Radiation modeling

palmgroup

Institute of Meteorology and Climatology, Leibniz Universität Hannover

Radiation modeling

Speaker:

Mohamed Hefny Salim, PhD
Geography Department
Humboldt-Universität zu Berlin

Radiation modeling

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Radiation modeling

Introduction

Radiation modeling

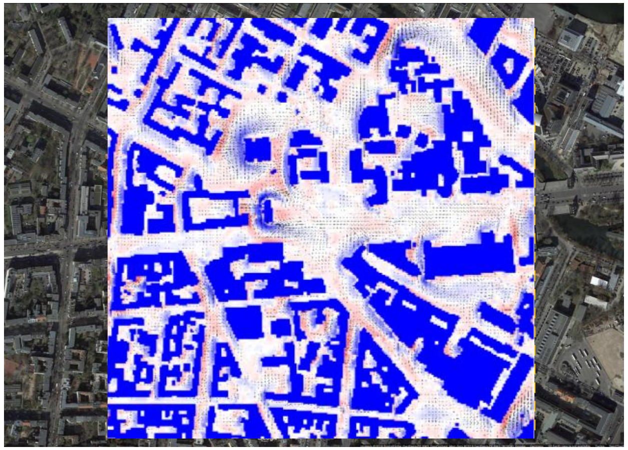
Introduction

Radiation, why should we care?

Inputs:
Terrain data, Buildings, Vegetation, Meteorology, etc.

Outputs:
Wind field (*u*, *v*, *w*), Momentum fluxes, etc.

Applications:
Dynamic effect of obstacles, Wind comfort, Pollutant dispersion, etc.



Something is missing?
Air temperature, surface temperature, etc.

Inputs + Solar radiation

Radiation modeling

Introduction

When to use a radiation model?

- ✓ Land surface module
- ✓ Urban surface module
- ✓ Chemistry module
- ✓ Plant canopy module
- ✓ Cloud microphysics
- ✓ Multi-agent system
- ✓ Human biometeorology
- ✓ Indoor climate and building energy demand

Radiation

When not then?!

Radiation modeling

Radiation models in PALM

Radiation modeling

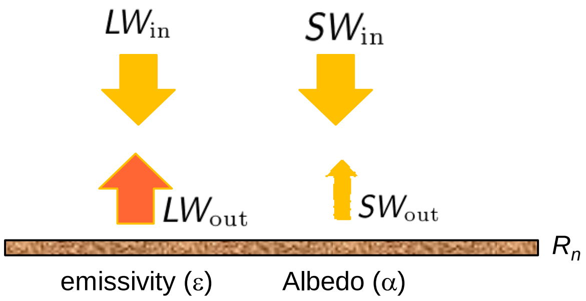
Radiation models in PALM

Simple models

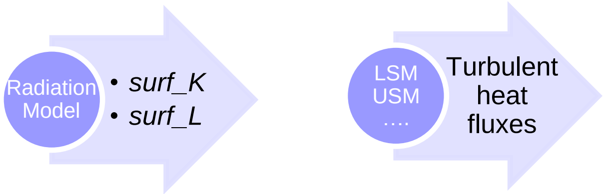
- Constant radiation „model"
  - constant net radiation at the surface: $R_n = const.$

$$R_\mathrm{n} = SW_\mathrm{in} - SW_\mathrm{out} + LW_\mathrm{in} - LW_\mathrm{out}$$

- Clear-sky model
  - Very simple parameterization of fluxes
  - No direct heating of air
  - Broadband albedo only



- External radiation
  - Radiative forcing (short- and longwave downwelling radiation) from a driver



Radiation modeling

Radiation models in PALM

Sophisticated models

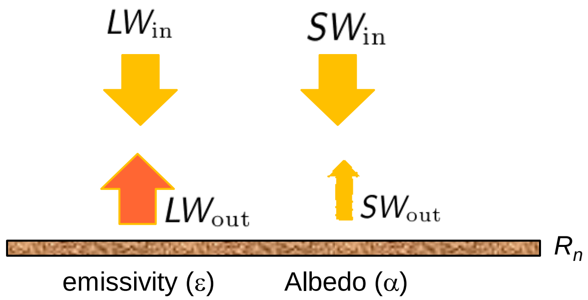
- RRTMG
    - Comprehensive radiation scheme
    - Single-column model for each vertical column of PALM
    - Coupled to PALM (black box)

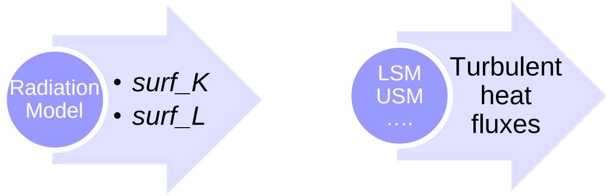
- TenStream
    - 3D radiation solver
    - Coupled to PALM (black box)

Model for non-building resolving simulations

- DCEP
    - The urban Double Canyon Effect Parametrization scheme (DCEP)

$$R_\mathrm{n} = SW_\mathrm{in} - SW_\mathrm{out} + LW_\mathrm{in} - LW_\mathrm{out}$$





Radiation Model

- *surf_K*
- *surf_L*

LSM
USM
….

