Why do we need improved vegetation-radiation interactions in Earth System Models?

Tristan Quaife [1,2], Renato Braghiere [1,4] and Robin Hogan [1,3].

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Forests are structurally complex

Oregon transect
Metolius "Young"
site, 2006

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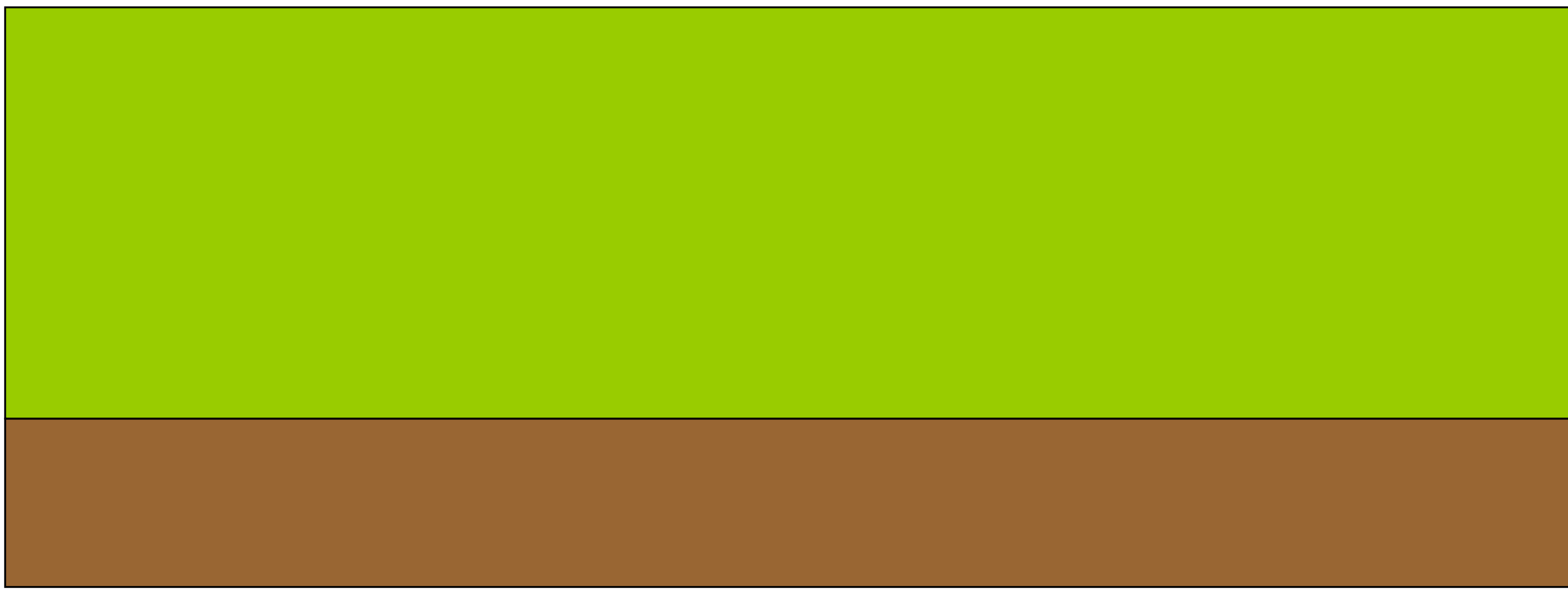
Most LSMs assume a 1D canopy

Leaves are infinitesimally small and distributed randomly throughout a plane parallel semi-infinite media:



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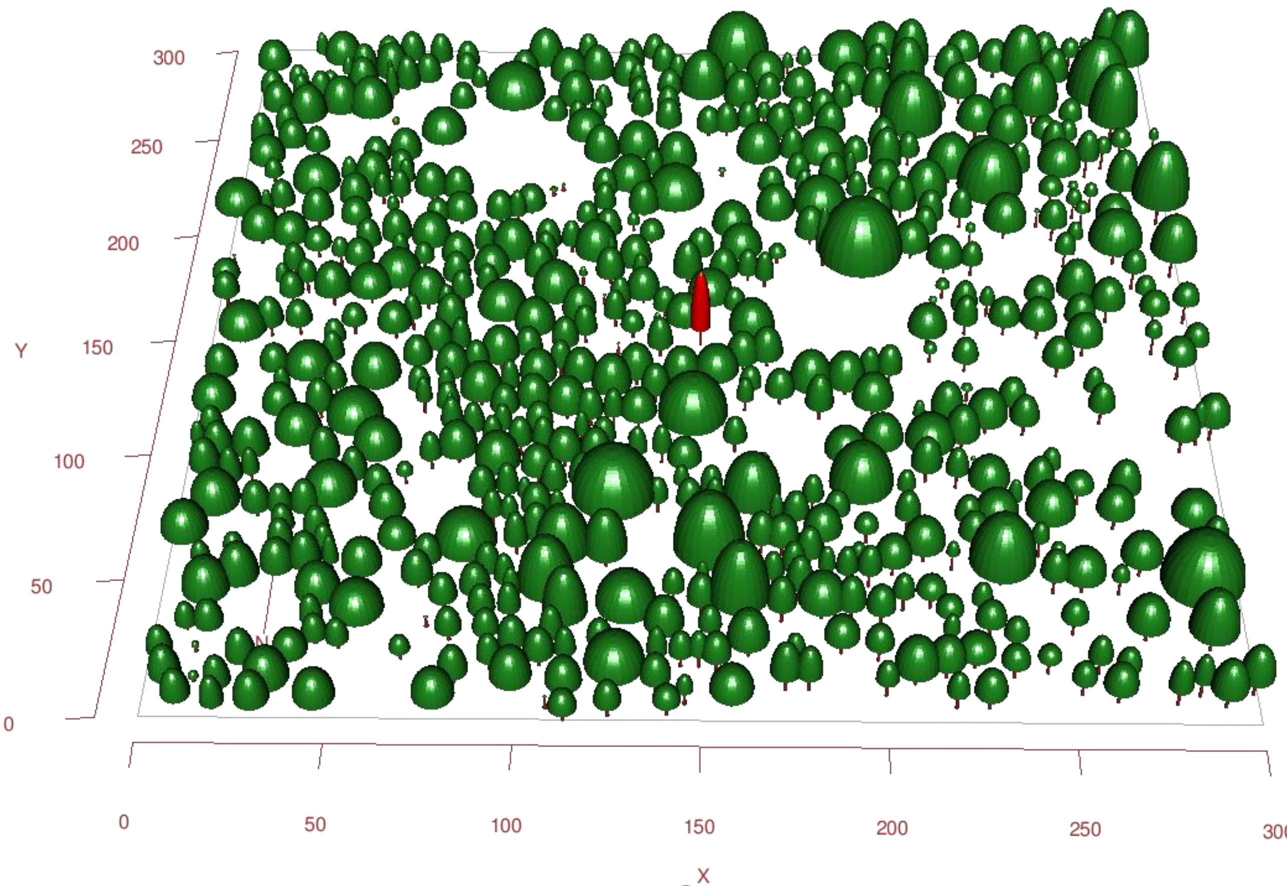
We have complex canopies in ecosystem models



