Review of paper:

***A simple parameterization of the shortwave aerosol optical properties for surface direct and diffuse irradiances assessment in a numerical weather model* by Ruiz Arias and Dudhia**

Positives - Interesting topic

Concerns - secondary detail (rel. hum dependence, TSI weighing, vertical distribution) is diverting attention - only two aerosol types are considered (one of them [urban] is unrealistically strong absorbing) - assumed SSA and ASY values in tables A3 to A6 seem incorrect (based on info given) - tests involving significant aerosol loads (those matter) are missing - little relevance for global applications

General comments

The paper evaluates a simple method to address aerosol impacts on downward solar broadband radiative fluxes at the surface and efforts to separate contributions attributed direct and diffuse radiation. The idea here is to use information on mid-visible aerosol optical depth which - if available and accurate – (along with data on atmospheric water vapor and ozone) should define the direct solar broadband flux component at clear-sky conditions (desired in solar energy applications). There is a reliance on that these AOD data are available and accurate. This may be difficult as satellite AOD are not always available and often inaccurate or as climatological values may not apply for any particular investigated condition. Most efforts are spent on defining solar sub-spectral properties of the RRTM radiative transfer model, as not only the mid-visible region but also other solar spectral regions contribute to solar broadband fluxes. The authors hope to cover aerosol impact (assuming AOD550 plus water and ozone column data are available) with one single (aged accumulation-mode) bi-modal size-distribution and with two different aerosol absorption choices. This is way too simple. There is no consideration for coarse aerosol (e.g. dust) and the assumed more absorbing composition is unrealistically strong. Also the validation is not convincing. The validation from direct comparisons focuses on very low AOD cases, so that potentially larger deviations (which should be expected at important larger AOD values) are avoided. Aerosol is highly variable in size and composition. The compositional differences are much larger than the addressed variability in relative humidity (different aerosol types respond also differently on rel.hum). So the extracted added diffuse solar flux attributed to aerosol, which was the purpose of this paper, is highly questionable. I see very little benefit to the community from the proposed approach.

Dr. Kinne, first of all, we would like to express our deepest gratitude for considering the revision of our manuscript. We greatly appreciate all your suggestions and comments on the major concerns you found. They will help us to leverage the quality and relevance of our work. We will start our response by explaining the motivations for this so deliberately simple parameterization.

The parameterization focuses on clear-sky surface downward fluxes. A principal set of applications lies within the solar energy industry, for which global (GHI) and direct (DNI) irradiances are important (Stoffel et al., 2010; Kleissl, 2013). Also, direct-and-diffuse partitioning of GHI allows for a more accurate computation of the energy budget at the soil-atmosphere boundary, particularly in mountainous areas (Hauge and Hole, 2003; Essery and Marks, 2007; Ruiz-Arias et al., 2011; Manners et al., 2012). Overall, however, our interest in diffuse irradiance (DIF) itself is marginal. In this sense, the current observational limitations regarding aerosol single-scattering properties do not help much in achieving a highly reliable wide-area estimation of DIF.

Albeit aerosol impact in GHI can be reasonably well parameterized using an aerosol climatology, this is not generally sufficient either for DNI or DIF, where biases greater than 15% can easily be reached if aerosol amount and its variability are not properly accounted for (Gueymard, 2012a; Ruiz-Arias et al., 2013a). Surely, the most appropriate and comprehensive approach to handle atmospheric aerosols (that would have allowed for a much more reliable evaluation of aerosol contents) is the use of an aerosol transport model with a detailed and speciated description of the aerosol-related microphysical atmospheric processes, including sources and sinks. They make it possible to account for aerosol-cloud-radiation feedbacks, which are very important for determining the atmospheric dynamics and its evolution. However, this overall modeling approach has a few drawbacks that may sometimes discourage its general use for surface applications.

First, they are complex to operate and require a higher level of expertise than the regular "atmosphere-only" weather models or parametric models such as in Gueymard (2012b). As a consequence, they are less accessible to broad sectors of the research and industry communities (e.g., PV, concentrating PV, concentrating solar power). Second, they are computationally costly. Surface applications usually require high spatio-temporal resolution simulations that can be hardly achieved with coupled atmosphere-chemistry models using regular computers, even though a certain degree of simplification might be applied to the parameterized microphysical aerosol processes. Third, aerosols initialization poses one additional level of complexity and uncertainty. Current satellite retrievals of aerosol-related properties from the atmospheric observing system are limited either in spatio-temporal coverage (Winker et al., 2010) or in number of reliably observed variables (Levy et al., 2010). In this respect, it is convenient to highlight that albeit the current retrieval uncertainty in AOD (for instance, from MODIS onboard Terra and Aqua satellites) is valuable for GHI assessment and, to a lesser extent, for DNI and DIF assessment (Ruiz-Arias et al., 2013a), the uncertainty in aerosol single-scattering properties is still poor with MODIS-like sensors (Levy et al., 2010). It can be considerably uncertain even from high-quality ground measuring stations (Dubovik et al., 2000).

All these reasons encouraged us to search for a simple and fast, yet sufficiently accurate, parameterization of aerosol optical properties for surface downward fluxes, with emphasis on GHI and DNI. One additional aspect of our approach is that, as its main input is AOD, it can be fed with AOD observations directly from any satellite platform (possibly, ground-corrected previously). On the contrary, in forecasting mode, AOD from a chemistry model such as MACC or GEOS-5 could be used. Overall, we envisage this modeling approach as an alternative for clear-sky surface downward fluxes modeling while the aerosol transport models and the Earth Observing System reach higher level of maturity and broader dissemination. We believe this parameterization is of large interest for people concerned with the modeling of solar resources over wide regions using limited-area regional models.