Turbulent heat fluxes

Radiation modeling

Simple radiation models

Radiation modeling

Simple radiation models

Clear-sky model

Radiative budget equation only at the surface:

$$R_n = \boxed{SW_{\mathrm{in}}} - \boxed{SW_{\mathrm{out}}} + \boxed{LW_{\mathrm{in}}} - \boxed{LW_{\mathrm{out}}}$$

$$SW_{\mathrm{in}} = S_0\ \tau\ \sin(\Psi)$$

$S_0 = 1368\,\mathrm{W\ m^{-2}}$: Solar constant $\tau = 0.6 + 0.2\ \sin(\Psi)$ Ψ: Zenith angle $(^\circ)$

$$SW_{\mathrm{out}} = \alpha\ SW_{\mathrm{in}}$$

α: surface albedo

$$LW_{\mathrm{in}} = \epsilon_{\mathrm{atm}}\ \sigma\ T_1^4$$

$\epsilon_{\mathrm{atm}} = 0.8$: Emissivity of the atmosphere T_1: Temperature at first grid level

$\sigma = 5.67 \cdot 10^{-8}\,\mathrm{W\ m^{-2}\ K^{-4}}$: Stefan-Boltzmann constant

$$LW_{\mathrm{out}} = \epsilon\ \sigma\ T_0^4$$

$\epsilon = 1$: surface emissivity

T_0: Skin-temperature

Radiation modeling

Sophisticated radiation models

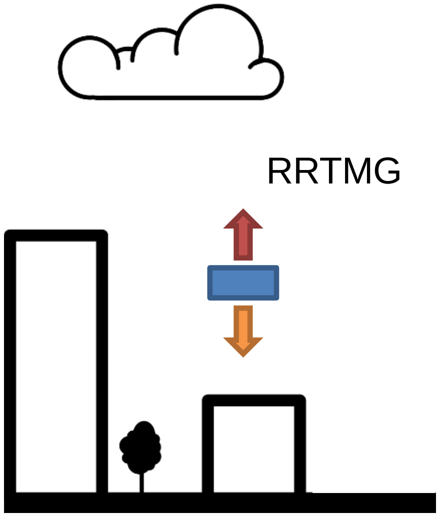
Radiation modeling

Sophisticated radiation models

RRTMG model

Rapid Radiative Transfer Model (for Global Climate Models) http://rtweb.aer.com

- Shipped and coupled to PALM (external library)
- Applied as column model at each vertical column
- Calculates radiative fluxes and heating rates for each grid volume
- Takes into account warm clouds (not ice-clouds)
- Works with bulk microphysics and Lagrangian cloud model



Limitations

- Does not work well with non-stratiform clouds
- Needs significant computational resources
- Information on the upper atmosphere and trace gases must be provided

Radiation modeling

Sophisticated radiation models

RRTMG usage:

⚠

- RRTMG library must be installed
- Re-compile PALM with pre-processor directive **`__rrtmg`**
- Provide LW/SW input files for RRTMG (*_rlw.nc, *_rwl.nc)

Inputs:

- day of the year (DOY), time (UTC)
- Profiles
  - Hydrostatic pressure
  - Temperature
  - Trace gas volume mixing ratios (H_2O, O_3, CO_2, CH_4, N_2O, O_2, CFC_{11}, etc.)
- Surface values:
  - Surface emissivity
  - Temperature
  - Albedo* ($\alpha_{sw,direct}$,$\alpha_{sw,diffuse}$,$\alpha_{lw,direct}$,$\alpha_{lw\_diffuse}$)

* based on Briegleb et al. (1986) and Briegleb (1992)

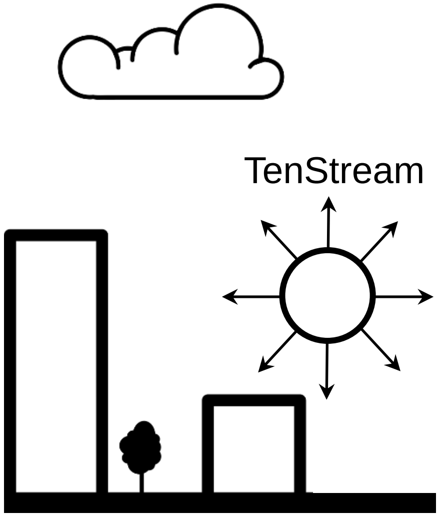
Radiation modeling

Sophisticated radiation models

TenStream radiative transfer model

Parallel approximate solver for the full 3-D radiative transfer equation

- Coupled to PALM (external library)
- 3-D propagation of radiation in the atmosphere.
- 3-D radiative fluxes and heating rates for each grid volume
- Interactions with atmospheric constituents, such as water vapor, fog, and clouds.
- Dynamic heterogeneities (moving clouds or fog).



Limitations

- Needs significant computational resources
- Information on the background atmosphere must be provided
- Look-Up-Tables (LUT): voxel radiation-transport coefficients required for performing the radiative transfer processes.

Radiation modeling

Sophisticated radiation models

TenStream usage:

⚠
- TenStream library must be installed (see installation instructions)
- Re-compile PALM with pre-processor directive `__tenstream`
- Provide LUT and background atmosphere input files

Inputs:

- day of the year (DOY), time (UTC)
- Profiles
  - Hydrostatic pressure
  - Temperature
  - Trace gas volume mixing ratios (H_2O, O_3, CO_2, CH_4, N_2O, O_2, CFC_{11}, etc.)
- Surface values:
  - Surface emissivity
  - Temperature
  - Albedo* ($\alpha_{sw,direct}$,$\alpha_{sw,diffuse}$,$\alpha_{lw,direct}$,$\alpha_{lw\_diffuse}$)

* based on Briegleb et al. (1986) and Briegleb (1992)