http://maespa.github.io/

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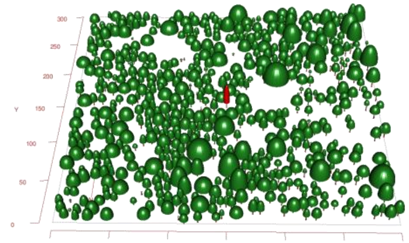
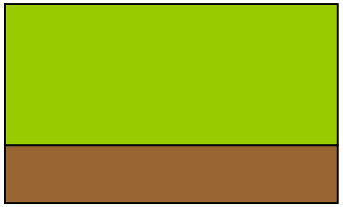
LAI, FAPAR & Clumping

If LAI

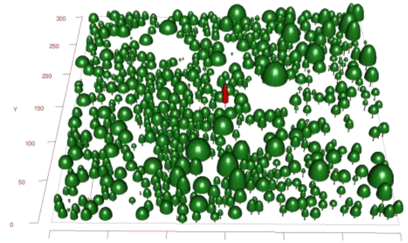


= LAI

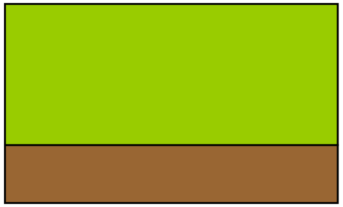


then

fAPAR



< fAPAR



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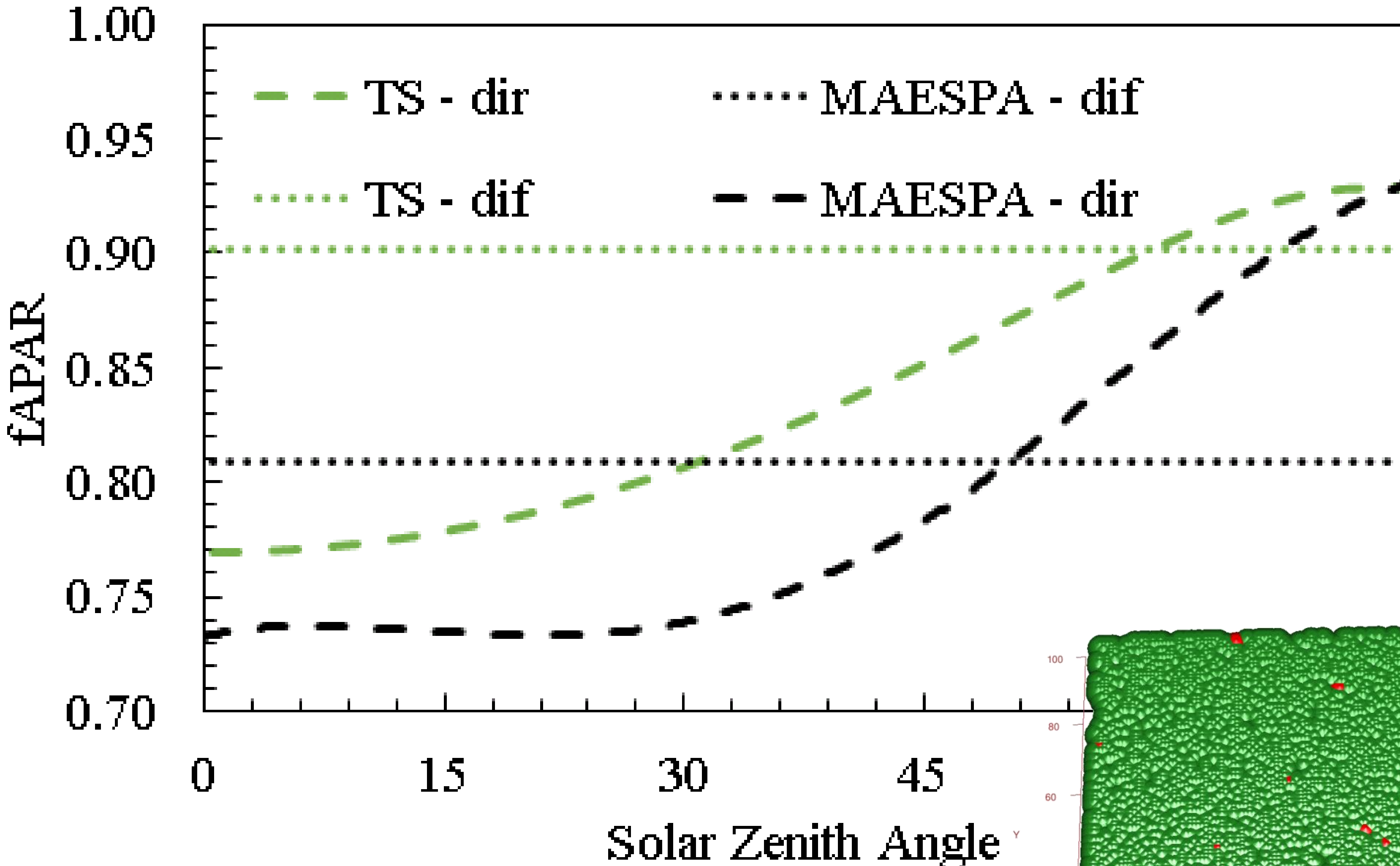

