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Interactive comment on "Wide Discrepancies in the Magnitude and Direction of Modelled SIF in Response to Light Conditions" *by* Nicholas C. Parazoo et al.

Nicholas C. Parazoo et al.

nicholas.c.parazoo@jpl.nasa.gov

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Reviewer

This paper compares different process based terrestrial biosphere model (TBMs) that include solar induced chlorophyll fluorescence (SIF) as output. The models are briefly introduced, with emphasis on the different representations of SIF. The model output with respect to SIF and gross primary productivity (GPP) output is inter-compared, and comparisons are made to a time series of field measurements. The models diverged, and the authors relate the differences among the models to the underlying process descriptions: the estimates of APAR, energy partitioning in the leaf and radiative transfer

of fluorescence.

The paper provides a good overview of current TBMs capable of simulating SIF. This is of interest to the readers. It has an informative title, abstract and figures. It does not introduce new concepts, but it compares existing model concepts and recommends strategies for improvement. The paper is well written and clear. I have the following recommendations to consider in the preparation of the final manuscript (all minor):

Author

Thank you for the very kind and helpful review.

Reviewer

1. Make the paper (even) more inviting for readers who are unfamiliar with the terminology of SIF. In Line 208, SIFyield is first used, later in lines 593-602, it is defined, and the difference with SIFrel is discussed. It may be helpful to introduce SIFyield, SIFrel and phi_F together and earlier, explaining why these three are used for comparison in this paper (in Figs 3 and 4), and what they mean.

Author

We thank the reviewer for this helpful suggestion. We added a new section toward the beginning of the methods to clarify these differences, merging information from line 208 and 593-602.

"2.2.2 SIF Yield

We define and clarify three important quantities that define the relationship between absorbed light and emitted SIF at leaf and canopy scales. ÏŢ_F is the quantum yield of fluorescence, representing the probability an absorbed photon will be fluoresced. This quantity can be observed at leaf level using PAM fluorimetry, or calculated by models as a function of rate coefficients for energy transfer (Sec 2.3.3). SIFyield is the canopy emitted SIF per photon absorbed. The quantify is estimated from models and observations as the ratio of absolute canopy SIF and APAR (SIFcanopy/APAR). SIFyield is our best attempt to account for the effect of (a) canopy absorbed light and (b) SIF re-absoprtion within the canopy on the canopy integrated emission of SIF. However, factors such as observation angle, fraction of sunit/shaded canopy components, and difference in footprint from APAR, necessitates an additional diagnostic variable defined as relative SIF (SIFrel). SIFrel is emitted SIF per reflected radiance in the far red spectrum where SIF retrievals occur (SIF/Reffr). This is useful because is normalizes for the exact amount of 'illuminated' canopy elements within the sensor field of view, whereas APAR measurements are integrated for the entire canopy.

These quantities represent different but equally important versions of reality. It is difficult for models to exactly reproduce the distribution and timing of sunlight in the canopy as observed by PhotoSpec. While SIFrel removes model-observations differences in illumination, it confounds our interpretation of the relationship with GPPyield, which is derived from APAR. As such, we provide both results to be comprehensive, but note the temporal stability associated with SIFrel as the more physical interpretation of canopy yield for this short period of study."

Reviewer

2. Lines 623-626. I did not grasp the following reasoning: 'Finally, we note that PhotoSpec scans of leaf-level emissions are averaged and reported here as canopy averages, while model output is reported at the top of the canopy, which accounts for within-canopy radiative transfer, re-absorption of SIF, and shaded canopies, causing lower emissions compared to the canopy average.' Aren't the top-of-canopy measurements also affected by within-canopy radiative transfer etcetera?

Author

Thank you for pointing out this source of confusion. We tried to clarify as follows:

"Finally, we clarify an important difference between observed and predicted estimates

of canopy average SIF. PhotoSpec scans direct emissions from sunlit and shaded leaves within the canopy, thus observing the 'total' emission from leaves in the instrument FOV. We then average each of these leaf-level scans and report as canopy averages. Model output, in contrast, is reported at the TOC, which represents the 'net' emission from leaves after attenuation in the canopy (through canopy radiative transfer, re-absorption of SIF, and shading). Assuming sunlit and shaded leaves within the canopy emit at the same rate as TOC leaves, attenuation will reduce the effective signal from leaf-level emissions within the canopy. As such, the average of leaf level emissions (canopy average) is expected to be lower than the net emission of leaves reaching the top of canopy. This is important because CLM4.5 shows strong attenuation of SIF from leaf-level to TOC, decreasing by a factor of 2-3 at midday (Fig S7). The interpretation here is that the model bias in absolute SIF may actually be higher than reported here; however, we note that more quantitative information on the observed fraction of sunlit vs shaded leaves and comparative top-of-canopy SIF values for the same canopy elements are needed (to account for off-nadir SIF viewing) for more accurate determination of scaling between observed canopy and top-of-canopy SIF."

