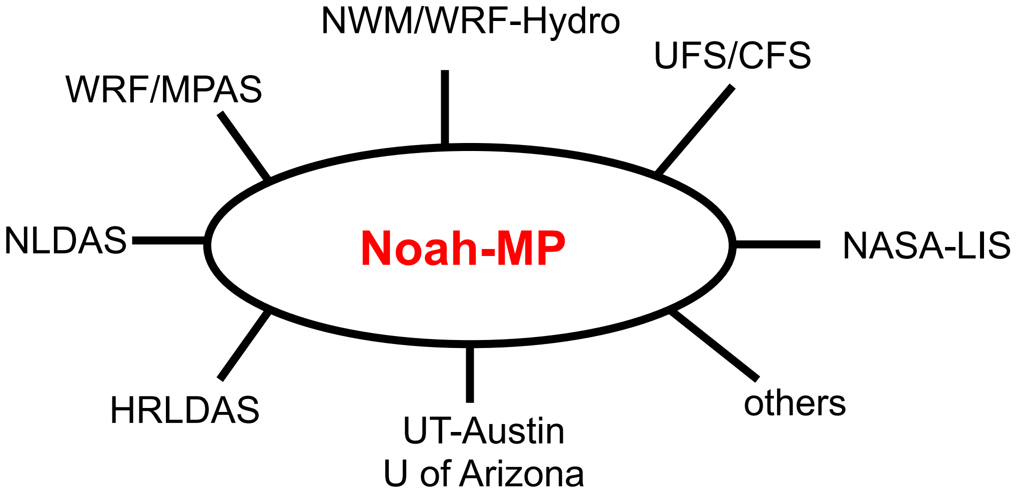
Noah-MP Land Surface Model Tutorial

Noah-MP®

DOI 10.5281/zenodo.7901855

Unified Noah-MP GitHub

Noah-MP® 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

Cenlin He

National Center for Atmospheric Research (NCAR)

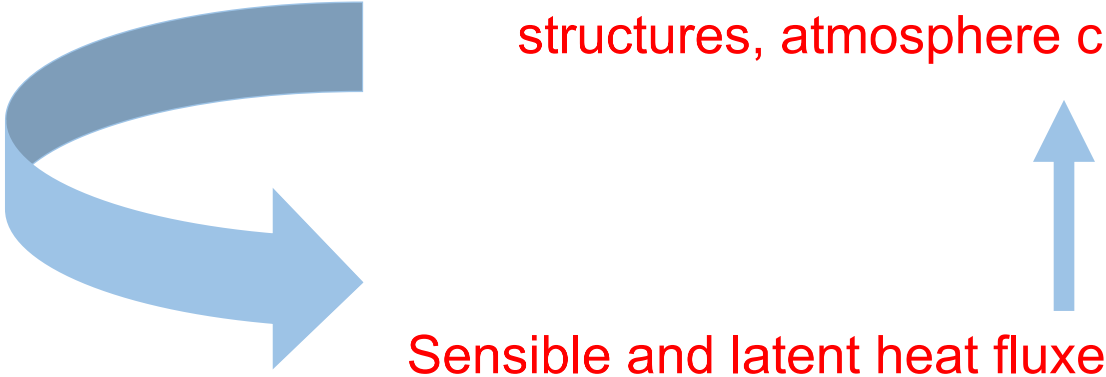
@AMS, January 27, 2024

Outline

- Noah-MP brief history and recent activities
- Noah-MP coupling structure with host models
- Noah-MP key processes and treatments
- Noah-MP current modeling capabilities
- Noah-MP model structure and process workflow
- Noah-MP specific physics namelist options
- Noah-MP GitHub repository

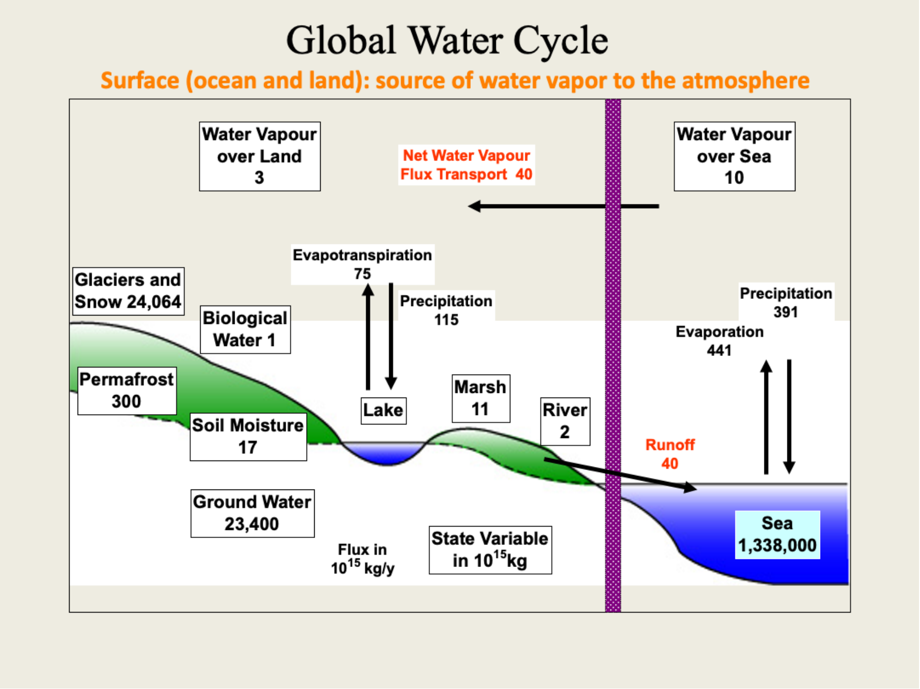
Noah-MP brief history

LSM provides lower boundary conditions to coupled weather/climate models

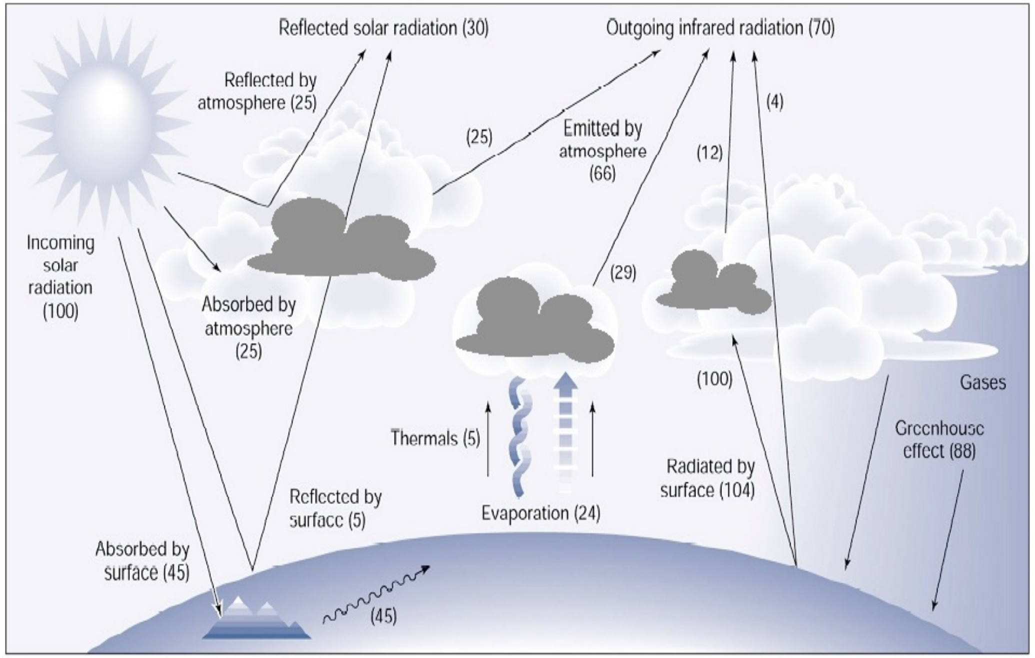


Temperature, wind, humidity, planetary boundary layer structures, atmosphere circulations, clouds, precipitation

Sensible and latent heat fluxes, albedo, surface temperature, carbon, nitrogen

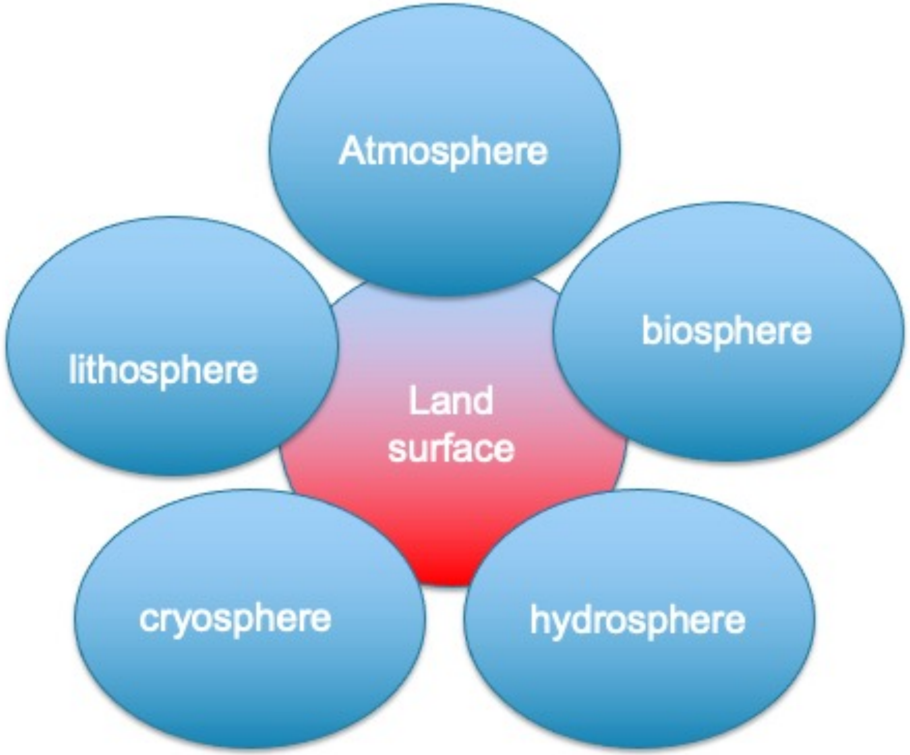


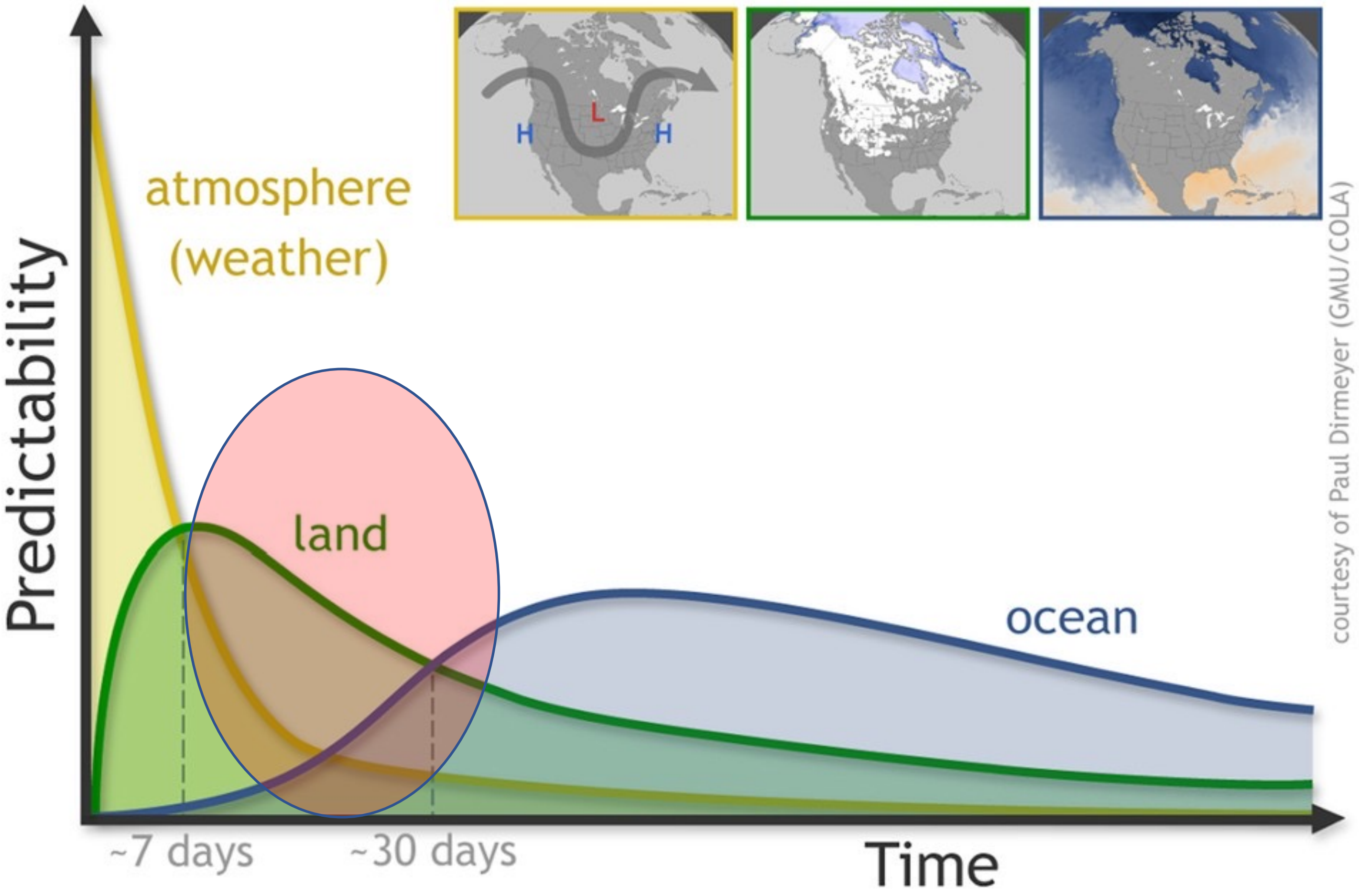
Beyond: soil moisture, snow depth, runoff, ET, biomass, etc



Courtesy of Fei Chen (NCAR)

land-atmosphere interactions are crucial to improving subseasonal and seasonal (S2S) predictability



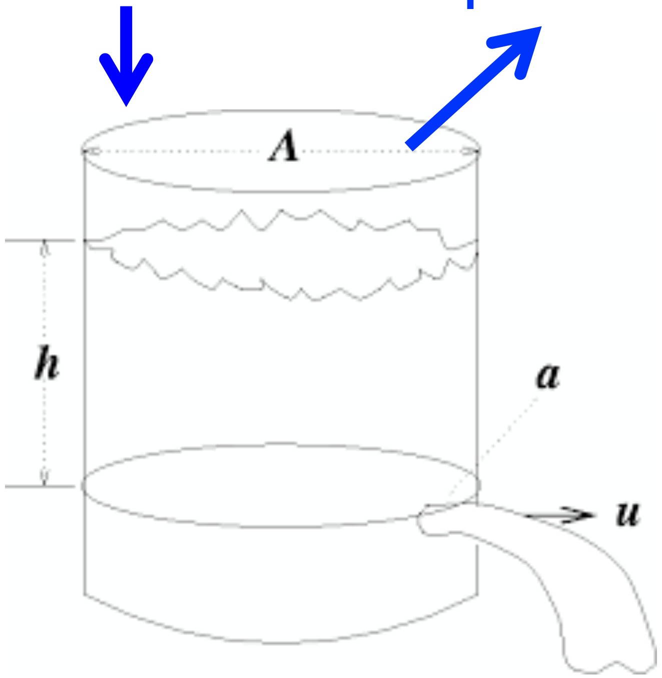


courtesy of Paul Dirmeyer (GMU/COLA)

Courtesy of Fei Chen (NCAR)

Land-surface model (LSM) development chronology

- Gen-0 (prior to 60s): lack of land-surface processes (prescribed diurnal cycle of surface temperature) in atmospheric models.
-
- Gen-1a (mid 60s): surface model with time-fixed soil moisture
- Gen-1b (late 60s): Bucket Model (Manabe 1969): time- and space-varying soil moisture



Bucket

rain

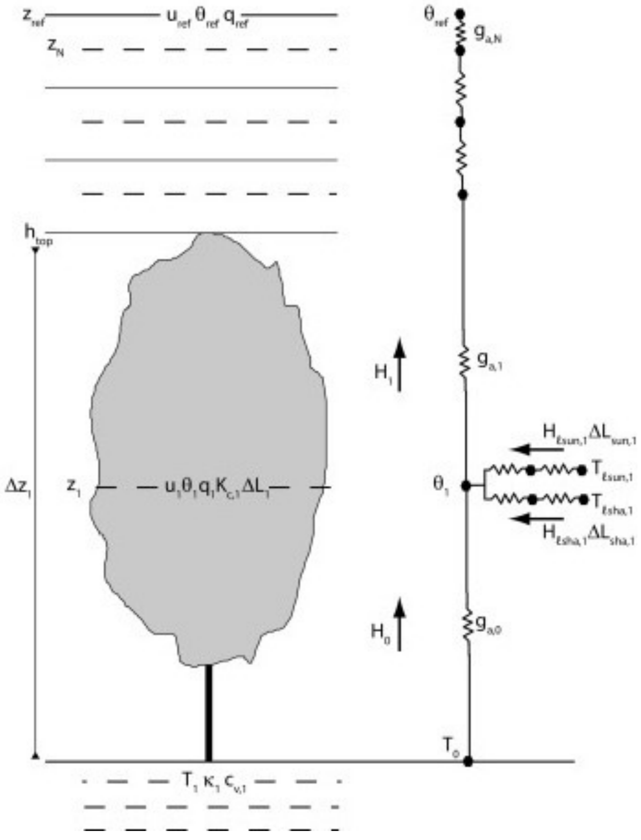
evaporation

runoff

Courtesy of Fei Chen (NCAR)

Land-surface model (LSM) development chronology (cont.)

- Gen-2 (70s): Big-leaf model (Deardorff 1978): explicit vegetation treatment; a major milestone
- Gen-3 (late 80s): more sophisticated models including hydrological, biophysical, biochemical, ecological processes (e.g., BATS, SiB, NCARLSM, Century)
- mid 90s: advanced LSMs at major operational numerical weather prediction centers (Noah at NCEP; ECMWF, UK Met Office, Meteo-France)
- After 2000: integrated Earth System Modeling: carbon, nitrogen, hydrology, and ecosystem
- Human dimension: urbanization, agriculture, forecast management, etc



Bonan et al. 2021

Courtesy of Fei Chen (NCAR)

Noah and Noah-MP development milestones

1

1984

Oregon State University 1-D PBL model (Ek, Pan, Mahrt)

2

1996

OSULSM in NCEP Eta (Mitchell and Chen)

3

2000

OSU in MM5 (Chen and Dudhia)

4

2003

Unified Noah and in GFS, MM5, and WRF (Mitchell, Wegiel, Ek, Chen)

5

2011

Noah-MP (Niu, Yang, Mitchelle, Chen, Ek, Barlage, etc)

6

2014

Noah-MP in WRF Barlage, Tewari, Chen

7

2017

Noh-MP in NWM and UFS (Gochis, Barlage, etc)

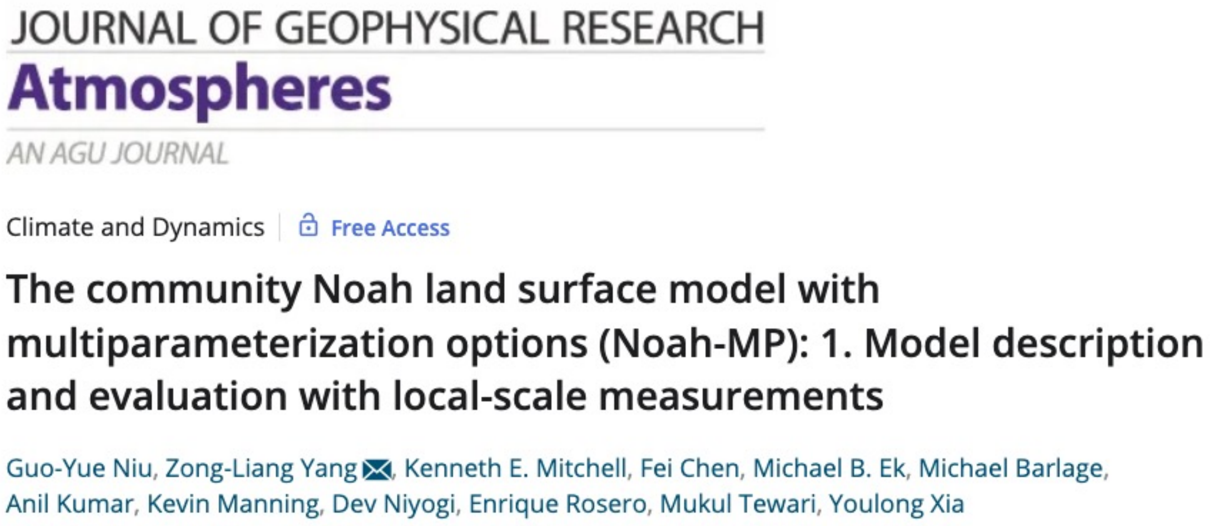
8

2023

Refactored Noah-MP v5 (He, Valayamkunnath, Barlage, etc)

Courtesy of Fei Chen (NCAR)

Community Noah-MP land model



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The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements

Guo-Yue Niu, Zong-Liang Yang, Kenneth E. Mitchell, Fei Chen, Michael B. Ek, Michael Barlage, Anil Kumar, Kevin Manning, Dev Niyogi, Enrique Rosero, Mukul Tewari, Youlong Xia

