2-Way Coupling the GFDL Land Model with FV3 Atmosphere in UFS

UFS Application – Global Applications Across Scales

Justin Perket (Princeton CIMES),
Elena Shevliakova (GFDL), Sergey Malyshev (GFDL)

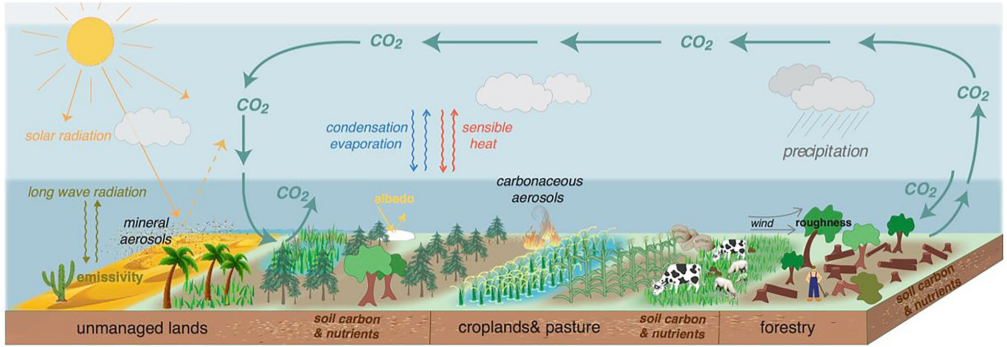
Publicly Released GFDL Land Models

3 CMIP6 configurations
- CM4.0: LM4.0
- SPEAR: LM4.0
- ESM4.1: LM4.1

Above-ground processes:
- Multi-layer snow
- River runoff and routing
- Lakes with ice/snow
- Plant phenology
- Plant hydraulics
- Dynamic veg. competition
- Prognostic dust
- Fires
- Crops

Below-ground processes:
- 20 soil layers to 10 m
- Thermal diffusion with freeze-thaw
- Surface and subsurface runoff and river routing
- Dynamic water table, including perched over permafrost

GFDL LM4.1 land model surface processes and land-atmosphere interactions (*JAMES* 2024)
https://doi.org/10.1029/2023MS003922

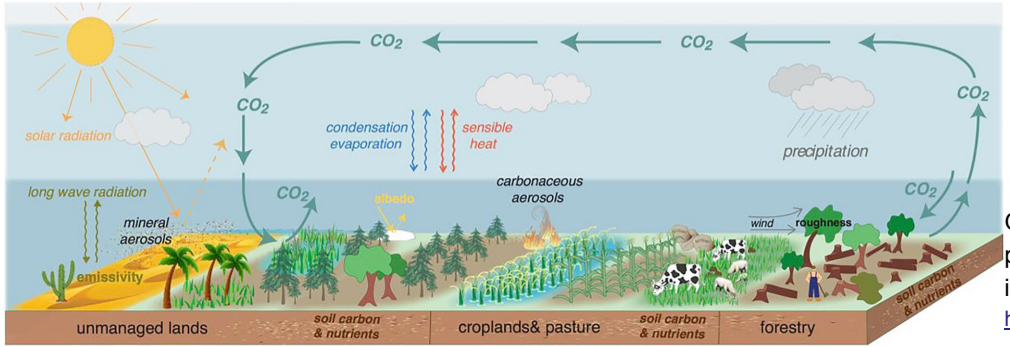


Coupling & heterogeneity:
- Implicit fluxes for each subgrid tile
- Static glaciers and ice sheets
- Dynamic land use, fire, and veg dynamics tiles

GFDL LM4.0 in UFS

LM4.0 as an Earth System land component model in UFS applicable for S2S time sales

- Static or prognostic treatment of vegetation including distribution, structure, and phenology
- Land characteristics dynamically change in response to meteorological conditions and disturbances (e.g., fire), can be important on longer-than-forecast scales
- Energy / water conservation in model and in system especially important on seasonal scales
- Prognostic river discharge from land to oceans and lakes



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GFDL LM4.0 in UFS

Abbreviated Tree

```
ufs-weather-model
│
…
├── LM4-driver
│   ├── LM4
│   ├── nuopc_cap
│   ├── CMakeLists.txt
│   ├── LICENSE.md
│   ├── lm4_src_files.cmake
│   └── README.md
…
```

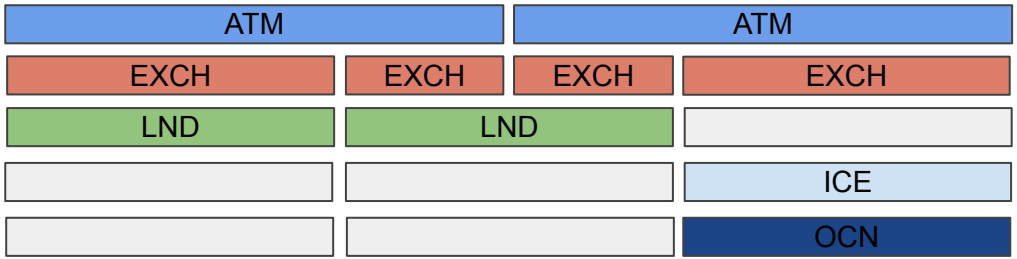
Merged into UFS on October 2024. First port of GFDL Land Model outside of GFDL

- CDEPS Data Atmosphere RTs: datm_lm4_gwsp3, datm_cdeps_lm4_gswp3_rst
- LM4 NUOPC driver github.com/NOAA-GFDL/LM4-NUOPC-driver
  - Uses GFDL LM4.0 release tag: github.com/NOAA-GFDL/lm4/releases/tag/land_lad2_2021.02
  - Driver is generic/flexible for all GFDL land versions
  - Incorporates some GFDL Coupler surface boundary layer and physics

LM4 within GFDL / FMS Coupler

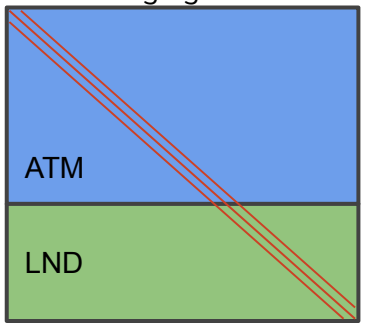
- In FMS Coupler, models communicate through exchange grid, uses implicit solver
- Surface boundary layer also on exchange grid
- Developed modified Land-only routines converted from FMS Coupler, with no exchange grid

1-D view of exchange grid



Adaptation from V. Balaji, et al. (2006): doi:10.1016/b978-044452206-1/50021-5.

Implicit Coupling w/ SBL on exchange grid



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LM4 Cap in UFS: Conversation of surface layer schemes

Abbreviated fast physics in FMS coupler:

- sfc_boundary_layer
  - Explicit fluxes and derivatives (1st pass)
- update_atmos_model_down
  - Downward sweep after radiation/dynamics
- flux_down_from_atmos
  - Fluxes and derivative for implicit treatment of atm diffusive fluxes
- **update_land_model_fast**
- update_ice_model_fast
  - Updated surface state
- flux_up_to_atmos
  - Update final fluxes and tend. with new surface states
- update_atmos_model _up
  - Propagates fluxes & tendencies to Atm

Modified fast physics routines in LM4 NUOPC Driver

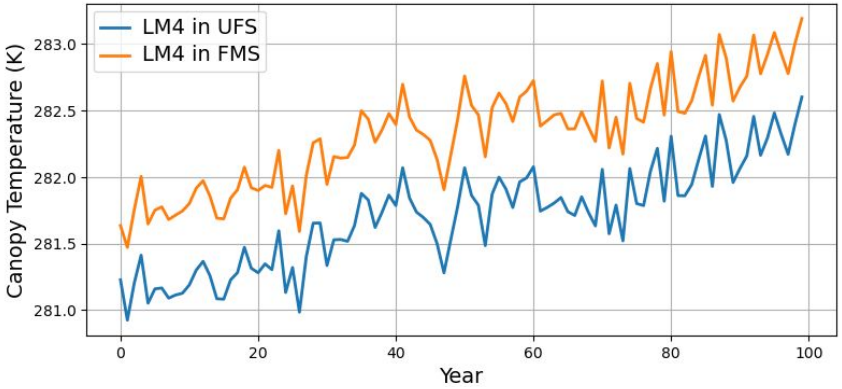
- sfc_boundary_layer
  - Use Import states (ex: q,u,v,p,t), calcs explicit fluxes and derivatives, u*, b*
  - Includes Monin-Obukhov calc
- update_atmos_model_down
  - gust calculated from u* and b*, if not from atm.
- flux_down_from_atmos
  - passes fluxes/derivatives to land
- **update_land_model_fast**
  - Calls main LM4 fast routine
- flux_up_to_atmos
  - Update final fluxes and tend. with new surface states
- update_atmos_model _up
  - Propagates fluxes & tendencies to Atm

