Validating Variance Similarity Functions in the Entrainment Zone Using Observations and LES Simulations

ARM ASR PI Meeting, 19-23 Mar 2018, Vienna, VA
B1 Wed 3:30 - 5:00 pm # 56

[1]M. K. Osman, [2]D. D. Turner, [3]T. Heus, [4]R. Newsom,
[1]CIMSS University of Oklahoma, Norman, OK; [2]NOAA Earth System Research Laboratory Global Systems Division, Boulder, CO;
[3]Department of Physics, Cleveland State University, Cleveland, OH; [4]Pacific Northwest National Laboratory, Richland, WA

Motivation

- 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
- Observations were made over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site.
- 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

Background

In the presence of shear, Sorbjan (2004, 2005) proposed the second-moments water vapor and the vertical wind fluctuations at the top of the CBL as

$$\overline{q'^2}_E = c_q w_*^2 \left(\frac{g_E}{N_E}\right)^2 f_q(Ri_E) \quad ......1$$

$$\overline{w'^2}_E = c_w w_*^2 f_w(Ri_E) \quad ......2$$

Solving for the functions, the above equations can be rewritten as

$$f_q(Ri_E) = \overline{q'^2}_E / C_q w_*^2 \left(\frac{g_E}{N_E}\right)^2 \quad ......1b$$

$$f_w(Ri_E) = \overline{w'^2}_E / c_w w_*^2 \quad ......2b$$

where c_w and C_q are constant, g_E is of the gradient of water vapor mixing ratio in the interfacial zone, N_E is the Brunt-Vaisala frequency in the interfacial layer and w_* is the convective velocity scale.

Sorbjan (2006) suggested the functional dependence of similarity functions on the interfacial zone Richardson number Ri_E (Eq. 1)

$$f_q(Ri_E) = \frac{1+c_r/Ri_E}{1+1/Ri_E} \quad ......3$$

and for the vertical wind variance (Eq. 2), the function becomes

$$f_w(Ri_E) = 1 + c_s/Ri_E \quad ......4$$

Objective

- To see if the similarity functions shown in Eqs. (3 & 4) are comparable to functions shown in Eqs. (1b & 2b)
- Attempt made to have general forms of the similarity functions that describe variances at the top of the CBL
- Observations and LES data were used to redefine and validate the similarity functions that are more comparable to Eqs. (1b & 2b).

Data selection and analysis technique

- The cases were identified during which the afternoon CBL was quasi-stationary and well mixed layers for 2 h period
- Auto covariance technique was utilized to separate out the instrument random error from the atmospheric variance
- Assuming that the atmospheric variance, $\overline{q'^2}$, is mainly as a result of isotropic turbulence within inertial subrange (*Monin and Yaglom* 1979), the ACF at lag τ, $M_{11}(\tau)$, can be approximated as

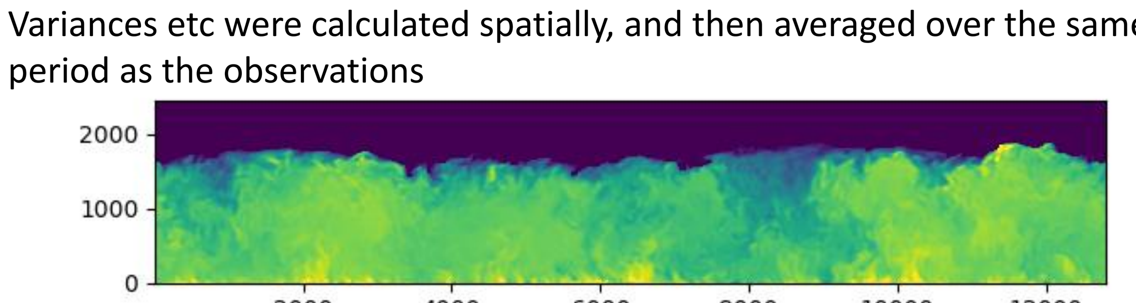
$$M_{11}(\tau) = \overline{q'^2} - C\tau^{2/3} \quad ......5$$

where C is a parameter that contains both the eddy dissipation and the scalar variance dissipation

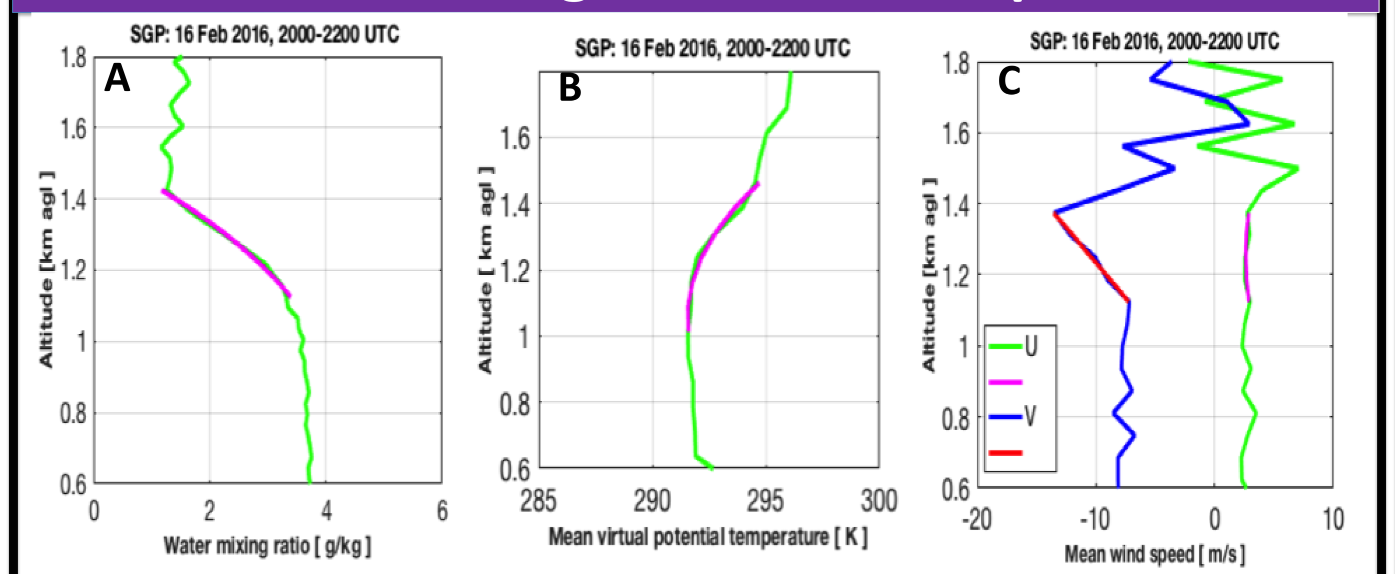
$$\overline{q'^2} = M_{11}(\tau \to 0) \quad ......6$$

Description of 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



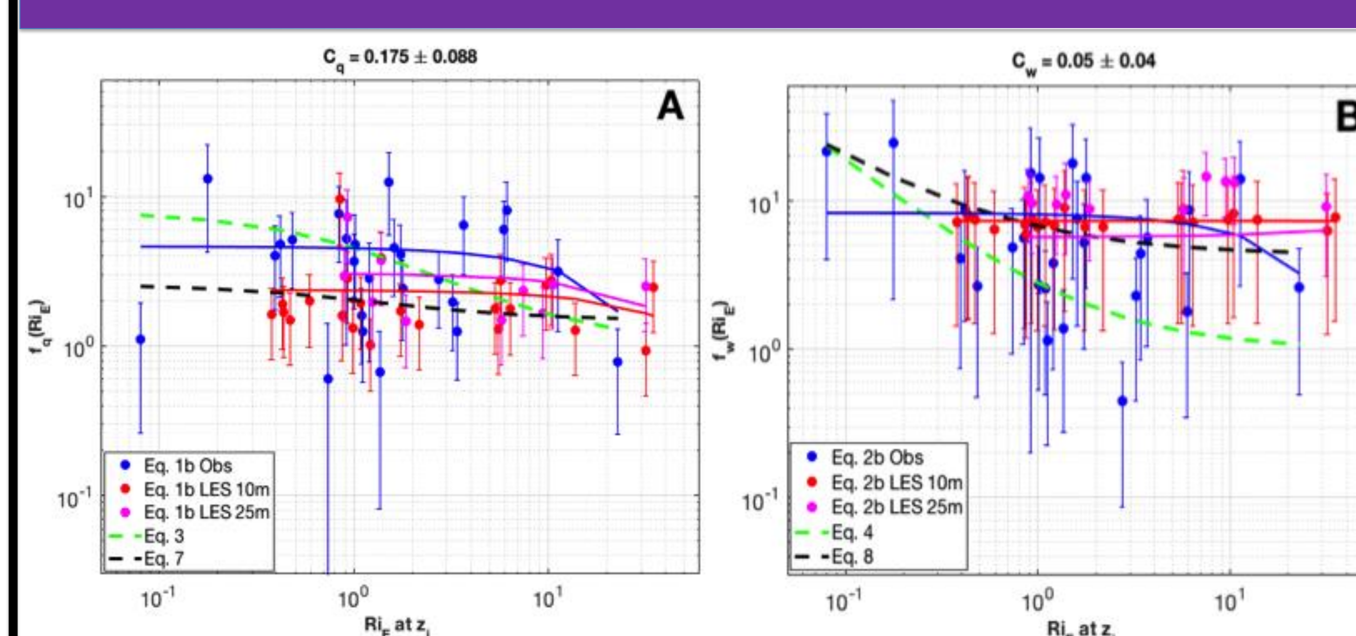
Calculation of gradients of the profiles



Vertical profiles of the 2-h mean water vapor mixing (g kg^{-1}) and virtual potential temperature (K) from Raman lidar and horizontal wind (m/s) from wind profilers at SGP site. The depth of the CBL, where water vapor variance becomes maximum, is 1.3 km.

- Illustrating the fittings around the entrainment zone using quadratic functions to obtain
- the gradient of water vapor mixing ratios
- the Brunt-Vaisala frequency
- the wind shear

Observations vs LES simulations: Richardson number



The dependence of the functions (Eqs. 1b, 2b, 3, 4, 7 and 8) on the Richardson number at z_i. The blue dots are obtained from observations, while the red and magenta dots are obtained from the LES simulations for vertical resolutions of 10 m and 25 m, respectively. The green dashed lines are from the functions shown in Eqs. (3 & 4), while the dark dashed lines are from Eqs. (7 & 8) using the the coefficients shown in the table. The solid lines are the lines of best fit for the corresponding data. Constants C_q=0.175±0.088 and c_w=0.05±0.04 were used in the calculations.

- The function shown shown in Eq. (4) seems to track the observation well but $f_q(Ri_E)$ does not seem to track the observation for smaller or higher Ri_E
- The newly defined functions for the water vapor variance seem to track better the observational data (i.e., Eqs. 1b & 2b) even for the smaller and larger Ri_E
- The newly define functions ($f_q(Ri_E)$) also appear to be roughly constant with the Richardson number unlike the previously proposed function
- LES simulations show that the functions depend slightly on Ri_E
- This property is also seen from the newly defined function (i.e., f_q(RiE)) and the vertical wind variance function for Ri_E > 6.
- The linear fittings reveal that both functions (observations) follow an overall the same variation with Ri_E

The newly defined functions are

$$fq(Ri_E) = \frac{c1 + c2 Ri_E^{-1}}{1 + Ri_E^{-1}} \quad ......7$$

$$f_w(Ri_E) = k_1 + k_2 Ri_E^{k_3} \quad ......8$$

where c1, c2, k1, k2 and k3 are constants to be determined.

The retrieved coefficients for the redefined formulas (Eqs. 7 & 8), the 1σ uncertainty in the coefficients and the degrees of freedom for signal (DFS) for each coefficient from the fitting process are shown in the table below.

Water vapor variance

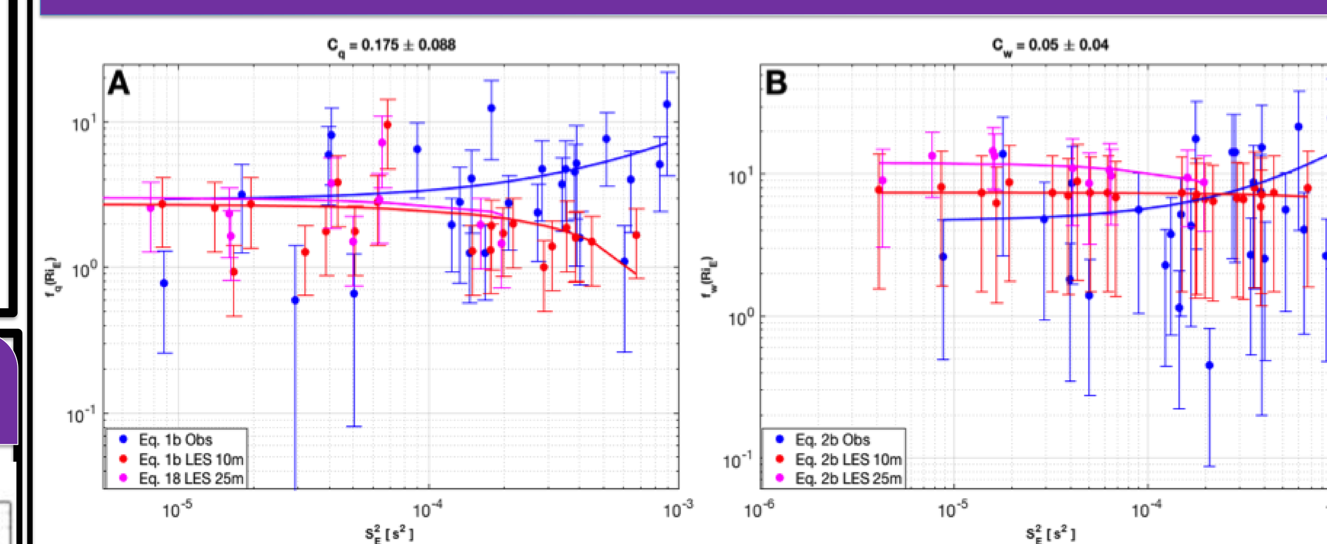
Coffs	Retrieved	1σ uncertainty	DFS
c1	1.48	0.60	0.84
c2	2.58	0.77	0.91
			1.75

Vertical wind variance

Coffs	Retrieved	1σ uncertainty	DFS
k1	4.30	1.92	0.71
k2	2.45	1.96	0.51
k3	-0.82	0.29	0.86
			2.09

- For water vapor variance, the total DFS is 1.75 of the total possible 2, while the total DFS is 2.09 of the total possible 3 for the vertical wind variance.
- The former particularly suggests that observations have high information content on two of the empirical coefficients.
- However, for one of the coefficients in Eq. (8), the observations provide limited information

