Characterizing turbulence in the CBL using ARM observations and LES

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Introduction

- The water vapor and vertical variances in the entrainment zone have been hypothesized to depend on two distinct functions
- We tested these hypotheses both observationally and numerically using a Large eddy simulation (LES) modeling
- The cases were identified from 2016 during which the convective boundary layer (CBL) is quasi-stationary and well mixed for at least 2 hours
- We simulated the CBL using an LES model for the selected cases at the SGP site and derived the variances to test the similarity functions.
- The coefficients that are used in defining the functions are determined observationally
- By simulating many days of dry CBL, we can generate a typical diurnal cycle profile of the higher order moments

1 - Variance scaling - Theory

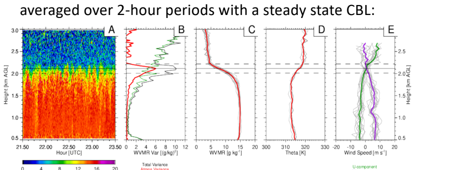
- Following Sorbjan (2004, '05, 06):

$$\overline{q_l'^2} = C_{q^2} S_q^2 f_{q^2}(R_I) = C_{q^2} w_*^2 \left(\frac{g_I}{N_I}\right)^2 f_{q^2}(R_I)$$

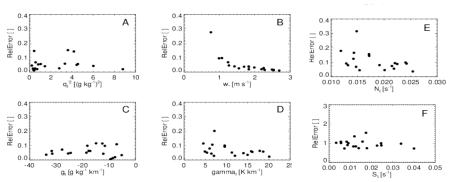
- With C a fitting constant, *g* the water vapor gradient, *N* the Brunt-Vaisala Frequency, and f some function of Richardson number
- Since *f(Ri)* is the only unknown in the top equation, we can now diagnose it from observations and LES
- We use Raman Lidar for atmospheric humidity and stability; the surface energy balance closes our observations

2 - Data overview

- Raman Lidar data is used for a range of days in 2016, and averaged over 2-hour periods with a steady state CBL:

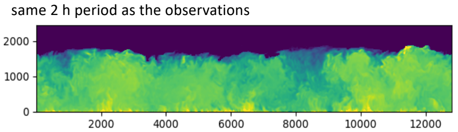


- Relative uncertainties are reasonably low, except perhaps for wind shear



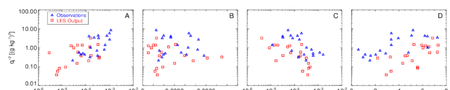
3 - MicroHH LES Simulations

- 22 Large Eddy simulations were performed using MicroHH (*van Heerwaarden et al, 2018)* for the same dates as used for the observations
- Boundary and initial conditions were retrieved using variational analysis (*Xie et al, 2004)*
- Standard runs at 10m resolution and 12.8km domain
- Simulations start at 6am LT and end at 7pm LT
- Additional simulations were run at 5m, 25m, and 50m resolution to test resolution independence
- Variances etc were calculated spatially, and then averaged over the same 2 h period as the observations



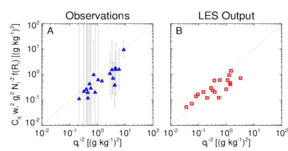
4 - Observed variance scaling

- The humidity variance seems to mostly correlate with the



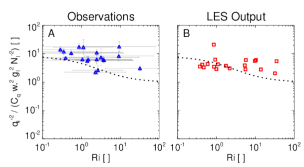
- For the most part, Observations and LES agree well
- We see a good match between Sorbjans form for *f(Ri)* and true variance:

$$f_{q^2}(R_I) = \frac{1+{}^{c_r}/_{R_I}}{1+{}^{1}/_{R_I}}$$

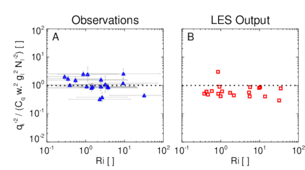


6 - Fitting (and ridding) of *f(Ri)*

- While the fit of Sorbjan shows reasonable agreement with our results (with Cq= 0.08):



- A recalibration of Cq to 0.55 shows little dependence of *f(Ri)* on the Richardson number:



Conclusions and Outlook

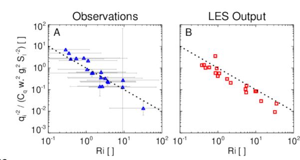
- Similar results from OBS and LES
- No significant scaling of humidity variance with shear was observed, both in OBS and LES
- Follow up study will include systematic shear experiments in LES
- Skewness in temperature shows double peak, consistently across many days
- Shape can be recreated with Bottom-up/Top-down scalars

5 – Shear Dependency

- The humidity variance could be equally well described as a function of Shear:

$$\overline{q_l'^2} = C_{q^2} w_*^2 \left(\frac{g_I}{S_I}\right)^2 f_{q^2}(R_I)$$

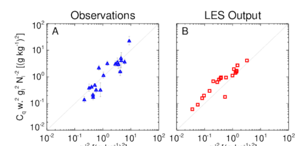
We now observe an inverse linear function for *f(Ri)*:



- As a result, the humidity variance is independent of shear:

$$\overline{q_l'^2} = C_{q^2} w_*^2 \left(\frac{g_I}{S_I}\right)^2 c\, R_I^{-1} = C'_{q^2} w_*^2 \left(\frac{g_I}{S_I}\right)^2 \frac{S_I^2}{N_I^2} = C'_{q^2} w_*^2 \left(\frac{g_I}{N_I}\right)^2$$

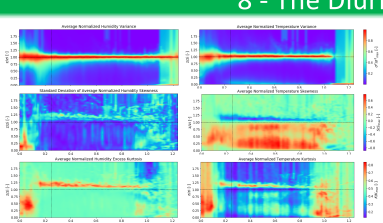
- With a good match between predicted and true variance:



7 - Bottom up/top down scalars

- We can capture the behavior of any CBL quantity with two diffuse scalars (Wyngaard and Brost, 1984)
- For the first time, we look at higher order moments in , we can capture the behavior of any well CBL quantity
- The *n*-th moment of scalar χ is equal to:
  - $\chi^n = \sum \binom{n}{m} a^m b^{n-m} \phi^n \psi^{n-m}$
  - With *a* and *b* fitting coefficients, easily derived from the surface and entrainment flux
- With scalar ϕ representing surface processes, and scalar ψ representing entrainment, we can attribute features to either process.

8 - The Diurnal Cycle of higher moments



- We average the moments after normalization with boundary layer height and solar time of day
- We find distinct patterns in the each of the moments
- The third moment of temperature shows a double peak
- We can mimic the shape of this peak well with the passive scalars