

Water

- Units

- Molarity=%/100, mole of substance per mole of air
- $M(\text{H}_2\text{O})=2*1+16=18 \text{ g/mol}$
- $\rho=(nM)/V=(1*18/22.4)=0.804 \text{ g/l} = \text{kg/m}^3$
- $C_i = V_i/V_a = n_i/n_a = p_i/p_a \text{ (l/l)=mol/mol=(Pa/Pa)}$
- $\rho/M=\text{const.}=44.6 \text{ mol/m}^3$, i.e. 22.4 l/mol

Compound	%	Molecular mass	Density at STP
N ₂	78	28.01	1.250
O ₂	21	32.00	1.429
CO ₂	0.036	44.01	1.977
H ₂ O	0...7	18.02	0.804
Air	100	28.97	1.292

- H₂O, high E density

- 75 J/mol +1°C
- 44,000 J/mol evaporation

Water

TABLE A4. Conversion factors

Length	$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm}$
Area	$1 \text{ m}^2 = 10,000 \text{ cm}^2 = 10^6 \text{ mm}^2$
Volume	$1 \text{ m}^3 = 10^6 \text{ cm}^3 = 10^9 \text{ mm}^3$
Density	$1 \text{ Mg/m}^3 = 10^3 \text{ kg/m}^{-3} = 1 \text{ g/cm}^{-3}$
Pressure	$1 \text{ kPa} = 10 \text{ mb}$
Heat	$1 \text{ Joule} = 0.2388 \text{ cal}$
Heat flux	$1 \text{ Watt} = 0.8598 \text{ kcal/hr}$
Heat flux density	$1 \text{ W/m}^2 = 0.8598 \text{ kcal m}^{-2} \text{ hr}^{-1}$
	$1 \text{ W/m}^2 = 1.433 \times 10^{-3} \text{ cal cm}^{-2} \text{ min}^{-1}$
	$1 \text{ W/m}^2 = 2.388 \times 10^{-5} \text{ cal cm}^{-2} \text{ s}^{-1}$

Water Vapor

TABLE A1. Temperature dependent properties of gases in air at 101 kPa.

<i>T</i> C	ρ mol m ⁻³	ν mm ² /s	D_H mm ² /s	D_v mm ² /s	D_c mm ² /s	D_o mm ² /s
0	44.6	13.3	18.9	21.2	13.9	17.7
5	43.8	13.7	19.5	21.9	14.3	18.3
10	43.0	14.2	20.1	22.6	14.8	18.8
15	42.3	14.6	20.8	23.3	15.3	19.4
20	41.6	15.1	21.4	24.0	15.7	20.0
25	40.9	15.5	22.0	24.7	16.2	20.6
30	40.2	16.0	22.7	25.4	16.7	21.2
35	39.5	16.4	23.3	26.2	17.2	21.9
40	38.9	16.9	24.0	26.9	17.7	22.5
45	38.3	17.4	24.7	27.7	18.2	23.1

Specific heat of air:

$$c_p = 29.3 \text{ J mol}^{-1} \text{ C}^{-1}$$

Molecular mass of air:

$$M_a = 29 \text{ g/mol.}$$

Molecular mass of water:

$$M_w = 18 \text{ g/mol.}$$

Water Vapor

Latent heat of vaporization

TABLE A2. Properties of water

<i>T</i> C	ρ_w MG/m ³	λ kJ/mol	ν mm ² /s	D_H mm ² /s	D_o mm ² /s	D_v mm ² /s
0	0.99987	45.0	1.79	0.134		
4	1.00000	44.8	1.57	0.136		
10	0.99973	44.6	1.31	0.140		
20	0.99823	44.1	1.01	0.144	0.002	0.002
30	0.99568	43.7	0.80	0.148		
40	0.99225	43.4	0.66	0.151		
50	0.98807	42.8	0.56	0.154		

Specific heat of water

Latent heat of freezing

Thermodynamic psychrometer constant at 20 C

75.4 J mol⁻¹ C⁻¹

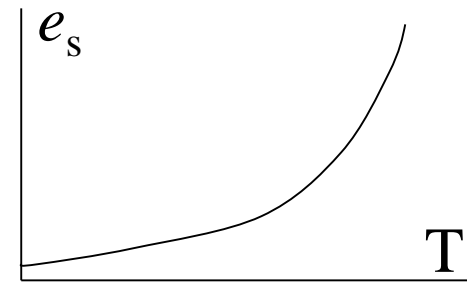
6.0 kJ mol⁻¹

0.000664 C⁻¹

$\gamma = C_p / \lambda$

Vapor saturation

Saturation = $f \{ T; P=f\{A\} \}$



Tetens formula:

Coefficients chosen according to env. Conditions

For environ. biophys.:

$$a=0.611 \text{ kPa}$$

$$b=17.502$$

$$c=240.97^\circ\text{C}$$

$$e_s(t) = a * \exp\left(\frac{bT}{T + c}\right)$$

Saturation pressure e_s roughly doubles for each 10°C increase:

$$e_s(0^\circ)=0.611 \text{ kPa}; e_s(10^\circ)=1.23 \text{ kPa}; e_s(20^\circ)=2.34 \text{ kPa}; e_s(30^\circ)=4.24 \text{ kPa}$$

Water Vapor (Fritzchen 1979, Chapter 6)

The *saturation deficit* or the *vapor pressure deficit*, VPD, is the difference between the saturation and actual vapor pressure at the same temperature and pressure. For example, at an air temperature of 29°C and vapor pressure of 2.005 kPa, the saturation vapor pressure is 4.005 kPa. Therefore the saturation deficit is 2.0 kPa.

The *relative humidity* of air, U , is the ratio in percent of water vapor of moist air relative to the saturation vapor pressure at the same temperature and pressure,

$$U = 100 \left(\frac{e}{e_w} \right). \quad (6.13)$$

Relative humidity of 50%, labeled on the right axis of Fig. 6.1, represents the condition where the atmospheric vapor pressure is equal to one half of the saturation vapor pressure at that temperature. Both saturation vapor pressure and relative humidity may be defined with respect to a plane surface of ice. The saturation vapor pressure of ice at 0°C is practically equal to that over water at 0°C.

Water Vapor (Fritzchen 1979, Chapter 6)

The *dew point*, T_d , is the temperature at which saturation will occur if moist air is cooled at constant pressure. This is also the condition in which the relative humidity is 100% and condensation occurs. To find the dew-point temperature of air at 50% relative humidity and 29°C temperature locate the intersection of 50% and 29°C in Fig. 6.1 and follow the 2.0 kPa line horizontally to the left until the 100% relative humidity line is reached. The isotherm intersecting this point, 17.6°C, is the dew-point temperature.

The *wet-bulb* temperature, T_w , of moist air at a given pressure and air temperature is the temperature attained when the moist air is brought adiabatically to saturation by evaporation of water into the moist air. The wet-bulb temperature for air of 50% U and 29°C air (Fig. 6.1) is found by moving from the 50% and 29°C intersection upward to the left parallel to the diagonal lines until the 100% U line is reached. The isotherm intersecting this point, 21.2°C, is the wet-bulb temperature.

