The Journal of Open Source Software

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

Matthias Demuzere*[1], Daniel Argüeso[2], and Andrea Zonato[3]

1 Urban Climatology Group, Department of Geography, Ruhr-University Bochum, Bochum, Germany **2** Physics Department, University of the Balearic Islands, Palma, Spain **3** Atmospheric Physics Group, Department of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy

DOI: 10.21105/joss.0XXXX

Software

- Review
- Repository
- Archive

Editor: Editor Name

Submitted: 01 January XXXX
Published: 01 January XXXX

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 on a worldwide basis, and 2) to provide tools that extract relevant urban parameters and properties for models and for model applications at appropriate scales for various climate, weather, environment, and urban planning purposes Jason Ching et al. (2019).

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.

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 online LCZ Generator (Demuzere et al., 2021), and 2) as of spring 2021, the new version 4.3 of WRF (Skamarock et al., 2021) is able to ingest 10 or 11 built classses (corresponding to WUDAPT's LCZs) by default, whereas previous versions required manual WRF code changes by the user (see Martilli et al. (2016), Andrea Zonato et al. (Under Review) and Andrea Zonato & Chen (2021) for more information). Because of these developments, we decided to simultaneously built an improved, Python-based, WUDAPT-to-WRF (W2W) routine, to make the translation of LCZ-based parameters better and more simple.

Initial data requirements

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

*corresponding author

1. A **geo_em.d0X** (.nc) file for the inner WRF model domain in which you 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). ** (**ANDREA?**): does a user needs to use specific settings here to create this file?? Please extend this section if needed.**

2. A **Local Climate Zone map** (.tif) file that is slightly bigger than the domain of the geo_em.d0X.nc file. There are a number of ways to obtain an LCZ map for your region of interest:

- Extract your domain 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 region of interest 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 region of interest. 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 (see TABLE XX) 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)).

MAKE A TABLE WITH ALL PARAMETERS, including abbrevation, long name, unit, type, source, etc …

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 variables LU_INDEX (land use index), LANDUSEF (land use fraction) and GREENFRAC (vegetation fraction). 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 (FRC_URB2D) values are assigned to the original 100 m resolution LCZ map, and are aggregated to the WRF resolution. Areas with FRC_URB2D $<$ .2 (frc) are currently considered non-urban (**ANDREA?**) - ADD SMALL SENTENCE TO STATE WHY THAT IS. The FRC_URB2D field is also used to mask all other urban fields, so that they are 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 argument bc appropriately.

- Step 4: Assign urban canopy parameters

Two pathways are followed when assigning the various urban canopy parameters to the Local Climate Zone Map:

- 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 value of the different urban morphology parameters 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 (A. 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 (available in the github repository), and are generally based on I. D. Stewart & Oke (2012) and Iain D. Stewart et al. (2014). Building width (BW) is taken from URBPARM_LCZ.TBL (available in WRF's run/ folder). And 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.

  In addition:

  - Plan (LP_), frontal (LF_) and total (LB_) area indices are based on formulas in A. Zonato et al. (2020).
  - HI_URB2D is obtained by fitting a bounded normal distribution to min, mean, max and std of the building height in LCZ_UCP_default.csv. Note that some default BH (max and std) values were altered a bit, as otherwise it was impossible to fit a proper bounded distribution. In addition, for computational efficiency, values lower than 5% were set to 0 after resampling, the remaining HI_URB2D percentages are re-scaled to 100%.
  - 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 during compilation to optimize memory storage.

- 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.

  Radiative and thermal 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.

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

Run the tool

With respect to the WRF pre-processing chain?

Potential use cases

Things to keep in mind (come up with better section title!!)

- best to use with BEP or BEP+BEM, because of the building heights / lowest model layer
- replace generic LCZ-based UCP values with site-specific ones when available
- Important to have good quality LCZ map, if not: garbage in, garbage out.
- netcdf4/hdf5 compilation?

Acknowledgements

We acknowledge contributions and support from Alberto Martilli, Alejandro Rodriguez Sanchez and Oscar Brousse.

References

Brousse, O., Martilli, A., Foley, M., Mills, G., & Bechtel, B. (2016). WUDAPT, an efficient land use producing data tool for mesoscale models? Integration of urban LCZ in WRF over madrid. *Urban Climate*, *17*, 116–134. https://doi.org/10.1016/j.uclim.2016.04.001

Ching, Jason, Aliaga, D., Mills, G., Masson, V., See, L., Neophytou, M., Middel, A., Baklanov, A., Ren, C., Ng, E., Fung, J., Wong, M., Huang, Y., Martilli, A., Brousse, O., Stewart, I., Zhang, X., Shehata, A., Miao, S., … Niyogi, D. (2019). Pathway using WUDAPT's Digital Synthetic City tool towards generating urban canopy parameters for multi-scale urban atmospheric modeling. *Urban Climate*, *28*, 100459. https://doi.org/10.1016/j.uclim.2019.100459

Ching, J., Mills, G., Bechtel, B., See, L., Feddema, J., Wang, X., Ren, C., Brorousse, O., Martilli, A., Neophytou, M., Mouzourides, P., Stewart, I., Hanna, A., Ng, E., Foley, M., Alexander, P., Aliaga, D., Niyogi, D., Shreevastava, A., … Theeuwesits, N. (2018). WUDAPT: An urban weather, climate, and environmental modeling infrastructure for the anthropocene. *Bulletin of the American Meteorological Society*, *99*(9), 1907–1924. https://doi.org/10.1175/BAMS-D-16-0236.1

Demuzere, M., Bechtel, B., Middel, A., & Mills, G. (2019). Mapping Europe into local climate zones. *PLOS ONE*, *14*(4), e0214474. https://doi.org/10.1371/journal.pone.0214474

Demuzere, M., Hankey, S., Mills, G., Zhang, W., Lu, T., & Bechtel, B. (2020). Combining expert and crowd-sourced training data to map urban form and functions for the continental US. *Scientific Data*, *7*(1), 264. https://doi.org/10.1038/s41597-020-00605-z

Demuzere, M., Kittner, J., & Bechtel, B. (2021). LCZ Generator: A Web Application to Create Local Climate Zone Maps. *Frontiers in Environmental Science*, *9*(April). https://doi.org/10.3389/fenvs.2021.637455

Kusaka, H., Kondo, H., Kikegawa, Y., & Kimura, F. (2001). A Simple Single-Layer Urban Canopy Model For Atmospheric Models: Comparison With Multi-Layer And Slab Models. *Boundary-Layer Meteorology*, *101*(3), 329–358. https://doi.org/10.1023/A:1019207923078

Li, Y., Fowler, H. J., Argüeso, D., Blenkinsop, S., Evans, J. P., Lenderink, G., Yan, X., Guerreiro, S. B., Lewis, E., & Li, X. F. (2020). Strong Intensification of Hourly Rainfall

Extremes by Urbanization. *Geophysical Research Letters*, *47*(14), 1–8. https://doi.org/10.1029/2020GL088758

Martilli, A., Brousse, O., & Ching, J. (2016). *Urbanized WRF modeling using WUDAPT*. http://www.wudapt.org/wudapt-to-wrf/. https://www.wudapt.org/wp-content/uploads/2016/05/Urbanized-WRF-modeling-using-WUDAPT-web-version-March2016.pdf%20(Accessed%20on%2011%20August%202021

Martilli, A., Clappier, A., & Rotach, M. W. (2002). An urban surface exchange parameterisation for mesoscale models. *Boundary-Layer Meteorology*, *104*(2), 261–304. https://doi.org/10.1023/A:1016099921195

Salamanca, F., Krpo, A., Martilli, A., & Clappier, A. (2010). A new building energy model coupled with an urban canopy parameterization for urban climate simulations—part I. formulation, verification, and sensitivity analysis of the model. *Theoretical and Applied Climatology*, *99*(3-4), 331–344. https://doi.org/10.1007/s00704-009-0142-9

Skamarock, W. C., Klemp, J. B., Dudhia, J. B., Gill, D. O., Liu, Z., Berner, J., Wang, W., Powers, J. G., Duda, M. G., Barker, D. M., & Huang, X.-Y. (2021). *A Description of the Advanced Research WRF Model Version 4.3* (July). National Center for Atmospheric Research. https://doi.org/10.5065/1dfh-6p97

Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Stewart, Iain D., Oke, T. R., & Krayenhoff, E. S. (2014). Evaluation of the 'local climate zone' scheme using temperature observations and model simulations [Journal Article]. *International Journal of Climatology*, *34*(4), 1062–1080. https://doi.org/10.1002/joc.3746

Varentsov, M., Samsonov, T., & Demuzere, M. (2020). Impact of Urban Canopy Parameters on a Megacity's Modelled Thermal Environment. *Atmosphere*, *11*(12), 1349. https://doi.org/10.3390/atmos11121349

Zonato, Andrea, & Chen, F. (2021). *Updates of WRF-urban in WRF 4.3: Local Climate Zones, Mitigation Strategies, building materials permeability and new buildings drag coefficient*. http://www.wudapt.org/wudapt-to-wrf/. https://ral.ucar.edu/sites/default/files/public/product-tool/urban-canopy-model/WRF_urban_update_Readme_file_WRF4.3.pdf

Zonato, A., Martilli, A., Di Sabatino, S., Zardi, D., & Giovannini, L. (2020). Evaluating the performance of a novel WUDAPT averaging technique to define urban morphology with mesoscale models. *Urban Climate*, *31*(May 2019), 100584. https://doi.org/10.1016/j.uclim.2020.100584

Zonato, Andrea, Martilli, A., Gutierrez, E., Chen, F., He, C., & Barlage, M. (Under Review). Exploring the effects of rooftop mitigation strategies on urban temperatures and energy consumption. *Journal of Advances in Modeling Earth Systems*, 1–29.