Satellite-constrained land model for the CliMA Earth System framework

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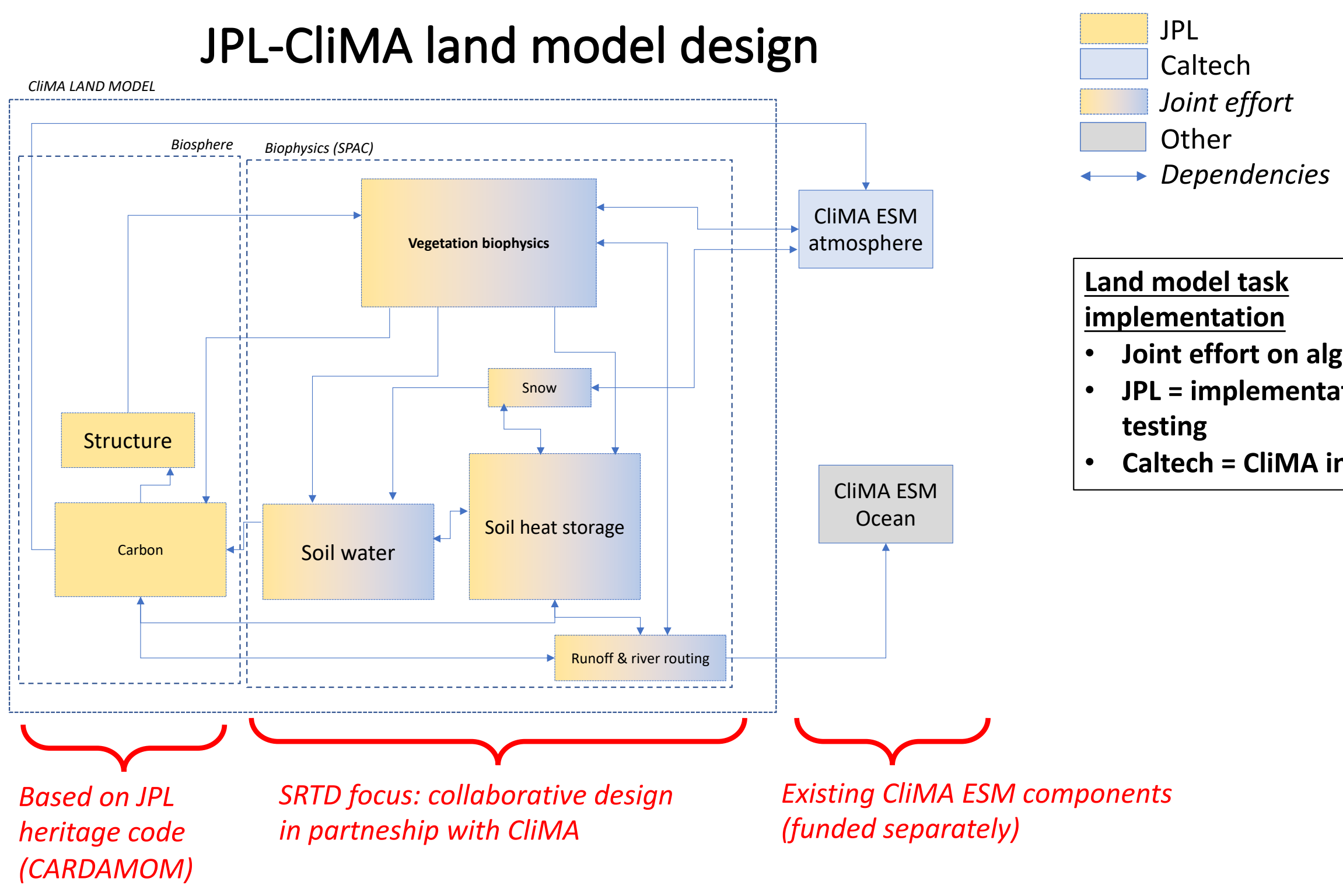
__Our objective__ was to build on JPL's existing observation-informed land carbon and water cycle modeling efforts (CARDAMOM, CMS-Flux) to build an ESM-compliant land surface and biosphere model informed and constrained by the satellite POR and surface site measurements; specifically, the model will comply with the Caltech CliMA Earth System Model (ESM) capability, directed by collaborator Tapio Schneider. In state-of-the-art conventional land models states and processes are typically tuned to data from a sparse network of sites, and consequently there is no confidence for representing the terrestrial land surface and predicting its future state. Integration of the ever-expanding set of satellite observations into land models is therefore critical for both resolving present-day land surface and land biosphere processes, and predicting their sensitivity to climate in the coming decades. Our technical objectives (TOs) can be summarized as follows: ***__Technical Objetive 1.__***Development of an "online" JPL-CliMA land model capability: adaptation and integrtation of the existing CARDAMOM land model into the CliMA framework to facilitate JPL-CliMA ESM capability, as informed by the satellite POR. ***__Technical Objetive 2.__*** Development of an "offline" JPL land model capability, based on the JPL land model adaptations and enhancements achieved in TO1, to facilitate dedicated scientific and mission formulation OSSE investigation.



