THE COMMUNITY NOAH LAND-SURFACE MODEL (LSM) WITH MULTI-PHYSICS OPTIONS
(Noah MP)

Internal Release

N: **N**ational Centers for Environmental Prediction (NCEP)
O: **O**regon State University (Dept of Atmospheric Sciences)
A: **A**ir Force (both AFWA and AFRL - formerly AFGL, PL)
H: **H**ydrology Lab - NWS (formerly Office of Hydrology - OH)

User's Guide

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Point of Contact: Guo-Yue Niu, niu@geo.utexas.edu, phone: 512-471-5355

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1.0 INTRODUCTION

This User's Guide provides execution guidance and physical description of the Multi-Physics (MP) version of the Noah land surface model (hereafter Noah_MP). Noah_MP is an uncoupled version to execute land-surface simulations. In this uncoupled mode, near-surface atmospheric forcing data are required as input forcing (see Sec 7.0). Noah_MP simulates soil moisture (both liquid water and ice content), soil temperature, skin temperature, snow depth (or snowpack density), snow water equivalent, canopy water content, and surface energy, water, and CO2 (if dynamic vegetation started) fluxes.

The public server directory `RELEASE/`in which this User's Guide resides also contains directories containing Noah LSM source code files (`Noah_code`), Noah driver and data input/output codes (`IO_code`), atmospheric forcing files for a sample one-year global simulation (`Noah_data/forcings`), and model output files (`Noah_data/results`).

This is an augmented version of Noah with multi-physics options. The augments include: 1) restructuring the model to include a separated vegetation canopy accounting for vegetation effects on surface energy and water balances, 2) a modified two-stream approximation scheme to include the effects of vegetation canopy gaps that vary with solar zenith angle and the canopy 3-D structure on radiation transfer, 3) a 3-layer physically-based snow model, 4) a more permeable frozen soil by separating a gridcell into permeable fraction and impermeable fraction, 5) a simple groundwater model with a TOPMODEL-based runoff scheme, and 6) a short-term leaf phonology model. On the basis of the modified Noah, we then designed options of schemes for leaf dynamics, radiation transfer, stomatal resistance, soil moisture stress factor for stomatal resistance, aerodynamic resistance, runoff, snowfall, snow surface albedo, supercooled liquid water in frozen soil, and frozen soil permeability, etc. Details about the model physical parameterizations can be referred to Niu et al. (2009).

2.0 MODEL HERITAGE

Beginning in 1990, and accelerating after 1993 under sponsorship from the GEWEX/GCIP Program Office of NOAA/OGP via collaboration with numerous GCIP Principal Investigators (PIs), the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) joined with the NWS Office of Hydrology (OH) and the NESDIS Office of Research and Applications (ORA) to pursue and refine a modern-era LSM suitable for use in NCEP operational weather and climate prediction models. Early in this effort, NCEP carried out an intercomparison of four LSMs, including 1) a simple bucket model, 2) the OSU LSM (known as the CAPS model in some PILPS studies), 3) the SSiB model, and 4) the Simple Water Balance model (SWB) of OH. The results of this intercomparison were reported in Chen et al. (1996, see references therein for the four cited LSMs). As a result of the good performance of the OSU LSM in this study and pre-existing hands-on experience with this LSM by various EMC staff members, including Hua-Lu Pan and Ken Mitchell, EMC chose the OSU LSM for further refinement and implementation in NCEP regional and global coupled weather and climate models (and their companion data assimilation systems). The results of the cited LSM intercomparison and the initial EMC refinements to the OSU LSM were reported in Chen et al. (1996).

At the beginning of the EMC LSM effort in 1990, the OSU LSM already had a 10-year history. Its initial development was carried out by OSU in a series of three papers (Mahrt and Ek, 1984; Mahrt and Pan, 1984; and Pan and Mahrt, 1987). As the EMC LSM effort unfolded during the 1990's, a series of NCEP extensions to the OSU LSM were a) added by EMC and its GCIP collaborators and b) tested and validated in both uncoupled and coupled studies (see review of these in Mitchell et al, 1999, 2000). At NCEP, the LSM was first coupled to the operational NCEP mesoscale Eta model on 31 Jan 96, with significant Eta LSM refinements subsequently implemented on 18 Feb 97, 09 Feb 98, and 03 Jun 98. Recently in 1999, with a) the new addition and testing of frozen soil and patchy snow cover physics in the uncoupled LSM used for the NCEP-OH submission to PILPS-2d (Valdai, Russia), and b) the growing number of external user requests for access to and use of the NCEP LSM (e.g. GCIP PIs), we decided the NCEP LSM had advanced to a stage appropriate for formal public release (first in March 99).

