Contents

1. Precipitation

As we saw earlier, global precipitation is affected by atmospheric circulation patterns. The formation of precipitation requires a four-step process:

1. Cooling of air to approx. the dew point temperature
2. Condensation on nuclei to form cloud droplets or ice crystals
3. Growth of droplets or crystals into raindrops, snowflakes or hailstones
4. Importation of water vapor to sustain the process.

1a. *Cooling*

to achieve dew point can come from 1. radiation 2. mixing with a cooler body of air 3. conduction to a cool surface 4. adiabatic cooling by horizontal movement to a region of lower pressure or 5. adiabatic cooling by vertical uplift. Cooling by the first four of these processes may produce fog or drizzle, but only vertical uplift can cause rates of cooling high enough to produce precipitation.

Cooling by uplift can occur in one of four ways: Uplift due to convergence, uplift due to convection, uplift due to orography

If the parcel is unsaturated, it will cool at the *dry adiabatic lapse rate* of 10 $^{\circ}C/km$. However, if condensation occurs, its temperature will decrease at the *moist adiabatic lapse rate* which varies with temperature, initial vapor pressure and elevation, but is typically about 5 or $5^{\circ}C/km$.

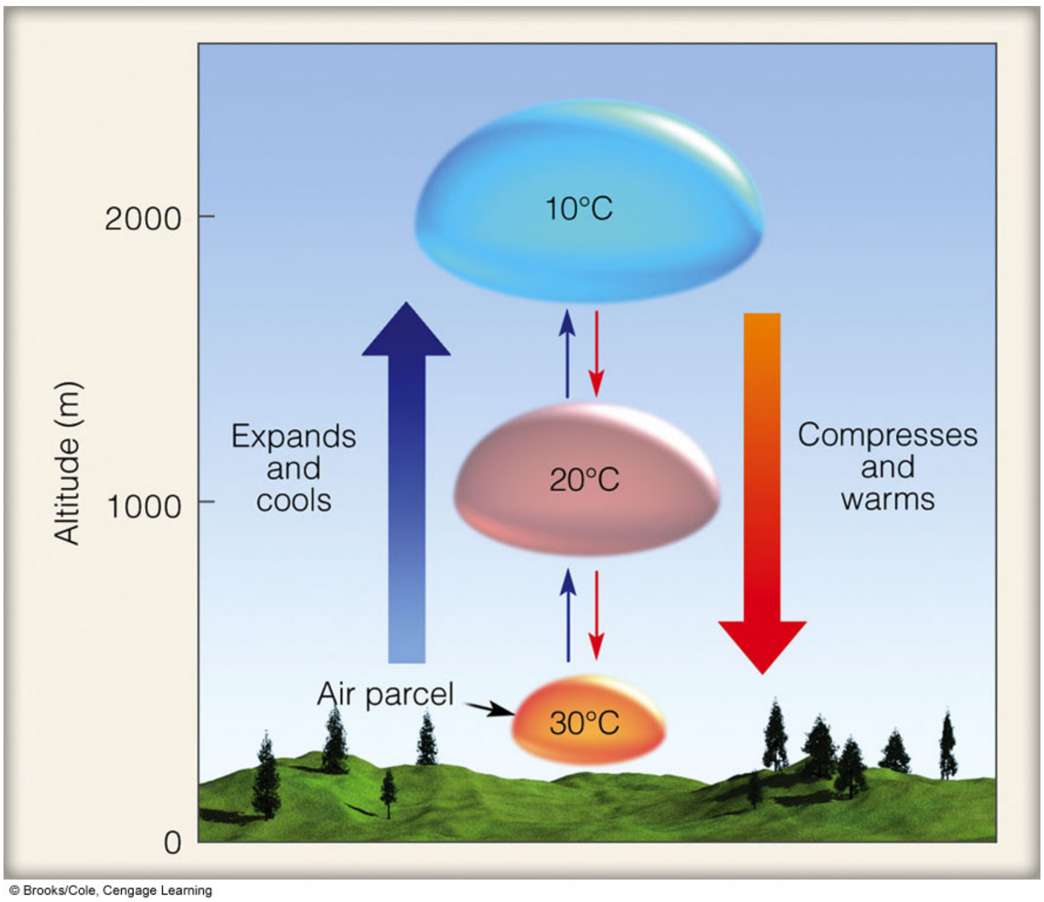

Figure 1: Unsaturated air adiabatic cooling and heating. from Ahrens

There are three different ways in which significant rates of adiabatic cooling by vertical uplift occur: **Uplift Due to Convergence**. Low pressure areas at the surface are associated with convergence where air is forced to rise and cause adiabatic cooling. There can be frontal convergence in the midlatitudes and nonfrontal convergence in the tropics. Between 30° and 60° (midlatitudes) the precipitation is associated with *extra-tropical cyclones*. These cyclones form where air masses of different characteristics meet. *Cyclogenesis* takes place at the fronts with a region of low pressure and cold air to the north and warm air to the south. A counter-clockwise circulation develops with a cold front to the west of the apex and a warm front to the east. Precipitation is associated to both fronts but mainly in the cold front. The isobars now form a circular pattern around the low pressure apex of around 1500km. Cold front usually takes over the warm front to form an occlusion. The process stops when the temperature differences and pressure differences erode. This process takes one or two days. The result of these storms, in addition to precipitation, is an equatorial transfer of cold air and a poleward transfer of warmer air and latent heat of condensation.

