Lecture 6: Cloud overview
Importance of Clouds

TOA Energy Balance/Climate

Atmospheric Heating Rates

Dynamics

Chemistry/Pollution

Clouds
Cloud "Taxonomy"

"In science there is only physics; all the rest is stamp collecting."

Ernest Rutherford, father of "nuclear physics"
Cloud “Taxonomy”

- Based on visual appearance
- 4 “genera” of clouds:

1. High (cirro-): >20,000 ft (6 km)
2. Mid (alto-): ~6,500 – 20,000 ft (2-6 km)
3. Low: < 6500 ft (< 2 km)
4. “Vertical”: Large vertical extent

Within families – an alphabet soup of Latin:

- *cumulus* (heap)
- *stratus* (layer)
- *cirrus* (curl of hair)
- *nimbus* (rain)

…and many, many more
## Cloud “Taxonomy”

<table>
<thead>
<tr>
<th>GENERA</th>
<th>SPECIES</th>
<th>VARIETY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cirrus</td>
<td>fibratus, uncinus, spissatus</td>
<td>intortus, radiatus, vertebratus</td>
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<tr>
<td></td>
<td>castellanus, floccus</td>
<td>duplicatus</td>
</tr>
<tr>
<td>Cirrocumulus</td>
<td>stratiformis, lenticularis</td>
<td>undulatus</td>
</tr>
<tr>
<td></td>
<td>castellanus, floccus</td>
<td>lacunosus</td>
</tr>
<tr>
<td>Cirrostratus</td>
<td>fibratus</td>
<td>duplicatus</td>
</tr>
<tr>
<td></td>
<td>nebulosus</td>
<td>undulatus</td>
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<tr>
<td>Altocumulus</td>
<td>stratiformis</td>
<td>translucidus, perlucidus</td>
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<tr>
<td></td>
<td>lenticularis</td>
<td>opacus, duplicatus</td>
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<tr>
<td></td>
<td>castellanus, floccus</td>
<td>undulatus, radiatus</td>
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<tr>
<td></td>
<td>flocce</td>
<td>lacunosus</td>
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<tr>
<td>Altostratus</td>
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<td>translucidus, opacus</td>
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<td></td>
<td>-</td>
<td>duplicatus, undulatus,</td>
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<tr>
<td></td>
<td>-</td>
<td>radiatus</td>
</tr>
<tr>
<td>Stratocumulus</td>
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<td>translucidus perlucidus</td>
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<tr>
<td></td>
<td>-</td>
<td>opacus, duplicatus</td>
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<tr>
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<td>undulatus, radiatus</td>
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<td></td>
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<td>lacunosus</td>
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<tr>
<td>Nimostratus</td>
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<td>Stratus</td>
<td>stratiformis lenticularis</td>
<td>translucidus, perlucidus</td>
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<td>opacus, duplicatus</td>
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<tr>
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<td>undulatus, radiatus</td>
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<td>-</td>
<td>lacunosus</td>
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<tr>
<td>Cumulus</td>
<td>nebulosus</td>
<td>opacus translucidus</td>
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<tr>
<td></td>
<td>fractus</td>
<td>undulatus</td>
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<tr>
<td>Cumulonimbus</td>
<td>humulis mediocris congestus</td>
<td>radiatus</td>
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<tr>
<td></td>
<td>fractus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>calvus</td>
<td>capillatus</td>
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</tbody>
</table>
Observed Properties of Clouds

- Cloud patterns associated with large-scale dynamics, convection, mixing
- Dynamics affected by diabatic heating in clouds (latent heat & radiative)
- Microstructure of Clouds Affects Microphysical Processes

MICROPHYSICAL PROCESSES

- Phase Changes of Water (Condensation, Evaporation, etc.)
- Formation and Growth of Cloud Droplets
- Formation and Growth of Ice Crystals
- Precipitation Processes
Measured Elements in Clouds

• Temperature
• Water Vapor
• Vertical Velocity
• Liquid Water Content (LWC)
  • Cloud Droplet Spectrum
  • Size Distribution of Raindrops
• Ice Water Content (IWC)
  • Size and Shape of Ice Crystals
  • Size Distribution of Frozen Precipitation
Controls of Cloud Behavior

• Cloud Base Temperature
• Cloud Top Temperature
• Liquid Water Content
• Strength of Updrafts
• Turbulence & Mixing
• Time Scales (Age of Clouds and Parcels)
Controls: Cloud Temperature

Cloud Base Temperature
Warmer base corresponds to higher saturation vapor pressure

Cloud Top Temperature
Probability of Ice within cloud

- $T = 0^\circ C$ 0%
- $T = -10^\circ C$ 50%
- $T = -20^\circ C$ 100%

Difference between Cloud Base & Top Temperatures
Cloud Depth (Probability of Precipitation increases with depth)
Liquid Water Content & Updraft Velocity

• Positively Correlated
• Both increase with height

**LWC**
High Values required for precipitation to occur (>0.5 gm\(^{-3}\))
Important for Radiative Processes

**Updraft Strength**
Suspension of Precipitation Particles
Important for Parcel Time Scale

**Turbulence**
Uniformity of cloud, lumpiness of cloud top
Time Scales of Clouds

Cloud Time Scale ($T_c$)
Cloud Lifetime or Age
Precipitation requires sufficient time for droplet growth

Parcel Time Scale ($T_p$)
Time for parcel to pass through cloud
Depends on cloud depth and vertical velocity
Precipitation requires sufficient time for droplet growth
# Comparison of Cloud Types

<table>
<thead>
<tr>
<th>Cloud Type</th>
<th>$T_c$</th>
<th>$T_p$</th>
<th>LWC ($g/m^3$)</th>
<th>$w$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratus</td>
<td>6-12 hr</td>
<td>3 hr</td>
<td>.05 - .25</td>
<td>0.1</td>
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<tr>
<td>Cumulus</td>
<td>10-60 min</td>
<td>10 min</td>
<td>.3</td>
<td>3</td>
</tr>
<tr>
<td>Cumulonimbus</td>
<td>1- 3 hours</td>
<td>5 min</td>
<td>1.5-4.5</td>
<td>30</td>
</tr>
</tbody>
</table>
Cloud particle size distributions

• $N(r)$, or $N(D)$: Number of particles per unit volume of a given radius, per unit size bin

![Diagram showing droplet spectra in trade-wind cumulus off the coast of Hawaii and continental cumulus over Blue Mts. near Sydney, Australia. (From Fletcher, 1962, after Squires, 1958a.)](image)
Cloud particle size distributions

- \( N(r) \), or \( N(D) \): Number of particles per unit volume of a given radius, per unit size bin

\[
\text{Number concentration} = \int N(r) \, dr
\]

\( n^{th} \) Moment: \( \int r^n N(r) \, dr \)

\[
\begin{align*}
\text{Mean size} &= \frac{\int r N(r) \, dr}{\int N(r) \, dr} \\
\text{Extinction} &= \beta = \sigma = \int Q_{ext} \pi r^2 N(r) \, dr \\
LWC &= \rho \int \frac{4}{3} \pi r^3 N(r) \, dr \\
\text{Radar Reflectivity} &= \alpha \int r^6 N(r) \, dr
\end{align*}
\]
Cloud particle size distributions
Clausius-Clapyeron Equation