Response to Comments of Reviewer 2

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Title: A Sub-Grid Parameterization Scheme for Topographic Vertical Motion in CAM5-SE

I appreciate the improved description of the parmaterization. It addresses several of the issues I raised in my first review. This is not a typical parameterization, as it does not appear in the physics package, but instead replaces the vertical pressure velocity "omega" used in the dynamical core. As this is slightly unconventional, it is good that it is clearly explained. Now that I understand this aspect of the approach, it raises additional questions:

1. What is omega_0 introduced in equation 5? This variable is not defined. Note that in Equation 7, we get the final form of \omega that will be used by the dynamical core. This final form depends on omega_0. Thus without knowing \omega_0, it is not possible to reproduce these results. From the author's review comments, I assume \omega_0 is the value of \omega computed by the dynamical core, from the standard diagnostic equation. But this needs to be clearly explained in the paper. And if my assumption is correct, the diagnostic equation for \omega_0 should be given along with

the other equations in Equation 2.

Reply: Thank you for your affirmation of the parameterization scheme. We would like to express our sincere thanks for your valuable comments. It is worth noting that we dose not replaces the vertical pressure velocity "omega" used in the dynamical core, but specifically added a term 'omega_s'. And we do apologize again for the inaccurate description of physical quantities. It is true that \omega_0 is the value of \omega computed by the dynamical core, from the standard diagnostic equation in equation 5. The diagnostic equations for \omega_0 is $\omega = Dp/Dt$ in CAM5, it has been shown in Line 130. Due to the fact that Formula 1, which we specifically discussed separately, was derived from the diagnostic equation, it was not given along with the other equations in Equation 2.

2. Continuing to assume that \omega_0 is the \omega computed by the standard diagnostic equation, then the final \omega used by the dynamical core appears to have some double counting: \omega_0 at the surface will be the model's horizontal velocity multipled by the gradient of the model's topography. The author's then add to this \omega_s, which has their more sophisticated representation of the surface omega, including subgrid topographic details. Assuming a very smooth mountain, well resolved by the model, then it seems that \omega_s and \omega_0 would agree, and thus we have some double counting. I would think \omega_0 needs to be reduced to zero as one approaches the surface in a way similar to how \omega_s is reduced away from the surface.

Reply: Thanks for your suggestion. \omega_0 is the \omega computed by the standard diagnostic equation, related to dp/dt, it does not include the influence of sub-grid topography. To distinguish it from the topographic vertical velocity, we call it omega_ 0, but omega_0 is actually the omega in Eq1. If the model cannot recognize small terrain, there is no topographic vertical motion. Obviously, it does not exist in CAM5-Ctl. Assuming that a smooth mountain has a hemispherical shape, well resolved by the model with a certaon resolution, it still has a slope, and the slope is completely equal for each sub grid. While omega_ s is the sub-grid scale topographic vertical motion calculated from DEM data with a resolution of 1 km×1 km. It dose not double counting in our parameterization scheme because the uplifting caused by its terrain still exists.

3. One potential difficulty with this approach (modifying \omega in the dynamical core): How would this be implemented in a model that uses potential temperature as a prognostic variable instead of temperature? With such a set of prognostic variables, \omega does not appear in the dynamical equations, and thus how would one modify the equations so that they could feel the influence of changing \omega near the surface?

Reply: Thanks for your suggestion. The first law of thermodynamics:

$$\mathrm{dQ} = C_v dT + p d\alpha \quad (R1)$$

where α is specific volume of dry air. According to the state equation:

$$p\alpha = RT \quad (R2)$$

Diagnostic equation:

$$\omega = \frac{\mathrm{dp}}{\mathrm{dt}} \quad (R3)$$

And the relationship between specific pressure heat capacity C_p and specific constant capacity heat capacity C_v:

$$C_v + R = C_p \quad (R4)$$

thus :

$$\frac{dT}{dt} = \frac{kT}{P}\omega + \frac{Q}{C_p} \quad (R5)$$

And $\theta = \mathrm{T}(\frac{p_0}{p})$^k, $\mathrm{k} = R/C_p$ is a constant. Finally, the potential temperature as a prognostic variable instead of temperature in a model is: $\theta' = \theta\left(1 + \frac{k\omega}{p}\mathrm{dt}\right)$(Omitting the intermediate derivation process). Thus, by modifying ω, the potential temperature θ can be further changed. Transforming dT/dt into dθ/dt is more complex than directly calculating temperature. This process is included in the Finite Volume Dynamical Core, but due to the fact that the potential temperature itself includes the factor of altitude, the improvement effect of changing the vertical velocity ω on precipitation is not significant. Therefore, we use Spectral Element Dynamical Core (CAM5-SE) in our manuscript.

4. Note that Equation 4 is only valid on the surface, so \omega on the left-hand-side needs an s subscript. Since Equation 5 comes from Equation 3 and Equation 4 (both only valid at the surface) it seems equation 5 is only valid at the surface. It is extended beyond the surface in equation 7. But

then there is a problem with the notation, since Equation 5 and Equation 7 both use \omega on the left hand side, but clearly these are different fields.

Reply: Thanks for your suggestion. We have revised the notation in Eq4 and Eq7 acccording to your comment. ω on the left-hand-side in Eq4 has been revised as ω_s. It indicated the topographic vertical velocity of the lowest model layer. ω on the left-hand-side in Eq7 has been revised as ω_l, it indicated the decrease of multi-layer topographic vertical velocity from lowest model layer up to the model layer that 150hPa above the lowest model layer.

The following are revised in the revision:

$$\omega_s = \frac{\partial p_s}{\partial t} + \vec{V_s} \cdot \nabla Z_s, \qquad (4)$$

$$\omega = \omega_0 + \omega_s = \frac{dp}{dt} + \omega_s \qquad (5)$$

$$\omega_l = \frac{dp_l}{dt} + \omega_s \times \gamma, \qquad (7)$$

Where ω_l is multi-layers topographic vertical velocity, p_l is multi-layers pressure. γ indicates the attenuation coefficient of topographic vertical velocity ω_s and it increases with the elevation.