1049 Regional Bowen Ratio Controls on Afternoon Moist Convection: A Large Eddy Simulation Study

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Introduction

- The observed afternoon precipitation peak is not accurately simulated in most large-scale models that employ parameterizations for the boundary layer and convective processes.
- Land surface influences moist convection by means of the boundary layer, in which turbulence is ubiquitous.
- This study employs LES with realistic surface flux fields to examine the effect of surface dryness (or wetness) on the development of afternoon moist convection.

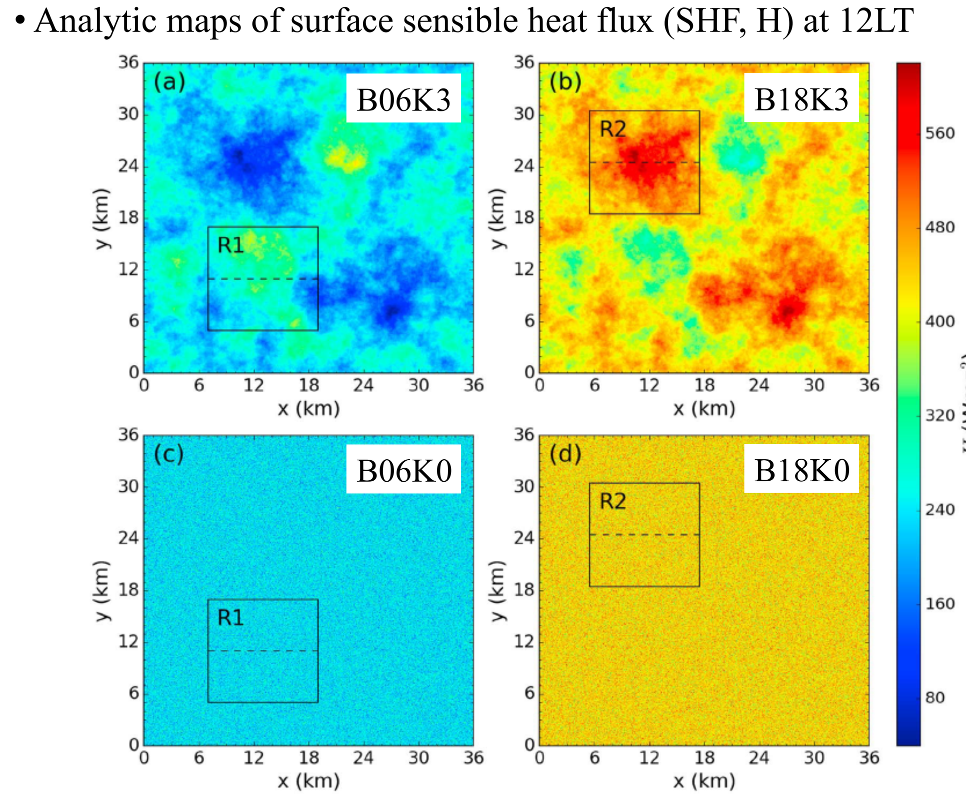
Model Setup & Run

- Model Configuration
  - Weather Research and Forecasting (WRF) model version 3.6 in an LES mode
  - The horizontal grid spacing Δx is 50 m
  - The vertical resolution is 285 levels with a 10 km model top, about 35m vertical grid spacing
  - Periodic lateral boundary conditions are used in both directions

- Statistics of the Analytic Surface Sensible Heat Flux (H) Fields at 12LT

Case	β	H	σ_H	Maximum	Minimum	25th Percentile	Median	75th Percentile
B18K0	1.80	432	45	633	233	402	432	462
B18K3	1.80	432	49	636	244	401	430	461
B06K0	0.56	240	45	439	39	210	240	270
B06K3	0.56	240	49	436	36	211	242	271

