Exercise 10: Cumulus Cloud With Bulk Cloud Physics

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Simulate a cumulus cloud:

- Initialize the simulation with a marine, cumulus-topped, trade-wind region boundary layer.
- Trigger the cloud by a bubble of rising warm air.
- Parameterize condensation using a simple bulk cloud physics scheme.
- Learn how to carry out conditional averages.

Hints I

The setup of this exercise is based on the LES-intercomparison BOMEX (Siebesma et al., 2003, J. Atmos. Sci.):

- In order to prescribe vertical profiles of temperature and humidity, set:
  `initializing_actions = 'set_constant_profiles',`
- `pt_surface = 297.9,`
  `pt_vertical_gradient = 0.0, 0.58588957,`
  `pt_vertical_gradient_level = 0.0, 740.0,`
- `q_surface = 0.016,`
  `q_vertical_gradient = -2.97297E-4, -4.5238095E-4, -8.108108E-5,`
  `q_vertical_gradient_level = 0.0, 740.0, 3260.0,`
- `surface_pressure = 1015.4,`
- Note that contrary to BOMEX, no geostrophic wind, no surface fluxes, and no subsidence is prescribed in this setup.
- domain size: about $1000 \times 3600 \times 3000\,\mathrm{m}^3$ $(x/y/z)$
- grid size: $50\,\mathrm{m}$ equidistant
- simulated time: $1800\,\mathrm{s}$

Hints II

How to initialize a bubble of warm air?

- In the subroutine `user_init`, initialize the bubble of warm air by a temperature excess at the first time step (`current_timestep_number == 0`)
- The temperature excess can be added directly to the three-dimensional field of liquid water potential temperature:

```
pt(k,j,i) = pt(k,j,i) + EXP( -0.5 * ( y / bubble_sigma_y )**2 ) * &
                        EXP( -0.5 * ( z / bubble_sigma_z )**2 ) * &
                        initial_temperature_difference
```

  with the locations:

```
y = j * dy - bubble_center_y
z = zu(k) - bubble_center_z
```

- Initialize the bubble by the following parameters:

```
bubble_center_y = 1800.0, bubble_center_z = 170.0,
bubble_sigma_y = 300.0, bubble_sigma_z = 150.0,
initial_temperature_difference = 0.4
```

- Think parallel: Mind that the domain of each PE extends only from `nxlg` to `nxrg` and `nysg` to `nyng`! (Note that the just mentioned dimensions include ghost points)

Hints III

Bulk cloud physics in PALM:

- PALM offers two bulk cloud physics schemes: A very simple, one-moment scheme by Kessler (1969, Meteor. Monogr.) and a state-of-the-art two-moment scheme by Seifert and Beheng (2006, Meteor. Atmos. Phys.).
- You will use the saturation adjustment scheme, as applied in the Kessler-scheme, for parameterizing condensation. (Note that this kind of scheme is used in the vast majority of today's bulk cloud physics parameterizations.)
- The liquid water is diagnosed by $q_l = \max(0, q_t - q_s)$: If the total water content q_t exceeds the saturation water content q_s, all supersaturations condensate immediately to liquid water. On the other hand, no liquid water is present in subsaturated conditions.

Turn on simple cloud microphysics in your parameter file (`inipar` namelist):

- `humidity = .TRUE., cloud_physics = .TRUE.,`
- `cloud_scheme = 'kessler', precipitation = .FALSE.`

Hints IV

What is conditional averaging?

- A horizontal average (e. g., for retrieving vertical profiles) might be inappropriate for the analysis of a heterogeneous phenomenon (e. g., cumulus clouds).
- A conditional average can restrict the analysis to the regions of interest (e. g., cloudy and non-cloudy regions).

What kind of conditional average are you going to derive?

