Professor Geoffrey Boulton's Lecture:
Tuesday 29 January 2008

Carol Tannahill
Good evening everyone and welcome to this second lecture in the Glasgow Centre for Population Health's fourth seminar series; it's amazing how time flies. My name is Carol Tannahill, I'm the Director of the Centre and I'm delighted to see you all here and, in particular, to welcome Geoffrey Boulton who is going to be delivering this evenings' lecture.

I'm going to hand over tonight to Duncan Booker who's our chair for the evening. Duncan, as many of you will know, heads up the health policy team at the City Council. Thanks Duncan.

Duncan Booker
Good afternoon everyone and welcome to this public lecture in the fourth seminar series organised by the Glasgow Centre for Population Health. It's a great privilege and a real pleasure to introduce our speaker today. Professor Geoffrey Boulton is Regis Professor of Geology and Mineralogy and also Vice Principal at the University of Edinburgh. He also heads up the Global Change Research Group which is hosted in Edinburgh and he has just told Carol and I that he has recently arrived back from China where he has been having discussions there with governmental and NGO representatives around global climate change and the role that China and it's industrialisation will be playing in that.

He's also a member of the Prime Minister's Council for Science and Technology and General Secretary of the Royal Society of Edinburgh, which is Scotland's National Academy, and was a member of the Royal Commission on Environmental Pollution. Professor Boulton's own research, for which he has received a number of international awards, is concerned with environmental change and with implications for issues such as the disposal of radioactive waste. Now Professor Boulton's work, initially on glaciation has lead him to an interest in earth system models which oceans, atmosphere, cryosphere and biosphere are coupled in the evolution of climate, and from there to a fundamental question of how human agency is shaping the planet and how it's now become as powerful and significant perhaps as those other forces.

We have considered at various previous seminars, including in this very venue, how stress affects us, humans, and how it can do so differentially. Now we are going to hear about the kinds of stresses that we humans in our activities are putting our own planet under. The title of Professor Boulton's talk is 'Learning to Live with an Angry Planet: human relations with the earth in the past and in the future'. Professor.

Professor Geoffrey Boulton
Let me do a sound check first of all. If I stand here and speak, can you hear me? Good. Geologists are used to shouting from mountain tops in a gale at their students. And I do speak as a geologist and as a geologist I look at our planet as a rather angry beast over the four and a half billion years of it's life time and in relation to what's happening in the present day, I think my general comment would be the last thing you do with an angry beast it poke it with a stick because you may not be sure what it might do to you.

Most societies that we know of, whether they are life civilisations or little small rural groupings, have views about their relationship to nature and the way in which they relate to it. Those views very often condition the way they live in a rather fundamental way, whether they tell themselves narrative tales about it or whether they use it as a basis to their economies, really the impacts are very substantial. In our society, in the west and Western Europe then much of the way in which we look at the earth we live in and the environment around it is conditioned by scientific discoveries. I would say that there probably have been three or four great scientific discoveries which to some degree have addressed the over weaning arrogance of the human species, that is we are often guilty of. Copernicus showed that the earth was not the centre of the universe but that it was a small planet in a rather insignificant star system on the edge of a major spiral galaxy. James Hutton showed that we were not, or it didn't seem to be that we were the epitome of creation, but we came rather late in the day in an earth, as he wrote, was as without vestige of a beginning without prospect of an end, an attitude that somehow we are so important in the evolution of this earth that Mark Twain, who in a sense was a great scientist, wrote that who can doubt he said that the one millimetre of paint on top of the Eiffel Tower was what it was built for! Subsequently, of course, Darwin, to the satisfaction of many of us, demonstrated that humanity is not the end point of a great evolution, but rather the consequence of a series of rather chance events in a complex and difficult history.

For most of my lifetime the presumption has been that the human drama is laid out against a static environmental backdrop, somehow that we can exploit the earth at whatever way we wish and the only consequence is that of our material benefit. At the same time, although we have known that the geological past has contained events that are dramatic in the extreme, somehow that's part of the past, it's unimaginably different and the present is something rather different from that past. And, of course, by saying all those things what I want to suggest is that all these presumptions may be wrong.

