Lecture 6

Moisture and Humidity

6.1 The Hydrologic Cycle

Precipitation in all its forms-rain, snow, hail, and so on- is for many people the most notable feature of the atmosphere. Though the amount and timing of precipitation vary markedly from one region of Earth to another, the total amount of precipitation for the entire globe is relatively constant from one year to the next- at about 104 cm per year. However, the precipitation is compensated by the evaporation from the surface water and the atmospheric store will remain constant. The movement of water between and within the atmosphere and Earth is referred to as the **hydrologic cycle**. Figure (6.1) is a depiction of the hydrologic cycle.

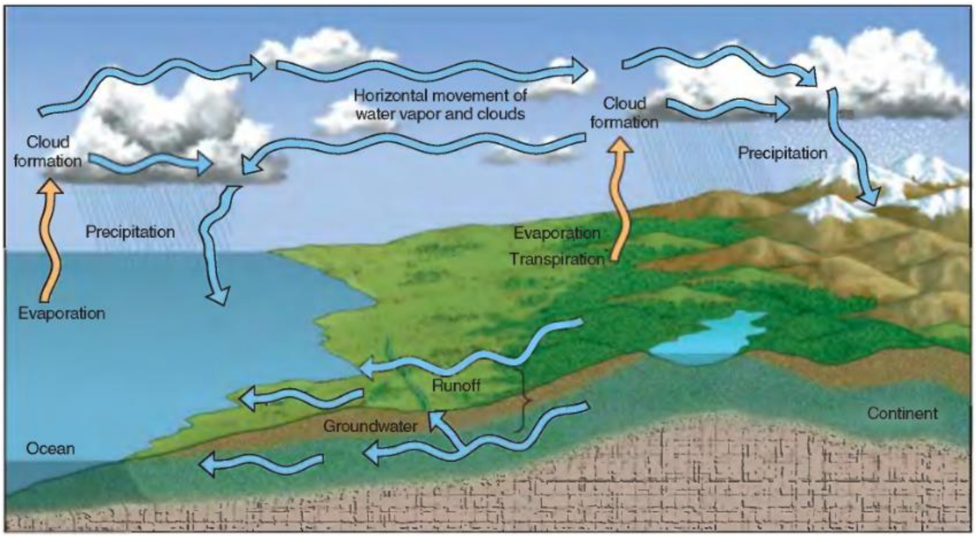


Fig. 6.1 The hydrologic cycle

6.2 Water Vapor and Liquid Water

Although matter in the gaseous phase is highly compressible, the density of a gas cannot be increased to an arbitrarily high level. At some point a limit is reached, forcing a change to liquid or solid state. For one atmospheric gas, water vapor, that limit is routinely achieved at temperatures and pressures found on Earth (other gases such as O_2 is liquefied at very low temperatures.)

Air that contains as much water as possible is said to be **saturated**, and the introduction of additional water vapor results in formation of water droplets or ice crystals.

6.3 Evaporation and Condensation

Figure (6.2) depicts a hypothetical experiment, in which a tightly sealed container is partially filled with pure water. Assume that at the onset of the experiment, no water vapor exists in the volume of the container above the water surface.

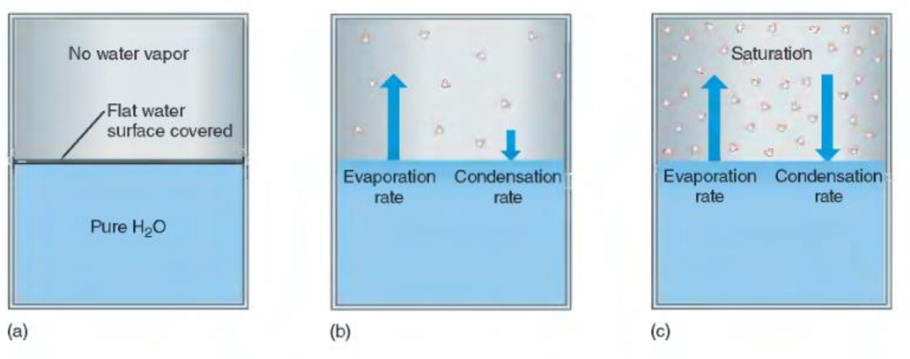


Fig. 6.2
A hypothetical experiment

Fig. 6.2b some of the molecules at the surface can escape into the overlying volume as water vapor. The process whereby molecules break free of the liquid volume is known as **evaporation**. The opposite process is **condensation**, wherein water vapor molecules randomly collide with the water surface and bond with the adjacent molecules.

At the early stages of evaporation, the low water vapor content prevents much condensation from occurring, and the rate of evaporation exceeds that of condensation. This leads to an increasing of water vapor content, however, the condensation rate likewise increases. Eventually, the amount of water vapor above the surface is enough for the rates of condensation and evaporation to become equal, as shown in Figure (6.2c). The resulting equilibrium state is called **saturation**. When this equilibrium is exists in the atmosphere, the air is said to be saturated. It is also important to realize that the exchange of water vapor and liquid described here applies as well to the change of the phase between water vapor and ice. The change of phase directly from ice to water vapor, without passing into the liquid phase, is called **sublimation**. The reverse process (from water vapor to ice) is called **deposition**.

6.4 Indices of Water Vapor Content

Humidity refers to the amount of water vapor in the air. Humidity can be expressed in a number of ways- in terms of the density of water vapor, the pressure exerted by water vapor, the percentage of the amount of water vapor that can actually exist, or several other methods. There is no single “correct” measure, but, rather, each has its own advantages and disadvantages, depending on the intended use. All measures of humidity have one thing in common, however-they apply exclusively to water vapor, and not to liquid droplets or ice crystals suspended in or falling through the air. Let us now take a look at these measures.

A. Vapor Pressure

Because water vapor seldom accouns for more than 4% of the total atmospheric mss, it exerts only a small percentage of the total air pressure. The part of the total atmospheric pressure due to water vapor is referred to as the **vapor pressure**.

The vapor pressure of a volume of air depends on both the temperature and the density of water vapor molecules. If the air temperature is high, water vapor molecules (along with all the other gaseous constituents of the atmosphere) more rapidly and exert a greater pressure. Similarly, a greater concentration of water vapor molecules means that a greater amount of mass is available to exert pressure. Because there is a maximum amount of water vapor that can exist, there is a corresponding maximum vapor pressure, called the **saturation vapor pressure**. The saturation vapor pressure does not represent the current amount of moisture in the air; rather, it is an expression of the maximum that *can* exist. The saturation vapor pressure depends on only one variable- temperature (see Fig. 6.3).

B. Absolute Humidity

Another measure of water vapor content is the **absolute humidity**, which is simply the density of water vapor, expressed as the number of grams of water vapor contained in a cubic meter of air. Because absolute humidity represents the amount of moisture contained in a volume of air, its value changes whenever air expands or contracts.

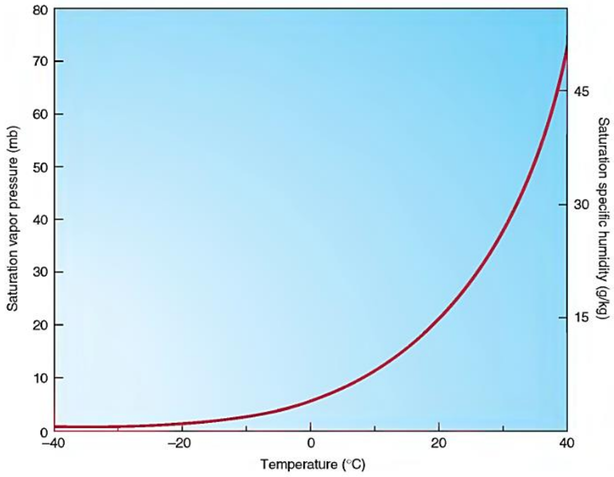


Fig. 6. 3. Saturation vapor pressure and saturation specific humidity as a function of temperature. The curve is steeper at higher temperatures, meaning that saturation vapor pressure is more sensitive to temperature changes when the air is warm.

C. Specific Humidity

Although not normally encountered outside scientific applications, specific humidity is a useful index for representing atmospheric moisture. Specific humidity expresses the mass of water vapor existing in a given mass of air. Most often, specific humidity is expressed as the number of grams of water vapor per kilogram of air. Specific humidity, q, is expressed mathematically as

$$q = \frac{m_v}{m} = \frac{m_v}{m_v + m_d}$$

where m_v is the mass of water vapor, m is the mass of atmosphere, and m_d is the mass of dry air (all the atmospheric gases other than the water vapor). Unlike absolute humidity, specific humidity has the advantage of not changing as air expands or contracts. Because there is a maximum amount of water vapor that can exist at a particular temperature, there is likewise a **maximum specific humidity** (see Fig 6.3),

D. Mixing Ratio

The mixing ratio is very similar to specific humidity. In the case of specific humidity, we express the mass of water vapor in the air as a proportion of *all* the air. In contrast, the mixing ratio, r, is a measure of the mass of water vapor relative to the mass of the other gases of the atmosphere, or $r = \frac{m_v}{m_d}$

Using the mixing ratio as an index of moisture content offers the same advantages as using the specific humidity. The maximum possible mixing ratio is called the **saturation mixing ratio**.

E. Relative Humidity

The most familiar measure of water vapor content is **relative humidity**, RH, which relates the amount of water vapor in the air to the maximum possible at the current temperature. The World Meteorological Organization (WMO) defines the relative humidity as,

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

Ex: mixing ratio= 6 g/kg for dry air, and the temperature of 14 ^{o}C yields a saturation mixing ratio of 10 g/kg of dry air. The relative humidity would thus be

$$RH = \frac{6}{10} \times 100\% = 0.6\ \times 100\% = 60\%$$

Whereas the American Meteorological Society has a slightly different definition,

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

The relative humidity is not uniquely determined by the amount of water vapor present. Because more water vapor can exist in warm air than in cold air, the relative humidity depends on both the actual moisture content and the air temperature. If the temperature of the air increases, more water vapor can exist and the ratio of the amount of water vapor in the air relative to saturation decreases. Thus, the relative humidity declines even if the moisture content is unchanged. Because of its dependence on temperature, the relative humidity will change throughout the course of the day even if the amount of moisture in the air is unchanged. Relative humidity is usually highest in the early morning – not because of abundant water vapor, but simply because the temperature is lower (see Fig. 6.4).

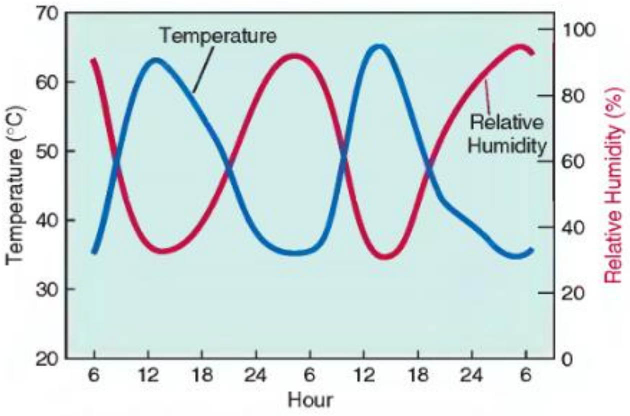


Fig. 6. 4. Typical pattern of daily temperature and relative humidity values

F. Dew Point

A useful moisture index that is free of the temperature relationship just described is the **dew point temperature** (or simply the **dew point**), the temperature at which saturation occurs. This quantity may seem confusing at first because it is expressed as a temperature, but it is a simple index to use an easy to interpret. It is dependent almost exclusively on the amount of water vapor present.

The dew point is a valuable indicator of the moisture content; when the dew point is high, abundant water vapor is in the air. Moreover, when combined with air temperature, it is an indicator of the relative humidity. When the dew point is much lower than the air temperature, the relative humidity is very low. When the dew point is nearly equal to the air temperature, the relative humidity is high. Furthermore, when the air temperature and the dew point are equal, the air is saturated and the relative humidity is 100%.

The dew point is always equal to or less than the air temperature; under no circumstances does it ever exceed the temperature. So what happens if the air temperature is lowered to the dew point and then cooled further? In that case, the amount of water vapor exceeds the amount that can now exist, and the surplus is removed from the air. This happens by condensation of water vapor to form a liquid of by the formation of ice crystals.

6.5 Measuring Humidity

The simplest and most widely used instrument for measuring humidity, the sling psychrometer (Fig 6.5), consists of a pair of thermometers, one of which has a cotton wick around the bulb that is saturated with water. The other thermometer has no such covering and simply measures the air temperature. The two thermometers, called the wet bulb and dry bulb thermometers, respectively, are mounted to a pivoting device that allows them to be circulated ("slung") through the surrounding air.

