SCOPE 2.0: A model to simulate vegetated land surface fluxes and satellite signals

Response to reviewers' comments (Referee #1)

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General comments

Thanks for inviting me to review this manuscript. Earlier versions of SCOPE have been widely used in SIF, GPP, energy balance and thermal signal simulations. This paper mainly summarized the recent progress of the revised version, SCOPE 2.0, which includes (1) the consideration of multi-layer vertical variation of chlorophyll content and leaf angle distributions; (2) the adoption of the BSM soil reflectance model to account for the soil moisture; (3) the impact of the xanthophyll cycle on the leaf-canopy reflectance and (4) speed acceleration optimization. I believe these advances are of interest to the remote sensing and ecology modeling communities, and thus this paper matches the scope of the GMD journal very well.

Overall, this paper is well written and structured. I have a few comments from the perspective of a SCOPE user, and the authors may choose to consider or not according to the long-term plan of SCOPE improvements and the amount of effort needed.

Dear Dr. Zeng, We thank you for the positive and encouraging feedback. We studied your comments with attention and revised our manuscript accordingly. Your comments are constructive and helpful, and we provide itemized responses to them below.

1. P21, L390: Currently in SCOPE2.0, atmospheric properties are the input parameters that determine the proportion of the direct and diffuse solar radiation. As the authors mentioned in Line 390, for the simulation of a specific site (e.g., some Fluxnet and PhenoCam sites), PAR and diffuse PAR ratio are usually available instead of the atmospheric properties. This makes the simulation of SIF and photosynthesis to be difficult at the diurnal or seasonal cycle with different diffuse PAR ratio. It would be more convenient for users in ecology community, if PAR and diffuse PAR ratio could be used as input parameters in SIF and photosynthesis simulations.

Response: Indeed, in many cases, the atmospheric properties or the incoming irradiance spectra are not available. We agree that the suggested option to provide the diffuse: direction ratio as input would then be convenient for the user. The reason why this option is absent is that the ratio varies with wavelength (diffuse radiation varies from blueish skylight to white light reflected by clouds, and direct radiation varies from white to reddish depending on the solar angle). Thus, the whole spectrum of the diffuse and direct radiation would be needed.

As an alternative to providing atmospheric properties, SCOPE 2.0 offers the option to provide direct and diffuse irradiance spectra as input. If the user has measurements of the direct: diffuse ratio, then the corresponding spectra could be estimated and provided as input, by making some assumptions about the spectral distribution of the ratio.

2. Second is about the validation. As far as I know, there is rare literature about the validation of SCOPE over high productivity areas with GPP > 40 umol CO2 m-2 s-1. From my experience of using SCOPE to simulate GPP of soybean at the Corn Belt in the US and in summer, it is very difficult to be able to achieve the GPP simulations to be larger than 40 umol CO2 m-2 s-1 with the field PAR, temperature, chlorophyll content, etc measurements, unless we set the unmeasured Vcmax to be larger than 200

umolm-2 s-1. Of course, this is unreasonable. Validation of SCOPE simulated GPP over high productivity areas would give more confidence and guidance to the SCOPE users in ecology community.

Response: We have checked the issue referred to in this comment and confirmed that the model indeed requires very high Vcmax to simulate GPP>40 umol CO2 m-2 s-1. For example, the values of GPP around 60 umol CO2 m-2 s-1 were achieved under the incoming radiation Rin of 1400 W/m2 (extremely high) and Vcmax of 200 as shown in the study of Wolanin et al (2019).

We have conducted several numerical experiments with different model parameterization. According to our investigation, we believe that this is most likely due to a limitation inherited from the FvCB photosynthesis model. This is an important topic, which requires a detailed investigation. Therefore, we don't want to rush in drawing any conclusion, or propose any solution in the current manuscript before a fundamental study on the photosynthesis model is done.

Wolanin, A., Camps-Valls, G., Gómez-Chova, L., Mateo-García, G., van der Tol, C., Zhang, Y., & Guanter, L. (2019). Estimating crop primary productivity with Sentinel-2 and Landsat 8 using machine learning methods trained with radiative transfer simulations. Remote Sensing of Environment, 225, 441–457. https://doi.org/10.1016/j.rse.2019.03.002

3. P 15, Fig. 4: For the xanthophyll cycle, Vilfan et al (2018) only focused on the leaf scale. In fact, there are already many canopy-scale PRI field observations acquired during the plant stress in recent studies. Showing the capability (and good performance) of SCOPE2.0 with field data to capture the plant stress by quick response (and accurate simulation) of PRI (or CCI) would be more interesting and convincing than model comparisons if possible.

Response: Yes, validating the model with field measurements of PRI or xanthophyll cycle induced reflectance variation is a necessary experiment to show the accuracy of the model. The challenge is the accurate parameterization of the model. Since we aim to capture small changes in reflectance from 520 to 560 nm, the inputs of the model variables have to be accurately provided. Although there are numerous data sets measuring canopy-scale PRI at diurnal and seasonal scale, the associated leaf biochemical and canopy structure measurements might not be sufficient to reproduce the PRI variations. We are working on this subject, but we think it requires many details, which is too much to be incorporated in the current manuscript.

