Transcript

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Course 1: An introduction to the science of climate and climate change

2.6 The main drivers of climate

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START AUDIO

Contributor: Hello again and welcome to the second video of this part of the course.

In the first video we took a look at all the different components that make up the climate system and how the various components interact.

In this video we are going to move on to take a look, in a bit more detail, at some of the main mechanisms that drive the climate to behave as it does.

In doing that we're going to consider another complex figure, which is why we thought perhaps a video might be useful in helping you to find your way around the figure and consider all the different processes at work.

It's clearly a highly complex system, where all these different processes occur and vary all over the surface of the globe and in time. But what you see in the figure here, is the annual and global mean and when we look at those longer-term means we can say something about the overall state of energy balance.

So it's a simplification but hopefully it's a useful one. And to make the figure simpler to find our way around, I thought we could look

first at energy balance at the top of the atmosphere. Then we'll look at the processes going on within the atmosphere itself and energy balance there. And then finally we will take a look at the processes occurring at the surface and consider energy balance there.

Just before we dive into doing that however, there's one concept which I thought it might be useful to consider on its own and to keep in mind when we then go on to look at this figure. And that's the concept of radiation and its relation to the temperature of an object and how that radiation interacts with matter, such as absorbing gases in the atmosphere.

We saw briefly in the first video that radiation from the sun travels through space by means of a wave-like motion, electromagnetic radiation, and that's how we receive it here on earth. What is useful to keep in mind also is that all objects emit radiation by virtue of the fact that they have a temperature, which means that their atoms and molecules are vibrating.

It's important to realise also that the hotter an object, the shorter the wavelength of the radiation that it emits. Which is basically why, looking at this simple figure here, the radiation from the sun, because the sun is much hotter than the earth or atmosphere system, the radiation that we receive from the sun is a much shorter wavelength than that emitted by the earth and the atmosphere.

So what I mean by wavelength, you see in these wavy curves here. The distance between successive crests of the wave, that's what I mean by the wavelength. And you can see here that the purple

which represents the radiation received from the sun is a much shorter wavelength than the green, which represents longer-wavelength radiation typical of that coming from the earth's surface and the atmosphere, which are both much cooler than the sun.

So that's a useful concept to keep in mind when we go on to consider the figure we're going to consider here.

Just before we do so, let's consider how the situation changes when we've got greenhouse gases in the atmosphere, which I've represented here very very simply by the grey slab. Just to remind you of the previous figure, so you can see how it's changed, when we have greenhouse gases in the atmosphere the short wave radiation from the sun can still pass straight through, with the exception of ozone, which we'll talk about later. But most of the greenhouse gases allow the short wave radiation from the sun to pass straight through. But they absorb strongly at the longer wavelengths typical of the surface and the atmosphere. So that's why you see there the green radiation, not so much of it makes it out of the atmosphere.

Now it's slightly misleading because it implies that none of that radiation gets out to space, which is not the case. It's an over-simplification from that point of view, but basically just trying to get across the concept that the greenhouse gases absorb the longer-wavelength radiation, the green that you see here. Their molecules and atoms then get excited by that radiation and they re-emit it in long wave radiation in all directions, and it's the downward component of that which gives the surface an extra input of energy that it wouldn't otherwise have if there were no greenhouse gases in the atmosphere.

So that's basically giving you a little bit of background to what's called the greenhouse effect. That's the way in which greenhouse gases in the atmosphere keep the surface warmer than it otherwise would be. And you're going to read more about that later in this unit, so I hope that will be helpful for that as well.

Moving on now though, and keeping those concepts in mind, let's go through the figure, the three regions I identified previously. Let's go through those one by one.

So we'll start by looking at energy balance at the top of the atmosphere. In doing this we're assuming that the atmosphere and the surface behave as if they're quite tightly coupled and effectively form one system. As it turns out that's actually not a bad approximation at all, so there is definitely something to be learned from an analysis such as this.

So let's look at the inputs and then the outputs at the top of the atmosphere. Here we have highlighted in green, the basic energy input at the top of the atmosphere and that's the incoming radiation from the sun. That very short wave radiation that was highlighted in purple in that simple schematic slide we just saw. That's what we call an external forcing to the climate system because it's essentially, that's the main energy input that essentially drives the whole climate system or sets it off in the first place if you like.

We've got 342 Watts per metre squared of that radiation. The unit Watts per metre squared essentially means, 1 Watt per metre squared means that one Joule of energy is passing through every square metre of area every second, so it's a measure of energy flow through an area. We don't actually need to worry too much

about that unit from now on, so let's just call them units from now on.

So there we have an energy input at the top of the atmosphere of 342 units. Let's now look at the energy outputs at the top of the atmosphere. There are two of those. Over on the left you can see that we've got 107 units of reflected solar radiation. So that's that very short wavelength radiation from the sun. It's being reflected. It literally just bounces straight off reflecting surfaces and back to space. So since it's been reflected it's still shortwave radiation.

And it's been reflected in the atmosphere by clouds and by aerosol, those particles suspended in the atmosphere. Also the solar radiation that's made it through to the surface gets reflected by the surface, snow, ice and other light-coloured highly reflective surfaces and straight back out to space again. So that's that 107 units of reflected radiation that you see there.

On the right hand side we've got the 235 units of outgoing long wave radiation. So that's the radiation that was green in my hand drawn slide. The long wave radiation emitted by the earth'-atmosphere system.

Now this is clearly an overall balanced situation. Now the processes going on at the surface and in the atmosphere are incredibly complex and indeed you can imagine the atmosphere is made up of various different layers, all of which have different temperatures, so will emit different amounts of radiation and they will absorb radiation from below and above and react with each other. And there's all sorts of different interactions going on. But what we're saying here is that the overall net effect of those

interactions is that 235 units of long wave radiation are going out of the system from the atmosphere and surface.

So those are the two energy outputs. To do the balance equation let's add those together. 107 plus 235 exactly balances the 342 units that are coming in. So in this longer-term global mean we've got a balanced situation where as much energy is coming in as is going out.

In such a balanced situation we would therefore expect that the mean climate isn't changing. If we were to perturb any one of those three processes however then clearly we would cause climate changes.

If for instance we were to change the amount of radiation coming from the sun, the output of the sun does vary naturally, but just imagine for the moment that we had a dial on the sun and we could literally turn up the sun radically and increase that 342 units that you see there. Then the amount of energy coming into the system would be greater than the amount going out, so we would expect the system to warm in response.

On the other hand we could for instance try and change that 107 units of reflected solar radiation. For instance by clearing away dark green forest and replacing it with highly reflective light-coloured surface. Then we would effectively change that 107 units and alter the energy balance that way.

So changes in those components will have the capacity to force changes in climate, but what we see here is a balanced situation in the longer-term mean.

Okay let's move on to consider some of the processes going on in this middle section, within the atmosphere itself. And let's look first at the energy inputs so we're looking at all the things with arrows pointing into the atmosphere. We've got four of those here.

Let's begin by looking at those 67 units of incoming solar radiation absorbed by the atmosphere. As I mentioned briefly earlier on, that's mainly due to the gas ozone, because on the whole the greenhouse gases don't absorb at the short wavelengths such as emitted by the sun. But the gas ozone does, it's very good at absorbing in both the short wave and the long wave. So essentially that 67 units represents absorption of solar radiation by the gas ozone. Most of which lives in the stratosphere which is that region of the atmosphere higher up that lives above the troposphere which is the lowermost region of the atmosphere where all the weather happens.

Okay next we've got 350 units of surface radiation. So that's the long wave radiation that's being emitted by the earth's surface and coming up, being absorbed by the atmosphere, so that's an input into the atmosphere that we see here.

We've then got 78 units of what you can see is called latent heat flux. And if you look lower down at the surface there are 78 units of energy used to evaporate water from the surface of the earth. So at the surface that's an output, but here, in the atmosphere it's an input. Because the energy is used at the surface to evaporate the water, which is then held as vapour in the atmosphere. But when that vapour condenses to form clouds, that energy is given back and that's called a latent heat flux. So in this region of the atmosphere that's 78 units of input of energy.

And then we've also got 24 units of input due to thermals. That's essentially referring to what we call convective processes. As you can see again we've got 24 units being used at the surface and input at the atmosphere. Essentially what's happening there is that radiation from the sun reaches the surface and warms the surface, so the lowest layers of the atmosphere get warmer. Warmer air is more buoyant so it tends to rise and sets up currents in the atmosphere that we call convective currents.

