Development and Evaluation of New Monin-Obukhov and Bulk Richardson Parameterizations to Improve the Representation of Surface-Atmosphere Exchange in Weather Forecasting Models

Temple R. Lee[1,2] and Michael Buban[1,2]

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100th Annual AMS Meeting
Boston, MA
16 Jan 2020

Monin-Obukhov Parameterizations

Gradients of temperature, moisture and wind can be written as functions of $\frac{z}{L}$, assuming a horizontally-homogenous near-surface flux layer:

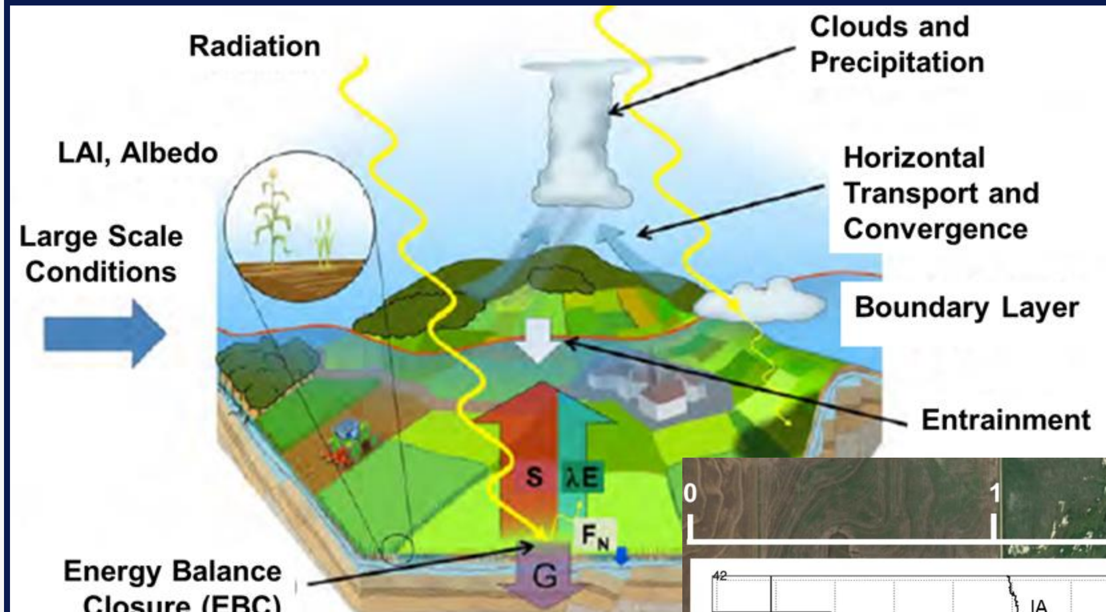
$$L = -\frac{\overline{\theta_v} u_*^3}{\kappa g \overline{w'\theta_{v0}'}}$$

$$\frac{\partial \bar{u}}{\partial z}\frac{\kappa z}{u_*} = \phi_m(\frac{z}{L}) \qquad \phi_m = \alpha_m(1-\beta_m\frac{z}{L})^{-\frac{1}{4}}$$

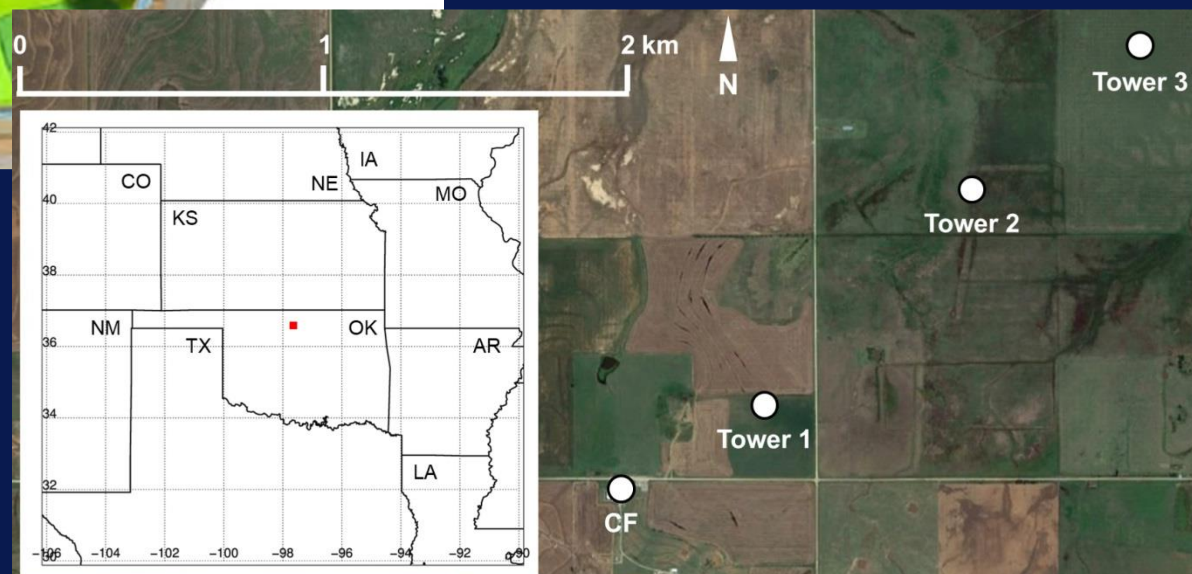
$$\frac{\partial \bar{\theta}}{\partial z}\frac{u_* \kappa z}{H} = \phi_h(\frac{z}{L}) \qquad \phi_h = \alpha_h(1-\beta_h\frac{z}{L})^{-\frac{1}{2}}$$

$$\frac{\partial \bar{q}}{\partial z}\frac{u_* \kappa z}{LE} = \phi_q(\frac{z}{L}) \qquad \phi_q = \alpha_q(1-\beta_q\frac{z}{L})^{-\frac{1}{2}}$$

Land Atmosphere Feedback Expt.