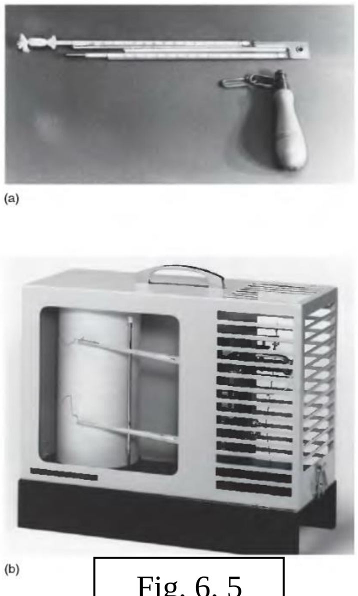


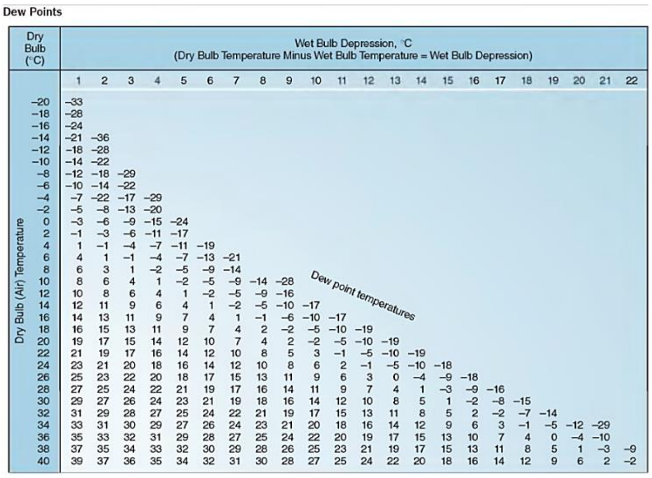
Fig. 6. 5

If the air is unsaturated, water evaporates from the wet bulb, whose temperature falls as latent heat is consumed. After about a minute or so of circulating, the amount of heat lost by evaporation is offset by the input of sensible heat from the surrounding, warmer air, and the cooling ceases. Thereafter, the wet bulb maintains a constant temperature no matter how long the instrument is swung around.

The difference between the dry and wet bulb temperatures, called the **wet bulb depression**, depends on the moisture content of the air. If the air is completely saturated, no net evaporation occurs from the wet bulb thermometer, no latent heat is lost, and the wet bulb temperature equals the dry bulb temperature. On the other hand, if the humidity is low, plenty of evaporation will take place from the wet bulb, and its temperature will drop considerably before reaching an equilibrium value. To determine the moisture content, first you note the difference between the dry and wet bulb temperatures. Then, with the use of certain tables (6.1), you obtain the dew point, relative humidity, etc.

Another alternative to the sling psychrometers is the hair hygrometer, whose basic part is a band of human hair. Hair expands and contracts in response to the relative humidity. By connecting stands of hair to a lever mechanism, we can easily determine the water vapor content. Often, the hygrometer is coupled with a bimetallic strip and a rotating drum to give a continuous record of temperature and humidity. Such a **hygrothermograph** is shown if Fig. (6.5b).

Table (6.1)

