7. MOISTURE

Reading Assignment:

- A&B: Ch. 5 (p. 123-134)
- CD: Tutorials 3 & 4 (Atm. Moisture; Adiab. Proc.)
  Interactive Ex.: Moisture
- LM: Lab# 7

1. Introduction

- Moisture in the atmosphere: in the form of
  - vapor: humidity
  - droplets: clouds, fog, rain
  - ice: clouds, fog, hail, snow, pellets

→ All three phases can exist at the same time

- Moisture in the atmosphere: is the most important agent of weather. It affects:
  - humidity: - radiation balance (longwave rad.!)  
    - human comfort (high humidity)
  - clouds: - radiation balance
    - longwave → emissivity
    - shortwave → reflectivity
    - energy balance (latent heat!)
    - precipitation

- Important concepts:
  - vapor pressure: see CD tutorial 3, 4
  - saturation: see CD Int. Ex. “Moisture”
2. Moisture Content: Measures of Humidity

- Important in latent heat transfer (i.e. energy transfer)
- Expresses amount of moisture in the air
- **Many different ways to express** moisture content or humidity of the atmosphere. For example:
  - **Absolute humidity or vapor density** ($\rho_v$)
  - **Specific humidity** ($q$)
  - **Relative humidity** ($RH$)
  - **Dew point temperature** ($T_{dew}$)
  - **Actual vapor pressure** ($e$ or $e_a$)

(i) Vapor Pressure - Equilibrium - Saturation

- Recall concept of gas pressure:

- **some of these molecules are water vapor:**
  - total (air) pressure = dry-air pressure + vapor pressure

$$P_{tot} = P_d + e$$
• **Thought Experiment:**
  - Liquid water and dry air in a closed volume
  - Some water molecules have enough energy to escape liquid → “evaporation” → vapor molecules
  - With more vapor molecules in air:
    - vapor pressure \( (e) \) increases
    - some return to liquid → “condensation” → water
  - When evaporation rate equals condensation rate:
    - equilibrium (output = input)
    - no more net water to vapor → no net evaporation
    - equilibrium → saturation

![Figure 5-1 (A&B)](image)

- **escape rate** (“evaporation”):
- **return rate** (“condensation”):
saturation vapor pressure (equilibrium) is only dependent on temperature

- **Saturation** (equilibrium) vapor pressure ($e_s$)

- Relation $e_s$ vs. $T$ is expressed in **Clausius-Clapeyron curve** (see Lab #7):
Significance of the **Clausius-Clapeyron curve**:

**Vapor Pressure** \( (e) \):

- **Vapor pressure** is the **partial pressure** exerted by the **water molecules in the atmosphere**
- **Vapor pressure** is expressed in \([\text{Pa}]\) or \(\text{mb}\)
- **Vapor pressure** is connected to **vapor density** \( (\rho_v) \) and **temperature** through the **ideal gas law**:

\[
e = \rho_v \cdot R_v \cdot T.
\]

\( R_v \): specific gas constant for water vapor = 462 J kg\(^{-1}\) K\(^{-1}\)
(ii) Vapor Density – Absolute Humidity ($\rho_v$)

Absolute humidity ($\rho_v$) = \frac{\text{Mass of H}_2\text{O vapor}}{\text{Volume of air}} \quad \text{kg/g or g/m}^3

- dependent on temperature and pressure
- occurs in vapor gas law
- not used widely

(iii) Specific Humidity (q)

Specific humidity (q) = \frac{\text{Mass of H}_2\text{O vapor}}{\text{Total mass of air}} \quad \text{kg/kg}

- Relative to: total mass of air = dry air + vapor
- If the volume changes - the mass remains constant:
  \[ \Rightarrow \]

\text{Changes in q always indicate a change in the amount of water vapor} in the atmosphere (e.g. from evaporation, condensation)
(vi) Relative Humidity (RH)

Relative humidity (RH) = \( \frac{\text{actual amount of vapor}}{\text{max. amount of vapor}} \times 100\% \)

- **RH**: extent of “unsaturation” in percent (%)
- **RH**: can be expressed in terms of vapor pressure \((e_a, e_s)\) or specific humidity \((q, q_s)\):
  \[
  \text{RH} = \frac{e_a}{e_s} \cdot 100\% = \frac{q}{q_s} \cdot 100\%
  \]

  - \(e_a\) or \(q\): actual amount of water vapor in the air
  - \(e_s\) or \(q_s\): saturation amount of water vapor in the air
- **RH** is very strongly temperature dependent !!!
- Typically, RH varies **inversely** with temperature:
  - **if** $T$ goes $\uparrow$, $e_s$ goes ........, RH goes ........
  - **if** $T$ goes $\downarrow$, $e_s$ goes ........, RH goes ........
  - **if** add H$_2$O vapor, RH goes ........
  - **if** remove H$_2$O vapor, RH goes ........
(v) Dew Point Temperature ($T_d$)

- $T_d$: moist air that is cooled (without loss of vapor, at constant pressure) until saturation is reached, is at the dew point temperature, $T_d$ [K]

- when air $T$ is cooled to saturation, dew will form (water condenses).

- **High $T_{dew}$** →

- **Small** difference: $T_{air} - T_{dew}$

- **Add** water vapor:

- **Remove** water vapor:

Problem
Figure 1: Graph of vapor pressure (mb) as a function of air temperature (°C)

(Saturation) Vapor Pressure (es) (mb)

(Air) Temperature (°C)

Super-

Saturated Vapor Pressure

T=12

ea=11.5 mb

es=14 mb

T_dew

T=12

Non-saturated
2. Variations in Atmospheric Moisture

- When comparing atmospheric moisture in space and time need to remember what is going to vary
  - E.g. RH varies with T

(i) Diurnal (within 24 h) variations of RH

- RH varies inversely with T

(ii) Spatial variation

Relative Humidity, RH
- high in tropics
- low 30° - warm desert
- high poles
(iii) Ocean current impacts

**Scenario:** Air comes across the ocean towards land

- It is likely about the same T as the water

- **Important:** what the sea surface Temperature is
- Distinguish: ocean currents $\rightarrow$ warm/cold?

**Summertime:**
- When the air comes on to the land - air will warm up.
- Important: temperature difference between the water and land

**Example in US**

- compare California and Georgia

  In both cases, air comes on to warm land from the sea. What happens to RH?

  CA:

  GA: