Noah-MP Land Surface Model Tutorial

Unified Noah-MP GitHub

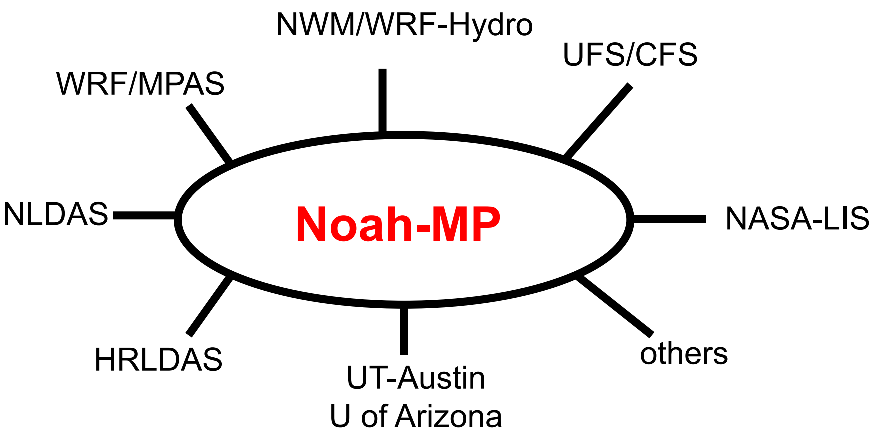
DOI 10.5281/zenodo.7901855

Noah-MP Community Model Repository

DOI 10.5281/zenodo.7901868

HRLDAS/Noah-MP GitHub

HRLDAS (High Resolution Land Data Assimilation System) Community Model Repository



- Noah-MP GitHub repo: https://github.com/NCAR/noahmp
- HRLDAS/Noah-MP GitHub repo: https://github.com/NCAR/hrldas
- Noah-MP Technical notes: http://dx.doi.org/10.5065/ew8g-yr95
- Noah-MP original version reference:
  Niu et al. (2011, doi:10.1029/2010JD015139)
  Yang et al. (2011, doi:10.1029/2010JD015140)
- Noah-MP (refactored) version 5 reference:
  He et al. (2023, https://doi.org/10.5194/egusphere-2023-675)
- HRLDAS reference:
  Chen et al. (2007, http://dx.doi.org/10.1175/JAM2463.1)
- HRLDAS/Noah-MP tutorial materials:
  https://github.com/NCAR/hrldas/tree/master/tutorial

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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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NCAR Technical Notes
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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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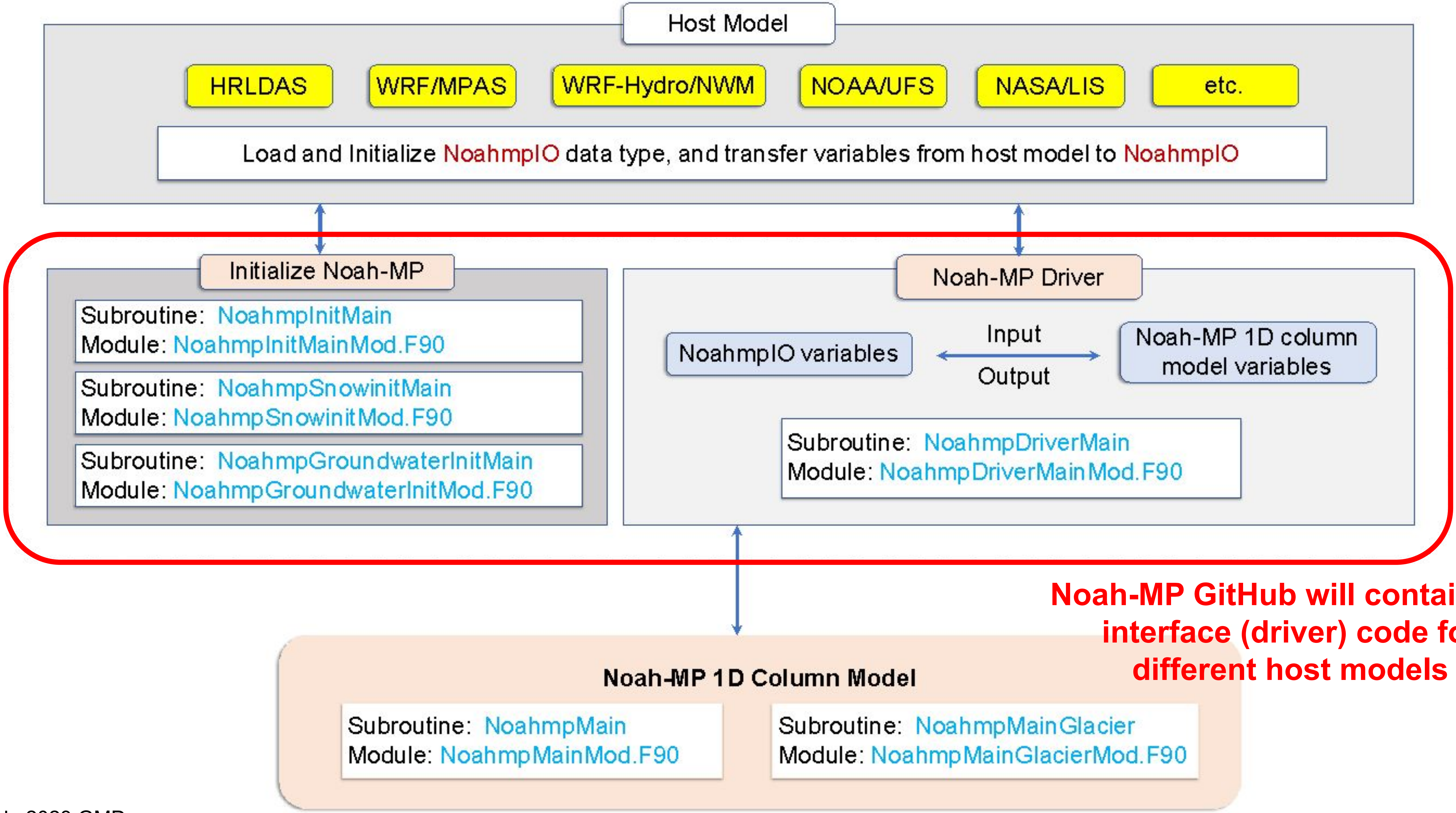
Outlines

- Noah-MP coupling with host models
- Noah-MP key processes and treatments
- Noah-MP current capabilities
- Noah-MP major model structure and workflow
- Noah-MP specific physics and namelist options
- Noah-MP version 5.0 GitHub and code structure

