Lecture 15, Water, Humidity, Pressure and Trace Gases, Part 2

- Atmospheric measures of humidity
- Observations of humidity
  - diurnal and seasonal patterns
  - Vertical and Horizontal Gradients
- Pressure

Vapor Pressure Deficit, D

$$D = e_s(T) - e_a = e_s(T)(1 - h_r)$$

e_s, saturation vapor pressure, kPa
e_a, vapor pressure
h_r, relative humidity

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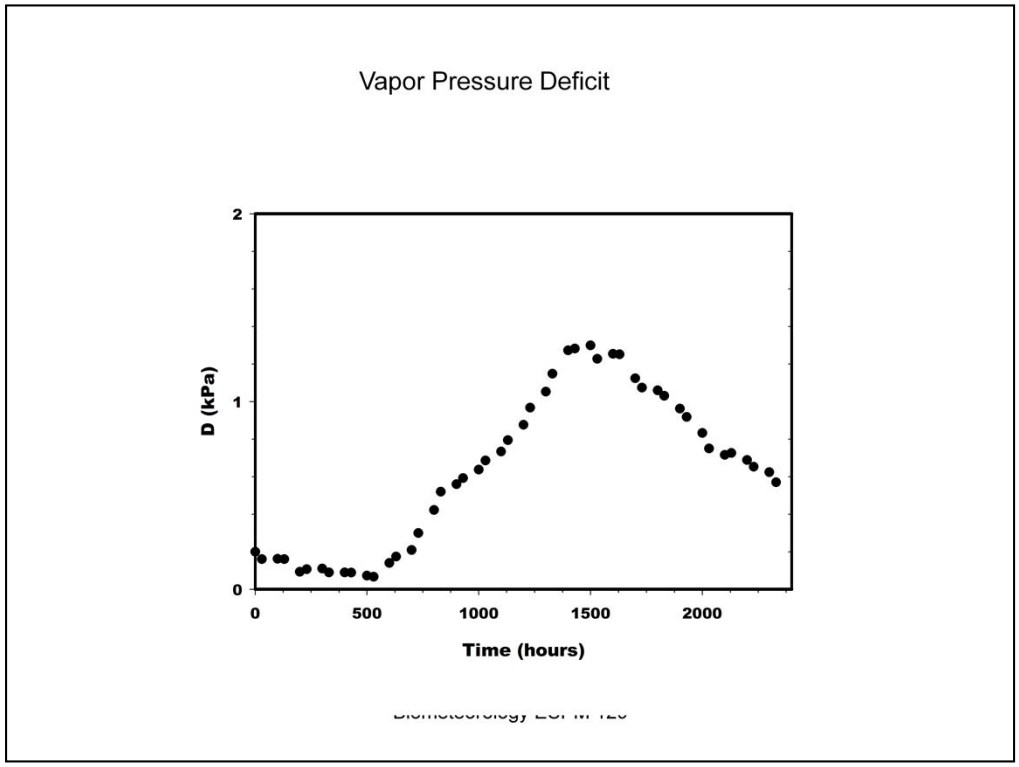
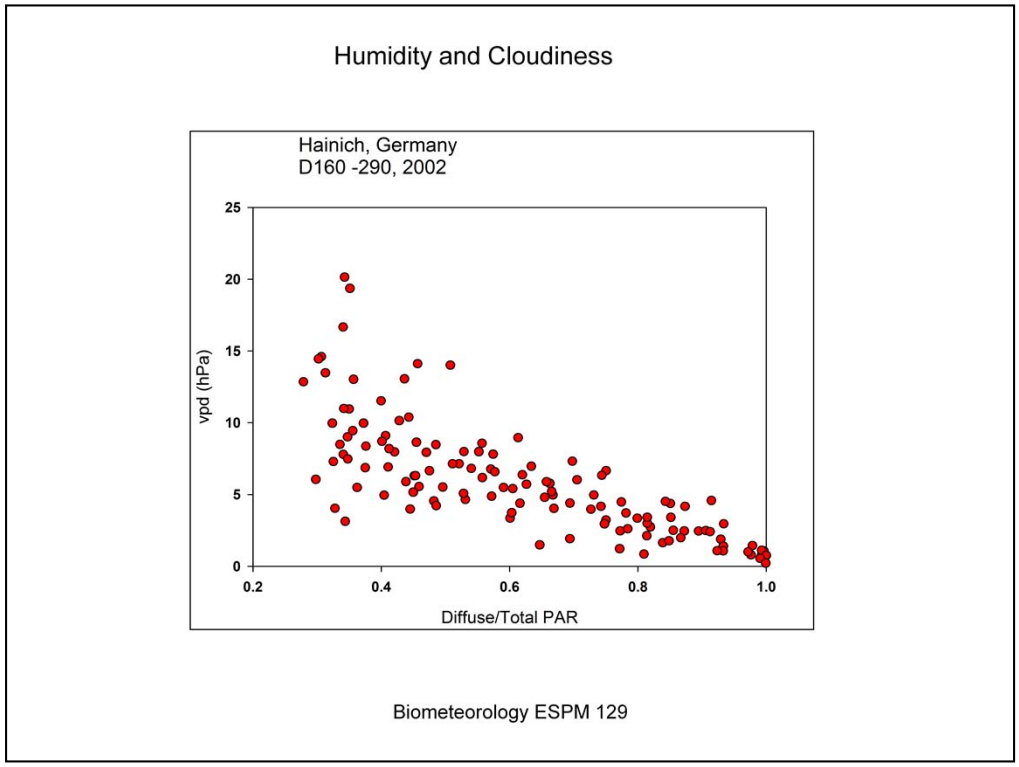
Vapor pressure deficit is the difference between the saturation vapor pressure at air temperature, minus the vapor pressure of the air. It has units of Pascals, pressure. It is also a function of relative humidity. It is important because it represents a driving force for evaporation from the land to the atmsophere.



