Lecture topics:

• **Moisture**
  – Mixing ratio
  – Vapor pressure
  – Relative humidity
  – Saturation vapor pressure
  – Dew point temperature

• **Cloud types**
  – Four categories of common clouds
  – Unusual types
9+ different variables:

1. absolute humidity,
2. specific humidity,
3. mixing ratio,
4. vapor pressure,
5. saturation vapor pressure,
6. relative humidity,
7. wet-bulb temperature,
8. dew point,
9. frost point,
10. etc., etc., etc.
5 primary moisture variables

• We can whittle this list down!
• The most important variables from the list for this class are these 5:
  1. mixing ratio \((w)\),
  2. vapor pressure \((e)\),
  3. saturation vapor pressure \((es)\),
  4. relative humidity \((rh)\), and
  5. dew point \(Td\).
Water in the Atmosphere

- Water molecule is $2 \, H + O$ atoms
- Water can exist in atmosphere as any of 3 states:
  - gas (vapor);
  - liquid (drops and droplets);
  - solid (ice).
Ice in the Atmosphere – part 1

- Water in solid state combines to form hexagonal (6-sided) shapes
Ice in the Atmosphere – part 2

- Ice has several forms in the atmosphere, all of which have 6-sided symmetry

Fig. 5.2
4 Transitions and Saturation

- Water molecules are constantly being exchanged across an interface: Example: air – liquid water - air
- **Evaporation**: liquid to vapor
- **Condensation**: vapor to liquid
- **Sublimation**: solid (ice) to vapor
- **Deposition**: vapor to solid (ice)
- **Saturation**: where number of molecules going from one state equals number going the opposite way.
Saturation versus Temperature

- Before a cloud can form, air must become saturated.
- That maximum amount of water vapor in the air depends on the temperature.
- A parcel of warm air can hold more water vapor than a cold air parcel. Note: the mass of air in the parcel that is not water is the same.
- Important implications for hurricanes.
Describing Atmospheric Moisture

Atmospheric water vapor has been defined several different ways.

These terms include absolute humidity, specific humidity, mixing ratio, vapor pressure, and relative humidity.

Figure 5.6
**Mixing Ratio (w)**

Specific humidity equals the mass of vapor divided by total mass of air in a parcel, and is not affected by changes in parcel volume.

<table>
<thead>
<tr>
<th>Mass of Parcel</th>
<th>Mass of H₂O Vapor</th>
<th>Specific Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg</td>
<td>1 g</td>
<td>1 g/kg</td>
</tr>
<tr>
<td>1 kg</td>
<td>1 g</td>
<td>1 g/kg</td>
</tr>
</tbody>
</table>

**Mixing Ratio (w)** is the mass of water vapor divided by the mass of DRY air in a given parcel of air. w is not affected by changes in parcel volume.

<table>
<thead>
<tr>
<th>Mass of Dry Air</th>
<th>Mass of H₂O Vapor</th>
<th>Mixing Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg</td>
<td>1 g</td>
<td>1 g/kg</td>
</tr>
<tr>
<td>1 kg</td>
<td>1 g</td>
<td>1 g/kg</td>
</tr>
</tbody>
</table>
Saturation mixing ratio ($w_s$) - Clouds

- For air parcel: $w$ is constant whether you warm the air parcel or change its altitude.
- The saturation mixing ratio ($w_s$) is the mixing ratio saturated air would have.
- $W_s$ changes with $T$ and with $P$.
- A cloud forms when a parcel of air changes $T$ and/or $P$ until the mixing ratio equals the saturation mixing ratio.
Vapor pressure (e)

• Recall: Pressure is force per unit area.
• Actual vapor pressure is only that force exerted by the water vapor molecules in a parcel of air. – so, it is independent of the surrounding dry air pressure.
• As temperature goes up, e increases.
• When more water molecules are present, e increases.
Saturation Vapor Pressure ($e_s$)

- **Recall**: Pressure is force per unit area.
- Saturation vapor pressure is only that force exerted by the water vapor molecules in a parcel of air – **when the air is saturated**.
- As temperature goes up, $e_s$ increases.
- When $e_s = P$ (or greater) then water boils.
Relative Humidity (rh)

• Measures ratio of number of molecules of water vapor present divided by the number needed for saturation and expressed as a %

• Saturated air as rh = 100%

• \( rh = 100 \times \frac{w}{w_s} \) and \( rh = 100 \times \frac{e}{e_s} \)

• Unlike mixing ratio, rh varies as a parcel changes its T, P, and/or altitude.

• Like mixing ratio, rh increases when water molecules added to the air.
Dewpoint - $T_d$

- Temperature at which air becomes saturated without changing the water vapor present or changing the pressure.

- Important uses:
  - Good indicator of water vapor content of air
  - When $T$ and $T_d$ are similar, $rh$ is high
  - $T_d$ used on charts to see important properties of the air and air parcels.
Test your understanding:

Patagonia $T=280$, $T_d=280$
LaCampana $T=320$, $T_d=290$
Both sites are near sea level.

1. Which has higher mixing ratio?  
   A: raining in Patagonia  
   B: sunny La Campana (Chile)

2. Which has higher vapor pressure?  
   B: sunny La Campana (Chile)  
   B: sunny La Campana (Chile)

3. Which has higher rh?  
   A: raining in Patagonia  
   B: sunny La Campana (Chile)

Photos © R. Grotjahn
Common Cloud Categories
10 Common Cloud Types

• 10 combinations of these 5 names:
  • **Cirrus**: wispy or hair-like (often high)
  • **Alto**: middle elevation
  • **Stratus**: sheet-like or layered.
  • **Cumulus**: puffy, heaped or vertical~horizontal
  • **Nimbus**: precipitating
# 4 Common Cloud Groups

<table>
<thead>
<tr>
<th>Table 6.2</th>
<th>The Four Major Cloud Groups and Their Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High clouds</td>
<td>3. Low clouds</td>
</tr>
<tr>
<td>Cirrus (Ci)</td>
<td>Stratus (St)</td>
</tr>
<tr>
<td>Cirrostratus (Cs)</td>
<td>Stratocumulus (Sc)</td>
</tr>
<tr>
<td>Cirrocumulus (Cc)</td>
<td>Nimbostratus (Ns)</td>
</tr>
<tr>
<td>2. Middle clouds</td>
<td>4. Clouds with vertical development</td>
</tr>
<tr>
<td>Altostratus (As)</td>
<td>Cumulus (Cu)</td>
</tr>
<tr>
<td>Altocumulus (Ac)</td>
<td>Cumulonimbus (Cb)</td>
</tr>
</tbody>
</table>
# Elevations of Common Cloud Groups

<table>
<thead>
<tr>
<th>CLOUD GROUP</th>
<th>TROPICAL REGION</th>
<th>MIDDLE LATITUDE REGION</th>
<th>POLAR REGION</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>20,000 to 60,000 ft</td>
<td>16,000 to 43,000 ft</td>
<td>10,000 to 26,000 ft</td>
</tr>
<tr>
<td></td>
<td>(6,000 to 18,000 m)</td>
<td>(5000 to 13,000 m)</td>
<td>(3000 to 8000 m)</td>
</tr>
<tr>
<td>Middle</td>
<td>6500 to 26,000 ft</td>
<td>6500 to 23,000 ft</td>
<td>6500 to 13,000 ft</td>
</tr>
<tr>
<td>As, Ac</td>
<td>(2000 to 8000 m)</td>
<td>(2000 to 7000 m)</td>
<td>(2000 to 4000 m)</td>
</tr>
<tr>
<td>Low</td>
<td>surface to 6500 ft</td>
<td>surface to 6500 ft</td>
<td>surface to 6500 ft</td>
</tr>
<tr>
<td>St, Sc, Ns</td>
<td>(0 to 2000 m)</td>
<td>(0 to 2000 m)</td>
<td>(0 to 2000 m)</td>
</tr>
</tbody>
</table>

## Table 6.2 The Four Major Cloud Groups and Their Types

1. High clouds  
   - Cirrus (Ci)  
   - Cirrostratus (Cs)  
   - Cirrocumulus (Cc)  

2. Middle clouds  
   - Altostratus (As)  
   - Altocumulus (Ac)  

3. Low clouds  
   - Stratus (St)  
   - Stratocumulus (Sc)  
   - Nimbostratus (Ns)  

4. Clouds with vertical development  
   - Cumulus (Cu)  
   - Cumulonimbus (Cb)
# Uncommon Cloud Categories

<table>
<thead>
<tr>
<th>TERM</th>
<th>LATIN ROOT AND MEANING</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenticularis</td>
<td>(lens, lenticula, lentil)</td>
<td>Clouds having the shape of a lens or an almond, often elongated and usually with well-defined outlines. This term applies mainly to cirrocumulus, altocumulus, and stratocumulus</td>
</tr>
<tr>
<td>Fractus</td>
<td>(frangere, to break or fracture)</td>
<td>Clouds that have a ragged or torn appearance; applies only to stratus and cumulus</td>
</tr>
<tr>
<td>Humilis</td>
<td>(humilis, of small size)</td>
<td>Cumulus clouds with generally flattened bases and slight vertical growth</td>
</tr>
<tr>
<td>Congestus</td>
<td>(congerere, to bring together; to pile up)</td>
<td>Cumulus clouds of great vertical extent that from a distance may resemble a head of cauliflower</td>
</tr>
<tr>
<td>Calvus</td>
<td>(calvus, bald)</td>
<td>Cumulonimbus in which at least some of the upper part is beginning to lose its cumuliform outline</td>
</tr>
<tr>
<td>Capillatus</td>
<td>(capillus, hair; having hair)</td>
<td>Cumulonimbus characterized by the presence in the upper part of cirriform clouds with fibrous or striated structure</td>
</tr>
<tr>
<td>Undulatus</td>
<td>(unda, wave; having waves)</td>
<td>Clouds in patches, sheets, or layers showing undulations</td>
</tr>
<tr>
<td>Translucidus</td>
<td>(transluere, to shine through; transparent)</td>
<td>Clouds that cover a large part of the sky and are sufficiently translucent to reveal the position of the sun or moon</td>
</tr>
<tr>
<td>Incus</td>
<td>(incus, anvil)</td>
<td>The smooth cirriform mass of cloud in the upper part of a cumulonimbus that is anvil-shaped</td>
</tr>
<tr>
<td>Mammatus</td>
<td>(mamma, mammary)</td>
<td>Baglike clouds that hang like a cow’s udder on the underside of a cloud; may occur with cirrus, altocumulus, altostratus, stratocumulus, and cumulonimbus</td>
</tr>
<tr>
<td>Pileus</td>
<td>(pileus, cap)</td>
<td>A cloud in the form of a cap or hood above or attached to the upper part of a cumuliform cloud, particularly during its developing stage</td>
</tr>
<tr>
<td>Castellanus</td>
<td>(castellum, a castle)</td>
<td>Clouds that show vertical development and produce towerlike extensions, often in the shape of small castles</td>
</tr>
</tbody>
</table>
Water versus Ice Cloud
Altocumulus

Mt. Rainer © R. Grotjahn
Altostratus & stratus
Nimbostratus

Wilson’s Prom, Australia © R. Grotjahn

Paria Canyon © R. Grotjahn

Mt. Cook, NZ © R. Grotjahn
Stratocumulus, cumulus

Photo © R. Grotjahn
Cumulus congestus, cumulonimbus
Summary of major cloud types

- **HIGH CLOUDS**
  - Cirrostratus
  - Cirrocumulus (mackerel sky) 7000 m
  - Halo around sun

- **MIDDLE CLOUDS**
  - Altostratus (sun dimly visible)
  - Altocumulus 2000 m

- **LOW CLOUDS**
  - Nimbostratus
  - Stratus
  - Stratocumulus
  - Cumulus

**CLOUDS WITH VERTICAL DEVELOPMENT**
- Cumulonimbus
- Anvil top
- Showery precipitation
- Steady precipitation
- 23,000 ft
- 6500 ft
Odd clouds – Part 1

Noctilucent clouds

Nacreous clouds
Odd clouds: Forced-uplift clouds

pileus

Wasatch Front UT © R. Grotjahn

Gibraltar © R. Grotjahn
Odd clouds: severe weather
Most Common: Altocumulus

Catskill Creek. T. Cole
End of lecture 3