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RESEARCH ARTICLE
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Key Points:
- We correct simulations of shallow cumulus cloud days with 1D radiative transfer for the 3D radiative effects in a post-processing step
- The probability distributions of diffuse and global radiation closely match the observations after filtering the surface diffuse radiation
- The filter size can be parameterized as a linear function of one or multiple cloud variables, resulting in a minimal computational overhead

Supporting Information:
Supporting Information may be found in the online version of this article.

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An Efficient Parameterization for Surface Shortwave 3D Radiative Effects in Large-Eddy Simulations of Shallow Cumulus Clouds

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Abstract Most atmospheric models consider radiative transfer only in the vertical direction (1D), as 3D radiative transfer calculations are too costly. Thereby, horizontal transfer of radiation is omitted, resulting in incorrect surface radiation fields. The horizontal spreading of diffuse radiation results in darker cloud shadows, whereas it increases the surface radiation in clear sky patches (cloud enhancement). In this study, we developed a simple method to account for the horizontal transfer of diffuse radiation. We spatially filter the surface diffuse radiation field with a Gaussian filter, which is conceptually simple and computationally efficient. We applied the filtering to the results of Large-Eddy Simulations for two summer days in Cabauw, the Netherlands, on which shallow cumulus clouds formed during the day. We obtained the optimal filter size by matching the simulation results with detailed high-quality observations (1 Hz). Without the filtering, cloud enhancements are not captured, and the probability distribution of global radiation is unimodal, whereas the observed distribution is bimodal. After filtering, the probability distribution of global radiation is bimodal and cloud enhancements are simulated, in line with the observations. We found that small changes in the filter width do not strongly influence the results. Furthermore, we showed that the width of the filter can be parameterized as a linear function of for example, the cloud cover. Hence, this work presents a proof-of-concept for our method to come to more realistic surface irradiances by filtering diffuse radiation at the surface.

Plain Language Summary The pattern of radiation at the surface is characterized by the presence of cloud shadows and peaks in the radiation caused by scattering of light by clouds. The amount of solar radiation that reaches the Earth's surface determines how much energy is produced by solar panels and how much heat and moisture is supplied to the clouds, thus it influences how the clouds develop. Existing models neglect the scattering of radiation in the horizontal direction, therefore the high peaks in the radiation are not modeled. In this paper, we show for 2 days with shallow cumulus clouds how we can include the effect of the horizontal propagation of radiation. We redistribute the radiation at the surface, and we compare our model results with measurements. After the redistribution, the high peaks in radiation are modeled. In general, we get a good match between the observed and modeled radiation distribution. We show that the redistribution can be made a function of the clouds in the model. Hence, this work presents a proof-of-concept for our method to come to more realistic surface radiation, without complex calculations.

1. Introduction

The amount of solar energy that reaches the earth surface is strongly influenced by the complex interactions between clouds and radiation. Therefore, solar energy partly reaches the surface directly and partly reaches the surface as diffuse radiation after it is scattered in the atmosphere by gases, aerosols and clouds. The total amount of solar energy reaching the surface, also referred to as surface irradiance or global radiation, governs many processes at the surface. It drives the sensible and latent heat fluxes, which supply moisture and energy to boundary layer clouds and thus determine their development. Apart from the surface fluxes, the surface irradiance also influences plant photosynthesis, as diffuse radiation is taken up by the canopy more efficiently than direct radiation (Kanniah et al., 2012). Furthermore, surface irradiance determines the production of renewable energy by solar panels. It is therefore important to have a good model representation of the surface irradiance and the partitioning between direct and diffuse radiation.

Currently, clouds as well as radiation are usually parameterized in weather and climate models. Existing param- ... Radiative transfer is considered ... generally neglect the horizontal transport of radiation.

What was done?

