Clouds

Visible aggregate of suspended water droplets and ice crystals above the Earth's surface is called

CLOUD

Cloud formation occurs as result of water vapor condensation.

Condensation takes place due to *air temperature* … and *amount of water vapor in* …

Air temperature decrease is a reason for cloud formation

Reasons for temperature variation	Layers		
	Surface	Boundary	Free atm.
Advection	+	+	+
Vertical motion	-	+	+
Radiation	+	+	-
Eddy mixing	+	+	-
Water phase transfer	+	+	+

Advection $$\left(\frac{\partial T}{\partial t}\right)_{adv} = -\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right)$$

Vertical motion

Type of vertical motion	***Order of magnitude m/s***
Small scale, convective type vertical motion	$10^{0} \cdots 10^{1}$
Large scale, dynamic type vertical motion	$10^{-3} \cdots 10^{-2}$
Topographic vertical motion	$10^{0} \cdots 10^{-1}$
Frontal vertical motion	$10^{-1} \cdots 10^{-2}$
Eddy type vertical motion	*Chaotic, not significant*

Water vapor content variation

$$\left(\frac{\partial s}{\partial t}\right)_{eddy} = \frac{1}{\rho}\frac{\partial}{\partial z}\left(K\rho\frac{\partial s}{\partial z}\right) \longrightarrow$$ *Eddy mixing*

$$\left(\frac{\partial s}{\partial t}\right)_{Adv} = -\left(u\frac{\partial s}{\partial x} + v\frac{\partial s}{\partial y}\right) \longrightarrow$$ *Advection*

$$\left(\frac{\partial s}{\partial t}\right)_{Div} = -s \cdot Div\vec{V} \longrightarrow$$ *Divergence*

These factors act in case there is a source of water to evaporate.

$$\frac{dE}{dT} = \frac{L}{R_w} \cdot \frac{E}{T^2}$$

$$E = 6.11 \times 10^{\frac{7.63 \cdot T}{241.9 + T}}$$

$$e = 6.11 \times 10^{\frac{7.63 \cdot \tau}{241.9 + \tau}}$$

$$s = 0{,}622\frac{e}{P} \qquad s_m = 0{,}622\frac{E}{P}$$

Classification of clouds

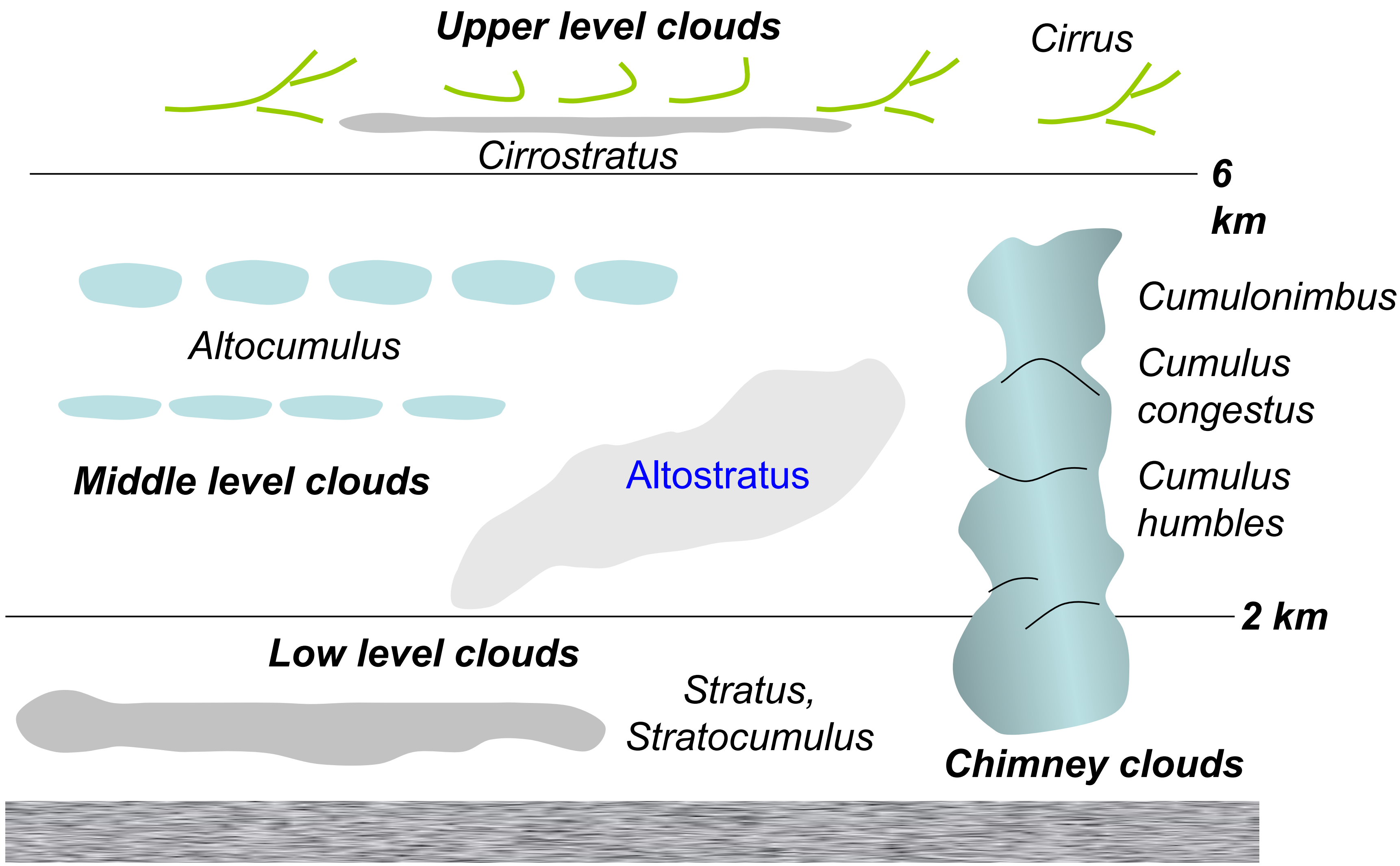
Classification on visual appearance and structure