Noah-MP coupling with host models

Noah-MP coupling with host/parent models

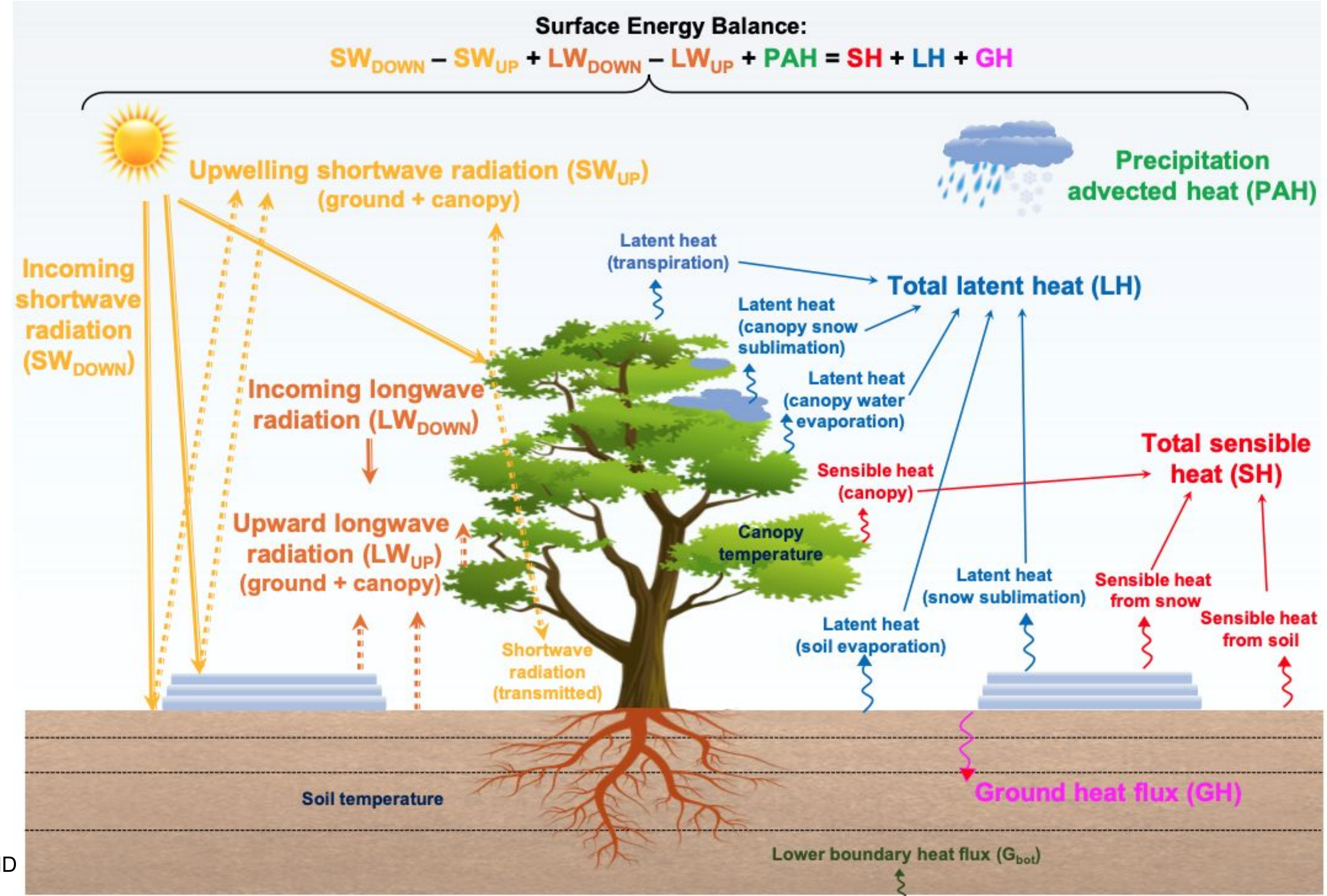


Noah-MP GitHub will contain the interface (driver) code for different host models

He et al., 2023 GMD

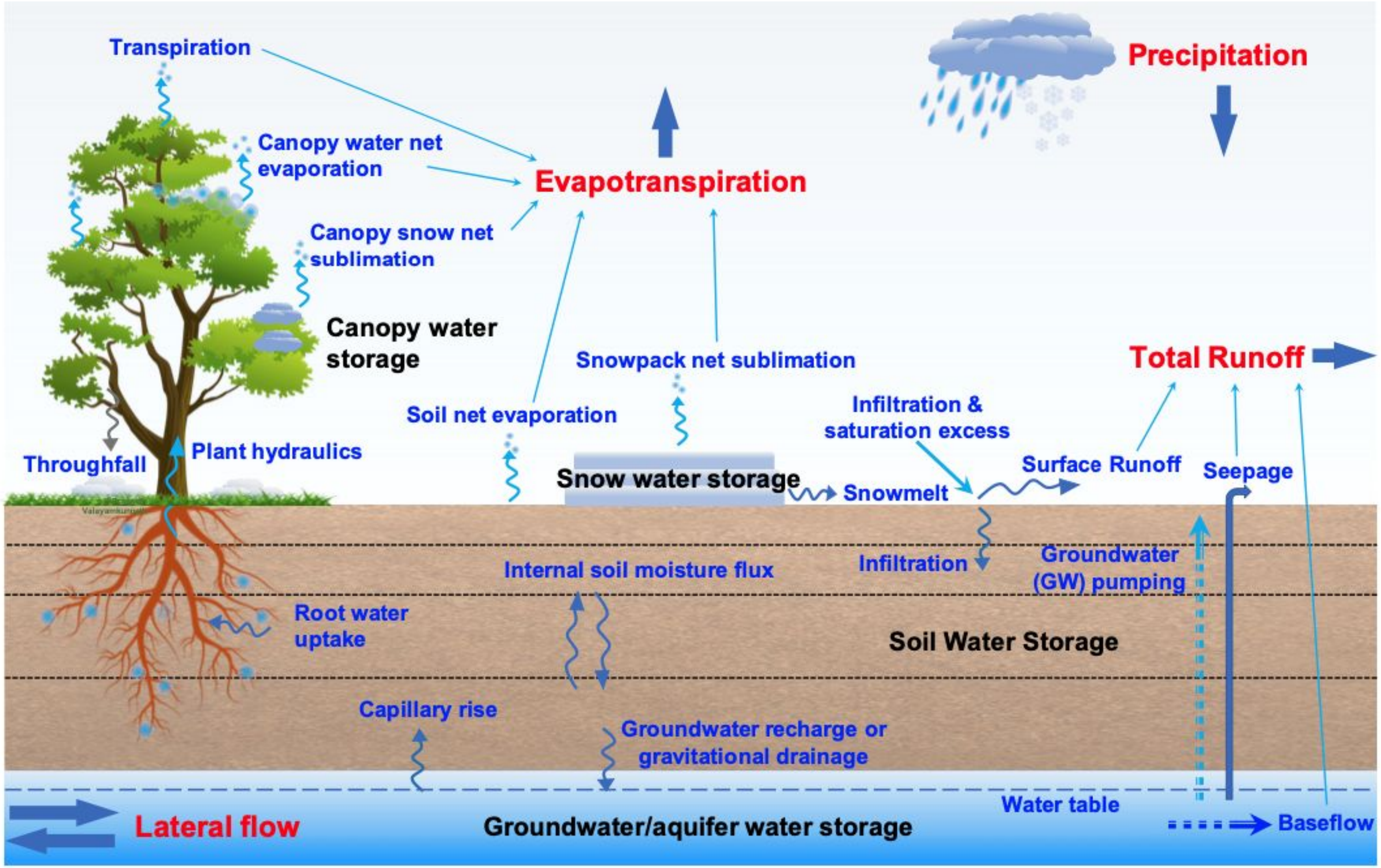
Noah-MP key processes and treatments

Noah-MP Energy Processes



He et al., 2023 GMD

Noah-MP Water Processes



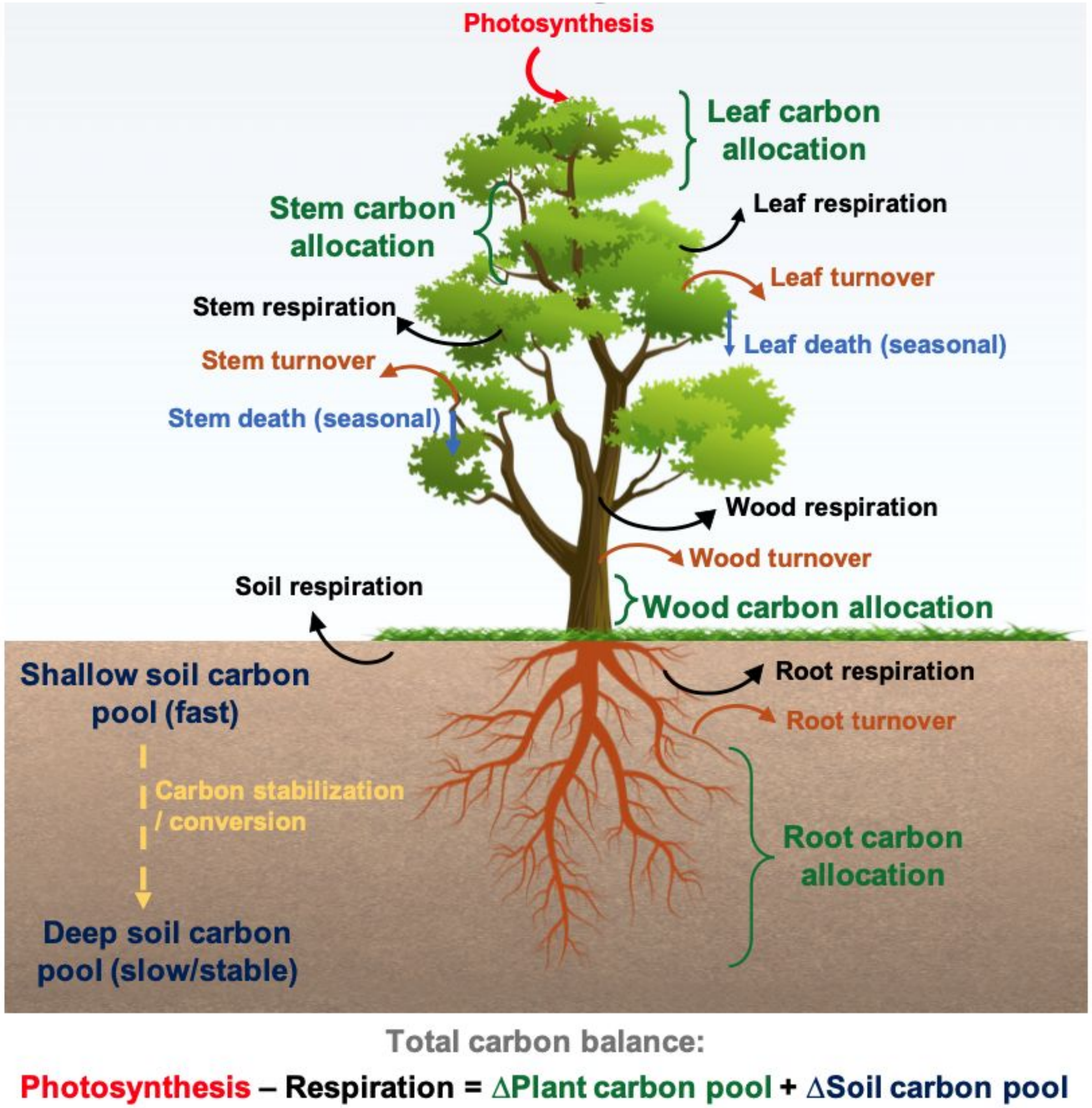
Only when groundwater scheme is on

Total water balance:

