A simple method for removing 3-D radiative effects in satellite retrievals of surface irradiance

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Abstract

As the spatial resolution of satellite sensors increase, estimates of surface solar irradiance (I_{SFC}) from space borne observations of top of the atmosphere reflected radiance (R_{TOA}) can actually become less accurate because of enhanced three-dimensional (3-D) radiative effects that are not generally considered in most retrieval algorithms. An elementary approach to improving retrievals is to incorporate some form of spatial averaging through the use of superpixels. Determining the best approach for averaging and the optimum size of the superpixel is the objective of this study. It is achieved by examining the bias, correlation coefficient, and root-mean-square error (RMSE) between the true and estimated I_{SFC} for a set of simulated cloud scenes and their radiative fields. Because of nonlinear effects, averaging within the superpixel should only be performed after I_{SFC} is retrieved from R_{TOA} independently for each pixel. For the combined set of stratocumulus and convective cloud fields that have a cloud fraction ranging from 0.25 to 1.0 used in this study, the optimal superpixel size is about 25 km. It is found that the bias is a function of solar and viewing angles and a correction is provided that improves the bias while leaving the correlation coefficient and root-mean-square error unchanged.

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1. Introduction

For understanding climate processes and validating climate models, an accurate understanding of the distribution of the solar radiation reaching the Earth’s surface is essential. Over the last few decades, obtaining estimates of the broadband shortwave surface irradiance (I_{SFC}) over large areas has been greatly enhanced through remote sensing techniques that relate I_{SFC} to satellite observations of reflected radiance (R_{TOA}; e.g., Bishop & Rossow, 1991; Gautier et al., 1980; Schmetz, 1989; Pinker et al., 1995). Whereas the retrievals can be quite accurate for clear or overcast conditions, substantial errors can arise for more complex cloud fields (Gautier & Landsfeld, 1997). Often the errors are related to issues of sampling where surface point measurements are compared to pixel values that are inherently area-averaged. However, with technological advances leading to satellite sensors of increasing spatial resolution, the source of the problem is becoming more physically based as three-dimensional (3-D) radiative effects of clouds take on greater importance. These effects include nonlocal cloud shadows, reflections from cloud sides, and enhancement of clear-sky downwelling radiation by photon diffusion from clouds. They are not presently accounted for in retrievals of I_{SFC} because most retrieval algorithms use an independent pixel approximation (IPA) whereby photons in an atmospheric column above the pixel do not travel horizontally for computational efficiency. A more detailed review of these issues is provided in our accompanying paper by Wyser et al. (2002).

There are several methods to mitigate the impact from nonlocal effects including: (1) using full 3-D radiative transfer models in the retrievals, (2) adding correction terms
to the IPA based algorithms, or (3) degrading the spatial resolution so that 3-D effects are reduced and the field becomes more amenable to the IPA assumption. Running a full 3-D radiative transfer model is very computationally expensive and not suitable for operational purposes. Corrections of IPA based retrievals are feasible but require information about the vertical structure of cloud fields (e.g., cloud top altitude) that is not always available (Wyser et al., 2002). The simplest approach, degrading the resolution through the use of superpixels (an area average in form of a square over a regular field of data), is the subject of this study.

Various empirical studies have examined the relationship between spatial scale and observations of $I_{SFC}$. While these investigations primarily focus on sampling issues, they implicitly include 3-D effects. Pinker and Laszlo (1992) compared GOES (8 km resolution) and ISCCP (30 km) retrievals of $I_{SFC}$ with ground observations at several locations. The skills of the retrievals are demonstrated not to be consistent, with a better result for GOES in one case but not the other. Comparing hourly averaged surface measurements with observations for a $10 \times 13$ km$^2$ pixel, Perez et al. (1997) showed retrievals having a root-mean-square error (RMSE) of about 23%. This value is slightly larger than the 15% to 22% found in a study by Noia et al. (1993). Examining the spatial structure of the $I_{SFC}$ field from ground only measurements, the RMSE between instruments 25 km apart is similar to that found in satellite images (Olseth & Skartveit, 2001; Zelenka et al., 1999). Over the same distance, Long & Ackerman (1995) demonstrated correlation coefficients greater than 0.9 when the data are averaged for periods of 5 min. For longer averaging periods or decreasing spatial separation, the correlation will improve as sampling problems are reduced. However, for comparing satellite retrievals to surface observations of $I_{SFC}$, increasing the spatial resolution (i.e., decreasing the distance between the center of a pixel and the sensor element of a ground instrument) may actually be detrimental because of enhanced 3-D effects.

