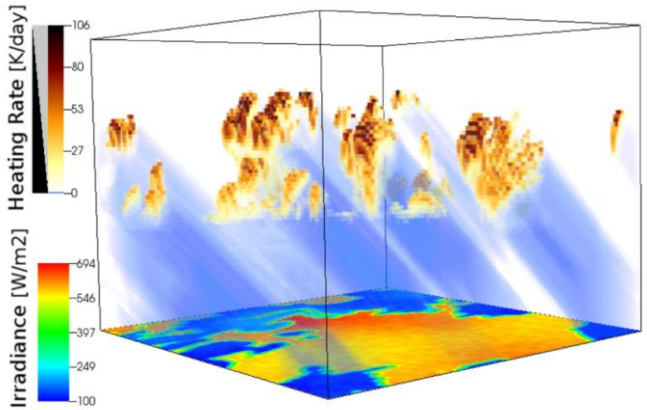
ΕΘΝΙΚΟΝ ΑΣΤΕΡΟΣΚΟΠΕΙΟΝ ΑΘΗΝΩΝ
NATIONAL OBSERVATORY ATHENS

EarthCARE Science and Validation Workshop 2025
1-5 December 2025 | The University of Tokyo | Tokyo, Japan

JAXA esa

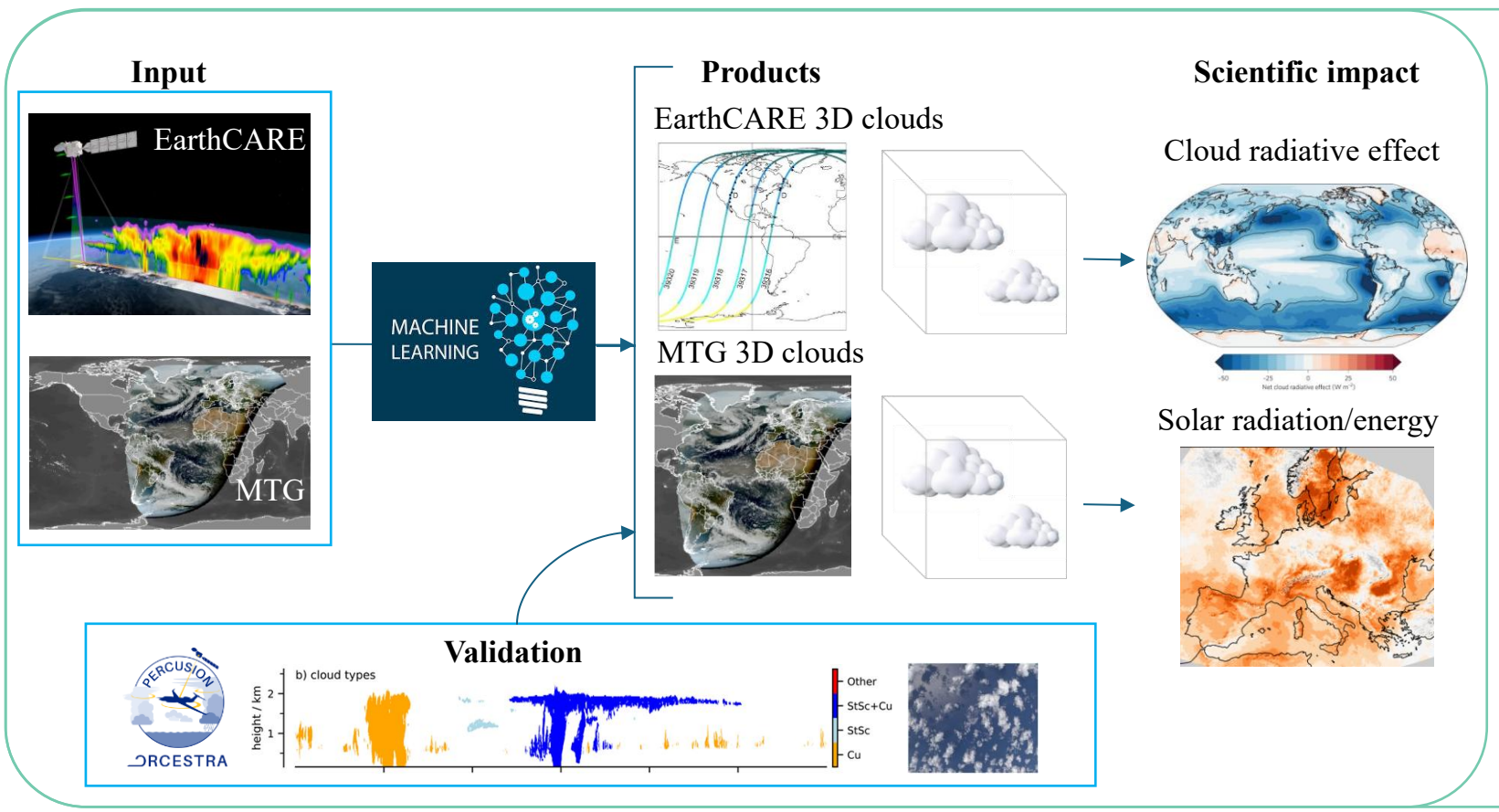
# 3D Cloud–Radiative Effects

- Clouds are still a **major source of uncertainty in climate projections**
- Clouds **reflect solar radiation** (cooling effect) and **absorb & re-emit thermal infrared radiation** (warming effect)
- Cloud Radiative Effect (CRE) is highly variable in space and time, influenced by cloud type, altitude, optical thickness, and 3D structure
- Traditional models often assume **1D, plane-parallel clouds**, ignoring 3D effects like horizontal photon transport and cloud heterogeneity
- **3D radiative transfer modeling** offers improved accuracy in quantifying CRE
- EarthCARE is the first satellite mission to provide 3D RT products




3D Radiative Transfer Model - MYSTIC (Mayer et al., 2009).
Simulation: Carolin Klinger, Fabian Jakub

