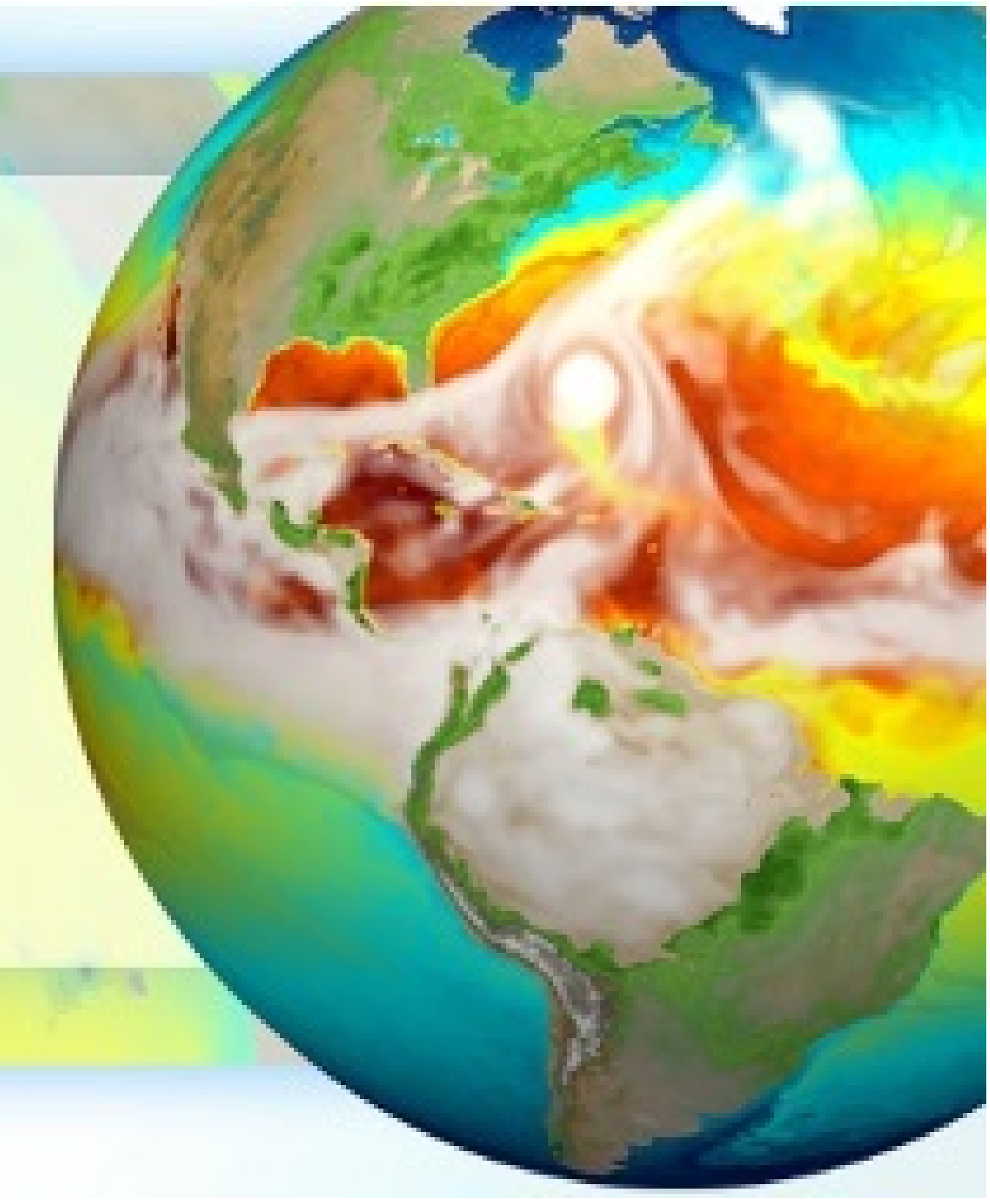# Development of a soil-plant-atmosphere continuum model with support for heterogenous computing architectures

Gautam Bisht[1], William Riley[2], Gil Boher[3], Ashley Mathney[4], Richard Mills[5]

