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

Response to reviewers' comments (Referee #2)

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General comments

This study improves the widely-used radiative transfer and biophysical model SCOPE by implementing 1) soil reflectance simulation, 2) xanthophyll cycle modulation, 3) vertical variations of vertical properties, 4) dynamic ground heat flux simulation, 5) a full energy balance closure solution, and 6) multiple strategies for computational efficiency. These improvements are significant advances and I believe the proposed SCOPE 2.0 will benefit the vegetation remote sensing community. The paper is well written and I only one major comment followed by several minor comments.

Dear reviewer, We thank you for your precious time as well as your constructive and positive comments. Please find ou

Major comments

1. While the improved algorithms are well described, the performance/effects of the new algorithms are not fully demonstrated.

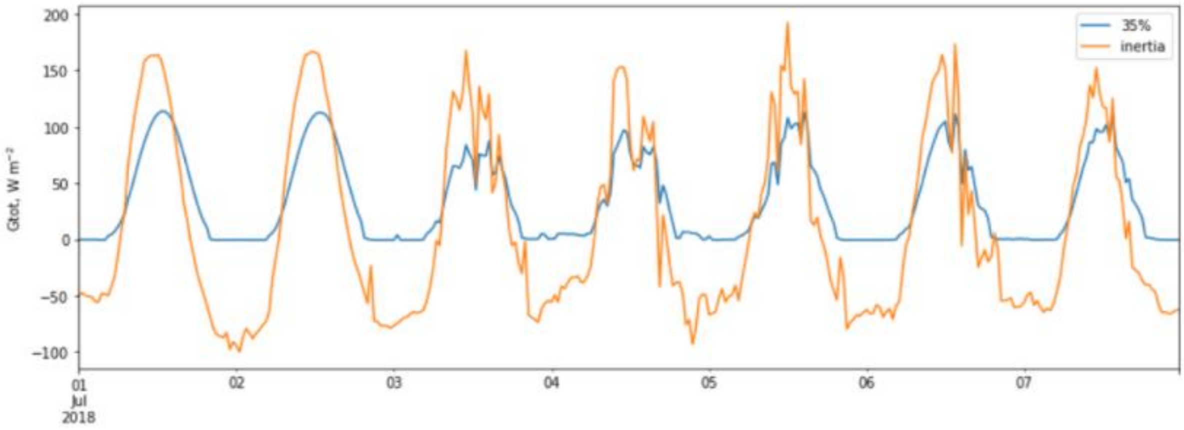
(1) Can you compare TOC reflectance, GPP and SIF between using a vertically variant Cab and using an invariant Cab? This is very interesting as I see many studies, including ESA's products, interpret canopy chlorophyll content as the product of LAI and Cab without considering the vertical variation of Cab. SCOPE 2.0 can help us understand this impact.

Response: We agree totally with the reviewer on the importance of vertical variation of leaf biophysical properties. Although the specific experiment/comparison is not included in this manuscript, we have already done this in the other paper about the mSCOPE model, which is a branch of the SCOPE model that includes vertical heterogeneity. In that work, we show the effects of vertical profiles of Cab on TOC reflectance, GPP, SIF and light use efficiency. To avoid repetition, we decided not to include such comparison in this manuscript, but added sentences clearly stating the comparison is available in the mSCOPE paper.

Yang, P., Verhoef, W., & van der Tol, C. (2017). The mSCOPE model: A simple adaptation to the SCOPE model to describe reflectance, fluorescence and photosynthesis of vertically heterogeneous canopies. Remote sensing of environment, 201, 1-11.

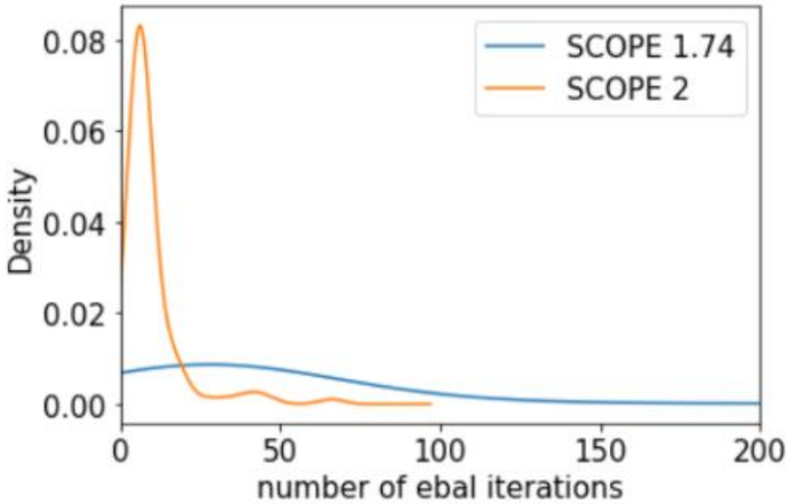
(2) Can you compare typical diurnal cycles of G between G = 0.35Rn and the new parameterization?