Cumuliform(cauliflower) clouds

Undulatiform(billow) clouds

Stratiform clouds

Classification based on altitude of the clouds



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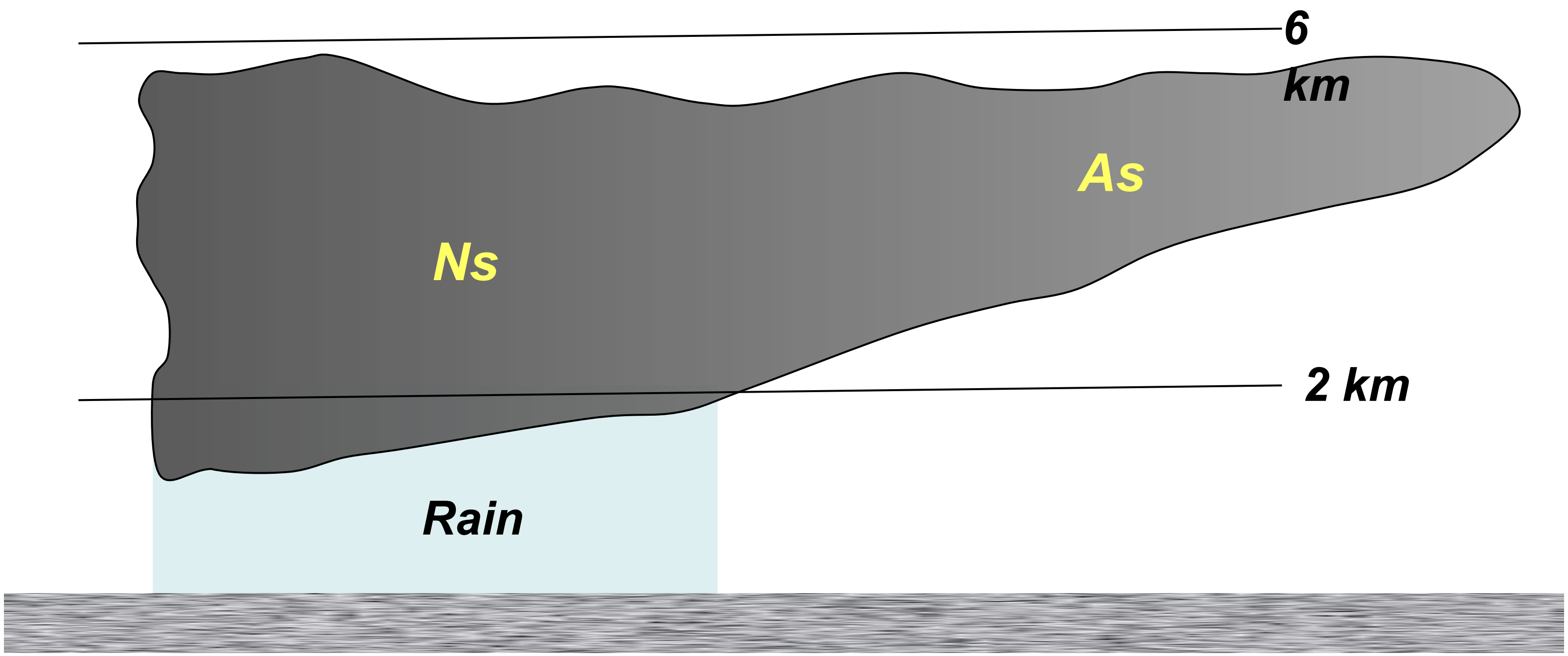
Nimbostratus