# 3D Cloud Microphysical Products Using EarthCARE, MTG and AI




Synergy with ESA/EC projects

Obs3RvE

CERTAINTY

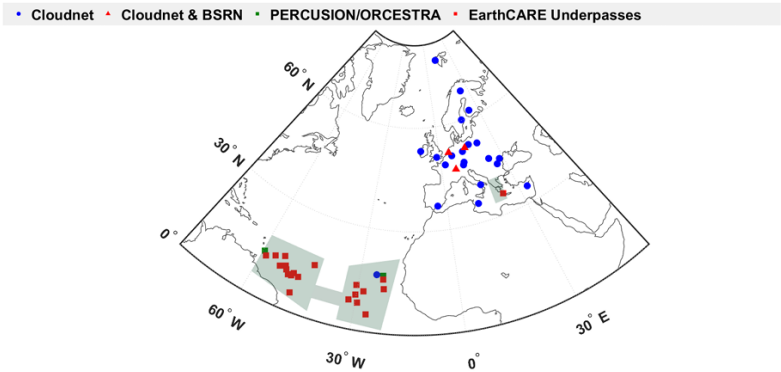
AIRSENSE

EarthCARE DISC
Data, innovation and science cluster

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

pmod wrc

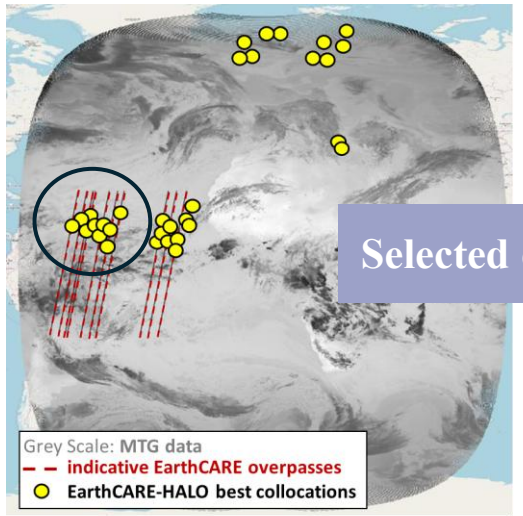
esa




Lobby9, Tsekeri et al., in poster session, Monday 1 December 16:30-18:00

**Website:** *https://climatehub.gr/react/Obs3RvE*

# Methodology




**Selected case study: 16/09/2024**

## Location

Cabo Verde Islands, Barbados and Across the Atlantic Ocean

## Period

10 August - 30 September 2024

**Support validation activities and closure studies**

**Website:** *https://orcestra-campaign.org/intro.html*

## EarthCARE 3D Cloud & Aerosol scenes

| | |
|---|---|
| Cloud phase | Liquid water content |
| Aerosol extinction coefficient | Water effecctive radius |

**3D RT calculations** — libRadtran, MYSTIC

- **Aircraft level**
- **Top-of-the-atmosphere (TOA)**

**RT closures:** Airborne / TOA validation framework

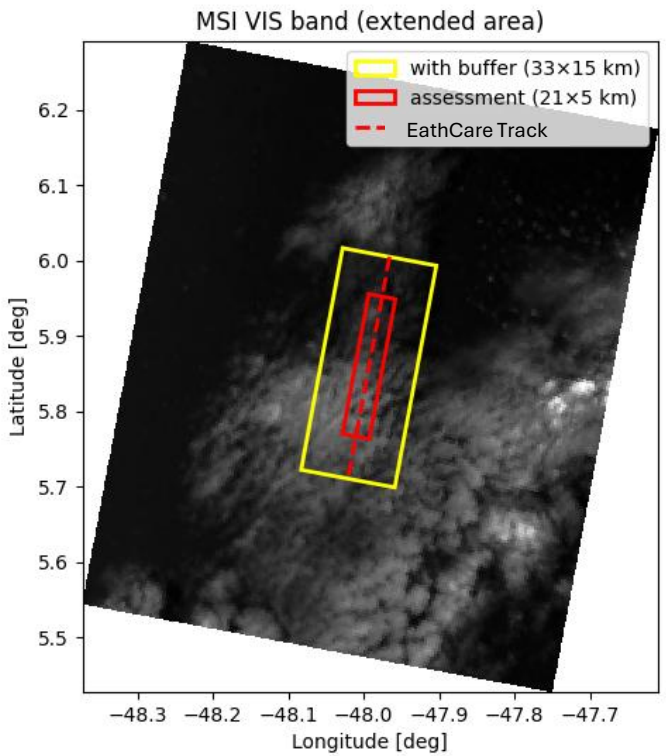
**Airborne**
Solar Radiation Measurements
**specMACS**

