# Moist Halo Region Around Shallow Cumulus Clouds in Large Eddy Simulations

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## 1. Introduction

The moist halo region, immediately outside the cloud, has no condensate but higher relative humidity than the remote environment. This region is not the same as the cloud downdraft shells but has important dynamical and thermodynamic effects on the development of clouds and non-negligible contribution to the radiative forcing. Characterizing the distribution of relative humidity in the moist halo region and the size of halo region can help define the correct properties to be entrained in a plume model of convection parameterization and can also help improve understanding of the radiative effect of the near-cloud environment. Nevertheless, there is a large uncertainty of halo size in the observations and also a lack of consensus of whether high-resolution numerical simulations can be robustly used to understand the moist halo region.

## 2. Objectives

- This study is designed to systematically investigate the halo region around shallow cumulus clouds using high-resolution large eddy simulations, including:
- **1. Relative humidity distribution**
- **2. Halo size**
- **3. Possible physical processes in halo formation**
- **4. Sensitivity to model resolution and numeric**

## 3. Methodology

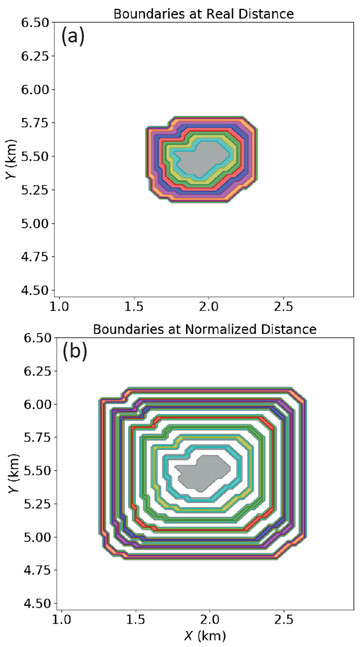
### 3.1. Large eddy simulation

**a. Model:**
Met Office-NERC Cloud (MONC) model
Cloud Model 1 (CM1)

**b. BOMEX case**;
**Horizontal Resolutions:** 10 m, 25 m, 50 m 100 m;
**Vertical Resolutions:** 10 m, 25 m, 25 m, 40 m;
**Grid Boxes:** 600 × 600
**Microphysics:** Simple cloud scheme with saturation adjustment;
**Sub-grid turbulence:** Smagorinsky-Lilly;
**Output:** 6 hours simulation, last hour (at equilibrium state) data for analysis, 1 min output frequency

**b. Sensitivity tests**;
**1. Mixing Length in Sub-grid Turb Scheme**
Cs = 0.10, 0.15, 0.23
2. **Different Model (CM1)**
Same model resolution as in MONC simulations
Domain Size: 7.2 × 7.2 (km)$^2$
Advection schemes: 3$^{rd}$, 5$^{th}$, 7$^{th}$, 9$^{th}$ WENO scheme