Dept. of Energy
Southern Great Plains Site
August 2017



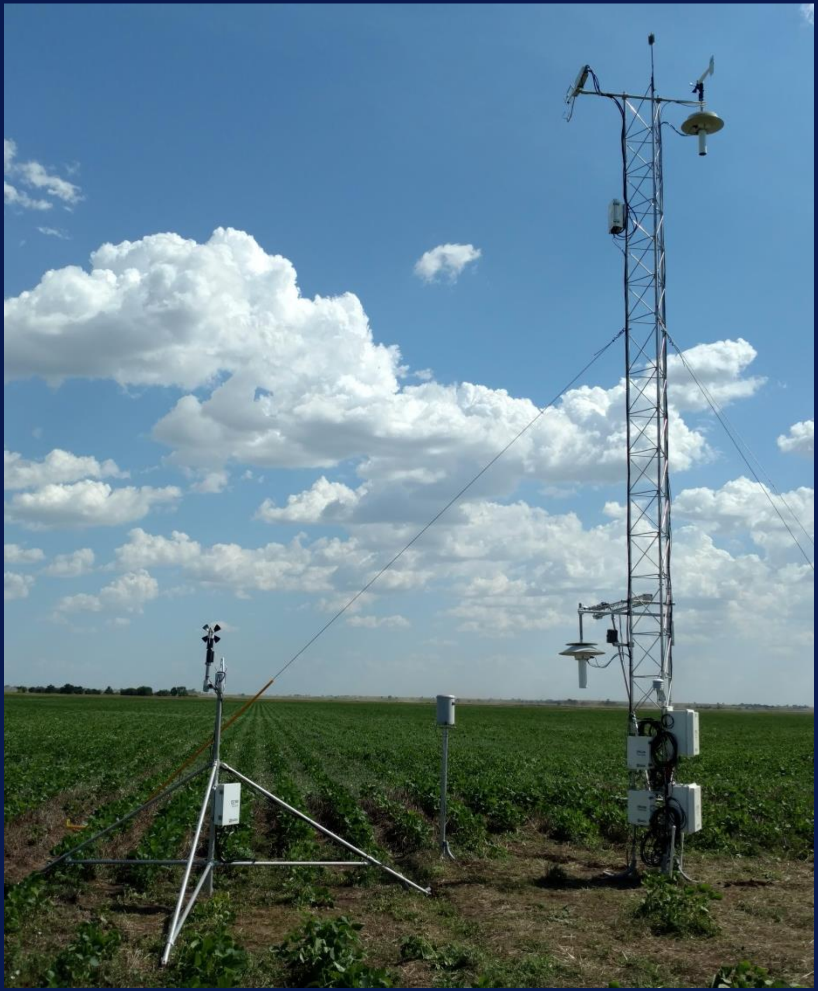
Array of sfc. instruments and PBL profilers to study interactions between the land-surface and atmosphere

ATDD Tower Measurements

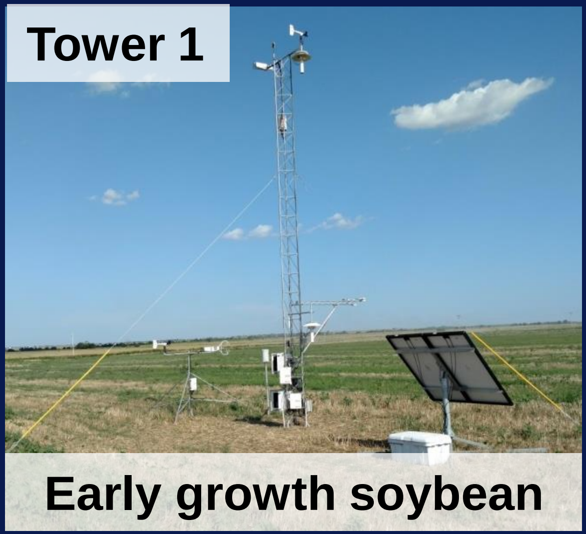
2 m Tripod	
Instrument	**Sampling Height(s) (m AGL)**
Propeller anemometer	2
Closed path gas analyzer	2
Sonic anemometer	2

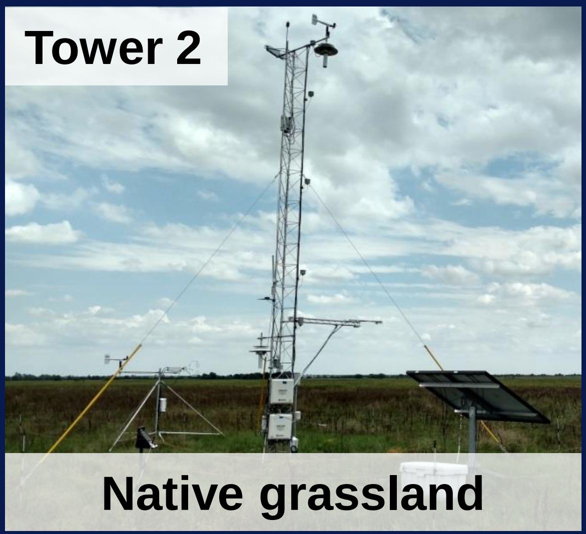
10 m Tower	
Instrument	**Sampling Height(s) (m AGL)**
HMP110 T, RH probe	2
Aspirated PRT	2 ,10
Pressure sensor	1
Hukseflux net radiometer	2.5
TP01 soil temperature probe	-0.05, -0.10, -0.20
Decagon soil moisture probe	-0.05, -0.10, -0.20
Propeller anemometer	2, 10
PAR sensor	2.5
Closed path gas analyzer	10
Sonic anemometer	10

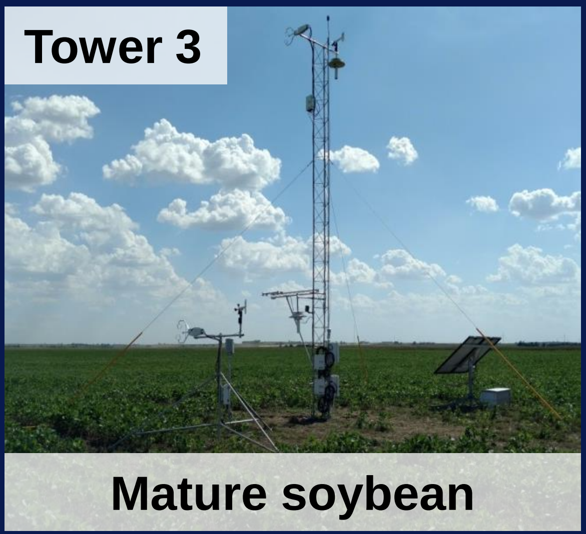
Other	
Instrument	**Sampling Height(s) (m AGL)**
Rain gauge	2.5

