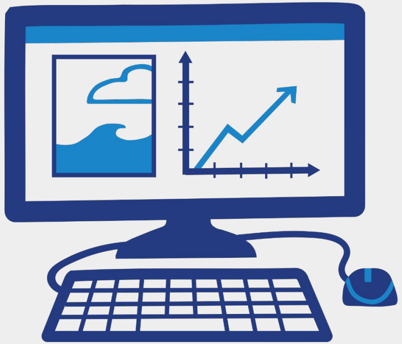


Terrestrial heterogeneity & cryosphere

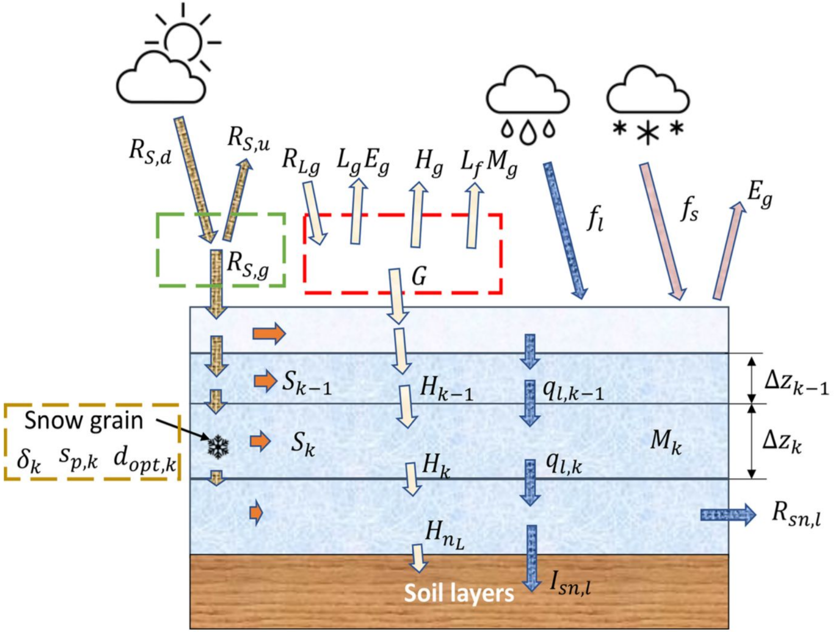
Sergey Malyshev and Land Modeling Team

Q1: Concerning GFDL's core strength of building and improving models of the weather, oceans, and climate for societal benefits, how can GFDL leverage advances in science and computational capabilities to improve its key models? What are the strengths, gaps, and new frontiers?

New Global LAnd Snow Scheme (GLASS) in LM4.1

Physically-based prognostic representation of major snow processes:

- Snow aging and its influence of reflectivity
- Change of snow grain size and dendricity
- Influence of Light-Absorbing Particles (LAPs: black carbon, organic aerosols, dust) on snow albedo
- Snow compaction
- Snow thermodynamics and insulation effect
- Flexible numerical scheme with dynamic layering

