ICON Documentation: Cloud Cover and Water Distribution

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1 Introduction

The treatment of the sub-grid-scale cloud distribution in the ICON model as used for NWP are described here. Note that the ICON-NWP model currently predicts and advects the grid-scale specific water quantities: water vapor, cloud liquid water, cloud ice, rain and snow. These grid-scale values are used by microphysics (named q1, q2, q3, q4 and q5). Note also that the turbulence scheme calculates a separate temporary cloud cover for use in the calculation of the buoyancy flux. The cloud schemes described below therefore currently only impact radiation. Diagnostic values for water vapor, cloud liquid water and cloud ice that include sub-grid scale variability are parameterized (named qv, qc, qi).

The ICON-ECHAM physics includes two more cloud options : (1) a relative humidity based scheme and (2) a prognostic total water variance scheme based on Tompkins (2002). They are not yet covered in this documentation.

2 Simple new diagnostic cloud scheme

Clouds are distinguished by their origin into stratiform and convective clouds.

2.1 Stratiform clouds

The top-hat or box-function is one of the most simple assumed PDF. It will be used to describe the distribution of water in a grid box. The liquid and ice clouds are treated separately due to their different microphysical time-scales involved. For mixed-phase clouds the liquid and ice clouds are assumed to exhibit a maximum overlap.

2.1.1 liquid cloud

In figure 1 such a box function distribution is illustrated. Cloud cover and mean specific liquid water can be calculated by integrating this box PDF with maximum PDF value p. First the full PDF to get unity.

$$1 = \int_{q_{bot}}^{q_{top}} p dq = 2p\triangle q \tag{1}$$

and therefore

$$p = \frac{1}{2\triangle q}. \tag{2}$$

The width of the box distribution is $2\triangle q$.

The specific total water is written here as $\overline{q} = \overline{q_v} + \overline{q_l}$. It can be diagnosed from the associated grid point variables $q_{v,grid}$ and $q_{l,grid}$ as $\overline{q}$ is conserved. Now we integrate the PDF from q_{sat} (assumed constant) to get cloud cover CC

$$CC = \int_{q_{sat}}^{q_{top}} p dq = \frac{q_{top} - q_{sat}}{2\triangle q} = \frac{1}{2}\Big(\frac{\overline{q} - q_{sat}}{\triangle q} + 1\Big). \tag{3}$$

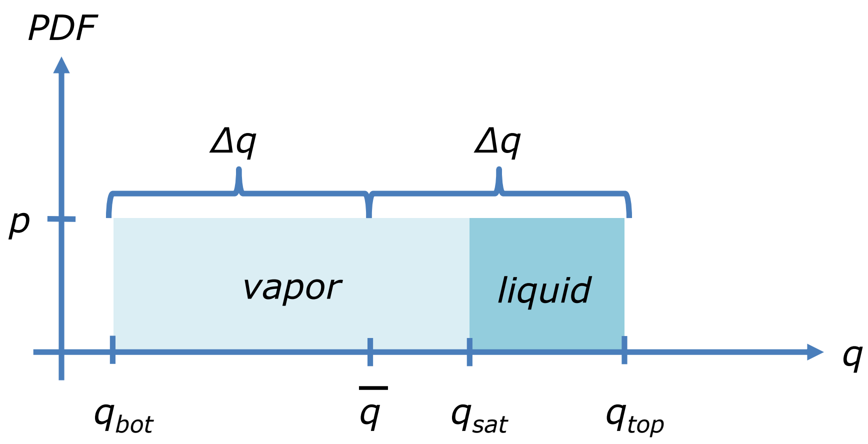

Figure 1: Box distribution of total water in a grid box that forms a liquid cloud.

The grid-box mean specific liquid water q_l can also be calculated.

$$\overline{q_l} = \int_{q_{sat}}^{q_{top}} (q - q_{sat}) p dq = \frac{(q_{top} - q_{sat})^2}{4\triangle q} = \frac{\triangle q}{4} \left(\frac{\overline{q} - q_{sat}}{\triangle q} + 1 \right)^2 \tag{4}$$

Note that

$$q_{top} = \overline{q} + \triangle q \tag{5}$$

Equations 3 and 4 are valid for partial cloud cover, that is for $q_{bot} < q_{sat} < q_{top}$. For $q_{sat} < q_{bot}$ trivial cloud properties can be written as

$$CC = 1 \tag{6}$$

and

$$\overline{q_l} = \overline{q} - q_{sat}. \tag{7}$$

2.1.2 ice cloud

The ICON microphysics works under the assumption that q_i is horizontally homogeneious in a grid-box. It allows for supersaturation with respect to ice and allows ice to survive in a subsaturated environment. In the sub-grid cloud scheme we make the assumption that the grid-scale microphysics produces a mixture of ice and vapor that is accurate also for the sub-grid scale microphysics. That means that the current threshold specific humidity q_{thresh} is equal to (1) $q_{v,grid}$ that is seen my the grid-scale microphysics for supersaturated environments and (2) $q_{sat,ice}$ for subsaturated environments. This can be written as

$$q_{thresh} = min(q_{v,grid}, q_{sat,ice}). \tag{8}$$

Now we can write analogous equations for CC and q_i as done for the liquid phase by replacing $q_{sat,liq}$ with q_{thresh}. This sub-grid ice cloud is only applied when grid-scale ice is predicted ($q_{i,grid} > 10^{-6}$kg/kg).