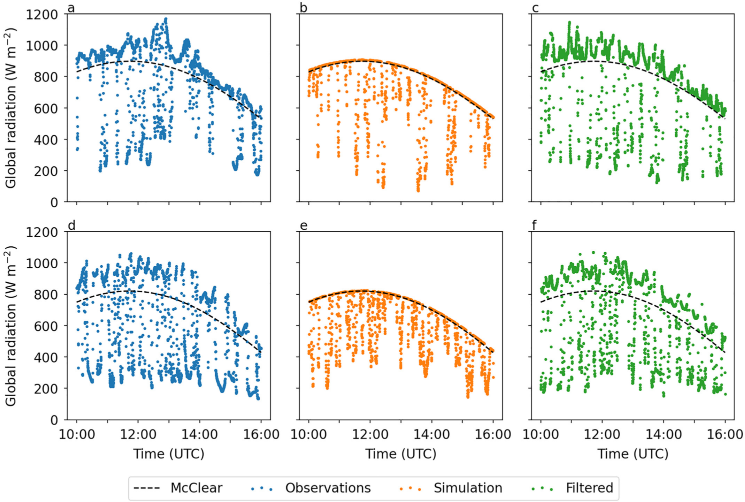
- Corrected unrealistic surface solar irrdaiance from LES with 1D radiative transfer
- Approximated horizontal spreading of the diffuse radiation by Gaussian filtering the diffuse radiation at the surface
- Did LES for two ShCu days (04.07.16 & 15.08.16) in Cabauw, Netherlands

Gaussian Filter / Weierstrass Transform

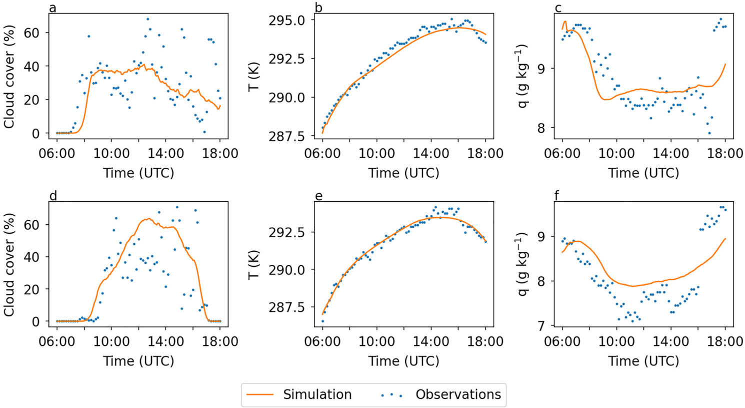
$$G(x, y) := \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-\frac{x^2 + y^2}{2\sigma^2})$$

$$[\mathbb{F}(r_{diff})](x, y) := [r_{diff} * G](x, y) :=$$
$$\frac{1}{\sqrt{2\pi\sigma^2}} \int_{\mathcal{D}} r_{diff}(\alpha, \beta) \exp(-\frac{(x-\alpha)^2 + (y-\beta)^2}{2\sigma^2}) d\alpha d\beta$$

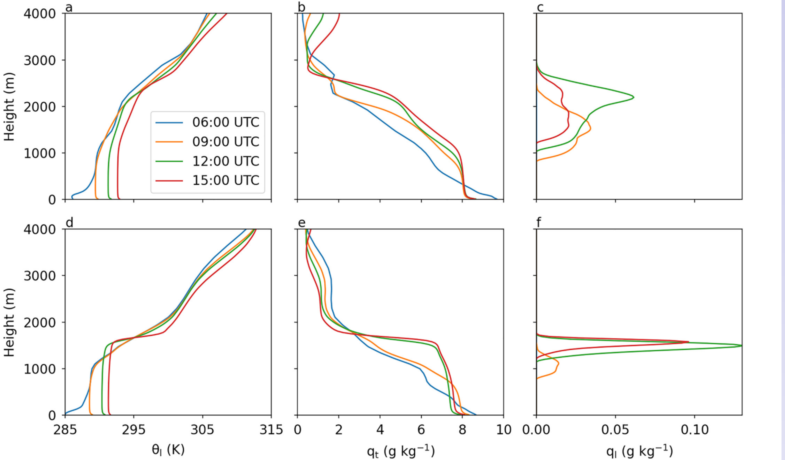
r_{diff} = diffuse radiation, $\mathcal{D}$ = domain, $\mathbb{F}$=filter