How does vpd vary during the course of a day. Air is cool at night and close to the dew point or the saturation vapor pressure, so vpd is lowest. While during the day there is transpiration and injection of moisture into the atmosphere, the vpd increasts because es(T) out paces ea, as the air warms.



We can see a nice correlation between vpd and diffuse fraction of radiation…As the fraction of diffuse light increases, with clouds, vpd approaches zero and saturation. Highest vpd is on the clear days with a low diffuse to total fraction. This interaction is important to tease out the combined role of more effective diffuse light and lower vpd on enhancing canopy photosynthesis and stomatal conductance

Linearized Humidity Deficit

$$e_s(T_s) - e_a = (e_s(T_a) - e_a) - s(T_a - T_s)$$

e_s, saturation vapor pressure, kPa
e_a, vapor pressure
h_r, relative humidity
s, slope of e_s vs T relation
T, temperature
T_a, air temperature
T_s, surface temperature

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Later in this course we will use a linearized version of vpd for computing evaporation with the Penman Monteith equation. Here we base the deficit on the basis of the temperature of the leaf, which we don't know yet. So the first term is based on air temperature and we solve for the air-surface temperature. This introduces a new parameter, s, which is the slope of the saturation vapor pressure curve.

Slope Saturation Vapor Pressure-Temperature Curve

$$\frac{de_s(T)}{dT} = s = \frac{0.611 \cdot 17.502 \cdot 240.97 \cdot \exp(\frac{17.502T}{240.97+T})}{(240.97+T)^2}$$

e_s, saturation vapor pressure, kPa
e_a, vapor pressure
h_r, relative humidity
s, slope of e_s vs T relation
T, temperature
T_a, air temperature
T_s, surface temperature

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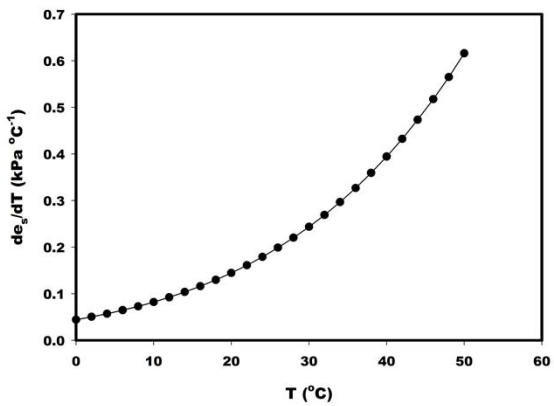
Here is the simple algorithm for s. It is highly non linear. In this form the units are kPa. In this form, T is in terms of Centigrade.

Slope of the saturation vapor pressure function and Temperature



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Visual of s vs T. The low values at low temperatures helps explain low rates of evaporation in the tundra and why the region remains wet even though precipitation is low, like a desert.

