Above a thin boundary layer, most atmospheric convection involved phase change of water:

Moist Convection

Moist Convection

- Significant heating owing to phase changes of water
- Redistribution of water vapor – most important greenhouse gas
- Significant contributor to stratiform cloudiness – albedo and longwave trapping

Water Variables

Mass concentration of water vapor (*specific humidity*):

$$q \equiv M_{H_2O} \big/ M_{air}$$

Vapor pressure (partial pressure of water vapor): *e*

Saturation vapor pressure: *e**

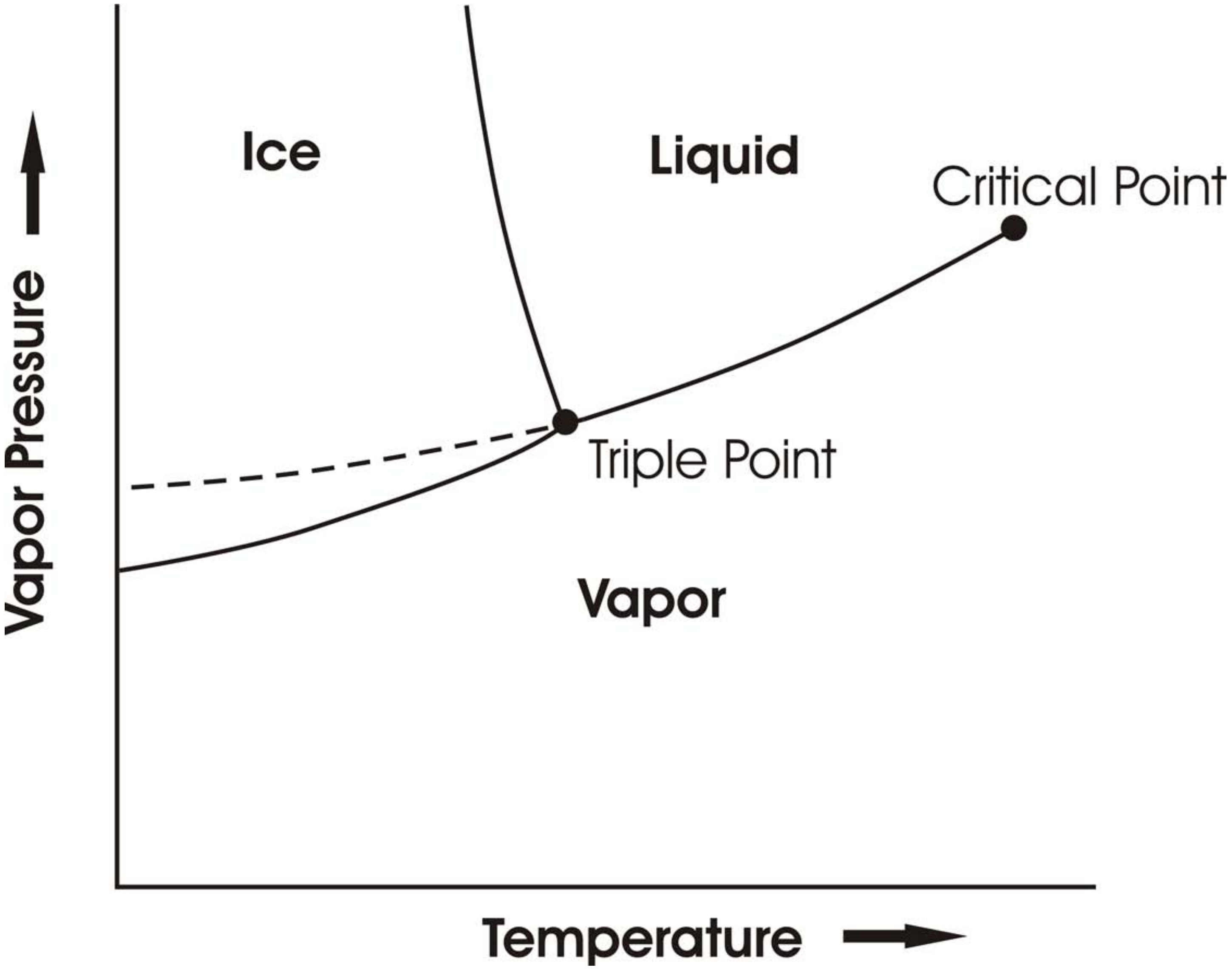
C-C: $$e^* = 6.112\, hPa\, e^{\frac{17.67(T-273)}{T+30}}$$

Relative Humidity: $$H \equiv e \big/ e^*$$

The Saturation Specific Humidity

Ideal Gas Law:

Phase Equilibria



Bringing Air to Saturation

$$e = qp\left(\bar{m}/m_v\right)$$

$$e^* = e^*(T)$$

1. Increase *q (or p)*
2. Decrease *e* (T)*

When Saturation Occurs…

- Heterogeneous Nucleation
- Supersaturations very small in atmosphere
- Drop size distribution sensitive to size distribution of cloud condensation nuclei

