

# Long-term observations of vertical velocity spectra in a convective mixed layer: Dependence on land-surface forcing

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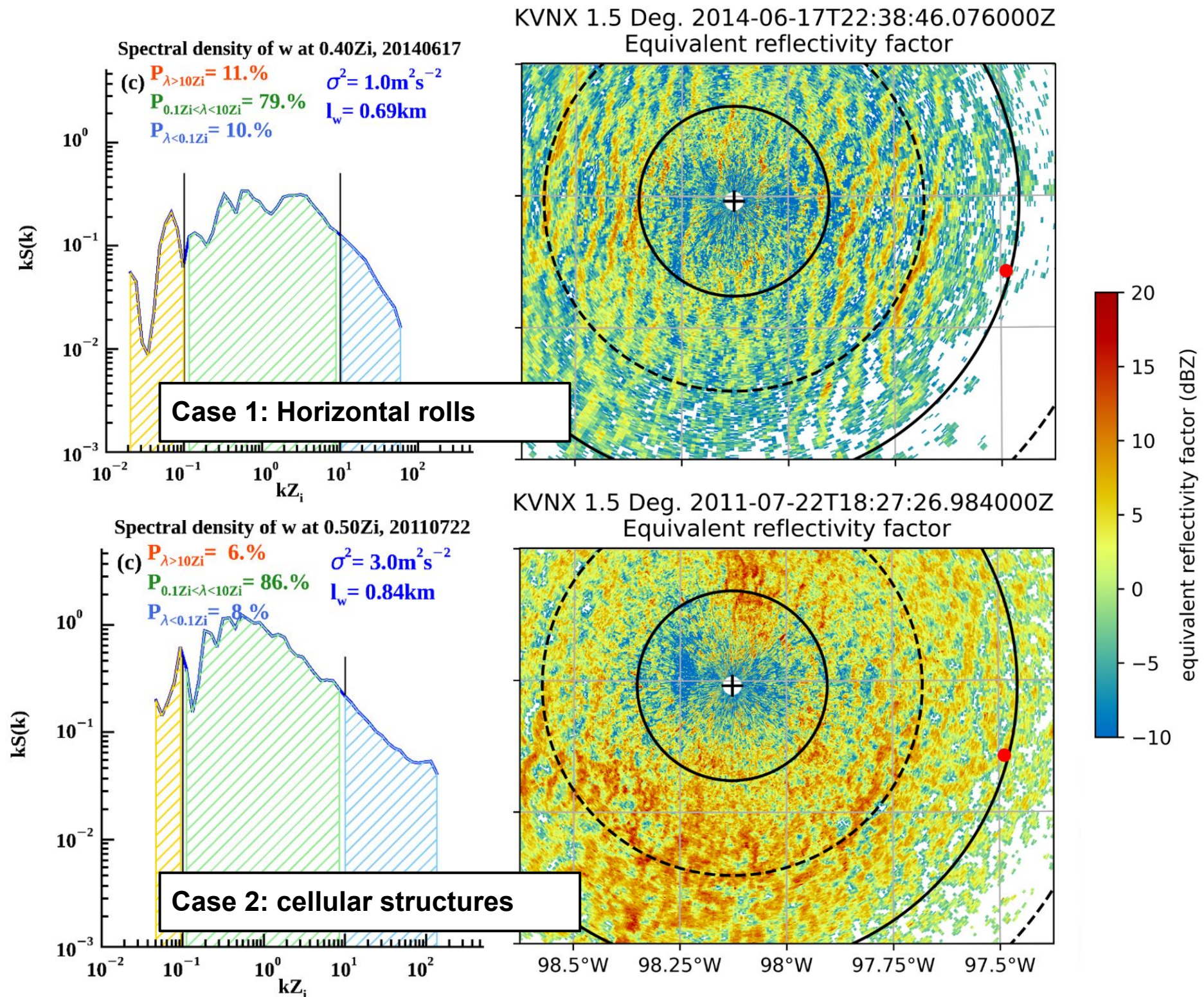
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## Motivation:

