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

-----------------------------Reviewer #3 -----------------------------

Reviewer #3

This study investigated 2-D stably stratified mean and turbulent flows above and within plan canopies in complex terrain by using the Renormalized Group (RNG) k-e turbulence model, an important topics in studying canopy micrometeorological processes. The stable stratification was generated by imposing persistent constant heat flux at the ground surface and linearly increasing cooling rate in the upper canopy layer. The terrain-induced influence in dynamic part was carried out by using a gentle hill and a steep hill. Mean and turbulence flows were then characterized by analyzing profiles of mean and turbulence quantities at different locations over the hill slopes. The model approach was sound enough for such a study; the analysis was comprehensive; the information was updated; and the results were unique. I would recommend its publica-tion with minor revisions.

Authors:

We are grateful for reviewer's positive comments!

Reviewer #3

(1). Introduction: Might be good to mention limitations of linear analysis models in studying stratified canopy flows over complex terrain.

Authors:

We added the limitations of linear analysis models to Introduction.

Reviewer #3

(2). Lines 5-10 on page 28487. The last half sentence seems not belong to this speculation.

Authors:

We rephrased this sentence.

Reviewer #3

(3). Lines 13-17 page 28488. Rewrite this long sentence

Authors:

We rephrased this long sentence.

Reviewer #3

(4). Lines 15-16 page 28489. Justify if these rates are commonly observed rates.

Authors:

The ambient temperature gradient of 6 K km^{-1} is appropriate to represent the typical nocturnal inversion strength, although the measured gradient of ambient temperature can be larger or smaller depending on surface condition and background wind. The data from Vertical Transport and Mixing (VTMX) experiment showed the gradient of ambient potential temperature of 10 K km^{-1} in the Utah's Salt Lake Valley in October 2000. Texas Air Quality Study II in August and September 2006 revealed inversion gradient at peak inversion strength of 8-16 K km^{-1}. The Slope Experiment near La Fouly (SELF-2010) showed a potential temperature gradient of 5.8. km^{-1} in the Alpine Slope in Val Ferret, Switzerland. On the onset of downslope flow, the gradient of potential temperature can be as low as 4 K km^{-1}, which is measured in September, Australia.

Reviewer #3
(5). Lines 16-17 page 28490. Was the surface cooling included in the boundary conditions instead of a source term?

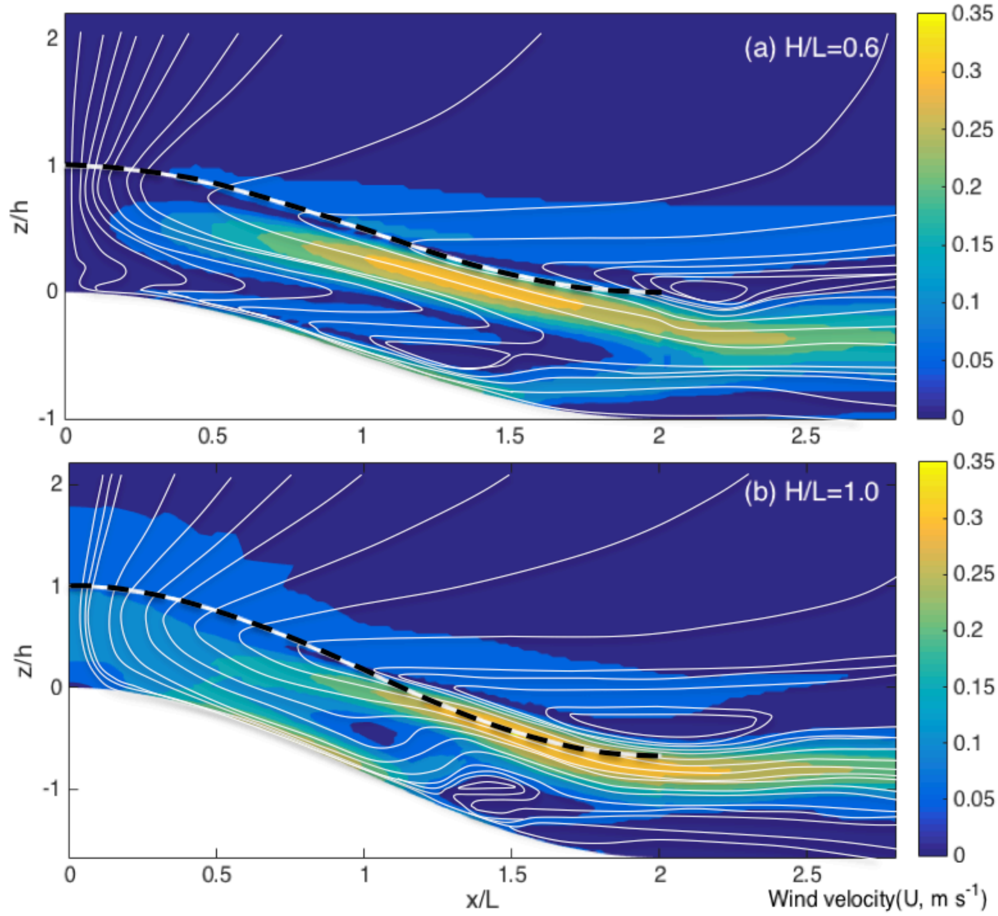
Authors:
Yes, the surface cooling is boundary condition.

