

# THE COMMUNITY Noah LAND-SURFACE MODEL (LSM)

## User's Guide Public Release Version 2.7.1

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[ftp://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/noahlsm/ver\\_2.7.1](ftp://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/noahlsm/ver_2.7.1)

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### 1.0 INTRODUCTION

This User's Guide provides execution guidance for and physical description of the public version of the community **Noah LSM**. This version of the **Noah LSM** is a stand-alone, uncoupled, 1-D column version used to execute single-site land-surface simulations. In this traditional 1-D uncoupled mode, near-surface atmospheric forcing data is required as input forcing (see Sec 6.0). This LSM simulates soil moisture (both liquid and frozen), soil temperature, skin temperature, snowpack depth, snowpack water equivalent (and hence snowpack density), canopy water content, and the energy flux and water flux terms of the surface energy balance and surface water balance. See Sec 10 for the lineage of key technical references.

The public server directory in which this User's Guide resides also contains the complete, self-contained **Noah LSM** source code file, input control file, input atmospheric forcing file, and example execution-time LSM output files for a full one-year 1998 simulation. This simulation is valid at the Champaign, Illinois surface-flux site (40.01 N, 88.37 W) of NOAA/ARL investigator Tilden Meyers. See Sec 3 for a "Quick-Start" guide to executing the **Noah LSM** code in this directory to duplicate the cited 1998 simulation at this site. To execute **Noah LSM** simulations at other sites for other initial times, study Secs 5 through 8.

(Reminder: See Sec 3 for a "Quick-Start" guide to executing the **Noah LSM**.)

## 2.0 MODEL HERITAGE

Beginning in 1990, and accelerating after 1993 under sponsorship from the GEWEX/GCIP/GAPP then GEWEX/GAPP Program Office of NOAA/OGP via collaboration with numerous GCIP/GAPP/GAPP 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 Coupled Atmospheric boundary layer - Plant - Soil, CAPS, model land-surface scheme 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/GAPP and other collaborators and b) tested and validated in both uncoupled and coupled studies (see review of these in Mitchell et al, 1999, 2000, and Ek et al. 2003). 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, 03 Jun 98, 24 Jul 01, 26 Feb 02 12 June 02. 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/GAPP PIs), we decided the NCEP LSM had advanced to a stage appropriate for formal public release (first in March 99).

In 2000, given a) the advent of the "New Millennium", 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:

- N: National Centers for Environmental Prediction (NCEP)
- O: Oregon State University (Dept of Atmospheric Sciences)
- A: Air Force (both AFWA and AFRL - formerly AFGL, PL)
- H: Hydrologic Research Lab - NWS (now Office of Hydrologic Dev -- OHD)

We in EMC strive to explicitly acknowledge both the multi-group heritage and informal "community" useage 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, Ek, Lohmann, Grunmann, Lin, Marshall, Chen, Rogers, Manikin, Pan)
- OSU: Oregon State University  
(Mahrt, Pan, Ek, Kim, Ruscher)
- HRL: NWS Hydrology Lab - formerly Office of Hydrology  
(Schaake, Koren, Duan)
- AFWA: Air Force Weather Agency - formerly AFGWC  
(Gayno, Mitchell, Moore)
- AFRL: Air Force Research Lab - formerly AFGL and PL  
(Mitchell, Chang, Hahn, Yang)

In addition to "in-house" **Noah LSM** development and validation by the above organizations, the following external PIs (primarily GCIP/GAPP), 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, Basara, and Crawford                   | U. Oklahoma         | (OU Mesonet)           |
| Bastidas, Burke, Yucel, Shuttleworth,<br>Sooroshian | U. Arizona          | (ARM/CART, AZNET)      |
| A. Robock and L. Luo                                | Rutgers U.          | (OU Mesonet, ARM/CART) |
| 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)         |
| L. Bowling and D. Lettenmaier                       | Univ. Washington    | (PILPS-2e)             |
| A. Boone and J. Noilhan                             | Meteo-France        | (Rhône/GLASS)          |
| K. Arsenault, B. Cosgrove, P. Houser                | NASA-HSB            | (LDAS)                 |

See Sec 10 for technical references on the above external validations.

Lastly, one crucial collaborator deserves special mention, namely the NESDIS Office of Research and Applications (Tarpley, Ramsay, Gutman, Kogan, Bailey), 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.

### 3.0 DIRECTORY CONTENTS AND QUICK-START GUIDE TO EXECUTION

#### 3.1 Basic\_with\_validation

The directory `/mmb/gcp/ldas/noahlsm/ver_2.7.1/basic_with_validation` on anonymous server `ftp.emc.ncep.noaa.gov` contains sixteen files as follows: 1) this User's Guide (file `NOAH_LSM_USERGUIDE_2.7.1.doc`), 2-3) the source code file split for the User's convenience into two mutually exclusive files representing a) "driver" routines and b) "physics" routines, 4) an input control file that defines model configuration and provides initial conditions, 5) an input atmospheric forcing file, 6) a doc file describing the source and valid period/location of this forcing file, 7-9) an input "namelist" file triad that allows input of non-default physical parameters, 10-14) five execution-time output files, resulting from an entire one-year 1998 simulation valid near the Champaign, Illinois surface-flux site of Tilden Meyers of NOAA/ARL. This site is located at the lat/lon coordinates of (40.01 N, 88.37 W), 15) this user's guide in text format, 16) a tar file that contains the aforementioned 15 files. The 16 filenames are listed below:

	<u>Filename</u>	<u>Contents</u>
1 --	<code>NOAH_LSM_USERGUIDE_2.7.1.doc</code>	This User's Guide
2 --	<code>DRIVER_WITH_VALIDATION.f</code>	"DRIVER" family of routines of <b>Noah_LSM</b>
3 --	<code>NOAH_LSM_SRC_2.7.1.f</code>	"PHYSICS" family of routines of <b>Noah_LSM</b> source code
4 --	<code>controlfile_ver_2.7.1</code>	Input control file
5 --	<code>forcing98_with_validation.dat</code>	Input near-surface atmospheric forcing file
6 --	<code>CHAMP_IL.doc</code>	Observing site description
7 --	<code>namelist_filename.txt</code>	1-line 50-char name of namelist-read input file
8 --	<code>soil_veg_namelist_ver_2.7.1</code>	namelist-read input file
9-	<code>doitall_2.7.1.sh</code>	Execute DRIVER and SRC
10-	<code>PRTSCREEN.TXT.Z</code>	Execution "print *" screen output
11-	<code>DAILY.TXT.Z</code>	Execution Output File 1
12-	<code>HYDRO.TXT.Z</code>	Execution Output File 2
13-	<code>THERMO.TXT.Z</code>	Execution Output File 3
14-	<code>OBS_DATA.TXT.Z</code>	Execution Output Data File
15-	<code>README</code>	This user's guide in text format
16-	<code>NOAH_LSM_2.7.1.tar</code>	tar file that contains the above 15 files