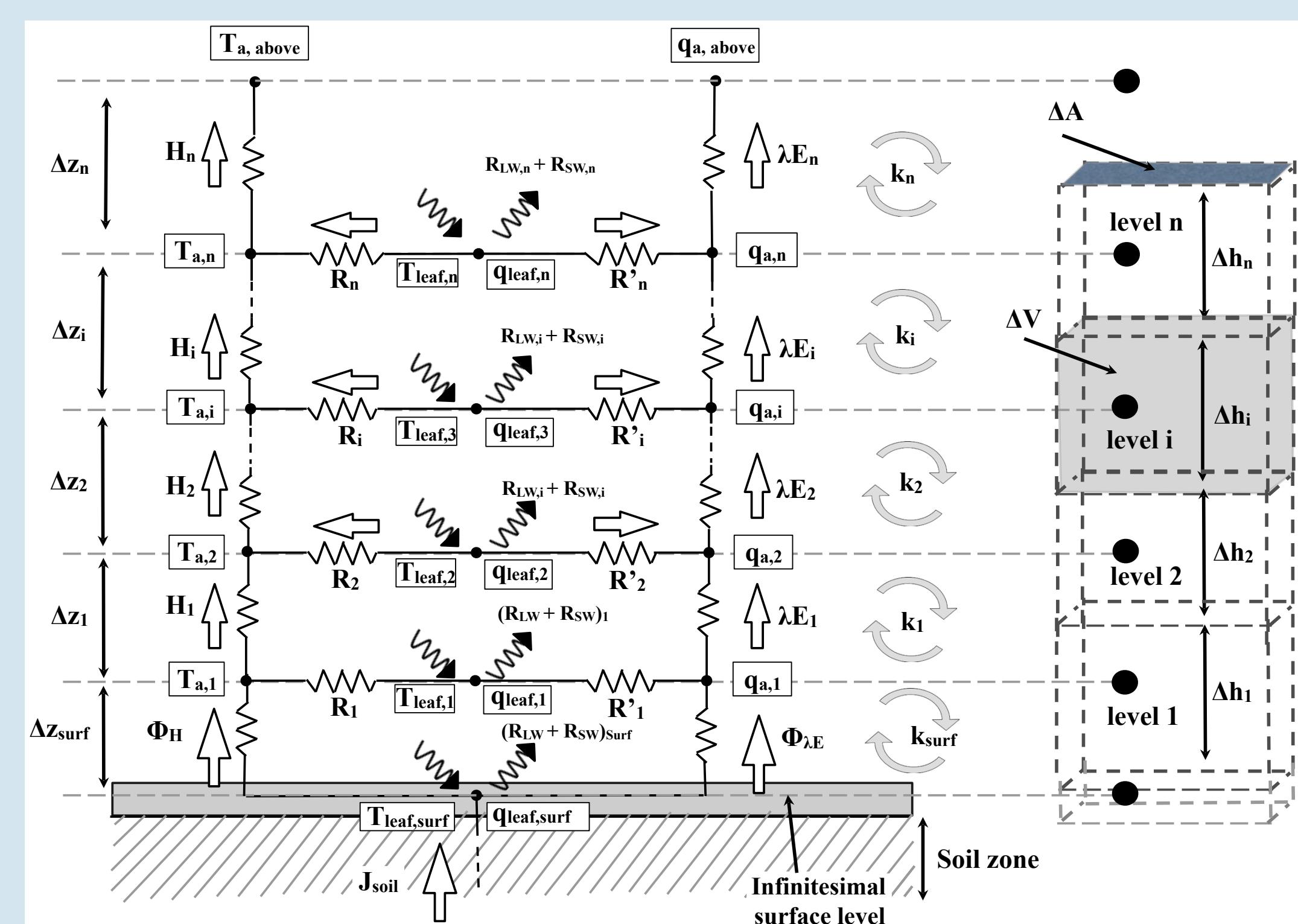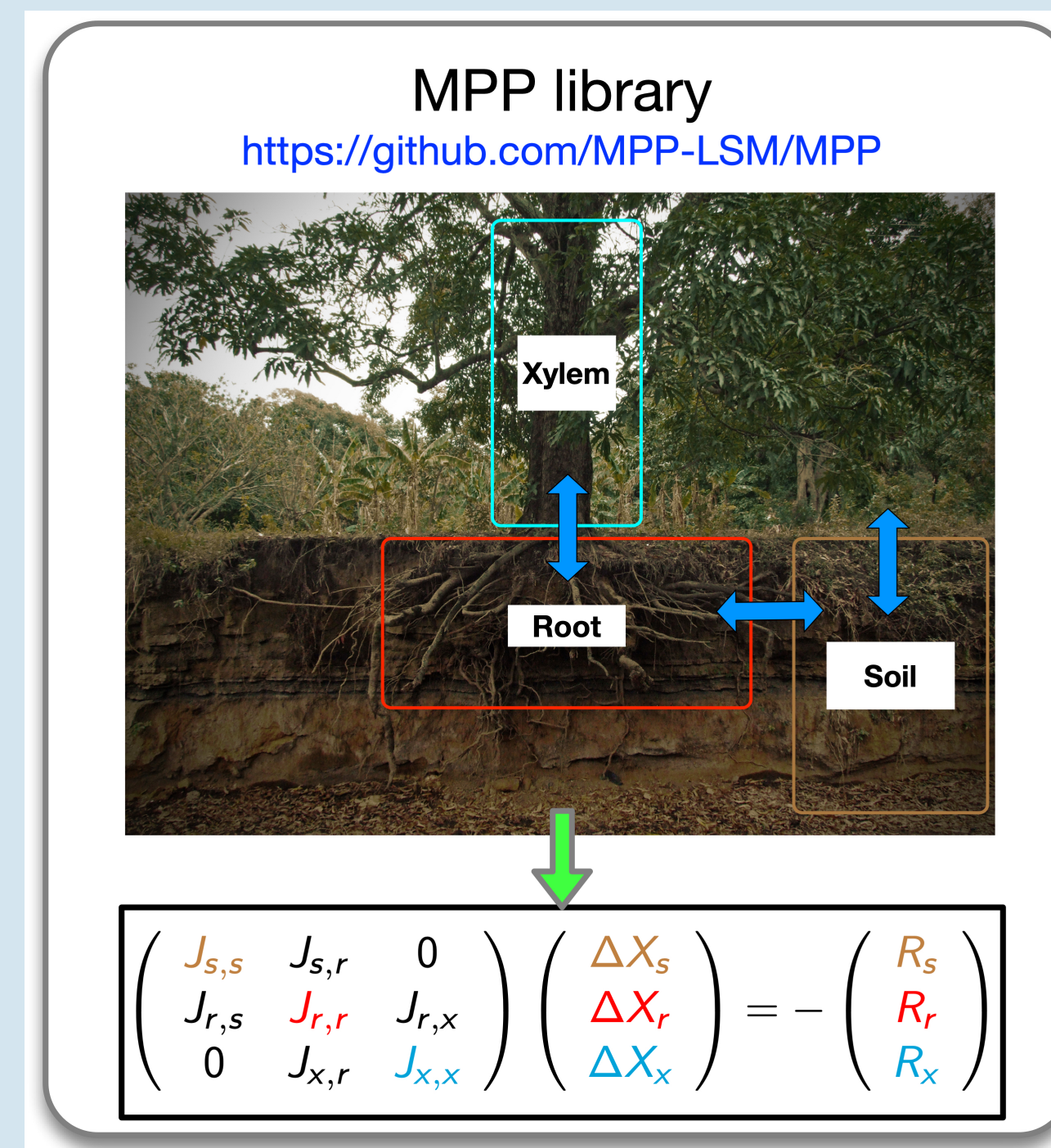[1]PNNL   [2]LBNL   [3]Ohio State Univ.   [4]Univ. Texas at Austin   [5]ANL

