

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.

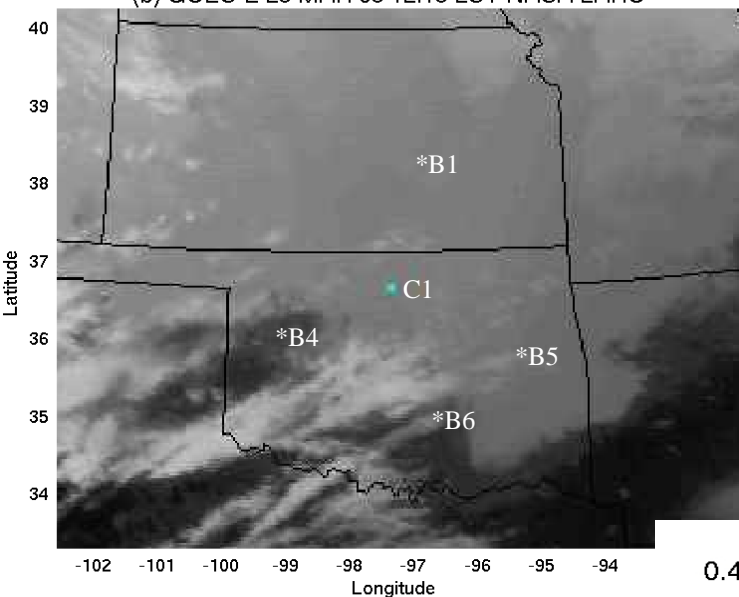
If it is reliable to use results from small-domain LESs without considering cloud mesoscale organizations to understand and parameterize physical processes in stratocumulus?

2. Drizzle is a common phenomenon associated with stratocumulus, and can have a significant impact on cloud development and cloud radiative properties.

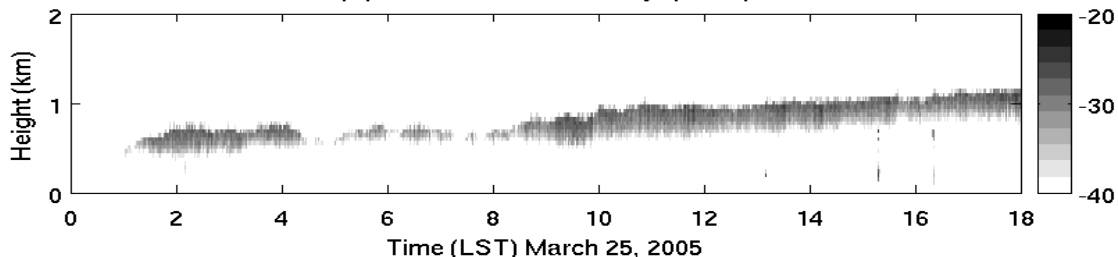
Can drizzle substantially affect cloud mesoscale organizations and vice versa?

Stratocumulus Case 1

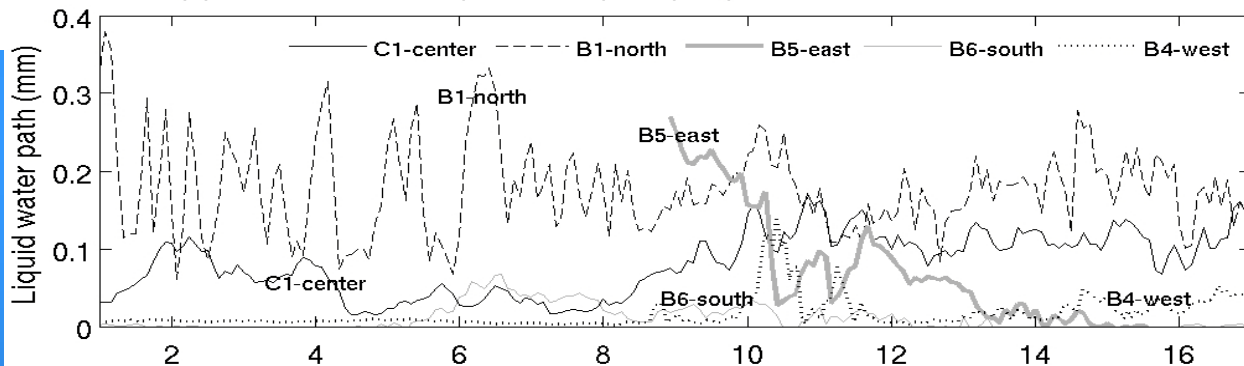
(b) GOES-E 25 MAR 05 12:15 LST NASA LARC



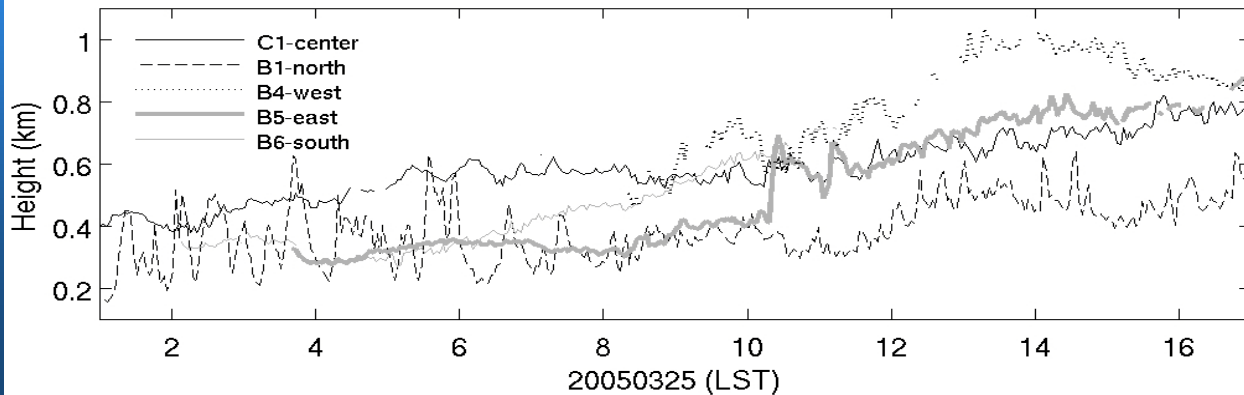
(a) MMCR reflectivity (dBZ)



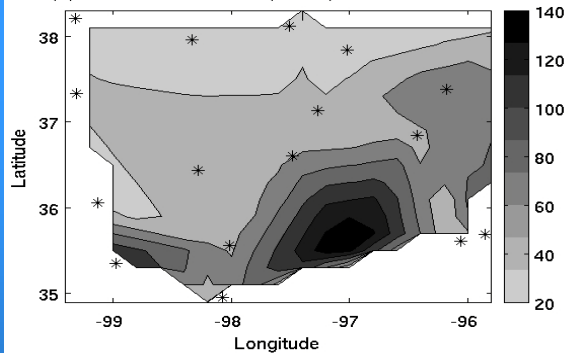
(a) MWR observed liquid water path (mm) at different facilities at SGP site



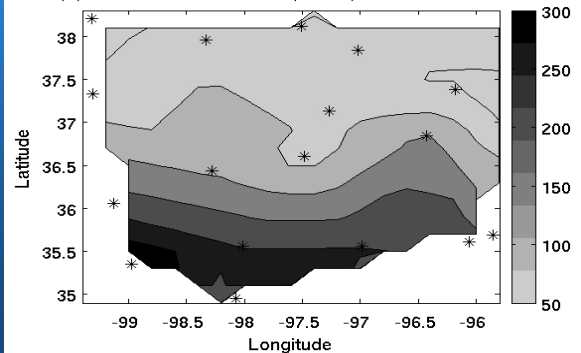
(b) Ceilometer detected cloud base (km) at different facilities at SGP site



