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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Stably stratified canopy flow in complex terrain" *by* X. Xu et al.

Anonymous Referee #2

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This manuscript presents numerical simulations of stably stratified flow within and above a canopy over an isolated, idealized two-dimensional hill. The numerical model uses the Renormalized Group (RNG) k-epsilon turbulence model. The topic is an interesting and important one. Flow decoupling and drainage flows under stable conditions are important in controlling nighttime fluxes from forest canopies. While the simulations are potentially interesting, I found the discussion of them rather confusing and not particularly enlightening. I also have a number of questions about the model itself. This is compounded by the English language. A number of sentences just didn't make sense and I was unable to work out what you were trying to say. In addition to my scientific suggestions below, the language in the manuscript needs careful proof reading. Given my long list of questions I recommend major revisions for this manuscript.

Major comments

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1) I'm not quite sure what the aim of the paper is. The abstract suggests that it is just showing that the model can successfully simulate stable canopy flows. It does simulate canopy flows which look reasonable and qualitatively reproduces some features seen in field observations, but since the simulations are very idealised there is no data to quantitative compare with and so it is impossible to be sure that the model really is "accurate".

2) Justification of the RNG closure. Two references are given to support the use of the RNG model over complex terrain. These are both for neutral flow. Only the previous paper by the authors has a canopy included (Xu and Yi, 2013), but this contains no validation of the model or comparison with observations. Has the RNG model been validated for canopy flows? Has it been validated for stable flows? The reader needs some evidence the model is correct before believing the results from this study.

3) In the description of the RNG model you state that "Tp is calculated as the residual of all other terms". How can you do that as you don't know what dk/dt is? Or do you assume dk/dt = 0 (implied later on in section 3.5)? In that case this is only a steady state turbulence closure model, but is applied to a time-varying model? Seems like a major limitation to me. Can you comment on this?

4) It is stated that the flow is sufficiently forced to ensure the flow remains turbulent. I find this a bit hard to believe with such stable layers. Accurately simulating stable flow is hard - and this comes back to my comments above about whether the model is really validated.

5) Key to interpreting these idealised simulations seems to be the drawing down of air into the canopy near the summit due to continuity. This is in part due to the idealised topography, and also the complete absence of any background flow. It would be interesting to know how more complex terrain and / or a weak (but non-zero) wind would modify the results. Is this something you have considered? It would at least be worth commenting on.

ACPD

14, C12003–C12009, 2015

6) These simulations should be entirely symmetric (in fact you state they are at the start of section 3), but the streamlines in figure 1 are not symmetric. Why? What breaks the symmetry?

7) Section 3.2. The pooling of cold air at the bottom of the slopes seems to be important in decelerating the flow. How is this influenced by the model geometry? Would the results differ with a wider domain? Did you test sensitivity to this? How would this translate to the real world with 3-d valleys? (As an aside, in order to reach a steady state, the cold air must go somewhere. I assume that there is outflow from the lateral boundaries?)

8) End of section 3.2. The effects of slope here controlling whether flow penetrates to the bottom of the canopy or not are interesting. You imply that this is due to the buoyancy force, which is in part true. I think there is more to it than that though. Even on a shallow slope there is a downslope drainage flow, and so by continuity some air must be drawn down deep into the canopy to compensate. I think this needs a more careful analysis to explain what is happening. It may also be amenable to some scaling analysis to show how the slope effect scales? Similarly I do not fully understand what causes the differences in the regions of baroclinicity at the bottom of the slope, and hence the differences in circulation. In particular the upslope flow in the mid canopy over the gentle slope seems odd. Is there any observational evidence of this? How much is this controlled by the cooling of cold air? These are the kind of details which may be sensitive to the turbulence parametrisation - which again comes back to the question of how well validated the model is.

9) I wasn't entirely clear from the text whether the canopy is only on the slope and not on the flat ground. This seems to be implied by Figure 2. This may have a significant effect in controlling what happens at the bottom of the slope and is an added complication. In particular, I wonder if this controls the vortices seen near the bottom the slopes. Did you try experiments with a fully forested domain?

ACPD
14, C12003–C12009, 2015

10) Section 3.3 I found to be rather unsurprising. The results seem entirely consistent with the observed mean flow and much of the section is just repeating other studies.

11) Section 3.4 is potentially interesting, but given the questions raised above about the RNG scheme and how well it has been validated in stable / canopy flows it is hard to have too much faith in the conclusions, particularly about the importance of the pressure term. Other observational studies do seem to suggest this is important though and it would be interesting to pin this down.

