

# PALM - Cloud Physics

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# Why simulating clouds?

- ▶ Atmospheric boundary layers are usually covered with shallow clouds like cumulus or stratocumulus which are the inherent characteristic of more realistic boundary layers.
- ▶ Optional feature to account for:
  - ▶ Microphysical processes
    - ▶ Evaporation / condensation of cloud droplets
    - ▶ Precipitation
    - ▶ Transport of humidity and liquid water
  - ▶ Radiation processes
    - ▶ Short-wave radiation
    - ▶ Long-wave radiation

## Approach

- ▶ One-moment bulk model  $\Rightarrow$  in contrast to PALM's Lagrangian cloud model (LCM) (see also `particle_model_cloud_physics.pdf`, Riechelmann et al., 2012)
- ▶ Dynamics like advection and diffusion are covered by Navier-Stokes equations (see `basic_equations.pdf`)
- ▶ Thermodynamics are considered by parameterizations  $\Rightarrow$  non explicit treatment of microphysical processes
- ▶ Total water specific humidity  $q$  is prognosed as an additional variable  $\Rightarrow$  one-moment
- ▶ Liquid water specific humidity  $q_l$  is determined diagnostically

PALM's basic equations are extended to account for cloud microphysics

## Definitions (I)

- ▶ Liquid water potential temperature  $\theta_l$  (defined by Betts, 1973)

$$\theta_l = \theta - \frac{L_v}{c_p} \left( \frac{\theta}{T} \right) q_l$$

$L_v$ : latent heat of vaporization;  $L_v = 2,5 \cdot 10^6$  J/kg  
 $c_p$ : specific heat of dry air;  $c_p = 1005$  J/kgK

is the potential temperature of an air parcel if all its liquid water evaporates due to an reversible moist adiabatic descent.

- ▶ Total water specific humidity  $q$

$$q = q_v + q_l$$

$q_v$ : specific humidity  
 $q_l$ : liquid water specific humidity

- ▶  $\theta_l$  and  $q$  are the prognostic variables when using PALM's cloud physics model

## Definitions (II)

- ▶ Why using  $\theta_l$  and  $q$ ?
  - ▶  $\theta_l$  and  $q$  are conservative quantities in the absence of precipitation, radiation and freezing processes.
  - ▶ Phase transitions do not have to be described explicitly in the prognostic equations.
  - ▶ In case of dry convection (no condensation):  $\theta_l \rightarrow \theta$  and  $q \rightarrow q_v$
  - ▶ Parameterizations of SGS-fluxes can be retained.
  - ▶ ...→ see also Deardorff, 1976
- ▶ Virtual potential temperature  $\theta_v$

$$\theta_v = \left[ \theta_l + \frac{L_v}{c_p} \left( \frac{\theta}{T} \right) q_l \right] (1 + 0,61q - 1,61q_l)$$

## Extension of basic equations (I)

- ▶ First principle is solved for  $\theta_l$  (instead of  $\theta$ )

$$\frac{\partial \bar{\theta}_l}{\partial t} = -\frac{\partial \bar{u}_k \bar{\theta}_l}{\partial x_k} - \frac{\partial H_k}{\partial x_k} + Q_\theta \quad \text{SGS flux: } H_k = \overline{u_k \theta_l} - \bar{u}_k \bar{\theta}_l$$

- ▶ Conservation equation for total water specific humidity  $q$  (instead of  $q_v$ )

$$\frac{\partial \bar{q}}{\partial t} = -\frac{\partial \bar{u}_k \bar{q}}{\partial x_k} - \frac{\partial W_k}{\partial x_k} + Q_\theta \quad \text{SGS flux: } W_k = \overline{u_k q} - \bar{u}_k \bar{q}$$

## Extension of basic equations (II)

- Sources / Sinks due to radiation (RAD) and precipitation (PREC)

$$Q_{\theta} = \left( \frac{\partial \bar{\theta}_l}{\partial t} \right)_{\text{RAD}} + \left( \frac{\partial \bar{\theta}_l}{\partial t} \right)_{\text{PREC}}$$

$$Q_W = \left( \frac{\partial \bar{q}}{\partial t} \right)_{\text{PREC}}$$

- Diagnostic approach for  $\bar{q}_l$  (all-or-nothing schema)

$$\bar{q}_l = \begin{cases} \bar{q} - \bar{q}_s & \text{if } \bar{q} > \bar{q}_s \\ 0 & \text{if } \textit{otherwise} \end{cases}$$

