

# NUDAPT 44 Documentation

**04/25/2013**

Tim Glotfelty<sup>1</sup>, Mukul Tewari<sup>2</sup>, Kevin Sampson<sup>3</sup>, Michael Duda<sup>4</sup>, Fei Chen<sup>5</sup>, Jason Ching<sup>6</sup>

<sup>1</sup>NCSU, Raleigh, NC-27695

<sup>2,3,4,5</sup>NCAR, Boulder, CO-80301

<sup>6</sup>UNC-Chapel Hill, NC-27599

## **Introduction:**

The overall goal of this National Urban Data and Access Portal Tool (NUDAPT) data set is to support the urban canopy models in WRF (Chen et al., 2011). Half the world's population now live in cities, this proportion will increase in time. In response, cities and their environment are in constant evolution. Urban areas both influence as well as are impacted by climate change. Urban planners need to address big deal issues like population growth, urban sustainability, health and quality of life issues and increasingly depended on advanced models. The morphology of the urban areas including building structures, their distribution and compositional materials, the imperviousness, perviousness and adjacent vegetative cover of the surfaces profoundly affect the urban boundary layer, and on a variety of scales. Such information is critical to the performance of meso-to-urban scale models; such models are in a continued state of development so as to provide a framework for addressing the increasingly more complex problems of urbanization. The NUDAPT project (Ching et al., 2009, Burian and Ching, 2010) was designed to provide specific information needs of these advance urban models. Emerged and in response to 9-11. This prompted the need to be proactive in developing advance modeling tools for urban applications. Several representatives from private, academic and public agencies formed a consortium; they proposed to develop a modeling database that would be capable of supporting the modeling community. This Consortium embraced the concept of a community-based system. A prototype was to be developed and tested along this concept. For this Prototype, the USEPA supported the collection and processing of a special urban canopy dataset of urban canopy parameters – for Houston TX. and for use in MM5. Other agencies contributed and the National Building Statistics Database emerged. The NBSD (Burian et al., 2007) was developed by NUDAPT consortium members utilizing airborne lidar data collected by USA Federal agencies for the building data. The NBSD included data for 44 cities in the USA the resulting set of UCPS were gridded at 1 km and 250 meter grids. This effort was focused primarily for the high density building districts. NCAR has agreed to host this data set and make it available to its community mesoscale modeling system, the Weather Research & Forecast (WRF) system.

The NUDAPT-NBSD dataset consists of the variables shown in Table 1. The implementation supports two WRF urban canopy models: Single layer Urban Canopy Model (SLUCM), (Kusaka et al., 2001), and the Multi-level Building Environment Parameterization (BEP), (Martilli et al., 2009) with the accompanying Building Energy Model (BEM), (Salamanca et al., 2010). Only the parameters of red, blue, or purple color in Table 1 are actually used to calculate WRF-Urban morphology and the remaining parameters will exist as a basis for future model development. Since this dataset does not contain urban fraction, it must be obtained from somewhere else. In order to overcome this shortfall the 30m resolution National Land Cover Data dataset was used. This data set possesses three urban categories: low density residential, high density residential, and commercial/industrial. The urban fraction variable was generated using an additional program, which enabled us to designate each urban category as urban fraction of unity, which the WPS program aggregated to a 1 km urban fraction. This approach produced a strong overestimation of the urban fraction especially in residential areas. In order to fix this source of error, a hybrid approach was developed in which the 30m NLCD classes were assigned the fractional value from the WRF-Urban parameter table. This produced a more reasonable fraction which represents a compromise between increasing the urban fraction heterogeneity as compared to the parameter table and decreasing the overestimation of the NLCD approach.

