Introduction to Remote Sensing of Environmental Change

Good afternoon everyone. As the introduction's told you my name's Mathias Disney and I'm a lecturer in the Department of Geography. I'll going to talk to you this afternoon about remote sensing environmental change. If you've never heard of remote sensing before, and you don't know much about environmental change, don't worry, I'm going to introduce what I mean by both of those things in the next few slides. So hopefully that will be clear to you as I go through my talk. If it's not, I haven't done my job properly. So, I'm going to talk a little bit about what remote sensing is. And hopefully you'll get an impression of why it's interesting, why it's useful, and why I do it. I do it because it's exciting, it's fun, and I think I'm finding out things about the world. I'm going to give you some general background and then I'm going to introduce a few examples of how we use remote sensing in monitoring environmental change. What I'm going to do is give you a few examples of current projects that I'm involved in right now. So, I just want you to look at this picture for a second here. It's a picture of a place called Abisko in northern Sweden, it's quite far north, it's quite cold. And the question I'm going to pose to you is this: Why is understanding this, why is this area so important for understanding global change? Why is this so important for understanding global change? Now hopefully this will become a bit clearer to you as I go through the talk. Hopefully you'll see why it's important. This could – it doesn't have to be here, it could be in a lot of places around the world. But hopefully you'll see as we go through why we're studying areas like this to try and understand how the environment is changing and how we can use the latest technology, the latest scientific developments to monitor this kind of change. So bear that question in mind, think to yourself, 'why is this important? Who cares? Who cares about this? It's nice, it's very beautiful, but why's it important?'

So, the general outline of what I'm going to say: I'm going to talk about, what is remote sensing? And I've put in brackets there, 'Earth observation'. Sometimes we use these phrases interchangably – we say remote sensing, we say Earth observation, it doesn't matter. Now some people would say, 'it does matter', and they would be correct in that remote sensing can encompass all sorts of things, not just the Earth. Astronomy, looking at the stars, looking at the planets, that's all remote sensing too. But generally what I mean by remote sensing is looking at the Earth. So we often use 'Earth observation' as a more direct phrase. I'm going to mention a little bit about environmental change. Now, I'm sure all of you have some ideas about what I mean by environmental change, so hopefully I'll make that a little bit more concrete. And I'm going to talk about how we use Earth observation to monitor environmental change. I mean this – these two points here sum up the main reason why we use remote sensing. Primarily because it gives us a global picture of things. It gives us a global view in a way that we just can't get any other way. It also allows us to make a view of a global system over time. Because of course, the Earth's system is changing, it's very dynamic. So we don't only want one picture, we want a picture through time, we want to see how things change. And remote sensing is a way of allowing us to do that. Also, the key part of this – the second key part – is it's quantitative. It means we can make direct measurements about things, we can make concrete measurements. So we can look at the way the system is changing from one place to another, from one time to another. And we can quantify those changes. So it's not just pretty pictures, it's not just pretty satellite pictures. You know, that's part of the attraction of it: satellites and aircraft can return wonderful pictures about the way the earth behaves. But they don't tell you an awful lot unless you can measure them and you can come up with numbers, and turn those numbers into something meaningful. And I'll – I'm going to, if you like, mix all this up by giving you some examples of how we use – monitoring and environmental change using remote sensing in practice.