### 3.2. Onion Algorithm




**Distribution in real distance**

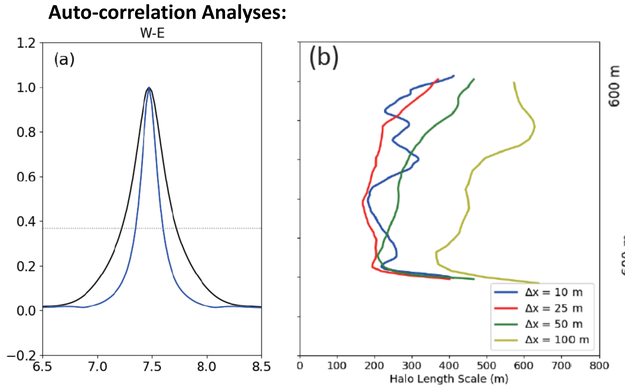
Gray:
**Cloud**

**Other colors:**
**Near cloud environment**

**Distribution in normalized distance**

## 4. Size of Moist Patches Outside Clouds

**Auto-correlation Analyses:**



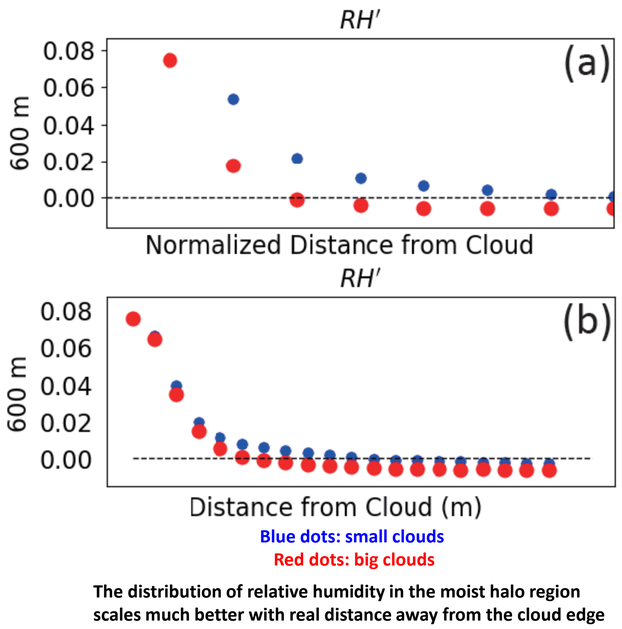

**a. Auto-correlation function**
**Black: Relative humidity**
**Blue: Cloud liquid water**

**b. Size of moist patches**
**Blue: 10 m; Red: 25 m**
**Green: 50 m;Yellow: 100 m**

**The size of moist patch is defined as the difference between the length scale of relative humidity ($L_{RH}$) and cloud liquid water ($L_{ql}$). It converged to 200-300 m when the model grid length is less than 50 m. This size might be larger than the real size around individual cloud.**

## 5. Distribution of RH

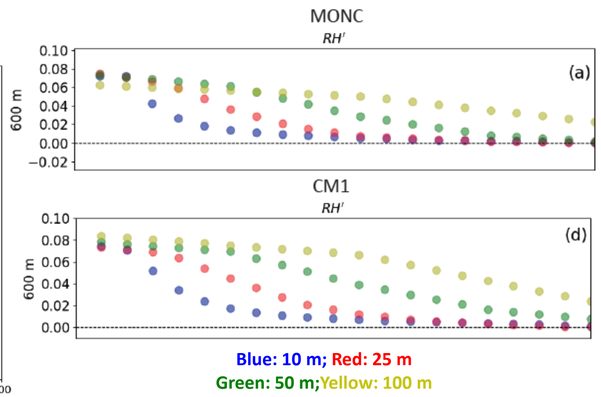
### 5.1. General Features




**Blue dots: small clouds**
**Red dots: big clouds**

**The distribution of relative humidity in the moist halo region scales much better with real distance away from the cloud edge than with cloud size.**

### 5.2. Sensitivity Tests



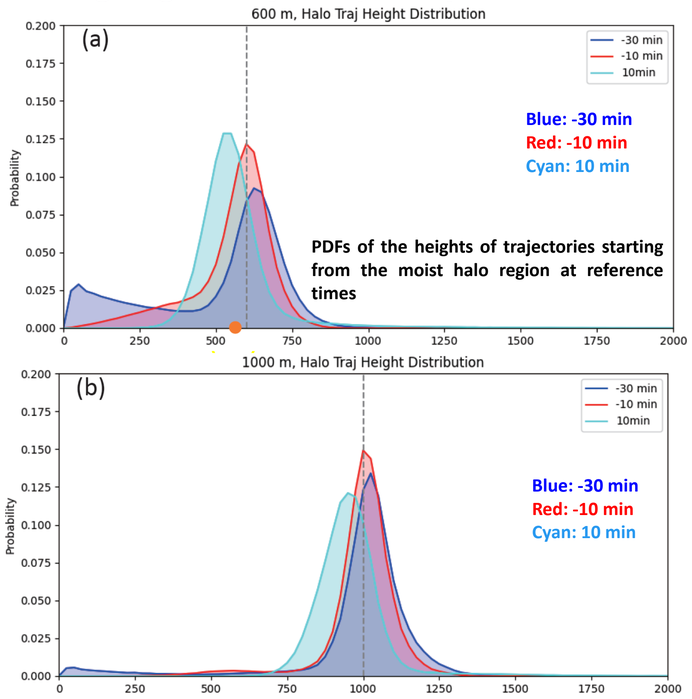

**Blue: 10 m; Red: 25 m**
**Green: 50 m;Yellow: 100 m**

**a. The decaying rate of relative humidity in the moist halo region is larger in finer resolution simulations;**

**b. The size of halo region around individual depends on model grid length, with finer resolution has smaller halo size. The halo size near cloud base is the largest.**

**c. The general features of relative humidity distribution are not sensitive to mixing length and advection schemes.**

## 6. Lagrangian Trajectory Analysis




**a. Starting from the particles in the moist halo region, we perform forward and backward trajectories of these particles to understand the possible physical processes.**

**b. The halo region near cloud base is closely related with the sub-cloud coherent structures and thus the halo size near cloud base may be related with length scale in the sub-cloud layer.**

**c. The halo region in the cloud layer is formed by the air parcels near the neighboring vertical levels. The halo size is possibly determined by some characteristic length scale in the cloud layer, for example, the buoyancy length scale.**

## 7. Summary

1. The average size of moist patches outside the shallow maritime cumulus clouds converges to 200-300 m when model resolution is below 50 m.
2. The decay of relative humidity in the moist halo region scales much better with real distance from cloud edge, not with cloud size.
3. The halo size around an individual cloud is largest near cloud base and may be affected by the characteristic length scale of the sub-cloud layer. The halo size in the cloud layer may be related with the buoyancy length scale.
4. The above general features of moist halo region are not sensitive to different large eddy models, the mixing length and the advection schemes.