When Saturation Occurs…

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

Percentage of clouds with ice particle concentrations above detectable level

Cloud top temperature (°C)

Image by MIT OpenCourseWare.
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:

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

\[ \alpha = \alpha(s_d, p) \]

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

\[ \alpha = \alpha(s, p, q_t) \]
Virtual Temperature and Density Temperature

Assume all condensed water falls at terminal velocity

\[ \alpha = \frac{V_a + V_c}{M_d + M_v + M_c} \]

\[ pV = nR \ast T \]

\[ V_a = \frac{R \ast T}{p} \left( \frac{M_d}{m_d} + \frac{M_v}{m_v} \right), \]
\[
\overline{m_d} \equiv \frac{1}{M_d} \sum_i \frac{M_i}{m_i}
\]

\[\rightarrow V_a = \frac{R_d T}{p} \left( M_d + \frac{M_v}{\varepsilon} \right),\]

where \[\varepsilon \equiv \frac{m_v}{\overline{m_d}} \approx 0.622\]

\[R_d \equiv \frac{R^*}{\overline{m_d}}\]
\[ \alpha = \frac{V_a + V_c}{M_d + M_v + M_c} = \frac{R_d T}{p} \left( 1 - q_t + \frac{q}{\varepsilon} \right) \left( 1 + \frac{q_c}{1 - q_c} \frac{\rho_a}{\rho_c} \right) \]

\[ \approx \frac{R_d T}{p} \left( 1 - q_t + \frac{q}{\varepsilon} \right) \]

\[ q_t \equiv \frac{M_v + M_c}{M}, \quad q \equiv \frac{M_v}{M} \]

**Density temperature:**

\[ T_\rho \equiv T \left( 1 - q_t + \frac{q}{\varepsilon} \right) \]

\[ \alpha = \frac{R_d T_\rho}{p} \]
Trick:

Define a saturation entropy, $s^*$:

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

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

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

$$\alpha \cong \alpha(s^*, p)$$
LCL for surface parcel
Stability Assessment using Tephigrams:
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Convective Available Potential Energy (CAPE):

\[ CAPE_i = \int_{p_n}^{p_i} (\alpha_p - \alpha_e) dp \]

\[ = \int_p^{p_i} R_d \left( T_{\rho_p} - T_{\rho_e} \right) d \ln(p) \]
Other Stability Diagrams:

![Mean Reversible Density Temperature Difference (K)](image)
“Air-Mass” Showers:

- Towering Cumulus Stage
- Mature Stage
- Dissipation Stage