Spatial Allocator Raster Tools v4.2: User's Guide

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1. Spatial Allocator Raster Tools

1.1 Background

The Spatial Allocator (SA) Raster Tools system is designed to process image or raster spatial data sets in SA. It contains programs to process various kinds of spatial data for meteorological and air quality modeling, particularly within the Weather Research and Forecasting (WRF) (http://www2.mmm.ucar.edu/wrf/users/) and Community Multiscale Air Quality (CMAQ) (http://www.cmascenter.org/cmaq/) modeling systems. The Raster Tools include land cover data processing tools, satellite cloud and aerosol product processing tools, agricultural fertilizer modeling tools, a domain grid shapefile generation tool, and other utilities.

All sample script files for the SA Raster Tools are stored in the raster_scripts directory of the installed Spatial Allocator system.

1.2 Troubleshooting

Users who have difficulties running the tools with the compiled libraries contained within the downloaded Spatial Allocator system should do the following:

1) delete installed open-source library directories under the ./src/libs directory
2) download new source packages and install them under the ./libs directory
3) compile downloaded packages and install them under {package_path}/local, following the src/libs/README file
4) modify paths in ./bin/sa_setup.csh and ./src/raster/Makefile
5) in ./src/raster, do the following:
    - make clean
    - make
    - make install

2. Domain Description in SA Raster Tools

The SA Raster Tools define the modeling domain using the following environment variables:

- GRID_PROJ – defines the domain grid projection using the PROJ4 projection description format (http://www.remotesensing.org/geotiff/proj_list/). The following sample projection descriptions are used to match the projections in WRF:
    - Lambert Conformal Conic: "+proj=lcc +a=6370000.0 +b=6370000.0 +lat_1=33 +lat_2=45 +lat_0=40 +lon_0=-97"
    - Polar stereographic: "+proj=stere +a=6370000.0 +b=6370000.0 +lat_ts=33 +lat_0=90 +lon_0=-97 +k_0=1.0"
    - Mercator: "+proj=merc +a=6370000.0 +b=6370000.0 +lat_ts=33 +lon_0=0"
    - Geographic: "+proj=latlong +a=6370000.0 +b=6370000.0"

- GRID_ROWS – number of rows of grid cells in the domain
- GRID_COLUMNS – number of columns of grid cells in the domain
- GRID_XCELLSIZE – grid cell size in *x* direction
- GRID_YCELLSIZE – grid cell size in *y* direction
- GRID_XMIN – minimum *x* of the domain (lower left corner of the domain)
- GRID_YMIN – minimum *y* of the domain (lower left corner of the domain)
- GRID_NAME – name of the domain, which is required by some of the tools

For WRF simulations, GRID_XMIN and GRID_YMIN can be computed using the first point longitude and latitude from the global attributes corner_lons and corner_lats in the domain's WRF GEOGRID output file. For instance, to compute a WRF Lambert Conformal Conic (LCC) domain with the GEOGRID output file attributes

:corner_lats = 20.85681f, 52.1644f, 50.63151f, 19.88695f, 20.84302f...

:corner_lons = -121.4918f, -135.7477f, -53.21942f, -69.02478f, -121.5451f…

users would use the cs2cs utility in the PROJ4 library directly at the command line (after installing the SA system):

```
>cs2cs +proj=latlong +a=6370000.0 +b=6370000.0 +to +proj=lcc +a=6370000.0
+b=6370000.0 +lat_1=33 +lat_2=45 +lat_0=40 +lon_0=-97
-121.4918   20.85681
-2622003.85   -1793999.28 0.00
```

Minimum *x* and *y* for the domain would be computed as follows:

GRID_XMIN = -2622003.85 - GRID_XCELLSIZE / 2

GRID_YMIN = -1793999.28 - GRID_YCELLSIZE / 2

3. Land Cover Data Processing Tools

There are two land cover processing tools in the SA Raster Tools: NLCD and MODIS land cover generation tool (Section 3.1), and Biogenic Emissions Landcover Database, version 4 (BELD4) land cover generation tool (Section 3.2).

3.1 NLCD and MODIS Land Cover Generation

The computeGridLandUse.exe tool is used to generate land cover data for the upgraded WRF/CMAQ Pleim-Xiu Land Surface Model (PX LSM) in the current WRF model release, by directly using downloaded 2001, 2006, or 2011 National Land Cover Data (NLCD) land cover data and the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) land cover products MCD12Q1 or MOD12Q1. This tool generates 40 land cover classes (20 from MODIS and 20 from NLCD) instead of the 50 classes generated by the previous land cover processing tool.