Inverting e_s=f(T)

Dew Point Temperature, T_d

$$T_d = \frac{240.97 \cdot \ln(e_a / 0.611)}{17.502 - \ln(e_a / 0.611)}$$

e_a, vapor pressure, kPa

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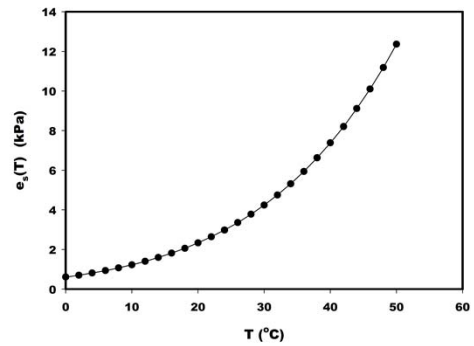
If we measure the temperature at which dew forms, we can invert the saturation vapor pressure equation and estimate vapor pressure. This is a great direct way to measure humidity with first principles.

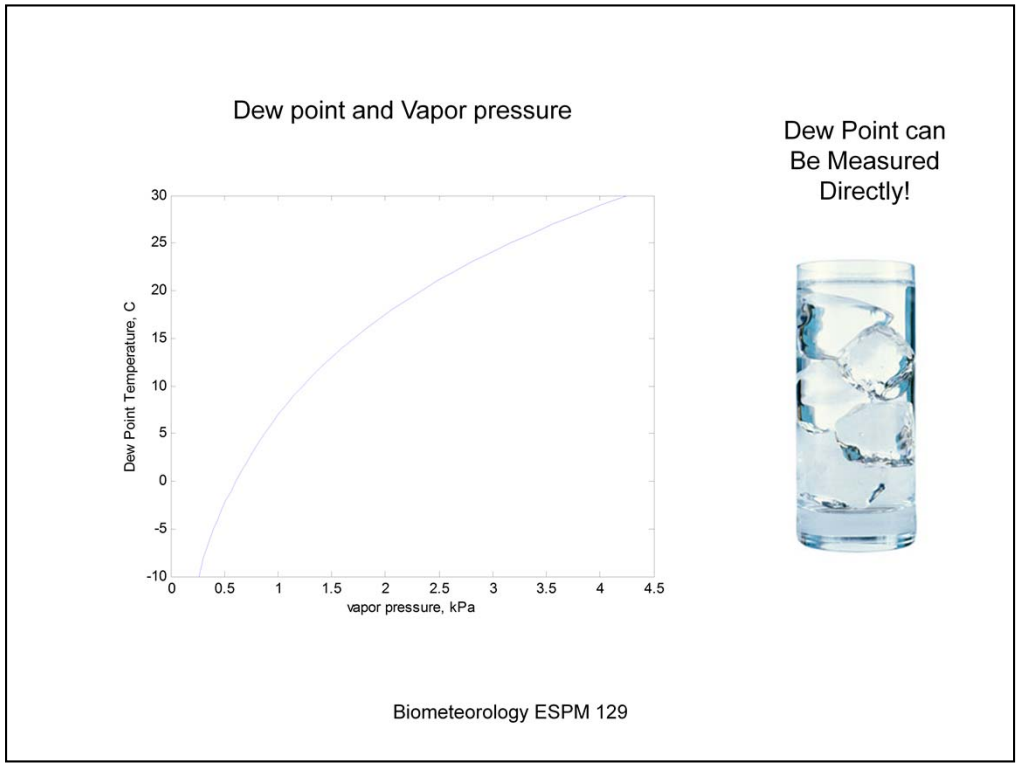
Saturation Vapor Pressure-Temperature Function

$$e_s(T_c) = a\exp\left(\frac{bT_c}{c+T_c}\right) \quad \text{kPa}$$

Over Water	Over Ice
a=0.611	a=0.611
b= 17.502	b= 21.87
c=240.97	c=265.5

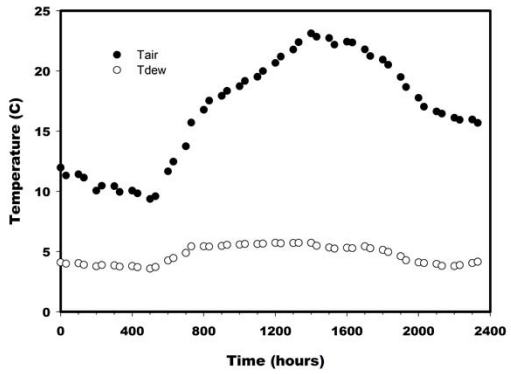


This is an important equation which is used a lot in biometeorology. You don't need to memorize it, but do feel comfortable to use it and recognize that saturation vapor pressure is an exponential function of temperature



Here is the plot of the dew point temperature and vapor pressure. Also very non linear

Diurnal Pattern of Dewpoint and Air Temperature



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Diurnal plots of air and dew point temperatures

Wet Bulb Temperature and Psychrometric relation.