Ice Nucleation Problematic

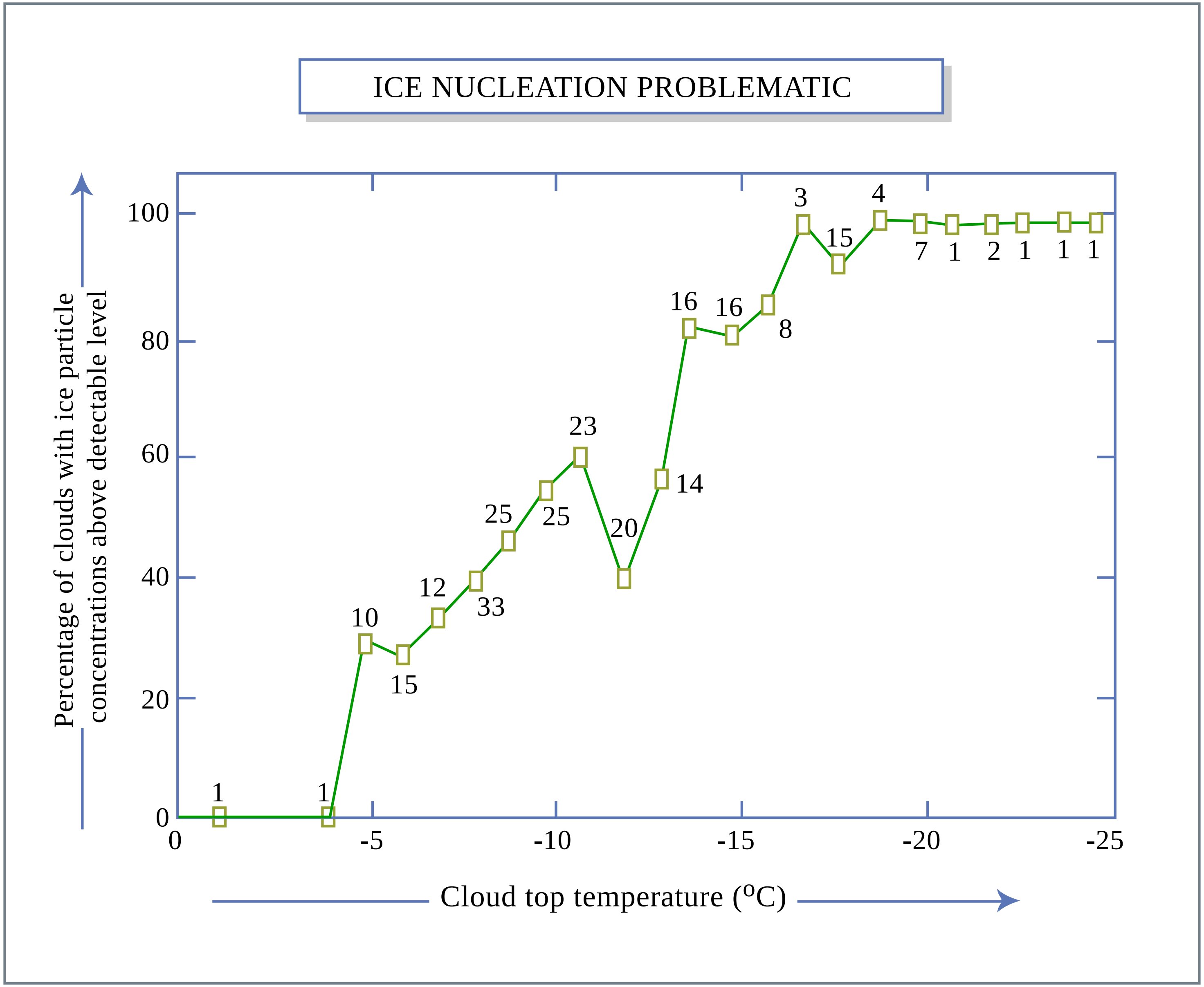


Figure by MIT OCW.

Precipitation Formation:

- Stochastic coalescence (sensitive to drop size distributions)
- Bergeron-Findeisen Process
- Strongly nonlinear function of cloud water concentration
- Time scale of precipitation formation ~10-30 minutes

Stability

No simple criterion based on entropy:

$$s_d = c_p \ln\left(\frac{T}{T_0}\right) - R_d \ln\left(\frac{p}{p_0}\right)$$

$$\alpha = \alpha\left(s_d, p\right)$$

$$s = c_p \ln\left(\frac{T}{T_0}\right) - R_d \ln\left(\frac{p}{p_0}\right) + L_v \frac{q}{T} - qR_v \ln\left(H\right)$$

$$\alpha = \alpha\left(s, p, q_t\right)$$

Trick:

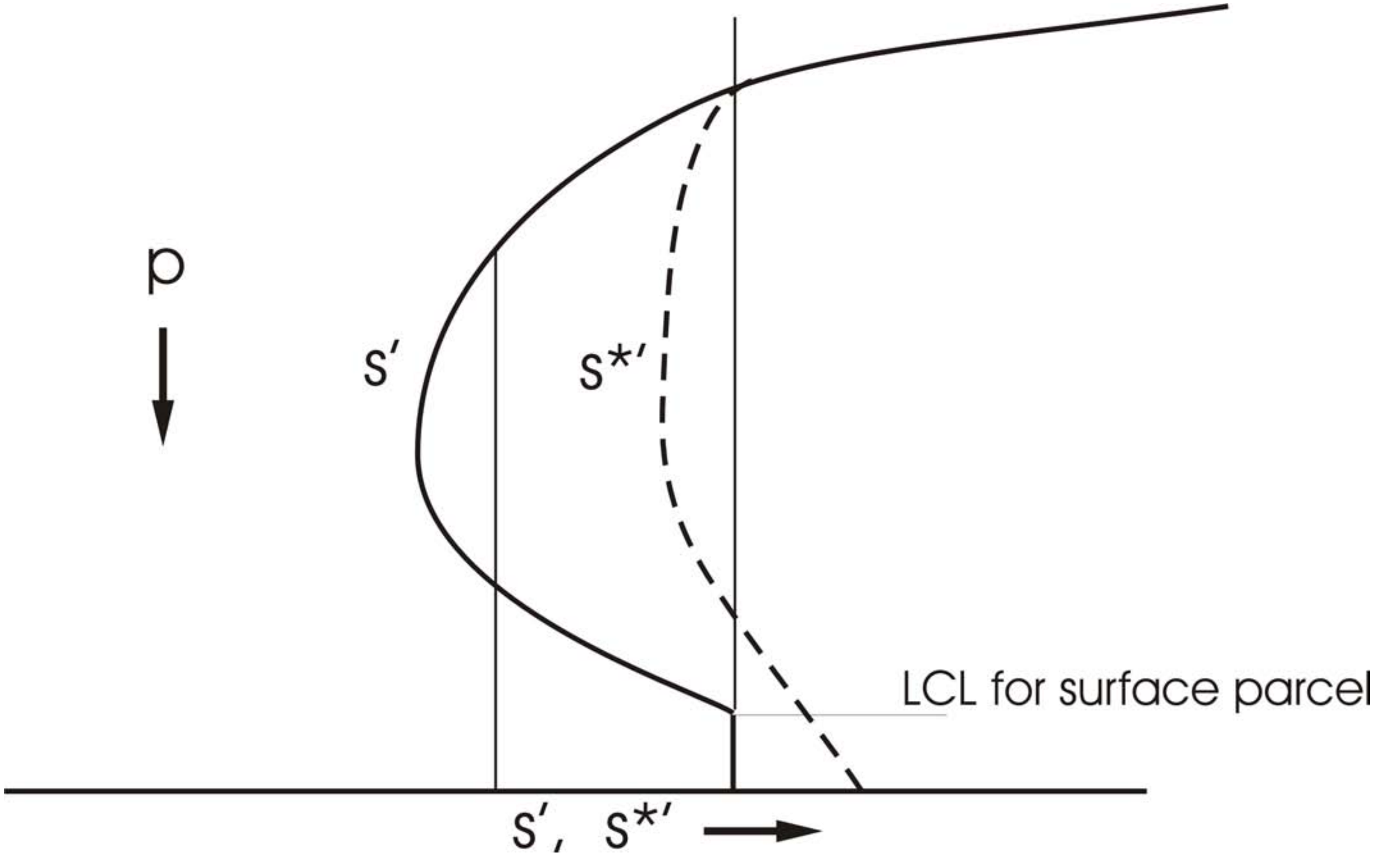
Define a *saturation entropy, s** :