All files are text files, except files `NOAH_LSM_USERGUIDE_2.7.1.doc` and `CHAMP_IL.doc`, which are MS Word files. Download the tar file `basic_with_validation.tar` that contains all 15

files to your workstation. Use Unix command “tar -xvf basic\_with\_validation.tar” to create a Proceed with a **Noah LSM** execution test as described below.

First uncompress the “\*.Z” files with the Unix uncompress command.

The uncompress yields five upper-case “\*.TXT” files. **These TXT files are output files. Move these “TXT\* files to a separate sister directory for later comparison to the equivalent output files from your own local execution.**

The four lower-case files given by filenames

```
controlfile_ver_2.7.1
forcing98_with_validation.dat
namelist_filename.txt
soil_veg_namelist_ver_2.7.1
```

are the four input files required during the execution of lsm.x. The “controlfile” (see Sec 5) contains model configuration variables such as number and thickness of soil layers, number and length of time steps, initial date/time of the simulation, lat/lon location of the simulation site, initial conditions for all state variables, and site-specific land classifications (integer indexes for vegetation-type, soil-type, and surface-slope category).

The file obs98.dat (see Sec 6) contains one year’s worth (1998) of 30-min observed atmospheric forcing data and independent observed verification data (e.g. surface energy fluxes and soil temperature) valid at the Champaign, Illinois surface-flux site operated and maintained by Tilden Meyers of NOAA/ARL. The site is located at the lat/lon coordinates of (40.01 N, 88.37 W).

Now invoking

```
“doitall_2.7.1.sh”
```

will launch and complete the 1998 one-year LSM simulation for the aforementioned Illinois site, producing the same 5 “\*.TXT” output files that you obtained originally from the NCEP server. Normal termination of the execution is marked by the termination message “STOP: 0”. Since all the “\*.TXT” files are ascii files, one can and should confirm that the 5 output files from the local simulation agree very closely with the originally downloaded output files from NCEP.

The output file PRTSCREEN.TXT contains the output from “Print \*” write statements in the MAIN program. In this Version 2.7.1, these are the block of three “Print \*” statements located within the time-step loop in the PROGRAM MAIN source shortly after the return from CALL SFLX . These three Print \* statements output the time step counter and the small surface energy balance residual during each of the first 50 time steps and then every 50 time steps thereafter. The other four output files are the execution output data files of greater interest and their contents are described in Sec 9.

One important degree of freedom regarding these remaining four output files must be cited here. The unit numbers for these output files are 43, 45, 47, and 49, which are explicitly assigned in PROGRAM MAIN (via variable names NOUT1, NOUT3, NOUT5, and NDAILY). The sign of these assigned unit numbers controls whether the output is ascii or binary. The sign of all four

unit numbers is determined by a signed parameter (IBINOUT) read-in from the control file (see Sec 5). When the sign of IBINOUT is positive (negative), the format of these four output files is binary (ascii). When the output format is ascii (binary) then the extension \*.TXT (\*.GRS, meaning GrADS-readable) appears on the generated filename. The ascii choice (negative unit number sign) was invoked in the default control run you obtain from the server.

### 3.2 Basic

The directory `/mmb/gcp/ldas/noahlsn/ver_2.7.1/basic` on anonymous server `ftp.emc.ncep.noaa.gov` contains the same files as in the directory `basic_with_validation` except for 2 different files `DRIVER_BASIC.f` and `forcing_basic98.dat`. The file `CHAMP_IL.doc` is missing as it is irrelevant. The basic driver `DRIVER_BASIC.f` reads the near-surface input file `forcing_basic98.dat` that contains only the 7 observed variables required for constructing **Noah LSM** forcing (cf. Sec. 6.2). This basic driver is designed for reading data from regular surface sites that do not measure surface fluxes or subsoil properties.

## 4.0 SUBROUTINE SUMMARY AND CALLING TREE

Below, we describe PROGRAM MAIN in the "Driver family" of subroutines (file `DRIVER_WITH_VALIDATION.f` or `DRIVER_BASIC.f` as described in Sec. 3.2) and the "Physics family" of subroutines (file `NOAH_LSM_2.7.1.f`), comprised of physics "sub-driver" routine `SFLX` and all subordinate subroutines.

### 4.1 The Driver Routines

Briefly the ten main steps of the MAIN program are:

- 1) read in control file ( model configuration, site characteristics, and initial conditions)
- 2) open output file unit numbers
- 3) invoke time-step loop (including optional spin-up loop if indicated by control file)
- 4) read atmospheric forcing data and change its sign and units as expected by `SFLX`
- 5) interpolate monthly-mean surface greenness and albedo to julian day of time step
- 6) assign downward solar and longwave radiation from input forcing
- 7) calculate actual and saturated specific humidity from input atmospheric forcing
- 8) assign wind speed from input forcing
- 9) invoke LSM physics (`CALL SFLX`) to update state variables / sfc fluxes over one time step
- 10) write simulation output data each time step to four output files

The section in driver PROGRAM MAIN associated with each of the above ten steps is clearly delineated with comment line "DRIVER STEP n".

NOTE: The section of PROGRAM MAIN for Step 6 includes optional code (presently commented out) for calculating the downward radiation from the input air temperature and humidity if the input forcing file does not provide it.

NOTE: The section of PROGRAM MAIN for Step 8 includes optional code (presently commented out) for invoking a User-provided routine to calculate the surface exchange coefficient for heat (Ch) in place of the default scheme.