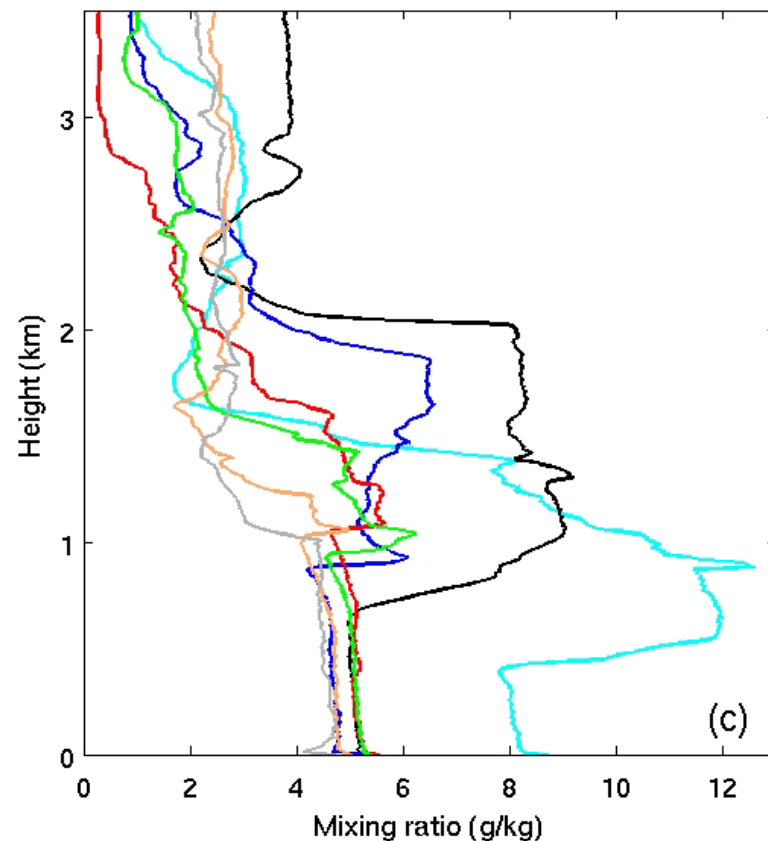
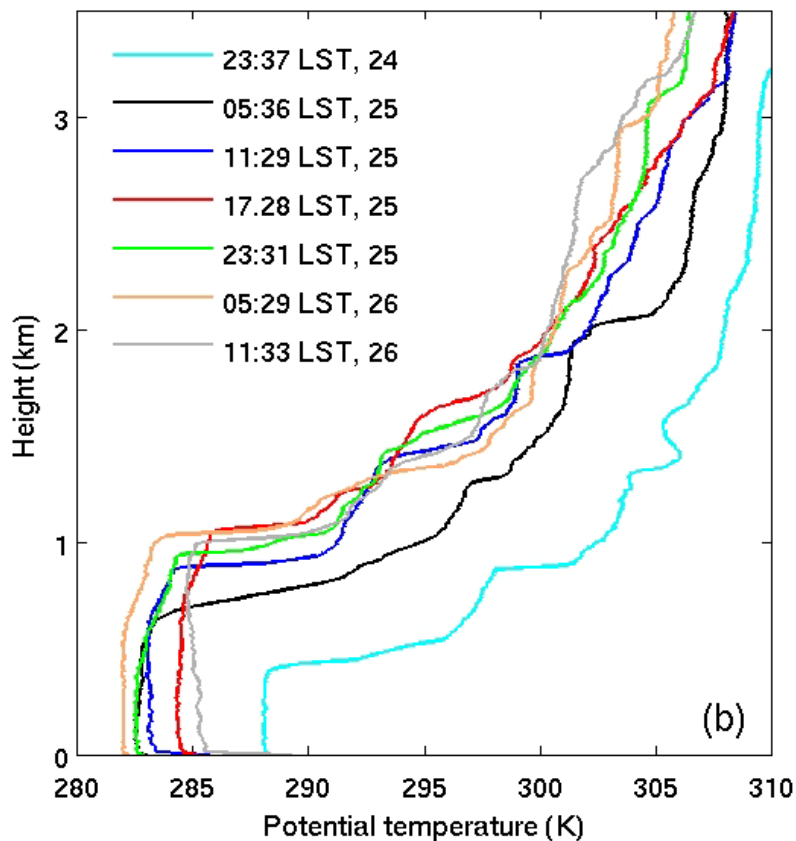
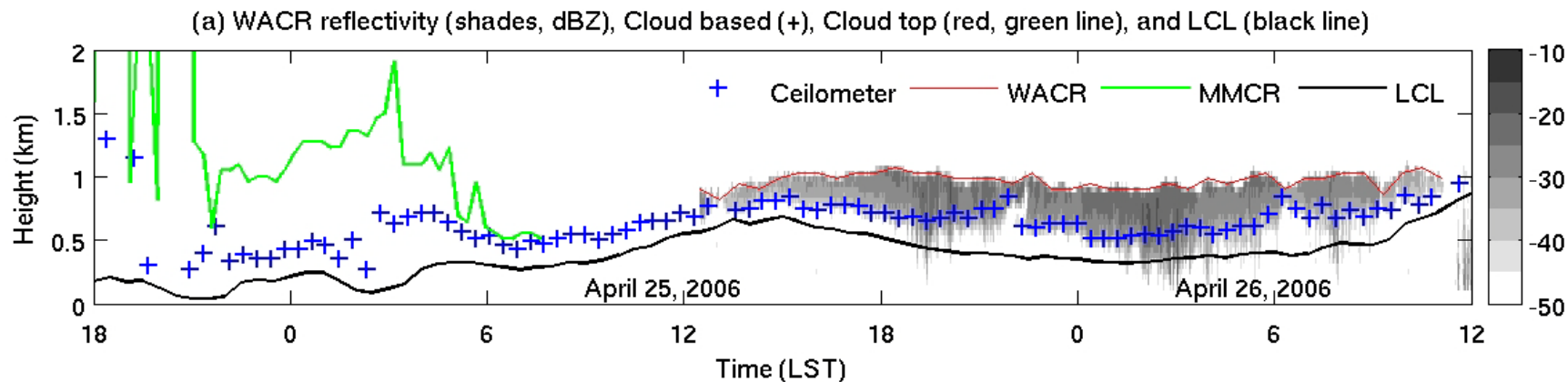
(a): Mean latent heat flux ($W m^{-2}$) over 14.5-15.5 LST