**Satellite Measurements**
EC Radiances & Fluxes
**BBR**

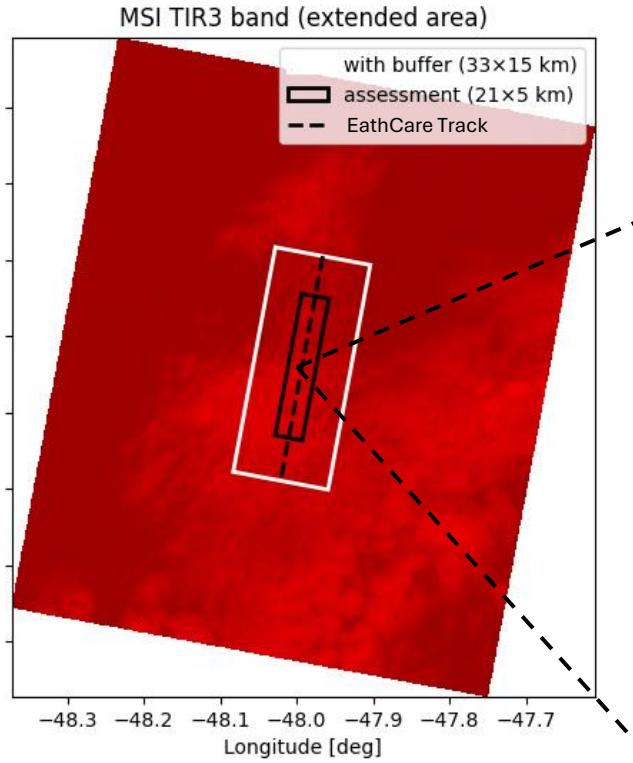
# 3D Scene

**MSI_RGR: BA Baseline**

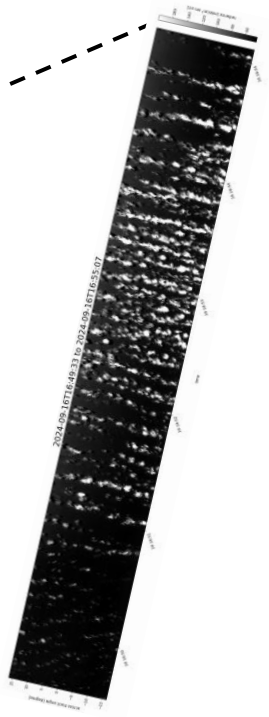
**MSI channel 1**




**MSI channel 7**




**specMACS/HALO** (Ewald et al., 2016)



# 3D Reconstructed Scene from ACMB-3D

**3D RT inputs**

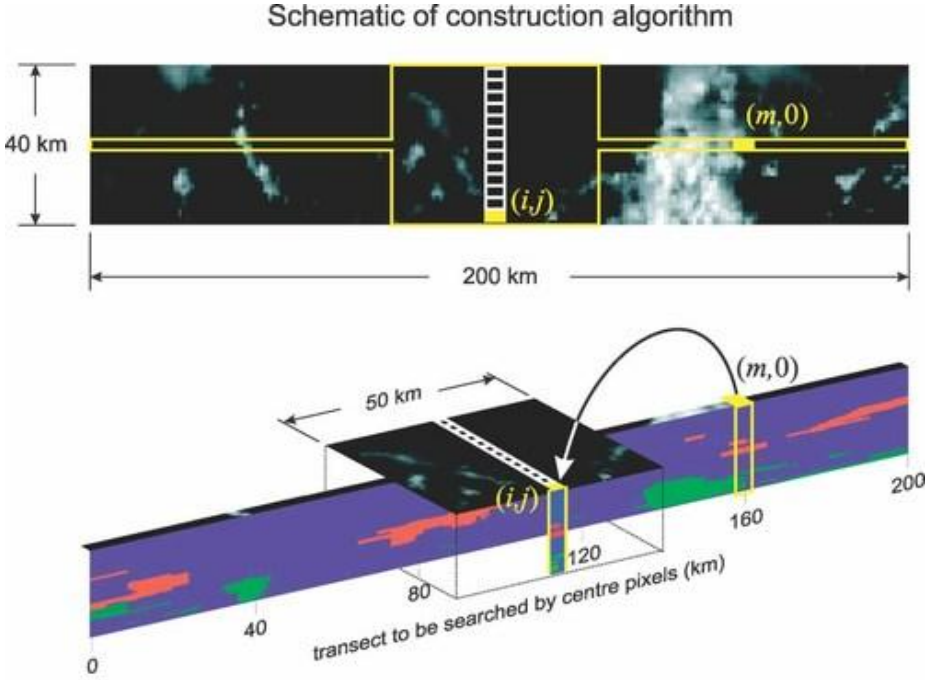
**3-D Scene Reconstruction**
(ACMB-3D/ALL_3D)[BA]
(Barker et al, 2011; Qu et al., 2023)

**Meteorological Profiles**
(ACM-COM) [BA]
(Cole et al., 2023)

**Cloud microphysical properties**
(ACM-CAP) [BC]
(Mason et al., 2023)

**Aerosol optical properties**
(ACM-CAP) [BC]
(Mason et al., 2023)

**3-D RT simulations with MYSTIC**
libRadtran
(Mayer et al. 2009)



# Cloud Microphysical Properties from ACM-CAP

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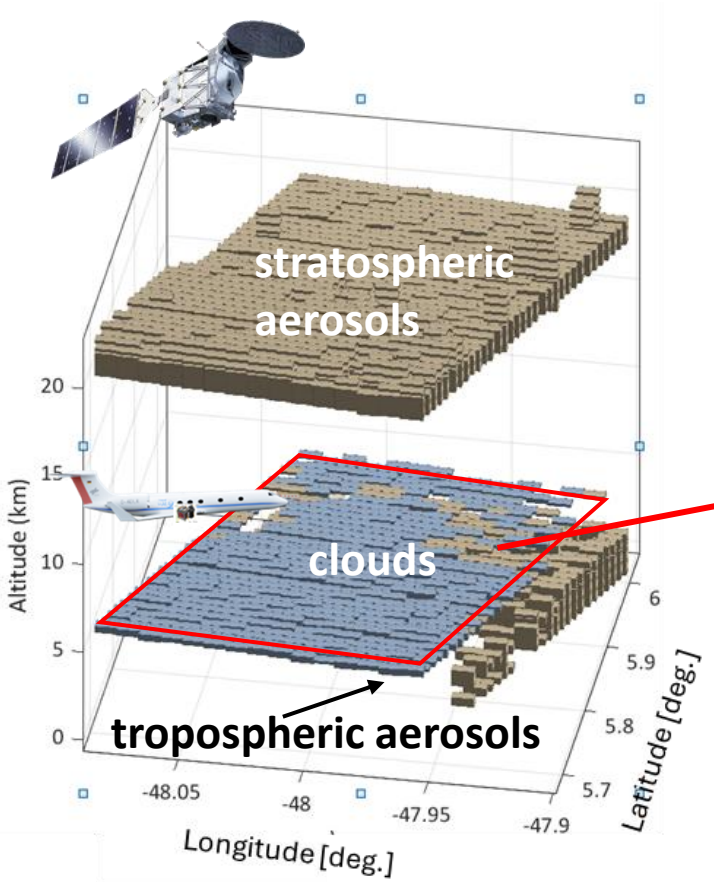
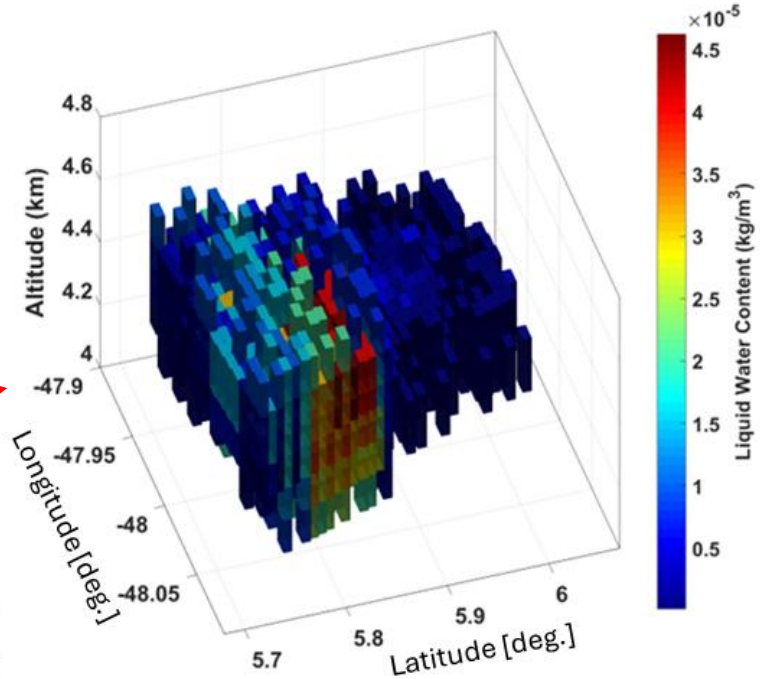
**EarthCARE**
**3D reconstructed scene**




**EarthCARE**
**liquid water content**



# Aerosol Optical Properties

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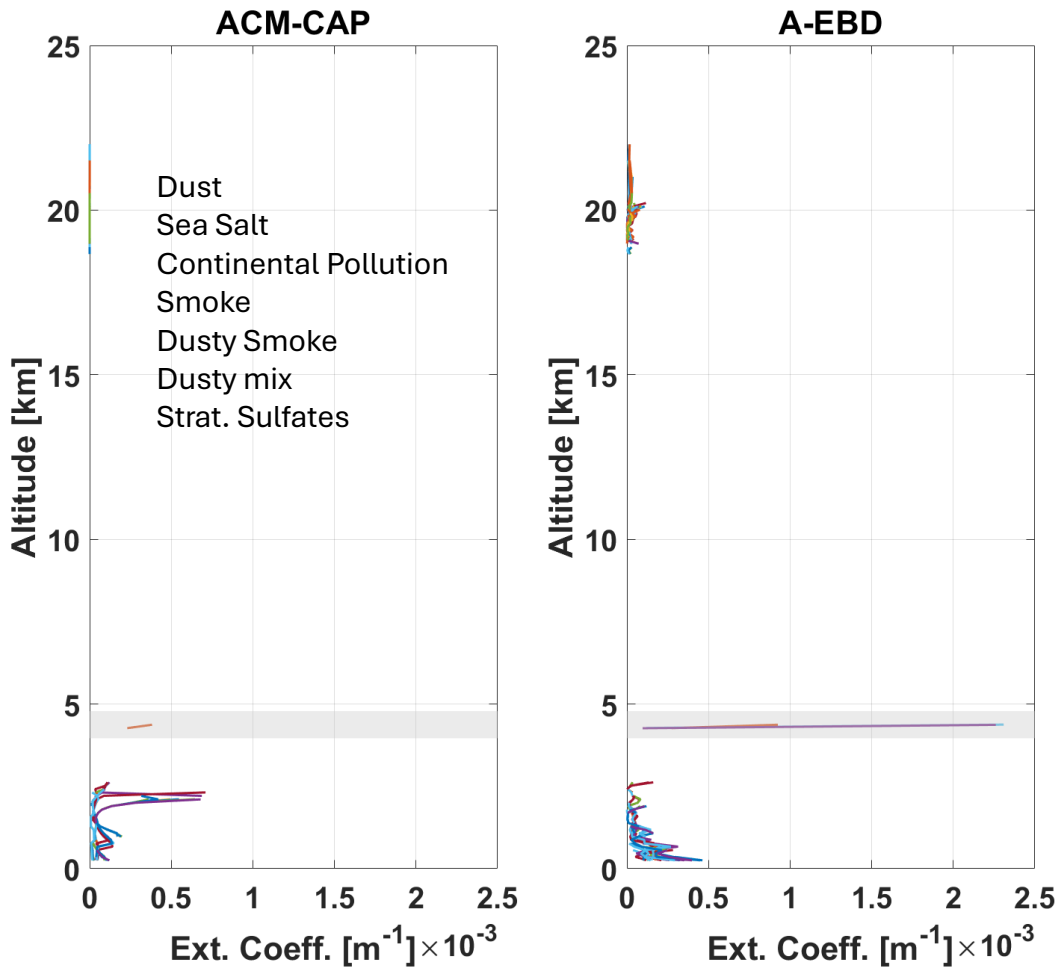