- Analytic maps of surface sensible heat flux (SHF, H) at 12LT

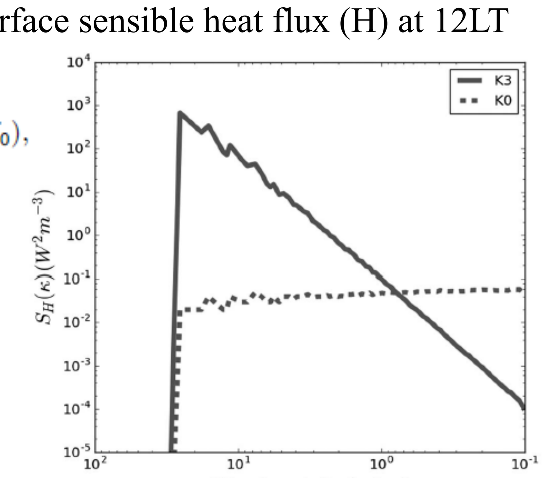


The heterogeneous surface cases : B06K3 and B18K3
The homogeneous surface cases : B06K0 and B18K0

- The averaged 2D spectra S(κ) of surface sensible heat flux (H) at 12LT

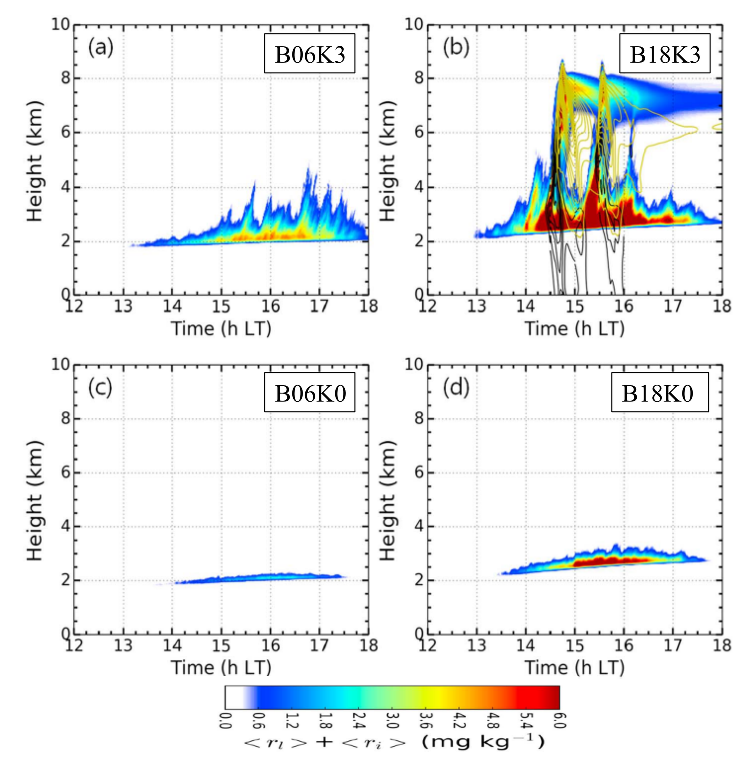
$$H(x_i;t) = H(x_i;t = 1200\ \mathrm{LT}) \times \sin(2\pi(t-6)/T_0),$$

$$\mathrm{LH}(x_i;t) = A(t) - H(x_i;t).$$



Moist Convection

- Temporal evolution of the vertical profiles of domain-averaged mixing ratios of liquid, ice water, rain, graupel, and snow.

