
# LIS Public Testcase Walkthrough

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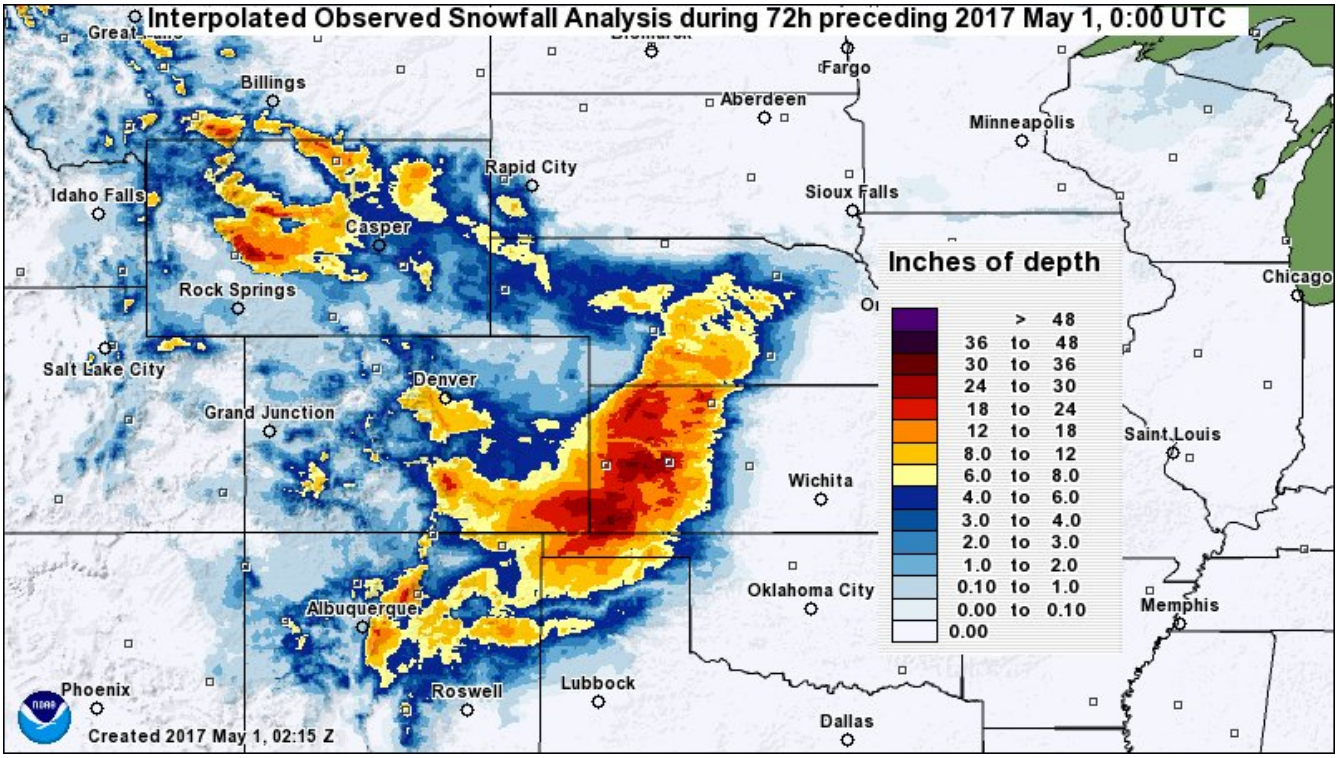
# Introduction

The Land Information System framework (LISF) public testcases described in this document are provided for users to learn how to run and test the LISF code. The testcases include a full end-to-end suite of Land Data Toolkit (LDT), Land Information System (LIS), and Land Verification Toolkit (LVT) cases that demonstrate how to generate model parameter and assimilation-based input files using LDT, run the Noah land surface model (LSM) for a sample "open-loop" (or baseline) experiment and a data assimilation (DA) experiment using LIS, and compare output from the sample experiments using LVT. While these testcases were created to demonstrate the use of LISF, the files provided *could* be expanded to support research-related model runs.

## The Testcase Event: Snow Blankets the Southern Great Plains

In late April of 2017, a major snow storm event occurred across the Southern Great Plains (SGP) and Rocky Mountains, an area spanning Colorado, Texas, Oklahoma, and southern Kansas. This storm event will be the focus of these testcases.




(*Image source*, *Data source*)

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# Setup

If you have not set up your computing environment to compile and run the LISF code, review the official documentation.

## Create a working directory

To begin, create and step into a working directory that you will use throughout the testcases. This directory will be referred to as `$WORKING_DIR` from this point forward. In the following example, the working directory is called `lis-public-testcases`:

```
% mkdir lis-public-testcases
% cd lis-public-testcases
```

## Clone the LISF Source Code Repository

While inside your `$WORKING_DIR` use `git` to clone the LISF repository and check out commit 3625aa3, a snapshot of the code known to be compatible with these testcases (*as of July 18, 2020*):

```
% git clone https://github.com/NASA-LIS/LISF.git
% cd LISF
% git checkout 3625aa3
```

## Configure and Compile the LISF Components

For information about configuration settings and detailed compilation instructions, see the official documentation. In general, the compilation process for each component is as follows:

```
% cd ldt
% ./configure
> # Select compile configuration settings (see Docs)...
% ./compile
> # Compilation output...
% mv LDT ../../            # move executable up into $WORKING_DIR
% cd ..                    # change directories back into LISF
```

Repeat the above process in the `lis/` and `lvt/` directories to generate the *LIS* and *LVT* executables.

Change directories back into your `$WORKING_DIR` which should now contain three executable files: `LDT`, `LIS`, `LVT`.

# Step 1: LSM Parameter Processing Run (LDT)

## Overview

In this step you will learn how to run LDT to perform parameter processing for the Noah-3.6 land surface model (LSM) and generate a Noah-3.6 parameter input file to be used by LIS (and LVT) in later steps.

### Steps to Running LDT

1. Gather input data needed by LDT
2. Modify `ldt.config` file to define runtime configuration settings
3. Run the LDT executable
4. Examine output

These testcases were designed to be run in sequential order and later steps require the output generated by earlier steps.

## Download Input and Target Files

The tar file for this step is approximately **350MB** compressed and **4.1GB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 1:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase1_ldt_parms.tgz
% tar -xzf testcase1_ldt_parms.tgz -C .
```

In addition to the `LISF/` directory and the three executables, your `$WORKING_DIR` should now contain the following directory and files:

| | |
|---|---|
| `INPUT/` | A directory that will hold parameter and input files needed throughout the testcases |
| `ldt.config.noah36_params` | The runtime configuration file read by LDT in this step |
| `target_lis_input.nldas.noah36.d01.nc` | The "target" NetCDF file generated by LDT in this step |
| `target_MaskParamFill.log` | The "target" mask-parameter log generated by LDT in this step |

Files and directories beginning with `target` are provided to compare with the output of your run.

# The LDT Configuration File

The LDT configuration file contains input settings used by LDT at run-time to generate input files for LIS. The configuration options are described in depth in the official documentation.

Before continuing, review the contents of the LDT configuration file for our LDT-based Noah.3.6 parameter test case by printing the file contents to the terminal with `cat` or opening the file with a text editor such as `vim` or `emacs`. Key elements of the file are highlighted below:

```
#Overall driver options
LDT running mode:                   "LSM parameter processing"
Processed LSM parameter filename:   ./lis_input.nldas.noah36.d01.nc ①
LIS number of nests:                1
Number of surface model types:      2
Surface model types:                "LSM" "Openwater"
Land surface model:                 "Noah.3.6" ②
...
LDT diagnostic file:                ldtlog ③
LDT output directory:               OUTPUT ④
Undefined value:                    -9999.0
...
#LIS domain ⑤
Map projection of the LIS domain:  latlon
Run domain lower left lat:         34.375
Run domain lower left lon:         -102.875
Run domain upper right lat:        39.625
Run domain upper right lon:        -96.125
Run domain resolution (dx):        0.25
Run domain resolution (dy):        0.25

# Parameters
Landcover data source:             MODIS_Native ⑥
Landcover classification:          IGBPNCEP
Landcover file:                    ./INPUT/LS_PARAMETERS/noah_2dparms/igbp.bin ⑥
Landcover spatial transform:       tile
...
```

① The name of the NetCDF-formatted parameter file to be generated which will be used by LIS

② The LSM to run (e.g., Noah.3.6)

③ The name of the diagnostic log file

④ The directory where LDT output will be placed

⑤ The grid projection, domain extents, and spatial resolution to be used by LIS (and LVT)

⑥ Data source settings and paths (e.g., landcover datasets, elevation datasets) and additional features of interest (e.g., irrigation settings)

LISF configuration files use relative paths to describe file locations. Keep this in mind if you encounter any file not found errors.

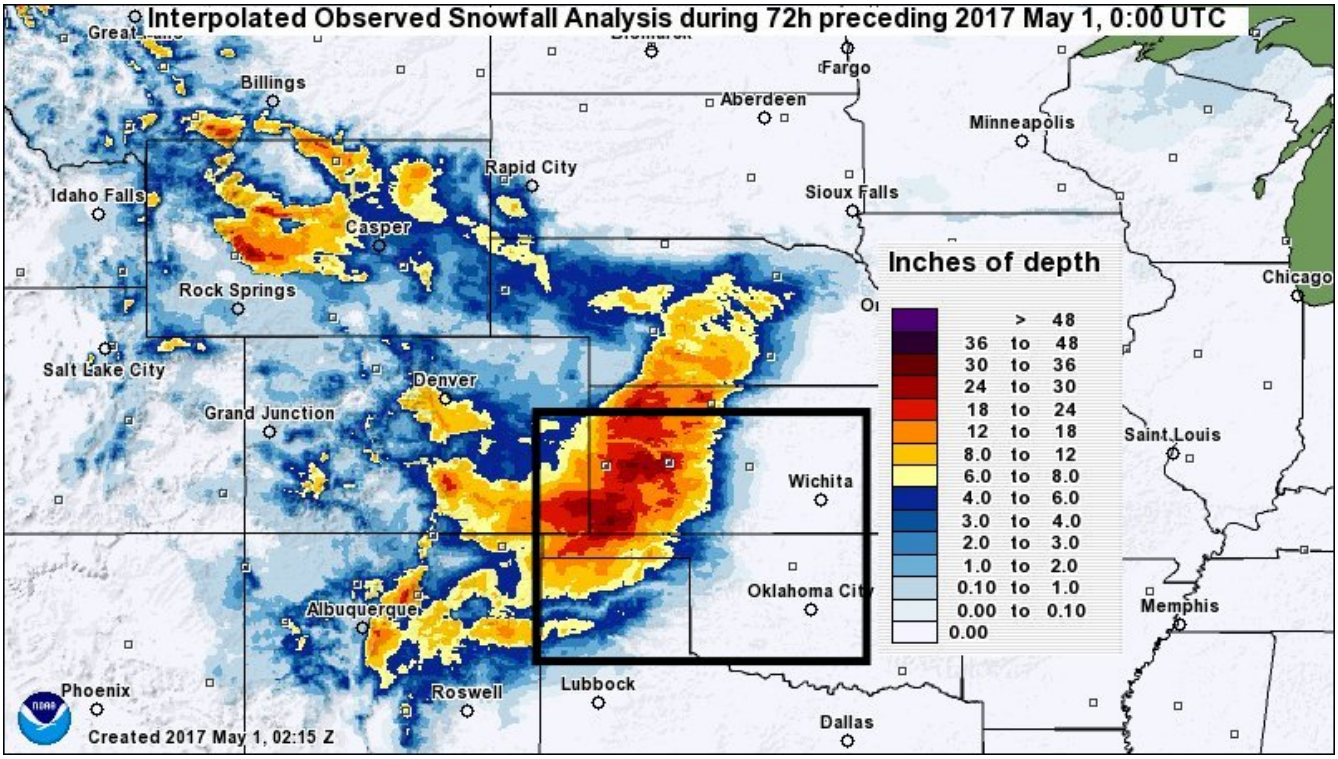
### Noah Land Surface Model Parameters

As you may have noticed, these testcases utilize NOAA/NCAR's Noah LSM, v3.6. The input parameters selected in include:

| Parameter | Dataset |
|---|---|
| Landcover | MODIS-based IGBP landcover map (~ 1 km, NOAA) |
| Soil texture | FAO+STATSGOv1 combined soil texture map (~ 1 km, NOAA) |
| Greenness fraction | AVHRR-based monthly climatology (1.0 deg, NOAA) |
| Snow-free albedo | Monthly climatology dataset (1.0 deg, NOAA) |
| Maximum snow albedo | MODIS-based maximum snow albedo (0.05 deg; Mike Barlage, NCAR) |
| Bottom of soil column temperature | ISLSCP-1 climatology dataset (1.0 deg) |

### Testcase Domain

The spatial domain defined in the LDT configuration file will be placed in `lis_input.nldas.noah36.d01.nc`, the NetCDF-formatted parameter file generated by LDT which LIS will read in automatically at run-time. For these testcases we will be using the domain depicted by the black box on this map:




*Testcase domain (geojson)*

# Run LDT - The Parameter Processing Step

Run the ***LDT*** executable using the LDT configuration file for this step:

```
% ./LDT ldt.config.noah36_params
```

The run should take a few minutes to complete. If the run aborts, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of `ldtlog.0000`. If no errors print to the terminal, verify that the run completed successfully by checking for the following confirmation at the end of the `ldtlog.0000`:

```
% tail ldtlog.0000
...
 -------------------------------
  Finished LDT run
 -------------------------------
```

If `ldtlog.0000` ends with the above message, the run completed successfully. Run `ls` in the terminal to see the new files created by LDT. In particular, verify that the LIS input file `lis_input.nldas.noah36.d01.nc` was produced.

# LDT Output Files

The following files are typically generated by an LDT parameter processing run:

| | |
|---|---|
| `lis_input.d01.nc` | The NetCDF-formatted model parameter file which LIS reads at runtime. `d01` refers to the indexed domain, typically used as "nests" for NASA-Unified WRF simulations. |
| `lislog.0000` | The runtime configuration file read by LDT in this stepThe output diagnostic file that provides runtime messages, including warnings and error messages. This file is useful for verifying successful run completion and troubleshooting unsuccessful runs. |
| `MaskParamFill.log` | The "target" NetCDF file generated by LDT in this stepThis diagnostic file informs of any disagreements between an LSM-based parameter and the landmask, and whether any parameter gridcells were "filled" to agree with the landmask. |

The output filenames for `lis_input.d01.nc` and `ldtlog.0000` can be defined in the `ldt.config` file, but the filename of `MaskParamFill.log` cannot be modified.

## The LIS Parameter File

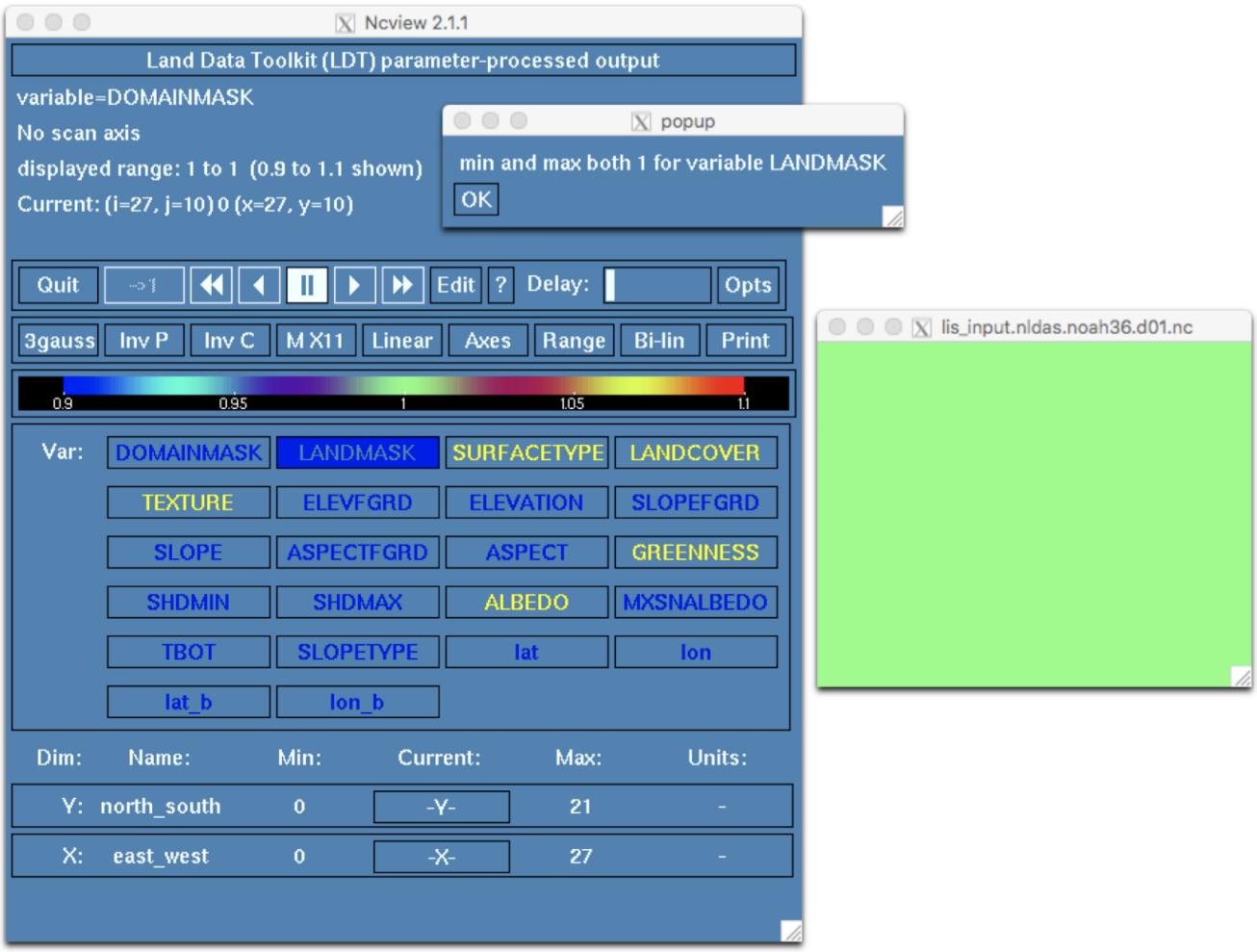
The contents of the LIS parameter input file produced by LDT can be examined visually using a command-line program such as `ncview` or a desktop application like NASA's Panoply. For this walkthrough we will be using `ncview`.

Open the LIS input file using `ncview`:

```
% ncview lis_input.nldas.noah36.d01.nc
```

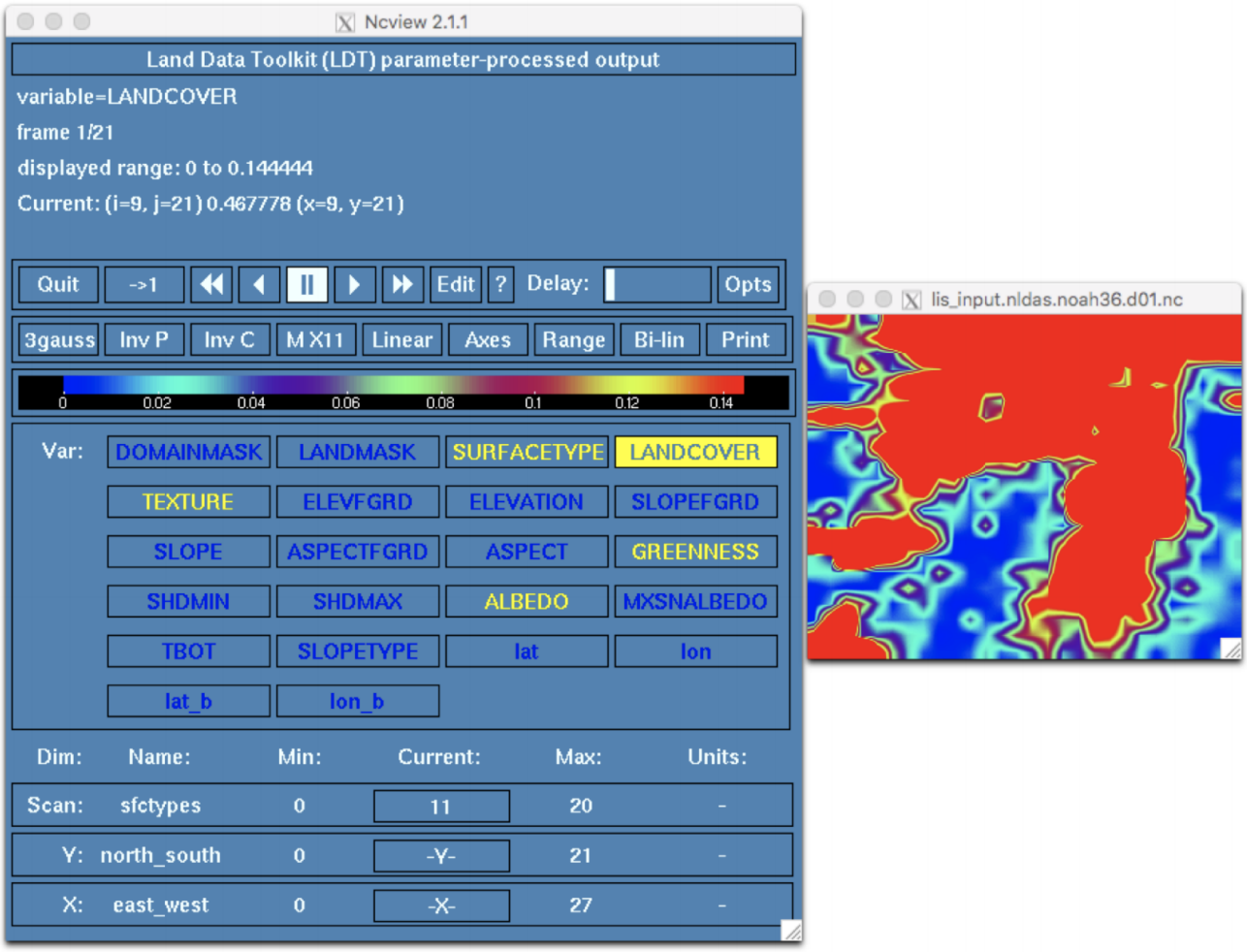
In the `ncview` window that opens, click on the widget labeled **DOMAINMASK**. A second window will open containing a map of the mask. The domain we are using is a simple rectangle so, as expected, all values are equal to `1`.

Click on the widget labeled **LANDMASK**. Again, the values are all equal to `1`. This indicates that all grid cells within the domain are treated as land and, as a result, the input file should *not* contain any undefined values (e.g., `-9999`).



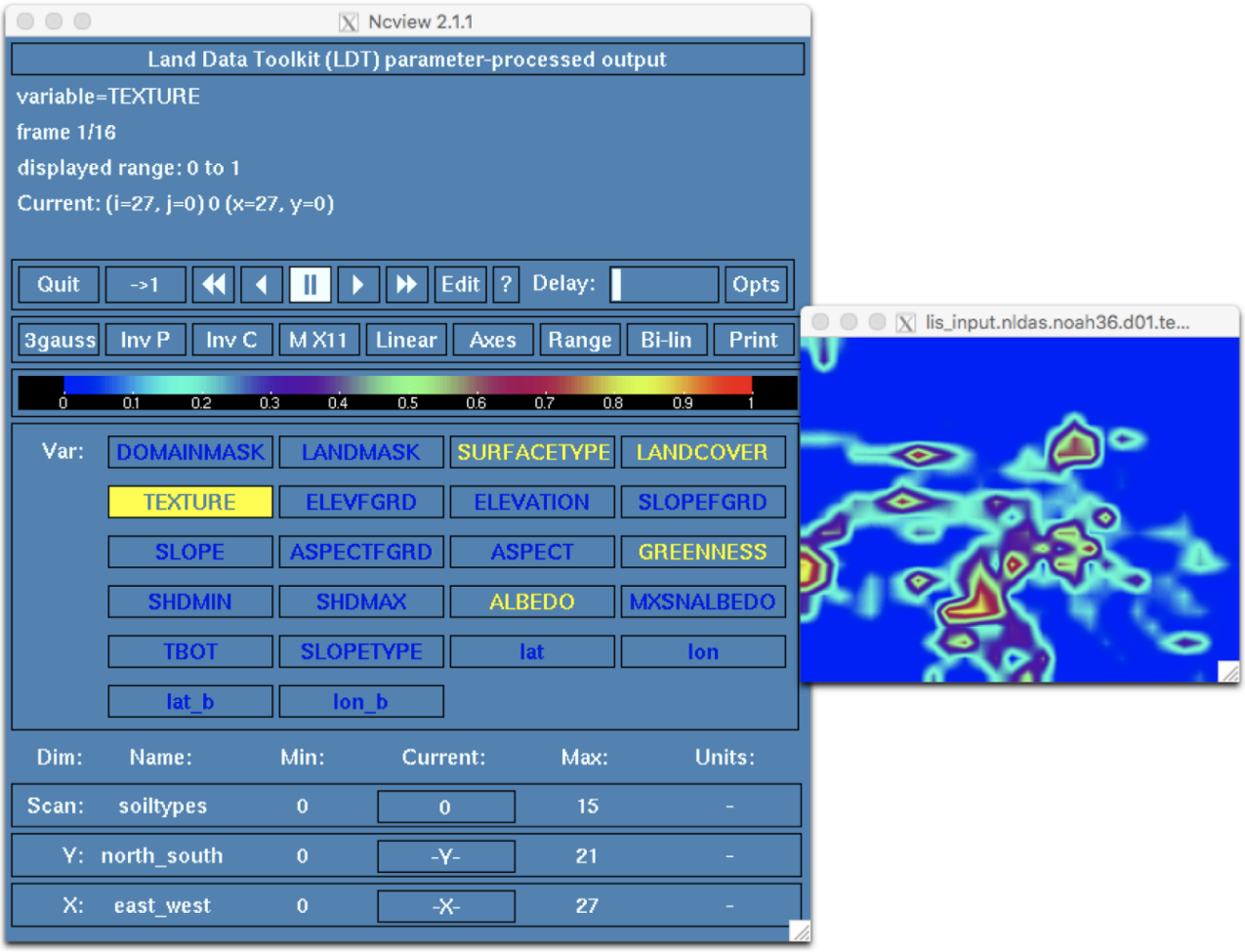

*LANDMASK dataset*

Click on the **LANDCOVER** widget to view the landcover variable. In the bottom third of the `ncview` window, click on the widget below the label *Current* to cycle through th 20 different IGBP landcover and land use classes. In the screenshot below the *Crop* class is selected (the classes are zero-indexed in `ncview`; add 1 to index to convert to IGBP class).




*The Crop class of the* **LANDCOVER** *dataset*

Click on the **TEXTURE** widget to view the soil texture dataset. Click on the widget below the label *Current*. This is the FAO+STATSGO soil texture map, aggregated using the `tile` option for the `Soil texture spatial transform:` setting in `ldt.config`. The map shows the fraction, or frequencies, of each soil type within each 0.25° degree grid cell of our domain.




*Soil texture, tile-based aggregation*

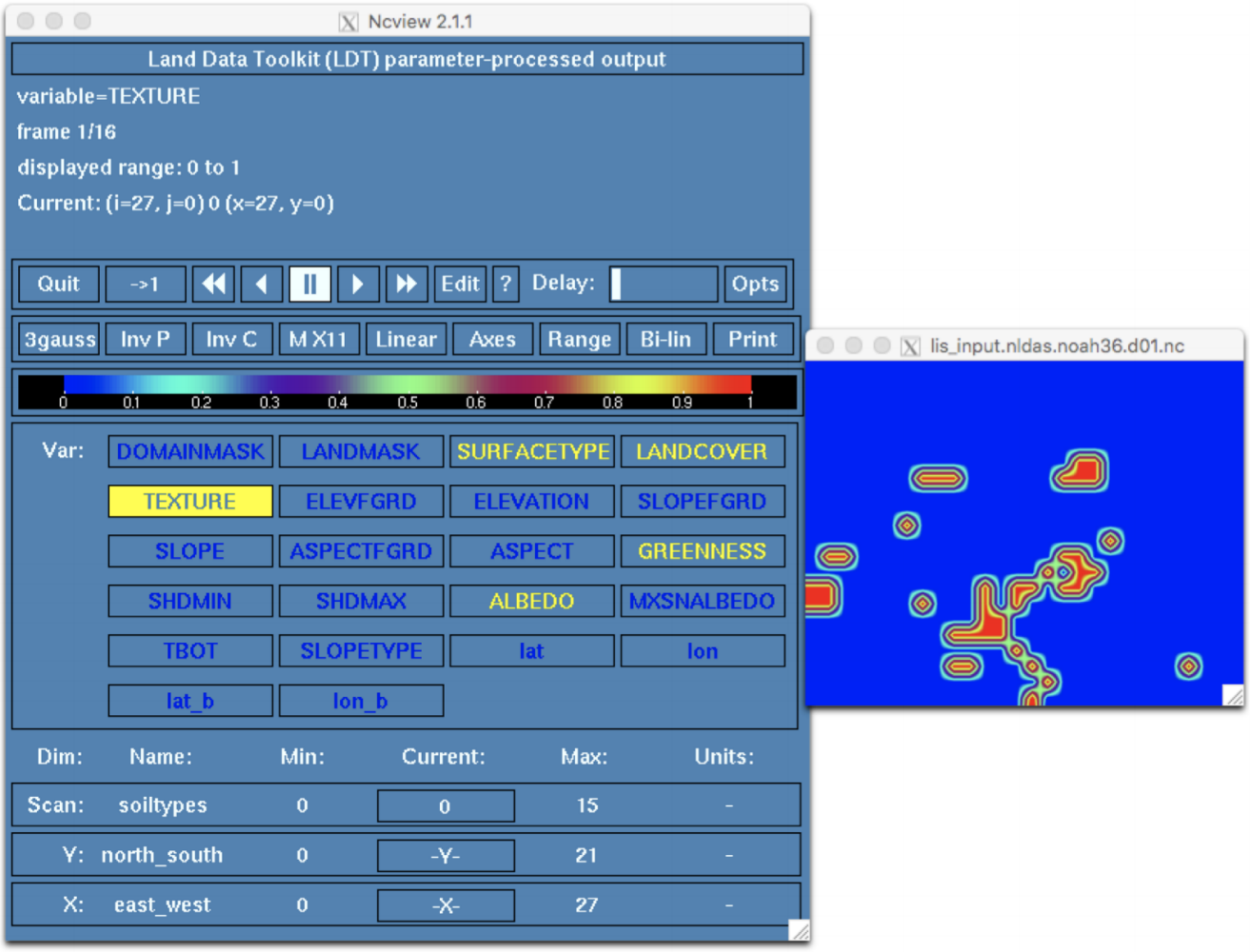
LDT provides several other options for grid cell aggregation including `none`, `mode`, and `neighbor`. What would the output look like if we were to rerun LDT after switching from `tile` to `mode`? Open `ldt.config.noah36_params` in a text editor and change the `Soil texture spatial transform` option from `tile` to `mode` as below:

```
...
Soil texture spatial transform: mode
...
```

Rerun LDT:

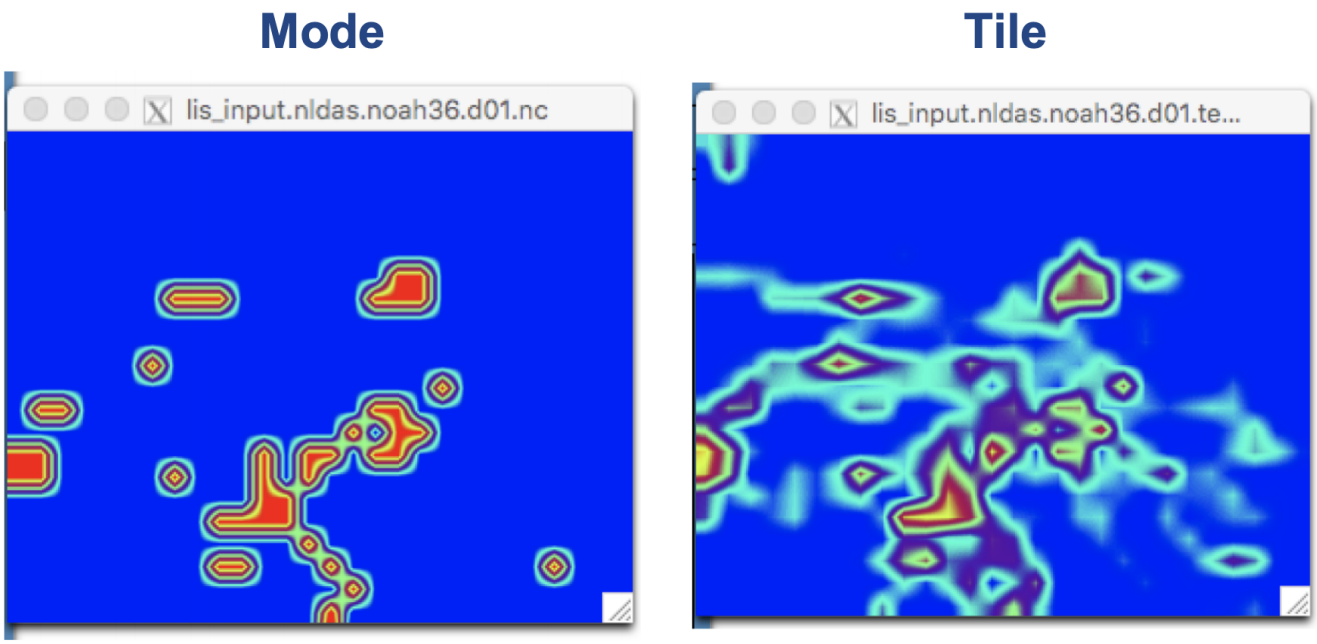
```
% ./LDT ldt.config.noah36_params
```

Check the end of `ldtlog.0000` to verify LDT ran successfully. Again, open the LIS input file using `ncview` and click on the **TEXTURE** widget.




Each soil type now shows a total value of 1 within each 0.25 degree grid cell of our domain. Why? The `mode` option selects the *dominant* soil type for each grid cell.

For comparison:




*Dominant vs. fractional soil type*

Another program called ncdump can be used to directly view the datasets contained in NetCDF files. For example, the -h flag can be used to print the dimensions, variable names, and attributes of the file to the terminal:

```
% ncdump -h lis_input.nldas.noah36.d01.nc
netcdf lis_input.nldas.noah36.d01 {
dimensions:
    east_west = 28 ;
    north_south = 22 ;
    east_west_b = 32 ;
    north_south_b = 26 ;
    month = 12 ;
    time = 1 ;
    sfctypes = 21 ;          # Note: 21 includes "openwater" surface type
    soiltypes = 16 ;
    elevbins = 1 ;
    slopebins = 1 ;
    aspectbins = 1 ;
variables:
    float time(time) ;
    float DOMAINMASK(north_south, east_west) ;
          DOMAINMASK:standard_name = "DOMAINMASK" ;
          DOMAINMASK:units = "" ;
          DOMAINMASK:scale_factor = 1.f ;
          DOMAINMASK:add_offset = 0.f ;
          DOMAINMASK:missing_value = -9999.f;
          DOMAINMASK:vmin = 0.f ;
          DOMAINMASK:vmax = 0.f ;
          DOMAINMASK:num_bins = 1 ;
global attributes:
    :MAP_PROJECTION = "EQUIDISTANT CYLINDRICAL" ;
    :SOUTH_WEST_CORNER_LAT = 34.375f ;
    :SOUTH_WEST_CORNER_LON = -102.875f ;
    :DX = 0.25f ;
    :DY = 0.25f ;
    :INC_WATER_PTS = "true" ;
    :LANDCOVER_SCHEME = "IGBPNCEP" ;
    :BARESOILCLASS = 16 ;
    :URBANCLASS = 13 ;
    :SNOWCLASS = 15 ;
    :WATERCLASS = 17 ;
    :WETLANDCLASS = 11 ;
    :GLACIERCLASS = 15 ;
    :NUMVEGTYPES = 17 ;
    :LANDMASK_SOURCE = "MODIS_Native" ;
    :SFCMODELS = "Noah.3.6+Openwater" ;
    :SOILTEXT_SCHEME = "STATSGO" ;
    :GREENNESS_DATA_INTERVAL = "monthly" ;
    :ALBEDO_DATA_INTERVAL = "monthly" ;
```

### Compare the Output

To further confirm that LDT ran successfully, you can compare your output with the "target" output included with the input files you downloaded earlier (files or directories beginning with `target_`). For example, use `nccmp` to compare your `lis_input.nldas.noah36.d01.nc` with `target_lis_input.nldas.noah36.d01.nc`:

```
% nccmp -mdfs lis_input.nldas.noah36.d01.nc target_lis_input.nldas.noah36.d01.nc
```

Where the flags enable the following options:

- `m`: compare metadata
- `d`: compare data
- `f`: force comparison to continue after differences found
- `s`: report identical files to terminal (by default `nccmp` runs silently if files are identical)

Some files may not be identical, but any differences reported should be small.

## Wrap-up

The LDT parameter processing run generates input parameters and files that LIS requires. Your `$WORKING_DIR` should now contain all the files needed to continue on to Step 2: LSM "Open-loop" (OL) Experiment (LIS).

# Step 2: LSM "Open-loop" (OL) Experiment (LIS)

## Overview

In this step you will learn how to run LIS with the Noah-3.6 LSM for an "open-loop" case. This test case uses the files generated by LDT in Step 1.

### Steps to Running LIS

1. Collect the input data needed by LIS
2. Modify the `lis.config` file to select runtime options
3. Run the LIS executable
4. Examine output

## Download Input and Target Files

The tar file for this step is approximately **67MB** compressed and **250MB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 2:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase2_lis_ol.tgz
% tar -xzf testcase2_lis_ol.tgz -C .
```

The following files and directories were added to your common working directory, `$WORKING_DIR`:

| | |
|---|---|
| `INPUT/wget_gesdisc_nldas2.sh` | A script to download NLDAS2 forcing data |
| `INPUT/NOAH36_OUTPUT_LIST.TBL` | Model output specification |
| `INPUT/forcing_variables.txt` | Forcing variable specification |
| `lis.config_noah36_ol` | The runtime configuration file that will be read by LIS |
| `target_log/lislog_ol.0000` | The "target" log file that should be produced by LIS in this step |
| `target_OL_OUTPUT/` | A directory containing containing the "target" open-loop (OL) output files that should be generated by LIS in this step |
| `target_ol.xdf`and `test_ol.xdf` | GrADS description files to visualize the output |

## Download the Meteorological Forcing Files

This testcase is set up to use the *North American Data Assimilation System, version 2 (NLDAS-2)* meteorological forcing dataset. This dataset is available via NASA GES DISC. A script has been provided in the input files that uses `wget` to download these data.

Before running the download script:

1. Ensure `wget` is installed, the script uses it to download the data.
2. Create a NASA Earthdata account if you do not already have one.
3. Follow steps 1-4 in these instructions to save your NASA Earthdata login credentials locally.

When you are ready to run the script, change directories into `INPUT/` and run the following command:

```
% sh wget_gesdisc_nldas2.sh
```

The script will download NLDAS-2 forcing data for the entire year of 2017 into a directory named `NLDAS2.FORCING/`. If the script completes without any errors, change up one directory back to your `$WORKING_DIR`. If any errors are thrown, attempt to resolve them.

Users on NASA's NCCS Discover HPC system do not need to download the forcing data because a copy is already available. Change directories into `INPUT/` and create a symlink to this local copy:

```
% ln -s /discover/nobackup/projects/lis/MET_FORCING/NLDAS2.FORCING
NLDAS2.FORCING
```

# The LIS Configuration File

The main LIS configuration file (`lis.config_noah36_ol`) is where runtime options and filepaths used during the run are defined. These include:

- The LSM of interest (e.g., Noah.3.6)
- The name of the NetCDF-parameter file created by LDT in the previous step (e.g., `lis_input.nldas.noah36.d01.nc`)
- The name of the LIS diagnostic file (e.g., `lislog`)
- The date and time inputs, model options, parallel domain entries, etc.
- Meteorological forcing dataset(s) selected; also some downscaling features
- Data assimilation entries, and other features, such as irrigation or runoff routing

Open the LIS configuration file in a text editor to view these settings and more.

You may notice that the grid domain is not contained in this file. The grid domain that was defined in the `ldt.config` file is now contained in the NetCDF-formatted parameter file (`lis_input.nldas.noah36.d01.nc`) and this information will be read by LIS at runtime.

# Run LIS - The "Open-Loop" (OL) Step

You are now ready to run LIS.

In your `$WORKING_DIR`, execute the following command:

```
% ./LIS -f lis.config_noah36_ol
```

LIS can also be run in parallel. The examples in this walkthrough, however, demonstrate how to run LIS on a single processor. To learn how to run LIS in parallel, see Chapter 6 in the official LIS documentation.

With a single processor the run should take approximately 20 minutes to complete. If the run fails, diagnose the issue by reviewing any errors that have printed to the terminal and by viewing the

contents of `lislog` files (if any are present). If no errors appear and the run appears to have completed successfully, examine the end of any `lislog` files present to check for a confirmation message:

```
% tail lislog.0000
 [INFO] LIS cycle completed
[INFO] LIS cycle time: 01/01/2018 00:00:00
 [INFO] getting file2a..
 ./INPUT/NLDAS2.FORCING/2018/001/NLDAS_FORA0125_H.A20180101.0100.002.grb
 [ERR] Could not find file:
 ./INPUT/NLDAS2.FORCING/2018/001/NLDAS_FORA0125_H.A20180101.0100.002.grb
 [INFO] Noah-3.6 archive restart written:
 ./OL_OUTPUT/SURFACEMODEL/201801/LIS_RST_NOAH36_201801010000.d01.nc

  LIS Run completed.
```

Use the `ls` command to view the new files and directories created by LIS.

## LIS Output Files

The output files created by LIS were placed into a new directory called `OL_OUTPUT`. Within this directory is another directory called `SURFACEMODEL` which contains subdirectories following the naming convention `YYYYMM`:

- YYYY → 4-digit year
- MM → 2-digit month

Within each of those subdirectories are NetCDF-formatted LIS output files that contain the Noah-3.6 fields of interest (e.g., soil moisture, runoff, evapotranspiration). Use any visualization package you are comfortable with to view the files (e.g., Matlab, GrADS, `ncview`). For GrADS users, descriptor files were provided with the input data.

## Wrap-up

You have now generated your LIS Noah-3.6 model run for the open-loop case. Use `diff` and `nccmp` to compare the output files you generated with the "target" versions found in `target_OL_OUTPUT/`. As in Step 1, the files you generated in this step will be used in Steps 3 and 4 of the end-to-end test case.

# Step 3: Ensemble Restart File Generation (LDT)

## Overview

In Step 1, you used LDT to perform parameter processing for the Noah-3.6 land surface model (LSM) to generate a Noah-3.6 parameter input file to be used by LIS (and LVT). In addition to

parameter processing, LDT can be used to *upscale* and *downscale* ensembles.

**Upscale:** generate a multi-member ensemble restart file from a single-member restart file

**Downscale:** generate a single-member ensemble restart file from a multi-member restart file

In this step you will learn how to use LDT to expand a single-member **restart** file generated by the LIS open-loop (OL) case in Step 2 into a restart file that contains an ensemble of size *N* (user specified). The ensemble restart file generated in this step will be used in Step 6 to **initialize** the LIS data assimilation (DA) run.