## **Preprocessing**

The original NUDAPT-44-NBSD dataset was provided as ESRI shape files on a universal transverse projection using either the WGS84 or the NAD83 datum. In order to convert these files to a format used by the WRF preprocessing system (WPS), they were re-projected into a spherical latitude and longitudinal projection using the WGS84 datum. The vertical parameters including Frontal Area Density, Plan Area Density, and Roof Area Density were averaged into 5m bins as the original vertical resolution was 1m and the tallest bin was capped at 75m. This was the best trade off in saving disk space and providing accurate descriptions of the cities' vertical distributions. The distribution of building heights were originally organized into 5m bins with units of number of buildings in the given height range for each grid cell. Similar to the other vertical parameters, the top was capped at 75m with the last bin consisting of buildings 70m or greater. The BEP and BEP\_BEM urban canopy models require this information as a percentage of buildings in each bin. The data was converted to this unit by dividing the number of buildings in each bin by the total number of buildings in the grid cell. After these conversions were complete, the files were then merged into a singular file for the conterminous United States and Hawaii. Next, the data was mapped onto a uniform grid with arc second resolution. This altered the resolution of the dataset so that the new resolution of the 1 km dataset became 30 arc seconds.

## Spatial Processing for NUDAPT Data

The goal of the geospatial processing of NUDAPT datasets was to find a common, global grid that would incorporate and preserve data amongst hundreds of individual study sites, within the constraints of the WRF pre-processors. The original scale for NUDAPT data was 1km, using a projected coordinate system, with unique grids for each study site. The resulting scheme for re-gridding this dataset is a grid at roughly 1km resolution on a hemispheric scale, in a geographic coordinate system. Due to processing constraints for that resolution and domain, a grid of tiles were created at 1.0 degree resolution, only where NUDAPT datasets intersect those tiles. A Python script (`grid_maker.py`) was developed that uses the Esri ArcGIS library (`arcpy`) to access and iterate over the selected tiles to partition them into model resolution grids (30 arc-seconds). These empty grids were then populated with the NUDAPT citywide datasets using a spatial join operation in ArcGIS, joining one input feature to one output feature (no aggregation) wherever input and output polygon features intersect. This methodology preserves the values of the original dataset.

The polygon feature classes exist in a geodatabase, and are thus not read by WRF. In order to transcribe the newly merged and re-gridded NUDAPT datasets into text files that can be converted to the binary format readable in WRF pre-processors, specific formatting and naming conventions are required. Using an ArcGIS ModelBuilder model that iterates over each grid tile, text files are iteratively written for each tile (120x120 cells). The text files are formatted such that the name follows the convention:

**<column start>-<column end>.<row start>-<row end>.txt**

where the column and row references are to the fine resolution grid (i.e. not the tiles). The result was a set of 66 tiles for the 1km NUDAPT dataset. This scheme preserves disk space by only creating a grid where data exists.

## NUDAPT in WPS

NUDAPT can be used in various formats within the WRF-Urban system, ranging from the simplistic to the complex. The most simple case relies on 30-arc-second MODIS land use data to determine urban areas. However, this approach is limited especially in regards to the urban fraction parameter, which is of great importance. Under this approach all urban areas are set to have an urban fraction of 0.90 and no distinction is given in the urban parameterizations for differences between residential and commercial/industrial urbanization, which have different properties. Therefore, it is not recommended that the user pursue this option as it may negate the purpose of using high resolution urban morphology data. Instead, it is recommended that the user use the National Land Cover Dataset (NLCD) urban land use categories to determine

urban areas and the additional utility that has been developed for generation of the urban fraction parameter from this dataset. This provides additional refinement in the urban parameterizations for the differences between low-density residential, high density residential, and commercial/industrial urbanization and high-resolution urban parameter comparable to the NUDAPT dataset.

