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Atmospheric Chemistry and Physics Discussions

Interactive comment on "How small is a small cloud?" *by* I. Koren et al.

I. Koren et al.

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We would like to thank the referees for their important comments and suggestions that hopefully have made this paper clearer.

We will address here the referee comments one by one (referee comment first and then the reply):

Referee #2 Minor points: 1. Abstract: "When changing the resolution from 30 m to 1 km (Landsat to MODIS) the average "cloud-free" reflectance at 1.65 micron increases more than 25%, the cloud reflectance decreases by half, and the cloud coverage doubles, resulting in an important impact on climate forcing estimations." I find the use of relative changes somewhat confusing, and would suggest to additionally quote absolute changes: the increase of cloud-free reflectance should be pretty independent of e.g. the surface albedo, at least to first order. However, changes of surface albedo will strongly modify the cloud-free reflectance, and cause large differences in the relative numbers. Similar arguments can probably be made for cloud reflectance/cover.

We agree with the reviewer that the absolute values are more important, so we have changed the relevant text as follows (in the abstract) : " When changing the resolution from 30 m to 1 km (Landsat to MODIS) the average cloud-free; reflectance at 1.65 μm increases from 0.0095 to 0.0115 ($>$ 20 %), the cloud reflectance decreases from 0.13 to 0.066 (˜50%), and the cloud coverage doubles, resulting in an important impact on climate forcing estimations. The apparent aerosol forcing is on the order of 0.5 to 1 Wmˆ-2 per cloud field."

2. Introduction: "when changing pixel size from 10 km to 100 km": please clarify whether is this area (then units of kmˆ2), or some effective diameter?

(Introduction): Changed to " when changing pixel size from 100 kmˆ2 to 10000 kmˆ2 (Krijger et al., 2006)."

3. Current operational cloud masks (e.g. MODIS) do not only use absolute thresholds in reflectance, but also thermal channels and spatial variability thresholds. How are the conclusions of the paper affected by the choice of cloud masking algorithm?

The reviewer is right, the MODIS-cloud-product cloud masking uses tests in few channels in the VIS IR and thermal to detect all possible clouds. Moreover, the MODIS-aerosol-product cloud masking is using thresholds on local variability of reflectance and not on the reflectance itself. The overall effect on the cloud and aerosol properties will depend on the type of clouds, and their spatial distribution and location. For this study we chose the idealized case of marine clouds far from glint with low aerosol loading to demonstrate the concept. Specifically for the cases of sparse low cumulus clouds we do not expect the thermal gradient to be significant and to contribute to cloud detection; also in high resolution the local variability test fails (the variability of the background is comparable to the variability of small weak clouds at such scales). For clarity we have added to the text (in section 4. Summary and Conclusions): " 4) The apparent direct aerosol forcing due to classifying cloud pixels as cloud-free in the sparse cumulus fields is on the order of -0.8 Wmˆ-2 (with an error of 0.2 Wmˆ-2) for the cloud field area. In reality the actual enhanced apparent forcing depends on the way clouds are detected in the algorithm. The specific MODIS errors in apparent direct aerosol forcing may be somewhat smaller than what is reported here due to the fact that clouds are detected by means of thresholds on the local variability in reflectance (Martins et al., 2002) rather than thresholds on the reflectance itself. Although we expect that the local variability of sub-pixel clouds will change similarly to the reflectance, cloud detection depends strongly on the thresholds (in reflectance or variability) and there may be cases where the variability method detects traces of sub-pixel clouds that the reflectance threshold will not."

Please also see our response to a similar comment by reviewer one.

4. As additional quantitative estimate of the impact, consider adding SW cloud radiative forcing to the cloud-covered parts of the image, to complement the cloud-free "aerosol radiative forcing". Or is this simply the aerosol radiative forcing multiplied by -1?

Will be answered together with the next point:

5. Eq. 1, and prior statement: "the nadir reflectance observed by ETM+ is a good surrogate for the radiative energy reflected back to space. "In other words, the authors assume that the anisotropy of individual pixels does not change with resolution, and TOA albedo and reflectance are directly related. However, using the Independent Pixel approximation as conceptual model to understand the resolution reduction, the anisotropy is expected to change non-linearly, due to changes of anisotropy with cloud properties (thin clouds have a more inhomogeneous radiation field than thick clouds). This point should be at least discussed. (see e.g. Kato, S., L. M. Hinkelman, and A. Cheng (2006), Estimate of satellite-derived cloud optical thickness and effective radius errors and their effect on computed domain-averaged irradiances, J. Geophys. Res., 111, D17201, doi:10.1029/2005JD006668.) Overall, the difference between directional and hemispheric radiances/reflectances should be discussed more explicitly.

The fact that albedo and nadir reflectance are indeed related is conveyed by the fact that we were able to use the two-stream expression of Bohren for albedo to fit the nadir reflectance (eq. B2) for values of optical thickness below 20. Admittedly, this was for plane-parallel DISORT calculation. But exactly because of the difficulties the reviewer mentions and the fundamental difference between directional and hemispheric reflectances we did not attempt to estimate errors in cloud radiative forcing due to degradation in detector resolution and the resulting spreading and thinning of the clouds. For aerosols, we related the background reflectance change to an AOD change and extrapolated to an aerosol radiative forcing change based on previous results. For clouds we cannot do so, and we therefore only quote the impact of resolution degradation in terms of nadir reflectance change (which should no be viewed as an albedo change). We now make this point more clearly. Note that the consequences of spatial resolution degradation as described in the paper ensure that the albedo of what is perceived as cloud will decrease, even if this change cannot be easily quantified (i.e., without applying a cloud retrieval algorithm). Due to the non-linear relationship between the apparent reduction (increase) in cloud optical thickness (aerosol optical thickness) when resolution is degraded, the cloud and aerosol forcing errors are not trivially related.

6. Appendix B, paragraph above formula B6: rich->reach, bottom of same page, "form the 3D effect" -> "from the 3D effect"

Changed, thanks.

7. Size of clouds: how is the size of a cloud calculated exactly (when are two cloudy pixels connected: only if they are neighbors in horizontal/vertical direction, or also if neighbors along the diagonal directions? Are the results sensitive to this choice?)

Cloud pixels are considered connected when neighbors exist along the diagonal directions. We have tried both ways (with and without considering diagonal neighbors) and the basic results does not depend on the way by which the pixels are considered con-

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nected (it changed the numbers of the size distribution but not the shape). We chose to use this definition because it is more conservative with respect to the importance of the small clouds (the other method resulted in more smaller clouds, but not by a significant amount). We added to the text (section 2. Analysis): "Pixels are considered to belong to the same cloud when two adjacent pixels are connected in any of the 8 possible directions."

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 6379, 2008.

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