# Aerosol Scenarios

**3D RT inputs**

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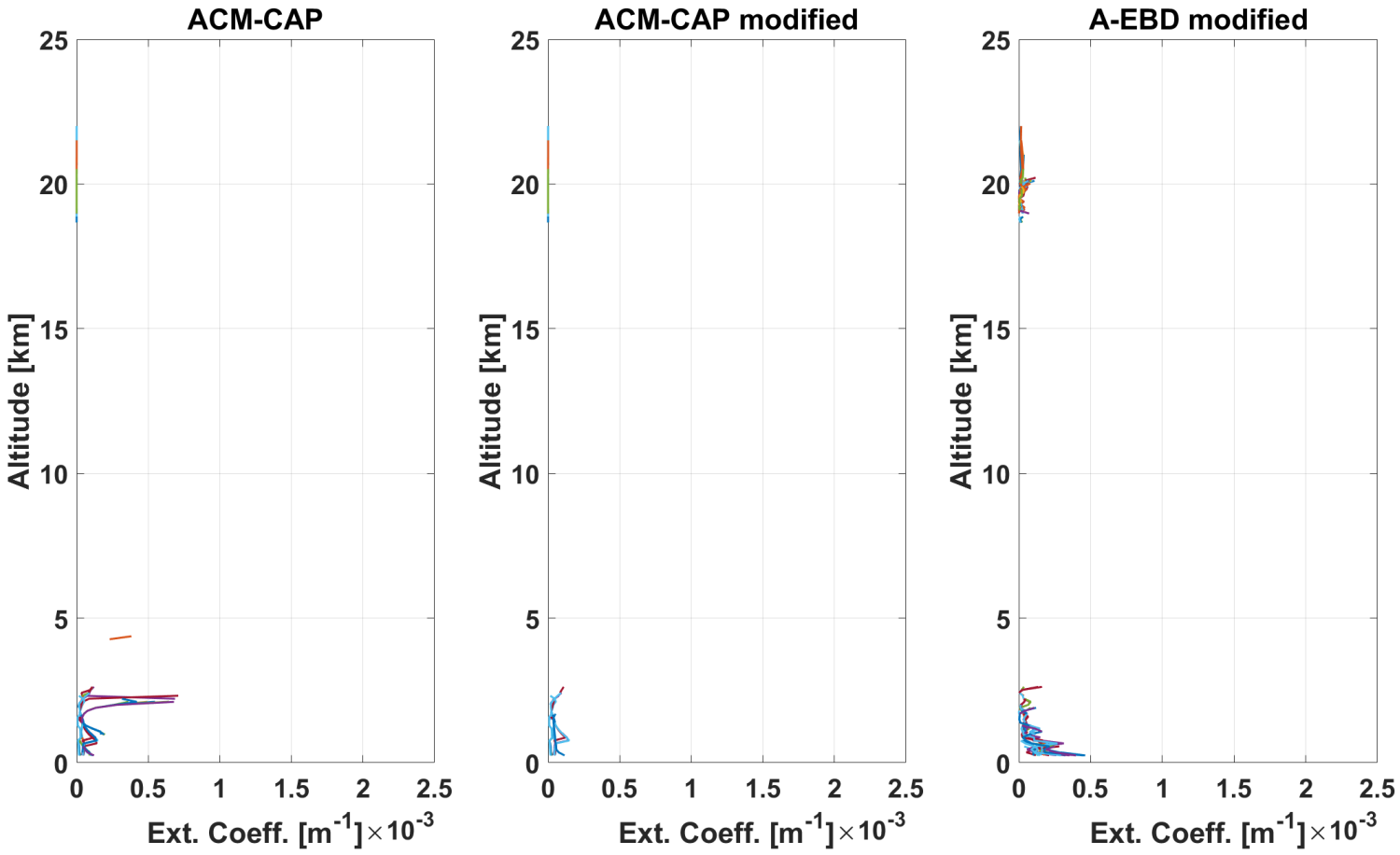

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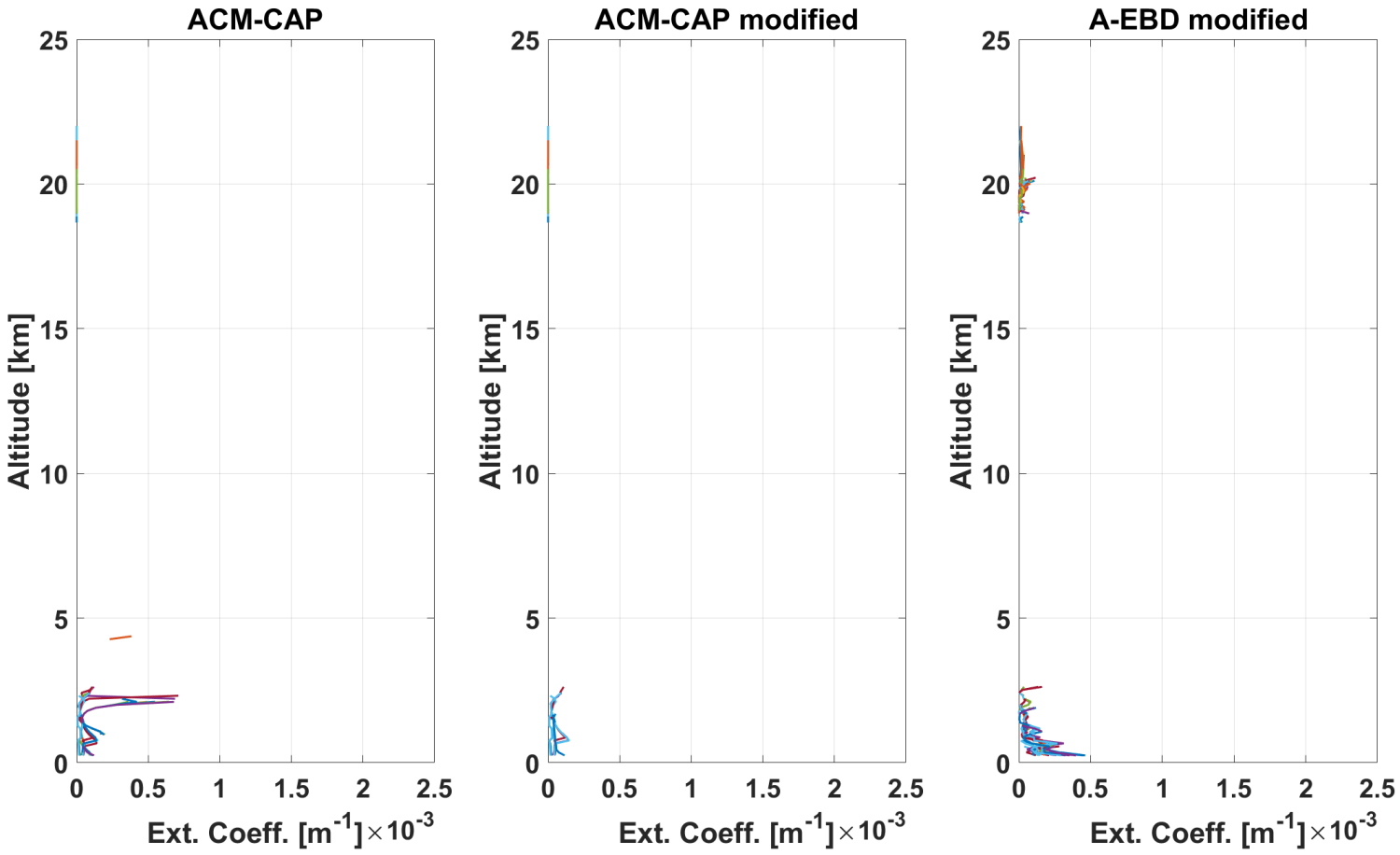
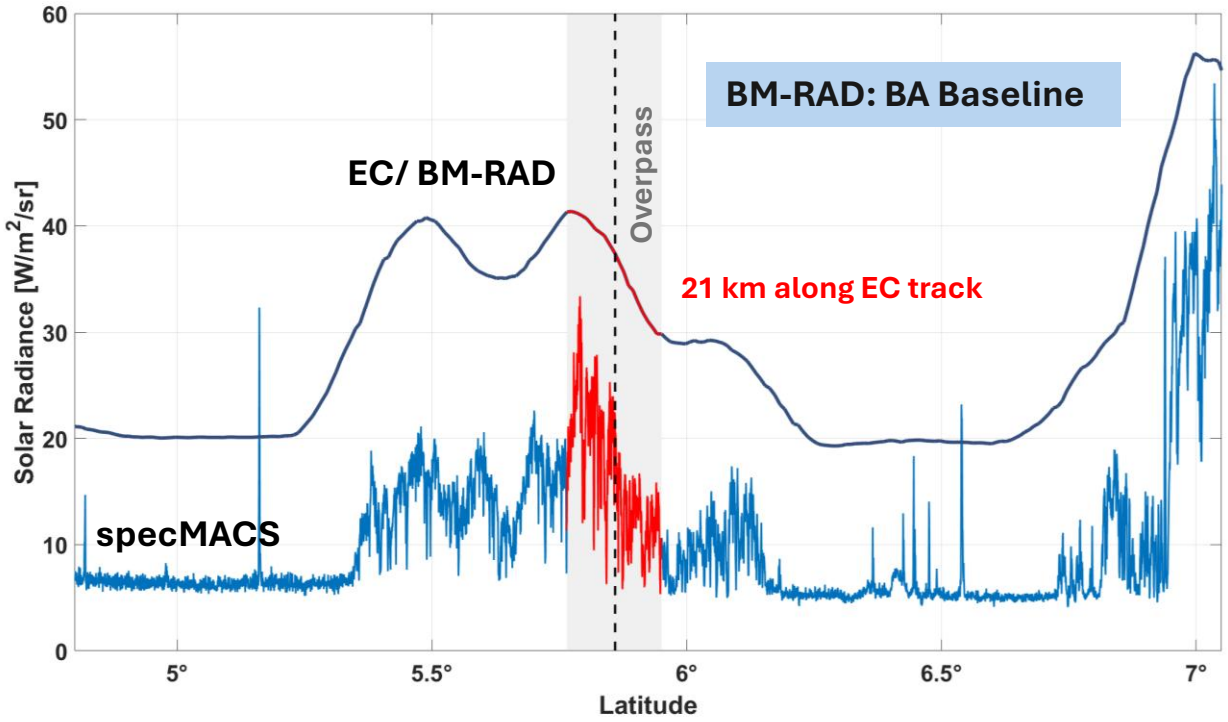


