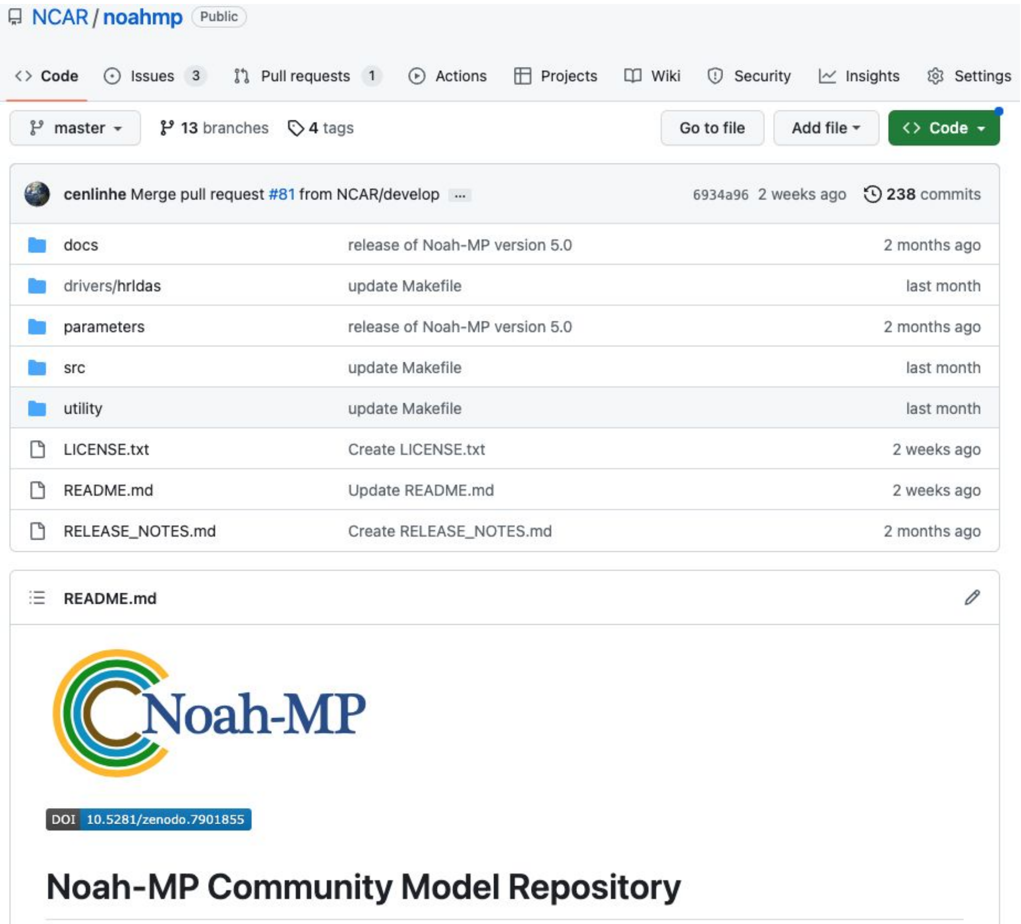
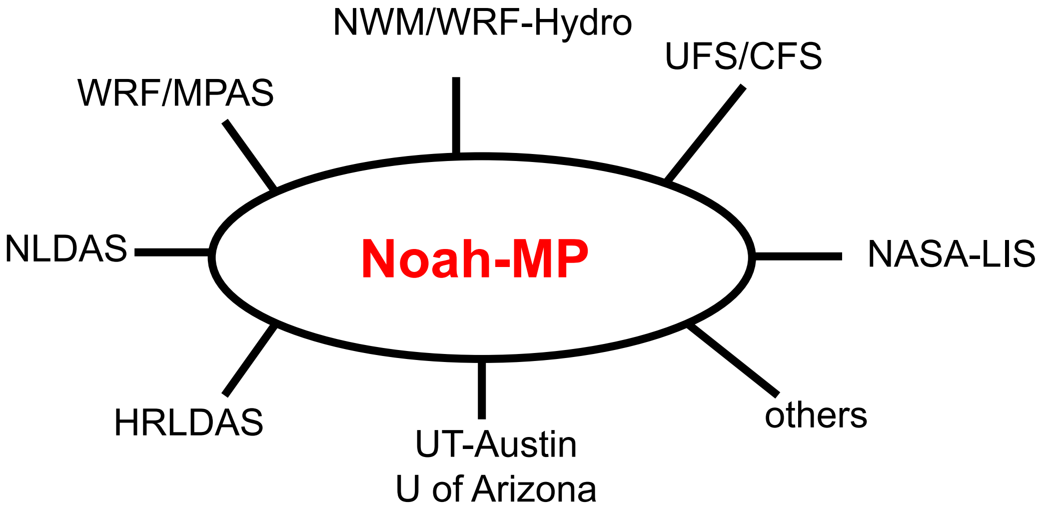
Overview of the modernized Noah-MP version 5.0



https://github.com/NCAR/noahmp

Unified Noah-MP GitHub



Cenlin He (NCAR)

Prasanth Valayamkunnath[1,5], Michael Barlage[2], Fei Chen[1], Dave Gochis[1], Ryan Cabell[1], Tim Schneider[1], Roy Rasmussen[1], Guo-Yue Niu[3], Zong-Liang Yang[4], Dev Niyogi[4], Michael Ek[1], and Noah-MP community

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2. NOAA Environmental Modeling Center (EMC), USA
3. University of Arizona, USA
4. University of Texas at Austin, USA
5. Indian Institute of Science Education and Research, India

Funding sources: USGS, NCAR Water System, NOAA

Motivations and goals for modernizing/refactoring Noah-MP model

- **Previous Noah-MP model code (prior to version 5.0):**

  code originally written about 12 years ago, which does not take advantage of modern Fortran language architecture;

  single lengthy (>12,000 lines) source file lumping together all model physics with complex code and data structures, inconsistent format, hard to modularize, and difficult to read, modify, and debug;

  These issues limit the development and application of Noah-MP.