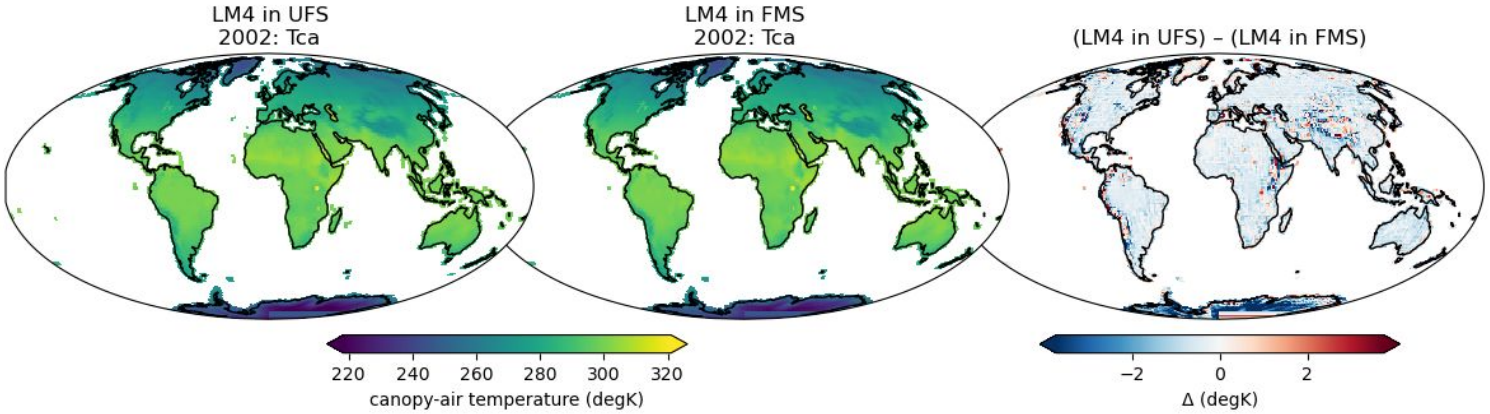
Color Key

ATM | LND | ICE | EXCH/CPL

Data atmosphere Spinup in UFS

- 100 years GSWP3 data
- Stress test of slow-timestep processes
- Evaluation of using UFS to generate land restarts





Coupling Atm - LM4.0 Configuration

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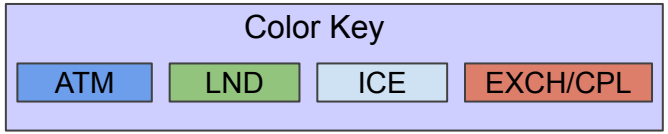

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- Explicit coupling with FV3 using kinematic fluxes
  - (toggle for possible use of implicit coupling)

- flux_up_to_atmos
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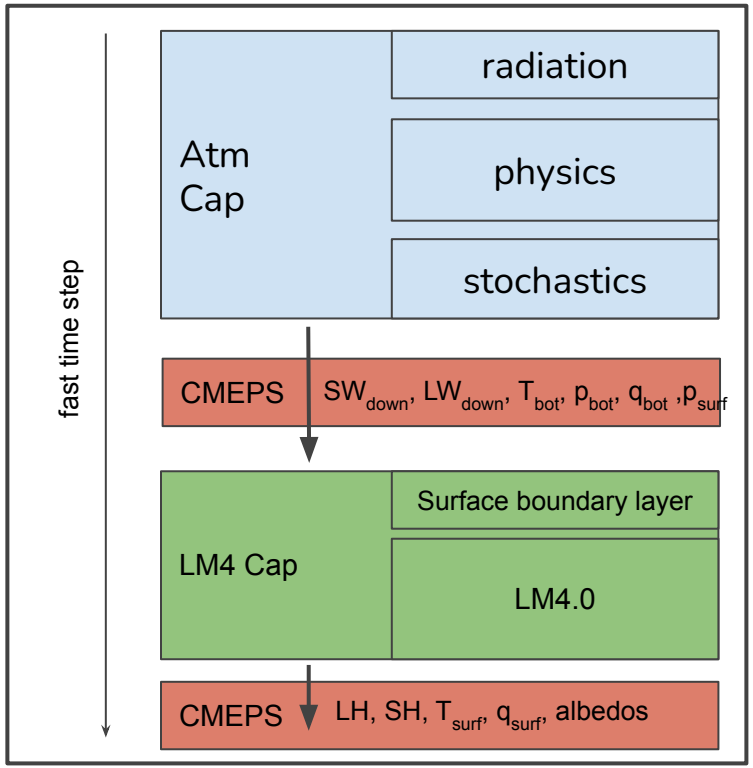
Explicit Coupling Strategy with Atm for LM4 in UFS



Condensed Call Order

- Radiation recieves LM4-sent albedo / temperature / emissivity
- Atm bottom layer state communicated through CMEPS
- LM4 sends back (currently) Latent heat, Sensibly, surface radiative temperature and humidity
- Reviewing physics to find more modular land/atm communications
- Functional but still implementing:
  - Aggregating outputs of surface boundary layer
  - Multiple vegetation tiles / grid cell
  - Some surface data communication

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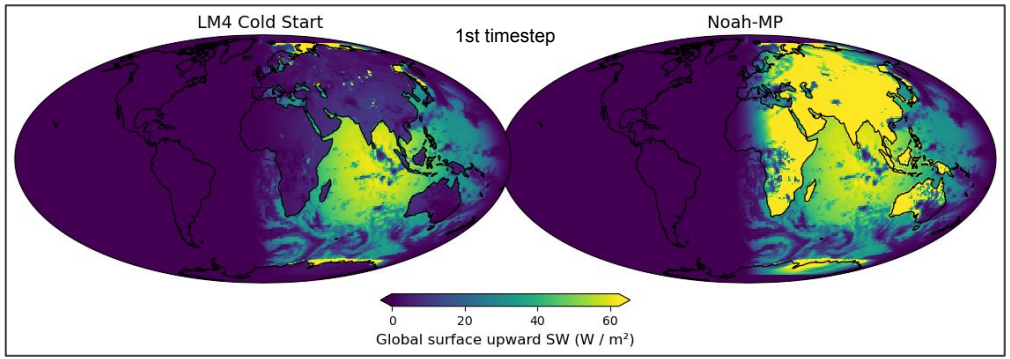
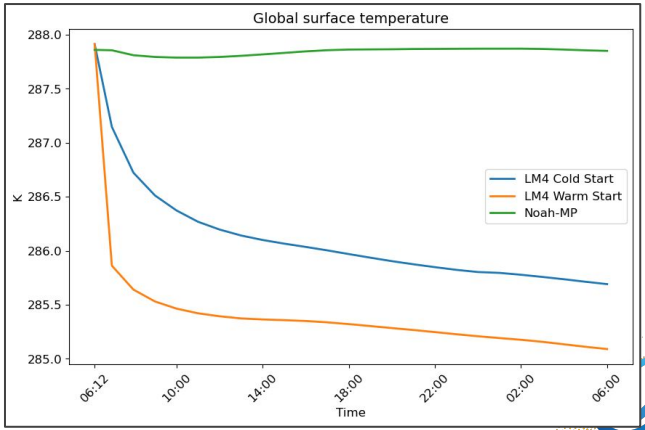
Preliminary Atmosphere-LM4 Coupling

- “Atm-LM4” p8-like config
- Cold and warm LM4 start, with same atm conditions
- Tests functionality, but not expected to produce realistic conditions





