Coupling between radiative flux divergence and turbulence near the surface

Pierre Gentine, Gert-Jan Steeneveld, Bert Heusinkveld, Bert Holtslag

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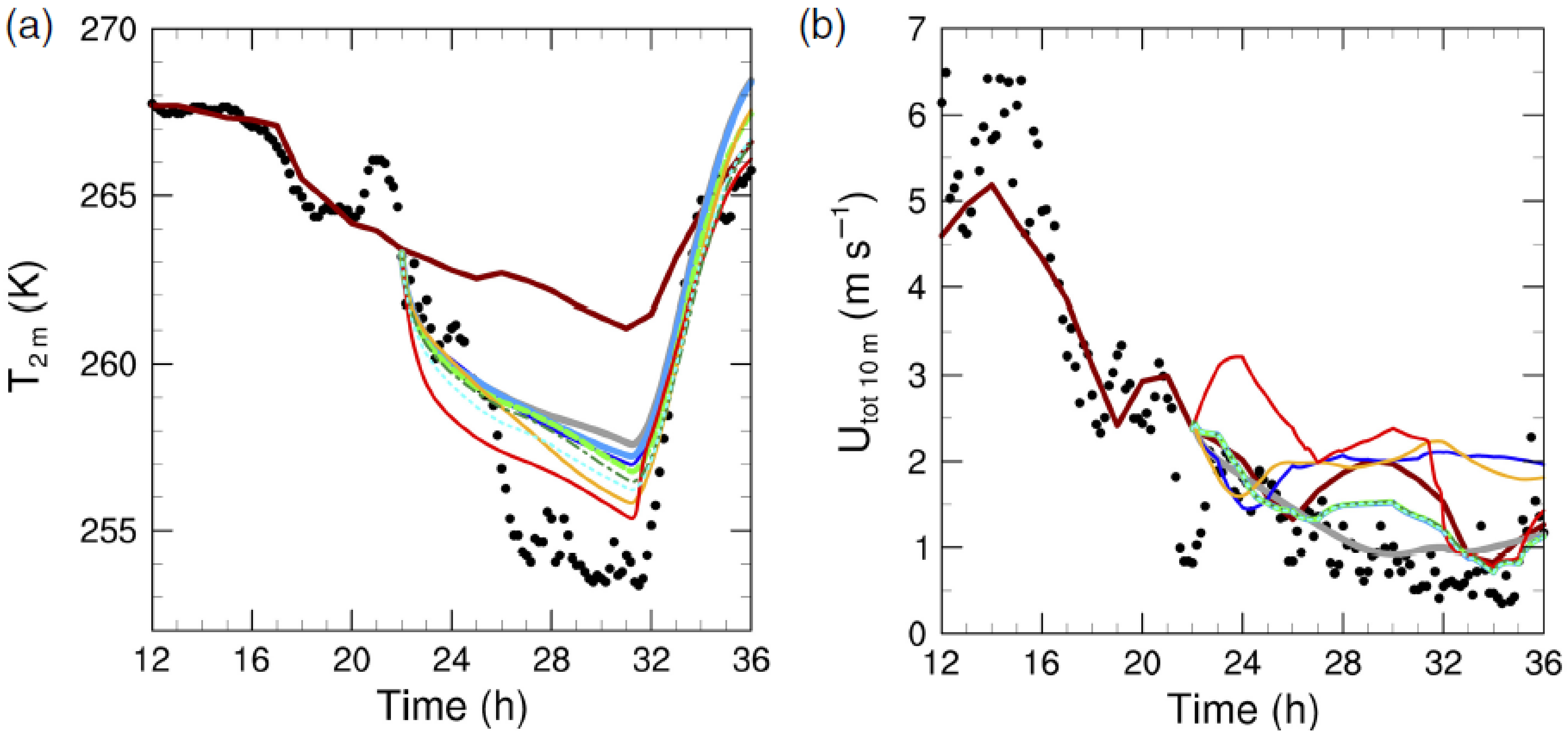
Motivation



WRF-1D for Cabauw case study over a snow surface (Sterk et al, 2015).

Motivation

$$\frac{\partial \theta}{\partial t} = -\frac{\partial w\theta}{\partial z} - \frac{\partial L_{net}}{\partial z}$$

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Questions

1. What is the relative contribution of longwave radiative cooling on the SBL?
2. Does radiation divergence affect turbulence spectra?
3. Does radiation divergence influence flux-profile relationships

Observational Campaign

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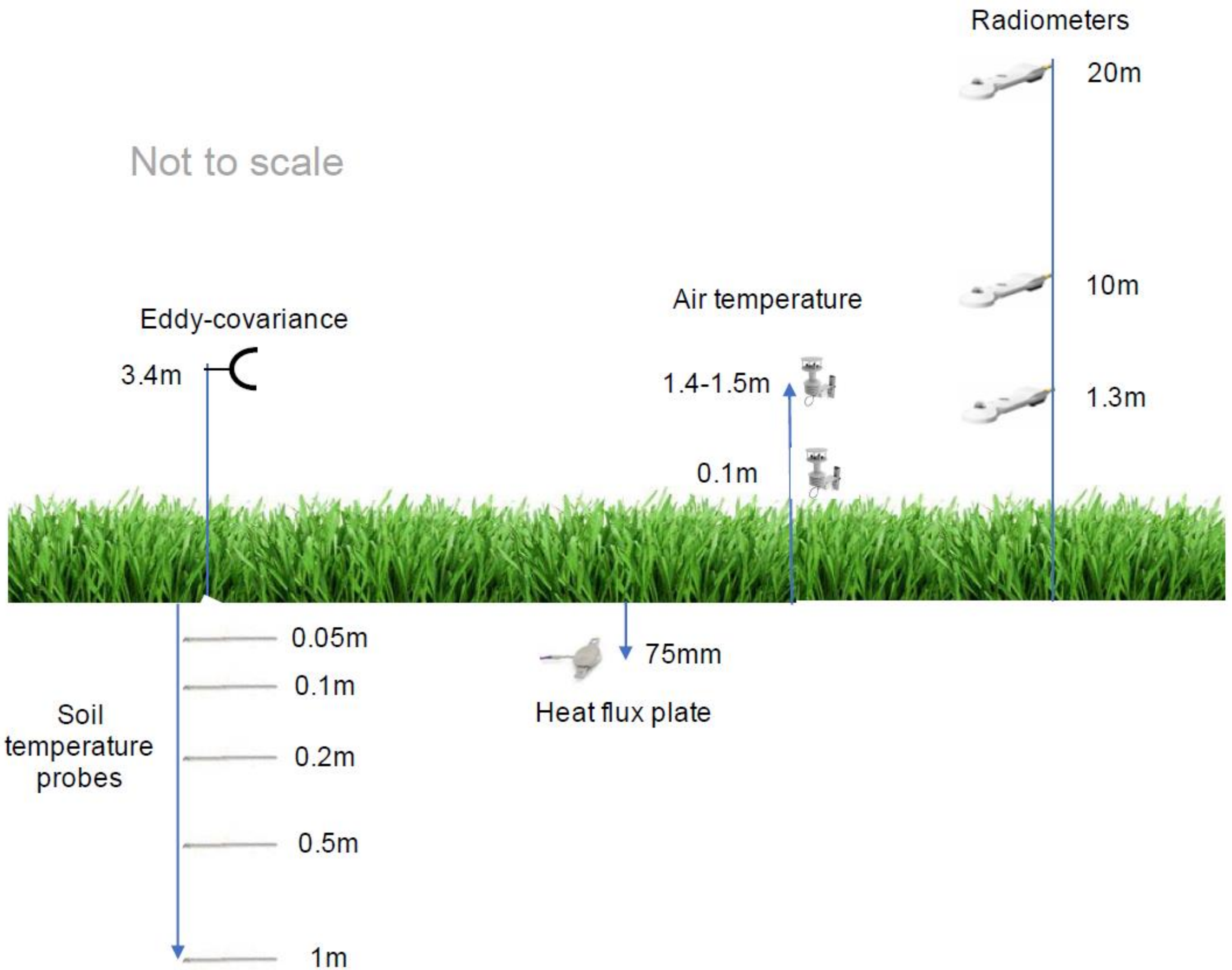
Observational Campaign