Numerous benchmark studies (Gueymard, 2003; Ineichen, 2006; Badescu et al., 2012; Gueymard, 2012b) have demonstrated the capability of simple clear-sky surface solar radiation models to provide high-quality solar flux estimates within, or near, the expected observational error range. The best ones parameterize the aerosol turbidity following the Ångström formulation, thus using a single spectral value of AOD (typically, between 500 nm and 1 micron) and the Ångström exponent. The inputs for single-scattering albedo and asymmetry factor are normally fixed at effective broadband values. This is consistent with the very limited availability of such observations and the high uncertainty usually attained to them (Dubovik et al., 2000). An alternative approach, available for use in many detailed radiative transfer models (RTM) such as SBDART (Ricchiazzi et al., 1998), MODTRAN (Berk et al., 2005), libRadTran (Mayer and Kylling, 2005) or SMARTS (Gueymard, 2001), is the use of a prescribed aerosol type from which to infer the spectral distribution of AOD and the spectral aerosol single-scattering properties. This has been the approach followed here in such a way that the aerosol type can be selected by the user according to the prevalent conditions expected in the region of interest during the simulation.

From the very beginning, we considered two options for the aerosol types to be implemented: the OPAC database (Hess et al., 1998) and an AERONET-based climatology. The latter is probably the most natural approach. However, it involves a profound research that was out of our immediate scope, which is more focused at promptly getting improved GHI and DNI estimates with respect to the no-aerosols case. Regarding the OPAC database, it offers up to 10 different aerosol types. However, as we were reviewing the literature we realized that the Shettle and Fenn (S&F) aerosol types (Shettle and Fenn, 1979) have been more widely tested than OPAC, mainly because they were derived first, with generally acceptable results for the purposes of this work. Hence, albeit we recognize the limitations and concerns that are attained to the S&F aerosol types, we decided to use S&F for two main reasons: first, they have demonstrated their ability to represent reasonably well clear-sky surface solar fluxes (Ricchiazzi et al., 1998; Gueymard, 2001; Carr, 2005; Gueymard, 2008), and second, they offer the possibility of a closer benchmarking against other RTMs. Notwithstanding, we admit the necessity of further improvements in the aerosol type modeling in order to represent more realistically the atmospheric aerosol contents and to span a broader range of situations such as, in particular, those in dusty desert areas. This must be done, however, admitting also that, from a user' standpoint, which is an important constraint of this method, it is desirable to have a simple approach that does not involve any decision at running time other than select among a set of fixed aerosol types regarding the mixture of aerosol species. The AERONET approach might fulfill this requirement and is going to be considered in the future.

The validation of the aerosol parameterization has been conducted throughout an entire year of observations in five main AERONET sites co-located with (or near to) BSRN sites, spread over diverse climate regions within the Contiguous US region. We recognize that the AOD range of values is limited, so that the validation is not conclusive regarding the performance of the parameterization under high loads of aerosols. However, it gives a measure of the expected model performance in the Contiguous US region and, hopefully, in regions with similar characteristics. The Contiguous US region is a large and important area for many of the applications envisaged for the parameterization. In particular, this work is part of a set of improvements carried out in the WRF system, overall referred as WRF-Solar, aiming at improving the skill of the WRF model for surface solar applications (Haupt, 2013).

We would like to add that, before addressing the validation of the aerosol parameterization under high AOD conditions, we believe it is pertinent to evaluate the skill of the RTMs and, in particular RRTMG, at predicting clear-sky surface solar fluxes in these situations under the best possible operating conditions. To our knowledge, this task has not been addressed so far. By best operating conditions we mean the use of aerosol and water vapor characterization from AERONET observations (input to the RTM) and surface irradiance validation against BSRN sites. This study will allow separating the potential RTM biases from those coming from the assumed aerosol type in the aerosol parameterization. In fact, the main author of this work is currently involved in such a study consisting of a thorough multi-year evaluation of the performance of the RRTMG 2-stream RTM and other parametric models, under cloudless and extremely high turbid conditions in arid/desert regions using co-located stations from the AERONET and BSRN networks. The validation dataset includes, among others, the well-known sites of Solar Village, Sede Boker and Tamanrasset. This same approach has been followed for the aerosol parameterization evaluated here (Ruiz-Arias et al., 2013b).

In our opinion, this work proves the validity of this very simple and direct parameterization of the aerosol optical properties for surface solar flux assessment and supports the future search for improved aerosol types to expand the areas of applicability of the parameterization.

Minor comments

Tables and figures (I started here, because they need to be self-explanatory)

Table 1 apparently values refer to the central wavelength of spectral solar sub-bands with respect to the wavelength (and solar energetically bands 13 and 14 are irrelevant)

 refers to the spectral-band mean wavelength. Bands 13 and 14 are not relevant for solar fluxes, but they are part of the RRTMG short-wave RTM. In fact, the irrelevant role of these bands is a motivating factor for the use of a TSI-based spectral weighting scheme.

To clarify the contents of the table, the caption will be extended as follows: *"Spectral distribution in RRTMG. From top to bottom rows, λ's (in nm) are band mean, minima and maxima values, respectively."*

Table 2 Relative humidity can swell aerosol size and reduce the Angstrom parameters. This is apparently considered here, although I would assume that rural aerosol sizes are often larger than sizes related to urban pollution (opposite as to what is shown here). Another concern is that the Angstrom parameter is mainly modulated by the dominant aerosol type, being lower than 0.5 for dust and larger than 1.5 for heavy pollution and wildfires. So the covered Angstrom range of the table is limiting to a specific aerosol type. It is also not clear from the table what the difference between α_1 and α_2 is? Apparently, it accounts for the spectral dependence of the Angstrom parameters given with different value for wavelengths below 550 nm (α_1) and above 550 nm (α_2). Again, this is detail for a specific aerosol type (and size). Given the actual diversity in aerosol type and size distribution, these assumptions are very limiting in applications.