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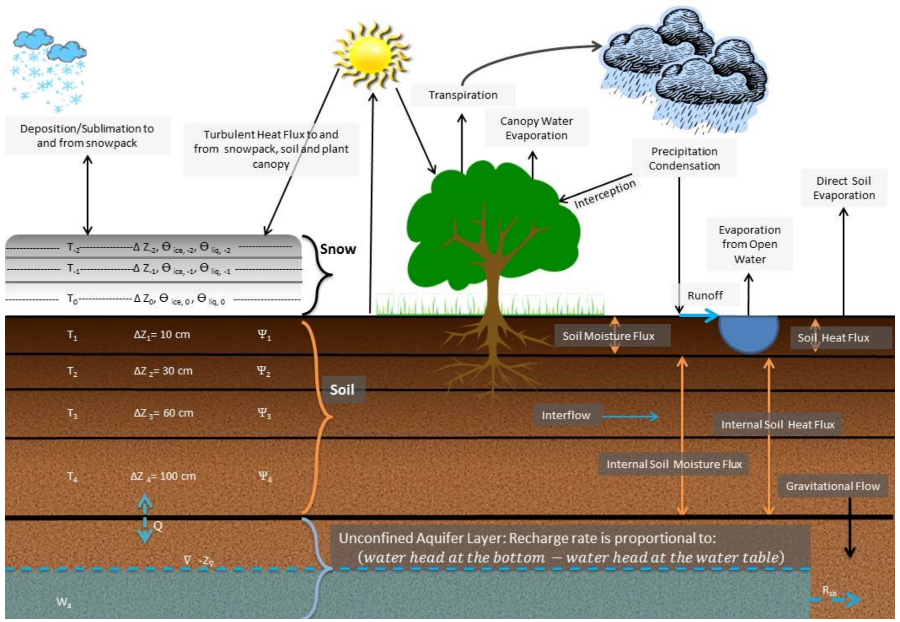
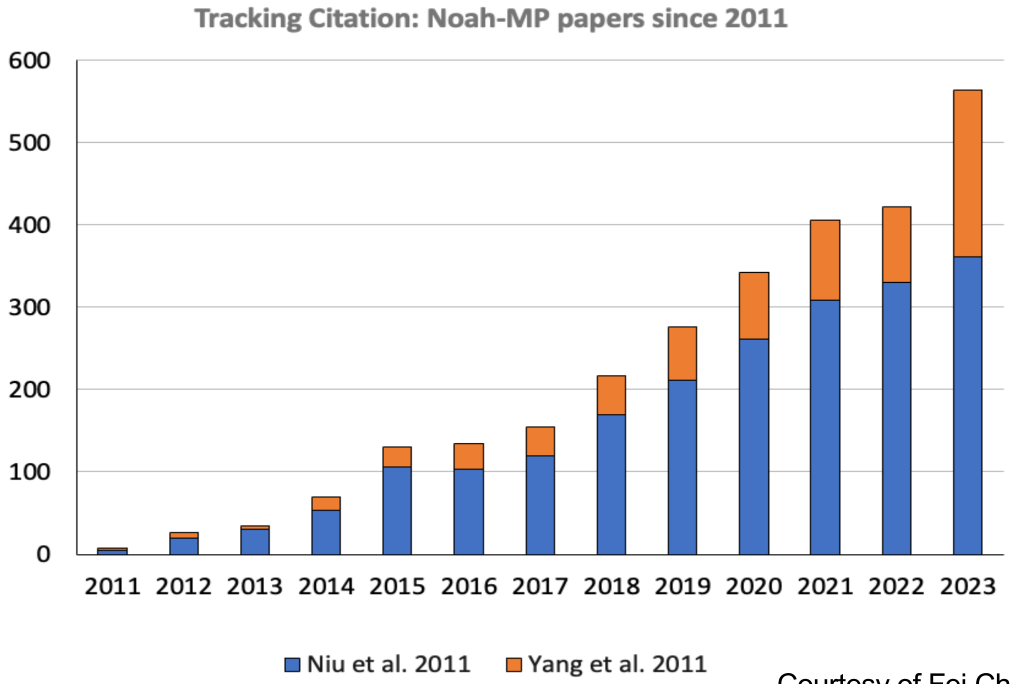
The community Noah land surface model with multiparameterization options (Noah-MP): 2. Evaluation over global river basins

Zong-Liang Yang, Guo-Yue Niu, Kenneth E. Mitchell, Fei Chen, Michael B. Ek, Michael Barlage, Laurent Longuevergne, Kevin Manning, Dev Niyogi, Mukul Tewari, Youlong Xia



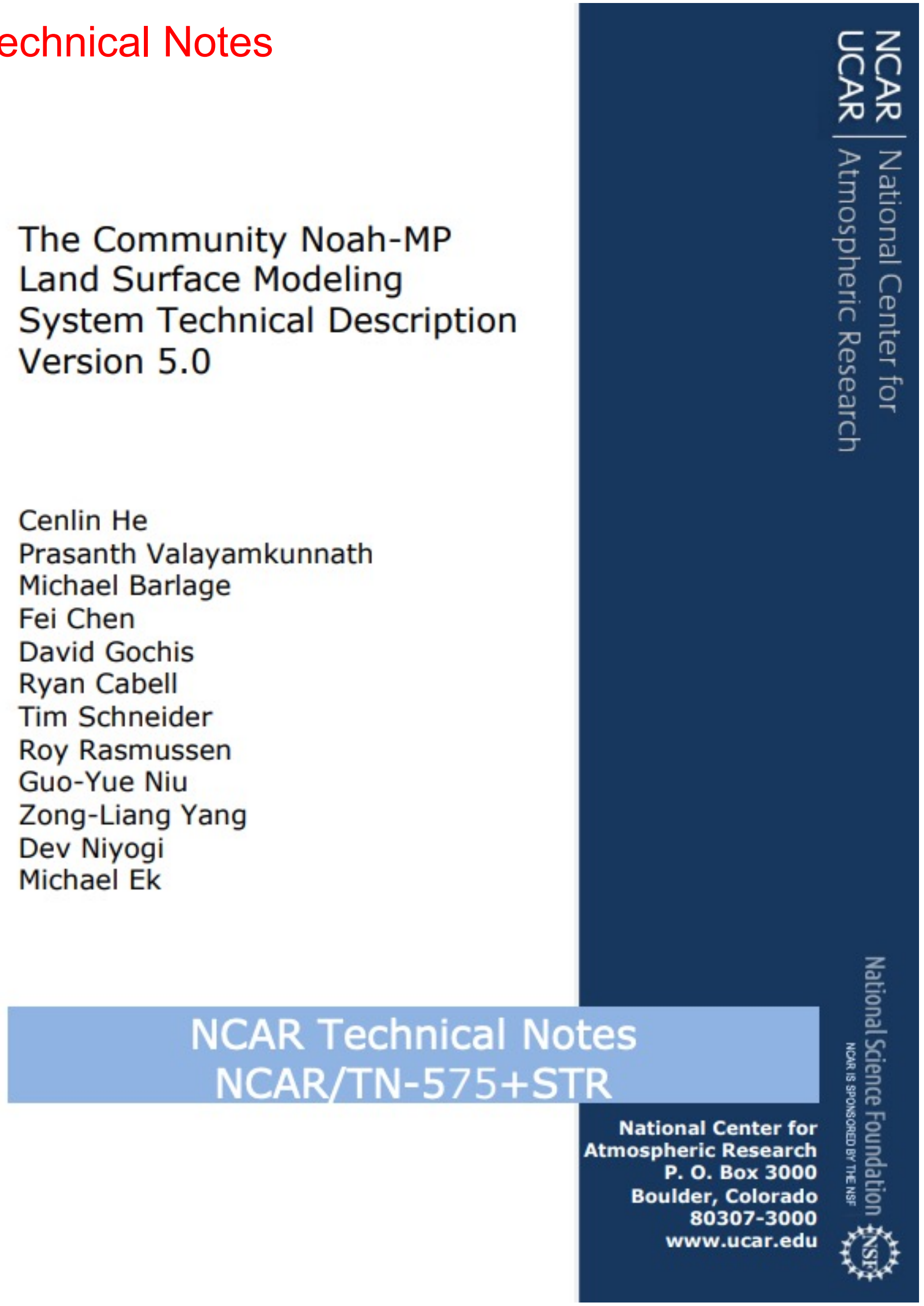


Courtesy of Fei Chen (NCAR)

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

Technical Notes

Refactored Noah-MP (version 5.0) Released in March 2023



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

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

NCAR Technical Notes
NCAR/TN-575+STR

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Geoscientific Model Development
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EGU

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

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

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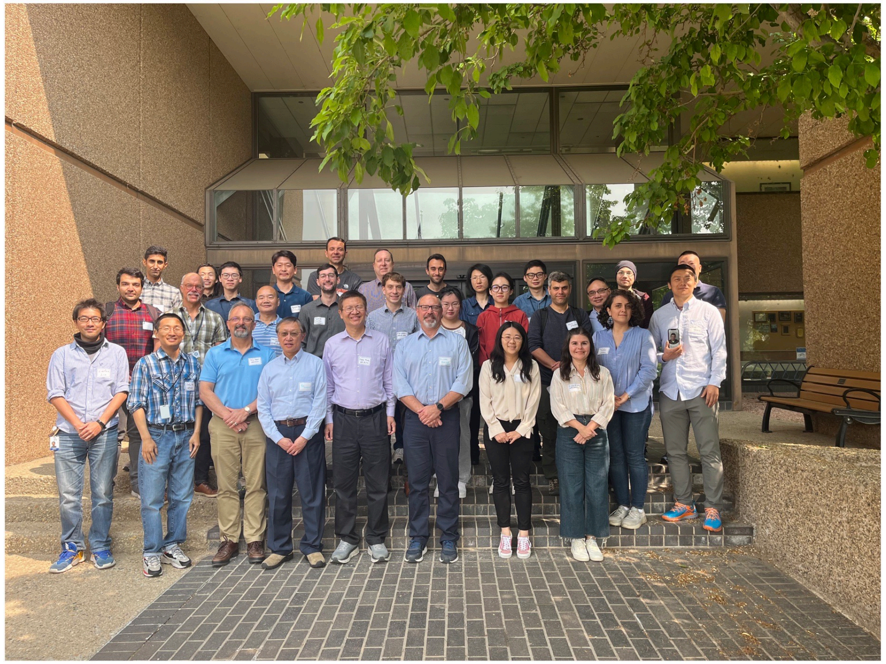
[2]NOAA Environmental Modeling Center (EMC), College Park, Maryland, USA
[3]Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, Arizona, USA
[4]Department of Earth and Planetary Sciences, University of Texas Austin, Austin, Texas, USA
[5]Indian Institute of Science Education and Research, Thiruvananthapuram, India

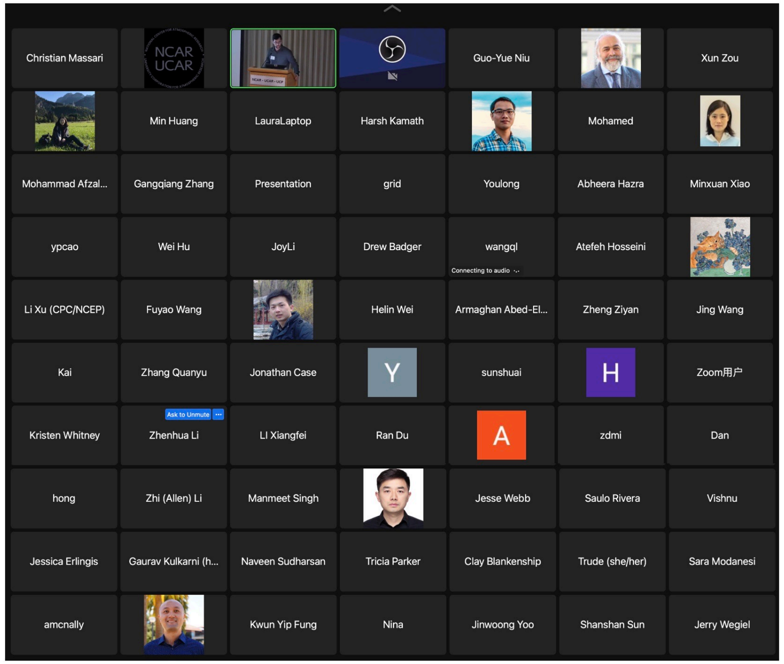
Noah-MP community recent activities

Noah-MP International Users’ Workshop (Hybrid)

23-25 May 2023, Boulder, CO

223 Workshop Participants from 16 countries





Noah-MP community
AGU get-together

Dec 2023, San Francisco, CA

Noah-MP community activities (cont.)

- **Future priorities summarized from Noah-MP workshop:** (https://doi.org/10.1175/BAMS-D-23-0249.1)

Bulletin of the American Meteorological Society

Enhancing the Community Noah-MP Land Model Capabilities for Earth Sciences and Applications

Cenlin He, Fei Chen, Michael Barlage, Zong-Liang Yang, Jerry W. Wegiel, Guo-Yue Niu, David Gochis, David M. Mocko, Ronnie Abolafia-Rosenzweig, Zhe Zhang, Tzu-Shun Lin, Prasanth Valayamkunnath, Michael Ek, and Dev Niyogi

1. land DA modeling framework;
2. land physics in S2S predictions particularly for hydroclimate extremes and informing resource management decisions
3. modeling anthropogenic processes (agricultural practices and human-managed land-use and land-cover change)
4. Noah-MP Academia Collaboratory consisting of universities and national laboratories

- **Noah-MP code review committee** formed to help model developments

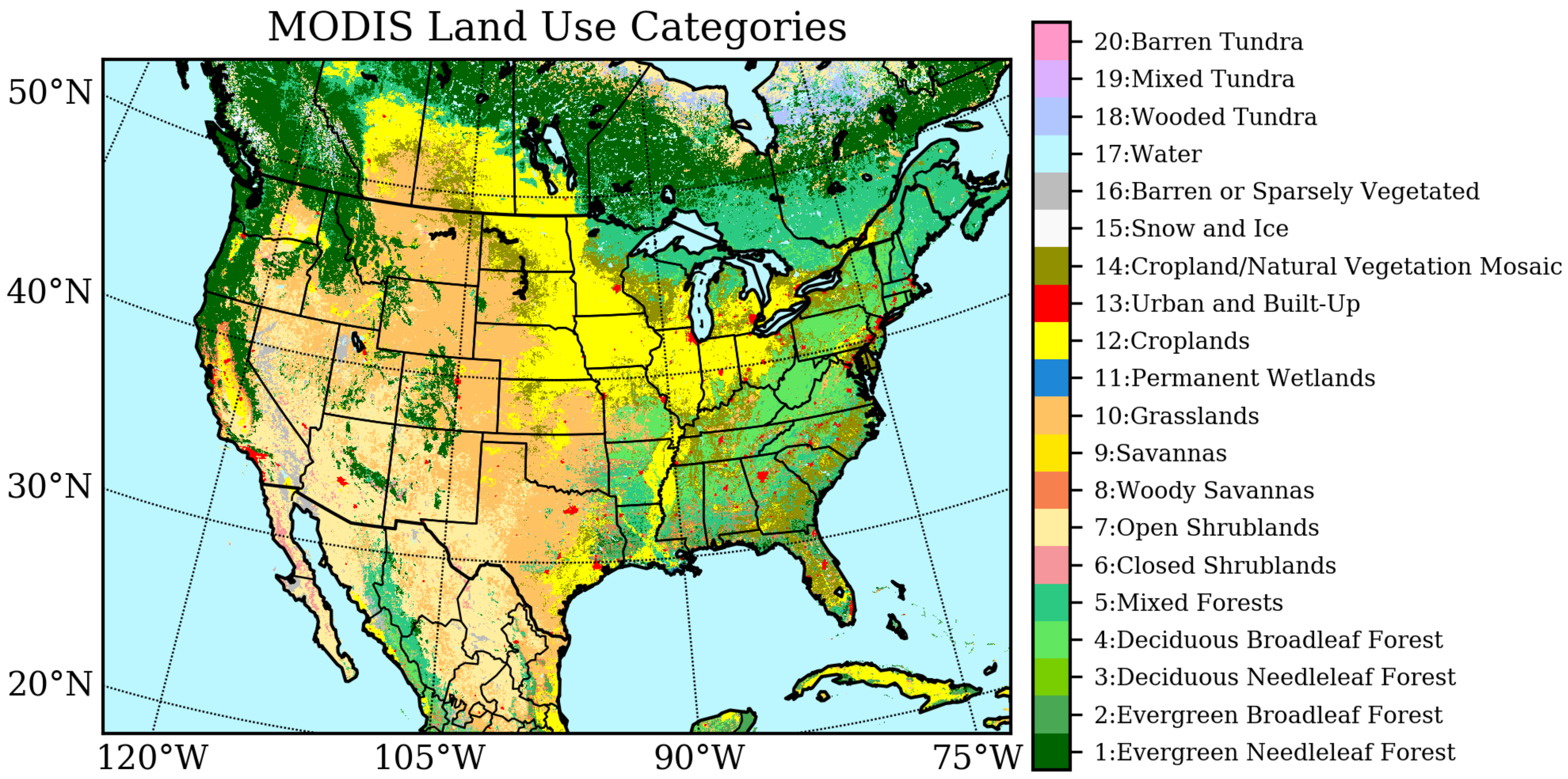
Many thanks to those of you who volunteer to contribute! If you are interested in joining this committee, please sign up here: https://docs.google.com/spreadsheets/d/13kGfVbf5TmFJm-wjis1ZQjmt7eCXFLfbZaqXkvPSi14/edit#gid=0

- **Noah-MP strategic planning committee** formed to help guide the community efforts and directions.

Cenlin He (NCAR, US), Mike Barlage (NOAA, US), Jerry Wiegel (NASA, US), Zong-Liang Yang (UT Austin, US), Dev Niyogi (UT Austin, US), Guo-Yue Niu (UofA, US), David Mocko (NASA, US), Fei Chen (HKUST, China), Myung-Seo Koo (KIAPS, Korea), Prasanth Valayamkunnath (IISER TVM, India), Xuemei Wang (Jinan Univ, China), Gonzalo Miguez-Macho (USC, Spain)

Noah-MP key inputs

Important input to Noah-MP: land-cover and land-use types



MODIS global 1-km 20-category land-cover and land-use map

Users can also use USGS land type map

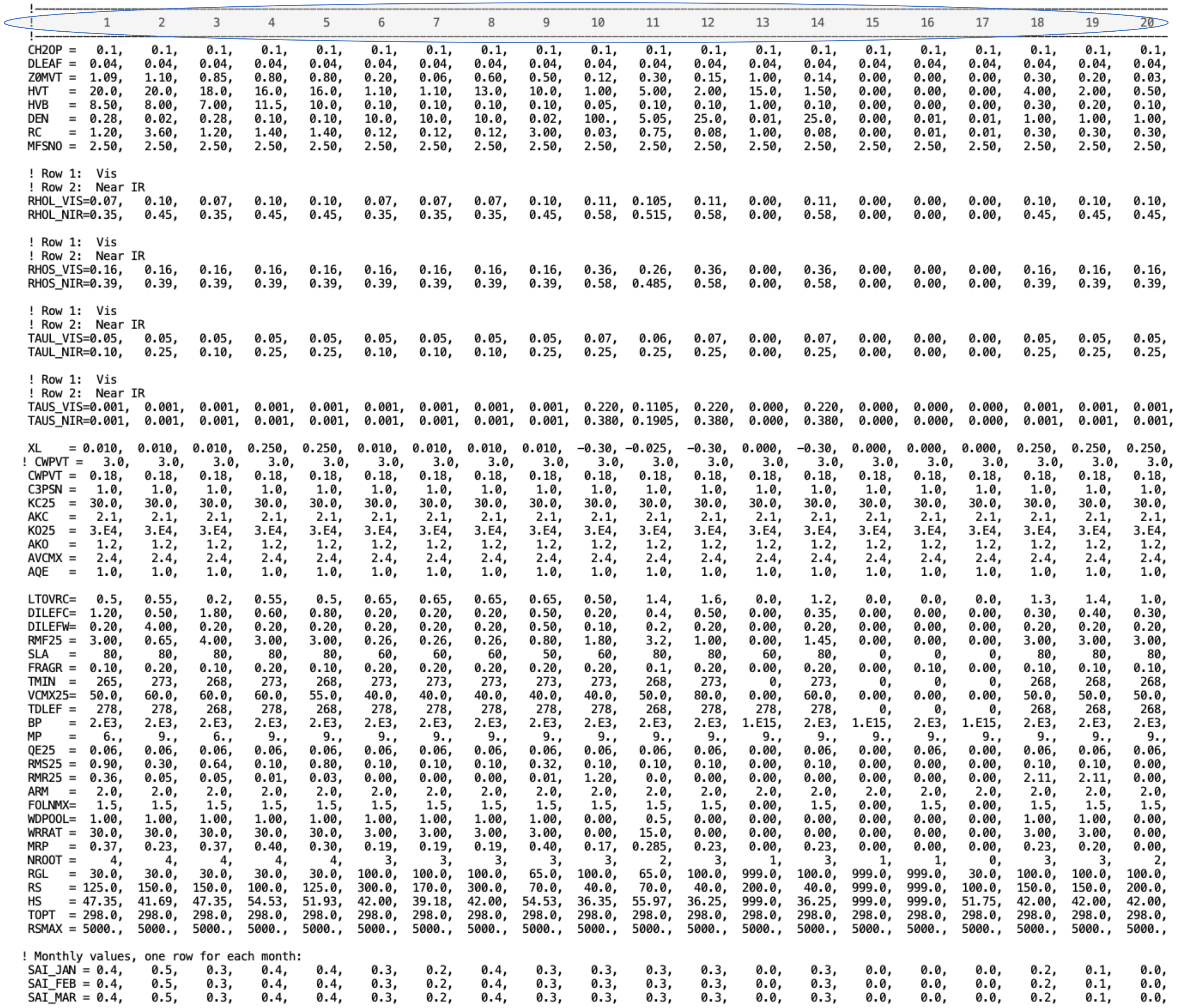
Courtesy of Fei Chen (NCAR)