- Boundary layer clouds may be sensitive to land surface forcing due to its effects on updraft size (i.e., turbulence scale).
- ARM Doppler lidar vertical velocity retrievals were analyzed for the scale and structure of mixed-layer turbulence over a 7-year period, on fair-weather warm season days (442 cases) in the U.S. Southern Great Plains.
- Spectral analyses were performed to quantify effects of surface forcing (sensible heat flux, friction velocity, and evaporative fraction) on turbulence scale.

Individual case studies showed evidence of organization into horizontal rolls and cellular structures. Cellular cases tended to have sharper spectral peaks, and occurred on drier days having higher sensible heat flux.

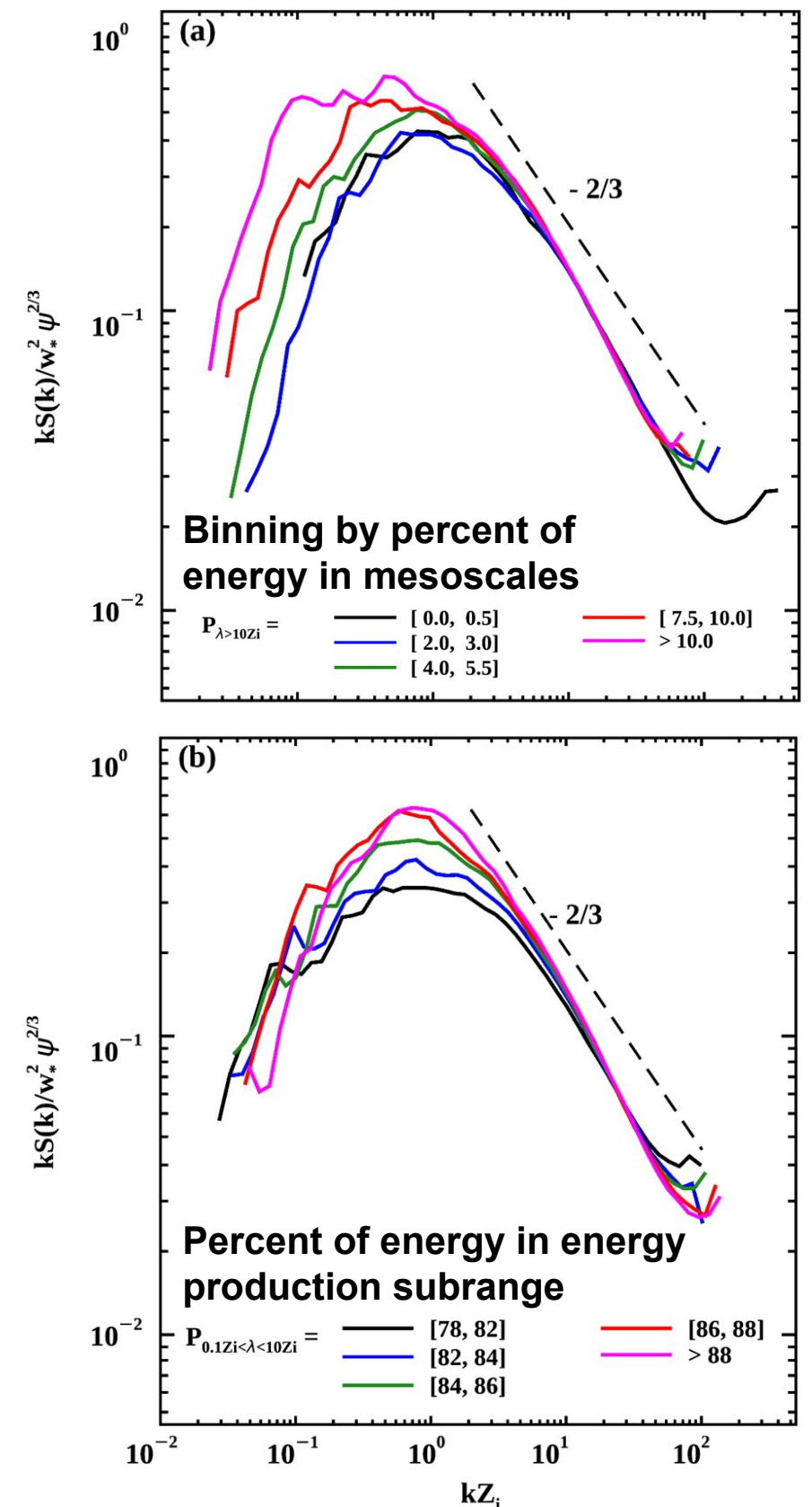
Figures: ARM Doppler lidar spectral density and corresponding radar reflectivity (clear air, boundary layer) for two case study days (late morning to afternoon). (top) Roll structures (with some cellular features) on June 17, 2014 at 22:38 UTC (16:38 Local Time), and (bottom) cellular structures on July 22, 2011.