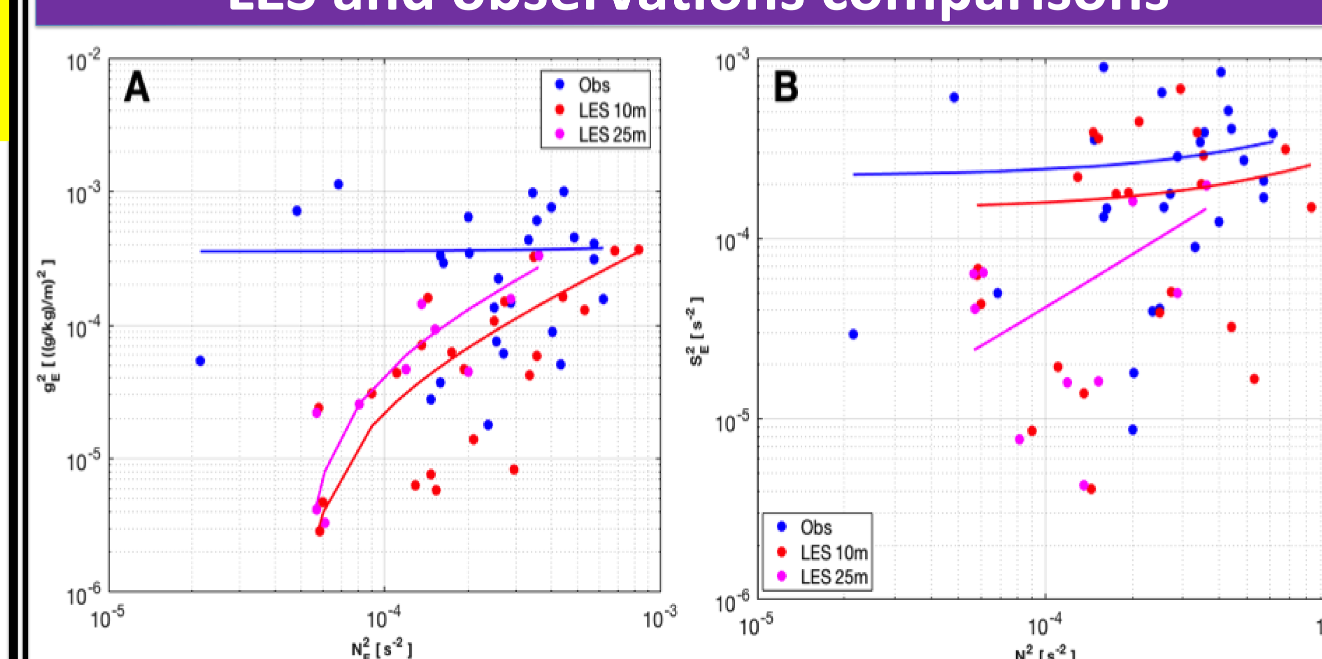
Observations vs LES simulations: wind shear



The dependence of the functions (Eqs. 1b and 2b) on the square of the wind shear at z_i. The blue dots are obtained from observations, while the red and magenta dots are obtained from the LES simulations for vertical resolutions of 10 m and 25 m, respectively. The error bars were computed using c_q=0.175±0.088 and c_w=0.05±0.04 in Eqs. (1b & 2b). The solid lines are the lines of best fit for the corresponding data.

- Just like with Ri_E, the LES simulations show that the functions have little dependence on the wind shear -- particularly for $f_w(Ri_E)$.
- This suggests that the variances (water vapor and vertical wind) at z_i do not depend of the Richardson number or the wind shear at z_i
- The observations tend to increase showing an overall larger values of the functions for larger values of wind shear that is not seen in the LES output

LES and observations comparisons



The relationship between (a) the gradient of water vapor at z_i and (b) the wind shear at z_i vs. the Brunt-Vaisala frequency at z_i obtained from observations and LES simulations (10 m and 25 m vertical resolutions) driven by ARM variational analysis. The solid lines are the lines of best fit for the corresponding data.

- LES simulations show strong correlations between g_E^2 and N_E^2 (0.80 and 0.89 for 10m and 25m resolutions, respectively)
- Observation shows weak correlations
- Observations and LES show weak correlations between N_E^2 and S_E^2 but both show large ranges of the Brunt-Vaisala frequency and wind shear at z_i suggesting different atmospheric conditions at z_i

Summary and Future outlook

- Previously proposed $f_q(Ri_E)$ in the water vapor variance similarity equation appears not to fit the obs well, particularly at smaller and higher Ri_E
- The newly defined functions that used retrieved values seem to track better the observation data including at both smaller and larger values of Ri_E
- The LES simulations show no-to-little dependence of the functions on the Richardson number or wind shear at z_i
- We would like to extend our study using the same procedure to validate Sorbjan's 2006 proposed expression for the profiles of the moments in the CBL with shear

Acknowledgement

➢ This project is funded by award DE-SC0014375 of the Atmospheric System Research program of the Department of Energy

Contact: mohammed.osman@noaa.gov