> **Restart files** contain all of the initial condition information necessary to restart from a previous simulation.
>
> — http://www.cesm.ucar.edu/models/ccsm2.0/csim/UsersGuide/ice_usrdoc/node21.html

# Download Input and Target Files

The tar file for this step is approximately **77KB** compressed and **180KB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 3:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase3_ldt_ensrst.tg
z
% tar -xzf testcase3_ldt_ensrst.tgz -C .
```

The following files and directories were added to your common working directory, `$WORKING_DIR`:

| | |
|---|---|
| `DA_ensrst/` | A directory containing the files below |
| `ldt.config` | The LDT config file for this step |
| `target_ldtlog.0000` | The target LDT log file |
| `target_LIS_EnRST_NOAH36_201801010000.d01.nc` | The target LDT-generated ensemble restart file ("EnRST") to start the Noah LSM DA run in Step 6 |

# The LDT Configuration File

Review the contents of `DA_ensrst/ldt.config` to view the configuration settings used for this step:

```
LDT running mode:                                "Ensemble restart processing"
Processed LSM parameter filename:                ./lis_input.nldas.noah36.d01.nc
...
LIS restart source:                              "LSM"
Ensemble restart generation mode:                "upscale" ①
Input restart filename:
../OL_OUTPUT/SURFACEMODEL/201801/LIS_RST_NOAH36_201801010000.d01.nc
Number of ensembles per tile (input restart):   1 ②
Number of ensembles per tile (output restart):  12 ③
```

① This entry tells LDT how to process the *ensemble* file

② Size of input ensemble restart file, in this case a single instance of model states

③ Size of upscaled multi-member ensemble restart file, in this case 12 members

In this walkthrough we are using the Noah.3.6 LSM, but these settings can be used to upscale/downscale routing models as well. For example:

```
LIS restart source:                              "Routing"
Ensemble restart generation mode:                "upscale"
Input restart filename:
./LIS_RST_HYMAP_router_201801010000.d01.bin
Output restart filename:                         ./ensrst.bin
Number of ensembles per tile (input restart):   1
Number of ensembles per tile (output restart):  12
```

# Run LDT - Generate Ensemble Restart File

You're now ready to run LDT:

1. Copy your compiled ***LDT*** executable into `$WORKING_DIR/DA_ensrst`
2. Run the ***LDT*** executable using the provided `ldt.config` file:

```
% ./LDT ldt.config
```

The run should take a few minutes to complete. If the run aborts, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of `ldtlog.0000`. If no errors print to the terminal, verify that the run completed successfully by checking for the following confirmation at the end of the `ldtlog.0000`:

```
% tail ldtlog.0000
...
 ---------------------------------
  Finished LDT run
 ---------------------------------
```

## LDT Output Files

During this run, LDT produced one output file named `LIS_EnRST_NOAH36_201801010000.d01.nc` and placed it into the `OL_OUTPUT/SURFACEMODEL` directory in your `$WORKING_DIR`.

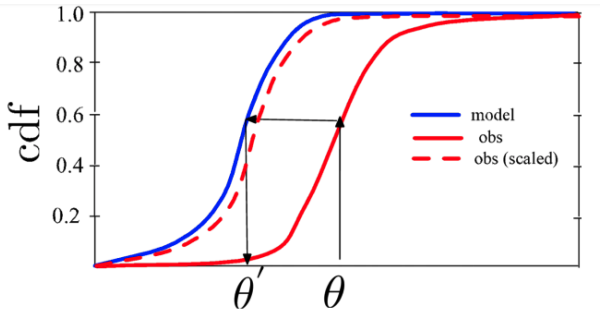
Use `ncview`, Panoply, Matlab or any other viewing package that supports NetCDF files. Compare what you see with the *target* version of this output file located in the `DA_ensrst` directory. You can also use `nccmp` to directly compare the contents of the file created by your LDT run and the target.

# Step 4: Generate LSM OL Cumulative Density Function-based Files (LDT)

## Overview

In the previous step you used LDT used to expand a single-member ensemble restart file into a multi-member restart file containing 12 ensemble members. In this step you will use LDT again to generate files that support scaling and bias-correction between the model open-loop states and satellite observations that will be assimilated in Step 6. LDT supports the generation of domain and statistical moment inputs for estimated cumulative distribution functions (CDFs), which can be used when performing the scaling necessary to assimilate certain observations in LIS. The model-based CDF files generated in this step, and those generated in Step 5 for the satellite observations, will be incorporated in the data assimilation run demonstrated in Step 6.

**CDF-based scaling** is used to match the CDF of a given observation to that of the model.




CDF generation and CDF-based scaling are performed separately for each grid point. CDF-based scaling corrects all moments of the distribution regardless of its shape and requires enough sampling density to derive these scaling parameters. By comparison, normal deviate-based scaling corrects the first and second moments (e.g., the mean and variance).

For more information on this topic:

- Reichle, R. H., and Koster, R. D. (2004), Bias reduction in short records of satellite soil moisture, *Geophys. Res. Lett.*, 31, L19501, doi:10.1029/2004GL020938.

# Download Input and Target Files

The tar file for this step is approximately **362KB** compressed and **815KB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 4:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase4_ldt_lsmcdf.tg
z
% tar -xzf testcase4_ldt_lsmcdf.tgz -C .
```

The following files and directories were added to your common working directory `$WORKING_DIR`:

| | |
|---|---|
| `DA_proc_LSM/` | A directory containing the files below |
| `ldt.config.noah36_cdf` | The LDT config file for this step |
| `target_ldtlog.0000` | The target LDT log file |
| `target_cdf_noah36_domain.nc` | The target LDT-generated Noah LSM *domain* file |
| `target_cdf_noah36.nc` | The target LDT-generated Noah LSM *CDF* file |
| `noah36_cdf.xdf` | GrADS description file for viewing `*cdf_noah36.nc` output and target files |
| `plot_noah36_cdf.gs` | GrADS script that plots an X-Y plot of `*cdf_noah36.nc` output and target files |

# The LDT Configuration File

Review the contents of `DA_proc_LSM/ldt.config.noah36_cdf` to view the configuration settings used for this step:

```
LDT running mode: "DA preprocessing" ①
...
DA preprocessing method:            "CDF generation"
DA observation source:              "LIS LSM soil moisture"
Name of the preprocessed DA file:   "cdf_noah36" ②
Apply anomaly correction to obs:    0
Temporal resolution of CDFs:        "yearly"
Number of bins to use in the CDF:   100
Observation count threshold:        30
Temporal averaging interval:        "1da"
Apply external mask:                0
External mask director:             none
...
LIS soil moisture output model name:        "Noah.3.6"
LIS soil moisture output directory:         ../OL_OUTPUT/
LIS soil moisture output format:            "netcdf"
LIS soil moisture output methodology:       "2d gridspace"
LIS soil moisture output naming style:      "3 level hierarchy"
LIS soil moisture output nest index:        1
LIS soil moisture output map projection:    "latlon"
LIS soil moisture domain lower left lat:    34.375 ③
LIS soil moisture domain upper right lat:   39.625
LIS soil moisture domain lower left lon:    -102.875
LIS soil moisture domain upper right lon:   -96.125
LIS soil moisture domain resolution (dx):   0.25
LIS soil moisture domain resolution (dy):   0.25
```

① The "DA preprocessing" mode is used to generate the observation domain and scaling parameters.

② A successful run will generate a domain file (i.e., `cdf_noah36_domain.nc`) and a LSM CDF file (e.g., `cdf_noah36.nc`).

③ The LDT run domain should reflect the intended observation grid (projection and resolution). *Note that this can differ from the model resolution and projection.*

# Run LDT - DA Preprocessing Step

You're now ready to run LDT:

1. Copy your compiled ***LDT*** executable into `$WORKING_DIR/DA_proc_LSM`
2. Run the ***LDT*** executable using the provided `ldt.config.noah36_cdf` file:

```
% ./LDT ldt.config.noah36_cdf
```

The run should take a few minutes to complete. If the run aborts, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of `ldtlog.0000`. If no errors print to the terminal, verify that the run completed successfully by checking for the

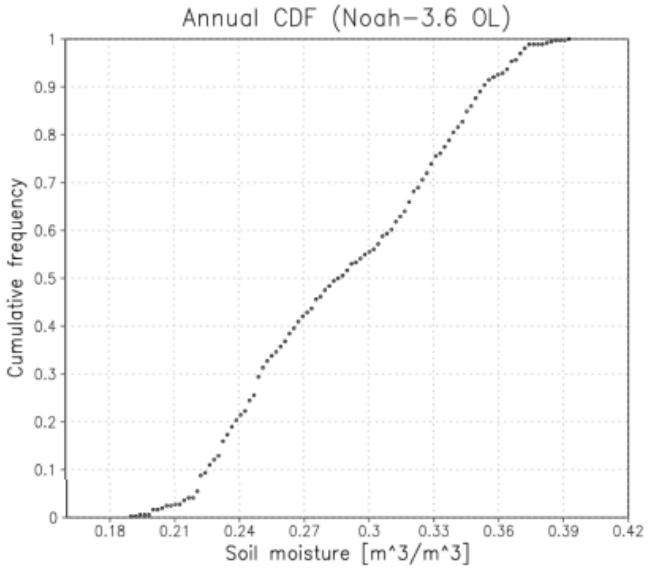
following confirmation at the end of the `ldtlog.0000`:

```
% tail ldtlog.0000
...
 --------------------------------
  Finished LDT run
 --------------------------------
```

## LDT Output Files

During this run, LDT produced a domain file, `cdf_noah36_domain.nc`, and a LSM CDF file, `cdf_noah36.nc`, and placed them into the `OL_OUTPUT` directory in your `$WORKING_DIR`. If GrADS is installed, use the provided GrADS descriptor files to plot the output shown below.

```
% grads -lc "plot_noah36_cdf.gs"
```




# Step 5: Generate Observations CDF-based Files (LDT)

## Overview

In this step you will use LDT to generate CDF files from the satellite-based soil moisture (SM) observations collected by NASA's **S**oil **M**oisture **A**ctive **P**assive (SMAP) mission. The observation based CDF files generated in this step will be used along with the model CDF files created in Step 4 for the data assimilation run in Step 6.