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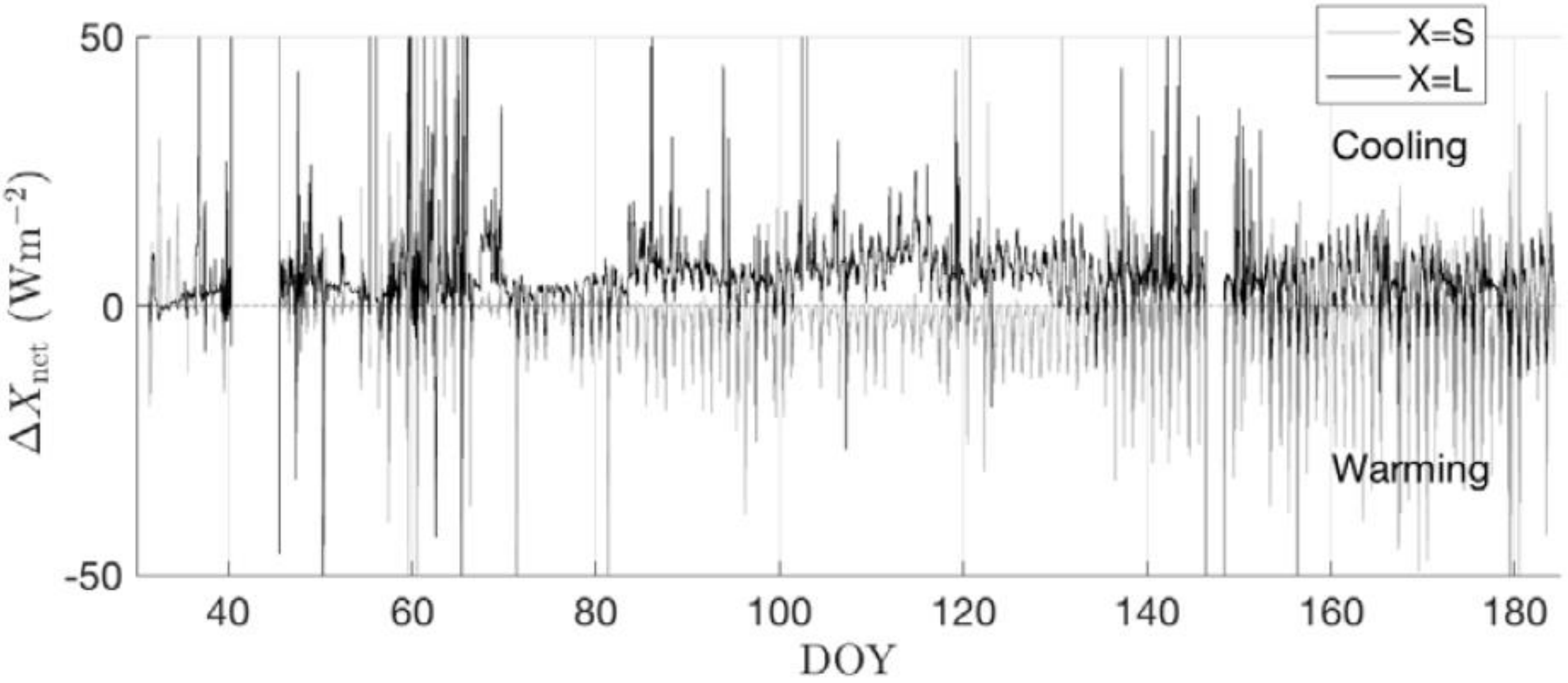
Results

