Review of "Large eddy simulations of surface roughness parameter sensitivity to canopy-structure characteristics" by Maurer et al.

I. General Comments

Parameterization of the momentum exchange between plant canopies and the atmosphere is of great importance in regional and global weather, climate and ecosystem models. The authors used large-eddy simulation (LES) to investigate the effects of four axes of canopy structures on the estimates of roughness parameters. These axes are (1) leaf area index (LAI), (2) vertical profile of leaf area density, (3) canopy height, and (4) canopy gap fraction. Results were compared with existing empirical models and evaluated against observations. These results are interesting and constructive. However, the manuscript needs substantial revision for publication.

Firstly, the authors should be careful about theories and concepts. For example, some statements of MOST were misleading (P16351, L15-16). The canopy roughness sublayer and the layer directly above rough surface are not identical (P16351, L16-17). The use of higher-order closure model is not only caused by the failure of MOST (P16351, L19). The definition of h_a does not agree with what we observe in Figs. 4, 5 and 6.

Secondly, the authors should provide more in-depth discussion for scientific methods, especially those in subsection 2.6. What are the most critical differences among these methods? What are the pros and cons for each method? What do we expect to see for the results? I suggest create a Table to compare these methods. The linear fitting used for Fig. 1 also needs justification. For results shown in Figs. 4, 5 and 6, the reason why Reynolds stress at the canopy top varied by a factor of 2 should be examined and explained.

Thirdly, the manuscript needs to be restructured. For example, section 2 is very long and goes to a lot of directions. It should be divided into at least two sections, one for numerical simulation only and the other for observations and empirical models. Specifically, subsections 2.3 — 2.6 can form a section "Large eddy simulations". The contents for these subsections should be restructured as well. Subsection 2.3 is a mix of model description and model setup. Subsections 2.4 and 2.6 have repetitive contents. I suggest restructure the subsections as "Model description", "Simulation setup" and "Determination of roughness parameters from simulation results". Another important issue is the missing of highlights of important results in the conclusions.

II. Specific Comments and Technical Corrections

Abstract

A. P16350, L1-9: There three sentences give motivation rather than an overview of a paper. They should be shortened to one sentence that occupies two lines at most.
B. P16350, L20:
   a. What does "our model-resolved parameters" mean?
   b. "Frictional velocity" and "friction velocity" were used alternatively throughout the manuscript. Please use the standard term "friction velocity" consistently.

C. P16350, L21-22:
   a. Does “it” mean “friction velocity” or “our model-resolved parameters”?
   b. What are the most important differences between “our model-resolved parameters” and “three other semi-empirical models”?

D. P16350, L23: Which models used “parameterizations with fixed representations of roughness”?

E. P16350, L24-25:
   a. What are “some empirical approaches”? What models used “some empirical approaches”?
   b. In what aspect and to what extent did “some empirical approaches” performed better?

1 Introduction

A. P16351, L15-16:
   c. “MOST is expected to be accurate in the inertial sublayer”: This statement is wrong, because MOST is an approximation based on certain assumptions.
   d. “High above the ground surface in the inertial sublayer”: This statement is misleading. ISL does not include all regions “high above the ground surface”.
   e. “The viscous effects of the rough underlying surface may be neglected” (in the ISL): This statement is wrong, because ISL is defined for wall-boundary-layer flow, where the flow is strongly affected by the wall.
   f. “The vertical flux of momentum is constant” (in the ISL): This statement is wrong. The vertical flux of momentum is not constant.

B. P16351, L17-21:
   a. “The rough surface” usually indicates a rough wall. Is the layer directly above the rough wall identical to the layer “near forest canopies”?
   b. Please clarify the reason why MOST is inapplicable to the canopy roughness sublayer.
   c. Please clarify the reason why higher-order closure models were used for the canopy roughness sublayer.

C. P16354, L4-8:
   a. “Unlike most LES”: This statement is misleading, as if there were very few existing LES studies resolving the canopy layer.
   b. “RAFLES does not use a prescribed 2-D roughness length”: This statement is misleading, as if models using roughness-length parameterization and models resolving the canopy layer were designed for the same research objectives.
   c. “RAFLES incorporates leaf-level drag heterogeneously in 3-D and dynamically in time”: This statement is misleading, as if RAFLES were resolving leaves and having these leaves interact with the flow dynamically.

2 Materials and methods

2.1 Theory

A. P16355, L1: Why is there a second title “Parameterization of aerodynamic canopy properties” for this subsection? Should it be combines with “Theory”?

B. P16355, L2-15:

a. "MOST describes the relationships between the mean horizontal wind speed and the friction velocity at all heights within the atmospheric surface layer": This statement is misleading, because MOST was originally developed for inertial sublayer only.
b. "The friction velocity is a property of the turbulence of the flow": This statement is vague. What specific characteristic of turbulence does friction velocity measure?
c. "MOST relates surface stress to d and z0": This statement is vague. What does it mean by "relates"?
d. Eq. (1): This is not the original MOST, because MOST was developed for inertial sublayer only. Please clarify that this is a modified version that accounts for the canopy roughness sublayer as well. What are the assumptions associated with modifying MOST to account for the canopy roughness sublayer? How accurate is this equation?

C. P16356, L8-9:
   a. "When conditions are neutrally buoyant": This statement is potentially confusing, because "neutrally buoyant" is also used to describe materials having the same density as the carrying fluid.
   b. "When conditions are neutrally buoyant, $\Psi_m(x)$ becomes negligible": This statement is misleading, because by definition $\Psi_m(x)$ is zero for neutral conditions.

D. P16356, L22: "h_a calculated from the horizontal wind profile": This statement is vague. The determination of h_a was restated on P16360, L18-19. This is difficult for readers to follow. See Comment #13 for additional issues associated with h_a.

E. P16357, L4-6: It sounds like that u_r' is calculated as $u_r' = u_r - \langle u_r \rangle$, where $u_r = (u^2+v^2)^{0.5}$. If this is not the case, please clarify mathematically how u_r' was calculated. If this is the case, please explain the physical meaning of u_r'.

2.2 Site description

2.3 Large eddy simulations

A. P16358, L6-8:
   a. "RAFLES resolves the canopy as a 3-D heterogeneous domain where the leaves interact with the flow": Same issue as 1C.
   b. "The canopy is represented as leaf density and volume restriction terms": Here comes the true description of RAFLES. Please clarify the physical meaning of this type of canopy representation. What specific effects of canopy on the flow were accounted for by RAFLES? What are the other potentially important effects of canopy on the flow that have not been accounted for by RAFLES?

B. P16358, L25-27:
   a. Were subgrid-scale fluxes and statistics available in the snapshots? If so, were they used in the calculation of fluxes and statistics? At least subgrid-scale fluxes of momentum and scalars should be included in the analysis.
   b. The description of how fluxes and statistics were calculated is unclear. Take $\langle u'w' \rangle$ (Reynolds stress) for example, it sounds like that it was calculated as $\langle u'w' \rangle = \langle (u'w' - \langle u'w' \rangle_{xy}) \rangle_{xyt}$, where subscript xy indicates average over the horizontal plane, and subscript xyt indicates average over the horizontal plane and time. This is not the definition of Reynolds stress. Please clarify the definition of Reynolds stress from

Reynolds decomposition. What would be the physical meaning for Reynolds decomposition using mean quantities determined by time, spatial and ensemble averaging, respectively? Which averaging is most appropriate for the analysis performed here?

C. P16359, L10: What is the mathematical expression for "a reflective top boundary"? Please explain the reason why a reflective boundary condition was chosen.
D. P16359, L13-14:
   a. "Surface boundary layer height": This is not a defined term. Is it "surface layer height" or "atmospheric boundary layer height"?
   b. "Surface boundary layer height was prescribed by the shape of the potential temperature profile": This statement is vague. Please clarify how "surface boundary layer height" was prescribed.
   c. The word "prescribed" leads to an impression that the "surface boundary layer height" does not evolve in time. Is it true? If so, please explain why a fix "surface boundary layer height" was used. If not, please replace the word "prescribed" with a more proper word.

2.4 Virtual experiment setup

2.5 Empirical determination of roughness parameters from simulation results

A. P16360, L18-19: Here comes the determination of h_a. What is the corresponding mathematical expression?
B. P16361, L2: What does "the lateral forcing of wind speed was effective" mean?
C. P16361, L6-8: The mean u_* and Obukhov length were used, implying u_* and Obukhov length varied with height. What are the degree of variations? What caused the variation? What averaging method was used to obtain the mean? Please also justify the physical meaning of the averaging method.

2.6 Surface roughness parameters:forest structure effects

A. P16361, L14-17: This sentence provides the same information as P16360, L3-6.

2.7 Testing empirical models linking roughness parameters to biometric measurements

A. P16361-16362: Please clarify the difference among the three methods: (a) "Biometric", (b) "Raupach (1994)" and (c) Nakai et al. (2008a). Why are they chosen as representatives for the determination of roughness parameters? What performance do we expect from a theoretical perspective?
B. P16363, L7-8: Please clarify the approach of "Yearly Observed".

3 Results

3.1 Virtual experiment to explore canopy-roughness relationships

3.2 Canopy-roughness improvements to surface flux models

4 Discussion

4.1 Response of roughness parameters to canopy structure change

A. P16367, L2-3: What does "the ability for eddies to transport momentum" mean? Does it precisely describe the physical meaning of the eddy penetration depth shown in Fig. 3a? What does the comparison "weakened" point to? Is it a comparison within a specific type of eddies or for the distribution of eddies on some characteristics scales?

B. P16367, L4: What does "sub-canopy turbulence" mean? Is it well characterized by vertical momentum flux only?

C. P16367, L16-17: Please specify "environmental forcing". Through what mechanism does "environment forcing" affect the values of roughness parameters?

4.2 Integrating canopy-structure characteristics into flux models

5 Conclusions

A. P16371, L4-22: I do not see highlights of the most important results from this paper.

References

A. P16377, L4: "Reynolds" should be capitalized.

Tables

Table 3

A. The value of r^2 is 0.80 for all cases. If it was calculated, please explain the reason why the same value was found for all cases. If it was prescribed, please clarify and explain why it was not calculated.

B. How do Biometric estimates of d and z_0 compare with observations and other models? Please discuss the discrepancies among d and z_0 and the effects of these discrepancies on the estimates of u_*.

Figures

Fig. 1

A. How do LES results of d and z_0 compare with other models? Please discuss the discrepancies.

B. The definition of "leaf-off" and "leaf-on" were given in the figure caption. They should also be stated in the text where these terms were first mentioned.

Fig. 2

A. Figs. 2a and 2c: The variation of h_a is within 0.3 m for the range of LAI (2a) and within 0.2 m for the range of gap fraction (for a fixed value of LAI in 2c). The dependence of h_a on LAI and gap fraction would only be convincing if the variation of ha is much larger than the uncertainty associated with the determination of h_a. What are the uncertainties associated with the estimates of h_a?

Fig. 4 — 6

1. Figs. 4a, 5a and 6a: It was stated on P16360, L18-19 that h_a was determined as the height of inflection point. However, in the figures the inflection points were visually below the corresponding values of h_a provided in Table A1. Please explain.
2. Fig. 4b, 5b and 6b: What caused Reynolds stress at the canopy top vary by a factor of two? Were all these simulations forced by the same geostrophic wind? To what degree did the atmospheric boundary height vary from one simulation to another?
3. "Reynold's stress" used in the figure captions is incorrect. See P16377, L4, "Reynolds stress" is the correct term.