What I want to do is first of all to talk about the way in which we think the earth works if it's left to itself and secondly how we might have affected the way in which the earth works. This is something called global challenger. It's a drilling vessel that's sailed through the earths oceans now for the best part of thirty years digging holes into the ocean floor. This is a result of the work of that vessel; those young students of ours are carrying the core that has been taken from the middle of the Atlantic in water depth of about five kilometres. On the presumption that the Atlantic Ocean is an enormous settlement basin in which the detritus of the continents are swept into the oceans, it settles onto the ocean floor and in some sense we can infer something of the history of the earth from that accumulation of sediment that sits on the ocean floor.

Here they've opened the core up and you can see sediment from the ocean floor here and you can see it's layered and that layering is like the leaves of a book which the latest page is like the top, the earliest page is somewhere down the bottom and the key question is can we read what's written on those geological pages to infer something about the history of the earth. The answer is yes, we can and one of the ways in which we do it is that that sediment contains micro-organisms such as this, this is a foraminifera that lives on the ocean surface waters, but also on floors of the ocean, it's about a millimetre in diameter or thereabouts and it has in the chemistry of it's shell a signal that tells us about the salinity of the water in which it lived and as a consequence by working down those cores we can deduce the changes of the salinity of the earth's oceans through time.

And if we do that in fact, we get records like this. This record goes back about three and a half a million years, timescales based on the changes in the earth's magnetic field and the oscillations you see here, from blue to the left and red to the right, are reflections on the salinity change of the oceans. Here when it oscillates to the left the oceans have a high salinity, when the curve oscillates to the right the have a low salinity. You can work out how big a change that implies. The easiest way to change the salinity of some water in a container is if you want to increase the salinity you put a fire underneath it, drive off water vapour and the salinity increases. If you want to decrease the salinity you simply decant some fresh water into the bucket.

Well the oceans are like an enormous bucket and we calculate how much water you would need either to evaporate or to decant in order to get the changes in salinity of that magnitude and the answer is quite a large number, it's about fifty million cubic kilolitres which is a lot of water. We think we know where that fifty million cubic kilolitres goes to when it comes out the oceans, where it comes from when it goes back into the oceans; we think it comes from the great ice sheets that have covered the earth from time to time.

We think that when the curve oscillates to the left then most of Eurasia including Scotland and Britain, most of North America were covered by great ice sheets with an elevation of the order three to four kilometres. When the curve oscillates to the right then they're relatively warm conditions similar to those of the present day. But the planet earth has ice sheets, Antarctica and Greenland, and they're about fifty million cubic kilometres worth of ice, but the cold earth has another fifty million cubic kilometres which comprises the great ice sheets on Eurasia and North America and what we're seeing here is an oscillation of the earth's climate through time between glacial periods in blue and cold and so called interglacial which are warm and red. The present day in fact, you can't quite see it but it comes up to about there. And so we think of the earth's climate as being unimaginably different in the past.

This is a computer model of the ice sheets that covered Eurasia. We are starting here about thirty thousand years ago at which time we think there was a big ice sheet on Scandinavia, Britain wasn't ice covered, but the shoreline was much further out than the present day because of the growth of ice on Scandinavia and North America were taking water up from the oceans, as a consequence you could have walked from the north east of England and Scotland across to Denmark and to northern France because the water that had been taken out of the oceans and put on the ice sheets. This model will show you how these ice sheets fluctuated through time, this is about thirty thousand years ago and the ice sheet is growing and for the first time we have got an ice sheet nucleating on Scotland as the climate gets colder and the ice sheets are growing together, they coalesce in the middle of the North Sea and because they put an enormous weight on the earth's lithosphere, on the earth's crust, they depress the crust and sea level is lowered by the fact that the water has been taken up into the ice sheets. This is the coldest part of the glacial period, about eighteen thousand years ago, about there, and then it's retreating again and you see the ice sheet over Scotland disappearing, it's now in the north west Highlands only, it then disappears about eleven thousand years ago.

What you'll see is there's a complete continuous straight of the sea between the east coast and west coast. Edinburgh to Glasgow would not have been on the sprinter train but would have been outdoors in a canoe. And the reason for that, of course, is that the land had been pushed down so much by the load of ice that sea levels were relatively high even though the global sea level was low and in places like Oban you can see these wonderful marine terraces on Kerrera and Lismore which are a consequence of this sort of behaviour.

So let's get rid of the ice sheet because we don't need it any more and let's look back again in time using these records.

This is a record again showing a proxy for salinity, high salinities here showing large amounts of global ice low salinity there given present day conditions, present day glacial conditions and looking back over three and a half million years or thereabouts and if you look back over the last seven hundred thousand years you see these great cycles between very warm periods like the present day here, here and there, there, there, there, there and very cold periods with enormous amounts of ice on earth and these points, one, two, three, four, five, six, seven. These are hundred thousand year cycles of climate change, the earth is behaving in an extraordinary fashion, we are getting these enormous rhythmic cycles. In fact if you wanted to, and it has been done, I've done it, you can actually write the music for this. It's in 13/17 time, which I think most might find difficult. What's interesting is if you go back beyond seven hundred thousand years ago you find that the cycle isn't a hundred thousand years long, it's forty one thousand years long, equally rhythmic, but the wave length is different.

So that's the evidence of the oceans, but there's also other critical evidence which comes from the earth's great ice sheets. This is photo of the Antarctic ice sheet. You're looking over the surface from an aeroplane, the surface of the ice sheets are about three kilometres elevation, there about four and half kilometres and you're looking through about 60 kilometres in distance. You can see the flow lines on the ice sheet. This is a radio echo sounder trace; it's rather like an ordinary echo sounder trace. Here you are identifying mountains beneath the ice sheet surface. That depth is about three and a half kilometres and so you see great valleys here between the mountains. These mountains are rather larger than the mountains of the western Highlands; they are completely drowned by the ice sheet. This valley here is in fact the valley for which this very strong flow takes place, but you can also see lowering of the ice. Now that layer is very important because ice sheets are effectively accumulations, layered accumulations of frozen atmosphere.

This is a photo from Greenland, a nice photo of the edge of the Greenland ice sheet and you can see the layering there. Those layers we know are annual layers. The snow accumulation of winter and summer would be different; we've identified the individual layers. If I had the time to count them there would be about 30 or 35 years of accumulation.

Now if we look at this ice, which comes across in an accumulation of snow crystals like this, those snow crystals soon, whose delicate and beautiful rings are electrically unstable and they soon melt and become steroidal in shape like this. This is snow near the surface and you can see there are lots of voids between the crystals as that snow is buried by more and more snow you find the voids become smaller as crystals are pushed together and eventually these voids no longer connect with the present atmosphere, but the voids themselves have trapped within them air from the surface at the time when the snow fell on this surface.

Some years ago a whole number of us tried and succeeded to persuade the European Commission to fund a major enterprise to drill a hole in the middle of the Greenland ice sheet. Here you see we're taking the core from the Greenland ice sheet analogous to the ocean core except made of ice, of course. You can see that its layered and we're looking here at ice as a sort of depth of about one point three kilometres and we know for reasons which I'm not going to tell you, but are rational, ice of that depth has got an age of about ninety thousand years and here is my gloved hand holding ninety thousand year ice and it's got lots of little bubbles of air. The air is the air that was on the surface of the ice sheet ninety thousand years ago. In fact if you pop it into your gin it crackles wonderfully because the bubbles explode because it has been under pressure so old ice is wonderful for gin in a way that modern ice from the freezer isn't. And because we can extract the air from those bubbles and because we can analyse the air and because we know the timescale of these cores… here's the present day, here we're going back six hundred thousand years. This is the way in which the composition of methane in those bubbles change through time. This is the way in which the composition of carbon dioxide changed through time and this is the inference at the temperature based on the chemistry of the ice which uses a technique which was developed by our own late and great Lord Kelvin. What you will see is that the temperature record here shows the same cycles that we saw in the ocean, these hundred thousand year cycles, these magnificent cycles of the warm interglacial periods here and very low temperatures of the glacial periods here. What you also see is that the composition of carbon dioxide follows the composition that the temperatures signal almost perfectly. There is no excursion of one without an excursion of the other, they clearly are linked in some quite fundamental way and the question is how and why.

Methane isn't quite so tight but essentially you see the methane concentrations are high in warm periods, here, here, here and here and low in cold periods. That's an enormously important discovery; it is reality irrespective of how you explain it. The question is how do you explain it? Now a few years ago George Bush would have explained by saying there is a process which causes carbon dioxide to fluctuate in the atmosphere and that process is temperature; the earth's temperature varies through time and that variation of temperature causes a change in the carbon dioxide concentration of the atmosphere. Well there are many of us who don't think that is correct.

Another fact is that if you do a very simple Newtonian calculation on the way in which the earth's orbit around the sun changes through time, you find there are three principle components of that orbit and those components have different timescales and variation and extraordinarily those timescales variation of a hundred thousand, forty thousand years and twenty thousand years. Those are frequencies that are contained in that ice core and indeed in marine records. In other words it is quite clear that there's a relationship between the orbit of the earth round the sun and the temper climate change on earth. Now it's unreasonable to suppose, I think it's unreasonable to suppose, that climate change on earth somehow determines the earth's orbiting round the sun. Much more reasonable to suppose the earth's orbit around the sun is a consequence of climate change dynamics and it is that that's sending the signal to the earth.

Now, we can calculate using the sorts of climate records I've shown you, the average change in global temperature from a warm period like the present day to a cold glacial period such as we had twenty thousand years ago and the average global temperature shift in that fluctuation is about five degrees Celsius, it doesn't seem very much. In some places in Scotland it's actually much, much bigger – it's like 15°C in Scotland for an average of about 5°C. We could compute what the consequences of these planetary changes were for the earth's surface, for the temperature of the earth's surface and the computation which I think is quite a robust one says it was able to produce changes of the order of half a degree Celsius. In other words the real change was ten times bigger than the change that this process itself could produce. And so the idea is this is the pacemaker for change, it's telling the earth's climate the direction in which to move, but it's not the determinant of the magnitude of the change. The question is what is the magnitude? Scientists have worked on this for many years and now there is a very general and a very broad consensus, which I guess some of you may not believe in, and it is this: essentially the earth's atmosphere is the earth's thermostat.

About six months ago I gave my clever bunch of third year students a problem to solve. I told them the distance of the planets of the solar system from the sun, I gave them the energy signal of the sun and asked them to calculate the planetary surface temperatures. They all got them wrong. Now they are quite clever and their calculations as far as they went were just fine, but what I didn't give them was the planetary atmospheric composition, the composition we actually give the planets. I did that and then gave the Arrhenius equation, which was fine – Swedish chemist, 100 years ago – and they put that into the calculations and got it right. In other words, the surface temperature of the planets of the solar system depend fundamentally on the composition of the atmosphere, it determines how much solar heat is retained by the planet. If that's true for Mercury, Venus and Mars, there's no reason why it shouldn't be true of the earth as well and most geologists now believe that earth's atmosphere is essentially the earth's thermostat over long periods of geological time.

The atmosphere is essentially about a hundred kilometres thick, but the bit that really matters to us it the troposphere which is about ten kilometres thick. When you're flying from here to Dubai or wherever you spend your weekends [*laughter]* then you fly just above the troposphere because that's the turbulent bit and what you hope to do is to set and direct the jet stream which blows across the top of it. So weather is something that happens in the troposphere. And, of course, the operation of the atmosphere is believed by most climate scientists to be a consequence of this greenhouse effect whereby radiation from the sun, shortwave radiation from the sun, is intercepted by the atmosphere or, more generally, intercepted by the earth, it's re-emitted from the earth's surface as long-wave radiation and gases in the atmosphere essentially absorb that long-wave radiation and they re-emit that energy as heat energy which effectively warms up the atmosphere. And if one again does the calculations – and they are intrinsically quite simple – and then determines how the magnification of the solar signal might be produced, and if it could be produced by the changes in the carbon dioxide concentration of the atmosphere, the calculations come back right. In other words, if you want to amplify the solar signal of half a degree Celsius to make it five degrees Celsius, the change in carbon dioxide concentration will do the job for you. So we geologists at least were convinced by this about twenty years ago, but, of course, if one's going to take it further they must be much more coherent.

So that's about changes in the physical earth and why, at least most of us think, they take place on quite a long term scale. Now let's have a look at life on earth and this is an object that was found about fifteen miles from here about ten years ago. Anyone guess what it is? Audience participation is permittable at this point. It's a tooth; it's actually a mammoth's tooth. This mammoth must have had terrible toothache because normally this axis is straight and this is bent and that occurred during its lifetime. We know what that fellow looked like, although not that particular one but what the species looked like. This is a mammoth found in 1908 in Russia. It is said that it was served up as a steak at the International Geological Congress meeting in St Petersburg in that same year. It's not said whether it was eaten or whether people were poorly because of it. You can see its lost part of its trunk because the dogs got to it before their minders and scientists did and it's now preserved in a terrible state in a museum in St Petersburg.