(b): Mean sensible heat flux ($W m^{-2}$) over 14.5-15.5 LST

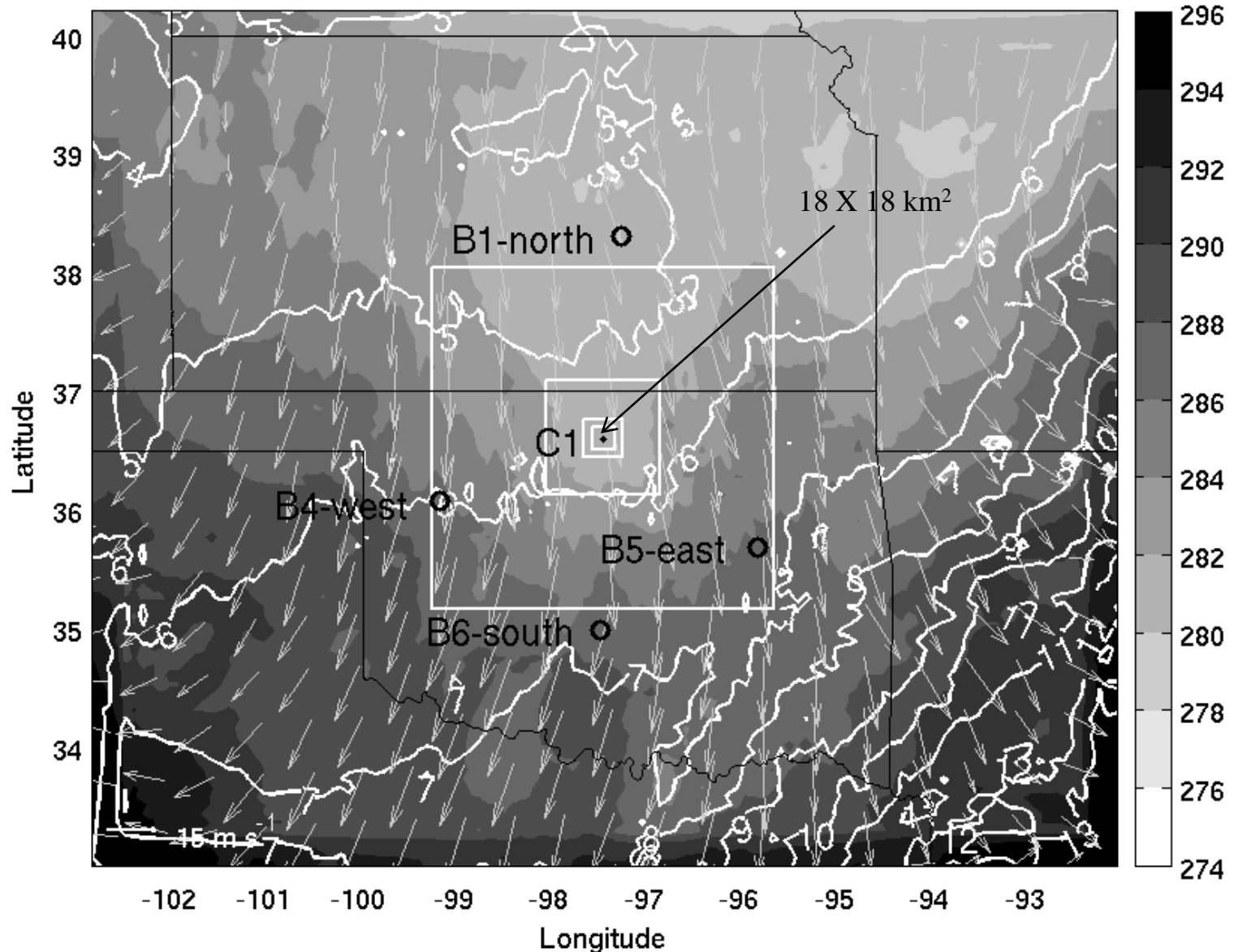


Stratocumulus Case 2

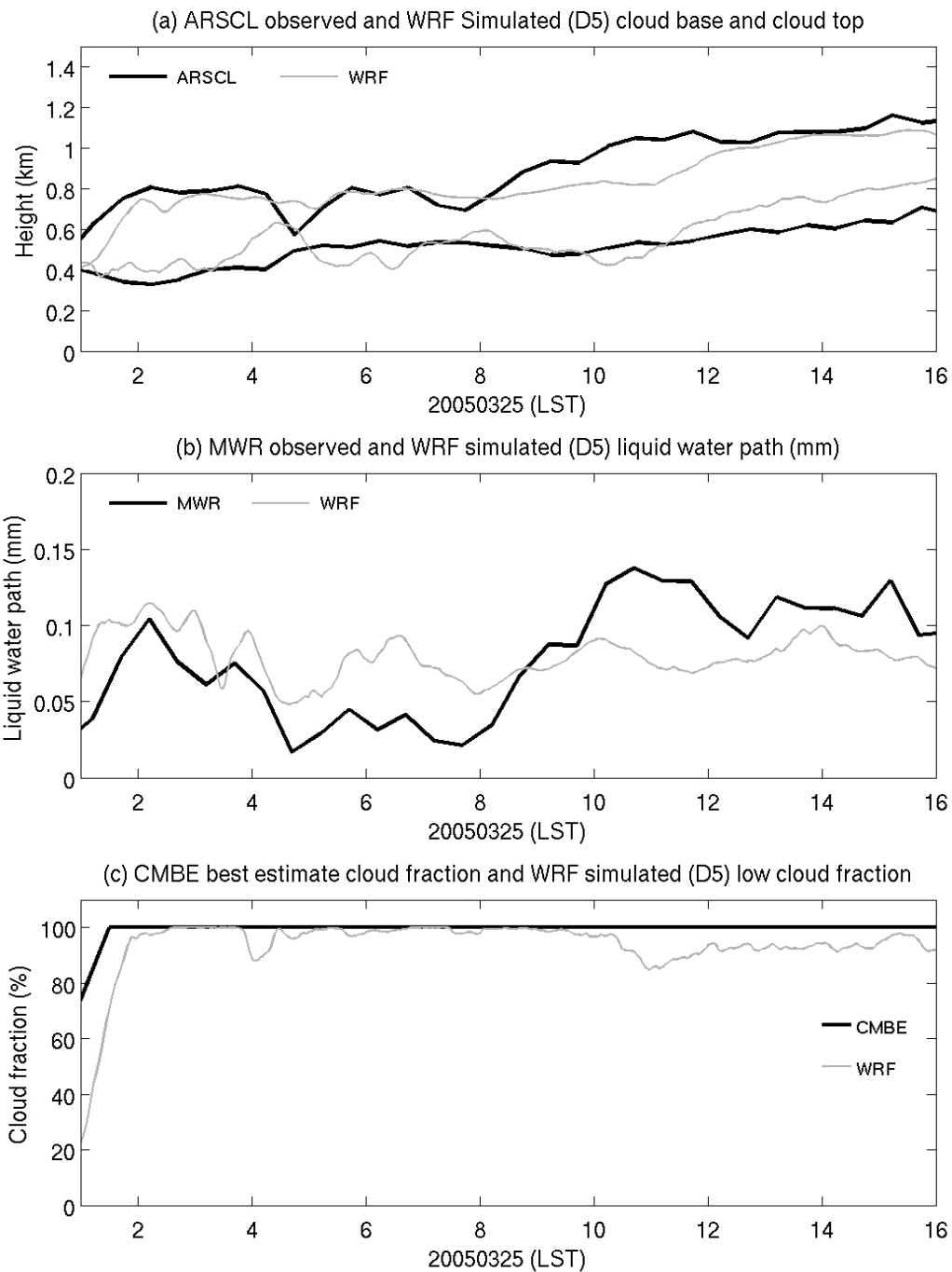


Multiple-Scale WRF Simulation

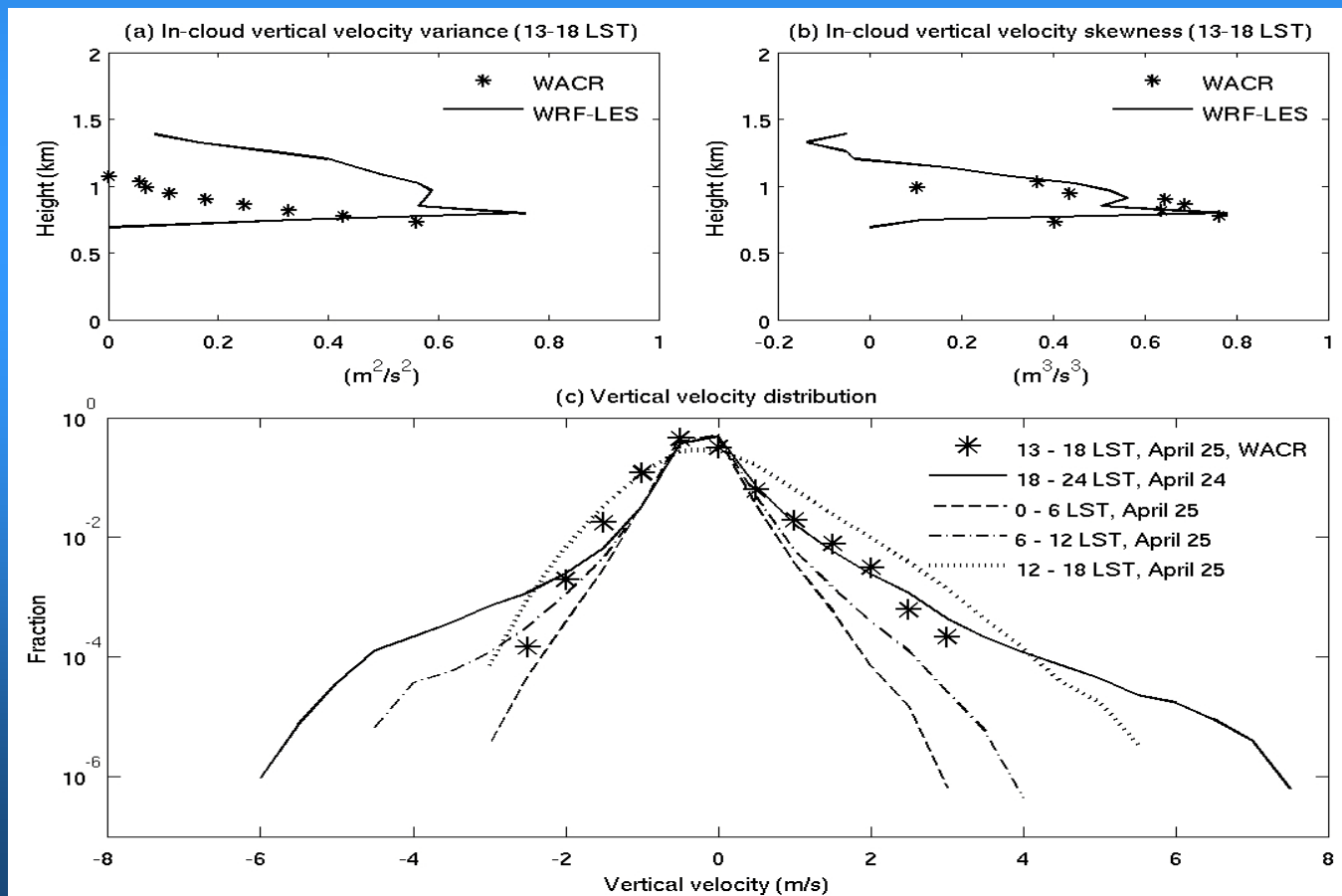
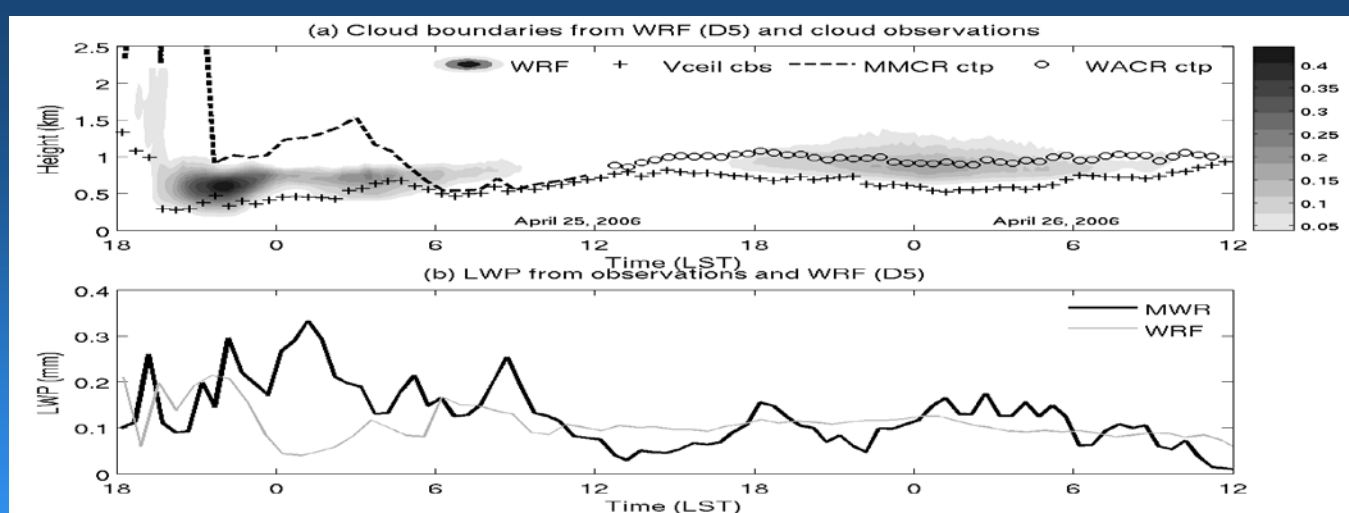
(c) Surface dynamic and thermodynamic fields at 12:15 LST



