Disappearing drizzle: Evaluating models with observations from ARM

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1. Introduction

Drizzle and light precipitation are very common in marine boundary layer (MBL) clouds - about two thirds of MBL clouds observed at the Eastern North Atlantic (ENA) site produce drizzle at cloud base. It is challenging for global models to get the **frequency and intensity of surface precipitation** right. Evaporation of drizzle not only returns vapour to the sub-cloud layer, but also cools and stabilises it. Thus **drizzle evaporation is an important factor in determining the boundary layer state** and cloud properties.

2. The Challenge

Global models have difficulty representing the properties of the MBL well; systematic biases in cloud water content and radiative effects are common, and most models produce light surface precipitation too frequently. When attempting to bring the model's cloud properties and surface precipitation rate closer to observed values, other aspects, such as the boundary layer temperature, humidity and wind can deteriorate. **The rate of drizzle evaporation**, which simultaneously impacts the water and energy budgets of the MBL, **is currently poorly constrained in models**. It is highly sensitive to assumptions about how the humidity varies horizontally within the model column and which part of the column the drizzle falls into, as this determines the amount of sub-saturation encountered. Fall speed and drop size also affect the rate at which the drizzle evaporates.

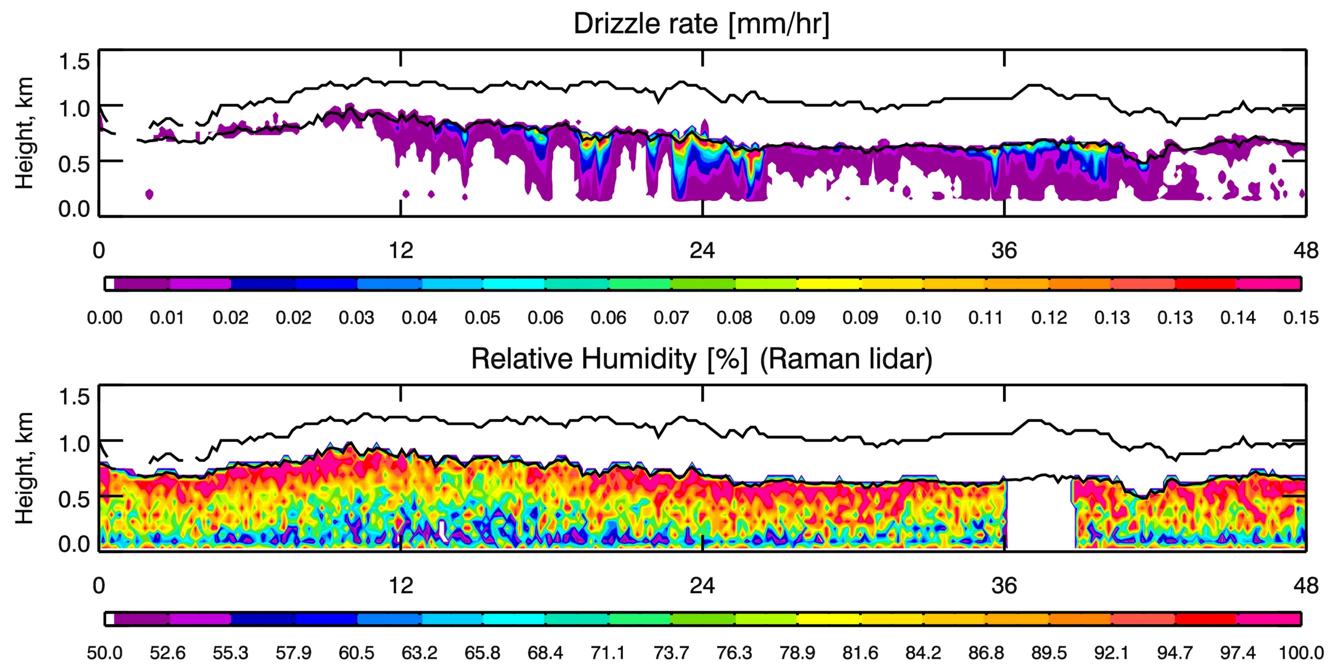

Figure 1 (Top) Drizzle rate retrieved from Doppler radar. Note that the magnitude of the drizzle flux within about 100m of cloud base is subject to large uncertainty. (Bottom) Raman lidar relative humidity at 10min temporal resolution. (Gap on second day due to instrument outage.) Solid black curves mark cloud base and top.

