Modelling 3-D radiative fluxes within the PALM-4U microscale urban climate model

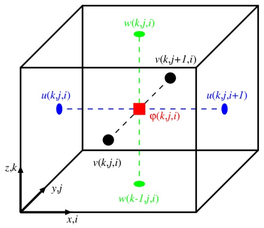
Pavel Krč[1,2] (krc@cs.cas.cz), Jaroslav Resler[1]
[1]Instutute of Computer Science, Czech Academy of Sciences, Prague
[2]Czech Institute of Informatics, Robotics and Cybernetics, Czech Technical University, Prague

PALM-4U

- A microscale urban climate modelling system
- Based on PALM large-eddy simulation model
- Written in Fortran+MPI, HPC enabled
- Open-source, community developed
- Development coordinator: Leibniz University Hanover

Geometry and discretization

- Core radiative elements: *faces* (grid cell sides at surfaces)
- Surface-to-surface radiative exchange: *view factors* (VF)
- Lambertian reflections



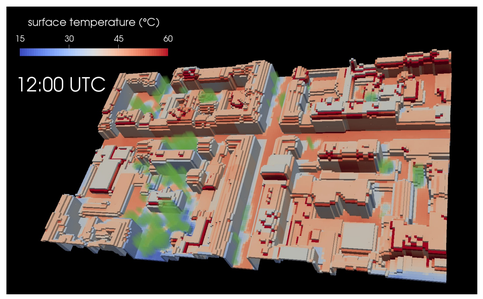
$$F'_{1\to 2} = \frac{dF_{1\to 2}}{dA_2} = \frac{\cos\theta_1 \cos\theta_2}{\pi s_{1,2}^2}$$

Legacy discretization of the view

- All mutually visible face pairs: $O(n^4)$ when increasing resolution
- Limiting available for maximum distance and minimum view factor value
- Normalization necessary ($\Sigma=1$)

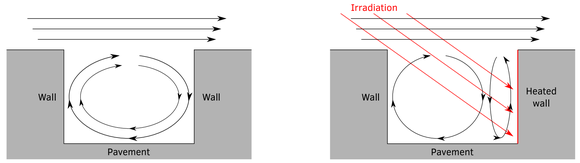
Angular discretization of the view

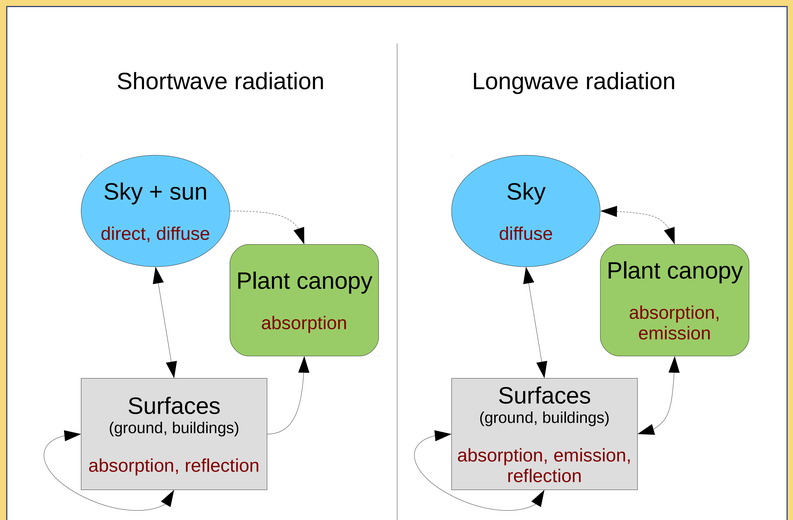
- Fixed number of azimuth and elevation angles (fixed angular resolution) per face: $O(n^2)$ when increasing resolution
- Decreased discretization error for nearby surfaces



