Thunderstorms are deep convective storms that turbulently mix air over the whole depth of the troposphere. The fuel for such storms is humidity in the prestorm mixed layer. When this ML air is drawn into the storm via the storm updrafts, water vapor condenses and falls out as rain. Meanwhile, drier air from the mid-troposphere is often brought down towards the surface to create a new, but drier, post-storm atmospheric boundary layer (ABL). Some of the falling rain can evaporate into this drier ML, increasing the humidity there.

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4.6. HUMIDITY INSTRUMENTS

Instruments that measure humidity are called **hygrometers**. Don't confuse the word with "hydrometers", which are used to measure specific gravity of fluids such as battery acid.

Dew-point hygrometers, also known as **chilled-mirror hygrometers**, reflect a beam of light off a tiny metal mirror. When the mirror is cooled to the dew-point temperature, dew forms on the mirror and the light beam scatters instead of reflecting into a detector. Electronics in the instrument cool or heat the mirror to maintain the surface precisely at the dew-point temperature, which is provided as an output. These are accurate instruments with relatively slow response. For cold temperatures and low humidities, **frost-point hygrometers** are used instead.

Hair hygrometers use organic fibers such as long hairs, anchored at one end and attached at the other end by amplifying levers to a dial that reads out relative humidity. As the RH increases, the hairs get longer, causing the dial to turn. These are inaccurate, but are inexpensive and are the most common hygrometers for home use. Any material that changes dimensions when absorbing water molecules can be used in hygrometers. One example is a **bi-material coil** that rotates as humidity changes.

Psychrometers are instruments with two liquid-in-glass thermometers attached to a board or frame. The bulb of one thermometer is surrounded by a sleeve or wick of cloth that is saturated with distilled water, while the other bulb remains dry. After both thermometers are actively ventilated [by whirling the instrument through the air on a hand-held axel (**sling psychrometer**), or by using a spring or electrically driven fan to blow air past the thermometers (**aspirated psychrometer**)], the two thermometers are read to give the **wet and dry-bulb temperatures**. The wet-bulb is cooler than the dry, because of the latent heat absorbed when water evaporates. This thermodynamic informa-

tion can be used with psychrometric tables or charts (Figs. 4.4 & 4.5) to determine the humidity. These instruments are extremely slow response, but relatively simple. Modern psychrometers replace the liquid-in-glass thermometers with electronic thermometers such as thermistors.

In old **radiosondes** (balloon-borne weather instruments), the electrical resistance across a carbon-coated glass slide was measured. In more humid air, this **carbon-film hygrometer** becomes more resistive. Modern radiosondes often measure the capacitance across a very thin dielectric plastic that is coated on both sides with a porous metallic grid. Both approaches are small and light enough to be carried aloft, but both sensors can be easily contaminated by chemical vapors that change their electrical properties.

Microwave refractometers draw air into a small chamber filled with microwaves. The refraction (bending) of these microwave beams depends on humidity (see the radar section of the Satellites & Radar chapter), and can be measured. These are very fast-response sensors.

Spectral absorption hygrometers, also known as **optical hygrometers**, transmit frequencies of electromagnetic radiation that are strongly absorbed by water vapor. By passing the beam of radiation across a short path of air to a detector, the amount of attenuation can be measured to allow calculation of the absolute humidity. One such instrument, the **Lyman-alpha hygrometer,** uses ultraviolet light of wavelength 0.121567 μm, corresponding to an absorption/emission line of hydrogen. Another, the **krypton hygrometer**, uses emissions at 0.12358 μm, generated by a glow tube filled with the noble gas krypton. Other instruments use absorption of infrared light (**infrared hygrometers**). These are all fast-response instruments. See the Satellites & Radar chapter for absorption spectra across the atmosphere.

Some **lidars** (laser radars) have been developed to transmit two neighboring wavelengths of electromagnetic radiation, one of which is affected by water vapor and the other which is not. Such **differential absorption lidars** (**DIAL**) can remotely measure humidity along vertical or slant paths, and can scan the atmosphere to measure the humidity in a volume or in a plane.