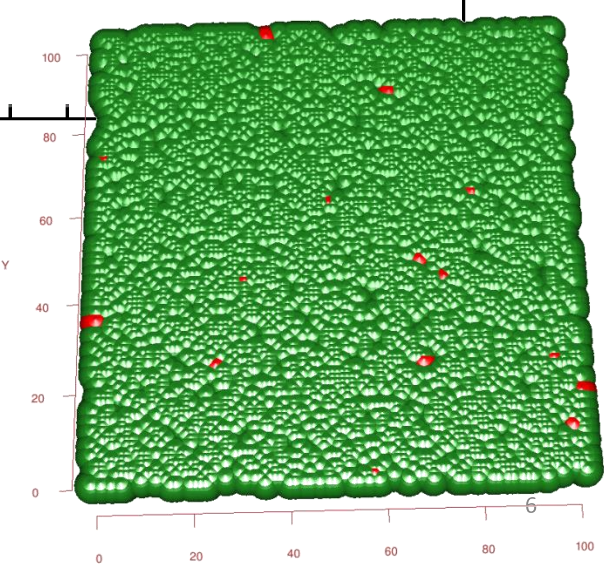

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JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, G02019, doi:10.1029/2010JG001511, 2011

RAMI4PILPS: An intercomparison of formulations for the partitioning of solar radiation in land surface models

J.-L. Widlowski,[1] B. Pinty,[1,2] M. Clerici,[1] Y. Dai,[3] M. De Kauwe,[4] K. de Ridder,[5] A. Kallel,[6] H. Kobayashi,[7,8] T. Lavergne,[9] W. Ni-Meister,[10] A. Olchev,[11,12] T. Quaife,[13] S. Wang,[14] W. Yang,[10] Y. Yang,[14] and H. Yuan[3]

Received 6 August 2010; revised 31 January 2011; accepted 10 February 2011; published 26 May 2011.

[1] Remotely sensed, multiannual data sets of shortwave radiative surface fluxes are now available for assimilation into land surface schemes (LSSs) of climate and/or numerical weather prediction models. The RAMI4PILPS suite of virtual experiments assesses the accuracy and consistency of the radiative transfer formulations that provide the magnitudes of absorbed, reflected, and transmitted shortwave radiative fluxes in LSSs. RAMI4PILPS evaluates models under perfectly controlled experimental conditions in order to eliminate uncertainties arising from an incomplete or erroneous knowledge of the structural, spectral and illumination related canopy characteristics typical for model comparison with in situ observations. More specifically, the shortwave radiation is separated into a visible and near-infrared spectral region, and the quality of the simulated radiative fluxes is evaluated

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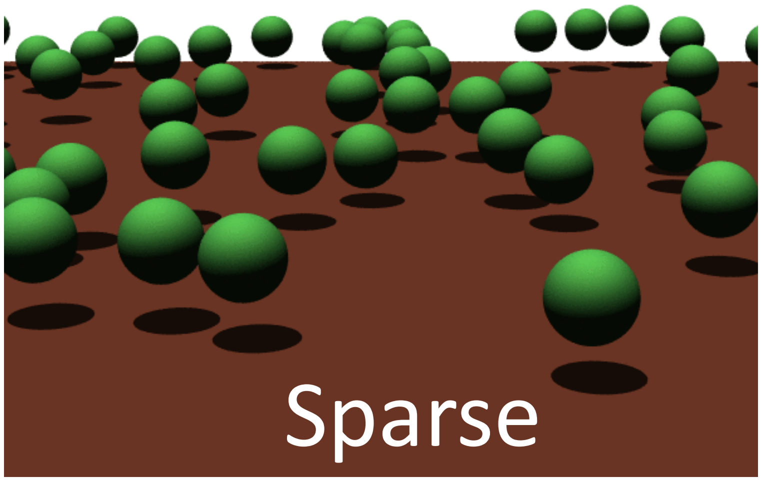
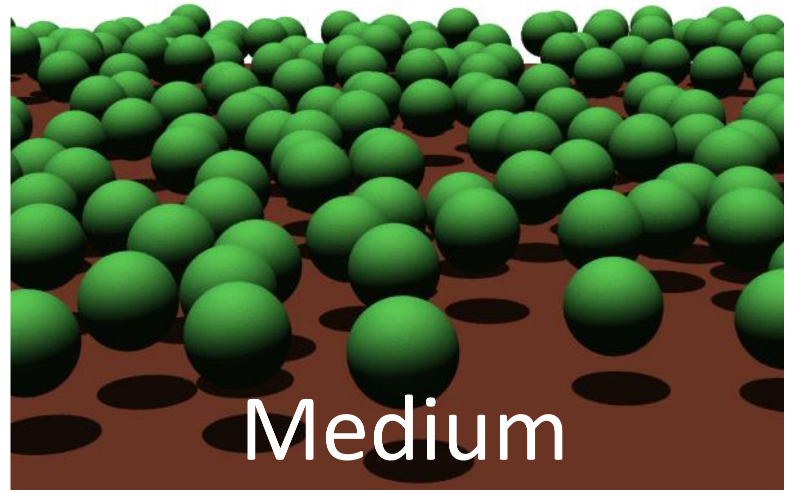
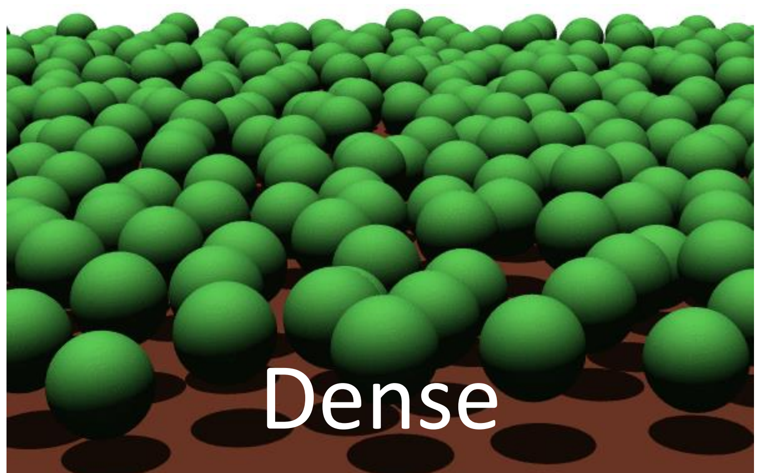
RAMI4PILPS 3D scenarios







Biogeosciences, 11, 1873–1897, 2014
www.biogeosciences.net/11/1873/2014/
doi:10.5194/bg-11-1873-2014

Biogeosciences
Open Access

Do we (need to) care about canopy radiation schemes in DGVMs? Caveats and potential impacts