$$s^* \equiv s\left(T, p, q^*\right)$$

$$\alpha = \alpha\left(s^*, p, q_t\right)$$

We can add an arbitrary function of q_t to s^* such that

$$\alpha \cong \alpha\left(s^{*\prime}, p\right)$$

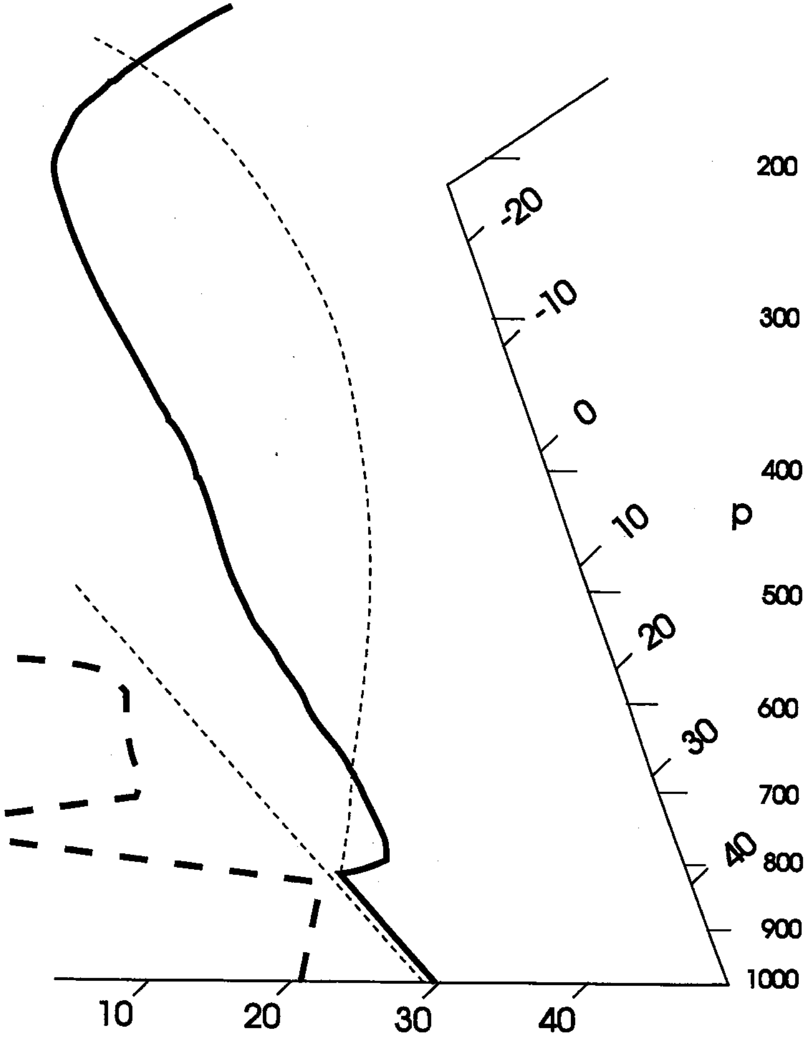

p
s′
s*′
LCL for surface parcel
s′, s*′

Stability Assessment using Tephigrams:

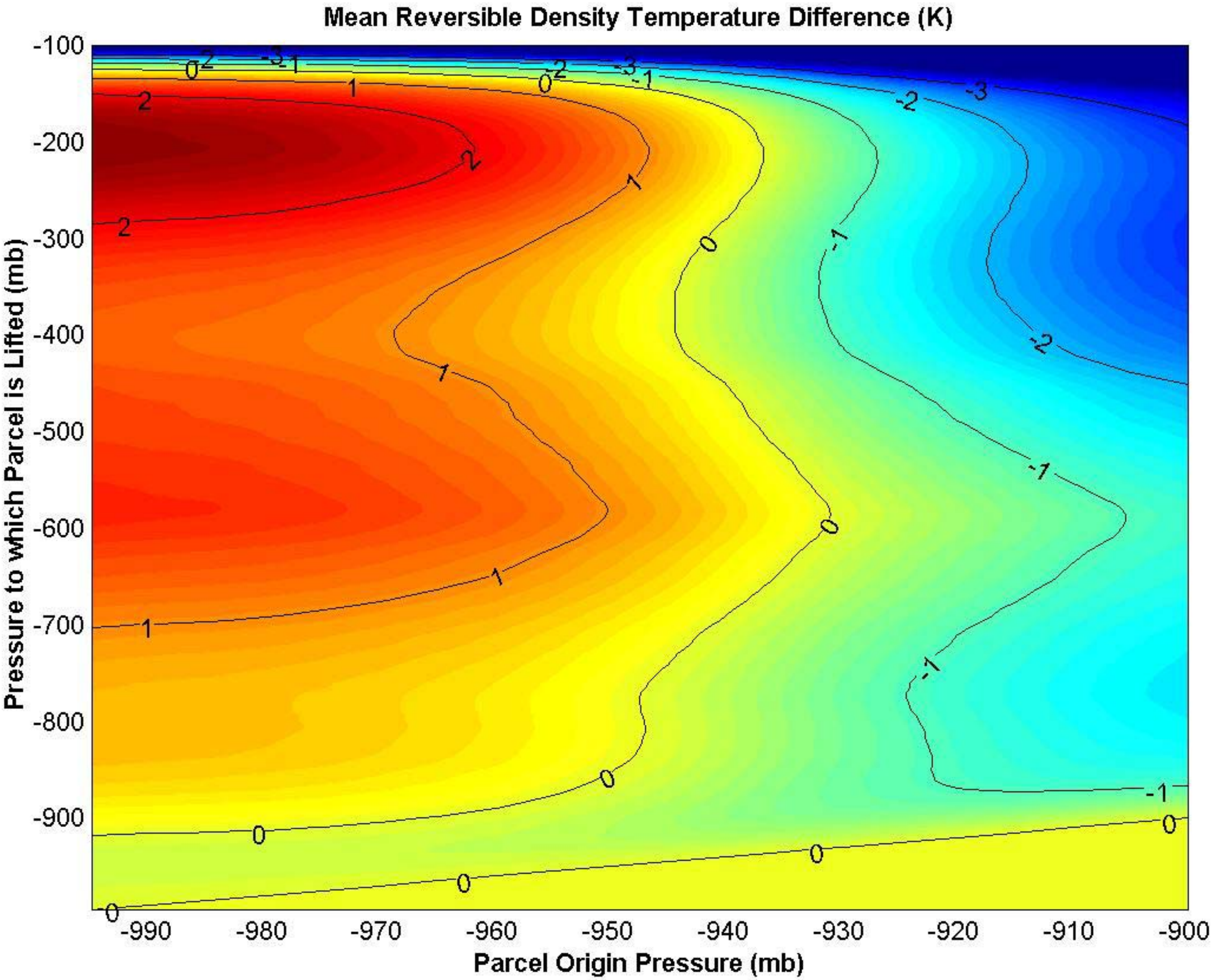
Convective Available Potential Energy (CAPE):

$$CAPE_i \equiv \int_{p_n}^{p_i} \left(\alpha_p - \alpha_e\right) dp$$

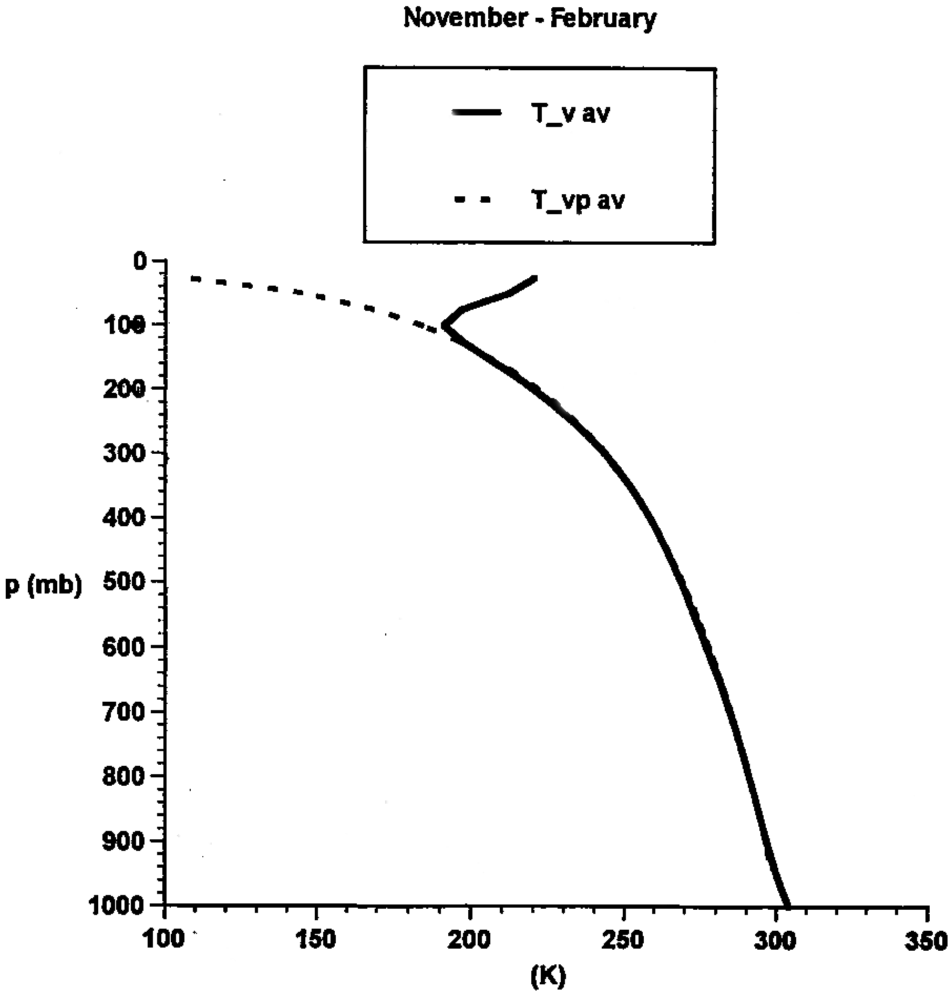
$$= \int_{p}^{p_i} R_d \left(T_{\rho_p} - T_{\rho_e}\right) d\ln\left(p\right)$$