- **Overall goal:**

  create an efficient, concise, well-organized, easy-to-maintain/read, documented and highly-modularized code for Noah-MP following the modern Fortran code and data structures.

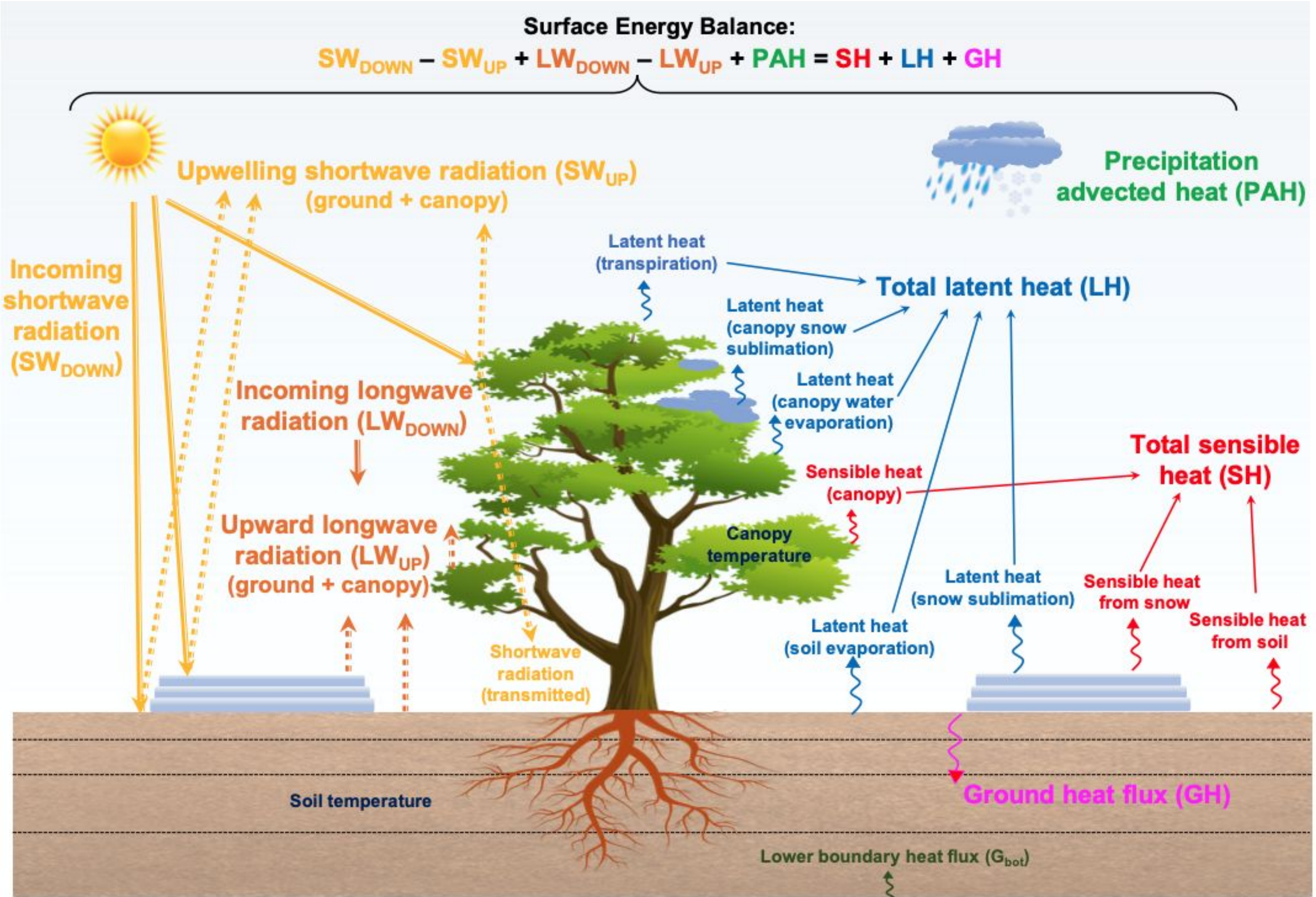
- **Noah-MP versions:**

  prior to v5.0: Noah-MP version follows WRF version number

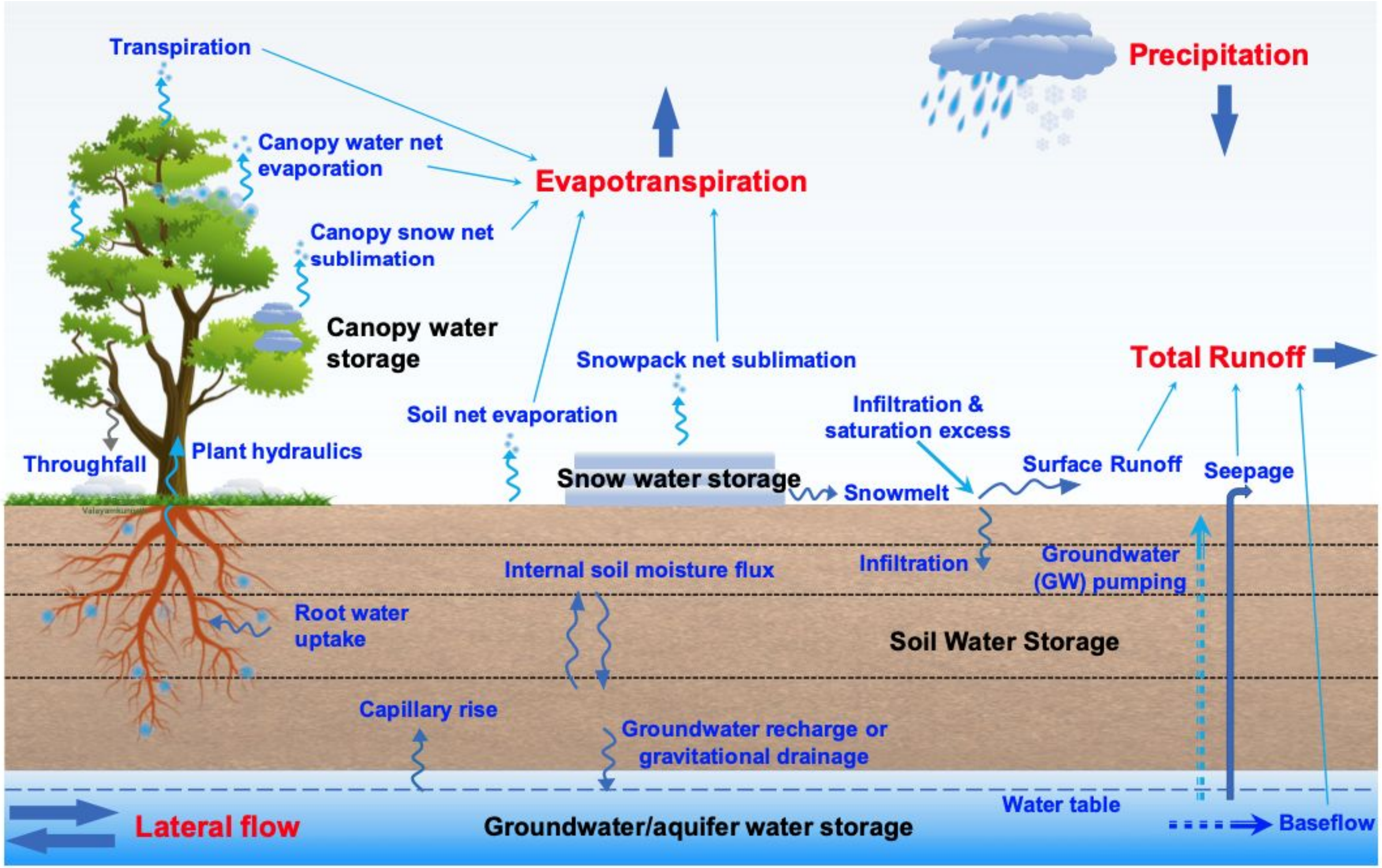
  since v5.0: Noah-MP uses its own version number