RTM within PALM

- Explicit 3-D radiation interactions within the urban layer
- Fully integrated, real-time interaction with flow dynamics
- Using matching 3D grid
- Same MPI parallelization scheme as the rest of the model



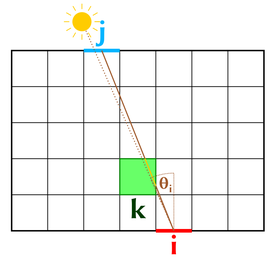


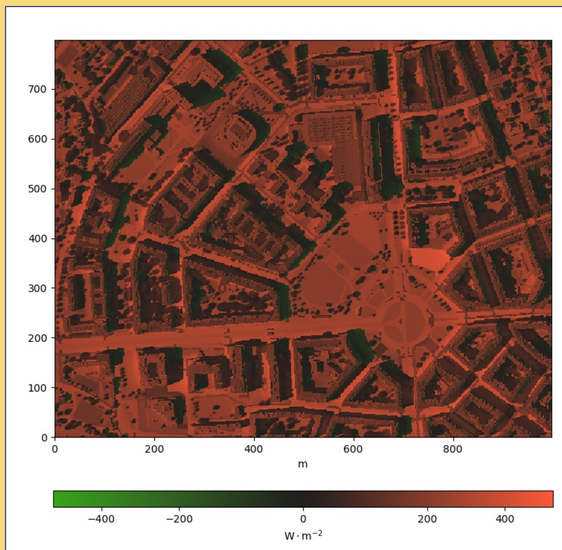
Sky and sun

- *Shortwave* radiation (SW): direct and diffuse solar radiation
- *Longwave* radiation (LW): thermal emission from the sky

Discretization

- RTM v. 1: virtual faces (domain boundaries)
- RTM v. 3: sky-view factor per face, discretized apparent solar position





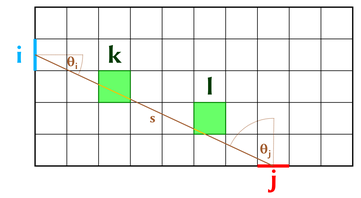
Radiation above the urban layer

- Multiple models available in PALM: fixed, clear-sky radiation, *RRTMG* model, external radiative model (from mesoscale model or observation)
- Two-way radiative exchange with RRTMG
- Longer ray paths: scattering and cooling factors available

Plant canopy

- Explicit 3-D represenation of the treetop structure by *leaf area density* (LAD)
- LAD determines partial absorption for each passing ray
- Interaction with surfaces by precomputed *canopy view factors* (CVF)
- SW: absorption (shading)
- LW: absorption and thermal emission
- Direct sensible heat exchange with surrounding air mass
- Latent heat flux: coupled to plant canopy transpiration model

$$T = \frac{\Phi_e^t}{\Phi_e^i} = e^{-\alpha a s}$$

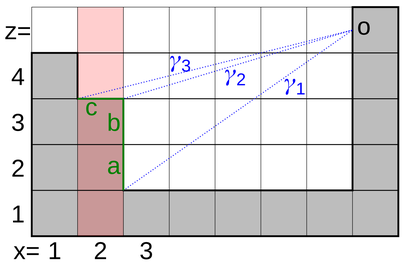


Computation

- Geometry (VF, SkyVF, CVF) precomputed before timestepping using *raytracing*

Raytracing

- Computationally expensive, MPI data exchange intensive
- Legacy discretization: single beam raytracing
- Angular discretization: optimized 2-D raytracing (whole vertical column at once)
- Obstacle detection and plant canopy transmittance
- Horizon height for SkyVF



Radiation within time-stepping

- View factors multiplied by actual SW and LW fluxes
- Fixed number of reflections
- ~0.5–2 % of time-stepping computational time (depending on domain size and geometry)

References

Resler, J., et al. "PALM-USM v1. 0: A new urban surface model integrated into the PALM large-eddy simulation model." *Geoscientific Model Development* 10.10 (2017): 3635.

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