Impact of Mesoscale Organizations and Precipitation on the Development of Continental Stratocumulus

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Motivation

1. Satellite images often show that there are cloud organizational features in stratocumulus with scales from a few kilometers to tens of kilometers (Wood and Hartmann, 2006), which are equivalent to or larger than typical domain size of LESs. If it is reliable to use results from small-domain LESs without considering cloud mesoscale organizations to understand and parameterize physical processes in stratocumulus?

2. Drizzle is a common phenomenon associated with stratocumulus, and can have a significant impact on cloud development and cloud radiative properties. Can drizzle substantively affect cloud mesoscale organizations and vice versa?
Stratocumulus Case 1

(a) MMCR reflectivity (dBZ)

(b) GOES-E 25 MAR 05 12:15 LST NASA LARC

(a) MWR observed liquid water path (mm) at different facilities at SGP site

(b) Ceilometer detected cloud base (km) at different facilities at SGP site
Stratocumulus Case 2

(a) WACR reflectivity (shades, dBZ), Cloud based (+), Cloud top (red, green line), and LCL (black line)

Time (LST)

Height (km)

April 25, 2006

April 26, 2006

(b) 

Potential temperature (K)

Height (km)

(c) 

Mixing ratio (g/kg)
Multiple-Scale WRF Simulation

(c) Surface dynamic and thermodynamic fields at 12:15 LST

18 X 18 km²
Case 1
Simulation
Observation
Comparison

(a) ARSCL observed and WRF Simulated (D5) cloud base and cloud top

(b) MWR observed and WRF simulated (D5) liquid water path (mm)

(c) CMBE best estimate cloud fraction and WRF simulated (D5) low cloud fraction
Case 2
Simulation
Observation
Comparison
Cloud Mesoscale Organization

WRF D3

(a) 03:00 LST

WRF D5

(a) 03:00 LST

(b) 03:00 LST

(a) MWR observed liquid water path (mm) at different facilities at SGP site

Distance (km)

Distance (km)

Height (km)

Distance (km)
\[ \overline{w' \psi'} = \sigma_{up}[w' \psi']_{w>0} + \sigma_{dn}[w' \psi']_{w<0} + M_c (\overline{\psi_{up}} - \overline{\psi_{dn}}) \]

Small-scale turbulence Coherent structure

Resolved fields averaged over 03:30-4:30 LST

Resolved fields averaged over 15:00-16:00 LST
2D Continuous Wavelet Transform (CWT)

Spatial x-y domain: \( W_{n_x,n_y}(s) = \sum_{n'=0}^{N_x-1} \sum_{n''=0}^{N_y-1} f(n',n'')\psi^* \left[ \frac{(n'-n_x)s}{s}, \frac{(n''-n_y)s}{s} \right] \)

Fourier domain: \( W_{n_x,n_y}(s) = \sum_{k=0}^{N_x-1} \sum_{l=0}^{N_y-1} \hat{f}(k,l)\hat{\psi}^* (s\eta_k, s\omega_l) e^{i\eta_k n_x \delta x} e^{i\omega_l n_y \delta y} \)

Wavelet Power Spectrum (WPS) \( |W_{n_x,n_y}(s)|^2 \)

Total energy is conserved under CWT \( \sigma^2 = C \delta \sum_{n_x=0}^{N_x-1} \sum_{n_y=0}^{N_y-1} \sum_{j=0}^{J-1} \left| \frac{W_{n_x,n_y}(s_j)}{s_j} \right|^2 \)

Morlet Wavelet
2D CWT Demonstration

Vertical velocity (m/s) at 730 m (03:00 LST)

Wavelet Power Spectra (m^2 s^-2)

Wavelet Power Spectra (m^2 s^-2)
WPS of TKE, $\tau$, and $w'\theta'_v$ in the evening (3-5 AM)
Effect of Precipitation

Cloud water mixing ratio (g/kg)

With precipitation

Cloud water mixing ratio (g/kg)

Without precipitation

Liquid water path

With precipitation

Without precipitation

Time (LST), Mar. 25, 2005
Comparison of Turbulent Structure (nighttime)

Resolved fields averaged over 03:30-4:30 LST (With Rain)

Resolved fields averaged over 5:00-6:00 LST (Without Rain)
Comparison of Turbulent Structure (daytime)

Resolved fields averaged over 15:00-16:00 LST (With Rain)

Resolved fields averaged over 15:00-16:00 LST (Without Rain)
Rain Effect on Mesoscale Organizations (Y-direction, 30-60km)
Rain Effect on Mesoscale Organizations (Y-direction, 10-30 km)
Summary

1. Continental stratocumulus clouds are strongly modulated by cloud mesoscale organizations. The impact of cloud mesoscale organizations on turbulent intensity and vertical transport is evident from the wavelet decomposition of turbulent fields. Thus, without considering cloud mesoscale organizations, statistics from small-domain of LES may be severely biased.

2. Although precipitation has a limited effect on cloud macro-properties and vertical turbulent structure, it can have strong impact on cloud mesoscale organizations. This interaction between drizzle and cloud mesoscale organization is an important internal process that needs to be considered in cloud parameterizations.