Response to comments of Referee #1

We wish to express our appreciation to Referee #1 for the instructive comments as well as the time and effort spent. We have carefully considered all comments that were expressed in the review. In the response below, we address each of these comments. Your comments are italicized, and our responses immediately follow.

General remarks

The authors present a study aiming at a more complete understanding of TOMS UV retrieval biases. It is based on a comparison of spectral ultraviolet (UV) irradiances retrieved from TOMS data and UV irradiances measured at 27 climatological sites maintained by the USDA UV-B Monitoring and Research Program. New is that the authors quantitatively identify systematic biases in the TOMS retrieval for all spectral channels. Spectral biases are discussed and explained in view of local conditions, especially due to effects of air pollution (SO_2, NO_2, O_3), aerosol loading, and cloud cover. The authors submit a comprehensive paper with a cognizable rationale. It is clearly written, well structured, and worthwhile to be published in ACP.

We thank the reviewer for appreciation of our work.

Beyond that I am interested in the following aspects which could be taken into account in chapters presenting results, respectively in concluding remarks:

The authors focus on summertime months (May-September) in the US to avoid possible contamination of snow cover, as they state. Considering the whole globe regions can certainly be found being snow free over the entire period from October to April but likewise affected by aerosols or pollution. What would be the magnitude of biases the authors expect for solar zenith angles being greater in the period from October to April (compared to May-September) but still relevant to surface UV?

We appreciate the reviewer's concern about the role of solar zenith angle (SZA) on the TOMS biases. Normally, in the wintertime from October to April, the slant column is longer than that in the summertime due to the greater solar zenith angle. The biases could be larger than those in the summertime given that the local conditions (aerosol loading and air pollution) are similar. On the other hand, the wintertime aerosol loading and air pollution concentration are usually smaller than their summertime values and the biases may be smaller than those in the summertime. We calculated the clear-sky wintertime biases for site FL02 at which the averaged AOD approximated the summertime value, and CA02 at which the averaged AOD was only a half of the summertime value. Both sites have no snow cover in the wintertime. The mean biases at FL02 increase by 6% for all wavelengths compared with those in the summertime, while the mean biases at CA02 decrease by 3-8%. Hence the SZA causes various degrees of effects on retrieval biases, depending on the local air conditions. Buchard et al. [2008] found that the relative biases between OMI UV data and ground-based measurements showed larger discrepancies for SZA larger than 65^{o} at two French sits. Kazadzis et al. [2009] showed no statistically significant dependence on SZA for the OMI-Brewer relative UV differences at a Greece site. Antón et al. [2010] found the OMI-Brewer relative biases were slightly decreased with SZA in clear-sky conditions. Our results here are consistent with those results. Since the summertime surface UV radiation is much stronger and more harmful to humans and ecosystems compared with the wintertime UV radiation, we focused our comparisons within summertime months and avoided the snow cover contamination at those northern sites in the wintertime. To address the reviewer's concern, we will add the following text in a new section "**5.4** Other factors for result limitations":

"Since the surface UV radiation is much stronger and more harmful to humans and ecosystems in summer than winter, we focus our comparisons in summertime months. This avoids the snow cover contamination at those northern high-altitude sites in winter. Note that the radiative transfer slant column is longer than in winter than summer due to greater solar zenith angle (SZA). The UV biases in winter could be larger than those in summer if the local conditions (aerosol loading and air pollution) are similar. On the other hand, aerosol loadings and pollutant concentrations are usually smaller in winter than summer and thus may produce smaller UV biases. For example, clear-sky biases for all 4 wavelengths from winter to summer decrease by 6% at FL02 with small SZA and increase by 3-8% at CA02 with heavy air pollutions. In consistence with our result, the SZA effects were found to cause various degrees of OMI UV retrieval biases, depending on local conditions [Buchard et al., 2008; Kazadzis et al., 2009; Antón et al., 2010]."

Is the temporal resolution of noontime satellite UV measurements sufficient in view of possible daytime dependent changes in aerosol loading and pollution? How would aspects of spatial and temporal resolution come into question here?

This is a good suggestion. The temporal resolution of satellite UV measurements is not sufficient to depict the rapid changes in aerosol loading and local pollution. This is why in this study we only compared the noontime irradiances that were measured approximately during the concurrent satellite overpasses. The UVMRP 3-minute measurements (irradiances at 4 wavelengths and AOD at 368 nm) were averaged within ±1 hour of the satellite overpass as a first-order approximation to account for the spatial and temporal difference between satellite and ground-based instruments. For pollution (SO_2 and NO_2) monthly data used in this study, they are also retrieved from satellite measurements (GOME and SCIAMACHY) with similar overpass time (10:00 AM vs.