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

He et al., 2023 GMD

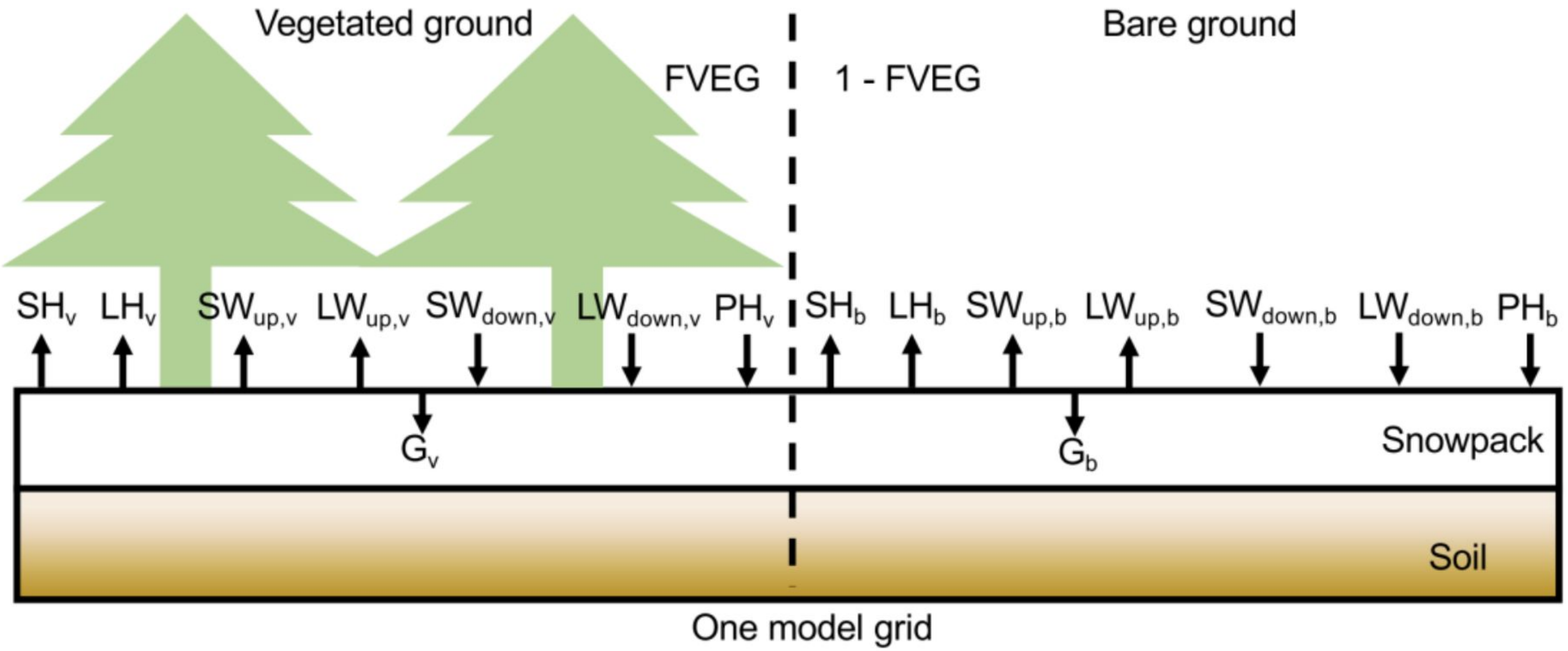
Noah-MP Carbon Processes



Only when dynamic vegetation scheme or crop model is on

He et al., 2023 GMD

Noah-MP subgrid treatment for energy



$$\text{netRad} + \text{PH} = \text{SH} + \text{LH} + \text{G}$$

$$\text{netRad} = \text{SW}_{\text{down}} - \text{SW}_{\text{up}} + \text{LW}_{\text{down}} - \text{LW}_{\text{up}}$$

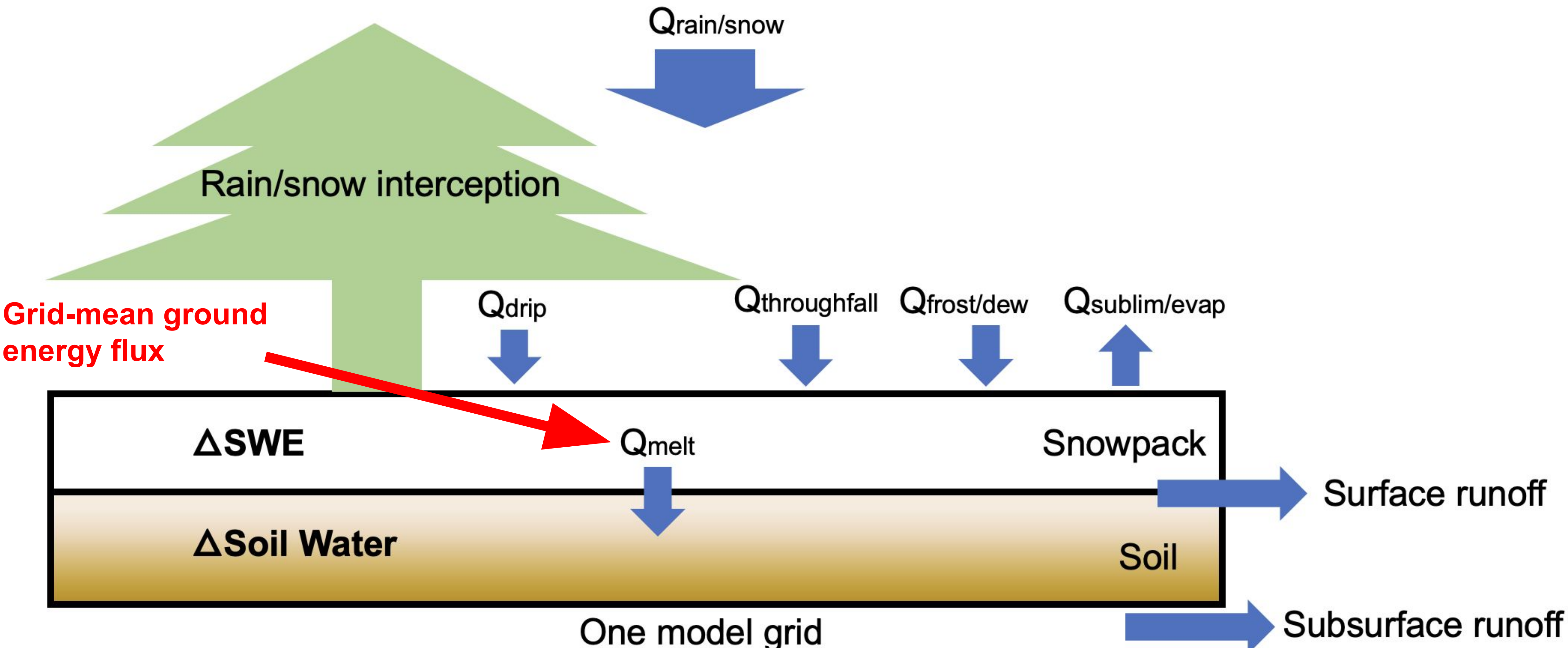
No sub-grid differentiation between vegetated and bare portion for snow-related energy treatment (e.g., ground snow cover and albedo)