Lnet(20m) – Lnet(1.3) m



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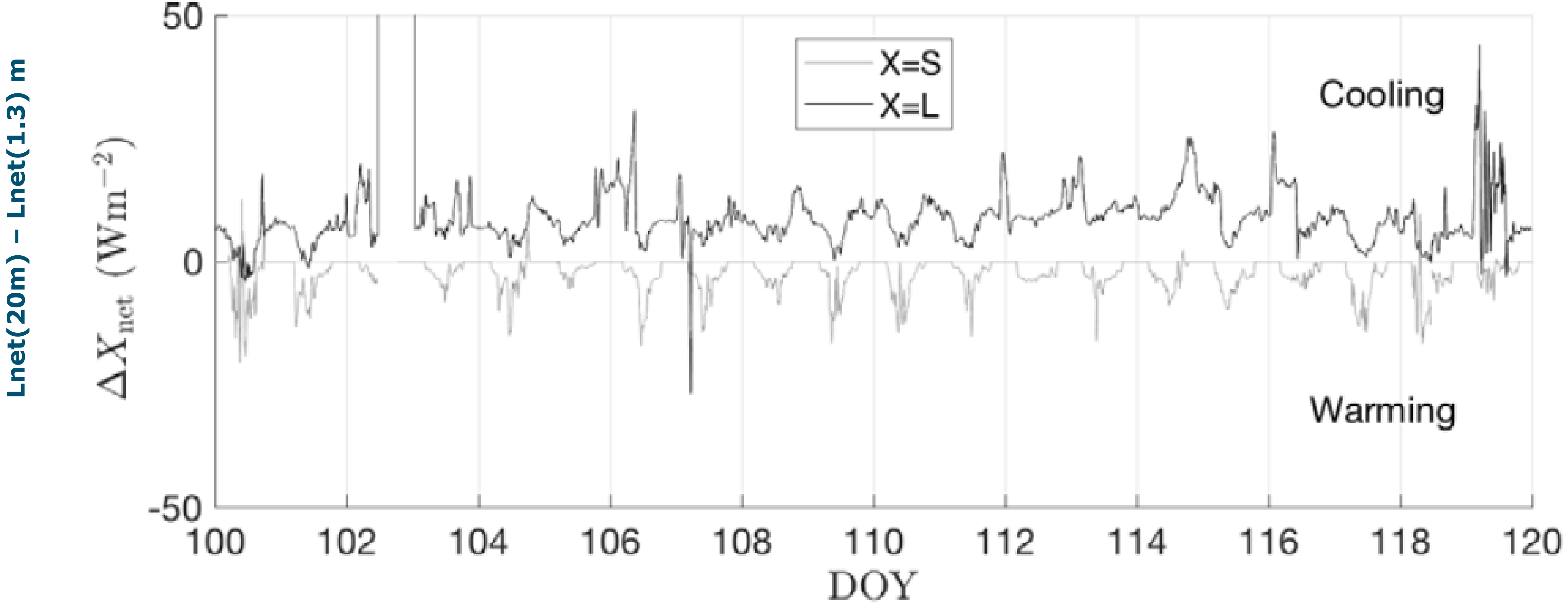
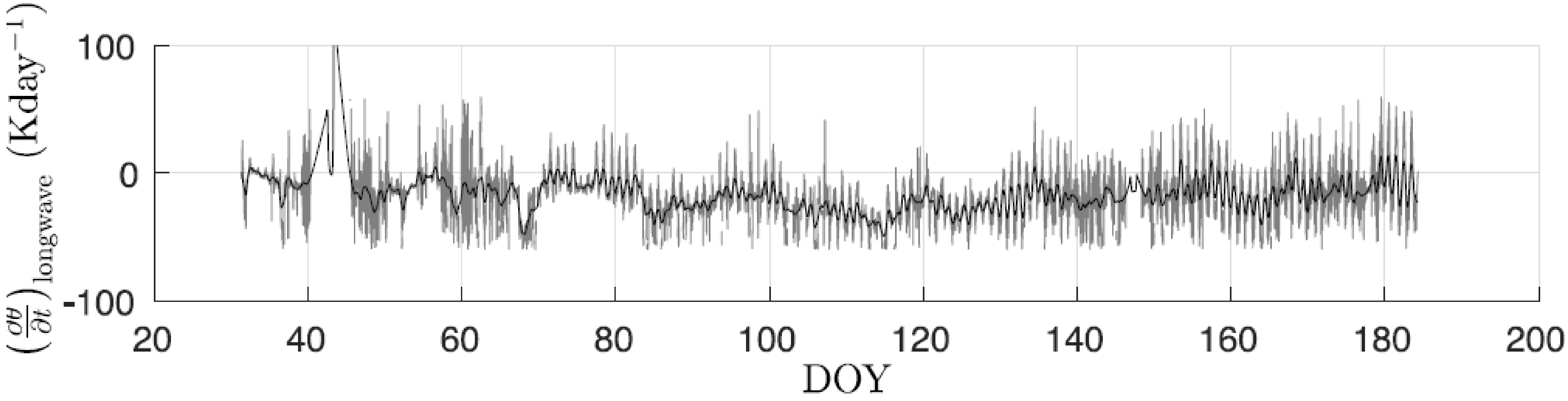
Results



Lnet(20m) – Lnet(1.3) m
50
0
-50
X=S
X=L
Cooling
Warming
100
102
104
106
108
110
112
114
116
118
120
DOY