Radiation modeling

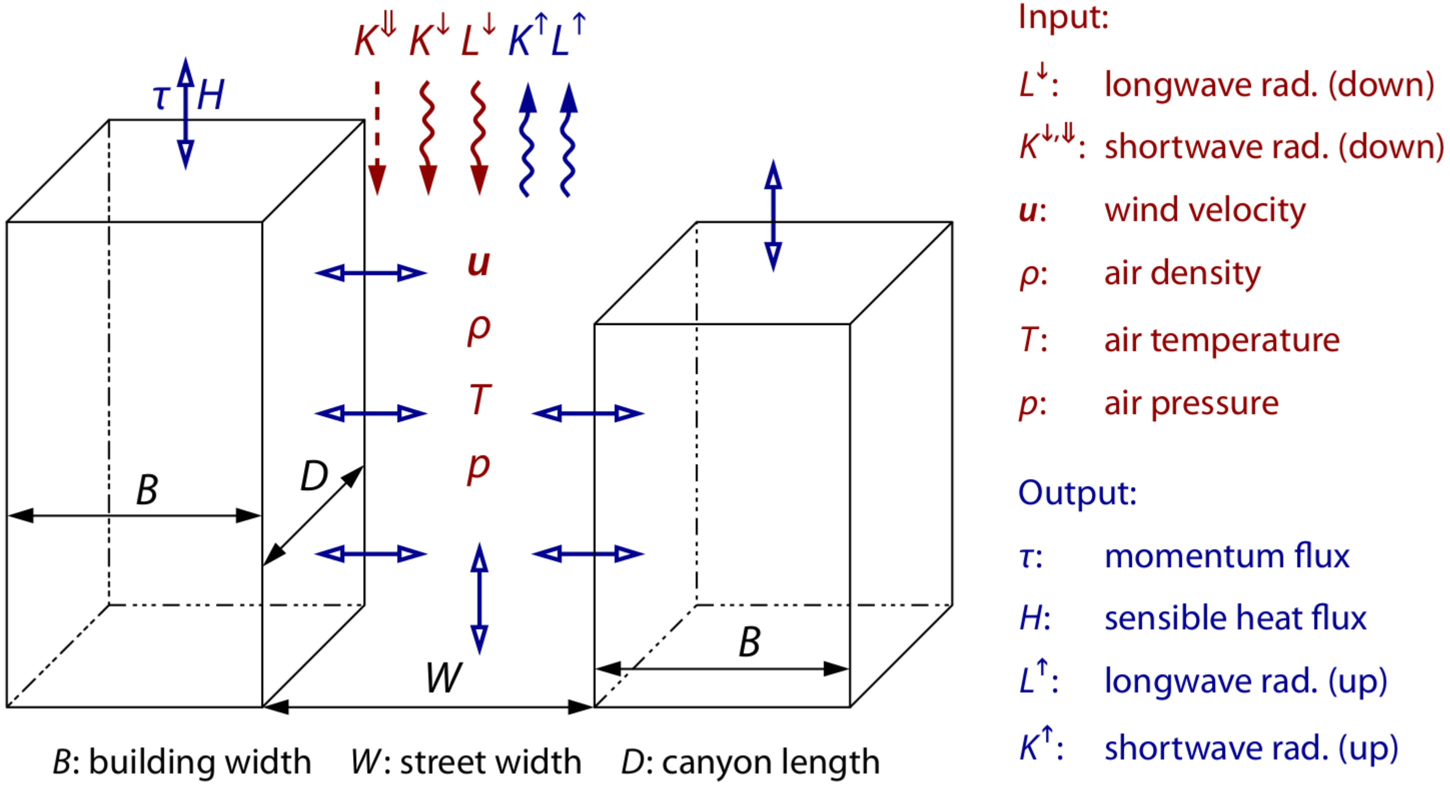
Radiation for non-building resolving simulations

Radiation modeling

Radiation for non-building resolving simulations

PALM/DCEP

DCEP: the urban Double Canyon Effect Parametrization scheme



B: building width W: street width D: canyon length

Input:

$L^{\downarrow}$: longwave rad. (down)

$K^{\downarrow,\Downarrow}$: shortwave rad. (down)

$\mathbf{u}$: wind velocity

ρ: air density

T: air temperature

p: air pressure

Output:

τ: momentum flux

H: sensible heat flux

$L^{\uparrow}$: longwave rad. (up)

$K^{\uparrow}$: shortwave rad. (up)

Radiation modeling

Radiation for non-building resolving simulations

Urban parametrization scheme DCEP

- multi-layer
- longwave and shortwave radiation with reflections
- momentum and heat fluxes, corresponding TKE production
- requires input parameters
    - urban or vegetation fraction
    - building height distribution
    - street and building width

alternative: use land use or local climate zone maps with typical values

- currently
    - no water and snow storage, no latent heat flux → in development
    - no building interior → developed, not yet implemented in PALM

Radiation modeling

Radiative transfer in urban area

Radiation modeling

Radiative transfer in urban area

Radiation modeling

Radiative transfer in urban area

London skyscraper Walkie Talkie

Royal Town Planning Institute: “.. a daily reminder never to let such a planning disaster ever happen again”