__Land model task implementation__
- **Joint effort on algorithm.**
- **JPL = implementation and testing**
- **Caltech = CliMA integration**

Figure 1 Depiction of interfaces between the CliMA ESM atmosphere and the land model. We will couple and adapt the existing CARDAMOM land biosphere model (currently represents carbon and soil water) with the vegetation biophysics model interface developed at Caltech to explicitly represent physical processes driving land-atmosphere interactions. Both interfaces will be implemented and tested with re-analysis data first (as place-holder meteorological drivers). Following the VVUQ of the finalized CARDAMOM-SPAC version, the model will be fully coupled into the CliMA system. Yellow (Blue)-colored boxes denote JPL(Caltech)-led activities, yellow-to-blue shading indicates joint activities.

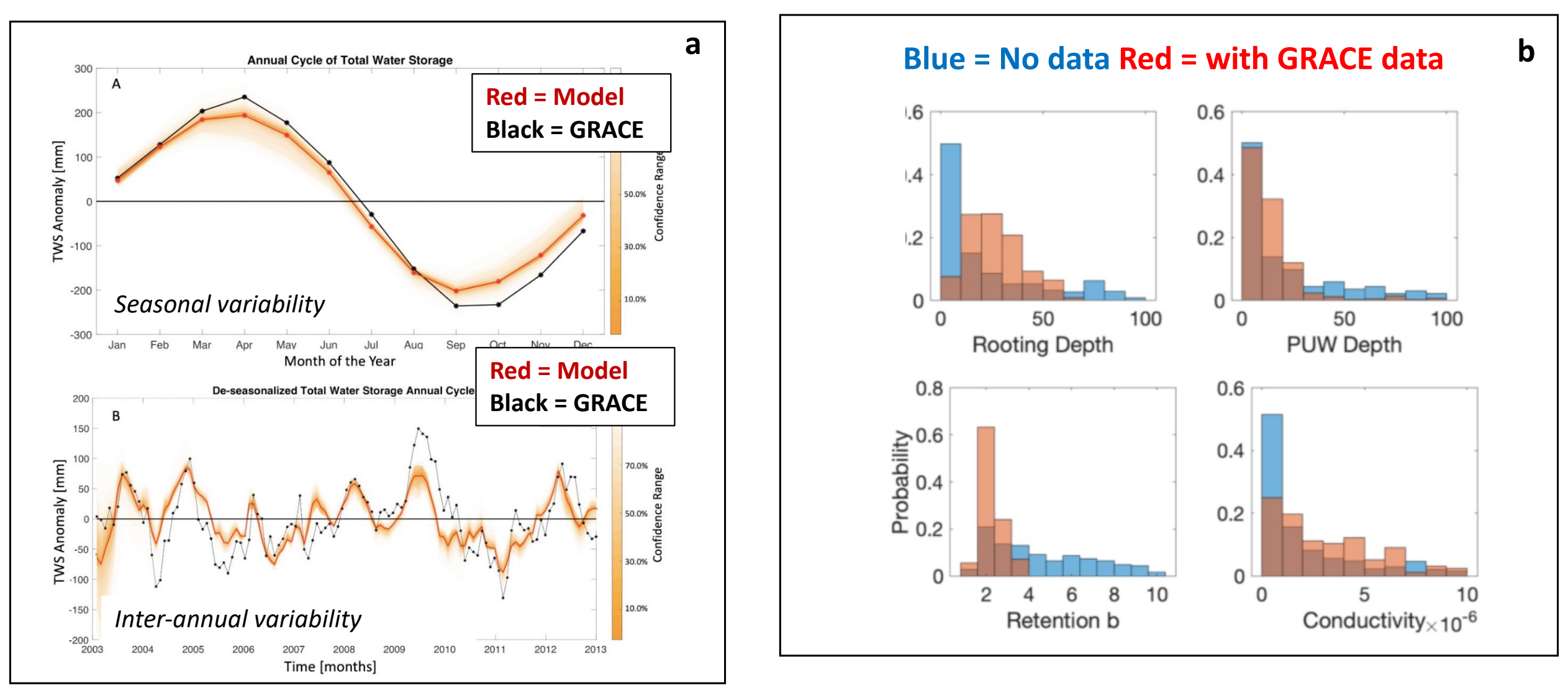


