Let's talk about the first problem first. To understand this, we need to understand where angular momentum comes from on the planet. Fundamentally, it comes from the rotation of the planet.

So let's begin by defining an angular momentum here, which is just the angular momentum per unit mass. It's the moment arm, which is the radius of the earth times the cosine of the latitude-- that's just the distance from any point at the surface to the rotation axis-- times the angular velocity of the earth's rotation times that moment arm, a cosine theta-- this is just the absolute velocity of the surface of the earth in the easterly direction-- plus any component u of wind relative to the surface. Now, here I've dropped the subscript "rel." And from now on, when I talk about wind, I'll be talking about wind relative to the surface.

So this is simply the total velocity of an air parcel in an inertial reference frame in the easterly direction times the moment arm. That's the angular momentum. Now, it can be shown that in the absence of friction or variations of the atmospheric flow in longitude that this angular momentum is conserved-- that is, following a chunk of air, the angular momentum stays constant.

Now, the problem is, there might not be enough angular momentum in the system to supply what's necessary to balance the thermal wind equation. So the maximum angular momentum we can have when we start from rest is the angular momentum of air at rest at the equator, where the moment arm is longest. So if the amount of angular velocity we need to balance thermal wind cannot be supplied by that angular momentum, then the solution isn't viable.

So let's have a look at that. Here, once again, is a picture of our exact solution-- radiative convective equilibrium in each latitude, warmer toward the equator, colder toward the pole. To balance this, we have to have a westerly wind which is increasing with height.

Now, how do you generate the west wind? Well, in an angular momentum conserving system, the only way to do that is to take air from rest and move it closer to the rotation axis, which means, in this case, toward higher latitudes-- that is, air moving along a sphere from lower to higher latitudes-- conserving its angular momentum, will begin to accelerate in the eastward direction.

But there might not be, if we start from rest at the equator, the question is, can we generate a wind strong enough through conservation of angular momentum to balance the temperature gradient? And the answer is, for the subtropics in the earth's case, no, we can't. And as a result of that, the pressure gradients cannot be entirely balanced by Coriolis accelerations. There's a residual acceleration down the pressure gradient. And the effect of this is to develop an overturning circulation, which alters the temperature gradient and drives it back toward the critical value, which is just such that there is just enough angular momentum to provide thermal wind balance.

So let's have a look at that. We can't quite balance-- in the subtropics, anyway-- we can't quite balance the pressure gradients with Coriolis torques because there isn't enough angular momentum in the system. There's a small residual pressure gradient acceleration in the north-south direction. This results in an overturning circulation shown by the yellow line here.

Now what happens with that circulation is that it's transporting hot air at high altitudes toward the poles, cold air at low altitudes toward the equator. It's also causing ascent, which tends to cool the air adiabatically in the tropics, and descent, which warms the air adiabatically at higher latitudes. The net result of this circulation is to cool down the tropics and warm up the middle latitudes.

That reduces the temperature gradient. It reduces the thermal wind that's necessary. And that circulation will drive the temperature gradient back very close to the critical value where there's just enough angular momentum in the system to balance the thermal wind equation. And that is the essential reason that we have Hadley circulations on the planet. And they do transport energy from the equator toward the poles.

We can see that in actual observations of the atmosphere. So what we see in this case are cross sections from the South Pole to the North Pole, the top one for the months of December through February and the bottom one for the months of June through August. And what's contoured on this diagram is something called the pressure velocity. It's the total time rate of change of pressure following parcels. It's the equivalent, in pressure coordinates, to a vertical velocity in geometric coordinates.

So where you have negative values, that means that parcels are moving from high to low pressure, which means upward in the atmosphere. So negative values of this quantity-- which, by the way, is called omega. It's given the symbol small Greek omega. Where it's negative, you have upward motion. Where it's positive, you have downward motion.

So if we look at December through February, we see very strong upward motion just south of the equator here and strong downward motion just north of the equator here. And this actually reflects one gigantic, overturning Hadley circulation that looks like that. And we have a weaker one in the southern hemisphere-- looks like that, OK?

On the other hand, in June through August, what we see is the maximum ascent has moved into the summer hemisphere, which in this case, is the northern hemisphere. A downward, of course, it was in the summer hemisphere in December through February as well-- the summer hemisphere being the southern hemisphere at this time of year. But what we have in June through August is strong sinking motion south of the equator, strong rising motion north of the equator, constituting a big overturning cell, Hadley cell, and a weaker Hadley cell on the north side here.

So the Hadley circulation is strongly varying with seasons. During the solstice months, mostly what you find is a great big cross-equatorial cell with a rising motion in the summer hemisphere and sinking motion in the winter hemisphere. During the equinox seasons, which are not shown in this particular diagram, you tend to have more symmetric Hadley cells with ascent at the equator and descent in the subtropics.

Here is a map showing the distribution of this pressure velocity, which, again, is like a vertical velocity. This is the pressure velocity at 500 millibars, roughly halfway up through the troposphere, in the month of July. And, again, negative values show upward motion. What do we see?

Well, just north of the equator is a narrow band of strong ascent. This is where the southeasterly and northeasterly trades collide, and you have upward motion. It's a region of strong precipitation, very strong convection. It's called the Intertropical Convergence Zone.

It's interrupted in the Arabian Sea here. There's not much indication of it. But there's strong ascent in a broad region from the Bay of Bengal south eastward to the Equatorial Western Pacific Ocean.

On the other hand, you have strong descent in the subtropics, particularly on the eastern side of ocean basins, like off of California, off of northeast Africa and southern Europe and so forth in the southern hemisphere. These are the descending regions of the Hadley circulation. In these regions, air is descending toward higher pressure. It's warming adiabatically.

It's relative humidity, therefore, falls. The air is very dry. These are the regions of the so-called great subtropical deserts on the planet, which include the Sahara, the Atacama Desert in South America, and so forth. So the actual Hadley circulation is, by no means, perfectly symmetric in the east-west direction because, of course, the real world has continents and other things that disrupt the zonal symmetry of the flow. But one can see, in broadest terms, ascent in the equatorial region, descent in the subtropics.

This is also evident in a climatology of precipitation. Here is a neat map showing rainfall climatology averaged over the years 1998 to 2007, detected from satellite. This is a satellite-mounted radar that looks at actual precipitation, droplets in the atmosphere.

Where you see green, that's where it's raining heavily. Where you see white, essentially not raining at all. And blues are in between. Beautiful Intertropical Convergence Zone here in the Eastern Pacific, in the Atlantic, and in the Western Pacific. But as one gets toward Indonesia, it's more of an amorphous region but, again, strong precipitation along the equator and just south of the equator in the Indian Ocean.

There's also this band extending southeastward from Indonesia called the South Pacific Convergence Zone. At higher latitudes, one sees a band of high precipitation over the Gulf Stream and Kuroshio currents. This precipitation is basically associated with middle latitude eddies. The dry subtropics are very much in evidence in the rainfall pattern. This is where one sees the descending branches of the Hadley circulation. Virtually the whole Sahara Desert, Saudi Arabia, these subtropical places are very dry because the air is descending in this region.