Results



Longwave cooling rate 20-1.3 m. Clear sky troposphere order 1-2 K/day

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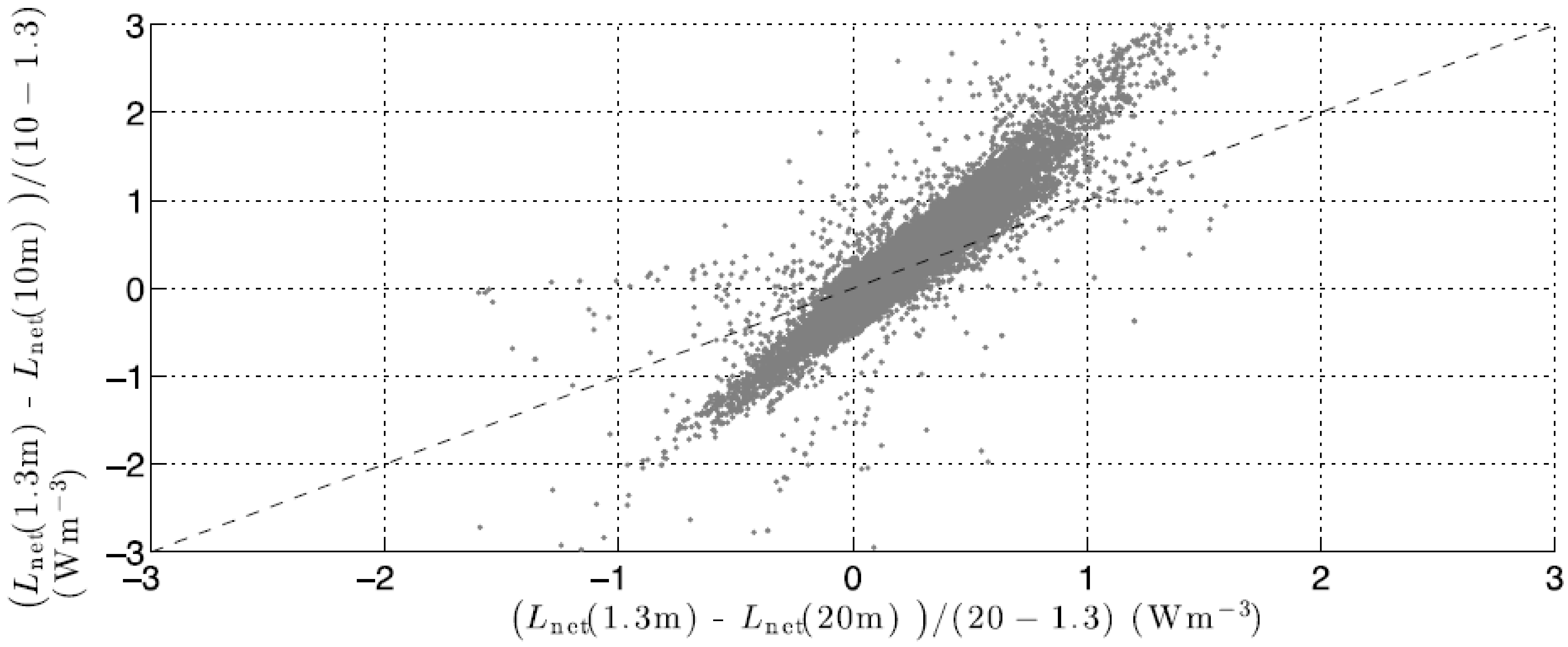
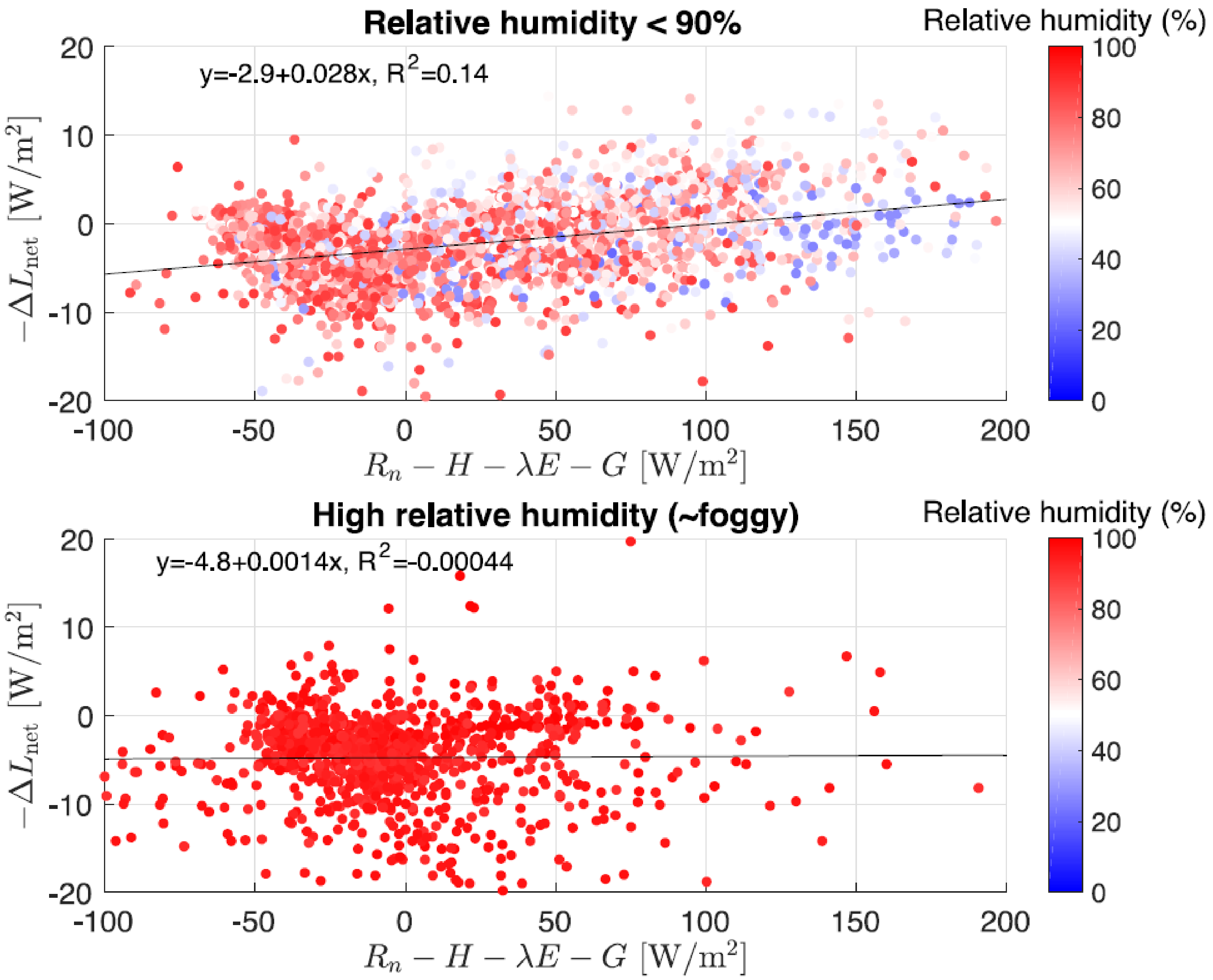
Results



Most divergence in 1.3-10 m layer

Energy budget closure

- Impact present
- Mainly during daytime
- No effect during fog



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Impact on spectra

$$\frac{\partial \overline{\theta'^2}}{\partial t} = -2\overline{w'\theta'}\frac{\partial \overline{\theta}}{\partial z} - \frac{\partial \overline{w'\theta'^2}}{\partial z} - \epsilon_{\theta,\theta} - \epsilon_R$$