The wet bulb temperature is defined as the temperature at which the change in the air's heat content equals the work associated with latent heat evaporated into the air.

It represents the adiabatic balance between latent and sensible heat exchange

$$C_p(T_a - T_w) = \frac{\lambda(e_s(T_w) - e_a)}{P}$$

e_s, saturation vapor pressure, kPa
e_a, vapor pressure
P, pressure, kPa
C_p, specific heat at constant pressure
λ, latent heat of evaporation
T_a, air temperature
T_w, wet bulb temperature

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Wet bulb temperature is another way to measure humidity. It comes from our manipulation of the first law of thermodynamics. Here we have an adiabtic balance between latent and sensible heat exchange. No heat is added or consumed. Just the change in internal energy is used to drive work associated with evaporation and the change in partial pressure of vapor.

$$e_a = e_s(T_w) - \frac{C_p}{\lambda} P(T_a - T_w)$$

e_s, saturation vapor pressure, kPa
e_a, vapor pressure
P, pressure, kPa
C_p, specific heat at constant pressure
λ, latent heat of evaporation
T_a, air temperature
T_w, wet bulb temperature

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Measure wet bulb temperature an solve for vapor pressure. We use a sling psychromater to measure wet bulb temperature. One thermometer is moistened with a wet wick. The other is dry. As the wet thermometer evaporates its temperature depresses. This is the same principle used to power swamp coolers in the less developed world and in LA and the bay area during the 1960s. This is a very energy efficient way to condition the air. It works best in dry environments with large wet bulb depressions.

Wet Bulb Effect

Drop In Temperature as you Drive by a Golf course or Alfalfa Field at Night

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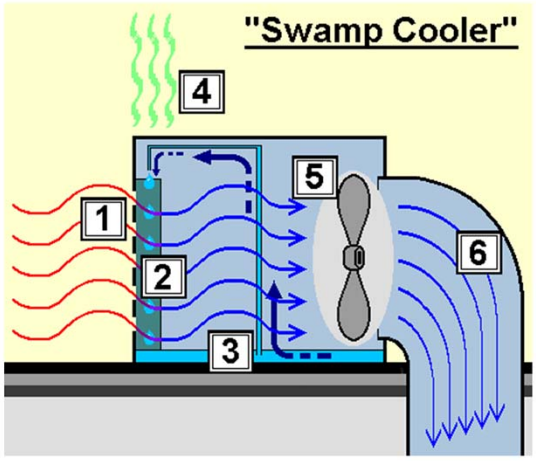
Have you ever drove by a golf course or alfalfa field at night with the window open. If so you would have sensed a drop in temperature, to the wet bulb temperature. Sensible heat from the air is being drawn and used to evaporate water from these freely evaporating surfaces, which then cause a drop in air temperature in their vicinity.



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Ever notice swamp coolers on the roofs of homes? These are effective and relativey cheap ways to provide air conditioning.

http://i211.photobucket.com/albums/bb194/ryhebert/swamp1.gif

Latent Heat of Evaporation

$$\lambda = 3149000 - 2370 \cdot T_k$$

(J kg-1)

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Equation to show how latent heat of evaporation varies with temperature

Latent heat of fusion (phase transition from solid, ice, to vapor)
334 J g^{-1} at 0 C

Latent heat of sublimation (phase transition from solid to vapor)
2830 J g^{-1} at ^{o}C