A. Loew[1], P. M. van Bodegom[2], J.-L. Widlowski[3], J. Otto[4], T. Quaife[5], B. Pinty[3], and T. Raddatz[1]

[1]Max Planck Institute for Meteorology, Hamburg, Germany
[2]VU University Amsterdam, Department of Ecological Science, Subdepartment of Systems Ecology, Amsterdam, the Netherlands
[3]European Commission, Joint Research Centre, Institute for Environment and Sustainability Joint Research Centre, Via E. Fermi 2749, 21027 Ispra (VA), Italy
[4]Laboratoire des Sciences du Climat et l'Environnement (LSCE), CEA-CNRS-UVSQ, Gif-sur-Yvette, France
[5]Department of Meteorology, University of Reading, Earley Gate, Reading, UK

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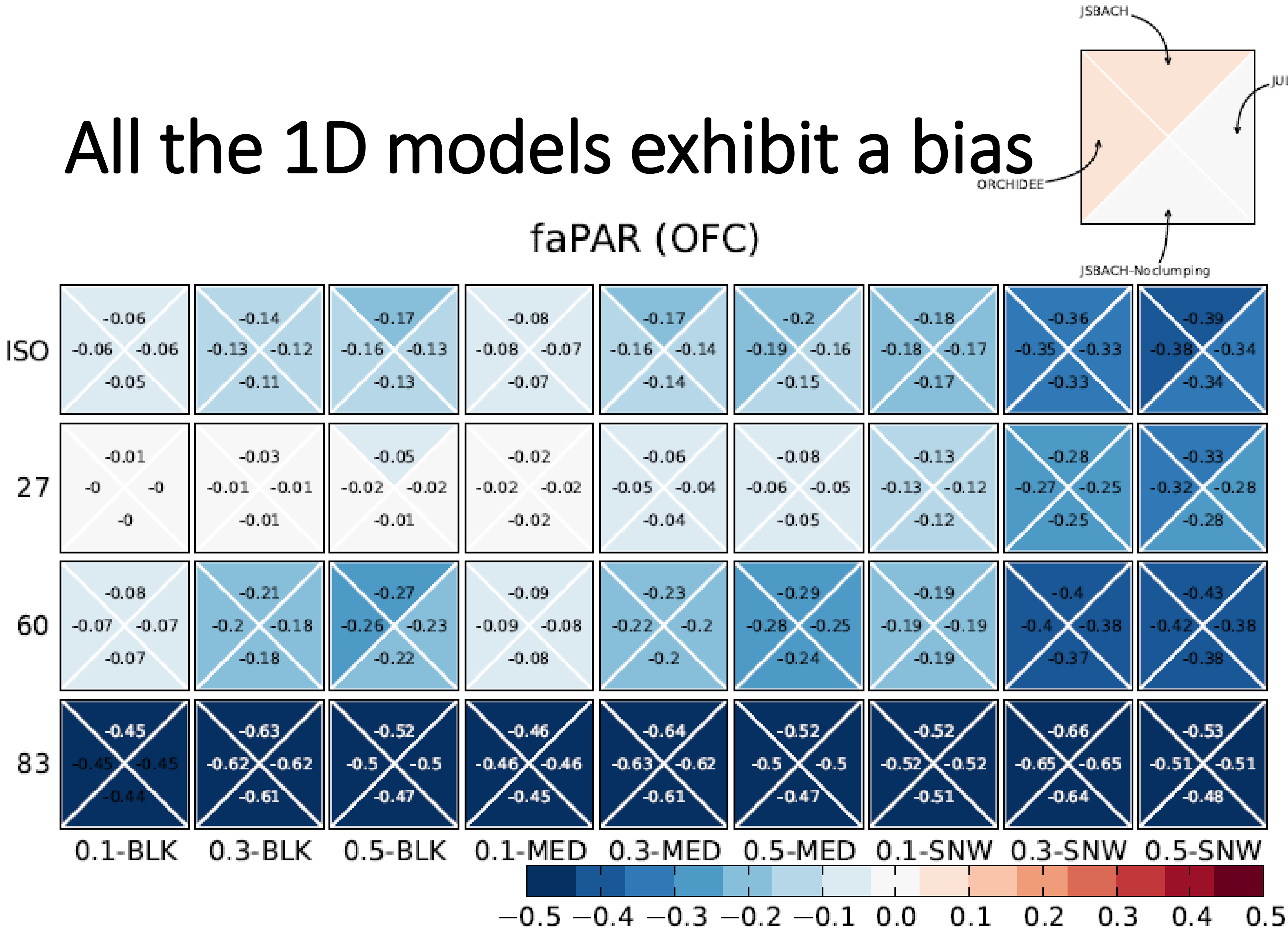
All the 1D models exhibit a bias