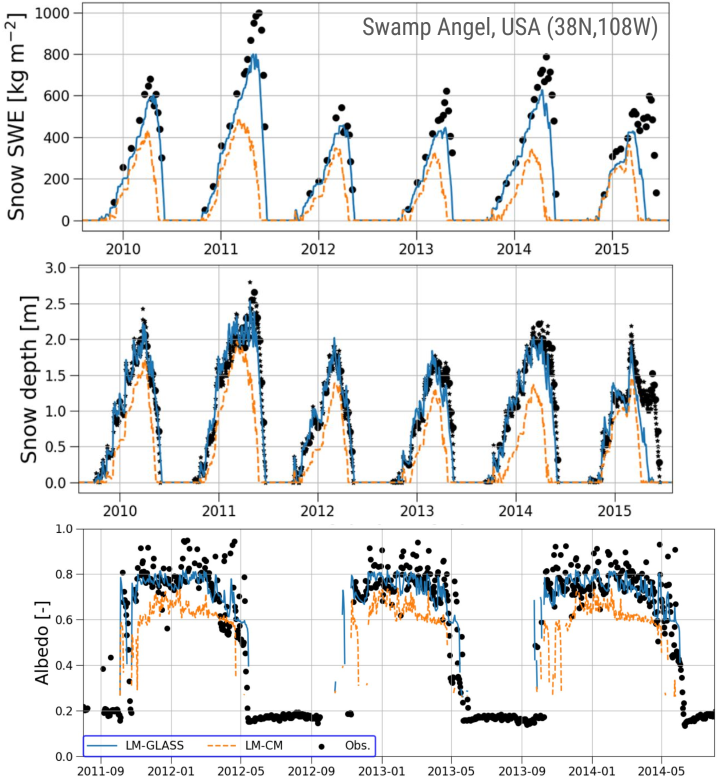


Zorzetto et al., GMD, 2024a,b

GLASS: Evaluation at SnowMIP Sites

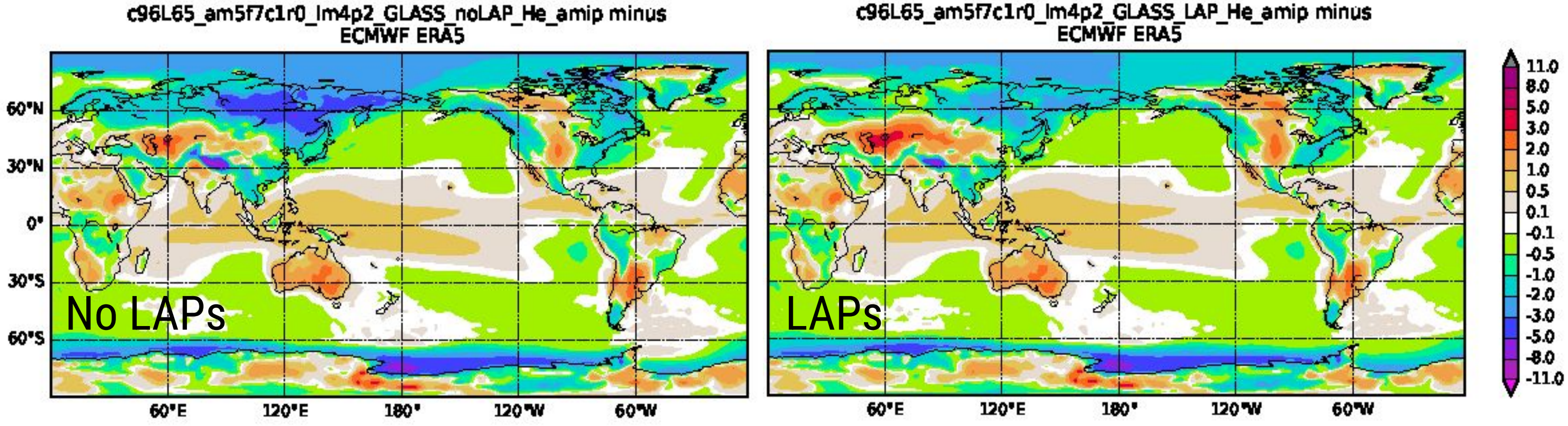
- Overall marked improvement of Snow Water Equivalent (SWE), compared to previous treatment (CM: Milly et al., 2014)
- Comparable results of snow depth
- Improved snow albedo: low bias removed
- Improvement of soil temperature: low bias removed consistently across all sites
- Effect of LAPs on snow is significant at all sites: dust dominates Western US; carbonaceous aerosols in Alps

Zorzetto et al. (2024a,b)



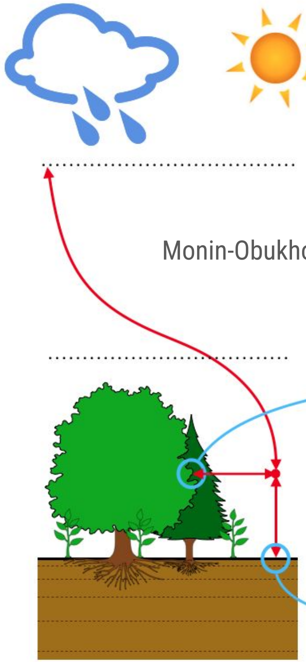
GLASS: Preliminary Results of Global Simulations

- LAPs reduce cold bias in Eurasia.
- GLASS has an effect extent on permafrost due to improved snow insulation properties: need longer simulations for quantify.
- GLASS, LAPs have effect on climate sensitivity through snow albedo feedback.