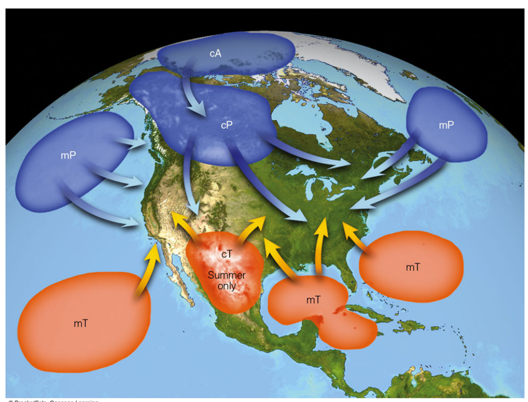

Figure 2: Air masses. from Ahrens

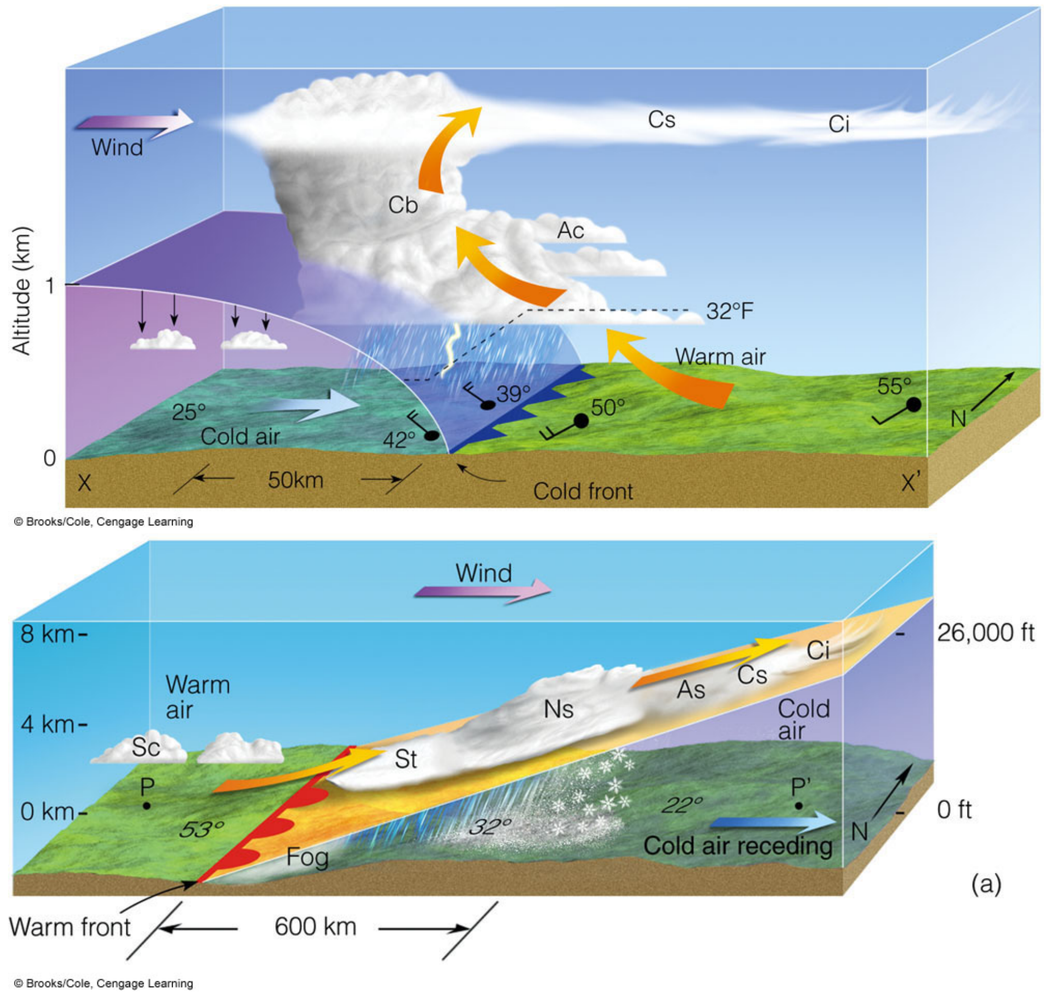

Figure 3: Cold front (top) and warm front (bottom). from Ahrens

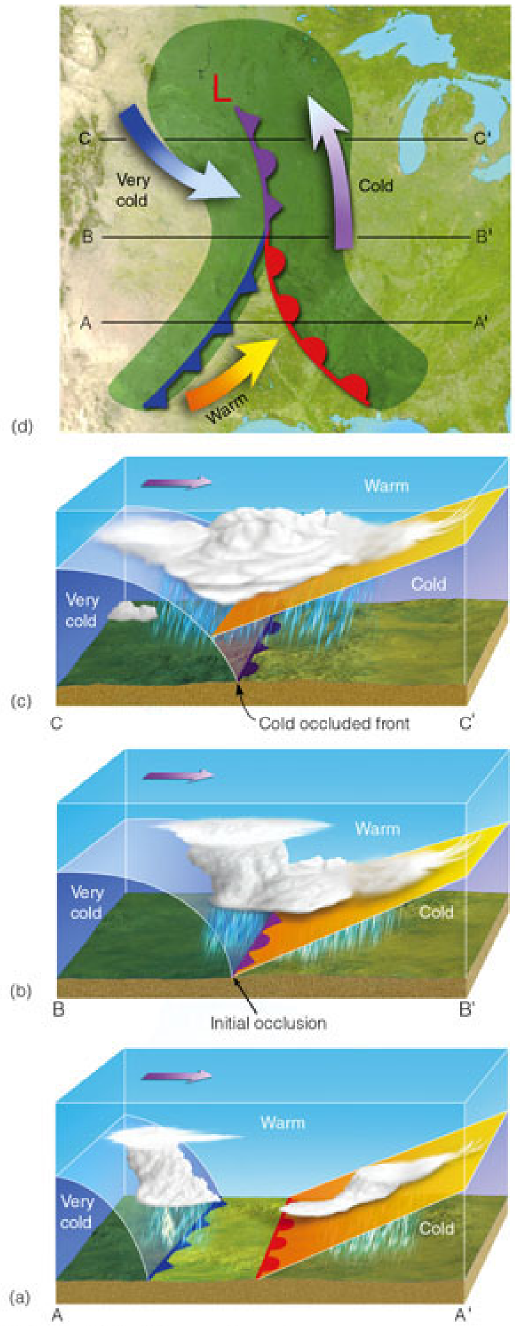

Figure 4: Occluded front. from Ahrens

Non-frontal Convergence in the tropics is associated with the ITCZ, and storms that form over the tropical ocean. The ITCZ forms an equatorial band of heavy precipitation. Tropical cyclones form over the oceans and can grow into hurricanes. Sea-surface temperatures of at least 27°C are required to induce high rates of evaporation - and the system is fed by evaporation.

Hurricanes develop as energy from the ocean (sensible and latent heat) is transferred into the storm.

1. The inflow at the surface from the winds picks up heat and moisture from the warm underlying ocean

2. There is a center of low pressure at the surface and the winds flow counterclockwise around the center in the NH.

3. This air is then lifted either in the outer rain bands or in the eyewall. Creates and maintains thunderstorms

4. At upper levels, the air is then carried anticyclonically outwards (divergent outflow) and subsides at outer radii, or it sinks in the eye.