$\bar{q}_s$  is the saturation value of the specific humidity which is determined based on Sommeria and Deardorff, 1977 and further described in [cloud\\_physics.pdf](#)



## Extension of SGS model (I)

- ▶ SGS fluxes are modelled by means of a down-gradient approximation

$$H_k = -K_h \frac{\partial \bar{\theta}_l}{\partial x_k} \quad ; \quad W_k = -K_h \frac{\partial \bar{q}}{\partial x_k}$$

- ▶ SGS flux of potential temperature  $\overline{u'_3 \theta'}$  in prognostic equation of the SGS-TKE  $\bar{\epsilon}$  is replaced by the flux of the virtual potential temperature  $\overline{u'_3 \theta'_v}$  which is modelled according to Deardorff, 1980 as:

$$\overline{u'_3 \theta'_v} = K_1 \cdot H_3 + K_2 \cdot W_3$$

## Extension of SGS model (II)

- ▶ The coefficients  $K_1$  and  $K_2$  depend on the saturation state of the grid volume (see also Cuijpers u. Duynkerke, 1993)
  - ▶ Unsaturated grid box ( $\bar{q}_l = 0$ )

$$K_1 = 1,0 + 0,61 \cdot \bar{q}$$

$$K_2 = 0,61 \cdot \bar{\theta}$$

- ▶ Saturated grid box ( $\bar{q}_l \neq 0$ )

$$K_1 = \frac{1,0 - \bar{q} + 1,61 \cdot \bar{q}_s \left(1,0 + 0,622 \frac{L_v}{RT}\right)}{1,0 + 0,622 \frac{L_v}{RT} \frac{L_v}{c_p T} \bar{q}_s}$$

$$K_2 = \theta \left( \frac{L_v}{c_p T} \cdot K_1 - 1,0 \right)$$

## Sources / Sinks (I)

- ▶ Radiation model (based on Cox, 1976)  $\Rightarrow$  scheme of effective emissivity
  - ▶ Very simple, accounts only for absorption and emission of long-wave radiation due to water vapour and cloud droplets and neglects horizontal divergences of radiation

$$\left(\frac{\partial \bar{\theta}_l}{\partial t}\right)_{\text{RAD}} = \left(\frac{\theta}{T}\right) \frac{1}{\rho c_p \Delta z} [\Delta F(z^+) - \Delta F(z^-)]$$

$\Delta F$ : Difference between upward and downward irradiance at grid points above ( $z^+$ ) and below ( $z^-$ ) the level in which  $\bar{\theta}_l$  is defined.

Further information: [cloud\\_physics.pdf](#)

## Sources / Sinks (II)

- ▶ Precipitation model (based on Kessler, 1969)
  - ▶ Simplified scheme which accounts only for the process of autoconversion for the formation of rain water.

$$\left(\frac{\partial \bar{q}}{\partial t}\right)_{\text{PREC}} = \begin{cases} (\bar{q}_l - \bar{q}_{l_{\text{crit}}})/\tau & \text{if } \bar{q}_l > \bar{q}_{l_{\text{crit}}} \\ 0 & \text{if } \bar{q}_l \leq \bar{q}_{l_{\text{crit}}} \end{cases}$$

- ▶ precipitation leaves grid box immediately if the threshold  $\bar{q}_{l_{\text{crit}}} = 0,5 \text{ g/kg}$  is exceeded.
- ▶ Timescale  $\tau = 1000 \text{ s}$ .

