Raw Ingredients for Evaluating and Improving Turbulence Parameterizations

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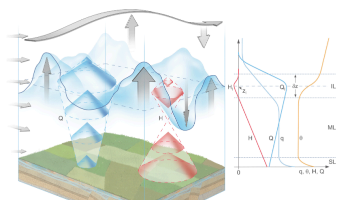
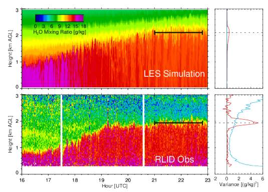
(1) Background

- Turbulence redistributes heat, momentum, and moisture in the boundary layer
- Subgrid scale in most models and needs to be parameterized in CRMs/GCMs
- Accurate representation of the fluxes of heat and moisture at the top of convective boundary layer (also called interfacial layer – IL) is critical
- Do LES models accurately capture structure of turbulence in CBL and fluxes at IL?





The high-resolution water vapor mixing ratio (q) data from a LES model run (top) compared with the observed q from the Raman lidar (bottom) at the ARM SGP site. The LES used the ARM-observed surface fluxes at the bottom, and RUC forcing at the boundaries (both to initialize and to nudge the mean fields during the simulation). Note the markedly smaller q variance in the IL.

(2) Scaling Relationships

- LES output used to derive different scaling relationships between variables predicted by most models with those that need to be parameterized
- Many studies have investigated relationships between higher order moments and fluxes with water vapor and temperature gradients
- Do observations support these relationships?

Scaling Variables S_x

$$S_w = w_*$$
$$S_L = \frac{w_*}{N_I}$$
$$S_\theta = S_L \gamma_I = w_* \frac{\gamma_I}{N_I}$$
$$S_q = S_L g_I = w_* \frac{g_I}{N_I},$$

$$Ri_I = \frac{N_I^2}{s_I^2}, \quad s_I^2 = \left(\frac{dU}{dz}\Big|_I\right)^2 + \left(\frac{dV}{dz}\Big|_I\right)^2$$

γ_I: Gradient in temperature at IL; g_I: Gradient in moisture at IL; N_I: Brunt Vaisala frequency

Second Order Moment Predictors at the IL

$$\overline{w'^2}_I = C_{w^2} S_w^2 f_{w^2}(Ri_I) = C_{w^2} w_*^2 f_{w^2}(Ri_I)$$
$$\overline{\theta'^2}_I = C_{\theta^2} S_\theta^2 f_{\theta^2}(Ri_I) = C_{\theta^2} w_*^2 \left(\frac{\gamma_I}{N_I}\right)^2 f_{\theta^2}(Ri_I)$$
$$\overline{q'^2}_I = C_{q^2} S_q^2 f_{q^2}(Ri_I) = C_{q^2} w_*^2 \left(\frac{g_I}{N_I}\right)^2 f_{q^2}(Ri_I).$$

Sensible and Latent Heat Flux Predictors at the IL

$$H_I = -C_H S_w S_\theta f_H(Ri_I) = -C_H w_*^2 \frac{\gamma_I}{N_I} f_H(Ri_I)$$
$$Q_I = -C_Q S_w S_\theta f_Q(Ri_I) = -C_Q w_*^2 \frac{g_I}{N_I} f_Q(Ri_I)$$

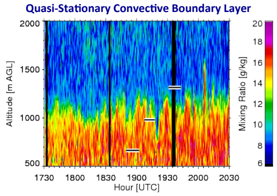
Unknown Function of Richardson Number R_i

$$f_{q^2}(Ri_I) = \frac{1}{C_{q^2}} \frac{\overline{q'^2}_I}{w_*^2 \left(\frac{g_I}{N_I}\right)^2}.$$

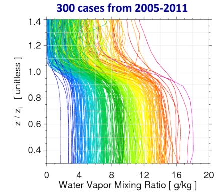
(3) Lidar Observations

- Raman lidar (RLID), high-spectral-resolution lidar (HSRL), and Doppler lidar have the temporal resolution, stability, and noise performance to look at higher order moments
- ARM dataset provides long time-series for analysis; currently data from the SGP have been (partially) analyzed

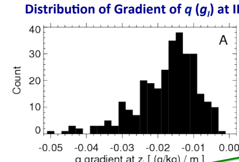
Identify the Cases from RLID
Quasi-Stationary Convective Boundary Layer