5. The air that sinks in the eye warms by compression creating the warm core and suppressing cloud development there.

6. This additional warming is crucial to maintaining such a low pressure at the surface. The divergence aloft is not nearly strong enough to maintain such a low pressure at the surface.

So the hurricane is a warm-cored, low pressure weather system. In order to maintain the low pressure (intensity) the upper-level warm core must be maintained.

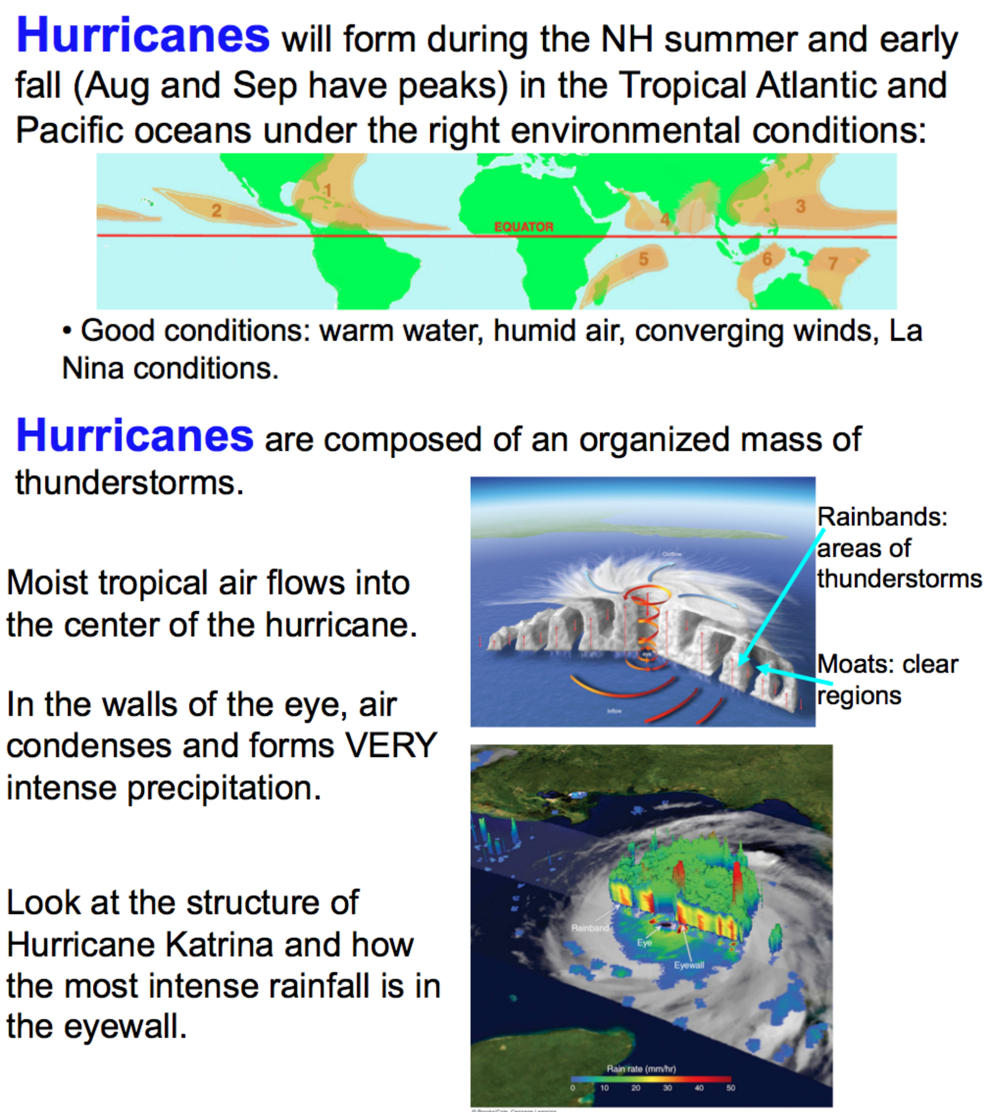

Figure 5: Hurricanes

Uplift due to Convection arises when parcels rise because they are less dense than the air that surrounds them. During the day, air in contact with the surface is warmed and rises. It cools initially at the dry adiabatic rate until it attains environmental temperature. If the parcel becomes saturated it starts to rise at the moist adiabatic lapse rate, you get popcorn cumulus clouds this way.

