Overlap statistics of shallow boundary layer clouds: Comparing ground-based observations with large-eddy simulations

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Boundary layer cloud overlap

Figure 1 - Real and simulated cumulus clouds.

Large-scale models for weather and climate cannot resolve clouds within a vertical grid column and rely on parameterizations, leading to uncertainty in the representation of clouds and the way they overlap in the vertical. The uncertainty in the cloud overlap remains a significant source of error in the Earth's radiation budget.

This study aims to compare shallow cumuli vertical overlap statistics derived from high-resolution ground-based measurements and LES simulations.

A better understanding of the unresolved cloud overlap now opens the door for parametrizations, leading to a more reliable cloud radiative budget in large-scale models.

Model and measurements

5 cases featuring boundary layer clouds at JOYCE

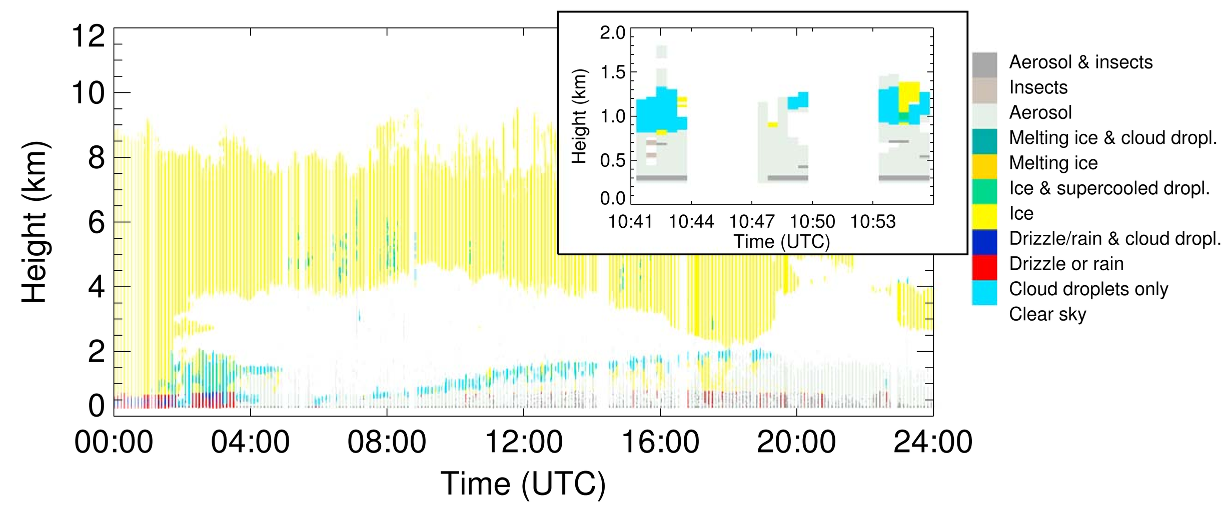

Figure 2 - Time-height section of Cloudnet cloud classification on 27 April 2013 at the Joyce supersite. The inlet illustrates a model grid with 15 min temporal and 1500 m vertical resolution. Ice pixels are yellow; liquid pixels are light blue.

Dutch Atmospheric LES model

- Homogeneously driven by ECMWF analyses
- Horizontal and vertical resolution: 50 m, 40 m

Cloudnet cloud classification

- "cloud droplets only" pixels are used
- Time and vertical resolution: 30 s, 30 m

Overlap efficiency

To mimic the discretization of large-scale models, daily time-height sections of the cloud masks are divided into equally sized grid boxes, using a temporal resolution of 3 or 15 min (~ 2 and 9 km assuming a wind speed of 10 m/s).

- Cloud cover by area C_a and by volume C_v are calculated using a vertical discretization ranging from 60 to 1500 m for LES and observations.