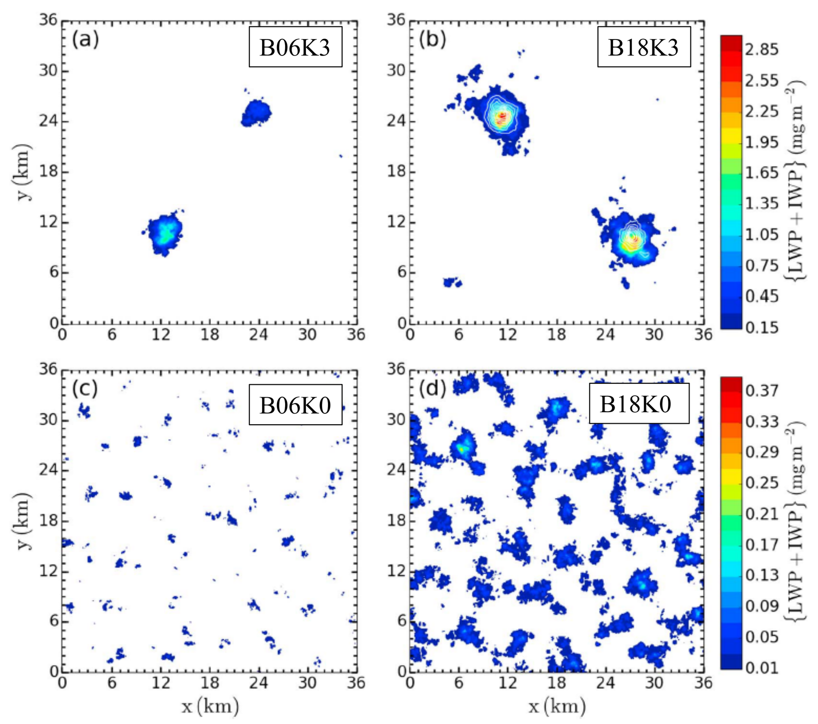


The heterogeneous, small β surface case (a), convective clouds develop but do not progress into precipitating convection (a).

For the heterogeneous, large β surface case (b), precipitating deep convection develops from around 1400 LT (a).

For the homogeneous surface cases only shallow clouds develop, but with somewhat thicker clouds in the large β case (d) than in the small β case (c).

- Spatial distribution of the sum of liquid water path (LWP) and ice water path (IWP)



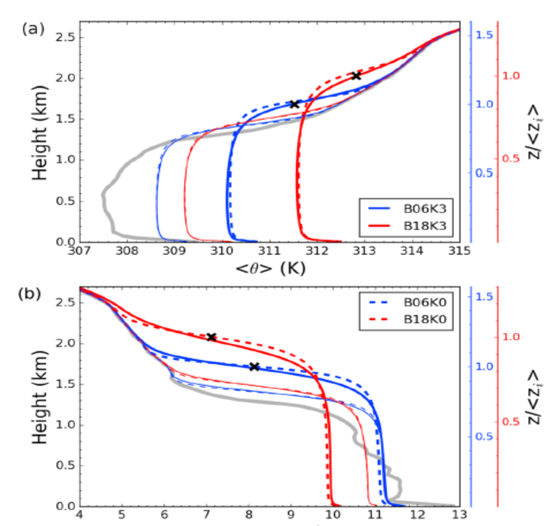
$$\mathrm{LWP}(x_i;t) = \int_{z_{sfc}}^{z_{top}} \langle\rho\rangle(z,t)\, r_c(x_i;z,t)\, dz,$$

For the heterogeneous surface cases (a and b), convective clouds are focused over the mesoscale subdomains of larger SHF, with much higher hydrometeor water path values in the large β case (b) than in the small β case (a).

For the homogeneous surface cases (c and d), however, shallow clouds randomly develop that are somewhat more significantly larger in the large β case (d) than in the small β case (c).

Mean CBL Structures

- Vertical profiles of <θ> and <r>



1200 LT (thin lines)
1400 LT (thick lines)

Although they are simulated with the same initial condition and surface available energy, the mean CBL structures of <θ> and <r> differ significantly among the four cases.

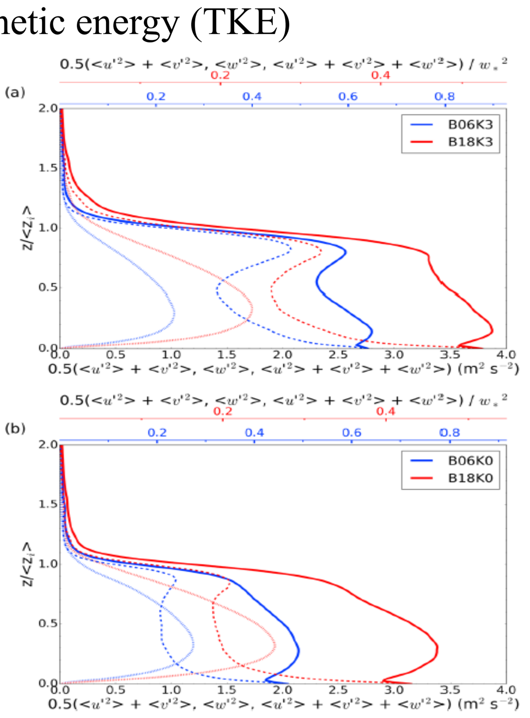
The differences in CBL structure are basically caused by the differing surface heat flux conditions.