$$e_a = e_s(T_w) - \gamma p_a (T_a - T_w)$$

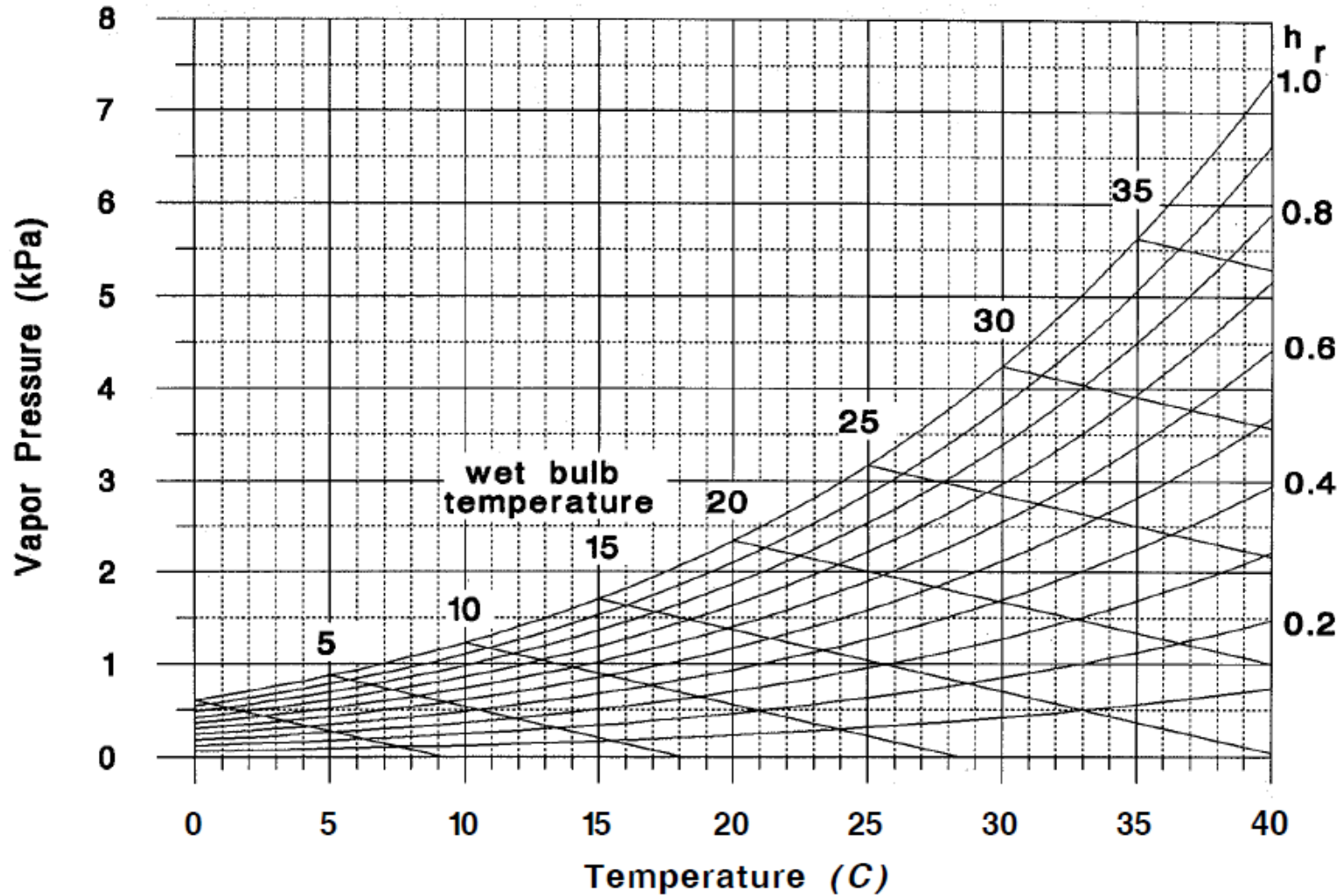


FIGURE 3.2. Vapor pressure-temperature-relative humidity-wet bulb temperature diagram. Wet bulb lines are for sea level pressure.

$$e_a = e_s(T_w) - \gamma p_a (T_a - T_w)$$

Partial saturation can be expressed in many ways. Such as
mole fraction, relative humidity, vapor deficit, dew point
temperature, wet bulb temperature

Show on the graph: VPD, wet bulb temperature

$$\gamma = c_p / \lambda$$

- γ : thermodynamic **psychrometer** constant
 C_p : the specific heat of air ($29.3 \text{ J mol}^{-1} \text{ K}^{-1}$)
 λ : latent heat of vaporization = 44 kJ mol^{-1}

Spatial and temporal variation

- Diurnal patterns determined by t°
- RH and VPD vary with t°
- e_a rather stable,
 - Variation minimal, yet:
 - During day - e_a decr. w/ height
 - During night - e_a incr. w/ height
- Because of strong t° -dependence, RH itself is a bad parameter, Convert to e_a or VPD