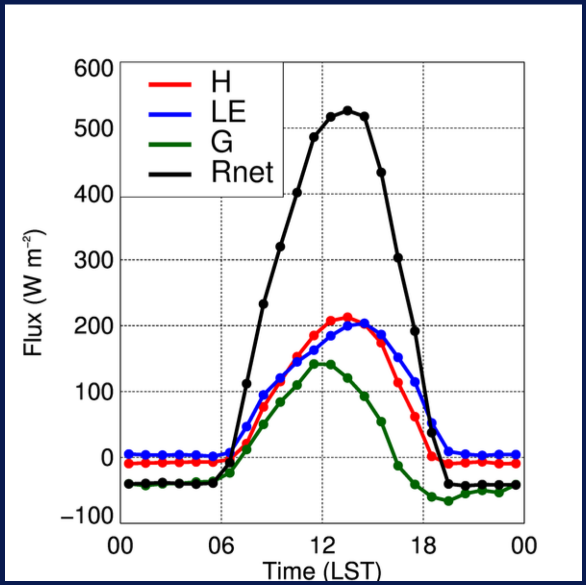


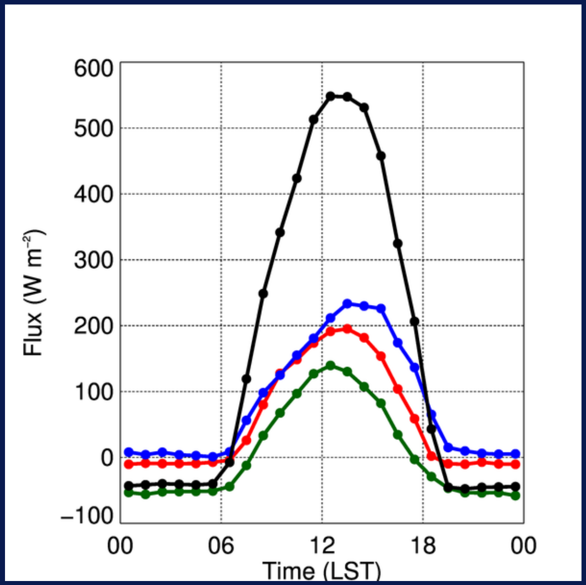
Site Characteristics

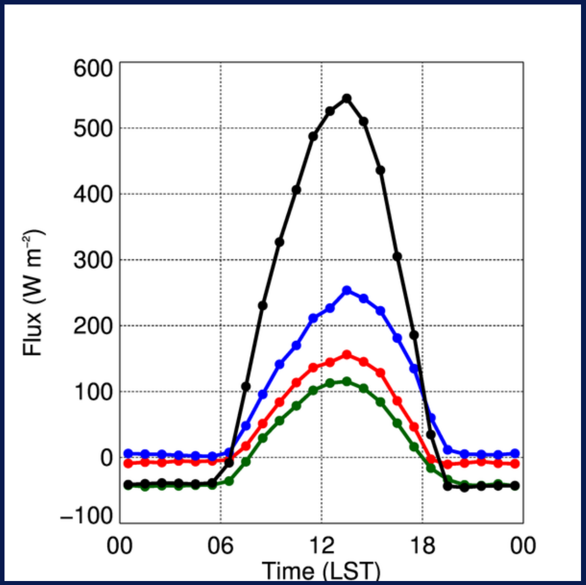




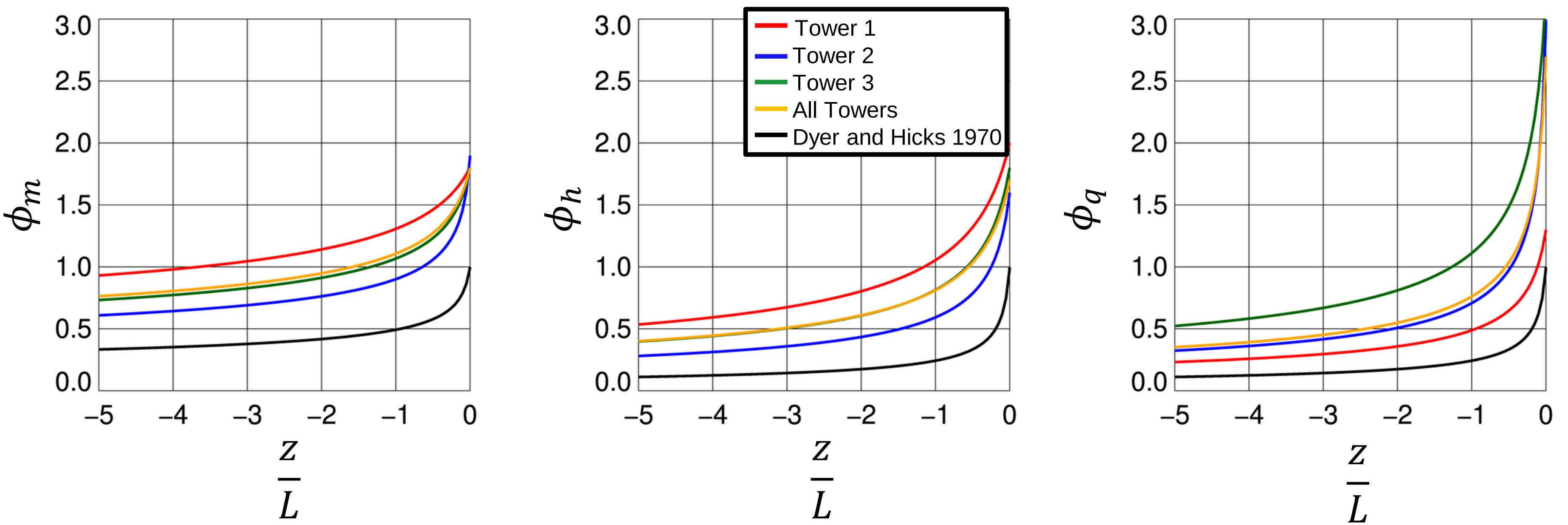








Monin-Obukhov Parameterizations



LAFE datasets show significant departure from classical relationships developed in the literature

Bulk Richardson Parameterizations

$$Ri = \frac{g \frac{\partial \overline{\theta_v}}{\partial z}}{\overline{\theta_v} \left[\left(\frac{\partial \bar{u}}{\partial z} \right)^2 + \left(\frac{\partial \bar{v}}{\partial z} \right)^2 \right]}$$

