Supplemental material for: Urban Weather Modeling using WRF: Linking Physical Assumptions, Code Implementation, and Observational Needs

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This document contains additional equations not presented in the main manuscript.

S1 Turbulent Flux

S1.1 Sensible Heat Flux Parameterizations

Unlike the Bulk model, the SLUCM employs two main formulations for estimating sensible heat fluxes (H), one applied to its roof (R) and green roof (GR) surfaces (eq. 8) and one applied to its wall (B) and ground (G) surfaces (sup eq. 1). This distinction is made as a consideration for the fact that the roof surfaces are closer to the first atmospheric level, than building walls and ground.

$$\underbrace{H_{[GR,R]}}_{\substack{\text{Lines: [1027,1149]} \\ \texttt{module\_sf\_urban.F}}} = RHO*CP*CH_{[GR,R]}*UA*(T_{[GR,R]}P-TA), \tag{S1}$$

where RHO denote the air density at the lowest atmospheric layer and CP denote the specific heat of dry air at constant pressure. Wind speed at the lowest atmospheric level, denoted as UA, is used for the roof surfaces and $CH_{[GR,R,B,G]}$ represent the surface exchange coefficients. Similarly, the air temperature at the lowest atmospheric level of the WRF mesoscale model TA is employed for roof surface calculations.

S1.2 Latent Heat Flux Parameterizations

When calculating the latent heat flux for each of its surfaces ($ELE_{[surface]}$), the SLUCM similarly considers the surface exchange coefficients for transport of moisture/heat (CH), the minimum moisture availability at the surfaces (BET), the wind speed, and the moisture gradient in the form of the difference in moisture at the surface (QS0) and in the atmosphere.

$$\underbrace{ELE_{[R]}}_{\substack{\text{Lines [1028]} \\ \texttt{module\_sf\_urban.F}}} = RHO*EL*CH_{[R]}*UA*BET_{[R]}*(QS0_{[R]}-QA), \tag{S2}$$

where EL represents the latent heat of vaporization. For the surface closest to the lowest atmospheric level (roof R) the lower atmospheric level wind (UA) and moisture (QA) are employed f.

S2 Radiative Flux

S2.1 Shortwave Radiative Flux Parameterizations

In the SLUCM, the SW radiation incident on the ground surface (rsg) is comprised of three components:

$$\underbrace{rsg}_{\substack{\text{Line } 3659\\ \texttt{module\_sf\_bep\_bem.F}}} = \underbrace{rsg_{s\to g}}_{\substack{\text{T1: Sky SWR incident on the}\\ \text{illuminated portion of the ground}}} + \underbrace{rsdif \times fsg}_{\substack{\text{T2: Diffuse SWR from the sky}\\ \text{to the ground surface}}} + \underbrace{\sum_{ju=1,nu}(rsw^{W}_{s\to ju} + rsw^{E}_{s\to ju})(1-pb(z_{ju+1}))fwg}_{\substack{\text{T3: Portion of total SWR at the wall surface that passed}\\ \text{through the east \& west walls that is seen by the ground}}} + \underbrace{\sum_{ju=1,nu}(rsw^{W}_{ju} + rsw^{E}_{ju})pb(z_{ju+1})albw \times fwg}_{\substack{\text{T4: Total SWR at the east \& west walls}\\ \text{that is reflected towards the ground by the portion of buildings at that level}}}, \qquad \text{(S3)}$$

with fwg representing the view factor of the ground looking at the wall, fsg signifying the sky view factor from the ground, $albw$ the albedo of the wall. $pb(z_{ju+1})$ can be thought of as a view factor between the iu^{th} element of the wall and the sky. N

S2.2 Longwave Radiative Flux Parameterizations

In the SLUCM, net LWR at the ground surface (RG) has additional terms to account for LWR emitted from the wall surface towards the ground surface (RG1-T2) as well as for reflected LWR reaching the ground surface (RG2)

$$\underbrace{RG1}_{\substack{\text{Line } 1284\\ \texttt{module\_sf\_urban.F}}} = EPSG(\underbrace{RX \times VFGS}_{\substack{\text{T1: LWR from the sky}\\ \text{seen by the ground}}} + \underbrace{EPSB \times SIG \times TBP^4 \times VFGW}_{\substack{\text{T2: LWR emitted by the}\\ \text{wall seen by the ground}}} - \underbrace{SIG \times TGP^4}_{\substack{\text{T3: LWR from the}\\ \text{ground to the sky}}}), \qquad \text{(S4)}$$

$$\underbrace{RG2}_{\substack{\text{Line } 1293\\ \texttt{module\_sf\_urban.F}}} = EPSG(\underbrace{RX \times VFWS(1-EPSB)VFGW}_{\substack{\text{T1: LWR from sky seen by the wall}\\ \text{reflected towards the ground}}} + \underbrace{EPSG \times SIG \times TGP^4 \times VFWG \times (1-EPSB)VFGW}_{\substack{\text{T2: LWR from ground seen by wall}\\ \text{reflected towards the ground}}} + \underbrace{EPSB \times SIG \times TBP^4 \times VFWW(1-EPSB)VFGW}_{\substack{\text{T3: LWR from wall seen by opposite}\\ \text{wall reflected towards the ground}}}), \qquad \text{(S5)}$$

The outgoing LWR flux depend on the surface temperature at the previous timestep where TGP stands for the ground temperature and TBP stands for the wall temperature.

In the BEP-BEM model, the incident LWR at the ground surface (rlg) is comprised of four components, including a weighted average of the contribution of the wall and window surface:

$$\underbrace{rlg}_{\substack{\text{Line: 3542}\\ \texttt{module\_sf\_bep\_bem.F}}} = \underbrace{rl \times fsg}_{\substack{\text{T1:LWR from sky}\\ \text{seen by ground}}} + \underbrace{2 \times \sum_{ju=1,nu} rl(1 - pb(z_{ju+1}))fwg}_{\substack{\text{T2: Portion of LWR from sky passed through}\\ \text{east \& west walls that is seen by ground}}} +$$

$$\underbrace{\left(\sum_{ju=1,nu} sigma(emw(1-pwin)(tw^{4,E} + tw^{4,W}))pb(z_{ju+1}) \times fwg + emwin \times pwin(twlev^{4,E} + twlev^{4,W})\right)}_{\substack{\text{T3: LWR emitted by the east}\\ \text{\& west walls seen by ground}}} + \tag{S6}$$

$$\underbrace{\sum_{ju=1,nu} (rlw^{E} + rlw^{W})pb(z_{ju+1})(1 - emw(1-pwin) - emwin * pwin)fwg}_{\substack{\text{T4: Total LWR at the east \& west}\\ \text{walls reflected towards ground}}},$$

where rl is the LWR from the sky. The outgoing LWR flux from the east and west wall depends on their surface temperature at the previous timestep, respectively tw^E and tw^W.