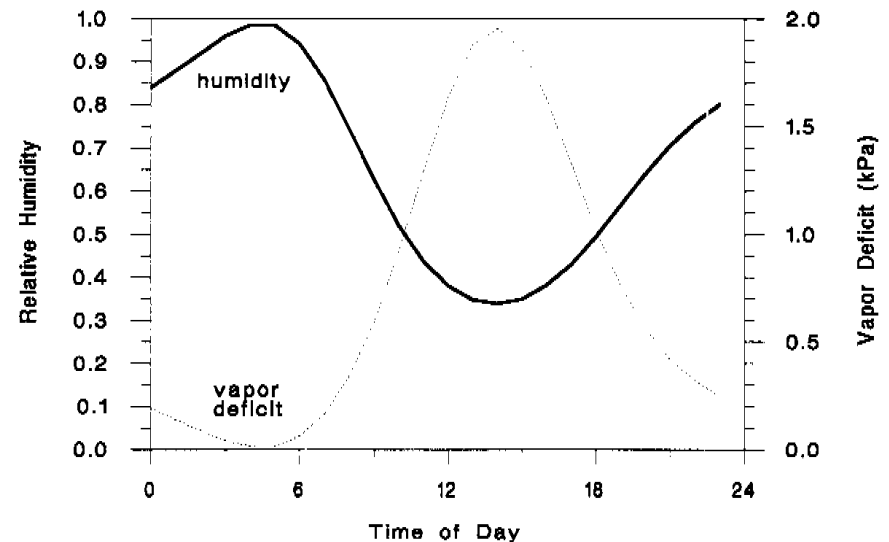


FIGURE 3-3. Diurnal variation in relative humidity and atmospheric vapor deficit for the temperature variation in Fig. 2.2. Vapor pressure is assumed to be constant throughout the day at 1.00 kPa.

Homework 1:

Due on Sept 26, 2017

GEO892: Micrometeorological Instrumentation and Measurements
09/07/2017

Calculating VPD and Related Variables

Vapor pressure, vapor pressure deficit (VPD), and other important physical variables are the necessary drivers in many ecosystem models. In practice, however, only air temperature (T_a , °C) and relative humidity (h, %) are measured or reported. This homework is designed to use the 30-min mean air temperature and relative humidity to calculate and graph changes of the following variables: VPD, e_s , e_a , T_d , and T_w . Here are some important relationships as discussed during the lecture:

1.1 Relationship between vapor density to pressure

$$E = \frac{2170 * e}{T_a}$$

where E is in kg.m^{-3} , e is in Pa, and T is in K.

1.2 Conversion of temperatures

$$T(^{\circ}\text{C}) = T(\text{K}) - 273.15$$
$$T(^{\circ}\text{C}) = T(^{\circ}\text{F}) * 9/5 + 32$$

1.3 VPD

$$\Delta = e_s - e_a$$

1.4 Calculation of e_s from T_a (Tetens equation)

$$e_s = 0.6118 * e^{\left(\frac{17.502 T_a}{T_a + 240.97}\right)}$$

where T_a is in C. Alternatively, Fritschen (1979) and Lowry (1977) used the following power functions:

$$e_s = (6.1078 + \frac{7}{T_a} (0.44365185 + \frac{7}{T_a} (0.01428945 + \frac{7}{T_a} (0.00026506485 + \frac{7}{T_a} (3.0312404 * 10^{-6} + \frac{7}{T_a} (2.034809 * 10^{-8} + \frac{7}{T_a} * 6.1368209 * 10^{-11})))))) / 10 \quad 1.5$$

calculation of E_s from T_a

$$E_s = \frac{e_s}{4.62 * 10^{-4} * (T_a + 273.15)}$$

1.6 Calculation of actual vapor density from h

$$E_a = \frac{h_r * E_s}{100}$$

Homework 1:

1.7 Calculation of actual vapor pressure (e_a). This is the reversion of 2.5

$$e_a = 4.62 * 10^{-4} * E_a * (T_a + 273.15)$$

1.8 Calculation of T_d (this is the reversion of the Tentens equation in 2.4). Note that parameters are slightly different because of the source (Fritschen 1979).

$$T_d = \frac{237.3 * \log\left(\frac{e_a}{0.61078}\right)}{17.269 - \log\left(\frac{e_a}{0.61078}\right)}$$

1.9 Calculation of T_w is given in Eq. 3.11 by Campbell & Norman (1998) on Page 42. By re-arrange the equation, T_w can be calculated as:

$$T_w = \frac{e_a + \gamma E_a T_a}{e_s + \gamma E_a}$$

where γ is called the thermodynamic psychrometer constant. It has a value of $6.66 * 10^{-4}$ with a slight temperature dependence. Note E_a should be in Pa.