Most recently in 2000, given a) the advent of the "New Millenium", b) a strong desire by EMC to better recognize its LSM collaborators, and c) a new NCEP goal to more strongly pursue and offer "Community Models", EMC decided to coin the new name "NOAH" for the LSM that had emerged at NCEP during the 1990s. With our choice of the "NOAH" acronym, already defined at the top of this User's Guide, we in EMC strive to explicitly acknowledge both the multi-group heritage and informal "community" usage of this LSM, going back to the early 1980’s. Since its beginning then at Oregon State University, the evolution of the present NOAH LSM herein has spanned significant ongoing development efforts by the following groups:

NCEP/EMC:	NCEP Environmental Modeling Center (EMC)
	(Mitchell, Chen, Ek, Lin, Marshall, Janjic, Manikin, Lohmann, Grunmann, Pan)
OSU:	Oregon State University
	(Mahrt, Pan, Ek, Kim, Rusher)
HL:	NWS Hydrology Lab - formerly Office of Hydrology
	(Schaake, Koren, Duan)
AFWA:	Air Force Weather Agency - formerly AFGWC
	(Moore, Mitchell, Gayno)
AFRL:	Air Force Research Lab - formerly AFGL and PL
	(Mitchell, Hahn, Chang, Yang)

In addition to “in-house” NOAH LSM development and validation by the above organizations, the following external PIs (primarily GCIP), have also performed valuable validations of the NOAH LSM and its immediate NCEP 1990's predecessors:

E.H. Berbery and Rasmusson:	U. Maryland	(ARM/CART)
C. Marshall and Crawford	U. Oklahoma	(OU Mesonet)
I. Yucel and Shuttleworth:	U. Arizona	(ARM/CART, AZNET)
A.K. Betts:	Atmospheric Res Inc	(ISLSCP/FIFE)
C.D. Peters-Lidard, Wood	Princeton U.	(TOPLATS extensions)
L. Hinkelman and Ackerman:	Penn State U.	(ARM/CART)
T.H. Chen, W. Qu, Henderson-Sellers, et al.	RMIT	(PILPS-2a)
E. Wood, Lettenmaier, Liang, Lohmann:	Princeton U.	(PILPS-2c)

A. Schlosser, A.G. Slater, Robock, et al.	U. Maryland	(PILPS-2d)
R. Angevine	NOAA/AL	(Flatland Exp)

One crucial collaborator deserves special mention, namely the NESDIS Office of Research and Applications (Tarpley, Gutman, Ramsay), which has been the source of critical global surface fields of a) vegetation greenness and its seasonality and b) realtime snow cover, plus important GOES, satellite-based, hourly surface validation fields of c) land surface skin temperature and d) solar insolation, both on a 0.50-degree lat/lon CONUS grid.

In the spring of 2007, Ken Mitchell visited University of Texas (UT) and discussed with Zong-Liang Yang and Guo-Yue Niu about the implementation of most recent advancements in snow, runoff, groundwater, and dynamic vegetation developed by the UT land surface group into Noah. Invited by Ken Mitchell, in May of 2007, Yang and Niu visited NCEP/land group and discussed with Ken Mitchell and Mike Ek the details about model physics, and decided to work on the implementations. After one more year's coding and testing work, the version is ready for internal release for further extensive testing.

3.0 DIRECTORY CONTENTS AND QUICK-START GUIDE TO EXECUTION

Under the main directory `RELEASE`, there are 4 directories and 4 files. The 4 files are 1) `READ_ME_NoahMP.pdf` (this user guide), 2) `Readme.txt`, a brief description of subdirectories and a simple instruction as how to run the model, 3) `Makefile`, and 4) `makefile`. The 4 directories are, 1) `IO_code` containing the model driver, model input, and output programs, 2) `Noah_code` including the major NoahMP source codes and utilities, 3) `Run`, the working directory, and 4) `Noah_data` including model inputs (forcing, vegetation, and soil data) and modeling results.

1) **`IO_code`** directory

There are three Fortran programs:

`Noah_driver.F`	model driver
`module_Noahlsm_gridded_input.F`	gridded inputs of forcing data and vegetation type and soil texture data
`module_Noah_NC_output.F`	gridded outputs of monthly mean results and initial conditions for prognostic variables

2) **`Noah_code`** directory

There are four Fortran programs:

`module_Noahlsm.F`	source code for model physics
`module_Noahlsm_utility.F`	air temperature and humidity conversion functions
`module_Noahlsm_param_init.F`	read-in of look-up tables
`module_date_utilities.F`	model timer

3) **`Noah_data`** directory

There are three subdirectories:

`results/` modeling results containing subdirectories:

`exp1/` directory for experiment 1 containing three subdirectories:

`3hrly/` 3hrly outputs for skin temperature and related surface energy budgets

`hist/` monthly-mean outputs of water, energy, and carbon fluxes and state variables, such as soil temperature and moisture.

`ini/` initial conditions, instantaneous values of the prognostic variables at the end of each year. These files can be used as initial conditions for further spin-up runs

`forcings/` near-surface hydro-meteorological variables reprocessed from Global Land Data Assimilation System (GLDAS).

`static/` static datasets including vegetation and soil information.

