

# 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.

#### 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.

$$1 = \int_{q_{bot}}^{q_{top}} p dq = 2p\Delta q \quad (1)$$

and therefore

$$p = \frac{1}{2\Delta q}. \quad (2)$$

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

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

$$CC = \int_{q_{sat}}^{q_{top}} p dq = \frac{q_{top} - q_{sat}}{2\Delta q} = \frac{1}{2} \left( \frac{\bar{q} - q_{sat}}{\Delta q} + 1 \right). \quad (3)$$

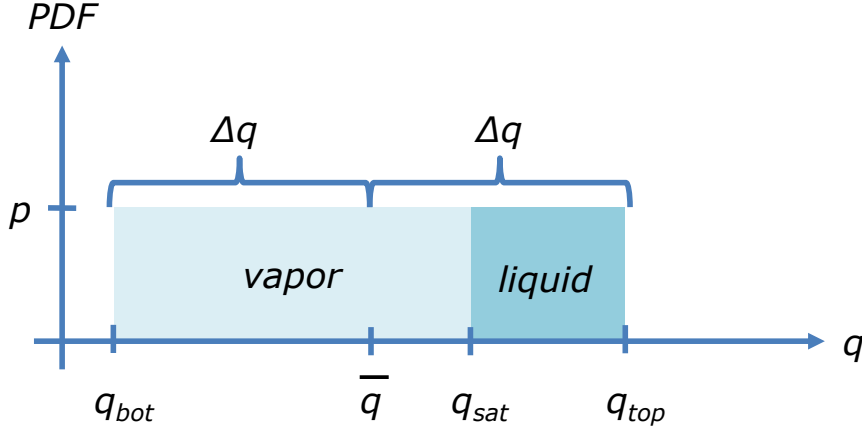


Figure 1: Box distribution of total water in a grid box that forms a liquid cloud.

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

$$\bar{q}_l = \int_{q_{sat}}^{q_{top}} (q - q_{sat}) p dq = \frac{(q_{top} - q_{sat})^2}{4\Delta q} = \frac{\Delta q}{4} \left( \frac{\bar{q} - q_{sat}}{\Delta q} + 1 \right)^2 \quad (4)$$

Note that

$$q_{top} = \bar{q} + \Delta q \quad (5)$$

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

$$CC = 1 \quad (6)$$

and

$$\bar{q}_l = \bar{q} - q_{sat}. \quad (7)$$

### 2.1.2 ice cloud

The ICON microphysics works under the assumption that  $q_i$  is horizontally homogeneous 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 by the grid-scale microphysics for supersaturated environments and (2)  $q_{sat,ice}$  for subsaturated environments. This can be written as

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

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 ( $q_{i,grid} > 10^{-6} \text{kg/kg}$ ).

### 2.1.3 mixed phase cloud

Mixed-phase liquid/ice stratiform clouds are treated by assuming that they occupy the same volume. The mixed-phase cloud cover is then the maximum of  $CC_{liq}$  and  $CC_{ice}$ . Note that if  $\Delta q_{liq} = \Delta q_{ice}$  then  $CC_{ice} > CC_{liq}$  following equ. 3.

### 2.1.4 tuning parameters

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

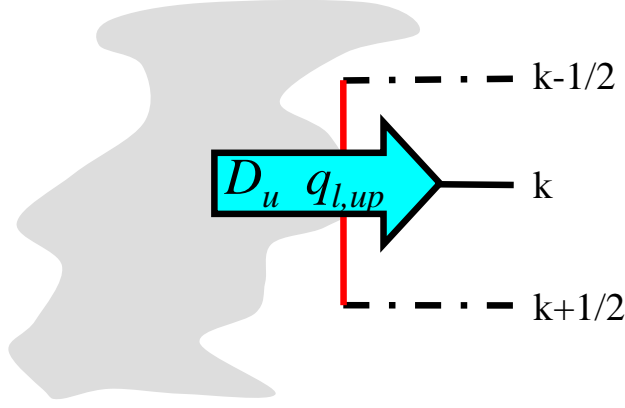


Figure 2: Detrainment terms from convection create an anvil.

## 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

$$\frac{\partial CC}{t} = (1 - CC) \frac{D_u}{\rho} - \frac{CC}{\tau_{decay}}. \quad (9)$$

The time derivative is neglected to arrive at a diagnostic equation that can be solved for  $CC$ .

$$CC = \frac{\frac{D_u}{\rho}}{\frac{D_u}{\rho} + \frac{1}{\tau_{decay}}} \quad (10)$$

The anvil decay time-scale  $\tau_{diss}$  is currently set to 30min. Observations of anvil life times are on the order of a few hours. This decay time-scale should be dependent on environmental relative humidity ([Tiedtke 1993](#), eq. 30-32).

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 stratiform/convective clouds

If stratiform and convective clouds exist in the same grid-box, the maximum value for  $CC$ ,  $\overline{q_l}$  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

$$q = \epsilon \frac{e}{p - (1 - \epsilon)e}, \quad (11)$$

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  $e_{sat}$

$$q_{sat} = \epsilon \frac{e_{sat}}{p - (1 - \epsilon)e_{sat}}. \quad (12)$$

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

$$RH = \frac{e}{e_{sat}} \quad (13)$$

the correct saturation specific humidity is

$$q_{sat} = \epsilon \frac{e_{sat}}{p - (1 - \epsilon)e}. \quad (14)$$

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

## References

- Tiedtke M. 1989. A comprehensive mass flux scheme for cumulus parameterization in large-scale models. *Mon. Wea. Rev.* **117**: 1779–1800.
- Tiedtke M. 1993. Representation of clouds in large-scale models. *Mon. Wea. Rev.* **121**: 3040–3061.
- Tompkins AM. 2002. A prognostic parameterization for the subgrid-scale variability of water vapor and clouds in large-scale models and its use to diagnose cloud cover. *J. Atmos. Sci.* **59**: 1917–1942.