Manual on using the single layer urban canopy model with spatial maps of urban morphological parameters and monthly-hourly varying anthropogenic heat in WRF

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1. How to use

1.1. Installation

This function is available by default from WRF v4.6. However, you need to download additional static data for WPS. Please download additional static data from

- A Tokyo Tech's website: https://urbanclimate.tse.ens.titech.ac.jp/database/slucm_distributed_drags_static_data/, or
- NCAR WRF website: https://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html.

The downloadable files are:

1. `AHE_2010s.tar.gz`: Global 2010s monthly-hourly varying anthropogenic heat map.
2. `AHE_2050s.tar.gz`: Global 2050s monthly-hourly varying anthropogenic heat map.
3. `urban_params.tar.gz`: Global 1 km resolution urban morphological parameters, for 2010s and 2050s.
4. `greenfrac_fcover_cgls.tar.gz` and `lai_cgls.tar.gz`: 2010-2019 averages of the global 1 km CGLS green cover and LAI datasets. Compared to the default MODIS data, the CGLS datasets have values also for urban grids.
5. `modis_landuse_20class_15s_2010s.tar.gz`: The default modis_landuse_20class_15s with all grids with LandScan population density greater than 1000 people/km^2 converted to urban category (number 13).
6. `modis_landuse_20class_15s_2050s.tar.gz`: Same as the above but projected 2050s population density is used.

7. `modis_landuse_20class_15s_2010s_with_lakes.tar.gz`, `modis_landuse_20class_15s_2010s_with_lakes.tar.gz`: Modified land use data with lake information.

After downloading and extracting the archives, your directory with the WPS static files should have the following structure:

```
WPS_GEOG/
├── AHE_2010s
│   ├── 2_bytes
│   └── 3_bytes
├── AHE_2050s
│   ├── 2_bytes
│   └── 3_bytes
├── greenfrac_fcover_cgls
├── lai_cgls
├── modis_landuse_20class_15s_2010s
├── modis_landuse_20class_15s_2050s
├── modis_landuse_20class_15s_with_lakes
├── modis_landuse_20class_30s_with_lakes
└── urban_params
    ├── 2010
    │   ├── d
    │   ├── H_avg
    │   ├── lambda_f
    │   ├── lambda_p
    │   └── z_0
    └── 2050
        ├── d
        ├── H_avg
        ├── lambda_f
        ├── lambda_p
        └── z_0
```

1.2. WPS

Please modify the `geog_data_res` in `namelist.wps` as follows. The example shows the setup for a 2-domain run. Be sure that you have the latest `GEOGRID.TBL` from WPS v4.6 onwards.

```
&geogrid
  geog_data_res = '30s+modis_2010+y2010_urb+cgls_veg+y2010_ahe'
'30s+modis_2010+y2010_urb+cgls_veg+y2010_ahe'
```

/
where

- `modis_2010` selects the modified 2010s land use,
- `y2010_urb` selects the 2010s urban morphological parameters,
- `y2010_ahe` selects the 2010s anthropogenic heat maps,
- `cgls_veg` selects the CGLS green fraction and LAI datasets. If you want to keep using the default MODIS data, using `modis_veg_no_search` is probably preferable.

In addition,

- If you want to do a future projection considering urbanization effects, change `2010` to `2050`.
- The urban morphological parameters and anthropogenic heat maps are independent from each other. You don't have to use both.
- If you have other sources of data for the anthropogenic heat and/or urban morphological parameters of your area of interest, it is possible to include it by modifying the GEOGRID.TBL. For details, refer to the WRF manual (https://www2.mmm.ucar.edu/wrf/users/wrf_users_guide/build/html/wps.html#geogrid-tbl-options)

After modifying the namelist to select the new static datasets, proceed to run `geogrid.exe` and other steps as usual.

1.3. WRF

Please add the following options to the `physics` section in `namelist.input`.

```
&physics
  slucm_distributed_drag = .true.
  distributed_ahe_opt = 1
  sf_urban_physics = 1 1 (Required)
  sf_surface_mosaic = 1 (Optional)
/
```

where

- `slucm_distributed_drag = .true.` enables the calculation that considers the 2D maps of urban morphological parameters.
- `distributed_ahe_opt` can take 3 values. The authors often use option 1.
  - 0: Do not add anthropogenic heat,
  - 1: Add anthropogenic heat to the temperature tendency of the first atmospheric level,
  - 2: Add anthropogenic heat to the surface with sensible heat flux.
- The two options above only work with `sf_urban_physics = 1` (Kusaka's single layer urban canopy model).

- You may wish to enable the `sf_surface_mosaic` option, but it's not required.

After modifying the namelist, run `real.exe` and `wrf.exe` as usual.

2. Description of the new options

2.1. The static data

- The urban morphological data was derived empirically and semi-empirically. For details, refer to the Supplementary material of Khanh et al., 2023 and the cited publications there.
- The anthropogenic heat datasets were derived top-down from data provided by the SSP Database, IEA, LandScan, VIIRS and others. For details, refer to the full paper of Varquez et al., 2021.

2.2. Modifications to the SLUCM

The following description was provided by Varquez et al., 2015.

2.2.1. Revision of the estimation of bulk transfer coefficients

The default urban canopy model relies on two z_0 values, for the roof and the canyon. Both are calculated from fixed building morphology using the method of Macdonald et al. (1998). Because the urban parameters were fixed depending on the default building classification, two fixed values were assigned for a homogeneous classification. For example, in high-density residential areas, zo values of 0.13 m and 0.33 m were used for the roof and canopy, respectively. Consequently, the local bulk transfer coefficients for the roof and canyon were also calculated separately (Chen et al., 1997). New aerodynamic parameters were derived to represent the canopy as a whole, disregarding the individual effects of the roof and canyon. For consistency in applying the distributed z_0, a top-down scheme (Kanda et al., 2005a) was employed wherein the surface layer bulk transfer was estimated and used to calculate, via weighted averaging, the transfer coefficients for each individual surface (roof, wall, and ground). This scheme is valid for applications generally focused on the surface layer at the mesoscale.

2.2.2. Consideration of 3-D urban surface features in the urban canopy model

To a certain extent, 2-D urban canopy features are inconsistent with the new 3-D surface-derived feedback parameters. As a supplement to using 3-D-generated roughness parameters, a gridded sky-view factor was also introduced and calculated based on H_{avg}, λ_p, and λ_f, using an equation regressed from a highly accurate 3-D scheme (Kanda et al., 2005a). Because the equation assumed infinitely long street canyons, the parameterisation of the sky-view factor was consistent with the default model's sky-view factor definition. The sky-view factor, from the floor to the sky, determined the amount of total solar radiation reaching the wall and ground within the canopy. λ_p is also essential because the direct solar radiation was evaluated from a weighted average according to the relative area of different canyons. The diffuse solar and downward longwave radiation were assumed to be isotropic.

2.2.3. Consideration of the effect of vegetation on local bulk transfer coefficient

The roughness length for heat is parameterised by default as a function of the roughness length for momentum. This function utilizes the Reynolds number, z_0. and roughness length for heat to estimate the transfer coefficient. Kawai et al. (2009) introduced an updated parameterisation of roughness length for heat, which considers the advection effect, or the enhancement of the transfer coefficients due to vegetation. This updated parameterisation was included into the urban canopy model along with the inclusion of a high spatial resolution vegetation fraction.

3. Citations

When you use the model and the datasets, please cite our work, for example, as follows.

> A version of the single layer urban canopy model that can consider spatial maps of urban morphological parameters (Khanh et al., 2023) and the AH4GUC monthly-hourly varying global 1 km anthropogenic heat maps (Varquez et at., 2021) were used.

Khanh, D. N., Varquez, A. C. G., & Kanda, M. (2023). Impact of urbanization on exposure to extreme warming in megacities. *Heliyon, 9*(4). https://doi.org/10.1016/j.heliyon.2023.e15511

Varquez, A. C. G., Kiyomoto, S., Khanh, D. N., & Kanda, M. (2021). Global 1-km present and future hourly anthropogenic heat flux. *Scientific Data, 8*(1), 64. https://doi.org/10.1038/s41597-021-00850-w

4. Disclaimer

The following disclaimer (derived from the MIT License) applies to the use of this model, manual, and datasets (the “Software”).

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Khanh, D. N., Varquez, A. C. G., & Kanda, M. (2023). Impact of urbanization on exposure to extreme warming in megacities. *Heliyon, 9*(4). https://doi.org/10.1016/j.heliyon.2023.e15511

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Varquez, A. C. G., Nakayoshi, M., & Kanda, M. (2015). The effects of highly detailed urban roughness parameters on a sea-breeze numerical simulation. *Boundary-layer meteorology, 154*, 449-469. https://doi.org/10.1007/s10546-014-9985-4

Varquez, A. C. G., Kiyomoto, S., Khanh, D. N., & Kanda, M. (2021). Global 1-km present and future hourly anthropogenic heat flux. *Scientific Data, 8*(1), 64. https://doi.org/10.1038/s41597-021-00850-w