4) Quick start guide

a) First, make sure your computer has NetCDF software installed and find the directory where the NetCDF library is and then modify the `Makefile` in `Run/` directory

replace "`-L/home/sn21/niu/NCARSOFTWARE/netcdf-3.5/lib –lnetcdf`" with your own.

b) Edit "`makefile`" in `RELEASE/` to add your NetCDF include directory, like,

`-I/home/sn21/niu/NCARSOFTWARE/netcdf-3.5/include`

c) Type "`make`" in dir `RELEASE/`

d) Edit "`noah_offline.namelist`" in `RELEASE/Run`

e) Type "`Noah_offline*`" to run the model.

4.0 SUBROUTINE SUMMARY AND CALLING TREE

Below, we split up the subroutine calling tree into the portion associated with PROGRAM MAIN in the "Driver family" of subroutines (`IO_code/Noah_driver.F`) and that portion associated with the "Physics family" of subroutines (`Noah_code/module_Noahlsm.F`), comprised of physics "sub-driver" routine SFLX and all subordinate subroutines.

4.1 The Driver Routines

The MAIN (`Noah_driver`) program calls the following subroutines:

```
call lsm_parm_init            reading soil & veg look-up tables
call readland                 reading static land data
```

```
call readveg                  reading monthly green vegetation fraction
call readinit                 reading initial conditions
!-----------------------------------------------------------------------------
!start temporal do-loop
!-----------------------------------------------------------------------------
      call readforc           reading forcing data
      call calendr            calendar day for computing solar zenith angle
!-----------------------------------------------------------------------------
!start spatial do-loop
!-----------------------------------------------------------------------------
            call lsmzen       calculating cosine of solar zenith angle
            call redprm       set up parameters according to veg & soil types
            call SFLX         calling LSM physics
            call nc_out       monthly-mean variables and output in NetCDF
                              format
            call nc_out_3hr   3hrly outputs in NetCDF format
!-----------------------------------------------------------------------------
!end spatial do-loop
!-----------------------------------------------------------------------------
      call geth_newdate       updating model time
      call write_ini          instantaneous outputs of prognostic variables
!-----------------------------------------------------------------------------
!end temporal do-loop
!-----------------------------------------------------------------------------
```

4.2 The SFLX Family of Subroutines

Major outputs from this subroutine:

SUBROUTINE SFLX Calling Tree

```
ATM                                 Reprocess atmospheric forcing
PHONOLOGY                           Leaf phonology
ENERGY                              Energy fluxes and temperatures
      THERMOPROP                    Thermal properties of snow and soil
            CSNOW                   Snow heat capacity and conductivity
            TDFCND                  Soil heat capacity and conductivity
      RADIATION                     Shortwave radiative fluxes
            ALBEDO                  Surface albedo
                  SNOW_AGE          Snow age
                  SNOWALB_BATS      BATS snow surface albedo scheme
                  SNOWALB_CLASS     CLASS snow surface albedo scheme
                  GROUNDALB         Ground surface (soil/snow) albedo
                  TWOSTREAM         Overall surface albedo, absorptivity, and
                                    transmitivity
            SURRAD                  Shortwave radiation fluxes
      VEGE_FLUX                     Energy fluxes and skin T, vegetated area
            ESAT                    es(T) and es(T)/dt for the canopy
            SFCDIF1                 Exchange coefficients CH&CM (M-O theory)
            SFCDIF2                 Exchange coefficients CH&CM (Chen 1997)
            STOMATA                 Ball-Berry stomatal resistance (sunlit)
            STOMATA                 Ball-Berry stomatal resistance (shaded)
            CANRES                  Jarvis stomatal resistance (sunlit)
            CANRES                  Jarvis stomatal resistance (shaded)
```

```
        RAGRB                   Under-canopy (Rag) and leaf boundary (Rb)
                                resistances
        ESAT                    es(T) and es(T)/dt for ground

    BARE_FLUX                   Energy fluxes and skin T, bare ground
        SFCDIF1                 Exchange coefficients CH&CM (M-O theory)
        SFCDIF2                 Exchange coefficients CH&CM (Chen 1997)
        ESAT                    es(T) and es(T)/dt for vegetated ground

    TSNOSOI                     The 3-L snow and 4-L soil temperatures
            HRT                 The A,B,C,R coefficients for the tri-
                                diagonal matrix
            HSTEP               Update snow/soil layer temperatures
                ROSR12          The tri-diagonal matrix solver
            PHASECHANGE         Phase change between ice and liquid water
                FRH2O           Maximum ice content of soil layers

WATER                           Water storages and fluxes
    CANWATER                    Canopy ice and liquid water and fluxes
    SNOWWATER                   Snow mass and snow depth
        SNOWFALL                Create new snow layers
        COMBINE                 Combine snow layers when the layer
                                thickness is below a certain value
            COMBO               Combine mass and energy
        DIVIDE                  Divide a layer into two layers when the
                                layer thickness is above a certain value
            COMBO               Divide mass and energy
        COMPACT                 Snow depth (or density)
        SNOWH2O                 Renew snow ice and liquid water
    SOILWATER                   Soil water storage and surface runoff
        ZWTEQ                   Equilibrium water table depth
        INFIL                   Infiltration-excess runoff (Schaake
                                scheme)
        SRT                     The A,B,C,R coefficients for soil
                                moisture tri-diagonal matrix
            WDFCND1             soil hydraulic diffusivity and
                                conductivity (linear frozen soil effects)
            WDFCND2             soil hydraulic diffusivity and
                                conductivity (non-linear frozen soil
                                effects)
        SSTEP
            ROSR12              The tri-diagonal matrix solver

    GROUNDWATER                 Groundwater recharge and discharge, water
                                table dynamics, and groundwater storage

 CARBON
    CO2FLUX                     Prognostic LAI and CO2 flux
!   BVOCFLUX                    BVOC fluxes (not tested)
!   CH4FLUX                     CH4 fluxes (under development)

 ERROR                          Water and energy balance check
```

Model outputs:

The model outputs include monthly history, initial, and 3hrly history.