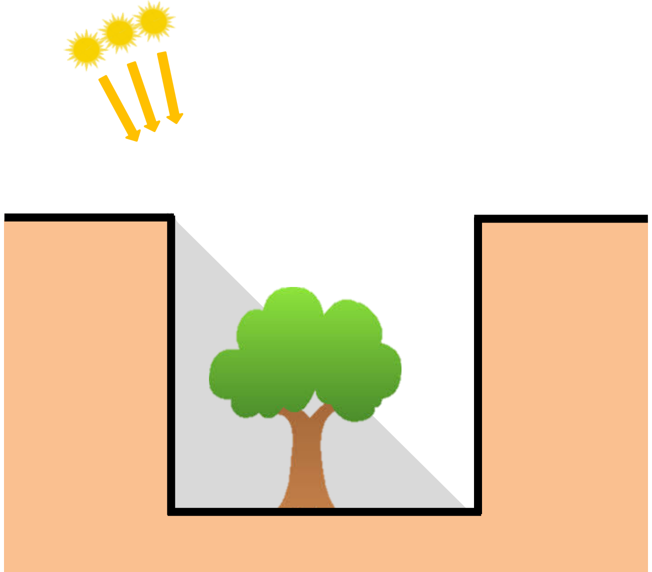
Photos source: http://www.gallopper.com/walkie-talkie-building/

Radiation modeling

Radiative transfer in urban area

Challenges (1)

- Visibility
  - Sun (shadows)
  - Sky (LW)
- Plant canopy (trees)
  - Transparency (SW)
  - LW absorption

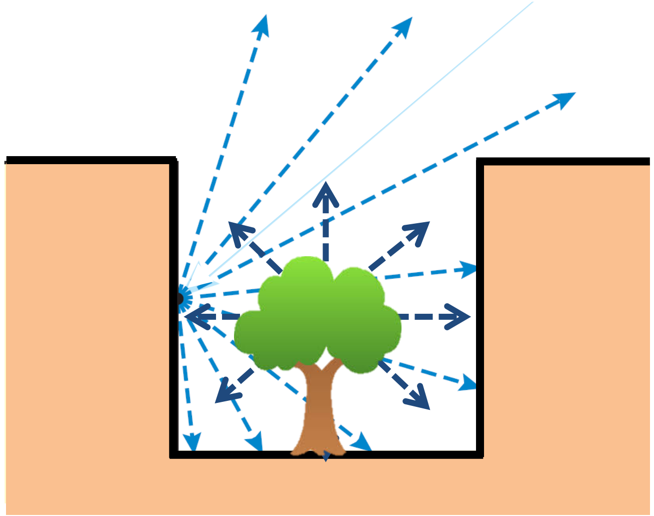


Radiation modeling

Radiative transfer in urban area

Challenges (2)

- Surface thermal emissions
  - Surface-surface
  - Surface-sky
- Plant canopy (trees) thermal emissions
  - Tree-surface
  - Tree-sky



Radiation modeling

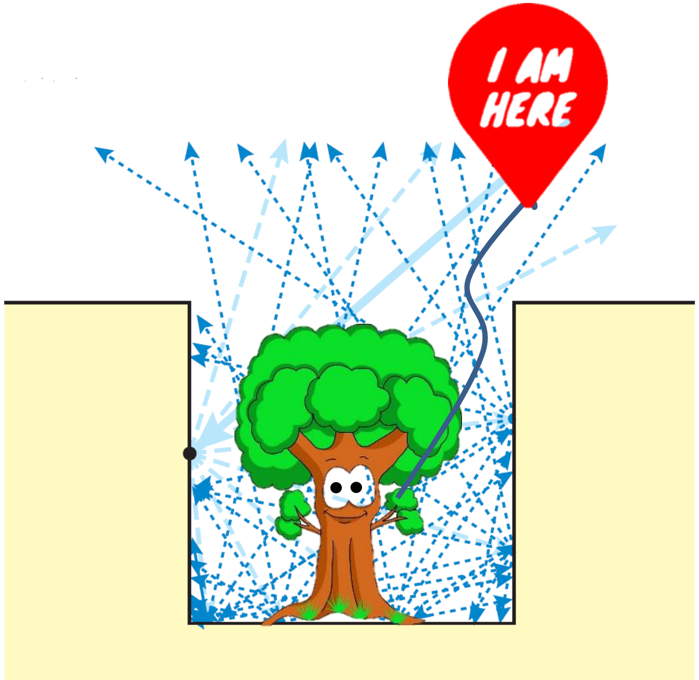
Radiative transfer in urban area

Challenges (3)

- Reflections
    - SW
    - LW

Something is missing?!

- Plant canopy (trees)
    - SW & LW absorption
    - LW reflections



Radiative transfer model (RTM)