Nimbostratus is the cloud that can be regarded both <u>middle</u> and <u>low level</u> cloud.

Usually, it appears in combination with altostratus.

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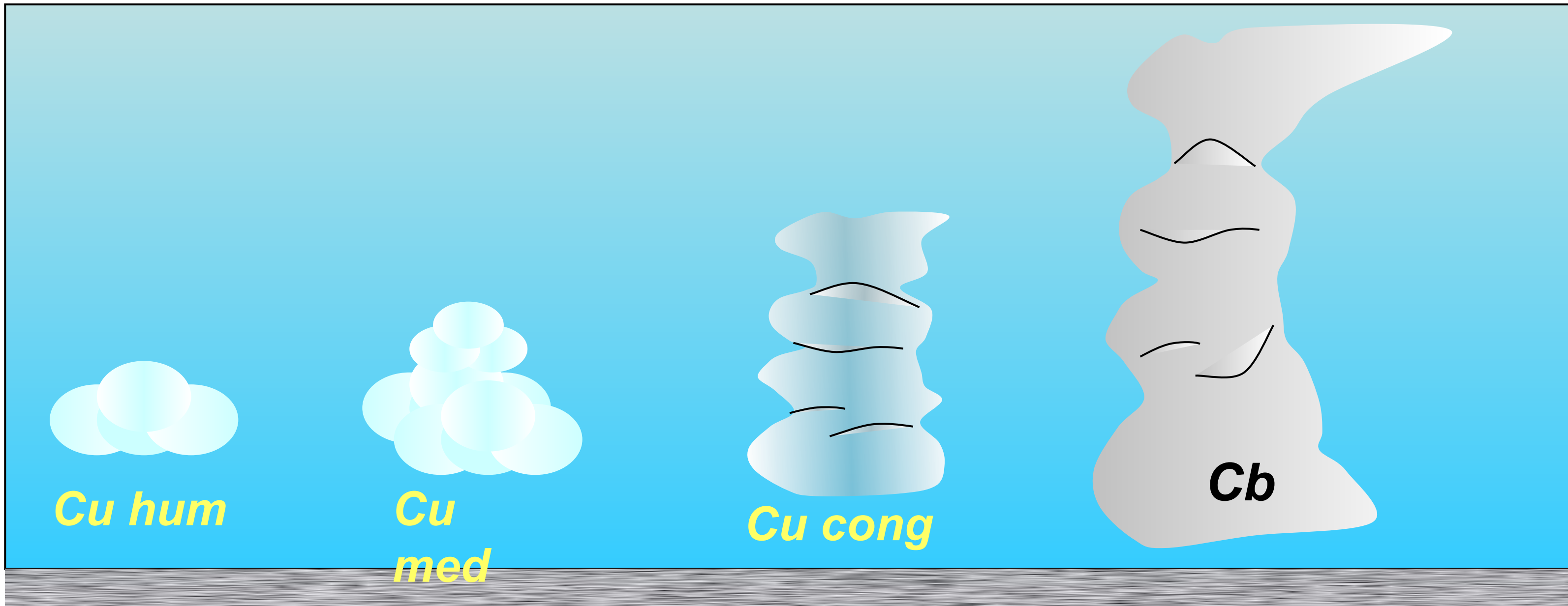
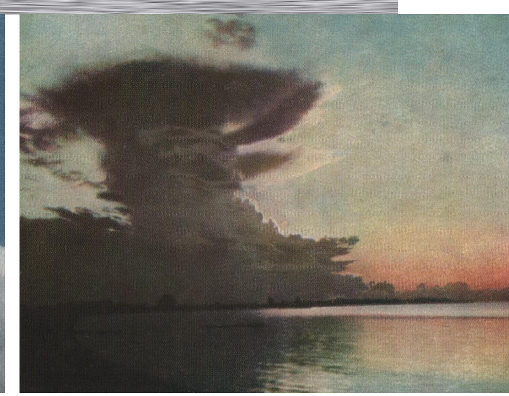
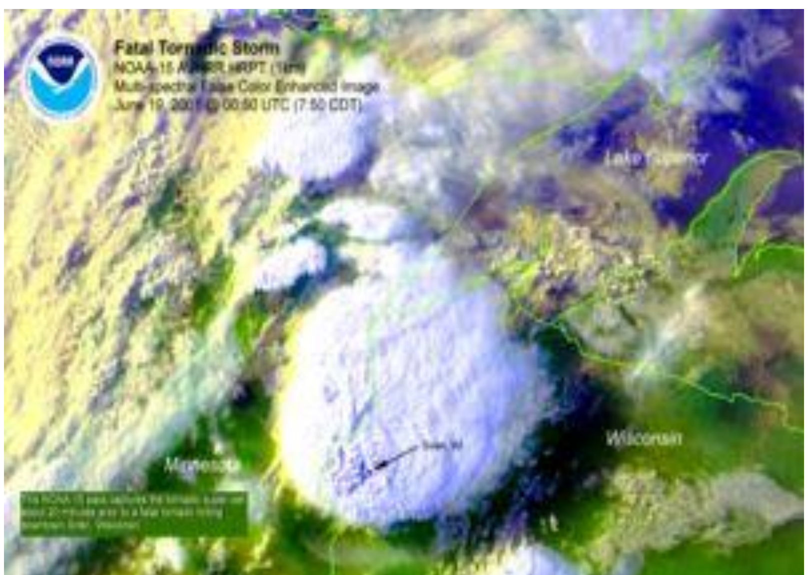
Chimney clouds