Non-SW energy flux

SW canopy radiative transfer

He et al., 2021 JGR

Noah-MP subgrid treatment for water



He et al., 2021 JGR

Noah-MP current capabilities

Current community Noah-MP version 5.0 capabilities

- **Canopy process**: rain/snow interception, radiative transfer, stomatal resistance, turbulence, evapo./sublime./melt/freeze, heat storage change, etc.
- **Snow process**: rain-snow partition, canopy interception, compaction, layer combination/division, melt/freeze/sublim/frost, sensible & latent heat, ground heat, radiation, temperature change, etc.
- **Soil process**: evapo/sublim/dew/frost/melt/freeze, supercooled water, infiltration, surface/subsurface runoff, radiation, sensible & latent heat, ground heat, temperature change, etc.
- Different main Noah-MP process and **soil process timesteps**
- **Groundwater process**: recharge/discharge, lateral flow, baseflow, aquifer storage change
- **Soil hydraulics**
- **Dynamic vegetation and crop growth**: key carbon processes in the previous slide
- **Tile drainage** schemes
- **Dynamic irrigation** processes
- Bulk urban treatment and coupling with external **urban canopy model**

Other Noah-MP capabilities that are currently not in the community version

- **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);

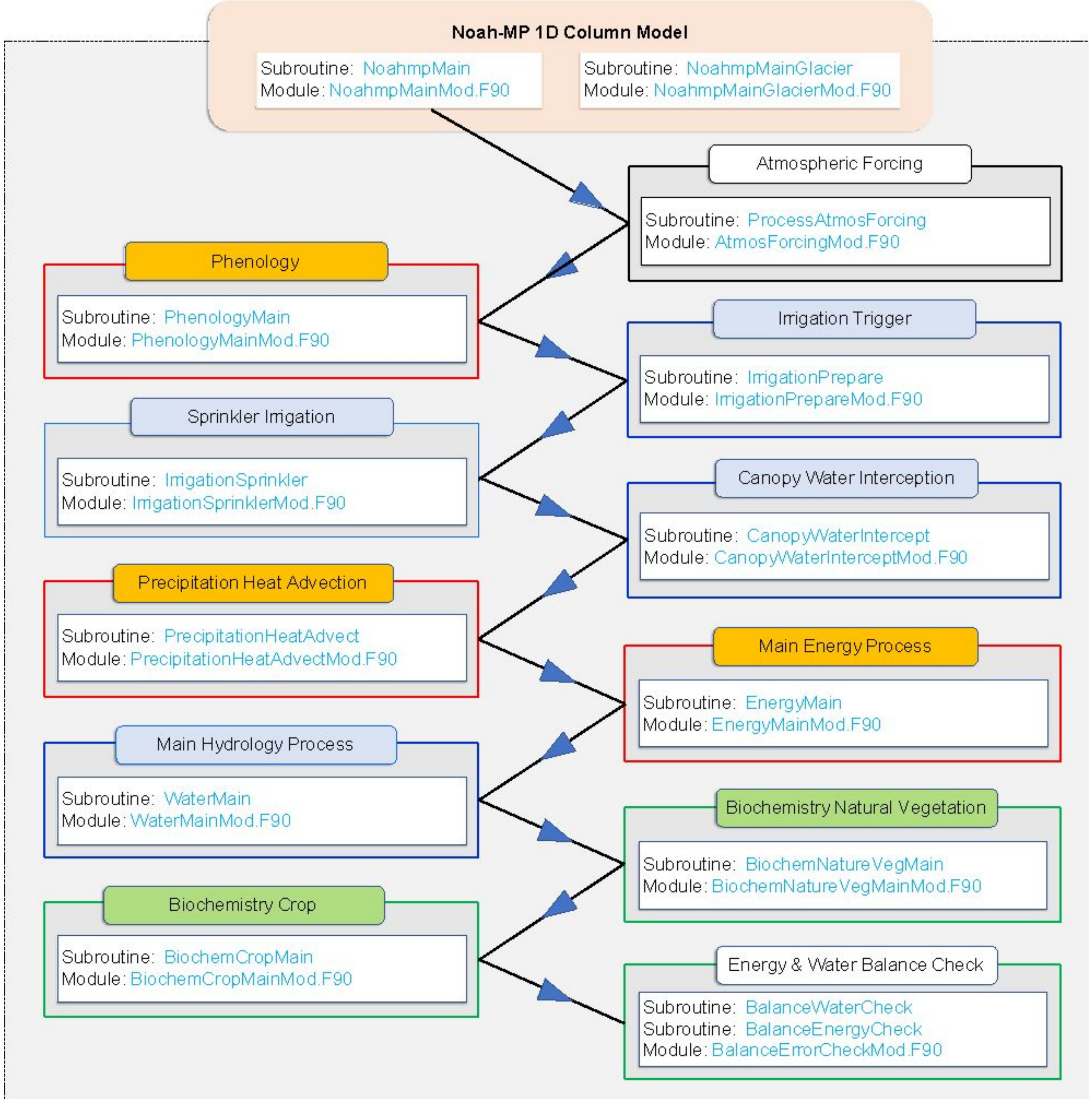
(14) new treatment of thermal roughness length (Chen and Zhang 2009);

(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).

Noah-MP major model structure and code workflow

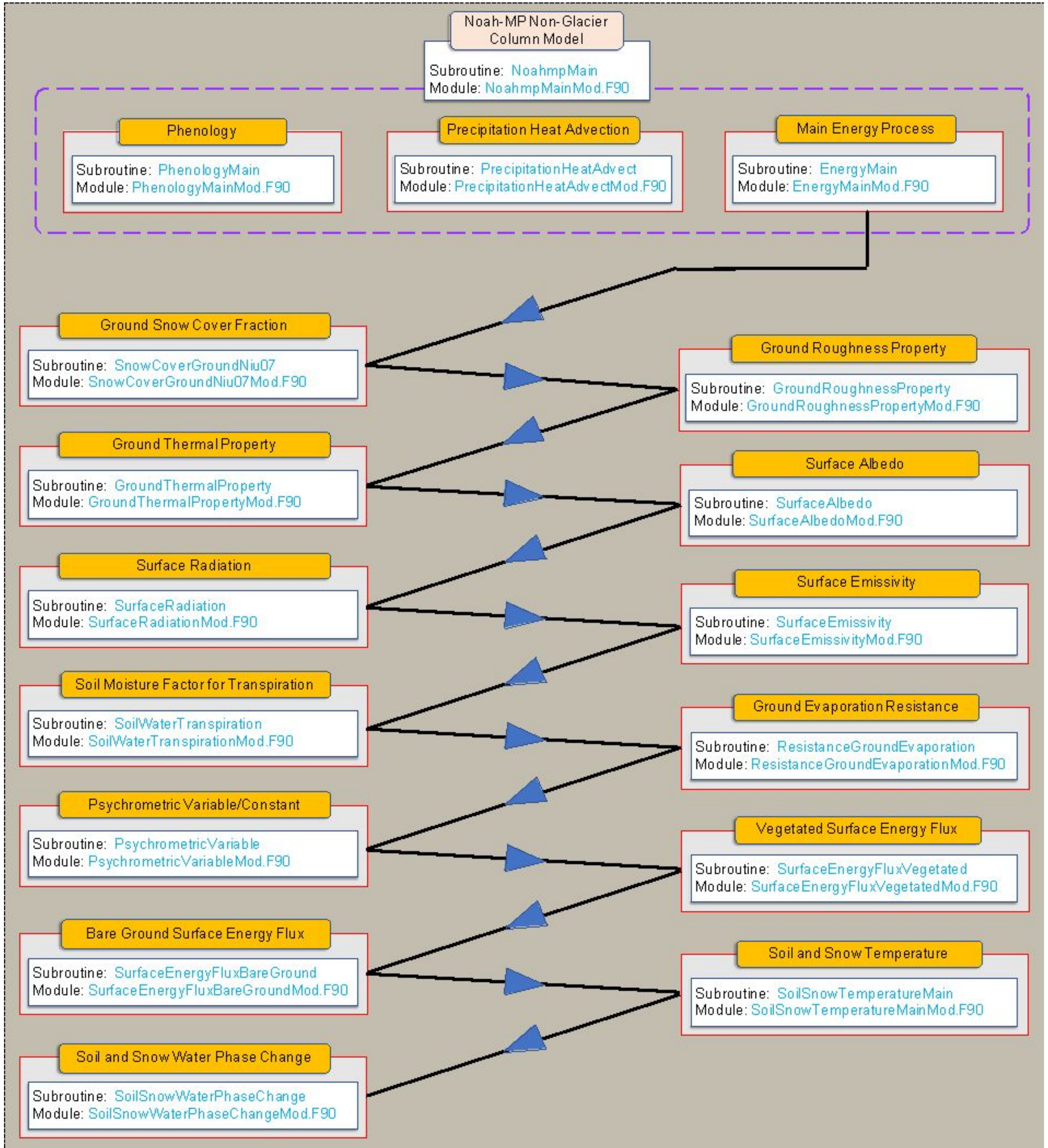
Noah-MP v5 main physics calling tree



The glacier model has similar structures as the main non-glacier model, except that the vegetation-related processes are removed and soil is replaced by glacier ice