  5.0.0: major physics/infrastructure update, annual minor physics update, bug fix

Noah-MP Energy Processes



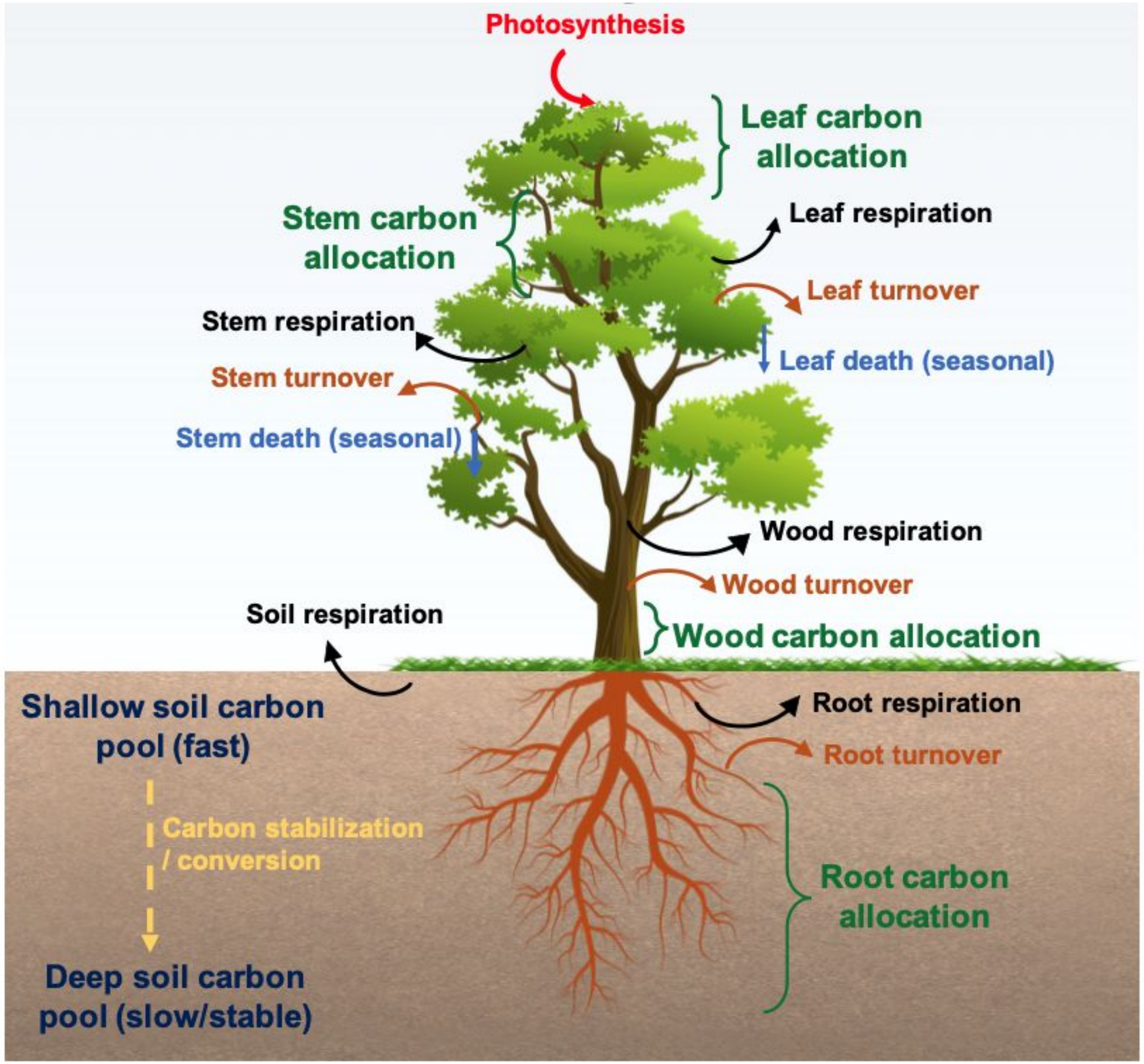
Noah-MP Water Processes



Total water balance:

Precipitation + lateral flow – Evapotranspiration – Total Runoff = Δ (water storage in canopy, snow, soil, aquifer)

Noah-MP Carbon Processes



Total carbon balance:

Photosynthesis – Respiration = ΔPlant carbon pool + ΔSoil carbon pool

Noah-MP physics updates since its original release in 2011

- **Included in the community Noah-MP v5.0 code:**

(1) the Miguez-Macho-Fan (MMF) groundwater scheme (Barlage et al., 2015);

(2) three additional runoff schemes: the Variable infiltration capacity (VIC), dynamic VIC, and Xinanjiang schemes (McDaniel et al., 2020);

(3) tile drainage schemes (Valayamkunnath et al., 2022);

(4) dynamic irrigation schemes (sprinkler, micro, and flooding irrigation) (Valayamkunnath et al., 2021);

(5) a dynamic crop growth model for corn and soybean (Liu et al., 2016) with enhanced C3 and C4 crop parameters (Zhang et al., 2020);

(6) coupling with urban canopy models (Xu et al., 2018; Salamanca et al., 2018) with local climate zone modeling capabilities (Zonato et al., 2021);

(7) enhanced snow cover, snow compaction, and wind-canopy absorption parameters (He et al., 2021);

(8) a wet-bulb temperature-based snow-rain partitioning scheme (Wang et al., 2019).

Noah-MP physics updates since its original release in 2011

- **Included in users' own Noah-MP code:**

(1) nitrogen dynamics (Cai et al., 2016);

(2) big-tree plant hydraulics (Li et al., 2021);

(3) dynamic root optimization (Wang et al. 2018) with an explicit representation of plant water storage (Niu et al., 2020);

(4) additional snow cover parameterizations (Jiang et al., 2020);

(5) coupling with a wind erosion model (Jiang et al., 2021);

(6) a wetland representation and dynamics (Z. Zhang et al., 2022);

(7) a unified turbulence parameterization throughout the canopy and roughness sublayer (Abolafia-Rosenzweig et al., 2021);

(8) enhanced snow albedo representations (Abolafia-Rosenzweig et al., 2022);

(9) coupling with a snow radiative transfer (SNICAR) model (Wang et al., 2020);

(10) an organic soil layer representation at forest floors (Chen et al., 2016) and a microbial-explicit soil organic carbon decomposition model (MESDM; X. Zhang et al., 2022b);

(11) coupling with atmospheric dry deposition of air pollutant (Chang et al., 2022);

(12) enhanced permafrost soil representations (X. Li et al., 2020);

(13) spring wheat crop dynamics (Zhang et al., 2023);