LULC categories

Vegetation parameters used in Noah-MP Physics

NoahmpTable.TBL

~50 parameters associated with vegetation properties



```
!-------------------------------------------------------------------------------------------------------------------------------------------------------------------------
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!-------------------------------------------------------------------------------------------------------------------------------------------------------------------------
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HVT   =  20.0,   20.0,   18.0,   16.0,   16.0,   1.10,   1.10,   13.0,   10.0,   1.00,   5.00,   2.00,   15.0,   1.50,   0.00,   0.00,   0.00,   4.00,   2.00,   0.50,
HVB   =  8.50,   8.00,   7.00,   11.5,   10.0,   0.10,   0.10,   0.10,   0.10,   0.05,   0.10,   0.10,   1.00,   0.10,   0.00,   0.00,   0.00,   0.30,   0.20,   0.10,
DEN   =  0.28,   0.02,   0.28,   0.10,   0.10,   10.0,   10.0,   10.0,   0.02,   100.,   5.05,   25.0,   0.01,   25.0,   0.00,   0.01,   0.01,   1.00,   1.00,   1.00,
RC    =  1.20,   3.60,   1.20,   1.40,   1.40,   0.12,   0.12,   0.12,   3.00,   0.03,   0.75,   0.08,   1.00,   0.08,   0.00,   0.01,   0.01,   0.30,   0.30,   0.30,
MFSNO =  2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,

! Row 1:  Vis
! Row 2:  Near IR
RHOL_VIS=0.07,   0.10,   0.07,   0.10,   0.10,   0.07,   0.07,   0.07,   0.10,   0.11,  0.105,   0.11,   0.00,   0.11,   0.00,   0.00,   0.00,   0.10,   0.10,   0.10,
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! Row 1:  Vis
! Row 2:  Near IR
RHOS_VIS=0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.36,   0.26,   0.36,   0.00,   0.36,   0.00,   0.00,   0.00,   0.16,   0.16,   0.16,
RHOS_NIR=0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.58,  0.485,   0.58,   0.00,   0.58,   0.00,   0.00,   0.00,   0.39,   0.39,   0.39,

! Row 1:  Vis
! Row 2:  Near IR
TAUL_VIS=0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.07,   0.06,   0.07,   0.00,   0.07,   0.00,   0.00,   0.00,   0.05,   0.05,   0.05,
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! Row 1:  Vis
! Row 2:  Near IR
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XL    = 0.010,  0.010,  0.010,  0.250,  0.250,  0.010,  0.010,  0.010,  0.010,  -0.30, -0.025,  -0.30,  0.000,  -0.30,  0.000,  0.000,  0.000,  0.250,  0.250,  0.250,
! CWPVT =   3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,
CWPVT =  0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,
C3PSN =   1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,
KC25  =  30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,
AKC   =   2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,
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LTOVRC=   0.5,   0.55,    0.2,   0.55,    0.5,   0.65,   0.65,   0.65,   0.65,   0.50,    1.4,    1.6,    0.0,    1.2,    0.0,    0.0,    0.0,    1.3,    1.4,    1.0,
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BP    =  2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,  1.E15,   2.E3,  1.E15,   2.E3,  1.E15,   2.E3,   2.E3,   2.E3,
MP    =    6.,     9.,     6.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,
QE25  =  0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.00,   0.06,   0.00,   0.06,   0.00,   0.06,   0.06,   0.06,
RMS25 =  0.90,   0.30,   0.64,   0.10,   0.80,   0.10,   0.10,   0.10,   0.32,   0.10,   0.10,   0.10,   0.00,   0.10,   0.00,   0.00,   0.00,   0.10,   0.10,   0.00,
RMR25 =  0.36,   0.05,   0.05,   0.01,   0.03,   0.00,   0.00,   0.00,   0.01,   1.20,    0.0,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   2.11,   2.11,   0.00,
ARM   =   2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,
FOLNMX=   1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,   0.00,    1.5,   0.00,    1.5,   0.00,    1.5,    1.5,    1.5,
WDPOOL=  1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   0.00,    0.5,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   1.00,   1.00,   0.00,
WRRAT =  30.0,   30.0,   30.0,   30.0,   30.0,   3.00,   3.00,   3.00,   3.00,   0.00,   15.0,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   3.00,   3.00,   0.00,
MRP   =  0.37,   0.23,   0.37,   0.40,   0.30,   0.19,   0.19,   0.19,   0.40,   0.17,  0.285,   0.23,   0.00,   0.23,   0.00,   0.00,   0.00,   0.23,   0.20,   0.00,
NROOT =     4,      4,      4,      4,      4,      3,      3,      3,      3,      3,      2,      3,      1,      3,      1,      1,      0,      3,      3,      2,
RGL   =  30.0,   30.0,   30.0,   30.0,   30.0,  100.0,  100.0,  100.0,   65.0,  100.0,   65.0,  100.0,  999.0,  100.0,  999.0,  999.0,   30.0,  100.0,  100.0,  100.0,
RS    = 125.0,  150.0,  150.0,  100.0,  125.0,  300.0,  170.0,  300.0,   70.0,   40.0,   70.0,   40.0,  200.0,   40.0,  999.0,  999.0,  100.0,  150.0,  150.0,  200.0,
HS    = 47.35,  41.69,  47.35,  54.53,  51.93,  42.00,  39.18,  42.00,  54.53,  36.35,  55.97,  36.25,  999.0,  36.25,  999.0,  999.0,  51.75,  42.00,  42.00,  42.00,
TOPT  = 298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,  298.0,
RSMAX = 5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,  5000.,

! Monthly values, one row for each month:
 SAI_JAN = 0.4,    0.5,    0.3,    0.4,    0.4,    0.3,    0.2,    0.4,    0.3,    0.3,    0.3,    0.3,    0.0,    0.3,    0.0,    0.0,    0.0,    0.2,    0.1,    0.0,
 SAI_FEB = 0.4,    0.5,    0.3,    0.4,    0.4,    0.3,    0.2,    0.4,    0.3,    0.3,    0.3,    0.3,    0.0,    0.3,    0.0,    0.0,    0.0,    0.2,    0.1,    0.0,
 SAI_MAR = 0.4,    0.5,    0.3,    0.4,    0.4,    0.3,    0.2,    0.4,    0.3,    0.3,    0.3,    0.3,    0.0,    0.3,    0.0,    0.0,    0.0,    0.2,    0.1,    0.0,
```
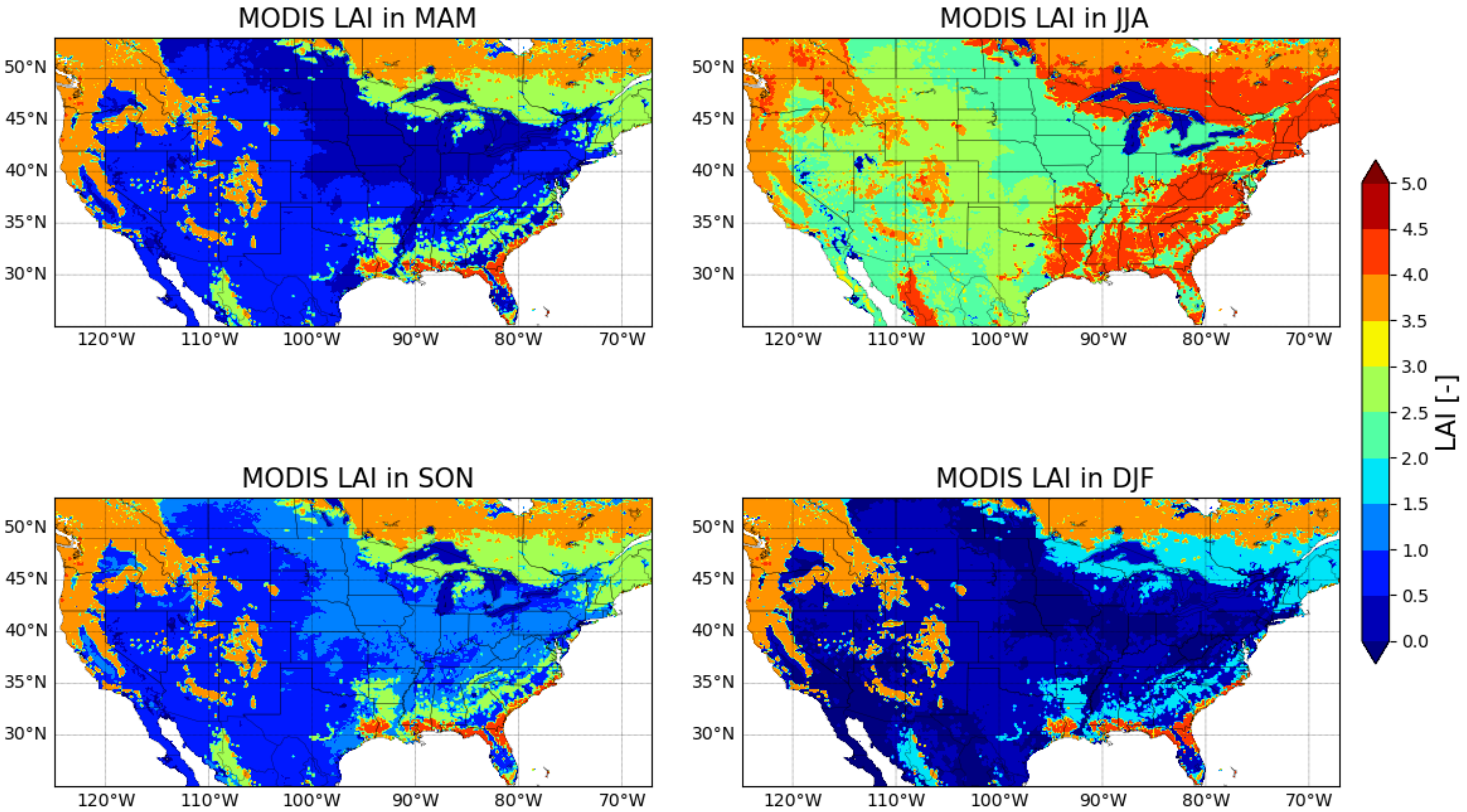

Courtesy of Fei Chen (NCAR)

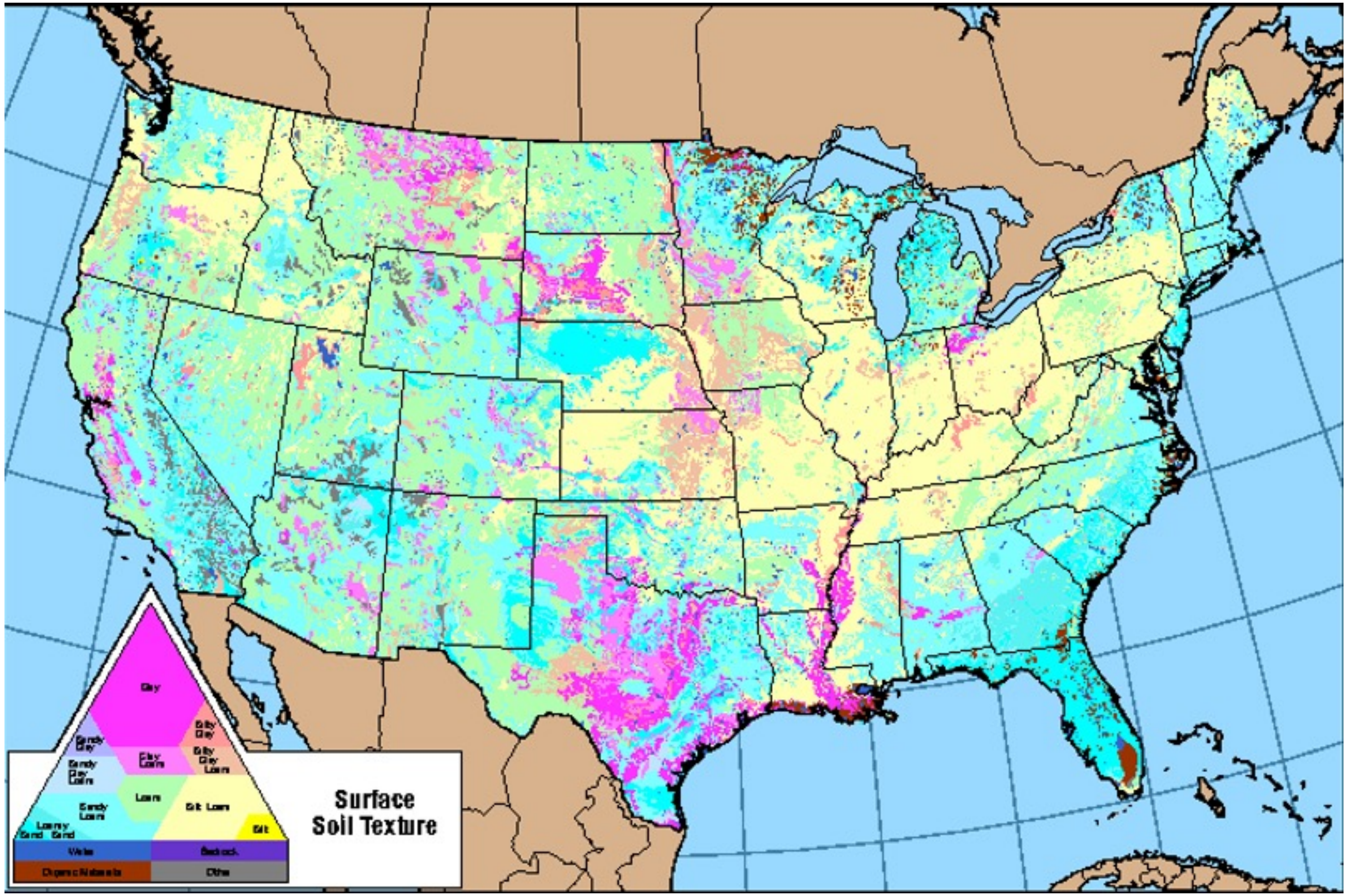
Important input to Noah-MP: Leaf Area Index (LAI) seasonality



MODIS 1-km monthly leaf area index (10-year climatology)

Courtesy of Fei Chen (NCAR)

Important input to Noah-MP: soil texture



STASGO 1-km Soil Texture Map

Courtesy of Fei Chen (NCAR)

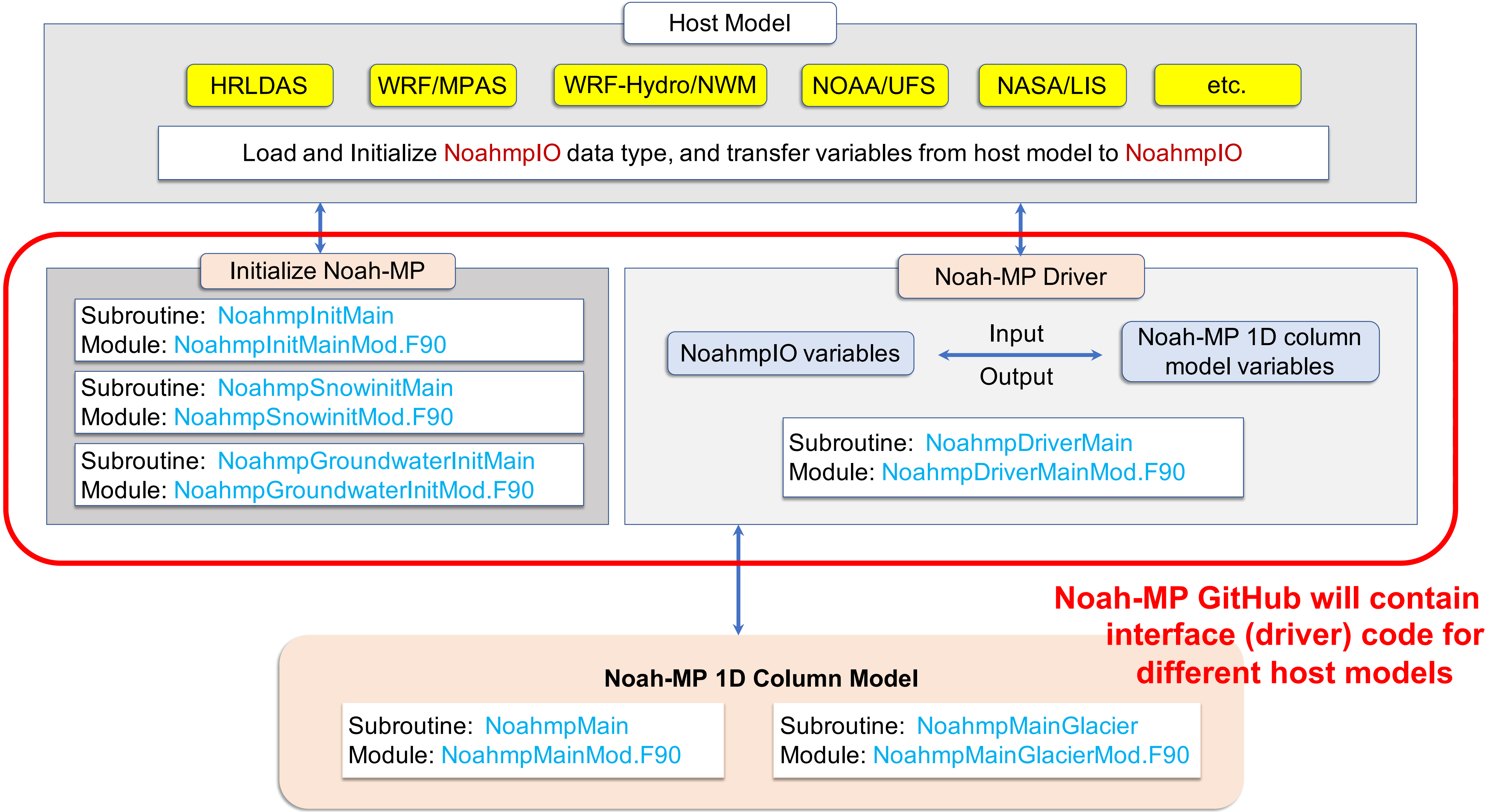
Noah-MP Soil Parameters (NoahmpTable.TBL)

Category Type	Class	BB	DRYSMC	F11	MAXSMC	REFSMC	SATPSI	SATDK	SATDW	WLTSMC	QTZ
Sand	1	2.79	0.010	-0.472	0.339	0.236	0.069	1.07E-6	0.608E-6	0.010	0.92
Loamy Sand	2	4.26	0.028	-1.044	0.421	0.383	0.036	1.41E-5	0.514E-5	0.028	0.82
Sandy Loam	3	4.74	0.047	-0.569	0.434	0.383	0.141	5.23E-6	0.805E-5	0.047	0.60
Silt Loam	4	5.33	0.084	0.162	0.476	0.360	0.759	2.81E-6	0.239E-4	0.084	0.25
Silt	5	5.33	0.084	0.162	0.476	0.383	0.759	2.81E-6	0.239E-4	0.084	0.10
Loam	6	5.25	0.066	-0.327	0.439	0.329	0.355	3.38E-6	0.143E-4	0.066	0.40
Sandy Clay Loam	7	6.66	0.067	-1.491	0.404	0.314	0.135	4.45E-6	0.990E-5	0.067	0.60
Silty Clay Loam	8	8.72	0.120	-1.118	0.464	0.387	0.617	2.04E-6	0.237E-4	0.120	0.10
Clay Loam	9	8.17	0.103	-1.297	0.465	0.382	0.263	2.45E-6	0.113E-4	0.103	0.35
Sandy Clay	10	10.73	0.100	-3.209	0.406	0.338	0.098	7.22E-6	0.187E-4	0.100	0.52
Silty Clay	11	10.39	0.126	-1.916	0.468	0.404	0.324	1.34E-6	0.964E-5	0.126	0.10
Clay	12	11.55	0.138	-2.138	0.468	0.412	0.468	9.74E-7	0.112E-4	0.138	0.25
Organic Material	13	5.25	0.066	-0.327	0.439	0.329	0.355	3.38E-6	0.143E-4	0.066	0.05
Bedrock	15	2.79	0.006	-1.111	0.20	0.17	0.069	1.41E-4	0.136E-3	0.006	0.07
Land ice	16	4.26	0.028	-1.044	0.421	0.283	0.036	1.41E-5	0.514E-5	0.028	0.25

Courtesy of Fei Chen (NCAR)

Noah-MP coupling structure with host models

Noah-MP coupling with host/parent models



Host Model

HRLDAS

WRF/MPAS

WRF-Hydro/NWM

NOAA/UFS

NASA/LIS

etc.