So, what is remote sensing? Well, there's lots of different definitions, some of them are more useful that others but, er, a sort of dictionary definition might be something like this: Remote sensing is a collection of techniques for collecting image or other forms of data about an object from measurements made at a distance from the object, and the processing and analysing of the data. So, that's one definition. It's a little bit long. It's a bit complicated. It's not very – it's not that clear. Another definition might be that remote sensing is the science, and to some extent art, of acquiring information about the earth's surface without actually being in contact with it. And that's the main point. Remote sensing is a way of allowing us to make measurements without actually having to be somewhere. We can make measurements about the environment, about the Earth's system, about, let's say, clouds or sea surface temperature, or population density, without actually having to go there on the ground or on the surface of the ocean and make those measurements. It doesn't allow us to completely get rid of those things, but it allows us to make measurements over much larger areas that we would ever be able to do if we had to go to places to make those measurements. It also allows us to make measurements in places which are hostile – hostile environments, difficult places to get to, areas which are politically difficult to get to. So it allows us to make measurements from a distance. Some slightly less serious definitions about what remote sensing is: Advanced colouring-in; seeing what can't be seen and then convincing someone that you've seen it; being as far away from your object of study as possible, and getting the computer to handle the numbers. So those are all less serious humorous definitions of remote sensing, but there is an element of truth in these things, in that remote sensing is, by definition, making a measurement of something by being far away from it. And so, that's one of the advantages but it's also one of the problems of remote sensing: I'm not actually there on the ground, and I may convince myself I've seen something that may not actually be there, so I have to be very careful about that. So, I've introduced some term of remote sensing, so, how does it operate in practice? When I say things like remote sensing you might think of satellites or aircraft, and I've already mentioned satellites and aircraft. But it's not always about big expensive processes and platforms. Remote sensing encompasses a whole range of scales. So, as an example, this is a photograph of me standing in a field – a field of barley – making a measurement with a camera, like this, and I'm trying to estimate the percentage cover of barley here. You might ask why, I'm not going to go into that now but the point is that a photograph is a remote sensing measurement. I'm capturing information about something that's going on here without actually having to measure it directly. So that's remote sensing. This is a photograph, an aerial photograph, of somewhere – I don't know where it is, but it's obviously a swimming pool and some palm trees, it looks very nice. It's taken from a kite. So, a little kite that someone's flown up in the wind and they've attached a camera to that kite and they've flown it over somewhere. They've enabled us to get a picture of the surface that we wouldn't be able to get if we were there on the ground. It gives us different information. This is a truck with a big arm on it and that's making a remote sensing measurement. But if you're doing it driving around a field making measurements, it's essentially like a big camera. Which, again, it's a remote sensing measurement. It's not a satellite, it's not an aircraft, but it's another widely used technology. Okay, this is where we start to get to the more, perhaps, familiar idea of what remote sensing might mean. Here are a collection of NASA aircraft. These are known as the Environmental Remote Sensing Aircraft that are run by NASA. Anyone know where that is? Anyone? San Francisco, the Golden Gate Bridge. So, does anyone also, does anyone recognise these aircraft at all? Ever seen them before? Say again. It's a very famous aircraft, it's an aircraft called the U2. You've heard of the band U2? That's where they get their name from, this aircraft. And it's famous because in the 19... – the late 1950s, one of these was shot down over Russia and the pilot was captured by the Russians and it became a very big propaganda incident for the Russians. And, of course, now we don't use these kind of spy aircraft any more because they're obsolete, they're too old, and so NASA bought them up to use for remote sensing. And so we put cameras underneath them, and we use them for environmental applications. So these aircraft have been around for thirty or forty years, and they're still going, they still have a job to do. We can even use – here's an example of people letting off balloons up through the atmosphere. This is remote sensing as well, you attach instruments to the balloon which measure the atmosphere as the balloon goes up through it. Again, not something we would think about, maybe, if we were thinking directly about remote sensing, but again it's just another – it's just another platform, it's just another way we can launch an instrument into an environment that we want to measure, without having to go there ourselves. This is perhaps what most people would think of as remote sensing. That is an artist's impression of an instrument – of a satellite called the Terra platform, which was launched by NASA at the end of 1999, it's been around for about seven or eight years. And this is one of the most widely used platforms in environmental remote sensing. It's about the size of a London bus, and it weighs about two tonnes, and it has five different instruments on board, each of which is designed for a whole range of different scientific applications. This is the same instrument again, and what you see here – this track, this shows you the view that this satellite can take of the earth's surface as it passes over. So every time the satellite orbits the earth, which it does about once every hundred minutes, so about once every hour and a half, the satellite goes round the earth, and it takes a view of the earth about two and a half thousand kilometres wide. The point here is you can see very quickly that this satellite goes round and round, and the earth turns like this, and very quickly we can build up a picture of the whole globe. So over the course of one day, we get to see fourteen or fifteen of these strips next to each other, which covers pretty much the whole globe. And the next day it does the same again, and the next day and the next day. And over day after day, week after week, we build up a changing picture of a whole range of processes going on in the earth's environment. The movie on the right is the same instrument again. All these things doing this, these are the different instruments on board the – on board the platform. And they're different colours which represent the five different instruments. They're essentially - one of them's looking at the atmosphere, there are two of them looking at the Earth's surface, one of them looking at the ocean and one of them looking at kind-of a mixture of all of those things. But each have their own particular set of processes that they're looking at. So that's an example of the kind of platform that we use every day when we're doing remote sensing.

So the other part of this then is, well, what's – what is environmental change? One of the key points I want to make here is that environmental change is not the same as climate change. Climate change and environmental change are obviously closely linked, but environmental change is more generally about the changing environment. It might change in response to climate, it might change naturally anyway, and also most of the change that we're talking about here is man-made. Now, of course, a lot of people are very interested in climate change and are very interested in what's going to happen over the next fifty, a hundred, years, can we do anything about climate change, do we need to do anything about it, all those kind of questions. I would argue that perhaps over the next thirty years – twenty to thirty years – so this is going to be a very important time for you. Over the next twenty or thirty years that it's environmental change rather than climate change that will be more important: how we use resources, how we manage the natural environment, how we use land, how we make changes to those – to land use. Agriculture, forestry, use of the oceans. Those are not directly related to climate, of course there is a link to climate. But essentially over the next twenty or thirty years it's likely to be those things which will be more important to – to many of you over the next tens – few tens of years. Things like, you know, availability of fresh water resources, availability of agricultural land, forestry, that kind of issue. The important issue then is we need to – we need to do several things. One of the key questions when we're talking about environmental change, changes in the environment, is understanding what those changes are, measuring them, so we need to understand how the systems work, complex natural systems, and we also need to know if we can exploit those systems sustainably. Can we go on chopping down trees, can we go on polluting fresh water resources? Well, if we do, what will happen? Those things aren't directly climate-related, but they are very important environmental change issues. So perhaps the most important part of this is that we need to measure the existing use, we need to measure changes over time, and we need to improve our understanding of the system. So what I'm going to talk about for the next sort-of fifteen or twenty minutes, is how we go about measuring the system and how we go about using that – those measurements to understand the system better.