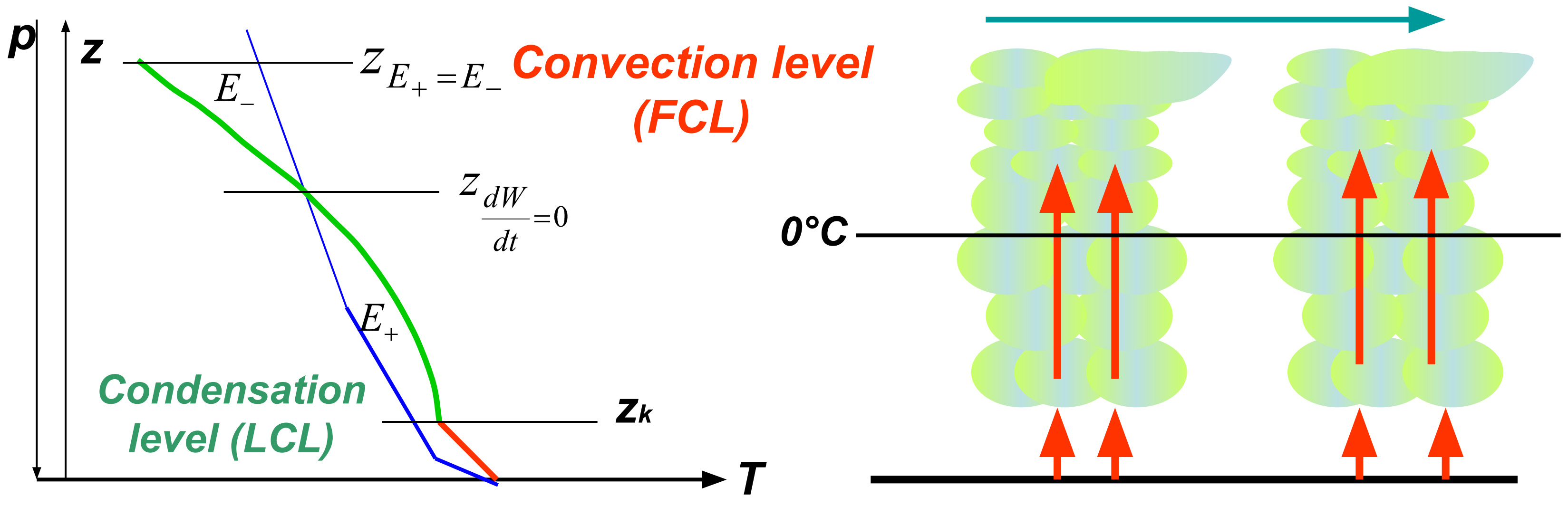




Meso – scale convective complexes (MCC)



Chimney cloud formation



Three important levels: ***lifting condensation level (Z_k)*** *practically coincides with cloud bottoms,* ***zero isotherm level (Z_0)*** *that separates super cooled (upper) part of the cloud water from non-super cooled (lower) one,* ***free convection level (Z_c)*** *practically coincides with the cloud top.*

Lifting condensation level

Determination of the lifting condensation level

$$S = 0{,}622\, e/P; \longrightarrow \ln S = \ln 0{,}622 + \ln e - \ln P$$

In case of adiabatic ascent

$$S = const; \longrightarrow \frac{dS}{dz} = 0$$

$$\frac{1}{S}\frac{dS}{dz} = \frac{1}{e}\frac{de}{dz} - \frac{1}{P}\frac{dp}{dz}$$

$$\boxed{\frac{1}{e}\frac{de}{dz} = \frac{1}{P}\frac{dp}{dz}} \qquad \frac{dP}{dz} = -\rho g = -\frac{P}{RT} g$$

Using Clausius Clapeyron equation

$$\boxed{\frac{dE}{E} = \frac{L}{R_w} \cdot \frac{dT}{T^2}} \longrightarrow \boxed{\frac{de}{e} = \frac{L}{R_w} \cdot \frac{d\tau}{\tau^2}} \longrightarrow \boxed{\frac{L}{R_w \tau^2} \cdot \frac{d\tau}{dz} = \frac{1}{P}\frac{dP}{dz}}$$

$$\boxed{\frac{L}{R_w \tau^2} \cdot \frac{d\tau}{dz} = -\frac{1}{P}\frac{Pg}{RT}} \rightarrow \boxed{-\frac{d\tau}{dz} = \gamma_\tau = \frac{gR_w}{RL}\frac{\tau^2}{T}} \qquad \boxed{\frac{gR_w}{RL} = \frac{9{,}8 \cdot 461}{287 \cdot 2{,}5 \cdot 10^6} \approx 6{,}3 \cdot 10^{-6}}$$

$$\gamma_\tau = \frac{gR_w}{RL}\frac{\tau^2}{T} = 6.3\cdot 10^{-6}\frac{\tau^2}{T}$$

$$\tau_0 - \gamma_\tau Z_k = T_0 - \gamma_a Z_k$$

$$(T_0 - \tau_0) = (\gamma_a - \gamma_\tau) Z_k$$

$$Z_k = \frac{T_0 - \tau_0}{\gamma_a - \gamma_\tau}$$

According to results of calculation dew point lapse rate in the conditions typical for the atmosphere in the extratropical latitudes, the value of this lapse rate can be adopted with the accuracy of 10% 0,17°/100m =const.

