We're now in the position to talk about the stability of an atmosphere in which water is changing phase. Now recall that in the case of a dry atmosphere, we were able to develop a criterion for stability based upon a single state variable, the entropy. We discovered that when entropy decreases the altitude, the fluid is unstable to convection and will overturn, with warmer fluid rising and cooler fluid sinking.

In the case of a moist atmosphere, there is no equivalent simple stability criterion. But we do observe, on the other hand, that air inside ascending cumulus clouds has roughly the same density as that of its environment. So the principle of neutrality to convection still holds in the case of moist convection. That is, moist convection renders the atmosphere in which it's occurring nearly neutral to itself.

Now it can be shown that neutral stability corresponds very nearly to the constancy of the saturation entropy, s*, which is defined this way. So saturation entropy contains three terms. The first term is proportional to the log of the temperature, multiplied by the heat capacity at constant pressure. The second term is proportional to minus the log of pressure, multiplied by the gas constant of dry air. These two terms together are actually the definition of the ordinary dry entropy. The saturation entropy contains a third term, which is the product of the latent heat of vaporization, L sub v, and the saturation specific humidity, q star, divided by the temperature.

The saturation specific humidity is just the concentration of water vapor the atmosphere would have if it were saturated with water vapor at its current temperature and pressure. So s* is itself only a function of temperature and pressure. And lines of constant s* in a plane in which temperature is the abscissa, and pressure is on ordinate, are called moist adiabats.

Now if we look at the tropical atmosphere, we find remarkably that on average the temperature profile lies along such a moist adiabat. So what we see here is a graph on which we have temperature on the abscissa, and pressure decreasing upward along the ordinate. Pressure, of course, decreases upward monotonically, so we consider it to be a proxy for altitude. The solid line on this graph, going from the surface all the way up to zero pressure, represents an average, over many tropical soundings, of a quantity called the virtual temperature, which is very similar to the actual temperature, but contains a small correction for the effect of water vapor on the density of the air. It also shows a contour and dashed, along which s* is constant.

And you'll notice that through the bulk of the troposphere, that is up to an altitude at which the pressure is about 100 of these units called hectopascals or millibars, the sounding lies along a surface of constant s*. That means the tropical atmosphere, where it's convecting, is very nearly neutral to moist convection.

Now we can be a little bit more quantitative about this in the next diagram. What we've done in this case is to look at, again, several thousand soundings from over the tropical oceans. We've taken test samples from near the surface, and lifted them by a reversible adiabatic process, that is a moist adiabatic process, so that when water changes phase, the latent heat of vaporization is released to the atmosphere.

Now this diagram has pressure on the ordinate. Ignore the minus signs, by the way. This is the pressure to which the test sample is lifted. And on the abcissa-- again, ignore the negative signs, the minus signs-- we see the pressure from which the sample has been lifted. So in this particular case, the surface pressure is around 995 millibars or hectopascals. So the surface is over on the left bottom corner of this diagram. And to take an example, a parcel lifted from just above the surface, say 990 millibars, to a pressure of 200 millibars, will have a temperature a little bit more than 2 degrees larger than that of its environment.

So the quantity that's being contoured here is the difference between the lifted parcel's virtual temperature and the temperature of the environment. By the way, this particular virtual temperature, called the density temperature, also accounts for the condensate loading of the lifted parcel.

So air lifted from very close to the ocean will be positively buoyant, but not by very much. 2 degrees is not much when one considers that the temperature of the troposphere changes from about 30 degrees Centigrade on the surface, to about minus 70 degrees at around 150 millibars. So the total temperature change is over 100 degrees C. For the sample to be only 2 degrees warmer than its environment means that, within 2% or so, the sample has the same temperature as the environment.

Notice also that if we lift the parcel from about 950 millibars here, which happens to be about 500 meters typically, above the surface, which is around the base of tropical cumulus clouds, the sample lifted reversibly has a temperature not very different from that of its environment-- only about a few tenths of a degree. And, in fact, that difference is not significant when weighed against the errors that accrue from the instruments on the weather balloons that made these measurements.

If we go even higher into the tropical boundary layer, say around 900 millibars, when you lift that sample from it's origin level up, it's negatively buoyant. So this diagram shows that at best the tropical atmosphere is slightly unstable to moist convection. On the whole, it's pretty close to neutrality.

Well the same principle we applied before to radiative convective equilibrium in a dry atmosphere can be applied to a moist atmosphere really with just a change of variables. Rather than to assume that the entropy itself is constant with height, we assume that at least above cloud base, the saturation entropy is nearly constant with height.