On February 27-28 2016, drizzling stratocumulus clouds were observed at the ENA site on Graciosa Island. Using radar Doppler moments to distinguish between suspended cloud droplets and falling drizzle, the drizzle rate profile can be retrieved (Luke and Kollias 2013). The Raman lidar provides coincident measurements of boundary layer temperature and moisture at 10min resolution.

As this case illustrates (**Fig. 1**), most of the cloud is drizzling at cloud base but it rapidly evaporates in the sub-cloud layer with only some periods where precipitation reaches the surface.

A similar cloud scene is forecast by the ECMWF Integrated Forecast System (**Fig. 2**). However**, the drizzle produced in-cloud only starts to evaporate once it reaches the drier near-surface layers**. A relative humidity threshold of around 80% prevents evaporation closer to cloud base, and has historically been used in the model for long timesteps to prevent gridbox saturation (and cloud formation) as the drizzle evaporates.

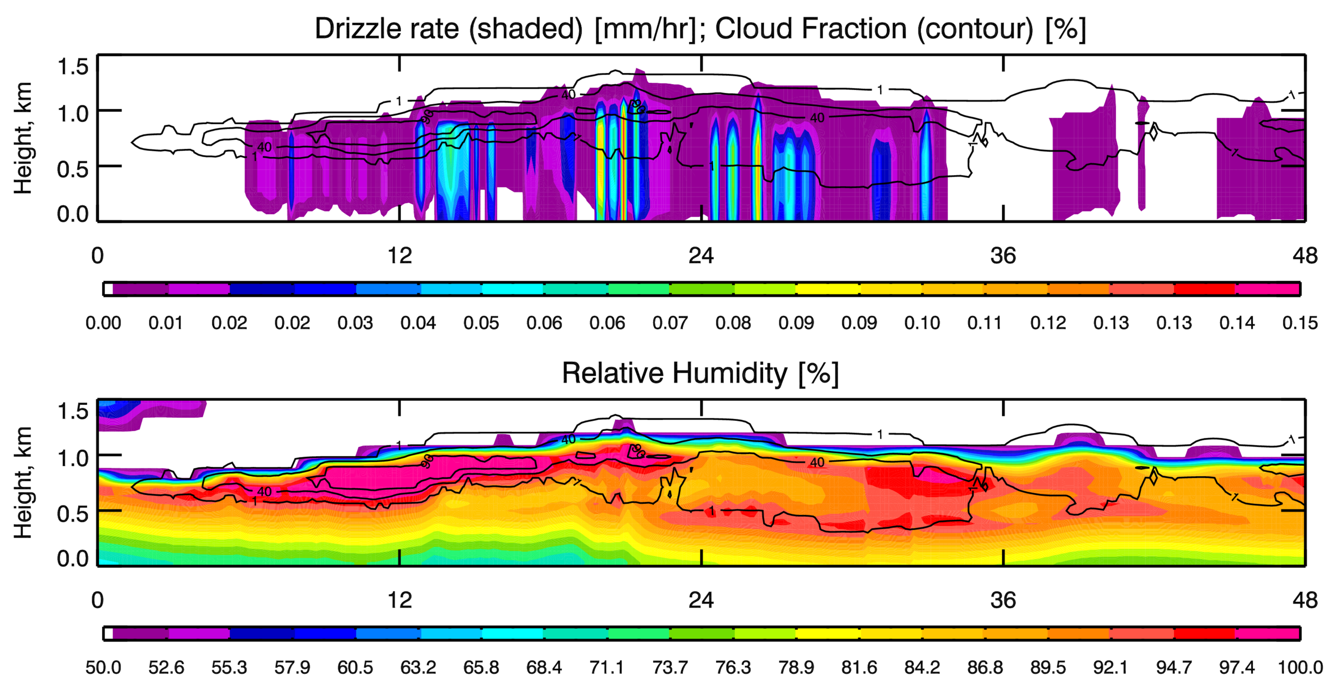

Figure 2 (Top) Drizzle rate from the ECMWF operational forecast model shown as coloured shading; cloud fraction shown as black contour. (Bottom) Model relative humidity.