Figure 2. Massoud et al., 2022. This study is a reduced-complexity representation of the CliMA soil hydrology processes tested out at an Amazon watershed, which includes key soil hydrogical parametrizations and associated uncertainties, including porosity, rooting depth, soil water retention and drainage parameters. The CARDAMOM framework was used to optimize the parameters and initial soil moisture conditions required to minimize mismatches between modelled and observed (GRACE) equivalent water thickness.

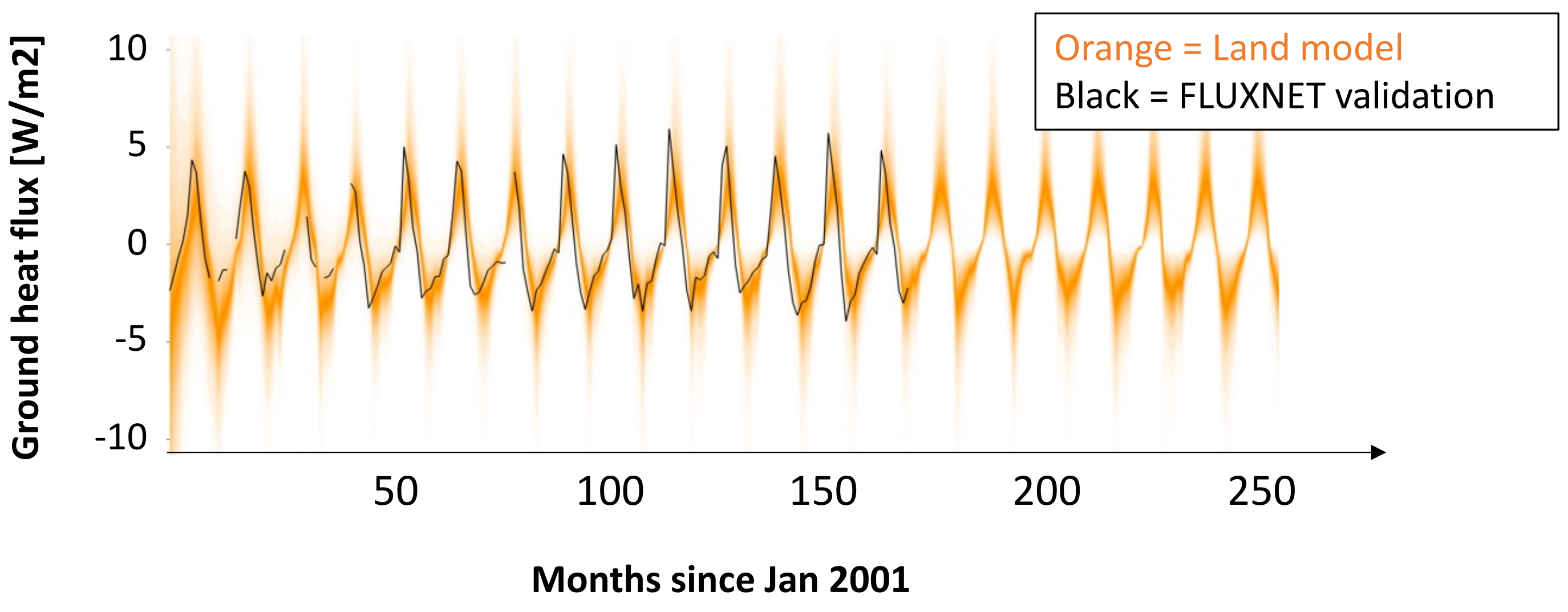


Figure 3. Reduced-complexity representation of the CliMA soil energy balance (ground heat flux at the top layer) tested at the Niwot Ridge (Colorado) FLUXNET validation site against withheld FLUXNET validation data. Land model parameters including rooting depth, thermal conductivity, and process parameters regulating radiative and turbulent energy fluxes were optimized using joint in-situ and satellite constraints on carbon, water and energy variables.

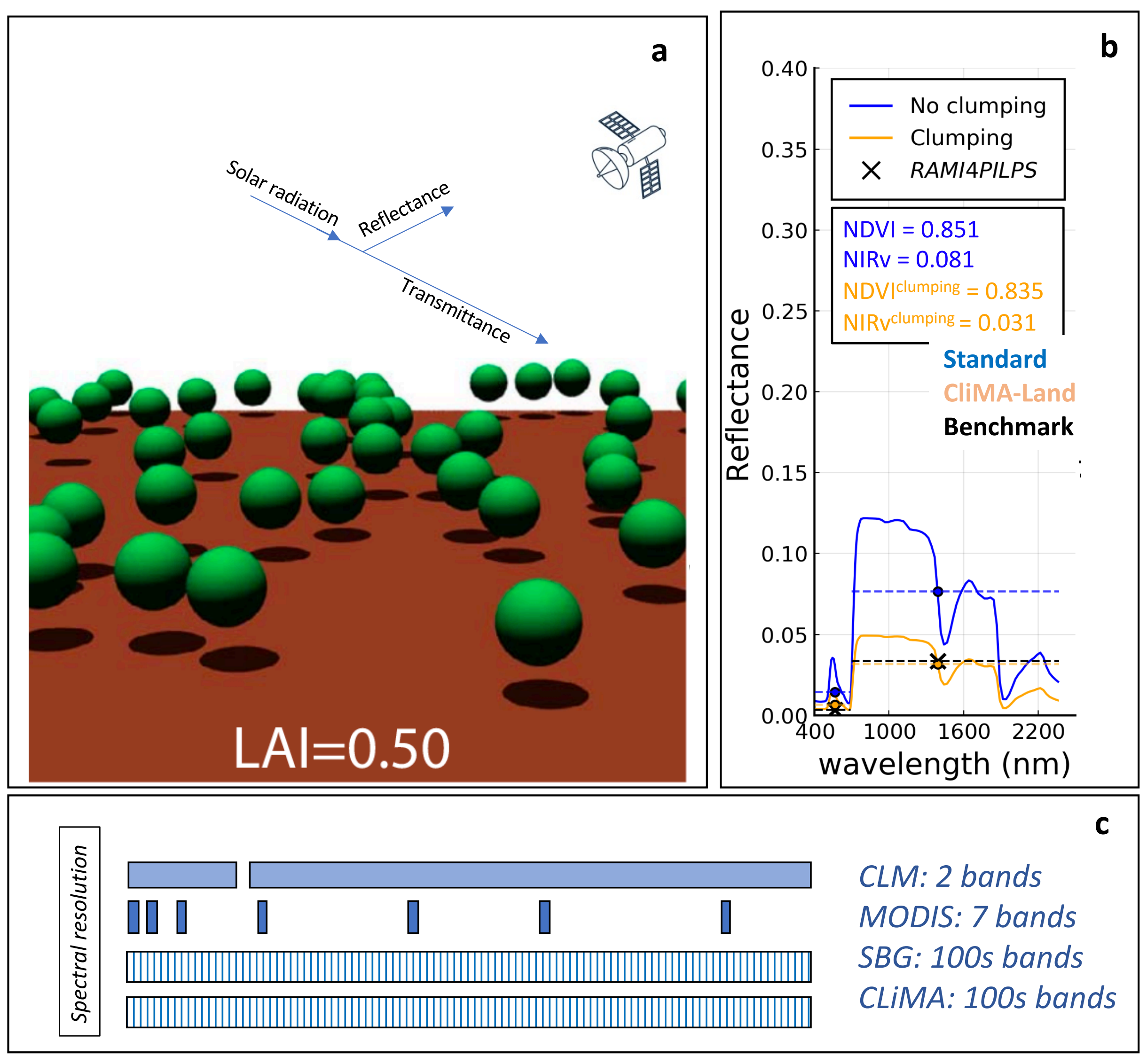
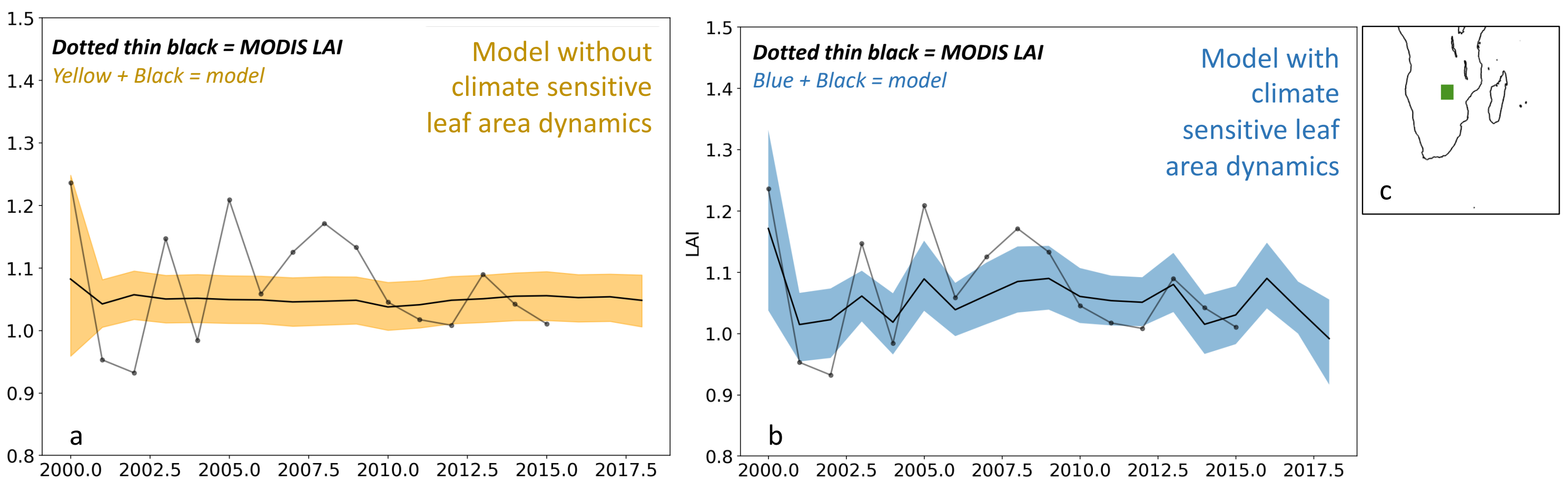
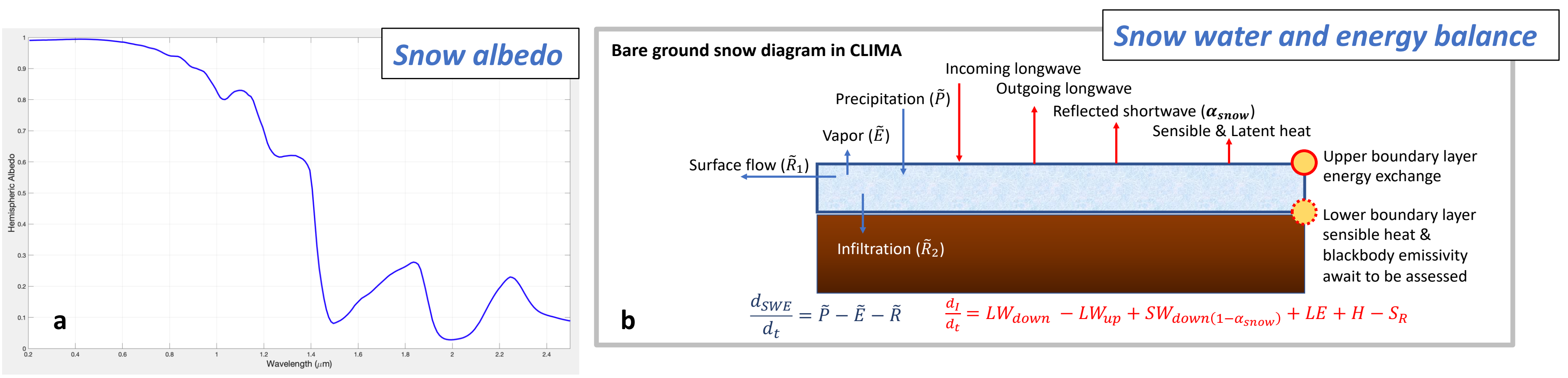