This tool requires the following data sets:

- NLCD land cover, canopy, and imperviousness data – can be obtained from http://www.mrlc.gov/nlcd2006.php.
- MODIS land cover data sets – can be obtained from http://ladsweb.nascom.nasa.gov/data/search.html. The tool can process MCD12Q1 data at 500 m from Combined Terra and Aqua MODIS, or can process MOD12Q1 data at 1 km from Terra MODIS.
- List of land cover data sets to be processed – this file has to have fixed header formats. Provided in the data directory are sample files for CMAQ 12-km domain 2001, 2006 and 2011 modeling: nlcd_modis_files_2001.txt, nlcd_modis_files_2006.txt, and nlcd_modis_files_2011.txt. Users have to modify the list file based on their NLCD and MODIS data location and names.

To run the computeGridLandUse tool, users can use the following sample script file, which has all of the required environment variables:

NLCD_MODIS_processor.csh

The tool generates one ASCII file and one NetCDF file:

- The ASCII file contains the imperviousness, canopy, and land cover percent variables (if the user set all land cover data to "YES" when running the script file) for each grid cell, in comma-separated-values (CSV) format.
- The NetCDF file contains imperviousness, canopy, and land cover fraction variables plus land/water mask and other variables that are similar to those in the WRF GEOGRID land cover output files. The land cover percentage variable contains the 40 classes in Table 1.

Table 1. NLCD/MODIS output land cover classes from the computeGridLandUse tool.

Array Index	MODIS Class IGBP (Type 1)	Class Name	Array Index	NLCD Class	Class Name
1	1	Evergreen Needleleaf forest	21	11	Open Water
2	2	Evergreen Broadleaf forest	22	12	Perennial Ice/Snow
3	3	Deciduous Needleleaf forest	23	21	Developed - Open Space
4	4	Deciduous Broadleaf forest	24	22	Developed - Low Intensity
5	5	Mixed forest	25	23	Developed - Medium Intensity
6	6	Closed shrublands	26	24	Developed High Intensity
7	7	Open shrublands	27	31	Barren Land (Rock/Sand/Clay)
8	8	Woody savannas	28	41	Deciduous Forest
9	9	Savannas	29	42	Evergreen Forest
10	10	Grasslands	30	43	Mixed Forest
11	11	Permanent wetlands	31	51	Dwarf Scrub
12	12	Croplands	32	52	Shrub/Scrub
13	13	Urban and built-up	33	71	Grassland/Herbaceous

Array Index	MODIS Class IGBP (Type 1)	Class Name	Array Index	NLCD Class	Class Name
14	14	Cropland/Natural vegetation mosaic	34	72	Sedge/Herbaceous
15	15	Snow and ice	35	73	Lichens
16	16	Barren or sparsely vegetated	36	74	Moss
17	0	Water	37	81	Pasture/Hay
18	18	Reserved (e.g., Unclassified)	38	82	Cultivated Crops
19	19	Reserved (e.g., Fill Value)	39	90	Woody Wetlands
20	20	Reserved	40	95	Emergent Herbaceous Wetlands

3.2 BELD4 Land Cover Generation

The BELD4 data with land cover, tree, and crop percentages can be computed using the computeGridLandUse_beld4.exe tool with directly downloaded USGS NLCD data sets, NASA MODIS land cover (MCD12Q1 or MOD12Q1) data tiles and tree and crop fractions at the county level. The following sample script file contains all of the required environment variables for running the tool:

landuseTool_WRFCMAQ_BELD4.csh

This tool requires the following data sets:

- Downloaded USGS NLCD data sets, including land cover, imperviousness, and canopy, can be obtained from the NLCD web site: http://www.mrlc.gov/nlcd2006.php.
- MODIS land cover tiles (MCD12Q1 or MOD12Q1) – can be obtained from the NASA MODIS land products web site: http://modis-land.gsfc.nasa.gov/landcover.html.
- List of land cover data sets to be processed – this file has to be fixed format with the data set headers included. Provided in the data directory are sample files for CMAQ 12-km domain 2001, 2006 and 2011 modeling: nlcd_modis_files_2001.txt, nlcd_modis_files_2006.txt, and nlcd_modis_files_2011.txt. Users have to modify the list file based on their NLCD and MODIS data location and names.
- BELD3 FIA tree fraction table at county level – provided in the data directory: beld3-fia.dat.
- National Agricultural Statistics Service (NASS) crop fraction tables at county level – provided in the data directory: nass2001_beld4_ag.dat for the 2001 NASS; nass2006_beld4_ag.dat for the 2006 NASS.
- Canada crop fraction table at Census-division level – provided in the data directory: can01_beld4_ag.dat for the 2001 Census of Agriculture; can06_beld4_ag.dat for the 2006 Census of Agriculture.
- List of land cover, tree, and crop classes for the BELD4 tool – provided in the data directory: beld4_class_names_40classes.txt.