Zorzetto et al., 2025, in prep.

Improving Representation of Land-Atmosphere Turbulent Exchange



- Exchange between land surface and the atmosphere depends on a number of resistances, including in-canopy resistances and surface resistances.
- Quasi-laminar resistances on the leaf surface are generally included in the models, but the soil surface resistance formulations are less well established

Laminar Resistance at the Soil Surface

Laminar resistance (LR) at the soil surface

- Laminar layer present at soil surface, providing extra resistance to fluxes
- Parameterisation is based on Eddy Replacement Theory (Haghighi & Or, 2013)
- LR reduces soil evaporation, leaving more water to transpiration through plants
- Longer-term effects include vegetation feedback, with vegetation reacting to more available soil moisture

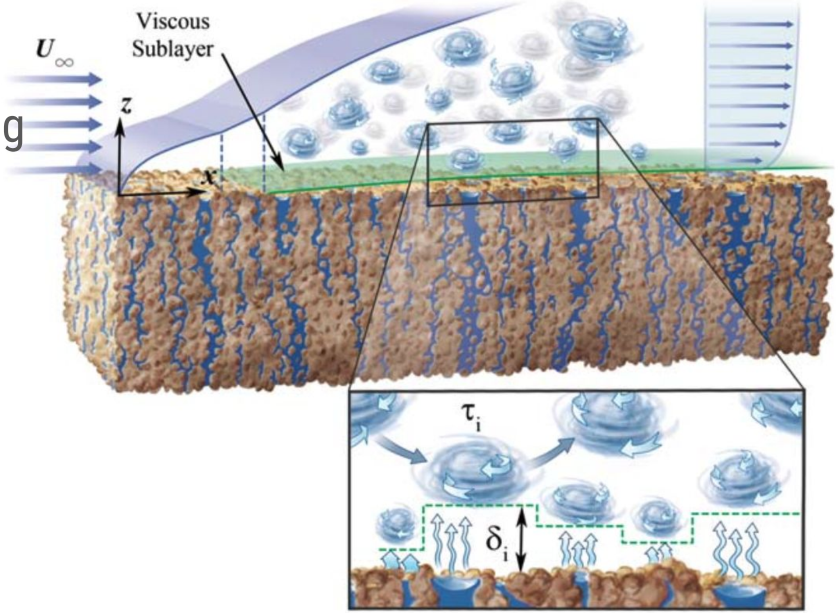


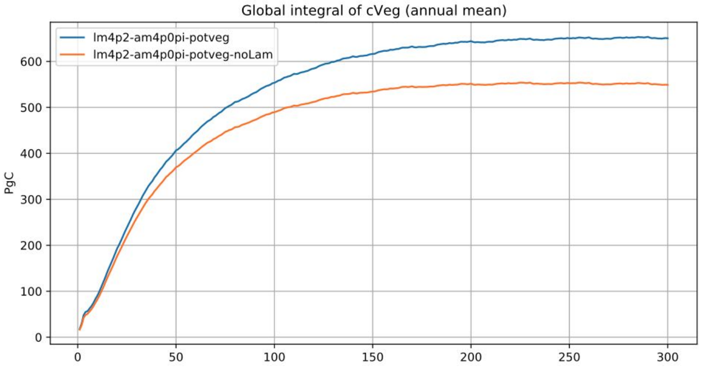
Illustration from Haghighi and Or (2013)

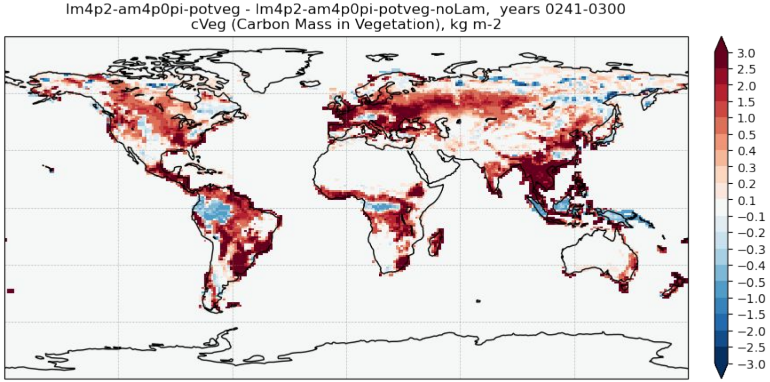
Malyshev et al., in prep.