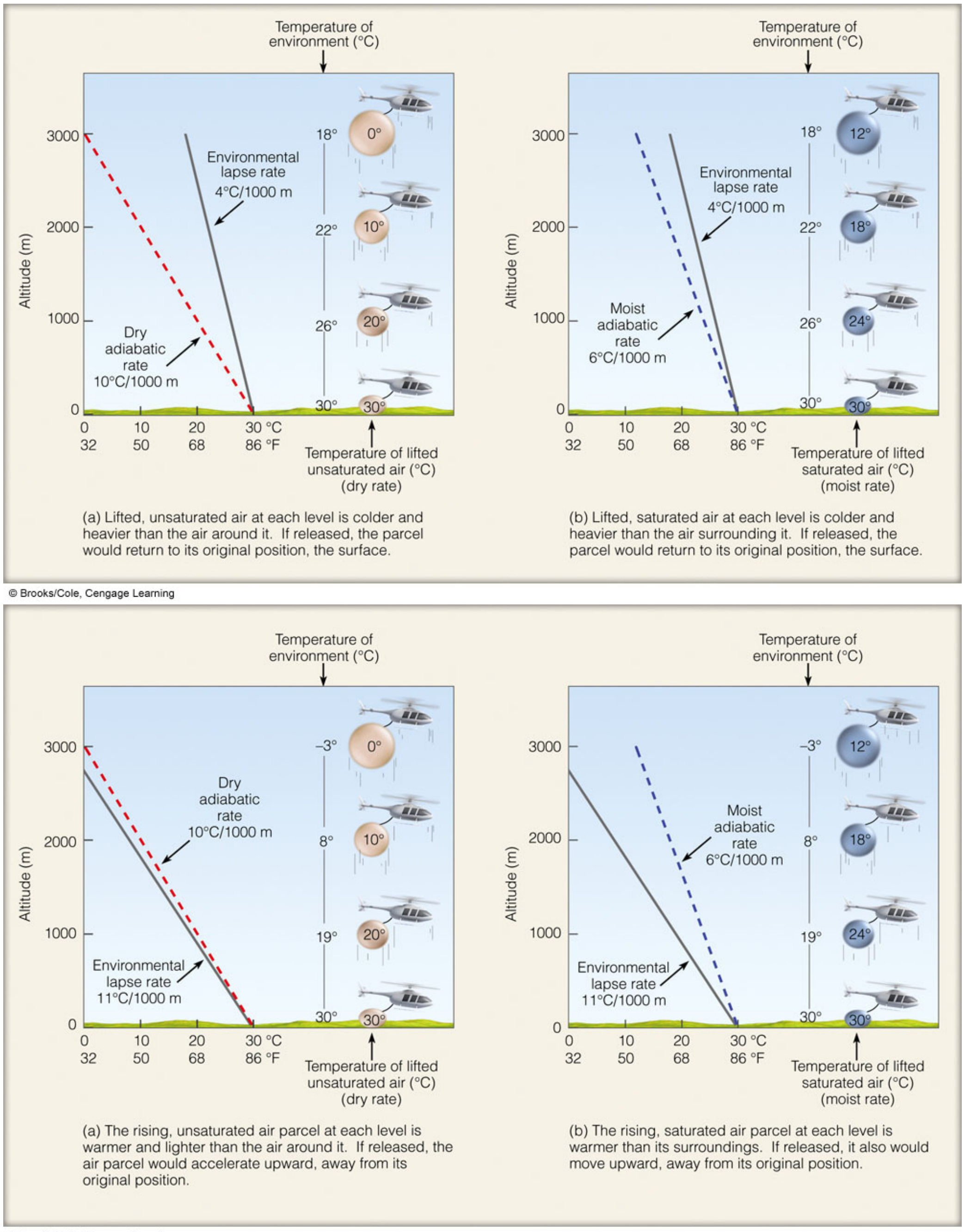

Figure 6: from Ahrens

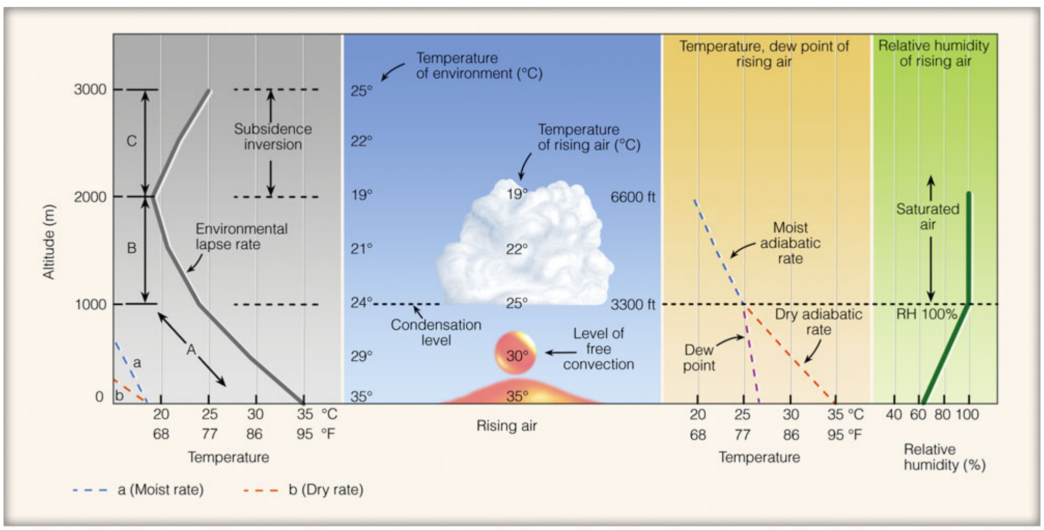

Figure 7: from Ahrens

Uplift due to orography occurs when air moving horizontally encounters a topographic barrier and acquires a vertical component of motion. Clouds and precipitation occur windward of the topographic crest, and as the air moves downward on the leeward slope there is adiabatic warming. The warming produces a rain shadow - typical of the Western US. In many, if not most, situations, orographic effects are the result of convective, frontal or cyclonic mechanisms interacting with topography. Topography has a tremendous effect on the spatial variation of precipitation.