$$Z_k = C_\gamma (T_0 - \tau_0)$$

$$C_\gamma = \frac{1}{0{,}98 - 0{,}17} \approx 1{,}23$$

$$Z_k = 1{,}23(T_0 - \tau_0)$$ ***h. m.***

$$Z_k = 123(T_0 - \tau_0)$$ ***m***

$$P_k = P_0 - 13{,}6(T_0 - \tau_0)$$

An example

$$T_0 = 15^0 C$$

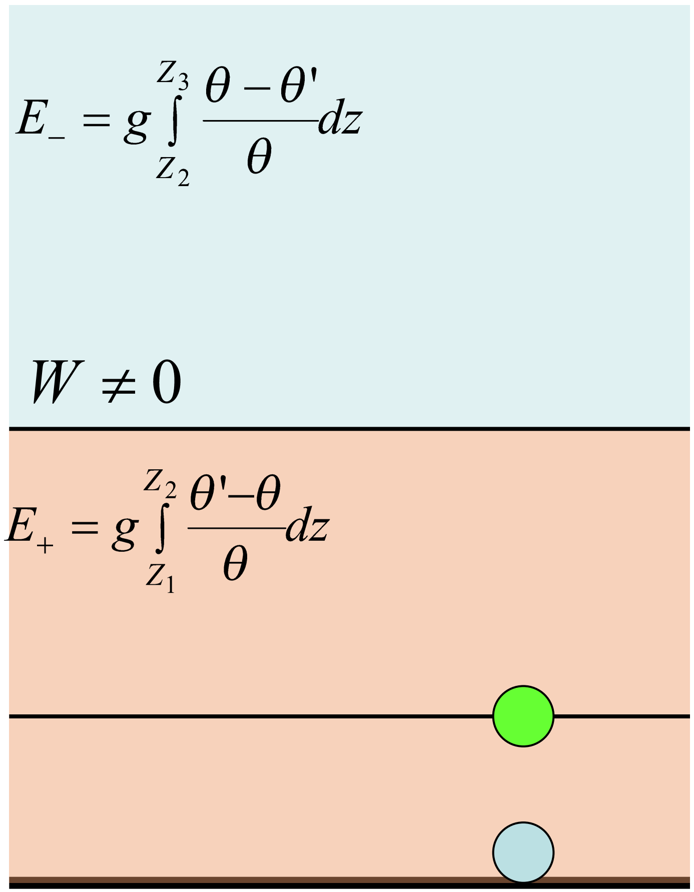
$$\tau_0 = 9^0 C$$

$$Z_k = 123\cdot(15-9) = 738$$ ***m***

$$Z_k = 1{,}23\cdot(15-9) \approx 7{,}4$$ ***h. m.***

$$T_k = 1{,}22\tau_0 - 0{,}22T_0$$

Free Convection level



Free convection level