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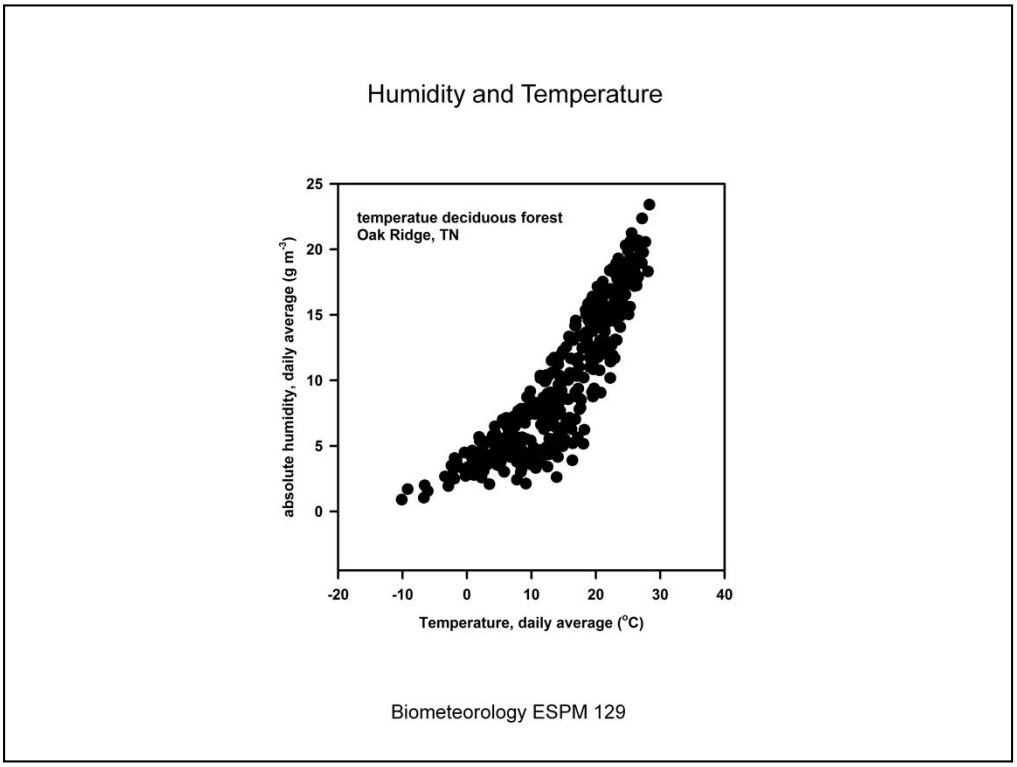
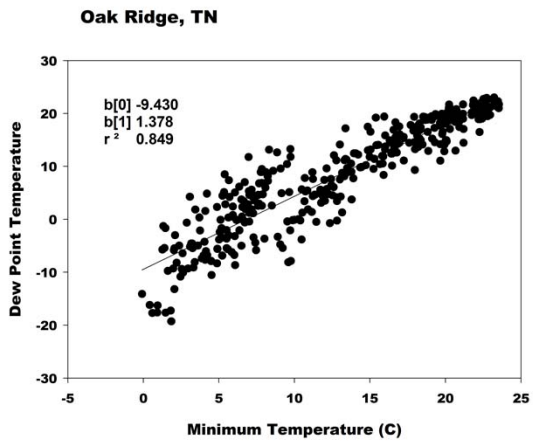
There is also latent heat exchange with freezing and melting ice.



It is often muggy in the tropics and eastern us as warmer air holds more moisture.

Dewpoint and minimum Temperature, Humid East



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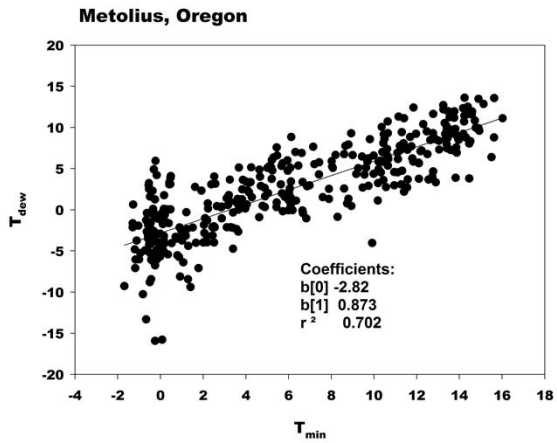
We often don't measure water vapor every where, but there are lots of networks of maximum and minimum temperature. Often at night the release of energy with condensation stops the decline of temperature further, so there is a practical link between minimum temperature and dew point. It is not perfect, but if you are a forest manager and need humidity information in remote areas for decisions on fire and water use, this is a great start. This figure is for the humid east