For a given set of cloud fields, a range of spatial resolutions or superpixel sizes should emerge that reduce errors associated with sampling while providing a large enough area to mitigate nonlocal effects. Strictly from empirical investigation, it is difficult to arrive at such a value because of the inability to systematically control the experiment. In the work presented here, theoretical simulations are used to assess the impact of spatial degradation on retrieval algorithms by examining the correlation, and trends in the bias and RMSE between simulations of true and retrieved surface irradiance. The shortwave radiative environment is simulated by a 3-D radiative transfer model for a set of convective and stratocumulus cloud fields generated from a mesoscale meteorological model. For each pixel or superpixel, the true surface irradiance, $I_{SFC}^{3D}$, and the top of the atmosphere radiance, $R_{TOA}$, are directly computed with a 3-D Monte Carlo model. The retrieved surface irradiance, $I_{SFC}^{3D}(R_{TOA})$ is then simulated with a model lookup table that relates SFC irradiance with TOA radiance. By comparing true $I_{SFC}^{3D}$ with retrieved $I_{SFC}^{1D}(R_{TOA})$, the following issues are addressed:

- How retrieval accuracy varies with superpixel size?
- When is averaging justified within the retrieval scheme?
- How ground point-measurements are impacted?
- How viewing and solar geometries influence retrievals?
- How biases of the retrieved surface irradiance can be corrected?

2. Method

2.1. Generation of simulated datasets

The generation of the cloud fields, the computation of the 3-D radiative environment, and creation of the lookup tables all use the same models and techniques described in a previous paper that examined corrections for 3-D cloud effects in the remote sensing of surface solar irradiance (Wyser et al., 2002).

The cloud fields used as input for generating the radiative environment are produced with the mesoscale atmospheric model, MM5 (Grell et al., 1995). The nonhydrostatic nature of MM5 allows the simulation of meteorological and microphysical variables with high spatial resolution. Ten cloudy scenes are selected from two MM5 simulations. Five scenes are from a simulation of a convective case from the TOGA–COARE area and five are extracted from a simulation of marine stratocumulus fields off the coast of California. The fractional cloud coverage for these scenes range from 0.25 to 1.0. Each cloudy scene consists of a $60 \times 60$ grid with 1-km horizontal resolution. There are 23 vertical $\sigma$-layers with resolution varying from 80 m close to the surface to 1500 m for the rigid model top at the 100 hPa pressure level. The vertically integrated optical thickness and fractional cloud coverage for each field is presented in Fig. 1.

The radiative environment for the 10 cloud scenes is computed using a 3-D radiative transfer model (SB3D) based on the Monte Carlo method (O’Hirok & Gautier, 1998). The downwelling shortwave irradiance, $I_{SFC}^{3D}(R_{TOA})$, is integrated over the wavelength from 0.25 to 5.0 $\mu$m. The upwelling radiance, $R_{TOA}$, is computed at a wavelength (0.6 $\mu$m) representative of satellite sensors in the visible shortwave. All simulations are performed for clouds over an ocean that has a Lambertian surface and an albedo of 0.05. Naturally, the ocean is far from being a perfect Lambertian reflector and the results presented here should not be applied to retrievals encountering sunglint. Outside these areas the surface reflectance is much lower than the value prescribed for the overall albedo and, therefore, the radiance from the ocean will be negligible compared to that coming from a
cloud. Computations are conducted for solar zenith angles of 0.0°, 41.4°, 60.0°, and 75.5°. Seven viewing angles are processed having zenith angles of 0°, 30°, and 60° with azimuths of 0°, 90°, and 180° relative to the sun azimuthal location of 0°. The setup results in a dataset with 280 members (10 scenes × 4 solar angles × 7 viewing angles).

In addition to the full 3-D radiative simulation, SB3D is also used in a 1-D mode where photons are confined to a single column simulating traditional plane-parallel radiative transfer computations. This mode is used to produce a lookup table for retrieving \( I_{SFC}^{1D} \) from \( R_{TOA} \). Employing the same 10 cloudy scenes and the same solar and viewing geometries as used in the 3-D computations, a set of 36,000 \((R_{TOA}, I_{SFC})\) pairs is generated for each combination of solar and viewing angle. Fig. 2 shows the result of a 1-D computation for one specific set of solar and viewing geometry (dots). There is a well-defined but nonlinear relationship between \( R_{TOA} \) and \( I_{SFC} \) that can be approximated with a fitted curve. The scatter in the plot is primarily caused by variations in the altitude of the cloud components among the independent atmospheric columns processed in the radiative transfer model. The range from 0 W m^{-2} to the maximum value of \( I_{SFC} \) is divided into 30 equal intervals and the median for all \((R_{TOA}, I_{SFC})\) pairs within each interval is computed. The set with the 30 median \((R_{TOA}, I_{SFC})\) values is then used as a lookup table to retrieve the surface irradiance \( I_{SFC}^{1D}(R_{TOA}) \). The procedure is repeated for all combinations of solar and viewing angles, each resulting in a different lookup table. In principle, the retrieval of the surface irradiance could be done with any other method that links \( R_{TOA} \) to \( I_{SFC}^{1D}(R_{TOA}) \) and we have adopted the lookup table mainly for simplicity. A further advantage is that both lookup table and 3-D Monte Carlo simulations are based on identical radiative transfer schemes and, hence, all discrepancies between \( I_{SFC}^{3D} \) and \( I_{SFC}^{1D}(R_{TOA}) \) can be assigned to solely 3-D effects from clouds.

2.2. Averaging procedures

Each scene has an array of 60×60 1-km pixels partitioned into four quadrants with the central points located at pixels (15,15), (15,45), (45,15), and (45,45) within an \( x-y \) coordinate system (Fig. 3). A square, referred to as a superpixel, is placed symmetrically around each central point and all pixels within that square are averaged equally together to create a single mean value. The superpixel’s size, \( s \), is the length of one side of the square. As is done for the radiative transfer modeling, cyclic boundary conditions are used for computing superpixels when they extend over an edge of a scene. Since the side of each scene is 60 km, the superpixels centered in each quadrant overlap for \( s \times 30 \) km. In these cases, the superpixels are no longer considered completely independent and some spatial correlations may impact the

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**Fig. 1.** The vertically integrated optical thickness for stratocumulus (top) and tropical convection (bottom) cloud fields used in the study. The number above each scene represents the fractional cloud coverage for each field.

**Fig. 2.** The simulated \((I_{SFC}, R_{TOA})\) data pairs used for producing the lookup table used in retrievals. Shown are results for \( \theta_{sun}=41.4° \) and \( \theta_{view}=30° \) for all cloud scenes. Solid line links the median value for \( I_{SFC} \) partitioned into 30 classes.
We assume the fully 3-D computed surface irradiance for comparisons irrespective of different solar zenith angle. The resulting surface irradiance is between 0 and 1 and allows surface irradiance for the given solar zenith angle. The pseudo-overlap between neighboring superpixels may occur for large solar or viewing zenith angles as 3-D effects can distribute the radiation beyond the immediate vicinity of a cloud parcel. Two methods are used to average the radiation within a superpixel. These are:

**Method 1:** retrieve $I_{SFC}^{1D}(R_{TOA})$ for each 1-km pixel in the superpixel of size $s$, and then average $I_{SFC}^{1D}(R_{TOA})$ over the superpixel.

**Method 2:** average first $R_{TOA}$ over a superpixel of size $s$ before retrieving $I_{SFC}^{1D}(R_{TOA})$ from the average.

The Method 2 is computationally more efficient than the first since only one retrieval is required per superpixel. However, Method 2 is expected to be less accurate since the relationship between $R_{TOA}$ and $I_{SFC}^{1D}(R_{TOA})$ is nonlinear. Another concern is that nonlinear effects (e.g., cloud-to-cloud reflection) will also make the second method less appropriate.

The skills of the averaging methods are evaluated by comparing $I_{SFC}^{1D}(R_{TOA})$ against the true surface irradiance $I_{SFC}^{3D}$ that has been computed with SB3D. Since irradiance varies largely with solar zenith angle, both $I_{SFC}^{3D}$ and $I_{SFC}^{1D}(R_{TOA})$ are normalized with the clear-sky value of the surface irradiance for the given solar zenith angle. The resulting surface irradiance is between 0 and 1 and allows for comparisons irrespective of different solar zenith angle. We assume the fully 3-D computed surface irradiance $I_{SFC}^{3D}$ to be the true value and compute bias, linear correlation coefficient and root-mean-square error between $I_{SFC}^{1D}(R_{TOA})$ and $I_{SFC}^{3D}$ for the 40 superpixels. Results are averaged over all viewing angles and, in most cases, over all solar zenith angles. Averaging over all angles as chosen since the focus of the present study is to investigate the effects from spatial averaging for the retrieved surface irradiance in a general sense, and not for any specific viewing geometry.

### 2.3. Corrections for oblique solar and viewing angles

The surface irradiance can formally be written as a combination of clear-sky and cloudy irradiance,

$$I_{SFC} = (1 - n)f_{SFC}^{clear} + nf_{SFC}^{cloud},$$

where $I_{SFC}^{clear}$ is the clear-sky irradiance, $I_{SFC}^{cloud}$ is the irradiance for an overcast sky, and $n$ is the cloud cover fraction. The IPA approach assumes that each cloudy grid point is horizontally homogeneous and infinite, and the retrieval therefore does not account for the influence from cloud sides. In reality, however, the cloud sides become important for oblique viewing or solar zenith angles. This effect can be accounted for by using a larger apparent cloud cover $n_{app}$ as suggested by Gautier (1998) that includes both the horizontal extension of clouds and the influence from cloud sides. The apparent cloud cover fraction can be related to the true cloud cover fraction by

$$n_{app} = n + f(\theta_{sol}, \theta_{view}),$$

where $f(\theta_{sol}, \theta_{view})$ is a function that depends on the solar zenith angle $\theta_{sol}$ and viewing angle $\theta_{view}$. The actual observed irradiance, $I_{SFC}^{app}$, is then

$$I_{SFC}^{app} = (1 - n_{app})I_{SFC}^{clear} + n_{app}I_{SFC}^{cloud},$$

and the true surface irradiance can be obtained by combining (1), (2), and (3) to yield

$$I_{SFC} = \frac{I_{SFC}^{app} + I_{SFC}^{clear}f(\theta_{sol}, \theta_{view})}{1 + f(\theta_{sol}, \theta_{view})}.$$  

The correction term $f(\theta_{view}, \theta_{sol})$ is defined as

$$f(\theta_{sol}, \theta_{view}) = \beta_{view} \tan \theta_{view} - \beta_{sol} \tan \theta_{sol}.$$  

The parameters $\beta_{view}$ and $\beta_{sol}$ can be determined from a training data set of observed surface irradiance, for example, a set of surface radiometers within the field of view of the satellite. The value for the $\beta$ parameters can then be found by minimizing the bias of $I_{SFC}^{1D}(R_{TOA})$ with respect to observed irradiance. Section 3.2 demonstrates the correction (4) on the data of this study when we assume that the true surface irradiance is given by $I_{SFC}^{3D}$. It is also shown how suitably chosen $\beta_{view}$ and $\beta_{sol}$ can reduce the bias without negative impact on RMSE or correlation coefficient.
3. Results

3.1. Mitigation of 3-D radiative effects through spatial averaging

We first assume that $\beta_{\text{view}}$ and $\beta_{\text{sol}}$ are unavailable and do not yet apply the geometric correction described in Section 2.3. Fig. 4 demonstrates the result of reducing 3-D radiative effects by comparing $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ and $I_{\text{SFC}}^{3D}$ for a scene of full-resolution (superpixel=1 km) and averaged (superpixel=25 km) pixels. Most apparent in the nonaveraged scene is that, when $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ is normalized by the clear-sky irradiance, it never exceeds unity, while $I_{\text{SFC}}^{3D}$ can be as high as 1.5 times the clear-sky value. These enhanced values stem from the 3-D diffusion of radiation from cloudy into clear pixels that cannot be accounted for in 1-D models. In the upper left (lower right) of this figure, another discrepancy appears where the $I_{\text{SFC}}^{3D}$ is much lower (higher) than $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ because of the horizontal displacement of cloud shadows that are also neglected when using the IPA assumption.