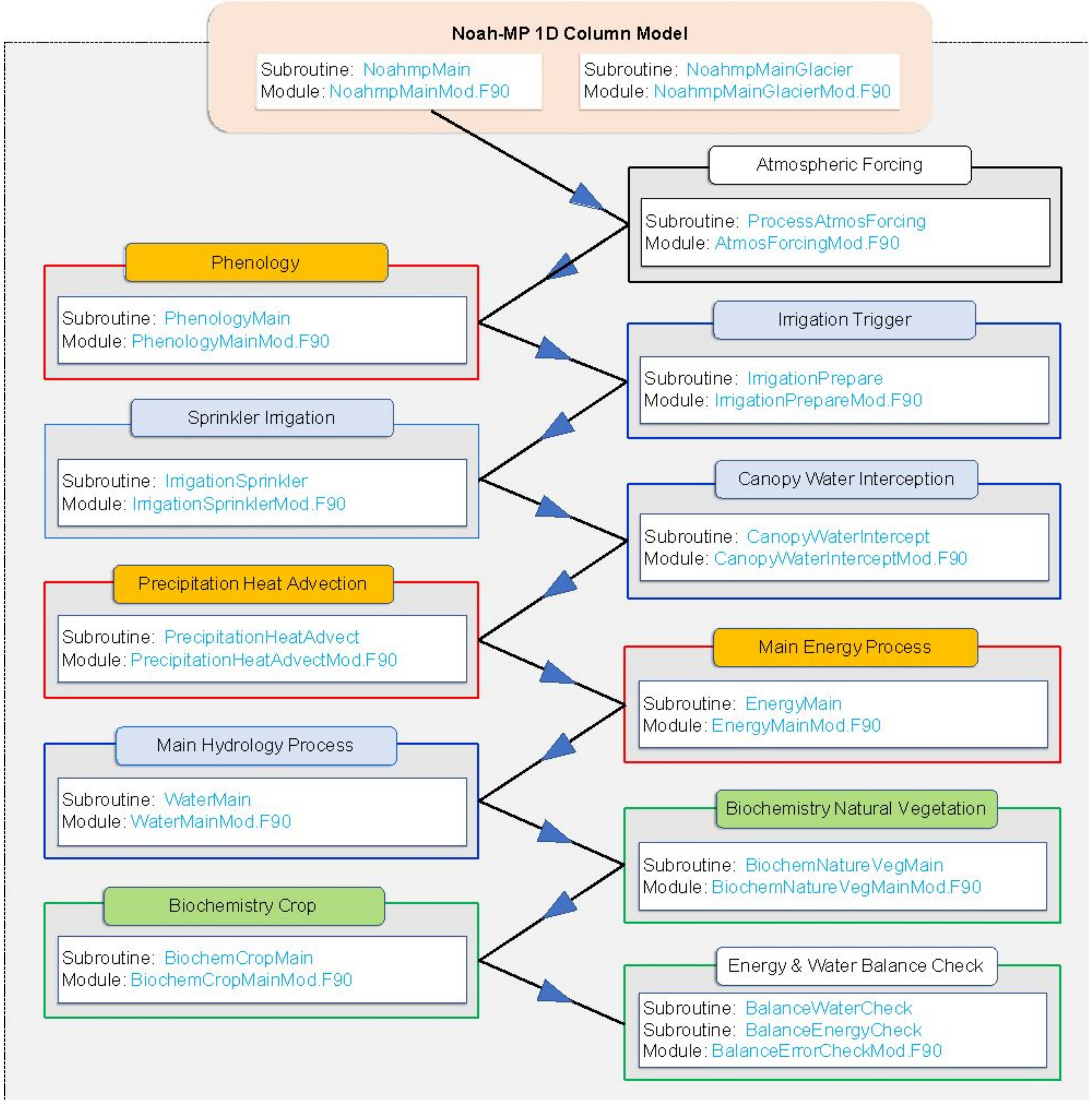
(14) new treatment of thermal roughness length (Chen and Zhang 2009);

(15) the Gecros crop model (Ingwersen et al., 2018; Warrach-Sagi et al., 2022);

(16) a 1-D dual-permeability flow model (based on the mixed-form Richards' equation) representing preferential flow through variably-saturated soil with surface ponding (University of Arizona).

(17) Coupled with Crocus glacier model (Eidhammer et al., 2021)

