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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Simulating 3-D radiative transfer effects over the Sierra Nevada mountains using WRF" *by* Y. Gu et al.

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We would like to thank this reviewer for the comprehensive comments. Below are our responses to these comments.

General Comments

This paper has proposed a method for handling sub-grid reflections of solar radiationin complex terrain. The idea looks good and original, and is worth publishing. I had several questions about the technique that I will list below. The results described some plausible effects, but there may be places where more explanation is needed, because the reasons for some results must have depended on features of the local sub-grid topography. The paper is generally well written and organized

Response: We appreciate your constructive comments and suggestions.

Specific Comments

1. p19902, line 16, should say "configuration factor, Ct," because Ct has not been defined.

Response: Thank you. 'Ct' has been added in the revision (page 5, lines 153).

2. p19902. What is the difference between Vd and Ct? Vd is sky view factor, and Ct is the area of surrounding mountains. This seems like the same information or at least highly correlated, so it needs to be made clearer why both are needed.

Response: An unobstructed horizontal surface (or simply a flat surface) will intercept radiation emitted from the sun in all directions. Over mountainous areas, however, the solar fluxes intercepted at a target point are subject to the blocking of surrounding mountains. Consequently, only a portion of the sky dome can be visible at the target point, which is defined by the term referred to as the sky view factor Vd. This parameter represents the shadow effect of the mountains on the direct and diffuse solar fluxes reaching the target point.

The term Ct is referred to as the terrain configuration factor, defined as the area of surrounding mountains visible to the target point which determines the solar fluxes reflected to the target point from the surrounding mountains. The parameter Ct will affect the direct- and diffuse-reflected fluxes as well as the coupled flux induced by mountain topography.

Following the reviewer's comment, we have incorporated additional discussions regarding the physical meaning of Vd and Ct in the revision (pages 4-5 , lines 144-154; see also Lee et al. 2011).

3. p19903. It is surprising that all the angular effects for direct radiation can be represented by one mean angle, mu. I would expect at least a seasonal dependence to account for the solar elevation for a given time of day. This needs to be explained. For

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example noon in midsummer would have different slope effects from noon in midwinter, and it is not clear a single mean parameter can represent this.

Response: The solar flux at the top of the atmosphere is governed by the cosine of the solar zenith angle, $\mu 0$, which is defined by the latitude, time of year, and the solar declination angle and is therefore seasonally dependent. The variable that is used to represent the angular effect of the direct flux component in the parameterization is the cosine of the solar incident angle μi, which accounts for the solar zenith angle, mountain slope, and slope orientation (see Lee et al. 2011). In the parameterization, we have used seven $\mu 0$ (cosine of the solar zenith angle) ranging from 0.1 to 1. The seasonal variation in the sun's position is defined by the values of $\mu 0$. When time of year is given (for example, noon, June 21 or noon, December 21), $\mu 0$ can then be computed from known mathematical expressions. Because $\mu 0$ corresponding to noon in the summer differs from that in the winter, different shadow effects are produced on a given target point with reference to solar flux.

Following the reviewer's comment, we have included the preceding discussions in the text (page 8, lines 230-234).

4. p19905, line 23. The model grid is 30 km, but the data were derived on a 20 km grid. It is not clear how this mismatch would be handled. Since the matrices were only derived for 80 20km squares, presumably only a subset of the domain has this treatment. Is it the sub-area plotted?

Response: The present parameterization has been developed using topographical data from the Sierras, which is divided into 80 20 x 20 km2 domains to represent the general terrain characteristics. In order to reduce the edge effect caused by the cyclic boundary condition used in the Monte Carlo photo tracing model, only the topographic information and surface radiative fluxes in the central 10 x 10 km2 area were used for the parameterization. To examine the compatibility of the parameterization at different horizontal resolutions, surface fluxes over larger domains (up to 50 x 50 km2)

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using the parameterization have been computed and compared with the “exact” Monte Carlo approach. The resulting coefficient of multiple regression between the results determined from the parameterization and the Monte Carlo calculation (true values) is generally larger than 0.95 for all flux components. For this reason, it is concluded that the present parameterization can be directly applied to horizontal resolutions up to 50 km without additional averaging requirements (see Lee et al., 2011).

Following the reviewer’s comments, however, we have incorporated the preceding discussions into the revision (page 6, lines 177-185).