Response: With 35% parametrization the soil heat flux (Gtot) does not go below 0 W m-2, resulting in overestimation of the total annual sums.



(3) Can you use figures/tables to show 1) how energy balance closure is improved by using the new iteration algorithm, and 2) why Eq. 7 is a sufficiently accurate approximation?

Response: The older version 1.74 requires on average 59 iterations to close the energy balance, the 2.0 version requires on average 9. Furthermore, the standard deviations are dramatically different 59+/- 92 vs 9 +/- 9 iterations. This is largely due to the use the Eq. 7.



Eq. 7 is a linearization of the relation between temperature and energy balance error (i.e., please see the derivations followed by this response). This linearization is estimated analytically, which is much faster than calculating the derivative numerically. It is sufficient because it provides the slope, and thus a good update step of the temperature. The update is not exact, because the net radiation of the leaves also depends on the temperature of the other leaves (through the radiative transfer model). This cannot be solved analytically. The estimate is still sufficiently accurate, because it results in quick energy balance closure. The number of iteration steps in SCOPE 2.0 is significantly lower than in earlier versions of the model.

$$\delta e_{bal} = Rn - \lambda E - H \quad (1)$$

$$\frac{\delta Rn}{\delta T} = \frac{\delta Rn_{sw}}{\delta T} + \frac{\delta Rn_{lw}}{\delta T} = 0 - \frac{\delta \sigma_{SB} * (T + 273.15)^4}{\delta T} = -4 * \sigma_{SB} * (T + 273.15)^3 \quad (2)$$

$$\frac{\delta H}{\delta T} = \frac{\delta \rho * c_p . / r_a * (T_c - T_a)}{\delta T} = \rho * c_p . / r_a \quad (3)$$

$$\frac{\delta \lambda E}{\delta T} = \frac{\delta \rho / (r_a + r_s) * \lambda * (q_i - q_a)}{\delta T} = \rho / (r_a + r_s) * \lambda * \frac{\delta q_i}{\delta T} \quad (4)$$

$$q_i = 6.107 * 10^{\frac{7.5 * T}{237.3 + T}} \quad (5)$$

$$\frac{\delta q_i}{\delta T} = s = q_i * ln(10) * \frac{7.5 * 237.3}{(237.3 + T)^2} \quad (6)$$

Minor comments:

1. L16: I would suggest add some introduction of other models that can simulate radiative transfer and fluxes and provide distinct feature of SCOPE comparing to these models.

Response: We have added an introduction to about some other models, such as ACACIA, CUPID, SiB.

2. L87: SCOPE lacks the consideration of clumping effect, right? If so, I suggest add some words about that so that users can keep it in mind.

Response: Yes, it is right, although we are working on including this effect. As suggested, we have added a sentence stating the lack of clumping effects in SCOPE2.0.

3. Table 1: The term "each leaf" is unclear. How many "leaves" in SCOPE 2.0? 13*36*n for sunlit and shaded, respectively?

Response: We see the confusion here. To make it clearer, we changed “each leaf” to “individual leaves”.

Yes, there are 13*36*n types of leaves in the canopy regardless whether they are sunlit and shaded. The leaves are different from each other by their orientation and leaf biophysical properties. In total, 13*36 types of leaf orientations are defined in SCOPE 2.0, and the biophysical properties of the leaves in the n vegetation layers can vary among the layers.

4. L128: What type of aerodynamic resistance scheme is used in SCOPE 2.0? Series or parallel?

Response: The leaves and soil are independently parallel sources, so the model is a multi-source model. Each leaf and soil element has three resistances in series: stomatal/soil surface (rs), leaf/soil laminar boundary (rb), within vegetation (rwc). These are parallel, merging to one level just above the vegetation. The resistance above the vegetation is common for all leaves and soil. The resistance scheme is described in more detail in Van der Tol et al. (2009) and Wallance and Verhoef (1997).

leaf i --->rs -> rb -> rwc ->

ra -> air

leaf n ---> rs -> rb -> rwc -->

5. L180: Why is z "typically 2.5 times the vegetation height"? If we use meteorological data from site data or reanalysis data, they are fixed, right?

Response: The resistance scheme assumes that at this height (2.5*hc), the logarithmic wind profiles starts. The height should be set to the height of the meteorological tower, and this height is used in the calculation of the aerodynamic resistance. The height 2.5* hc is the minimum height. In case the height z is less than 2.5* hc, then the resistance of the roughness layer may be overestimated.