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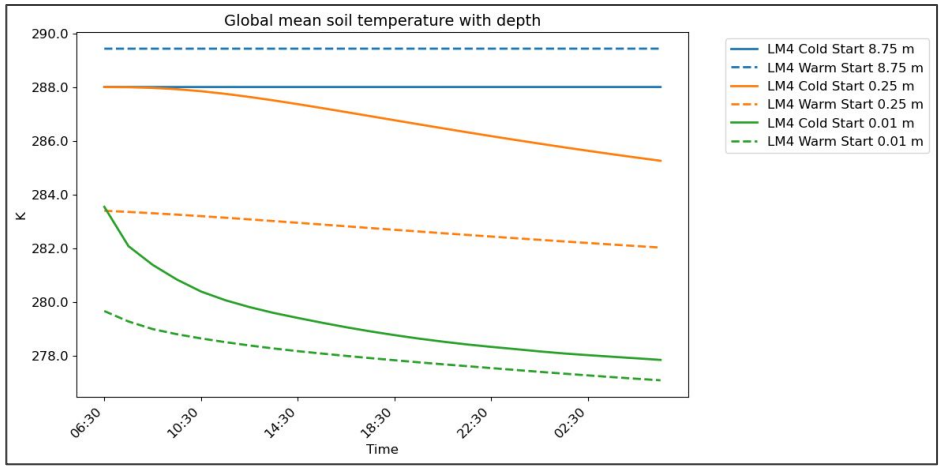
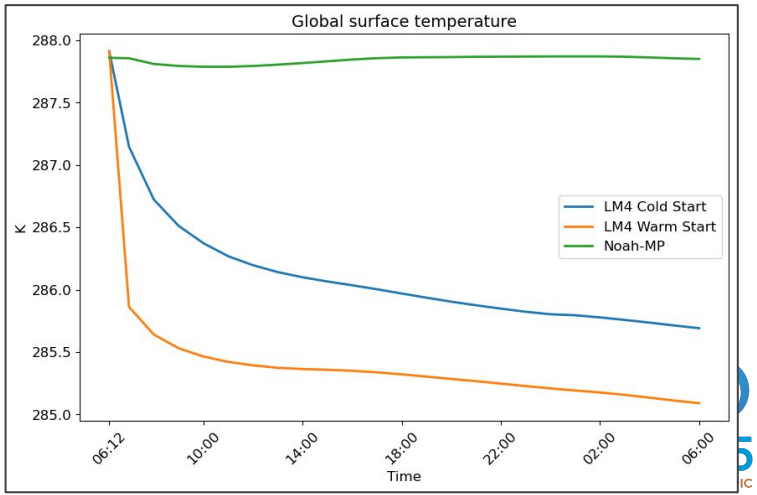
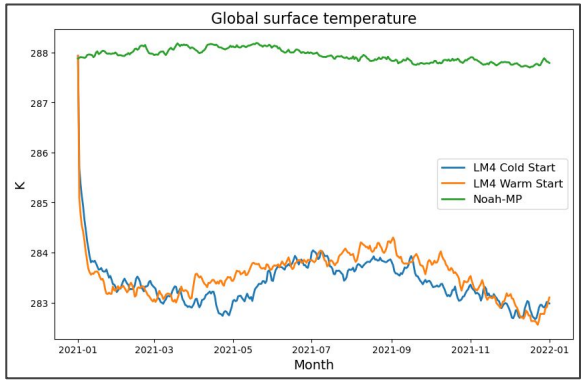
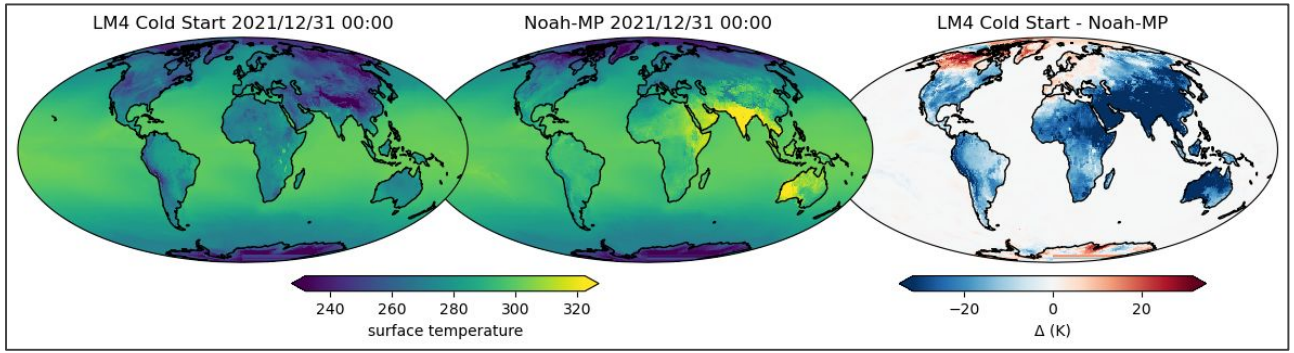




Preliminary Atmosphere-LM4 Coupling

- “Atm-LM4” p8-like config extended to 1 year
- Restarts from data-atmosphere GSWP3 run