So here's an example of – a simple example of environmental change. This is not climate change, this is environmental change, basically man-made change here. This is an example that's widely used, this is a satellite image of Rondonia in Brazil, in 1975 one of the most densely forested parts of the Amazon rainforest. Don't worry too much about the colouring here, but bear in mind that the – the sort of deeper the red, very red stuff is dense vegetation, lots of trees. The stuff where it's blue is – well, what do you think these blue lines are here? Rivers, okay. What's this then? The other way around. Yes, so this is a road and this bit's a river. So you can see the man-made bit is a kind-of bright blue colour. This is one of the major advantages of remote sensing, it allows us to take a big-picture view of things and to highlight features very quickly. Okay, so this is all dense vegetation and there's a little road here running next to the river. This bit down here is bare rock, but don't worry about that for now. That's 1975. That's 1986. Eleven years later we have these very clear, very characteristic herring-bone patterns. It looks like a herring-bone, a fish skeleton, the spine, the ribs coming out. This is very typical of Amazonian deforestation. What happens – we have a road, this was our original road here, and at this cross-roads a town springs up, and from that town we have ribs going out into the forest which are roads that are cut down, that allow the loggers to go in to the forest to cut down either side, drag the logs out back to the main road and probably float them down the river as well, and when we start penetrating into the forest, the further we get, we go out in these sideways patterns. So you can see very quickly there's been a lot of change. That's environmental change. And it's down to one thing, it's down to man – man-made change. So, 1986. 1992. It's even more extreme now, and there are patches here that are completely bare. This is usually burning that's gone on. So areas have been cleared and then burnt for secondary agriculture, often cattle-grazing or the growing of soya. Soya is an important cash crop in this area, but of course you need to cut down the trees. So, that's the way that satellite data enables us to make a very clear picture of how a large environment is changing over time. It's impossible to go there and measure that directly, you need a lot of people, you need a lot of time, you need cooperation from the local government, the national government. We can get snapshots very quickly, that are very effective in highlighting this change. And if we want to, we can measure the amount of area that's been deforested over time.

Don't worry too much about all the numbers here. What I'm showing here is a schematic diagram of the global carbon cycle. The global carbon cycle is one of the least-well understood part of the global climate, but it's also one of the bits that we have the biggest interaction with. You all know that, you know, when we burn fossil fuels we release carbon dioxide into the atmosphere, and the atmosphere potentially gets warmer, greenhouse gasses and so on. This is a diagram that sort-of highlights the numbers involved here. The reason I mention this is because the examples I'm going to show you a little bit later are to do with how we understand how this – this carbon cycle works. In particular, what happens here? The exchange between the land and the atmosphere of carbon. That happens basically through vegetation: through trees and plants; when they photosynthesize they absorb carbon dioxide, they release oxygen. And they store that carbon. Trees are mostly made of carbon, solid wood material in trees and plants is mostly carbon. If you cut them down and burn them you release it again. If you let them decay naturally most of that carbon ends up down here in the soil. And it stays there unless something comes along and changes that. So again, bear in mind here – and the numbers here we're talking are – PGC is petagrams of carbon, and a petagram of carbon is a billion tonnes. So we're talking – there's about 500 billion tonnes of vegetation on earth, and there's about 1500 billion tonnes of soil, organic matter, underneath it. So there's a lot more carbon in the soil, but it's a lot less dynamic, it stays there. Where as vegetation is very changable. So just bear that in mind. The climate cycle is a very important part of the climate. We'll see why in a second. You may or may not have seen a figure that looks a bit like this, particularly over the last couple of weeks, now that the Intergovernmental Panel on Climate Change has just released its latest report. You can forget all of the other parts of this diagram here, the most important part of this is this here. This shows the changes in carbon dioxide in the atmosphere over the last forty years, okay, from 1960 to 2000. Can you see it's sort of wiggly? That wiggle is called by the seasons changing from summer to winter, summer to winter. And the – in the summer, more CO_2 is absorbed by plants and in the winter more is released. So there's this little sort-of wiggle that we might expect. What we didn't expect, when people started measuring this, is the fact that it's basically going up very quickly. It's gone up from 320 to over 360 parts per million in the atmosphere. That's just in forty years. If we look back around 600,000 years of that record, you see that we're just in this last tiny bit here, and this is how the atmosphere changes over time, this is the carbon dioxide over the last 600,000 years. In the last 600,000 years it's never been above 300. Atmospheric concentration of carbon dioxide has never gone above 300. Here, this is what's happened to us in the last forty years. And this is what's happened to us in the last hundred years, hundred and fifty years since the industrial revolution. So, we don't need to worry about how we get that information, the important thing is things are changing much faster now than they have, essentially, for nearly a million years and we're now at levels, above which the earth has not seen. In a million years, CO_2 in the atmosphere has never exceeded 300 parts per million by volume. We already went through that about a hundred years ago, and on the current predictions we're likely to double from 300 up to 600 within the next hundred years.