- Vertical profiles of turbulence kinetic energy (TKE)

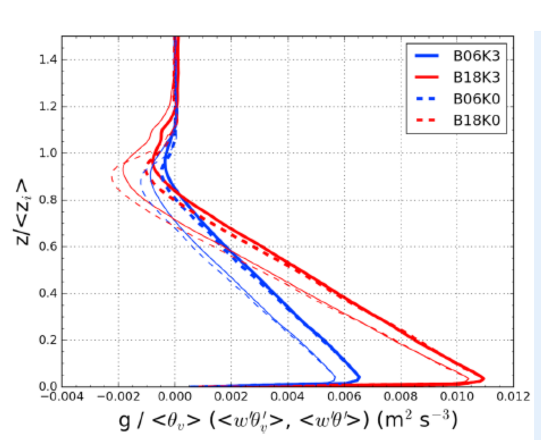
0.5(<u'²> + <v'²> + <w'²>) (solid line)
0.5(<u'²> + <v'²>) (dashed lines)
0.5(<w'²>) (dotted lines)

The TKE is about 20–30% larger in the large β cases than in the small β cases. These larger TKE values originally come from the larger SHF values of the large β cases.

The larger SHF compensates for the smaller LHF, and vice versa, with the same surface available energy at every grid point. But, SHF is much more effective in producing TKE than LHF.



- Vertical profiles of the time tendency of the TKE



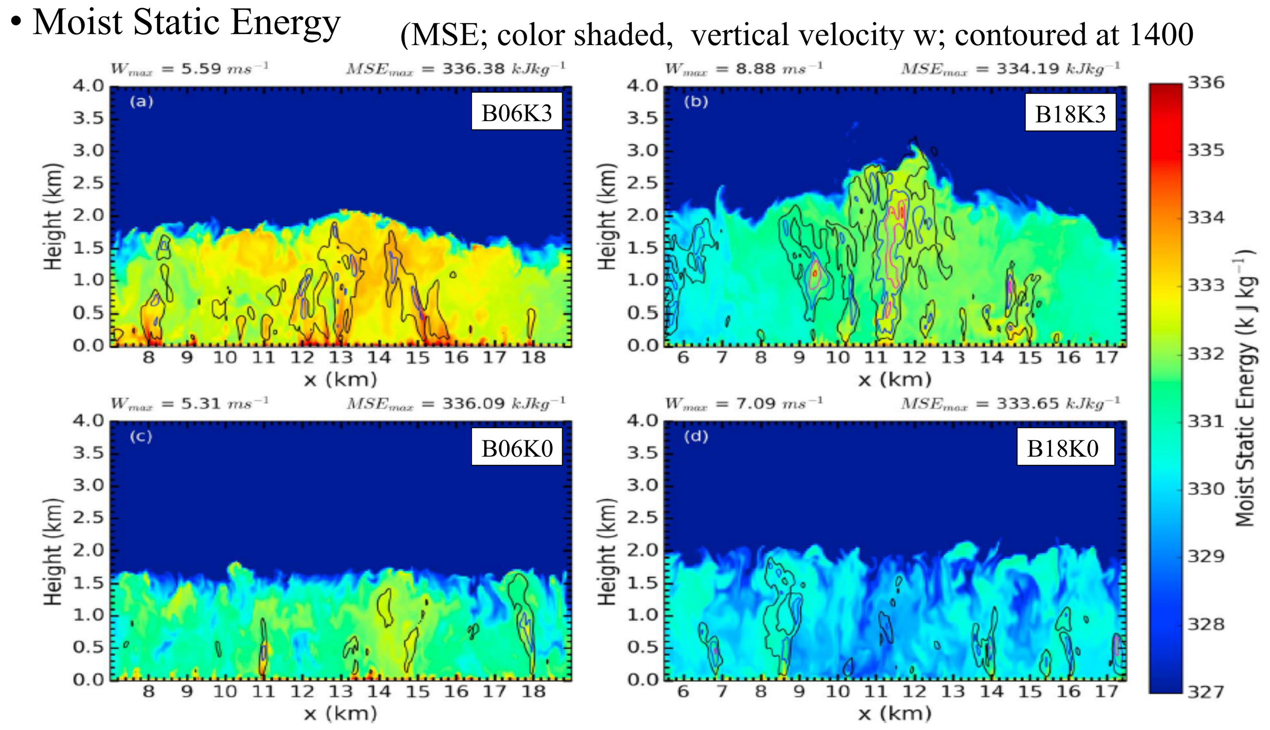
$g/\langle\theta_v\rangle \langle w'\theta'_v\rangle$ (Thick line)
$g/\langle\theta_v\rangle \langle w'\theta'\rangle$ (Thin lines)