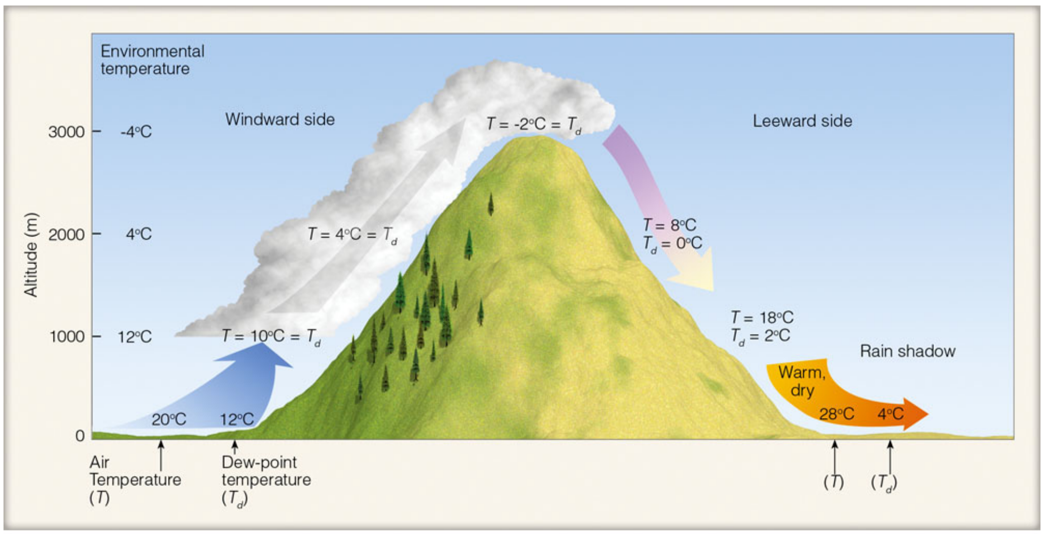

Figure 8: from Ahrens

2. Sources of Precipitation for the Monsoon Region

Most of the moisture at upper levels originates in the Gulf of Mexico and enters the region from the east, while lower-level moisture of oceanic sources originates predominantly from the tropical Pacific Ocean and the Gulf of California (Schmitz and Mullen 1996; Adams and Comrie 1997; Higgins et al. 2003). Surface moisture in the NAMS region also directly contributes to precipitation by providing evaporative sources for precipitable water (Bosilovich et al.,2003 and Dominguez et al.,2009).