Case 1 Simulation Observation Comparison

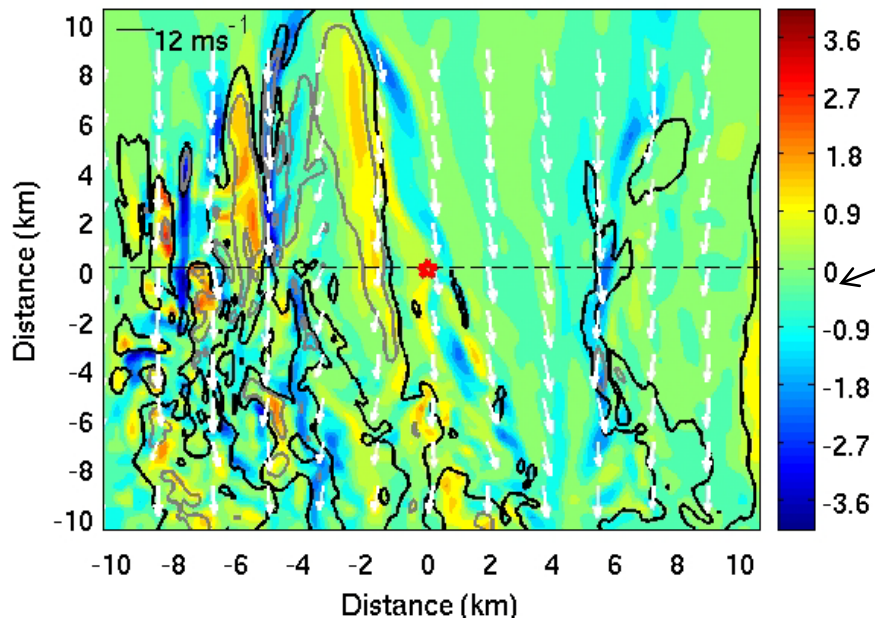


Case 2 Simulation Observation Comparison

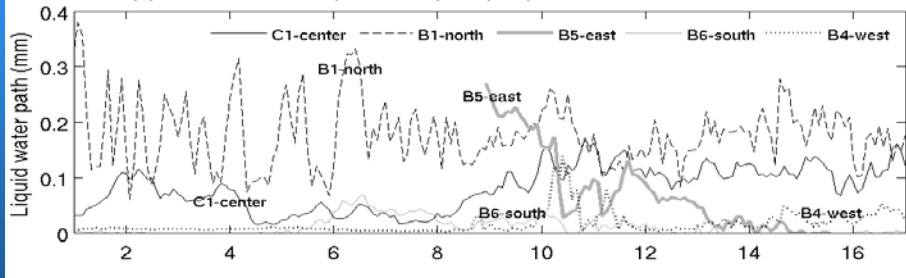


Cloud Mesoscale Organization

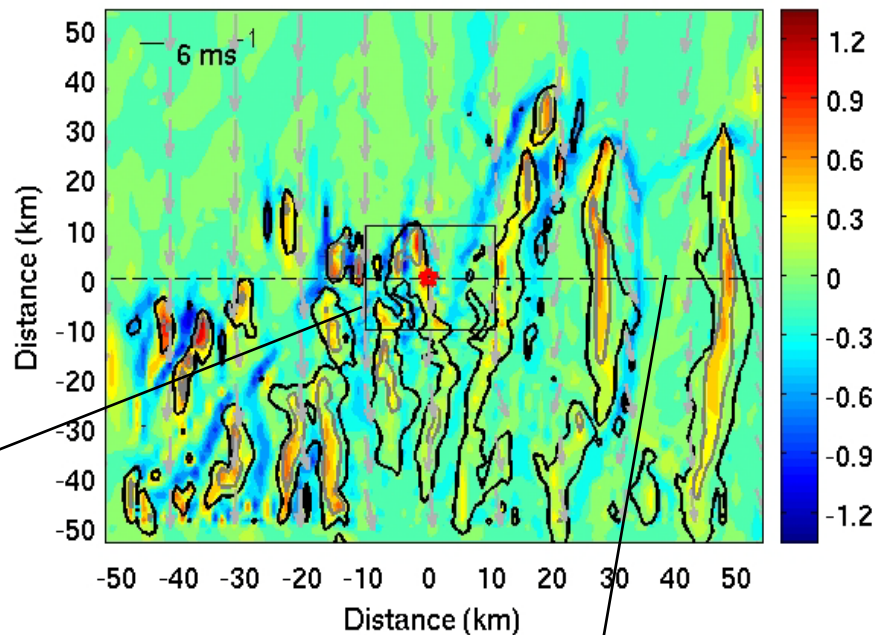
WRF D5 (a) 03:00 LST



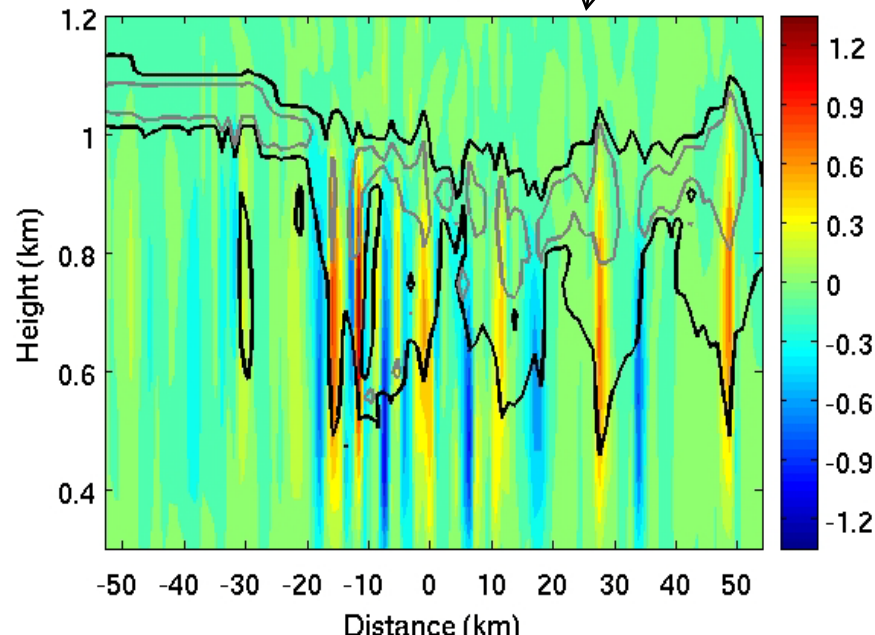
(a) MWR observed liquid water path (mm) at different facilities at SGP site



WRF D3 (a) 03:00 LST



(b) 03:00 LST

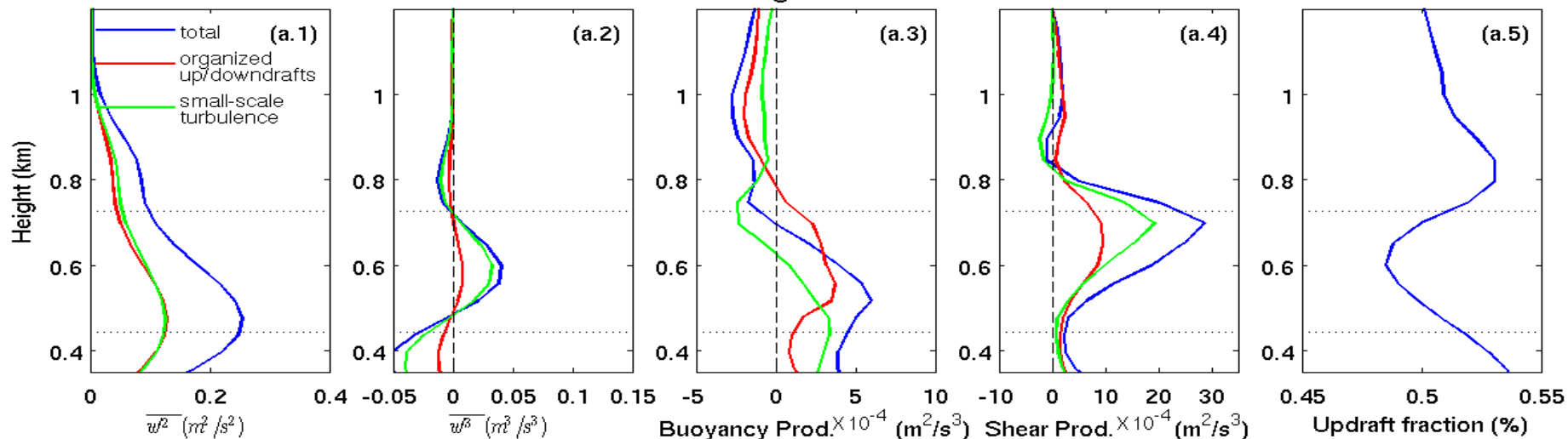


$$\overline{w' \psi'} = \sigma_{up} [\overline{w' \psi'}]_{w>0} + \sigma_{dn} [\overline{w' \psi'}]_{w<0} + M_c (\overline{\psi}_{up} - \overline{\psi}_{dn})$$