The contribution from the nonvertical heat flux term to the TKE time tendency increases with height.

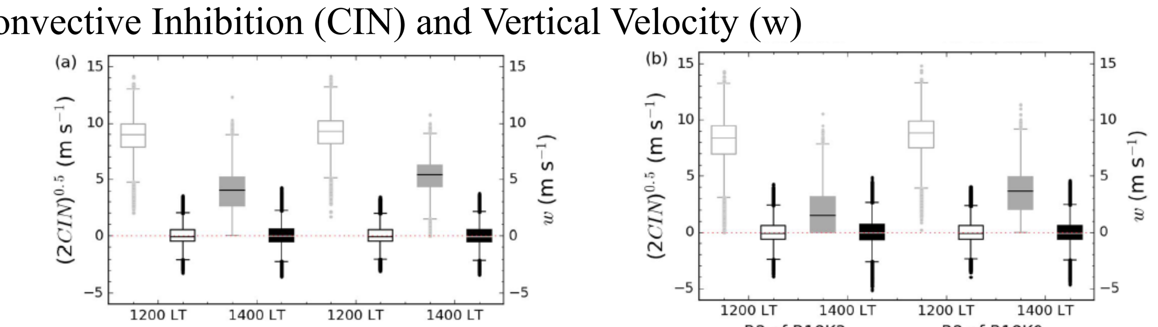
The results from the intense entrainment of the dry free atmosphere responding to the strong overshooting of vigorous thermal updrafts.

Mechanism for Moist Convection

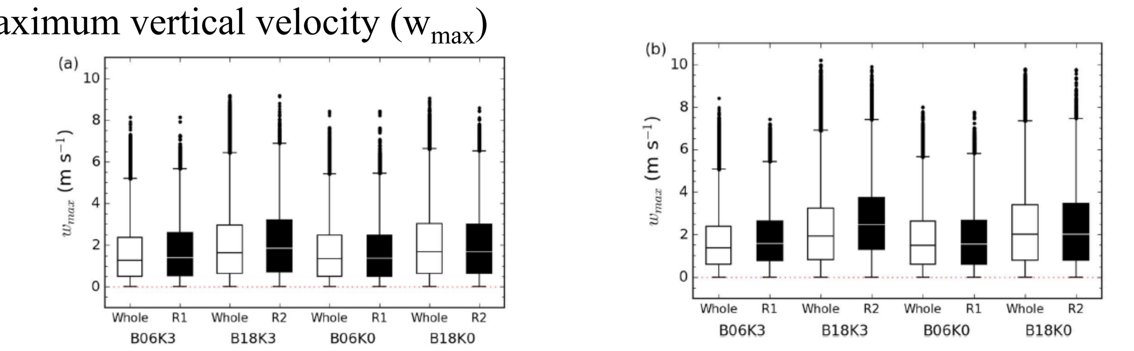
- Moist Static Energy (MSE; color shaded, vertical velocity w; contoured at 1400