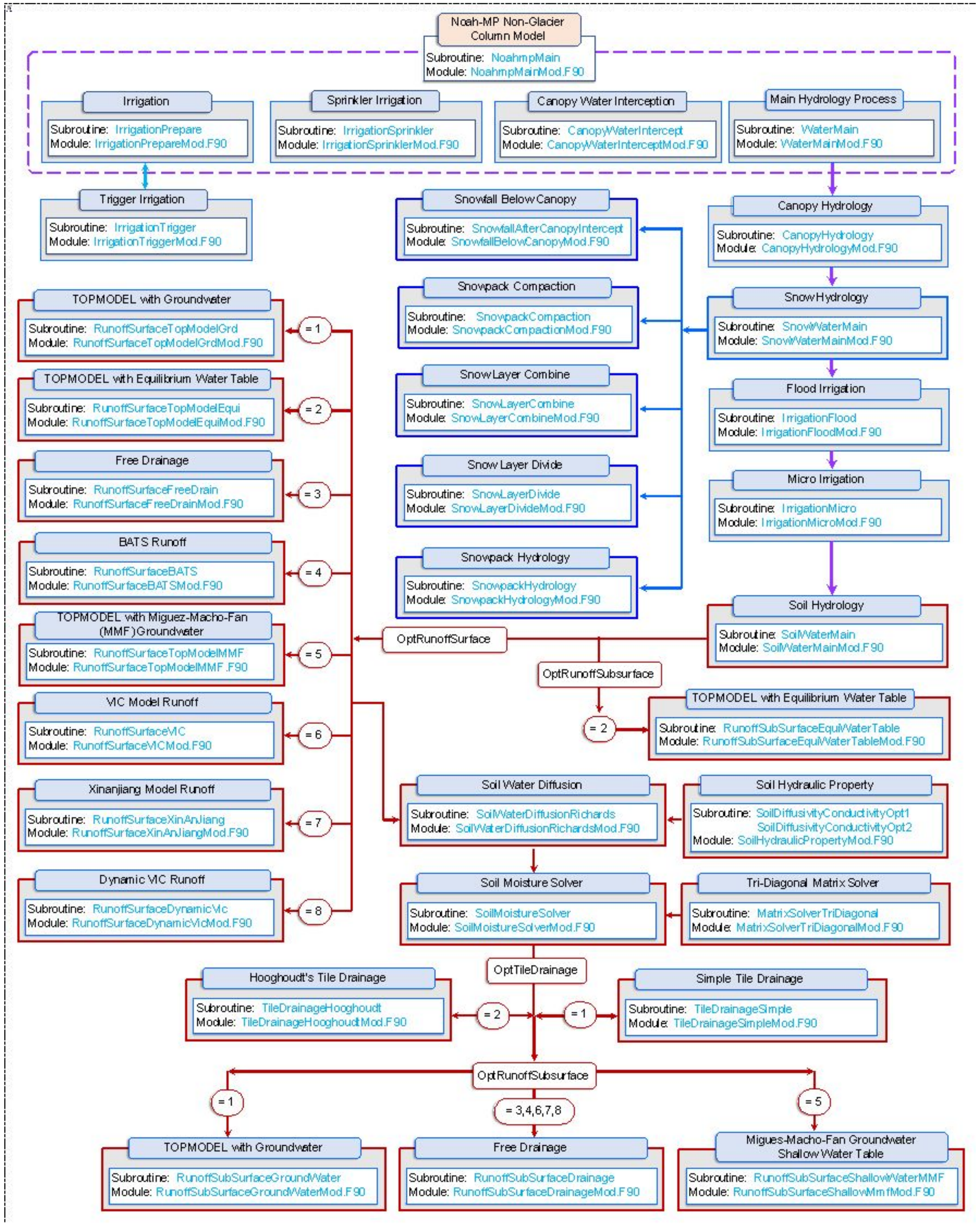
He et al., 2023 GMD

Noah-MP v5 Energy process calling tree



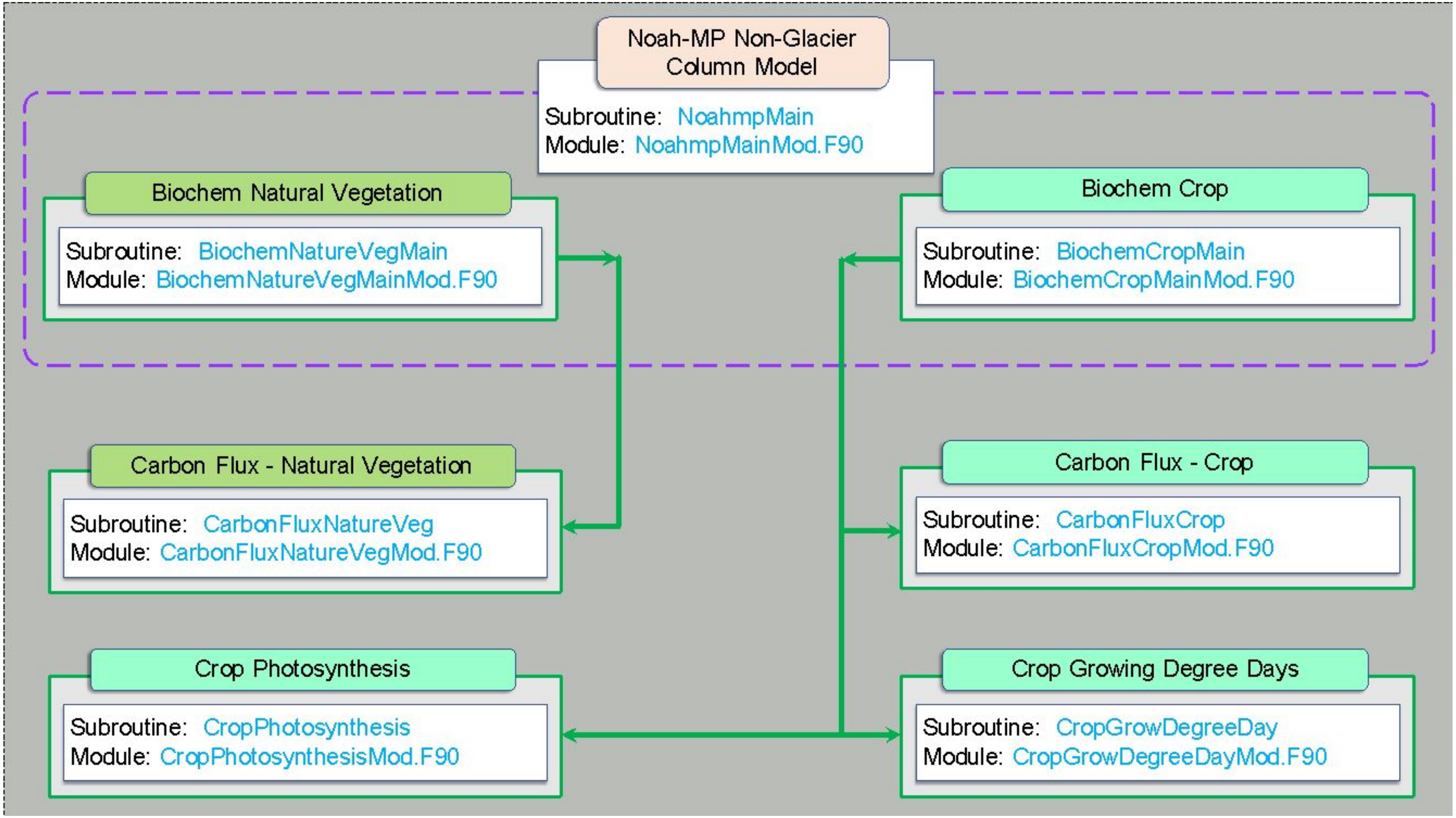
He et al., 2023 GMD

Noah-MP v5 Water process calling tree



He et al., 2023 GMD

Noah-MP v5 Carbon process calling tree



He et al., 2023 GMD

Noah-MP specific physics and namelist options

Noah-MP physics namelist option: dynamic vegetation

HRLDAS run namelist:
DYNAMIC_VEG_OPTION

OptDynamicVeg

options for dynamic (prognostic) vegetation

1	off (use table LeafAreaIndex; use VegFrac = VegFracGreen from input) (Niu et al., 2011; Yang et al., 2011)
2	on (together with OptStomataResistance = 1) (Dickinson et al., 1998; Niu and Yang, 2003)
3	off (use table LeafAreaIndex; calculate VegFrac)
4*	off (use table LeafAreaIndex; use maximum vegetation fraction)
5	on (use maximum vegetation fraction)
6	on (use VegFrac = VegFracGreen from input)
7	off (use input LeafAreaIndex; use VegFrac = VegFracGreen from input)
8	off (use input LeafAreaIndex; calculate VegFrac)
9	off (use input LeafAreaIndex; use maximum vegetation fraction)