Load and Initialize NoahmpIO data type, and transfer variables from host model to NoahmpIO

Initialize Noah-MP

Subroutine: NoahmpInitMain
Module: NoahmpInitMainMod.F90

Subroutine: NoahmpSnowinitMain
Module: NoahmpSnowinitMod.F90

Subroutine: NoahmpGroundwaterInitMain
Module: NoahmpGroundwaterInitMod.F90

Noah-MP Driver

NoahmpIO variables

Input

Output

Noah-MP 1D column model variables

Subroutine: NoahmpDriverMain
Module: NoahmpDriverMainMod.F90

Noah-MP 1D Column Model

Subroutine: NoahmpMain
Module: NoahmpMainMod.F90

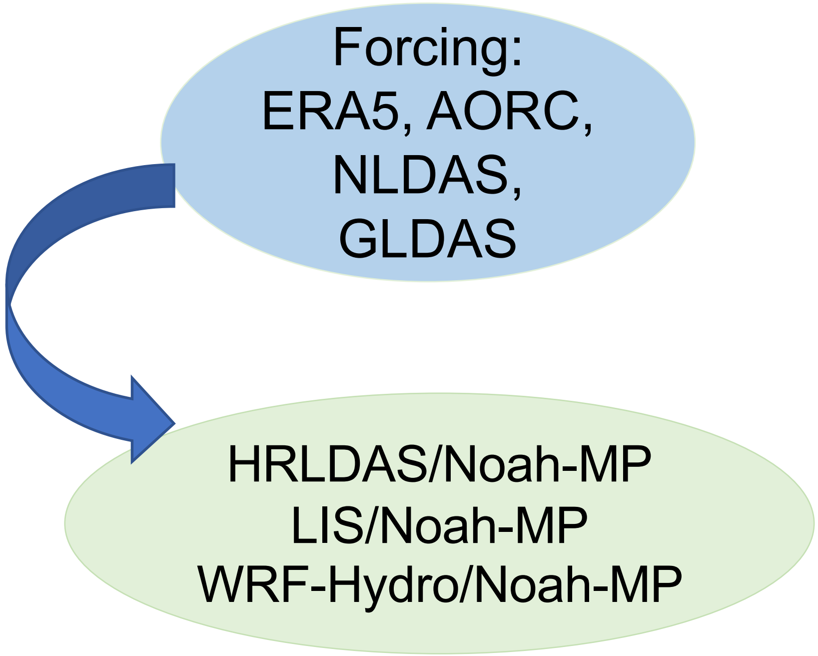
Subroutine: NoahmpMainGlacier
Module: NoahmpMainGlacierMod.F90

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

He et al., 2023 GMD

Typical applications of Noah-MP

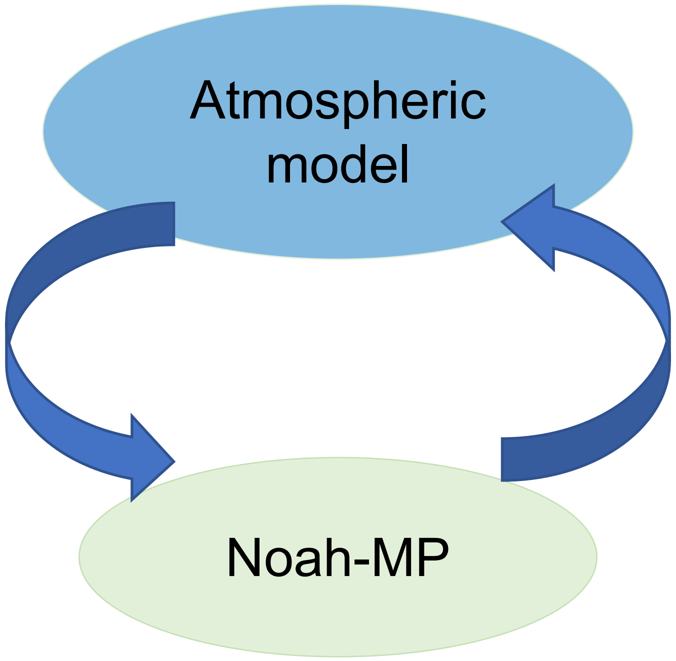
uncoupled standard-alone runs (single point or 2-D)



Forcing:
ERA5, AORC,
NLDAS,
GLDAS

HRLDAS/Noah-MP
LIS/Noah-MP
WRF-Hydro/Noah-MP

Coupled with atmospheric models (WRF, UFS, etc)



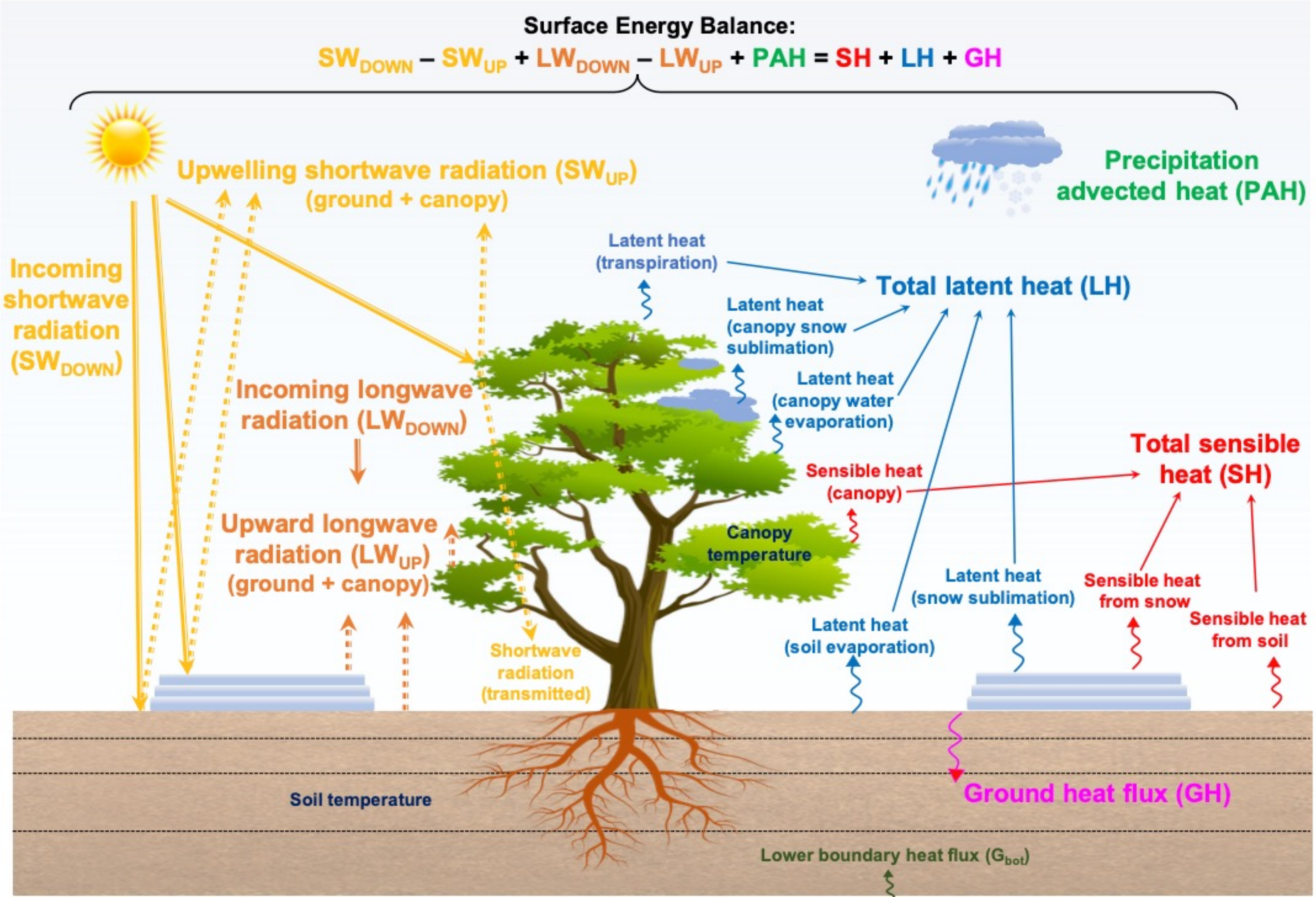
Atmospheric model

Noah-MP

Courtesy of Fei Chen (NCAR)

Noah-MP key processes and treatments

Noah-MP Energy Processes



Surface Energy Balance:

$$SW_{DOWN} - SW_{UP} + LW_{DOWN} - LW_{UP} + PAH = SH + LH + GH$$

Incoming shortwave radiation (SW_{DOWN})

Upwelling shortwave radiation (SW_{UP}) (ground + canopy)

Incoming longwave radiation (LW_{DOWN})

Upward longwave radiation (LW_{UP}) (ground + canopy)

Shortwave radiation (transmitted)

Precipitation advected heat (PAH)

Latent heat (transpiration)

Total latent heat (LH)

Latent heat (canopy snow sublimation)

Latent heat (canopy water evaporation)

Sensible heat (canopy)

Total sensible heat (SH)

Canopy temperature

Latent heat (snow sublimation)

Sensible heat from snow

Sensible heat from soil

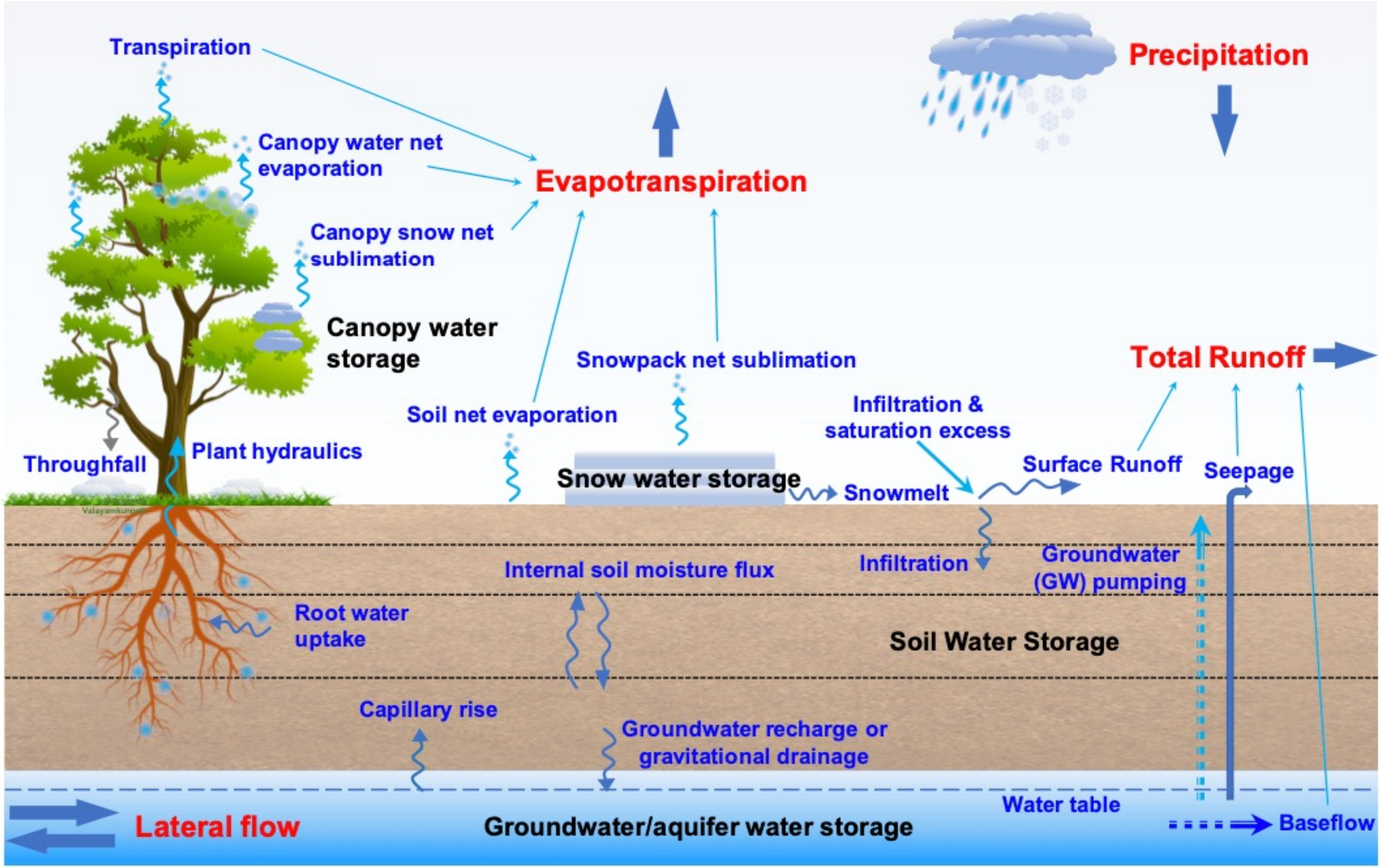
Latent heat (soil evaporation)

Soil temperature

Ground heat flux (GH)

Lower boundary heat flux (G_{bot})

Noah-MP Water Processes

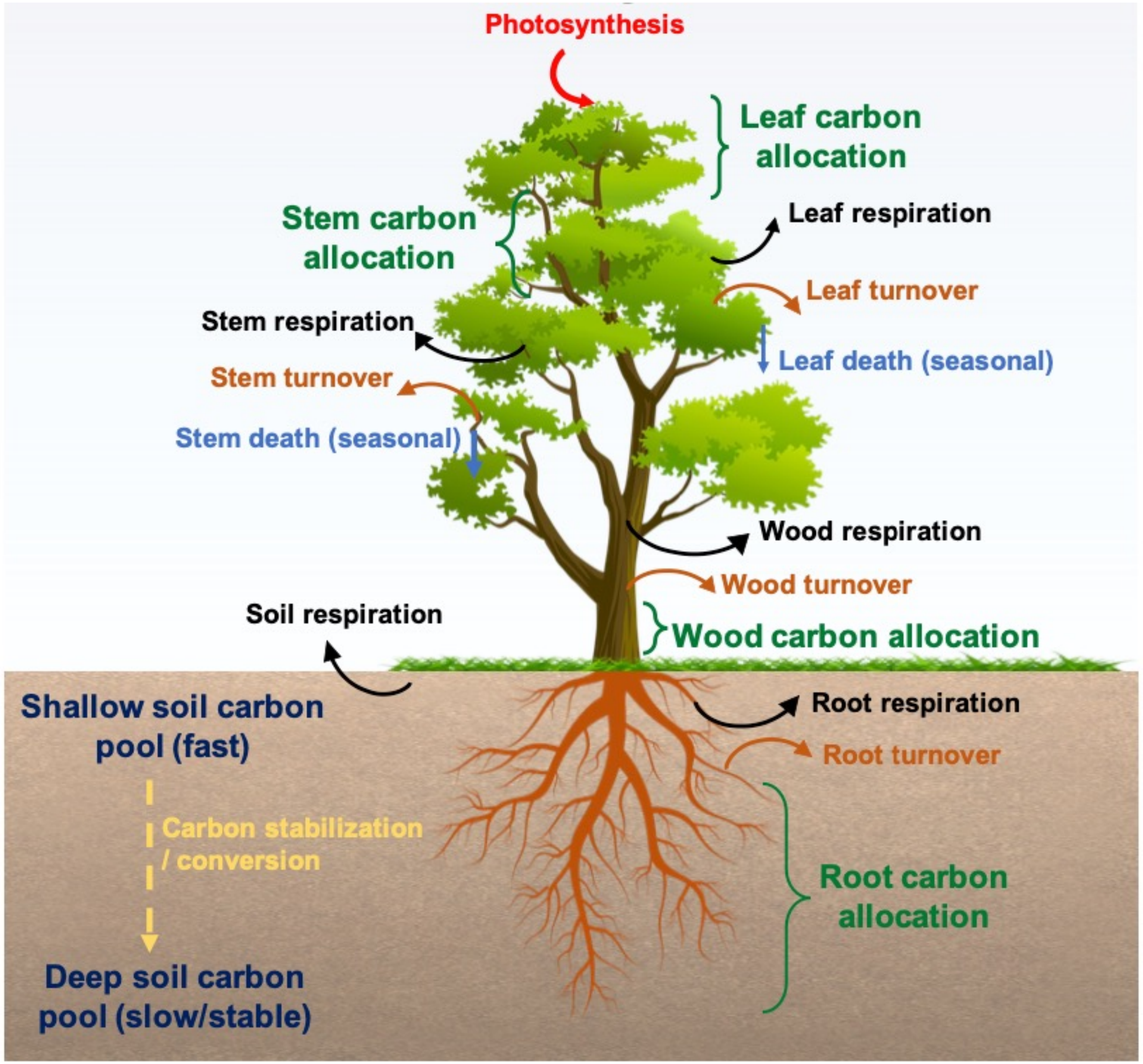


<u>Only when groundwater scheme is on</u>

Total water balance:

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

Noah-MP Carbon Processes

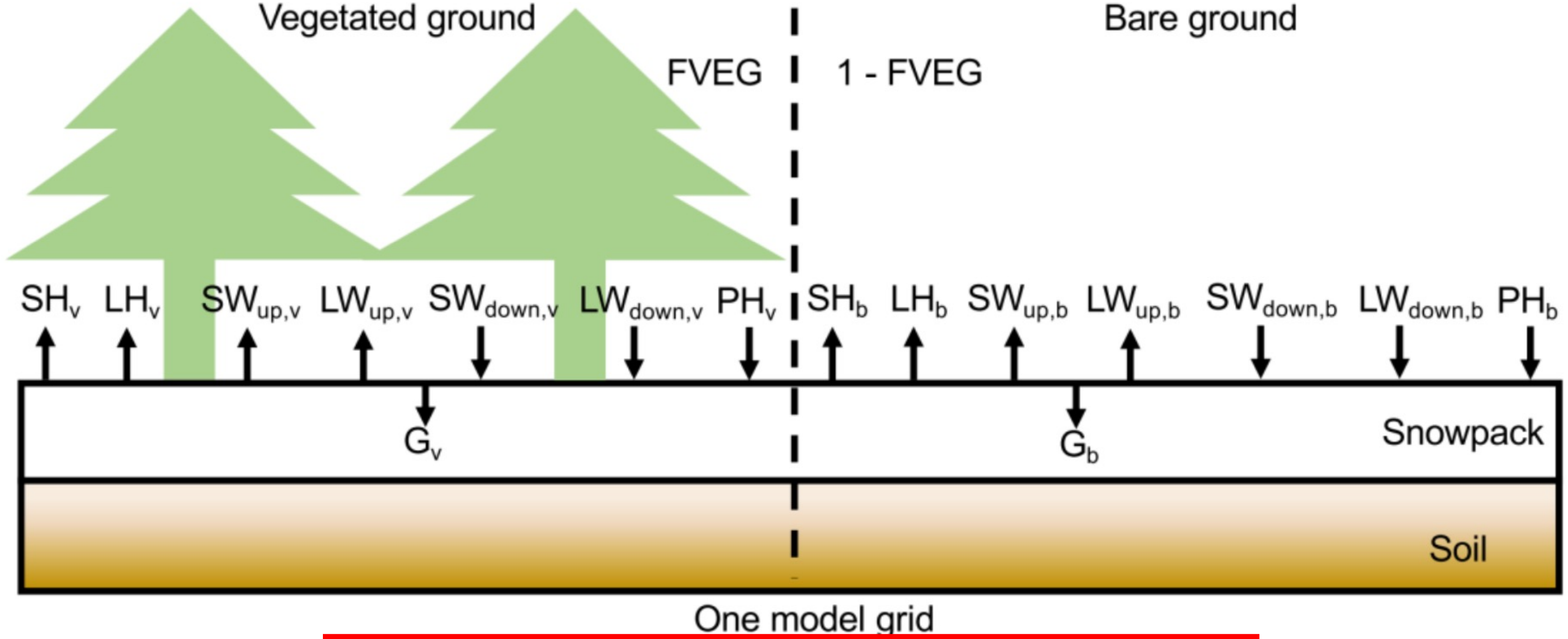


Total carbon balance:

Photosynthesis – Respiration = ΔPlant carbon pool + ΔSoil carbon pool

Only when prognostic vegetation scheme or crop model is on

Noah-MP Subgrid Treatment for Energy



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

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

Radiative transfer

Turbulent transfer

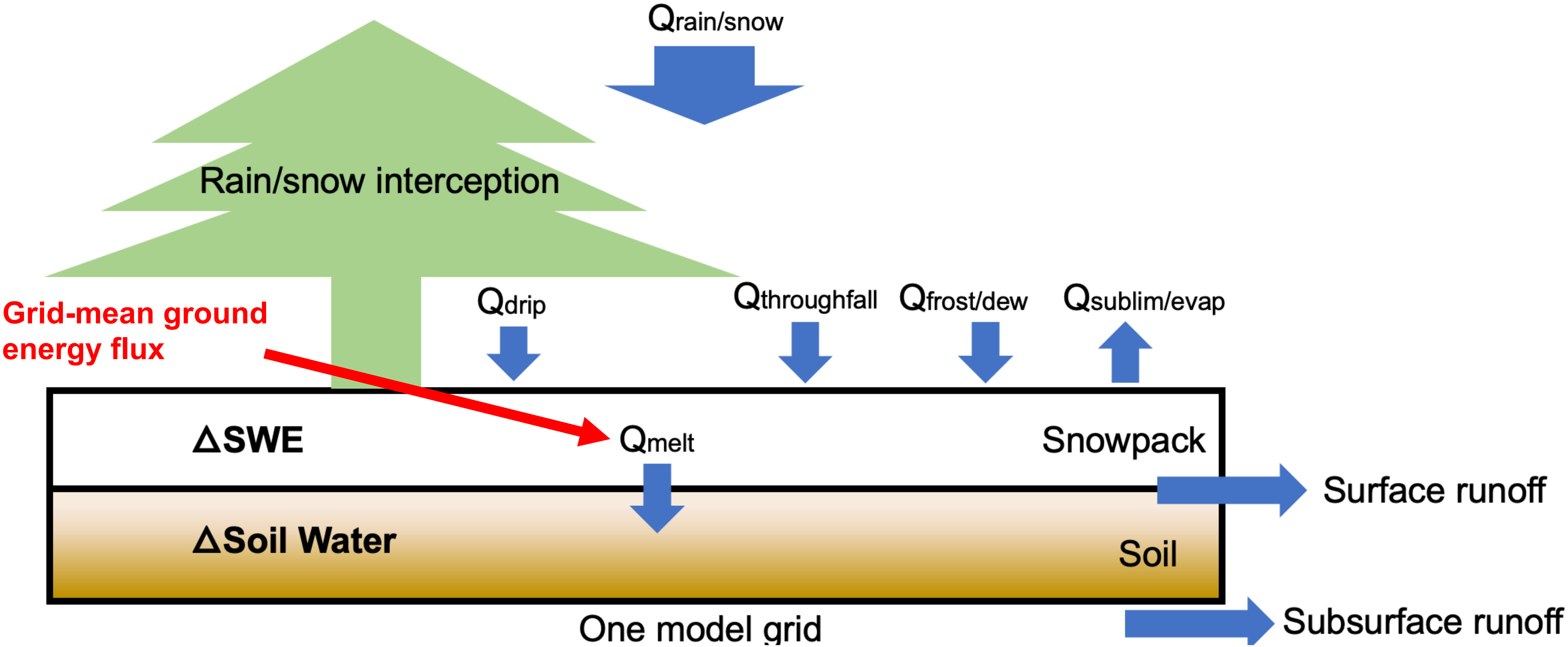
Ground snow cover: a function of snow depth; no subgrid treatment.