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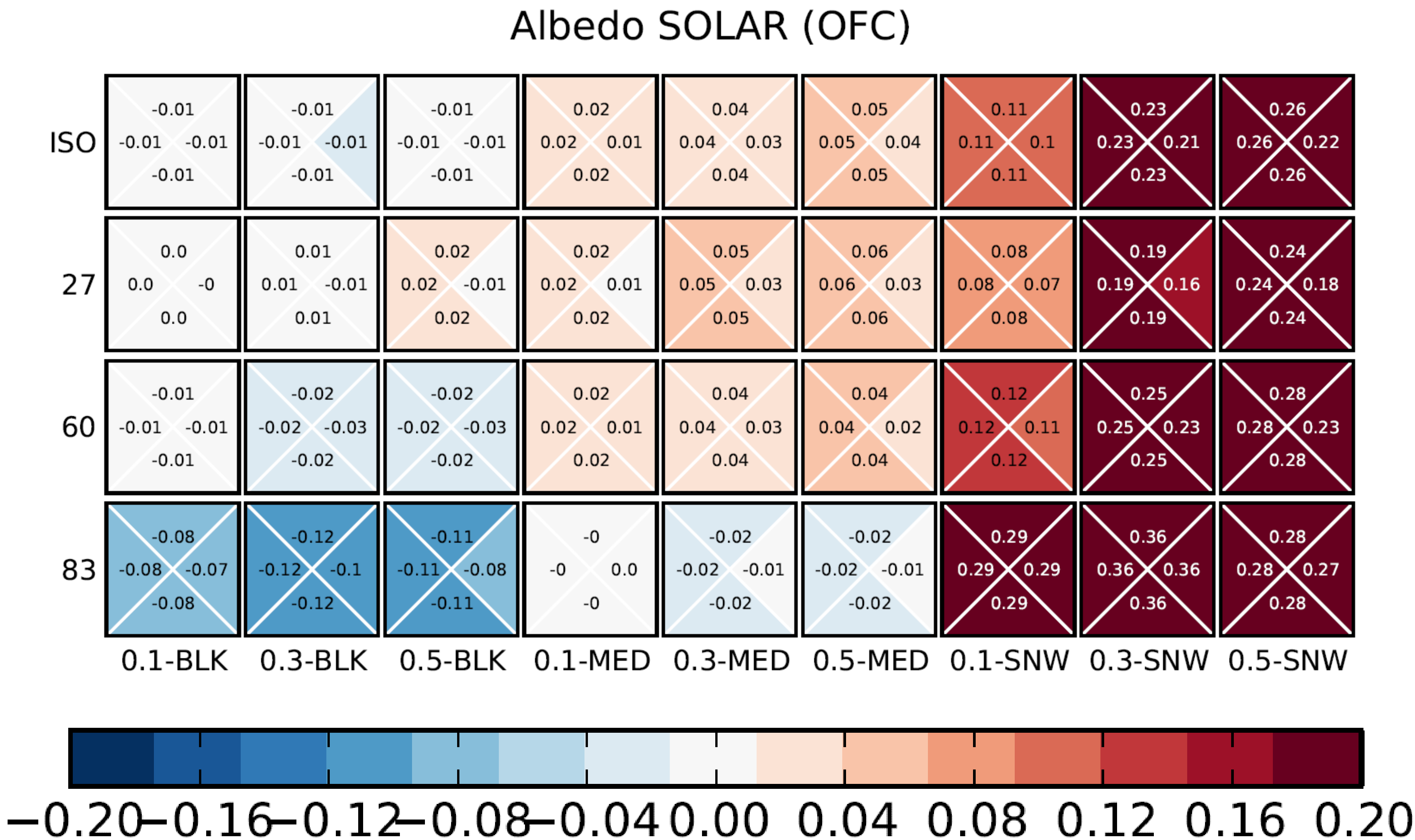
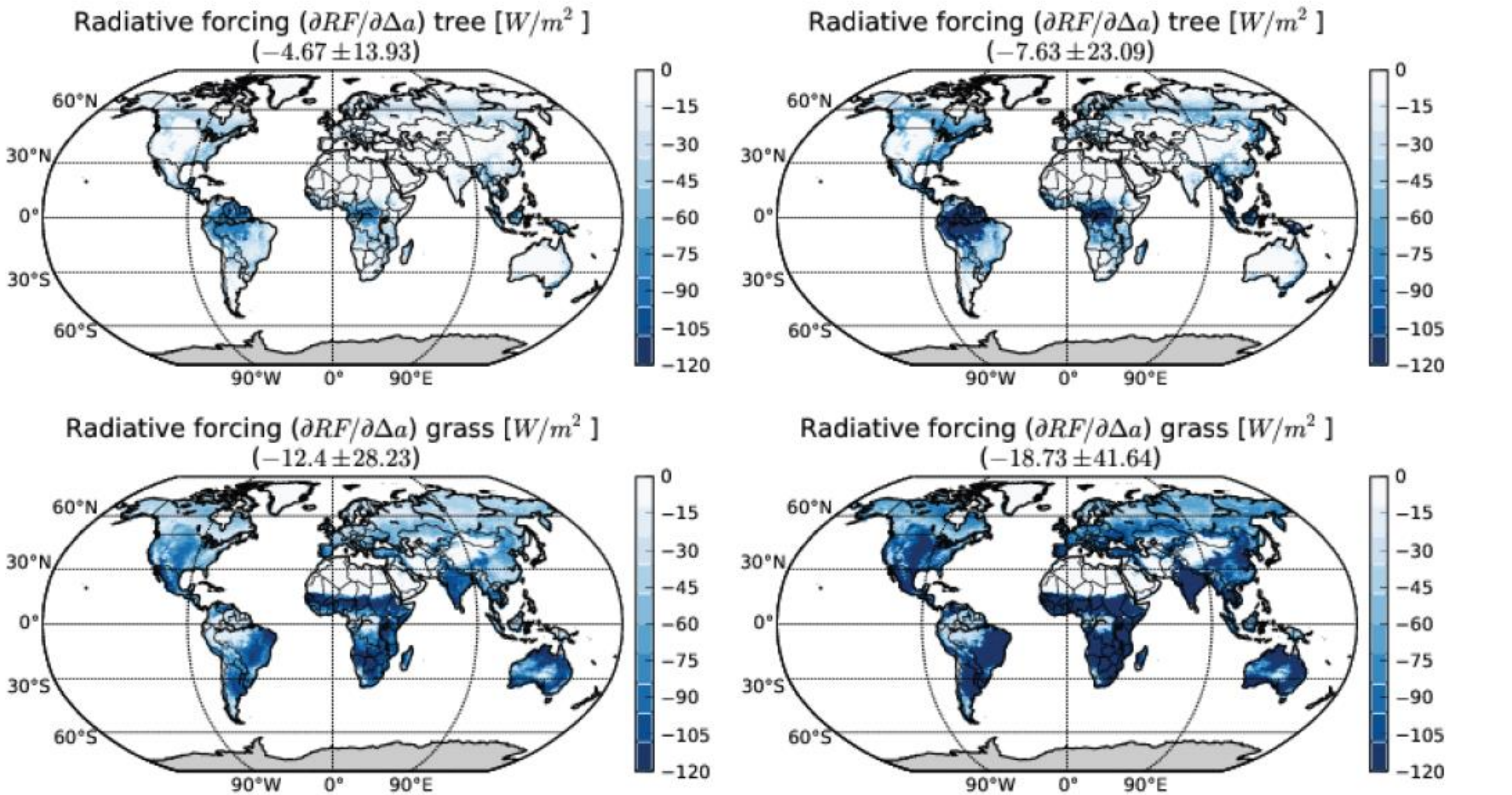


Albedo SOLAR (OFC)
ISO
27
60
83
0.1-BLK
0.3-BLK
0.5-BLK
0.1-MED
0.3-MED
0.5-MED
0.1-SNW
0.3-SNW
0.5-SNW
−0.20
−0.16
−0.12
−0.08
−0.04
0.00
0.04
0.08
0.12
0.16
0.20

Change in radiative forcing



Loew, Alexander, P. M. van Bodegom, J-L. Widlowski, Juliane Otto, Tristan Quaife, Bernard Pinty, and Thomas Raddatz. "Do we (need to) care about canopy radiation schemes in DGVMs? An evaluation and assessment study." *Biogeosciences Discussions* 10, no. 10 (2013): 16551-16613.