So, bottom line, atmospheric carbon dioxide has increased forty percent in two-hundred years. What does that mean for us? What is the feedback between that? You know, what's that got to do with the climate? And the carbon cycle? And how can we monitor and how can we manage this feedback? The reason why it's important for us is again, you don't have to worry too much about what's going on here, but notice this is – this is time, going from 1850 to 2100, so going into the future by about a hundred years. What we're noticing here is the amount of carbon that the land's surface can absorb. Which is a good thing, it's absorbing it out of the atmosphere, basically by plants growing more and absorbing more carbon dioxide. This is what can happen if we have a climate model that doesn't include the carbon cycle. So it just ignores it. This is what used to happen until about ten years ago: people thought, the carbon cycle's not that important so let's just forget about is because it's too complicated and we'll model everything else. And the model tells us that, erm, oh, it's fine. The earth will carry on absorbing more and more carbon so as we pump more carbon out we'll absorb more, it doesn't matter. If we include the feedback to the carbon cycle, what we find is that after about 2050 it stops absorbing carbon any more, it reaches a point of saturation and it starts actually releasing carbon. And so carbon in the atmosphere will increase much much more rapidly. This this is a very important result. It's not to say that it's absolutely certain this is going to happen, but it's a good indication that we need to consider the carbon cycle very carefully.

So let's go back to the picture I showed you at the beginning where I asked you to think about why this sort of thing's very important. The reason it's important is because – it's twofold. Firstly, it's a relatively untouched environment. There's not – there is some manmade impact here, but it's very much less that in most of the northern hemisphere, western Europe. We still don't even know, even to this stage, we don't really know if this area – this type of area – is a net source or a net sink of carbon. What I mean by that is, is the net balance of carbon in to the atmosphere – is it releasing carbon to the atmosphere – or is it absorbing carbon from the atmosphere? We still don't even know if it's a net sink or a source of carbon. So we can't even say whether more carbon is coming out than is going in. Because it's a very difficult problem, there's so many difficult elements to it. Is it changing? And this is where it links to climate: as things get warmer, we have areas like this where there's permafrost – the ground's permanently frozen through the year, and a lot of carbon is trapped in there. Over time, if it gets warmer, that carbon will be released. So we need to know how this – this sort of area is changing, and why, and how fast.

This is a very simple diagram about what's going on here. We have some plants and some soil. We have some sunlight coming in that helps them grow. We have some carbon dioxide which they have to have to grow. We have some water and a nice growing temperature. Now, these terms here represent the fact that the plants don't just take in carbon. If we look at the system as a whole, what we have here – this is what we call the net ecosystem production, it's how much carbon this ecosystem deals with, how much it can absorb. It's a function of the total amount of plant growth here – so how big and how fast the plants grow – minus – there's all these small animals and plants in the soil which do all the decomposing, they have to breathe as well. So if we want to consider the total cabon balance, we have to consider their respiration. And also plants that don't only absorb carbon dioxide and release oxygen. They do the other way around as well. So it's a balance between total plant growth minus these other terms here. This is the bit that we're interested in, though. This is the bit we're interested in, we're interested in total plant growth minus all the other bits. So what are the plants doing? So just remember this net ecosystem production bit is the bit that we're interested in. So how do we go about measuring this, and how is this linked to remote sensing? Well, we have things like special towers that have instruments on them which we put in forests, we put in savannahs, we put all over the world. And they essentially measure the amount of carbon that these – these forests and areas are breathing in and out. And this is a really nice illustration over five years, five, six years, of a forest breathing in and out. What we see here is that – this is time through the day, so this is slices, each line along here is a slice through a day. And as we move up here we're moving through the seasons, we're moving through winter, summer, winter, summer, winter and so on. And what you see here, if we look at the numbers, the positive numbers, the red ones, are where the forest is absorbing lots of carbon. The blue ones are where it's releasing it. So if we look along this way to start with, we can see that at night time the forest gives up carbon to the atmosphere, it's not photosynthesizing, there's no sunlight. During the daytime, the plant starts being active as the sun comes up, the plant starts being active and it starts to absorb carbon dioxide. We also see this seasonality. In the winter, it's basically flat, there's not much going on; in the summer it's very active. And it's – we use this kind of equipment here to make these figures over time. So for one forest, that's fine. What about for all the forests in the northern hemisphere? All the global forests? Well, we can put multiple towers around, but they're expensive, they require people to operate them and so on. We can do the same thing for the soil, we can put these little sort-of robots on the soil, which measure the amount of material coming from the microbes and so on. But again, you know, these things cost several tens of thousands of dollars each, they only measure an area about that big. You know, how do I extend that to the whole of the northern hemisphere? The thing I'm going to talk about – the example here, is a project that we have called ABACUS. Which stands for Arctic Biosphere Atmosphere Coupling across multiple Scales. I don't want you to worry too much about it, but what we're trying to do with ABACUS is to measure the carbon, the water, the energy exchange in relatively small locations. The feedback between them – the key point here is that what we're trying to do is we're trying to move to bigger scales. We're trying to take these small measurements and extend them up to much larger areas. And the way we do that is by using remote sensing. Remote sensing does not allow us to measure these things directly, but if we combine them with models of how these processes work, we can use satellite data and aircraft to help us fill in the gaps.

