

W2W: A Python package that injects WUDAPT's Local Climate Zone information in WRF

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Summary

The Python-based WUDAPT-to-WRF (W2W) package is developed to translate Local Climate Zone (LCZ) maps into urban canopy parameters readable by WRF, the community “Weather Research and Forecasting” model (Skamarock et al., 2021). It is the successor of the Fortran-based W2W package developed by Brousse et al. (2016) and Martilli et al. (2016), and provides an improved, simpler, and more efficient procedure to use LCZ information in WRF. Some important changes include a direct manipulation of the geogrid files (without the creation of temporary files), and the use of average LCZ-based urban morphological parameters instead of assigning them to the modal LCZ class.

This development of this package is in line with the objectives of WUDAPT, the World Urban Database and Access Portals Tools community project, that aims to 1) acquire and make accessible coherent and consistent information on form and function of urban morphology relevant to climate weather, and environment studies, and 2) provide tools that extract relevant urban parameters and properties for models and model applications at appropriate scales for various climate, weather, environment, and urban planning purposes (Ching et al., 2018).

Statement of need

Since the pioneering work of Brousse et al. (2016) and Martilli et al. (2016), the level-0 WUDAPT information, the Local Climate Zone maps, have been used increasingly in WRF.

We expect this trend to continue, because of three recent developments: 1) the creation of city-wide LCZ maps is now easier than ever with the launch of the LCZ Generator web application (Demuzere et al., 2021), 2) the availability of a global LCZ map (Demuzere et al., 2022), and 3) WRF versions > 4.3 (Skamarock et al., 2021) are able to ingest 10 or 11 built classes (corresponding to WUDAPT's LCZs) by default, whereas previous WRF versions required manual code changes (see Martilli et al. (2016), Zonato & Chen (2021) and Zonato et al. (2021) for more information).

Because of these developments, an improved, Python-based, WUDAPT-to-WRF (W2W) routine is presented here, so as to make the translation of LCZ-based parameters better and simpler.

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Initial data requirements

In order to use the tool, two input files are required:

1. A **geo_em.d0X** (.nc) file for the inner WRF model domain in which one would like to use the LCZ-based information. This file can be produced by WRF's `geogrid.exe` tool as part of the WRF Preprocessing System (WPS), without additional modifications of the standard procedure.
2. A **Local Climate Zone map** (.tif) file that is slightly bigger than the domain extent of the `geo_em.d0X.nc` file. There are a number of ways to obtain an LCZ map for your region of interest (ROI):
 - Extract your ROI from the global LCZ map (Demuzere et al., 2022), or the continental-scale LCZ maps for Europe (Demuzere et al., 2019) or the United States (Demuzere et al., 2020) (see also [here](#) for more info).
 - Check if your ROI is already covered by the many LCZ maps available in the [submission table](#) of the LCZ Generator.
 - Use the [LCZ Generator](#) to make your own LCZ map for your ROI. See also [here](#) for more information. When using LCZ maps produced with the LCZ Generator, by default the Gaussian filtered LCZ map is used (corresponding to argument `--lcz-band = 1`).

Note: When using LCZ information from any of the large-scale LCZ maps, please make sure to crop your domain of interest first, in order to avoid memory issues.

Workflow

The goal of the Python-based W2W tool is to obtain an inner WRF domain file (`geo_em.d0X.nc`) that contains the built LCZ classes and their corresponding urban canopy parameters relevant for all urban parameterizations embedded in WRF: the single layer urban canopy model (Noah/SLUCM, Kusaka et al. (2001)), the Building Environment Parameterization (BEP, Martilli et al. (2002)), and BEP+BEM (Building Energy Model, Salamanca et al. (2010)).

To get to that point, a number of sequential steps are required:

Step 1: Remove the default urban land cover

The default urban land cover from MODIS is replaced with the dominant surrounding vegetation category, as done in Li et al. (2020). This procedure affects WRF's parameters `LU_INDEX`, `LANDUSEF` and `GREENFRAC`. First, an initial number of neighbouring pixels (corresponding argument `--npix-area`, default = `--npix-nlc ** 2`) are selected using the k-d tree algorithm, to find the nearest pixels based on the great circle arc length, specifically [the chord length formula](#). Afterwards, the `LU_INDEX` is set by sampling the dominant category from the corresponding argument `--npix-nlc` (default = 45) nearest initial grid points (excluding ocean, urban and lakes). `GREENFRAC` is calculated as the mean over all grid points with that dominant vegetation category among the `--npix-nlc` nearest points. For each grid point, if `LANDUSEF` had any percentage of urban, it is set to zero and the percentage is added to the dominant vegetation category assigned to that grid point.

Resulting output: **geo_em.d0X_NoUrban.nc**

75 Step 2: Define the LCZ-based urban extent

76 LCZ-based impervious fraction values (FRC_URB2D, available from LCZ_UCP_default.csv)
 77 are assigned to the original 100 m resolution LCZ map, and are aggregated to the WRF
 78 resolution. Areas with FRC_URB2D < 0.2 (corresponding to argument --frc-threshold)
 79 are currently considered non-urban. This choice has been made to avoid the use of the
 80 urban schemes in areas where the majority of the landuse is vegetated, since the impact of
 81 the impervious surfaces is low. The FRC_URB2D field is also used to mask all other urban
 82 parameter fields, so that their extent is consistent.

83 Resulting output: `geo_em.d0X_LCZ_extent.nc`

84 Step 3: Introduce modal built LCZ classes

85 For each WRF grid cell, the mode of the underlying built LCZ classes is added to LU_INDEX
 86 (numbered from 31-41). See [here](#) for more info. Note that the W2W routine by default considers
 87 LCZ classes 1-10 as built classes (corresponding to argument --built-lcz). In some cases,
 88 also LCZ E (or 15 - Bare rock or paved) can be considered as a built LCZ class, as it might
 89 reflect large asphalt surfaces such as big parking lots or airstrips. In that case, the user must
 90 make sure the --built-lcz argument is set appropriately.

91 Step 4: Assign urban canopy parameters

92 Two procedures are followed when assigning the various urban canopy parameters to the LCZ
 93 map and translating this information onto WRF's grid:

94 **Procedure 1: Morphological parameters** are assigned directly to the high-resolution LCZ
 95 map, and are afterwards aggregated to the lower-resolution WRF grid. As a result, the method
 96 produces a unique urban morphology parameter value for each WRF grid cell. This was found
 97 to be more efficient in reproducing urban boundary layer features, especially in the outskirts of
 98 the city (Zonato et al., 2020), and is in line with the [WUDAPT-to-COSMO](#) routine (Varentsov
 99 et al., 2020).

100 Morphological urban canopy parameter values are provided in LCZ_UCP_default.csv, and
 101 are generally based on values provided in Stewart & Oke (2012) and Stewart et al. (2014).
 102 Note however that the values of MH_URB2D_MIN, MH_URB2D, MH_URB2D_MAX for
 103 LCZ 7 are set to 4, 5 and 6 m instead of 2, 3 and 4 m, because the minimum building height
 104 that can be assigned to BEP-BEM is 5m if dz_u = 5m (standard value) is used.

105 In addition:

- 106 ■ While URBPARM_LCZ.TBL (stored in WRF's run/ folder) has values on street width
 107 (SW), W2W derives street width from the mean building height (MH_URB2D) and the
 108 Height-to-Width ratio (H2W), to have these fields consistent.
- 109 ■ Building width (BW), is derived from (BLDFR_URB2D / (FRC_URB2D - BLDFR_URB2D))
 110 * SW, these values being available from the look-up table LCZ_UCP_default.csv.
- 111 ■ Plan (LP_URB2D), frontal (LF_URB2D) and total (LB_URB2D) area indices are based
 112 on formulas in Zonato et al. (2020).
- 113 ■ HI_URB2D is obtained by fitting a bounded normal distribution to the minimum
 114 (MH_URB2D_MIN), mean (MH_URB2D), and maximum (MH_URB2D_MAX)
 115 building height, as provided in LCZ_UCP_default.csv. The building height
 116 standard deviation is also required, and is approximated as (MH_URB2D_MAX -
 117 MH_URB2D_MIN) / 4.
- 118 ■ For computational efficiency, HI_URB2D values lower than 5% were set to 0 after
 119 resampling, the remaining HI_URB2D percentages are re-scaled to 100%.

120 **Procedure 2:** In line with the former Fortran-based W2W procedure, **radiative and thermal**
121 **parameters** are assigned to the modal LCZ class that is assigned to each WRF grid cell (see
122 *Step 3*). These parameter values are not stored in the NetCDF output, but are read from
123 URBPARAM_LCZ.TBL and assigned automatically to the modal LCZ class when running the
124 model.

125 **Step 5: Adjust global attributes**

126 In a final step, some global attributes are adjusted in the resulting NetCDF files:

- 127 ▪ NBUI_MAX is added as a global attribute, reflecting the maximum amount of
128 HI_URB2D classes that are not 0 across the model domain. This parameter can be
129 used when compiling WRF, to optimize memory storage.
- 130 ▪ NUM_LAND_CAT is set to 41, to reflect the addition of 10 (or 11) built LCZ classes.
131 This is not only done for the highest resolution domain file (e.g. d04), but also for **all of**
132 **its lower-resolution parent domain files (e.g. d01, d02, d03)**. As such, make sure
133 these files are also available in the input data directory. In case the parent domain files
134 have NUM_CAT_LAND \neq 41, new parent domain files will be written to your drive
135 with the extension _41.

136 Resulting output: **geo_em.d0X_LCZ_params.nc** (and **geo_em.d0X_41.nc**)

137 **Integration in WRF's preprocessing**

138 The current tool is designed to work with the geo_em.d0X files produced by geogrid.exe, which
139 is available in the WRF Preprocessing System (WPS). WPS needs to be at a version >3.8 ,
140 in order to incorporate the urban geometrical parameters in the URB_PARAM matrix (Glotfelty
141 et al., 2013). The user should run geogrid.exe using its default settings, which will provide
142 the various geo_em.d0X.nc files containing the static data fields. No additional variables
143 are required, neither in the namelist.wps nor within the GEOGRID.TBL table. The W2W tool
144 ([Figure 1](#)) reads the standard geo_em.d0X.nc files (for all the domains) and produces the
145 aforementioned **geo_em.d0X_LCZ_params.nc** files. The user should then simply rename
146 these files to the standard name for each of the domains (e.g. rename geo_em.d01_41.nc
147 to geo_em.d01.nc, geo_em.d04_LCZ_params.nc to geo_em.d04.nc, ...), which will serve as
148 input to the metgrid.exe module ([Figure 1](#)).

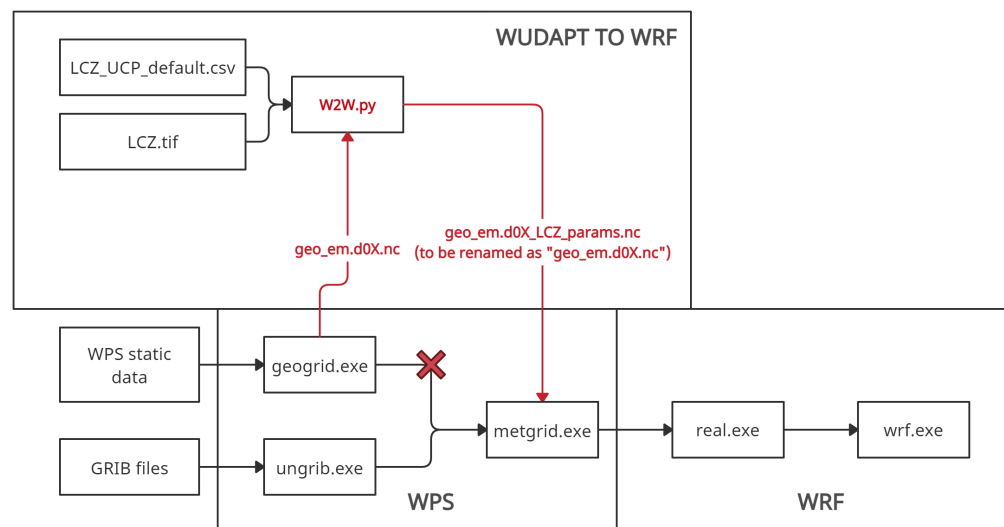


Figure 1: Modified workflow to set-up and run a WRF simulations including urban parameters derived from LCZs using W2W.

Potential use cases

The files provided as output by W2W allow a wide range of applications, including - but not limited to - addressing the impact of:

- urbanization, by running WRF with the default `geo_em.d0X.nc` and the `geo_em.d0X_NoUrban.nc` files (see for example Li et al. (2020) and Hirsch et al. (2021)).
- an improved urban land cover extent description, by running WRF with the default `geo_em.d0X.nc` and the `geo_em.d0X_LCZ_extent.nc` files (similar to for example Bhati & Mohan (2018) and Mallard et al. (2018)).
- a more detailed (LCZ-based) urban description, by running WRF with the default `geo_em.d0X.nc` and the `geo_em.d0X_LCZ_params.nc` files (see for example Brousse et al. (2016), Hammerberg et al. (2018), Molnár et al. (2019), Wong et al. (2019), Patel et al. (2020), Zonato et al. (2020), Ribeiro et al. (2021), Hirsch et al. (2021) and Patel et al. (2022)).

Important notes

- Make sure to set `use_wudapt_lcz=1` (default is 0) and `num_land_cat=41` (default is 21) in WRF's `namelist.input` when using the LCZ-based urban canopy parameters.
- The LCZ-based urban canopy parameter values provided in `LCZ_UCP_default.csv` and `URBPARM_LCZ.TBL` are universal and generic, and might not be appropriate for your ROI. If available, please adjust the urban canopy parameters values according to the characteristics of your ROI. A custom csv file can be specified using the `--lcz-ucp path/to/custom_file.csv` flag.
- It is advised to use this tool with urban parameterization options BEP or BEP+BEM (`sf_urban_physics = 2` or `3`, respectively). In case you use this tool with the SLUCM model (`sf_urban_physics = 1`), make sure your lowest model level is above the highest building height. If not, `real.exe` will provide the following error message:

174 ZDC + ZOC + 2m is larger than the 1st WRF level - Stop in subroutine
 175 urban - change ZDC and ZOC.
 176 ■ At the end of running W2W, a note is displayed that indicates the nbui_max value,
 177 e.g. for the sample data: Set nbui_max to 5 during compilation, in order to
 178 optimize memory storage. This is especially relevant for users that work with the
 179 BEP or BEP+BEM urban parameterization schemes (sf_urban_physics = 2 or 3,
 180 respectively). See also num_urban_nbui in [WRF's README.namelist](#) for more info.
 181 ■ It is advised to use WRF versions > 4.3, that are able to ingest 10 or 11 built classes
 182 (corresponding to WUDAPT's LCZs) by default (Skamarock et al., 2021), and WPS
 183 versions > 3.8, in order to incorporate the urban geometrical parameters in the URB_P
 184 ARAM matrix (Glotfelty et al., 2013).

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