The monthly outputs include:

Energy related variables:

```
FSA    !total absorbed solar radiation (w/m2)
FSR    !total reflected solar radiation (w/m2)
FIRA   !total net LW rad (w/m2)    [+ to atm]
FSH    !total sensible heat (w/m2) [+ to atm]
FCEV   !canopy evaporative heat flux (w/m2) [+ to atm]
FGEV   !ground evaporative heat flux (w/m2) [+ to atm]
FCTR   !transpiration heat (w/m2) [+ to atm]
SSOIL  !ground heat flux (w/m2)   [+ to soil]
APAR   !photosynthesis active radiation by the canopy (W/m2)
SAV    !solar radiation absorbed by vegetation (W/m2)
SAG    !solar radiation absorbed by ground (W/m2)
```

Water related variables:

```
ECAN   !evaporation of intercepted water (mm/s)
ETRAN  !transpiration rate (mm/s)
EDIR   !soil surface evaporation rate (mm/s]
RUNSRF !surface runoff [mm/s]
RUNSUB !baseflow (saturation excess) [mm/s]
```

Note: The water and energy balance of the above variables can be found in subroutine `“ERROR”` in `Noah_code/module_Noahlsm.F.`

Carbon related variables:

```
PSN    !total photosynthesis (umol co2/m2/s) [+]
FVEG   !green vegetation fraction [0.0-1.0]
NEE    !net ecosys exchange (g/m2/s CO2) or net CO2 flux
GPP    !net instantaneous assimilation [g/m2/s C]
NPP    !net primary productivity [g/m2/s C]
LAI    !leaf area index [-]
```

State variables:

```
TRAD   !surface radiative temperature (k)
TV     !vegetation temperature (k)
TG     !ground temperature (k)
STC    !snow/soil layer temperatures [k]
SH2O   !liquid soil moisture [m3/m3]
SMC    !total soil moisture (ice + liquid) [m3/m3]
SNOWH  !snow height [m]
SNEQV  !snow water equivalent [mm or kg/m2]
FSNO   !snow cover fraction on the ground (-)
ZWT    !depth to water table [m]
WA     !water storage in aquifer [mm]
```

The 3hrly outputs just include skin temperature and its related energy fluxes for the year of 2004. One may change “`if(iyloop == 2004) then`” in “`RELEASE/IO_code/Noah_driver.F`” to control the output for the year you want.

Model options:

The model options are now set up in `Noah_code/module_Noahlsm.F`. Combinations of these optional schemes can be up to 5,000 and more. So, only a limited number of the combinations were tested as shown in Niu et al. (2009).

```
! options for dynamic vegetation:
! 1 -> off ; 2 -> on (can only work Ball-Berry type: OPT_CRS = 1)

  INTEGER, PARAMETER :: DVEG    = 2   !

! options for canopy stomatal resistance
! 1-> Ball-Berry; 2->Jarvis

  INTEGER, PARAMETER :: OPT_CRS = 1    !(must be 1 when DVEG = 2)

! options for soil moisture factor for stomatal resistance
! 1-> Noah (soil moisture)
! 2-> CLM  (matric potential)
! 3-> BATS (matric potential)

  INTEGER, PARAMETER :: OPT_BTR = 1    !(suggested 1)

! options for runoff and groundwater
! 1 -> TOPMODEL with groundwater (Niu et al. 2007 JGR) ;
! 2 -> TOPMODEL with an equilibrium water table (Niu et al. 2005 JGR)
! 3 -> original surface and subsurface runoff (free drainage)
! 4 -> BATS surface and subsurface runoff (free drainage)

  INTEGER, PARAMETER :: OPT_RUN = 1    !(suggested 1)

! options for surface layer drag coeff (CH & CM)
! 1->new, smaller ; 2->original Noah, larger (Chen)

  INTEGER, PARAMETER :: OPT_SFC = 1    !(suggested 1 or 2)

! options for supercooled liquid water (or ice fraction)
! 1-> no iteration (Niu and Yang, 2006 JHM); 2: Koren's iteration

  INTEGER, PARAMETER :: OPT_FRZ = 1    !(suggested 1)

! options for frozen soil permeability
! 1 -> linear effects, more permeable (Niu and Yang, 2006, JHM)
! 2 -> nonlinear effects, less permeable (old)

  INTEGER, PARAMETER :: OPT_INF = 1    !(suggested 1)

! options for radiation transfer
```

```
! 1 -> modified two-stream (gap = F(solar angle, 3D structure ...)<1-FVEG)
! 2 -> two-stream applied to grid-cell (gap = 0)
! 3 -> two-stream applied to vegetated fraction (gap=1-FVEG)

  INTEGER, PARAMETER :: OPT_RAD = 1    !(suggested 1)

! options for ground snow surface albedo
! 1-> BATS; 2 -> CLASS

  INTEGER, PARAMETER :: OPT_ALB = 2    !(suggested 2)

! options for partitioning  precipitation into rainfall & snowfall
! 1 -> Jordan (1991); 2 -> BATS: when SFCTMP<TFRZ+2.2 ; 3-> SFCTMP<TFRZ

  INTEGER, PARAMETER :: OPT_SNF = 1    !(suggested 1)

! options for lower boundary condition of soil temperature
! 1 -> zero heat flux from bottom (ZBOT and TBOT not used)
! 2 -> TBOT at ZBOT (8m) read from a file (original Noah)

  INTEGER, PARAMETER :: OPT_TBOT = 2   !(suggested 2)

! options for snow/soil temperature time scheme (only layer 1)
! 1 -> semi-implicit; 2 -> full implicit (original Noah)

  INTEGER, PARAMETER :: OPT_STC = 1    !(strongly suggested 1)
```