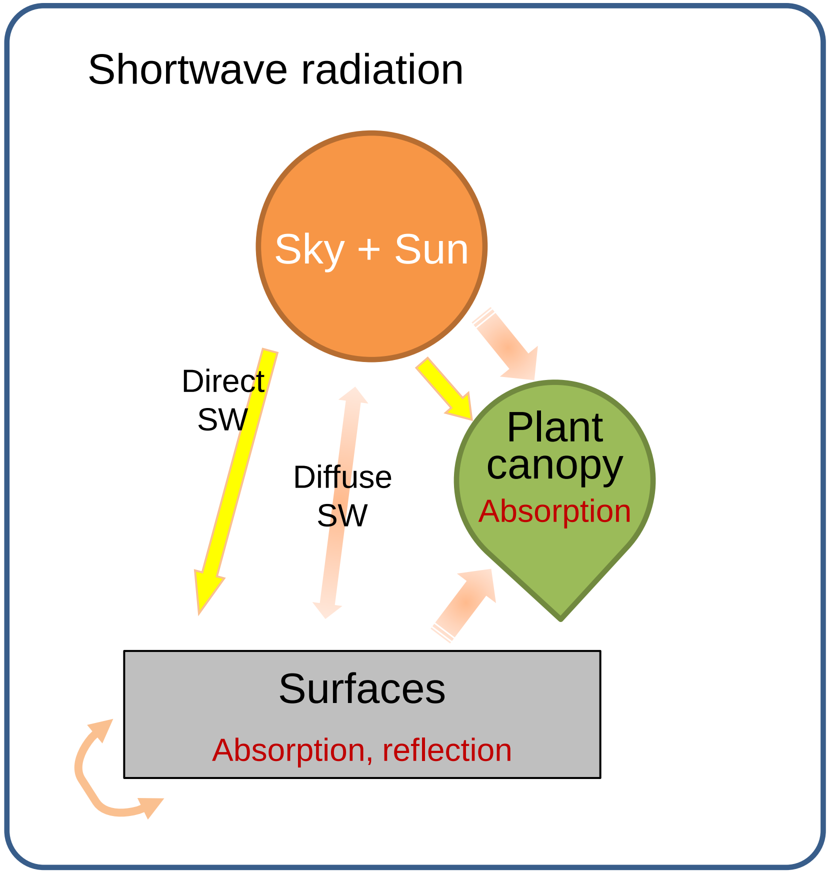
Radiation modeling

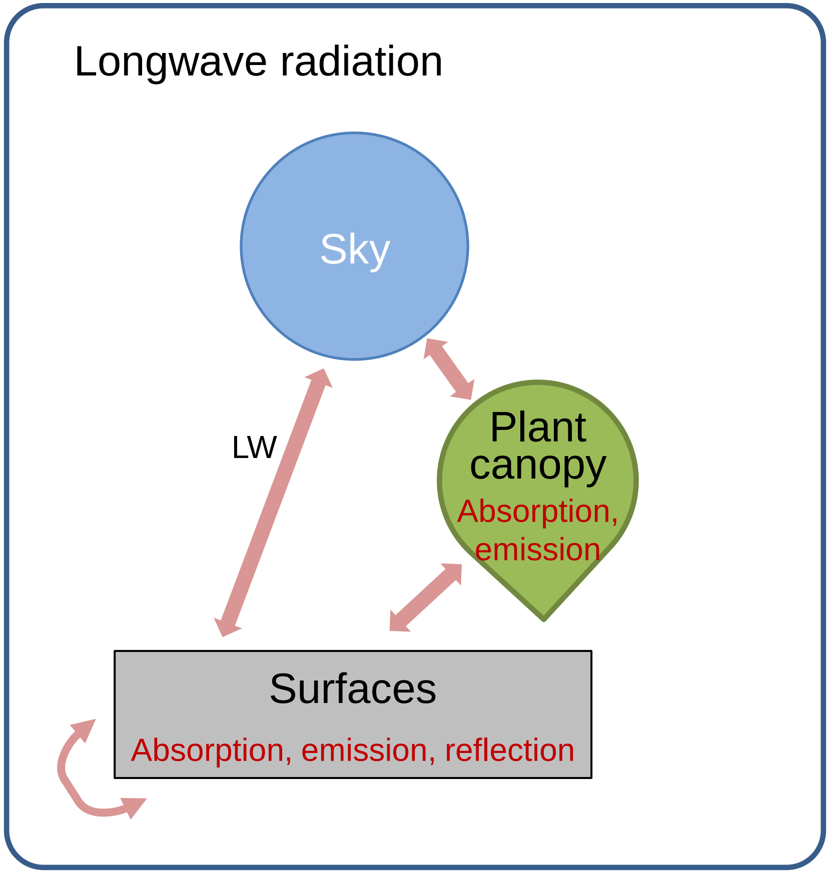
Representation of radiative transfer model

Radiation modeling

Representation of radiative transfer model

Radiative processes simulated by RTM



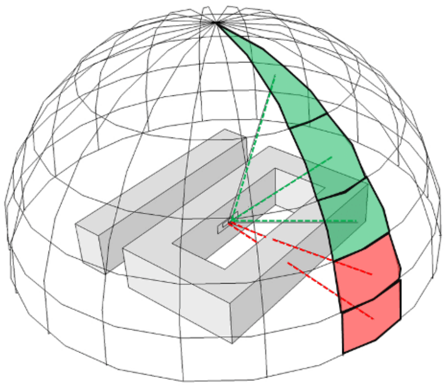


Radiation modeling

Representation of radiative transfer model

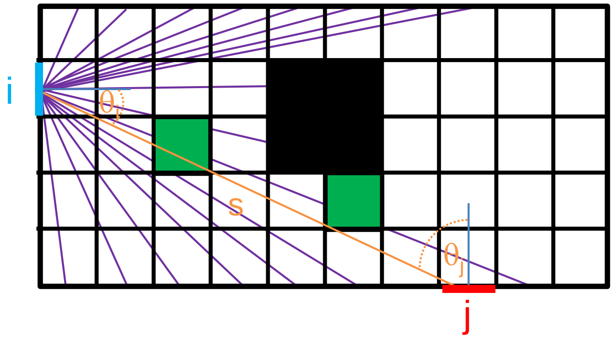
Representing radiative interactions

- View factors
  - Sky view factors (direct SW)
  - Sky view factors (diffuse SW, LW_{sky})
  - Surface view factors (LW: emission, reflections)



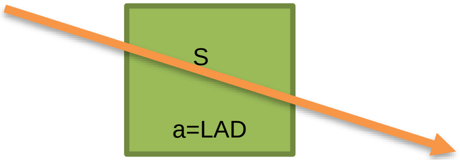
$$F_{i\to j} = \frac{\cos\theta_i \cos\theta_j}{\pi s^2} \qquad \sum_{j=1}^{n} F_{i\to j} = 1$$

- Ray tracing



- Plant canopy sink factors
  - CSF

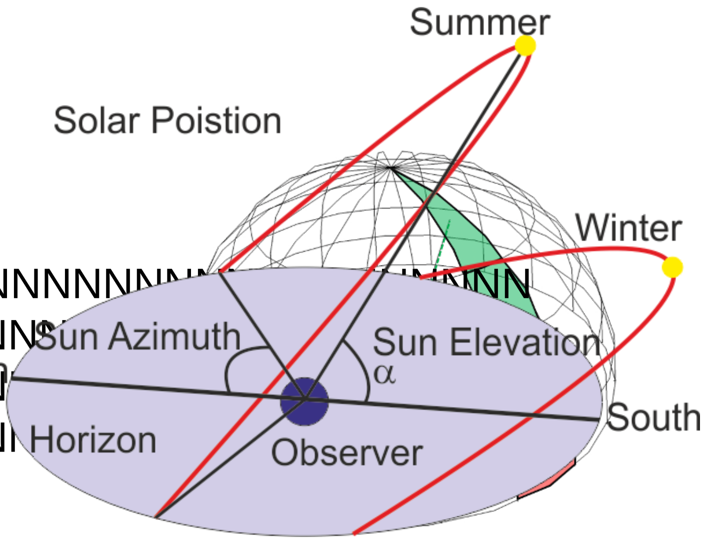
Transmittance: $T = \frac{\Phi_e^t}{\Phi_e^i} = e^{-\alpha a s}$



Radiation modeling

Representation of radiative transfer model

Problems



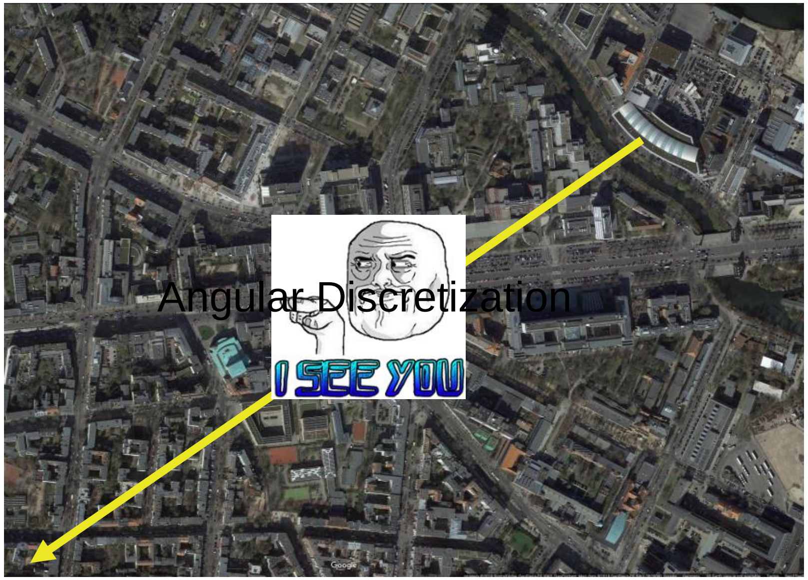
- View factors are M~~A~~NY

MANNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN

- Parallelization issues

How to fix that?

- OPTIMIZATION
- Write out SVF



Radiation modeling

Representation of radiative transfer model

RTM limitations

- Finite reflection number (4 is fine)
- Diffuse reflection (Lambertian reflectors)
- No interaction with air
- No thermal capacity of plant leaves
- No plant canopy internal interactions
- Surface temperature of leaves is set to air temperature

Radiation modeling

Representation of radiative transfer model

Coupling to RRTMG

RRTMG: 1D radiation above canopy layer

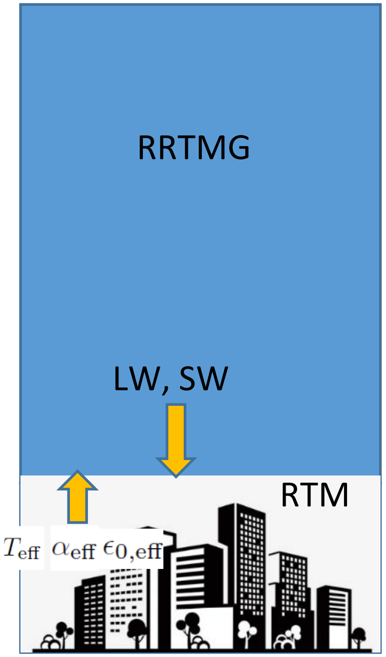
RTM : 3D radiation below canopy layer

Effective radiation surface parameters

T_{eff} α_{eff} $\epsilon_{0,\text{eff}}$

$$SW^{\uparrow} = \alpha_{\text{eff}} SW^{\downarrow}$$

$$LW^{\uparrow} = \epsilon_{\text{eff}} \sigma T_{0,\text{eff}}^{4} + (1 - \epsilon_{0,\text{eff}}) LW^{\downarrow}$$



Radiation modeling

Usage and special features

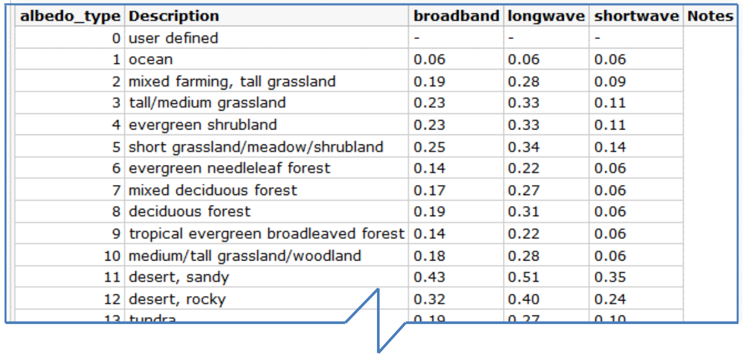
Radiation modeling

Usage and special features

Radiation namelist

radiation_scheme:
'constant', 'clear-sky', 'external' , 'rrtmg'

dt_radiation: timestep of radiation model



albedo_type	Description	broadband	longwave	shortwave	Notes
0	user defined	-	-	-	
1	ocean	0.06	0.06	0.06	
2	mixed farming, tall grassland	0.19	0.28	0.09	
3	tall/medium grassland	0.23	0.33	0.11	
4	evergreen shrubland	0.23	0.33	0.11	
5	short grassland/meadow/shrubland	0.25	0.34	0.14	
6	evergreen needleleaf forest	0.14	0.22	0.06	
7	mixed deciduous forest	0.17	0.27	0.06	
8	deciduous forest	0.19	0.31	0.06	
9	tropical evergreen broadleaved forest	0.14	0.22	0.06	
10	medium/tall grassland/woodland	0.18	0.28	0.06	
11	desert, sandy	0.43	0.51	0.35	
12	desert, rocky	0.32	0.40	0.24	
13	tundra	0.19	0.27	0.10	

Number of reflection steps

```
&radiation_parameters

    radiation_scheme = ‘rrtmg',
    dt_radiation = 60.0,
    albedo = 0.2,
    albedo_type = 17,
    constant_albedo = .F.,
    nrefsteps = 4,
    max_raytracing_dist = 200.0,
    min_irrf_value = 0.000001,
    plant_lw_interact, = .T.,
    rad_angular_discretization = .T.,
    radiation_interactions_on = .T.,
    raytrace_discrete_azims = 40,
    raytrace_discrete_elevs = 80,
    raytrace_mpi_rma = .T.,
    skip_time_do_radiation = 0.0,
    surface_reflections = .T.,
    unscheduled_radiation_calls = .T.,
/
```

https://palm.muk.uni-hannover.de/trac/wiki/doc/app/radiation_parameters

Radiation modeling

Usage and special features

Runtime parameters namelist

- outputs
    - Profile data
    - 3D data (volume)
    - Sectional data (e.g. xy)

```
&runtime_parameters

   data_output_pr = !-- 1) profile data
            'u','wu','w"u"','w*u*','u*2',
            'v','wv','w"v"','w*v*','v*2',
            'w','w*2','e', 'e*','w*e*',
            'rad_lw_in','rad_lw_out',
            'rad_sw_in','rad_sw_out',
            'wthetav','w"thetav"','w*thetav*',

   data_output = !-- 2) Volume data
            'theta','theta_av','q','q_av','u','u_av',
            'v','v_av','w','w_av','e','e_av',
            'rtm_rad_pc_inlw','rtm_rad_pc_insw',
            'rtm_rad_pc_inswdir','rtm_rad_pc_inswdif',
            'rtm_rad_pc_inswref',

                 !-- 3) section data (e.g., x,y)
            'rad_net*_xy','rad_net*_xy_av',
            'rad_lw_in*_xy','rad_lw_out*_xy',
            'rad_sw_in*_xy','rad_sw_out*_xy',
            /
```

Radiation modeling

Usage and special features

Surface data output parameters namelist

- Surface outputs
  - NetCDF file
  - vtk files

```
&surface_data_output_parameters

   data_output_surf = 'theta_surface', 'theta_surface_av‘,
                          'rad_net', 'rad_net‘_av,
                          'rad_lw_in','rad_lw_in_av',
                          'rad_lw_out','rad_lw_out_av',
                          'rad_lw_dif','rad_lw_dif_av',
                          'rad_lw_ref','rad_lw_ref_av',
                          'rad_lw_res','rad_lw_res_av',
                          'rad_sw_in','rad_sw_out',
                          'rad_sw_dif','rad_sw_ref',
                          'rad_sw_res','rad_sw_dir',

   dt_dosurf = 3600.0,
   averaging_interval_surf = 3600,
   dt_dosurf_av = 3600,
   to_netcdf = .TRUE.,
   to_vtk = .TRUE.,
   skip_time_dosurf = 86400.0,

/
```

