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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The effect of sensor resolution on the number of cloud-free observations from space" *by* J. M. Krijger et al.

J. M. Krijger et al.

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1 General

First the authors would like to thank the referee for his useful comments.

As stated by both reviewers the presented analysis is important for trade-off analysis for future satellite sensors. This is indeed the main purpose of this manuscript. So far only two studies addressing this topic have appeared, none of which in a peer-reviewed journal. Moreover, these studies -which we make extensive refence to in our manuscript- are either not dealing with a global dataset (Tjemkes et al.) or only consider a very limited amount of data (one day in 2004, ESA, 2001). Our analysis represents a much more extended analysis regarding this topic.

Nonetheless, we decided -upon advice from the referee- to enhance the temporal sampling of the dataset used in this paper in order to further substantiate the representivity of our analised dataset. We have done this for the entire global dataset because of the relevance of such an analysis for future (global-scale) missions. All the analyses were therefore repeated for four days per month (1st, 8th, 15th, 22nd of the month) instead of the original two days (1st, 15th). In addition, we extended the study over major European cities to include all days during the summer of 2004 (see results Table 1).

2 Specific

The referee further raises three important points that (s)he feels were not adequately addressed in the original manuscript:

a. Is the data statistically sufficient?
b. How accurate is the methodology (scene analysis method)?
c. An error analysis is needed.

Each issue is addressed in the following sections and we explain how it is incorporated in the revised manuscript.

3 Statistically Sufficient

As described above, for this reason we decided to enhance the temporal sampling of our dataset. All results (figures and tables) presented have been updated accordingly. As can be seen by comparison with the previous version of the manuscript where two days per month were used, hardly any significant difference is observed in the results

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with the most notable exception in figure 3 in the case of Northern Europe spring and summer. The latter is caused by an unusual clouded day in the original six days, which decreases in significance with the large temporal sampling, while the former is caused by an unusual cloud-free day over Central Europe in the original six days.

For the analysis over European cities we enhanced the sampling even further to include all days in the summer of 2004. As such Table 1 in the new manuscript has been updated and now also includes the standard deviation on the averages.

4 Methodology Accuracy, accuracy scene analysis method

The following text was added to provide information on the quality of the MODIS cloud mask: *Validating cloud masks is difficult, yet several papers address the accuracy of the MODIS Cloud Mask (MOD35) by comparing it with other algorithms. Ackerman et al. (2002) show that the MODIS cloud mask agrees between 86-92% with ground-based measurements. Berendes et al. (2004) shows an 80% agreement with ARM measurements, but attributes the difference due to difficulty of detecting low fog above the snowy Arctic (an area which is excluded from this study) and MODIS better cirrus-detection. Heidinger et al. (2004) shows how MODIS improves the capability to detect clear scenes over AVHRR methods. Thomas et al. (2004) shows the global MODIS cloud amount to be 8% higher than AVHRR on average, but most of this difference is due to differences on high latitudes (which are excluded from this study). These differences are likely an actual improvement due to MODIS improved spectral information (Thomas et al. 2004).* As such the MODIS Cloud Mask product is thought as an improvement to earlier algorithms and a trusted and much used product in the scientific community.

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5 Error Analysis

In most of the above mentioned validation papers the confident clear (99%) and probably clear (95%) MODIS scenes were designated clear. We therefore adopted the same criteria in our study. Nonetheless, one can determine the effect of this choice on the results. As such the analysis were redone but now for all three MODIS confidence levels (the fourth confidence level is equivalent to all scenes being flagged clouded, resulting in a constant fraction of cloud-free observations of zero). Some results are shown in Fig. 1.

The following text is added in the manuscript : *In this study all scenes with a 95% confidence or more were designated clear. When instead the 99% or more confidence level was used to flag clear scenes, the fraction of cloud-free observations drops for all footprint sizes with a almost constant factor of 0.73 $\pm$0.06, while the slope remains constant. Employing the 66% confidence level results in much more clear scenes and thus a larger fraction of cloud-free observations , again with the same slope as the results obtained with the 95% confidence level, but offset by a relative factor of 1.23$\pm$0.05. The standard deviation due to temporal variability is quite insensitive to the confidence level remaining almost constant with respect to changes in confidence level employed in all cases. Most importantly however the slope or relative reduction as function of footprint area remains constant.*

Moreover, visual inspection of the MODIS real color images shows that considering only confident clear as "clear" results in the detection of many small non-existent clouds, while considering only confident cloud as "cloudy" results in many overlooked clouds. As such the choice to designate all scenes with a 95% confidence or more as clear is considered to best represent the "real" cloud cover. A final independent check of the absolute numbers is provided in section 4.1. More important it is shown that our findings compare well with and significantly extend earlier studies which are all limited in region and resolution (ESA, 2001; Tjemkes et al., 2003; Breon et al., 2005;

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Meerkotter et al, 2004; Massons etal, 1998)

6 Conclusion

The purpose of the paper is not the validation of the cloud algorithm over a specific region or time of year, but the effect of sensor resolution for future missions. This application has a global focus, where certain specific regions were only zoomed into to address certain questions in relation to this main purpose.

In response to the referee's comments, we have doubled the temporal sampling of our dataset and so shown that the employed data is statistically sufficient. For the major European cities we even took all daily values during the summer 2004. We have also added information on the quality of the MODIS cloud mask (the scene analysis method). In addition, we added a more rigorous error analysis addressing the effect of the MODIS confidence levels for cloud detection.

As such we feel that we were able to improve the manuscript significantly and address all the comments made by the referee #1.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 4465, 2006.

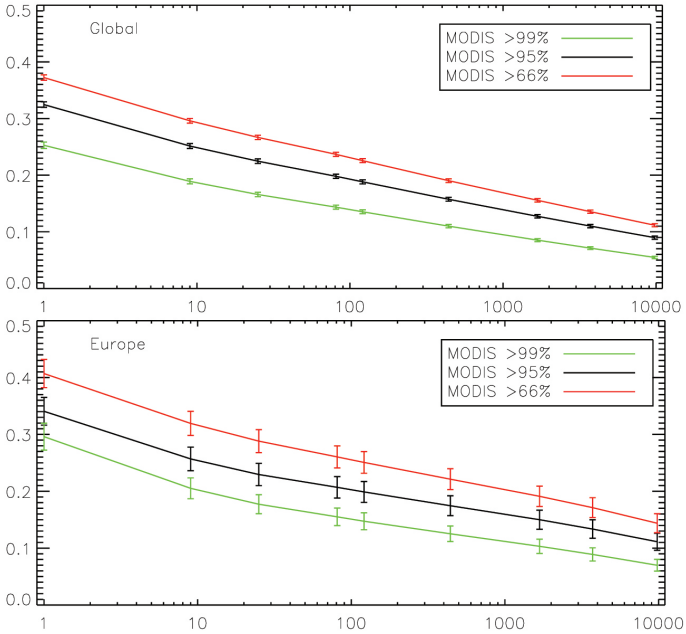

Figure 1: The fraction of cloud-free observations as a function of sensor resolution (footprint area) for the 3 different MODIS cloud confidence levels. For clarity only the 5% cloud threshold is shown here. Top panel: globally averaged between latitudes of -70° and 70°. Bottom panel: the same plot but averaged over Europe (latitude range 35° N–73° N; longitude range 10° W–36° E) for MODIS categories land, coast, and desert.

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