Ground albedo: weighted average of snow and soil albedo

$$M_{grd,grid} = f_{veg} \times M_{veg,grd} + (1 - f_{veg}) \times M_{bare,grd}$$

He et al., 2021 JGR; He et al., 2023 GMD

Noah-MP Subgrid Treatment for Water



He et al., 2021 JGR; He et al., 2023 GMD

Noah-MP current modeling capabilities

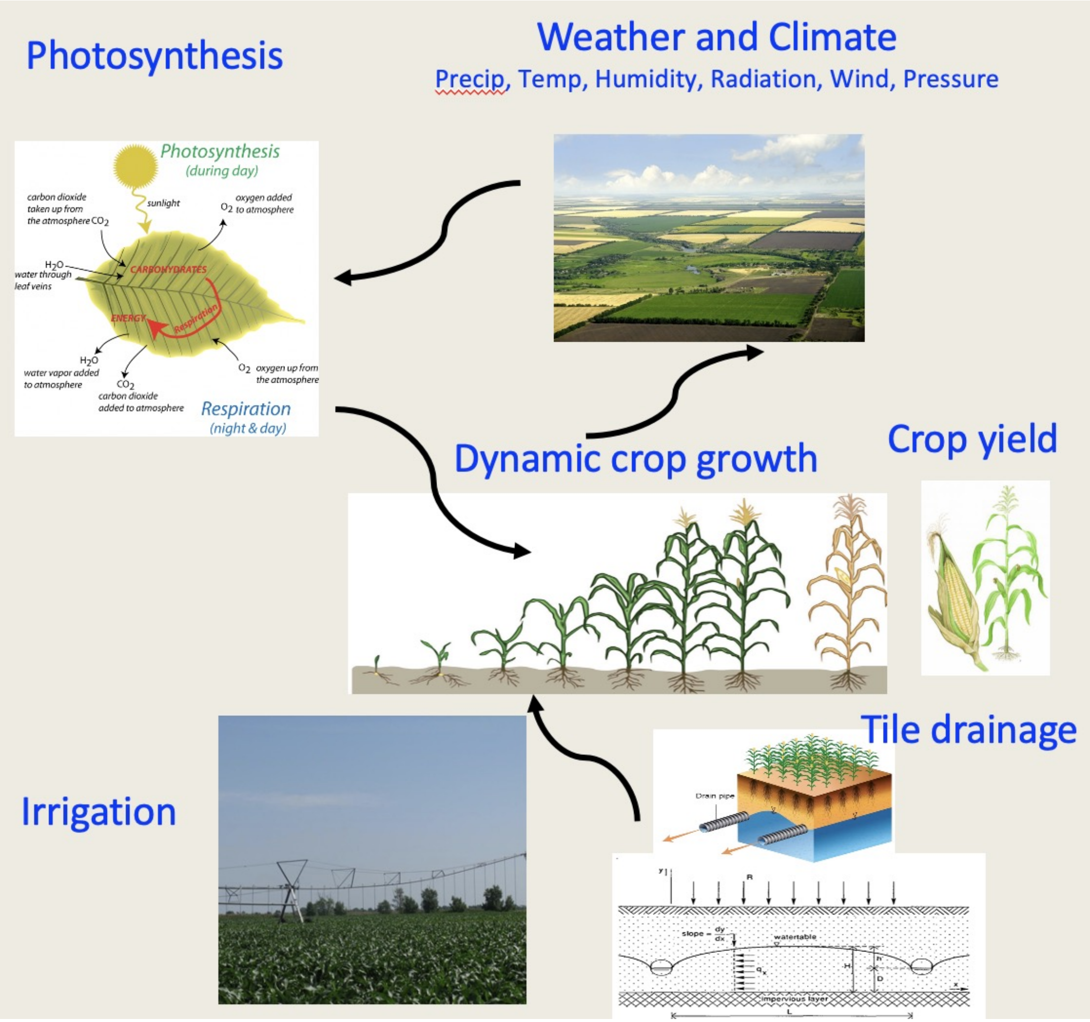
Current community Noah-MP capabilities

- **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, soil hydraulics, 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
- **Dynamic vegetation and crop growth**: key carbon processes
- **Tile drainage** schemes
- **Dynamic irrigation** processes
- Bulk urban treatment and coupling with external **urban canopy model**

Highlights: modeling anthropogenic processes (urban and agriculture)!

Noah-MP-Agriculture coupled modeling capabilities

Integrated Noah-MP-Crop model



Photosynthesis

Weather and Climate

Precip, Temp, Humidity, Radiation, Wind, Pressure

Dynamic crop growth

Crop yield

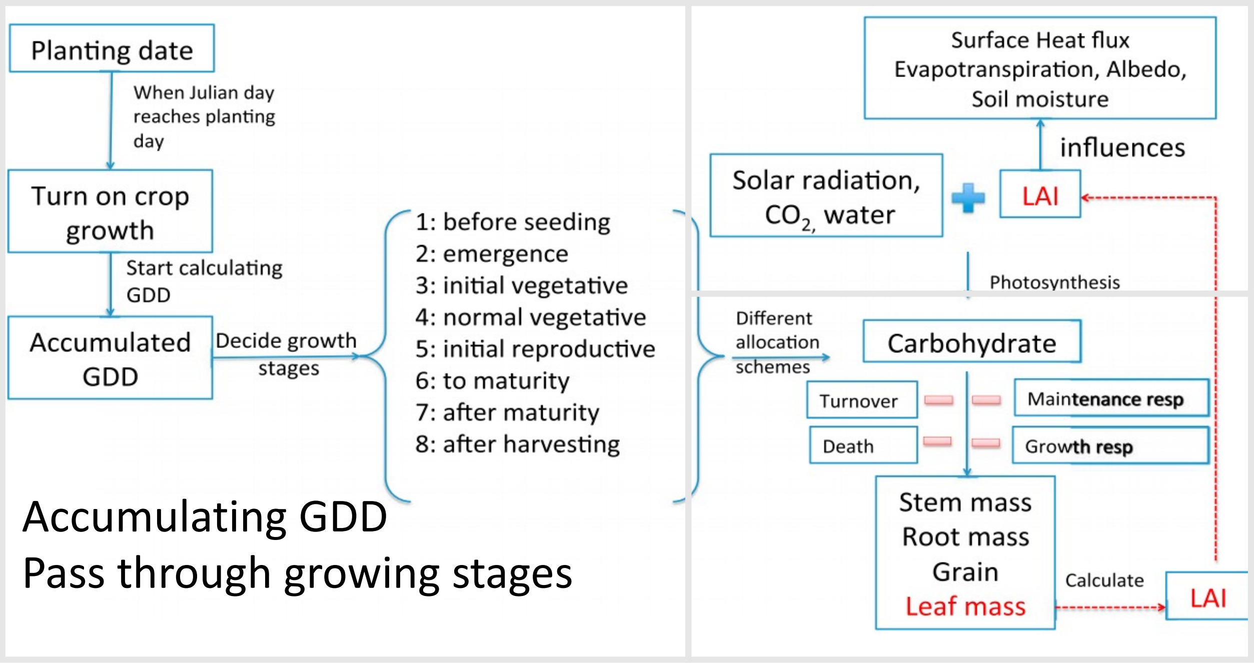
Tile drainage

Irrigation

Liu et al., 2016; Zhang et al., 2022

Climate forcing

Photosynthesis
Stomatal



Planting date

When Julian day reaches planting day

Turn on crop growth

Start calculating GDD

Accumulated GDD

Decide growth stages

1: before seeding
2: emergence
3: initial vegetative
4: normal vegetative
5: initial reproductive
6: to maturity
7: after maturity
8: after harvesting

Accumulating GDD
Pass through growing stages

Surface Heat flux
Evapotranspiration, Albedo,
Soil moisture

influences

Solar radiation, CO_2, water ✚ LAI

Photosynthesis

Different allocation schemes

Carbohydrate

Turnover

Death

Maintenance resp

Growth resp

Stem mass
Root mass
Grain
Leaf mass

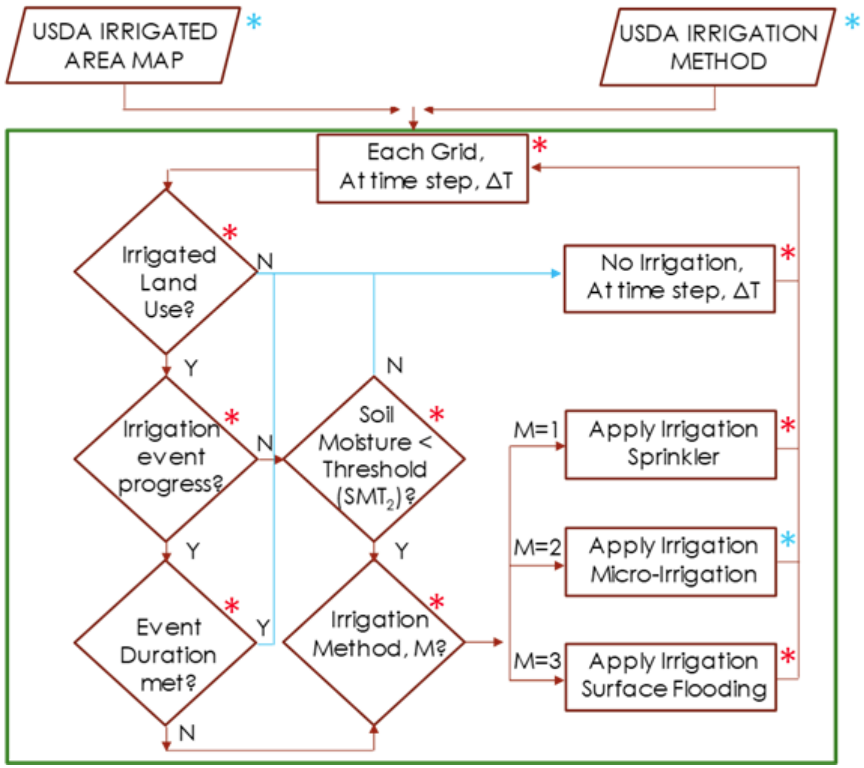
Calculate

LAI

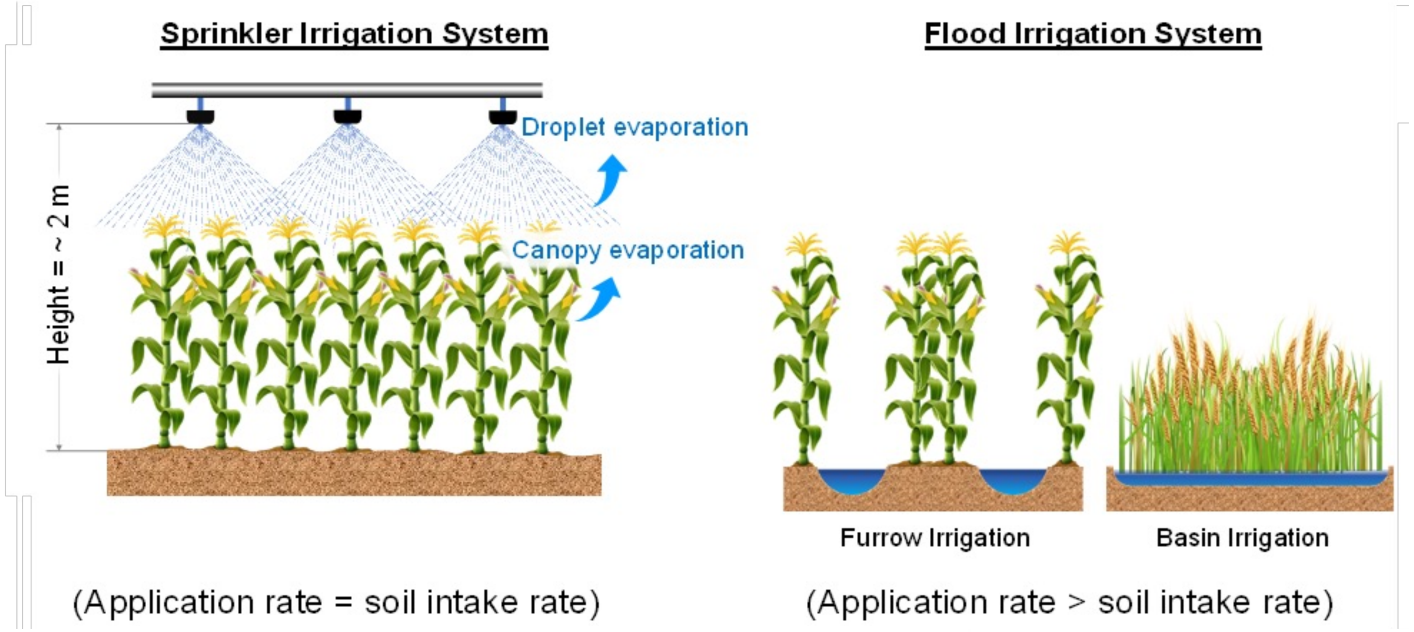
Biomass partitioning

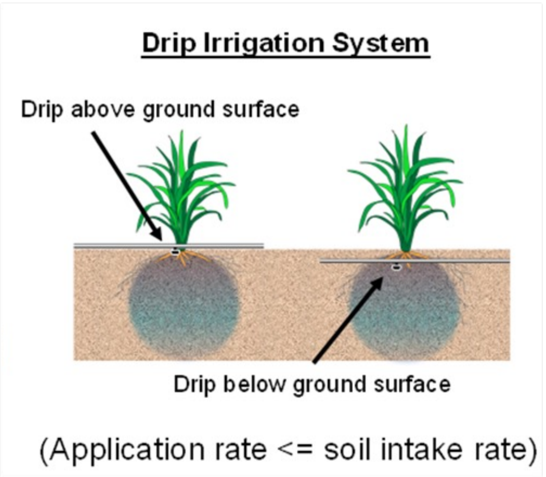
Noah-MP-Agriculture coupled modeling capabilities

Noah-MP Dynamic Irrigation Scheme



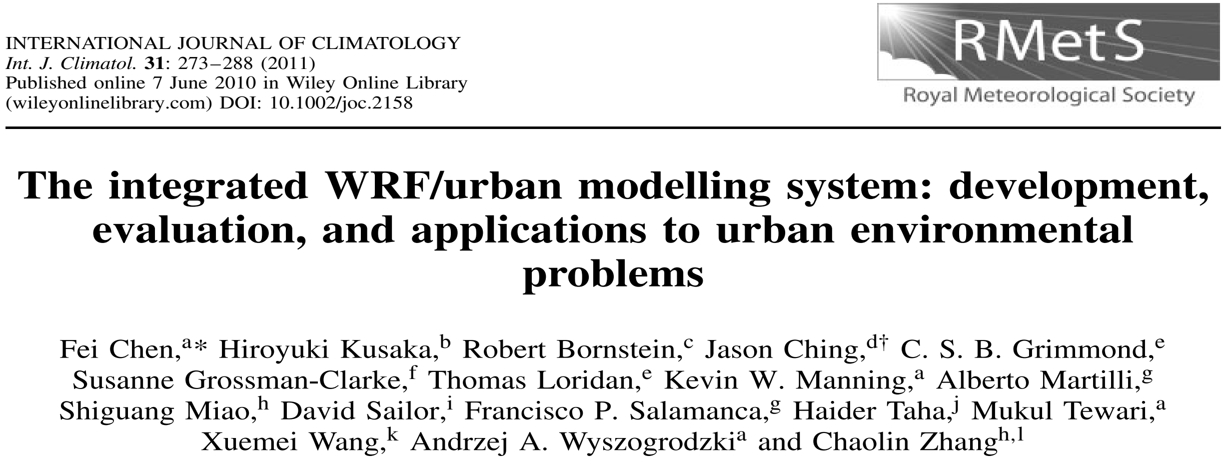
1) where to irrigate?
2) when to irrigate?
3) what amount of water to irrigate? and
4) how to irrigate?





Three irrigation methods have different effects on surface energy & water balance

Noah-MP-Urban coupled modeling capabilities



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RMetS
Royal Meteorological Society

The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems

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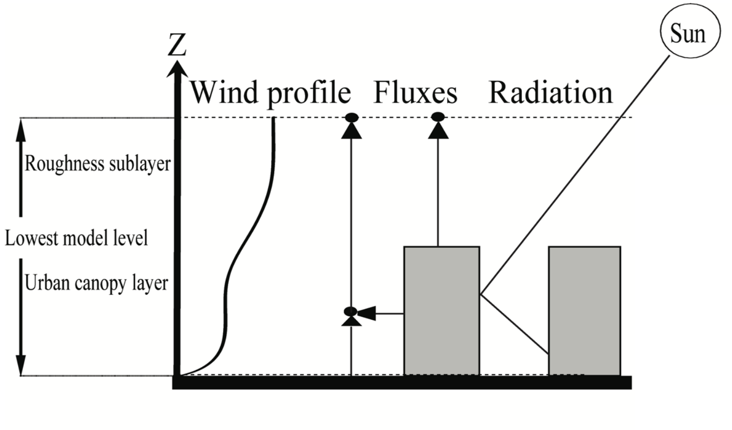
We can run urban models with Noah-MP both offline (in HRLDAS) and online (in WRF) !

urban physics option = 1

Single-layer urban canopy model (SLUCM)



SLUCM

Kusaka et al. 2001

urban physics option = 2

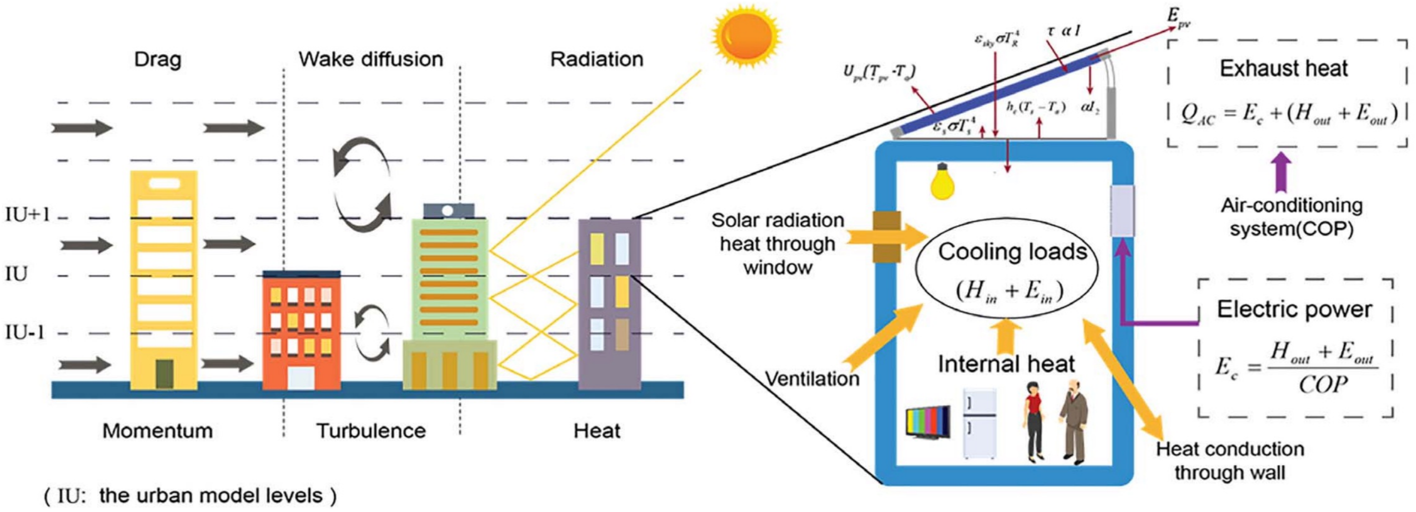
Multi-layer UCM

urban physics option = 3

Multi-layer UCM with building energy

Building Effect Parameterization(BEP)

Building Energy Model(BEM)



Martilli et al. 2002; Salamanca and Martilli 2010

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

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

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

(7) coupling with a snow radiative transfer (SNICAR) model (Tzu-Shun Lin et al., in prep);

(8) 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);

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

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

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

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

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

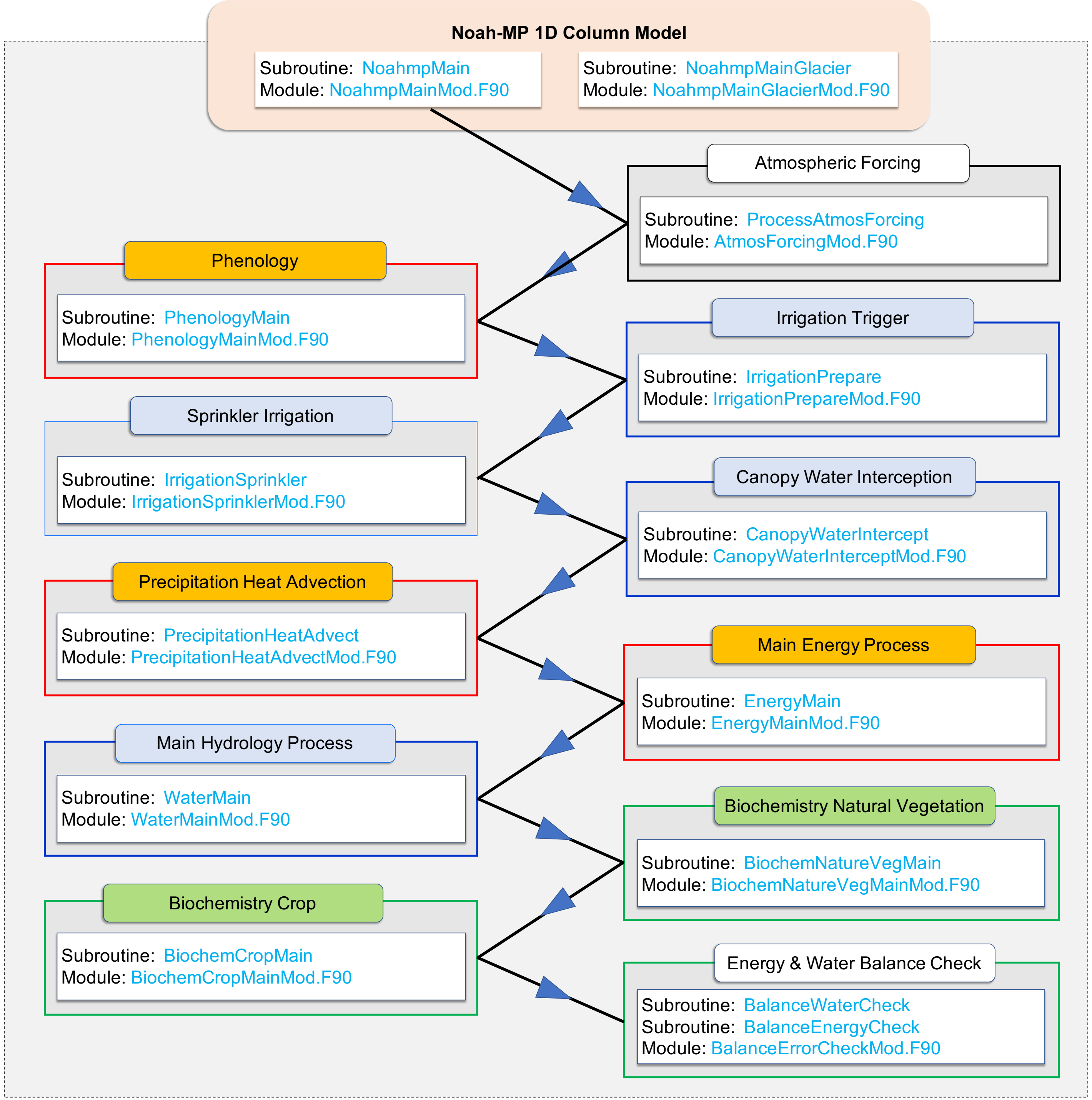
(14) a 1-D dual-permeability flow model (based on the mixed-form Richards' equation) representing preferential flow through variably-saturated soil with surface ponding (University of Arizona).