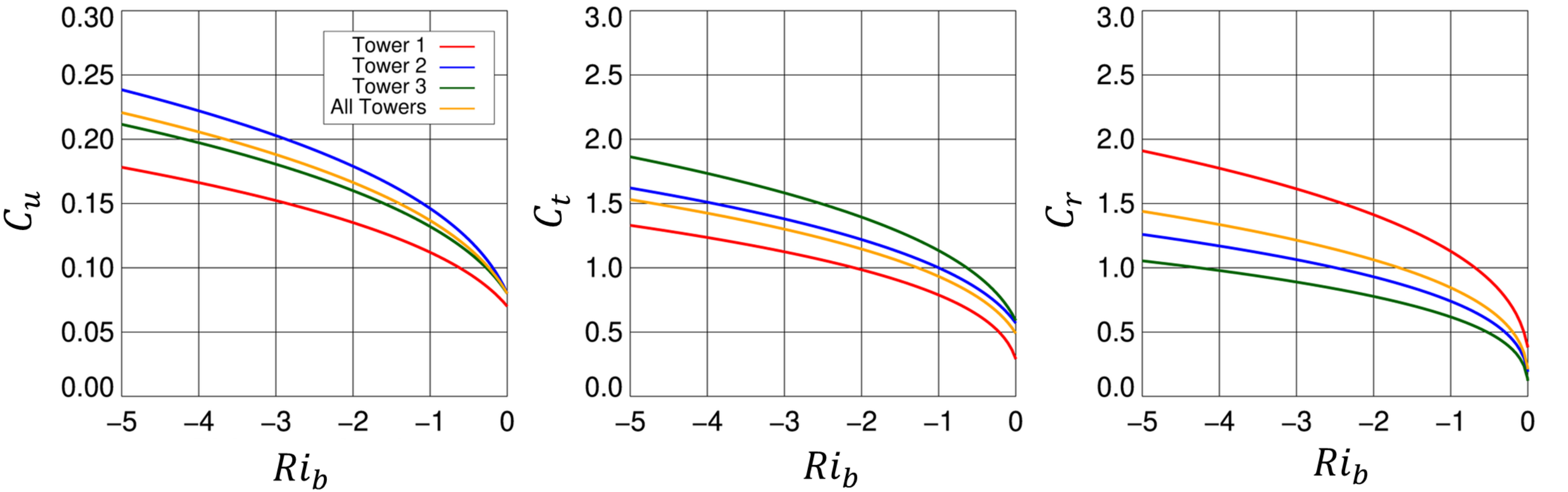
From Deardorff (1972):

$$C_u = \frac{u_*}{U_{10}} \qquad C_u = \alpha_u (1 - \beta_u Ri_b)^{\frac{1}{3}}$$

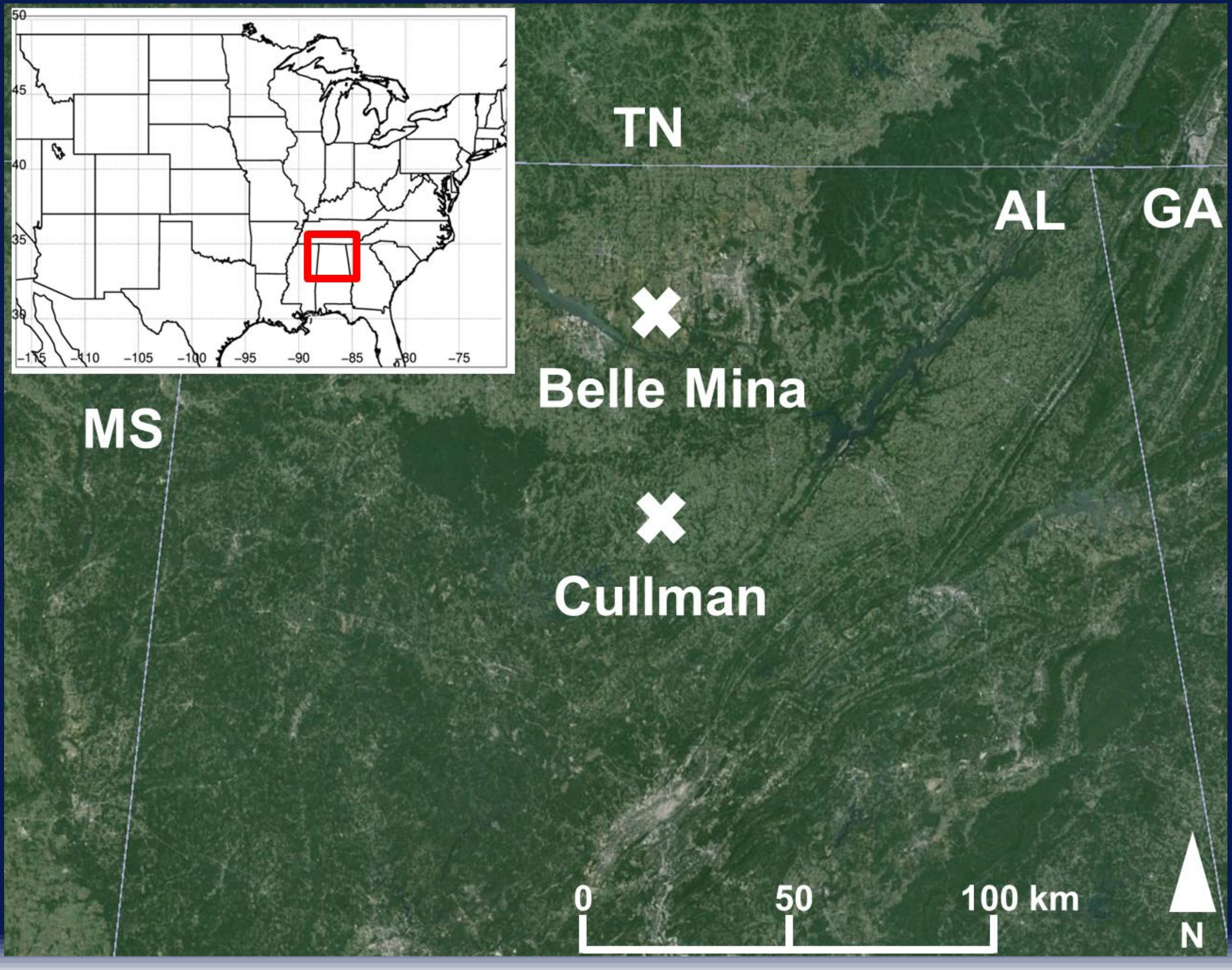
$$C_t = \frac{\theta_*}{(\theta_v - \theta_{vs})} \qquad C_t = \alpha_t (1 - \beta_t Ri_b)^{\frac{1}{3}}$$

$$C_r = \frac{(-\overline{w'q'})_s}{u_*(q - q_s)} \qquad C_r = \alpha_r (1 - \beta_r Ri_b)^{\frac{1}{3}}$$

Bulk Richardson Parameterizations



Evaluation Study Area



Evaluating MOST Functions

$$U_{10} = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) - \psi_m\left(\frac{z-d}{L}\right) + \psi_m\left(\frac{z_0}{L}\right)\right]$$

$$\Delta\theta = \frac{\theta_*}{\kappa}\left[\ln\left(\frac{z_2-d}{z_1-d}\right) - \psi_h\left(\frac{z}{L}\right)_2 + \psi_h\left(\frac{z}{L}\right)_1\right]$$

$$\Delta q = \frac{q_*}{\kappa}\left[\ln\left(\frac{z_2-d}{z_1-d}\right) - \psi_q\left(\frac{z}{L}\right)_2 + \psi_q\left(\frac{z}{L}\right)_1\right]$$

Where,

$$\psi_m = 2\ln\left(\frac{1+\phi_m^{-1}}{2}\right) + \ln\left(\frac{1+\phi_m^{-2}}{2}\right) - 2\tan^{-1}\phi_m^{-1} + \frac{\pi}{2}$$

$$\psi_h = 2\ln\left(\frac{1+\phi_h^{-2}}{2}\right)$$

$$\psi_q = 2\ln\left(\frac{1+\phi_q^{-2}}{2}\right)$$

LAFE MOST Parameterizations

$$\phi_m = \alpha_m\left(1-\beta_m\frac{z}{L}\right)^{-\frac{1}{4}}$$

$$\phi_h = \alpha_h\left(1-\beta_h\frac{z}{L}\right)^{-\frac{1}{2}}$$

$$\phi_q = \alpha_q\left(1-\beta_q\frac{z}{L}\right)^{-\frac{1}{2}}$$

Evaluating Ri_b Functions

$$C_u = \frac{u_*}{U_{10}}$$

$$U_{10} = \frac{u_*}{\mathrm{C_u}}$$

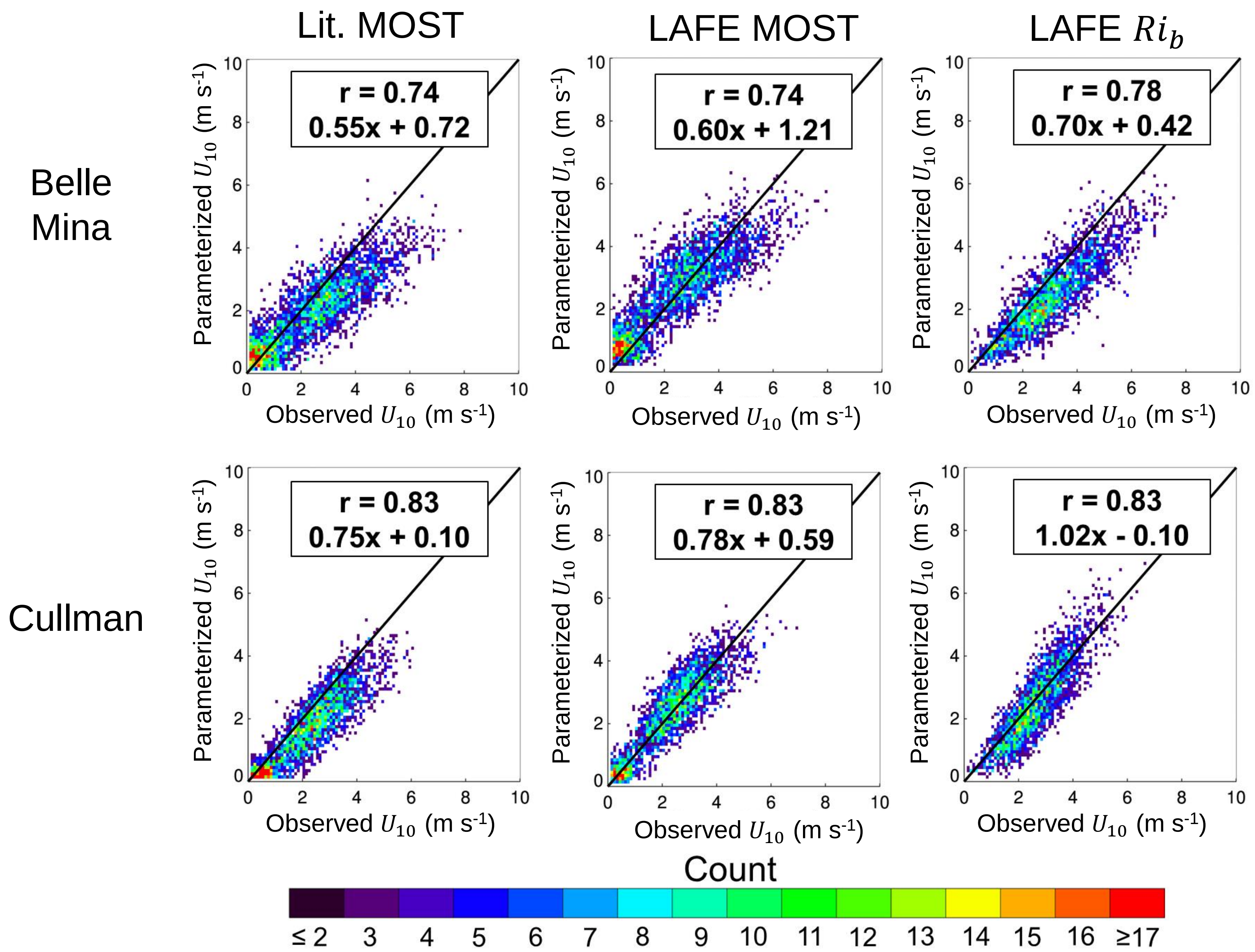
$$C_t = \frac{\theta_*}{(\theta_v - \theta_{vs})}$$