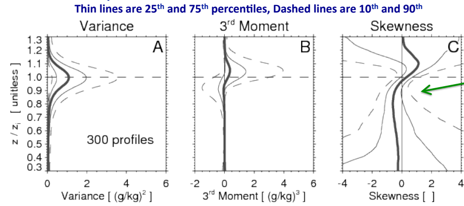
Mean q Profiles from the RLID
300 cases from 2005-2011



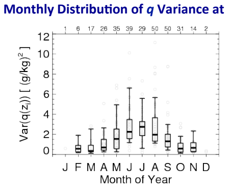
Distribution of Gradient of q (g_I) at IL



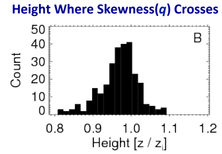
Median q Variance, 3rd Moment, and Skewness Profiles from RLID
Thin lines are 25th and 75th percentiles, Dashed lines are 10th and 90th



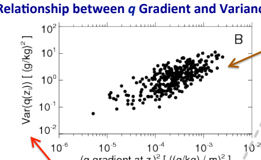
Monthly Distribution of q Variance at IL



Height Where Skewness(q) Crosses Zero



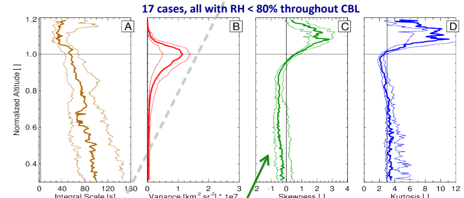
Relationship between q Gradient and Variance at IL



$$\overline{q'^2}_I = C_{q^2} w_*^2 \left(\frac{g_I}{N_I}\right)^2 f_{q^2}(Ri_I).$$

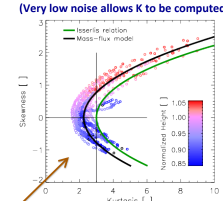
We can compute N_I

HSRL Aerosol Backscatter Dataset in Norman, OK in 2012
17 cases, all with RH < 80% throughout CBL

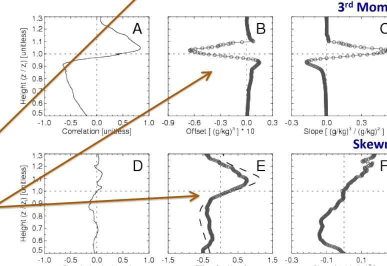


Skewness profile in HSRL aerosol backscatter very similar to skewness profile or RLID q (i.e., negative in CBL, crosses zero at ~0.95 z_i)

HSRL Skewness vs. Kurtosis at IL
(Very low noise allows K to be computed)



Relationships between RLID q Variance at IL and Profiles of:



- Able to predict q variance at IL from q gradient (and other variables)
- Relationship between skewness and kurtosis around IL is well defined
- Able to predict shape/magnitude of the 3rd moment and skewness profile from the q variance at IL
- Does LES output match these properties? Why not?

Take Home Point: The long-term high-resolution ARM lidar data sets are illuminating properties of the turbulent convective boundary layer that need to be represented by numerical models.

References:

1. Wulfmeyer, V., A. Behrendt, Z. Sorbjan, D.D. Turner, and R.M. Hardesty, 2015: **Determination of convective boundary layer entrainment fluxes, dissipation rates, and the molecular destruction of variances: Theoretical description and a strategy for its confirmation with a novel lidar system synergy**. *J. Atmos. Sci.*, submitted.
2. McNicholas, C., and D.D. Turner, 2014: **Characterizing the convective boundary layer turbulence with a high spectral resolution lidar**. *J. Geophys. Res.*, **119**, 12910-12927, doi:10.1002/2014JD021867.
3. Turner, D.D., V. Wulfmeyer, L.K. Berg, and J.H. Schween, 2014: **Water vapor turbulence profiles in stationary continental convective mixed layers**. *J. Geophys. Res.*, **119**, 11151-11165, doi:10.1002/2014JD022202.
4. Turner, D.D., R.A. Ferrare, V. Wulfmeyer, and A.J. Scarino, 2014: **Aircraft evaluation of ground-based Raman lidar water vapor turbulence profiles in convective mixed layers**. *J. Atmos. Oceanic Technol.*, **31**, 1078-1088, doi:10.1175/JTECH-D-13-00075-1.

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