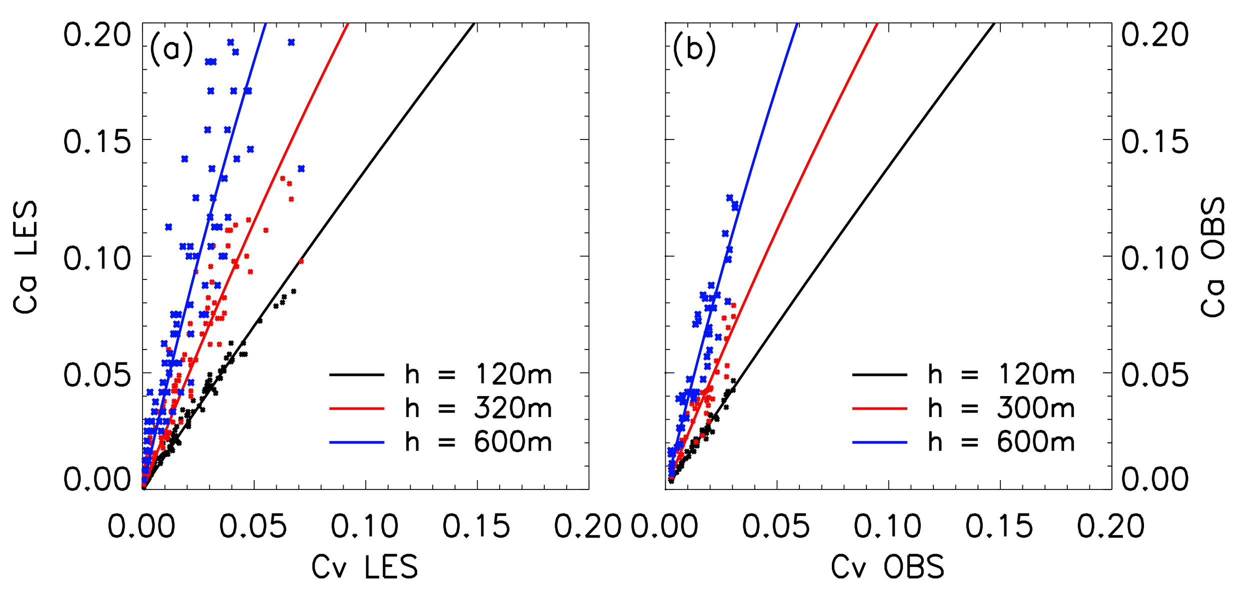

Figure 3 - Scatterplots of C_a vs C_v for 15 minutes time resolution from observations (a) and LES simulations (b) for three different vertical resolutions (120, 320 and 600m).

Cloud overlap efficiency as a function of layer depth ***h*** is described by:

1. Overlap ratio R — $R = C_v / C_a$
   fit parameter β — $R(h) = (1+\beta h)^{-1}$
2. Overlap parameter α — $C_a = \alpha C_{maximum} + (1 - \alpha) C_{random}$
   decorrelation length Z_0 — $\alpha(h) = \exp(-h / Z_0)$

Inefficient cloud overlap at small scales is supported by observations

- Agreement is found between R derived from observations and simulations.
- Decorrelation lengths are much smaller (< 300 m) than previously reported (> 1 km).
- Including stratiform ice cloud (fig. 2) β drops by one order of magnitude.

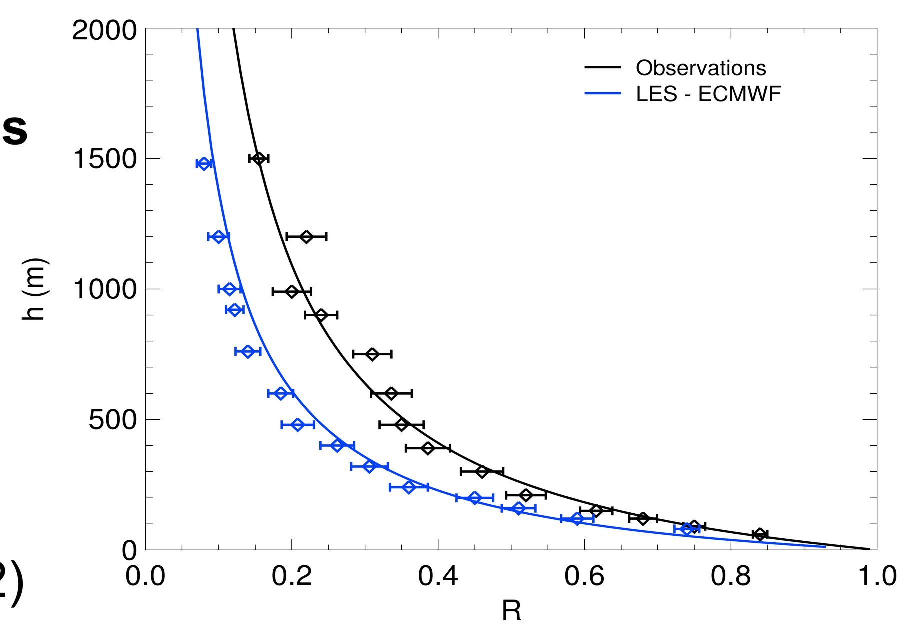

Figure 4 - Daily mean values (diamonds) and inverse linear fitting curves (thick lines) of the overlap ratio R as a function of vertical grid resolution h on 5 June 2013. Error bars are the standard deviation of the mean overlap ratio within the time period considered.