As evident in the two right frames of Fig. 4, averaging balances most of the errors. Averaging Method 1 provides better results than Method 2 because of the nonlinear relationship between $R_{\text{TOA}}$ and $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$. Performing a retrieval of $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ on individual 1-km pixels prior to applying the superpixel averaging is more accurate than conducting the retrieval on the average $R_{\text{TOA}}$. The bias, correlation coefficient and RMSE associated with these two methods are shown in Fig. 5 as a function of averaging size. On the figure, all solar and viewing angles are combined and plotted against superpixel size, $s$. As shown, the bias decreases as $s$ increases until it remains relatively constant for $s>25$ km. For Method 1, the bias is completely removed beyond 25 km but remains negative for Method 2 because of the previously discussed non-linear relationship between $R_{\text{TOA}}$ and $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$. The correlation coefficient begins with a value near 0.5 for no smoothing and increases to above 0.9 (above 0.8 for Method 2) when $s>25$ km. The improvement in the RMSE with increasing $s$ is very similar to that found for correlation coefficient.

So far, we have shown that the retrieval of surface irradiance is improved with spatial averaging. This result has been obtained by averaging both retrieved $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ and true $I_{\text{SFC}}^{3D}$ the same manner. The question is how this result changes if the true $I_{\text{SFC}}^{3D}$ is not averaged but the value from the center point of each superpixel is used instead. This is equivalent to having a small sensor on the ground that measures surface irradiance that is used for comparison against retrieved $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$. The large scatter for the

Fig. 4. The normalized retrieved $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ vs. true $I_{\text{SFC}}^{3D}$ for two different superpixel sizes. The left frame shows the non-averaged result for $s=1$ km, while the two right frames are for $s=25$ km using the two averaging methods described in the text.

Fig. 5. Bias (top), correlation coefficient (middle), and root-mean-square error (bottom) of the retrieved $I_{\text{SFC}}^{1D}(R_{\text{TOA}})$ for all solar and viewing angles combined as a function of the superpixel size, $s$. Solid lines represent results using Method 1 and dashed lines show results for Method 2.
non-smoothed field as demonstrated in Fig. 4 (left frame) reveals the problem inherent in comparing a single-point surface observation with typical satellite "snapshot" retrievals. The question is whether or not averaging of the retrieved irradiance is beneficial when comparing against ground instruments. To investigate this question, we examine the bias, correlation coefficient, and RMSE between retrieved $I_{SFC}^{1D}(R_{TOA})$ and true $I_{SFC}^{3D}$ as before, but rather than averaging the $I_{SFC}^{3D}$ over the entire superpixel only the value of the center pixel is used. As shown in Fig. 6, the skills of the retrieval become rather insensitive to spatial averaging for $s>5$ km. The bias remains positive and, in contrast to the previous result, Method 2 in this case demonstrates superior results. Both the correlation coefficient and RMSE also show weak results, with the best values for these fields occurring when $s=5$ km. For these measures, increasing the superpixel size beyond 5 km actually reduces the skill of the retrieval. The poor findings can be attributed to both 3-D geometric effects and issues related to sampling. This result suggests that, when satellite retrievals of $I_{SFC}^{1D}(R_{TOA})$ are compared to ground truth, the use of large superpixels is unwarranted. This result is in contrast to that of Barnett et al. (1998) who found that a 5-min average radiometer measurement corresponds well to a $60 \times 60$ km$^2$ pixel. The difference between their findings and ours may be caused by the stochastic nature of the cloud fields being examined rather than to any radiative effects.

### 3.2. Geometric correction

When the cloud field is observed from directly above, it may be expected that performance should improve as oblique projections of clouds are eliminated. Fig. 7 shows the bias, correlation coefficient and RMSE statistics when observations are limited to the nadir view. While the difference between these results and the findings for all viewing angles (Fig. 5) is negligible for the correlation coefficient and RMSE statistics, the overall bias becomes more negative. At nadir view, the cloud albedo is always lower for full 3-D computations than for 1-D due to photon leakage through cloud sides. At other viewing angles, there can be some compensation from photons escaping from neighboring clouds, but the cloud albedo is still generally smaller for the 3-D case. The lower radiance at the top of the atmosphere implies a higher $I_{SFC}^{1D}(R_{TOA})$ and therefore leads to the more negative bias.

When all the geometries of the satellite viewing and solar zenith angles are statistically combined, there tends to be greater cancellation between negative and positive biases as illustrated in Fig. 8. Here, the bias is shown for all viewing angles considered together but partitioned among the

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**Fig. 6.** As Fig. 4, but the true $I_{SFC}^{3D}(R_{TOA})$ superpixel average is replaced by value of the center pixel.