PhenologyMainMod.F90

If using table LAI: Linearly interpolate between monthly values into specific day value

NoahmpTable.TBL

Stand-scale LAI not pixel-scale

```
! LAI: MODIS monthly climatology (2000-2008) leaf area index (one row for each month) (Yang et al., 2011)
LAI_JAN  =   4.0,    4.5,    0.0,    0.0,    2.0,    0.0,    0.0,    0.2,    0.3,    0.4,    0.2,    0.0,
LAI_FEB  =   4.0,    4.5,    0.0,    0.0,    2.0,    0.0,    0.0,    0.2,    0.3,    0.5,    0.3,    0.0,
LAI_MAR  =   4.0,    4.5,    0.0,    0.3,    2.2,    0.3,    0.2,    0.4,    0.5,    0.6,    0.3,    0.0,
LAI_APR  =   4.0,    4.5,    0.6,    1.2,    2.6,    0.9,    0.6,    1.0,    0.8,    0.7,    0.5,    0.0,
LAI_MAY  =   4.0,    4.5,    1.2,    3.0,    3.5,    2.2,    1.5,    2.4,    1.8,    1.2,    1.5,    1.0,
LAI_JUN  =   4.0,    4.5,    2.0,    4.7,    4.3,    3.5,    2.3,    4.1,    3.6,    3.0,    2.9,    2.0,
LAI_JUL  =   4.0,    4.5,    2.6,    4.5,    4.3,    3.5,    2.3,    4.1,    3.8,    3.5,    3.5,    3.0,
LAI_AUG  =   4.0,    4.5,    1.7,    3.4,    3.7,    2.5,    1.7,    2.7,    2.1,    1.5,    2.7,    3.0,
```

Noah-MP physics namelist option: rain-snow partitioning

HRLDAS run namelist:
PCP_PARTITION_OPTION

AtmosForcingMod.F90

OptRainSnowPartition options for partitioning precipitation into rainfall & snowfall	1*	Jordan (1991) scheme
	2	BATS: when TemperatureAirRefHeight < freezing point+2.2 (Yang and Dickinson, 1996)
	3	TemperatureAirRefHeight < freezing point (Niu et al., 2011)
	4	Use WRF microphysics output (Barlage et al., 2015)
	5	Use wet-bulb temperature (Wang et al., 2019)

Jordan 1991 scheme:

$$F_{snowfall} = \begin{cases} 0.0, & T_{sfc} > T_{frz} + 2.5 \\ 0.6, & T_{frz} + 2.0 < T_{sfc} \le T_{frz} + 2.5 \\ 1.0 - (-54.632 + 0.2 \times T_{sfc}), & T_{frz} - 0.5 < T_{sfc} \le T_{frz} + 2 \\ 1.0, & T_{sfc} \le T_{frz} - 0.5 \end{cases}$$

Wang 2019 wet-bulb temperature scheme:

$$F_{snowfall} = \frac{1}{(1 + a \times e^{b \times (T_{wetb} + c)})}$$

Noah-MP physics namelist option: soil water transpiration factor

HRLDAS run namelist:
BTR_OPTION

OptSoilWaterTranspiration	1*	Noah (soil moisture) (Ek et al., 2003)
	2	CLM (matric potential) (Oleson et al., 2004)
options for soil moisture factor for stomatal resistance & ET	3	SSiB (matric potential) (Xue et al., 1991)

SoilWaterTranspirationMod.F90

$$\beta_{tr} = \sum_{i=1}^{N_{root}} (r_i \times w_i)$$

$$r_i = \frac{D_{zsnso}(i)}{-Z_{soil}(N_{root})}$$

$$w_i = \begin{cases} \dfrac{W_{liq,soil}(i) - \theta_{soil,wilt}(i)}{\theta_{soil,ref}(i) - \theta_{soil,wilt}(i)} & (Noah) \\ \dfrac{\psi_{soil,wilt} - \psi_{soil}(i)}{\psi_{soil,wilt} + \psi_{soil,sat}(i)} & (CLM) \\ 1 - e^{-5.8 \times ln\left(\frac{\psi_{soil,wilt}}{\psi_{soil}(i)}\right)} & (SSiB) \end{cases}$$

Noah-MP physics namelist option: ground resistance to evaporation

HRLDAS run namelist:
SURFACE_RESISTANCE_OPTION

ResistanceGroundEvaporationMod.F90

OptGroundResistanceEvap

options for ground resistent to evaporation/sublimation

1*	Sakaguchi and Zeng (2009) scheme
2	Sellers (1992) scheme
3	adjusted Sellers (1992) for wet soil
4	Sakaguchi and Zeng (2009) for non-snow; rsurf = rsurf_snow for snow (set in NoahmpTable.TBL)

Option = 1:

$$R_{grd,evap} = \frac{Z_{soil,dry}}{D_{vap,red}}$$

$$Z_{soil,dry} = -Z_{soil}(1) \times \frac{e^{\left[1-\min(1,\frac{W_{liq,soil}(1)}{\theta_{soil,max}(1)}\right]^{R_{s,exp}}} - 1}{2.71828-1}$$

$$D_{vap,red} = 2.2 \times 10^{-5} \times \theta_{soil,max}(1) \times \theta_{soil,max}(1) \times \left(1 - \frac{\theta_{soil,wilt}(1)}{\theta_{soil,max}(1)}\right)^{2+\frac{3}{B_{exp}(1)}}$$

Option = 2:

$$R_{grd,evap} = f_{snow} \times 1.0 + (1 - f_{snow}) \times e^{8.25-4.225 \times B_{evap}}$$

Option = 3:

$$R_{grd,evap} = f_{snow} \times 1.0 + (1 - f_{snow}) \times e^{8.25-6.0 \times B_{evap}}$$

$$B_{evap} = \max(0, \frac{W_{liq,soil}(1)}{\theta_{soil,max}(1)})$$

Option = 4:

$$R_{grd,evap} = \frac{1}{f_{snow} \times \frac{1}{R_{sno,evap}} + (1-f_{snow}) \times \frac{1}{\max(0.001, R_{grd,evap0})}}$$

Noah-MP physics namelist option: surface drag/resistance

HRLDAS run namelist:
SURFACE_DRAG_OPTION

SurfaceEnergyFluxVegetatedMod.F90
SurfaceEnergyFluxBareGroundMod.F90

OptSurfaceDrag		
options for surface layer drag/exchange coefficient	1*	Monin-Obukhov (M-O) Similarity Theory (Brutsaert, 1982)
	2	original Noah (Chen et al. 1997)

$$R_{h,can} = \max(1, \frac{1}{C_{h,can} \times U_{ref}})$$

$$R_{m,can} = \max(1, \frac{1}{C_{m,can} \times U_{ref}})$$

Option = 1:

ResistanceAboveCanopyMostMod.F90

ResistanceAboveCanopyChen97Mod.F90

Option = 2:

ResistanceBareGroundMostMod.F90

ResistanceBareGroundChen97Mod.F90

Noah-MP physics namelist option: stomata resistance

HRLDAS run namelist:
CANOPY_STOMATAL_RESISTANCE_OPTION

SurfaceEnergyFluxVegetatedMod.F90

OptStomataResistance options for canopy stomatal resistance	1*	Ball-Berry scheme (Ball et al., 1987; Bonan, 1996)
	2	Jarvis scheme (Jarvis, 1976)

Option = 1:

ResistanceCanopyStomataBallBerryMod.F90

Option = 2:

ResistanceCanopyStomataJarvisMod.F90

Noah-MP physics namelist option: snow albedo

HRLDAS run namelist:
SNOW_ALBEDO_OPTION

SurfaceAlbedoMod.F90
SurfaceAlbedoGlacierMod.F90

OptSnowAlbedo	1*	BATS snow albedo (Dickinson et al., 1993)
options for ground snow surface albedo	2	CLASS snow albedo (Verseghy, 1991)