5.0. CONTROL FILE CONTENTS AND FUNCTION

The filename of the control file is “`Run/noah_offline.namelist`”. The user may want to have a printout of the control file handy (about one page) when reviewing the comments below.

The control file is read-in early in the MAIN program and provides inputs of the following types of information: 1) the starting year, month, date, and time, 2) data directory containing forcing data and model output data, 3) time step and the height of the reference level. It looks like

```
 DIR  = "/home/sn21/niu/drbackup2/RELEASE/Noah_data"
 fini = 'arbitrary initialization'
 EXP         = "exp1"
 NSOIL       = 4
 NX          = 360
 NY          = 180
 NPOINT      = 15182
 ZSOIL(1)    = -0.10
 ZSOIL(2)    = -0.40
 ZSOIL(3)    = -1.00
 ZSOIL(4)    = -2.00
 START_YEAR  = 1980
 START_MONTH = 01
 START_DAY   = 01
 START_HOUR  = 00
 START_MIN   = 00
 end_year    = 1980
```

```
DT          = 10800.
ZLVL        = 10.0
```

NOTE: The control file does not provide model physical parameters. Physical parameters are set in subroutine `REDPRM` and many of these parameters are dependent on the veg-type index and soil-type index.

The control file consists of 19 data lines that contain the following:

`DIR`: The data directory containing directory `forcings/` for the atmospheric forcing data and directory `results/` for model results output.

`FINI`: The initial filename and directory. For the first run of the model, one does not have a global initial file, thus `fini` can be set to "arbitrary initialization". In such a case the model will automatically set up arbitrary initial values for all the prognostic variables. The model will output initial values once a year at the end of the year and save them in a directory named like "`Noah.ini.yyyy12312400.dat`" under directory `results/exp1/ini.` This initial file can then be used in reruns. Then `fini = "/home/sn21/niu/drbackup2/RELEASE/Noah_data/results/exp1/ini/Noah.ini.198012312400.dat"` for the spin-up run

`EXP:` The directory name for an experiment under directory `results/.` Before a new case run, one should manually create a new directory named like `exp2`/ under `results/`, and `hist/, ini/`, and `3hrly`/ under `exp2`/.

`NSOIL`: The number of soil layers. Note: `NSOIL` must be 2 or greater, NOT to exceed 20, strongly recommend at least 4

`NX`: The number of gridcells in east-west direction (360 for 1 degree resolution).

`NY`: The number of gridcells in north-south direction (180 for 1 degree resolution).

`NPOINT:` The total number of land points in the model domain. It is determined by the atmospheric forcing data.

`ZSOIL(1):` Layer-bottom depth of the 1st soil layer in meter.
`ZSOIL(2):` Layer-bottom depth of the 2nd soil layer in meter.
`ZSOIL(3):` Layer-bottom depth of the 3rd soil layer in meter.
`ZSOIL(4):` Layer-bottom depth of the 4th soil layer in meter.

Note: The physical equations in the LSM predict the soil moisture/temperature state variables at the midpoint of each model soil layer. **NOTE: The sum of all soil layer thicknesses should not exceed 7.5 meters** because lower boundary condition TBOT of soil temperature is applied at a hard-wired depth of 8.0 meters via hardwired value of ZBOT in routine HRT.

For beginners, we strongly suggest not to change the number of layers and thicknesses of layers, because we did not test these changes.

`START_YEAR:` Starting year (for the sample run = 1980)
`START_MONTH:` Strating month (for the sample run = 01)
`START_DAY:` Starting day (for the sample run = 01)
`START_HOUR:` Starting hour (for the sample run = 00)
`START_MIN:` Starting minutes (for the sample run = 00)

Note: These should be set up as exactly as possible in a case of point-scale run. The model will use these parameters to compute solar zenith angle (SZA). Also, to save computational time, surface albedos are not computed during nighttime (when SZA<0).