**Fig. 7.** As Fig. 4, but restricted for nadir viewing angle only.
different solar zenith angles used in the study. The bias for Method 1 from Fig. 5 is repeated at the bottom of this figure. The bias approaches zero for \( s > 25 \) km for all angles considered together. However, for the individual solar zenith angles, the bias varies with the location of the sun. It is generally negative for overhead sun and turns positive as the sun approaches the horizon. This variation is indicative of the IPA approach overestimating the surface irradiance because it cannot properly account for the solar beam impinging the side of a cloud as the sun approaches the horizon.

To reduce the bias for individual solar zenith and viewing angles, the correction described in Section 2.3 is applied to \( I_{SFC}^{1D}(R_{TOA}) \). For the 10 scenes of this study, we find \( \beta_{\text{sol}} = 0.03 \) and \( \beta_{\text{view}} = 0.055 \) minimize the mean squared difference between corrected \( I_{SFC}^{1D}(R_{TOA}) \) and \( I_{SFC}^{3D}(R_{TOA}) \). The correlation coefficient and RMSE are largely unchanged, but the bias is significantly improved for both overhead sun and at the large solar zenith angle of 75° (Fig. 8). While imperceptible, there is also a minimal difference for the 60° and the all solar angles plots. The difference is small because the average of the correction term in Eq. (4) for the considered viewing and solar zenith angles is near zero. The choice of \( \beta \) values here minimizes the bias for a large \( s \) of around 20 km, but in principle, \( \beta \) could be allowed to vary with \( s \) as well.

4. Conclusion

This study has demonstrated how spatial averaging reduces the negative impact of nonlocal cloud shadows, reflections from cloud sides, and photon diffusion by clouds on the retrieval of surface irradiance. In comparisons between true \( I_{SFC}^{3D} \) and retrieved \( I_{SFC}^{1D}(R_{TOA}) \), this simple procedure improves the correlation coefficient and RMSE. The bias is also reduced, but only when the results are averaged over all solar and viewing angles. For individual angles, a correction for oblique viewing and solar zenith angles has been developed. The correction has been found to successfully reduce the bias for large superpixels without negatively impacting the correlation coefficient or RMSE. Because of the nonlinear relationship between \( R_{TOA} \) and \( I_{SFC}^{1D}(R_{TOA}) \), the retrievals should be performed for individual pixels prior to the spatial averaging of a superpixel. Still, the results illustrate that the more efficient method of performing only a single retrieval on the \( R_{TOA} \) superpixel can be utilized without too much cost in accuracy.

For the range of cloud fields explored in this study, a superpixel size in the range of 20 to 25 km provides a conservative starting point for removing most of the errors associated with 3-D radiative effects. At this scale, the bias attains a constant value, a correlation coefficient of 0.9 is reached and the RMSE of about 0.1 is achieved—a value that is close to the intrinsic error of 12% found by Zelenka et al. (1999). As discussed, when comparing the retrievals to ground measurements, it is important that the true (observed) value be also spatially averaged. Since ground measurements normally entail just a single radiometer, the spatial averaging needs to be simulated through temporal averaging. An estimate for the averaging period can be obtained by dividing the typical superpixel size of 25 km with a typical wind advection of 5 to 10 m s\(^{-1}\), resulting in approximately 1 h for the time average. However, such long comparisons require homogeneous conditions that are often difficult to achieve (e.g., relatively stable cloud field) and need to be designed carefully.

This paper has looked at the retrieval of surface irradiance from space and how 3-D radiative effects can be mitigated through spatial averaging. It is true that the size of superpixel suggested here does not take full advantage of the high resolution presently offered by modern sensors. If it is preferable to retrieve \( I_{SFC}^{1D}(R_{TOA}) \) at these higher resolutions and if ancillary data (i.e., cloud top height) is available, then correction methods as described in Wyser et al. (2002) may be more suitable. However, the high spatial resolution of these sensors is still
exploited since the bias is lower for retrievals that are averaged within a superpixel than for a direct retrieval from a single pixel of equivalent size. Hence, for accurate retrievals without bias over large domains and at spatial resolutions higher than those found in current global circulation models, the method described is simple to implement and computationally inexpensive.

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References