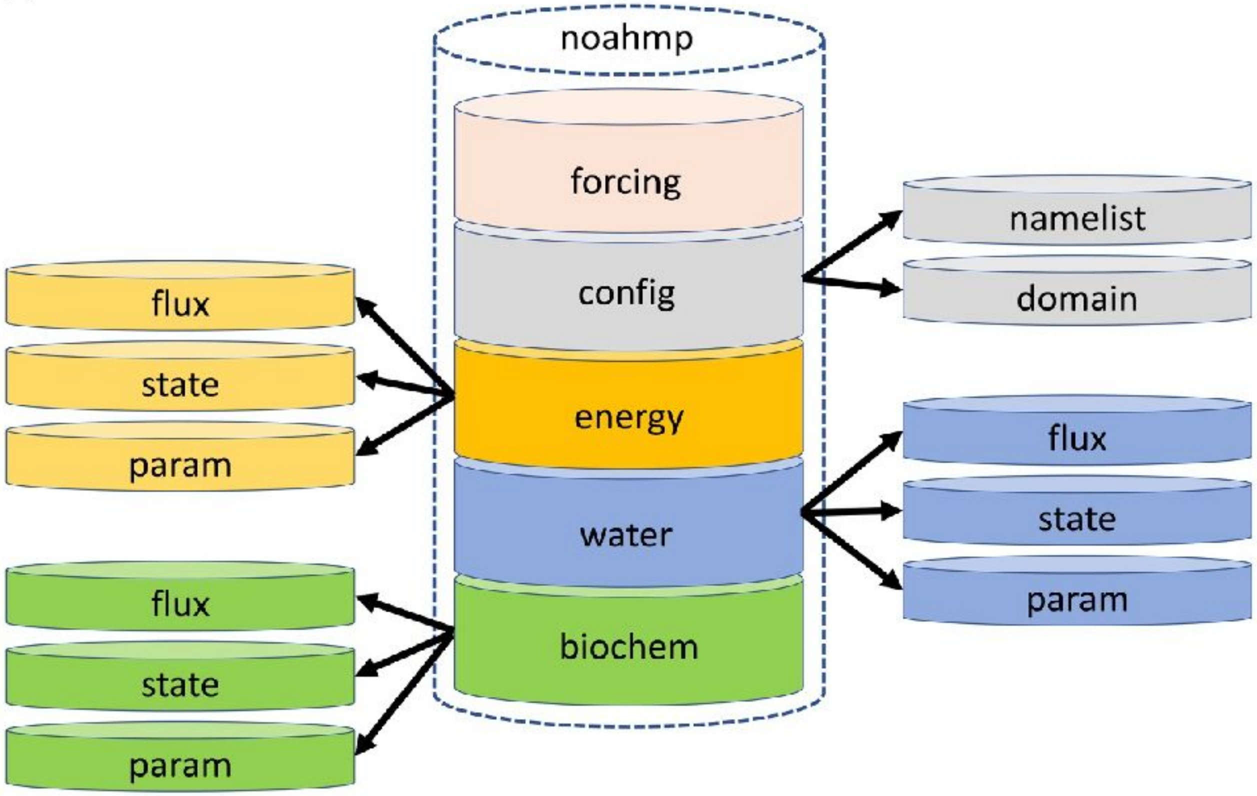
Key features of modernized/refactored Noah-MP version 5.0: Enhanced Modularization



https://github.com/NCAR/noahmp

Key features of modernized/refactored Noah-MP version 5.0: Enhanced data structure

(a)



(b)

```
noahmp%forcing%PressureAirRefHeight
noahmp%forcing%RadLwDownRefHeight
noahmp%forcing%RadSwDownRefHeight
noahmp%config%nmlist%OptSnowSoilTempTime
noahmp%config%domain%FlagCropland
noahmp%config%domain%FlagSoilProcess
noahmp%config%domain%NumSoilTimeStep
noahmp%config%domain%SoilTimeStep
noahmp%water%param%IrriFracThreshold
noahmp%water%state%IrrigationFracGrid
noahmp%energy%state%LeafAreaIndEff
noahmp%energy%state%StemAreaIndEff
noahmp%energy%state%VegFrac
noahmp%energy%flux%HeatLatentIrriEvap
noahmp%energy%flux%HeatPrecipAdvCanopy
```

https://github.com/NCAR/noahmp

Key features of modernized/refactored Noah-MP version 5.0: Enhanced code structure

Original Noah-MP source code

```
MODULE MODULE_SF_NOAHMPLSM

CONTAINS

 SUBROUTINE  NOAHMP_SFLX  (parameters, ILOC, JLOC, LAT,  &
              YEARLEN , JULIAN, COSZ, DT, DX, DZ8W,       &
              NSOIL, ZSOIL, NSNOW, SHDFAC, SHDMAX,        &
              VEGTYP, ICE, IST, CROPTYPE, SMCEQ,          &
              ...., ...., ...., ....,                     &
              PAHG, PAHB, PAH, LAISUN, LAISHA, RB)

  CALL SUBROUTINE  ATM  (parameters, SFCPRS, SFCTMP, Q2, &
              PRCPCONV, PRCPNONC, PRCPSHCV,   &
              PRCPSNOW, PRCPGRPL, PRCPHAIL,   &
              ...., ...., ...., ....,         &
              RAIN, SNOW, FP, FPICE, PRCP)

  CALL SUBROUTINE  PHENOLOGY  (parameters,VEGTYP,  &
              SNOWH, TV, LAT, YEARLEN, JULIAN,     &
              LAI, SAI, TROOT, ELAI, ESAI, IGS, PGS)
        ... ... ... . ... ... ... . ... ... ...
        ... ... ... . ... ... ... . ... ... ...

 END SUBROUTINE  NOAHMP_SFLX

 SUBROUTINE  ATM  (parameters, SFCPRS, SFCTMP, Q2, &
              PRCPCONV, PRCPNONC, PRCPSHCV,   &
              PRCPSNOW, PRCPGRPL, PRCPHAIL,   &
              ...., ...., ...., ....,         &
              RAIN, SNOW, FP, FPICE, PRCP)
   ... ... ... . ... ... ... . ... ... ...
   ... ... ... . ... ... ... . ... ... ...

 END SUBROUTINE  ATM
        ... ... ... . ... ... ... . ... ... ...
        ... ... ... . ... ... ... . ... ... ...

END MODULE MODULE_SF_NOAHMPLSM
```

