Now, what happens when the atmosphere convects, and water changes phase? Well, in the tropics we have observed-- and, in fact, in the mid-latitudes-- we have observed that convection develops through a typical evolution, and consists of what we call convective cells typically a few kilometers in diameter, and reaching anywhere from a few kilometers above the surface all the way to the tropopause. And these cells evolve over a period of roughly an hour.

And it's convenient to quantize that evolution into three stages. The first stage, we call the towering cumulus stage. It may be the first 15 to 20 minutes of the lifetime of a cloud, shown here on the left. During this stage, air ascends to cloud base, water vapor condenses into tiny cloud droplets, which remain in suspension. But there has not been enough time, on the other hand, for this condensed water to develop into precipitation, through either the Bergeron process or through stochastic coalescence. So at this stage, the cloud has not precipitated.

Maybe 10 or 20 minutes later, the cloud or the cell may have developed all the way up to the tropopause, much deeper. And enough time has elapsed that precipitation forms. Now, some of this precipitation-- shown here, for example-- will fall outside of the envelope of saturated air that we call the cloud into unsaturated air and partially, or perhaps completely, re-evaporate. When this happens, the latent heat of the vaporization is absorbed. The air cools. And because it's cold, it's negatively buoyant and begins to accelerate downward toward the surface in the form of a downdraft.

This cold air spreads out at the surface, and the leading edge of that cold air-- shown, for example, here and here-- can often be very sharp. We call it a gust front. And it's one of the telltale signs of a convective shower or thunderstorm. As it approaches the observer, this front will go by. The wind will rapidly shift to be blowing away from the region of heaviest precipitation. And the temperature may drop a few degrees to as much as 10 degrees centigrade when that gusts front goes by.

Now, that cold, negatively buoyant air spreads out and gradually chokes off the supply of potentially buoyant air to the convection leading to the cell entering what's called its dissipation stage here. During this time, the cloud gradually mixes with its environment, the cloud water evaporates, and the cell dies over a period of about a half an hour or so.

Now, the typical air-mass shower consists not of one cell, but an agglomeration of cells. So here is a diagram of such an agglomeration, which is a typical summer afternoon thunderstorm at mid-latitudes, or a typical convective shower of the tropics. The scale here is in the units of statute miles. That's five statute miles there.

This shows the collection of cells in various stages of their evolution. And on the right-hand side, the same collection about 10 minutes later. So one can we see that there's been an evolution of some of the cells over that period of time. This sort of amorphous collection of cells is what we know as a summer afternoon thunder shower, or a convective shower, in the tropics. That's the form that deep moist convection usually takes in the climate system.

Here's a photograph taken in the Seychelles Islands, which are in the southern Indian Ocean near the equator, showing a collection of fairly shallow cumulus cells, but deep enough to precipitate. How do we know they're precipitating? Well, for one thing, we've got a rainbow here, which can only happen when sunlight refracts through drops large enough to fall as rain.

Here is your instructor walking on the beach. This is a nice photograph of a collection of these convective cells in the tropics. Here, at the top of the clouds, detrains from the cloud into the environment. And if this happens enough, the environment itself gets saturated, and you get these layers, in this case, of alto-cumulus clouds here, that result from the detrainment of the condensed and vapor phase water from the clouds.

Now, one property of moist convection that makes it very different from dry convection is the strong asymmetry between upward motion and downward motion. In ordinary dry convection, there's almost perfect up-down symmetry. The downdrafts look like the updrafts upside down. But this is not the case in precipitating convection. Air rises through these deep convective towers-- shown here, for example. And it rises quite quickly, at the rate of a few meters per second.

But air in between the clouds is sinking through an atmosphere which is stable to dry convective displacements-- that is, its dry entropy is actually increasing with altitude - it's stable. And so air has to cross surfaces of constant dry entropy. The only way it can do that in equilibrium is for the air to lose entropy, which it does by radiating in the infrared to space.

Well, on average, in a deep convecting atmosphere approximately in radiative moist convective equilibrium, the air in between clouds is cooling at a rate of between one degree and two degrees centigrade per day-- not very fast. And that air is sinking on the order of one or two centimeters per second. So we have a profound asymmetry in moist convection updrafts, on the order of one or two meters per second, occur inside clouds. And downdrafts on the order of one or two centimeters per second occur in between clouds.

The same amount of mass, on the other hand, has to be going up as coming down in equilibrium. And the only way to make that work out is if the deep clouds cover a very small fractional area of the sky. So typically in the tropics, deep convection occupies well less than 1% of the fractional area. This is a point we made earlier by looking at the photograph of moist convection. From an airplane, one sees that the fractional area covered by clouds in this photograph is quite small. Most of the sky is clear. The air is sinking while radiating heat to space in between the clouds-- again, at the slow rate of about a centimeter per second, whereas air is rising, particularly within deep clouds like this one, at the rate of a meter per second, or perhaps a bit more. The deep clouds particularly are widely spaced.

Let's do a recap of the properties of moist convection, as we observe and as theory informs us. As we have just said, convective updrafts are widely spaced. In equilibrium, the turbulent flux of enthalpy from the service must equal the vertically integrated radiative cooling. In other words, there must be enough convective flux of heat from the surface-- we'll call that the enthalpy flux-- to balance the vertically integrated radiative cooling.

Another aspect of this balance is that the air descending in between clouds is in thermal equilibrium, in the sense that the vertical velocity of the clouds represented here is a mass flux M times the temperature, times the vertical gradient of dry entropy, must equal the net radiative cooling. This mass flux is the same quantity as the net upward mass flux in clouds. It simply says that what goes up must come down. The upward mass flux in clouds must be the downward mass flux in between clouds. Again, that multiplied by the dry entropy gradient must balance radiative cooling, so that the temperature of any fixed point in space doesn't change in time.

Another balance that we must see in moist radiative convective equilibrium is a mass balance-- the amount of water evaporating from the ocean must equal the amount of water reentering the ocean through precipitation. So precipitation equals evaporation. But most of the surface enthalpy flux in the Earth's tropics is in the form of a latent heat flux-- that is, it's evaporation multiplied by the latent heat of evaporation.

So from the second statement above, we also have that evaporation is proportional to the radiative cooling of the atmosphere, which is a very important equilibrium for considering how the climate system works. A very important point about moist radiative convective equilibrium is that the radiation and convection are highly interactive. This is not a one-way street.

Radiation is what ultimately destabilizes the atmosphere and drives the convection. But convection lofts water substance, which through both its vapor and condensed phases, strongly affects radiative transfer. So the radiative transfer is strongly modulated by convection, and radiative cooling of the atmosphere is ultimately what drives the convection. All the proceeding allows us to construct a very simple radiative convective model for the moist atmosphere, and that will be the subject of the next video.