### PROGRAM MAIN Calling Tree

- READCNTL: read control file (including LSM initial conditions and site characteristics)
- ----- Begin optional Multi-year Spin-Up Loop: if invoked by control file -----
- ----- Begin: Time Step Loop -----
- READBND : read atmospheric forcing data (and observed validation variables)
- MONTH-D: interpolate monthly albedo and veg greenness to current julian day
- -- JULDATE: determine julian day for current time
- QDATAP: calculate actual and saturated specific humidity
- -- E (function) calculate vapor pressure
- DQSDT (function): slope of sat specific humidity wrt air temp (needed in PENMAN)
- -- DQS (function) intermediate value for routine dqsd
- SFLX: call to family of physics routines (see Sec 4.2) \*\*\*\* key call \*\*\*\*
- PRTDAILY: write daily total values to output file 1 (once a day only)
- PRTHYDF: write LSM water related variables to output file 2 (every time step)
- PRTHMF: write LSM energy related variables to output file 3 (every time step)
- PRTBND: write out input atmospheric forcing to output file 4 (every time step)
- ----- End: Time Step Loop -----
- -----End: Optional Multi-year Spin-Up Loop-----
- STOP 0

### 4.2 The SFLX Family of Subroutines

The SFLX family of subroutines contain the physics of the LSM and is rather self-contained. Each user should become familiar with the argument list of SFLX. This argument list is thoroughly documented at the top of subroutine SFLX. Once becoming familiar with the argument list, users could if they so choose create their own MAIN driver program with reasonably little effort. Calling SFLX each time step updates and returns all the LSM state variables and all the surface energy balance and surface water balance terms. In using SFLX in a coupled atmospheric model, the output arguments needed from SFLX are:

- ETA - latent heat flux
- H - sensible heat flux
- T1 - skin temperature (from which to calculate upward longwave radiation)
- ALBEDO - (including snowpack effects) for calculating upward solar radiation

### SUBROUTINE SFLX Calling Tree

- REDPRM -- set land-surface parameters
  - set soil-type dependent parameters
  - set veg-type dependent parameters
  - set other land-surface parameters

SNO\_NEW – update snow depth and snow density to account for new snowfall  
SNFRAC – determine snow cover fraction  
ALCALC – determine surface albedo (including snow cover fraction)  
TDFCND – compute soil thermal diffusivity  
SNOWZ0 – compute snow roughness length (currently a null/no effect process)  
SFCDF -- calculate surface exchange coefficient for heat/moisture  
PENMAN – compute potential evaporation  
CANRES – compute canopy resistance

**NOPAC** – this path invoked if ZERO snowpack on ground and zero snowfall (frozen precip)  
-- surface skin temperature updated via surface energy balance

**SMFLX** – compute a) surface water fluxes and b) layer soil moisture update

DEVAP- compute direct evaporation from top soil layer

TRANSP – compute transpiration from vegetation canopy

SRT – compute time-rate-of-change of soil moisture

WDFCND – compute hydraulic conductivity and diffusivity

SSTEP – forward time-step integration of soil moisture rate-of-change

ROSR12 – tri-diagonal matrix solver

TDFCND – compute soil thermal diffusivity

**SHFLX** – compute a) ground heat flux and b) layer soil temperature update

HRT – compute time-rate-of-change of soil temperature

TDFCND – compute soil thermal diffusivity (dependent on soil moist.)

TBND – determine soil layer interface temperature

SNKSRC –(function) compute heat sink/source from soil ice phase change

TDFCND – compute soil thermal diffusivity

FRH2O – (function) calculate subzero unfrozen soil water

(or HRTICE – as in HRT, but for sea-ice pack)

HSTEP – forward time step integration of soil temperature rate-of-change

ROSR12 – tri-diagonal matrix solver

**SNOPAC** – this path invoked if NONZERO snowpack on ground and/or NONZERO snowfall

- surface skin temperature updated via surface energy balance
- new patchy snow cover treatment in above
- snowmelt computed if thermal and available energy conditions warrant

**SMFLX** – see above

DEVAP – see above

TRANSP – see above

SRT – see above

WDFCND – see above

SSTEP – see above

ROSR12 – see above

**SHFLX** – see above

HRT – see above

TDFCND – see above

TBND – see above

SNKSRC – see above

TDFCND – see above



FRH2O – see above  
HSTEP – see above  
ROSR12 – see above  
SNOWPACK – update snow depth and snow density owing to snow compaction

### **NOTES on SFLX Calling Tree:**

- 1 – Both the NOPAC and SNOPAC branches treat freezing processes within soil
- 2 – Calling sequences **under** NOPAC and SNOPAC via SMFLX and SHFLX are very similar
- 3 – Snowpack physics in SNOPAC are treated mainly “in-line”, before calls to SMFLX/SHFLX
- 4 – SHFLX and subordinates do heat fluxes and soil temperature update
- 5 – SMFLX and subordinates do water fluxes and soil moisture update
  - SMFLX operates independently of the soil thermodynamics (SHFLX) and can stand alone, requiring only inputs of precipitation and potential evaporation
  - SHFLX cannot operate independently of soil hydraulics, unless thermal conductivity dependence on soil moisture dependence is removed (in routine TDFCND)

## **5.0 CONTROL FILE CONTENTS AND FUNCTION**

The filename of the control file is “controlfile\_ver\_2.7.1”. 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: a) valid location and start date/time of simulation, b) model configuration, c) name of input forcing file, d) integer indexes for land-sfc classes for the site, e) initial values of all the model state variables.

**NOTE:** The control file does not provide model physical parameters, except for the lower boundary condition on the soil temperature (which should be assigned the value of the annual mean sfc air temperature for the simulation location). Physical parameters are set in subroutine REDPRM and many of these parameters are dependent in REDPRM on the veg-type index and soil-type index read from the control file.

### **The control file consists of 30 data lines that contain the following:**

Line 01: LAT - simulation site latitude (positive N from equator, hundredths of a degree)

Line 02: LON - simulation site longitude (positive W from Greenwich, hundredths of a degree)

Note: The above serve only to document the valid site of the input forcing data.

The physics do not use the above, since forcing data provides downward solar radiation.

Above would be needed by a MAIN driver that had to calculate downward solar radiation

Line 03: IBINOUT - either positive interge "1", or negative integer "-1".

Negative sign invokes ascii text output files with extension \*.TXT

Postive sign invokes binary output files with extension \*.GRS -denoting GrADS readable

Line 04: JDAY - Integer Julian Day (1-366) of start of forcing data (start of simulation)  
Line 05: TIME - 4-digit "hhmm" integer time of day (local) at start of forcing data,  
hh is 2-digit hour (0-23) and mm is 2-digit minute (0-59).