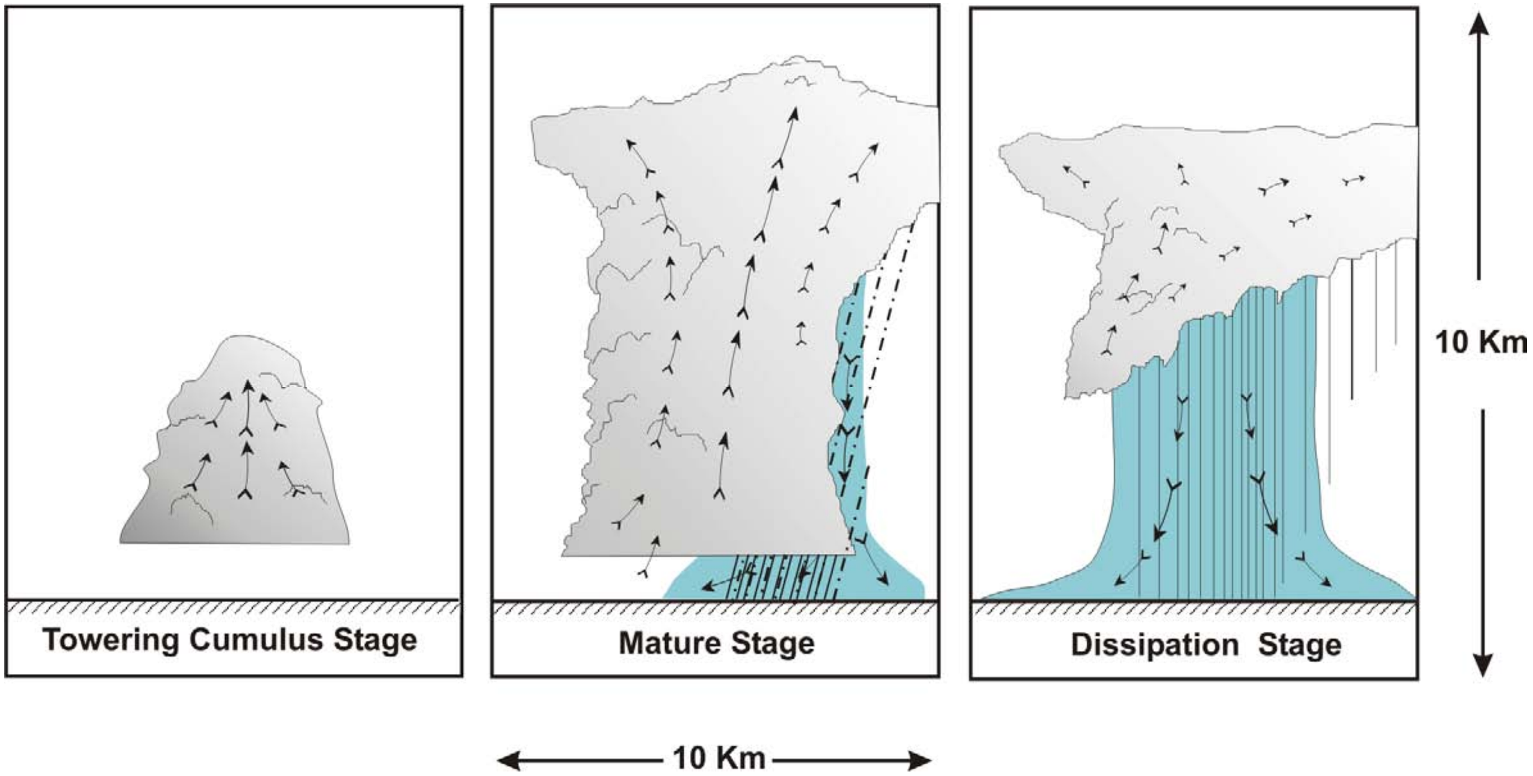
Other Stability Diagrams:



Tropical Soundings



“Air-Mass” Showers:



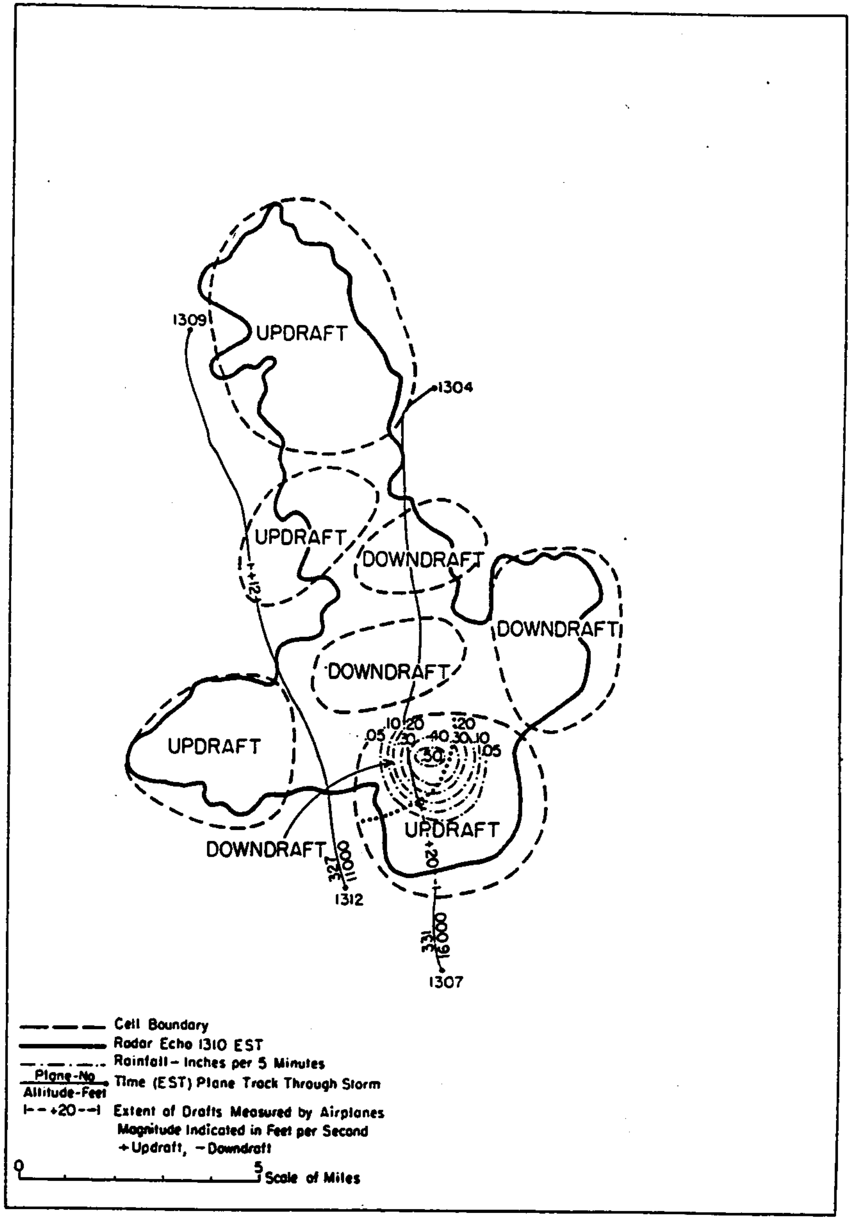


FIG. 15. Radar echo, plane paths, measured draft data, and cell outlines, 1310 EST 9 July 1946.

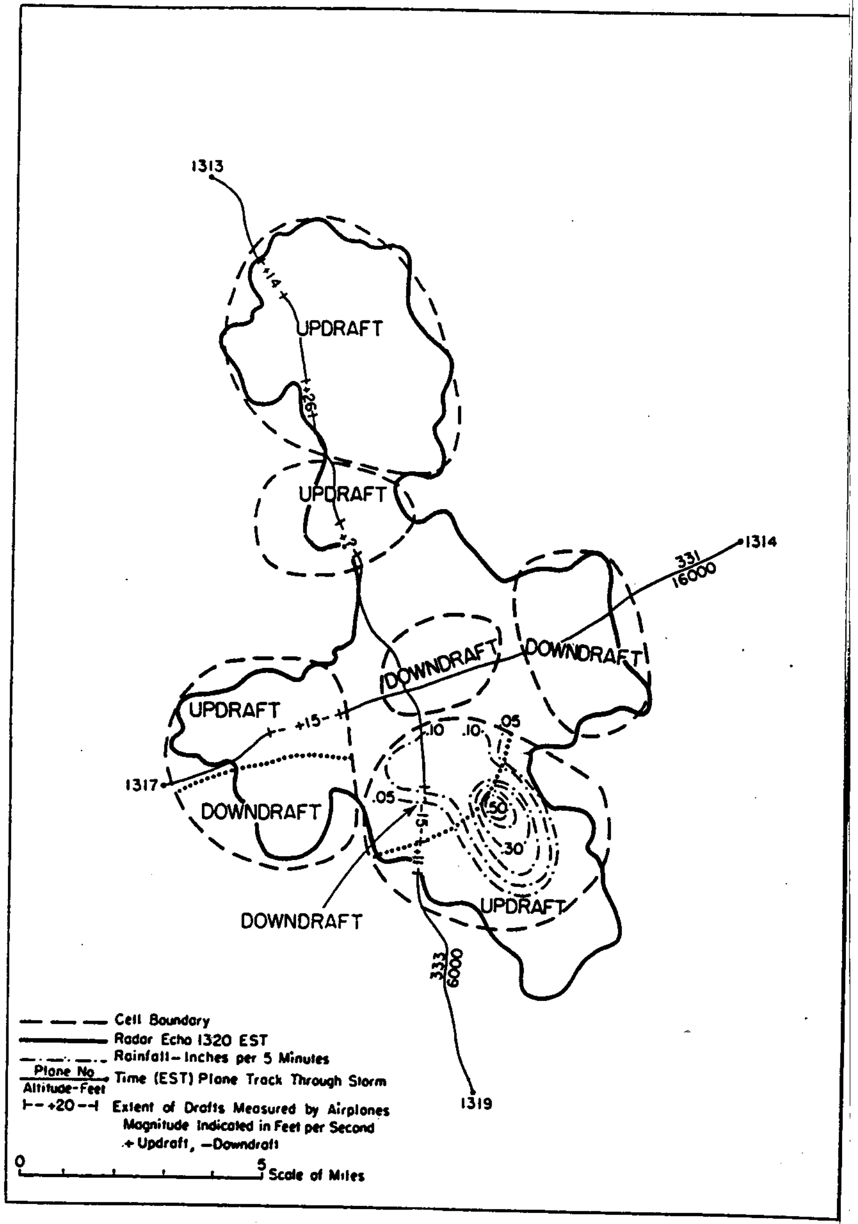
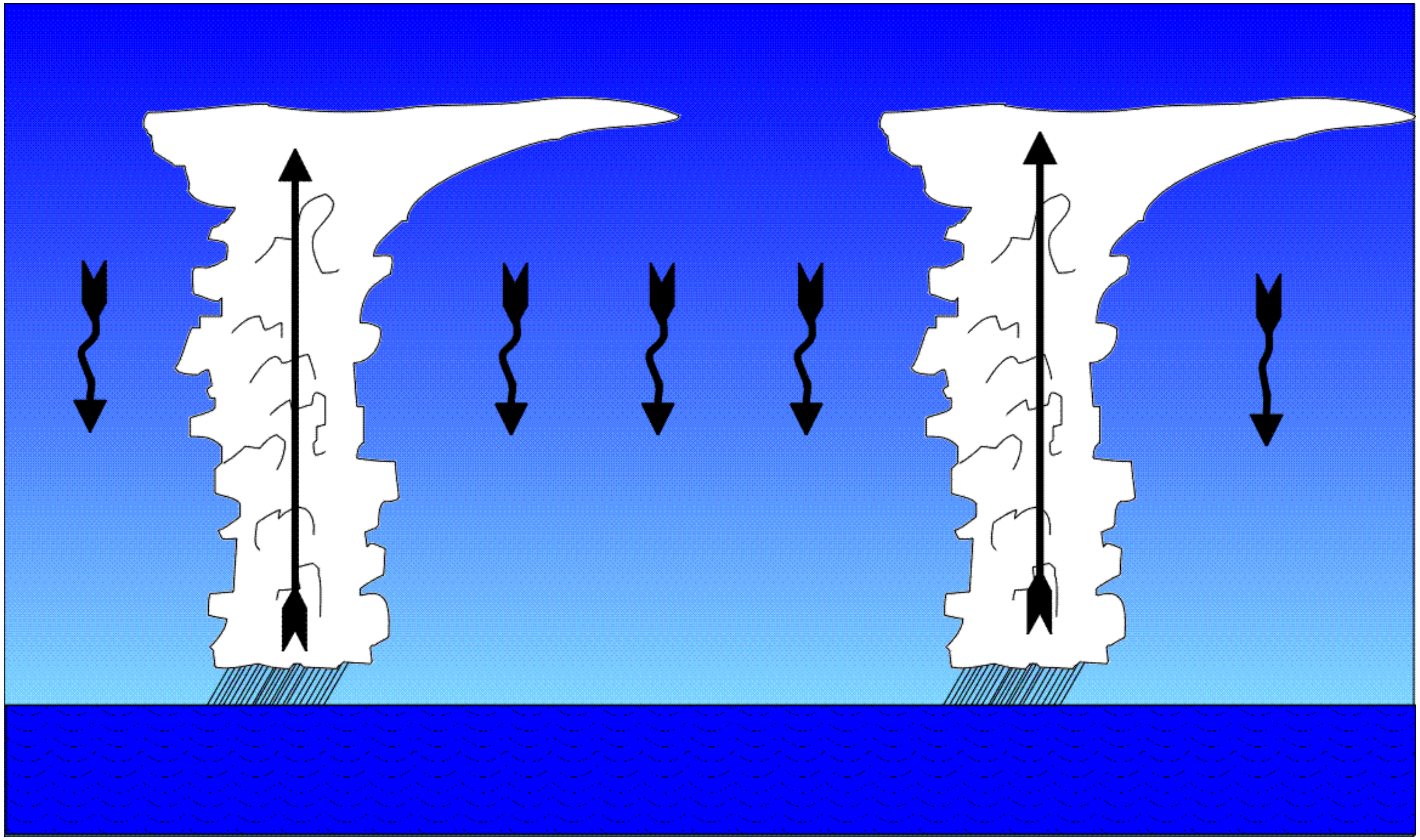