Laminar Resistance at the Soil Surface

- Significantly improves in T/ET, from 41% without LR to 57.8% with LR (compared to observational estimate of 57.2±6.8%, Wei et al. 2017)
- Generally increases near-surface temperature, reduces precipitation over land by about 10%
- Has a long-term effect on the state of vegetation due to increased availability of water: increase of biomass globally and in most regions.

Malyshev et al., in prep.

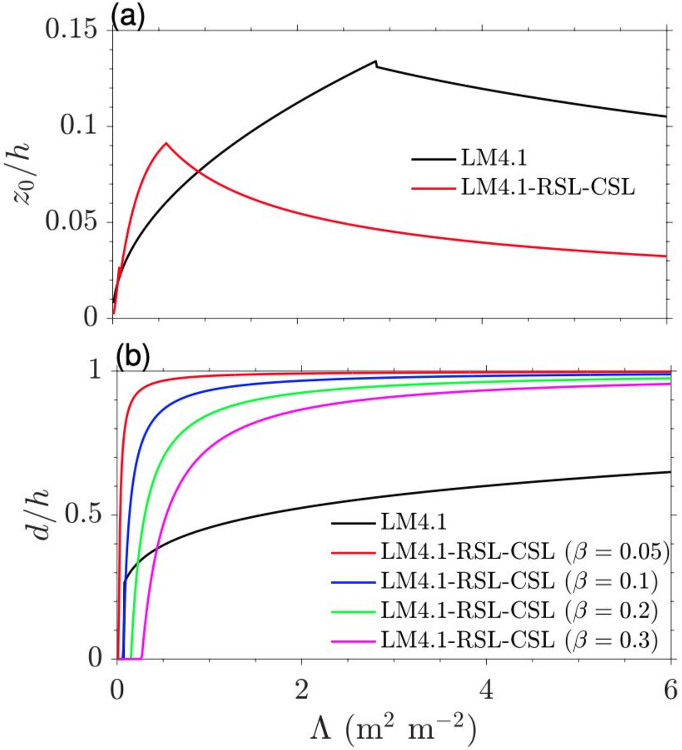




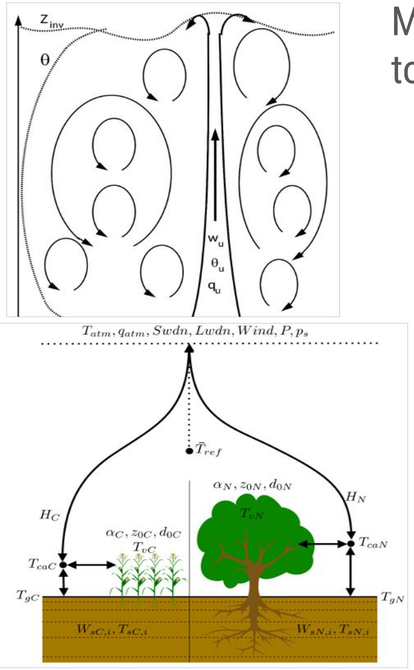
Improving In-canopy Turbulence Processes

- Updated structural parameters of canopies: roughness length and displacement height
- Updated in-canopy turbulence parameterisation:
  - In-canopy wind decay is calculated dynamically, consistent with the above-canopy turbulence
  - Friction velocity at the soil surface consistent with near-surface turbulence
- Improved diurnal cycle compared to AmeriFlux data in wide range of vegetation parameters
- Improves deposition of chemical species (e.g. ozone)

Ghannam et al. (2024).



CLASP-EDMF: Effects of Land Heterogeneity on Planetary Boundary Layer

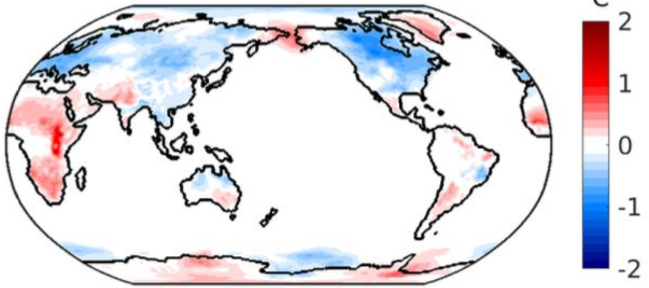


Ghannam et al., in prep.

