Absolute and Specific Humidity

Fig. 4-8, p. 89

$$Specific\ humidity\ (q) = \frac{mass\ of\ water\ vapor}{total\ mass\ of\ air}$$

$$mixing\ ratio\ (r) = \frac{mass\ of\ water\ vapor}{mass\ of\ dry\ air}$$

- Since usually mass of water vapor << mass of dry air
  Under most situations, $q \approx r$

- *r* is one of the most commonly used measure of moisture

Relative Humidity

- Relative humidity (RH) measures how close the air is from saturation

$$RH = \frac{water\ vapor\ content}{water\ vapor\ capacity}$$

- In terms of vapor pressure (e):

$$RH = \frac{actual\ vapor\ pressure}{saturation\ vapor\ pressure} \times 100\% = \frac{e}{e_s} \times 100\%$$

- In terms of the mixing ratio (r):

$$RH = \frac{actual\ mixing\ ratio}{saturation\ mixing\ ratio} \times 100\% = \frac{r}{r_s} \times 100\%$$

- Hence RH can change due to:
  - Actual change in water vapor content (e or r)
  - Change in temperature, which gives rise to change in saturation vapor pressure (or saturation mixing ratio)

Saturation vapor pressure (e_s)

- e_s increases rapidly with T

- <u>Clausius-Clapeyron equation</u>

$$e_s = e_0 \exp\left[\frac{L}{R_v}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right]$$ Stull (5.1)

Figure illustrating how change in RH can be due both to change in temperature (changing e_s) or change in dew point (changing e)

Fig. 4-10, p. 91

Boiling occurs when saturation vapor pressure equals atmospheric pressure. Since saturation vapor pressure increases with temperature, boiling point temperature increases when atmospheric pressure increases (and decreases when atmospheric pressure decreases).

Fig. 1, p. 92

Numerical calculations using Stull Table 5-1

- e_s can also be found from Stull Table 5-1 (you will use that table for homework set 11)
- Note that dew point temperature is temperature at which air becomes saturated, with no change in water vapor content
- Hence

$$e_s(T_d) = e$$

- Hence if we know T_d, we can find e
- Alternatively, knowing e, we can find T_d from Table 5-1
- See also Ahrens p. 102 (9th Edition)

Numerical Example

- If the temperature is 30°C, and the dew point temperature is 16°C, what is the relative humidity? (Use Stull Table 5-1)
  - $$RH = \frac{e}{e_s} \times 100\%$$
  - $T = 30°C$, $e_s = 4.367$ kPa (Stull Table 5-1)
  - $T_d = 16°C$, e_s at 16°C = 1.835 kPa
  - Actual vapor pressure (e) = e_s at dew point
    - Hence e = 1.835 kPa
  - RH = e/e_s x 100% = 1.835/4.367 x 100% = 42%

Numerical example

- If the vapor pressure is 14 hPa, what is the dew point? (Use Stull Table 5-1)
  - e = 14 hPa = 1.4 kPa
  - $e = e_s$ when $T = T_d$
  - From Table 5-1, when e = 1.4 kPa, T_d = 12 °C

Classwork Exercise

- Using Stull Table 5-1, find e_s, T_d, and RH if T = 18 °C and e = 14.1 hPa
  - T = 18 °C: From table, e_s = 2.088 kPa
  - e = 14.1 hPa = 1.41 kPa: From table, T_d = 12 °C
  - RH = e/e_s × 100% = 1.41/2.088 × 100% = 67.5%

- If T = 18 °C, and T_d = -14 °C, what is the RH?
  - T = 18 °C: From table, e_s = 2.088 kPa
  - T_d = -14 °C: From table, e = 0.209 kPa
  - RH = e/e_s × 100% = 0.209/2.088 × 100% = 10%

Other humidity variables

- If we know e, other humidity variables can be found, as follows:

$$\rho_v = \frac{e}{R_v T}$$ Stull (5.5)

$$q \approx \frac{\varepsilon \cdot e}{p}$$ Stull (5.4)

Where $\varepsilon = R_d/R_v = 0.622$

and $$r = \frac{\varepsilon \cdot e}{p - e}$$ Stull (5.3)

Numerical example

- Find the saturation values of mixing ratio, specific humidity, and absolute humidity for air of temperature 10°C and pressure 850 hPa, using e_s from Table 5-1 of Stull.
  - 850 hPa = 85000 Pa
  - From Table 5-1 of Stull, at 10°C, e_s = 1.233 kPa = 1233 Pa
  - Using Stull (5.3) for mixing ratio
    - Hence $r_s = 0.622 \times 1233/(85000-1233) = 0.0092$ kg/kg
  - Using Stull (5.4) for specific humidity
    - Hence $q_s = 0.622 \times 1233/85000 = 0.0090$ kg/kg
  - Using Stull (5.5) for absolute humidity
    - Hence $\rho_{vs} = 1233/461/(273.15+10) = 0.0094$ kg m^{-3}

Note: use SI units here!!

Lifting Condensation Level (LCL)

- When an air parcel is lifted, it expands and cools
  - Question: at what rate does a dry air parcel cool?
- As the air parcel cools, its RH increases
- Eventually, the RH reaches 100%, and condensation occurs
- The altitude at which this occurs is called the LCL
- Given the temperature and the dew point, the height of the LCL above the height where the T and Td are measured can be found approximately by

$$\Delta z_{LCL} = a(T-T_d) \qquad \text{(Stull 5.8)}$$

-- $a = 0.125$ km/°C

Saturated Adiabatic Lapse Rate

- Unsaturated air parcel, when lifted, cools at the dry adiabatic lapse rate
- When an air parcel is lifted above the LCL, it becomes saturated, and further cooling will lead to condensation of water vapor
- When water condenses, latent heat of condensation is released
- Hence a saturated air parcel cools at a rate slower than an unsaturated air parcel
- The saturated adiabatic lapse rate is about 4 K/km near the ground, and changes to 6-7 K/km in the mid-troposphere