3. Recent model changes

The numerical treatment of the microphysical processes is important for a model such as the IFS which is used in configurations at both low and high resolution with widely varying timesteps. In particular the numerics of the sedimentation process for rain can be problematic. This was the case in the IFS which lead to a time-step dependence of the precipitation rate. This is illustrated in an idealised single column model drizzling diurnal cycle of stratocumulus case in **Fig. 3** (top panel). In addition, this example shows the lack of evaporation in the sub-cloud layer until very close to the surface due to the 80% relative humidity threshold for evaporation (again, there for numerical reasons for long timesteps).

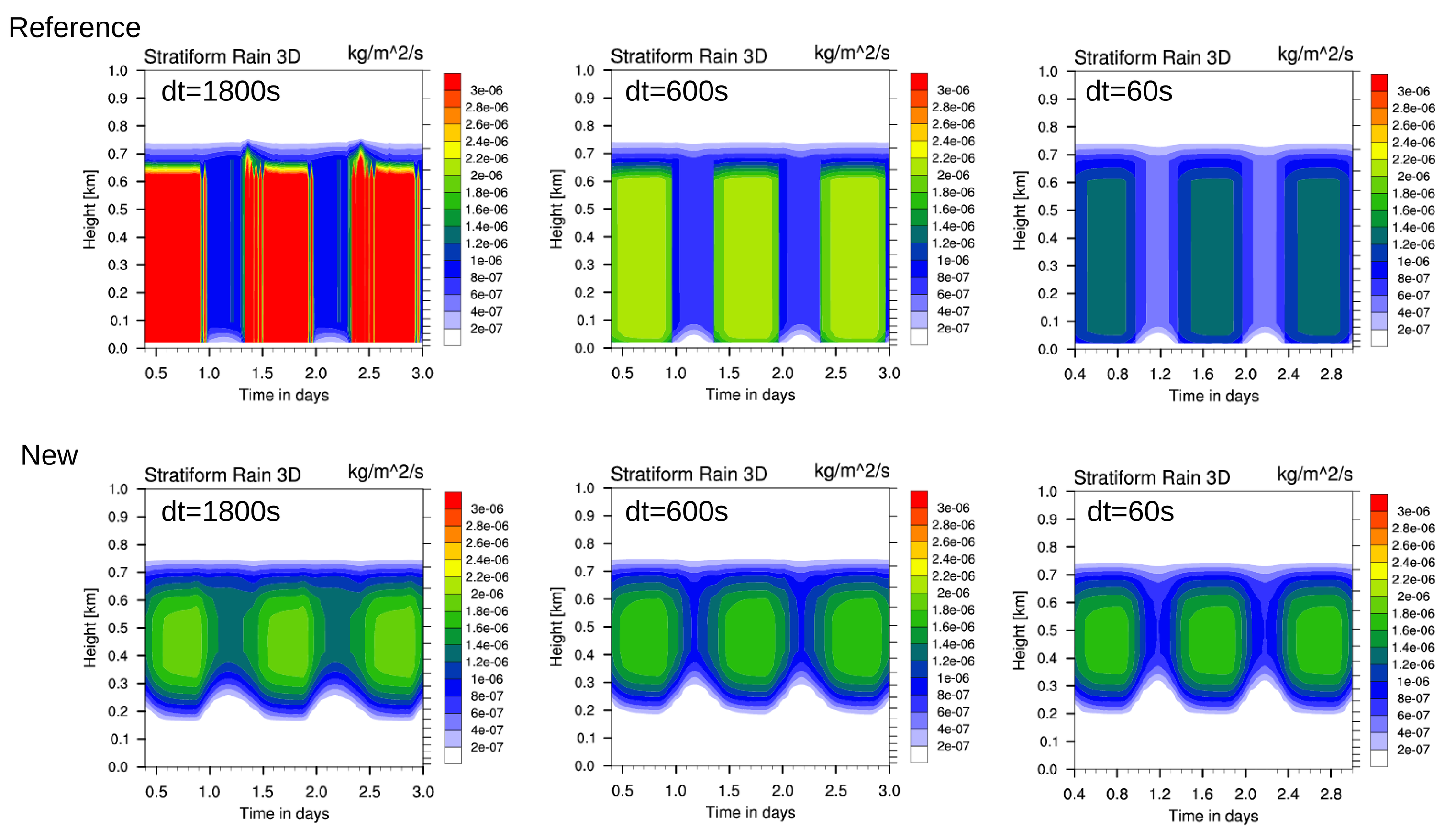

Figure 3 (Top row) Drizzle rate in single column model case of an idealised diurnal cycle of stratocumulus (three day simulation), for three different time steps (30 mins, 10 mins, 1 min) to emphasise timestep dependence. (Bottom row) Drizzle rate for the same case with new timestep-independent numerics, and a relaxed RH threshold (95%) for evaporation.

