3D CLOUD RECONSTRUCTION FROM ALL-SKY CAMERA IMAGES FOR THE ANALYSIS OF THEIR IMPACT ON SKY RADIANCES AND RETRIEVED AEROSOL PROPERTIES

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INTRODUCTION

Cloud presence enhances the sky radiance (*Herrero-Anta et al., 2025*). When sky radiance measurements are used to retrieve aerosol properties under partially cloudy conditions using an inversion algorithm that is designed only for cloud-free conditions, it is observed a bias in the retrieved aerosol properties. This study proposes the **correction of the enhancement of sky radiances** using the **cloud enhancement factor (CEF),** which is defined as the ratio between the sky radiance under partially cloudy conditions and under the equivalent cloud-free situation; these values are calculated using the 3D radiative transfer model MYSTIC. For that, it is proposed a **method to reconstruct the cloud cover in 3D** using an all-sky camera and a ceilometer. The CEF obtained has been used to correct the sky radiances measured by CE318-T photometers from AERONET (*Holben et al., 1998*) and retrieve again the aerosol properties using GRASP code. A case study is presented.

SITE

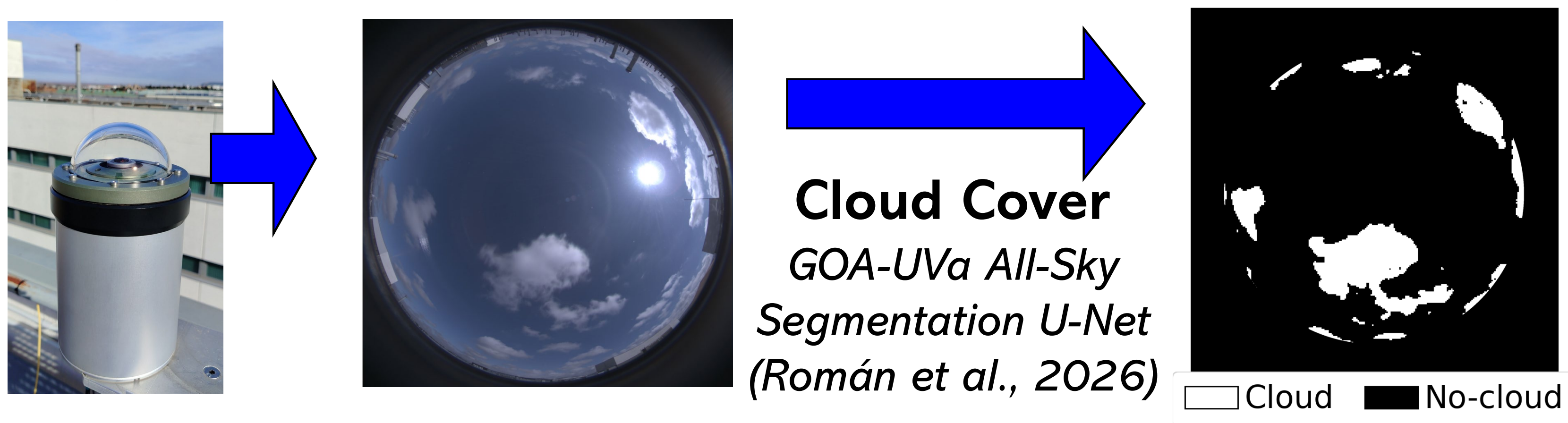
Rooftop of the Faculty of Sciences at the University of **Valladolid (Spain)**: 41.66° N; 4.71° W; 705 m a.s.l.

DATA

***Jakub and Gregor (2022)* cloud maps dataset:** 6 h of single layer shallow cumulus with an ever increasing cloud deck. Clouds defined by liquid water content (**LWC**) and droplets effective radius (r_{eff}) in 3D maps of 256×256 pixels (25 m resolution) and 119 vertical layers. Temporal resolution: 10 s.

INSTRUMENTATION & MODELS

- **All-sky camera OMEA-3C** *(Alcor System)*: HDR all-sky images calibrated (zenith & azimuth of each pixel are known).

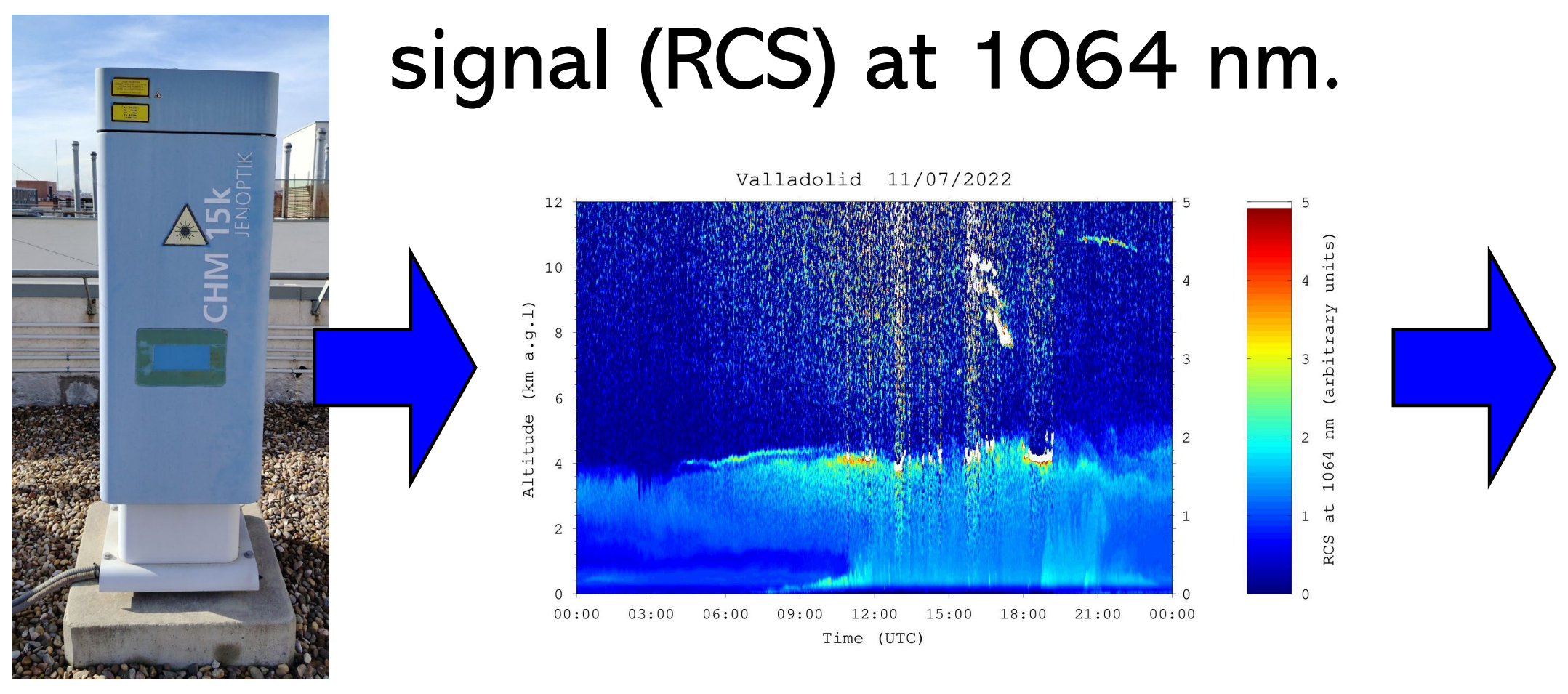


Cloud Cover

GOA-UVa All-Sky Segmentation U-Net (Román et al., 2026)

☐ Cloud ■ No-cloud

- **Ceilometer CHM15k-Nimbus** *(Lufft)*: Range corrected signal (RCS) at 1064 nm.



Cloud base height (**CBH**)
Max Cloud depth (**CDmax**)

- **MYSTIC:** 3D radiative transfer model (*Emde et al., 2010*) to **simulate sky radiances** in **cloudy** and **cloud free scenarios**.
- **GRASP:** **Inversion strategy GRASPpac** (*Román et al. 2018*). Uses aerosol optical depth (AOD) and sky radiances at 440, 675, 870 &1020nm (CE318-T) and RCS at 1064nm (ceilometer).

3D CLOUD RECONSTRUCTION

1. **Cloud base position**: Projection of the Cloud Cover from the HDR images at the CBH altitude, in a 2D grid of 2000x2000 pixels (50x50 km).
2. **Cloud depth:** Statistic study using clouds extracted from the cloud maps in *Jakub and Gregor (2022)*. First, it is obtained the 2D projection of the cloud. The distance to the cloud edge (**DCE**) of each pixel in the projection has been correlated with the cloud depth (**CD**) for that pixel. Considering all the clouds, it is obtained that: $CD = -0.449(DCE)^2 + 1.449\,DCE$
3. **Cloud microphysics:** LWC and r_{eff} are determined at each altitude (z) within the cloud following the adiabatic model (*Pörtge, 2024*):

$$LWC = f_{ad} C_W (z - CBH)$$

$$r_{eff} = \left(\frac{LWC}{4\pi\rho k N_d}\right)^{1/3}$$

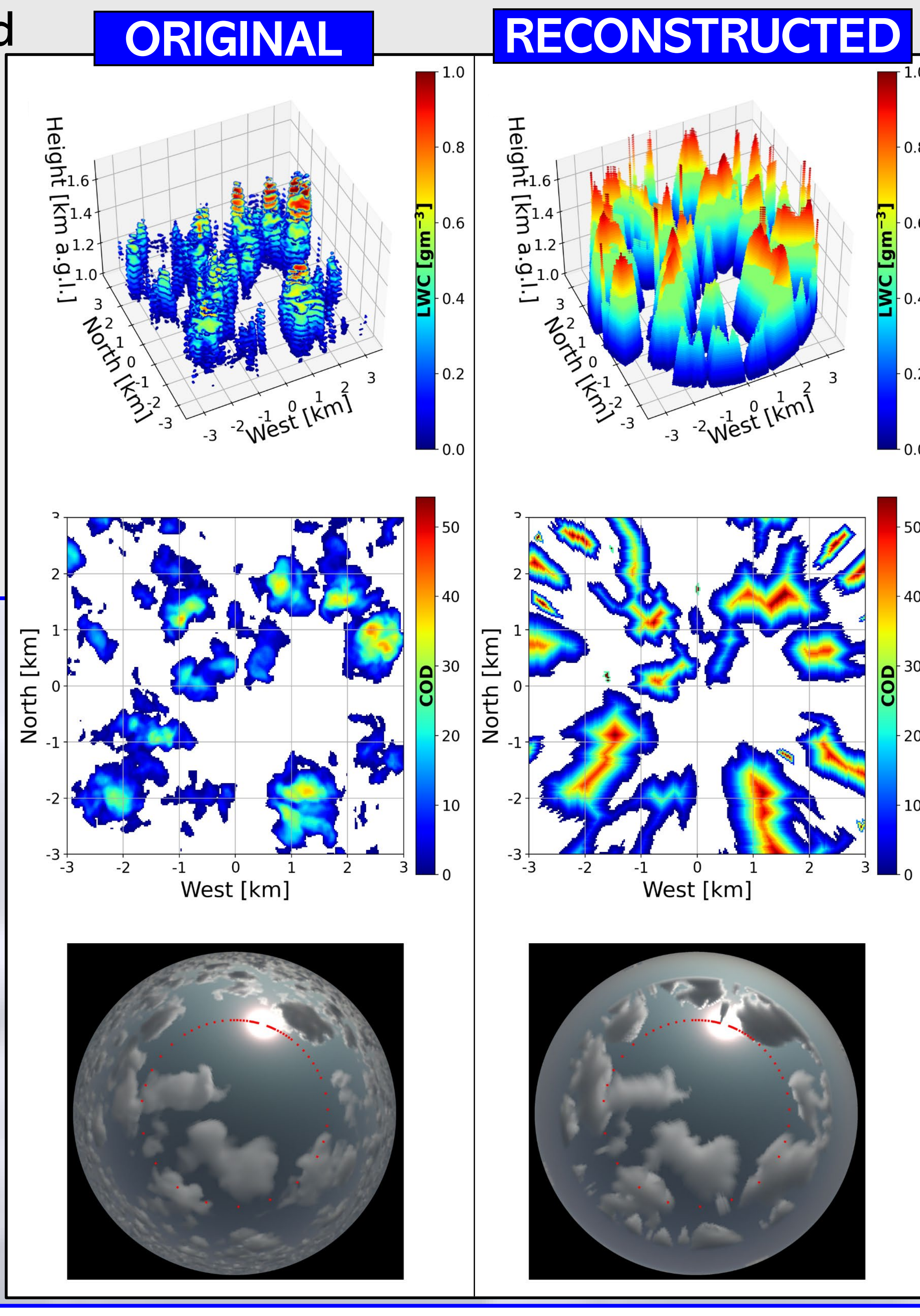
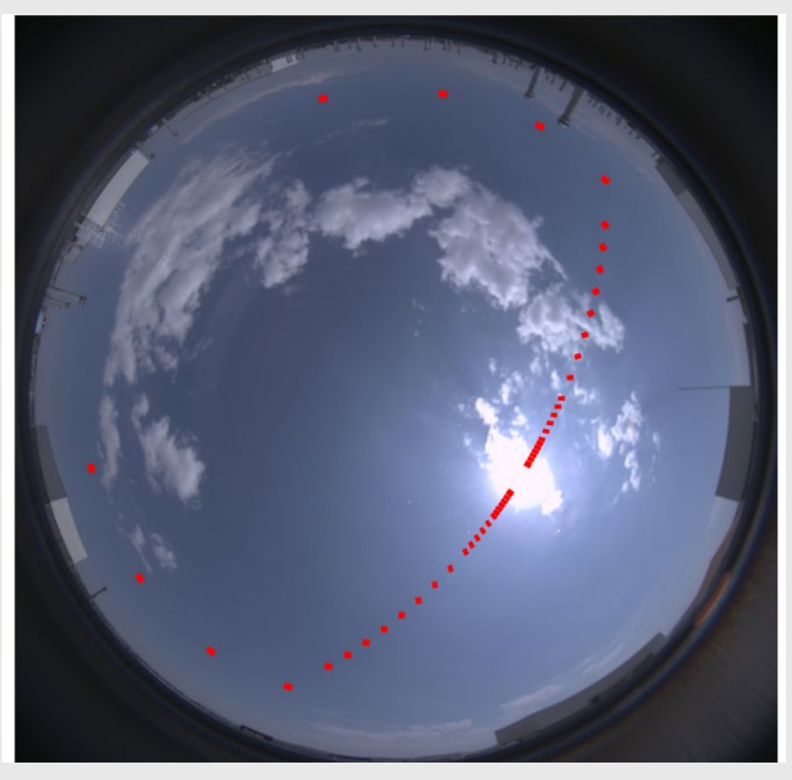
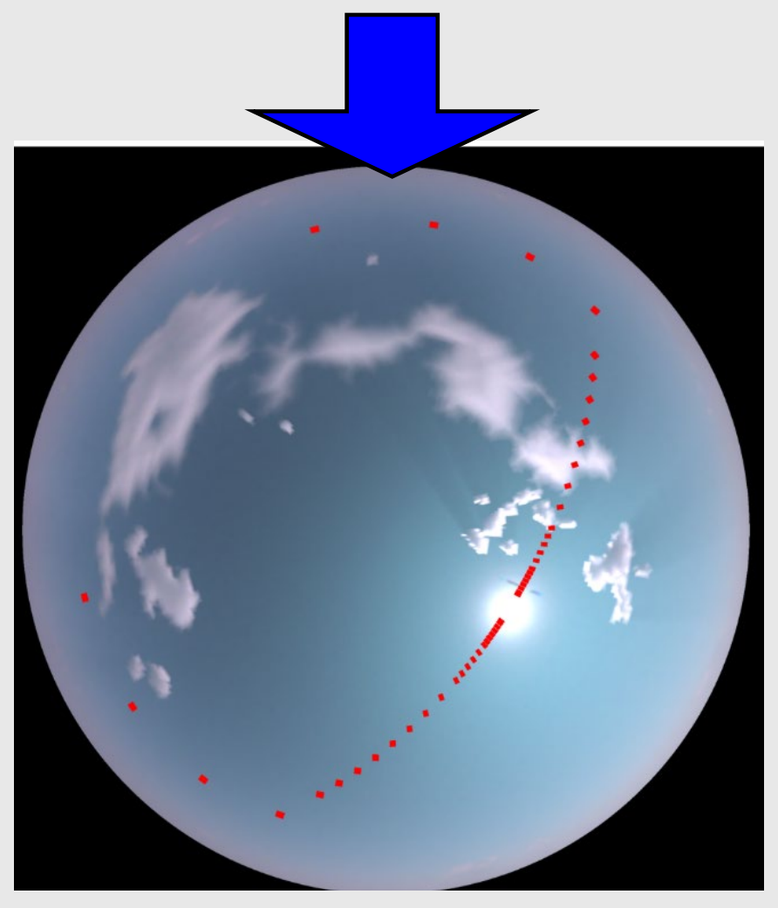