The documentation on how to download and use the NLCD urban land use classes can be found in Chapter 3 of the ARW Users' Guide. (Note: If using a larger region with multiple cities the steps in the prior documentation must be repeated for each tile of NLCD data and multiple GEOGRID.TBL entries must be added each with a higher number for the priority). Following the procedure in the ARW Users' Guide involves downloading the NLCD land cover data and applying a utility program to extract only the urban classes. The utility allows the user to define an urban fraction value for each 30-m NLCD urban class grid cell. If the user has no special insight into how to assign the urban fraction, a hybrid approach with WRF-Urban's look up table is recommended. With this approach the values 0.5, 0.9, and 0.95 are given to the low density residential (31), high density residential (32), and commercial/industrial (33) classes respectively. To add this urban fraction parameter to the WPS the following entry must be added to the GEOGRID.TBL:

```
=====
name=FRC_URB2D
  priority=1
  dest_type=continuous
  fill_missing = 0.
  interp_option=default:four_pt+average_4pt
  abs_path=/data_directory/
```

---

(Note: If the application is for a larger region, multiple urban fraction datasets will need to be produced from the NLCD data and each dataset will require an additional GEOGRID.TBL entry with an increasing value for the priority). This approach helps to provide more heterogeneity to the city's urban fraction than the default look-up table but this step is not required as WRF-urban will run with the default look-up table for urban fraction.

Before creating a WRF domain with the WPS, the NUDAPT dataset should first be downloaded from the WRF download page. The link to the NUDAPT data is located near the link to download the standard geographical datasets. After downloading the NUDAPT tar file, the dataset should be unpacked in the same directory as the other static geographical data; if this is not possible (e.g., due to file system permissions), the absolute path of the NUDAPT data can be set in the GEOGRID.TBL entry mentioned below.

---

The actual NUDAPT-44 data as it exists for use in WPS is bundled together into a single array called URB\_PARAM which contains all the urban canopy parameters with the indices for each parameter shown in Table-1. In the geo\_em and met\_em files that will be generated by the WPS, the UCPs appear as a multidimensional array but later individual parameters will be separated out using the real program in WRF. To add the dataset into the WPS system, simply uncomment the URB\_PARAM section in the GEOGRID.TBL:

---

```

name=URB_PARAM
  priority=1
  dest_type=continuous
  fill_missing = 0.
  z_dim_name=num_urb_params
  interp_option=default:nearest_neighbor
  rel_path=NUDAPT_1KM_Binary/

```

---

(Note: The interpolation option should always be set to nearest neighbor as the sparseness of the data can generate unrealistic parameter values when interpolating in space.)

NUDAPT Parameter (WRF Variable Name)	URB_PARAM Index
Frontal Area Density at 0° (FAD0_URB2D)	1-15
Frontal Area Density at 135° (FAD135_URB2D)	16-30
Frontal Area Density at 45° (FAD45_URB2D)	31-45
Frontal Area Density at 90° (FAD90_URB2D)	46-60
Plan Area Density (PAD_URB2D)	61-75
Roof Area Density (RAD_URB2D)	76-90
Plan Area Fraction (LF_URB2D)	91
Mean Building Height (MH_URB2D)	92
Standard Deviation of Building Height (STDH_URB2D)	93
Area Weighted Mean Building Height (HGT_URB2D)	94
Building Surface to Plan Area Ratio (LF_URB2D)	95
Frontal Area Index (LF_URB2D)	96-99
Complete Aspect Ratio (CAR_URB2D)	100
Height to Width Ratio (H2W_URB2D)	101
Sky View Factor (SVF_URB2D)	102
Grimmond and Oke (1999) Roughness Length (ZOS_URB2D)	103
Grimmond and Oke (1999) Displacement	104

<b>Height (ZDS_URB2D)</b>				
<b>Raupach (1994)</b>	<b>Roughness</b>	<b>Length</b>	105,107,109,111	
<b>(ZOR_URB2D)</b>				
<b>Raupach (1994)</b>	<b>Displacement</b>	<b>Height</b>	106,108,110,112	
<b>(ZDR_URB2D)</b>				
<b>Macdonald et al. (1998)</b>	<b>Roughness</b>	<b>Length</b>	113-116	
<b>(ZOM_URB2D)</b>				
<b>Macdonald et al. (1998)</b>	<b>Displacement</b>	<b>Height</b>	117	
<b>(ZDM_URB2D)</b>				
<b>Distribution of Building Heights (HI_URB2D)</b>			118-132	

