PALM - Cloud Physics

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Notes

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

Notes

Approach

- One-moment bulk model ⇒ 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 ⇒ non explicit treatment of microphysical processes
- Total water specific humidity q is prognosed as an additional variable ⇒ one-moment
- Liquid water specific humidity q_l is determined diagnostically

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

Notes

Definitions (I)

- Liquid water potential temperature θ_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 speciffic humidity

- θ_l and q are the prognostic variables when using PALM's cloud physics model

Notes

Definitions (II)

- Why using θ_l and q?
  - θ_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.
  - ...$\rightarrow$ see also Deardorff, 1976
- Virtual potential temperature θ_l

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

Notes

Extension of basic equations (I)

- First principle is solved for θ_l (instead of θ)

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

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

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

Notes

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

Notes

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 $\bar{e}$ is replaced by the flux of the virtual potential temperature $\overline{u_3'\theta_v'}$ which is modelled according to Deardorff, 1980 as:

$$\overline{u_3'\theta_v'} = K_1 \cdot H_3 + K_2 \cdot W_3$$

Notes

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 ($\bar{q}_l \neq 0$)

$$K_1 = \frac{1,0 - \bar{q} + 1,61 \cdot \bar{q}_s \left(1,0 + 0,622 \frac{L_v}{RT}\right)}{1,0 + 0,622 \frac{L_v}{RT} \frac{L_v}{c_p T} \bar{q}_s}$$
$$K_2 = \theta \left(\frac{L_v}{c_p T} \cdot K_1 - 1,0 \right)$$

Notes

Sources / Sinks (I)

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

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

ΔF: 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

Notes

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 $\tau = 1000\,\text{s}$.
  - $\left(\frac{\partial \bar{\theta}_l}{\partial t}\right)_{\text{PREC}} = \frac{L_v}{c_p} \left(\frac{\theta}{T}\right) \left(\frac{\partial \bar{q}}{\partial t}\right)_{\text{PREC}}$

Notes

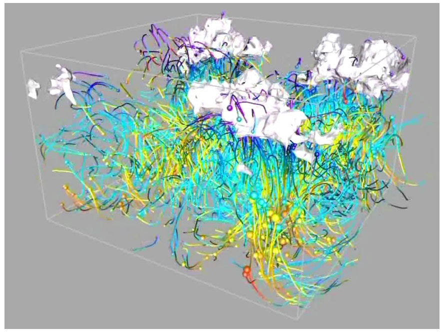
Control parameters

- 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

Notes

Example - Setup for a cloudy boundary layer

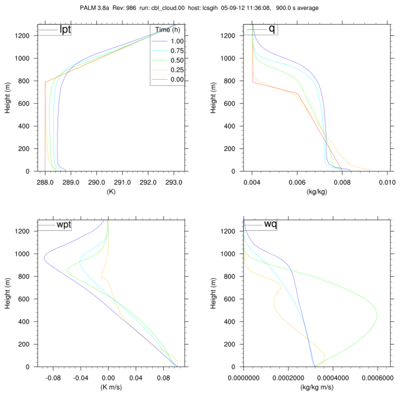
CBL with shallow cumulus clouds:

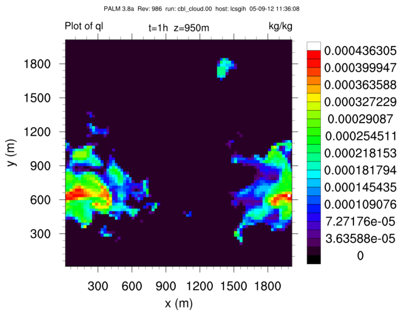


```
cbl_cloud_p3d
&inipar nx = 79, ny = 79, nz = 80,
        dx = 25.0, dy = 25.0, dz = 25.0,
        dz_stretch_level = 1200.0,

        fft_method = 'temperton-algorithm',

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

        pt_surface = 288.0,
        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*','wpt',
                         'w"vpt"', 'w*vpt*', 'wvpt',
                         'w"q"', 'w*q*', 'wq',
                         'w*2', 'pt*2', 'q*2'

        dt_data_output = 3600.0,
        data_output = 'ql','ql_xy','w_xy','lwp*_xy'

        nz_do3d = 50,
        section_xy = 1,8,24,32, /
```


Notes

Example - Model output





Notes

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cloud_physics.pdf: *Introduction to the cloud physics model of PALM.*
`trunk/DOC/tec/methods/cloud_physics/cloud_physics.pdf`.

Notes