This is actually quite extraordinary, it's a find that was made some years ago in Creswell in Nottinghamshire and it's our own Lascaux Niaux, these are paleolithic paintings on the walls of a cave in England. Here you see what we think is a mammoth, it has a very distinctive dome shaped head here, its tusks are somewhere here and its trunk, that's its trunk. We're not quite sure of the age of that, but it's about twenty thousand years old at a time when only about fifty kilometres north the terminus of the great ice sheet that covered much of Britain. On the same wall there are scribbles like this and someone, quite remarkably, noticed that you can distinguish some of the scribbles and they began to take them apart and that came out. It's even been suggested that these rather prominent eyes are something else that we know from the modern day where Inuit Eskimos used bone with slits in them against snow blindness. This appears to be a sketch of a contemporary human from some twenty thousand years ago. It's interesting that it's been scribbled out and one just wonders whether this might have been taboo.

Of course, these humans as humans tend to were up to no good at all and by eight thousand years ago the mammoth populations were suffering desperately by mammoth hunters on the Steps of North Eastern Europe and Siberia. This is a mammoth hunter's camp from about nine thousand years ago. They had seasonal camps and what they've done here is used, these are jaw bones of mammoths and they've used them essentially to hold down their skin tent. The last mammoth we are aware of comes from Pribilof Island just of the northern coast of Siberia and was dated at about five thousand eight hundred years ago and we believe the mammoth was almost certainly extinguished as a consequence of human activity. But before that happened we also seen this as a sketch from a cave in northern Spain and there's a mammoth, a very distinctive piece again, and this sketch is from about thirteen thousand years ago and you can see this rather peculiar object here and it almost looks as if a mammoth had been domesticated when you are looking at some sort of a cage with in which the mammoth was held, like a sheep pen.

Of course, human occupation develops and evolves as climate gets warmer and at the end of the glacial period, about ten thousand years ago, what had been a very strong oscillation of climate during the cold period became much steadier through time, much simpler and much warmer. Just before the beginning of the warm period this is in fact the earliest tell from Jericho. It's dated at about twelve and half thousand years ago and you can see the base of the tower here and for me at least this is rather powerful as a symbol because at the time when Jericho was a thriving city with streets that we would have recognised and presume merchants to, then Inverness, Glasgow, Oslo, Stockholm were covered by more than a kilometre of ice. In other words a modern earth was here, but an unimaginably different earth was in a part of the world that we know. I think, for me at least, that connects our modern earth that's noble and knowledgeable from this unimaginably different earth of the past.

One of the things that's also rather clear from the archaeological records, and becomes more and more clear as time has gone on, is that we see strong evidence of well developed civilisations that founder. Now it may well be that part of the founding of those civilisations is a consequence of political activity, warfare and the like, but it's also because of association – it's becoming increasingly clear with much collapse with a number of civilisations that we know a great deal about may well have been produced by environmental degradation. These are three periods from the eastern Mediterranean region which has been, in the past, prone during our present interglacial to perennial drought or periodic drought where we have evidence of very sustained drought over longer periods of time which almost certainly would have diminished the productivity of agriculture when of course these civilisations where based on the capacity both to tax and to draw in agricultural production and the major civilisations simply cannot survive if the agricultural economic base is damaged.

This is a powerful example from the Maya civilisations of Central America which collapsed rather dramatically after a flowering of some several hundreds of years and we vaguely understand why it collapsed. This is an index of aridity – the further left you go on this graph the wetter it is; further to the right the greater the aridity. This is time – fifteen hundred years BC; present day here – and we see this phase during the later period of Maya civilisation when there was a series of very sustained droughts and there is a great deal of evidence based on the nature of agricultural production, based on pollen analysis, that in fact the whole economic and agricultural basis of Maya civilisation collapsed as a consequence of these sustained periods of drought. So it's happened before, the question is can it happen again? Whilst this was going on, of course, the nature of the environment was changing. Those of you who have been up our Scottish mountains will recognise this sort of sight, this is a peat bog, it's on the side of Ben Lawers and contained within the peat bog is a pine stump. Now that pine stump has peat on top of it so it's not a modern pine stump, in fact one can date that pine stump and it's about six and a half thousand years old.