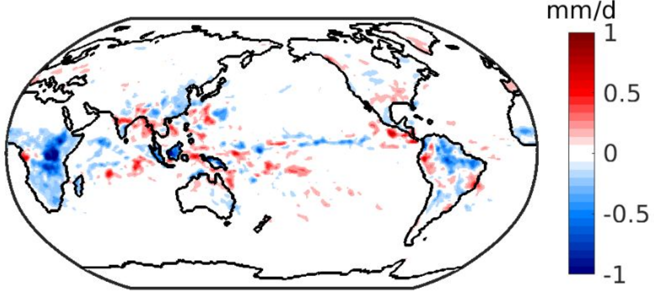
Modification of Eddy-Diffusivity Mass Flux (EDMF) to account for sub-grid scale heterogeneity:

- Land surface is heterogeneous (due to land use, disturbances, etc.), and can provide measures of heterogeneity to the atmosphere
- In CLASP-EDMF, updraft areas are calculated using measures of surface heterogeneity, in contrast to a predefined constant in the standard EDMF treatment
- In CLASP-EDMF, updraft properties (velocity, temperature, humidity) take into account measures of surfaces heterogeneity, such as subgrid-scale variations of temperature and humidity.

Annual mean T_2m:
AM4 EDMF-HET minus AM4 EDMF

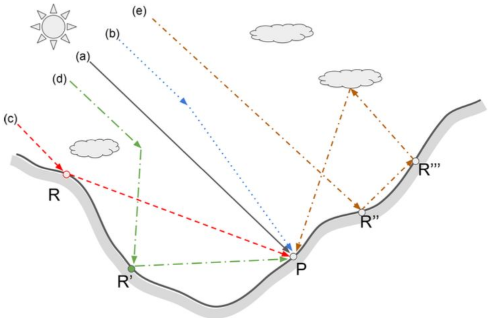


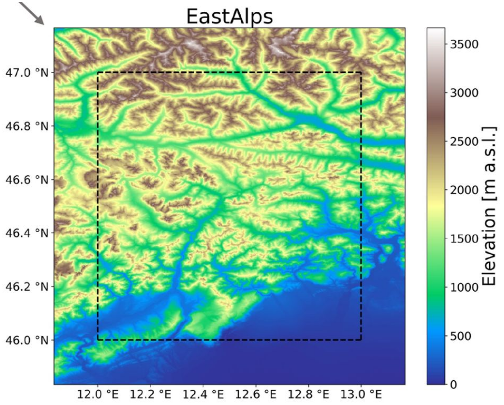
Annual-mean precipitation:
AM4 EDMF-HET minus AM4 EDMF



Improvement in Radiation Exchange in Complex Terrain

- In complex terrains, light undergoes a number of re-reflections among mountain slopes and atmosphere
- accounting for the sub-grid spatial variability of solar irradiance leeds to significant local differences compared to plane-parallel case.
- Using Monte-Carlo ray tracing, a parameterization is developed to represent sub-grid scale effects using limited number of sub-gris tiles.
- Sub-grid tile clustering is based on high-res digital elevation model: slope orientation, terrain, sky view factor.