Note: Except for use of JDAY to to temporal interpolation of monthly greenness and albedo read-in later below, the above JDAY and TIME serve only to document the valid start date/time of the input forcing data. The physics do not use the above, since forcing data provides downward solar radiation. Above would be needed by a MAIN driver that had to calculate downward solar radiation

Line 06: NCYCLES – number of times the integration will cycle through the input forcing data (useful for multi-year spin-up runs, wherein input forcing file spans one complete year)

Line 07: SYDAYS - number of days in spin-up year (either 365 or 366)  
(relevant only if NCYCLE is 2 or greater)

Line 08: L2nd\_data: logical variable: value of .true. or .false.

**if TRUE:** then NCYCLES must be set to 2 or greater, and thus invokes spin-up runs of NCYCLE-1 spin-up years with first forcing file given below, followed by 1 final cycle (not necessarily full year)executed from second forcing file below and representing the final production run period. Will write output only during final cycle, unless two forcing files have the same name, then will write output from each cycle

**if FALSE:** then only first named forcing file is used, still for the number of cycles given by NCYCLE, and will write output from every cycle

Note: The true option for L2nd\_data is useful for multi-year "PILPS-type" spin-up runs

For forcing files spanning only a partial year, L2nd\_data should be false and NCYCLE=1

Line 09: NRUN is the total number of simulation time steps per cycle.

Line 10: DT – floating point length of time step (secs) used in physical integration

Note: DT should NOT be larger than one hour (3600 secs)

Note: There must be one forcing data record in forcing file for each time step

Line 11: NSOIL - integer number of soil layers

Note: **NSOIL must be 2 or greater, NOT to exceed 20, strongly recommend at least 4**

Line 12: Z – 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 for Z.

Line 13: SLDPTH - thickness values for the NSOIL soil layers in meters (chosen by user), starting with the uppermost layer and proceeding downward

Note: We recommend that each succeeding soil layer downward not exceed 3 times the thickness of the soil layer above it. For the common 4-layer configuration, we recommend

Layer 1: 10 cm (.10 m)  
Layer 2: 30 cm (.30 m)  
Layer 3: 60 cm (.60 m)  
Layer 4: 100 cm (1.0 m)

Note: The physical equations in the LSM predict the soil moisture/temperature state variables at the midpoint of each model soil layer.

**NOTE:!! Sum total of all soil layer thicknesses should not exceed about 2/3 of depth parameter ZBOT.** The lower boundary condition TBOT of soil temperature is applied at the depth specified by parameter ZBOT, whose current default value of -8.0 meters is set in routine REDPRM (ZBOT follows negative sign convention for soil depth), but this default can be changed via the optional NAMELIST I/O in REDPRM.

Line 14: - filename of the first input forcing file (up to 72 characters)

Line 15: - filename of the second input forcing file (up to 72 characters)

Note: see above discussion of logical variable "L2nd\_data

Note: the two forcing files may be the same name (used for both spin-up and production years)

**NOTE !! : User should contact NCEP Point of Contact given at top of Page 1 for recommended values for Lines 12-18**

Line 16: SOILTYP - soil type integer index (range 1-9), see definitions in routine REDPRM

Line 17: VEGTYP veg type integer index (range 1-13), see definitions in routine REDPRM

Line 18: SLOPTYP sfc slope integer index (range 1-9), see definitions in routine REDPRM

Note: SLOPTYP is a sfc slope category (flat, steep, mixed, etc) used in the bottom drainage

Line 19: ALBEDO – 12 monthly values of surface albedo fraction (snow-free) for simulation site

Note: LSM physics will internally add snow cover effects to ALBEDO

Line 20: SHDFAC - 12 monthly values of green vegetation fraction for simulation site

**NOTE !!** See contact point at top of this User's Guide to get monthly vegetation greenness values for your simulation site of interest.

NCEP now sets monthly SHDFAC using 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 (thus LAI becomes a tuning parameter). NCEP has obtained reasonable behavior with LAI=4.

Line 21: SNOALB – maximum albedo expected over deep snow

Note: NCEP takes the above from the 1-degree, N. Hemisphere, digital database of Robinson, D.A., and G. Kukla, 1985: Maximum surface albedo of seasonally snow-Covered Lands in the Northern Hemisphere. J. Climate Appl. Meteor., 23, 1626-1634 (See Fig. 4 therein for depiction from digital database).

Line 22: ICE – Flag to invoke sea-ice physics (always set to 0 for land-mass simulations)

Note: The integer flag “ICE” forces branch to sea-ice physics in LSM.  
Be aware that this ICE flag has no bearing on soil ice physics in NCEP LSM.

Line 23: TBOT – set to the climo annual mean sfc air temperature (K) for the modeled site

Note: TBOT serves as the annually fixed, soil-temperature bottom-boundary condition at a soil depth of ZBOT. ZBOT is currently set at a default 8-meter depth (-8.0) in routine REDPRM. ZBOT is the assumed nominal soil depth where the amplitude of the soil-temperature annual cycle is near zero (e.g. about double the e-folding depth in the soil of the annual cycle of surface air temperature).

#### **Initial conditions for all state variables follows:**

Line 24: T1 – initial skin temperature (K). Can be set to initial air temperature. Model physics rapidly spins this up in first few 2-3 time steps.

Line 25: STC (1-NSOIL): initial soil temperature (K), in each soil layer

Line 26: SMC (1-NSOIL): initial volumetric total soil moisture (liquid and frozen) in each layer (usually in the range .1-.43)

Note: Initial SMC should not exceed soil saturation (porosity), as set in routine REDPRM for given soil class.

Line 27: SH2O (1-NSOIL): initial volumetric liquid soil moisture (unfrozen) in each layer

Note: initial SH2O must not exceed porosity, nor exceed initial SMC

NOTE: During conditions of no soil freezing, SH2O=SMC in each layer.

NOTE: Initializing soil ice (case of SH2O less than SMC) is very difficult. Recommend starting the model run in the warm season and letting the physics spin-up soil ice, or running multi-year spin-up cycles.

Line 28: CMC – initial canopy water content (m). Set to zero as physics rapidly spins this up.

Line 29: SNOWH – initial snow depth (m)

Line 30: SNEQV – initial water equivalent (m) of above snowdepth. If not observed, dividing SNOWH by 5 gives a nominal initial value.