`END_YEAR:` Ending year (for the sample run = 1980). Note: the model will stop at the end of year 1980, i.e., 21:00 of 12/31, and save initial values for future use.

`DT:` Time step in seconds (3 hours for the sample run and determined by the GLDAS forcing data frequency).

`ZLVL:` Height in meters above ground of atmospheric forcing data. Note: In observed forcing data, the height of the temperature/humidity observation (e.g. 2 m) is often different from the height of the wind observation (e.g. 10 m). When that is the case, we recommend using the height of the wind observation.

6.0. MODEL INPUTS: 1. STATIC DATA

Under `RELEASE/Noah_data/static,` there are static data files at 1 degree resolution for determining model static parameters:

```
gvf.nc          landmask.nc     plotmask.nc     tbot.nc
gvf_org.nc      lon_lat.nc      soilcolor.nc    veg_soil.nc
```

`gvf_org.nc` contains the global, 12 month values of green vegetation fraction (GVF) aggregated from the global database and publication of

Gutman, G. and A. Ignatov, 1998: The derivation of the green vegetation fraction from NOAA/AVHRR for use in numerical weather prediction models. International Journal of Remote Sensing, 19, 1533-1543.

This latter work provides a 5-year, monthly mean, global database of green vegetation fraction at 0.144 degree resolution, obtained from NDVI. The authors forcefully argue that the two AVHRR channels that are used to derive NDVI do NOT provide sufficient degrees of freedom to derive BOTH vegetation greenness and LAI independently. They instead argue for embracing all the seasonality of vegetation in the greenness fraction and holding the LAI at a fixed constant annual value in the range of 1-5.

`gvf.nc` is only different from gvf_org.nc over boreal forest regions in winter months. `gvf_org.nc` over boreal forest in wintertime are unreasonably low, we replaced its wintertime GVF data over boreal forest grids with their annual mean values. This is the actual dataset used in the model.

`landmask.nc` contains the land-sea mask, land points are designated with 1, while the ocean points with 0. This file was derived from the GLDAS atmospheric forcing data.

`lon_lat.nc` contains the latitude and longitude of each of the model grid point. These values are mainly used to compute solar zenith angle.

`plotmask.nc` contains sequence numbers of land points. It is used to convert the forcing data in a 1-d array (see section 7.0) to a 2-d array and locate the land points in a way like:

```
do i=1,ix
do j=1,jx
  var2d(i,j)    = var1d(plotmask(i,j))
end do
end do
```

`tbot.nc` is the 1-degree annual mean 2-m air temperature used as the lower boundary condition for soil temperature.

`soilcolor.nc` is the soil color data to determine ground surface albedo over visible and near-infrared bands. It has 8 categories ranging from 1 to 8 to represent soil colors from light to dark.

```
! saturated soil albedos: 1=vis, 2=nir
    DATA(ALBSAT(I,1),I=1,8)/0.15,0.11,0.10,0.09,0.08,0.07,0.06,0.05/
    DATA(ALBSAT(I,2),I=1,8)/0.30,0.22,0.20,0.18,0.16,0.14,0.12,0.10/

! dry soil albedos: 1=vis, 2=nir
    DATA(ALBDRY(I,1),I=1,8)/0.27,0.22,0.20,0.18,0.16,0.14,0.12,0.10/
    DATA(ALBDRY(I,2),I=1,8)/0.54,0.44,0.40,0.36,0.32,0.28,0.24,0.20/
```

NOTE: for a case lack of soil color data, one may choose a medium dark color index (= 4 or 5). For a sandy soil or desert, it is better to choose the lightest index (=1).

`veg_soil.nc` contains the global vegetation type, top 30cm soil type, and 30cm-100cm soil type indices. These data are aggregated from the USGS 30 arc-second global vegetation type and the hybrid STATSGO/FAO soil texture datasets, maintained by the Research Application Laboratory (RAL) of NCAR and available at http://www.rap.ucar.edu/research/land/technology/lsm.php.

7.0 MODEL INPUTS: 2. ATMOSPHERIC FORCING DATA

Under `RELEASE/Noah_data/forcings,` there are 8 atmospheric forcing data files reprocessed from the Global Land Data Assimilation System (GLDAS) [*Rodell et al*., 2004] for one year period of 1980 at 1 degree resolution and 3-hourly interval.

```
lwdn_1980.nc   qair_1980.nc   snow_1980.nc   tair_1980.nc
psur_1980.nc   rain_1980.nc   swdn_1980.nc   wind_1980.nc
```

`tair_1980.nc`: air temperature at height Z above ground (K)
`qair_1980.nc`: specific humidity at height Z above ground (kg/kg)
`psur_1980.nc`: surface pressure at height Z above ground (pa)
`wind_1980.nc`: wind speed at height Z above ground (m/s)
`lwdn_1980.nc`: surface downward longwave radiation (W/m2)
`swdn_1980.nc`: surface downward solar radiation (W/m2)
`rain_1980.nc`: rainfall (mm/s)
`snow_1980.nc`: snowfall (mm/s)