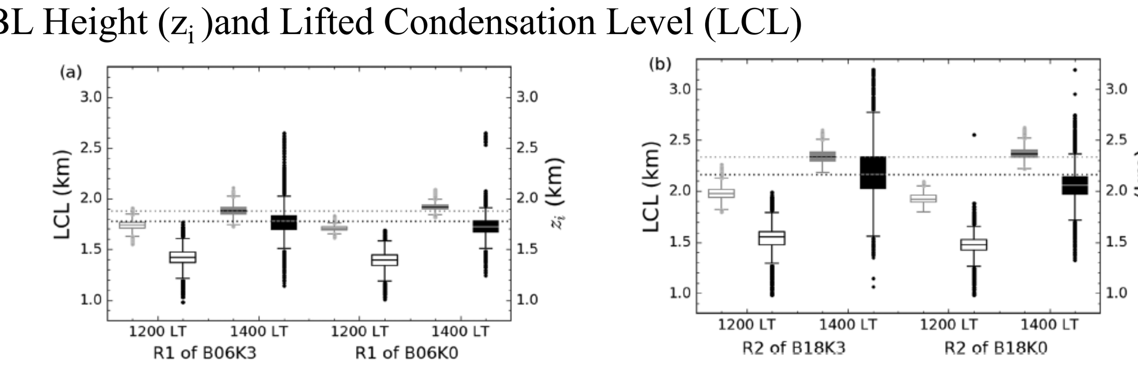
- Convective Inhibition (CIN) and Vertical Velocity (w)



- Maximum vertical velocity (w_{max})

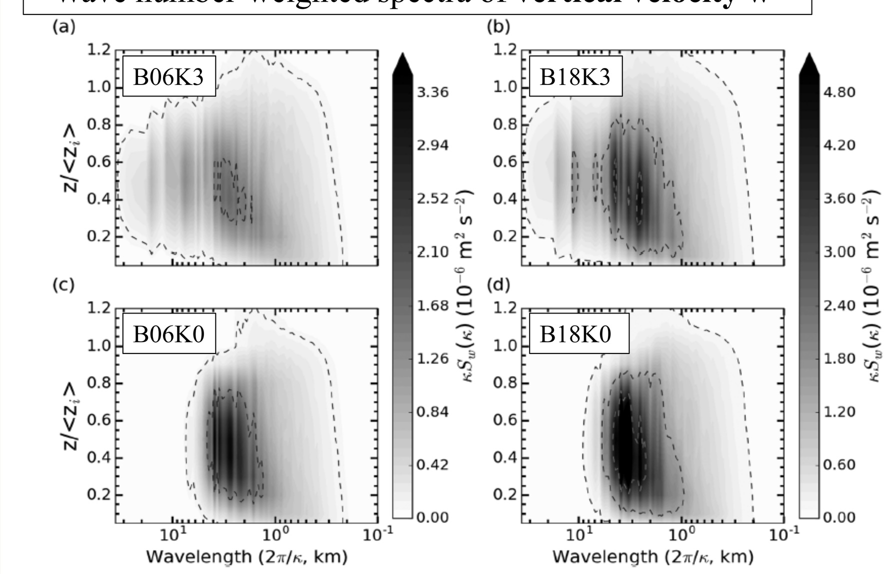


- CBL Height (z_i)and Lifted Condensation Level (LCL)