- Upper part 4 July 2016
- Bottom part 15 August 2016



- Temperature and humidity at 10m height
- Upper part 4 July 2016
- Bottom part 15 August 2016



- Upper part 4 July 2016
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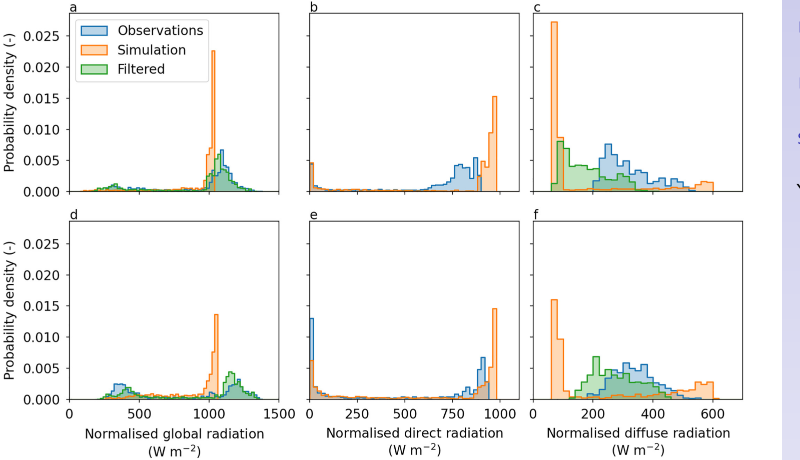
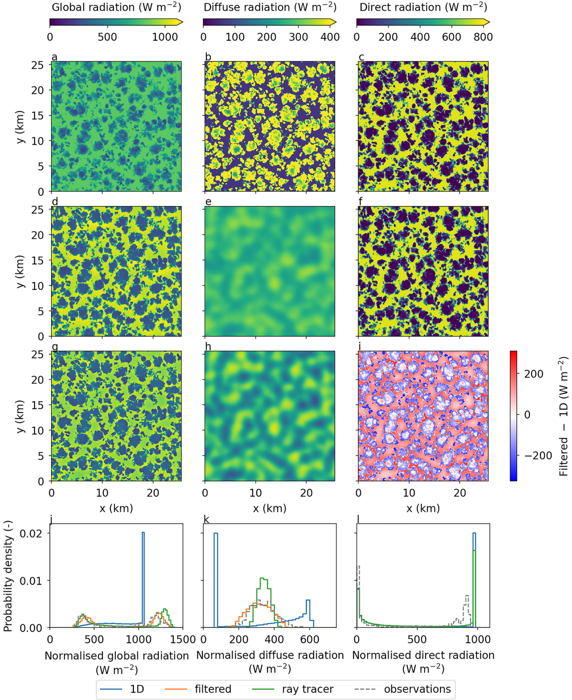


- Data for PDF just from 10 to 16 UTC
- Upper part 4 July 2016
- Bottom part 15 August 2016



Global radiation (W m^{-2})
Diffuse radiation (W m^{-2})
Direct radiation (W m^{-2})
a
b
c
d
e
f
g
h
i
j
k
l
y (km)
x (km)
Filtered − 1D (W m^{-2})
Probability density (-)
Normalised global radiation (W m^{-2})
Normalised diffuse radiation (W m^{-2})
Normalised direct radiation (W m^{-2})
1D
filtered
ray tracer
observations

Review

- filtering enhanced radiation in cloud free areas
- PDF of global radiation looks better after filtering the diffuse radiation

- nice to read
- Just two days
- Overfitting? by choosing depth of filter by observations
- No new physical insights by applying a filter / smoothen things out