Noah-MP model structure and process workflow

Noah-MP 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 1D Column Model

Subroutine: NoahmpMain
Module: NoahmpMainMod.F90

Subroutine: NoahmpMainGlacier
Module: NoahmpMainGlacierMod.F90

Atmospheric Forcing

Subroutine: ProcessAtmosForcing
Module: AtmosForcingMod.F90

Phenology

Subroutine: PhenologyMain
Module: PhenologyMainMod.F90

Irrigation Trigger

Subroutine: IrrigationPrepare
Module: IrrigationPrepareMod.F90

Sprinkler Irrigation

Subroutine: IrrigationSprinkler
Module: IrrigationSprinklerMod.F90

Canopy Water Interception

Subroutine: CanopyWaterIntercept
Module: CanopyWaterInterceptMod.F90

Precipitation Heat Advection

Subroutine: PrecipitationHeatAdvect
Module: PrecipitationHeatAdvectMod.F90

Main Energy Process

Subroutine: EnergyMain
Module: EnergyMainMod.F90

Main Hydrology Process

Subroutine: WaterMain
Module: WaterMainMod.F90

Biochemistry Natural Vegetation

Subroutine: BiochemNatureVegMain
Module: BiochemNatureVegMainMod.F90

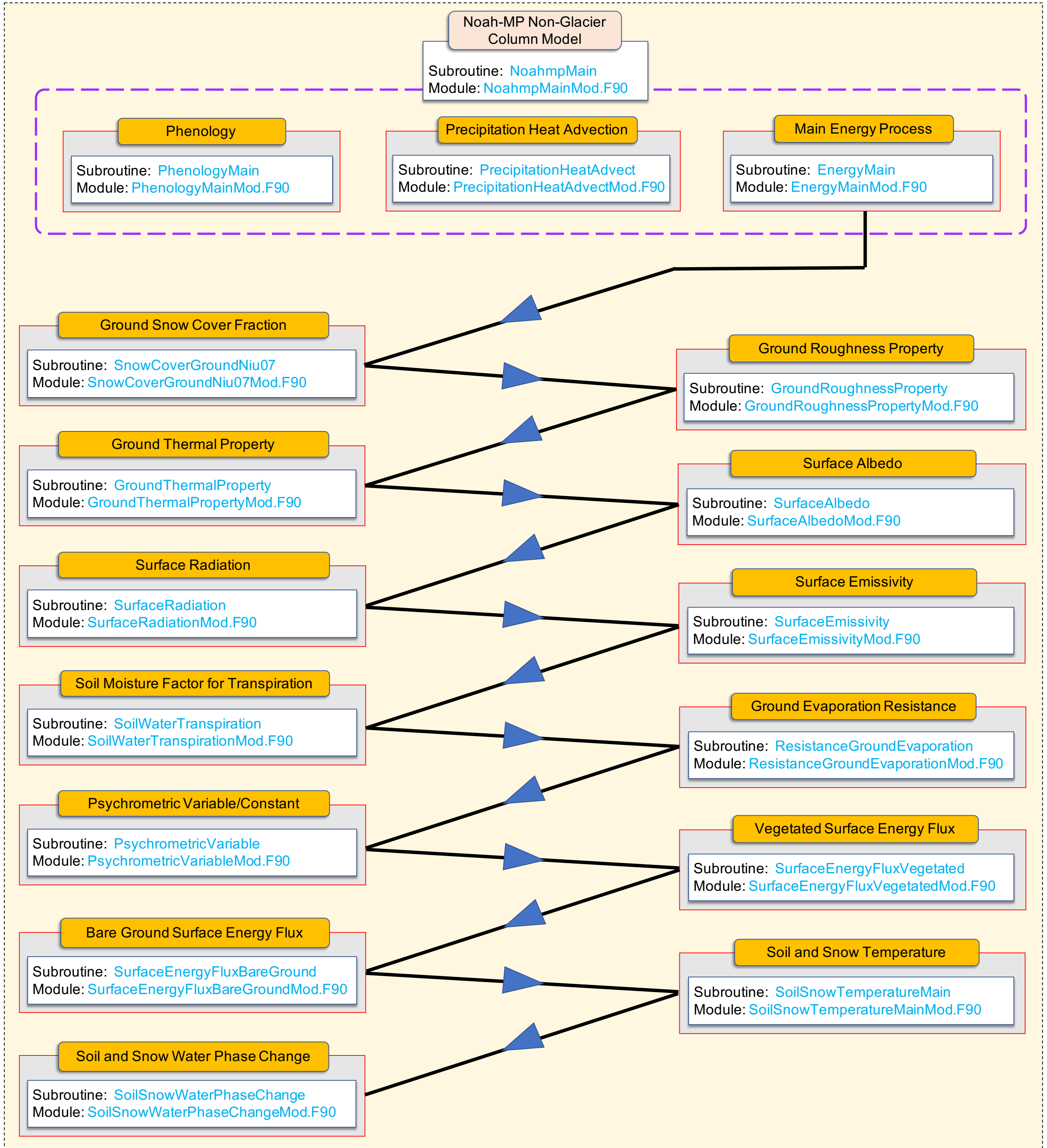
Biochemistry Crop

Subroutine: BiochemCropMain
Module: BiochemCropMainMod.F90

Energy & Water Balance Check

Subroutine: BalanceWaterCheck
Subroutine: BalanceEnergyCheck
Module: BalanceErrorCheckMod.F90

Noah-MP Energy process calling tree



Noah-MP Non-Glacier Column Model
Subroutine: NoahmpMain
Module: NoahmpMainMod.F90

Phenology
Subroutine: PhenologyMain
Module: PhenologyMainMod.F90

Precipitation Heat Advection
Subroutine: PrecipitationHeatAdvect
Module: PrecipitationHeatAdvectMod.F90

Main Energy Process
Subroutine: EnergyMain
Module: EnergyMainMod.F90

Ground Snow Cover Fraction
Subroutine: SnowCoverGroundNiu07
Module: SnowCoverGroundNiu07Mod.F90

Ground Roughness Property
Subroutine: GroundRoughnessProperty
Module: GroundRoughnessPropertyMod.F90

Ground Thermal Property
Subroutine: GroundThermalProperty
Module: GroundThermalPropertyMod.F90

Surface Albedo
Subroutine: SurfaceAlbedo
Module: SurfaceAlbedoMod.F90

Surface Radiation
Subroutine: SurfaceRadiation
Module: SurfaceRadiationMod.F90

Surface Emissivity
Subroutine: SurfaceEmissivity
Module: SurfaceEmissivityMod.F90

Soil Moisture Factor for Transpiration
Subroutine: SoilWaterTranspiration
Module: SoilWaterTranspirationMod.F90

Ground Evaporation Resistance
Subroutine: ResistanceGroundEvaporation
Module: ResistanceGroundEvaporationMod.F90

Psychrometric Variable/Constant
Subroutine: PsychrometricVariable
Module: PsychrometricVariableMod.F90

Vegetated Surface Energy Flux
Subroutine: SurfaceEnergyFluxVegetated
Module: SurfaceEnergyFluxVegetatedMod.F90

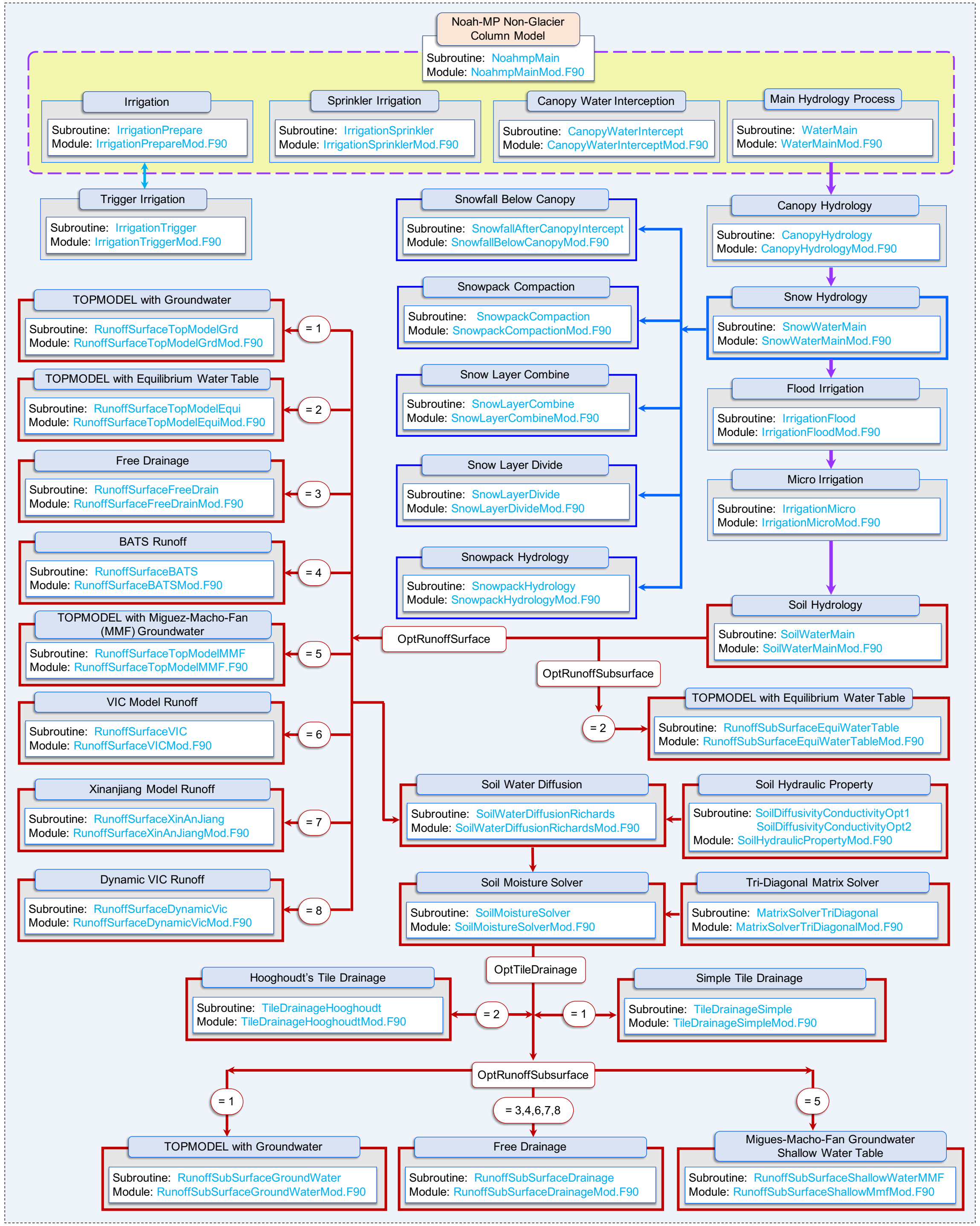
Bare Ground Surface Energy Flux
Subroutine: SurfaceEnergyFluxBareGround
Module: SurfaceEnergyFluxBareGroundMod.F90

Soil and Snow Temperature
Subroutine: SoilSnowTemperatureMain
Module: SoilSnowTemperatureMainMod.F90

Soil and Snow Water Phase Change
Subroutine: SoilSnowWaterPhaseChange
Module: SoilSnowWaterPhaseChangeMod.F90

He et al., 2023 GMD

Noah-MP Water process calling tree



Noah-MP Non-Glacier Column Model
Subroutine: NoahmpMain
Module: NoahmpMainMod.F90

Irrigation
Subroutine: IrrigationPrepare
Module: IrrigationPrepareMod.F90

Sprinkler Irrigation
Subroutine: IrrigationSprinkler
Module: IrrigationSprinklerMod.F90

Canopy Water Interception
Subroutine: CanopyWaterIntercept
Module: CanopyWaterInterceptMod.F90

Main Hydrology Process
Subroutine: WaterMain
Module: WaterMainMod.F90

Trigger Irrigation
Subroutine: IrrigationTrigger
Module: IrrigationTriggerMod.F90

Snowfall Below Canopy
Subroutine: SnowfallAfterCanopyIntercept
Module: SnowfallBelowCanopyMod.F90

Canopy Hydrology
Subroutine: CanopyHydrology
Module: CanopyHydrologyMod.F90

Snowpack Compaction
Subroutine: SnowpackCompaction
Module: SnowpackCompactionMod.F90

Snow Hydrology
Subroutine: SnowWaterMain
Module: SnowWaterMainMod.F90

Snow Layer Combine
Subroutine: SnowLayerCombine
Module: SnowLayerCombineMod.F90

Flood Irrigation
Subroutine: IrrigationFlood
Module: IrrigationFloodMod.F90

Snow Layer Divide
Subroutine: SnowLayerDivide
Module: SnowLayerDivideMod.F90

Micro Irrigation
Subroutine: IrrigationMicro
Module: IrrigationMicroMod.F90

Snowpack Hydrology
Subroutine: SnowpackHydrology
Module: SnowpackHydrologyMod.F90

Soil Hydrology
Subroutine: SoilWaterMain
Module: SoilWaterMainMod.F90

OptRunoffSurface

= 1
TOPMODEL with Groundwater
Subroutine: RunoffSurfaceTopModelGrd
Module: RunoffSurfaceTopModelGrdMod.F90

= 2
TOPMODEL with Equilibrium Water Table
Subroutine: RunoffSurfaceTopModelEqui
Module: RunoffSurfaceTopModelEquiMod.F90

= 3
Free Drainage
Subroutine: RunoffSurfaceFreeDrain
Module: RunoffSurfaceFreeDrainMod.F90

= 4
BATS Runoff
Subroutine: RunoffSurfaceBATS
Module: RunoffSurfaceBATSMod.F90

= 5
TOPMODEL with Miguez-Macho-Fan (MMF) Groundwater
Subroutine: RunoffSurfaceTopModelMMF
Module: RunoffSurfaceTopModelMMF.F90

= 6
VIC Model Runoff
Subroutine: RunoffSurfaceVIC
Module: RunoffSurfaceVICMod.F90

= 7
Xinanjiang Model Runoff
Subroutine: RunoffSurfaceXinAnJiang
Module: RunoffSurfaceXinAnJiangMod.F90

= 8
Dynamic VIC Runoff
Subroutine: RunoffSurfaceDynamicVic
Module: RunoffSurfaceDynamicVicMod.F90

OptRunoffSubsurface

= 2
TOPMODEL with Equilibrium Water Table
Subroutine: RunoffSubSurfaceEquiWaterTable
Module: RunoffSubSurfaceEquiWaterTableMod.F90

Soil Water Diffusion
Subroutine: SoilWaterDiffusionRichards
Module: SoilWaterDiffusionRichardsMod.F90

Soil Hydraulic Property
Subroutine: SoilDiffusivityConductivityOpt1
SoilDiffusivityConductivityOpt2
Module: SoilHydraulicPropertyMod.F90

Soil Moisture Solver
Subroutine: SoilMoistureSolver
Module: SoilMoistureSolverMod.F90

Tri-Diagonal Matrix Solver
Subroutine: MatrixSolverTriDiagonal
Module: MatrixSolverTriDiagonalMod.F90

OptTileDrainage

= 2
Hooghoudt's Tile Drainage
Subroutine: TileDrainageHooghoudt
Module: TileDrainageHooghoudtMod.F90

= 1
Simple Tile Drainage
Subroutine: TileDrainageSimple
Module: TileDrainageSimpleMod.F90

OptRunoffSubsurface

= 1
TOPMODEL with Groundwater
Subroutine: RunoffSubSurfaceGroundWater
Module: RunoffSubSurfaceGroundWaterMod.F90

= 3,4,6,7,8
Free Drainage
Subroutine: RunoffSubSurfaceDrainage
Module: RunoffSubSurfaceDrainageMod.F90

= 5
Migues-Macho-Fan Groundwater Shallow Water Table
Subroutine: RunoffSubSurfaceShallowWaterMMF
Module: RunoffSubSurfaceShallowMmfMod.F90

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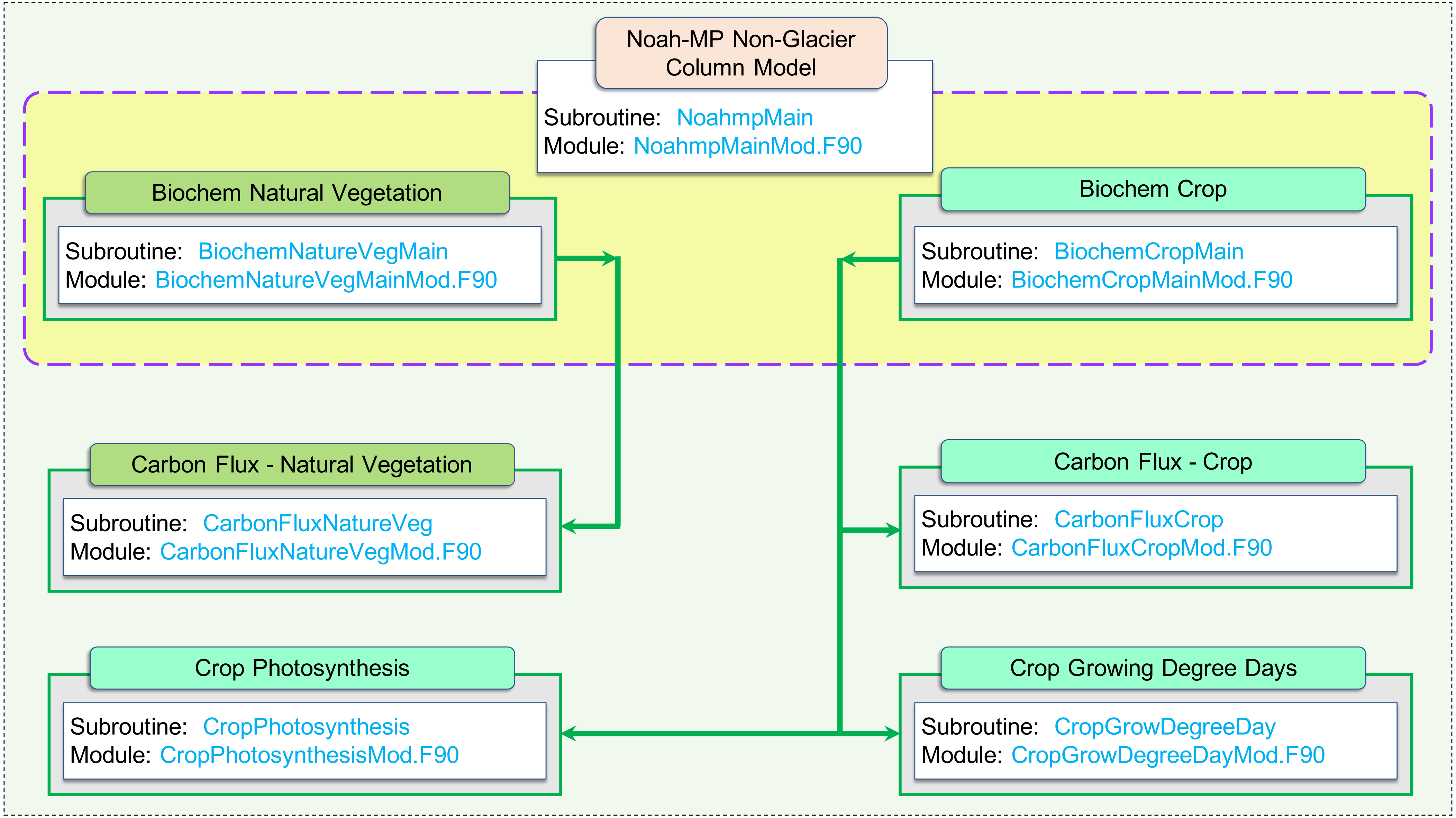
Noah-MP Carbon process calling tree



Noah-MP Non-Glacier Column Model

Subroutine: NoahmpMain
Module: NoahmpMainMod.F90

Biochem Natural Vegetation

Subroutine: BiochemNatureVegMain
Module: BiochemNatureVegMainMod.F90

Biochem Crop

Subroutine: BiochemCropMain
Module: BiochemCropMainMod.F90

Carbon Flux - Natural Vegetation

Subroutine: CarbonFluxNatureVeg
Module: CarbonFluxNatureVegMod.F90

Carbon Flux - Crop

Subroutine: CarbonFluxCrop
Module: CarbonFluxCropMod.F90

Crop Photosynthesis

Subroutine: CropPhotosynthesis
Module: CropPhotosynthesisMod.F90

Crop Growing Degree Days

Subroutine: CropGrowDegreeDay
Module: CropGrowDegreeDayMod.F90

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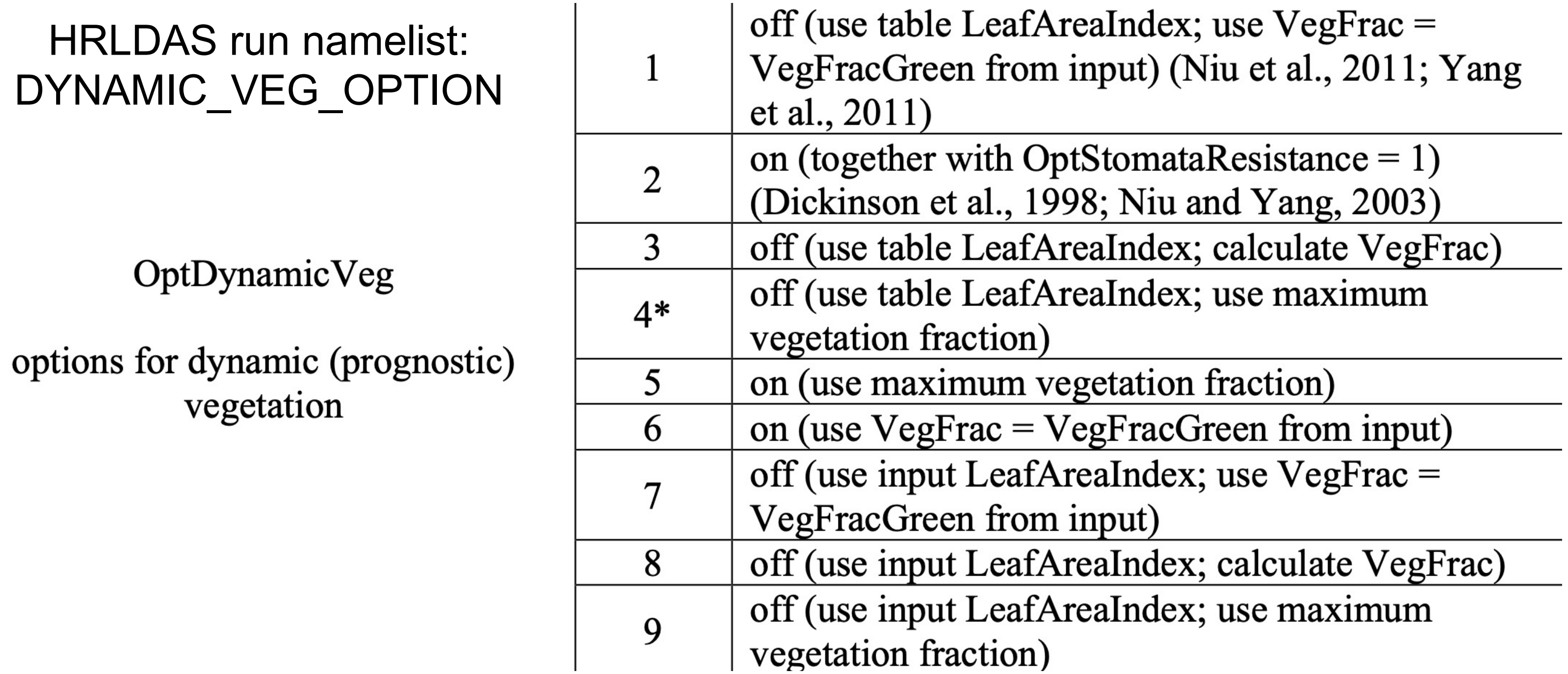
Noah-MP specific physics namelist options