Spectral Analyses

- Wave number-weighted spectra of **vertical velocity w**



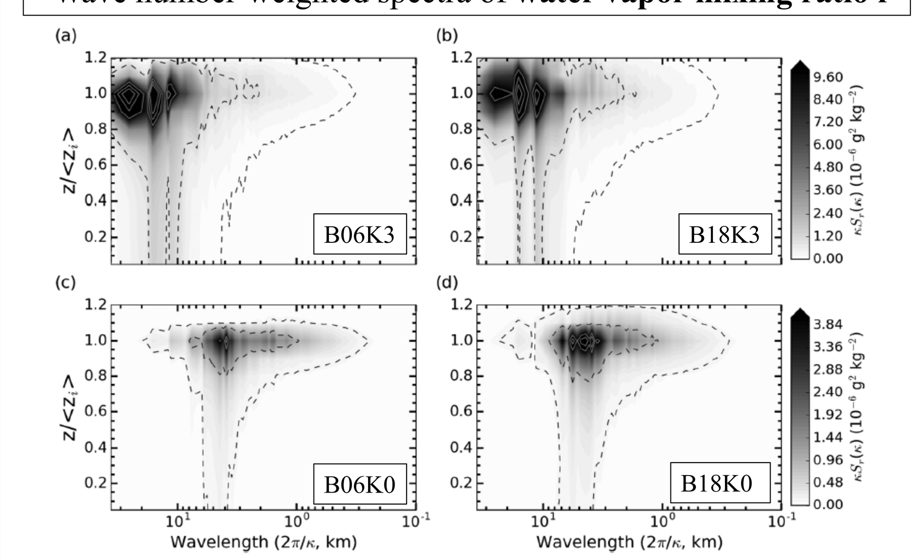
In the large β cases (B18K3 and B18K0)
: the CBL heights are higher and thus the spectral peaks are shifted into larger wavelengths

In the heterogeneous surface cases (B06K3 and B18K3)
: the r variability is associated with the surface heterogeneity-induced mesoscale circulations, which are on scales longer than 10 km, throughout the CBL including the entrainment zones (mixing ratio).

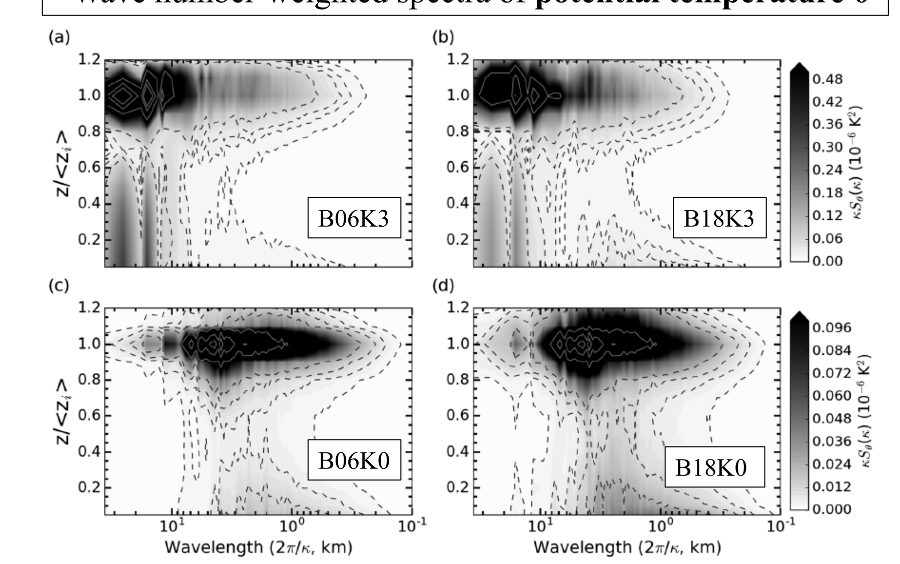
In the homogeneous cases (at lower level, B06K0 and B18K0)
: the spectral peak wavelength of the θ spectra, which is 2–3 km, is shorter than the peak wavelength of the r spectra, which is about 4 km.

The different dominant length scales between r and θ are basically caused by the differing roles of the entrainment. The entrainment of θ reduces the vertical gradient between the surface and the CBL top, but the entrainment of r enhances the gradient.