5. p19907. It would have been useful to have maps showing (a) the full domain with the plotted sub-domain marked, and (b) the detailed topography used to derive the data. The plots given do not indicate how complex the topography is in that region. If this can be overlaid with the boundaries of the 80 sub-regions, it would be even more useful.

Response: The reviewer’s point is well taken. In response, we have added a new figure (Fig. 1) to illustrate the topography (Fig. 1b) and domain (Fig. 1a) used to derive the parameterization data, with the 80 sub-regions marked by ‘x’.

6. p19908, line 10. This explanation only works if the morning was clear, and these convective clouds formed as a result of direct radiation effects. Also, were these high clouds from the convective scheme or low clouds from the microphysics only, e.g. upslope flow? This needs to be checked and stated.

Response: There was no synoptic frontal system over that area during the time period simulated in this study. Clouds began to form over the CWP area shown in Fig. 5a (original Fig. 4a) at about noon time, suggesting that clouds formed as a result of direct radiation effects. The clouds were low clouds, with no evidence of ice formation. These clouds likely developed in response to the solar heating, which gradually built up since the morning. As is common in mountain environments, upslope flow probably has contributed to convection and cloud formation as the elevated surface in mountains was heating up relative to the surrounding air, and such effect should be important from about 2 pm to late afternoon when the differential heating between the mountain surface and the surrounding air is largest. A reduction in surface insolation can therefore reduce upslope flow and convection, leading to reduced CWP. The reviewer's point is well taken and a brief explanation has been added in the revision (page 12, lines 317-327).

7. p19910, line 4. It is not easy to imagine why higher elevations have a maximum reduction at 2pm, while lower elevations have a reduction at 10am. Was this due to the geometry of the mountains or cloud formation timing? It would improve this paper to have an explanation of this result. Presumably the lower elevation areas also include the higher elevation areas as a subset.

Response: The maximum reduction of surface solar flux over higher elevations at 2 pm is likely due to the topographic characteristics of the Sierras, which have sharper cliffs over the northeast side of the mountains (see Fig. 1). Therefore, for higher elevations, a portion of the northern slopes will be shadowed even when the position of the Sun is at 2 pm, during which the available solar flux is near its maximum, leading to the maximum reduction of surface solar flux. When lower elevations are included, most of the lower mountain areas are visible to the Sun. Because the higher elevated region only constitutes a portion of the total area, reduction at 2 pm becomes smaller. Clouds do not contribute to the difference in timing of maximum reduction at the higher and lower elevations. As discussed in our response to comment #6 above, clouds only began to form around noon and occurred mainly at the higher elevation. Cloud water path was found to decrease due to mountain effects that reduced surface solar flux, so the cloud response is to compensate partly for the solar flux change rather than to shift the maximum reduction of solar flux to 2pm.

Following the reviewer's comment, we have added more explanation in the revised manuscript (page 15, lines 383-395).

8. Figure 2d. The southern area seems to be generally cooler. Is this due to the

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geometry of the slopes that might favor a northward slope in that area? It also appears in the day-averaged result, and should be explained.

Response: The southern area is a valley with mountains located to both the north and south; hence, it experiences more shadow effects and appears to be cooler. A brief explanation has been added in the revision (page 11, line 294-296).

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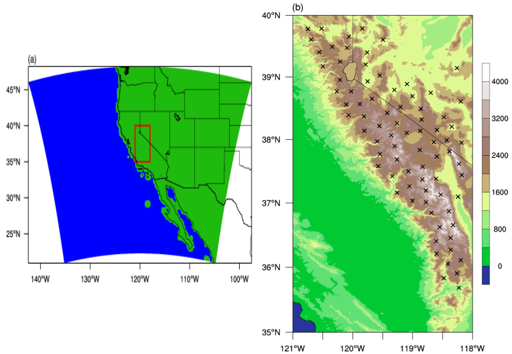

Fig. 1. (a) The domain of the western United States, where the red box denotes the study region over the Sierras. (b) The topography for the study region using the digital elevation model (DEM) at a resolution of 1 km. The scale on the right is in units of meter. The x's represent 80 sub-regions with a resolution of 20 km from which the parameterization data involving 3D radiative transfer was derived (Lee et al. 2011).

Fig. 1.

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