The expected trend in Ångström exponent (AE), as you point out, is to get a decreasing value as the mean aerosol size increases. However, in the S&F aerosol types, AE values for the urban type are smaller than for the rural type. The approach we follow for the AE modeling is based on SMARTS (Gueymard, 2001). Our computation is, however, independent from the one in this RTM. The values and trends of AE we obtain are consistent with those used in SMARTS (Fig. B.2, Gueymard, 2001), and also in SBDART (Fig. 2, Ricchiazzi et al., 1998). Our explanation for the counter-intuitive trend is that the so-called urban and rural S&F types are not 100% urban and rural, respectively, but rather two mixtures that resemble urban and rural aerosols.

We included the rural aerosol type in the aerosol parameterization to represent the most typical large-scale average conditions. Very large or very small aerosol sizes still remain unaccounted for.

To clarify the contents of Table 2, the caption will be extended as follows: *"Ångström exponents for each band (computed as described in Sect. 3.1), aerosol type and relative humidity."*

Table A1 – A6 In the table apparently extinction ratios (with respect to the reference wavelength at 550nm), SSA and ASY values for all 14 RRTM solar spectral bands for the two considered aerosol types are offered. These two aerosol types hardly cover the spread of aerosol properties (e.g. check with optical and microphysical AERONET statistics). I am puzzled about the assumed mid-visible absorption of 'urban' aerosol. The SSA is extremely low (SSA at 550nm: 0.64 at 50%rh and 0.78 at 80% rh – check with AERONET).

Right. These two aerosol types do not span all the range of possible SSA and ASY values. As we mentioned earlier, from the very beginning, we considered the implementation of an extended set of aerosol types from the OPAC database. However, we were interested in the validation of this parameterization approach and the S&F types offered a closer benchmark against other RTMs. For this reason we are only offering two aerosol types at this early stage of development. In the future, once that the validity of the method has been stated, we plan to focus at getting improved aerosol types, either from existent databases such as OPAC or from an observation-based perspective from the long observational record now available in AERONET. The SSA values are indeed low as compared with Level-2 AERONET. We provide an extended discussion in one of your upcoming comments.

Figure 1 Scaling factors are presented for the rural aerosol type for all 14 solar spectral sub-bands as function of the relative humidity. I wonder, why only rural and not urban aerosol factor are presented? I do not understand the difference between 'weighted' and 'unweighted' results, which are quite different. Generally I wonder about the scaling factors, which range from values below 1 and well above 1. (I guess these are just the extinction factor with respect to the 550nm reference wavelengths as the values for band 10 (533nm) are close to 1). I assume that the factor change at higher relative humidity is due to size-increase (water uptake). How are changes in atmospheric water vapor accounted for (which affect the extinction in near-IR bands? Or is this ignored?). Given that water vapor in the atmospheric column should have a strong impact it seem more logical to me to include aside from AOD,550nm also atmospheric water as other variable (with relative humidity impacts on AOD only as secondary effect… also since some aerosol types resist water uptake, like dust or fresh BC).

The one reason to show the AOD spectral scale factor only for rural aerosol was conciseness. The case of urban aerosol is shown in Fig. R1. As for the rural aerosol, the urban type responses to changes in relative humidity only above 70%. However, it does so with opposite tendency for relative humidity values between 70% and 90% in the spectral bands 1 through 9 and 14.

As AOD has to be provided to RRTMG as a single value for each spectral band, some kind of aggregation has to be addressed from the spectral specification in the S&F types. We do it as depicted in Eq. (2) in the manuscript. We include in the expression the spectral extraterrestrial solar irradiance to consider the fact that some bands are thick and/or irrelevant for solar calculations, such as the case of band 14. This is the "weighted" case in

Fig. 1 and Fig. R1. In the “un-weighted” approach, the solar irradiance spectrum is considered unity for any wavelength.

As you suggest, relative humidity is an input to the parameterization that is taken directly from the numerical weather model and its value is updated every time the radiation model is run.