- U.S. county shapefile – provided in the data directory: county_pophu02_48st.shp.
- Canada Census-division shapefiles – provided in the data directory: can2001_cd_sel.shp for the 2001 Census; can2006_cd_sel.shp for the 2006 Census.

The tool generates one ASCII file and one NetCDF file:

- The ASCII file contains the imperviousness, canopy, and land cover fraction variables (if the user set all land cover data to "YES" when running the script file) for each grid cell, in CSV format.
- The NetCDF file contains imperviousness, canopy, land cover, tree, and crop percentage variables as well as land/water mask and other variables that are similar to those in the WRF GEOGRID land cover output files.

The land cover data generated by applying this tool are used in CMAQ bidirectional ammonia flux modeling and are used in CMAQ biogenic, land surface, and dry deposition modeling. The land cover percentage array in the output contains 20 NLCD land cover classes and 20 MODIS IGBP land cover classes (see Table 1). The tree percentage variable in the NetCDF output file contains the 194 BELD4 tree classes shown in Table 2, and the crop percentage variable contains the 42 crops listed in Table 3.

Table 2. BELD4 tree classes.

Index	Variable	Index	Variable	Index	Variable	Index	Variable	Index	Variable
1	Acacia	40	Hackberry	79	Oak_bur	118	Paulownia	157	Pine_whitebark
2	Ailanthus	41	Hawthorn	80	Oak_CA_black	119	Pawpaw	158	Pine_Wwhite
3	Alder	42	Hemlock	81	Oak_CA_live	120	Persimmon	159	Pine_yellow
4	Apple	43	Hickory	82	Oak_CA_white	121	Pine_Apache	160	Populus
5	Ash	44	Holly_American	83	Oak_canyon_live	122	Pine_Austrian	161	Prunus
6	Basswood	45	Hornbeam	84	Oak_chestnut	123	Pine_AZ	162	Redbay
7	Beech	46	Incense_cedar	85	Oak_chinkapin	124	Pine_Bishop	163	Robinia_locust
8	Birch	47	Juniper	86	Oak_delta_post	125	Pine_blackjack	164	Sassafras
9	Bumelia_gum	48	KY_coffeetree	87	Oak_Durand	126	Pine_brstlcone	165	Sequoia
10	Cajeput	49	Larch	88	Oak_Emery	127	Pine_chihuahua	166	Serviceberry
11	Califor-laurel	50	Loblolly_bay	89	Oak_Engelmann	128	Pine_Coulter	167	Silverbell
12	Cascara-buckthor	51	Madrone	90	Oak_evergreen_sp	129	Pine_digger	168	Smoketree
13	Castanea	52	Magnolia	91	Oak_Gambel	130	Pine_Ewhite	169	Soapberry_westrn
14	Catalpa	53	Mahogany	92	Oak_interio_live	131	Pine_foxtail	170	Sourwood
15	Cedar_chamaecyp	54	Maple_bigleaf	93	Oak_laurel	132	Pine_jack	171	Sparkleberry
16	Cedar_thuja	55	Maple_bigtooth	94	Oak_live	133	Pine_Jeffrey	172	Spruce_black
17	Chestnut_buckeye	56	Maple_black	95	Oak_Mexicanblue	134	Pine_knobcone	173	Spruce_blue
18	Chinaberry	57	Maple_boxelder	96	Oak_Northrn_pin	135	Pine_limber	174	Spruce_Brewer
19	Cypress_cupress	58	Maple_FL	97	Oak_Northrn_red	136	Pine_loblolly	175	Spruce_Englemann
20	Cypress_taxodium	59	Maple_mtn	98	Oak_nuttall	137	Pine_lodgepole	176	Spruce_Norway
21	Dogwood	60	Maple_Norway	99	Oak_OR_white	138	Pine_longleaf	177	Spruce_red
22	Douglas_fir	61	Maple_red	100	Oak_overcup	139	Pine_Monterey	178	Spruce_Sitka
23	East_hophornbean	62	Maple_RkyMtn	101	Oak_pin	140	Pine_pinyon	179	Spruce_spp