Option = 1:

SnowAlbedoBatsMod.F90

Option = 2:

SnowAlbedoClassMod.F90

Noah-MP physics namelist option: canopy radiative transfer

HRLDAS run namelist:
RADIATIVE_TRANSFER_OPTION

CanopyRadiationTwoStreamMod.F90

OptCanopyRadiationTransfer options for canopy radiation transfer		
	1	modified two-stream (gap = *f* (solar angle,3D structure, etc) < 1-VegFrac) (Niu and Yang, 2004)
	2	two-stream applied to grid-cell (gap=0) (Niu et al., 2011)
	3*	two-stream applied to vegetated fraction (gap=1-VegFrac) (Dickinson, 1983; Sellers, 1985)

If OptCanopyRadiationTransfer = 1:

$$P_c = min\begin{cases} 1 - f_{veg} \\ P_{bc} + P_{wc} \end{cases}$$

$$K_{open} = 0.05$$

If OptCanopyRadiationTransfer = 2:

$$P_c = 0.0$$

$$K_{open} = 0.0$$

If OptCanopyRadiationTransfer = 3:

$$P_c = 1 - f_{veg}$$

$$K_{open} = 1 - f_{veg}$$

Noah-MP physics namelist option: soil/snow temperature time scheme

HRLDAS run namelist:
TEMP_TIME_SCHEME_OPTION

SoilSnowThermalDiffusionMod.F90
GlacierThermalDiffusionMod.F90

OptSnowSoilTempTime options for snow/soil temperature time scheme (only layer 1)	1*	semi-implicit; flux top boundary condition (Niu et al., 2011)
	2	full implicit (original Noah); temperature top boundary condition (Ek et al., 2003)
	3	same as 1, but snow cover for skin temperature calculation (Niu et al., 2011)

matrix coefficients for the tri-diagonal matrix (temperature solver):
For top snow/soil layer:

$$B_I(i) = \begin{cases} -C_I(i) & \text{OptSnowSoilTempTime} = 1,3 \\ -C_I(i) + \dfrac{K_{heat,snso}(i)}{0.5 \times Z_{snso}(i) \times Z_{snso}(i) \times C_{heat,snso}(i)} & \text{OptSnowSoilTempTime} = 2 \end{cases}$$

Noah-MP physics namelist option: snow thermal conductivity

HRLDAS run namelist:
SNOW_THERMAL_CONDUCTIVITY

SnowThermalPropertyMod.F90

OptSnowThermConduct	1*	Stieglitz scheme (Yen,1965)
	2	Anderson (1976) scheme
options for snow thermal conductivity	3	Constant (Niu et al., 2011)
	4	Verseghy (1991) scheme
	5	Douvill scheme (Yen, 1981)

$$k_{snow} = \begin{cases} 3.2217 \times 10^{-6} \times \rho_{snow}^2, & OptSnowThermConduct = 1 \\ 2 \times 10^{-2} + 2.5 \times 10^{-6} \times \rho_{snow}^2, & OptSnowThermConduct = 2 \\ 0.35, & OptSnowThermConduct = 3 \\ 2.576 \times 10^{-6} \times \rho_{snow}^2 + 0.074, & OptSnowThermConduct = 4 \\ 2.22 \times \left(\frac{\rho_{snow}}{1000}\right)^{1.88}, & OptSnowThermConduct = 5 \end{cases}$$

Noah-MP physics namelist option: low boundary soil temperature

HRLDAS run namelist:
TBOT_OPTION

SoilSnowThermalDiffusionMod.F90

OptSoilTemperatureBottom	1	zero heat flux from bottom (DepthSoilTempBottom & TemperatureSoilBottom not used) (Niu et al., 2011)
options for lower boundary condition of soil temperature	2*	TemperatureSoilBottom at DepthSoilTempBottom (8m) read from a file (original Noah) (Ek et al., 2003)

F_{bot} [W/m^2] is the heat flux from deep soil bottom defined as:

$$F_{bot} = \begin{cases} 0 & \text{OptSoilTemperatureBottom} = 1 \\ -K_{heat,snso}(N_{soil}) \times D_h(N_{soil}) & \text{OptSoilTemperatureBottom} = 2 \end{cases}$$

Noah-MP physics namelist option: soil supercooled water

HRLDAS run namelist:
SUPERCOOLED_WATER_OPTION

SoilSnowWaterPhaseChangeMod.F90

OptSoilSupercoolWater	1*	No iteration (Niu and Yang, 2006)
options for soil supercooled liquid water	2	Koren's iteration (Koren et al., 1999)

Option = 1:

SoilWaterSupercoolNiu06Mod.F90

Option = 2:

SoilWaterSupercoolKoren99Mod.F90

Noah-MP physics namelist option: surface runoff

HRLDAS run namelist:
SURFACE_RUNOFF_OPTION

SoilWaterMainMod.F90

OptRunoffSurface

options for surface runoff

1	TOPMODEL with groundwater (Niu et al., 2007)
2	TOPMODEL with an equilibrium water table (Niu et al., 2005)
3*	Schaake scheme (original Noah) (Schaake et al., 1996)
4	BATS surface and subsurface runoff (Yang and Dickinson, 1996)
5	Miguez-Macho & Fan (MMF) groundwater scheme (Fan et al., 2007; Miguez-Macho et al. 2007)
6	Variable Infiltration Capacity Model surface runoff scheme (Liang et al., 1994)
7	Xinanjiang Infiltration and surface runoff scheme (Jayawardena and Zhou, 2000)
8	Dynamic VIC surface runoff scheme (Liang and Xie, 2003)

Noah-MP physics namelist option: subsurface runoff

HRLDAS run namelist:
SUBSURFACE_RUNOFF_OPTION

SoilWaterMainMod.F90

OptRunoffSubsurface options for drainage & subsurface runoff	1~8	similar to runoff option, separated from original Noah-MP runoff option, currently tested & recommended the same option# as surface runoff (default)

Noah-MP physics namelist option: dynamic VIC infiltration

HRLDAS run namelist:
DVIC_INFILTRATION_OPTION

RunoffSurfaceDynamicVicMod.F90

OptDynVicInfiltration options for infiltration in dynamic VIC runoff scheme	1*	Philip scheme (Liang and Xie, 2003)
	2	Green-Ampt scheme (Liang and Xie, 2003)
	3	Smith-Parlange scheme (Liang and Xie, 2003)

Option = 1:

SoilWaterInfilPhilipMod.F90

Option = 2:

SoilWaterInfilGreenAmptMod.F90

Option = 3:

SoilWaterInfilSmithParlangeMod.F90

Noah-MP physics namelist option: frozen soil permeability

HRLDAS run namelist:
FROZEN_SOIL_OPTION

SoilHydraulicPropertyMod.F90

OptSoilPermeabilityFrozen	1*	linear effects, more permeable (Niu and Yang, 2006)
options for frozen soil permeability	2	nonlinear effects, less permeable (Koren et al., 1999)

Option = 1:

SoilDiffusivityConductivityOpt1

Option = 2:

SoilDiffusivityConductivityOpt2

Noah-MP physics namelist option: tile drainage

HRLDAS run namelist:
TILE_DRAINAGE_OPTION

SoilWaterMainMod.F90

OptTileDrainage options for tile drainage currently only tested & calibrated to work with runoff option=3	0*	No tile drainage
	1	on (simple scheme) (Valayamkunnath et al., 2022)
	2	on (Hooghoudt's scheme) (Valayamkunnath et al., 2022)

Option = 1:

TileDrainageSimpleMod.F90

Option = 2:

TileDrainageHooghoudtMod.F90

Noah-MP physics namelist option: Irrigation trigger

HRLDAS run namelist:
IRRIGATION_OPTION

IrrigationPrepareMod.F90
IrrigationTriggerMod.F90

OptIrrigation

options for irrigation

0*	No irrigation
1	Irrigation on (Valayamkunnath et al., 2021)
2	irrigation trigger based on crop season planting and harvesting dates (Valayamkunnath et al., 2021)
3	irrigation trigger based on LeafAreaIndex threshold (Valayamkunnath et al., 2021)

Noah-MP physics namelist option: Irrigation method

HRLDAS run namelist:
IRRIGATION_METHOD

IrrigationPrepareMod.F90
IrrigationTriggerMod.F90

OptIrrigationMethod options for irrigation method, only works when OptIrrigation > 0	0*	method based on geo_em fractions
	1	sprinkler method (Valayamkunnath et al., 2021)
	2	micro/drip irrigation (Valayamkunnath et al., 2021)
	3	surface flooding (Valayamkunnath et al., 2021)