Figure 1: *ORIGINAL cloud map extracted from the dataset by Jakub and Gregor (2022) at 9120 s, the corresponding cloud optical depth in the 2D projection and the All-sky image simulated with MYSTIC. The same plots are shown for the cloud map RECONSTRUCTED using the All-sky image simulated using the original cloud map.*

CASE STUDY: 2 AUG 2022 10:27 UTC (AOD 440 nm = 0.29)

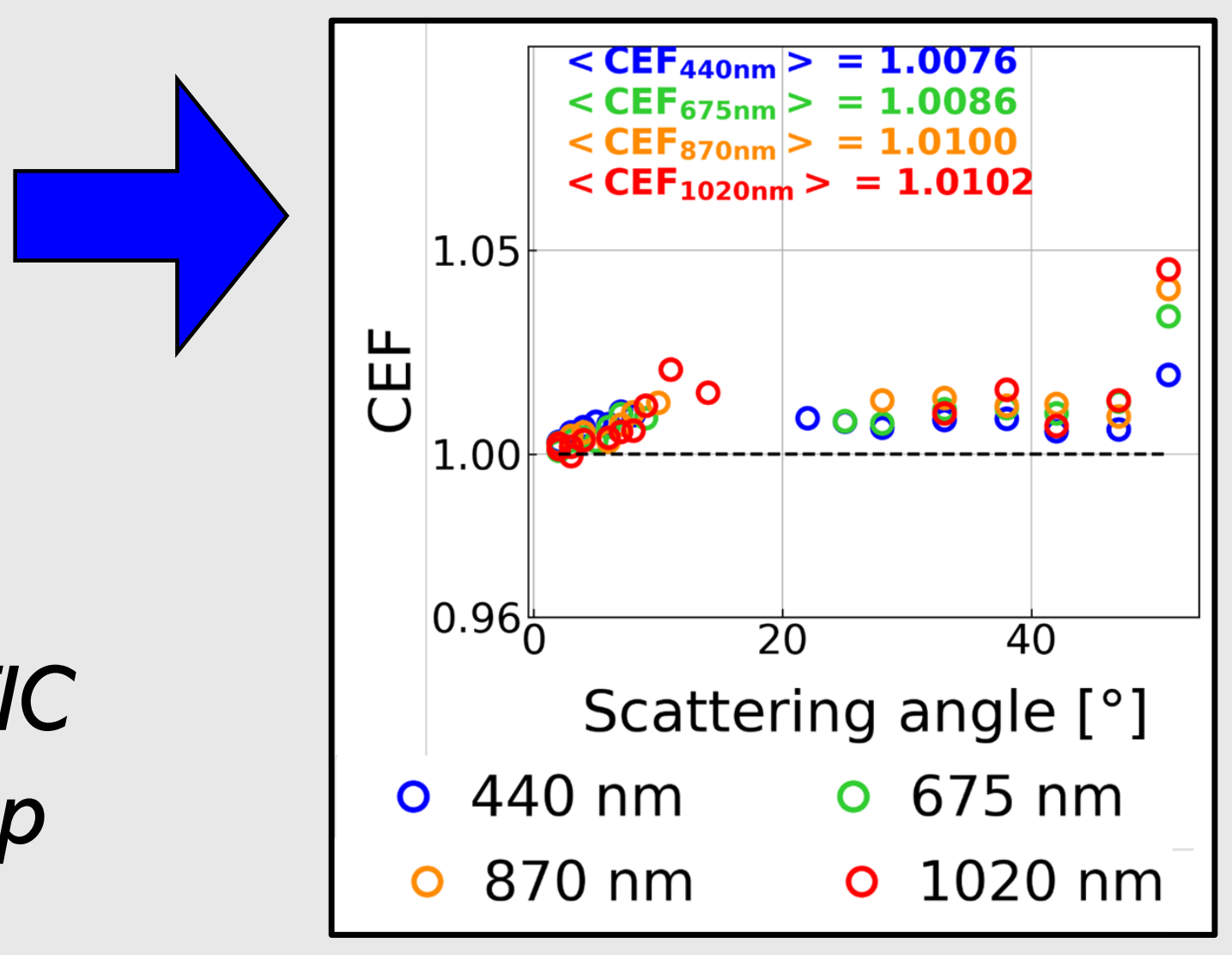


HDR all-sky image from the OMEA-3C



RGB all-sky image simulated with MYSTIC for the 3D cloud map reconstructed

The CEF at each angle of scattering measured by the CE318-T in this case of study (red points in the all sky images) is calculated. These values are used to correct the sky radiance measurements from the CE318-T and retrieve again the aerosol properties.