$$\Delta\theta = \frac{\theta_*}{C_t}$$

$$C_r = \frac{(-\overline{w'q'})_s}{u_*(q - q_s)}$$

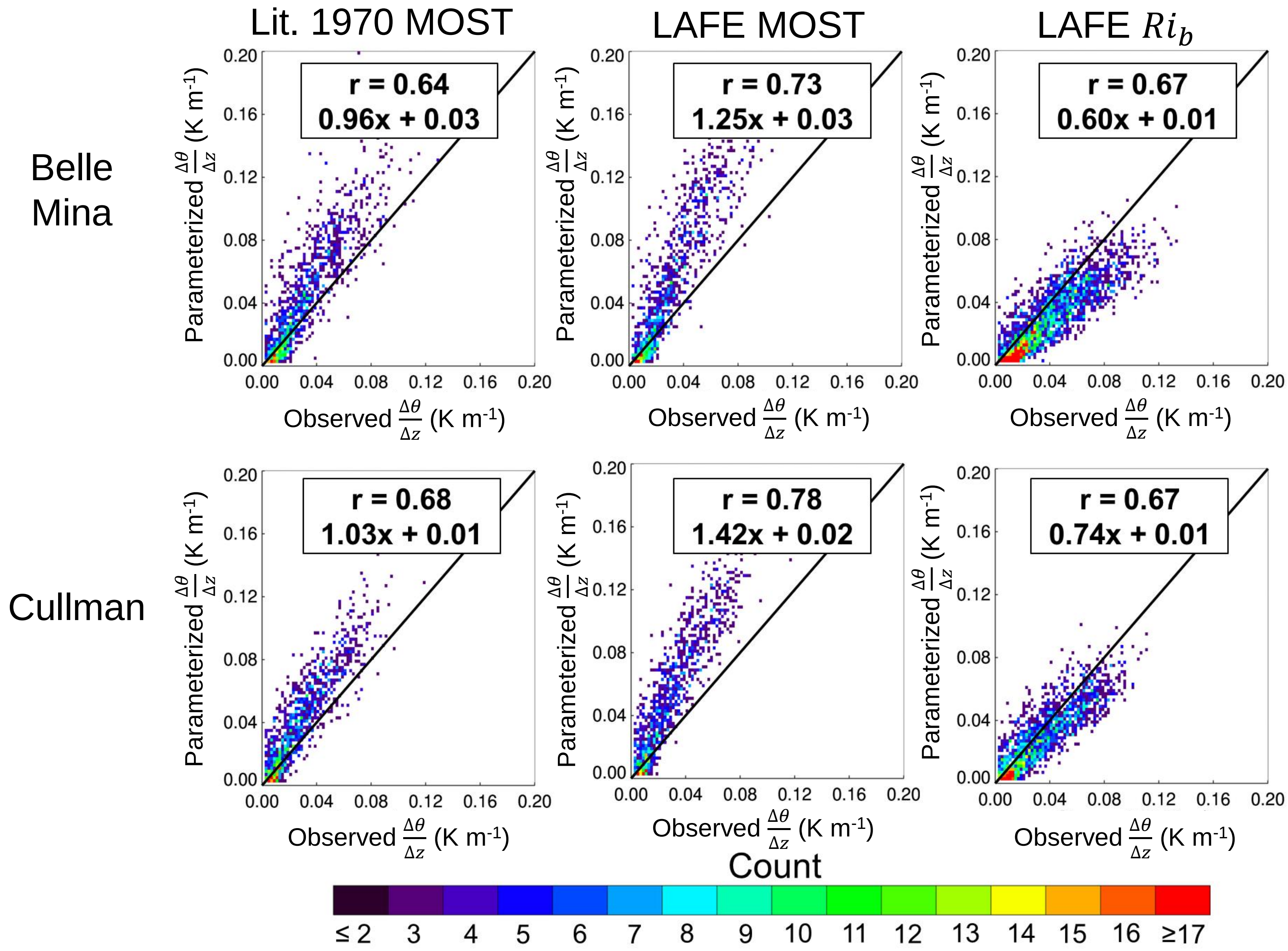
$$\Delta q = \frac{q_*}{C_r}$$

U_{10}



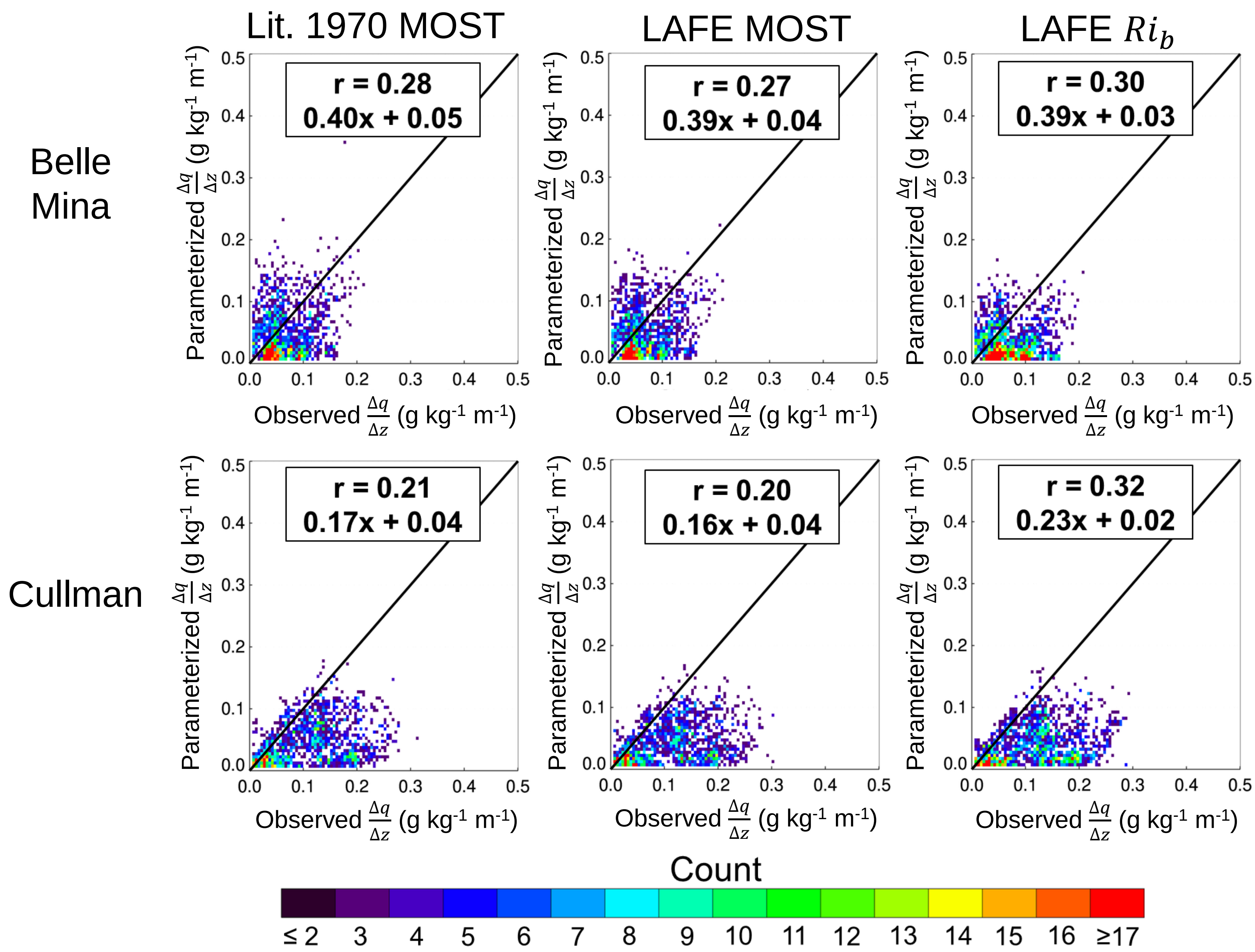
Lit. MOST
LAFE MOST
LAFE Ri_b
Belle Mina
Cullman
r = 0.74
0.55x + 0.72
r = 0.74
0.60x + 1.21
r = 0.78
0.70x + 0.42
r = 0.83
0.75x + 0.10
r = 0.83
0.78x + 0.59
r = 0.83
1.02x - 0.10
Parameterized U_{10} (m s^{-1})
Observed U_{10} (m s^{-1})
0 2 4 6 8 10
Count
≤ 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 ≥17