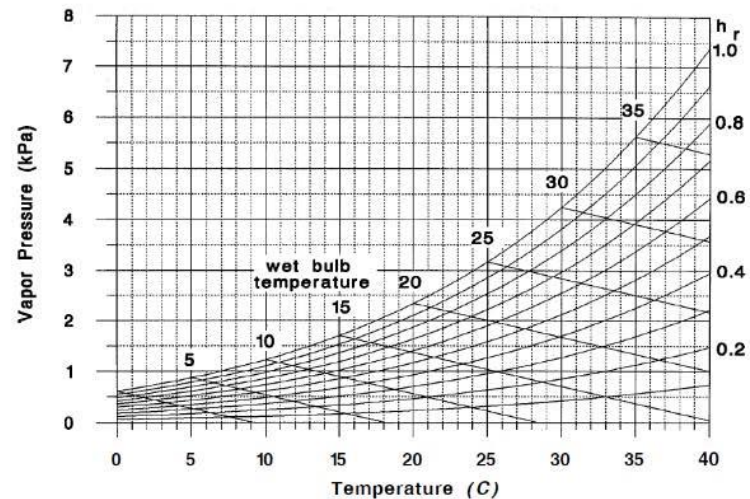


FIGURE 3.2. Vapor pressure-temperature-relative humidity-wet bulb temperature diagram. Wet bulb lines are for sea level pressure.

Water Vapor

TABLE A3. Temperature dependence of saturation vapor pressure, slope of the vapor pressure function, black body emittance, radiative conductance, and clear sky emissivity.

Temp K	Temp C	$e_s(T)$ kPa	Δ PaC ⁻¹	B W m ⁻²	g_r mol m ⁻² s ⁻¹	ϵ_α
268.2	-5	0.422	32	293	0.149	0.66
269.2	-4	0.455	34	298	0.151	0.67
270.2	-3	0.490	36	302	0.153	0.67
271.2	-2	0.528	39	307	0.154	0.68
272.2	-1	0.568	42	311	0.156	0.68
273.2	0	0.611	44	316	0.158	0.69
274.2	1	0.657	47	320	0.160	0.69
275.2	2	0.706	50	325	0.161	0.70
276.2	3	0.758	54	330	0.163	0.70
277.2	4	0.813	57	335	0.165	0.71
278.2	5	0.872	61	339	0.167	0.71
279.2	6	0.935	65	344	0.168	0.72
280.2	7	1.001	69	349	0.170	0.72
281.2	8	1.072	73	354	0.172	0.73
282.2	9	1.147	77	359	0.174	0.73
283.2	10	1.227	82	365	0.176	0.74
284.2	11	1.312	87	370	0.178	0.74
285.2	12	1.402	92	375	0.179	0.75
286.2	13	1.497	98	380	0.181	0.75
287.2	14	1.597	104	386	0.183	0.76
288.2	15	1.704	110	391	0.185	0.76

Lab Exercise: Programming multiple TCs, HMP45C, 107B, and LI190SB with CR23

- Parameters and sensor manuals
- Wiring and locations for data
- Scheduling (30 min vs 1-hour) (P92)
- Summary statistics (P71, 72, 73, etc.)
- Using the “Shortcut” in LoggerNet

Water

TABLE A5. Physical constants

Speed of light in vacuum	$2.997925 \times 10^8 \text{ m/s}$
Avagadro constant	$6.02252 \times 10^{23} \text{ mol}^{-1}$
Planck constant	$6.6256 \times 10^{-34} \text{ Js}$
Gas constant	$8.3143 \text{ J mol}^{-1} \text{ C}^{-1}$
Boltzmann constant	$1.38054 \times 10^{-23} \text{ J C}^{-1}$
Stefan-Boltzmann constant	$5.6697 \times 10^{-8} \text{ W m}^{-2} \text{ C}^{-4}$