Noah-MP physics namelist option: dynamic vegetation

HRLDAS run namelist:
DYNAMIC_VEG_OPTION



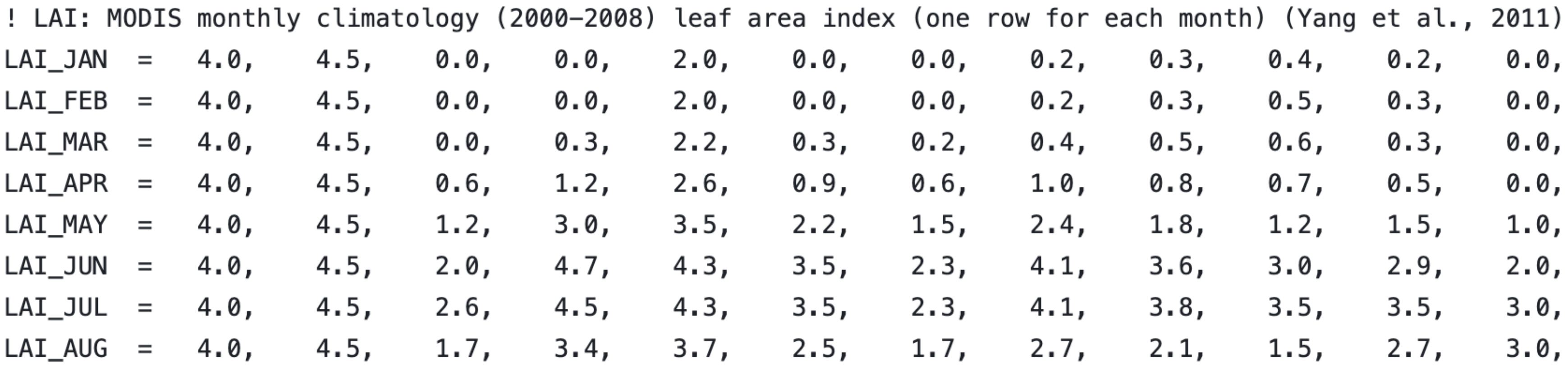
OptDynamicVeg options for dynamic (prognostic) vegetation	1	off (use table LeafAreaIndex; use VegFrac = VegFracGreen from input) (Niu et al., 2011; Yang et al., 2011)
	2	on (together with OptStomataResistance = 1) (Dickinson et al., 1998; Niu and Yang, 2003)
	3	off (use table LeafAreaIndex; calculate 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

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)

AtmosForcingMod.F90

Jordan 1991 scheme:

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

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/wetness factor

HRLDAS run namelist:
BTR_OPTION

OptSoilWaterTranspiration

options for soil moisture factor for stomatal resistance & ET

1*	Noah (soil moisture) (Ek et al., 2003)
2	CLM (matric potential) (Oleson et al., 2004)
3	SSiB (matric potential) (Xue et al., 1991)

SoilWaterTranspirationMod.F90

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

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

$$w_i = \begin{cases} \dfrac{W_{liq,soil}(i) - \theta_{soil,wilt}(i)}{\theta_{soil,ref}(i) - \theta_{soil,wilt}(i)} & (Noah) \\[2ex] \dfrac{\psi_{soil,wilt} - \psi_{soil}(i)}{\psi_{soil,wilt} + \psi_{soil,sat}(i)} & (CLM) \\[2ex] 1 - e^{-5.8 \times ln\left(\frac{\psi_{soil,wilt}}{\psi_{soil}(i)}\right)} & (SSiB) \end{cases}$$

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 = 4:

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

Option = 2:

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

Option = 3:

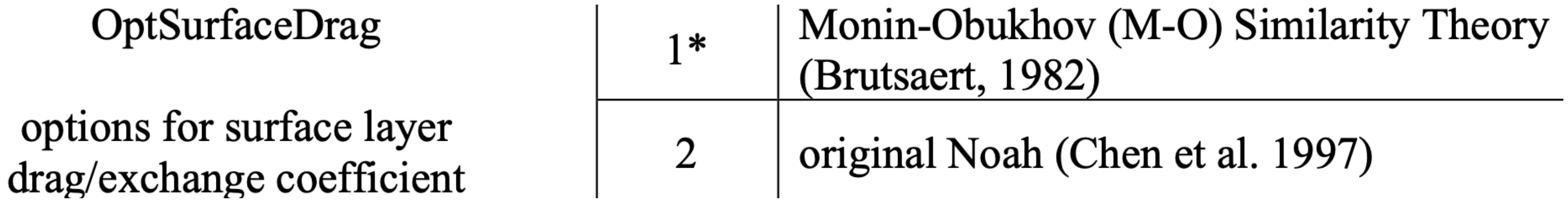
$$R_{grd,evap} = f_{snow} \times 1.0 + (1 - f_{snow}) \times e^{8.25-6.0 \times B_{evap}}$$

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

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

ResistanceBareGroundMostMod.F90

Option = 2:

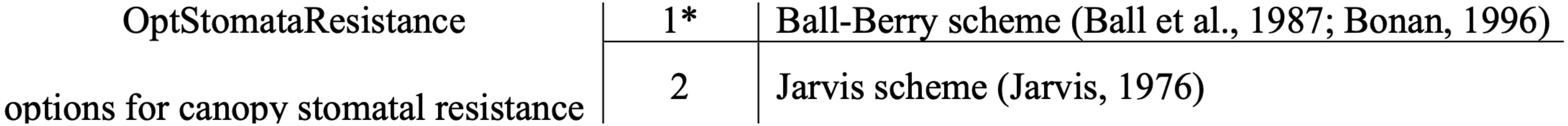
ResistanceAboveCanopyChen97Mod.F90

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

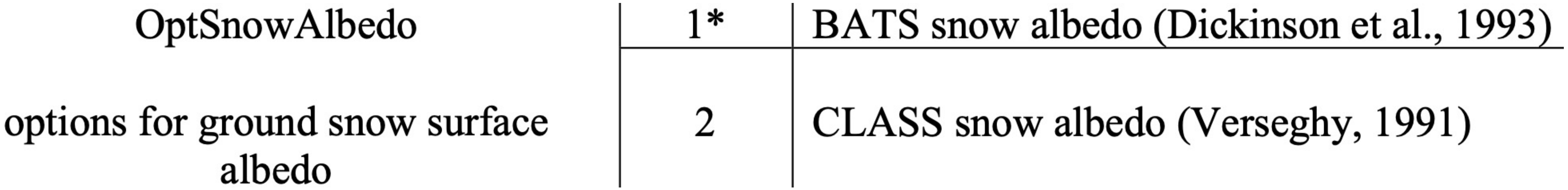
Option = 2:

ResistanceCanopyStomataJarvisMod.F90

Noah-MP physics namelist option: snow albedo

HRLDAS run namelist:
SNOW_ALBEDO_OPTION

SurfaceAlbedoMod.F90
SurfaceAlbedoGlacierMod.F90



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

Option = 1:

SnowAlbedoBatsMod.F90

Option = 2:

SnowAlbedoClassMod.F90

Option = 3 (upcoming):

SnowAlbedoSnicarMod.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:

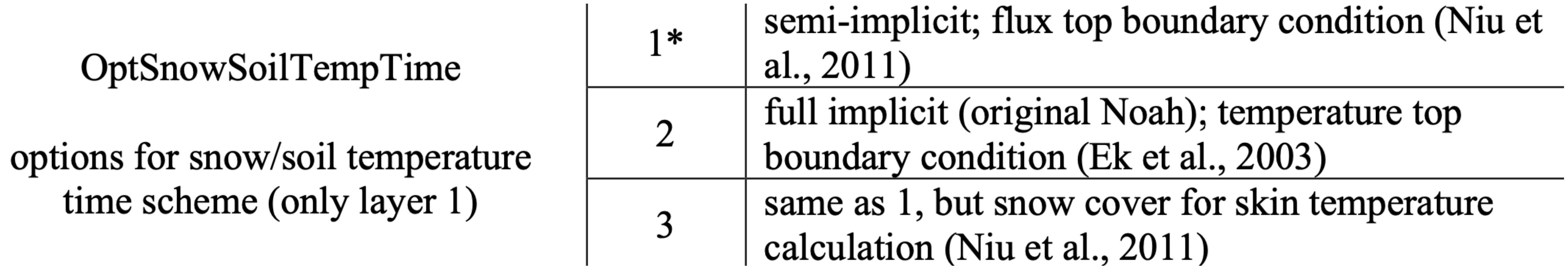
$$P_c = 1 - f_{veg}$$

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

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

options for snow thermal conductivity

1*	Stieglitz scheme (Yen,1965)
2	Anderson (1976) scheme
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)

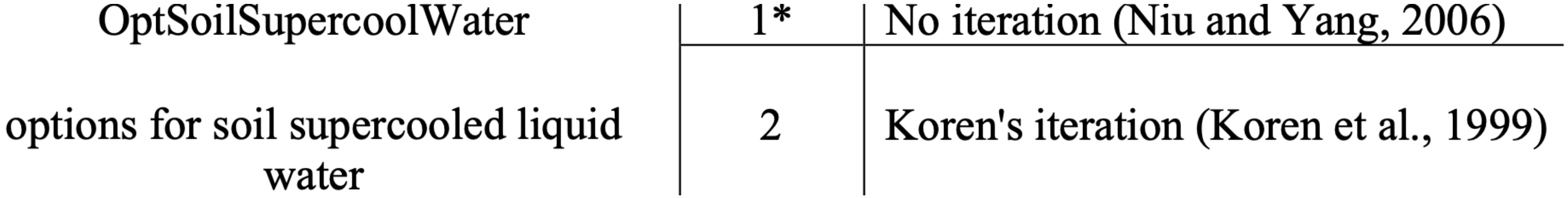
F_{bot} [W/m^2] is the heat flux from deep soil bottom defined as:

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

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

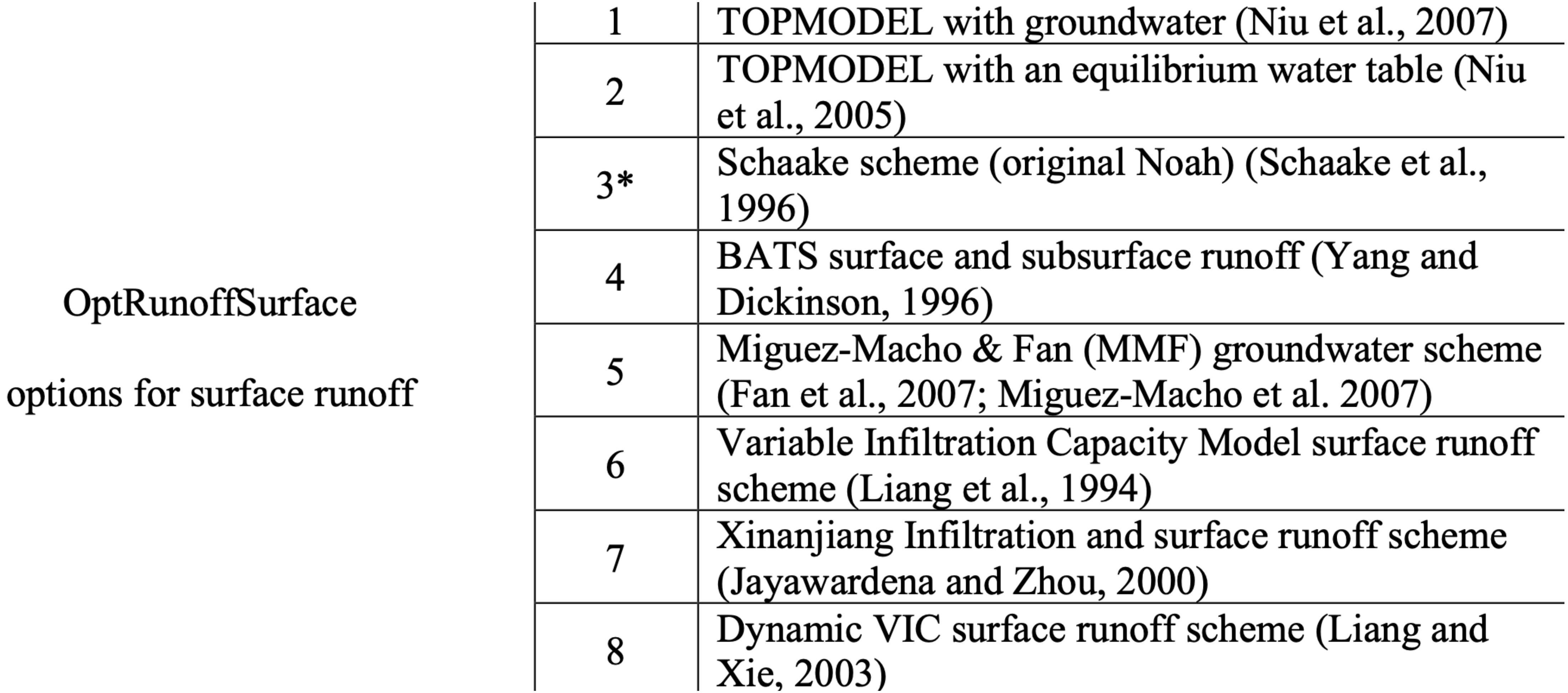
Option = 2:

SoilWaterSupercoolKoren99Mod.F90

Noah-MP physics namelist option: surface runoff

HRLDAS run namelist:
SURFACE_RUNOFF_OPTION

SoilWaterMainMod.F90

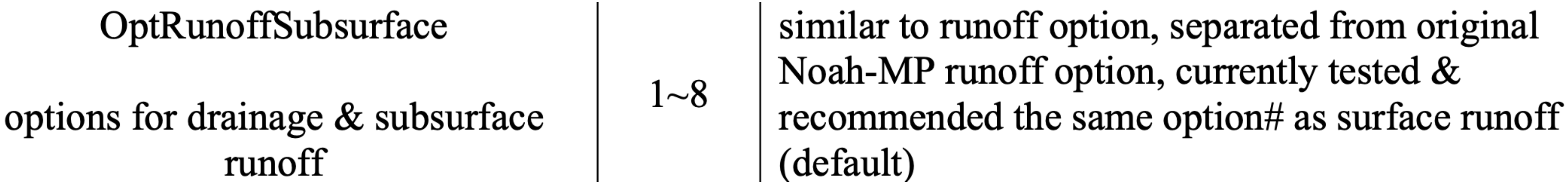


OptRunoffSurface options for surface runoff	1	TOPMODEL with groundwater (Niu et al., 2007)
	2	TOPMODEL with an equilibrium water table (Niu et al., 2005)
	3*	Schaake scheme (original Noah) (Schaake et al., 1996)
	4	BATS surface and subsurface runoff (Yang and Dickinson, 1996)
	5	Miguez-Macho & Fan (MMF) 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)

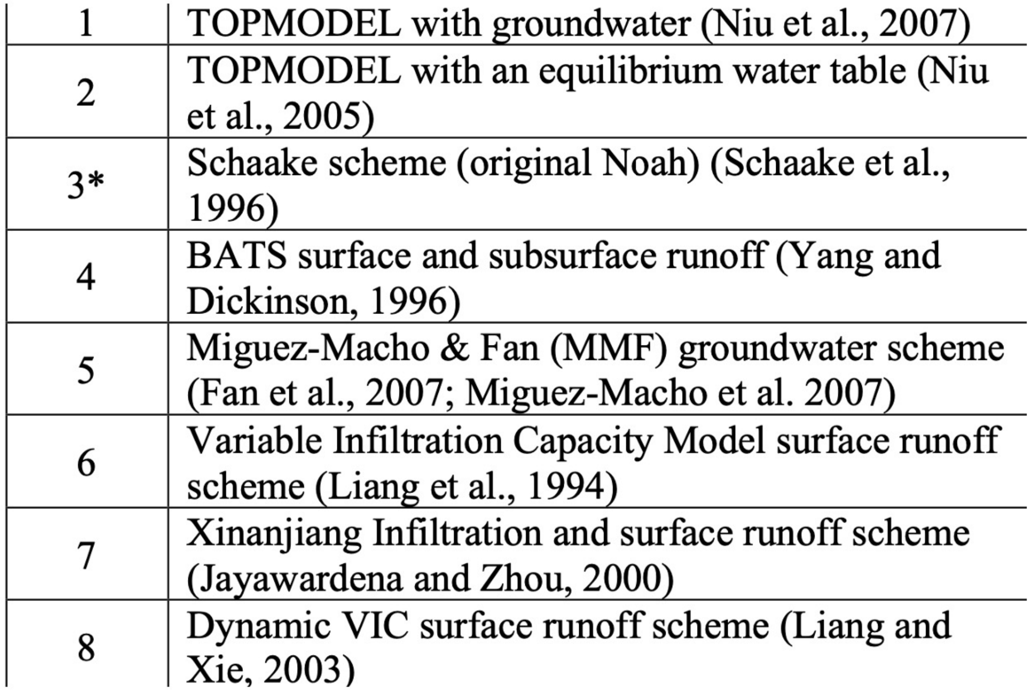
Noah-MP physics namelist option: subsurface runoff

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)

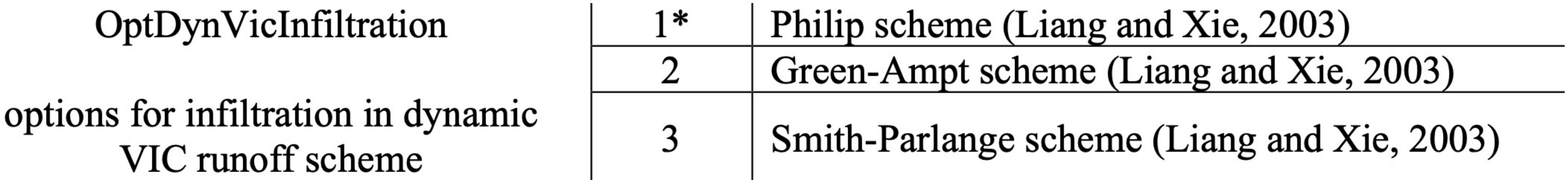


1	TOPMODEL with groundwater (Niu et al., 2007)
2	TOPMODEL with an equilibrium water table (Niu et al., 2005)
3*	Schaake scheme (original Noah) (Schaake et al., 1996)
4	BATS surface and subsurface runoff (Yang and Dickinson, 1996)
5	Miguez-Macho & Fan (MMF) groundwater scheme (Fan et al., 2007; Miguez-Macho 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: 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

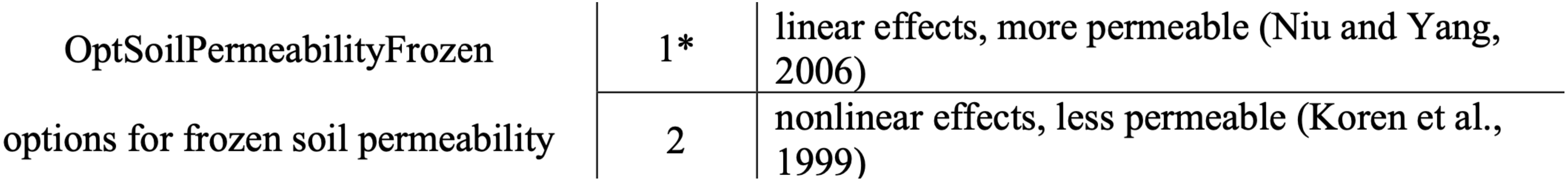
Option = 3:

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

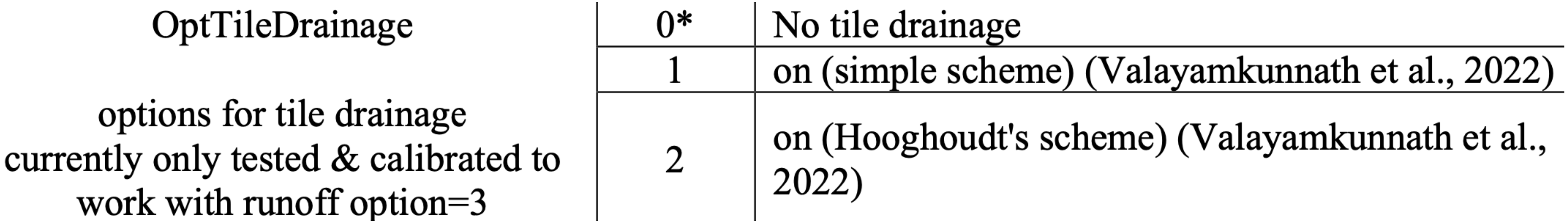
Option = 2:

SoilDiffusivityConductivityOpt2

Noah-MP physics namelist option: tile drainage

HRLDAS run namelist:
TILE_DRAINAGE_OPTION

SoilWaterMainMod.F90



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

Option = 1:

TileDrainageSimpleMod.F90

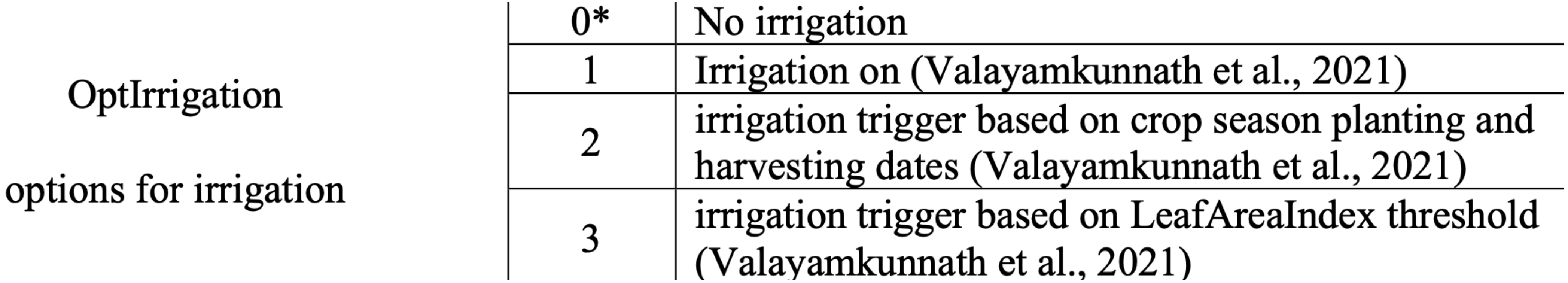
Option = 2:

TileDrainageHooghoudtMod.F90

Noah-MP physics namelist option: Irrigation trigger

HRLDAS run namelist:
IRRIGATION_OPTION

IrrigationPrepareMod.F90
IrrigationTriggerMod.F90

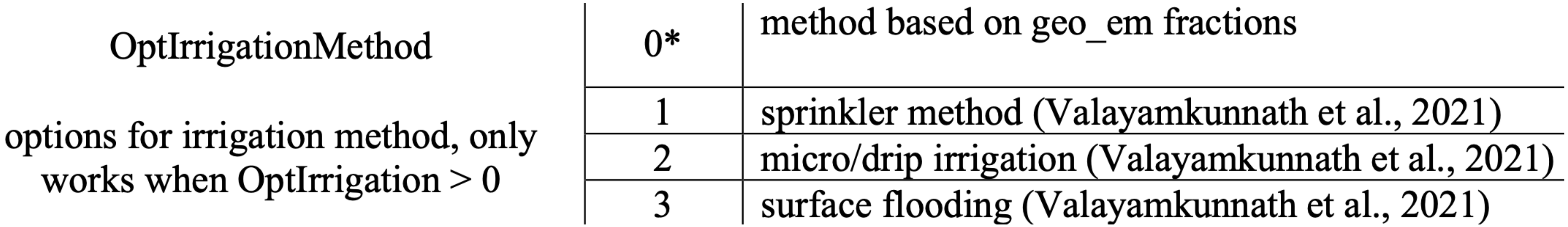


OptIrrigation options for irrigation	0*	No irrigation
	1	Irrigation on (Valayamkunnath et al., 2021)
	2	irrigation trigger based on crop season planting and harvesting dates (Valayamkunnath et al., 2021)
	3	irrigation trigger based on LeafAreaIndex threshold (Valayamkunnath et al., 2021)

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

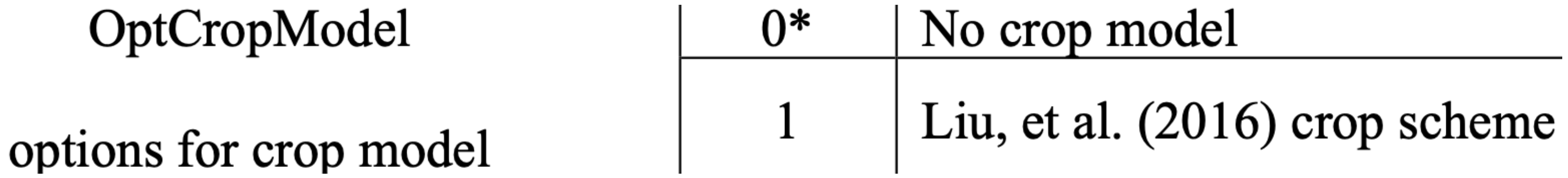
Option = 3:

IrrigationMicroMod.F90

Noah-MP physics namelist option: Crop model

HRLDAS run namelist:
CROP_OPTION

PhenologyMainMod.F90
BiochemCropMainMod.F90

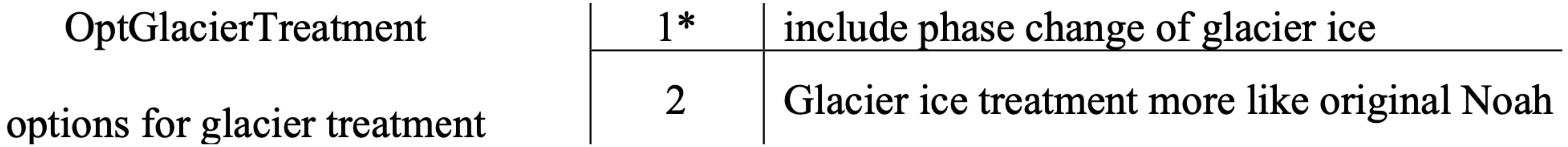


OptCropModel options for crop model	0*	No crop model
	1	Liu, et al. (2016) crop scheme

Noah-MP physics namelist option: Glacier ice treatment

HRLDAS run namelist:
GLACIER_OPTION

GlacierPhaseChangeMod.F90



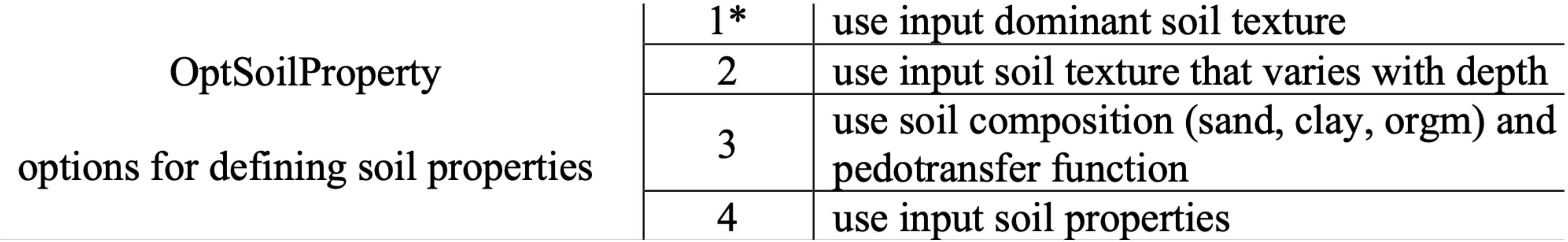
OptGlacierTreatment options for glacier treatment	1*	include phase change of glacier ice
	2	Glacier ice treatment more like original Noah

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

Noah-MP physics namelist option: input soil data

HRLDAS run namelist:
SOIL_DATA_OPTION

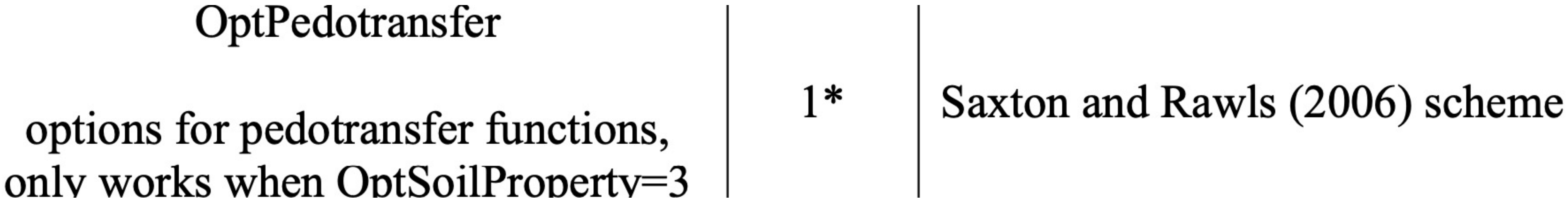
hrldas/IO_code/module_NoahMP_hrldas_driver.F



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

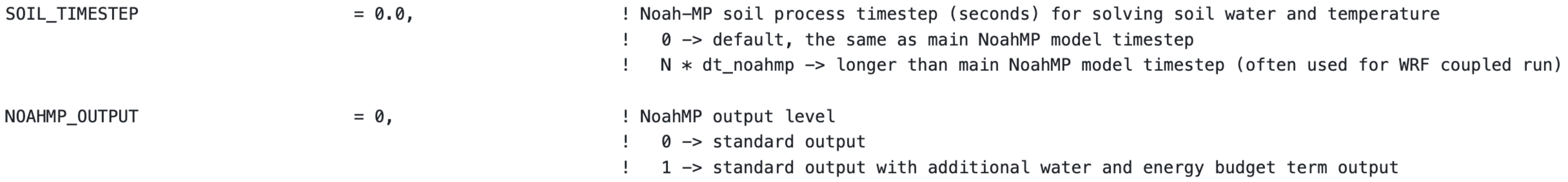
HRLDAS run namelist:
PEDOTRANSFER_OPTION

noahmp/drivers/hrldas/PedoTransferSR2006Mod.F90



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

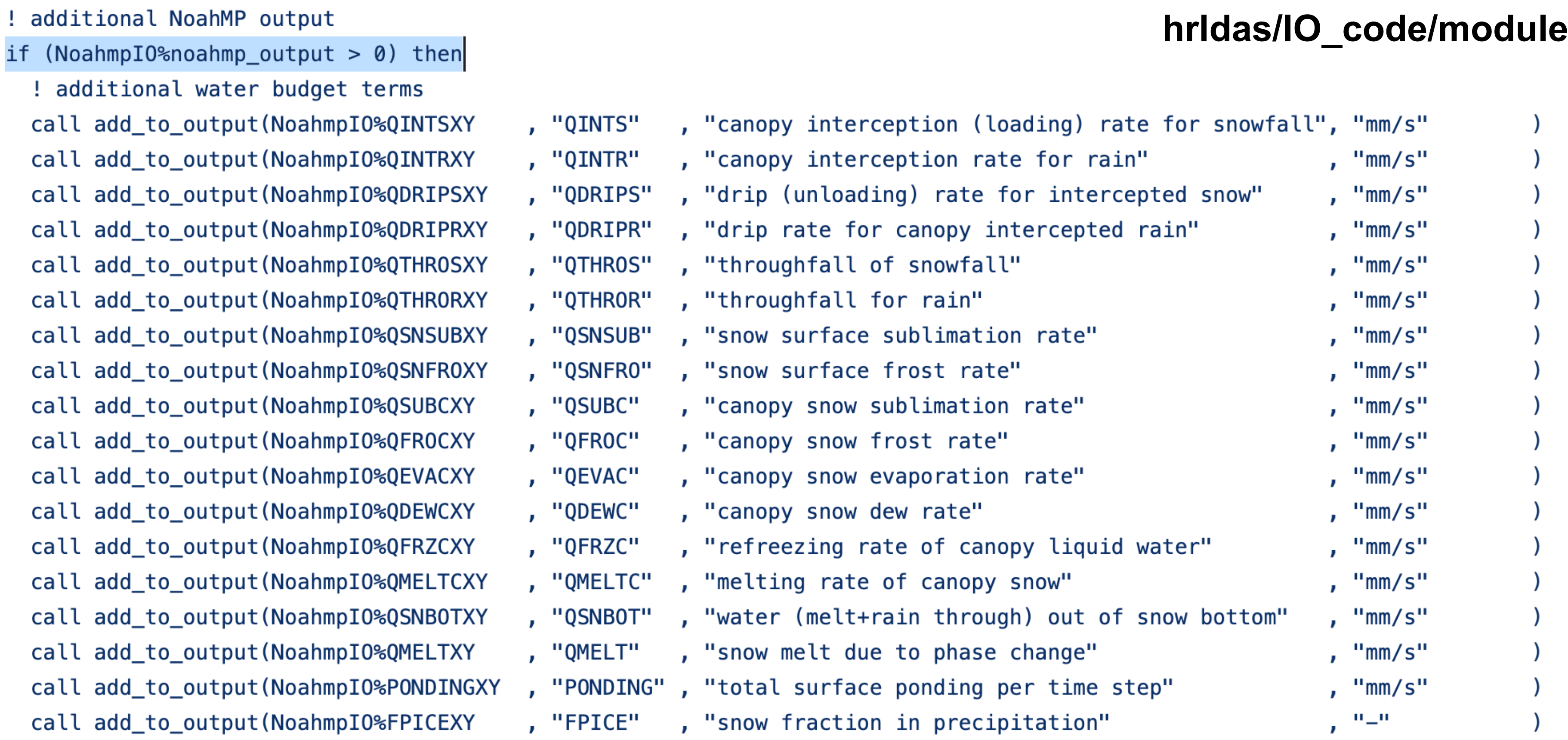
Noah-MP physics namelist option: soil timestep & output diagnostic



```
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

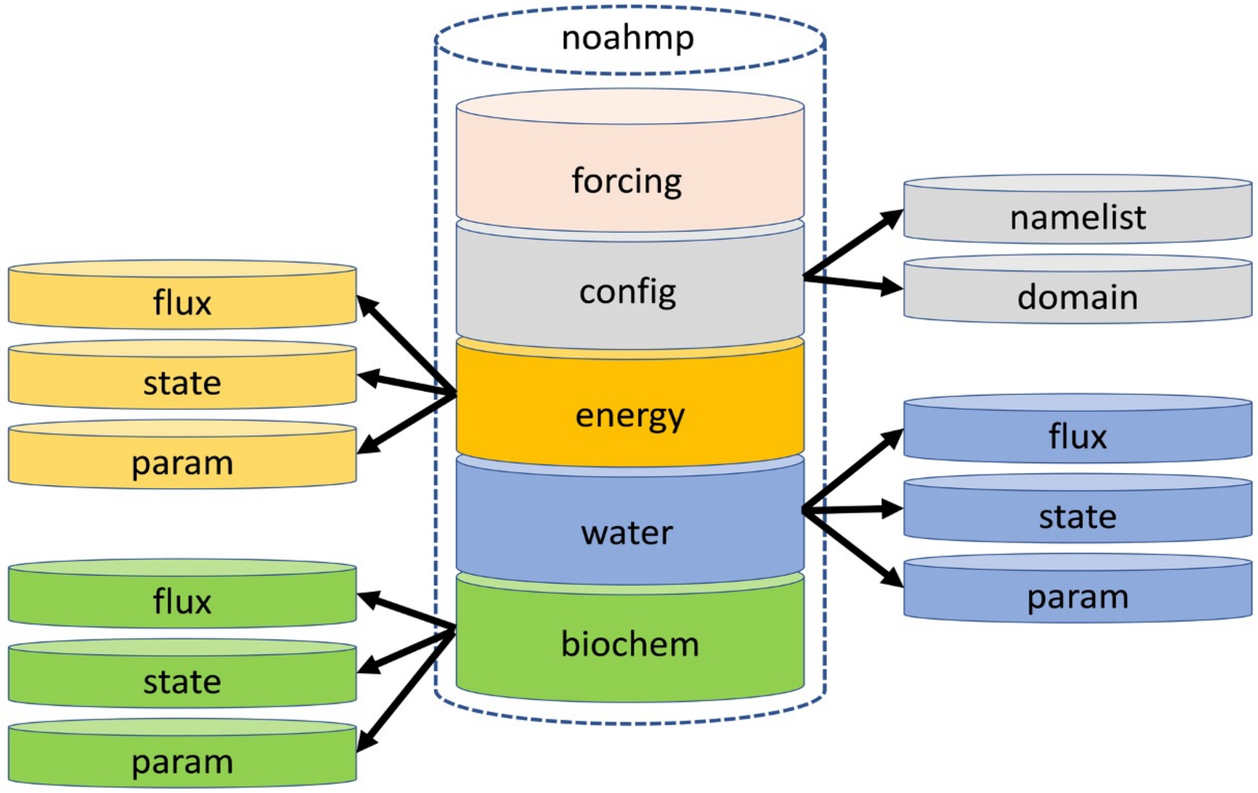


```
  ! additional NoahMP output
  if (NoahmpIO%noahmp_output > 0) then
    ! additional water budget terms
    call add_to_output(NoahmpIO%QINTSXY     , "QINTS"    , "canopy interception (loading) rate for snowfall", "mm/s"        )
    call add_to_output(NoahmpIO%QINTRXY     , "QINTR"    , "canopy 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 v5 data types

(a)



noahmp

forcing

config

energy

water

biochem

namelist

domain

flux

state

param

flux

state

param

flux

state

param

(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

Q & A

If you are interested in joining our Noah-MP community email list, please send me an email!

cenlinhe@ucar.edu

Additional Resources

- Noah-MP & HRLDAS GitHub structures：

  https://github.com/NCAR/noahmp
  https://github.com/NCAR/hrldas

- HRLDAS/Noah-MP offline run tutorial materials

  https://github.com/NCAR/hrldas/tree/master/tutorial

- HRLDAS/Noah-MP offline run step-by-step demon (next part taught by Dr. Zhe Zhang)

Additional resources

- WRF model: https://www.mmm.ucar.edu/weather-research-and-forecasting-model; github.com/wrf-model/WRF/branches
- Noah-MP code repository: github.com/NCAR/noahmp
- HRLDAS code repository: //github.com/NCAR/hrldas
- Noah-MP model references:
  - Niu, G.-Y., Z.-L. Yang, et al.,2011: The Community Noah Land Surface Model with Multi-Parameterization Options (Noah-MP): 1. Model Description and Evaluation with Local-scale Measurements. *J. Geophys. Res*., doi:10.1029/2010JD015139.
  - Barlage, M., M. Tewari, F. Chen, G. Miguez-Macho, et al., 2015: The Effect of Groundwater Interaction in North American Regional Climate Simulations with WRF/Noah-MP. Climatic Change, DOI 10.1007/s10584-014-1308-8
  - Liu, X., F. Chen, M. Barlage, G. Zhou, D. Niyogi, 2016: Noah-MP-Crop: Introducing Dynamic Crop Growth in the Noah-MP Land-Surface Model. *J. Geophys. Res., doi:10.1002/2016JD025597.*
  - He, C., P. Valayamkunnath, M. Barlage, F. Chen, D. Gochis, R. Cabell, T. Schneider, R. Rasmussen, G.-Y. Niu, Z.-L. Yang, D. Niyogi, and M. Ek, 2023: Modernizing the open-source community Noah-MP land surface model (version 5.0) with enhanced modularity, interoperability, and applicability, Geosci. Model Dev., https://doi.org/10.5194/gmd-16-5131-2023.
- Noah-MP model evaluation examples:
  - Yang, Z.-L., G.-Y. Niu, et al., 2011: The Community Noah Land Surface Model with Multi-Parameterization Options (Noah-MP): 2. Evaluation over Global River Basins. *J. Geophys. Res.,* doi:10.1029/2010JD015140.
  - Chen, F., M. Barlage, M. Tewari, R. Rasmussen, J. Jin, D. Lettenmaier, et al, 2014: Modeling seasonal snowpack evolution in the complex terrain and forested Colorado Headwaters region: A model inter-comparison study. *J. Geophys. Res.,*119, 13,79 5–13,819.
  - Zhang, G., F. Chen, and Y. Gan, 2016: Assessing uncertainties in the Noah-MP ensemble simulations of a cropland site during the Tibet Joint International Cooperation program (JICA) field campaign. *J. Geophys. Res., 121, doi:10.1002/2016JD024928.*
  - Gan, Y., X. Liang, Q. Duan, F. Chen, J. Li, 2019: Assessment and Reduction of the Physical Parameterization Uncertainty for Noah-MP Land Surface Model. *Water Resources Research, https://doi.org/10.1029/2019WR024814*.
  - Li, J., F. Chen, X. Lu, W. Gong, G. Zhang**,** and Y. Gan, 2020: Quantify contributions of uncertainties in physical parameterization schemes and model parameters to overall errors in Noah-MP dynamic vegetation modeling. *J. Adv. Model. Earth Syst., DOI: 10.1029/2019MS001914.*
  - Zhang, Z., Y. Li, et al., 2020: Joint modeling of crop and irrigation in Central U.S. using Noah-MP land surface model. *J. Adv. Model. Earth Syst., DOI: 10.1029/2020MS002159.*
- WRF convection-permitting regional climate simulation evaluation:
  - Rasmussen, R., C. Liu, K. Ikeda, et al., 2011: High-Resolution Coupled Climate Runoff Simulations of Seasonal Snowfall over Colorado: A Process Study of Current and Warmer Climate. *J. Climate*, 24, 3015-3048.
  - Liu, C., Ikeda, K., Rasmussen, R., Barlage, et al, (2017). Continental-scale convection-permitting modeling of the current and future climate of North America. Climate Dynamics, 49(1–2), 71–95.
  - Prein, A. F., Liu, C., Ikeda, K., Bullock, R., Rasmussen, et al., (2017). Simulating North American mesoscale convective systems with a convection-permitting climate model. Climate Dynamics, 55, 95–110.
  - Zhang, Z., et al. 2018: Evaluation of WRF CONUS on the relationship between soil moisture and heatwaves. *Climate Dynamics.,* https://doi.org/10.1007/s00382-018-4508-5
  - He, C., F. Chen, M. Barlage, C. Liu, A. Newman, W. Tang, K. Ikeda, and R. Rasmussen, 2019: Can convection-permitting modeling provide decent precipitation for high-resolution snowpack simulations over mountains? *J. Geophys. Res.-Atmos, DOI: 10.1029/2019JD030823.*