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

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**Software**

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## Summary

An important objective of WUDAPT, the World Urban Database and Acces Portals Tools community project, is to 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. It is the successor of the Fortran-based `W2W` package developed by Brousse et al. (2016) and Martilli et al. (2016), and provides a more simple, efficient and improved 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 two recent developments: 1) the creation of city-wide LCZ maps is now easier than ever with the launch of the online LCZ Generator (Demuzere et al., 2021), and 2) WRF versions > 4.3 (Skamarock et al., 2021) are able to ingest 10 or 11 built classses (corresponding to WUDAPT's LCZs) by default, whereas previous WRF versions required manual code changes (see Martilli et al. (2016), Zonato et al. (Under Review) and Zonato & Chen (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 continental-scale LCZ maps for Europe (Demuzere et al., 2019) or the United States (Demuzere et al., 2020) (see 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 an LCZ map for your ROI. See also here for more information.



## Workflow

The goal of the Python-based `W2W` tool is to obtain a 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 followed:

- *Step 1: Remove the default urban land cover*

The default urban land cover from MODIS is replaced with the dominant surrounding vegetation category, as is 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 $nlus$ (default $=$ 45) nearest grid points (excluding ocean, urban and lakes). LANDUSEF and GREENFRAC are calculated as the mean over all grid points with that category among the $nlus$ nearest points. **@ DANIEL: CORRECT??**

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 ($frc$) are currently considered non-urban. This choice has been made to avoid to employ 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**

- *Step 3: Introduce modal built LCZ classes*

For each WRF grid cell, the mode of the underlying built LCZ classes is added to LU_INDEX (numbered from 31-41). See here for more info. Note that the `W2W` routine by default considers LCZ classes 1-10 as built classes ($bc$). Sometimes, also LCZ E (or 15 - Bare rock or paved) can be considered as a built LCZ classes, as it might reflect large asphalt surfaces such as big parking lots or airstrips. In that case, make sure to set the $bc$ argument appropriately.

- *Step 4: Assign urban canopy parameters*

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

**Pathway 1**: **Morphological parameters** are assigned directly to the high-resolution LCZ map, and are afterwards aggregated to the lower-resolution WRF grid. In this way, the method produces a unique urban morphology parameter value for each WRF grid cell. This was found to be more efficient in reproducing urban boundary layer features, especially in the outskirts of the city (Zonato et al., 2020), and is in line with the WUDAPT-to-COSMO routine (Varentsov et al., 2020).

Morphological urban canopy parameter values are provided in `LCZ_UCP_default.csv`, and are generally based on values provided in Stewart & Oke (2012) and Stewart et al. (2014). In addition:

- Building width (BW), available in `LCZ_UCP_default.csv`, is taken from `URBPARM_LCZ.TBL` (stored in WRF's run/ folder).
- While `URBPARM_LCZ.TBL` also has values on street width, `W2W` derives street width from the mean building height (MH_URB2D) and the Height-to-Width ratio (H2W), to have these fields consistent.
- Plan (LP_URB2D), frontal (LF_URB2D) and total (LB_URB2D) area indices are based on formulas in Zonato et al. (2020).
- HI_URB2D is obtained by fitting a bounded normal distribution to the minimum (MH_URB2D_MIN), mean (MH_URB2D), and maximum (MH_URB2D_MAX) building height, as provided in `LCZ_UCP_default.csv`. The building height standard deviation is also required, and is approximated as (MH_URB2D_MAX - MH_URB2D_MIN) / 4.
- For computational efficiency, HI_URB2D values lower than 5% were set to 0 after resampling, the remaining HI_URB2D percentages are re-scaled to 100%.

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

- *Step 5: Adjust global attributes*

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 paramater 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 parent domain files (e.g. d01, d02, d03)**. As such, make sure these files are also available in the input data directory.

Resulting output: **geo_em.d0X_LCZ_params.nc**

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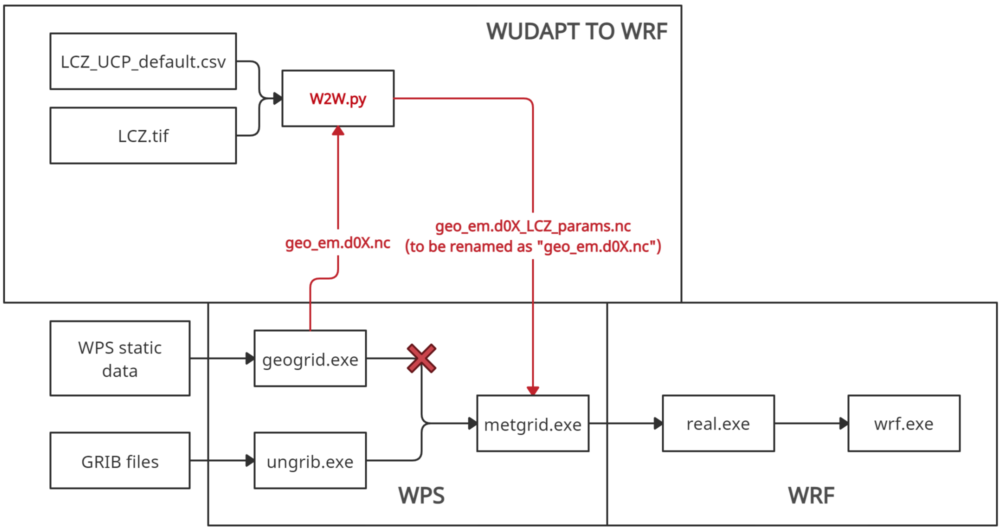
## Integration in WRF's preprocessing

The current tool is designed to work with the geo_em.d0X files produced by the geogrid.exe, in the context of the WRF Preprocessing System (WPS). The user should standardly run the geogrid.exe, which provide the various geo_em.d0X.nc containing the static data fields. No additional variable are required, neither in the namelist.wps nor within the GEOGRID.TBL. The w2w tool reads the standard geo_em.d0X.nc files (for all the domains) and produces the aforementioned **geo_em.d0X_LCZ_params.nc**. The user should then simply rename those files with its standard name for each domain, respectively. Figure (**i don't know hoy to ref in github**) shows the modified workflow to set-up and run a WRF simulations including urban parameters derived from LCZs.




## 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 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. (2021)).

## Important notes

- 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 values according to the characteristics of your ROI.

- It is advised to use this tool with urban parameterization options BEP or BEP+BEM (`sf_urban_physics = 2 or 3`). 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 + Z0C + 2m is larger than the 1st WRF level - Stop in subroutine urban - change ZDC and Z0C`

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