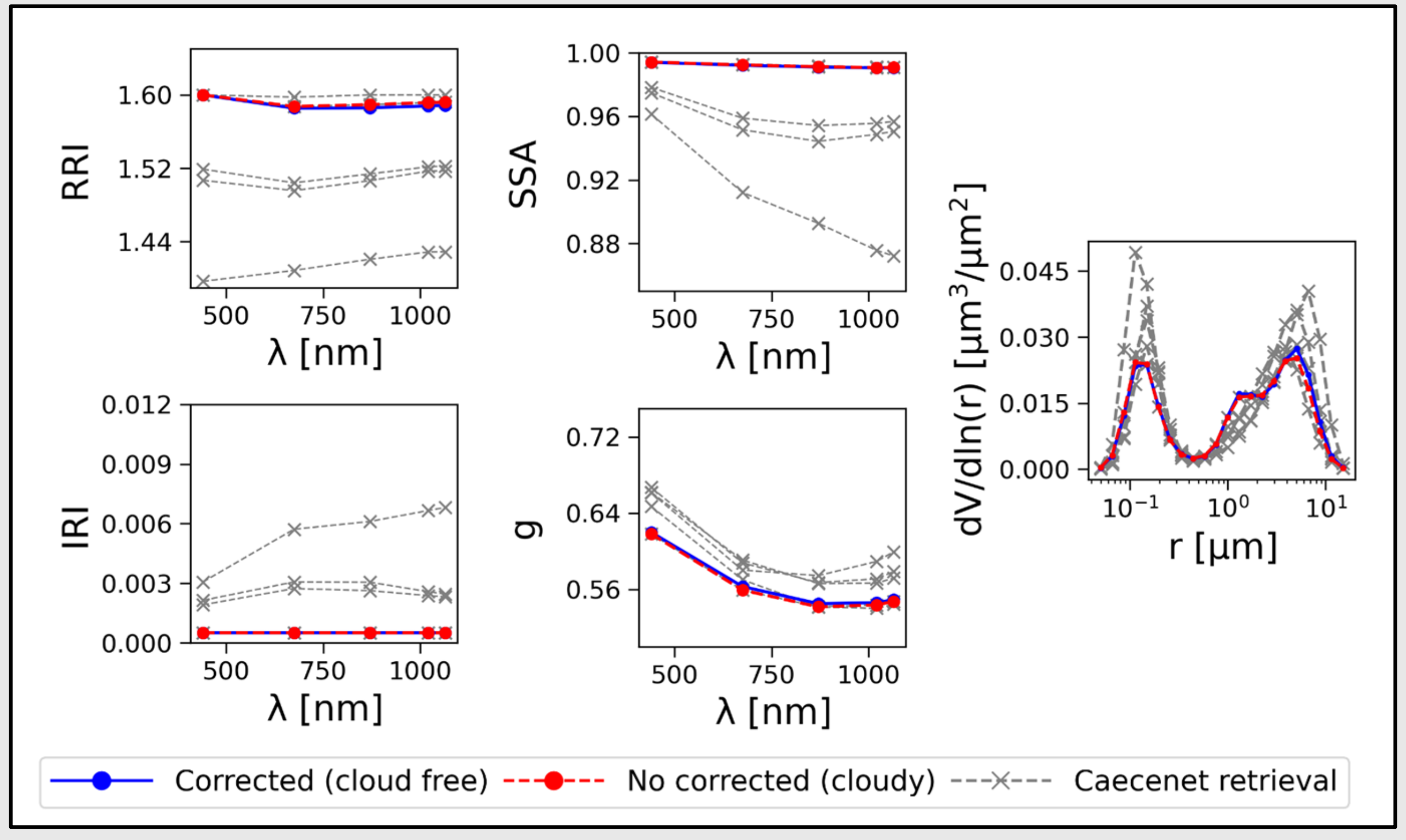


Figure 2: *Aerosol properties obtained with GRASPpac using measurements taken under cloudy conditions (No corrected) and once the sky radiances are corrected by the CEF (corrected). The rest of aerosol properties retrieved that day in cloud free conditions are included (Caecenet retrieval). Real (RRI) and imaginary (IRI) parts of the refractive index, single scattering albedo (SSA), asymmetry factor (g) and volume size distribution.*

CONCLUSIONS

- The 3D cloud reconstruction allows to reproduce realistic cloud maps.
- Not including the clouds in the horizon in the reconstruction causes a significant underestimation of the clouds enhancement.
- The case of study analyzed shows low CEF values, which correlates with the low bias observed when obtaining the corrected aerosol properties, in accordance with the results from *Herrero-Anta et al., (2025)* for low cloud impact.

References

Emde et al., (2010): 10.5194/acp-10-383-2010; Herrero-Anta et al. (2025): 10.1016/j.atmosres.2025.107938; Herrero-Anta et al. (2025): 10.1016/j.atmosres.2025.107938; Holben et al., (1998): 10.1016/S0034-4257(98)00031-5, Jakub and Gregor (2022): 10.57970/5d0k9-q2n86; Pörtge (2024), PhD thesis; Román et al. (2026): 10.5281/zenodo.18894939.

Aknowledgements

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