The processes of convection tend to form very very deep heavy clouds and tend to be particularly important in low latitudes in tropical regions.

So that's what's meant by the thermals there and that gives us an input to the atmosphere of 24 units.

So if we add up those inputs, we've got 67 plus 24 plus 78 plus 350, giving a total of 519 units input to the atmosphere. Don't worry if you can't follow the sums that quickly, because in the next section there's going to be activities which encourage you to re-do these calculations to check your understanding and to check that you understood the balance equations that are going on here.

So that's the inputs to the atmosphere. Let's now look at the outputs. We've got two of those. We've got 165 plus 30 of long wave radiation emitted by the atmosphere. That's actually 165 units emitted by the atmosphere and 30 units emitted by clouds. And that's basically that long wave radiation that I talked about earlier, typical of the atmosphere and the surface itself.

So the other output from the atmosphere region is those 324 units of back radiation. Again that's the net effect of long wave radiation

emitted by the atmosphere system, down towards the surface and that's what gives the surface that extra input of energy and keeps the surface warmer than it otherwise would be without greenhouse gases.

So those are both long wave emissions, those two terms there. And if we add those together we've got 165 plus 30 plus 324, which equals 519, which exactly balances the inputs. So again we've got a balanced situation where energy out equals energy in.

Of course I can't stress enough that we're looking here at a very simplified balanced situation. If anything acts to change those components then that's when we have the capacity to force changes and make the climate change.

Okay so let's look finally at what's going on at the surface. I think we should find now that we've actually touched on all these processes already. So let's look first at the inputs to the surface. So that's all the ones with arrows pointing down into the surface. So as you can see there we've got 168 units of short wave solar radiation absorbed by the surface. So that's the sun's rays that make it directly to the surface and don't get reflected. And we've also got 324 units of the back radiation from the atmosphere, so that's the longer-wavelength radiation, what was the green colour radiation in my very simple hand drawn slide.

So those are the inputs to the surface. If we add those together we get 492 units. Let's now look at the outputs from the surface, and there are three of those. 390 units of surface radiation, so again that's just the long wave radiation emitted by the surface. 78 units of evapotranspiration, that's the energy used to evaporate water

from the earth's surface. And 24 units due to thermals, that's the convective processes I mentioned whereby warm air rises and sets up convection currents in the atmosphere.

So if we add those three together we get 492 units which exactly balances the energy inputs. So here we're seeing another balanced situation where the energy input exactly balances the energy output. As I said you will get the chance in the next section to re-do these calculations and confirm that for yourself.

Okay, finally there are just two other main concepts that I wanted to highlight for you.

The first one is to introduce a concept or a technical term called the planetary albedo. And if we consider this region of the figure here, we see that of the 342 units of radiation coming in from the sun, 107 units are reflected straight back to space so that they're still short wave radiation. That 107 units is made up of 77 units that are reflected in the atmosphere by clouds and aerosol and also the 30 that are reflected by the surface. So the total 107 units reflected, as a proportion of the 342 coming in in the first place, that's roughly a third and that's what's meant by the planetary albedo. It's a measure of the reflectiveness of the planet.

If we do 107 divided by 342 and multiplied by 100 to get a percentage, then it comes to about 31%. So around a third of all the incoming radiation from the sun is reflected straight back to space, without having a chance to heat the atmosphere or the surface or affect the climate in any way.

And finally, just to point out another concept to you, and you may have spotted as we worked our way around the figure, that of the

390 units of surface radiation, that's the long wave radiation emitted by the surface, only 350 get absorbed by the atmosphere. As you can see the other 40 actually manage to escape directly into space. They do so because they can pass through what's called the atmospheric window. And this is a region of the spectrum, so among all the different wavelengths there's a region of the spectrum that contains wavelengths at which none of the gases in the atmosphere absorb at all. So it's effectively literally just like an open window that allows radiation of those wavelengths to pass straight out to space.

So if for instance we had a satellite instrument way above the earth looking down and measuring the radiation it sees coming from the earth and atmosphere, if it sees radiation in those particular wavelengths then we know that that radiation has originated at the surface. Okay and we call that region of the spectrum the atmospheric window.

Okay I think that covers everything that I wanted to cover in this slide. I hope the concepts will be useful to you as you go on through the course.

Thank you for listening and I very much hope that you enjoy the rest of the course.

Thank you.

END AUDIO