$(\varepsilon_R / \varepsilon_{\theta,\theta})$

$$N_* = 16\sigma \overline{T}^3 / \left(\rho_0 C_p u_*\right)$$

N*> 0.2 -> spectra affected

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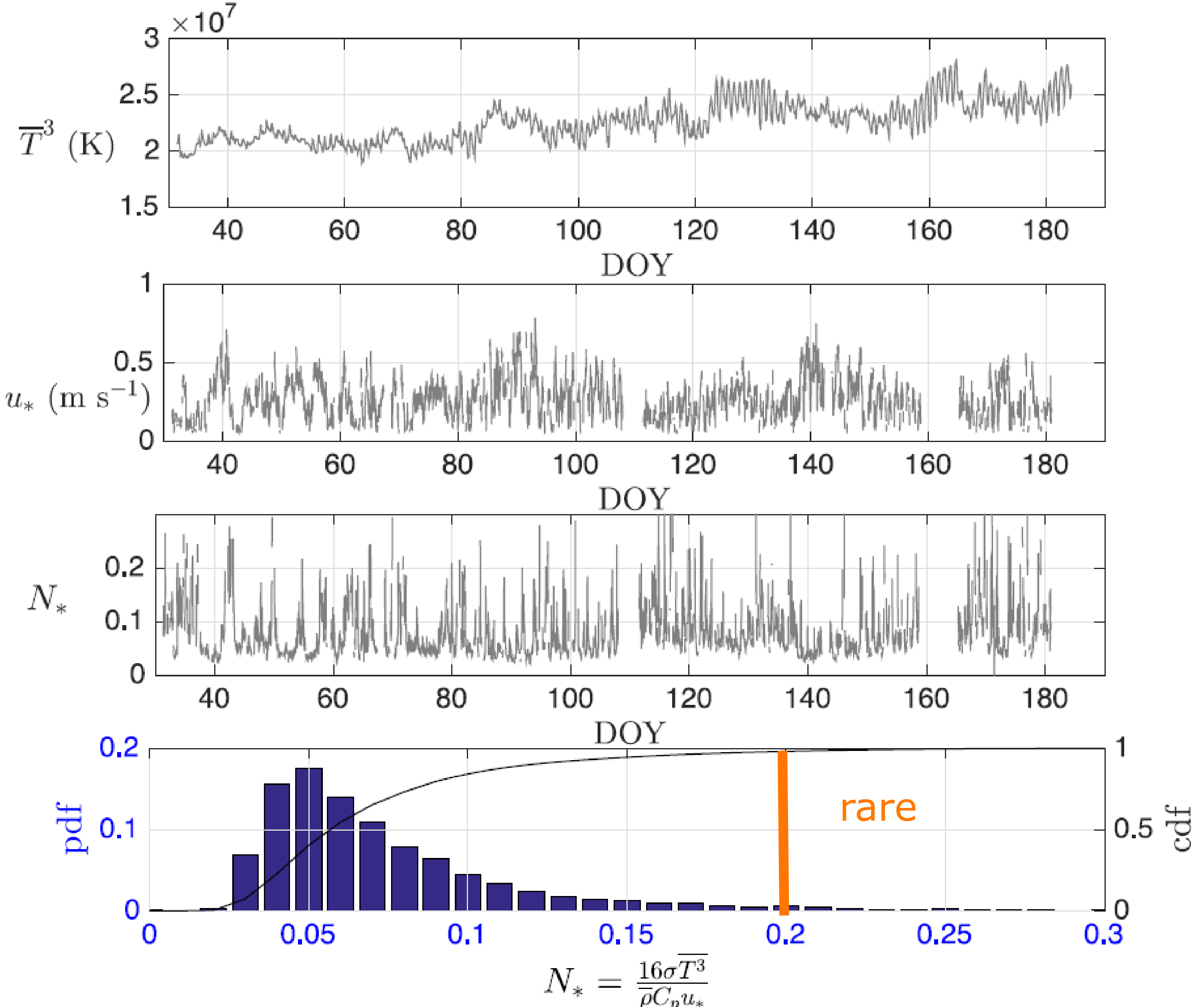

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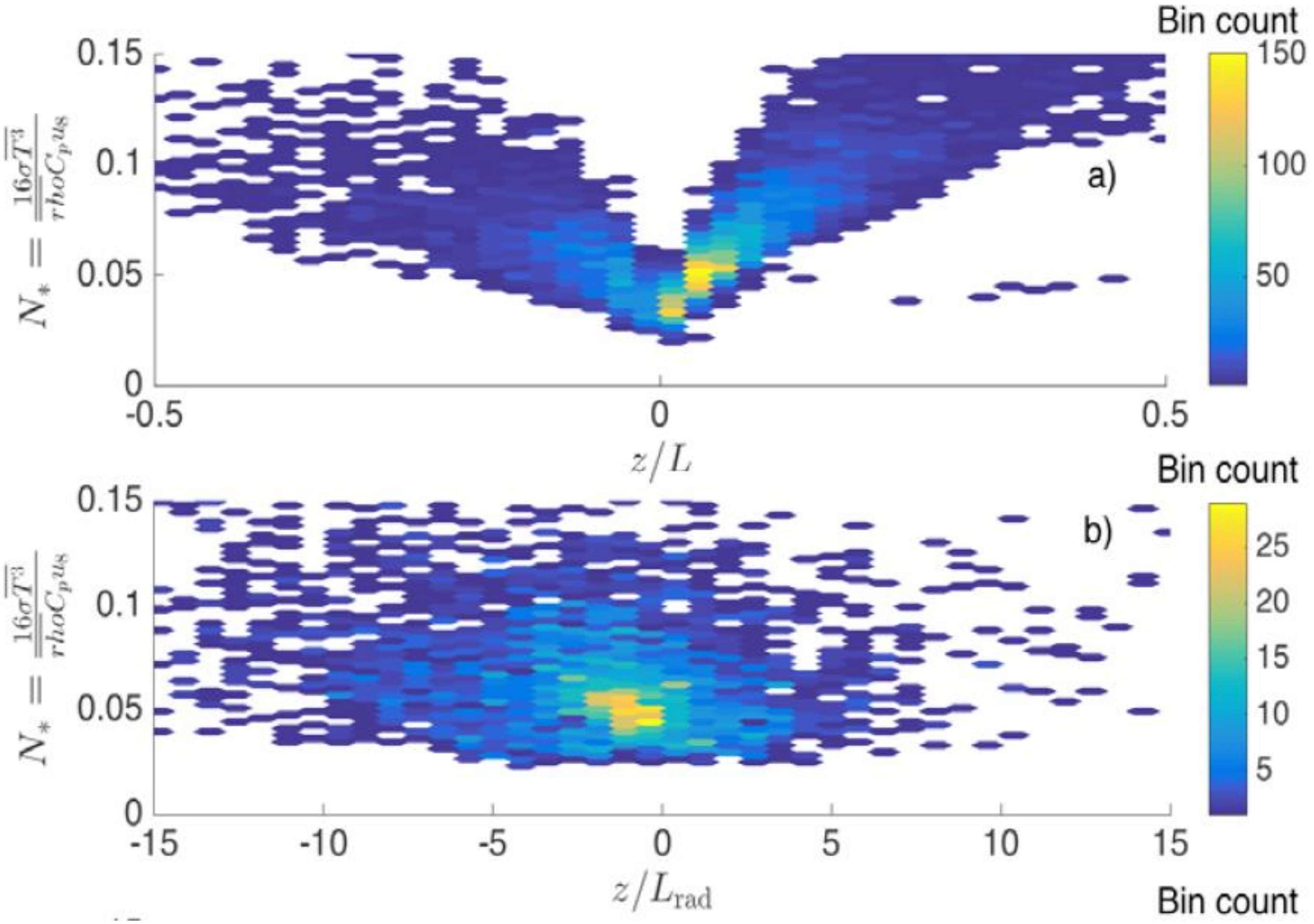
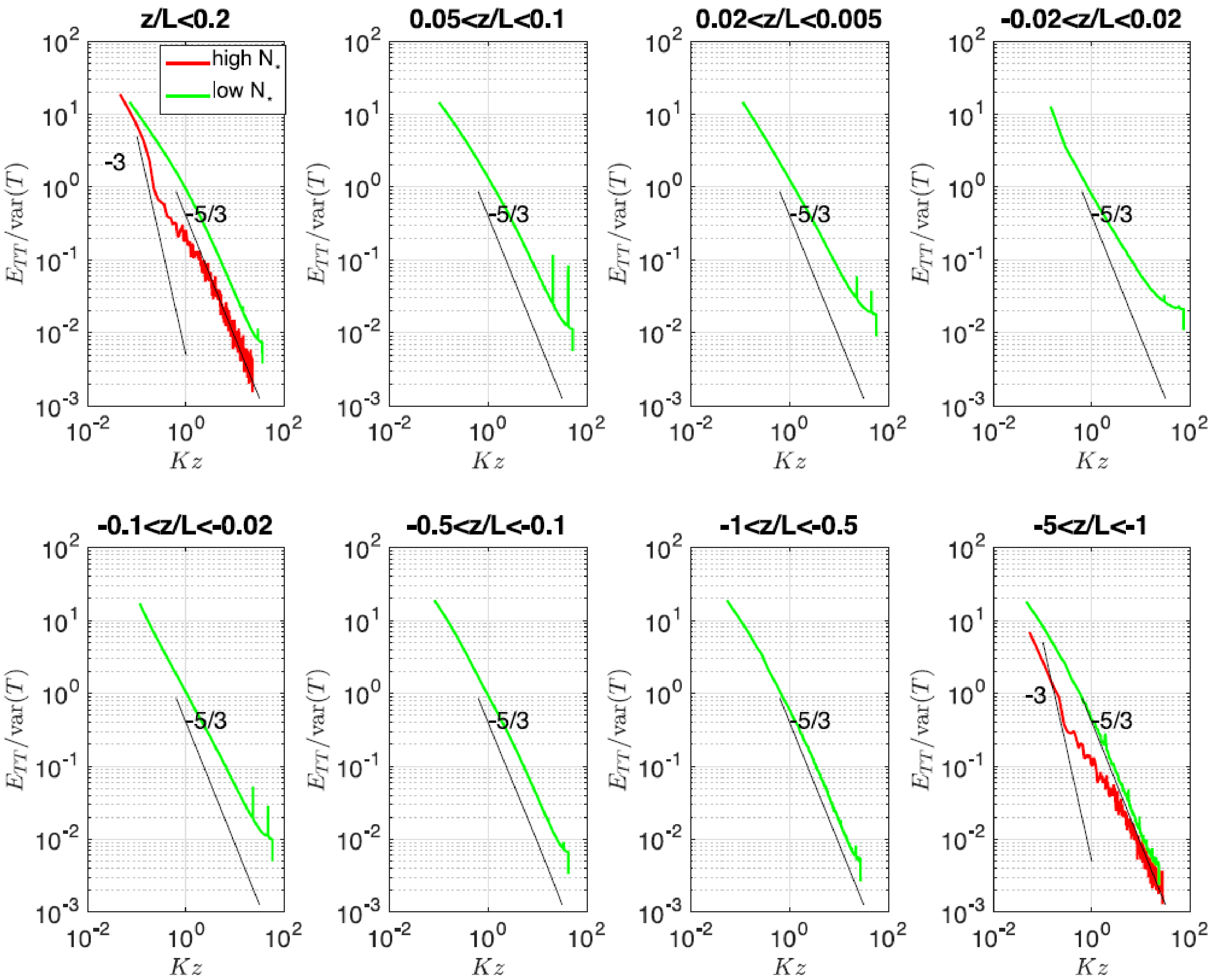
In search for correlations N* on temp budget and temp var

$$L_{\text{rad}} = \overline{\rho} C_p \overline{w'\theta'} / \left(-\partial L_{\text{net}} / \partial z\right)$$

No cor



Impact on spectra



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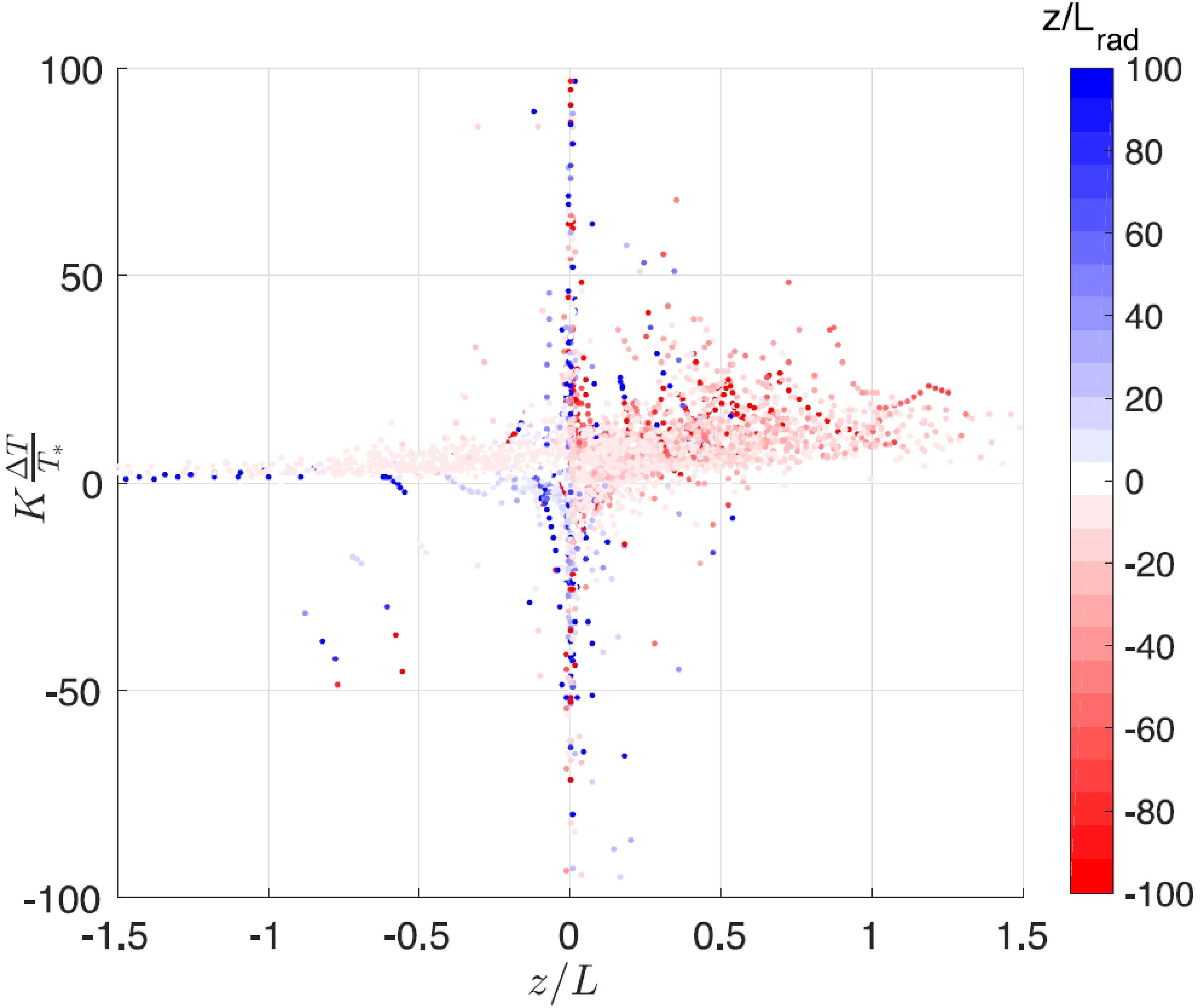
Coupling to between rad div and turbulence

We use

$$-\frac{Kzu_*}{\overline{w'\theta'}}\frac{\partial\overline{\theta}}{\partial z}=\phi_h\left(\frac{z}{L}\right)$$

But could it be:

$$-\frac{Kzu_*}{\overline{w'\theta'}}\frac{\partial\overline{\theta}}{\partial z}=\phi_h\left(\frac{z}{L},\frac{z}{L_{\mathrm{rad}}}\right).$$



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Some math ...

$$\frac{\partial\bar{\theta}}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{w'\theta'} + \frac{Rad}{\bar{\rho}C_p}\right)$$

$$\bar{\rho}C_p\overline{w'\theta'} + Rad = cst \ .$$

$$\bar{\rho}C_p u_*\theta_*(z) = \bar{\rho}C_p u_*\theta_*(0)\left(1 + \frac{1}{\bar{\rho}C_p u_*}\underbrace{\bar{\epsilon}(0 \to z)\pi\frac{dB}{dT}_{|T}\left(\frac{1}{K}\left(\ln\left(\frac{z}{z_{0,h}}\right) - \Psi_h(z/L) + \Psi_h(z_{0,h}/L)\right)\right)}_{\Delta L_{\uparrow}}\right)$$