So, this is the same photo – the photo that you saw before of the sort-of plain looking out towards the lake, with the trees and so on. And I asked you to remember it. That is here, the lake is along the front here. We were taking that photo from a mountain up here. And this project, what we aim to do, is to make measurements across the landscape at small locations where we have a lot of measurements and we understand the processes very well. What we don't understand is – is well, how does a measurement here relate to a measurement here or a measurement over here? And we use satellite data to allow us to fill in those gaps, or we can use aircraft. So, as part of this project we were working with a team at Edinburgh who have one of these little aircraft, which is great fun, it's very, very good fun to fly, this thing, but it's also very useful because we can put instruments on board this aircraft, and we can turn it into a scientific measuring platform. For a few tens of thousands of dollars, we can do things with this that we can't do with satellites that cost hundreds of millions of dollars. We can fly it when we want to, where we want to, we can fly low, we can fly high, we can do all sorts of things that we wouldn't otherwise be able to do. And we can do it, as I say, for a few tens of thousands of dollars rather than a few millions of dollars. It has its drawbacks, but it's a very powerful way of working. This is another view of the same area again, these are the mountains in the background, this is the mountain from where I took that photo, looking out across this landscape. This is a complex environment. There are mountains, there's glaciers down here, you can see clouds down here. There's lots of patchy areas of vegetation. There's a big lake. There's a bit of – there's a road and railway along here, erm, and that's the only people you'll find. And this small village here next to a research station, then there's nobody for about six hundred kilometres until you get to Norway that way, and if you go that way, north, you won't see anybody until you reach the North Pole. And if you go down this way, you'll probably have to walk for about fifty or a hundred kilometres before you find another person. So, although it's not completely remote, because there is this railway line along here, you step away from that railway line and it's a very remote environment. The other reason that I didn't mention earlier – why is it so important to understand this area? Because these areas are going to change – perhaps they're the most vulnerable to climate change. Because they are in an area where when the warming starts to happen if the climate starts to warm up, even by a very small amount, these areas will feel that change, more-so than areas – for example, the tropics where they're used to experiencing temperature changes of ten, twenty degrees every day, that's not the case here. So it's very sensitive to small changes. So if we can see the impact of those changes here, maybe we can say something about what's going to happen elsewhere.