# Airborne and Satellite Radiation Measurements

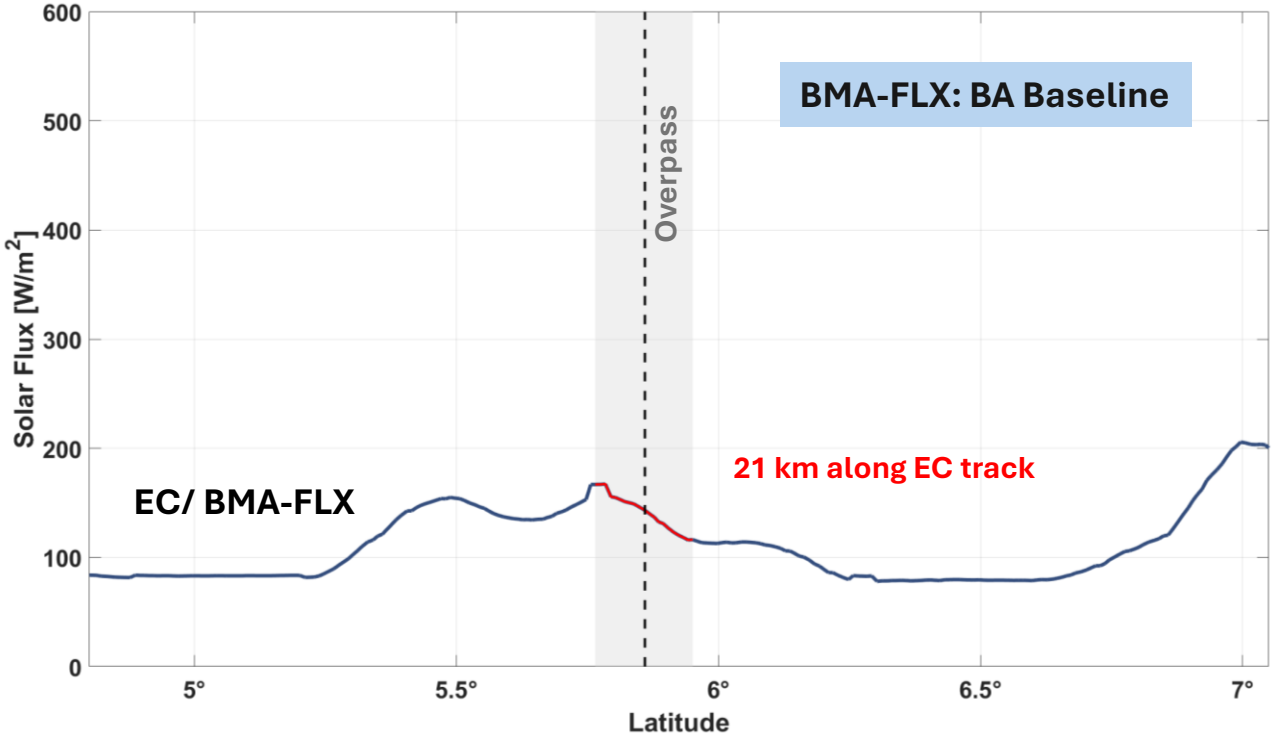
**specMACS** (Airborne Radiances) & **EarthCARE** (TOA Radiances)