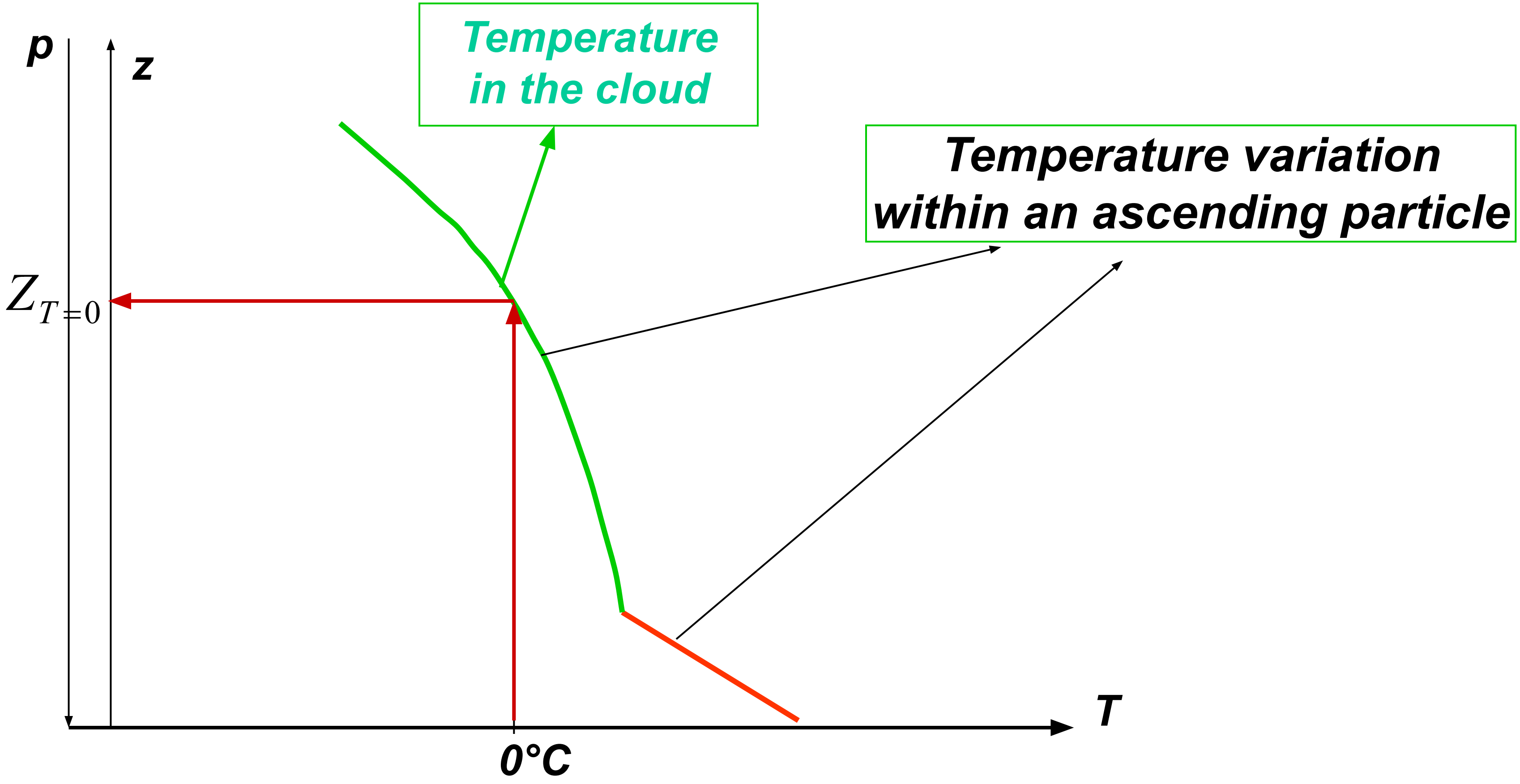
$$W = 0$$

$$E_+ = E_-$$

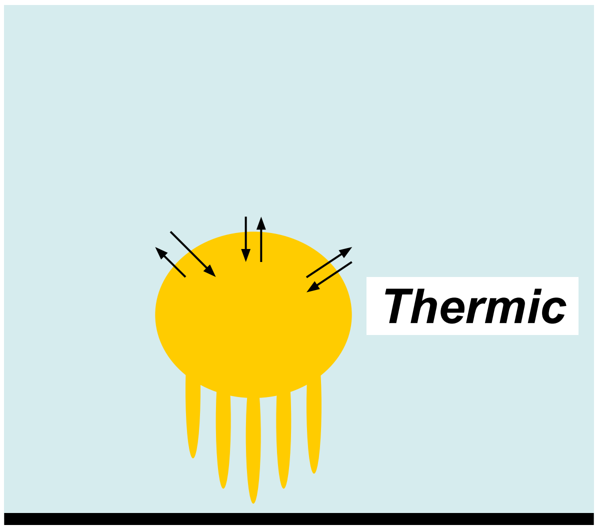
$$Z_{\theta' = \theta} \qquad \frac{dW}{dt} = 0$$

Lifting condensation level

Level T=0°C determination



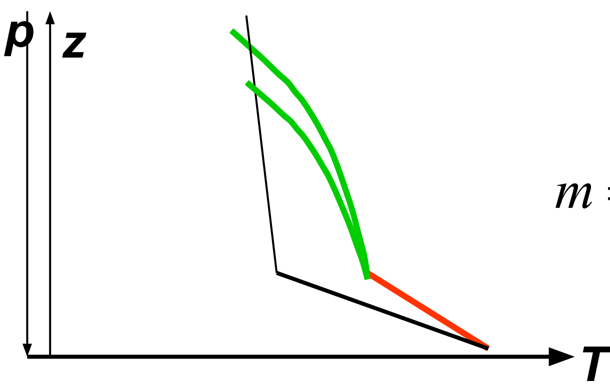
Entrainment



Ascending particle (thermic) is not isolated. It exchanges mass, momentum, heat, moisture etc with ambient air

Ascending cloud air is (a) warmer, (b) saturated; ambient air is not saturated.

