README
The new version of the BEP+BEM scheme in WRF 4.3: Local Climate Zones, Mitigation Strategies, building materials permeability and new buildings drag coefficient

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Introduction

The new version of the BEP+BEM urban multilayer scheme (Martilli et al., 2002; Salamanca et al., 2010), implemented in WRF, allows now to incorporate 10 urban classes corresponding to the WUDAPT (`http://www.wudapt.org/`) Local Climate Zones (LCZ) . The code still work with the traditional 3 urban classes, but some adjustments should be done in the URBPARM.TBL, as shown in the next section.
Moreover, we added novel parameterization schemes that model the effect of green roof (GR) and photovoltaic panels (PVP) on urban environment, along with a parameterization, similar to the SLUCM (Kusaka et al., 2001), which accounts for the permeability of urban materials, that now are sensible to precipitation and evaporation.

1 Incorporation of Local Climate Zones into WRF

While previous versions of WRF accounted only for 3 urban classes (31-33 in the USGS and MODIS classifications, describing "Low Density Residential", "High Density Residential" and "Industrial of Commercial", respectively), now it allows to incorporate the Local Climate Zones created through the WUDAPT method, for example following the steps reported in `http://www.wudapt.org/wudapt-to-wrf/` (Martilli et al., 2016) or with the proper tool (`https://wudapt.cs.purdue.edu/wudaptTools/default/city_for_wrf`), and already adopted in several works (Brousse et al., 2016; Hammerberg et al., 2018; Zonato et al., 2020). Following Stewart and Oke (2012), the urban landuse is classified as follows:

31) LCZ 1: Compact high-rise;

32) LCZ 2: Compact midrise;

33) LCZ 3: Compact low-rise;

34) LCZ 4: Open high-rise;

35) LCZ 5: Open midrise;

36) LCZ 6: Open low-rise;

37) LCZ 7: Lightweight low-rise;

38) LCZ 8: Large low-rise;

39) LCZ 9: Sparsely built;

40) LCZ 10: Heavy industry;

41) LCZ E (LCZ 11): Rock and paved;

LCZ E (or LCZ 11) has been added to the traditional ten urban classes, to take into account large asphalt surfaces such as big parking lots or airstrips. WRF look-up tables have been modified to consider the new urban classes. In particular, LANDUSE.TBL, VEGPARM.TBL and MPTABLE.TBL MODIS and USGS tables have been extended from 33 to 41 classes, and URBPARM.TBL from 3 to 11 urban classes.

From LCZ to traditional WRF urban classes

The code still works with the original 3 urban classes; however, the urban features of the 31-33 landuse classes does not correspond to the LCZ 1,2 and 3 in the URBPARM.TBL look-up table in terms of building geometries and urban fraction. There are two possible ways to make them correspond.

1) Modification of the input landuse

To match the traditional urban with the new LCZ, one should modify the input variables LU_INDEX and IVGTYP in the following way:

- 31 (Low Density Residential) $\longrightarrow$ 36 (Open low-rise)
- 32 (High Density Residential) $\longrightarrow$ 32 (Compact midrise)
- 33 (Industrial or commercial) $\longrightarrow$ 38 (Large low-rise)

in this way, one makes the urban geometries of the traditional urban classes to match with the correct number in terms of the new LCZ.

2) Modification of the URBPARM.TBL

The second way for matching the old urban classes with the new ones, is to modify the parameters or the first 3 urban classes in the URBPARM.TBL . Basically, one should copy the value of the 6^{th} (LCZ 6), 2^{nd} (LCZ 2) and 8^{th} (LCZ 8) value in the vector of each urban geometry variable and replace the 1^{st}, 2^{nd} and 3^{rd} respectively, in order to make the first three values of the vector to correspond to the traditional 31-33 urban classes.

2 Rooftop Mitigation Strategies and building materials permeability

The BEP+BEM schemes now allows to take into account the effect of Green Roof and Photovoltaic panels. Some new variables have been added in the URBPARM.TBL look-up table, in order to turn on and control there new schemes. The variables are:

- GR_TYPE (1 or 2): 1 is grass vegetation, 2 sedum vegetation;
- GR_FLAG (0 or 1): setting it to 1 turn on the green roof parameterization;
- GR_FRAC_ROOF (from 0 to 1): fraction of roof covered by green roof;
- PV_FRAC_ROOF (from 0 to 1): fraction of roof covered by photovoltaic panels;
- IRHO (from 0 to 1 for each hour of the day): it allows to turn on drip irrigation over the roof, for the hours of the day desired. The value of 1 correspond to an irrigation of 25 $L/m^2/\mathbf{week}$, and lower values to its fraction.

The photovoltaic panel and the green roof modules are coupled, so it is even possible to test a case of GRs shielded by PVPs. The following variables have been added to the Registry files:

- EP_PV_URB3D: Electricity produced by photovoltaic panels (W/m^2)
- T_PV_URB3D: Temperature of the photovoltaic panel (K)
- TRV_URB4D: Temperature in each layer of the green roof (K)
- QR_URB4D: Soil moisture in each layer of the green roof (m^3/m^3)
- TGR_URB3D: Average Temperature of the green roof (K)
- QGR_URB3D: Average soil moisture in each layer of the green roof (m^3/m^3)
- DRAIN_URB4D: Drainage from the green roof (mm)
- DRAINGR_URB3D: Accumulated drainage from the green roof (mm)
- SFRV_URB3D: Sensible heat flux from the green roof (W/m^2)
- LFRV_URB3D: Latent heat flux from the green roof (W/m^2)

- DGR_URB3D: Roof layer depth water retention (mm)
- DG_URB3D: Ground layer depth water retention (mm)
- LFR_URB3D: Latent heat flux from roof surfaces (>0 only is DGR_URB3D is >0) (W/m^2)
- LFG_URB3D: Latent heat flux from ground surfaces (>0 only is DG_URB3D is >0) (W/m^2)

3 New buildings drag coefficient

In the BEP(+BEM) schemes in the previous WRF versions, the drag coefficient induced by buildings for mean wind speed and turbulent kinetic energy is $C_D = 0.4$, constant for all buildings packing density (or building plan area fraction). Following Santiago and Martilli (2010) and Gutiérrez et al. (2015), now the drag coefficient is modeled as:

$$C_D(\lambda_p) = \begin{cases} 3.32\,\lambda_p^{0.47} & \text{for } \lambda_p \leq 0.29 \\ 1.85 & \text{for } \lambda_p > 0.29 \end{cases}$$

where λ_p is the buildings plan area fraction.

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