Option = 1:

IrrigationSprinklerMod.F90

Option = 2:

IrrigationFloodMod.F90

Option = 3:

IrrigationMicroMod.F90

Noah-MP physics namelist option: Crop model

HRLDAS run namelist:
CROP_OPTION

PhenologyMainMod.F90
BiochemCropMainMod.F90

OptCropModel	0*	No crop model
options for crop model	1	Liu, et al. (2016) crop scheme

Noah-MP physics namelist option: input soil data

HRLDAS run namelist:
SOIL_DATA_OPTION

hrldas/IO_code/module_NoahMP_hrldas_driver.F

OptSoilProperty options for defining soil properties	1*	use input dominant soil texture
	2	use input soil texture that varies with depth
	3	use soil composition (sand, clay, orgm) and pedotransfer function
	4	use input soil properties

HRLDAS run namelist:
PEDOTRANSFER_OPTION

noahmp/drivers/hrldas/PedoTransferSR2006Mod.F90

OptPedotransfer options for pedotransfer functions, only works when OptSoilProperty=3	1*	Saxton and Rawls (2006) scheme

Noah-MP physics namelist option: Glacier ice treatment

HRLDAS run namelist:
GLACIER_OPTION

GlacierPhaseChangeMod.F90

OptGlacierTreatment	1*	include phase change of glacier ice
options for glacier treatment	2	Glacier ice treatment more like original Noah

Option = 2: glacier ice is frozen forever and there is no glacier ice phase change

Noah-MP physics namelist option: soil timestep & output diagnostic

```
SOIL_TIMESTEP                   = 0.0,                   ! Noah-MP soil process timestep (seconds) for solving soil water and temperature
                                                         !   0 -> default, the same as main NoahMP model timestep
                                                         !   N * dt_noahmp -> longer than main NoahMP model timestep (often used for WRF coupled run)

NOAHMP_OUTPUT                   = 0,                     ! NoahMP output level
                                                         !   0 -> standard output
                                                         !   1 -> standard output with additional water and energy budget term output
```

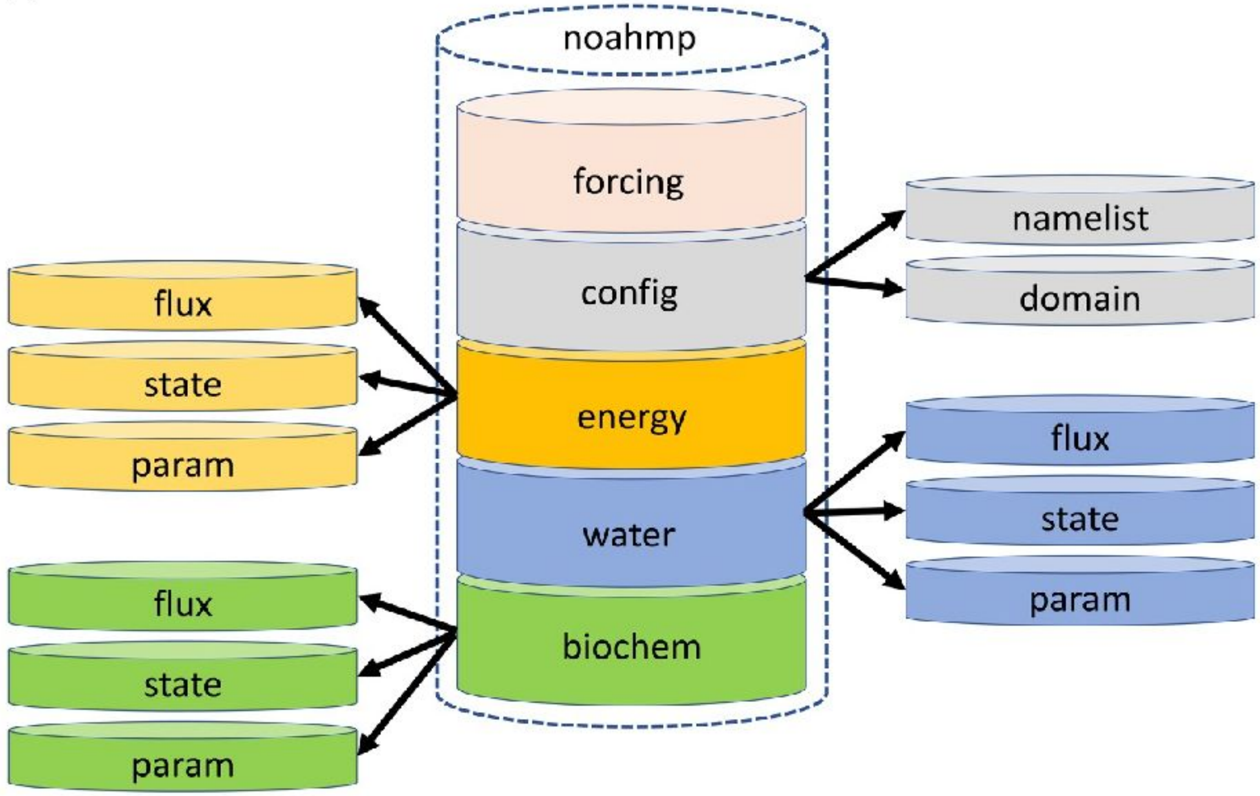
hrldas/IO_code/module_NoahMP_hrldas_driver.F

```
! additional NoahMP output
if (NoahmpIO%noahmp_output > 0) then
  ! additional water budget terms
  call add_to_output(NoahmpIO%QINTSXY    , "QINTS"   , "canopy interception (loading) rate for snowfall", "mm/s"      )
  call add_to_output(NoahmpIO%QINTRXY    , "QINTR"   , "canopy interception rate for rain"              , "mm/s"      )
  call add_to_output(NoahmpIO%QDRIPSXY   , "QDRIPS"  , "drip (unloading) rate for intercepted snow"     , "mm/s"      )
  call add_to_output(NoahmpIO%QDRIPRXY   , "QDRIPR"  , "drip rate for canopy intercepted rain"          , "mm/s"      )
  call add_to_output(NoahmpIO%QTHROSXY   , "QTHROS"  , "throughfall of snowfall"                        , "mm/s"      )
  call add_to_output(NoahmpIO%QTHRORXY   , "QTHROR"  , "throughfall for rain"                           , "mm/s"      )
  call add_to_output(NoahmpIO%QSNSUBXY   , "QSNSUB"  , "snow surface sublimation rate"                  , "mm/s"      )
  call add_to_output(NoahmpIO%QSNFROXY   , "QSNFRO"  , "snow surface frost rate"                        , "mm/s"      )
  call add_to_output(NoahmpIO%QSUBCXY    , "QSUBC"   , "canopy snow sublimation rate"                   , "mm/s"      )
  call add_to_output(NoahmpIO%QFROCXY    , "QFROC"   , "canopy snow frost rate"                         , "mm/s"      )
  call add_to_output(NoahmpIO%QEVACXY    , "QEVAC"   , "canopy snow evaporation rate"                   , "mm/s"      )
  call add_to_output(NoahmpIO%QDEWCXY    , "QDEWC"   , "canopy snow dew rate"                           , "mm/s"      )
  call add_to_output(NoahmpIO%QFRZCXY    , "QFRZC"   , "refreezing rate of canopy liquid water"         , "mm/s"      )
  call add_to_output(NoahmpIO%QMELTCXY   , "QMELTC"  , "melting rate of canopy snow"                    , "mm/s"      )
  call add_to_output(NoahmpIO%QSNBOTXY   , "QSNBOT"  , "water (melt+rain through) out of snow bottom"   , "mm/s"      )
  call add_to_output(NoahmpIO%QMELTXY    , "QMELT"   , "snow melt due to phase change"                  , "mm/s"      )
  call add_to_output(NoahmpIO%PONDINGXY  , "PONDING" , "total surface ponding per time step"            , "mm/s"      )
  call add_to_output(NoahmpIO%FPICEXY    , "FPICE"   , "snow fraction in precipitation"                 , "-"         )
```

Noah-MP version 5.0 data types and code structures

Noah-MP data types

(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
```

Noah-MP v5 code structure and subroutine interface

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
```

Noah-MP v5 new variable names

https://github.com/NCAR/noahmp/tree/master/docs

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

Switch to Noah-MP GitHub screen to demonstrate:

1. GitHub structure

2. basic data type and code structures

Thank you!

We will have another AMS tutorial on Noah-MP in January 2024

Stay tuned!

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