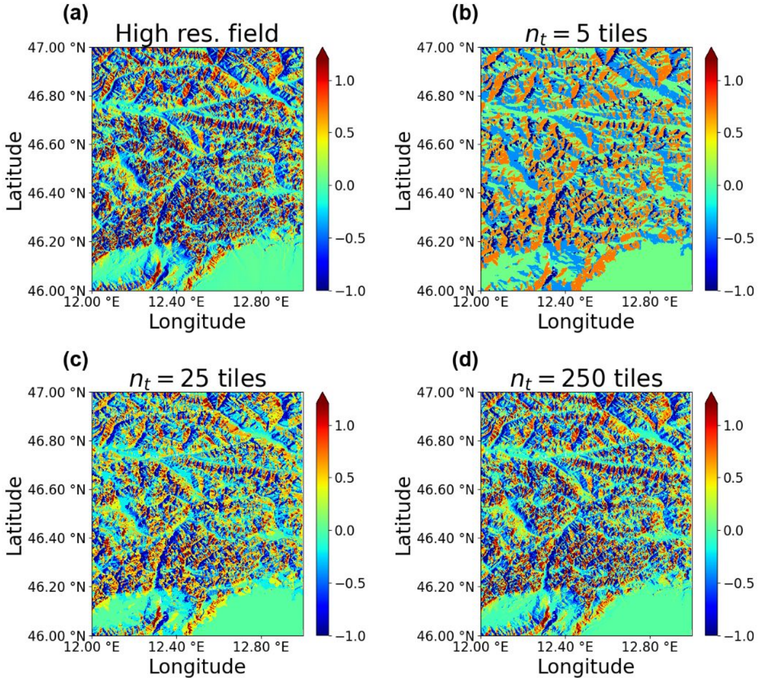




Zorzetto et al., 2023

Improvement in Radiation Exchange in Complex Terrain (cont)

- Even a limited number of sub-grid tiles (10) can lead to recovering more than 60% of the spatial variability of solar irradiance over a mountainous area.
- The results are consistent over different geographical domains (Eastern Alps, Peru, Tibet)
- Increased number of tiles improves not only the spatial variances, but also higher-order statistics



Normalized direct radiation flux difference between high-resolution and parameterisation, depending on number of sub-grid tiles

Zorzetto et al., 2023

Publications and Presentations

K. Ghannam, F. Paulot, S. Malyshev (2024) **A New Parameterization of Vegetation Micrometeorology in the GFDL Land Model LM4.1: Performance Evaluation and Climate Implications**. *AGU 2024*

K. Ghannam, S. Malyshev, F. Paulot, E. Shevliakova. **Revised Formulations of Vegetation Micrometeorology in the GFDL Land Model (LM4.1): Performance Evaluation and Implications on Near Surface Climate.** In preparation for *Journal of Advances in Modeling Earth Systems*

K. Ghannam, S. Malyshev , E. Shevliakova , Z. Tan, E. Bou-Zeid, and N. Chaney. **Sub-grid Surface Heterogeneity to the Convective Boundary Layer in the GFDL Global Atmosphere-Land Model AM4.0/LM4.0: Parameterization Development and Climate Implications**. In preparation for *Geoscientific Model Development*.

S. Malyshev, E.Shevliakova. **Effects of the Surface Resistance Formulations on the Near Surface Climate, Hydrological Cycle, and Terrestrial Vegetation**. In preparation for *Geoscientific Model Development*

E. Shevliakova, et al. (2024): The Land Component LM4.1 of the GFDL Earth System Model ESM4.1: **Model Description and Characteristics of Land Surface Climate and Carbon Cycling in the Historical Simulation**. *Journal of Advances in Modeling Earth Systems*, 16, No.5, doi:10.1029/2023ms003922.

E. Zorzetto, S. Malyshev, P. Ginoux, and E. Shevliakova (2024a): **A global land snow scheme (GLASS) v1.0 for the GFDL Earth System Model: formulation and evaluation at instrumented sites**. *Geoscientific Model Development*, 17, No.19, 7219-7244, doi:10.5194/gmd-17-7219-2024.

E. Zorzetto, P. Ginoux, S. Malyshev, and E. Shevliakova (2024b): **Quantifying radiative effects of light-absorbing particles deposition on snow at the SnowMIP sites**. *Cryosphere*, in press

E. Zorzetto, S. Malyshev, N. Chaney, D. Paynter, R. Menzel, and E. Shevliakova (2023): **Effects of complex terrain on the shortwave radiative balance: a sub-grid-scale parameterization for the GFDL Earth System Model version 4.1**. *Geoscientific Model Development*, 16, No.7, 1937–1960, doi:10.5194/gmd-16-1937-2023.

E. Zorzetto, S. Malyshev, P. Ginoux, and E. Shevliakova (2024c) **Contrasting the contributions of vegetation and snow properties to surface albedo feedback predictions**. *AGU 2024*