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Two potential next steps

Need fast solutions that are compatible with existing land models.

1. Take the existing Sellers model (used in, e.g. JULES and CLM) and modify solution to include
2. Adapt work on 3D cloud scattering for vegetation

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1. Adapt the Sellers 2Stream solution

$$-\bar{\mu}\frac{dI^{\uparrow}}{dL} = \omega\beta I^{\downarrow} - (1-(1-\beta)\,\omega)\,I^{\uparrow} + \omega\bar{\mu}K\beta_0 e^{-KL},$$

$$\bar{\mu}\frac{dI^{\downarrow}}{dL} = \omega\beta I^{\uparrow} - (1-(1-\beta)\,\omega)\,I^{\downarrow} + \omega\bar{\mu}K\,(1-\beta_0)\,e^{-KL},$$

$$K = G\,(\mu)\,/\mu.$$

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Addition of structural terms

$$G\zeta\left(\mu\right) = G\left(\mu\right)\zeta\left(\mu\right)$$

$$K = G\zeta\left(\mu\right)/\mu,$$

$$\bar{\mu} = \int_0^1 \frac{\mu'}{G\zeta(\mu')} du',$$

$$a_s\left(\mu\right) = \frac{\omega}{2}\int_0^1 \frac{\mu' G\zeta\left(\mu\right)}{\mu' G\zeta\left(\mu\right) + \mu G\zeta\left(\mu'\right)} du',$$

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Candidate formulations for ζ

Pinty et al. (2006):

$\zeta(\theta)=a+b(1-\cos(\theta))$

Kucharik et al. (1999):

$\zeta(\theta)=(ND/\sqrt{A})^{0\cdot 7}/(1+b.\exp(-k\theta^{p}))$

Ni-Meisters et al. (2009):

$\zeta(\theta)=[1-(2tr\Gamma+1)\exp(2tr)/(2t^{2}r^{2}\Gamma^{2})]3/(4tr\Gamma)$

$\Gamma(\theta)= \sqrt{[(1+(b/r)^{2}\tan^{2}\theta)/(1+\tan^{2}\theta)]}$

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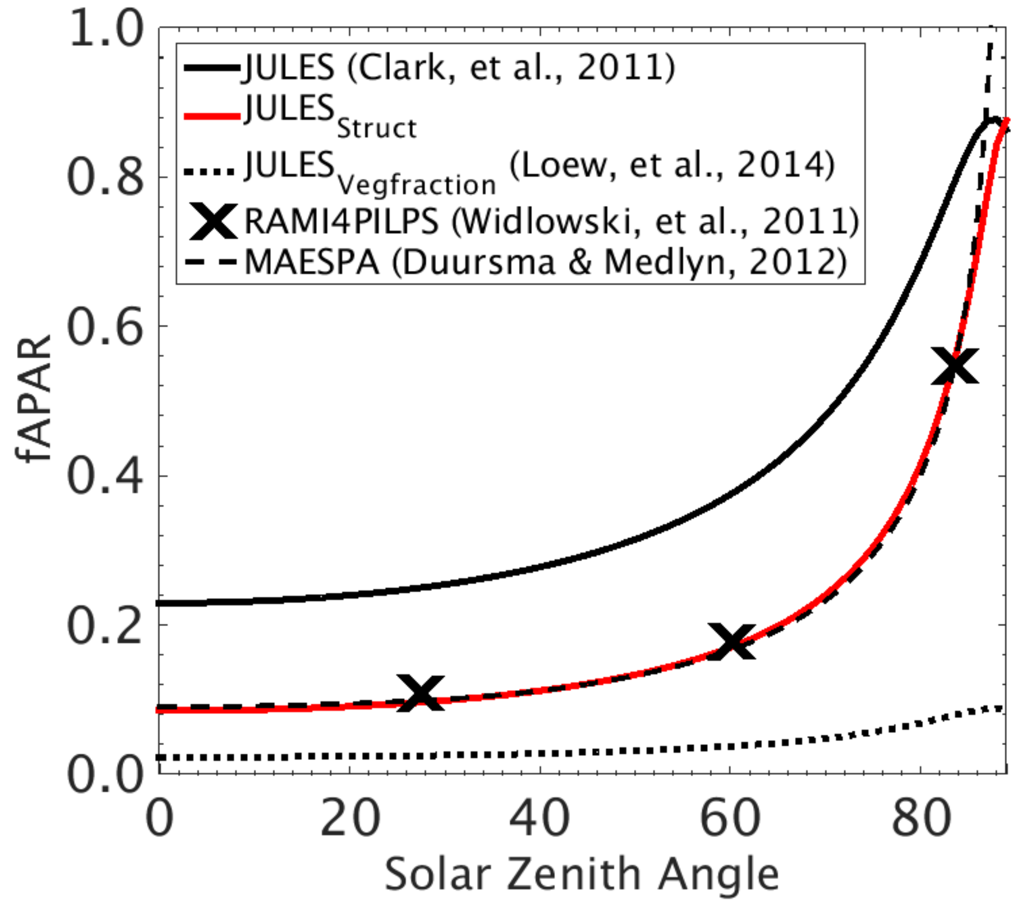
FAPAR for RAMI4PILPS sparse canopy



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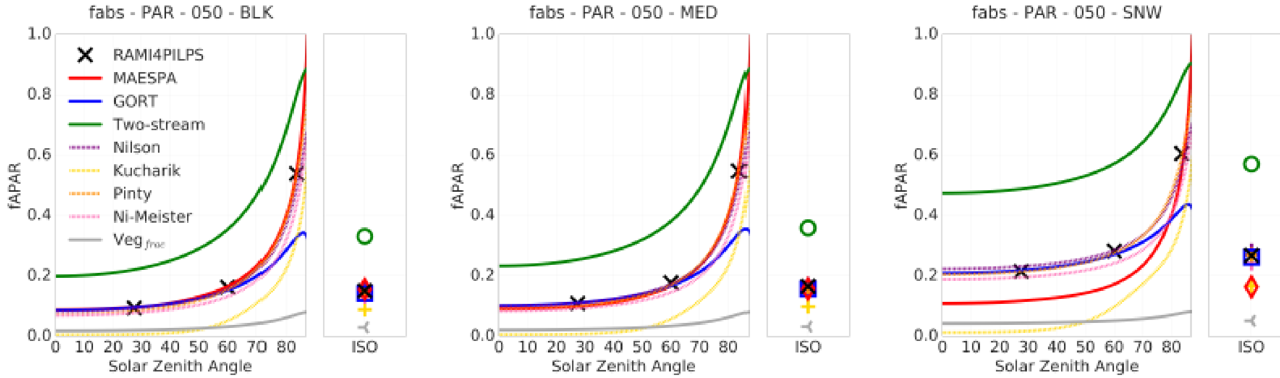
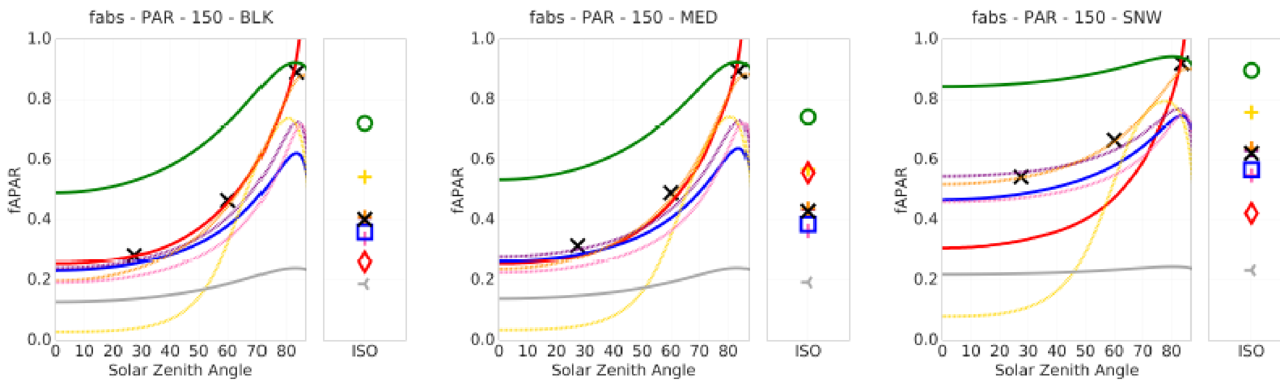
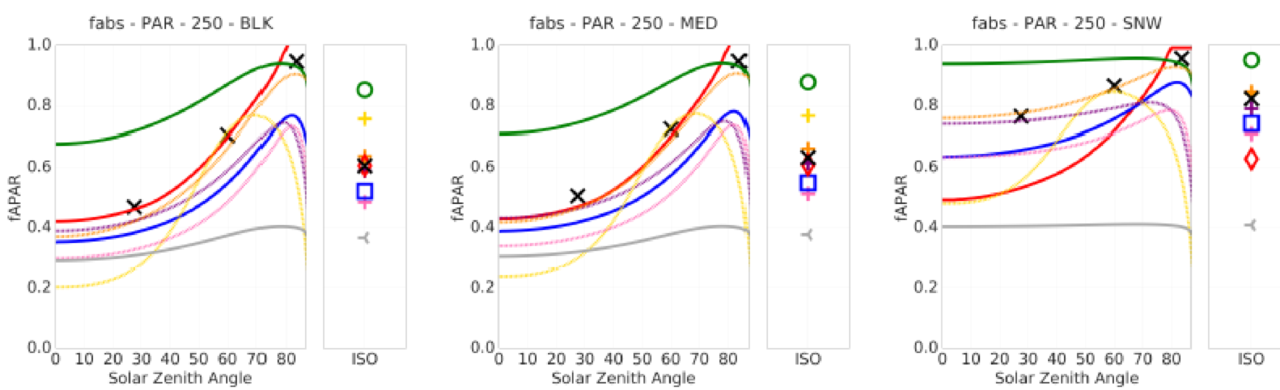


(a) Sparse



(b) Medium



2. SPARTACUS

Geosci. Model Dev., 11, 339–350, 2018
https://doi.org/10.5194/gmd-11-339-2018

Geoscientific Model Development
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Fast matrix treatment of 3-D radiative transfer in vegetation canopies: SPARTACUS-Vegetation 1.1

Robin J. Hogan[1,2], **Tristan Quaife**[2], **and Renato Braghiere**[2]

[1]European Centre for Medium-range Weather Forecasts, Reading, UK
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SPARATCUS schematic

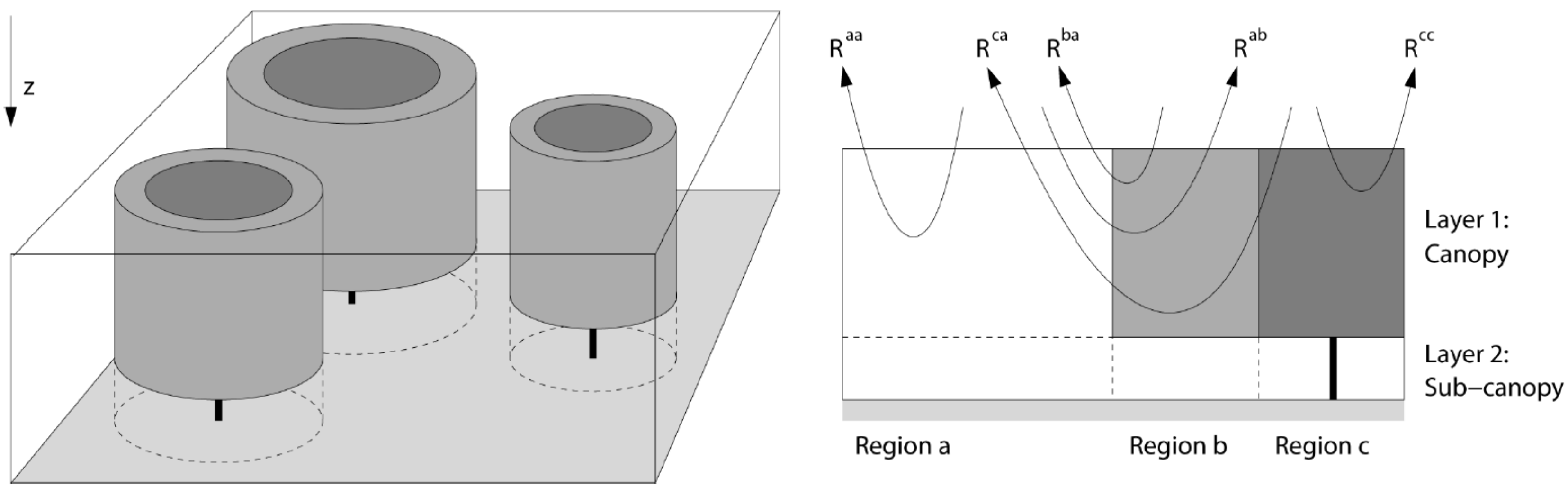
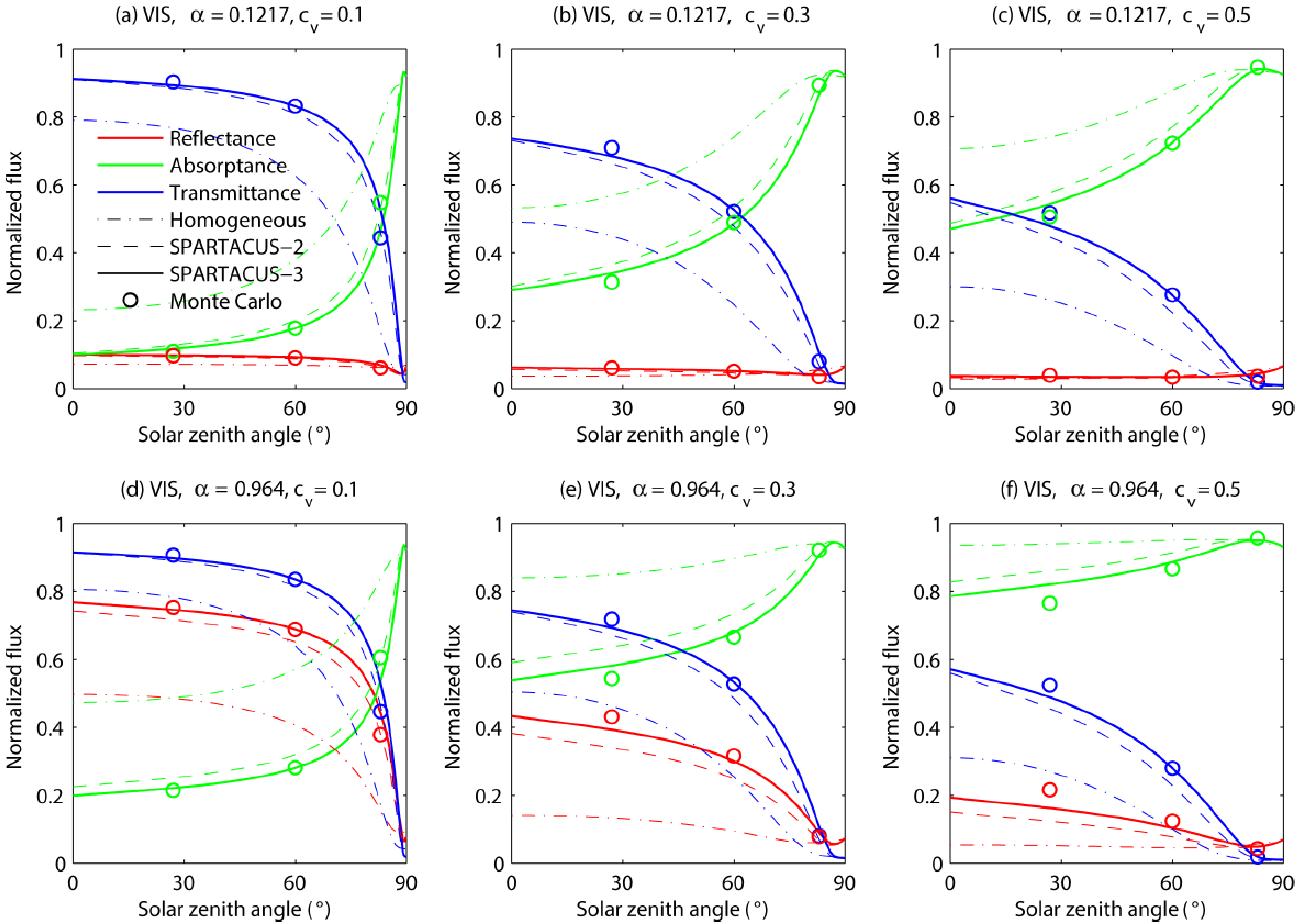


Figure 1. Schematic of the idealized vegetation considered in this paper, illustrating the meanings of Layers 1 and 2 and Regions a, b and c. The diagram on the right also illustrates the interpretation of the elements of the reflectance matrix **R** given in Eq. (24).


(a) VIS, α = 0.1217, c_v = 0.1
(b) VIS, α = 0.1217, c_v = 0.3
(c) VIS, α = 0.1217, c_v = 0.5
(d) VIS, α = 0.964, c_v = 0.1
(e) VIS, α = 0.964, c_v = 0.3
(f) VIS, α = 0.964, c_v = 0.5
Normalized flux
Solar zenith angle (°)
Reflectance
Absorptance
Transmittance
Homogeneous
SPARTACUS−2
SPARTACUS−3
Monte Carlo
0
0.2
0.4
0.6
0.8
1
0
30
60
90

Knowledge about global canopy structure and clumping is limited

- Either model relies on information about vegetation structure
- Ideally this would be prognosed by the model itself
  - For example ED2
- Alternately need to find data
  - For example NASA GEDI mission

Conclusions

- 3D canopy structure has a significant impact on the energy and carbon fluxes at the Earth's surface
- These effects are not well reproduced by current land models

Two potential 2-stream based solutions:

- Modified Sellers scheme
- SPARTACUS

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Conclusions

- Modified Sellers scheme
  - Easily implemented in LSMs that use the Sellers scheme
  - Very small additional computational cost
  - Parameters are not directly observable
- SPARTACUS
  - Requires larger changes to existing LSMs
  - Slightly more computational cost
  - Parameters are physical properties of the vegetation

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