Table 1. β Parameter (m^{-1}) (Fitted Using Daily Mean R Values) and Decorrelation Length (m) on Different Days in 2013 Featuring Boundary Layer Clouds Calculated From Observations and LES Simulations for 3 and 15 min Time Resolutions

	3 min				15 min			
	$\beta \times 10^3$		Decorrelation Length		$\beta \times 10^3$		Decorrelation Length	
Day	Observations	LES	Observations	LES	Observations	LES	Observations	LES
27 Apr	4.9	4.5	590	180	-	-	-	-
19 May	5.8	6.2	157	127	-	-	-	-
5 Jun	4.7	6.5	160	148	5.2	6.3	170	202
10 Jun	4.4	4.9	253	104	4.7	5.7	213	153
20 Aug	5.3	6.6	249	120	5.0	7.0	237	239

Diurnal cycle

Investigation of the time evolution of β during the diurnal development of the shallow cumulus-capped boundary layer is performed for one case study. The period featuring boundary layer cloud is discretized into 1 h bins, for each of which the overlap ratio values are averaged using a temporal resolution of 15 min.

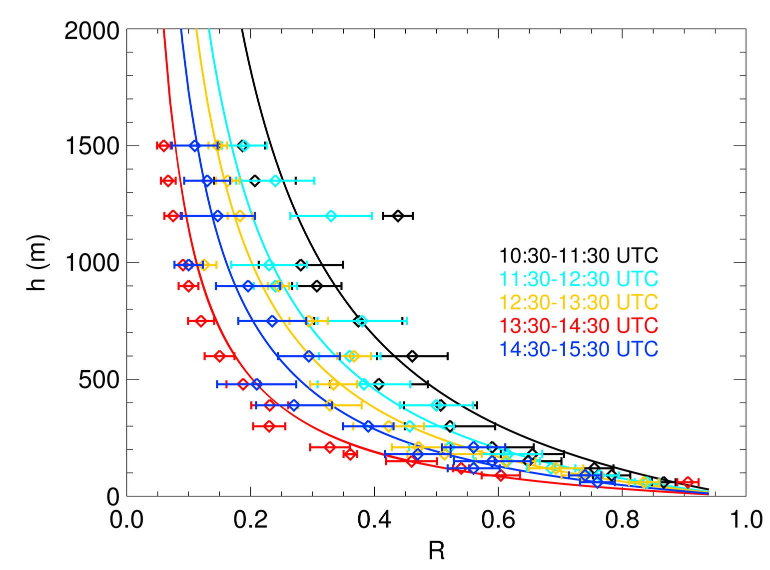

Figure 5 - Daily mean values (diamonds) and inverse linear fitting curves (thick lines) of the overlap ratio R as a function of vertical grid resolution h on 5 June. Error bars are the standard deviation of the mean overlap ratio within the time period considered.

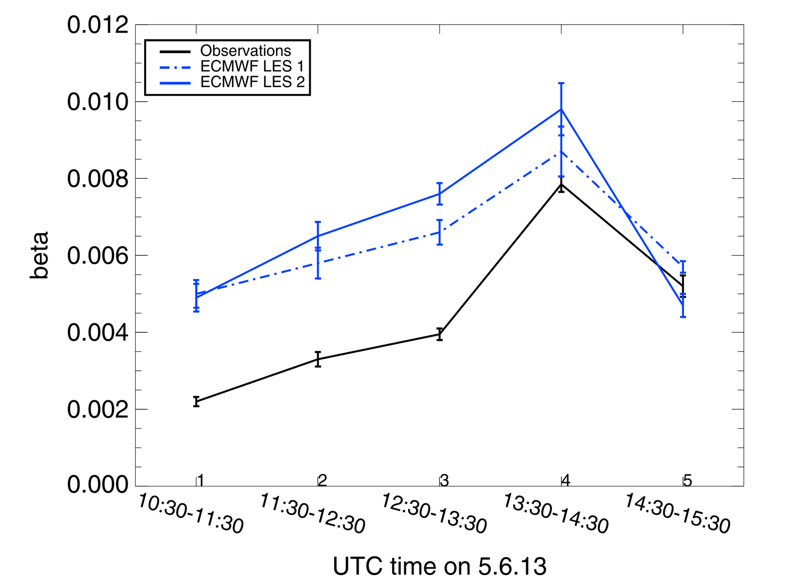

Figure 6 - Time series of fit parameter β (m−1) from observations (black) and ECMWF-driven (blue) LES simulation for two randomly chosen locations. Error bars are standard error of mean β parameter over the time period considered.

- Overlap efficiency, together with cloud cover, decreases with time after cloud onset.
- LES and observations show similar behaviour.
- Previous study reports an opposite behaviour for a case of transient continental cumulus at the ARM SGP site.
- The factor controlling the overlap efficiency evolution remains unclear and will be investigated in future studies.

Conclusion and perspective

- Inefficient overlap for shallow boundary layer clouds is supported by observations and LES.
- Observations and LES depict a decreasing overlap efficiency with time after cloud onset.
- Agreement between observations and LES models suggest their use as a virtual laboratory for parameterization development for larger scale models.

Next step: long-term rigorous verification of LES results at fixed meteorological supersites with continuously operated instrumentation.