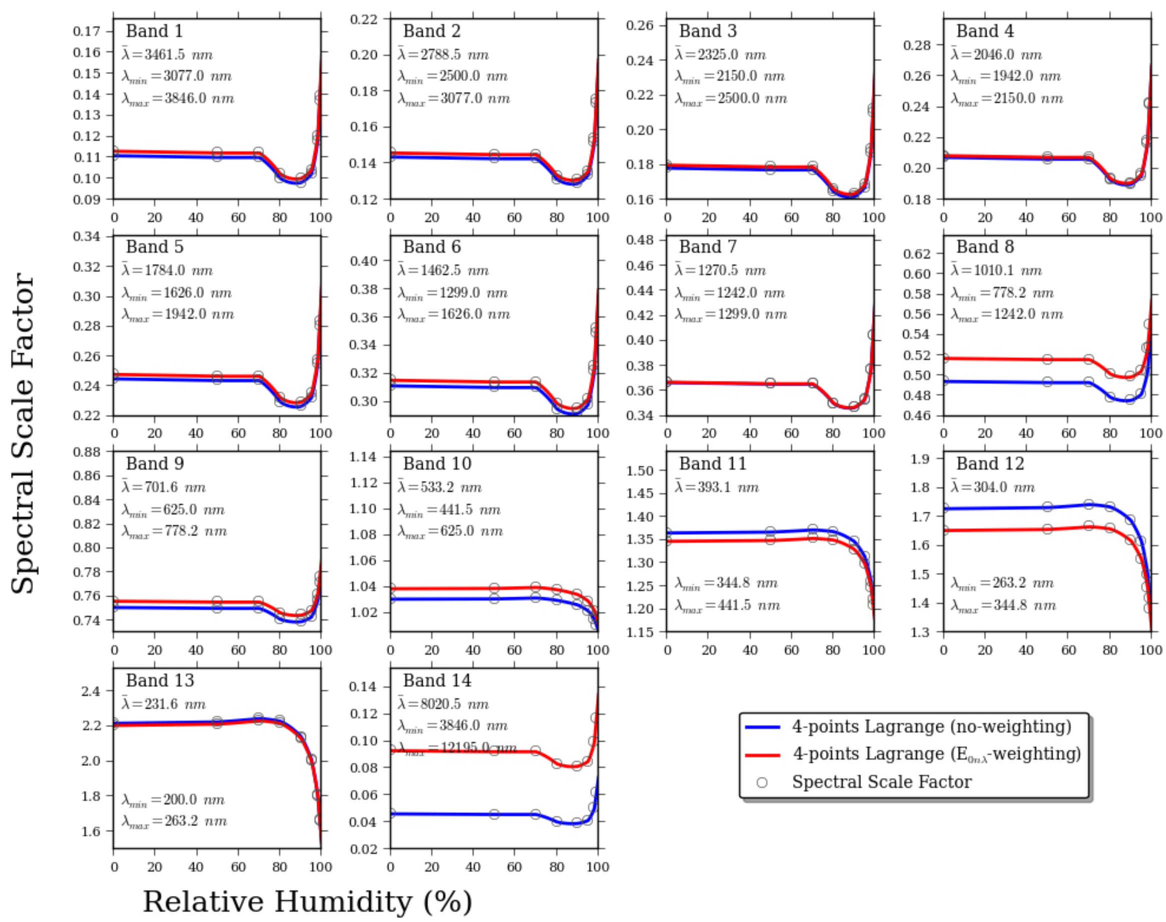

Figure R1. As Fig. 1 in the manuscript but for urban aerosol.

Figure 2 It is difficult to see the details (possibly ignore band 14 for a better spread). Again the urban aerosol absorption potential (1-SSA) is very large (unrealistic for typical conditions).

We would like to maintain all the spectral bands because, in particular, band 14 illustrates the convenience of using the “weighted” average scheme.

Figure 3 Results are investigated apparently for six sites. A 5% error seems unacceptably large (e.g. 40W/m2 at 800W/m2 solar insolation). I think that the broadband solar flux observational (measurement) error is only at 5 to 10W/m2. From the comparisons I conclude that the generally good agreement for solar downward fluxes at all-sky conditions is based on the prescribed AOD and larger deviations for diffuse radiation indicate problems with the assumed aerosol absorption.

The reference for shortwave solar measurements is the World Radiometric Reference (WRR), whose absolute uncertainty is claimed to be 0.3%, but it is only defined at 700

W/m^2 or greater. Thus, generally the uncertainty estimates are referred to high irradiance values, 700 W/m^2 or greater (personal communication with Daryl Myers, 2014). Even in these conditions, the uncertainty in well-maintained pyranometers can be as high as 4%, and as high as 3% for pyrheliometers (Reda, 2011; Habte et al., 2014; Michalsky et al., 2011). The main sources of uncertainty are related to calibration, responses to changes in solar position (zenith and azimuth), spectral distribution of irradiance, temperature,… If the instruments are not maintained in a regular daily basis, uncertainty can arguably reach 5% by sun-tracking or soiling issues, for instance.

Figure 4 Only AOD,550nm up to values of 0.2 are investigated (there are often many times larger AOD values)? What are the very low SSA values in the frequency distribution? Are they related to very low AOD values… in which case they are meaningless. Make a frequency distribution for AAOD (=AOD*[1-SSA]) rather than SSA. Again the reference data seem WRF simulations. Measurements (e.g. AERONET) would be much more useful, especially if there are many modeling issues to potentially contaminate (unless WRF skill has been demonstrated against AERONET statistics). If the total flux error is at 5% then I expect the diffuse percentage error to be much larger than the direct percentage error at cloud free/low aerosol conditions.

The SSA values in the frequency distributions are AERONET Level-1.5 observations (blue) (therefore, non-limited by AOD at 440 nm), the SSA values with the rural aerosol type (green) and with the urban aerosol type (red) [We have detected a typo during this revision process. In page 608 line 27 should read that 95% of the SSA values for the rural type are between 0.92 and 0.94. The mean value is at 0.93]. The SSA values estimated with the aerosol types are fixed values, only dependent on the relative humidity. The frequency distribution in the rural and urban types is thus only due to WRF model changes in relative humidity. Note therefore that the only way WRF modifies the SSA values is through relative humidity variations.

We would like to comment here on the major (instrumental) limitation of AERONET at measuring SSA, since only values observed with AOD at 440 nm greater than 0.4 are considered reliable enough for research purposes (Level-2 data). This is a very severe limitation in regions with regularly low AOD values, such as the Contiguous US. Level-1.5 SSA data are cloud-screened but have not been yet corrected for likely calibration drifts (usually small corrections). They neither incorporate the minimum 0.4-AOD threshold requirement. The consequence is that Level-1.5 SSA values are less reliable (more uncertain) than the Level-2 counterpart (Dubovik et al., 2000). To our understanding, this does not mean they are useless, but rather that they must be used carefully. Of course, Level-1.5 data should not be used as the main dataset supporting new model developments.

Fig. R2 shows the distribution of SSA values at 440 nm as a function of AOD at 440 nm at four sites in the Contiguous US region, three of them are included in the validation dataset of our aerosol parameterization. Open squares are the counts for Level-1.5 data, and filled squares are the counts for Level-2 data. For AOD at 440 nm greater than 0.4, the mean SSA value (red and green lines) is above 0.9, which is seen as a typical and reliable value of SSA. However it is representative of abnormally high AOD values (at least for these sites), thus it may not be representative of their typical conditions. Level-1.5 values suggest that, for lower turbidities, the aerosol scattering efficiency decreases, although this conclusion must be always subject to the concerns inherent to AERONET observations of SSA under AOD at 440 nm below 0.4.