**Altitude:** HALO aircraft [~15 km]

**Output:** Integrated Radiances [500-900 nm]

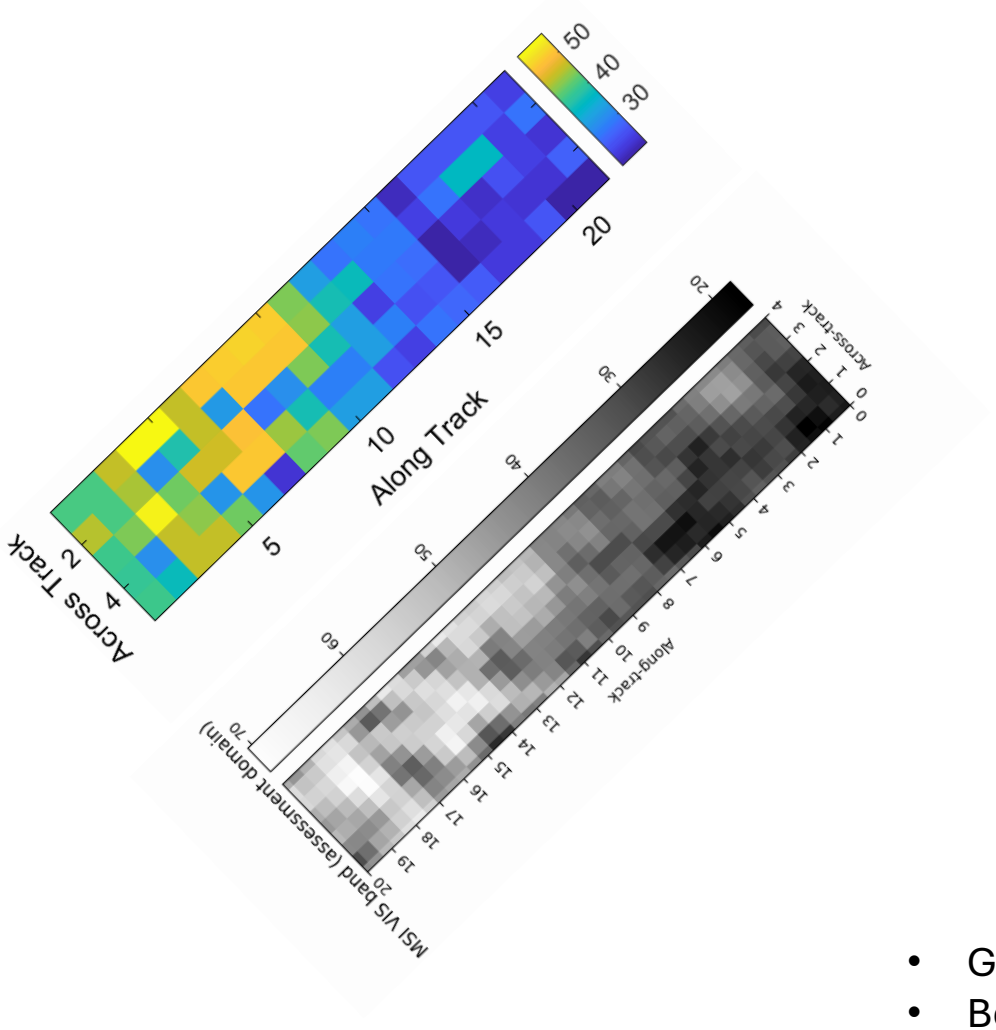
**EarthCARE** (TOA Solar Fluxes)