12) In the concluding remarks you say that no comparison with field observations is possible. There may not be detailed measurements of all the relevant terms in the TKE budget, but there are (limited) measurements of mean flow and turbulent fluxes from multi-tower, multi-level experiments as stated. The model could, and should, be compared with these to validate it. The other source of data is wind-tunnel experiments which are generally better observed and more controlled. There have been recent experiments at the CSIRO Pye Lab wind tunnel with stable canopy flows. These are not yet published, but if and when the data is published this would be another valuable source of validation data.

Minor comments

1) p28488, line 14. You state that the benefit of the RNG model is the lack of any tuneable empirical parameters. This is not true as the model contains 7 empirical constants (see p28493, lines 14-15).

2) p28490, line 9. What is θ_∞ ? How does this differ from θ_{00} defined on the previous page?

3) Eqs 7-9. Why is this form of the drag force taken rather than the more usual F = $C_D au|U|?How does this compare?$

4) Section 2.3. What is the Prandtl number taken as? No value is given in the text.

5) p28495, line 19. Should be "The Richardson number..."

ACPD

14, C12003–C12009, 2015

6) p28496, line 1. Should be "with" not "With" at the start of the line.

7) p28496. There are several references to subfigures 4a - 4f. Figure only contains 4 subfigures though, and these are not actually labelled. Do you mean the profiles a-f in the figures? If so, this is a very confusing notation. Please change.

8) p28496, line 23. Why is the depth of the secondary super stable layer "due to strong temperature inversion"? Is the strong inversion not just part of the super stable layer? I found this sentence confusing.

9) p28497, lines 1-2. Do you really mean stronger entrainment at the summit? Why just there? I interpret entrainment to be mixing due to turbulence. Is it not the mean flow, i.e. air being drawn down into the canopy over the summit to balance the downslope flow which is suppressing the secondary super-stable layer?

10) p28497, lines 8-9. I don't see the point of this sentence. Previous studies have already observed the stable canopy layer and linked it to decoupling. How does this clarify that?

11) p28497, line 10. "van Gorsel" not "Gorsel".

12) p28497, line 21. "from the terrestrial ecosystem."

13) p28497, lines 25-29. I found these sentences rather unclear. The phrases "undergoes direction shift within canopy." is odd. The English needs improving here to make the meaning clearer.

14) p28498, line 10. What do you mean by "lateral sides"? This sentence is unclear.

15) p28498, lines 10-11. This sentence is also very unclear. Why is the sinking motion diverted? What do you mean by top canopy layer?

16) p28498 and figure 5. Again confusing whether Fig 5.d is referring to a subfigure or the location of a particular profile. Figure 5 seems to contain two subfigures labelled a), b) etc. I would suggest using a different naming convention for the profile locations

ACPD
14, C12003–C12009, 2015

to avoid confusion.

17) p28498, line 19 and figure 5. How can the velocity maximum be below the lower stable layer? The model description implies a no-slip lower boundary (the roughness length is given), but Figure 5 seems to show a non-zero velocity at the surface, in fact a velocity maximum occurs there. How can this be? Is the lower boundary actually free slip? Please explain, and if free slip then justify this choice.

18) p28498, lines 24-25. This sentence doesn't make sense. What do you mean by "...determines the shift direction within canopy."

19) p28505, lines 3-4. ".. with additional strong non-linear terms". What additional terms? Do you mean the RNG turbulence closure? I don't see the point of this sentence anyway.

20) p28505, lines 13-14. "... at the ultra-short wave scale in the whole spectrum of atmospheric turbulence study." This sentence doesn't make sense. Do you mean you are looking at very small-scale flows?

21) Figure 1. Can you mark the canopy on this figure? Figure is not very good quality, and is difficult to read when printed.

22) Figure 2. Caption mentions green dashed lines, but lines appear to be white to me?

23) Figure 3. The second sentence in the caption is very poorly phrased. When you say "... which is normalized by the half length scale L" you presumably mean the locations. I would split this sentence and say "The locations of the size sections are labelled as (a-f). Horizontal distances are normalized by the half length, L, of the hill." or something similar. The caption mentions a green curve. It looks more like light blue to me?

24) Figure 4. Resolution is not sufficiently good when printed. Are these bitmaps rather than vector graphics?

ACPD

14, C12003–C12009, 2015

25) Figure 9 and 10. Plot the y-axis on the edge of the figures, not on the x = 0 line for clarity.

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ACPD

14, C12003–C12009, 2015