## 6.0 ATMOSPHERIC FORCING FILE

### 6.1 Forcing with Validation

As is typical with many off-line, uncoupled LSMs, the NCEP LSM requires the following near-surface atmospheric forcing data, preferably at 30-minute time intervals (or interpolated to 30-minute time intervals or smaller from say 1-6 hour interval observations -- Aside note: for observation intervals longer than 1-hour, the incoming surface solar insolation needs to be interpolated with a solar zenith angle weighting, in order to capture the full amplitude of the diurnal solar insolation).

Air temperature at height Z above ground  
Air humidity at height Z above ground  
Surface pressure at height Z above ground  
Wind speed at height Z above ground  
Surface downward longwave radiation  
Surface downward solar radiation  
Precipitation

For the example one-year LSM simulation provided with this User's Guide, we were extremely fortunate to benefit from the collaboration of GCIP/GAPP-sponsored PI Tilden Meyers of NOAA/ARL, who operates a flux site located just south of Champaign, IL (40.01 N lat, 88.37 W lon).

The site characteristics and observing instrumentation are described in the MS Word document CHAMP\_IL, provided by courtesy of Tilden Meyers, and available in same directory as this User's Guide.

The 1998 forcing file from the above flux site is available as filename "forcing98\_with\_validation.dat" in the same directory as this User's Guide. This file contains one record for each 30-minute observation time and the file spans the entire calendar year of 1998 (hence  $2 \times 24 \times 365 = 17520$  records). Each 30-min record provides the following 33 observed variables (including the 7 required LSM forcing variables, marked by "\*\*\*"), listed in the order they appear in each record of the file:

jday                      Julian Day

	time	LST, half hour ending
	w_speed	propeller anemometer (10 meters, Bondville ISIS)
	w_dir	wind direction (10 meters, Bondville ISIS)
**	Ta	air temperature (C), at 3 m
**	RH	relative humidity at 3 m (list continued)
**	Pres	surface pressure in mb
**	Rg	incoming solar radiation (W/m2)
	Par_in	incoming visible radiation (0.4-0.7 um) in uE/m2/s
	Par_out	outgoing or reflected visible light
	Rnet	net radiation (W/m2)
	GHF	soil or ground heat flux (W/m2)
**	rain	total rain for half hour (inches)
	wet	wetness sensor (in voltage with higher values indicating wetness)
	IRT	surface or skin temp (C)
	2_cm	soil temp at 2 cm (C)
	4_cm	soil temp at 4 cm
	8_cm	soil temp at 8 cm
	16_cm	soil temp at 16 cm
	32_cm	soil temp at 32 cm
	64_cm	soil temp at 64 cm
**	u_bar	average wind vector speed at 6-meters (m/s)
	u'w'	kinematic shear stress (m2/s2)
	u'2	streamwise velocity variance (m2/s2)
	v'2	crosswind velocity variance (m2/s2)
	w'2	vertical velocity variance(m2/s2)
	H	sensible heat flux (W/m2)
	LE	latent energy flux (W/m2)
	CO2	CO2 flux (mg CO2/m2/s)
**	LW_in	downwelling longwave from sky (W/m2)
	sm_5	soil volumetric water content at 5 cm zone (after November 19 1997)
	sm_20	soil volumetric water content at 20 cm zone (after November 19 1997)
	sm_60	soil volumetric water content at 60 cm zone (after November 19 1997)

In the LSM, program MAIN reads in all 33 of the above variables at each time step via the call to subroutine READBND, which also fills in occasional missing observations. Missing obs are very sparse and virtually always involve missing values of the wind speed (u\_bar at 6 m), for which the READBND software substitutes (w\_speed at 10 m with a reduction factor). Finally, the last section of routine READBND performs unit conversions on “rain”, “Ta”, and “Pres” to convert them to the units expected in the call to SFLX .

In addition to the LSM-required atmospheric forcing variables in the above list, the other variables in the list represent either a) independent validation data or b) useful initial conditions for the LSM state variables. LSM initial conditions are discussed in the next section.

At each time step in the MAIN program, after the return from the physics update in CALL SFLX, useful LSM validation data from the above observation file is written out to validation

output file OBS\_DATA.TXT via call to routine PRTBND (e.g. LE, H, GHF, RNET, IRT, and the layer by layer soil moisture and temperature).

## 6.2 Basic Forcing

The basic input near-surface atmospheric forcing file forcing98\_basic.dat is a subset of the input file forcing98\_with\_validation.dat described in Section 6.1. This basic input forcing file is located at: [ftp://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/noahlsn/ver\\_2.7.1/basic](ftp://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/noahlsn/ver_2.7.1/basic)

This file contains one record for each 30-minute observation time and the file spans the entire calendar year of 1998 (hence  $2 \times 24 \times 365 = 17520$  records). Each 30-min record provides the following 9 observed variables (including the 7 required LSM forcing variables, marked by “\*\*”), listed in the order they appear in each record of the file:

	jday	Julian Day
	time	LST, half hour ending
**	Ta	air temperature (C), at 3 m
**	RH	relative humidity at 3 m
**	Pres	surface pressure in mb
**	Rg	incoming solar radiation (W/m2)
**	rain	total rain for half hour (inches)
**	u_bar	average wind vector speed at 6-meters (m/s)
**	LW_in	downwelling longwave from sky (W/m2)

## 7.0 LSM INITIAL CONDITIONS

The LSM requires input values (read-in from control file in routine READCNTL, see Sec 5 for details on units) of the following state variable initial conditions :

- 1 – SMC: total volumetric soil moisture (liquid and frozen) in each soil layer
- 2 – SH2O: liquid volumetric soil moisture in each soil layer
- 3 – STC: temperature in each soil layer
- 4 – T1: skin temperature
- 5 – CMC: canopy water content
- 6– SNOWH: snow depth
- 7 - SNEQV: water-equivalent snow depth

Typically, a number of these state variables are not observed at a given validating observation site. The following initial variables were not available in the site observation file (obs98.dat):

SNEQV, SNOWH, CMC, nor SMC (and SH2O) below 60 cm

Since January 1998 was mild (El’Nino) at the given site, we assumed a) zero snow cover (SNOWH=0.0, SNEQV=0.0) and b) zero soil ice (SMC=SH2O), plus we set CMC=0.