- You will derive vertical profiles of **cloud cover** and **cloud core cover**. These profiles are the basis for more complex profiles (e. g., the cloud core vertical velocity).
- Cloudy grid cells are defined as grid cells with a non-zero liquid water content ($q_\mathrm{l} > 0$, `ql(k,j,i) > 0.0`). Cloud core grid cells are defined as cloudy grid cells, which are also positively buoyant with respect to the slab average ($\theta_\mathrm{v} > \langle\theta_\mathrm{v}\rangle$, `vpt(k,j,i) > hom(k,1,44,sr)`).

Hints V

PALM offers a convenient way to compute and output user-profiles:

- In the subroutine `user_statistics`, you can compute the cloud cover profile by counting all cloudy grid cells at a certain grid level `k`:

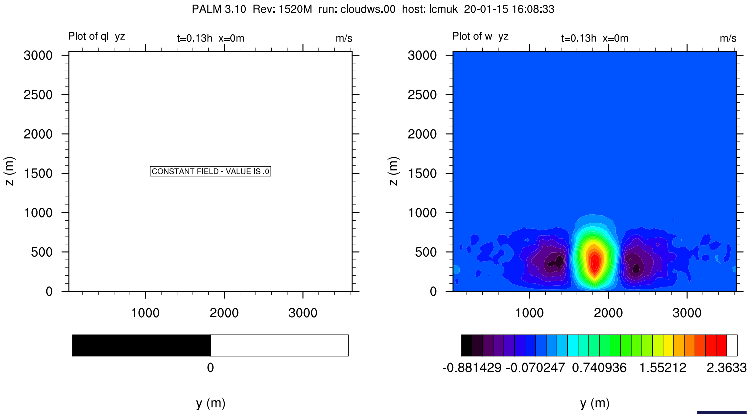
```
IF ( ql(k,j,i) > 0.0 ) THEN
   sums_l(k,pr_palm+1,tn) = sums_l(k,pr_palm+1,tn) + 1.0
ENDIF
```

- The computation of the cloud core cover profile is up to you!
- PALM automatically cares for the summation across the PE's boundaries and the normalization of the profiles (i. e., dividing it by the total amount of grid cells in horizontal directions).
- Do not forget to adapt `user_check_data_output_pr` (for defining your user-profiles) and your parameter file (`userpar` namelist) for the output (with the parameter `data_output_pr_user = 'your_profile'`)!
- Check the online documentation of PALM for more detailed information on the implementation of user profiles:
  `http://palm.muk.uni-hannover.de/trac/wiki/doc/app/userint/output#part_1`
  Further examples are also provided within the subroutines `user_statistics` and `user_check_data_output_pr`.

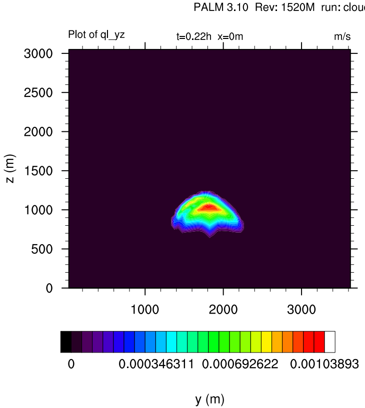
Tasks to be done:

- Output instantaneous yz-cross sections of `ql` and `w` at `section_yz = 0`. (`pt`, `q` and `vpt` are also interesting!) An output interval of 60 s is adequate.
- Output instantaneous vertical profiles of cloud cover and cloud core cover! Again, an output interval of 60 s is adequate.
- Answer the following questions:
  - How does the cloud develop?
  - Can you identify the *actively growing* and the *decaying stage* of the cloud's life cycle by comparing the profiles of cloud and cloud core cover profiles? (Mind the profiles' definitions and physical implications!)
- If you are really fast: What changes during the cloud's development turning on precipitation (`precipitation = .TRUE.`)?