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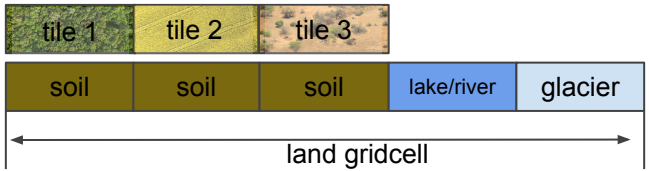
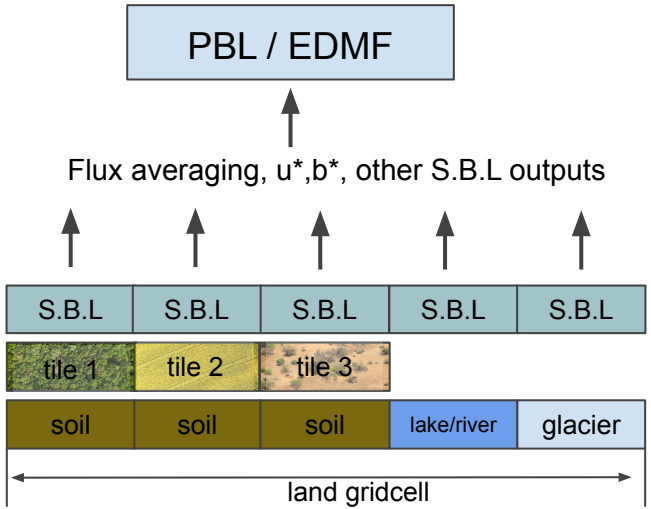
Approaches on multi-tile and surface exchange

- so far has used singular land tile / gridcell,
- currently implementing LM4's multi tile treatment
  - Each vegetation has non-isothermal canopy, own soil layer
  - Dynamic vegetation and land use crop
  - lake/river and glaciers have own surface boundary exchange



Multi-tile Surface Layer Treatment



- Similar to Noah-MP, ground, understory,canopy vegetation, and canopy air have different temps and properties
- LM4 + FMS Surface Boundary Layer akin to Noah-MP calling GFS stability internally
- Can use similar treatment in UFS for fractional grid, or PBL requiring more than mean flux

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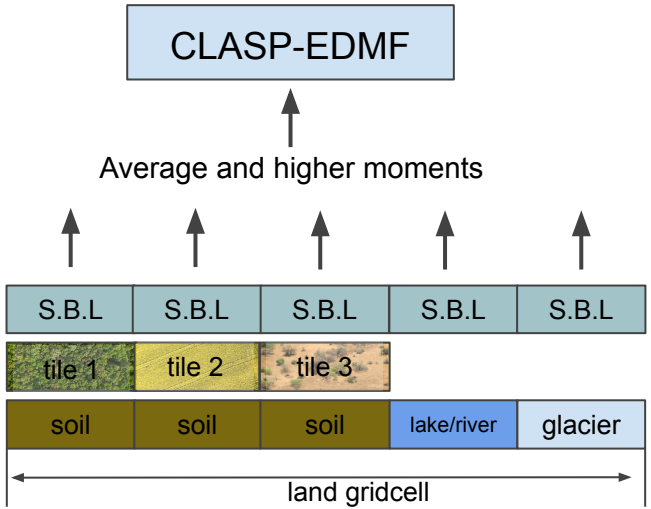
Multi-tile Surface Layer Treatment



- One approach at GFDL is using an EDMF scheme that incorporates tile-level heterogeneity without operating over every tile by using pdfs

Khaled Ghannam, et al. Coupling Subgrid-Scale Surface Heterogeneity to the Convective Boundary Layer in the GFDL Global Model (AM4.0-LM4.0): Parameterization Development and Climate Impacts. *Submitted to JAMES.*

Preprint at ESS Open Archive here. DOI: 10.22541/essoar.175308919.98162649/v1

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LM4 in UFS, Completed

- Data-atmosphere capability in repository, with cold & warm start regression tests and baselines
- LM4.0 representation of glaciers, lakes and rivers
- Basics of Coupling with FV3 Atmosphere

LM4 in UFS, Continued Development

- Finish Atmosphere coupling, work towards energy and water balance
- Dynamic subgrid land tiling
- River routing connection to ocean

Special Thanks to Michael Barlage (GSL), Ufuk Turuncoglu (NCAR),
and GFDL Modeling Systems Division

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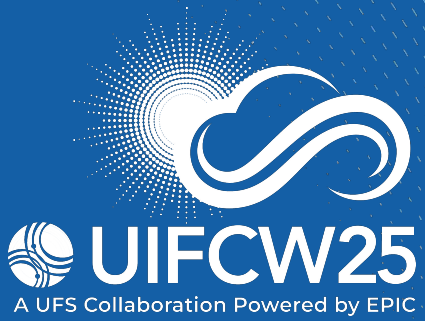
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