Single Fortran file of >12,000 lines of code

→

Refactored Noah-MP source code

```
module NoahmpMainMod

contains

 subroutine NoahmpMain(noahmp)

   type(noahmp_type), intent(inout) :: noahmp

   call ProcessAtmosForcing(noahmp)

   call PhenologyMain(noahmp)
        .......... .......... ............
        .......... .......... ............
 end subroutine NoahmpMain(noahmp)

end module NoahmpMainMod
```

Individual process-level modules

```
module AtmosForcingMod

contains

 subroutine ProcessAtmosForcing(noahmp)
   type(noahmp_type), intent(inout) :: noahmp
        .......... .......... ............
        .......... .......... ............
 end subroutine ProcessAtmosForcing

end module AtmosForcingMod
```

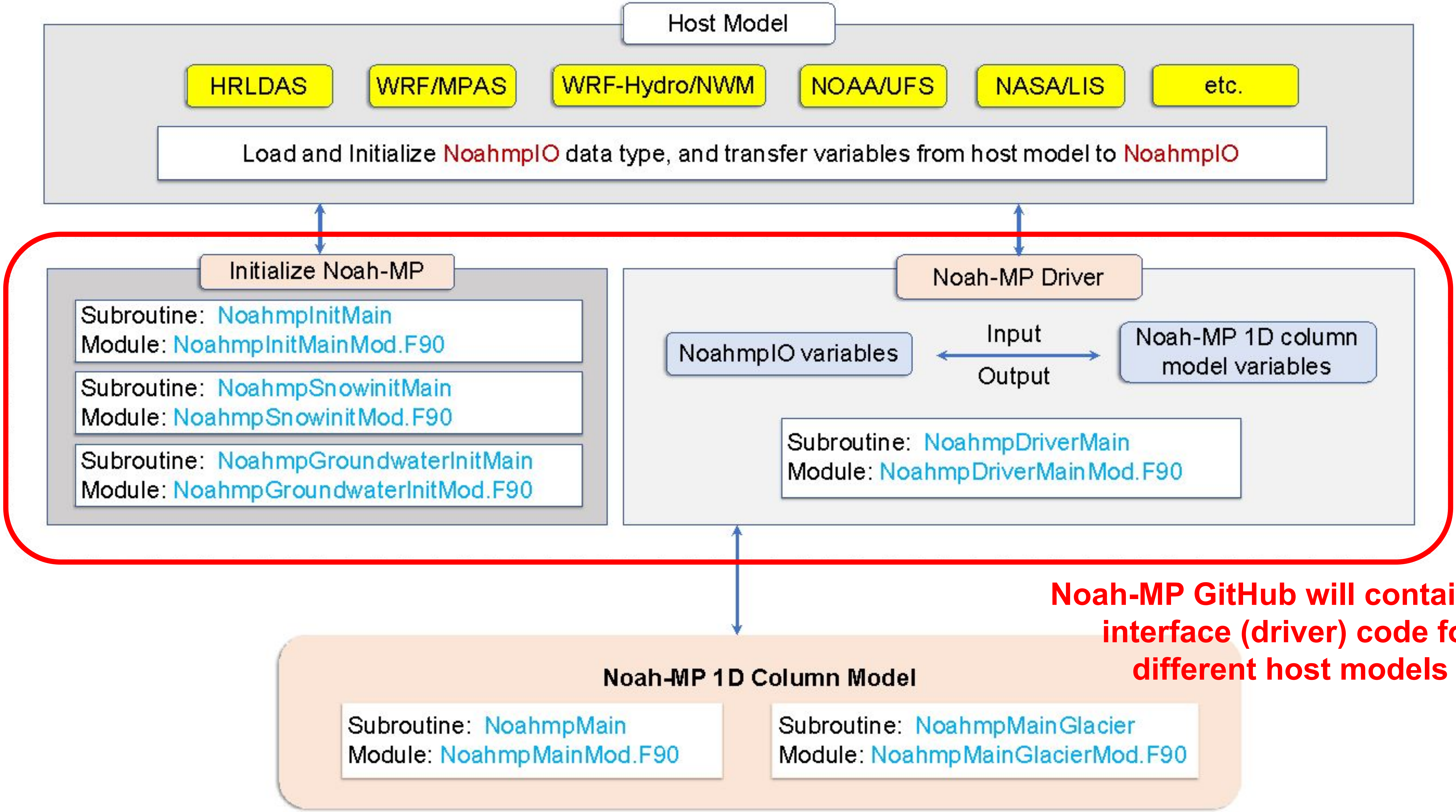
https://github.com/NCAR/noahmp

Key features of modernized/refactored Noah-MP version 5.0: Enhanced variable names