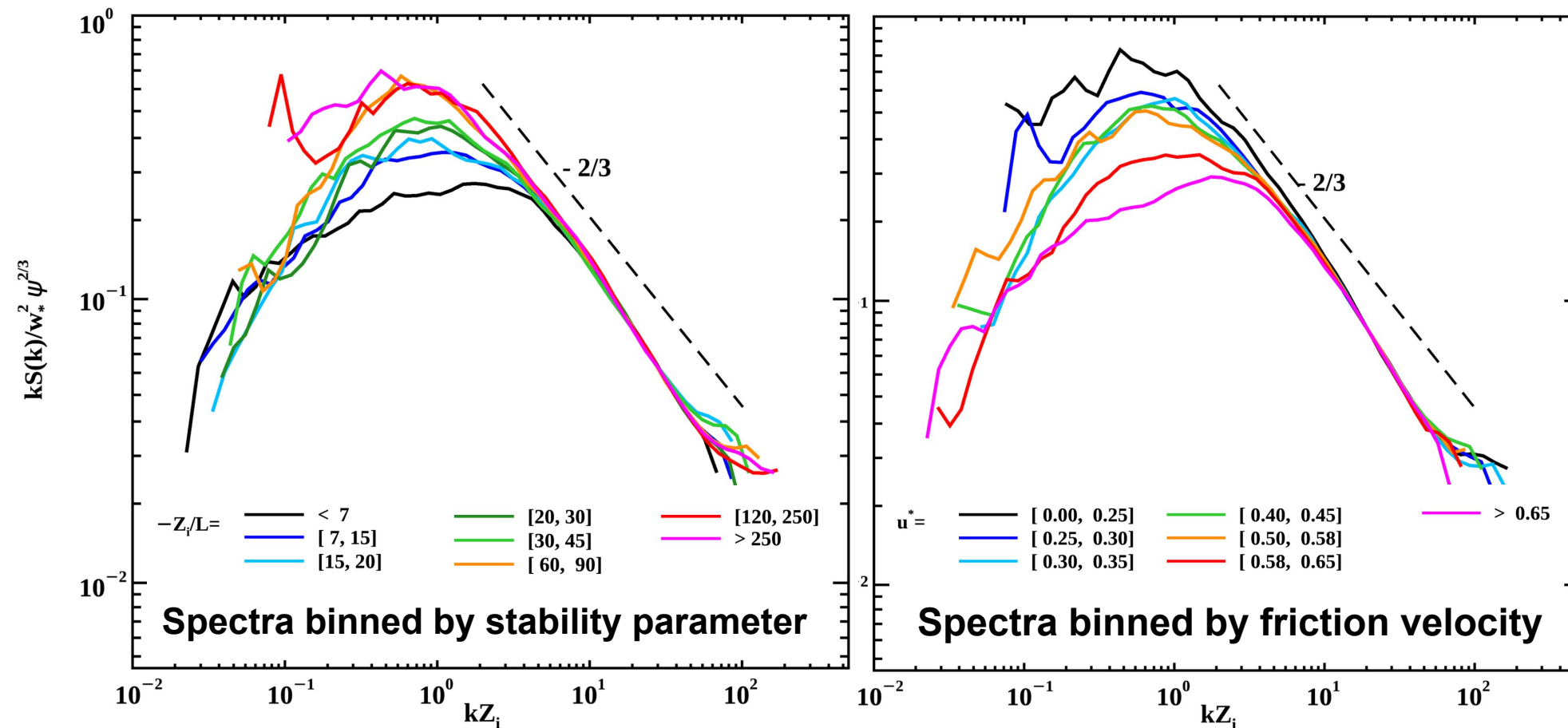
- Earlier studies found no systematic relationship between stability parameter ( $-Z_i/L$ ) and length scale in the unstable regime.
- We first asked if there is any systematic variation in turbulence scale, by averaging spectra binned by energy portion at the largest scale (mesoscale).
- We found substantial variations in spectral density in the mesoscale (nearly an order of magnitude), and the energy production subrange.

Figure: Normalized Doppler lidar spectra at 0.5 Zi binned by percentages of energy content (P) at the (a) mesoscale and (b) energy production subranges. Colors represent energy portion bin values defined at the top of the figure. The black dashed line is Kolmogorov's (-2/3) slope for the inertial subrange. There were approximately 46-64 case days per bin.

$Z_i$  = Mixed layer depth;  $L$  = Obukhov length



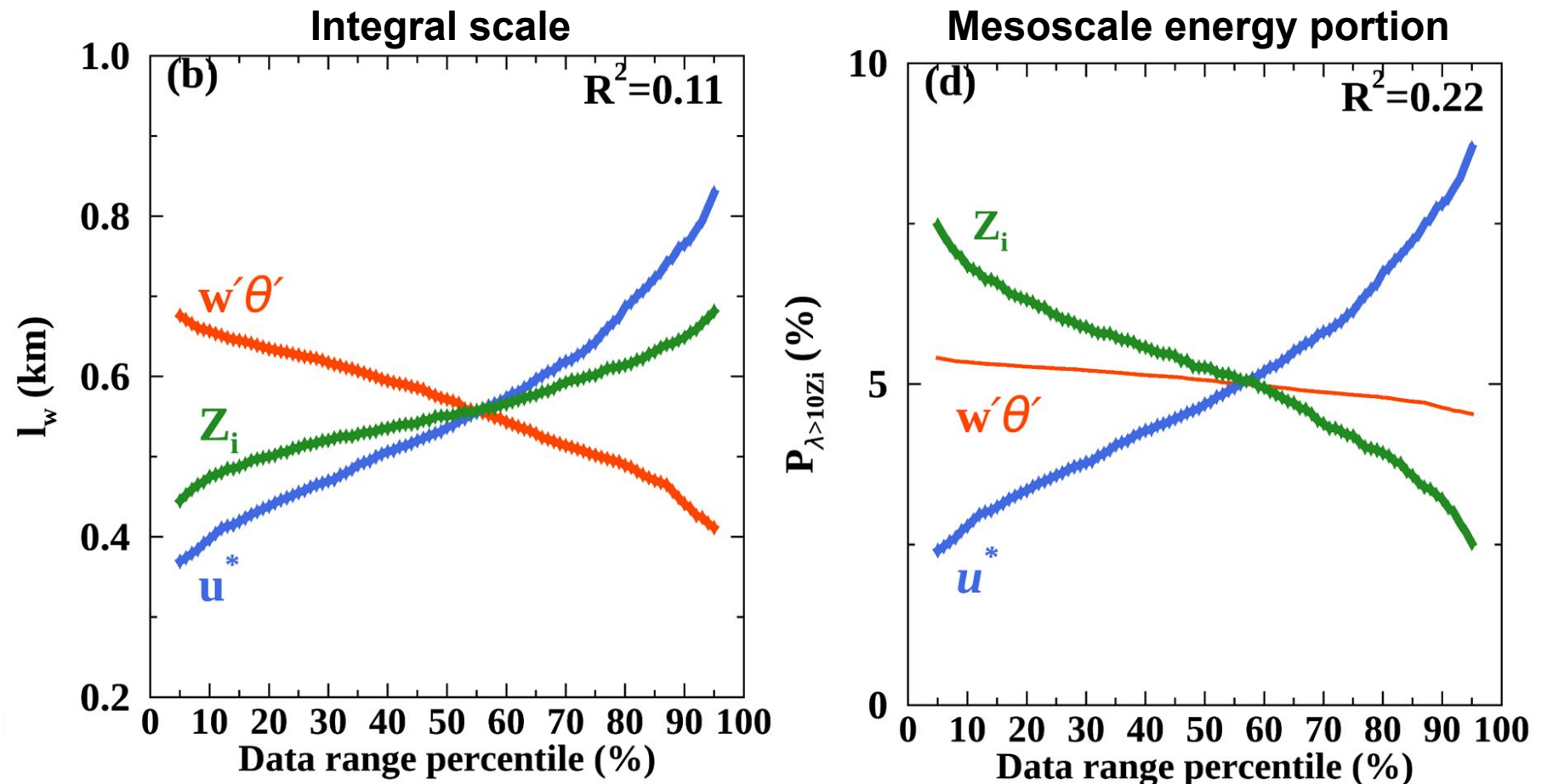
- To explore the connection to surface forcing, spectra were further binned by stability parameter and friction velocity ( $u_*$ ).
- Surface friction velocity can explain part of the large variation in the mesoscale subrange that is not captured by the stability parameter.



Figures: Doppler lidar spectra at 0.5  $Z_i$  binned by (left panel) stability parameter and (right panel) friction velocity ( $u_*$ ). Spectral peaks shift toward larger scales as friction velocity decreases. However, *relatively* more energy is partitioned to the larger scales as friction velocity increases; this can be seen by the larger decrease in spectral density with increasing  $u_*$  near the peak in the spectra, especially for higher friction velocities.

- Multilinear regression suggests that updrafts increase in intensity but decrease in width (according to integral scale) with increasing sensible heat flux.
- When analyzed separately of  $u_*$ , in a univariate regression (not shown in figure here), the relationship between integral scale and sensible heat flux is weakly positive, indicating that surface effects on updraft width are multivariate.
- The portion of energy in the largest scales increases with  $u_*$  and decreases with  $Z_i$ . The results further suggest an influence of  $u_*$  (or wind shear) at the largest scales.

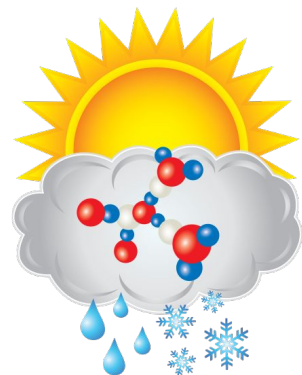
Figure: Predicted change in (left panel) integral scale and (right panel) mesoscale energy portion, obtained by varying each predictor from its lower 5<sup>th</sup> percentile to upper 95<sup>th</sup> percentile using the multi-linear regression model. Thick lines indicate significant predictors ( $p < 0.05$ ).



# Summary and acknowledgments

- Turbulence spectra show wide variation in energy content in energy-production and mesoscale regimes relevant to boundary layer clouds
- The portion of energy in the largest scales varies with surface friction velocity, implying shear instability in secondary circulations.
- Friction velocity (shear) masks the role of surface sensible heat flux in transitions of turbulence structure from intense narrow updrafts to roll and wave-like structures.

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