Each file contains one-year data, or 2928 (1980 is a leap year) time steps at 3-hourly interval. To save disk space, only the land points, which were re-organized to a 1-d array, are included. Totally, the GLDAS dataset has 15182 land points. Each land point is located by its corresponding latitude/longitude saved in `RELEASE/Noah_data/static/plotmask.nc` by converting the 1d array to a 2d array in the code:
`RELEASE/IO_code/module_Noahlsm_gridded_input.F`

```
do i=1,ix
do j=1,jx
  var2d(i,j)    = var1d(plotmask(i,j))
end do
end do
```

8.0. INITIAL CONDITIONS

The model requires initial conditions for the prognostic variables. In case of lack of an initial condition file, one should start the model with "arbitrary initialization". The arbitrary initial conditions are set up in `RELEASE/IO_code/module_Noahlsm_gridded_input.F`, through `subroutine READINIT`.

The arbitrary initial conditions of all the prognostic variables are globally constants. The total volumetric soil moisture and liquid water volume are 60% of saturation. Soil temperature is given a global constant profile (274.0, 278.0, 280.0, and 284.0 from the 1st layer to the 4th layer). Canopy intercepted water (ice and liquid) is 0.0. Canopy temperature and ground surface temperature are 287.0. Snow water equivalent and snow depth are 0.0. Aquifer water storage is given as 4900.0 mm water to produce a 2.5m water table depth. The carbon storages, leaf, stem, fast& stable soil carbon, root, and wood, are set up as relatively small values to mimic young plants. These small values will affect plant and soil respiration and NPP. For short term leaf dynamics, the leaf mass is the most important and the fastest part to reach its equilibrium state.

Besides the above variables, we have some other non-prognostic variables that need arbitrary initial values:

```
   fwet        = 0.0     ! wetted fraction of canopy
   sneqvo      = 0.0     ! snow water equivalent at last time step
```

```
qsnow        = 0.0     ! snowfall on the ground through the canopy
wslake       = 0.0     ! lake water storage
eah          = 2000.   ! water vapor pressure within the canopy air
xlaixy(:,:) = 0.1     ! leaf area index
xsaixy(:,:) = 0.1     ! stem area index
```

One does not need to take care of these variables. Only the "wslake" should be taken care in a case when the lake water storage capacity can be determined from DEM.

When snow water equivalent and snow depth are not zero, subroutine "snow_init" in RELEASE/IO_code/module_Noahlsm_gridded_input.F will divide them into layers and set up initial temperature profile.

Once the model finishes a year run, the model will save the instantaneous values of all the prognostic variables as initial conditions for future use. The model will read in these values through "SUBROUTINE READINIT".

9.0. SPECIFYING MODEL PARAMETERS

The model parameters can be divided into two parts: the previous version Noah and the augmented parts.

The parameters used for the previous version Noah are all set in "GENPARM.TBL", "VEGPARM.TBL", and "SOILPARM.TBL".

The augmented parts still use the soil parameters of the previous version Noah "SOILPARM.TBL". Most of the vegetation parameters are set through "MODULE VEG_PARAMETERS" in "Noah_code/module_Noahlsm.F". The radiative parameters are set through "MODULE RAD_PARAMETERS" in "Noah_code/module_Noahlsm.F". The runoff-related and parameters remain buried inside the "Noah_code/module_Noahlsm.F". Snow-related parameters are set at the beginning part of "Noah_code/module_Noahlsm.F" in "MODULE NOAHLSM_GLOBALS".

A combination of optional schemes will automatically find all of its default parameters regardless of choices of the previous version of Noah schemes or the augmented parts. But, one should be very careful about changing parameters under a combination of optional schemes. Changing parameters in a scheme for a specific process may not function at all. For instance, if you change the runoff parameters of SIMGM but you select the Schaake99 runoff scheme, the change will not take effects.

A) Parameters used in the previous version of Noah

These parameters only function for schemes inherited from the previous version of Noah including:

1) Jarvis type stomatal resistance (OPT_CRS=2)
2) Soil moisture factor for stomatal resistance: Option Noah (OPT_BTR=1)

3) Original surface and subsurface runoff (free drainage) (`OPT_RUN=3`)
4) Surface layer drag coeff (CH & CM): original Noah (Chen97) (`OPT_RUN=2`)
5) supercooled liquid water: Koren's iteration (`OPT_FRZ=1`)
6) frozen soil permeability: nonlinear effects, less permeable (`OPT_INF=2`)
7) lower boundary condition of soil temperature: TBOT at ZBOT (8m) read from a file (`OPT_TBOT = 2`).