Reviewer #3
(6). Page 28495. Explain in more detail why a strong inversion layer was found across the lower jar.

Authors:
Three contributions can be contributed to the strong inversion across the lower jaw: (1) the air in the lower jaw is initially colder than the air in upper jaw, (2) the slope surface has a stronger cooling rate (-15Wm^2), (3) the cool dense air near slope surface is flowing down the slope and accumulates on the cooler slope flow below.

Reviewer #3
(7). Figure 1. Label the streamlines with wind speeds so as to give a clue about the distributions of wind fields.

Authors:
We have tried to add the wind speed as a background in the figure 1 as suggested by the reviewer #3 but the new figure looks a little bit messed-up. Due to the addition of wind speed makes more sense, we added following figure as a new figure (Figure 6) in the revision.



Reviewer #3
(8). Section 3.1. How the dynamics influences the thermal structures is analyzed in some degree. A clear summary might be necessary to help readers construct a clear structure about these linkages.

Authors:
We summarized the interaction of the flow dynamics and thermal structure in the Concluding remarks.

Reviewer #3
(9) How much did the flow structures impact the formation of the primary/secondary stable layers?

Authors:
The radiative cooling in the canopy and slope surface is primary driving force of the flow structure and temperature inversion. The flow structure with upper-canopy drainage flow (UDF) and lower-canopy drainage flow (LDF) determines the location of super stable layers at levels with $\partial\bar{U}/\partial z = 0$. The drainage flows intensify the temperature inversion $\partial\bar{\theta}/\partial z$ down the slope, thus intensify the stability of super stable layers.

Reviewer #3
(10). Explain more why UDF was deeper than the LDF on the gentle slope.

Authors:
The drainage flow is controlled by competition between hydrodynamic pressure gradient $F_{hd} = d\Delta p/dx \approx U^2H/L^2$ and buoyancy force (or hydrostatic pressure gradient) $F_{hs} = g(\Delta\theta/\theta_0)\ \sin\alpha \approx g(\Delta\theta/\theta_0)H/L$, *where α is the slope angle, $\Delta\theta$ is the potential temperature difference between the ambient air and the colder slope flow, θ_0 is the ambient potential temperature (Belcher et al., 2008).* Froude number $Fr=U/NL=\sqrt{F_{hd}/F_{hs}}$, where $N = (g/\theta_0)d\theta/dz$, L is the hill length scale. When Fr <<1, the hydrostatic pressure gradient is large enough to initialize drainage flow. On the slope, the flow is flowing along the shape of canopy layer forming the UDF. The LDF is formed by the air drainage from the hillcrest. The intensity of drainage flow is proportional to slope angle, that the sinking motion is weaker on the gentle slope. Less air sinking to the deep canopy results in the shallower LDF than UDF.

Reference:

Belcher, S. E., Finnigan, J. J., Harman, I. N.: Flows through forest canopies in complex terrain. Ecol. Appl. 18, 1436-1453, 2008.

Reviewer #3
(11). It looked that the TKE was larger on the gentle slope than on the steep slope. Was that due to the small wake production?

Authors:
The larger TKE on gentle slope is mainly due to the supply of TKE transport of pressure perturbation to compensate TKE loss by buoyancy consumption. The uncertainty remains because the pressure perturbation is calculated as a residue term. There is evidence that pressure perturbation is important to provide TKE in lower canopy under unstable condition (Dwyer et al., 1997). We do not have data to validate if buoyancy can induce larger pressure perturbation under stable condition.

Reference:

Dwyer, M. J., Patton, E. G., Shaw, R. H.: Turbulent kinetic energy budgets from a large-eddy simulation of airflow above and within a forest canopy. Bound.-Layer Meteor. 84, 23-43, 1997.

Reviewer #3
(12). Given the closely packed iso-streamlines in figure 1, it seems that horizontal advection played a role in TKE. Please explain.

Authors:
The advection transport of TKE is relatively larger near the top of canopy than other height, especially at the mid- and lower-slope. However, advection of TKE is not

important when compared with buoyancy and wake production in our stably stratified canopy flow.

Reviewer #3
(13). Section 4 could be largely shorted and just emphasize the major conclusions

Authors:
We shortened the section 4 and summarized the interactions of flow dynamics and thermal structure for comment (8).

Reviewer #3
(14). It could be better to enlarge Figure 4.

Authors:
Figure 4 is updated.