# Download Input and Target Files

The tar file for this step is approximately **4.5GB** compressed and **5.3GB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 5:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase5_ldt_obscdf.tg
z
% tar -xzf testcase5_ldt_obscdf.tgz -C .
```

The following files and directories were added to your common working directory `$WORKING_DIR`:

| | |
|---|---|
| `DA_proc_SMAP/` | A directory containing the files below |
| `ldt.config.smapobs_cdf` | The LDT config file for this step |
| `target_ldtlog.0000` | The target LDT log file |
| `target_cdf_smapobs_domain.nc` | The target LDT-generated Noah LSM *domain* file |
| `target_cdf_smapobs.nc` | The target LDT-generated Noah LSM *CDF* file |
| `RS_DATA.tgz` | A tar file containing sample SMAP soil moisture observations |

Unpack `RS_DATA.tgz` in your `$WORKING_DIR`:

```
% tar -xzf RS_DATA.tgz -C .
```

A new directory named `RS_DATA` contains sample soil moisture observations from the *SMAP L3 Radiometer Global Daily 36 km EASE-Grid Soil Moisture* data product.

*SMAP SPL3SMP.005 dataset description:*

> This Level-3 (L3) soil moisture product provides a composite of daily estimates of global land surface conditions retrieved by the Soil Moisture Active Passive (SMAP) passive microwave radiometer. SMAP L-band soil moisture data are resampled to a global, cylindrical 36 km Equal-Area Scalable Earth Grid, Version 2.0 (EASE-Grid 2.0).

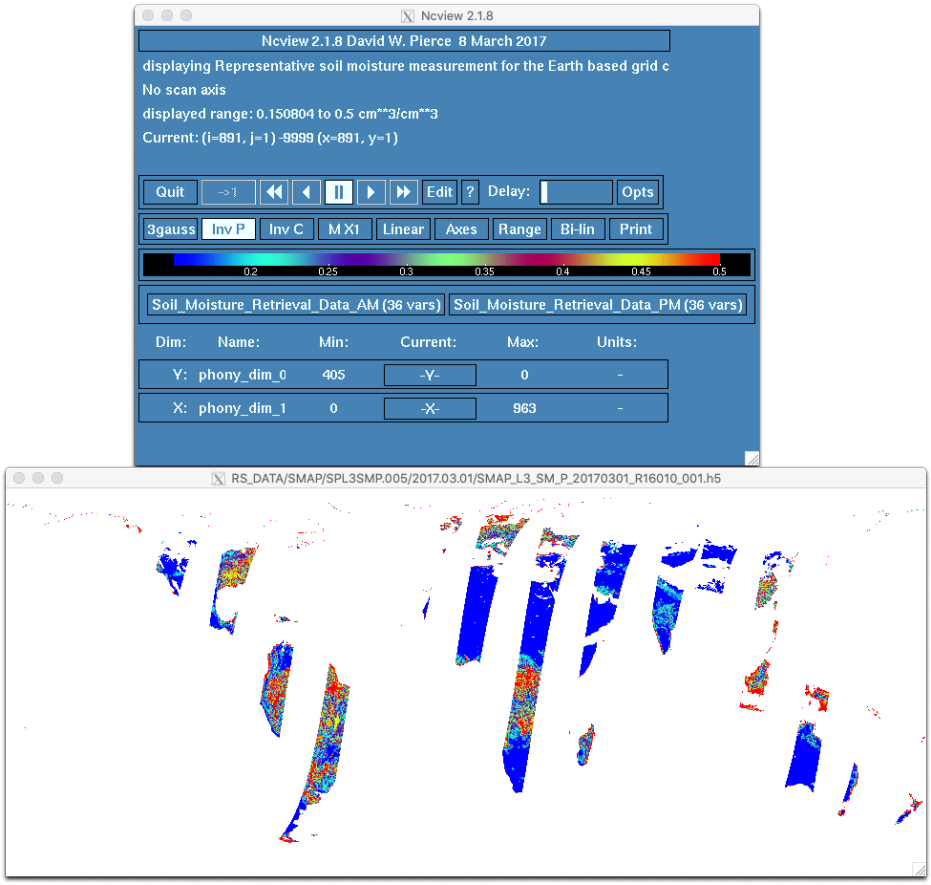
Use `ncview` to view the data for 3/1/2017.

```
% ncview RS_DATA/SMAP/SPL3SMP.005/2017.03.01/SMAP_L3_SM_P_20170301_R16010_001.h5
```

When `ncview` opens, click and hold on one of the subdataset buttons under the color bar (e.g.,

`Soil_Moisture_Retrieval_Data_AM (36 vars)`) to open the list of variables. Release the mouse button on the variable you would like to plot (e.g., `soil_moisture`).

Due to the way the data is formatted, the plot will appear upside down. Click on the *Inv P* button in the main `ncview` window to invert the plot.




# The LDT Configuration File

Review the contents of `DA_proc_SMAP/ldt.config.smapobs_cdf` to view the configuration settings used for this step:

```
LDT running mode: "DA preprocessing" ①
...
DA preprocessing method:            "CDF generation"
DA observation source:              "NASA SMAP soil moisture"
Name of the preprocessed DA file:   "./cdf_smapobs" ②
Apply anomaly correction to obs:    0
Temporal resolution of CDFs:        "yearly" ③
Number of bins to use in the CDF:   100
Observation count threshold:        30
Temporal averaging interval:        "1da"④
Apply external mask:                0
External mask director:             none
...
NASA SMAP soil moisture observation directory: ../RS_DATA/SMAP/SPL3SMP.005  ⑤
NASA SMAP soil moisture data designation:      SPL3SMP ⑥
NASA SMAP search radius for openwater proximity detection: 3 ⑦
SMAP(NASA) soil moisture Composite Release ID (e.g., R16): R16 ⑧
```

① *DA preprocessing* mode is used to generate the observation domain and scaling parameters.

② Prefix of output files (e.g., `cdf_smapobs_domain.nc`).

③ Temporal resolution of resultant CDF. Specifies whether to generate lumped (i.e., considering all years and all seasons) CDFs or to stratify CDFs for each calendar month.

④ Averaging interval used while computing CDF. In this case, one day.

⑤ Relative path to the directory containing SMAP observation data.

⑥ Specifies which SMAP data product is being used.

⑦ Specifies the radius in which LDT search to detect open water Then removes all pixels within the radius in the CDF calculations.

⑧ Specifies the release ID of the SMAP dataset.

See the official LDT documentation for more information about configuration settings.

# Run LDT - DA Preprocessing Step

You're now ready to run LDT:

1. Copy your compiled ***LDT*** executable into `$WORKING_DIR/DA_proc_SMAP`
2. Run the ***LDT*** executable using the provided `ldt.config.smapobs_cdf` file:

```
% ./LDT ldt.config.smapobs_cdf
```

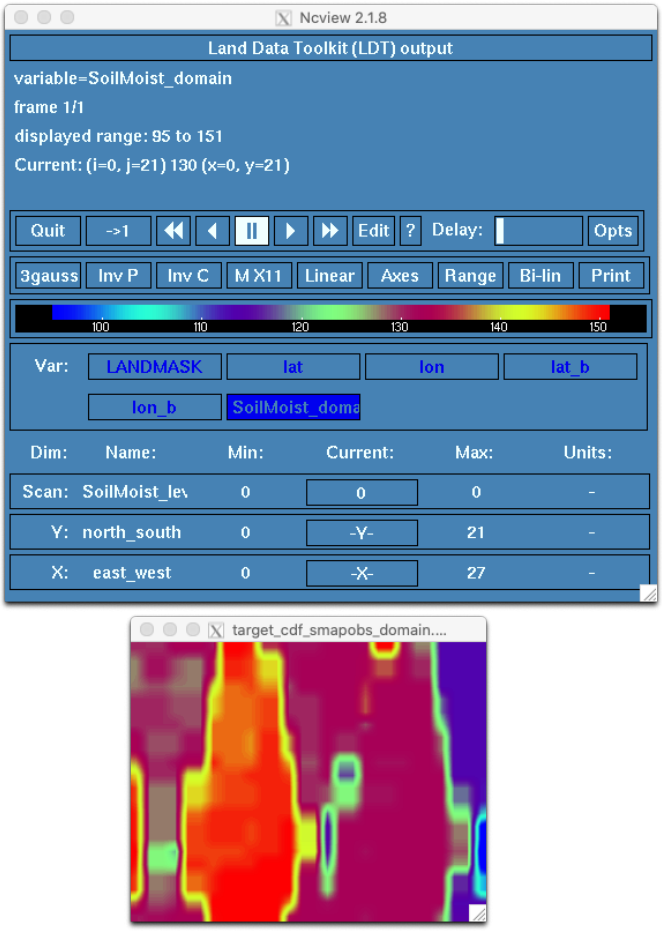
The run should take a few minutes to complete. If the run aborts, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of `ldtlog.0000`. If no errors print to the terminal, verify that the run completed successfully by checking for the following confirmation at the end of the `ldtlog.0000`:

```
% tail ldtlog.0000
...
 --------------------------------
  Finished LDT run
 --------------------------------
```

The run created two new files:

- `cdf_smapobs.nc`
- `cdf_smapobs_domain.nc`

Use `ncview` to plot the `SoilMoist_domain` variable contained in `cdf_smapobs_domain.nc`:




Use `nccmp` to directly compare the contents of `cdf_smapobs_domain.nc` with the provided target. They should be identical.

```
% nccmp -dsf cdf_smapobs_domain.nc target_cdf_smapobs_domain.nc
Files "cdf_smapobs_domain.nc" and "target_cdf_smapobs_domain.nc" are identical.
```

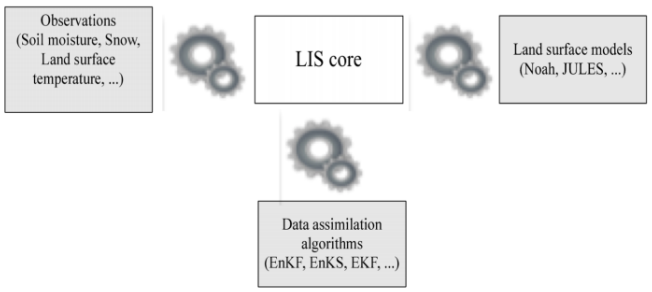
# Wrap Up

You now have all of the files needed to perform the data assimilation run.

# Step 6: LSM Data Assimilation (DA) Experiment (LIS)

## Overview

The **Data Assimilation (DA) subsystem** in LIS is primarily used for state estimation (i.e., correction of model states based on observations) and supports the interoperable use of multiple land surface models, algorithms, and observational data sources. The DA subsystem also provides support for concurrent data assimilation, forward models, radiance assimilation, and observation operators employing advanced data fusion methods (i.e., deep learning). Advanced data assimilation algorithms such as *Ensemble Kalman Filter (EnKF)* and *Ensemble Kalman Smoother (EnKS)* are available.



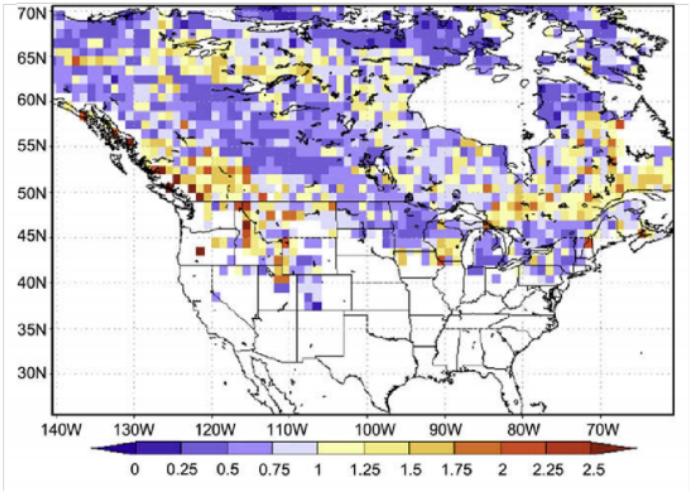

For more information:

Kumar, S. V., R. H. Reichle, C. D. Peters-Lidard, R. D. Koster, X. Zhan, W. T. Crow, J. B. Eylander, and P. R. Houser, 2008: A Land Surface Data Assimilation Framework using the Land Information System: Description and Applications, *Adv. Wat. Res.*, 31, 1419-1432, doi:10.1016/j.advwatres.2008.01.013.

The DA subsystem outputs a number of diagnostics including:

- DA innovations, normalized innovations, and ensemble spread
- Processed/bias-corrected/quality-controlled (QC'd) observational data

The Land Verification Toolkit (LVT) handles automated processing of these outputs.




*Example DA output: variance of normalized innovations*

# Download Input and Target Files

The tar file for this step is approximately **80MB** compressed and **220MB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 6:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase6_lis_da.tgz
% tar -xzf testcase6_lis_da.tgz -C .
```

The following directories and files were added to your common working directory `$WORKING_DIR`:

| | |
|---|---|
| `DA_INPUT/` | Contains the perturbation files used in the DA run |
| `lis.config_noah36_smapda` | The LIS config file for this step |
| `target_SMAPDA_OUTPUT/` | Contains the target DA output generated by LIS |
| `target_log/lislog_smapda.0000` | The target LIS log file |
| `target_da.xdf` & `test_da.xdf` | GrADS description files to view the output |

This step relies on files downloaded or generated in the previous steps. In addition to the files just downloaded, ensure the following directories are present in `$WORKING_DIR`:

| | |
|---|---|
| `DA_ensrst/` | Ensemble restart files generated in Step 3 |
| `DA_proc_LSM/` | LSM-based CDF files generated in Step 4 |
| `DA_proc_SMAP/` | Observations-based CDF files generated in Step 5 |
| `RS_DATA/` | Observation data files downloaded in Step 5 |
| `INPUT/` | NLDAS2 forcing and Noah model files downloaded in Step 2 |

# The LIS Configuration File

Review the contents of `lis.config_noah36_smapda` to view the configuration settings used for the DA run:

*Restart options*

```
...
Start mode:                                restart ①
...
Number of ensembles per tile:              12 ②
...
Noah.3.6 restart file:
./DA_ensrst/LIS_EnRST_NOAH36_201801010000.d01.nc ③
...
```

① Select "restart" mode to use a restart file (compare with coldstart mode).

② # of ensemble members to use (matches ensemble restart file).

③ Filepath of the 12 member ensemble restart file generated in Step 3.

*Data assimilation options*

```
...
Number of data assimilation instances:               1

Data assimilation algorithm:                         "EnKF"
Data assimilation set:                               "SMAP(NASA) soil moisture"
Number of state variables:                           4
Data assimilation use a trained forward model:       0
Data assimilation trained forward model output file: none
Data assimilation exclude analysis increments:       0
Data assimilation output interval for diagnostics:  "1da"
Data assimilation number of observation types:       1
Data assimilation output ensemble spread:            1
Data assimilation output processed observations:     1
Data assimilation output innovations:                1
...
```

*Scaling strategy options*

```
...
Data assimilation scaling strategy:     "CDF matching"
Data assimilation observation domain file:  ./lis_input.nldas.noah36.d01.nc

Bias estimation algorithm:                "none"
Bias estimation attributes file:          "none"
Bias estimation restart output frequency:
Bias estimation start mode:
Bias estimation restart file:
...
```

*Perturbation options*

```
...
Perturbations start mode:                "coldstart"
Perturbations restart output interval:   "1mo"
Perturbations restart filename:          "none"
Apply perturbation bias correction:      0
...
Forcing perturbation algorithm:          "GMAO scheme" ①
Forcing perturbation frequency:          "1hr"
Forcing attributes file:                 ./DA_INPUT/forcing_attribs.txt
Forcing perturbation attributes file:    ./DA_INPUT/forcing_pert_attribs.txt

State perturbation algorithm:            "GMAO scheme" ②
State perturbation frequency:            "6hr"
State attributes file:                   ./DA_INPUT/noah_sm_attribs.txt
State perturbation attributes file:      ./DA_INPUT/noah_sm_pertattribs.txt

Observation perturbation algorithm:      "GMAO scheme" ③
Observation perturbation frequency:      "6hr"
Observation attributes file:             ./DA_INPUT/smap_attribs.txt
Observation perturbation attributes file: ./DA_INPUT/smap_pertattribs.txt
```

① Forcing perturbation options

② State perturbation options

③ Observation perturbation options

*Observation data options*

```
SMAP(NASA) soil moisture data designation:       SPL3SMP
SMAP(NASA) soil moisture data directory:        ./RS_DATA/SMAP/SPL3SMP.005
SMAP(NASA) soil moisture use scaled standard deviation model: 0
SMAP(NASA) soil moisture apply SMAP QC flags:                 1
SMAP(NASA) model CDF file:              ./DA_proc_LSM/cdf_noah36.nc
SMAP(NASA) observation CDF file:        ./DA_proc_SMAP/cdf_smapobs.nc
SMAP(NASA) soil moisture number of bins in the CDF:          100
SMAP(NASA) soil moisture use scaled standard deviation model: 0
```

See the official LIS documentation for more information about configuration settings.

# The Perturbation Configuration Files

## Forcing Perturbations

Forcing variables and perturbation settings are defined in the files named `forcing_attribs.txt` and `forcing_pert_attribs.txt`, respectively. The paths to these files are set in the LIS configuration file (see *Forcing perturbation options* annotation above).

`forcing_attribs.txt` *specifies the variables and their ranges:*

```
#nfields
4
#varmin  varmax
Incident Shortwave Radiation Level 001
0.       1300.
Incident Longwave Radiation Level 001
-50.     800.
Rainfall Rate Level 001
0.0      0.001
Near Surface Air Temperature Level 001
220.0    330.0
```

For each variable listed in the snippet above, the name is given followed by the min and max values.

`forcing_pert_attribs.txt` *specifies perturbation settings:*

```
#ptype   std    std_max   zeromean  tcorr  xcorr ycorr ccorr
Incident Shortwave Radiation Level 001
1        0.20   2.5       1         86400  0     0     1.0  -0.3 -0.5  0.3
Incident Longwave Radiation Level 001
0        30.0   2.5       1         86400  0     0    -0.3   1.0  0.5  0.6
Rainfall Rate Level 001
1        0.50   2.5       1         86400  0     0    -0.5   0.5  1.0  -0.1
Near Surface Air Temperature Level 001
0        0.5    2.5       1         86400  0     0     0.3   0.6  -0.1  1.0
```

In the snippet above, the column headings represent:

- `ptype`: Perturbation type; additive (0) or multiplicative (1)
- `std`: Standard deviation of perturbations
- `std_max`: Maximum allowed normalized perturbation relative to *N(0, 1)*
- `zeromean`: Enforce zero mean across the ensemble; off (0) or on (1)
- `tcorr`: Temporal correlation scale (in seconds) used in the AR(1) model
- `xcorr` & `ycorr`: Spatial correlation scale (deg)
- `ccorr`: Cross-correlations with other variables

## State Perturbations

State variables and perturbation settings are defined in the files named `noah_sm_attribs.txt` and `noah_sm_pertattribs.txt`, respectively. The paths to these files are set in the LIS configuration file (see *State perturbation options* annotation above).

`noah_sm_attribs.txt` *specifies perturbation settings:*

```
#nfields
4
#varmin  varmax
Soil Moisture Layer 1
 0.01    0.55
Soil Moisture Layer 2
 0.01    0.55
Soil Moisture Layer 3
 0.01    0.55
Soil Moisture Layer 4
 0.01    0.55
```

`noah_sm_pertattribs.txt` *specifies the variables and their ranges:*

```
#perttype  std    std_max   zeromean  tcorr    xcorr ycorr ccorr
Soil Moisture Layer 1
  0        0.02   0.1       1          10800   0     0     1.0 0.0 0.0 0.0
Soil Moisture Layer 2
  0        0.00   0.1       1          10800   0     0     0.0 1.0 0.0 0.0
Soil Moisture Layer 3
  0        0.00   0.1       1          10800   0     0     0.0 0.0 1.0 0.0
Soil Moisture Layer 4
  0        0.00   0.1       1          10800   0     0     0.0 0.0 0.0 1.0
```

## Observation Perturbations

Observation variables and perturbation settings are defined in the files named `smap_attribs.txt` and `smap_pertattribs.txt`, respectively. The paths to these files are set in the LIS configuration file (see *Observation perturbation options* annotation above).

`smap_attribs.txt` *specifies perturbation settings:*

```
#nfields
1
#varmin  varmax
SMOPS soil moisture
 0.01    1.0
```

`smap_pertattribs.txt` *specifies the variables and their ranges:*

```
#perttype std  std_max  zeromean  tcorr  xcorr ycorr ccorr
SMOPS soil moisture
 0        0.04 2.5      1         43200  0     0     1.0
```

# Run LIS - SMAP DA Experiment

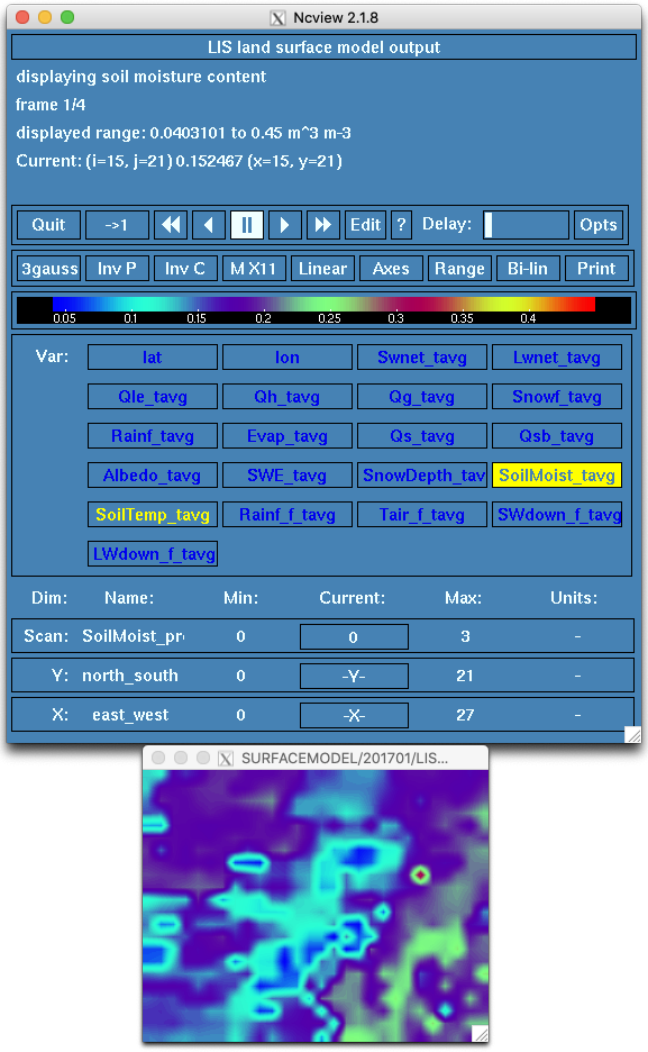
You're now ready to run LIS to perform the SMAP DA experiment. From `$WORKING_DIR`, run the LIS executable with the config file for this step:

```
./LIS -f lis.config_noah36_smapda
```

Using one processor, as we are here, the run will take approximately 30 minutes to complete. If the run fails, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of `lislog_smapda.0000`. If no errors print to the terminal, verify that the run completed successfully by checking for the following confirmation at the end of the `lislog_smapda.0000`:

```
% tail lislog_smapda.0000
...
LIS Run completed.
```

View the output of the run using GrADS, ncview, Matlab, or other software. Compare the output generated by this run with the output of the Open-Loop case from Step 2.