Index	Variable	Index	Variable	Index	Variable	Index	Variable	Index	Variable
24	Elder	63	Maple_silver	102	Oak_post	141	Pine_pinyon_brdr	180	Spruce_white
25	Elm	64	Maple_spp	103	Oak_scarlet	142	Pine_pinyon_cmn	181	Sweetgum
26	Eucalyptus	65	Maple_striped	104	Oak_scrub	143	Pine_pitch	182	Sycamore
27	Fir_balsam	66	Maple_sugar	105	Oak_shingle	144	Pine_pond	183	Tallowtree-chins
28	Fir_CA_red	67	Mesquite	106	Oak_Shumrd_red	145	Pine_ponderosa	184	Tamarix
29	Fir_corkbark	68	Misc-hardwoods	107	Oak_silverleaf	146	Pine_red	185	Tanoak
30	Fir_fraser	69	Mixed_conifer_sp	108	Oak_Southrn_red	147	Pine_sand	186	Torreya
31	Fir_grand	70	Mountain_ash	109	Oak_spp	148	Pine_scotch	187	Tung-oil-tree
32	Fir_noble	71	Mulberry	110	Oak_swamp_cnut	149	Pine_shortleaf	188	Unknown_tree
33	Fir_Pacf_silver	72	Nyssa	111	Oak_swamp_red	150	Pine_slash	189	Walnut
34	Fir_SantaLucia	73	Oak_AZ_white	112	Oak_swamp_white	151	Pine_spruce	190	Water-elm
35	Fir_Shasta_red	74	Oak_bear	113	Oak_turkey	152	Pine_sugar	191	Willow
36	Fir_spp	75	Oak_black	114	Oak_water	153	Pine_Swwhite	192	Yellow_poplar
37	Fir_subalpine	76	Oak_blackjack	115	Oak_white	154	Pine_tablemtn	193	Yellowwood
38	Fir_white	77	Oak_blue	116	Oak_willow	155	Pine_VA	194	Yucca_Mojave
39	Gleditsia_locust	78	Oak_bluejack	117	Osage-orange	156	Pine_Washoe		

Table 3. BELD4 crop classes.

Index	Variable	Index	Variable	Index	Variable
1	Hay	15	Cotton	29	SorghumSilage
2	Hay_ir	16	Cotton_ir	30	SorghumSilage_ir
3	Alfalfa	17	Oats	31	Soybeans
4	Alfalfa_ir	18	Oats_ir	32	Soybeans_ir
5	Other_Grass	19	Peanuts	33	Wheat_Spring
6	Other_Grass_ir	20	Peanuts_ir	34	Wheat_Spring_ir
7	Barley	21	Potatoes	35	Wheat_Winter
8	Barley_ir	22	Potatoes_ir	36	Wheat_Winter_ir
9	BeansEdible	23	Rice	37	Other_Crop
10	BeansEdible_ir	24	Rice_ir	38	Other_Crop_ir
11	CornGrain	25	Rye	39	Canola
12	CornGrain_ir	26	Rye_ir	40	Canola_ir
13	CornSilage	27	SorghumGrain	41	Beans
14	CornSilage_ir	28	SorghumGrain_ir	42	Beans_ir

3.3 Current and Future Development for the Land Cover Data Processing Tools

We will enhance the tool to use the released NLCD 2011 data sets with created 2011 crop tables for both US and Canada. In addition, in the future we plan to use USDA's NLCD Cropland Data Layer (CDL) data instead of NASS crop fractions at the county level for the BELD4 data tool. This will allow us to use USDA crop spatial coverage NLCD data instead of county-based crop census data in computing crop fractions within each grid cell.

4. Satellite Cloud and Aerosol Product Processing Tools

4.1 GOES Cloud Product Processing Tool

The GOES data tool processes the Geostationary Operational Environmental Satellite (GOES) data downloaded from the Earth System Science Center (ESSC) at the University of Alabama in Huntsville. The GOES data web site is http://satdas.nsstc.nasa.gov/.

Downloaded GOES data need to be stored under subdirectories named using this format: gp_YYYYMMDD. The ./util/goes_untar.pl utility can be used to unzip downloaded GOES data (daily tar files) into the daily directories required by the tool.

The following sample script file contains all of the required environment variables for running the tool:

allocateGOES2WRFGrids.csh

The tool contains the following three programs:

- correctGOESHeader.exe – to correct GOES data position shifting by redefining a new Earth radius and new image extent. The program converts GOES data in Grib (i.e., *.grb) format to files in ERDAS Imagine (i.e., *.img) format with corrections.
- computeGridGOES.exe – to regrid corrected Imagine-format GOES data to a defined grid domain.
- toDataAssimilationFMT.exe – to convert the gridded NetCDF file into a format suitable for WRF assimilation.

The released GOES data has changed to ASCII format from GRIB format last year. We plan to update the tool in the coming months.