Dewpoint and minimum Temperature, Semi-Arid West



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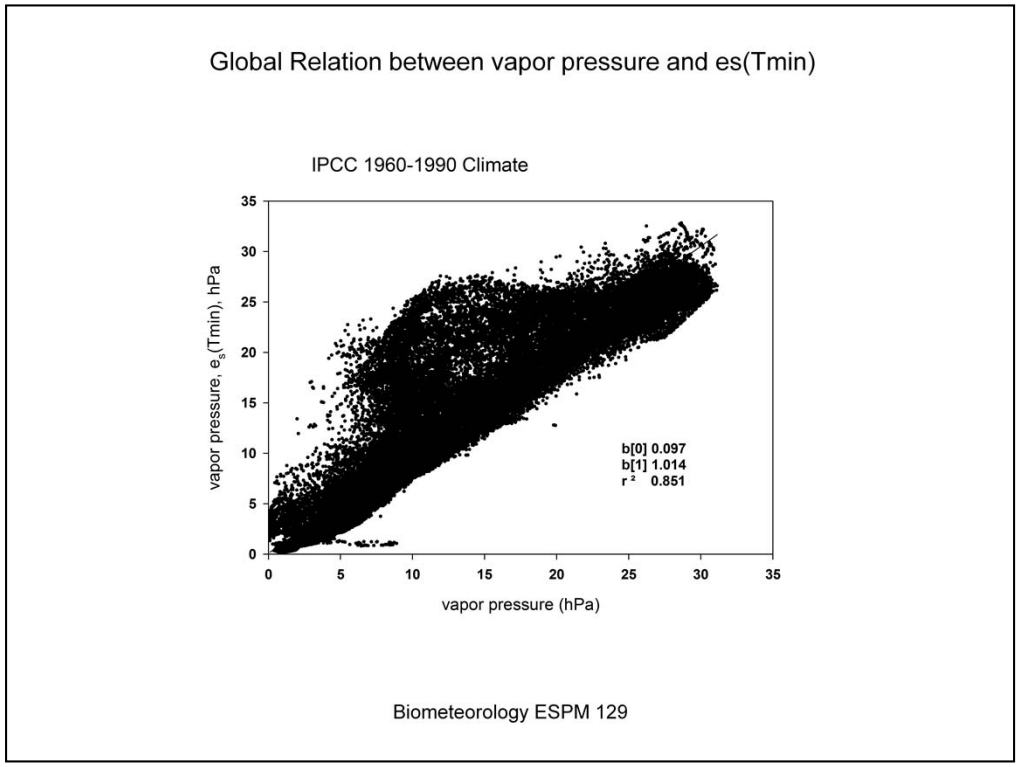
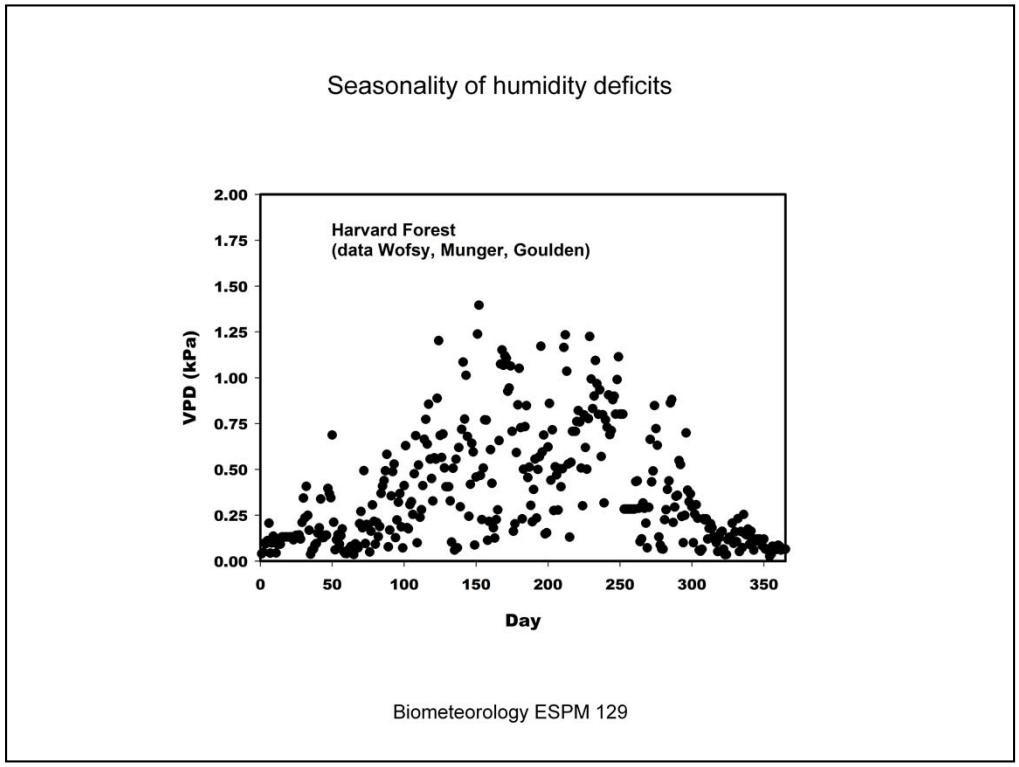
This figure is for the semi arid west

