Snow on Land Surfaces for Urban Applications with PALM

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Motivation

There are currently no Large Eddy Simulation models incorporating snow that are specifically tailored for urban environments. Implementation of a robust snow scheme in PALM moves urban numerical weather prediction tools beyond state-of-the-art and will further our understanding of the urban energy balance.

Implementation

The snow scheme solves a prognostic system of equations to model the evolution of a bulk-layer snowpack.

$$\frac{\partial T}{\partial t}=\frac{1}{C_{eff}}(R-H-LE-G)$$

$$\frac{\partial S}{\partial t}=P_s+c_{sn}(P_l-E-M)-\mathrm{MAX}\left(c_{sn}P_l-\frac{S_l^c-S_l}{\Delta t},0\right)$$

$$\frac{\partial \rho}{\partial t}=\rho\left[\frac{\sigma}{\eta}+\xi+\frac{1}{S_l^c-S_l}\mathrm{MAX}\left(0,\frac{\partial S_l}{\partial t}\right)\right]$$

The prognostic equations are linearized using a Taylor Series expansion and solved with a Runge-Kutta method the same way the surface temperature prognostic equation is.

$$A_x=\left.\frac{\partial x}{\partial t}\right|_t+B_x x_t$$

$$B_x=-\frac{\partial}{\partial x}\left(\frac{\partial x}{\partial t}\right)_t$$

$$x_{t+1}=\frac{A_x\Delta t+x_t}{1+B_x\Delta t}$$

The melting scheme breaks each timestep down into sub-timesteps. The first sub-step raises the temperature to freezing. The next melts the snowpack. Energy remaining from the surface energy balance after complete melting is fed directly into the soil model through additional ground heat flux. A visualization of this melt scheme is provided in Fig. 1.

IF

$$T_{t+1}>T_f$$

THEN

$$T_{t+1}=T_f$$

$$\Delta t_1=\frac{T_f-T_t}{A_T-B_T T_f}$$

$$\Delta t_2=\Delta t-\Delta t_1$$

$$M=\left[\frac{1}{L_f}(R-H-LE-G)\right]\frac{\Delta t_2}{\Delta t}$$

IF

$$S_{t+1}<0$$

THEN

$$S_{t+1}=0$$

$$\Delta t_3=-\frac{T_t}{A_T}$$

$$\Delta t_4=\Delta t_2-\Delta t_3$$

$$G_{t+1}=\left[\frac{T_{t+1}-T_{soil}}{r_{sn}}\right]\frac{\Delta t_1+\Delta t_3}{\Delta t}+\left[\frac{1}{C_{eff}}(R-H-LE-G)\right]\frac{\Delta t_4}{\Delta t}$$

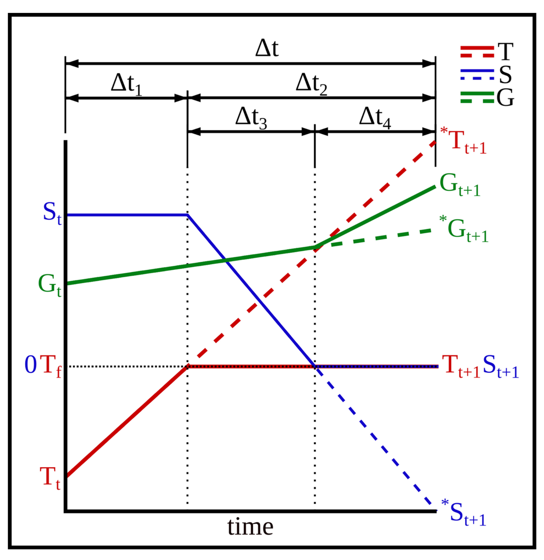


Figure 1. Visual representation of the melt scheme and break-down into sub-timesteps.

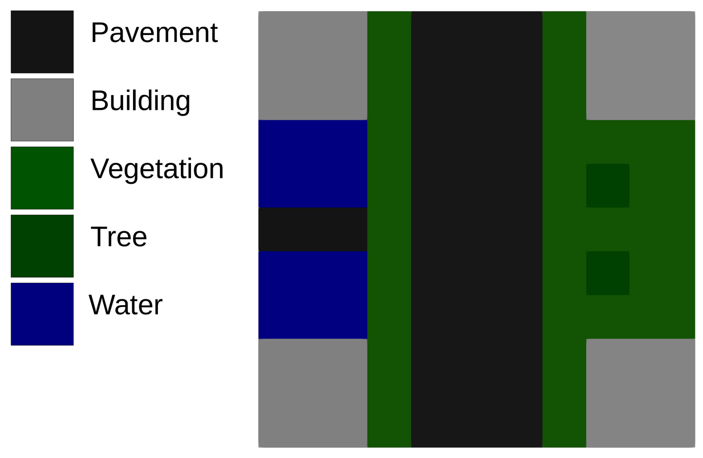
PALM Usage:
In p3d

```
&land_surface_parameters
    snow = .T.,                               ! flag to turn snow model on
    snow_init_depth = 0.00,                   ! depth of uniform snowpack upon initialization in m
    constant_precip_rate_solids = 0.00,       ! rate of precipitation of graupel, ice, and snow in mm/h
    constant_precip_rate_liq = 0.00 ,         ! rate of precipitation of clouds and rain in mm/h
```

Results

The snow implementation can run in three modes: 1) constant precipitation of solids (ice, graupel, and snow) and/or liquids (clouds and rain), 2) uniform, domain-wide snowpack on initialization, 3) precipitation from the bulk cloud model. Example simulations were run for modes 1 and 2 in a simplified, faux urban environment to demonstrate the capabilities of the new snow scheme. The domain was 40 x 40 m with a 2 m grid-spacing (Fig. 2). In principle all three modes could be used simultaneously.

Figure 2. Domain for demonstration simulations. The top of the domain is North.



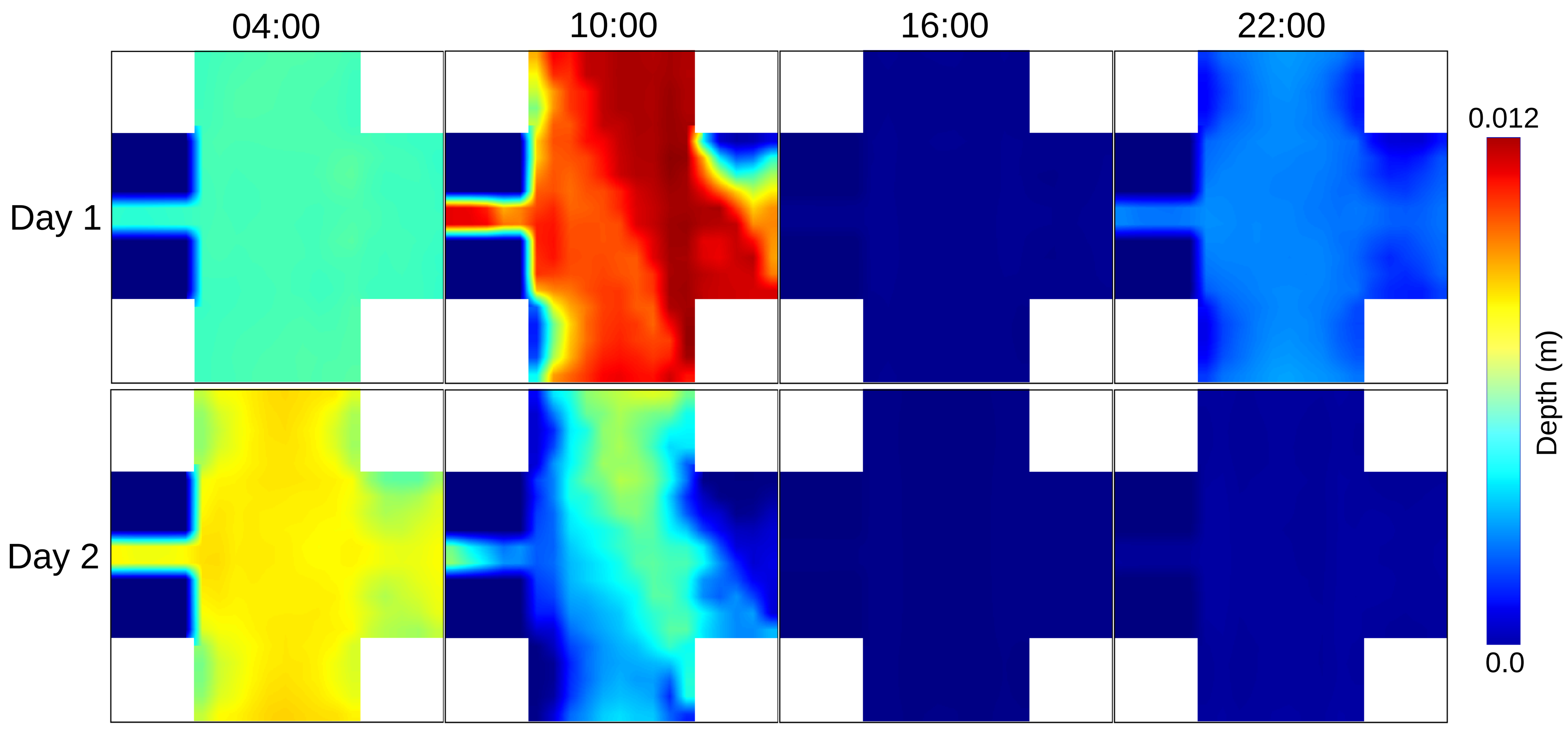
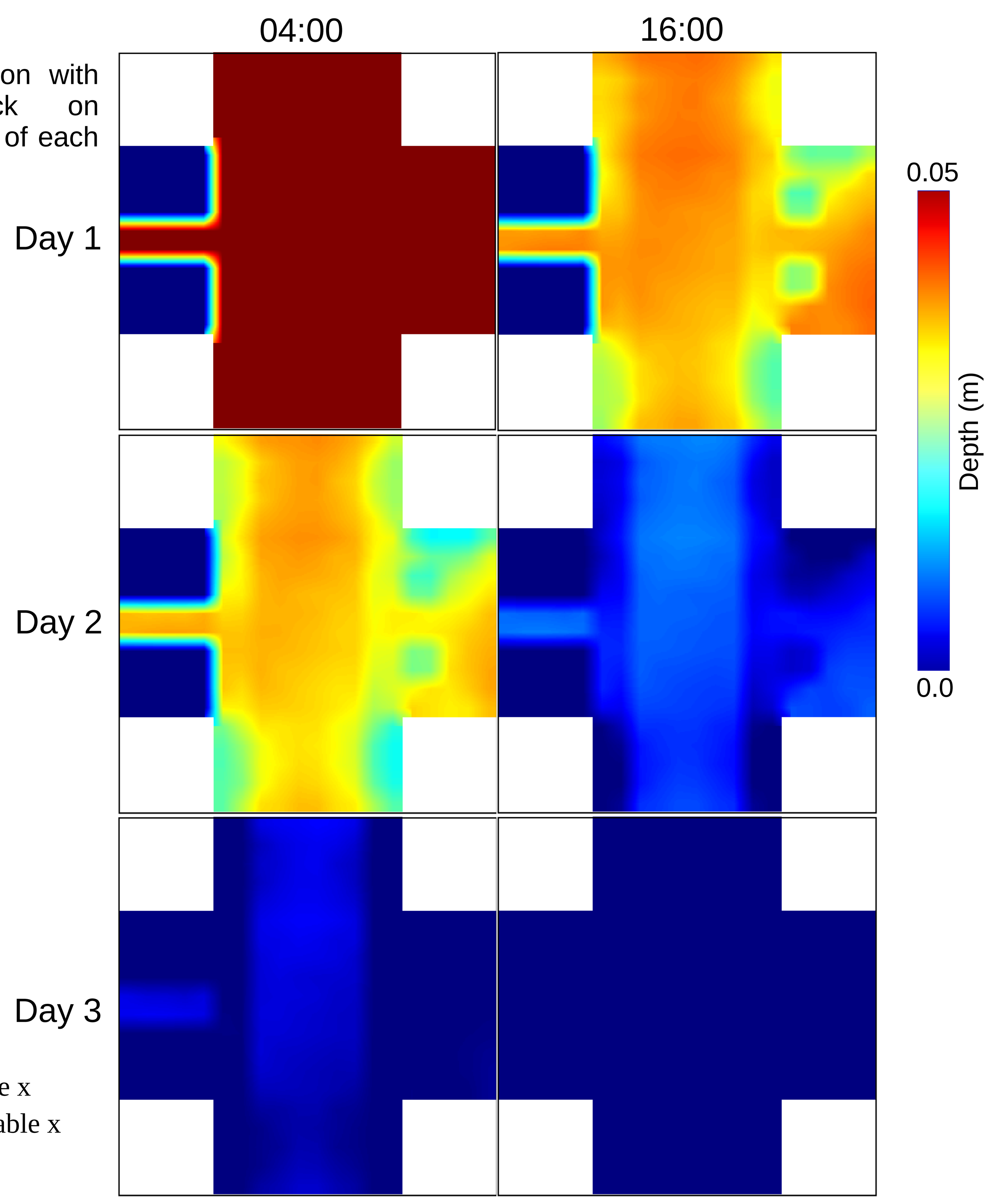


Figure 3. Snow depth for simulation with constant precipitation of solids at 0.1 mm·h^{-1}. Time of day is listed at the top of each column.

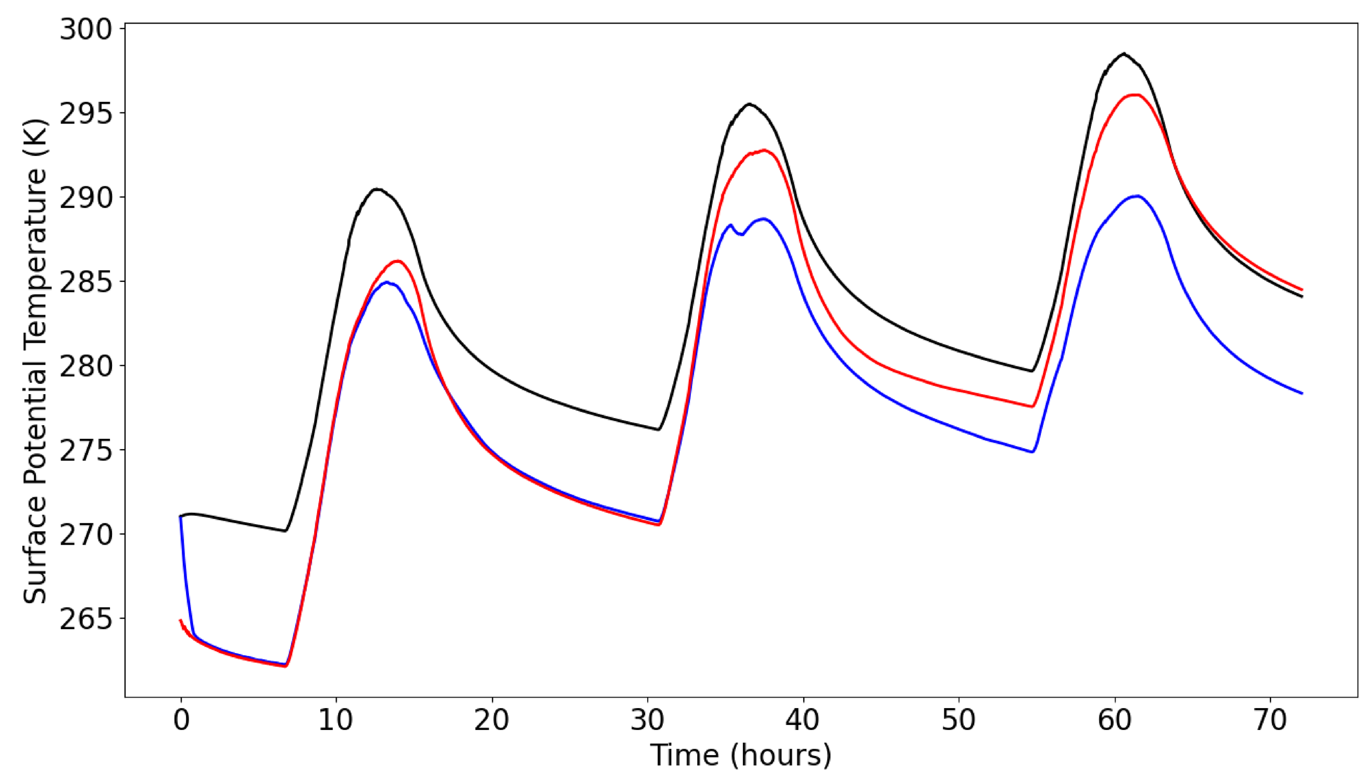
Figure 4. Snow depth for simulation with uniform, domain-wide snowpack on initialization. Time is listed at the top of each column.



List of Symbols

T	snow temperature
t	time
C_{eff}	effective heat capacity of snow
R	net radiative flux
H	sensible heat flux
LE	latent heat flux
G	ground heat flux
S	snow water equivalent
P_s	precipitation mass flux of solids
P_l	precipitation mass flux of liquids
c_{sn}	fractional coverage of snow
E	evapotranspiration mass flux
M	meltwater mass flux
S_l	snow liquid water
S_l^c	snow liquid water capacity
ρ	snow density
Δt	timestep
σ	overburden pressure
η	snow viscosity
ξ	metamorphism parameter
A_x	first prognostic coefficient of variable x
B_x	second prognostic coefficient of variable x
x	arbitrary variable
T_f	freezing temperature

Figure 5. Surface potential temperature for a no-snow reference simulation (black), mode 1 simulation (blue), and mode 2 simulation (red).



For more information go to:
http://uc2-program.org
http://palm4u.org

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