Note: When running the GOES cloud product processing tool, the Geospatial Data Abstraction Library (GDAL) will generate the following messages:

- Warning: Inside GRIB2Inventory, Message # 2
- ERROR: Ran out of file reading SECT0

These messages do not indicate any errors in regridding and so can be ignored.

4.2 MODIS Level 2 Cloud/Aerosol Products Tool

The MODIS Level 2 (swath) cloud and aerosol products tool processes MODIS L2 cloud or aerosol products for a defined grid domain. MODIS data in HDF4 format can be downloaded from the NASA Level 1 and Atmosphere Archive and Distribution System (LAADS) web site: http://ladsweb.nascom.nasa.gov/data/search.html.

MODIS cloud product variables contain 5-km and 1-km data. To use this regridding tool, users need to download the following cloud data and Level 1 Geolocation 1-km data into the input directory:

- MOD06_L2 and MOD03 (Level 1 Geolocation 1-km) for Terra, or
- MYD06_L2 and MYD03 (Level 1 Geolocation 1-km) for Aqua

The following download options can be selected during the downloading process:

MODIS Cloud:

- Select Level 2 products and select L2 Cloud products
- Select time: "your download time period"
- Collection 5
- Select Latitude/Longitude with area longitude and latitude extent
- Coverage options: select day, night, and both (all)
- Select all other defaults and click search
- Display all files
- Download all files into one directory

MODIS Geolocation 1-km:

- Select Level 1 products and select 03 Geolocation - 1km
- Select time: "same as cloud products"
- Collection 5
- Select Latitude/Longitude with the above geographic extent
- Coverage options: select day, night, and both (all)
- Display all files
- Download all files into the MODIS Cloud file directory

MODIS aerosol products contain variable data at 10-km resolution (nadir). Users need to download MOD04 for Terra or MYD04 for Aqua into the input data directory. The download options below can be selected when downloading Terra aerosol products. Downloading Aqua aerosol products involves similar options. The tool generates one NetCDF file for the defined domain.

- Select Terra MODIS
- MODIS Aerosol products
- Select Level 2 products and select L2 aerosol product
- Select time: "your download time period"
- Collection 5
- Select Latitude/Longitude with area longitude and latitude extent

- Coverage options: select day, night, and both (all)
- Select all other defaults and click search
- Display all files
- Download all files into one directory

Users can modify the following sample script file provided for regridding:

allocateMODISL2CloudVars2Grids.csh

4.3 OMI Level 2 Product Tool

The OMI Level 2 product (swath) tool is used to regrid Ozone Monitoring Instrument (OMI) L2 aerosol and NO_2 products for a defined grid domain. The input data can be downloaded from the NASA mirador site: http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=OMI.

The downloaded data are in HDF5 format and should be stored in one directory, which is defined in the following sample script file:

allocateOMIL2vars2Grids.csh

4.4 OMI L2G and L3 Product Tools

The OMI L2G and L3 product tools process the following OMI products:

- OMI L3 aerosol products (OMAEROe) in HDF4
- OMI NO2 L2G products (OMNO2G) in HDF4
- OMI NO2 L3 products (NO2TropCS30) in HDF5

The data can be downloaded from the NASA Giovanni web site:
http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=omi

OMI product information can be viewed from http://disc.sci.gsfc.nasa.gov/giovanni/additional/users-manual/G3_manual_Chapter_10_OMIL2G.shtml#what_l2g and from ftp://aurapar2u.ecs.nasa.gov/data/s4pa//Aura_OMI_Level2/OMAERUV.003/doc/README.OMI_DUG.pdf

The following sample script can be modified for regridding:

allocateOMIvar2Grids.csh

5. Agricultural Fertilizer Modeling Tools

There are four tools that can be used when performing Environmental Policy Integrated Climate (EPIC) modeling; they generate gridded agricultural fertilizer data to be used in CMAQ bidirectional NH_3 flux modeling. These tools are the EPIC site information generation tool, the MCIP/CMAQ-to-EPIC tool, the EPIC-to-CMAQ tool, and the EPIC yearly extraction tool

(Sections 5.1 through 5.4).They can be called from the Fertilizer Emission Scenario Tool for CMAQ (FEST-C) interface (http://www.cmascenter.org/fest-c/) based on user input information, and can be run by script files with defined environment variables at the command line.

5.1 EPIC Site Information Generation Tool

This tool generates two CSV data files that are needed to create EPIC site databases for a user-defined domain:

- EPICSites_Info.csv – contains GRIDID, XLONG, YLAT, ELEVATION, SLOPE_P, HUC8, REG10, STFIPS, CNTYFIPS, GRASS, CROPS, CROP_P, COUNTRY, and COUNTRY-PROVINCE items.
- EPICSites_Crop.csv – contains GRIDID, 42 crop acreages, COUNTRY, and HUC8 items.

The tool processes the set of input spatial data files below, which have been modified specifically for use with the tool and can be obtained from the CMAS:

- BELD4 file for the domain (beld4_cmaq12km_2006.nc)
- U.S. county shapefiles (co99_d00_conus_cmaq_epic.shp)
- North American State political boundary shapefile (na_bnd_camq_epic.shp)
- U.S. 8-digit HUC shapefile (conus_hucs_8_cmaq.shp)
- Elevation image file (na_dem_epic.img)
- Slope image file (na_slope_epic.img)

Users can follow the sample script file below, which has all of the environment variables required for running the tool from the command line window:

generateEPICSiteData.csh

5.2 MCIP/CMAQ-to-EPIC Tool

This tool generates EPIC daily weather and nitrogen deposition data files from MCIP meteorology and CMAQ nitrogen deposition files for EPIC modeling sites. The input MCIP and CMAQ data are stored in two directories defined by the environment variables DATA_DIR and DATA_DIR_CMAQ.

MCIP output files must have names of the format METCRO2D*{date} (e.g., METCRO2D_020725). The date format can be in one of the following formats:

YYYYMMDD *or* YYMMDD *or* YYYYDDD *or* YYDDD

CMAQ dry and wet deposition files must have names of the format *DRYDEP*{date} and *WETDEP*{date} (e.g., CCTM_N4a_06emisv2soa_12km_wrf.DRYDEP.20020630 and CCTM_N4a_06emisv2soa_12km_wrf.WETDEP1.20020630). The date can be in any of the formats listed above.

Deposition inputs for EPIC modeling can take one of the following three inputs:

1) Directory containing a CMAQ dry and wet deposition file
2) Zero – assume zero nitrogen deposition
3) Default – assume nitrogen mix ratio of 0.8 ppm for wet default deposition computation

The input site location file defined by the environment variable EPIC_SITE_FILE has to be a CSV file, with the first three items being site ID, longitude, and latitude.

The tool generates three outputs:

- dailyWETH directory containing EPIC daily weather and nitrogen deposition files with names of the format "grid ID".dly (e.g., 96.dly). The daily file contains the 14 variables listed in Table 4.
- NetCDF file with daily weather and nitrogen deposition data for all EPIC sites.
- EPICW2YR.2YR, to be used for daily weather file input list in EPIC modeling.

Table 4. EPIC daily weather and nitrogen deposition variables.

Index	Variable	Index	Variable
1	Year	8	Daily Average Relative Humidity
2	Month	9	Daily Average 10m Windspeed (m s^-1)
3	Day	10	Daily Total Wet Oxidized N (g/ha)
4	Daily Total Radiation (MJ m^02)	11	Daily Total Wet Reduced N (g/ha)
5	Daily Maximum 2m Temperature (C)	12	Daily Total Dry Oxidized N (g/ha)
6	Daily minimum 2m temperature (C)	13	Daily Total Dry Reduced N (g/ha)
7	Daily Total Precipitation (mm)	14	Daily Total Wet Organic N (g/ha)

Users can follow the sample script file below, which has all of the environment variables required for running the tool from the command line window:

generateEPICsiteDailyWeatherNdep.csh

5.3 EPIC-to-CMAQ Tool

This tool processes merged daily output from EPIC simulations for the 42 crops defined for the BELD4 tool output. It generates two types of outputs in NetCDF format for CMAQ bidirectional NH_3 modeling:

- soil output file
- EPIC daily output files

The 13 variables contained in the soil output file are listed in Table 5.

Table 5. EPIC-to-CMAQ soil output variables.

Index	Name	Soil Variable	Index	Name	Soil Variable
1	L1_SoilNum	Soil Number (none)	8	L2_Bulk_D	Layer2 Bulk Density (t/m**3)
2	L1_Bulk_D	Layer1 Bulk Density (t/m**3)	9	L2_Wilt_P	Layer2 Wilting Point (m/m)
3	L1_Wilt_P	Layer1 Wilting Point(m/m)	10	L2_Field_C	Layer2 Field Capacity (m/m)
4	L1_Field_C	Layer1 Field Capacity (m/m)	11	L2_Porocity	Layer2 Porocity (%)
5	L1_Porocity	Layer1 Porocity (%)	12	L2_PH	Layer2 PH (none)
6	L1_PH	Layer1 PH (none)	13	L2_Cation	Layer2 Cation Ex (cmol/kg)
7	L1_Cation	Layer1 Cation Ex (cmol/kg)			

EPIC daily output files for CMAQ contain the 59 variables listed in Table 6.