2.1.3 mixed phase cloud

Mixed-phase liquid/ice stratiform clouds are treated by assuming maximum overlap.

2.1.4 tuning parameters

The width of the box function needs to be specified. For liquid clouds we assume $\triangle q = 0.1 q_{sat,liq}$ and for ice clouds a narrower $\triangle q = 0.05 q_{sat,ice}$. This corresponds to a threshold relative humidity of 90% and 95% respectively.

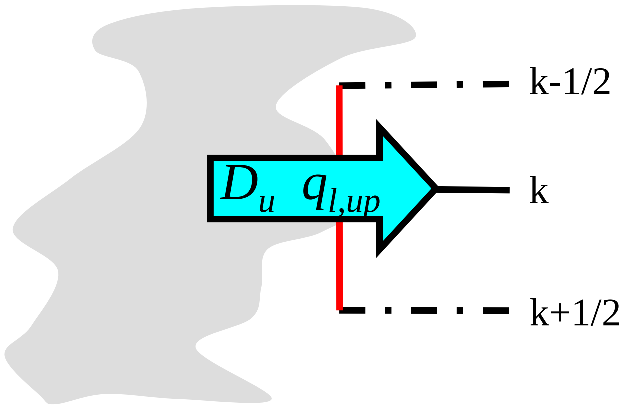

Figure 2: Detrainment terms from convection create an anvil.

2.2 Convective clouds

The Tiedtke (1989) convection scheme provides detrainment properties that we are using to create a diagnostic anvil (see figure 2). In particular three parameters calculated by the convection scheme are available: detrainment rate D_u, updraft liquid water $q_{l,up}$ and ice water $q_{i,up}$. The anvil cloud cover can be estimated from

$$\frac{\partial CC}{t} = \frac{D_u}{\rho} - \frac{CC}{\tau_{diss}}. \tag{9}$$

The time derivative is neglected to arrive at a diagnostic equation that can be solved for CC. The anvil dissipation time-scale τ_{diss} is set to 30min

The updraft values $q_{l,up}$ and $q_{i,up}$ are used as in-cloud specific water and ice. They are limited to $0.1 * q_v$. One might consider to write similar decay equations as in equ. 9 for the updraft water values.

2.3 Mixed stratifom/convective clouds

The maximum value in CC, $\overline{q_l}$ and $\overline{q_i}$ is used.

3 Prognostic cloud scheme

An option to predict moments of the sub-grid cloud water distribution will be developed.

4 COSMO diagnostic cloud scheme

The COSMO diagnostic cloud scheme has been implemented. Details can be found in Axel Seifert's "A short introduction to clouds in the COSMO model".

5 Technical aspects

The namelist parameter "inwp_cldcover" in namelist "nwp_phy_ctl" specifies the sub-grid cloud scheme with the following options.

0. no clouds
1. diagnostic cloud cover
2. prognostic total water variance (not yet available)
3. clouds as in COSMO

4. clouds as in turbulence

5. grid-scale cloud cover [1 or 0]

The default scheme is the diagnostic scheme described in section 2.

The code includes the following files.

```
atm_phy_nwp/mo_nh_interface_nwp.f90
shared/mo_physical_constants.f90
atm_phy_scheme/mo_cover_koe.f90
atm_phy_scheme/mo_cover_cosmo.f90
atm_phy_scheme/mo_cloud_diag.f90
atm_phy_scheme/mo_phyparam_turb.f90
```

6 Saturation specific humidity and relative humidity

Special care needs to be taken in the calculation of saturation specific humidity over liquid q_{sat} and similarly over ice (not shown). Let's first define the specific humidity as

$$q = \epsilon \frac{e}{p - (1-\epsilon)e}, \tag{10}$$

with $\epsilon = \frac{R_d}{R_v} = 0.622$, e the vapor pressure, p the total air pressure and R_d and R_v ideal gas constants of dry air and water vapor.

If we would write the saturation specific humidity simply by exchanging all e with e_{sat}

$$q_{sat} = \epsilon \frac{e_{sat}}{p - (1-\epsilon)e_{sat}}. \tag{11}$$

we could have a singularity when the denomiator becomes zero. This is wrong. It can be shown that consistent with the customary definition of relative humidity as

$$RH = \frac{e}{e_{sat}} \tag{12}$$

the correct saturation specific humidity is

$$q_{sat} = \epsilon \frac{e_{sat}}{p - (1-\epsilon)e}. \tag{13}$$

The only unfortunate fact is that this formula depends on e, the current specific humidity.