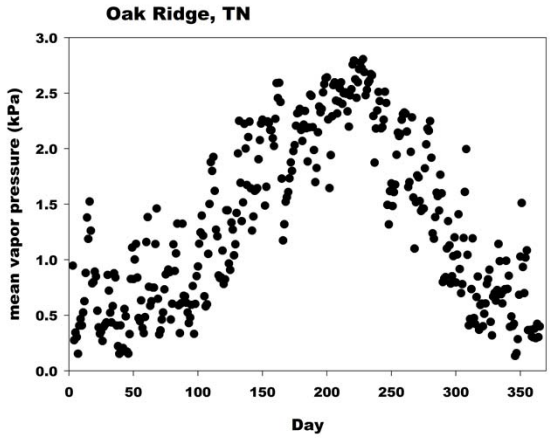


Here is a global plot with gridded data



Humidity changes with seasons.

Seasonality of humidity



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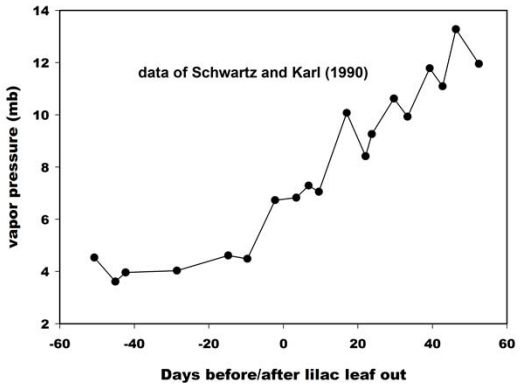
Phenology, Transpiration and Humdity



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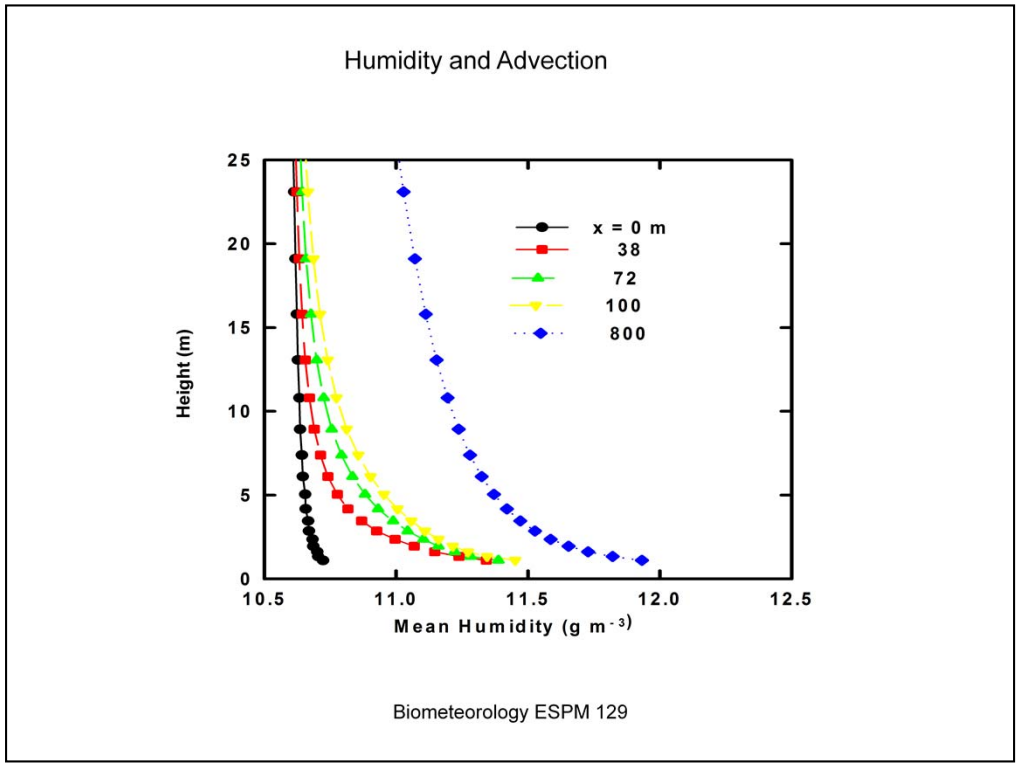
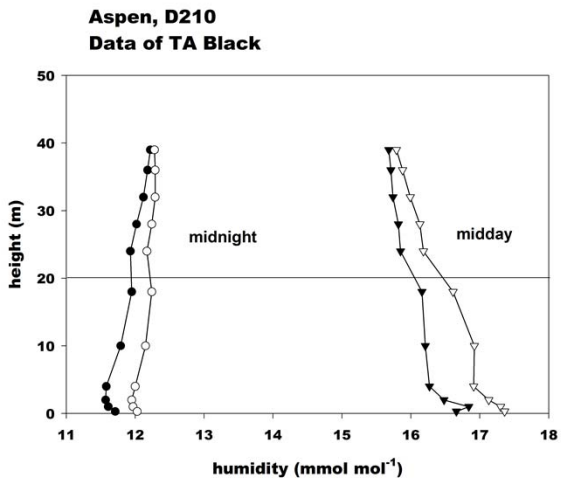
Changes in phenology has a great impact on vapor pressure/



There are vertical variations in humidity.. We also see advection across a desert and irrigated field.

Gradients in Forests



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Profiles of humidity over and within a forest. Evaporation leads to lower vapor pressure above and greater in the canopy. The reverse gradient occurs at night as there is dew deposition.

How Pressure changes with Height

$$\frac{dp}{dz} = -g\rho$$

g, acceleration due to gravity, m s^{-2}
ρ, air density, g m^{-3}

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What is the Overhead Pressure Burden?

$$p(z) = \int_{z}^{\infty} g\rho\, dz$$

$$\frac{dp}{p} = -\frac{g}{RT} dz$$

$$p = p(0)\exp(-\frac{g}{R}\int_{0}^{z}\frac{dz}{T})$$

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How Pressure changes with Temperature

$$\frac{dP}{dT} = \frac{\rho R}{m} = 344 PaK^{-1}$$

R, universal gas constant
m, molecular weight of air
ρ, air density, g m^{-3}

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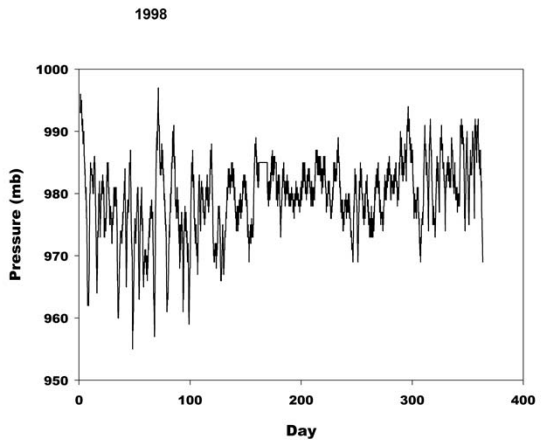
$$\frac{1}{\rho}\frac{d\rho}{dz} = -\frac{1}{T}\left(\frac{dT}{dz} + \frac{g}{R}\right)$$

Seasonal Change in Pressure



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Summary

- Humidity Measures
  - Vapor pressure and Saturated vapor pressure
  - Relative Humidity
  - Absolute humidity
  - Vapor Pressure Deficit
  - Wet Bulb Temperature
  - Dewpoint Temperature
  - Virtual Temperature

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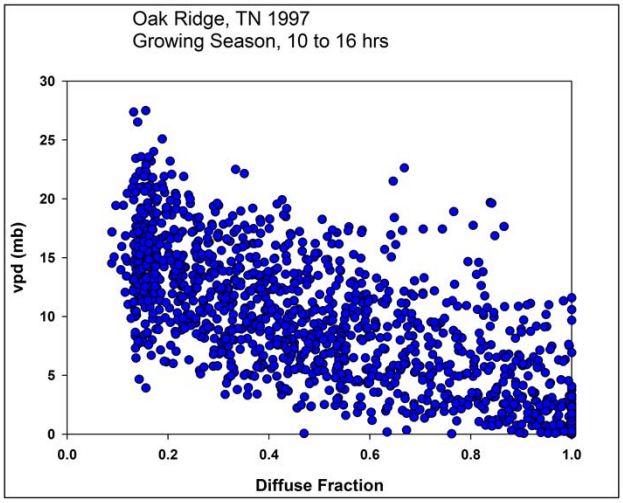
Humidity and Cloudiness



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