While we in general found the physical behavior of the observed data in file obs98.dat to be very good, inspection of the **observed** soil moisture at the 20 and 60 cm levels showed them to be virtually time invariant over the entire year, despite substantial wetting and drying periods. Hence their accuracy is very suspect.

It is typical for LSM simulations at a particular observation site to be hampered by non-observed (e.g. snowdepth, frozen soil moisture, deep soil moisture ) or ill-observed initial state variables (e.g. soil moisture). Facing this dilemma, the Project for Intercomparison of Land-Surface Process Schemes (PILPS) has come to urge modelers to use a one-year spin-up protocol, whereby the simulation for a desired period (1998 here) is preceded by a spin-up year (say 1997 in this case) where the spin-up year forcing is repeated several years to allow the LSM to essentially achieve equilibrium.

Tilden Meyers provided us with the 1997 forcing data for his site, and we proceeded to execute the PILPS-recommended spin-up protocol to provide all initial soil states for the one-year 1998 production run provided in this directory.

Specifically, in a prior run using the same model configuration as in the control file given here and using L2nd\_data = .false., NCYCLES= 10, and the aforementioned 1997 forcing file we call "obs97.dat", we executed a 10-year spin-up run over the 1997 annual cycle in order to derive initial conditions of soil state and snow state (turned out zero snowpack, because of warm fall and early winter in 1997) for the 1998 production run provided here in the directory with this User's Guide. In practice, a full 10-years of spin-up is not needed. We generally recommend 3-5 years of spin-up.

## 8.0 SPECIFYING MODEL PARAMETERS

The vast majority of the **Noah LSM** land-surface parameters are set in subroutine REDPRM. However, the assignment of some land-surface parameters have not yet been "collected" into the REDPRM setting and remain buried deep in the LSM code. We feel these exceptions are primarily parameters of secondary or tertiary importance. A few exceptions may be some parameters used in the snowpack physics, such as the parameter that controls the amount of supercooled water allowed in the soil over a range of sub-freezing temperatures. We are working to identify such parameters and bring them into the REDPRM setting in a future release.

In a broader sense, one should also consider the number (NSOIL) and thickness (SLDPTH) of the soil layers (especially thickness of top soil layer) specified in the control file to be adjustable parameters.

Before proceeding further in this section, the reader should have on hand a copy of the subroutine REDPRM.

In REDPRM, we define the NAMELIST named "/SOIL\_VEG/", which includes **ALL** the parameters defined in REDPRM, including parameter arrays whose elements depend on soil type, vegetation type, or slope type. Moreover, this namelist includes three variables that respectively define the number of classes (up to a maximum of 30) that we carry for soil type,





& BB, DRYSMC, F11, MAXSMC, REFSMC, SATPSI, SATDK, SATDW,  
 & WLTSMC, QTZ, LPARAM, ZBOT\_DATA, SALP\_DATA, CFACTR\_DATA,  
 & CMCMAX\_DATA, SBETA\_DATA, RSMAX\_DATA, TOPT\_DATA,  
 & REFDK\_DATA, FRZK\_DATA, BARE, DEFINED\_VEG, DEFINED\_SOIL,  
 & DEFINED\_SLOPE, FXEXP\_DATA, NROOT\_DATA, REFKDT\_DATA, Z0\_DATA,  
 & CZIL\_DATA, LAI\_DATA, CSOIL\_DATA, SMLOW\_DATA, SMHIGH\_DATA

In the above list, there are five kinds of land-surface parameters, reviewed in order below.

- a) single universal values
- b) values dependent on the soil class index (default categories are 1- 9)
- c) values dependent on the vegetation class index (default categories are 1-13)
- d) values dependent on the surface slope index (default categories are 1-7)
- e) parameters specifying the numbers of vegetation, soil, and slope classes

**A) Universal values (16)** (current default value in this release listed)

**CZIL** = 0.20: 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 Meteorol.*, 85, 391-421

**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.

**ZBOT** = -8.0 m: nominal depth of TBOT: lower boundary condition on soil temp (range 3-20m) (see discussion of ZBOT in discussion of TBOT in notes below Lines 13 and 23 of Control File in Section 5.0)

**SMLOW** = 0.5: ‘spread’ factor for SMCWLT

**SMHIGH** = 3.0: ‘spread’ factor for SMCREF

**FXEXP** = 2.0: bare soil evaporation exponent (=1 yields linear reduction of bare soil evaporation with decreased soil moisture between SMCMAX and SMCDRY, >1 yields greater-than-linear reduction)

**SBETA**= -2.0:used to compute veg canopy effect on ground heat flux as a function of greenness

**CSOIL** = 2.00E+6: soil heat capacity (J/m\*\*3/K)

**SALP** = 2.7.1:shape parameter used in function to infer percent area snow cover from snow depth

**CFACTOR** = 0.5: exponent used in function for canopy water evaporation

**CMCMAX** =0.0005 (m): maximum canopy water capacity used in canopy water evaporation

**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

**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

**RTDIS**: array specifying vertical root distribution, i.e. the fraction of total root mass present in each soil layer

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

Note: Presently, RTDIS is set universally (not dependent on vegetation class) and assumes a uniform root distribution throughout the specified number of root layers for the given vegetation class.

## **B) Soil-class dependent parameter arrays (10)**

Routine REDPRM applies 9 soil texture classes. These classes are defined near the top of routine REDPRM. The parameters dependent on soil class are:

**SMCMAX**: maximum volumetric soil moisture (porosity)

**SMCREF**: soil moisture threshold for onset of some transpiration stress

**SMCWLT**: soil moisture wilting point at which transpiration ceases

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

**DKSAT**: saturated soil hydraulic conductivity

**PSISAT**: saturated soil matric potential

**B**: the “b” parameter in hydraulic functions

**DWSAT**: saturated soil water diffusivity

**QUARTZ**: quartz content, used to compute soil thermal diffusivity

**FRZFACT**: a parameter used with FRZK to compute the value of parameter FRZX

Note: if soil parameters such as SMCMAX and SMCREF or soil classification scheme are changed, then parameters FRZK and FRZFACT must be changed

## **C) Vegetation-class dependent parameters arrays (7)**

Routine PRMVEG applies the 13 “SiB” vegetation classes. These classes are described in the comment block at the top of routine PRMVEG. The seven veg-class dependent parameters are:

**Z0:** (m) roughness length

**RCMIN** (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

**LAI:** presently set to universal value of 4.0 across all vegetation classes

Note: seasonality of vegetation greenness carried by fraction of green vegetation (SHDFAC)

**NROOT:** number of soil layers from top down reached by roots; note:  $NROOT \leq NSOIL$

**SNUP:** the water-equivalent snowdepth upper threshold at which

- 1) 100 percent snow cover is achieved for given veg class
- 2) maximum snow albedo is achieved for given veg class

#### **D) Surface-slope dependent parameter arrays (1)**

Routine REDPRM embodies 7 categories of surface slope. These categories are described in a comment block near the top of routine REDPRM. The parameter dependent on slope class is:

**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

#### **E) Classification dimension parameters (3)**

Vegetation Types ("SiB-1") after Dorman and Sellers (1989; JAM)

**DEFINED\_VEG** = 13: the number of SiB-1 vegetation class categories, assigned as follows:

- 1: BROADLEAF-EVERGREEN TREES (TROPICAL FOREST)
- 2: BROADLEAF-DECIDUOUS TREES
- 3: BROADLEAF AND NEEDLELEAF TREES (MIXED FOREST)
- 4: NEEDLELEAF-EVERGREEN TREES
- 5: NEEDLELEAF-DECIDUOUS TREES (LARCH)
- 6: BROADLEAF TREES WITH GROUNDCOVER (SAVANNA)
- 7: GROUNDCOVER ONLY (PERENNIAL)
- 8: BROADLEAF SHRUBS WITH PERENNIAL GROUNDCOVER
- 9: BROADLEAF SHRUBS WITH BARE SOIL
- 10: DWARF TREES AND SHRUBS WITH GROUNDCOVER (TUNDRA)
- 11: BARE SOIL
- 12: CULTIVATIONS (THE SAME PARAMETERS AS FOR TYPE 7)
- 13: GLACIAL (THE SAME PARAMETERS AS FOR TYPE 11)

Soil Types after Zobler (1986), except for quartz after Cosby et al (1984)

**DEFINED\_SOIL** = 9: the number of Zobler soil class categories, assigned as follows:

	<u>TEXTURE</u>	<u>DESCRIPTION</u>	<u>QUARTZ CONTENT</u>
1	COARSE	LOAMY SAND	(0.82)
2	MEDIUM	SILTY CLAY LOAM	(0.10)
3	FINE	LIGHT CLAY	(0.25)
4	COARSE-MEDIUM	SANDY LOAM	(0.60)
5	COARSE-FINE	SANDY CLAY	(0.52)
6	MEDIUM-FINE	CLAY LOAM	(0.35)
7	COARSE-MED-FINE	SANDY CLAY LOAM	(0.60)
8	ORGANIC		(0.40)
9	GLACIAL LAND ICE	LOAMY SAND	(0.82)

Slope Types after Zobler (1986)

**DEFINED\_SLOPE** = 9: the number of Zobler defined slope categories, assigned as follows:

SLOPE CLASS	PERCENT SLOPE
1	0-8
2	8-30
3	> 30
4	0-30
5	0-8 & > 30
6	8-30 & > 30
7	0-8, 8-30, > 30
8	GLACIAL ICE
9	OCEAN/SEA

## 9.0 EXECUTION OUTPUT FILES

There are five execution-time output files:

**PRTSCREEN.TXT**: holds results from “Print \* “ output via execution command line syntax of “lsm.x >PRTSCREEN.TXT” (i.e. capture of “screen” print). Presently file contains the surface energy balance residual and time-step value for first 50 time steps, then every 50 steps thereafter.

- a) **DAILY.TXT**: contains daily-defined output values once-per-day, from routine **PRTDAILY**, such as daily total evaporation and precipitation.
- b) **HYDRO.TXT**: contains water related outputs at every "time step", from routine **PRTHYDF**, such as actual and potential evaporation, soil moisture, snowdepth, snowmelt, runoff.
- c) **THERMO.TXT**: contains energy related outputs at every "time step", from routine **PRTHMF**, such as skin temperature, soil temperature, and all surface energy fluxes
- d) **OBS\_DATA.TXT**: output of observed input forcing/validation data, from routine **PRTBND**,

such as incoming radiation, skin temperature, soil temperature, precip, net radiation, latent, sensible, and ground heat fluxes (i.e. this file echoes the input observation file “obs98.dat”, but with some units conversion for compatibility with other model outputs)

## 10.0 MODEL HISTORY

Directory Contents/Notes

---

AFWA/ nearly equivalent to ver 2.2

---

Eta\_2.3/ ops version of Noah LSM ver 2.3

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Eta\_2.3.1/ ops version of Noah LSM ver 2.3.1

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ver\_2.3/ Noah LSM in operational mesoscale Eta model, nearly identical physics to version 2.2 (July 2001)

---

ver\_2.3.1/ ver 2.3 +  
modifications to soil heat flux for patchy snow cover

---

ver\_2.3.2/ ver 2.3.1 +  
modification to soil moisture availability function in bare soil evaporation calculation

---

ver\_2.4/ identical physics to ver 2.3, but with code re-organization, more efficient code, comments, etc.

---

ver\_2.5/ bug fix to TDFCND  
soil heat capacity =  $2.0E+6$  [J/m<sup>3</sup>/K]  
ZBOT = -8 (meters)

---

ver\_2.5.1/ ver 2.5 +  
modifications to soil heat flux for patchy snow cover

---

ver\_2.5.2/ ver 2.5.1 +  
modification to soil moisture availability function in bare soil evaporation calculation

---

ver\_2.6/ ver 2.5.2 +  
change parameter CZIL from 0.20 to 0.075  
reduce the parameter SMCREF  
reduce interval between SMCREF and Field Capacity by 1/2  
remove vegetation greenness factor from snow-albedo functn  
reduce value of parameter SNUP by 1/2  
increase value of parameter SALP from 2.6 to 4.0

---

ver\_PILPS-2e/ nearly identical to ver 2.5 model physics, but with  
driver program specific to PILPS-2e

---

ver\_2.7.1

FROZEN PRECIP TYPE - add so-called 'Lackmann' change to the determination of frozen precip type in the Noah LSM, i.e. in the coupled mode pass Eta-microphysics determined precip type (i.e. frozen or not) to the Noah LSM, vs poor-man use of Tair (1st model level above the surface), with snow for  $T < 0C$ , rain otherwise. In the offline mode this change may be null since the same precip-type determination procedure may be (is?) employed, use of the 'poor-man' lowest level atmospheric temperature check for precip type, though in the driver program rather within the SFLX code.