Table 1: Includes a list of NUDAPT-44-NBSD Parameters including their WRF variable name and their index in the URB\_PARAM array. Parameters that contain 15 indices are vertically resolved with 5m bins spanning 0-75m. Those with 4 indices contain four wind directions (0°, 135°, 45°, 90°), which can be projected another 180°. The parameters in red are used exclusively in the BEP and BEP\_BEM parameterizations. Those parameters in blue are used exclusively by the single layer parameterization. Finally, those in purple are used in all the urban parameterization schemes.

## NUDAPT in WRF

When the user invokes the “real” program, the URB\_PARAM array will be split into the individual urban parameter variables. The WRF variable names of all UCPs along with their indices in the URB\_PARAM array are shown in Table 1. Currently only the highlighted parameters are actually used by the WRF code. If the user wishes to use additional parameters they will need to add the parameters to the physics initialization subroutine (module\_physics\_init.F) as well as the call to the physics initialization subroutine (module\_first\_rk\_step\_part1.F and solve\_em.F).

In order to determine if NUDAPT is being used the urban initialization routine in module\_sf\_urban.F will look to see if the area weighted mean building height is greater than zero. If this condition is met then the NUDAPT data will be read into WRF. If this is not true the parameters will all be set to zero and the urban morphology will be read in from the urban parameter table.

The BEP and BEP\_BEM schemes have four urban morphology parameters including building width, street width, street direction, and distribution of building heights. The distribution of building heights comes directly from the NUDAPT data. The building width is a function of the plan area fraction, the building surface to plan area ratio, and the mean building height and the street width is calculated based on the same parameters as well as the urban fraction. If using NUDAPT with the BEP or BEP\_BEM schemes the user will need to adjust several namelist variables and parameters.

- 1) BEP
  - a. Set the number of vertical layers in each urban grid (`nz_um`) to 15 or larger in the BEP code (`module_sf_bep.F`) before compiling the WRF code.
  - b. In the namelist the user will need to adjust `num_urban_layers` appropriately as it is a function of the `nz_um` parameter (See BEP code).
  - c. An additional namelist variable must be set for the dimension of the distribution of building height called `num_urban_hi` and it must be set to 15.
- 2) BEP\_BEM
  - a. Set the number of vertical layers in each urban grid (`nz_um`) to larger than 15 in the BEP\_BEM code (`module_sf_bep_bem.F`) before compiling the WRF code.
  - b. Set the maximum number of building types in each urban grid (`nbui_max`) to 15 in the BEP\_BEM code (`module_sf_bep_bem.F`) before compiling the WRF code.
  - c. In the namelist the user will need to adjust `num_urban_layers` appropriately as it is a function of the `nz_um` and `nbui_max` parameters (See BEP\_BEM code).
  - d. An additional namelist variable must be set for the dimension of the distribution of building height called `num_urban_hi` and it must be set to 15.

In the single layer urban parameterization the parameters of mean building height, standard deviation of building height, and plan area fraction are used directly and replace those values that come from the look up table. The street width and building width calculations are done in the same manner as those in the BEP scheme and are used to compute the normalized building height. Ultimately, the NUDAPT-44-NBSD parameters are used to calculate the roughness length, the roughness length of the building roof, the displacement height and the sky view factors for each grid cell.

## User Instructions

- 1) Using the `bep` or `bep_bem` option requires some additional parameters to be changed in the code prior to compiling WRF.
  - a. BEP
    - i. Set the number of vertical layers in each urban grid (`nz_um`) to 15 or larger in the BEP code (`module_sf_bep.F`) before compiling the WRF code.