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Some observational data

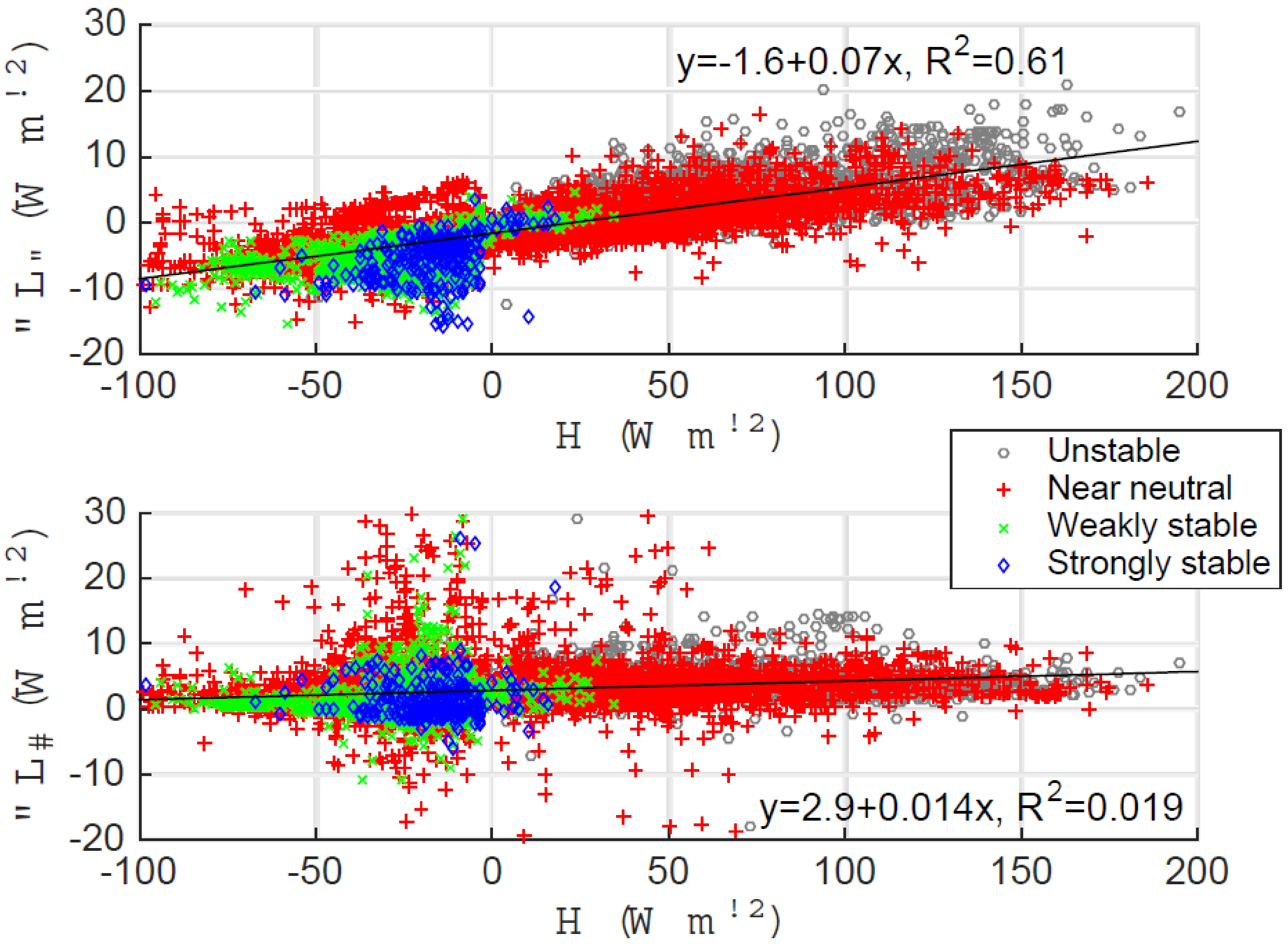

Figure 11: Longwave upward (top) and downward divergence (bottom) as a function of surface sensible heat flux in non-foggy conditions, defined as relative humidity less than 90%. Buoyancy effects of water vapor lead to non-zero cutoff between stable and unstable conditions in terms of sensible heat flux.

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Conclusions

- Radiation divergence is a substantial term in the near surface layer, not only at night but throughout the course of the day.
- Mostly present in the lower 10m of the surface layer, and daily-mean temperature tendencies by longwave radiation divergence of -10 to -20 K/day are typical
- Sensible heat flux and longwave divergence are strongly coupled, through changes in the surface layer profiles.

Gentine, P. , Steeneveld, G. , Heusinkveld, B. G. and Holtslag, A. A. (2018), Coupling between radiative flux divergence and turbulence near the surface. Q J R Meteorol Soc. In press . doi:10.1002/qj.3333

Conclusions

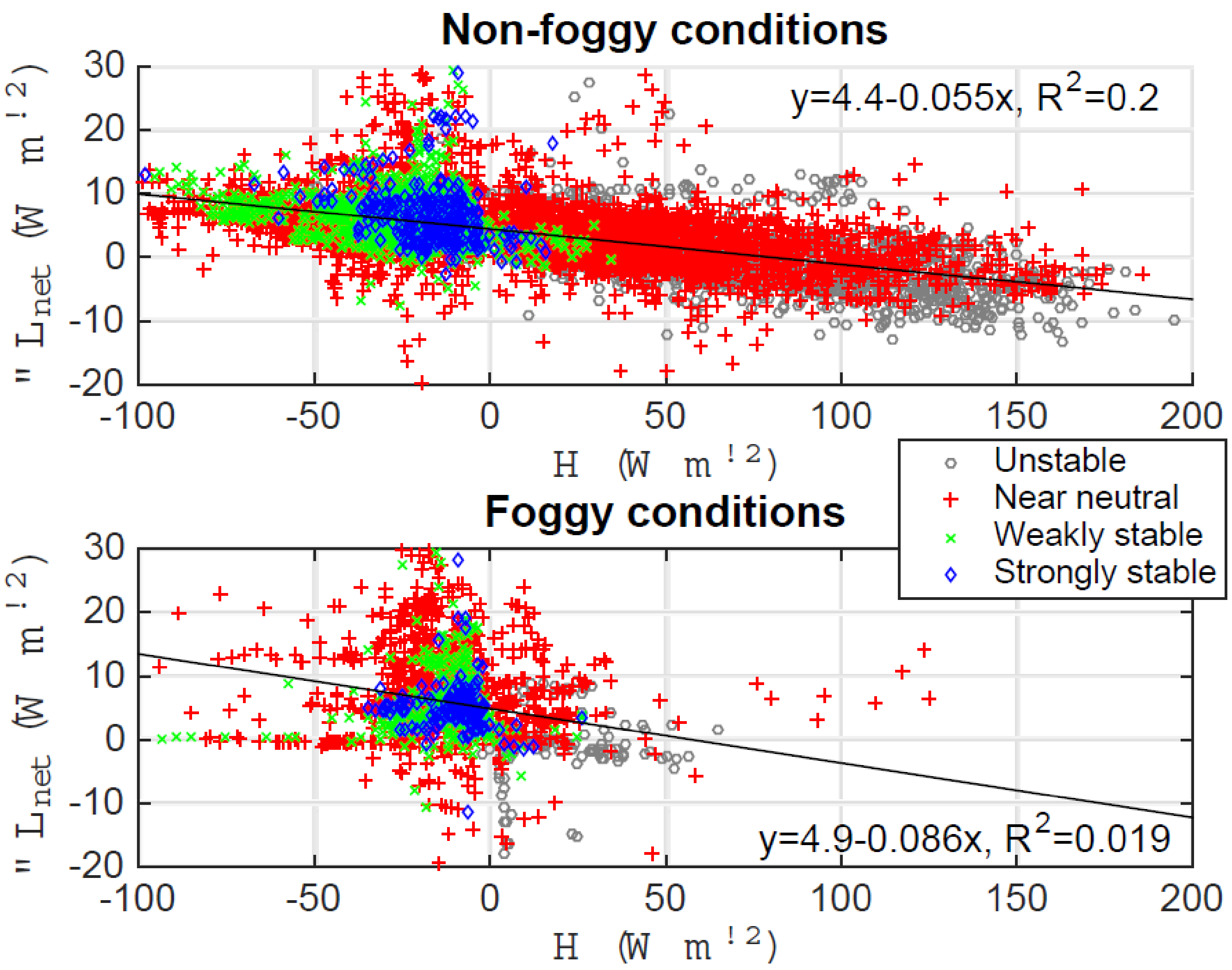

Figure 10: Dependence of longwave radiative cooling ΔL_{net} on sensible heat flux in non-foggy (top) and foggy conditions, defined as relative humidity above 90% (bottom). Buoyancy effects of water vapor lead to non-zero cutoff between stable and unstable conditions in terms of sensible heat flux.

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