In the course of the exchange, the entrained air make the cloud air temperature lower ad drier. As result some droplets evaporate, that makes the temperature even more lower, and energy of instability decreases.



$$m = \rho \frac{4}{3} \pi R^3$$

$$\frac{dm}{dz} = \rho \frac{4}{3} \pi R^2 3 \frac{dR}{dz} = 4 \rho \pi R^2 \frac{dR}{dz}$$

$$a = \frac{1}{m} \frac{dm}{dz}$$

entrainment index

$$\frac{dm}{dz} = 4\rho\pi R^2 \frac{dR}{dz}$$

Parameter a **is entrainment index**

$$a = \frac{4\rho\pi R^2 \frac{dR}{dz}}{\rho \frac{4}{3}\pi R^3} = \frac{3}{R}\frac{dR}{dz} = \frac{C}{R}$$

$$C = 3\frac{dR}{dz}$$

$$R = R_0 + \alpha z$$

According to measurements (with radar) $\alpha = \frac{dR}{dz} = 0.2 \ldots 0.25$

For practical purposes we can adopt it as a constant.

$$a = \frac{3\alpha}{R}$$

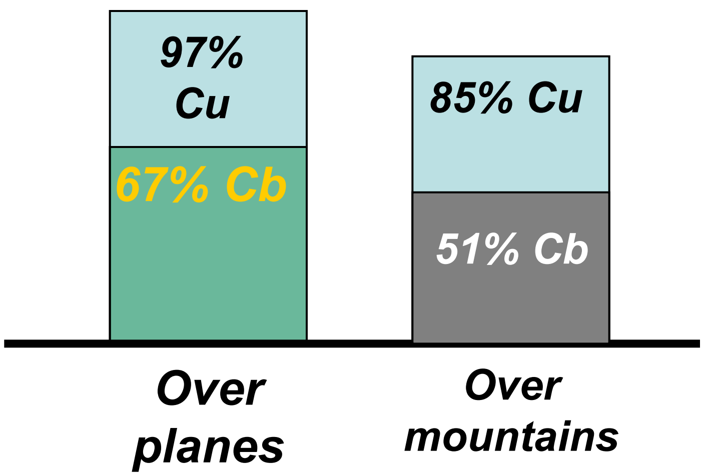
Since $\alpha = const,\ a = a(R)$ ***only.***

$$\Delta R > 0 \rightarrow \Delta a < 0$$

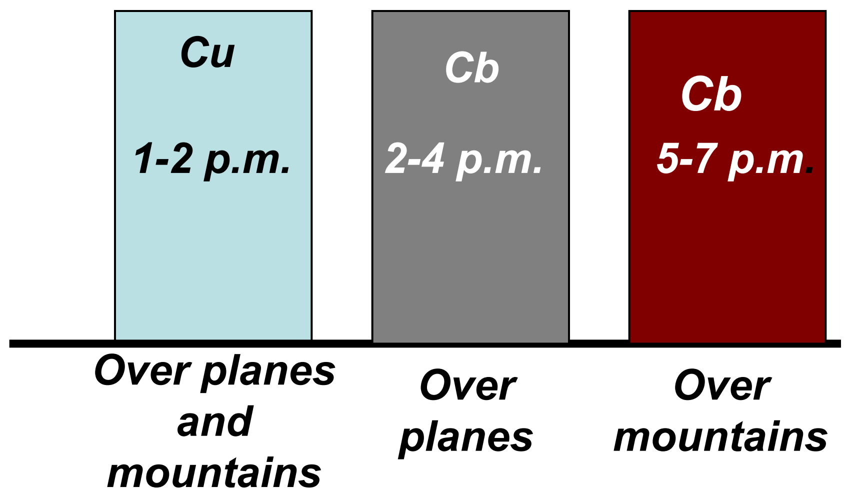
$$\Delta R < 0 \rightarrow \Delta a > 0$$

Chimney clouds diurnal and annual variation

Maximal occurrence between 9 a.m. and 7 p.m.



Maximal development



Maximal occurrence (48%) is in summer, 17% - in autumn, 5% - in winter, and 30 % - in spring.

Mountain thunderstorm in San Juan Mountains (Whiteman ppt)

Whiteman (2000)