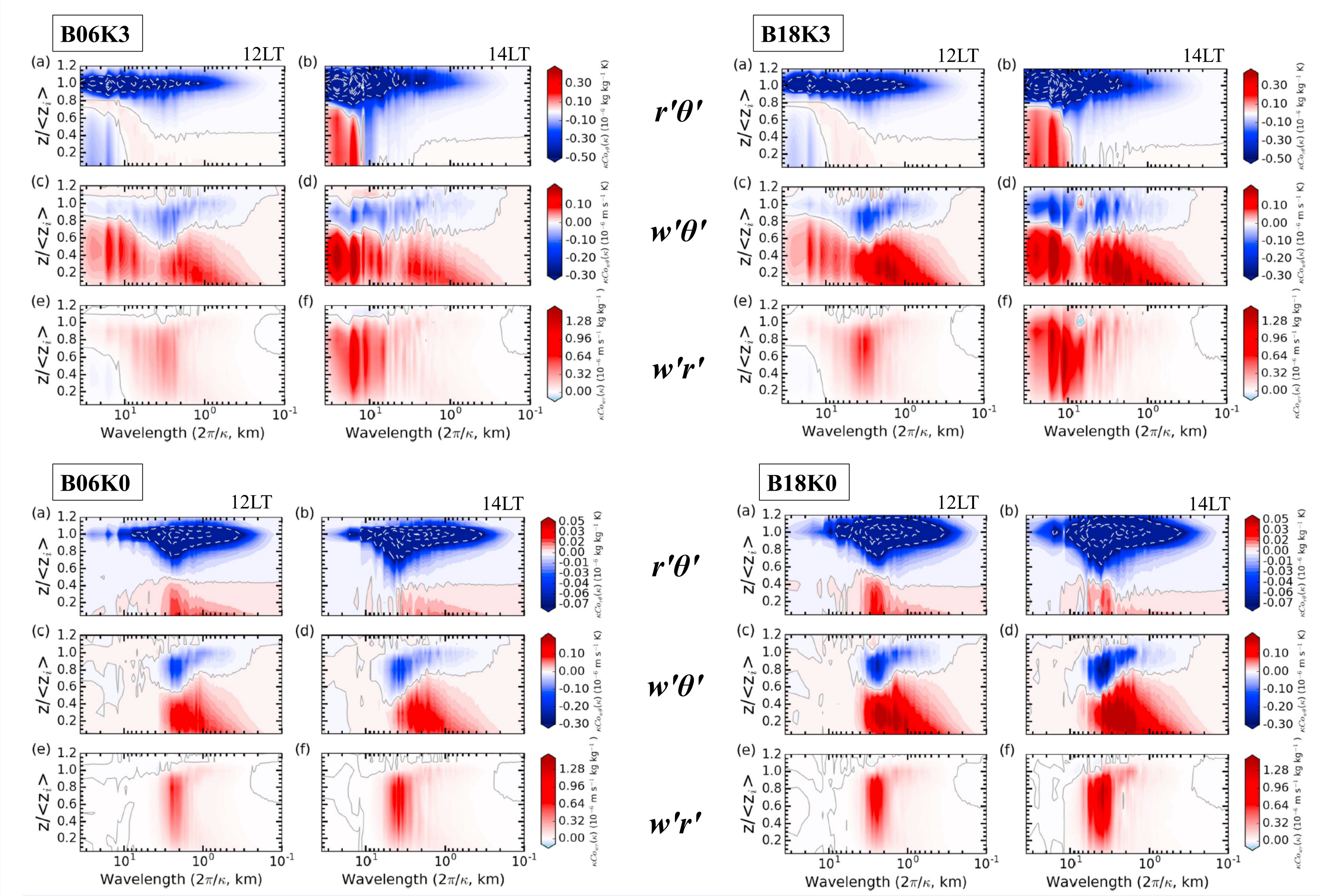
- Wave number-weighted spectra of **water vapor mixing ratio r**



- Wave number-weighted spectra of **potential temperature θ**



Cospectral Analyses



This cospectral analysis demonstrates that LES quickly produces the typical low-level CBL turbulence of positive r'θ', positive w'θ', and positive w'r'.
The signs of both(B18K3 and B06K3) $\kappa Co_{r\theta}(\kappa)$ and $\kappa Co_{wr}(\kappa)$ change from negative at 1200 LT to positive at 1400 LT. At 1200 LT, the combination of negative r'θ', positive w'θ', and negative w'r'. The results show a property of thermally induced mesoscale circulation in the low-level CBL particularly on scales ≥10 km. But at 1400 LT, the rθ and wr correlations become positive, along with the positive wθ correlation, which results from the advection of moisture by the surface heterogeneity.

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