11:15 AM for TOMS). So the different overpass time among those retrievals will have limited errors. For the OMI AOD data, the overpass time difference between TOMS and OMI is larger than 2 hours. This may be one of the reasons for the weak correlation between OMI AODs and TOMS biases. The diurnal variations in aerosol loading, air pollution, and cloudiness will cause much larger uncertainties on satellite UV daily products (daily erythemal dose) as compared with noontime (overpass time) irradiances analyzed in this study. Martin et al. [2000] and Bugliaro et al. [2006] found the uncertainty on daily dose due to diurnal variation of cloudiness alone was around 20-35%. To address the review's concerns, we will add the following text in a new section "**5.4** Other factors for result limitations":

"Note that the TOMS UV measurements only available at noontime are not sufficient to resolve rapid diurnal changes in local aerosol loading and air pollution. Our results may be limited by different satellite overpass times for TOMS surface UV irradiances, OMI AODs, and GOME and SCIAMACHY air pollution data. They are also limited to the first-order approximation that averages ground-based measurements (AOD and surface UV irradiances) within ±1 hour of the satellite overpass at noon to account for the spatial and temporal resolution differences between TOMS and MFRSR. The diurnal variations in aerosol loading, air pollution, and cloudiness are expected to cause larger uncertainties on satellite UV daily erythemal dose products than the overpass noontime irradiances analyzed in this study. Martin et al. [2000] and Bugliaro et al. [2006] found that the uncertainties on daily dose due to diurnal variations of cloudiness alone were around 20-35%."

The authors mention in the summary that the latest OMI retrieval algorithm can at least be improved based on the findings presented. However, regarding the whole globe and the long-term UV data sets from TOMS, I would conclude that it is de facto very difficult or almost impossible to improve retrieved UV irradiance data sets due to the lack of concurrent AAOD or pollution data. Is this true?

We thank the reviewer for the suggestion. We believe it is still possible to improve retrieved UV irradiance data for at least two reasons. First, the global coverage AAOD since October 2004 and pollution data (NO_2 and SO_2) since 1996 are available from recent satellites [Richter et al., 2000, 2005; van der A et al., 2008; and Torres e al., 2007], and their retrieved methods and data products can be improved after rigorous intercomparisons against ground measurements. Second, the AAOD and pollution data directly measured by the ground-based instruments can be used to post-calibrate satellite retrievals to improve the resulting UV irradiances [Krotkov et al., 2005]. We will add the following text to replace the sentence "Our findings …" in summary (page 10991, line 26-28):

“Given recent satellite retrievals of AAOD and air pollution data with better accuracy after intensive cross-validation against ground-based measurements, our findings can be applied along with the post-calibration method of Krotkov et al. [2005] to improve the satellite UV retrieval algorithm for the latest OMI as it is a heritage and extension of that for TOMS.”

Related to 3.: The first sentence in the introduction repeats the well-known fact that UV is harmful to humans, livestock, agricultural crops, and forest ecosystems and that high-quality UV information should be provided. On the other hand, humans, livestock, crops, and (cultivated) forest are prevalently found in or near to areas of higher population density where aerosol loadings or pollution are concentrated. How would the authors comment on this?

Although in urban area the aerosol loading and pollution are high and they can attenuate the UV radiation, UV radiation is still high in summer and harmful to humans and livestock especially if they experience long-term exposure under sun. Second, people spent more time on their vacation in rural scenic spots and beaches since the quicker and more affordable travel than before is available. It increases the chances of sun burn and skin cancer by UV radiation. Armstrong and Kricker [1993] found that about 90 percent of non-melanoma skin cancers are associated with exposure to UV radiation from the sun. Third, the air quality in urban areas has been steadily improved and the potential UV damage still exists. On the other hand, UV radiation is active in the photochemical reaction in urban areas. It plays a significant role in forming smog and aerosols. These chemicals are harmful to human health and it can be thought as the indirect effects by the surface UV radiation. To address the reviewer’s concerns, we will add the following text before “Therefore” in the introduction part (line 1, page 10971):

“In urban areas where population is dense, large aerosol loadings and heavy air pollutions can cause certain attenuations, but UV amounts are still high and harmful for long exposure under the sun, especially in summer. Chances of sun burn and skin cancer from UV radiation increase as people are spending more time in rural scenic spots and beaches for vacations. In addition, UV radiation is an active agent for photochemical reactions to form smog and particular matters, which are also harmful to public health.”

Minor comments:

Page 17: RM for SO2 for 311nm in Table 3 (0.42) is different to the number (0.43) given in line 356 on page 17.

We thank reviewer for pointing out this inconsistency. The number in Table 3 (0.42) is typo and will be corrected to 0.43.

Table 1: An additional map showing the geographical distribution of measuring sites would be more illustrative. Maybe areas with heavy pollution and enhanced aerosol loading can somehow be marked (also related to explanations given on page 21).

We thank reviewer for the good suggestion. Since UVMRP official website has the geographical distribution map for measuring sites, we will add the following sentences in line 11, page 10975 and the caption of table 2:

"The geographical distribution map for the monitoring sites can be found at the UVMRP website (http://uvb.nrel.colostate.edu/UVB/uvb_network.jsf)."

The areas with heavy pollution and enhanced aerosol loading are not marked, as they are more appropriately illustrated in the figures by AODs and SO_2 values.

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