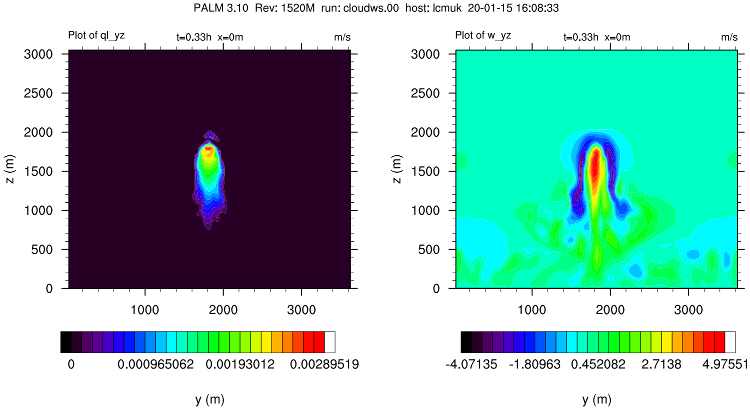
yz-cross sections at $t \approx 500\,\mathrm{s}$



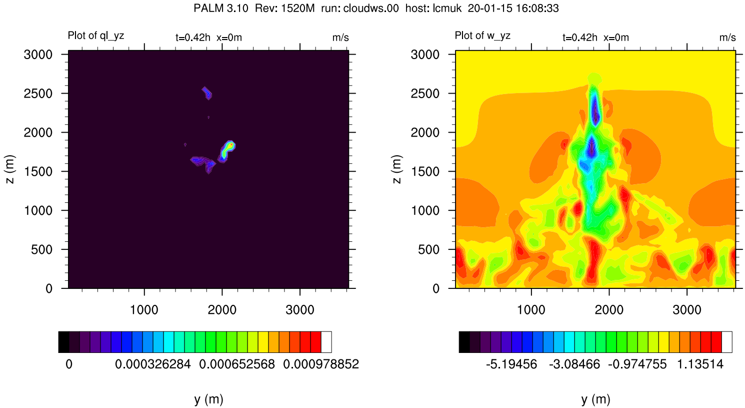
yz-cross sections at $t \approx 800\,\mathrm{s}$



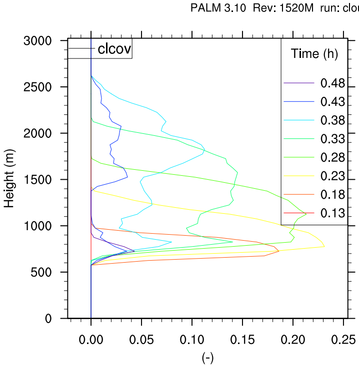
yz-cross sections at $t \approx 1200\,\mathrm{s}$



yz-cross sections at $t \approx 1500\,\mathrm{s}$



Cloud cover (clcov) and cloud core cover (cocov) profiles



Answers to questions I

How does the cloud develop?

- See frames 9 – 12: The clouds develops from a rising bubble of warm air ($t \approx 500\,\mathrm{s}$). Reaching the condensation level ($t \approx 800\,\mathrm{s}$), the cloud appears as the bubble's visible top. Afterwards, the cloud starts to grow more vigorously by the release of latent heat ($t \approx 1200\,\mathrm{s}$). In the end of the cloud's life-cycle, the cloud dissipates by turbulent entrainment of environmental air and the subsequent evaporation of the cloud ($t \approx 1500\,\mathrm{s}$).

Answers to questions II

Can you identify the (i) actively growing and (ii) decaying stage of the cloud's life cycle by comparing the profiles of cloud and cloud core cover profiles?

- See Frame 13: As long as the cloud core is present, i. e., a positively buoyant region producing upward motion, the cloud grows actively (until 1400 s). From 1500 s on, no cloud core is visible. As a result, the cloud's upward motion decelerates and the rate of condensation decreases. Thus, the cloud's dilution by the entrainment of environmental air can not be counterbalanced anymore. As a consequence, the cloud decays and finally dissipates.

Answers to questions III

What changes during the cloud's development turning on precipitation (`precipitation = .TRUE.`)?

- Almost nothing. The simulated cloud is very shallow, therefore no significant masses of rain are produced that might alter the cloud.