So this is our field site. Again, what you should notice here is that it's a very patchy environment. There are trees, and then there's no trees, and then there's marsh, and then there's water. So very – there's patches of different parts of the environment. Here's one of our measuring towers right in the middle, you can see it in a bit more detail down there. So here's our measuring tower that's measuring the forest breathing in and out, solar panels and so on. This is going back to my photo again, our other part – that last photo was taken – was down here, that area. We're also interested in the mountainous regions, the mountainous regions, these areas are only separated by about two or three kilometres, but they're very different environments, very different environments. And that's part of the difficulty of understanding a global environment, you can't just say, well, I measure it in one place and then it's all the same. It's not, you know, you look at a ten metre bit, it's all different, you look at one metre, it's all different, you can even look at a space of ten by ten centimetres and you'll find, you know, different plants and animals in that ten centimetres than you will in one right next-door. It's part of the problem. So here's our tundra site here, up on the mountainside. We're also interested – so we're interested in establishing how these areas behave. One of the things we need to know about is dynamics, seasonality, it's a very dynamic environment. This is in April – end of April, beginning of May. Lots of snow on the ground, no leaves on the trees. This is in early September, all the plants are dying off at the end of the season, it's a very short growing season because it's quite far north. So, through the whole summer, the sun stays up in the sky the whole day, which is quite strange if you're not used to that environment, you know, two o'clock in the morning you can wander outside and it's bright daylight. But of course if you go there now, you'll never see the sun from one week to the next. There are other dynamics going on here, other disturbances. Large herds of reindeer, which are natural to that environment, but these are managed by the local people, the Sami population of northern Sweden and Norway. They're the native inhabitants and they rely on reindeer herding for their livelihood. So, of course, for them, this is how they survive, this is how they make their living. And anything that changes to make this herding reindeer more difficult, has a big impact on them. But, of course, the reindeer change the landscape. Reindeer eat vegetation, they do all sorts of things to the landscape so we need to understand that as well. And it can be quite a challenge, working in an area where you have – you can't touch the reindeer, they're not scared of you, and these things are about this big and they're quite scary. So if they have – if they have young calves you have to run away. And, you know, you hope that they're not going to destroy your five-thousand dollar, you know, wind turbine, or stand on your laptop, which they might do and there's nothing you can do about it, you just have to have insurance. Try and scare them away but they're not scared of you. So, we need to use models to understand and predict these systems. And models need to have observations in order to work properly. So this is a very simple representation of a sort-of model of an environment, we have some carbon, some water and some energy, and some flows between these things. We can put in things related to the vegetation, and that drives the carbon part of it. We can put things related to temperature, and water. And other things to do with carbon fluxes, don't worry too much about that. The point is we can construct models that have these types of elements in them. Models are great, models are really really useful for all sorts of things. But, models can go wrong and models are only as good as the foundations on which they're built. If the model foundations are wrong then it doesn't matter how good your model predictions will be, they will be nonsense. So you have to have these sorts of things around here, you need to know these things. If your model's going to be any good, you need to know these things. These are things we can provide through remote sensing. So as an example of the sort of thing we do with this kind of approach, here's an example of a system in Sweden which has a simple model like this, and what we're interested in here is total amount of leaves. Leaves are important because they absorb radiation, they release water. Leaves are the engine of the whole system. So we need to know how much leaf area there is, it is changing over time? And the answer is yes, it does change over time. We see a sort-of seasonal cycle: the leaves come on, the leaves drop off. What our model does is, our model predicts what the leaf area should be over time. This is over a whole year. And, yep, the model can go ahead, and it can do it, it can predict the leaf area, but what we notice is, you see this spread? The green spread here? This tells us how – how bad our model's getting, it's the uncertainty, the error. And you see that over time the error gets larger and larger. So by here, my leaf area could be down here or it could be up there. It's a huge difference between being in one place and the other. In terms of the carbon, in one area there's almost no leaf at all, down here. And up here you're in a tropical rainforest. There's a big difference. And our model doesn't know any better, it's just going along, doing its thing. Now, can we use satellite data to put into the model and say, look, this is where you should be going? And this is an example of doing that. Now, we see that our model hasn't changed dramatically in terms of where the solid line is. But you see this – this spread here is much, much narrower. So we've kept our model a lot more on track and we've reduced the uncertainty in our model prediction. Going back to this – you remember this property of net ecosystem production? Total amount of carbon. We can see here that if we don't have our satellite observations, we get a number, but that number isn't very plausible. We get a number here and we get an uncertainty. When we plug the satellite data in, we get a number that's about half the size of the other one and the uncertainty's about half the size. So we've changed – we've hugely changed – if we'd had no satellite observations, we'd have to go with this because that's all we've got. But we know it's probably not very good. Now we see that it's not very good because our satellite data says, 'whoa, hang on a minute.' You know, you've got way too much NEP here and the uncertainty is very big. So this is a – this is a very good example, if you like, of how we're using satellite observations to improve our understanding, our predictive ability. We can translate that – that's – we look at that, it's not very exciting. It's a graph – you know, if you're not an expert in this sort of thing you think, 'well, so what?' The nice thing about using satellite data is it allows us to make pictures of a global environment. So here we have the annual – so we add up this, this, NEP over a whole year and we can do it over the whole globe. And now you see that we go from about -180 up to about 2000. And, not surprisingly, we see big variations over the globe. You can see that – look, here's the Amazon, and sub-Saharan Africa and down into southern central Africa. We've got – through this tropical band, we've got very very high production. It's not surprising, this is the rainforest, this is the sort of tropical forest of Africa, and the rainforests of central and south-east Asia. So we can just see on a picture, this is the sort of thing that enab.... – is a very powerful tool to get this across to people, is that look, most of the production in the world in terms of the carbon, is coming in this small band across here. Now if you were to lose this, or that, or that, that makes a huge difference to the earth's ability to absorb carbon from the atmosphere. You don't need to be an expert to be able to see that. The picture like this – there's the old phrase, a picture tells a thousand words, in this case it very much does so. You know, you look up here, there's not much going on up here because it's far north. The whole area across here, the whole of the far Northern Hemisphere, there's very very very much less going on that there is in this tropical part here. And this is the – the difference between these two graphs is the difference of adding our satellite data. It's broadly the same, but what you can see here is that we get very different numbers, particularly over south-east Asia. When we add the satellite data we get rather different numbers. Look at Australia. Australia's kind-of covered in green there, it all looks rather good, you know, we're up here somewhere: great. But here, we add the satellite data and suddenly Australia's moved right down there. That can have a major impact on the – our estimates of where the carbon is going in the environment. It also might have significant political impacts for somebody like Australia, as to whether they sign up to the Kyoto protocol, or how they manage their fossil fuel resources. If they look at that picture they might think, 'hey, it's all good, it's fine, we don't have to worry about it.' They look at that picture and they think, 'oh dear.' So that's a very important thing to understand, and to be able to quantify that. The picture is one thing, but we can also attach real numbers to these things, so these are our best estimates. So, we can also use this to highlight areas that are different between the two, where our model's getting it wrong, why is it getting is wrong? We can start to look at where the models are going wrong, and then of course we want to know why, why are the models not working in certain areas? what are we getting wrong here? how is our understanding not working? And so this is a sort of – a synthesis of those results. This is the terrestrial – total terrestrial carbon that's absorbed from space, 1999, so this is six or seven years ago now. But this, as I say, is a very powerful way of getting this – what is a complicated scientific process across. Satellite data allows us to do that. If we don't have satellite data, we cannot make these pictures. Or, we can, that's not quite true, but we have to do them using models. And as we saw earlier, models are essentially – they can be very sophisticated but very stupid. Because they only do what you tell them to do.

So, we've learned a little bit about how satellite data allow us to quantify how good our models are; where and when the models work and don't work; and crucially, how to monitor globally – how to monitor things globally, not just locally. That's a key part of why remote sensing has become vital for environmental science, is that: yes, we need to understand the very fine-scale behaviour of the system, and sometimes that means down to the molecular, microscopic level. But that doesn't tell you how these processes interact globally. We need to understand the whole system. We need better models as well, we need – this is an example of some work that we do looking at building computer simulation models of how sunlight interacts with vegetation. This is an oil plant plantation in Indonesia, that – some work that we did with an Indonesian PhD student a few years ago, looking at how oil plant plantations affect the environment, how they change from forest to oil plant. Er, this is some work we did looking at the growth rates of Scots Pine trees and how we can exploit our understanding of how the system works to look at carbon and look at the feedback between carbon and climate. So very detailed computer simulation models. These are – you can't really tell so much, but this is Birch trees looking down from above. That Birch forest, that I was talking about before, this is a model of that environment where we can use this as a virtual laboratory. We can create a computer simulation model and say, 'okay, what happens if I do this? What happens if I cut half the trees down? What happens if I double the number of trees? What happens if I change the soil?' Some sort-of general things that we've learnt through doing this work – and when I say us, I mean the ecological community, scientific community in general – over the last ten years: the Northern Hemisphere is getting greener, there's more plants, more plants and vegetation. It's due to the rising carbon dioxide. Because plants grow more – if you put more carbon dioxide in the atmosphere, plants grow faster. But, that doesn't go on indefinitely. If you keep adding more and more carbon dioxide eventually the plants will stop absorbing any more and they'll reach a plateau. So at the moment, the vegetation is doing us a big favour. At some point in the future, we don't know when yet but we know it's going to come, the vegetation will stop doing us that big favour and things will get worse more quickly. Now, we also use – another couple of very quick examples here at the end – we use earth observation data, remote sensing data, to tell us about how things are changing over time. I showed you about how we understand the system. Here's an example of a NASA product that we helped develop, that looks at mapping burned area. Fire is an incredibly important part of the carbon cycle, there's a big link to climate and of course it's a very important part of the feedback with us, mankind, living in and exploiting this environment. We want to know how much fire there is, where it is, how severe it is. The fire has all sorts of different types. Some fires can pass through and burn very little vegetation. Some fires burn very intensely and burn everything. And it's very difficult to tell – unless you're actually there, of course, you don't want to be too close to it, but it's very difficult to tell what type of fire is going on. But what type of fire it is has a very big impact on the feedback to carbon. So this is burned area in southern Africa, and the colour is the day of burn. So, where it's red, that was yesterday, moving to blue where it's somewhere about three weeks ago. So going from red through to blue is about three weeks in time. And so you can see that the fire's burned here more recently and there are lots of little patches, and here it's burned a sort-of longer time ago. And the colour here is how severe the burn is, so the red is the very severe and the blue is the less severe. So again, this now is over thousands of square kilometres. We can come up with estimates of how much stuff is burned and when. And of course that's a key issue for understanding, you know, what the impact of those fires are. We can also use remote sensing data to monitor changes that we make deliberately, fire may be accidental but it also may be deliberate, it may be part of a management strategy. Things that – we've got a project just started in the UK where our – our landscape is very managed, you know even when you see sort-of wild parts of England, it's very much a managed environment, it's managed by farming, agriculture over time. And now some areas of this the government is deciding to return to its natural environment, reducing the amount of impact on the land. And they're doing this in lots of different ways, and there's no real coherent picture of how this is going to change over time. So what we're saying is, 'well, look, perhaps the only way you can do this, to monitor the changes that you make and see whether they do the things that you think they will, is by using satellite data.' Because only satellite data can cover those large areas. So, the last – the conclusion, that environmental observation data, remote sensing data is basically the only way really of measuring the world globally. We can have lots of models that work globally, but models are not measurements. They allow us – remote sensing data allow us to ask questions or even provide answers, start to provide answers to things like, how good is our understanding of the system? And where it's not very good, how can we improve that? What is the future going to look like for large areas of the globe under environmental change and under climate change. And one of the key issues for us as human beings is, can we develop sustainably? Can we avoid making catastrophic mistakes in terms of management which mean that we lose the ability to exploit our natural environment in a way that will allow it to recover sustainably. And as I say, this is perhaps one of the biggest questions that we're likely to face in the next twenty or thirty years. It is linked to climate change but it's not the same thing. Climate change, you know, might get us in 100 years, who knows? But over the next twenty or thirty years, if you can't feed yourself, that's certainly going to get you. So these are the questions that we need to – we need to be able to answer. Not only for ourselves in the developed world but over large parts of the globe, and remote sensing data allow us to do that. And that's it. Questions? Anyone want me to answer any questions? Has no-one got any questions?

[question] [...]

Yes, and the reason I don't mention it is that my interest is in the land surface and the sort-of – the trite argument is that we live on the land surface so that's the mainly important bit, and although the oceans cover seventy percent of the surface of the earth, they're a lot more homogeneous than the land surface. Firstly we don't live there; secondly they're a lot more homogeneous. So there is a – you can make smaller measurements and scale them up much much more easily. The issue of the sinks in the oceans again is something – in the same was as the land surface, there's lots of plants on the surface of the oceans and it's that sort-of plant and animal life on the surface that, of course, absorbs carbon. And again, it's only over the last ten or fifteen years – you know, ten years ago if you'd asked people, 'are we able to change this whole cycle in terms of the ocean', for example, you know, it's three times as much land mass – as much area as the land mass, and so on. People would – even experts would have said, 'look, it's very unlikely, the system's so large and we won't be able to perturb it.' But we're now realising that we are, because it's in a very very very sensitive balance. And it only needs a very slight nudge one way or the other to change rather dramatically. And we're providing that nudge at the moment. And so, the first issue with this is, 'oh dear there seems to be a problem.' Then the next issue is, you know, how bad is it? Or what is the state of the sytem now? So that's – we're only really starting to understand what the – put numbers on those carbon sinks in the ocean. As I say, land surface, for large parts of it, we don't even know whether it's a source or a sink, still. The ocean, we know that it's a sink, but it's those numbers: how big a sink is it? And how sensitive is that to change? And we've just started to really put a lot of effort into measuring that, because we've realised how important it is. Anyone else want to ask any questions?

[question] In the slide there was CO2 / CH4. What means CH4?

CH4 is methane. Methane? Methane. So, it's a flammable natural gas, and it's much less – it's much less abundant than carbon dioxide, but it's much more important as a greenhouse gas. So although there's a small amount of it, it's about twenty times more powerful as a greenhouse gas. So if you have – one unit of methane is equivalent to twenty units of CO2. And a lot of the carbon material, that's particularly in these areas in northern Sweden, Scandinavia, Canada, Siberia, a lot of the carbon is – would be released as methane. And that's really bad news, because if you have a kilogram of carbon, you know, and you have a choice to release it as CO2 or methane, you know, you want to release it as CO2, if you're going to release it; not methane. And of course what happens when these areas of permafrost start to thaw, much of the carbon is released as methane because of – it comes from small microbes, microscopic animals that are breaking down the organic material and they give off methane.

[question] Is the only source of methane – excuse me – from animals?

From – no, it’s – well, there are other sources of methane that we understand even less about, but they’re less dynamic. So there are things called methane hydrates, which are essentially solid. If you put methane under great pressure and you make it very cold, i.e. at the bottom of an ocean, you can solidify methane. And there are these great pictures that you see in some of the research on this where you can dig out chunks of solid methane, you can bring them up to – it’s essentially ice, it looks like ice, it’s freezing like ice, but if you touch a match to it, it will burn. So they call it burning ice. And they – we believe there are large deposits of these methane hydrates on the ocean seabed in certain areas. But they stay there unless something catastrophic happens: if there’s an under... – you know, a submarine volcano, then a lot of that can be released. But in terms of the feedback to our changing the climate, we’re not likely to do a great deal of damage to those. So there’s a lot of stuff there. Although having said that there’s one element where if you warm the oceans up too much, of course you’ll start to melt that stuff, and then that’ll be a positive feedback. But we believe at the moment that we’d have to raise the temperature of the oceans quite a lot, and so we’re nowhere near that, we’re sort-of several thousand years away from that. But of course, you know, our understanding of that is very poor at the moment. So these things could change very quickly.

Anyone else? No other questions? Well thankyou for listening, I hope it’s been understandable and interesting.