In particular, for the BSRN_BAO_Boulder site, Ruiz-Arias et al. (2013b) chose a series of clear-sky days with abnormally low SSA values (similar to those assumed by the urban aerosol type). They used these AERONET-observed SSA values as inputs to the RRTMG model resulting in improvements for DIF computation. Of course, these SSA values are not frequently registered in this site, and they have considerable uncertainty. However, from an application point of view, they resulted in overall improvements.

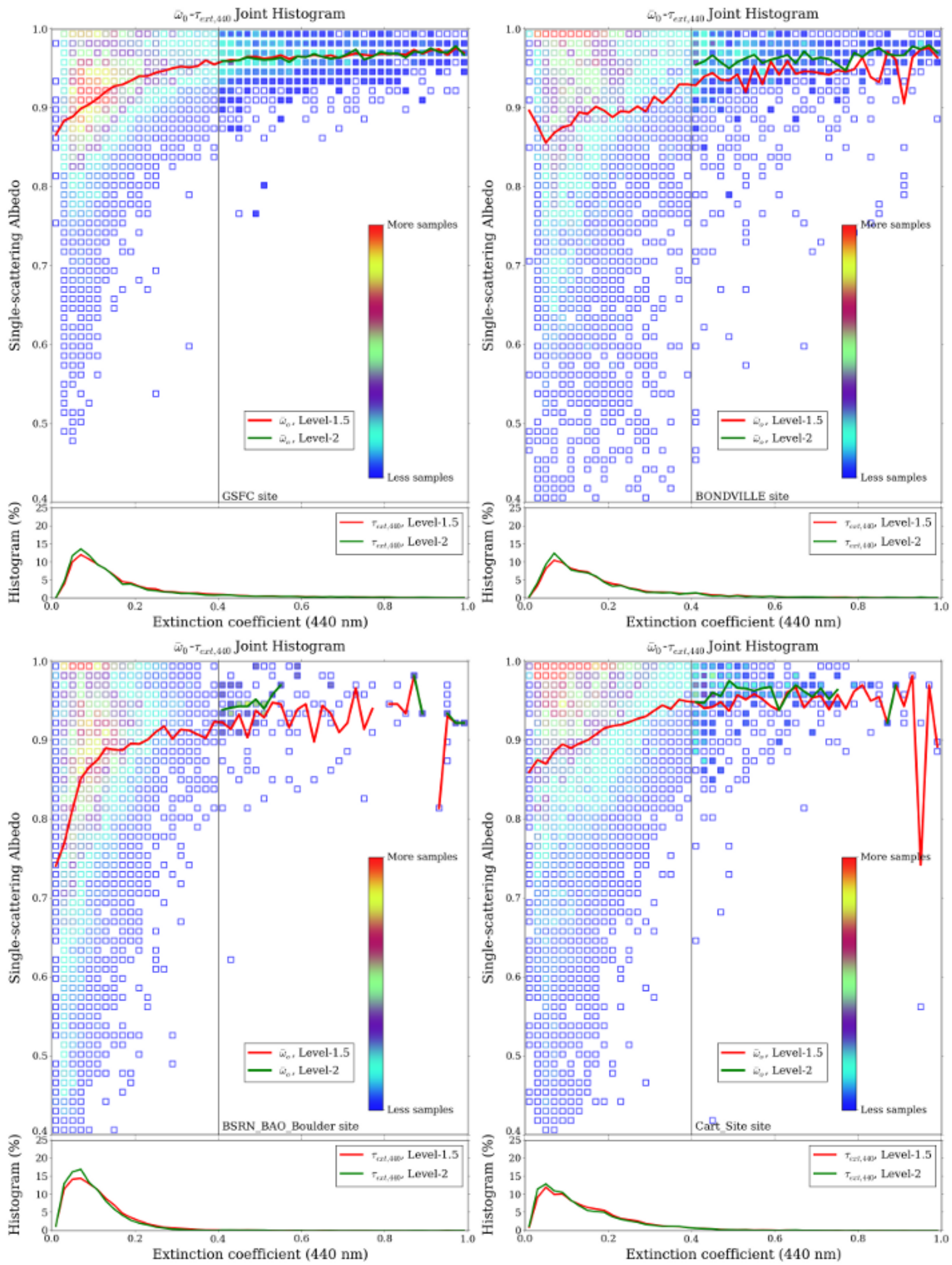

Figure R2. Distribution of SSA values at 440 nm as a function of AOD at 440 nm at four AERONET sites in the Contiguous US region: GFSC (top-left), Bondville (top-right), BSRN-BAO-Boulder (bottom-left) and Cart-Site (bottom right). For each site, the upper panel shows the counts of SSA Level-1.5 data (open squares) and SSA Level-2 data (filled squares). The red and green lines are, respectively, the mean SSA Level-1.5 and SSA Level-2 values as a function of AOD at 440 nm. The lower panel for each site shows the histogram of the extinction coefficient at 440 nm.

Figure 5 This figure was included to demonstrate progress over the Duhia model… but its underlying assumptions (strength and limitations) of that model need to be addressed in order to judge on progress.