Changes to the IFS have been proposed to address the numerics of the warm-rain, sedimentation and evaporation processes. The numerics of the implicit timestepping for sedimentation have been rewritten to reduce the time-step dependence, and the RH threshold for evaporation has been increased to 95% (**Fig. 3**, bottom row). This gives significantly reduced timestep dependence and more realistic profiles of evaporating drizzle, but we need observations for a quantitative evaluation.

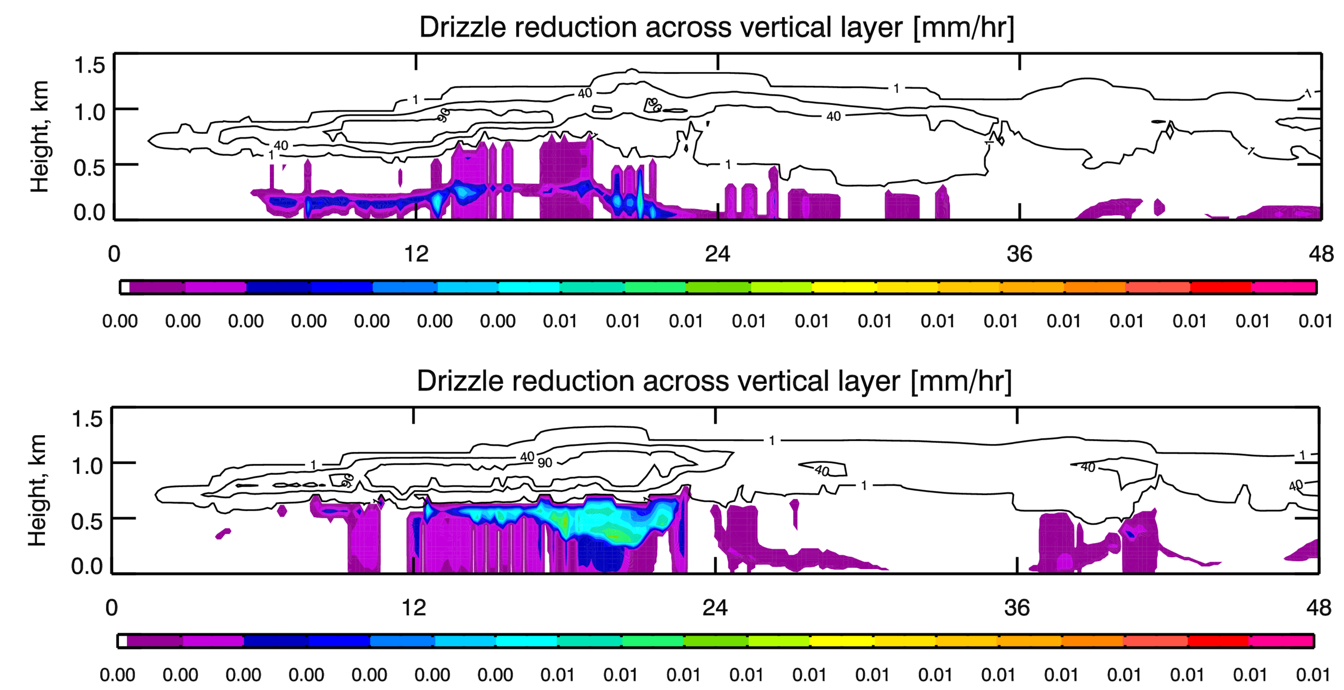

Figure 4: Shading shows the drizzle rate reduction across a vertical layer for (top) the reference IFS with a RH evaporation threshold of 80% and (bottom) the modified IFS with a threshold of 95%. Contours show cloud fraction.