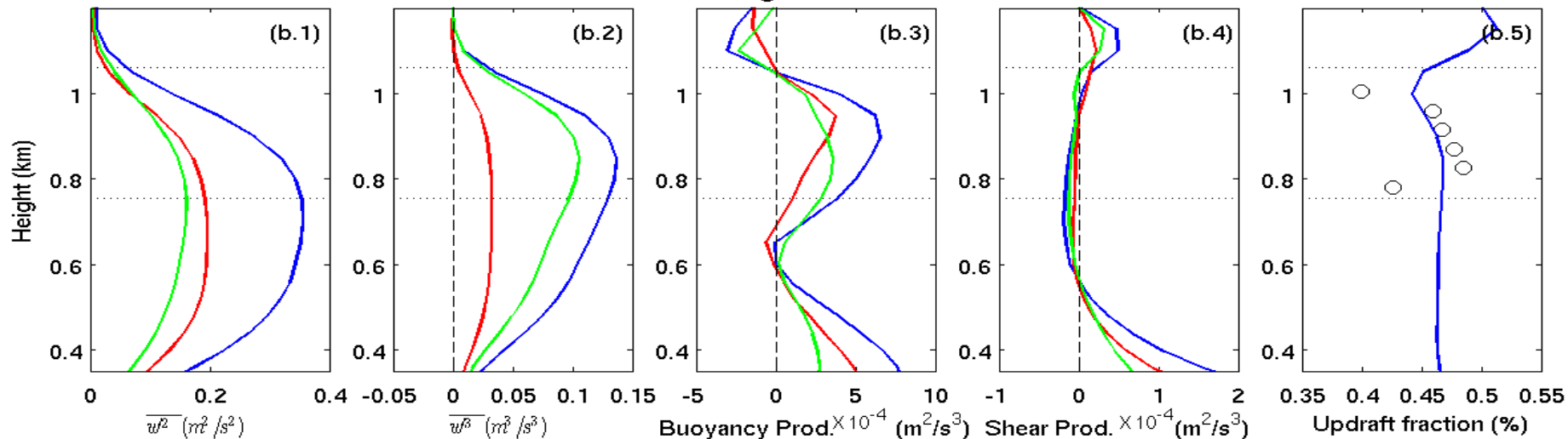
Small-scale turbulence

Coherent structure

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



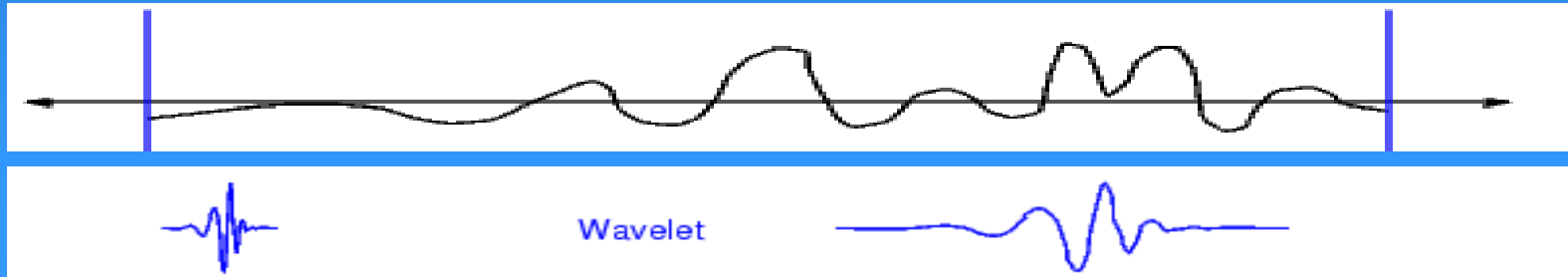
Resolved fields averaged over 15:00-16:00 LST



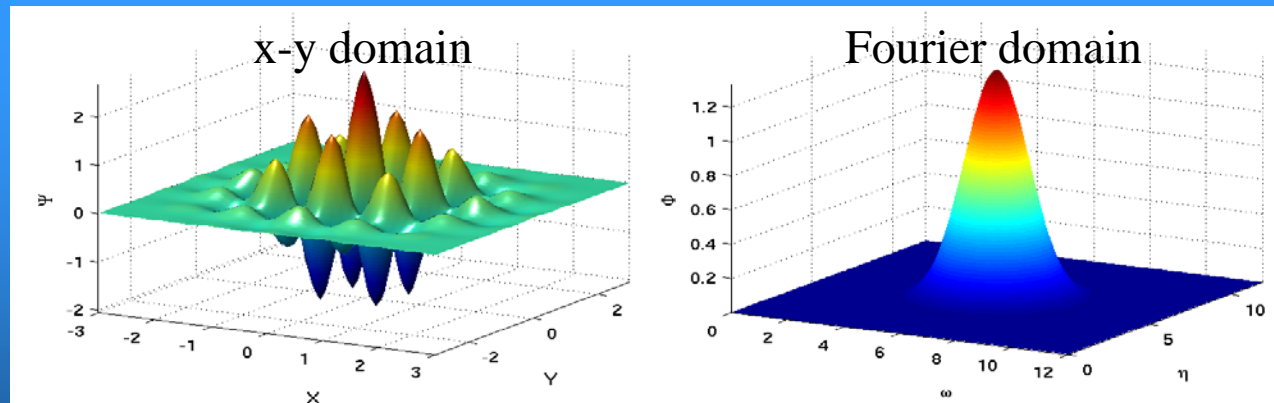
2D Continuous Wavelet Transform (CWT)

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

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



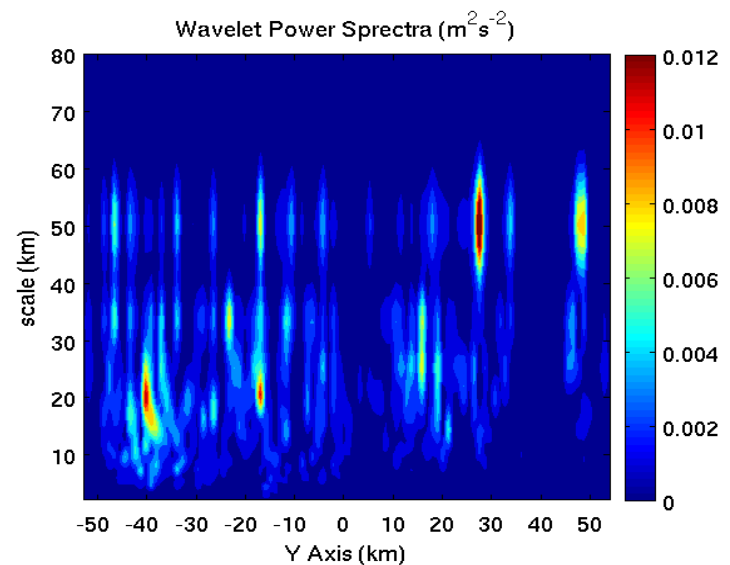
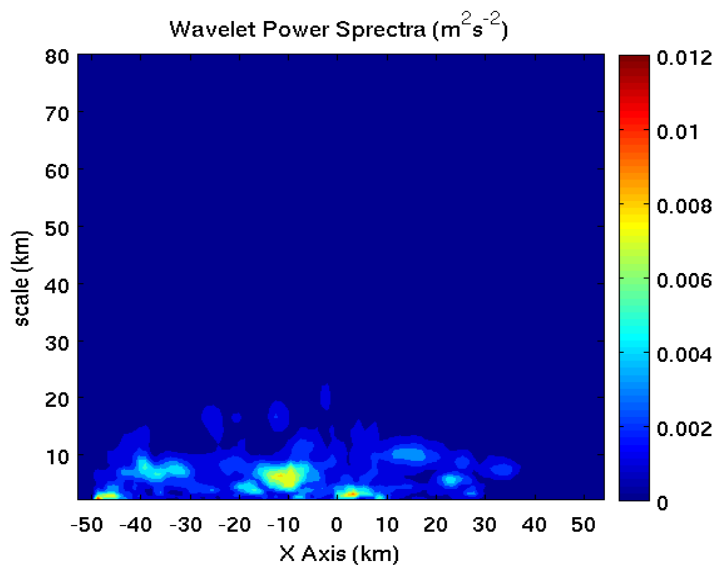
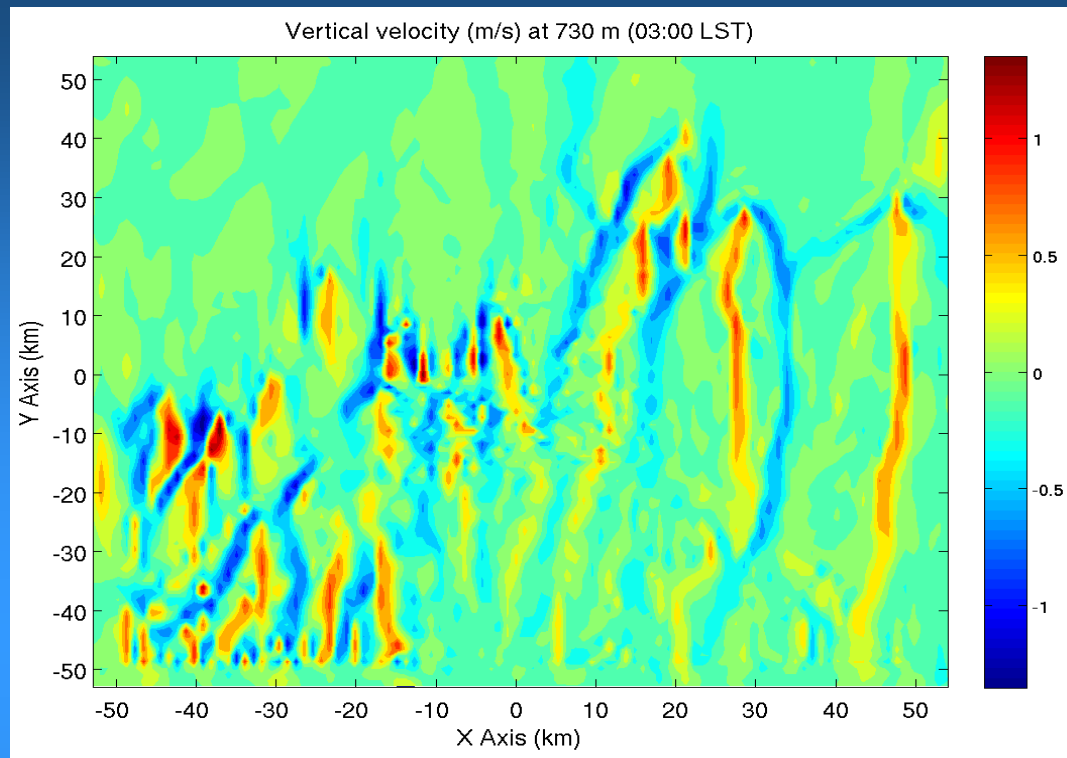
Morlet
Wavelet



