

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

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Summary

An important objective of WUDAPT, the World Urban Database and Access Portals Tools community project, is 1) to acquire and make accessible coherent and consistent information on form and function of urban morphology relevant to climate weather, and environment studies, and 2) to 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).

The Python-based WUDAPT-to-WRF (W2W) package is developed in this context, and translates 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, more simple, 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.

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 more simple.

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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 ($-l = 1$).

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`. `LU_INDEX` is selected as the dominant category from the $-n$ (default = 45) nearest grid points (excluding ocean, urban and lakes). `GREENFRAC` is calculated as the mean over all grid points with that dominant vegetation category among the $-n$ 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**

- *Step 2: Define the LCZ-based urban extent*

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

Resulting output: **geo_em.d0X_LCZ_extent.nc**

79 ▪ *Step 3: Introduce modal built LCZ classes*

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

86 ▪ *Step 4: Assign urban canopy parameters*

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

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

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

100 In addition:

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

115 **Procedure 2:** In line with the former Fortran-based W2W procedure, **radiative and thermal**
 116 **parameters** are assigned to the modal LCZ class that is assigned to each WRF grid cell
 117 (see *Step 3*). These parameter values are not stored in the netcdf output, but are read from
 118 `URBPARM_LCZ.TBL` and assigned automatically to the modal LCZ class when running the
 119 model.

120 ▪ *Step 5: Adjust global attributes*

121 In a final step, some global attributes are adjusted in the resulting netcdf files:

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

Resulting output: `geo_em.d0X_LCZ_params.nc` (and `geo_em.d0X_41.nc`)

Integration in WRF's preprocessing

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

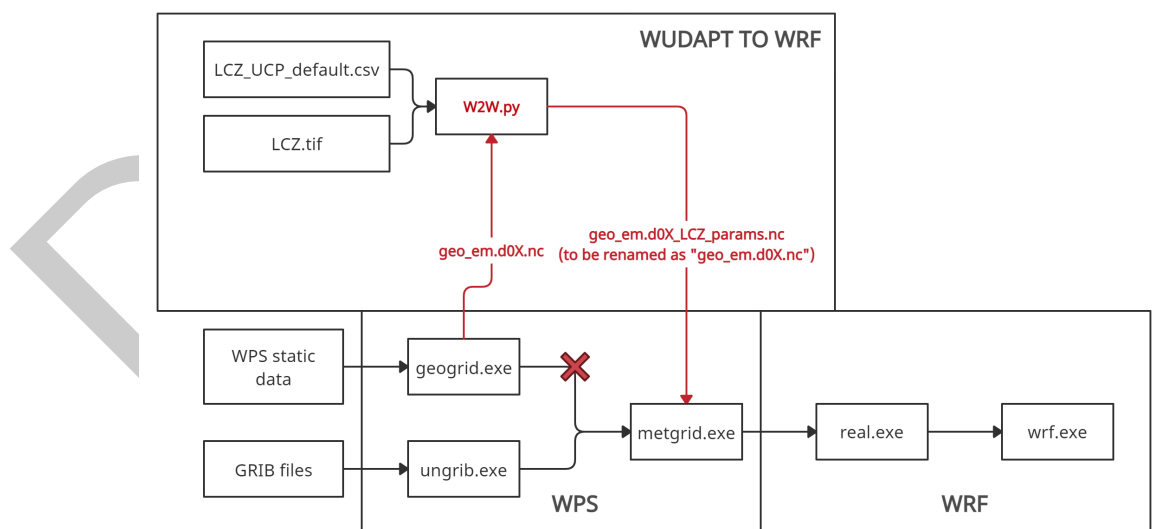


Figure 1: Modified workflow to set-up and run a WRF simulations including urban parameters derived from LCZs using W2W.

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 `URBPARAM_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: `ZDC + ZOC + 2m is larger than the 1st WRF level - Stop in subroutine urban - change ZDC and ZOC`.
- It is advised to use WRF versions > 4.3 , that are able to ingest 10 or 11 built classes (corresponding to WUDAPT's LCZs) by default (Skamarock et al., 2021), and WPS versions > 3.8 , in order to incorporate the urban geometrical parameters in the `URB_PARAMETERS` matrix (Glotfelty et al., 2013).

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