This is some evidence from a place called Black Loch in Fifeshire. You'll see time on the left hand axis from fourteen thousand years ago to the present day here and let me direct your attention to this graph on the right hand side. This shows the proportion of the total vegetation that's made out of trees here in black or by grasses here in two lighter shades. And what you see is at the end of the glacial period, about 10,000 years ago about here, that prior to that there had been largely a tundra landscape, a grassy tundra landscape, but after this we see expansion of trees, first of all birch and pine and then mixed oak forest and beech and by about seven or eight thousand years ago here, we have largely a forest cover with some grass land.

But after about six thousand years ago we see the forest cover diminishes dramatically and if we raise and carry the curve a little bit further to about fifteen hundred BC the forest cover had diminished almost zero. This part of the change is a consequence of the warming earth. We are replacing tundra by forests, this part of the journey is us, that's human occupation, it's the consequence of the cutting of forest to create arable land and pasture. In North Western Europe we see very, very clearly this Neolithic and Bronze Age dramatic deforestation – particularly strong in bonze age – and essentially we've had in Europe deforested landscape since Roman times. The nadir in Scotland was probably about 1750, 1740 where we had something like seven per cent of the total of forest cover that had existed in the early part of the interglacial and since then, of course, the forest cover has been increasing as a consequence of plantation for commercial purposes. So there has been a dramatic change in the forest cover, the human impact has been extremely powerful during that period and the fundamental nature of the environment has shifted.

As we move through this period of time from an early part of the interglacial when we have the strong forest cover, we had rich soils at that time… We had rich soils because the glaciers that had been swept down from the Highlands had broken off chunks of feldspar and pyroxene and other minerals which contain within themselves the nutrients that plants need. They contain iron, manganese, potassium, phosphorous and the like and when those minerals break down by weathering then they release those nutrients, which are taken up by plants. Progressively, of course, during the interglacial period those plants take up the nutrients and the soil will start to deteriorate in its quality. In fact, if you make a map globally of soil quality you find that there are two sorts of areas where there are good soils; one is where there had been glaciers and the other is where there have been volcano's because those are sources of fresh mineral materials which can go on to provide nutrients for growing plants. Those which are inherently infertile are places where that has not happened. Australia is a continent that is inherently infertile. Much of West Central Africa is inherently infertile and, of course, human activity has impacted on that dramatically.

You might remember Charles Dickens in a Tale of Two Cities wrote about the best of times, the worst of times and arguably the present epitomises that. You could say it's the best of times in the sense that, even in the last fifty years, the average lifespan at birth has improved globally from about forty six to sixty four years and the gap between the developed and the developing world has diminished from about twenty four years to a still disgraceful twelve years. So on one hand we have clearly seen progress, we have seen progress in human health. We may, however, also be on the verge of the worst of times. Human populations in about 1830 were about one billion people, the present day it's six point five billion, by 2050, barring accidents, then it will be about nine billion.

If you ask 'well, how do we feel about that nine billion?' the answer is an interesting one because arguably our capacity to feed people has been sustained over the last thirty to forty years by the so-called green revolution where now, last year, about fifty per cent of all the atoms of nitrogen and phosphorous that went into growing the plants on the continents came not from the natural biogeochemical cycles which develop the biosphere and which struggle to sustain them, but from artificial fertilisers. In other words, if you tell me that organic agriculture is a solution to the world's problems you're not in the right ball park. At the moment our attempts to feed the world are largely based on artificial fertiliser, to a very great extent and there is a severe doubt as to whether we may already have passed the earth's carrying capacity in relation to the way in which we now live, what we eat, how we eat it and the energy we use.

Individually now we use about fourteen times the energy subsidy that our hunter-gatherer ancestors had. That energy has to come from somewhere and we have to use it efficiently. There are many people who believe that they very phrase 'sustainable development' itself may have been damaging; the idea somehow that development that we currently know is actually sustainable. Arguably it's led many politicians off book. If we look at the way in which we have depleted the earth's resources then our soil resource is massively depleted. It's depleted because we're losing vast quantities of soil; last year in China about twenty billion tonnes of soil found its way into the South China Sea and the Yellow Sea and the reason it found its way there was because there was very little forest vegetation to retain it and it's getting worse. At the same time that soil is losing its natural fertility because of the processes I've spoken of and the only thing that retains that fertility is artificial fertiliser. In terms of biological productivity, it's something like sixty to sixty-five per cent of the total biological productivity of the continents we use for our own purposes, and we intercept and use about seventy per cent of all the usable fresh water on the continents. In other words we don't leave very much for the other inhabitants of Noah's Ark.