FIG. 16. Radar echo, plane paths, measured draft data, and cell outlines, 1320 EST 9 July 1946.

Image courtesy of AMS.

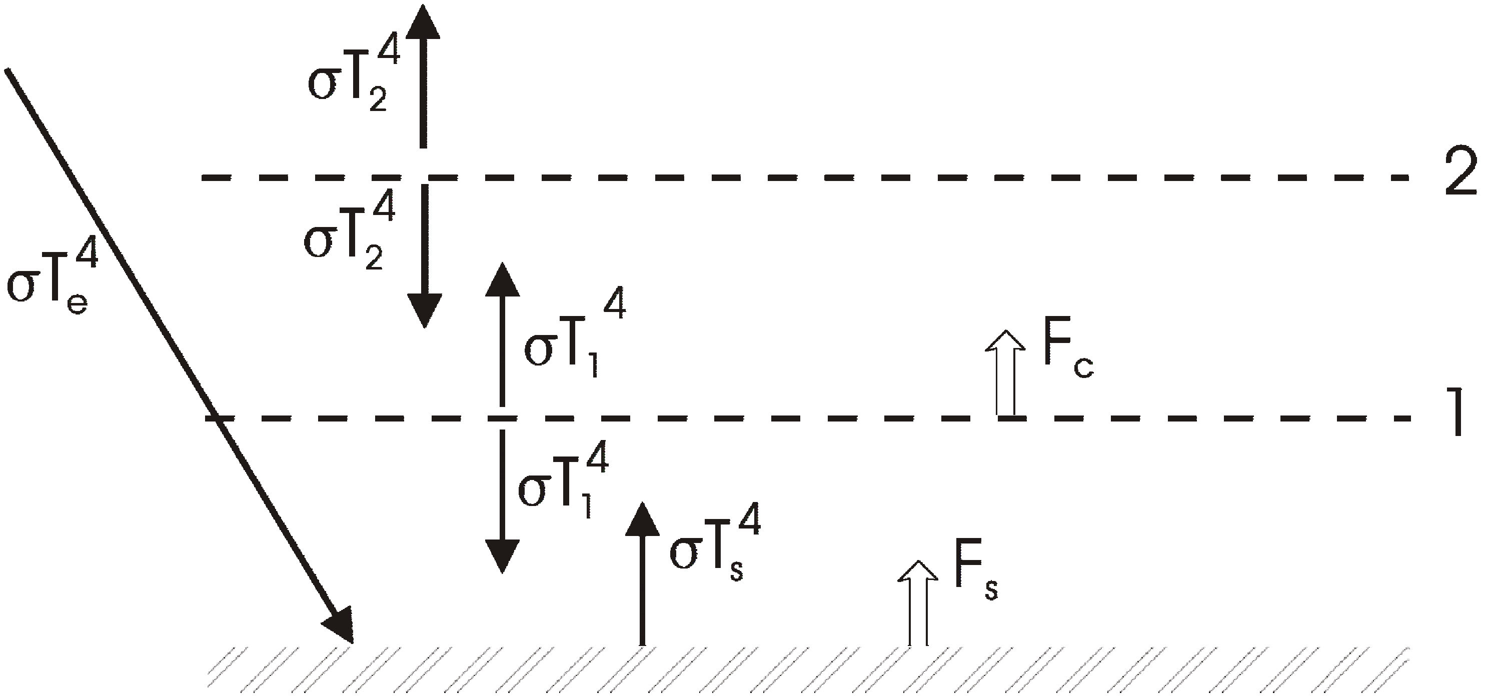
Precipitating Convection favors Widely Spaced Clouds (Bjerknes, 1938)



Properties:

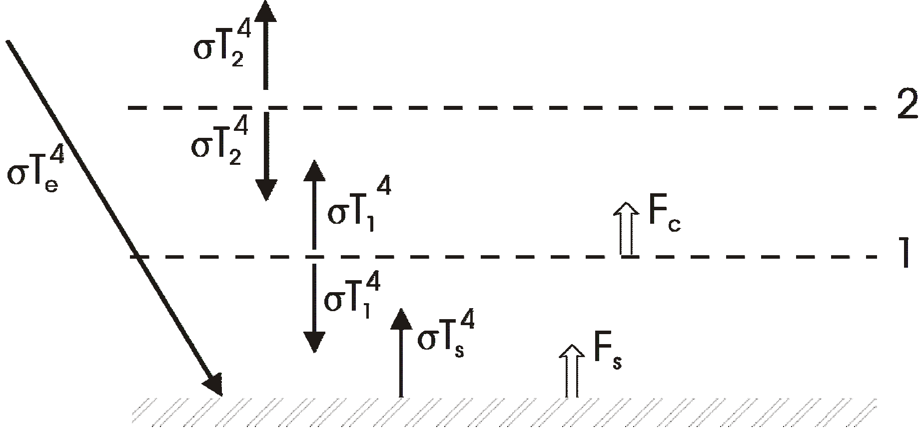
- Convective updrafts widely spaced
- Surface enthalpy flux equal to vertically integrated radiative cooling
- $$M \frac{c_p T}{\theta} \frac{\partial \theta}{\partial z} = -\dot{Q}$$
- Precipitation = Evaporation = Radiative Cooling
- Radiation and convection *highly* interactive

Simple Radiative-Convective Model



Enforce convective neutrality:

$$T_1 = T_2 + \Delta T,$$
$$T_s = T_2 + 2\Delta T$$



$$TOA: \quad T_2 = T_e \rightarrow T_1 = T_e + \Delta T, \quad T_s = T_e + 2\Delta T$$

$$Surface: \quad F_s + \sigma T_s^{\,4} = \sigma T_e^{\,4} + \sigma T_1^{\,4}$$

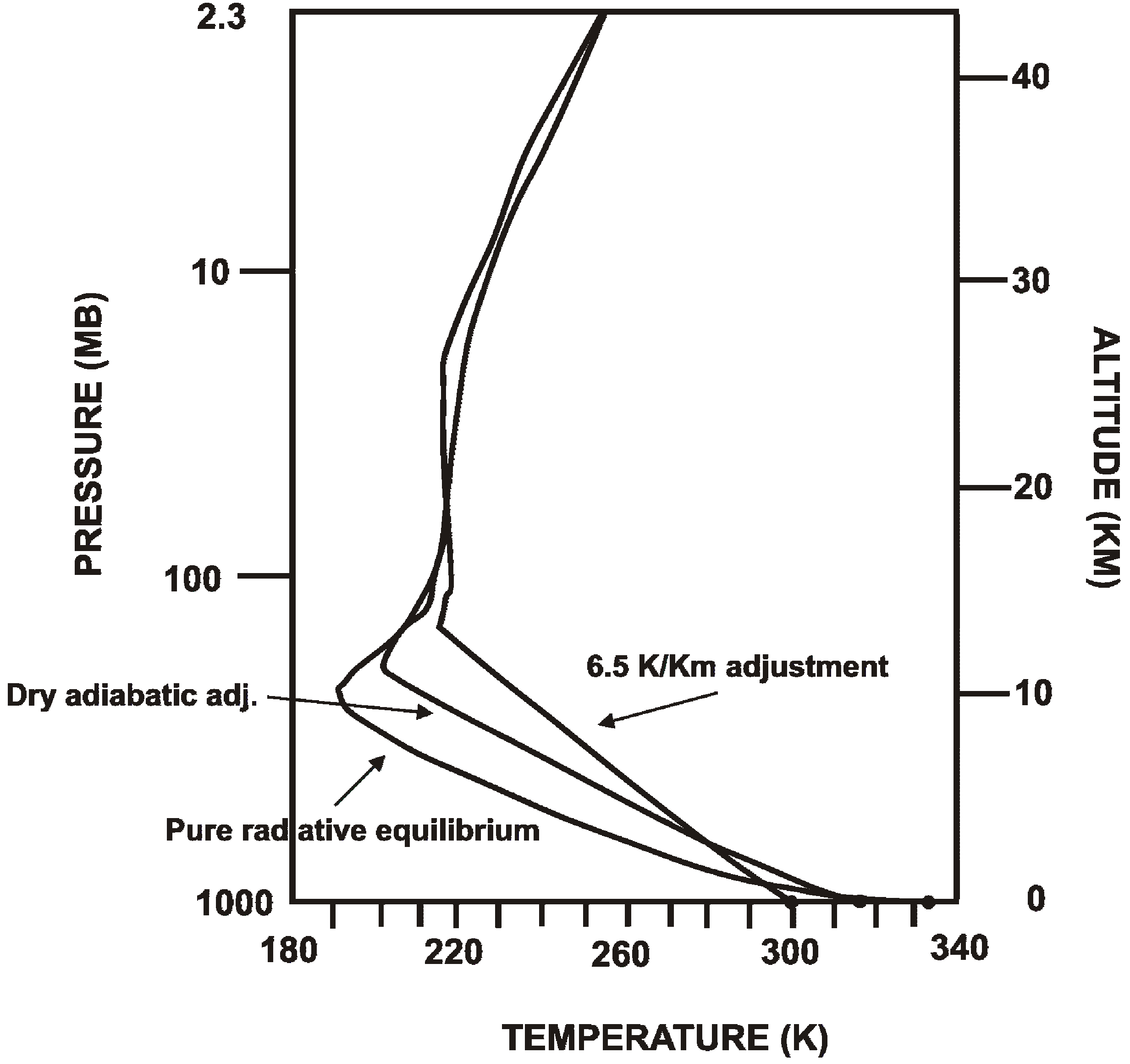
$$Layer\ 2: \quad 2\sigma T_e^{\,4} = \sigma T_1^{\,4} + F_c$$

$$Define \quad x \equiv \Delta T \big/ T_e ,$$

$$F_s = \sigma T_e^{\,4}\left[1 + (1+x)^4 - (1+2x)^4\right],$$

$$F_c = \sigma T_e^{\,4}\left[2 - (1+x)^4\right]$$

Manabe and Strickler 1964 calculation:



Effect of Moist Convective Adjustment on Climate Sensitivity