- ii. In the namelist the user will need to adjust `num_urban_layers` appropriately as it is a function of the `nz_um` parameter (See BEP code).
    - iii. An additional namelist variable must be set for the dimension of the distribution of building height called `num_urban_hi` and it must be set to 15.
  - b. BEP\_BEM
    - i. Set the number of vertical layers in each urban grid (`nz_um`) to larger than 15 in the BEP\_BEM code (`module_sf_bep_bem.F`) before compiling the WRF code.
    - ii. Set the maximum number of building types in each urban grid (`nbui_max`) to 15 in the BEP\_BEM code (`module_sf_bep_bem.F`) before compiling the WRF code.
    - iii. In the namelist the user will need to adjust `num_urban_layers` appropriately as it is a function of the `nz_um` and `nbui_max` parameters (See BEP\_BEM code).
    - iv. An additional namelist variable must be set for the dimension of the distribution of building height called `num_urban_hi` and it must be set to 15.
- 2) Before creating a WRF domain with the WPS, the NUDAPT dataset should first be downloaded from the WRF download page. The link to the NUDAPT data is located near the link to download the standard geographical datasets.
- 3) After downloading the NUDAPT tar file, the dataset should be unpacked in the same directory as the other static geographical data; if this is not possible (e.g., due to file system permissions), the absolute path of the NUDAPT data can be set in the GEOGRID.TBL entry.
- 4) Download and process the NLCD land use data following the instructions found in Chapter 3 of the ARW Users' Guide.
- 5) Use the additional utility mentioned in Chapter 3 of the ARW Users' Guide to generate the urban fraction parameter using either preexisting knowledge of the urban area or the default version based on the WRF urban parameter table.
- 6) Add the urban fraction and NLCD entries to the GEOGRID.TBL.
- 7) Uncomment the NUDAPT GEOGRID.TBL entry.
- 8) Run WPS using selected domain, `URB_PARAM` variable should be visible in `geo_em` and `met_em` files.
- 9) Run `real.exe`, individual urban parameters should be visible in the `wrfinput_d0X` file.
- 10) Run WRF for selected application.

## References

- Burian S., N. Augustus, I.Jeyachandran and M. Brown, 2007: National Building Statistics Database, Version 2. Los Alamos National Laboratory, Rept LA-UR-08-1921, 81 pages
- Burian, S., and J. Ching, 2010: Development of Gridded Fields of Urban Canopy Parameters for Advanced Urban Meteorological and Air Quality Models. Project Report: EPA/600/R-10/007
- Chen, F., H. Kusaka, R. Bornstein, J. Ching, C.S.B. Grimmond, S. Grossman-Clarke, T. Loridan, K. Manning, A. Martilli, S. Miao, D. Sailor, F. Salamanca, H. Taha, M. Tewari, X. Wang, A. Wyszogrodzki, and C. Zhang, 2011: The integrated WRF/urban modeling system: development, evaluation, and applications to urban environmental problems. *International Journal of Climatology*, 31, 273-288. DOI: 10.1002/joc.2158.
- Ching, J., M. Brown, S. Burian, F. Chen, R. Cionco, A. Hanna, T. Hultgren, T. McPherson, D. Sailor, H. Taha, and D. Williams, 2009: "National Urban Database and Access Portal Tool (NUDAPT). *Bulletin of American Meteorological Society*, 90(08), 1157-1168.
- Kusaka, H., H. Kondo, Y. Kikegawa, and F. Kimura, 2001: A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and slab models. *Bound. Layer Meteorol.*, 101, 329-358.
- Martilli, A, S. Grossman-Clarke, M. Tewari, and K.W. Manning, 2009: Description of the modifications made in WRF.3.1 and short user's manual of BEP. <http://www.ral.ucar.edu/research/land/technology/urban.php>
- Salamanca, F, A. Krpo, A. Martilli and A. Clappier, 2010: A new building energy model coupled with an urban canopy parameterizations for urban climate simulations- Part 1. Formulation, verification and sensitivity analyses of the model. *Theoretical and Applied Climatology*, 99 (3-4): 331-344 doi:10.1007/s00704-009-0142-9.