Objectives

- The need to mechanistically simulate transport of water through the soil-plant-atmosphere continuum (SPAC); and vertical regimes of light, water vapor, and momentum within the canopy air space (CAS) have been recognized as key processes to accurately capture vegetation response to future climate change.
- It is imperative that all new model developments include support for heterogenous computing architectures, which will be the norm in upcoming Exascale class of DOE supercomputers.

Approach

- Developed an open-source library (libMPP) for solving terrestrial multi-physics processes with support for flexible coupling strategy.
- libMPP uses PETSc to provide numerical solution of discretized equations.
- Method of manufactured solutions are used to verify the numerical implementations in libMPP.
- Plant hydraulics model solves vertical transport of water through root-soil-xylem
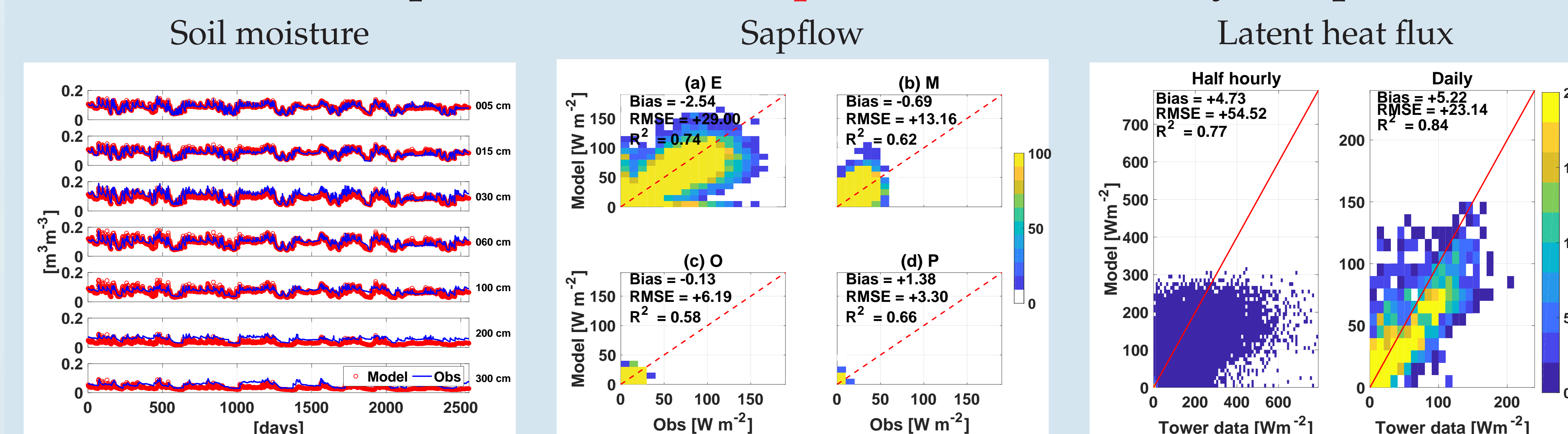- Multi-layer canopy model includes:
  1. Two-stream shortwave and longwave radiation model.
  2. Boundary layer model.
  3. Photosynthesis model (Ball-Berry and Medlyn).
  4. Roughness sublayer (RSL) turbulence model.
  5. Leaf energy balance model.
  6. Vertical transport of scalars (such as water vapor and energy) in CAS.

MPP library
https://github.com/MPP-LSM/MPP

$$\begin{pmatrix} J_{s,s} & J_{s,r} & 0 \\ J_{r,s} & J_{r,r} & J_{r,x} \\ 0 & J_{x,r} & J_{x,x} \end{pmatrix} \begin{pmatrix} \Delta X_s \\ \Delta X_r \\ \Delta X_x \end{pmatrix} = - \begin{pmatrix} R_s \\ R_r \\ R_x \end{pmatrix}$$

Source: Ryder el al. (2016)

## Results: Plant hydraulics model

- Simulations performed for US-UMB study site for 2010-2016.
- Early successional, maple, oak, and pine share a soil column.
- Boundary and source-sink conditions:
  - A time-varying top pressure boundary condition.
  - A time-invariant water table as a lower boundary condition.
  - A time and space varying potential transpiration is prescribed.
- The model computes actual transpiration based on xylem pressure.