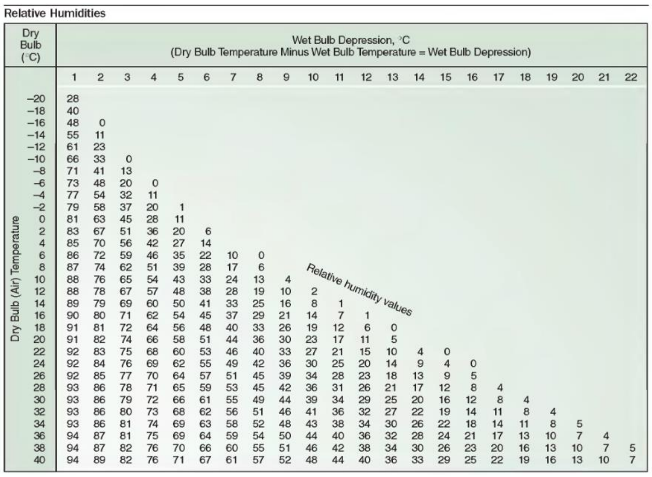


Dew Points

Dry Bulb (°C)	Wet Bulb Depression, °C (Dry Bulb Temperature Minus Wet Bulb Temperature = Wet Bulb Depression)																					
Dry Bulb (Air) Temperature	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
−20	−33																					
−18	−28																					
−16	−24																					
−14	−21	−36																				
−12	−18	−28																				
−10	−14	−22																				
−8	−12	−18	−29																			
−6	−10	−14	−22																			
−4	−7	−22	−17	−29																		
−2	−5	−8	−13	−20																		
0	−3	−6	−9	−15	−24																	
2	−1	−3	−6	−11	−17																	
4	1	−1	−4	−7	−11	−19																
6	4	1	−1	−4	−7	−13	−21															
8	6	3	1	−2	−5	−9	−14															
10	8	6	4	1	−2	−5	−9	−14	−28													
12	10	8	6	4	1	−2	−5	−9	−16													
14	12	11	9	6	4	1	−2	−5	−10	−17												
16	14	13	11	9	7	4	1	−1	−6	−10	−17											
18	16	15	13	11	9	7	4	2	−2	−5	−10	−19										
20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19									
22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19								
24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18							
26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9	−18						
28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3	−9	−16					
30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1	−2	−8	−15				
32	31	29	28	27	25	24	22	21	19	17	15	13	11	8	5	2	−2	−7	−14			
34	33	31	30	29	27	26	24	23	21	20	18	16	14	12	9	6	3	−1	−5	−12	−29	
36	35	33	32	31	29	28	27	25	24	22	20	19	17	15	13	10	7	4	0	−4	−10	
38	37	35	34	33	32	30	29	28	26	25	23	21	19	17	15	13	11	8	5	1	−3	−9
40	39	37	36	35	34	32	31	30	28	27	25	24	22	20	18	16	14	12	9	6	2	−2

Dew point temperatures

Table (6.2)



Relative Humidities

Dry Bulb (°C)	Wet Bulb Depression, °C (Dry Bulb Temperature Minus Wet Bulb Temperature = Wet Bulb Depression)																					
Dry Bulb (Air) Temperature	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
−20	28																					
−18	40																					
−16	48	0																				
−14	55	11																				
−12	61	23																				
−10	66	33	0																			
−8	71	41	13																			
−6	73	48	20	0																		
−4	77	54	32	11																		
−2	79	58	37	20	1																	
0	81	63	45	28	11																	
2	83	67	51	36	20	6																
4	85	70	56	42	27	14																
6	86	72	59	46	35	22	10	0														
8	87	74	62	51	39	28	17	6														
10	88	76	65	54	43	33	24	13	4													
12	88	78	67	57	48	38	28	19	10	2												
14	89	79	69	60	50	41	33	25	16	8	1											
16	90	80	71	62	54	45	37	29	21	14	7	1										
18	91	81	72	64	56	48	40	33	26	19	12	6	0									
20	91	82	74	66	58	51	44	36	30	23	17	11	5									
22	92	83	75	68	60	53	46	40	33	27	21	15	10	4	0							
24	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4	0						
26	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9	5						
28	93	86	78	71	65	59	53	45	42	36	31	26	21	17	12	8	4					
30	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16	12	8	4				
32	93	86	80	73	68	62	56	51	46	41	36	32	27	22	19	14	11	8	4			
34	93	86	81	74	69	63	58	52	48	43	38	34	30	26	22	18	14	11	8	5		
36	94	87	81	75	69	64	59	54	50	44	40	36	32	28	24	21	17	13	10	7	4	
38	94	87	82	76	70	66	60	55	51	46	42	38	34	30	26	23	20	16	13	10	7	5
40	94	89	82	76	71	67	61	57	52	48	44	40	36	33	29	25	22	19	16	13	10	7

Relative humidity values

Homework:

1. What is the hydrologic cycle?
2. What is the deposition and sublimation?
3. What is vapor pressure?
4. Explain the concepts of equilibrium and saturation.
5. Define relative humidity.
6. Why is relative humidity a poor indicator of the amount of water vapor in the air?
7. Define dew point. What characteristics make this measure superior to relative humidity?
8. What are psychrometers? How do they work?