4. P17, L 345-350: Usually it is difficult to determine how many layers should be set in SCOPE for a specific vegetation species, e.g., corn with narrow and long inclined leaves, or taro with big leaves but not many layers. In my understanding, the layers in SCOPE and the leaf layer in reality are different. For example, if there is only one flat big leaf over the ground, sensors can always observe the hot-spot effect in all viewing directions, while this kind of situations are difficult to consider in model settings. Of course, this is the gap between abstract models and nature in reality. The current model is correct under general assumptions of radiative transfer modelling, while caveats and more guidance may be still needed for users to correctly use the model and achieve accurate simulations.

Response: Yes, the reviewer is totally right on the difference between the numerical differentiation into layers in SCOPE and leaf-layers in a vegetation canopy. SCOPE, as well as SAIL, assumes the canopy is a turbid medium. The layers are needed for numerical discretization.

We also agree that more guidance on the setting of SCOPE 2.0 for multilayer canopies is needed. It is possible to parameterize vertical heterogeneity in the vegetation canopy. We will revise the text with the following addition:

"The true heterogeneity of leaves within a vegetation canopy may be too large to fully implement in the model. Thus, a simplification of the canopy may be needed: Two- or three-layer representations are most common. However, it is noted that more layers are possible in SCOPE 2.0 for specific purposes as illustrated in Yang et al. (2017)".

The hotspot effects have been included by correcting the directional radiance for the effects of finite size of leaves. The parameter that is used is the ratio between leaf width and vegetation height. Otherwise, the dimensions and shapes of leaves are not used in the model.

5. P16, Fig. 5: Does SCOPE2.0 have the capability to simulate the scene with different leaf sizes at different layers? Even if the leaf size is the same for all layers, the hot spot factor or leaf specific dimension could vertically vary with different multi-layer leaf angle distributions (Kuusk 1991). Seems this issue was not considered and the hot-spot effect was not evaluated or discussed in mSCOPE and SCOPE2.0 manuscripts. Not quite sure how large are the uncertainties by this issue to the reflectance around the hot spot directions. If fixed as one value, I suppose the multi-layer hot spot factor could be closer to the hot spot factor of the upper layer instead of the vertically averaged value. Maybe uncertainties by this issue could be evaluated by 3D multi-layer simulations.

Kuusk, A. (1991). The hot spot effect in plant canopy reflectance. In Photon-Vegetation Interactions (pp. 139-159). Springer, Berlin, Heidelberg.

Response: Yes, it is possible, but the option is not provided in the model input. In the mSCOPE model, this has not been considered, and we assumed the hotspot implementation in mSCOPE remains correct as it is identical to the SAIL model.

As the reviewer mentioned, the leaf size would only affect reflectance/radiance simulation in the hotspot direction in SCOPE 2.0. We feel it is an advanced use of the multi-layer radiative transfer modelling. For the general use of the model, this might not be a major issue, and introduction of the vertical variation of the leaf size could be a distraction to users. However, we would be happy to discuss the potential of this option.

6. P12, L230: The BSM model which simulates the isotropic soil reflectance was adopted in this study. For sparse vegetation canopies such as shrubland with low fractional vegetation cover and considerable soil roughness, the soil anisotropy and hot-spot effects are also important to the canopy reflectance for the chlorophyll content and leaf area index retrievals. Hope in the future the soil anisotropic model, e.g., the Hapke model, could be incorporated in the SCOPE framework at least for the soil single scattering contribution.

Response: Thank you for the suggestion. We totally agree that the importance of the hotspot effects of soil reflectance, which is not considered the BSM model. The combination of the Hapke and BSM models could be an improvement. We will consider this as an improvement of the SCOPE 2.0 model.

7. A discussion paragraph or section maybe needed to show the future directions of SCOPE improvements. Recently the leaf specular reflection has been reported to considerably contribute to the canopy reflectance especially over needle leaf forest, while this effect seems was not well considered in the current version. Besides, the 3D complex forest structures which can cast crown-scale dark shadows may also be the challenge for the current 1D models.

Response: Thank you for the suggestion. We have decided to add several sentences at the end of the conclusion about the future directions.

With the aim for accurate simulations of vegetative land surface processes and remote sensing signals, the models are constantly improved. Some important features, such as canopy clumping effects, crop yield simulation, leaf specular reflection and soil BRDF effects, are considered as the future directions of SCOPE improvements.

8. Seems the canopy coverage Cv was considered in the code of SCOPE2.0, while was not mentioned in the current manuscript.

Response: Cv was introduced with the intention to include the clumping effects. However, we find the effects of clumping is rather complicated and thus we have removed this parameter in the code. Our plan is to include the clumping effects in the future.

9. Congratulations to the authors for the several important advances of SCOPE2.0, and I can foresee that this paper as a milestone of SCOPE will have considerable impact on the remote sensing and SIF community. Not all my concerns need to be addressed this time according to the feasibility and available dataset, and some of them could be in the discussion. The accurate description and guidance of the model can better meet the users' needs and expectations. The well validation of the model by field observations can help to bridge the gap between abstract models (modeler community) and complex reality (user community with observations), and is also helpful for the future model improvements.

Response: Thank you again for your comments. We totally agree with your points as model developers. We aim at providing a tool for the community to better understand the real world. We have revised the manuscript by accounting for most of the comments from you and the reviewer #2. We hope our revision and response have addressed your concerns.