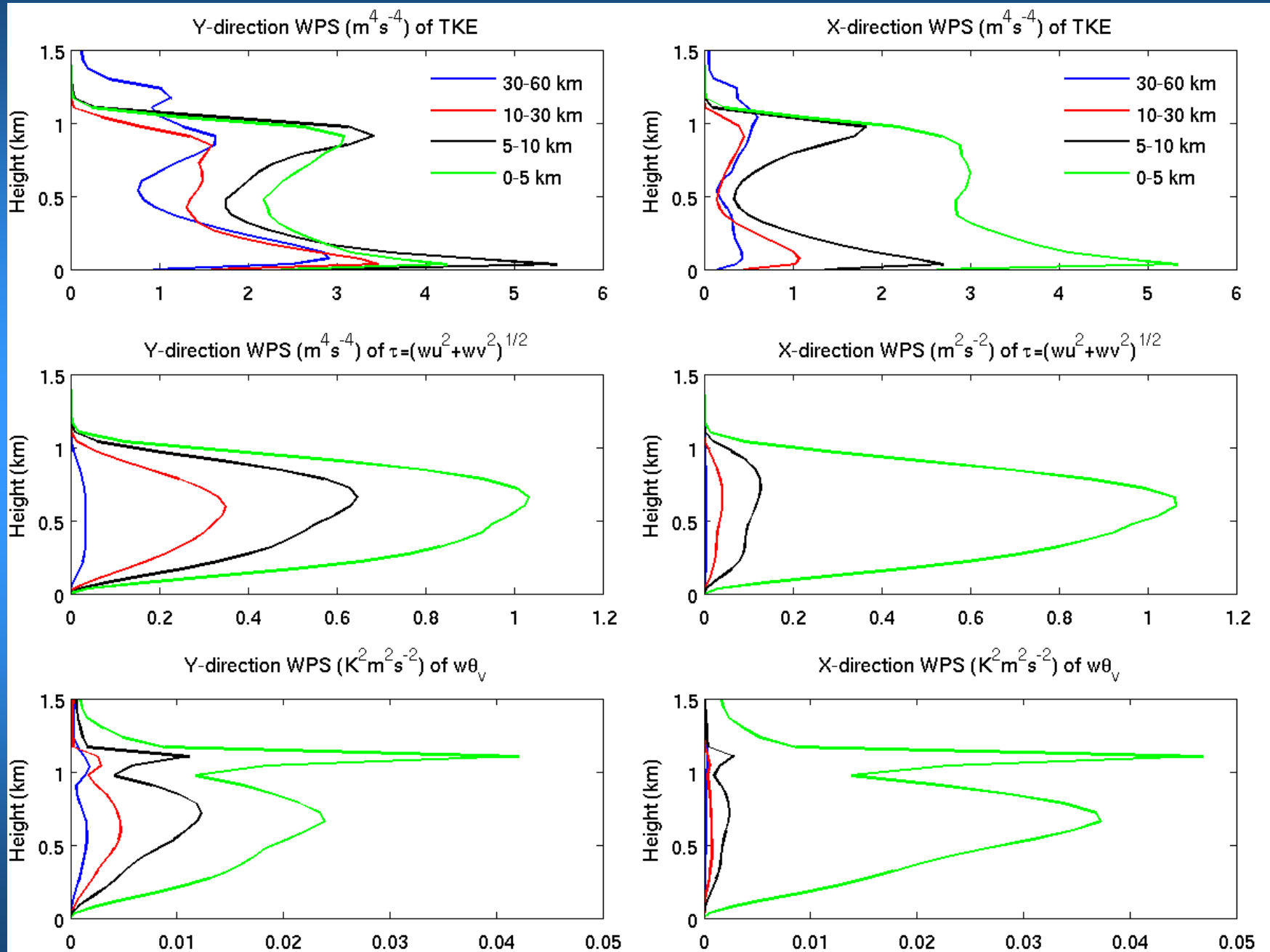
Wavelet Power Spectrum (WPS) $|W_{n_x, n_y}(s)|^2$

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

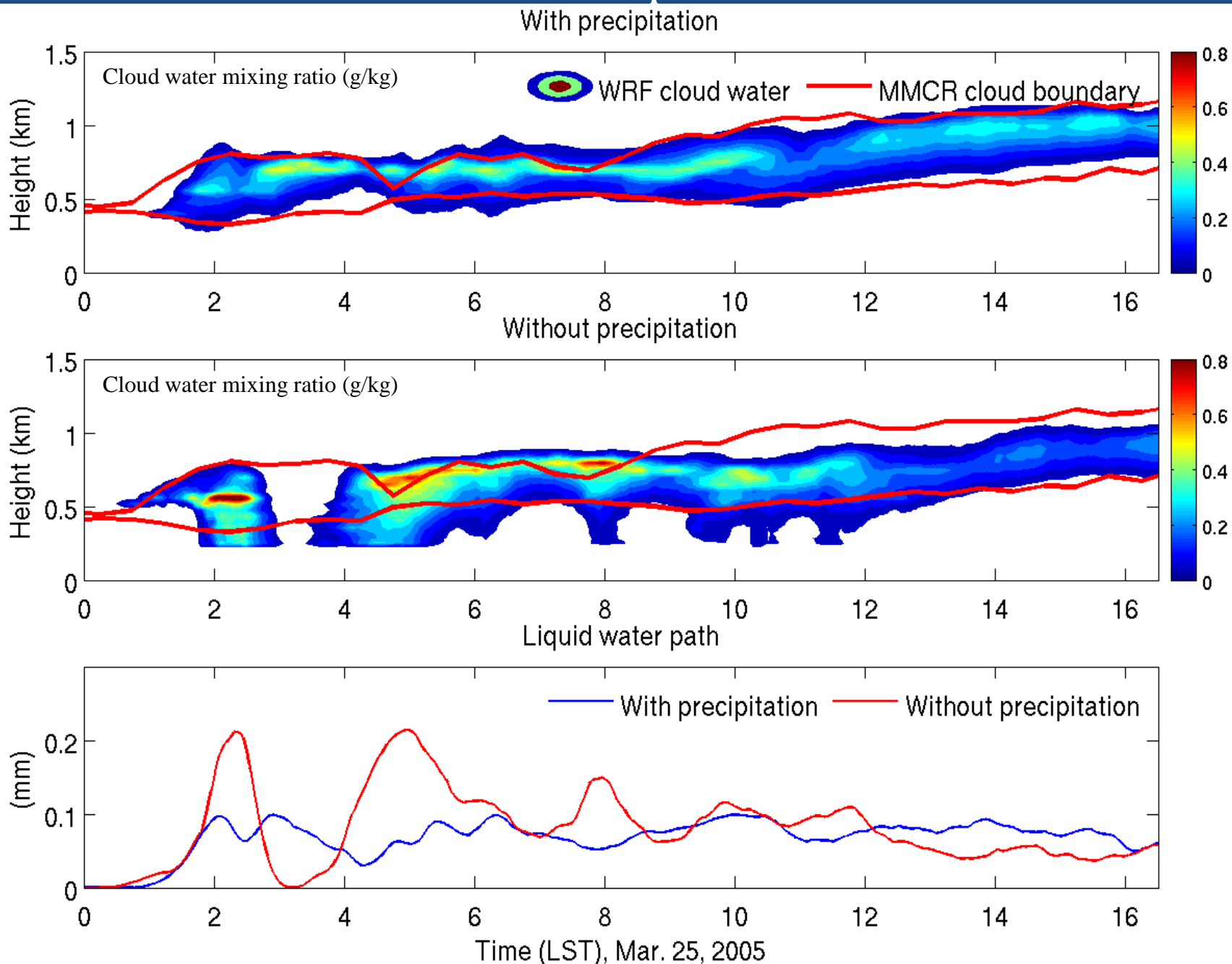
2D CWT Demonstration



WPS of TKE, τ , and $\overline{w'\theta'_v}$ in the evening (3-5 AM)