Figure 4 illustrates the impact of these changes for the case study, showing the drizzle reduction across vertical model layers (due to evaporation) for the reference case from **Fig. 2**, and the updated version of the model (also shown in **Fig. 5**). In the new version of the IFS, drizzle evaporation starts right below cloud base.

References:
Luke, E.P. and Kollias, P., 2013. Separating cloud and drizzle radar moments during precipitation onset using Doppler spectra. Journal of Atmospheric and Oceanic Technology, 30(8), pp.1656-1671.
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4. Evaluation with observations

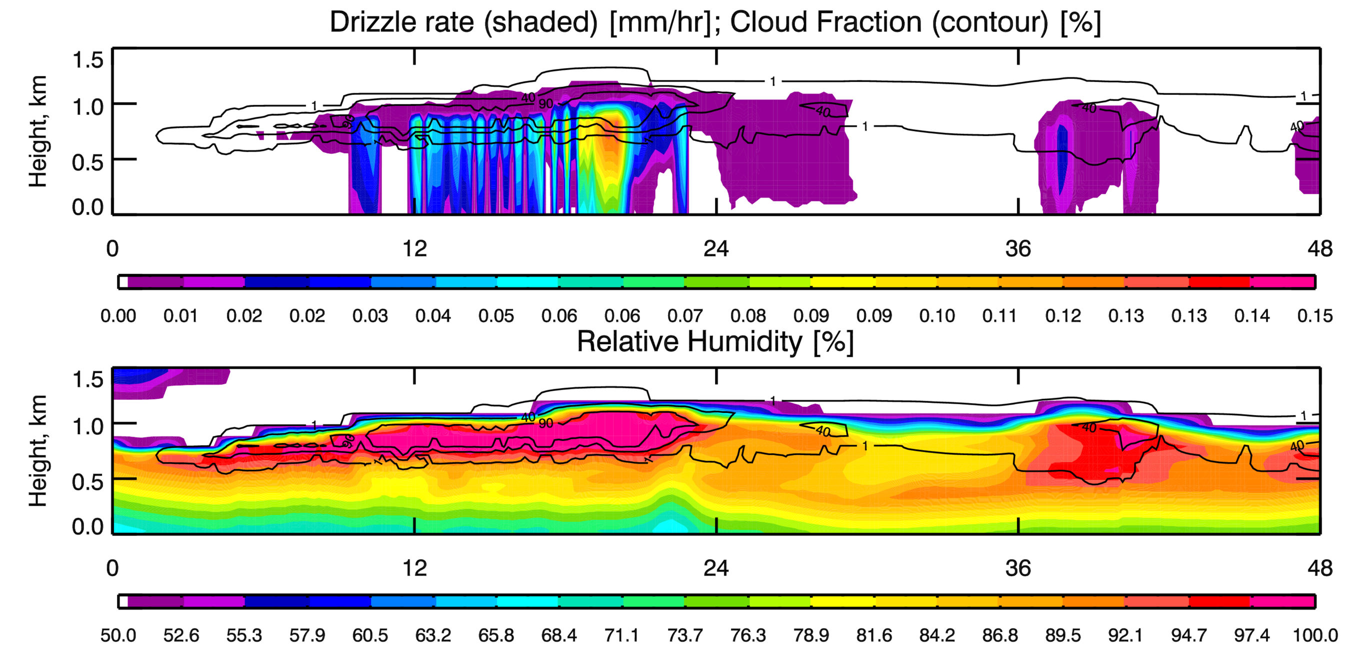

Figure 5: (Top) Drizzle rate from the updated version of the IFS shown as coloured shading; cloud fraction shown as black contour. (Bottom) Model relative humidity.

Fig. 6 shows vertical profiles averaged across the two-day period of the case study for the observations and the two versions of the model. The reference version of the IFS produces a slightly moister boundary layer state than observed, which improves slightly in the new version. The model cloud evolves into cumulus-below-stratocumulus on day two, with reduced cloud cover compared to the overcast conditions observed. This model cloud is created and maintained by a combination of the shallow convective parameterization and the large-scale cloud scheme, and two thirds of the drizzle is produced by the convection scheme (panel d). While the new version of the IFS leads to more rapid evaporation of drizzle generated by the large-scale cloud scheme (dashed curves), the response from the convection scheme is not the same. This is the result of remaining inconsistencies in microphysical assumptions between the convection and large-scale scheme, affecting the evaporation rate.