Reviewer

3. Continuation of previous point: The difference between the measurements and the simulations is that the measurements are the average of small footprints at multiple viewing angles, whereas the models are nadir values, as explained in the 'apples to apples' section (line 691). I presume the radiative transfer factor _740 was derived from SCOPE simulations in nadir. With SCOPE it is possible to estimate _740 (_o) for multiple observation angles, and then take the average. Thus it is possible to compare apples to apples. I understand the TBM's do not have this right now, but at least I would have expected that to be part of the discussion, or as part of recommendation 5, which now only mentions instruments with a wider FOV.

Author

Very excellent point. We added the following sentence to recommendation 5

"More effort is also needed to better align models with observations, for example by leveraging three-dimensional capabilities in SCOPE (and other RTMs) to directly account for multiple observation angles."

Reviewer

4. Line 566, Strictly, x is not the fraction of absorbed light not used in photosynthesis, if this refers to the variable 'x' in the model of Lee et al. and Van der Tol, because when x = 0, this fraction is 0.17 due to constitutive heat dissipation.

Author

Thank you for clarifying. We removed the statement that x refers to the "fraction of absorbed light not used in photosynthesis"

Reviewer

5. Line 728-730. 'The fact that relative SIF is the least sensitive [] reduces the sensitivity to APAR and reveals a strong SIF response to changes in photochemical quenching'. Yes, that seems to be the case, but perhaps a few lines can be added to guide the reader through this argument (see also point 1).

Author

We agree this is a difficult concept to grapple with. We try to clarify as follows:

"Our results indicate a wide range of SIF responses to APAR: TBM-SIFs and SCOPE are usually far too sensitive to APAR, observations of absolute SIF are less sensitive, and observations of relative SIF (SIFrel) are least sensitive (Fig. 5D). We remind the reader that SIFrel is normalized by the amount of far red light reflected from leaves in the FOV of PhotoSpec, and thus has reduced sensitivity to absorbed light than absolute SIF. The fact that SIFrel is the least sensitive to APAR means other processes are driving changes in SIF under increased light absorption. In this case, it reveals a

strong SIF response to changes in photochemical quenching."

Reviewer

6. Line 811, recommendation 2. Is it the water stress formulation, or the parameter values, i.e. the values for the Ball-Berry parameters?

Author

Here, we are referring to different kinds of the stomatal conductance models (ball-berry, leuning) and water stress (e.g., soil moisture scalar for attenuating conductance). We clarify

"The underlying photosynthetic models fail to simulate the magnitude of depression of observed GPP in the afternoon, regardless of how stomatal-conductance and water stress models and parameters are formulated"

Following Reviewer 1, we also advocate for more use of stomatal optimization models

"We also recommend more inclusion of stomatal optimization models (e.g., Eller et al., 2020) as optional parameterizations for TBMs, to better account for plant hydraulic functioning under water stress compared to the more widely used semi-empirical models."

Reviewer

7. In Line 680, there is a reference to Figure 6, which is not in the manuscript

Author

Good catch, we refer to Fig S8 now.

Reviewer

8. Figure 3C and 3D. What is the temporal resolution of these data? Multiple-day averages? It takes some effort to relate the spikes to the wet and dry periods described in the text.

Author

Thank you. We have clarified the temporal resolution in the text and figure caption.

Reviewer

Technical comments

Line 290, sentence starting ‘The quantum yield’ has an extra ‘to’: Line 365 and elsewhere, I recommend to spell out ‘met forcing’: Line 508, ‘eaves’ should be ‘leaves’: Figures S1 and S4 are reversed: The labels in Figure S7 are too small The legend in Figure S8 is too small

Author

All corrected

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