Soil moisture | Sapflow | Latent heat flux

Results: Multi-layer canopy model

- Idealized simulation of a CAS shared by a single tree with sunlit and shaded leaves is performed.
- The simulation configuration includes models for RSL, leaf energy balance, and vertical transport scalars in CAS.
- The model includes flexibility for multiple trees to share a single CAS.
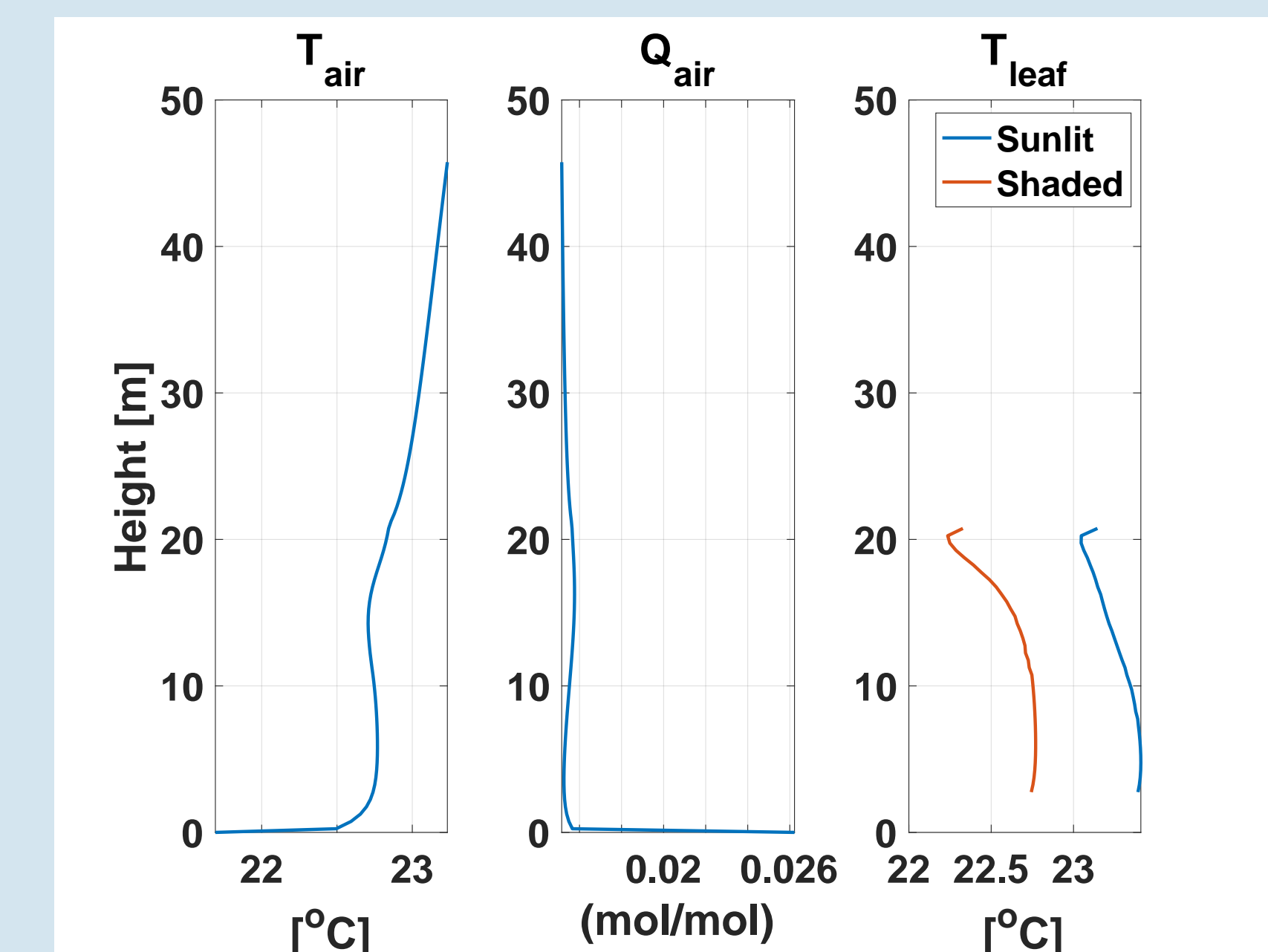
Model performance on Summit
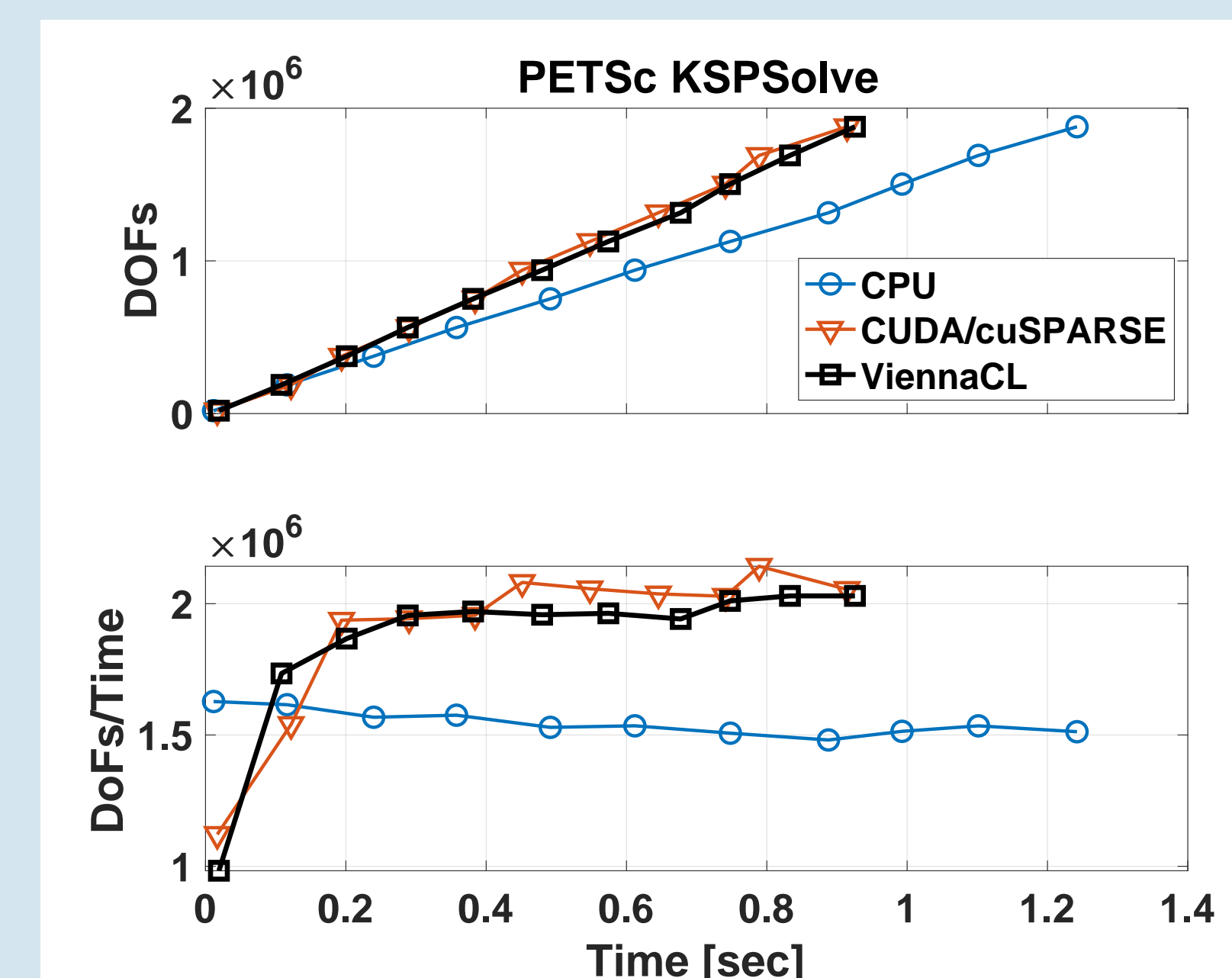
- PETSc:
  - Support GPUs using CUDA and ViennaCL.
  - Allows user code to be written independent of computing architecture.
  - Provides runtime options to choose numerical methods.
- Model was configured for a single CAS to be shared by 50 trees leading to 18,786 degree of freedoms (DoFs)
- Simulations are performed on ORNL's Summit supercomputer for 1–100 CAS systems with a maximum 1.8×10^6 DoFs.

E3SM Energy Exascale Earth System Model

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