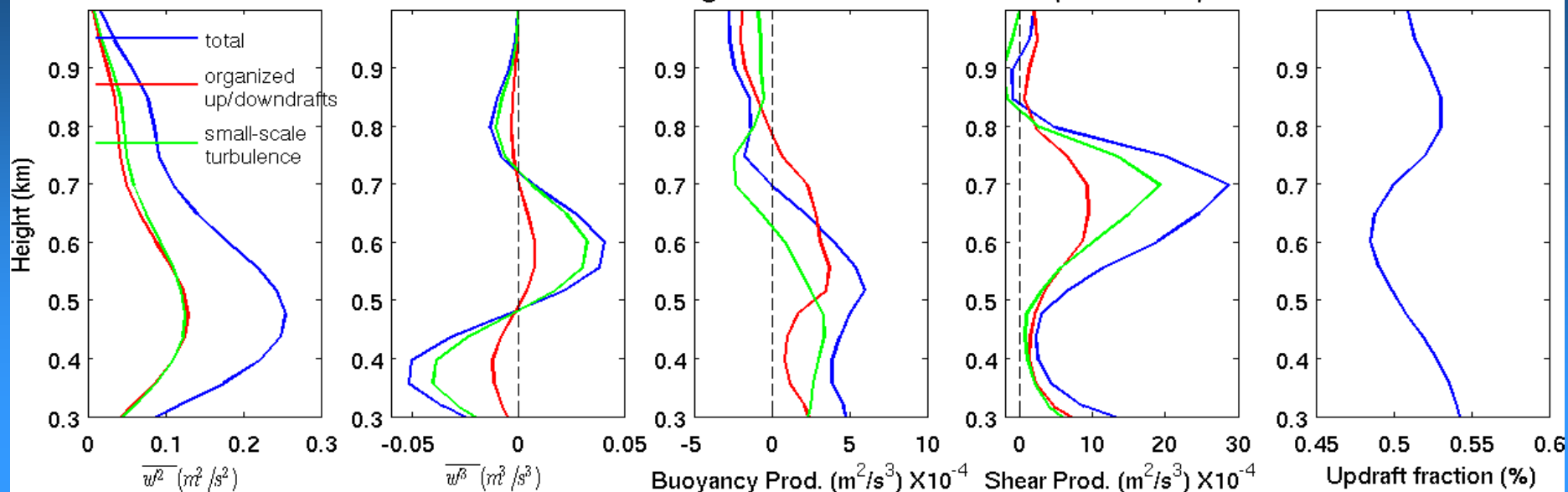


Effect of Precipitation

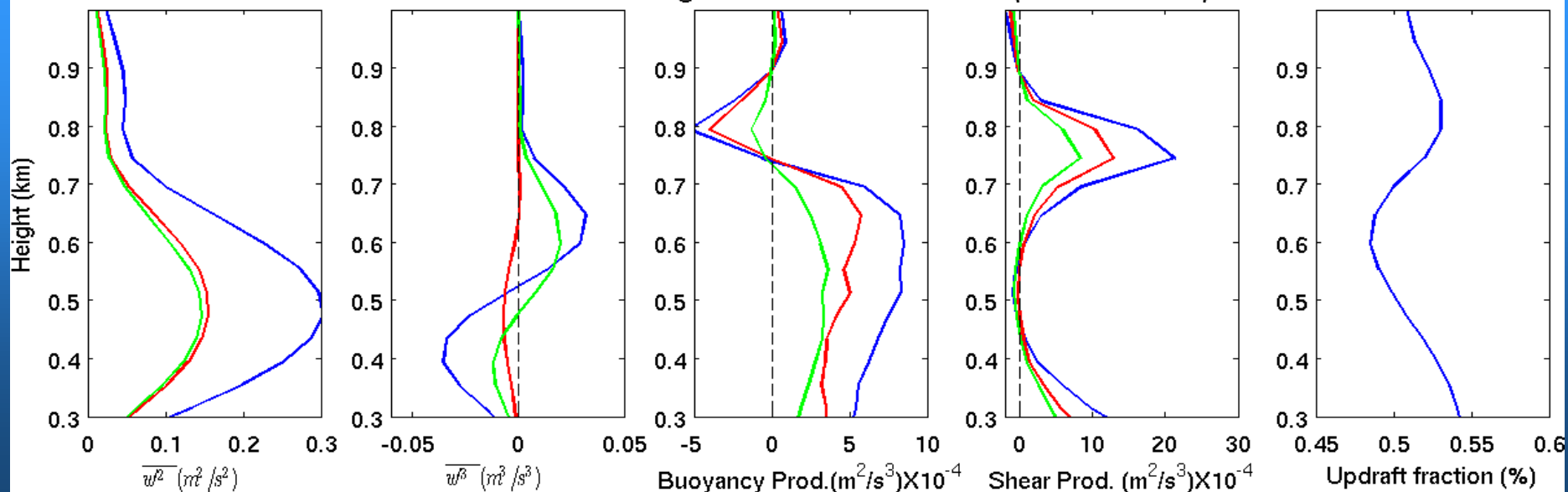


Comparison of Turbulent Structure (nighttime)

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

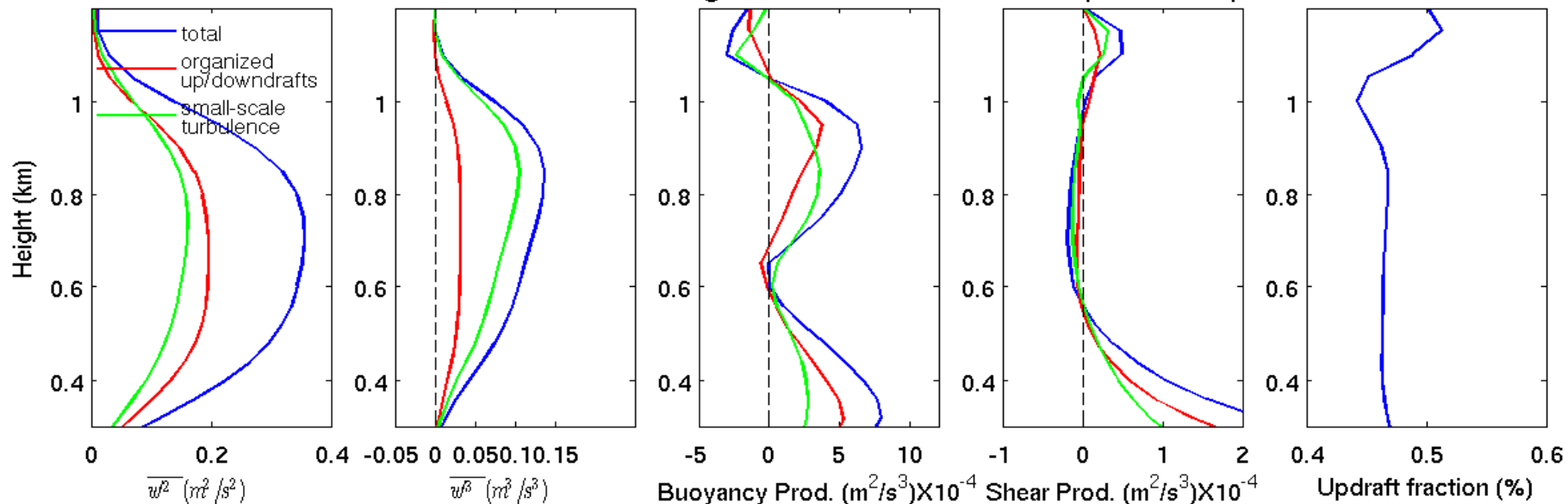


Resolved fields averaged over 5:00-6:00 LST (Without Rain)