$\Delta\theta$



Lit. 1970 MOST
LAFE MOST
LAFE Ri_b
Belle Mina
Cullman
r = 0.64
0.96x + 0.03
r = 0.73
1.25x + 0.03
r = 0.67
0.60x + 0.01
r = 0.68
1.03x + 0.01
r = 0.78
1.42x + 0.02
r = 0.67
0.74x + 0.01
Parameterized $\frac{\Delta\theta}{\Delta z}$ (K m^{-1})
Observed $\frac{\Delta\theta}{\Delta z}$ (K m^{-1})
0.00
0.04
0.08
0.12
0.16
0.20
Count
≤ 2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
≥17

Δq

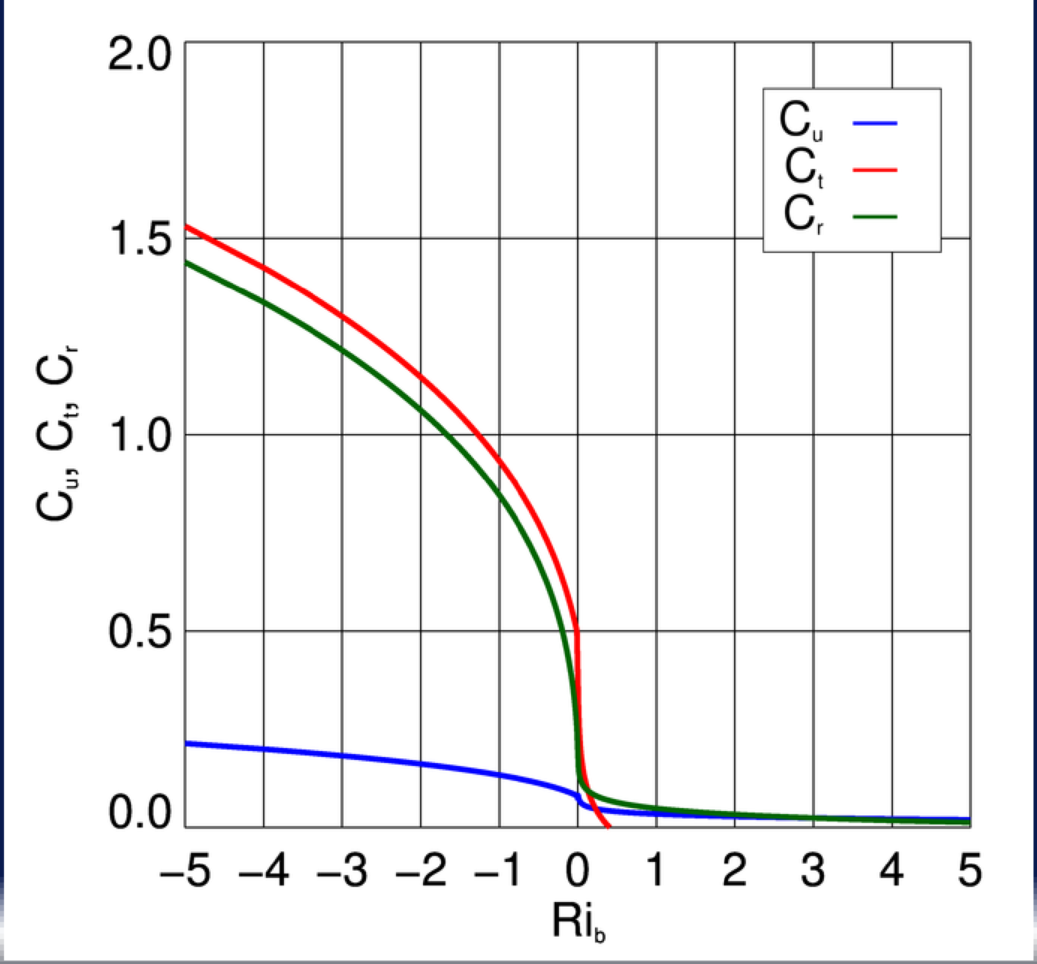


Lit. 1970 MOST
LAFE MOST
LAFE Ri_b
Belle Mina
Cullman
r = 0.28
0.40x + 0.05
r = 0.27
0.39x + 0.04
r = 0.30
0.39x + 0.03
r = 0.21
0.17x + 0.04
r = 0.20
0.16x + 0.04
r = 0.32
0.23x + 0.02
Parameterized $\frac{\Delta q}{\Delta z}$ (g kg^{-1} m^{-1})
Observed $\frac{\Delta q}{\Delta z}$ (g kg^{-1} m^{-1})
0.0 0.1 0.2 0.3 0.4 0.5
Count
≤ 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 ≥17