The next brief overview of the WRF's Dudhia short-wave scheme will be included in the manuscript: *"The Dudhia SW solar radiation scheme is a simple broadband parameterization that considers extinction by Rayleigh atmosphere and water vapor. It does not account for multiple scattering effects. Extinction by ozone, aerosols, and other molecular absorbers is not explicitly parameterized (Dudhia, 1989). Instead they are all accounted for by using a bulk scattering parameter that was empirically fixed for average turbidity conditions (Zamora et al., 2003, 2005). Further references may be found in Ruiz-Arias et al., (2013)"*

Text

Chapter 1 (Introduction) Just to get the terms correct… GHI = DNI +DIF… if there is no terrain issue which you neglect. Correct?

GHI=DNI*cosZ+DIF, where cosZ is the cosine of solar zenith angle. Where surface reflected irradiance is non-negligible (for instance, in mountains, particularly if they are covered with snow) the reflected irradiance from surroundings must be also added.

I wonder about the usefulness of so called 'simple methods' (Dudhia 1989) – no link found?

The Dudhia scheme (described in Dudhia, J.: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model, J. Atmos. Sci., 46, 3077–3107, 1989. 596, doi: 10.1175/1520-0469(1989)046%3C3077:NSOCOD%3E2.0.CO;2) is a comparatively fast broadband short-wave scheme against other RTMs such as RRTMG. It accomplishes a fairly simple modeling of upper-atmosphere solar fluxes and relies on empirical corrections to achieve a reliable estimate of GHI. At the high resolution (both temporal and spatial) achieved in limited area models such as WRF, the short- and long-wave radiation schemes are a computational bottle-neck. For this reason, for those applications focused on surface fluxes, fast radiation schemes are desirable, sometimes even at the expense of less reliable simulation of upper-atmosphere fluxes.

What do you mean with "run with near instantaneous observations"… what observations, how included?

Sometimes (and not negligibly) aerosol effects in surface fluxes are evaluated from averaged aerosol optical properties, from daily to seasonal periods. We want to emphasize here that we are using direct (instantaneous) observations from AERONET.

Chapter 2 With respect to aerosol induced changes in GHI by the DNI and DIF changes are of opposite sign but do not offset each other completely as with more aerosol… less GHI.

We totally agree. In fact, we admit that our sentence "Thus, errors in DNI and DIF fluxes caused by a misrepresentation of the aerosol load cancel out in GHI" is inappropriate since it wrongly states that changes in DNI and DIF by aerosols totally cancel out each other. We didn't mean that. Therefore, we will update that sentence in the manuscript to become:

“Thus, errors in DNI and DIF fluxes caused by a misrepresentation of the aerosol load partly cancel out in GHI, in the general case”.

I would say that AERONET offers all relevant AOP data (AOD, size-distr and ref.indices at 4 solar wavelengths so that AOD, SSA and ASY could be (MIE) easy determined)… apparently these data are used in the evaluation of the described approach

Yes, we use as skill reference for the evaluation of the aerosol parameterization with prescribed aerosol type, the case when RRTMG is run using exclusively aerosol inputs from AERONET observations (Ruiz-Arias et al., 2013b).

As we recognize the fact that some local applications might have access to AERONET or similar data, the implementation of the parameterization in WRF has been such that, the value of AE, SSA and ASY can be chosen from either a prescribed aerosol type (then the parameterization is fully used) or use a time-varying value from, normally, ground (AERONET-like) observations (then, the aerosol parameterization is not used).

Chapter 3 I am wondering about the (two) aerosol models that are used. These models are very old, while in contrast there is now much more info on aerosol properties from AERONET sun-photometer statistics (collected over more than 10 years at many sites globally) available. The aerosol models (rural and urban) have an effective radius of about 0.067um. Thus, all aerosol particles are concentrated in a relatively small size accumulation mode. In that context also the Angstrom parameters given in Table 2 are inconsistent with that size-distribution. The adoption of 20% soot for the ‘urban’ aerosol is unrealistic, as such high BC content (on top of already absorbing aerosol) is rather rare. The result is very low SSA values. And such low SSA values are not (AERONET) observed, unless for extremely rare events, if at all. (Why relying on such an old reference data, as we have learned so much more from AERONET statistics?)

We agree with you. We have already added comments on our reasons to rely on S&F aerosols. But, to add a bit more on this, we would like to highlight that we simply adopted a pragmatic approach. S&F types have proven to produce reasonable results (essentially, the rural type), not only in our validating tests, but also with other RTMs. However, for all the reasons you have exposed, some better/deeper research to get more appropriate aerosol types for our surface requirements is pertinent and timely as well. AERONET data may serve as a starting point for this task. However, this task very likely needs also ancillary datasets from aerosol transport models. Overall, it is a hard task and, in the meantime, S&F can be used to provide DNI/DIF estimates and, later, used as a skill reference for new AERONET-based aerosol types.

Chapter 3.1 With only one realistic choice for absorption and only one choice for the aerosol size-distribution (Shettle and Fenn), all the additional efforts on accounting for (e.g. Angstrom) spectral dependence, on considering impacts of a changed relative humidity and on the weighing via the solar constant (TSI) within solar spectral subbands (the largest rel. errors probably occur in extreme [uv, ir] bands, where solar insolation is relatively small so that the overall the impact should be close to negligible) seem almost irrelevant. To correct: Shettle and Fenn provide information on the (bimodal) size-distribution and on spectral refractive indices from which SSA and ASY can be derived (with MIE simulations) - they do not provide SSA and ASY value. When applying the rural bimodal size-distribution (999.* 0.03/1.42 and 0.125*0.5/1.5) and refractive indices (at 550nm 0%rh: 1.59 / -.66e-2) as given in Shettle and Fenn, I get a SSA,550nm of only 0.87 and an ASY,550nm of 0.52.

Both values are lower than those given in Tables A3 and A5. This makes me wonder on what undisclosed assumptions the values in Tables A1 to A2 are based on.