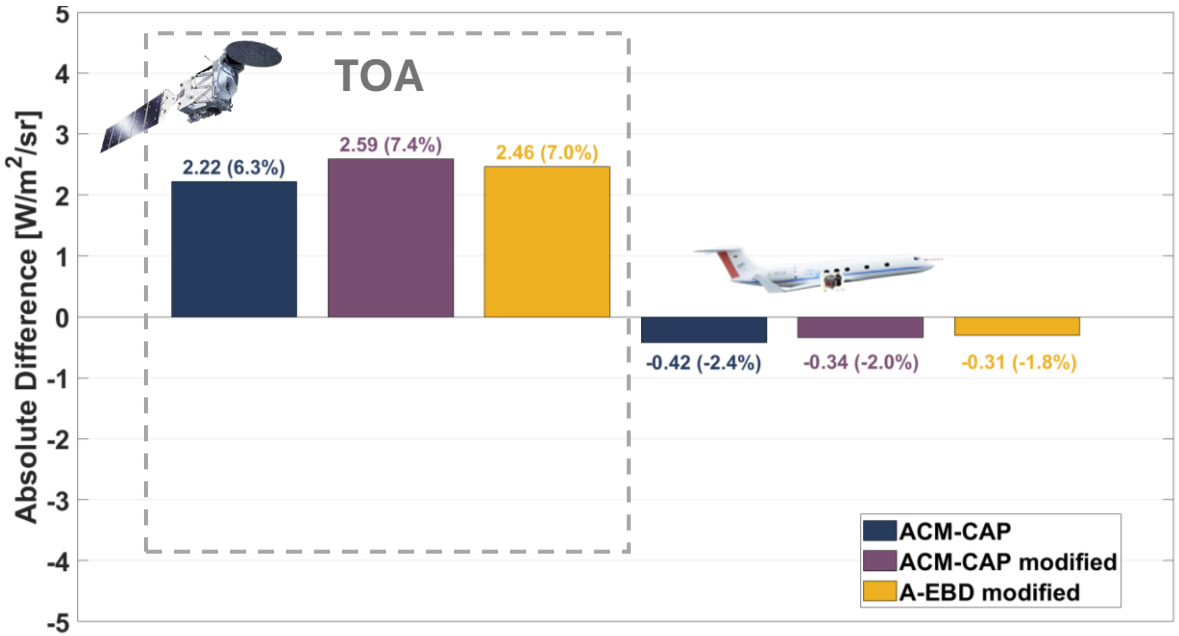



**Altitude:** TOA

**Output:** Integrated Radiances [250-4000 nm]

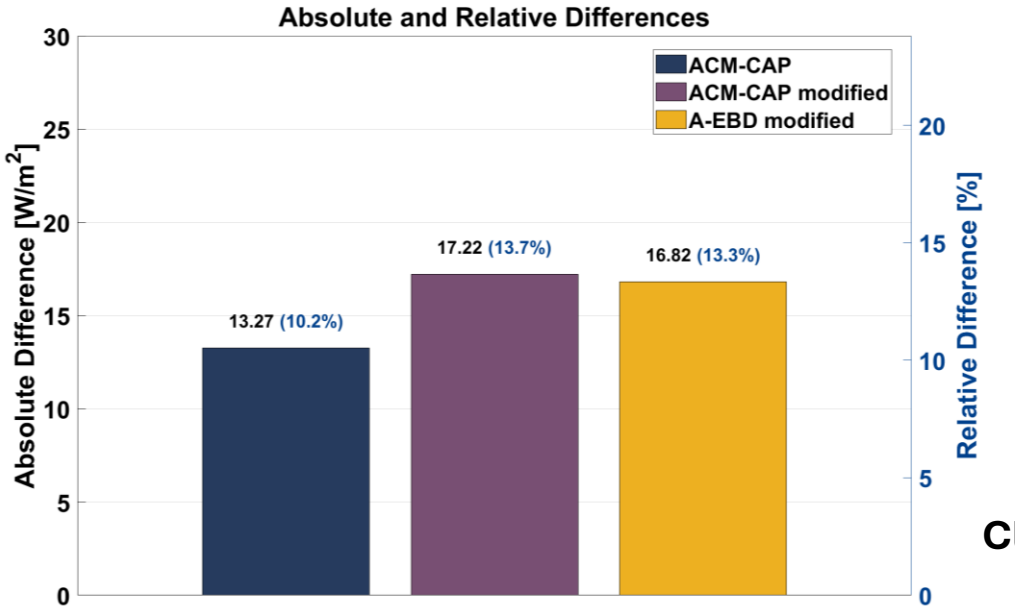
# Results – Closures with BBR and specMACS Radiances




- Good agreement with both TOA (BBR) and aircraft (HALO) altitude observations
- Better closure with aircraft observations

# Results – Closure with BBR Effective Fluxes & Cloud Radiative Effect




- Better agreement in the case of ACM-CAP derived aerosol extinction coefficient values
- Difference with BBR effective fluxes for ACM-CAP ~13W/m$^2$ close to EarthCARE target of 10W/m$^2$

**CRE: ~50 W/m$^2$**

**Cloud Radiative Effect (CRE)** = all-sky fluxes – cloud free sky at TOA

These results should be compared with **ACMB-DF** EarthCARE product (not available for this scene)

# Conclusions

- 3D RT simulations were performed based on EarthCARE cloud and aerosol products and compared with specMACS airborne radiances as well as with BBR broadband unfiltered radiances and effective fluxes
- Overall good agreement between 3D simulated radiances and fluxes with observations at TOA (BBR) and flight altitude (specMACS)
- Deviations in aerosol extinction coefficient inputs revealed small differences in the case of radiances, but larger differences in the case of fluxes

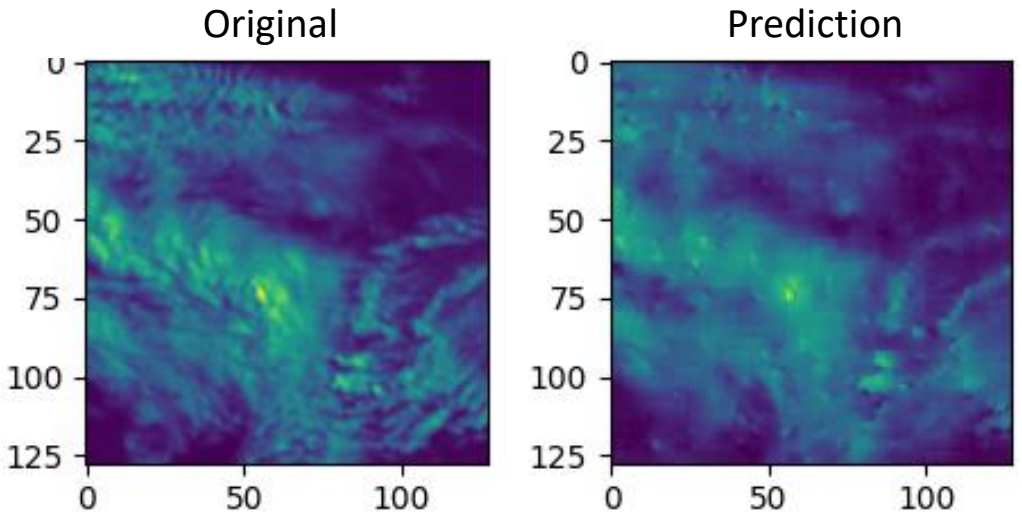
# Future Steps with New 3D Cloud Scenes

**Science goal: improving the quantification of cloud radiative effect**

**New EarthCARE 3D cloud scenes from Obs3RvE**:

- Investigate more PERCUSION cases under different atmospheric conditions (e.g., cloud, aerosol types)
- Comparison of radiative closures at TOA with ACMB-DF EarthCARE product

**Obs3RvE first results of 2D cloud scene reconstruction with ML using MTG observations**



This work has been financially supported by the Obs3RvE (Optimising 3D RT Earthcare product using geostationary observations and AI) project, funded from the European Space Agency under Contract No. 4000147848/25/I/AG, the COST Action < HARMONIA, CA21119>, supported by COST (European Cooperation in Science and Technology), the CERTAINTY project (Grant Agreement 101137680) funded by Horizon Europe program, the EarthCARE DISC project, funded by the European Space Agency under Contract No. 4000144997/24/I-NS and the AIRSENSE (Aerosol and aerosol cloud Interaction from Remote SENSing Enhancement) project, funded from the European Space Agency under Contract No. 4000142902/23/I-NS.

**Thank you!**

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ΤΟ ΕΡΓΟ ΧΡΗΜΑΤΟΔΟΤΕΙΤΑΙ ΑΠΟ ΤΟ ΕΘΝΙΚΟ ΣΚΕΛΟΣ ΤΟΥ ΠΔΕ ΕΘΝΙΚΟ ΠΡΟΓΡΑΜΜΑ ΑΝΑΠΤΥΞΗΣ 2021-2025 ΥΠΟΥΡΓΕΙΟ ΑΝΑΠΤΥΞΗΣ – ΓΕΝΙΚΗ ΓΡΑΜΜΑΤΕΙΑ ΕΡΕΥΝΑΣ ΚΑΙ ΚΑΙΝΟΤΟΜΙΑΣ