The following sample script file with all required environment variables can be modified and run at the command line:

epic2CMAQ.csh

Table 6. EPIC for CMAQ daily output variables.

Index	Name	Variable	Index	Name	Variable
1	QNO3	N Loss in Surface Runoff (kg/ha)	30	L2_ON	Layer2 Organic N (kg/ha)
2	SSFN	N in Subsurface Flow (kg/ha)	31	L2_P	Layer2 Mineral P (kg/ha)
3	PRKN	N Loss in Percolate (kg/ha)	32	L2_OP	Layer2 Organic P (kg/ha)
4	DN	N-NO3 Denitrification (kg/ha)	33	L2_C	Layer2 Carbon (kg/ha)
5	DN2*	N-N2O from NO3 Denitrification (kg/ha)	34	L2_NITR	Layer2 N - Nitrified NH3 (kg/ha)
6	AVOL*	N-NH3 Emission (kg/ha)	35	T1_DEP	Layert Depth (m)
7	HMN	OC Change by Soil Respiration (kg/ha)	36	T1_BD	Layert Bulk Density (t/m**3)
8	NFIX	N Fixation (kg/ha)	37	T1_NO3	Layert N - Nitrate (kg/ha)
9	YP	P Loss with Sediment (kg/ha)	38	T1_NH3	Layert N - Ammonia (kg/ha)
10	QAP	Labile P Loss in Runoff (kg/ha)	39	T1_ON	Layert Organic N (kg/ha)
11	YON	N Loss with Sediment (kg/ha)	40	T1_P	Layert Mineral P (kg/ha)
12	YW	Wind Erosion (ton/ha)	41	T1_OP	Layert Organic P (kg/ha)
13	Q	Runoff (mm)	42	T1_C	Layert Carbon (kg/ha)
14	HUSC	Heat Unit Schedule (none)	43	T1_NITR	Layert N - Nitrified NH3 (kg/ha)
15	HU_BASE0	Base Heat Unit (none)	44	L1_ANO3	Layer1 N-NO3 AppRate (kg/ha)
16	HU_FRAC	Heat Unit fraction (none)	45	L1_ANH3	Layer1 N-NH3 AppRate (kg/ha)
17	L1_DEP	Layer1 Depth (m)	46	L1_AON	Layer1 ON AppRate (kg/ha)
18	L1_BD	Layer1 Bulk Density (t/m**3)	47	L1_AMP	Layer1 MP AppRate (kg/ha)
19	L1_NO3	Layer1 N - Nitrate (kg/ha)	48	L1_AOP	Layer1 OP AppRate (kg/ha)
20	L1_NH3	Layer1 N - Ammonia (kg/ha)	49	L2_ANO3	Layer2 N-NO3 AppRate (kg/ha)
21	L1_ON	Layer1 Organic N (kg/ha)	50	L2_ANH3	Layer2 N-NH3 AppRate (kg/ha)
22	L1_P	Layer1 Mineral P (kg/ha)	51	L2_AON	Layer2 ON AppRate (kg/ha)

23	L1_OP	Layer1 Organic P (kg/ha)	52	L2_AMP	Layer2 MP AppRate (kg/ha)
24	L1_C	Layer1 Carbon (kg/ha)	53	L2_AOP	Layer2 OP AppRate (kg/ha)
25	L1_NITR	Layer1 N - Nitrified NH3 (kg/ha)	54	UN1	N Uptake by Crop (kg/ha)
26	L2_DEP	Layer2 Depth (m)	55	HUI	Heat Unit Index (none)
27	L2_BD	Layer2 Bulk Density (t/m**3)	56	LAI	Leaf Area Index (none)
28	L2_NO3	Layer2 N - Nitrate (kg/ha)	57	CPHT	Crop Height (m)
29	L2_NH3	Layer2 N - Ammonia (kg/ha)			

*DN2 is currently under revision, and AVOL is an initial estimate that is revised within the bidirectional CMAQ.

5.4 EPIC Yearly Extraction Tool

This tool is used primarily to provide data for performing quality assurance (QA) for EPIC runs.

- For EPIC spin-up runs, it extracts average EPIC values from the last five years of the spin-up simulations.
- For EPIC application runs, it extracts application-year EPIC variables.

In both cases, the tool outputs one crop-specific NetCDF file with 31 variables and one crop-weighted NetCDF file with 22 variables; Table 7 shows the two lists of variables.

Table 7. EPIC yearly extraction output variables.

epic2cmaq_year.nc - crop specific output					
Index	Name	Variable	Index	Name	Variable
1	GMN	N Mineralized (kg/ha)	19	T_YLDG	T - Grain Yield (1000ton)
2	NMN	Humus Mineralization (kg/ha)	20	YLDF	Forage Yield (t/ha)
3	NFIX	N Fixation (kg/ha)	21	T_YLDF	T - Forage Yield (1000ton)
4	NITR	N - Nitrified NH3 (kg/ha)	22	YLN	N Used by Crop (kg/ha)
5	AVOL	N - Volatilization (kg/ha)	23	YLP	P Used by Crop (kg/ha)
6	DN	N-NO3 Denitrification (kg/ha)	24	FTN	N Applied (kg/ha)
7	YON	N Loss with Sediment (kg/ha)	25	FTP	P Applied (kg/ha)
8	QNO3	N Loss in Surface Runoff (kg/ha)	26	IRGA*	Irrigation Volume Applied (mm)
9	SSFN	N in Subsurface Flow (kg/ha)	27	WS	Water Stress Days (days)
10	PRKN	N Loss in Percolate (kg/ha)	28	NS	N Stress Days (days)
11	FNO	N - Organic Fertilizer (kg/ha)	29	IPLD	Planting Date (Julian Date)
12	FNO3	N - Nitrate Fertilize (kg/ha)	30	IGMD	Germination Date (Julian Date)
13	FNH3	N - Ammonia Fertilize (kg/ha)	31	IHVD	Harvest Date (Julian Date)
14	OCPD	Organic Carbon in Plow Layer (mt/ha)	32	YP	P Loss with Sediment (kg/ha)
15	TOC	Organic Carbon in Soil Profile (mt/ha)	33	QAP	Labile P Loss in Runoff (kg/ha)
16	TNO3	Total NO3 in Soil Profile (kg/ha)	34	YW	Wind Erosion (ton/ha)
17	DN2	N-N2O from NO3 Denitrification (kg/ha)	35	Q*	Runoff (mm)
18	YLDG	Grain Yield (t/ha)			

epic2cmaq_year_total.nc - crop weighted output					
Index	Name	Variable	Index	Name	Variable
1	T_GMN	N Mineralized (mt - metric ton)	14	T_OCPD	Organic Carbon in Plow Layer (1000mt)
2	T_NMN	Humus Mineralization (mt)	15	T_TOC	Organic Carbon in Soil Profile (1000mt)
3	T_NFIX	N Fixation (mt)	16	T_TNO3	Total NO3 in Soil Profile (mt)
4	T_NITR	N - Nitrified NH3 (mt)	17	T_DN2	N-N2O from NO3 Denitrification (mt)
5	T_AVOL	N - Volatilization (mt)	18	T_YLN	N Used by Crop (mt)
6	T_DN	N-NO3 Denitrification (mt)	19	T_YLP	P Used by Crop (mt)
7	T_YON	N Loss with Sediment (mt)	20	T_FTN	N Applied (mt)
8	T_QNO3	N Loss in Surface Runoff (mt)	21	T_FTP	P Applied (mt)
9	T_SSFN	N in Subsurface Flow (mt)	22	T_IRGA*	Irrigation Volume Applied (mm)
10	T_PRKN	N Loss in Percolate (mt)	23	T_YP	T - P Loss with Sediment (mt)
11	T_FNO	N - Organic Fertilizer (mt)	24	T_QAP	T - Labile P Loss in Runoff (mt)
12	T_FNO3	N - Nitrate Fertilizer (mt)	25	T_YW	T - Wind Erosion (1000ton)
13	T_FNH3	N - Ammonia Fertilizer (mt)	26	T_Q*	T - Runoff (mm)

*Water on agricultural lands.

The following sample script file, which is contained in the Raster Tools script directory, has all required environment variables and can be modified and run at the command line:

epicYearlyAverage4QA.csh

6. Other Tools and Utilities

6.1 Domain Grid Shapefile Generation Tool

Users can apply the domain grid shapefile generation tool to generate a polygon shapefile for a defined grid domain with the GRIDID attribute. The GRIDID attribute has values ranging from 1 for the grid cell in the lower left corner of the domain to the maximum number of cells for the grid cell in the upper right. The following sample script file can be modified for domain shapefile generation:

generateGridShapefile.csh

6.2 Other Utilities

The following utility programs are stored in the **util** directory:

- **goes_untar.pl** – used to untar downloaded GOES data into the format required for the GOES cloud product processing tool.
- **updateWRFinput_landuse.R** – used to update the wrfinput file using generated land use data by the NLCD and MODIS land cover generation tool (see Section 3.1). The updated

wrfinput file can be used in WRF simulations with the WRF Pleim-Xiu Land Surface Model, using the 40 classes of NLCD/MODIS land cover data shown in Table 1.

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