How to interface between Shallow Cumulus Modelling and Stereo Camera Observations

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Abstract

Shallow cumulus clouds **(ShCu) measurements** are crucially **important in evaluating** Large-Eddy Simulations **(LES) and ShCu-parameterizations** in numerical weather and climate models. However, these data **still** mainly **consist of one-dimensional profile data**, often sampled by lidars or radars. A **new method** for **adding multi-dimensional information** is to **use networks of multiple hemispheric cameras**, which **remotely observe** ShCu in unprecedented spatial details constantly at **high temporal frequency**. These cameras provide a **large field of view,** enabling us to observe whole ShCu-life cycles. Thus, these networks **strongly complement existing ground-based instruments**. To objectively estimate camera networks' accuracy, we have to **test them against virtual LES-cloud fields**, that act as ground truth. However, for this purpose **virtual camera projections** of these cloud fields **are needed.**

Our study aims to generate such projections by combining radiative transfer theory with open-source path-tracing. With these projections, **we emulate our camera network**, currently installed at the Jülich Observatory for Cloud Evolution (JOYCE), Germany as **part of the ongoing SOCLES project**. As **input**, we use **LES-cloud fields**. Via the emulated camera images, we **reconstruct the cloud fields back** in the same way the camera network does it from real-world images. However, by using **artificial images over real-world images**, we have the **advantage of** already **knowing the whole cloud field**. This knowledge enables us to **statistically analyze and optimize our network**. Concretizing this, here are our **research objectives**:

- Objectively estimate the **efficiency of our camera network**
- Analyze the **capability of our camera network** by investing how much of a cloud shell is on average visible
- **Optimize the camera network**, using our new insights

Our camera network emulation works well in this workflow. For the selected days, about **70% of the mutually visible cloud grid boxes were rightly reconstructed** by our artificial camera network. **About 53% of a ShCu-cloud shell is averagely visible by a single** stereo camera **pair** of our network **at a single time point.** With **increasing distance** between the two cameras of such stereo camera pairs, **fewer cloud shell areas are detected.** In fact, f**or every extra kilometer, about 3.3% of a cloud shell is lost** on average.

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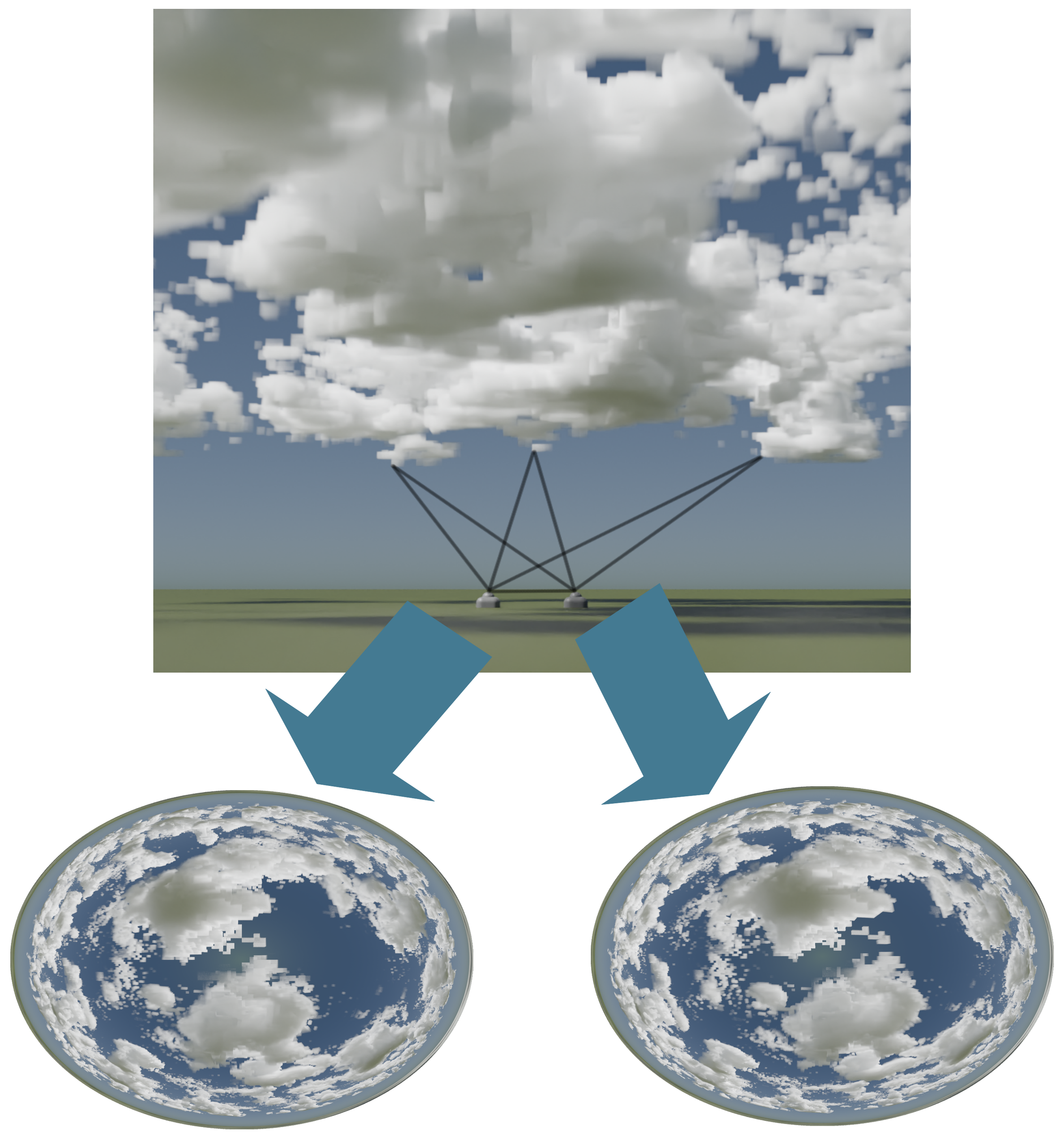
1. Introduction

- **Most** ground-based cumulus (Cu) **observations** consist of **one-dimensional profile data,** often sampled by lidars or radars [Zha+21, Sch+21, Fie+20].
- **Satellite** imagery typically **misses** the **fine-sacel structures** or **lacks the temporal resolutions** to study cloud evolution [Sch+21, Fie+20].
- A recently explored method of circumventing these issues relies on **networks of multiple** high-resolution **cameras** [Blu+21, Nou+19, R&Ö18].
- Given the promising results with real stereo camera networks, we aim to take the next step and **combine this technique with Large-Eddy Simulations (LES)**.

Goal

Apply the camera network cloud reconstruction technique to pairs of hemispheric images generated from the resolved Cu of LES.



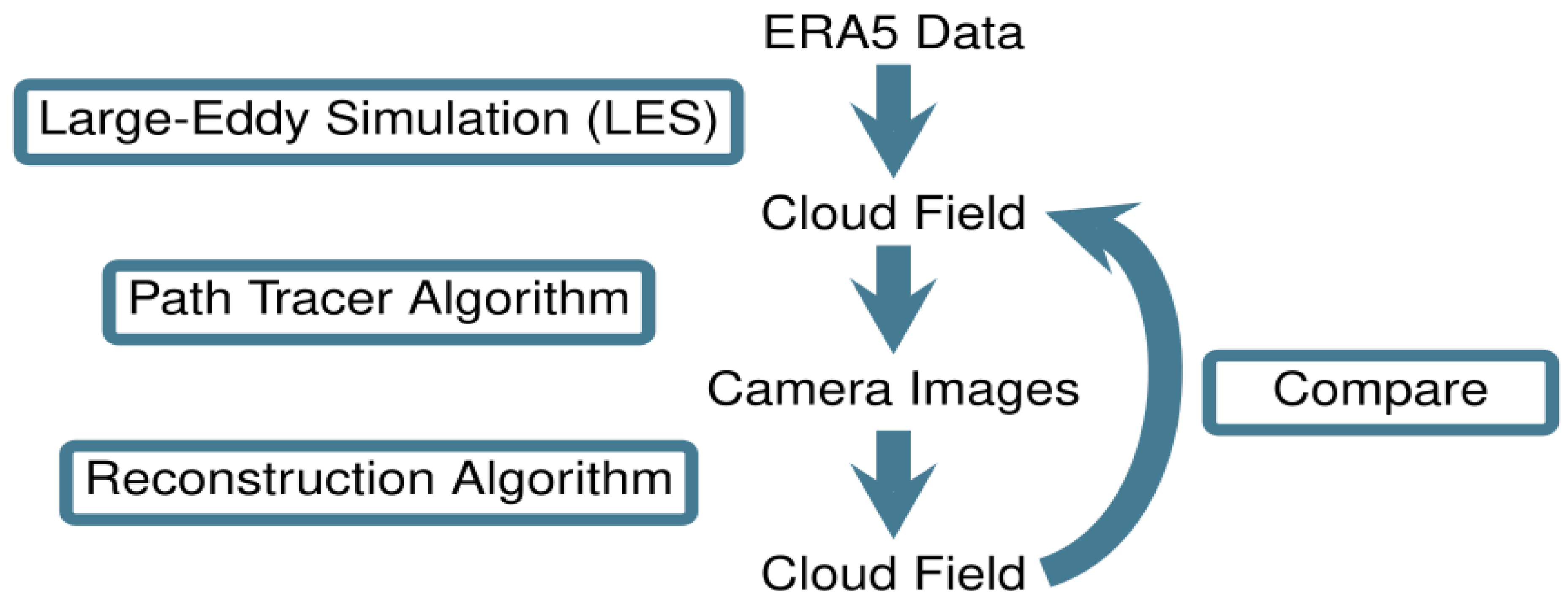
Camera Simulator

In this study, a **path tracing algorithm** is applied to generate camera projections. With these projections, it would thus become possible to **emulate networks of multiple** stereo **all-sky-imagers** at meteorological sites of interest. This emulation technique opens up a new way of **evaluating** Cu geometry in **LES** models **against observational data.**

2. Objectives

- Provide an **interface between simulations and camera observations** based on path tracing which enables unprecedented direct comparisons
- Provide Observing System Simulation Experiments (OSSEs) to **optimize** stereo **camera networks**
- Provide a technique for directly **evaluating cumulus simulations** against real-world three-dimensional camera data
- Provide the capability to **gain insights into cloud geometry, spacing, movement,** and **evolution**

3. Methods



Large-Eddy Simulation (LES)

The **Dutch Atmospheric Large-Eddy Simulation (DALES)** model ([Heu+10]) was used with a 25.6 x 25.6 km² domain and a horizontal resolution of 50 m to simulate two contiguous shallow cumulus days. DALES has been used in many recent intercomparison studies for cumulus days.

Path Tracer Algorithm

To emulate the camera network and create visualizations, we consolidated the idea of [Heu+21] to use the render engine Cycles included in the **open-source software blender.** Cycles provide GPU rendering via **path tracing,** which is a Monte Carlo method approximating the solution of the rendering equation. It takes about **3-4 mins to render a** decent camera **image** on a single GPU (tried on NVIDIA Tesla K80, NVIDIA Tesla M40, and NVIDIA Quadro M6000).

Stereo Reconstruction Algorithm

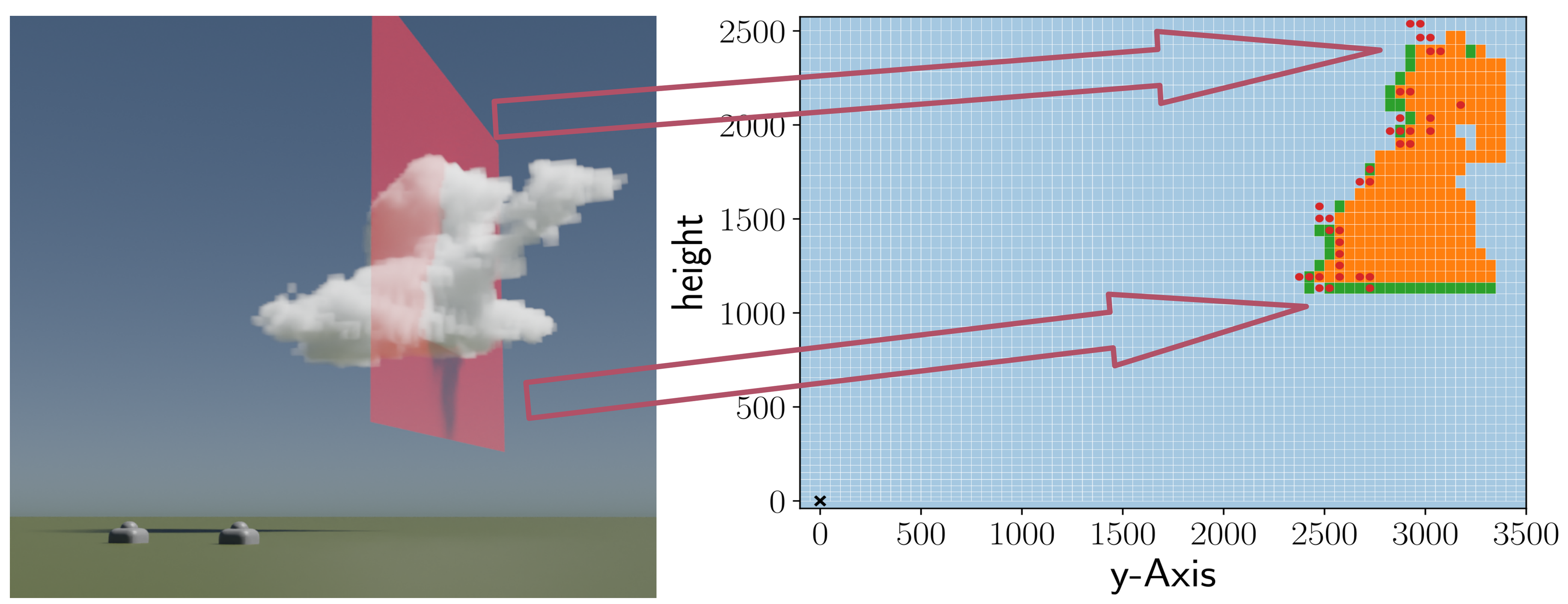
The reconstruction algorithm used for our All-Sky Images is based on [Bee+16]. Note that in contrast to [Bee+16] the reconstruction algorithm was **run on images generated from LES data.**

Compare

The original LES cloud field was compared against the reconstructed cloud field. It was examined

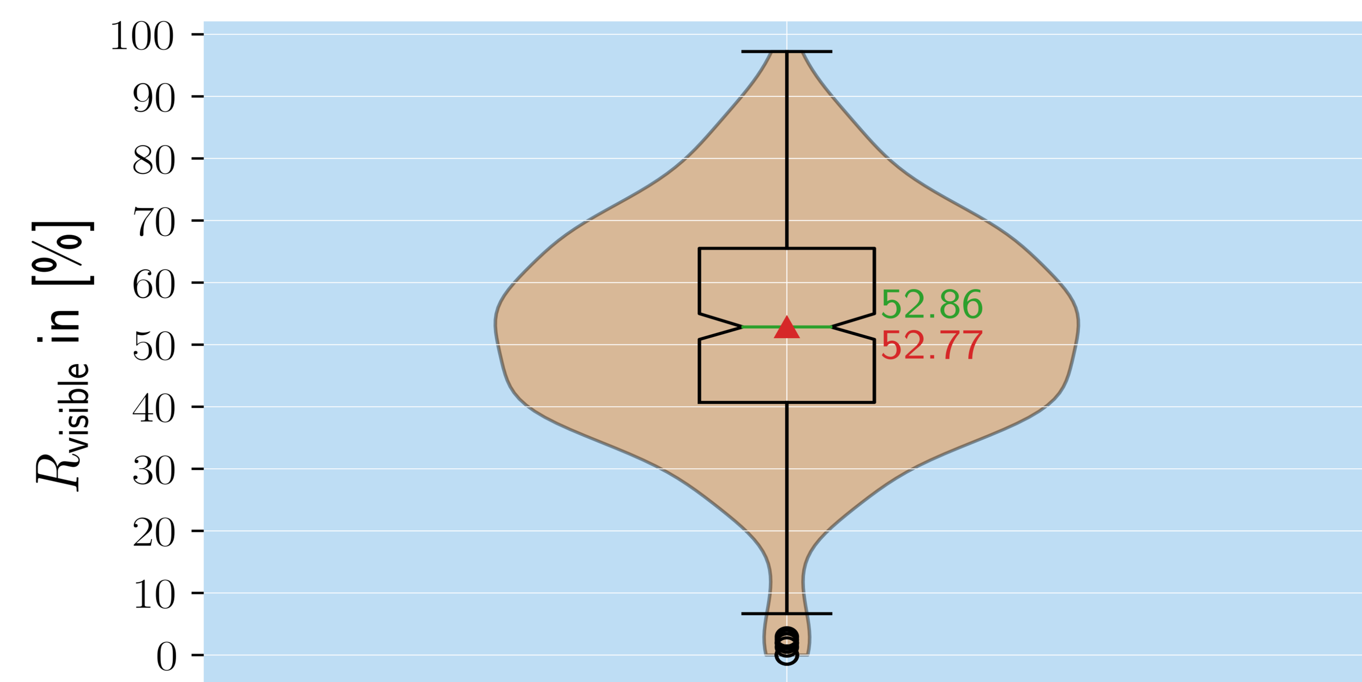
- How many grid boxes of cumulus cloud fields are **theoretically reconstructable,**
- How many grids are **indeed reconstructed** by our stereo algorithm, and
- How many additional **error grid boxes** occurred.

4. Example: Single Cloud



5. Results

- About **52% of a cumulus cloud edge is theoretically reconstructable** on average (R_{visible}) by a single stereo camera pair. Theoretically reconstructable means that the grids are seen by both cameras simultaneously.
- About **69%** of the theoretically reconstructed grid boxes **are reconstructed** by a single stereo camera pair at a single time step
- About **1%** of the reconstructed grid boxes are **errors**



The violin-looking **brown surface** is the mirrored **distribution,** the red-filled **triangle** is the **mean,** and the green **line** is the **medians.** The **notches** around the median visualize the **95%-confidence interval of the median.** The **interquartile range** is indicated by the **box,** and the **whiskers extend this** range **by 1.5.** Data points outside of the whiskers are **outliers** and plotted as **circles.**

6. Main Points

- We provided an **interface between** high-resolution Large-Eddy Simulations **(LESs) and camera observations.**
- The interface **works well for** both **visualization and** three-dimensional cloud edge **reconstruction.**
- The interface can be used as an Observing System Simulation Experiment (OSSE) to **improve camera networks**
- The interface provides unprecedented ways of **comparing** cloud geometry and cloud evolution of **LES to** real-world **camera data.**

References

[Bee+16] Beekmans et al. (2016). Cloud photogrammetry with dense stereo for fisheye cameras. Atmospheric Chemistry and Physics, 16 (22), 14231–14248. doi: 10.5194/acp-16-14231-2016
[Blu+21] Blum et al. (2021). Cloud height measurement by a network of all-sky imagers. Atmospheric Measurement Techniques, 14 (7), 5199–5224. doi: 10.5194/amt-14-5199-2021
[Fie+20] Fielding et al. (2020). Parametrizing cloud geometry and its application in a subgrid cloud-edge erosion scheme. Quarterly Journal of the Royal Meteorological Society, 146 (729), 1651–1667. doi: 10.1002/qj.3758
[Heu+10] Heus et al. (2010). Formulation of the dutch atmospheric large-eddy simulation (DALES) and overview of its applications. Geoscientific model development, 3 (2), 415–444. doi: 10.5194/gmd-3-415-2010
[Heu+21] Heus et al. (2021). Efficient rendering of simulated cloud fields using blender. AGU. URL: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/865504
[Nou+19] Nouri et al. (2019). Cloud height and tracking accuracy of three all sky imager systems for individual clouds. Solar Energy, 177 , 213–228. doi: 10.1016/j.solener.2018.10.079
[R&Ö18] Romps, & Öktem (2018). Observing clouds in 4d with multiview stereophotogrammetry. Bulletin of the American Meteorological Society, 99 (12), 2575–2586. doi: 10.1175/BAMS-D-18-0029.1
[Sch+21] Schulz et al. (2021). Characterization and evolution of organized shallow convection in the downstream north atlantic trades. Journal of Geophysical Research: Atmospheres, 126 (17), e2021JD034575. doi: 10.1029/2021JD034575
[Zha+21] Zhan et al. (2021). Convective boundary layer clouds as observed with ground-based lidar at a mid-latitude plain site. Remote Sensing, 13 (7), 1281. doi: 10.3390/rs13071281

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