Weather radars and other microwave profilers can be used to measure profiles of humidity in the atmosphere, because the speed and/or polarity of microwaves through air depends on humidity.

Some sensors measure path-averaged humidity. One example is the **water-vapor channel on weather satellites**, which measures infrared emissions from water vapor in the air. As discussed in

the Satellites & Radar chapter, such emissions come from a layer of air several kilometers thick in the top third of the troposphere. These instruments have the advantage of remotely sampling the atmosphere at locations that are difficult to reach otherwise, such as over the oceans. A disadvantage is that they have difficulty seeing through clouds.

Transmissions from **Global Positioning System** (**GPS**) satellites are slightly delayed or refracted by humidity along the path of the beam through the atmosphere. However, data from many such crossing beams from the constellation of GPS satellites can be computationally inverted to yield vertical profiles of humidity, similar to the medical X-ray tomography methods used for brain scans.

4.7. REVIEW

Many different variables can be used as measures of water-vapor content in air, including: water-vapor partial pressure (known as vapor pressure in meteorology), mixing ratio, absolute humidity, specific humidity, relative humidity, dew-point temperature, lifting condensation level, and wet-bulb temperature. Some of these variables can be used to quantify total water (vapor + liquid + ice).

Formulas exist to convert between these different variables. Some of these humidity variables can be easily measured by instruments called hygrometers, others are useful in conservation equations, while others are commonly known by the general public.

The amount of water actually being held in the air might be less than the maximum amount that could be held at equilibrium, where this equilibrium value is known as the saturation humidity. Cooler air can hold less water vapor at saturation than warmer air — a fact that is critical in understanding why clouds and storms form in rising, cooling air.

By following such a rising or sinking air parcel we can write a Lagrangian moisture budget and calculate adiabatic temperature changes for air that is saturated (foggy or cloudy). A graphical description of this process can be represented as moist adiabats on a thermo diagram. Saturated rising air does not cool as rapidly with altitude as dry air. Thermo diagrams can also include isohume lines that relate humidity state to temperature and pressure.

An alternative frame of reference is Eulerian, which is fixed relative to a location on the Earth's surface. To forecast humidity in such a fixed frame, we can account for the advection of moisture by the winds, the fluxes of moisture due to turbulence, and effects due to precipitation. Clouds and precipitation are discussed in subsequent chapters.

4.8. HOMEWORK EXERCISES

4.8.1. Broaden Knowledge & Comprehension

B1. Use the internet to acquire the current humidity at a weather station near you. What type of humidity variable is it?

B2. Use the internet to acquire a current weather map of humidity contours (isohumes) for your region. Print this map and label regions of humid and dry air.

B3. At the time this chapter was written, a web page was available from the National Weather Service in El Paso, Texas, that could convert between different weather variables (search on "El Paso weather calculator"). How do the formulas for humidity on this web page compare to the ones in this chapter?

B4. Use your internet search engine to find additional "weather calculators" that can convert between different units, other than the calculator mentioned in the previous problem. Which one do you like the best? Why?

B5. Use the internet to acquire the company names and model numbers of at least two different instruments for each of 3 different methods for sensing humidity, as was discussed on the previous page.

B6. Two apparent-temperature indices (humidex and heat index) describing heat stress or summer discomfort were presented in the Thermodynamics chapter. Use the internet to acquire journal articles or other information about any two additional indices from the following list:
• **apparent temperature**,
• **discomfort index**,
• **effective temperature**,
• **humisery**,
• **humiture**,
• **index of thermal stress**.
• **livestock weather safety index**,
• **summer simmer index**,
• **temperature-humidity index** (THI),
• **wet-bulb globe temperature**,

B7. Use the internet to acquire a weather map for your region showing isohumes (either at the surface, or at 85 or 70 kPa). For one Eulerian location chosen by your instructor, use the winds and horizontal humidity gradient to calculate the horizontal moisture advection. State if this advection would cause the air to become drier or more humid. Also, what other factors in the Eulerian water balance equation could