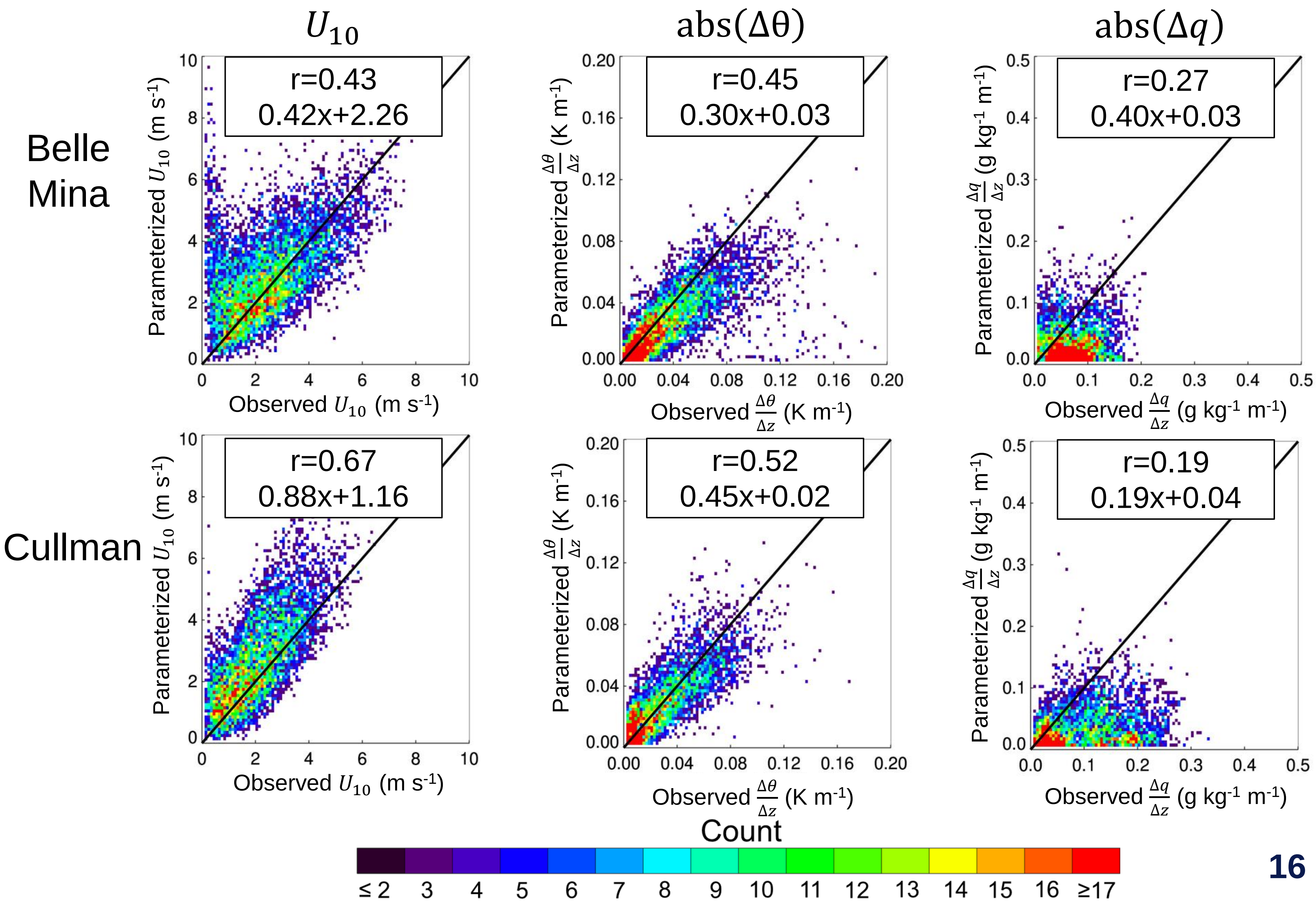
Ri_b Fits for Unstable and Stable Conditions

For $Ri_b > 0$

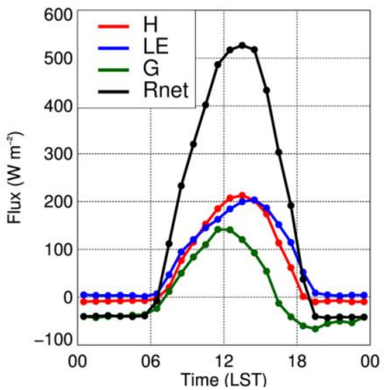
$$C_{u,t,r} = \alpha_{u,t,r} \ln(Ri_b) + \beta_{u,t,r}$$



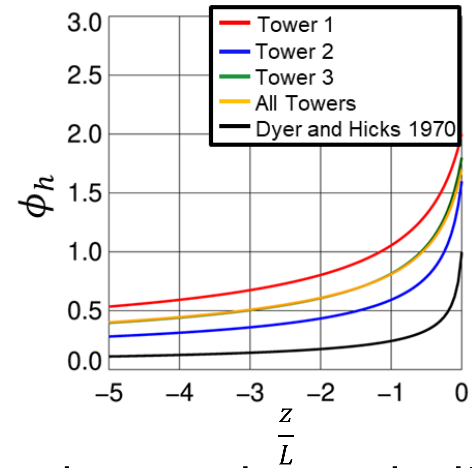
$U_{10}, \Delta\theta, \Delta q$ for $-5 < Ri_b < 5$



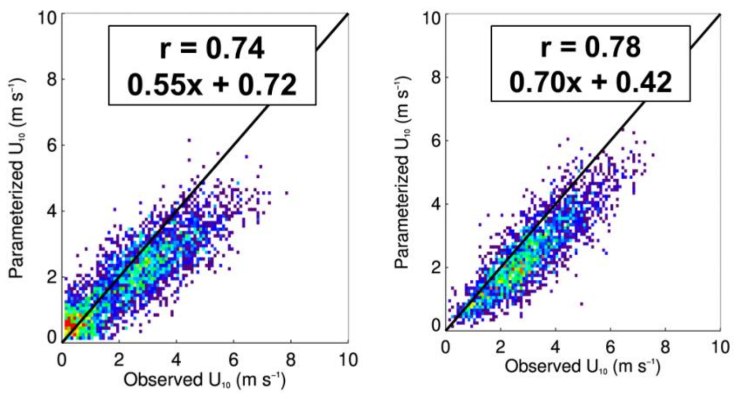
Summary and Outlook



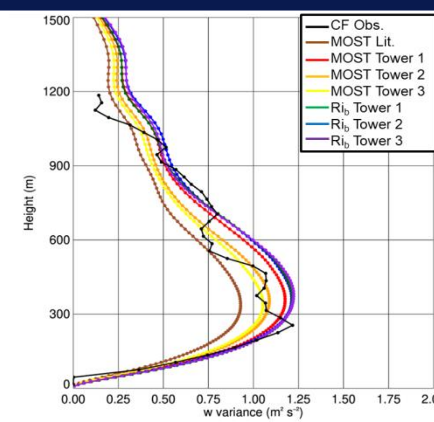
Flux tower measurements from LAFE used to evaluate MOST and Ri_b relationships



LAFE dataset shows significant departures from MOST



Ri_b relationships developed; showed better agreement with obs. based on independent dataset



Next step: incorporate Ri_b relationships into LES, HRRR

Preliminary results are encouraging