DIURNAL ALBEDO - pass net solar (SOLNET in the calling argument list) to Noah LSM from the offline driver, or in the case of the coupled (meso Eta model) land-surface driver the solar net value implicitly accounts for the solar zenith angle correction of the solar albedo.

PATCHY SNOW COVER MOISTURE FLUX - include separate calculation of snow sublimation and evap from non-snow-covered surface.

## 11.0 TECHNICAL REFERENCES

### 11.1 Model Physics Lineage (OSU, AFGL/PL/AFRL, AFGWC/AFWA, NCEP, OH/OHD)

*Original soil hydrodynamic physics:*

Mahrht and Pan, 1984, Boundary Layer Meteorol, 29, 1-20.

*Stability-dependent Penman potential evaporation:*

Mahrt and Ek, 1984, J. Clim. Appl. Meteorol, 23, 222-234.

*Original soil thermodynamic physics:*

Pan and Mahrht, 1987, Boundary Layer Meteorol, 38, 185-202.

*Time-integration scheme advancements:*

Kalnay and Kanamitsu, 1988: Mon. Wea. Rev., 116, 1945-1958

*Canopy resistance advancements:*

Chen, F., K. Mitchell, et al, 1996: J. Geophys. Res., 101, No. D3, 7251-7268 (Secs. 3.1.1-3.1.2)

*Surface infiltration advancements:*

Schaake, J., et al., 1996: J. Geophys. Res., 101, 7461-7475.

*Surface-layer turbulence advancements:*

Chen, F., Z. Janjic, and K. Mitchell, 1997, Boundary-Layer Meteorol, 85, 391-421.

*Bare soil evaporation and vegetation greenness advancements:*

Betts, A., F. Chen, K. Mitchell, and Z. Janjic, 1997: Mon. Wea. Rev., 125, 2896-2916.

Gutman, G., and A. Ignatov, 1998: Int. J. Remote Sensing, 19, 1533-1543.

Ek, M., K. Mitchell, E. Rogers, et al, 2001: AMS 9<sup>th</sup> Mesoscale conference.

Mitchell, K., M. Ek, D. Lohmann, et al, 2002: AMS 16<sup>th</sup> Hydrology conference.

*Snowpack and frozen ground physics advancements:*

Koren, V., et al., 1999: J. Geophys. Res., 101, No. D3, 7251-7268.

Ek, M., K. Mitchell, E. Rogers, et al, 2001: AMS 9<sup>th</sup> Mesoscale conference.

Mitchell, K., M. Ek, D. Lohmann, et al, 2002: AMS 16<sup>th</sup> Hydrology conference.

*For subsurface heat flux advancements:*

Peters-Lidard, C., M. Zion, and E. Wood, 1997: JGR, 102, No. D4, 4303-4324 (Sec. 2.1.2)

Peters-Lidard, C., 1998: J. Atmos. Sci., 55, 1209-1224. (Sec. 2.b)

Lunardini, V., 1981: Heat Transfer in Cold Climates. Van Nostrand Reinhold, 1-731 (Sec. 4.12.1.1)

Chang, S., D. Hahn, C.-H. Yang, D. Norquist, and M. Ek, 1999: J. Appl. Meteorology, 38, 405-422.

Ek, M., K. Mitchell, E. Rogers, et al, 2001: AMS 9<sup>th</sup> Mesoscale conference.

Mitchell, K., M. Ek, D. Lohmann, et al, 2002: AMS 16<sup>th</sup> Hydrology conference.

## **11.2 OSU Heritage: 1981-1998 (OSU)**

### Uncoupled

Mahrt and Pan, 1984, Boundary Layer Meteorol, 29, 1-20.

Mahrt and Ek, 1984, J. Clim. Appl. Meteorol, 23, 222-234.

Pan and Mahrt, 1987, Boundary Layer Meteorol, 38, 185-202.

OSU 1-D PBL Model User's Guide, Version 1.0.0, 1988.

OSU 1-D PBL Model User's Guide, Version 1.0.4, 1991.

Ek, M., and R. Cuenca, 1994, Boundary-Layer Meteorology, 70, 369-383.

## **11.3 Air Force Lineage: 1985-present (AFGWC, AFGL/PL/AFRL)**

### Uncoupled

Mitchell, 1985 (AFGWC Tech Report)

Moore, B., K. Mitchell, et al., 1990: 20th AMS Conf. Ag and Forest Meteorology, 7-11.

Chang, S., D. Hahn, C.-H. Yang, D. Norquist, and M. Ek, 1999: J. Appl. Meteorology, 38, 405-422.

### Coupled

Yang, C.-H., et al., 1989, AFGL Tech Report, GL-TR-89-0158, 262 pp.

## **11.4 NCEP Lineage: 1990-present (NMC, NCEP)**



### Uncoupled

- Chen, F., K. Mitchell, et al., 1996: J. Geophys. Res., 101, No. D3, 7251-7268 (Secs. 3.1.1, 3.1.2)
- Chen, F., and K. Mitchell, 1999: J. Meteorol. Soc. of Japan, 77, 167-182. (GSWP Special Issue)
- Mitchell, K., et al., 2000: 15th AMS Conf. on Hydrology, 1-4.
- Chen, T. H., Henderson-Sellers, et al, 1997: J. Climate, 10, 1194-1215. (PILPS-2a)
- Qu, W., Henderson-Sellers, et al, 1998: J. Atmos. Sci., 55, 1909-1927. (PILPS-2a)
- Liang, X., E. Wood, D. Lettenmaier, et al., 1998: Global and Planetary Change, 19(1-4), 137-159. (PILPS-2c).
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## **11.5 OHD Heritage: 1995-present (OH, HRL, OHD)**

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## **11.6 External Validators of NCEP Noah Model**

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- PILPS-2c (three papers)
- PILPS-2d (three papers)
- PILPS-2e (three papers)
- GSWP (several papers)
- Rhône/GLASS (one paper)

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### **11.7 NESDIS/ORA Land Surface Fields for NCEP Operational Use**

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