Description	New name	Old name	Type
Variable physical meaning/definition	**New name**	**Original name**	**Variable Type**
State			
wetted or snowed fraction of canopy (-)	CanopyWetFrac	FWET	Real
canopy intercepted liquid water (mm)	CanopyLiqWater	CANLIQ	Real
canopy intercepted ice (mm)	CanopyIce	CANICE	Real
canopy intercepted total water (CANICE+CANLIQ) (mm)	CanopyTotalWater	CMC	Real
canopy capacity for snow interception (mm)	CanopyIceMax	MAXSNO	Real
canopy capacity for liquid water interception (mm)	CanopyLiqWaterMax	MAXLIQ	Real
ice fraction at previous timestep	SnowIceFracPrev	FICEOLD_SNOW	Real
ice fraction in snow layers	SnowIceFrac	FICE_SNOW	Real
bulk density of snowfall (kg/m3)	SnowfallDensity	BDFALL	Real
snow cover fraction [-]	SnowCoverFrac	FSNO	Real
partial volume ice of snow [m3/m3]	SnowIceVol	SNICEV	Real
partial volume liq of snow [m3/m3]	SnowLiqWaterVol	SNLIQV	Real
snow effective porosity [m3/m3]	SnowEffPorosity	EPORE_SNOW	Real
snow layer ice [mm]	SnowIce	SNICE	Real
snow layer liquid water [mm]	SnowLiqWater	SNLIQ	Real
snow mass at previous time step(mm)	SnowWaterEquivPrev	SNEQVO	Real
snow water eqv. [mm]	SnowWaterEquiv	SNEQV	Real
snow depth (mm)	SnowDepth	SNOWH	Real
ice fraction in soil layers	SoilIceFrac	FICE_SOIL	Real
equilibrium soil water content [m3/m3]	SoilMoistureEqui	SMCEQ	Real
soil water content between bottom of the soil and water table [m3/m3]	SoilMoistureToWT	SMCWTD	Real
soil moisture (ice + liq.) [m3/m3]	SoilMoisture	SMC	Real

https://github.com/NCAR/noahmp

Key features of modernized/refactored Noah-MP version 5.0: Enhanced coupling structure



Noah-MP GitHub will contain the interface (driver) code for different host models

https://github.com/NCAR/noahmp

Benchmarking for Noah-MP version 5.0

- Conducted a series of **hierarchical test simulations** during the course of Noah-MP refactoring to benchmark the functionality, reproducibility (bit-for-bit consistency), and computational efficiency.

- **Three sets of benchmark simulations**:
  1. 21-year (2000-2020) 12-km continental US simulations driven by the NLDAS-2 atmospheric forcings (Xia et al., 2012);
  2. 10-year (2009-2018) point-scale SNOTEL 804-site simulations over the western US driven by observed precipitation and temperature as well as other NLDAS-2 atmospheric forcings downscaled to 90-m spatial resolution (He et al., 2021);
  3. 1-year (2000) 4-km dynamic crop simulations over the U.S. Corn Belt region driven by the convection-permitting WRF modeling (Zhang et al., 2020);

- Archived all the atmospheric forcing datasets, model setup input datasets, and model output datasets for these benchmark simulations.

- Stored in the NCAR high-performance supercomputer (HPC) campaign storage file system (data path: /glade/campaign/ral/hap/cenlinhe/NoahMP_benchmark/) and can be provided by the corresponding author upon request, due to the extremely large data size (8.8 TB).

Noah-MP Technical notes

http://dx.doi.org/10.5065/ew8g-yr95

The Community Noah-MP Land Surface Modeling System Technical Description Version 5.0

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Noah-MP

The Community Noah-MP Land Surface Modeling System Technical Description Version 5.0

Originated: March 7, 2023

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Noah-MP version 5.0 reference

https://doi.org/10.5194/egusphere-2023-675

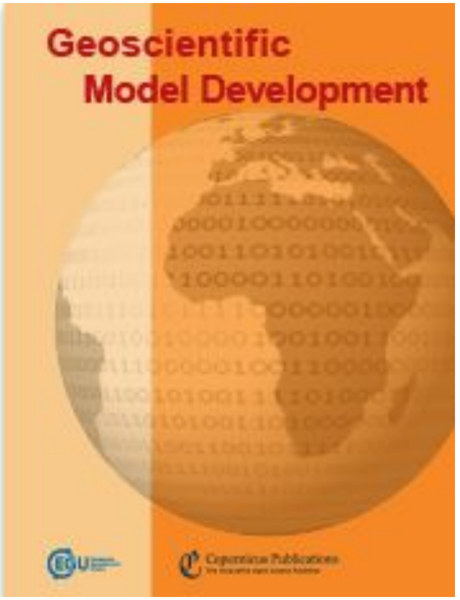
Abstract | Discussion | Metrics

12 Apr 2023

Status: this preprint is open for discussion.

Modernizing the open-source community Noah-MP land surface model (version 5.0) with enhanced modularity, interoperability, and applicability

Cenlin He, Prasanth Valayamkunnath, Michael Barlage, Fei Chen, David Gochis, Ryan Cabell, Tim Schneider, Roy Rasmussen, Guo-Yue Niu, Zong-Liang Yang, Dev Niyogi, and Michael Ek



https://doi.org/10.5194/egusphere-2023-675

- Noah-MP model code: https://github.com/NCAR/noahmp
- HRLDAS/Noah-MP model code: https://github.com/NCAR/hrldas

On-going & future efforts

Couple modernized Noah-MP version 5.0 with other community host models:

1. coupling with NASA/LIS (collaborating with LIS group; on-going)
2. coupling with NOAA/UFS (collaborating with Mike Barlage and NOAA/EMC land team; future)
3. coupling with NWM/WRF-Hydro (collaborating with the WRF-Hydro team; on-going)
4. coupling with WRF and MPAS (collaborating with WRF and MPAS teams; future)

Thank you!

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