We assume that all the meteorological data are collected at the same height. However, for reanalysis data, in the case that wind speed is taken at 10m, air temperature at 2m, the more accurate way is to convert these measurements into the same height instead of setting z=2.5hc.

6. Table 2: Is there a relationship between Cab and Cs because senescenced leaves have lower Cab? Is there a relationship between Vcmax and Cab in terms of vertical variation? Why is Ball-Berry intercept parameter missed? Are their emissivity parameters?

Response: There are empirical relationships between Cab and Cs, Vcmax and Cab. As the reviewer expected, some studies reported an inverse relationship between Cab and Cs, and a positive linear relationship between Vcmax and Cab. However, these relationships are not universal, but vary with a number of factors, such as vegetation types. As a model designed for "all" plants, we have not introduced such empirical relationships in the model. It is our mistake for not including the Ball-Berry intercept parameter. We have added it to the table accordingly.

Yes, there are emissivity parameters for both leave and soil in the model. We have included the broadband thermal reflectance in the revised manuscript, which is 1-emissivity.

7. L218: I'm confused here. If we need to conduct a time series simulation or spatial simulation, do we need to provide variant tau and rho parameters?

Response: No, the users do not need to provide tau and rho parameters. They will be simulated by the vegetation model.

8. L227: While canopy FPAR can be obtained from outputs by FPAR = APAR/PAR, how can we get FPAR for leaves (sunlit/shaded at different layers)?

Response: Leaf FPAR is not specifically computed in the model, but it is linked with the absorptance of the leaf, which is 1-leaf reflectance –leaf transmittance. Strictly speaking, leaf FPAR is a spectrally integrated variable, and should be computed as APAR/PAR, where APAR $= \int_{400}^{700} E(\lambda)[1-\rho(\lambda)-\tau(\lambda)]d\lambda$ and where APAR $= \int_{400}^{700} E(\lambda)d\lambda$.

9. Table 3: What's the relationship between LST, Tcave and Tsave? Is this LST term comparable to ground/satellite estimates?

Response: LST is determined by Tcave and Tsave. From the energy balance routine, we obtain the temperature of each individual leaf. Tcave represents the average temperature of all the leave. Similarly Tsave is the average temperature of sunlit and shaded soil. LST is computed from the Planck's law. Soil and leaf temperature, together with the net radiation, determine the canopy outgoing radiance, which is simulated with the radiative transfer models. From the outgoing radiance, we can estimate the black-body radiometric land surface temperature.

Yes, LST is comparable with remote sensing estimates with thermal sensors. For example, Duffour et al. (2015) compared the simulated LST with the measurements.

Duffour, C., Olioso, A., Demarty, J., Van der Tol, C., and Lagouarde, J.-P.: An evaluation of SCOPE: A tool to simulate the directional anisotropy of satellite-measured surface temperatures, Remote sensing of environment, 158, 362–375, 2015.

10. Section 3.3: How to input multi-layer vegetation parameters seems not mentioned. Also curious if vertical variation of meteorological data is modeled?

Response: We have added that "In comparison with the original SCOPE, SCOPE 2.0 accepts vertical profiles of leaf properties (such as chlorophyll content) as inputs. If single values of the Fluspect parameters in Table 2 are provided, the model will assume the canopy is vertically homogeneous. "

11. Figure 5: This figure is not cited in the text.

Response: Thank you for sorting this out. We have cited this figure in the text in section 3.3.

12. Figure 8: Does the bias indicate that the lite option is not suitable for thermal remote sensing? I think such clarification might be useful to users.

Response: We agree that such clarification is needed. The Figure shows that the difference in TOC SIF is around 0.1 Wm-2um-1sr-1, and around 1 degree in the surface temperature simulation. However, the applicability of the lite option depends on specific purposes and the desired accuracy.

13. L418. While the "improved computational efficiency" is shown in Table 4, the "improved model stability" does not have evidence in the manuscript.

Response: We have solved a few bugs in the code in the past 11 years, which led to a more stable model.

14. L419. The topic "understory and overstory" is never mentioned in the manuscript. Does SCOPE 2.0 has understory and overstory LAI separated?

Response: Canopies with understory and overstory are considered as a two-layer canopy. This can be simulated with SCOPE 2.0. We have introduce the idea of understory and overstory in section 3.3 as follows:

"In reality heterogeneity of leaves within a vegetation canopy might be infinitely large and cannot be specified in a model. This requires a simplification of the canopy in the model, and the use of two- or three-layer representation is the most common way. For example, forests usually have understory and overstory, and crops at the senescent stage have two or three distinctive layers with brown or green leaves.