Figure 5. Interaction of solar radiation with plant structure and biophysical processes (photosynthesis, leaf area, vegetation water content) and their response to climate are critical for ES prediction (panel a). In the above example, the vegetation biophysics radiative transfer model (Braghiere et al., in prep., developed jointly with collaborator Christian Frankenberg at Caltech) allows for accurate estimation of plant biophysical states and fluxes. The CliMA-Land model spectral resolution (panel c) is being tailored to accommodate existing observing systems (MODIS, TROPOMI) and upcoming missions (SBG).

Figure 4. JPL-developed leaf area index (LAI) dynamics, and their sensitivity to climatic factors, namely their response to temperature, available water, radiation (Norton et al., in prep); the incorporation of climate sensitivity (panel b) is critical to represent year-to-year variations in LAI. State-of-the-art land models prescribe climate sensitivity on a plant-functional scale; in contrast, the JPL-CliMA LAI model is informed by co-located satellite-based LAI estimates.



Norton et al., (2022, in prep).



$$\frac{d_{SWE}}{d_t} = \tilde{P} - \tilde{E} - \tilde{R} \qquad \frac{d_I}{d_t} = LW_{down} - LW_{up} + SW_{down(1-\alpha_{snow})} + LE + H - S_R$$

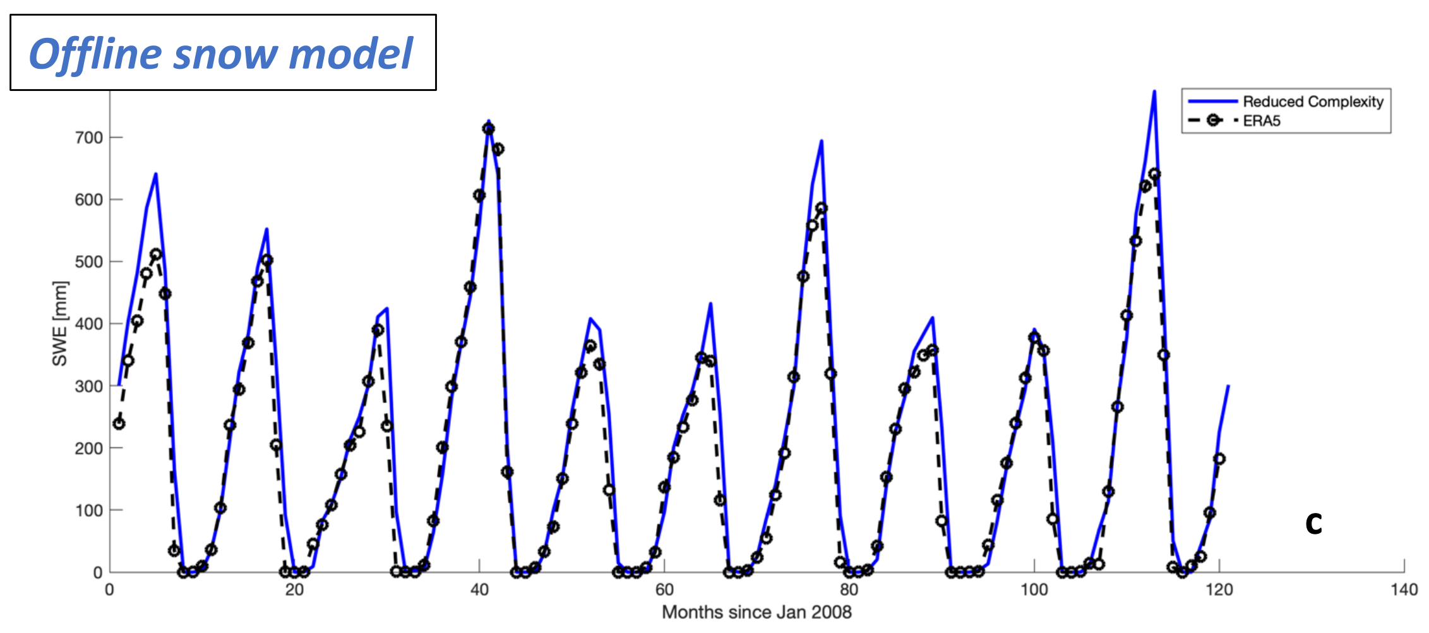


Figure 6. The CliMA land model snow module co-developed by JPL and Caltech, with an explicit hyperspectral representation of snow albedo (panel a) and snow water and energy states (panel b). The snow pack water and energy balance closure is a key component of the land-surface water and energy cycles and their impacts on the Earth System; furthermore, explicit dynamical representation of snow states is critical for integrating observations into the CliMA ESM framework. Reduced complexity snow model (panel c) meets the requirements for offline carbon-water-energy simulations required for JPL science and OSSE efforts.

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