We used the reference "Shettle, E. P. and Fenn, R. W.: Models for the aerosols of the lower atmosphere and the effects of humidity variations on their optical properties, Tech. Rep. AFGL-TR-79-0214, Air Force Geophys. Lab., 1979. 600, 601, 603, 604, 626" As an independent benchmarking, our results are consistent with the values used in SMARTS. Again, we acknowledge that these aerosol types are not likely realistic, and probably have to be improved, but they are however reasonably accurate for the requirements in many surface applications.

Chapter 3.2 Again, weighing the TSI weighing [SSA (with AOD and TSI) and ASY (with SSA, AOD and TSI)] is only of secondary importance. Getting the appropriate size-distributions is much more important.

Yes, it is. But, in our opinion, the weighting scheme is reasonable, independently of whether size distribution is more or less realistic.

Chapter 3.3 Also the vertical distribution is only a secondary importance. It would be though interesting if the approach compares well to CALIPSO space-lidar statistics on aerosol vertical distributions.

The typical assumption is to consider an exponential profile. CALIPSO reveals that this is a reasonable assumption many times, but not always. Achieving a more realistic vertical profile would require very likely the use of a different modeling approach considering, particularly, the vertical distribution of aerosol species. But this is something that we deliberately are trying to avoid to keep things simpler and faster.

Chapter 4.1 What AERONET data are actually used (only AOD550 and water column data?). If only these data were used was there a sanity check? Were predicted sub-spectral AOD data of the WRF model compared to the sub-spectral AOD (440,500, 670, 870, 1020nm) AERONET data? Has WRF modified the originally supplied AOD550nm to be spatially consistent with other site data and if so, by how much? Or are simply off-line radiative transfer simulations applied? Please clarify.

In the control experiment (Ruiz-Arias et al., 2013b), all AOP (namely, AOD, AE, SSA and ASY) and water vapor column amount came from AERONET observations (off-line simulations). In particular, AE values are the ones provided by AERONET from sub-spectral observations of AOD between 440 and 870 nm. As in the Contiguous US region the availability of SSA Level-2 data is very limited, we used Level-1.5 observations with the corresponding concerns about its increased uncertainty (estimated in about 0.05-0.07, Dubovick et al., 2000). Five independent simulations were run in the experiment, using a local domain for each one of the five sites. Model water vapor column amount was scaled at each model time step to the observed values in the AERONET site.

Chapter 4.2 The test case combines poor spectral definitions for AOD, SSA and ASY at non 550nm wavelengths due an inappropriate assumption for the size-distribution (failure to be AERONET consistent)

The aerosol optical properties in the test case are fully described from observations gathered at AERONET sites at the 4 standard wavelengths (namely, 440, 500, 670 and 870 nm). It may represent a poor spectral description but AERONET, however, implements the highest quality routine observations of aerosol microphysical and optical properties in a global basis. The GHI, DNI and DIF values obtained using the aerosol parameterization are benchmarked against the results obtained using fully described aerosols from AERONET observations.

For the Table Mountain site (TBL) it is argued that the strong absorption aerosol type is relevant. But is not Table Mountain a very remote site, where urban pollution should not be an issue, unless there was a wildfire in which case I would expect elevated AOD? For the case of low SSA match it also would be of interest what the associated AOD is. In case of a very low AOD (very noisy)... who then cares?

The case of TBL is just a case example. We don't mean the typical aerosol in TBL is very absorbing. For the days tested in this site, the registered SSA values were very low, with also a low value of AOD. By not rejecting these days we are simply explicitly testing whether the use of Level-1.5 SSA observations may be useful in some cases, regardless of their inherent higher uncertainty. Actually, the use of this SSA data resulted valuable for the DIF estimates, as can be seen in Fig. 5 in Ruiz-Arias et al. (2013b). Furthermore, Fig. 3 in this manuscript shows how, for the specific days simulated in TBL (with low Level-1.5 SSA values), this particular urban aerosol resulted in good agreement with the observed DIF. We expect however that the rural type is generally better than the urban type (it is more realistic), but the latter may be better for some very specific cases and situations.

Chapter 5 Please briefly describe the Duhia SW scheme (how many spectral bands?) and assumed simplifications.

A brief description of this scheme will be included in the manuscript.

Chapter 5.1 The validated AOD range only addresses AOD values up to 0.2 (the average value of 0.06 corresponds to clean oceanic background!). Thus a real test for strong aerosol loading is avoided… so at minimum the 'validation' is incomplete.

The validation for high AOD values has not been intentionally avoided. Figure R3 shows the histograms of the historic Level-2 records of AOD at 550 nm at the 5 sites tested in this work (panels a-e) and four more reference sites for different aerosol climate conditions: GFSC (urban), Mongu (Zambia) (biomass burning), Lanai (Hawai) (maritime conditions) and Solar Village (desert dust). As can be seen in panels (a) to (e), the mean values of AOD are below 0.2 except for Bondville (0.28). In all these five sites, more than half of the AOD records have values below 0.2. Thus, we have not avoided deliberately high AOD cases. Furthermore, we are currently conducting a study at evaluating the RRTMG skills at predicting clear-sky surface solar fluxes under high turbidity conditions, with predominant coarse mode, such as in Solar Village. We aim at characterizing the real skills of RRTMG in these conditions before addressing the parameterization of an appropriate aerosol type for these specific sites.