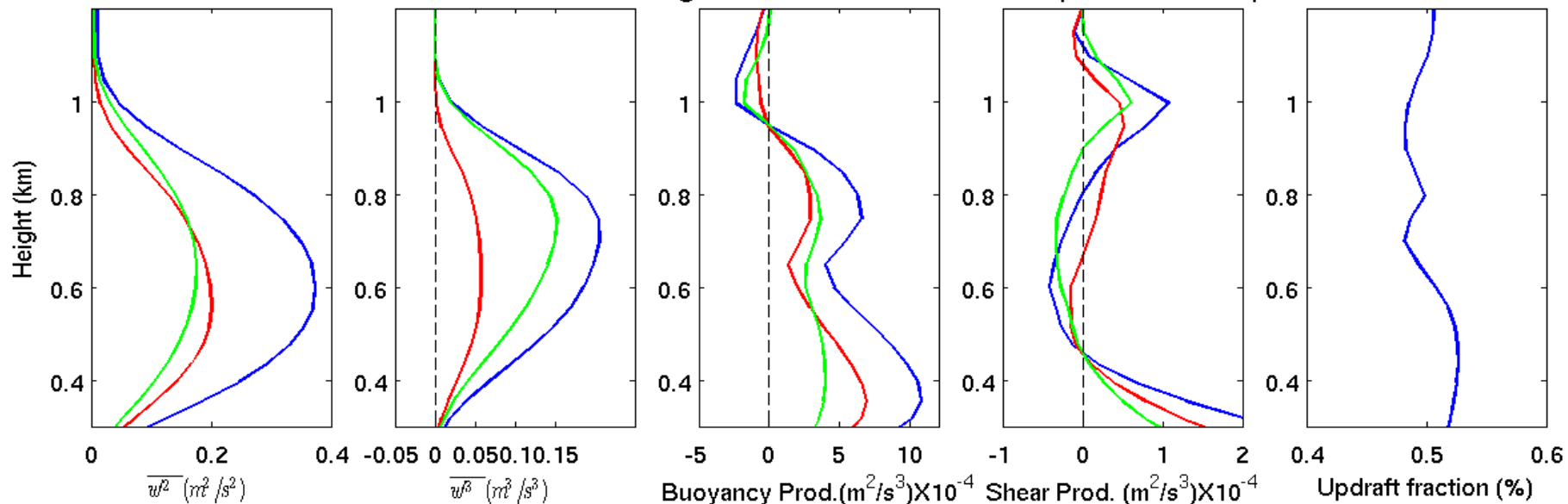


Comparison of Turbulent Structure (daytime)

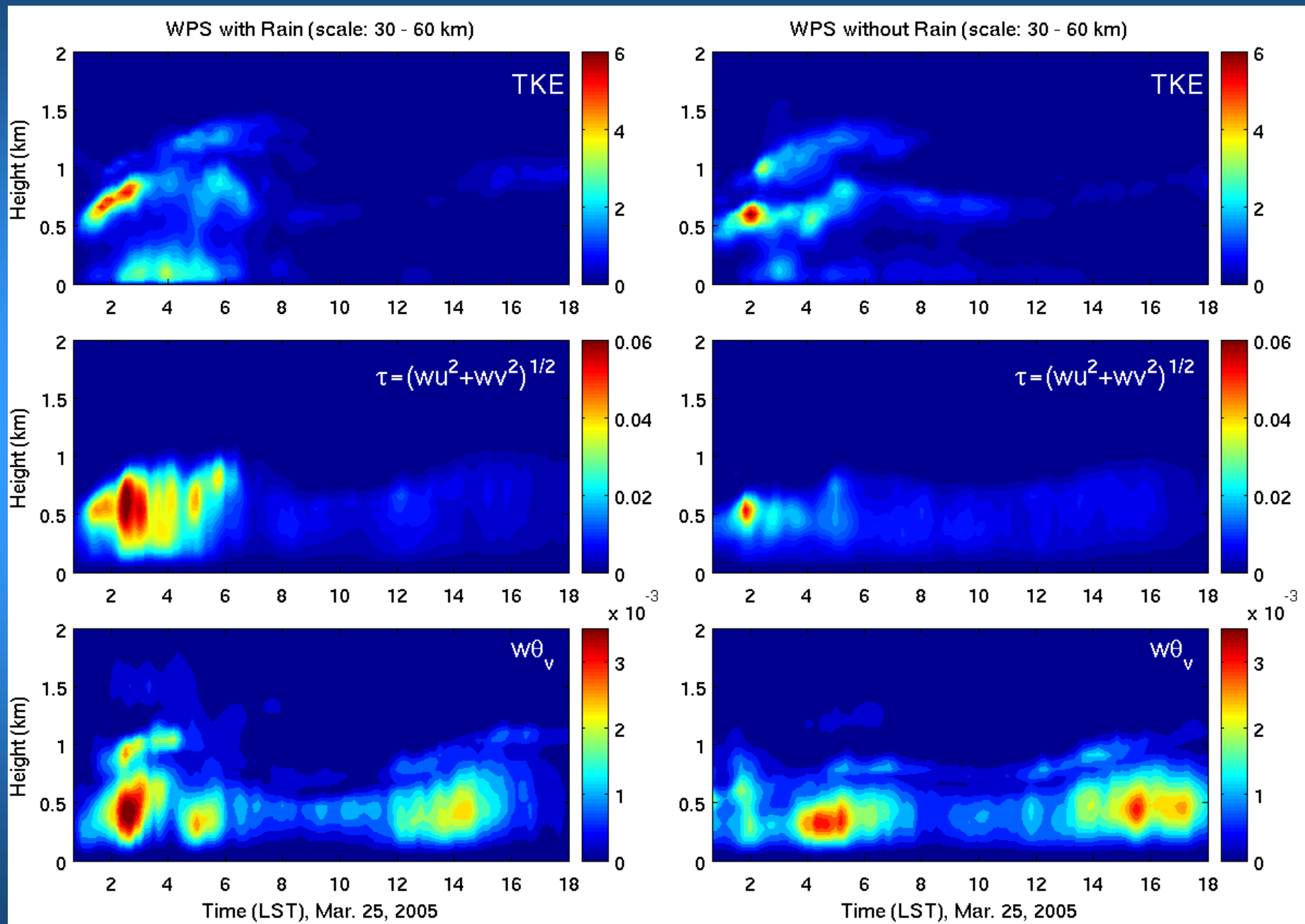
Resolved fields averaged over 15:00-16:00 LST (With Rain)



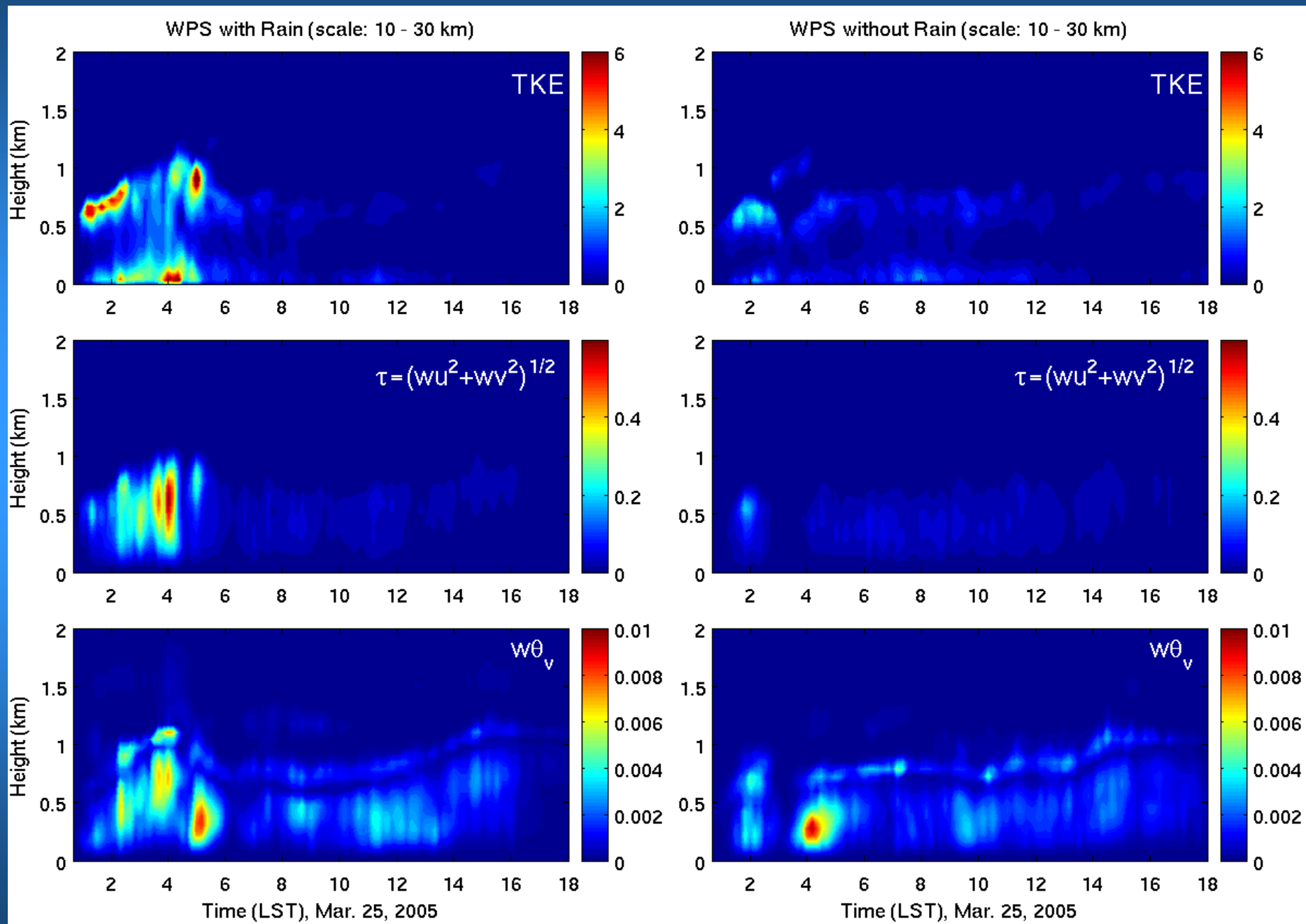
Resolved fields averaged over 15:00-16:00 LST (Without Rain)



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.