## Wrap Up

You have completed the SMAP Data Assimilation Experiment. In Step 7, you will use the Land Verification Toolkit (LVT) to process the output of the OL and DA runs.

# Step 7: Comparison of OL and DA Experiments (LVT)

## Overview

In this step you will use the Land Verification Toolkit (LVT) to compare the output generated in the open-loop (Step 2) and data assimilation (Step 6) experiments. Since LVT is a verification and validation software, you will need to plot the output using Python, Matlab, GrADS, etc. LVT offers a range of features and configuration settings so we strongly encourage users to review the official documentation.

## Download Input and Target Files

The tar file for this step is approximately **150KB** compressed and **700KB** unpacked. Ensure that you have enough storage available before downloading testcase files.

The tar files used in this walkthrough are available on the LIS Testcase website. From within your `$WORKING_DIR`, download and unpack the compressed tar file containing the inputs and target outputs for Step 7:

```
% curl -O
https://portal.nccs.nasa.gov/lisdata_pub/Tutorials/Web_Version/testcase7_lvt_expcomp.t
gz
% tar -xzf testcase7_lvt_expcomp.tgz -C .
```

The following files and directories were added to your common working directory `$WORKING_DIR`:

| | |
|---|---|
| `lvt.config.ol.da` | The LVT config file for the OL and DA runs |
| `lvt.config_smapDAobs` | The LVT config file for the SMAP observations used in the DA run |
| `METRICS.TBL` | A text file that defines the statistical metric options used by LVT |
| `TS_LOCATIONS.TXT` | A text file that specifies the points or regions in the domain where ASCII time series data are to be derived |
| `target_STATS.ol.da/` | A directory containing the target LVT output for the OL and DA runs |

| | |
|---|---|
| target_STATS.smapDAobs/ | A directory containing the target LVT output for the SMAP DA obs run |
| target_log/ | A directory containing target log files |
| target_fig/ | A directory containing target figures |
| plot_TS.m | A Matlab script to generate plots of the output |
| plot_noah36_smapda_littlewashita.plt<br>plot_noah36_smapda_fortcobb.plt | gnuplot scripts to generate plots of the output |

# The LVT Configuration Files

Review the two LVT configuration files for this step.

lvt.config.ol.da:

```
#Overall driver options
LVT running mode:                       "Data intercomparison"
Map projection of the LVT analysis:     latlon
LVT output format:                      netcdf
LVT output methodology:                 "2d gridspace"

Analysis data sources:               "LIS output"  "LIS output"
...

#     Datastream 1             |            Datastream 2
LVT datastream attributes table::
SoilMoist  1 1  m3/m3   - 1 4     SoilMoist  1 1  m3/m3    - 1 4
RootMoist  1 1  m3/m3   - 1 1     RootMoist  1  1 m3/m3    - 1 1
...
```

`lvt.config.smapDAobs`:

```
#Overall driver options
LVT running mode:                       "Data intercomparison"
Map projection of the LVT analysis:     latlon
LVT output format:                      netcdf
LVT output methodology:                 "2d gridspace"

Analysis data sources:                  "LIS DAOBS"  "none"
...

## DATA STREAM INPUTS ....

#Observation
LIS DAOBS output directory:  ./SMAPDA_OUTPUT/DAOBS
LIS DAOBS domain file:       ./lis_input.nldas.noah36.d01.nc
LIS DAOBS instance index:     1
LIS DAOBS use scaled obs:     1
LIS DAOBS output interval:    "15mn"
LIS DAOBS observation type:   "soil moisture"
...
```

# Running LVT

First, run LVT to process the OL vs. DA soil moisture output:

```
% ./LVT lvt.config.ol.da
```

If the run fails, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of any log files present (e.g., `lvtlog*.0000`). Otherwise, verify that the run completed successfully by checking for the confirmation message at the end of `lvtlog_ol_da.0000`:

```
% tail lvtlog_ol_da.0000
...
[INFO] Finished LVT analysis
 [INFO] ---------------------------------------
```

The output generated by this run can be found in the `STATS.ol.da` directory and should include point data for "Fort Cobb" and "Little Washita", locations specified in the `TS_LOCATIONS.txt` file. Compare these files with the target output in `target_STATS.ol.da` using `nccmp` to compare the NetCDF files and `diff` to compare the `.dat` files.

Next, run LVT to process the SMAP DA observations so it can be easily compared with our model output:

```
% ./LVT lvt.config.smapDAobs
```

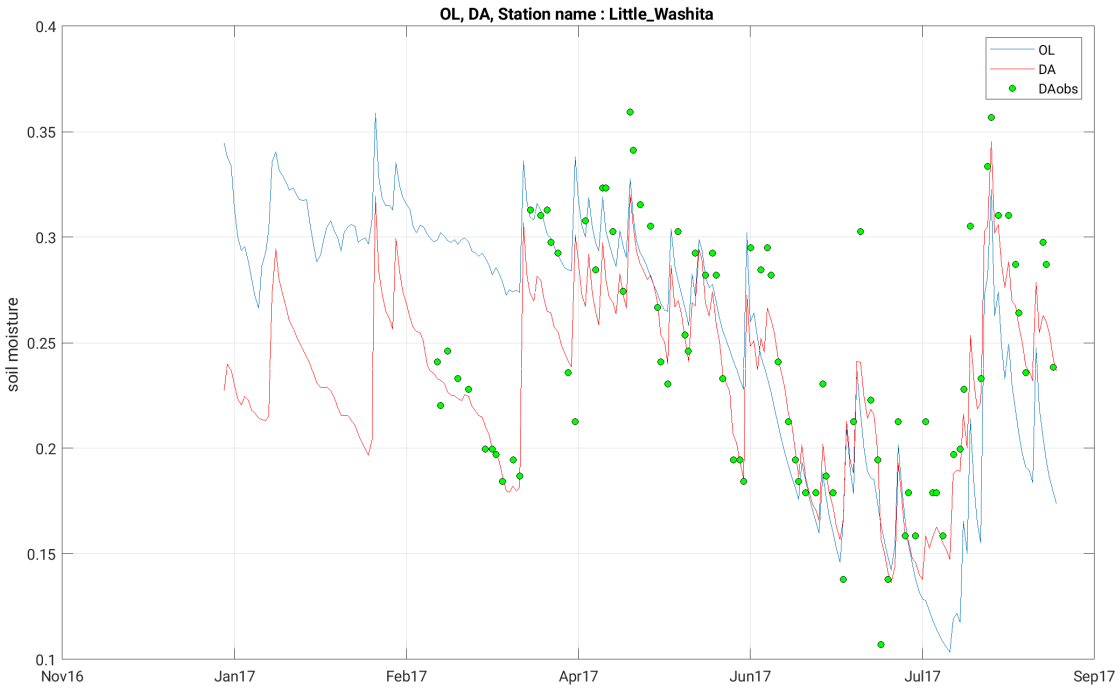
If the run fails, troubleshoot the issue by reviewing any errors printed to the terminal and by viewing the contents of any log files present (e.g., `lvtlog*.0000`). Otherwise, verify that the run completed successfully by checking for the confirmation message at the end of `lvtlog.smapDAobs.0000`:

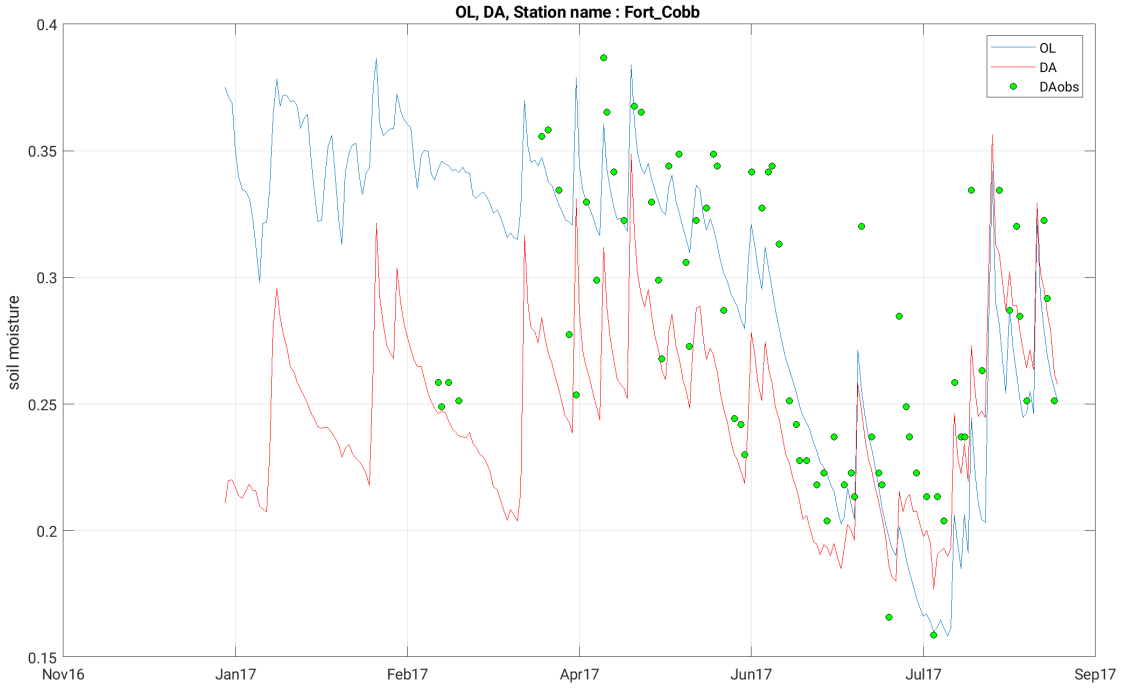
```
% tail lvtlog.smapDAobs.0000
...
[INFO] Finished LVT analysis
 [INFO] ------------------------------------
```

The output generated by this run can be found in the `STATS.smapDAobs` directory and should include point data for "Fort Cobb" and "Little Washita", locations specified in the `TS_LOCATIONS.TXT` file. Again, compare these files with the target output in `target_STATS.smapDAobs` using `nccmp` to compare the NetCDF files and `diff` to compare the `.dat` files.

# Plot the Results

To create plots of the data contained in the output files you can use the visualization software of your choice (e.g., Matlab, GrADS, Python, IDL, NCL). Sample scripts are provided to generate plots in Matlab (`plot_TS.m`) and `gnuplot` (`plot_noah36_smapda_littlewashita.plt`). The Matlab script will produce two figures:






The `gnuplot` scripts will also create one plot for each location: