Hygrometry refers to the measurement of atmospheric humidity

- Several variables describe the quantity of water vapor in the atmosphere
  - Absolute humidity ($\rho_v$, i.e., density of water vapor)
  - Specific humidity ($q$)
  - Mixing ratio ($w$)
  - Vapor pressure ($e$)
  - Relative humidity ($e/e_s$)
  - Dewpoint ($T_d$)
  - Wet bulb temperature ($T_w$)
- Can convert from one variable to another with knowledge of temperature and pressure

**Review: Saturation vapor pressure**

- The Clausius-Clapeyron equation gives the saturation vapor pressure over a plane surface of water as a function of temperature:
  \[ e_s = e_o \exp \left[ \frac{L}{R_v} \left( \frac{1}{T_0} - \frac{1}{T} \right) \right] \]
  - $e_o = 610.78$ Pa
  - $T_0 = 273.15$ K
  - $R_v = 461.5$ J kg$^{-1}$ K$^{-1}$
  - $L = (2.501 \times 10^6$ J kg$^{-1}) - (2340$ J kg$^{-1}$ K$^{-1})T_C$

**Saturation vapor pressure over water and ice**

- The Clausius-Clapeyron equation also gives the saturation vapor pressure over ice as a function of temperature:
  \[ e_s = e_o \exp \left[ \frac{L_s}{R_v} \left( \frac{1}{T_i} - \frac{1}{T} \right) \right] \]
  - $e_o = 611.20$ Pa
  - $T_i = 273.16$ K
  - $R_v = 461.5$ J kg$^{-1}$ K$^{-1}$
  - $L_s = 2.834 \times 10^6$ J kg$^{-1}$

**Saturation vapor pressure is a function of temperature**

- Saturation Vapor Pressure vs. Temperature
  - $e_s$ over water
  - $e_s$ over ice
Review: Dewpoint temperature

- The dewpoint temperature is the temperature to which a given air parcel must be cooled at constant pressure and water vapor content in order for saturation to occur.
- Substitute \( e \) for \( e_s \) and \( T_d \) for \( T \) in the Clausius-Clapeyron equation:

\[
e = e_s \exp \left[ \frac{L}{R_s} \left( \frac{1}{T_s} - \frac{1}{T_d} \right) \right]
\]

Review: Wet-bulb temperature

- The wet-bulb temperature is the temperature to which air may be cooled by evaporating water into it at constant pressure until it becomes saturated.
- \( T - T_w \) is the wet-bulb depression

\[
T_d \leq T_w \leq T
\]

Methods of measuring humidity

- Thermodynamic methods
  - Psychrometer
- Hygroscopic substance
  - Hair hygrometer
- Condensation methods
  - Chilled mirror
- Sorption methods
  - Chemical
  - Electrical
- Diffusion methods
- Optical methods

Psychrometry

- Two temperature sensors
  - One temperature sensor measures the ambient (dry-bulb) temperature (\( T \))
  - The other measures the wet-bulb temperature (\( T_w \))

Psychrometry: \( T_w \) vs. Relative Humidity

- Static sensitivity increases with increasing air temperature
- Static sensitivity increases with decreasing relative humidity

- Psychrometric formula relates the wet-bulb depression (\( T - T_w \)) to vapor pressure

\[
e = e_s(T_w) - \frac{p_c \gamma}{\gamma_d}(T - T_w)
\]

Psychrometric constant:

\[
\gamma = \frac{p_c \gamma_s}{\gamma_d} \approx 0.65 \text{ mb at standard SLP}
\]

Experimentally,

\[
e = e_s(T_w) - A(T - T_s)
\]

A=0.00062°C\(^{-1}\) for water-covered wet bulbs
A=0.00054°C\(^{-1}\) for ice-covered wet bulbs
Requirements for a successful psychrometric measurement

- Two well-matched thermometers
- Adequate ventilation (> 3 m s⁻¹)
- Radiation shield
- Distilled water to moisten the wick
  - Dissolved salts affect the evaporation rate
- Clean wick
  - Special psychrometer wick with no hydrophobic chemicals (not cotton)

Psychrometers

- Assman psychrometer
- Sling psychrometer

Equilibrium sorption of water vapor

- Many hygrometers use the process of sorption to measure water vapor
  - **Absorption**: uptake of water into the bulk of the substance
  - **Adsorption**: surface retention of water molecules
  - Mass of water is proportional to relative humidity
- Consequences of sorption processes:
  - Material expands/contracts
  - Resistance or capacitance of material changes

Hair hygrometer

- The length of human and animal hair varies nonlinearly as a function of relative humidity
- Once used widely by the NWS
- Drawbacks: Drift, hysteresis, large lag times

Bulk polymer resistive sensor

- Measures resistance of a conductive polymer
- Sorbed water provides alternative conductive paths
- Resistance decreases as RH increases
Carbon hygristor

- As relative humidity increases:
  - Linear dimension increases
  - Distance between carbon particles increases
  - Resistance increases
- Used only on radiosondes

Capacitive sensors

- Porous Top Electrode (gold)
- Polymer
- Sensing Electrode (silver)
- Substrate

The dielectric constant of the polymer changes with relative humidity

Overview: Functional model for electric hygrometers

Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

- Mirror cooled via Peltier effect until dew/frost forms
- Thermistor or RTD embedded in mirror detects T

Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

- No dew/frost detected
- Dew/frost detected

Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

- Mirror cooled via Peltier effect until dew/frost forms
- Thermistor or RTD embedded in mirror detects T
Spectroscopic Techniques

- Measure the attenuation of certain bands of radiation due to water vapor absorption
- Primary water vapor absorption bands:
  - 121.56 nm (0.12 μm) – Ultraviolet
    - Lyman-alpha emission line of atomic hydrogen
    - Fastest response of all humidity sensors
    - Terrible drift (i.e., within minutes)
  - 2.6 μm – Infrared
    - Expensive
    - Slow response

Infrared Water Vapor Absorption

- Beer’s Law
  - The fraction of incident radiation, $\tau$, transmitted through an atmospheric path
    \[ \tau = \frac{I(s)}{I_0} = \exp(-k_\lambda \rho_v ds) \]
  - $k_\lambda$: absorption coefficient (m² kg⁻¹)
  - $\rho_v$: water vapor density
  - ds: measurement path length
  - I: intensity of attenuated radiation
  - $I_0$: intensity of source radiation

Schematic of an IR water vapor sensor

- Requires two filters to compensate for drift or dirty lenses:
  - Reference band
  - Absorbing band

Campbell Scientific KH20 Krypton Hygrometer

UV radiation emitted by a krypton lamp at 123.58 nm and 116.49 nm