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

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**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

**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

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

**Legacy discretization of the view**
- All mutually visible face pairs: O(n²) when increasing resolution
- Limiting available for maximum distance and minimum view factor value
- Normalization necessary (Z=1)

**Angular discretization of the view**
- Fixed number of azimuth and elevation angles (fixed angular resolution) per face: O(d²) when increasing resolution
- Decreased discretization error for nearby surfaces

**Computation**
- Geometry (VF, SkyVF, CVF) precomputed before time stepping 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 transmitance
  - Horizon height for SkyVF

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

**Plant canopy**
- Explicit 3-D representation 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

**References**
Křč, P., et al. "Radiative Transfer Model 3.0 integrated into the PALM model system 6.0." Geoscientific Model Development (in preparation)

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