In "`GENPARM.TBL`":

`SLOPE` a coefficient between 0.1-1.0 that modifies the drainage out the bottom of the last soil layer. A larger surface slope implies larger drainage

`SBETA` `=-2.0`: used to compute veg canopy effect on ground heat flux as a function of greenness (not in use in the current version because of the separation of the canopy layer from the soil, but it is remained here to represent the effects of leaf litter in future)

`FXEXP` `= 2.0`: bare soil evaporation exponent (not actually in use)

`SALP` `= 2.6`: shape parameter used in function to infer percent area snow cover from snow depth (not actually in use)

`CSOIL` `= 2.0E+6`: soil heat capacity (J/m**3/K)

`REFDK` `=2.0E-6`: a parameter used with REFKDT below to compute sfc runoff parameter KDT

`REFKDT` `= 3.0`: surface runoff parameter (nominal range of 0.5 – 5.0)

NOTE: REFKDT is a tuneable parameter that significantly impacts surface infiltration and hence the partitioning of total runoff into surface and subsurface runoff. Increasing REFKDT decreases surface runoff. See next publication:

Schaake, J., V. Koren, Q.-Y. Duan, K. Mitchell, and F. Chen, 1996: Simple water balance model for estimating runoff at different spatial and temporal scales. J. Geophysical Res., 101, No. D3.

Note: REFDK corresponds to the saturation hydraulic conductivity Ksat for silty clay loam. If the latter parameter value is changed, then REFDK must be equated to that new value.

`FRZK` `=0.15` a base reference value (for light clay soil type) of parameter for the frozen-soil freeze factor representing the ice content threshold above which frozen soil is impermeable

ZBOT = -8.0 m: nominal depth of TBOT: lower boundary condition on soil temp (range 3-20m)

CZIL = 0.10: Zilintikevich parameter (range 0.0 - 1.0), recommended range 0.2 - 0.4

Note: CZIL is a tuneable parameter, which controls the ratio of the roughness length for heat to the roughness length for momentum, and is known as the Zilintikevich coefficient. This parameter effectively allows tuning of the aerodynamic resistance of the atmospheric surface layer. Increasing CZIL increases aerodynamic resistance. For a full description and example impacts of this primary parameter, see the article by

Chen, F, Z. Janjic, and K. Mitchell, 1997: Impact of the atmospheric surface-layer parameterizations in the new land-surface scheme of the NCEP mesoscale Eta model. Boundary-Layer Meteor., 85, 391-421

In "VEGPARM.TBL":

SHDFAC: green vegetation cover fraction (not in use, but use NESDIS monthly global dataset)

NROOT: number of soil layers from top down reached by roots

RS: (s/m) minimal stomatal resistance used in canopy resistance of routine CANRES

RGL: radiation stress parameter used in F1 term in canopy resistance of routine CANRES

HS: coefficient used in vapor pressure deficit term F2 in canopy resistance of routine CANRES

RSMAX =5000 (s/m) maximum stomatal resistance used in canopy resistance routine CANRES

TOPT = 298(K) optimum air temperature for transpiration in canopy resistance routine CANRES

Note: RSMAX and TOPT are not functions of vegetation class.

BARE: = 19, the barren surface type index.

Note: RTDIS was removed, but should be added back to represent a non-uniform vertical root-distributions dependent on vegetation class in future. A simple test showed the model is very sensitive to the vertical root distributions, while this sensitivity was not found in the NCAR CLM.

In "SOILPARM.TBL":

BB: the "b" parameter in hydraulic functions

DRYSMC: top layer soil moisture threshold at which direct evaporation from soil ceases

F11: soil thermal diffusivity/conductivity coefficient (not actually in use)

MAXSMC: maximum volumetric soil moisture (porosity)

REFSMC: soil moisture threshold for maximum transpiration

SATPSI: saturated soil matric potential

SATDK: saturated soil hydraulic conductivity

SATDW: saturated soil water diffusivity

WLTSMC: soil moisture wilting point at which transpiration ceases

QTZ: quartz content, used to compute soil thermal diffusivity

Note: FRZFACT is defined in the SUBROUTINE REDPRM

B) Parameters used in the augmented parts:

The parameters are described in detail through modules: MODULE VEG_PARAMETERS and MODULE RAD_PARAMETERS in RELEASE/Noah_code/module_Noahlsm.F. The rest are buried in the codes.

10.0 ISSUES TO BE ADDRESSED IN FUTURE RELEASES

10.1. Model physics developments

1. Lake model: explicit representation of lake water storage, sunlight through lake with different purity, turbulent mixing of surface lake water, snow on frozen lake, etc.

2. Shallow snow without a layer: melting energy should be more elaborately taken care.

3. Urban model to be added.

4. Irrigation component.

5. Lake and wetland dynamics and related CH4 emissions

6. Soil nitrogen and phosphorous cycles

10.2. IO part

1. The model parameters for the original Noah schemes and the augmented parts should be consistently set up in the future.

2. The model outputs for history files can be more flexibly chosen among 3hrly, daily monthly.

3. Initialization of the model and North America initialization products.

11.0 TECHNICAL REFERENCES

Niu G.-Y., Z.-L. Yang, K. E. Mitchell, F. Chen, M. B. Ek, M. Barlage, L. Longuevergne, M. Tewari, et al., 2009: The Community Noah Land Surface Model with Multi-Physics Options, JGR (to be submitted).