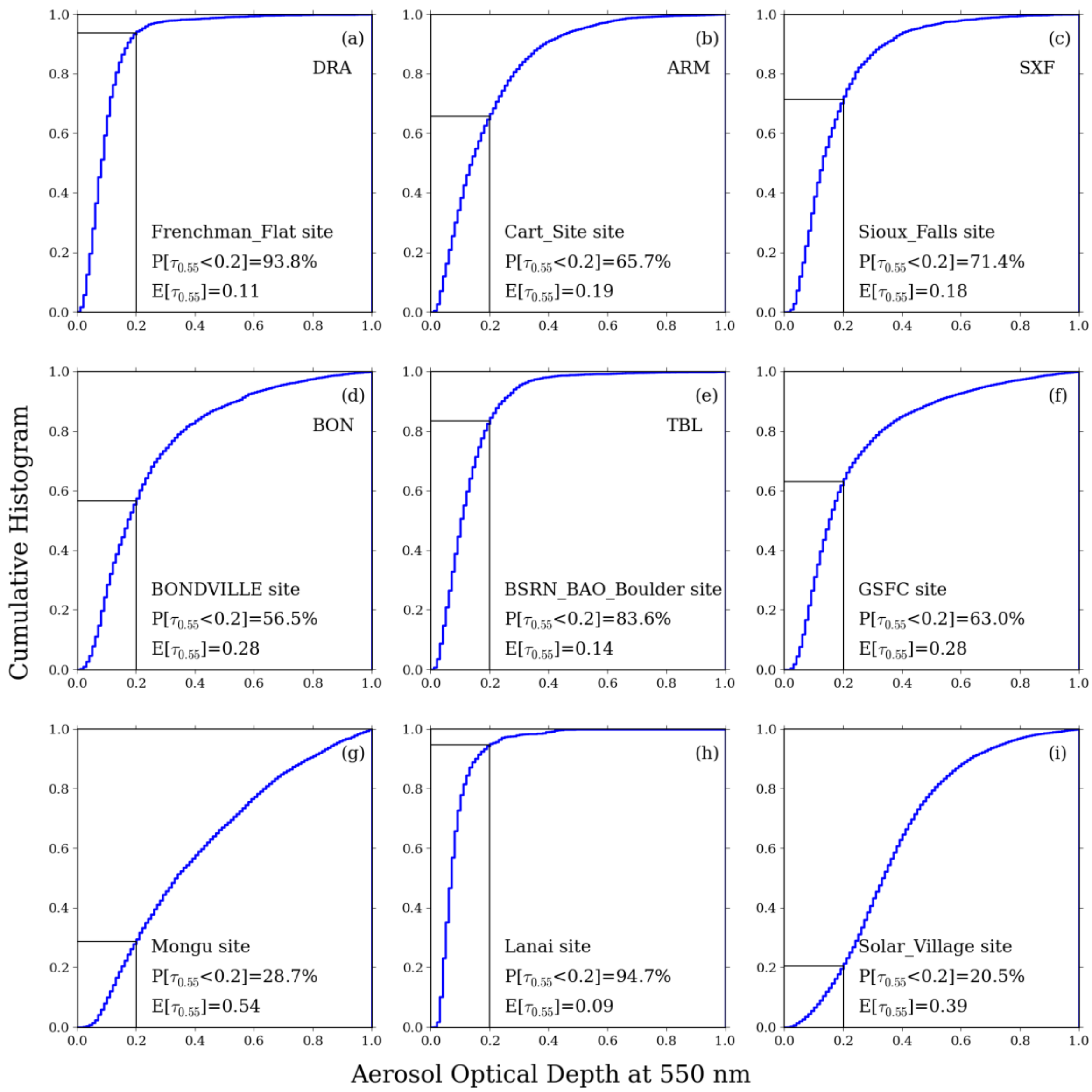

Figure R3. Distributions of AOD at 550 nm from the historic Level-2 records at AERONET at the 5 experimental sites evaluated in this manuscript and four more reference sites for different aerosol climatic conditions: GFSC (urban), Mongu (Zambia) (biomass burning), Lanai (Hawai) (maritime conditions) and Solar Village (desert dust)

Chapter 5.2 I do not understand this paragraph. If seasonal varying AOD data are used as input certainly this is better than using an annual average value. It is unclear tough why the Duhia model underestimates solar fluxes in winter, as the largest AOD values over the continental US are usually observed during spring and summer.

The reason is that, as AOD levels are higher in spring and summer than in autumn and winter, the mean AOD value throughout the year is greater than the typical values in winter. Thus, the constant yearly-mean AOD assumed by the Dudhia's model is higher than the actual winter values. This explains the overall flux underestimation in winter.

Chapter 6 I wonder about the (dis-) agreement of sub-spectral AOD and SSA of AERONET to those of your spectral assumptions for the test-cases. I agree that that the AOD550nm value, if available and accurate is a good first order estimate to constrain impacts on solar fluxes at the surface (and you should have stopped here). I am not sure if the method can be unilaterally applied globally, since the rural mode only addresses the fine (or accumulation) mode aerosol size and many (potentially available) AOD maps from satellite data are often inaccurate and biased (due to a-priori assumptions for aerosol absorption and size and for surface reflectance). I completely agree with the last sentence... what do YOU do with this approach in cases of dust?

Of course, the method cannot be applied globally. That is why we state at the end of Sect. 6 that *"...it is evident that they do not cover all the possible range of climatic situations regarding aerosols and new aerosol types should be incorporated and validated. Of particular interest for solar energy applications is the case of desert areas, dominated by dust aerosols, since they hold much of the worldwide solar energy potential."* We also recognize that satellite data are still noisy (Ruiz-Arias et al. 2013a; Ruiz-Arias et al., 2013c). But they are the best current approach for regional evaluation of aerosols, particularly, AOD. Besides, models are also noisy, and previous evaluation under best-case conditions are necessary (Ruiz-Arias et al., 2013b).

In case of dust, we still have to add a specific aerosol type, and this is on-going research, that has started with the evaluation of RRTMG in highly turbid conditions. In the mean time, typical constant values can be used in the WRF simulations, and these values can be fixed specifically for each particular model set-up.

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