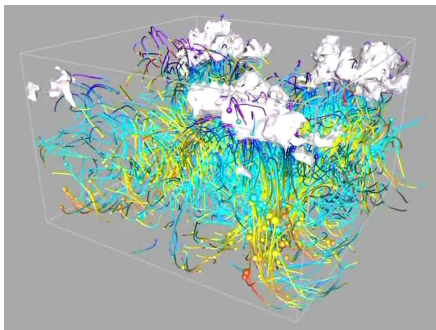
- ▶ 
$$\left(\frac{\partial \bar{\theta}_l}{\partial t}\right)_{\text{PREC}} = \frac{L_v}{c_p} \left(\frac{\theta}{T}\right) \left(\frac{\partial \bar{q}}{\partial t}\right)_{\text{PREC}}$$

# Control parameters

- ▶ The following settings in the parameter file enable the use of the bulk cloud model:
  - ▶ humidity = .TRUE.                    } : prognostic equations for specific specific humidity  $\bar{q}$  is solved
  - ▶ humidity = .TRUE.  
cloud\_physics = .TRUE.                } : prognostic equations for liquid water potential temperature  $\bar{\theta}_l$  and total water specific humidity  $\bar{q}$  are solved
  - ▶ humidity = .TRUE.  
cloud\_physics = .TRUE.  
precipitation = .TRUE.  
radiation = .TRUE.                    } : Kessler precipitation scheme and radiation model are solved

# Example - Setup for a cloudy boundary layer

CBL with shallow cumulus clouds:



```
cb1_cloud_p3d |
&inipar rx = 79, ny = 79, nz = 80,
dx = 25.0, dy = 25.0, dz = 25.0,
dz_stretch_level = 1200.0,

fft_method = 'temperton-algorithm',

initializing_actions = 'set_constant_profiles',
ug_surface = 0.0, vg_surface = 0.0,

pt_surface = 298.0,
pt_vertical_gradient = 0.0, 1.0,
pt_vertical_gradient_level = 0.0, 800.0,

surface_heatflux = 0.1, bc_pt_b = 'neumann',

humidity = .TRUE., cloud_physics = .TRUE.,

q_surface = 0.008,
q_vertical_gradient = -0.00029, -0.002, 0.0,
q_vertical_gradient_level = 0.0, 700.0, 800.0,

surface_waterflux = 3.20E-4, bc_q_b = 'neumann',

bc_e_b = 'neumann', /

&d3par end_time = 3600.0,

create_disturbances = .T.,
dt_disturb = 150.0, disturbance_energy_limit = 0.01,

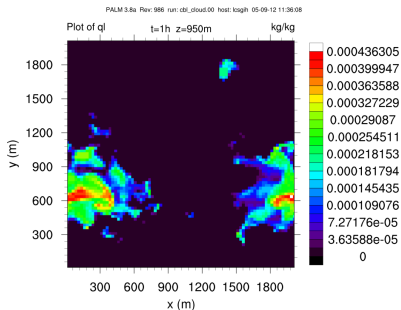
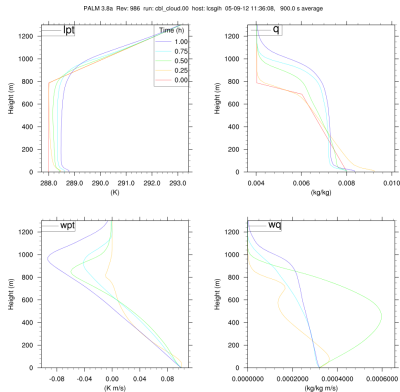
dt_run_control = 0.0,

dt_dopr = 900.0, averaging_interval_pr = 900.0,
dt_averaging_input_pr = 10.0,
data_output_pr = '#pt', '#lpt', '#vpt', '#q', '#qv', 'ql',
                'w'pt', 'w'pt*', 'u'pt',
                'w'vpt', 'u'vpt*', 'wvpt',
                'w'q', 'w'q*', 'u'q',
                'w'2', 'pt'2', 'q'2'

dt_data_output = 3600.0,
data_output = 'ql', 'ql_xy', 'u_xy', 'lup*_xy'

nz_do3d = 50,
section_xy = 1.8,24.32, /
```

# Example - Model output



# Bibliography



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CLOUD\_PHYSICS.PDF: *Introduction to the cloud physics model of PALM*.  
trunk/DOC/tec/methods/cloud\_physics/cloud\_physics.pdf.