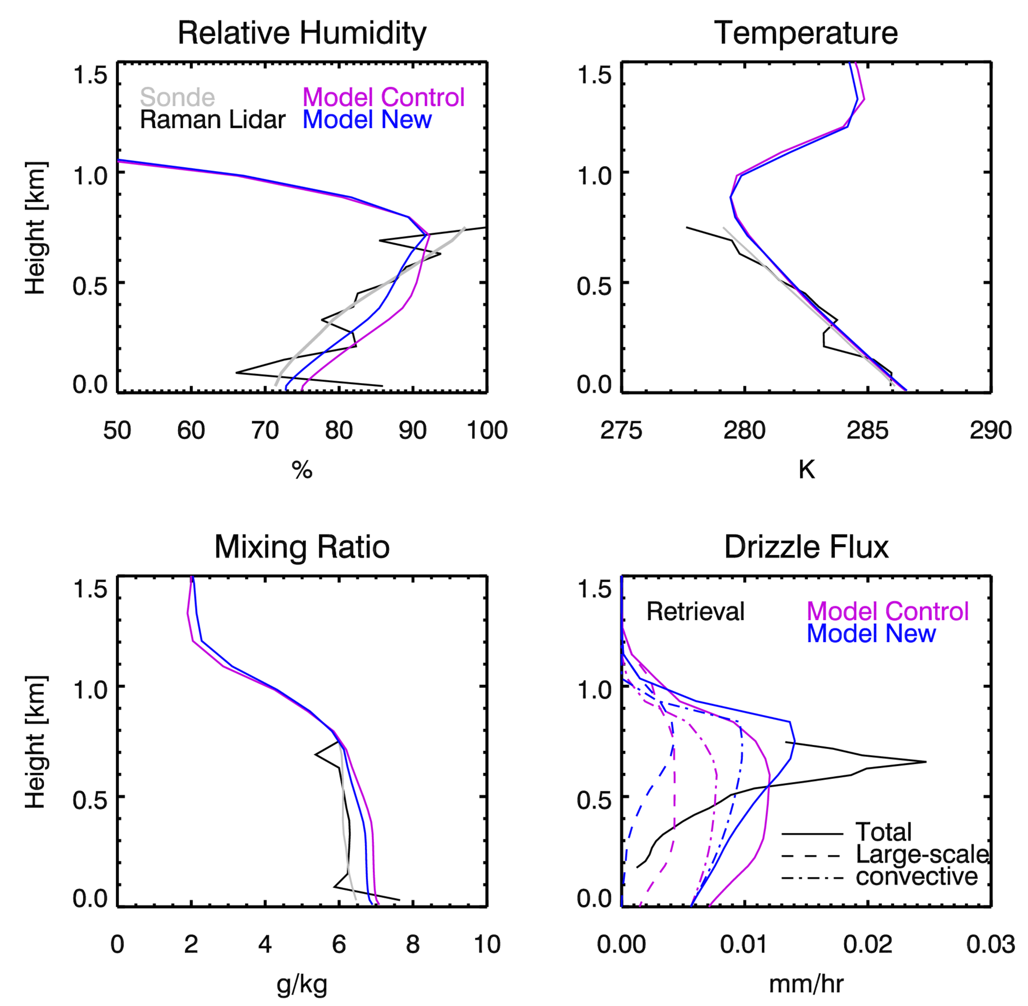

Figure 6: Mean profiles for the 2-day case study of (a) relative humidity, (b) temperature, (c) vapour mixing ratio and (d) drizzle rate. Contributions to the model drizzle rate from the large-scale cloud scheme (dashed) and the convective parameterization (dot-dashed) are shown separately in (d).

5. Conclusions and next steps

- The drizzle retrieval and Raman lidar observations provide the necessary information to evaluate whether the model's drizzle evaporation rate is realistic, given the right forcing.
- The case study shown here gives insights into qualitative improvements that have been achieved with recent model changes.
- To quantify these improvements and ensure conclusions drawn from case studies are representative of the varying conditions encountered at the site, we will analyse the full time series available from ENA as a next step.
- Improving the consistency between microphysical assumptions in the large-scale cloud scheme and convective parameterization remains a priority and needs further work.