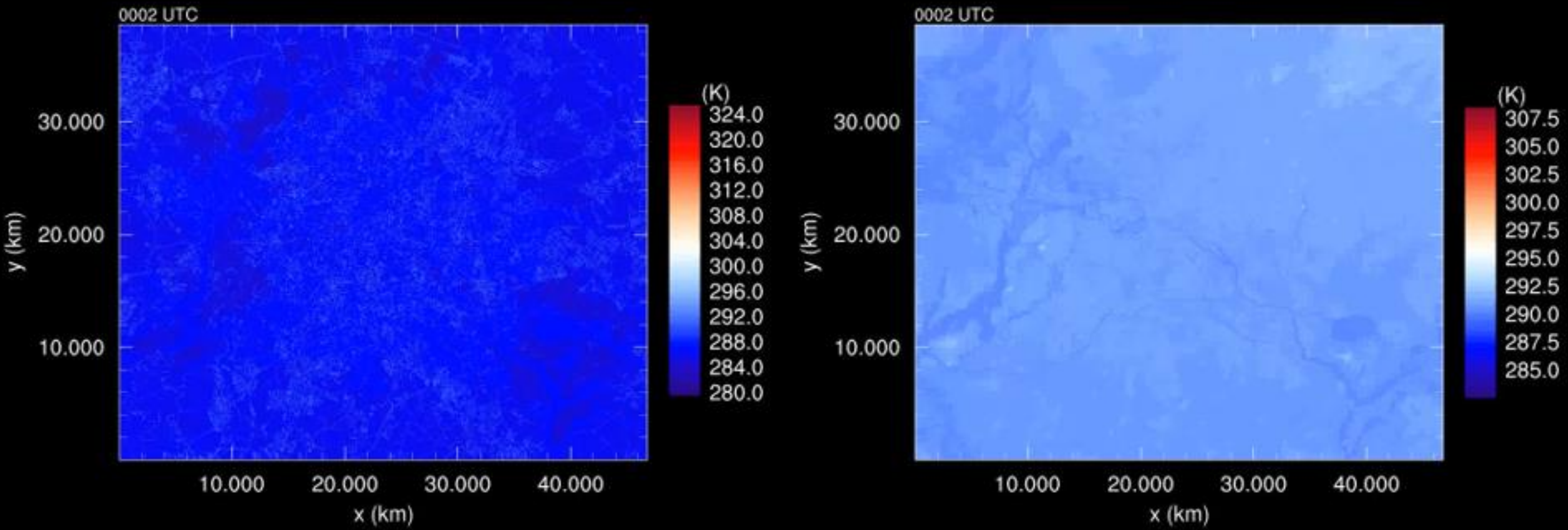
https://palm.muk.uni-hannover.de/trac/wiki/doc/app/surface_data_output_parameters

Radiation modeling

Example

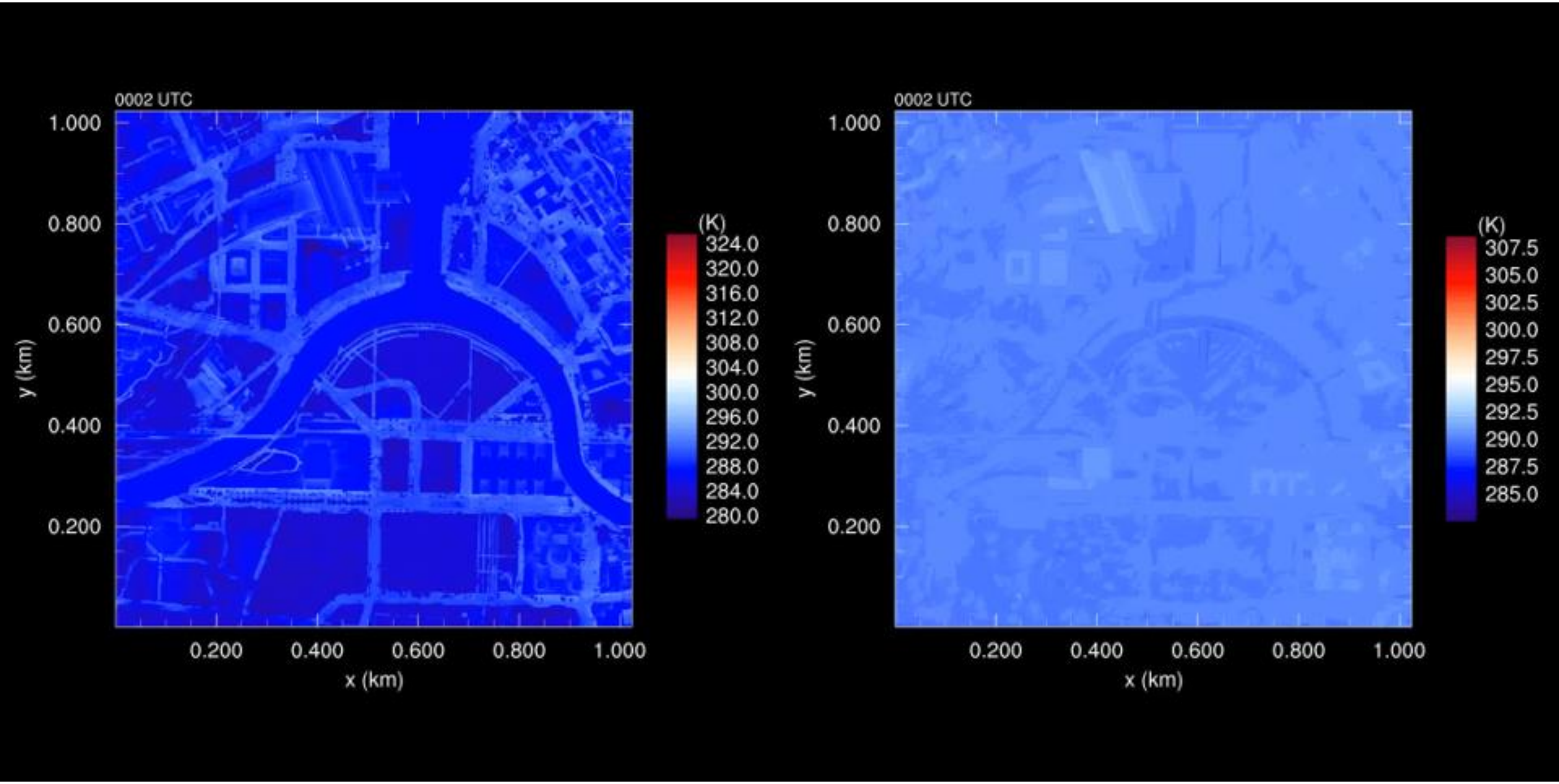
Radiation modeling

Example



Radiation modeling

Example



Radiation modeling

Example

Thank you!