I want to say just a few things about hydrocarbons and minerals and then something about the atmosphere. You will have heard of this idea of peak oil. Well there are now not many economists or geologists who seriously consider this issue who do not believe that we have either passed the point of peak oil production or are shortly coming to it and the price rises we see in the present day are going to be sustained into the future. Cheap oil has been the basis of our economy for the last hundred years and it is a questionable issue of whether we can replace it in ways that can sustain our current lifestyle. The atmosphere is something which had a major impact. This is rather an emotive slide, but nonetheless it's real, it happens. We're pouring CO_2 into the atmosphere on a massive scale, but if we look at the way in which say carbon dioxide and methane, about which I showed you grafts earlier, have changed through time… These are records from the ice cores, they're from exactly the same source as the other data that I've showed you, they show the last thousand years and you see, in terms of carbon dioxide concentration, normal interglacial concentration just about this level has now in fact gone up to almost four hundred parts a million; this is a rather outdated slide. It's about up here now and the same is happening to methane. If we are right in saying that these atmospheric gases are part of the earth's thermostat then we ought to be concerned about what the impacts might be.

This is the data plotted on one of those ice core records I showed you before. In red here we're looking at carbon dioxide and that's a natural record of carbon dioxide through time. That's where we are, in fact, we're about here now, we have high levels of CO_2 in the atmosphere, we've known for about thirty million years. Is there anything to stop it going up here? We don't know whether the earth will suddenly begin to absorb, or the oceans will suddenly begin to absorb much of the excess CO_2. If we look at the mean temperatures in the northern hemisphere computed from a whole variety of proxy records over the last thousand years, we see this dramatic shift in temperature. This rise in temperature now is of the order of point seven degrees Celsius on average. That might not seem very much, but of course it's more than a tenth of an ice age. So in global terms it's a very large change.

If we go to all the continents and look at the average temperature changes through time over the last hundred years we see that in every case we see evidence of temperature rise. If we look at the records that derive from the satellites looking at the top of the troposphere and the surface of the earth, these are the changes in the mean annual temperature since '69; in the last thirty years the change has been dramatic and you can see that at the surface the increases in temperature have been particularly important and powerful in northern latitudes.

The impacts are there already. These are representative images from Central Ladakh from '69, '79, '89; they show the cover of snow and, in fact, glacier ice. The reason why that's important is that during the dry season something like 80% of the flow of the rivers of the great north Indian plain, the Indus, the Ganges, the Brahmaputra, about eighty per cent of that dry season flow comes from snow and melting glaciers. Already in the last fifteen years we've seen dramatic reductions in dry season flow. Calculations by glaciologists now suggest that by 2050 most of the Himalayan glaciers will have gone and the impact on dry season flow of those great rivers will be dramatic in the extreme. They could be reduced between twenty and thirty per cent of their current dry season flow with devastating impacts on agriculture in both India and Pakistan and indeed, in Western China.

This is an image of the Greenland ice sheet, a great ice flow about three kilometres thick. This is the area which normally, in former times at least, this is an area of snow accumulation with the melting restricted to the margins. Now you see this zone of melting very, very much bigger and systematically year on year we see the same. This is where there was going to be an animation of last summer's sea ice concentration in the Arctic Ocean basin, just in case it didn't work I put in a picture. This is the extended sea ice on the Arctic Ocean basin this last August, no it's actually 25th of September. That's the area of sea ice there, you will see that for the first time you could have got through the North West passage without any problem, but that's the norm, that's the average extent of sea ice in the summer. Last winter, for example, Spitsbergen here, which I know very well, there was no Fjord ice at all last winter in Spitsbergen and the same is true of Alaska and that is quite unknown, completely new. The models suggest that what ought to be happening is the impacts are meant to be bigger in polar regions, the real observation show that they are. Sea ice and glaciers, they're not emotional things, they don't respond to tomorrow's heat wave or last summers snow fall. They integrate climate through time. What they're telling you about is the trends; they're much more reliable indices of trends than let's say a summer's weather.

So what about forecasting? Let me try to hurry through this quite quickly. First of all we use computers. Why? We use computers because suggesting where cause and effect might lie in relation to the climate is not something that is accessible to the sort of unaided reason that you and I typically do. We typically see a phenomenon here and we ask the question, what caused it? And they give us something over here that we can imagine might have caused it. This is a coupled multilineal system system. All the elements of this system are interacting. It's a bit like having a billiard table and seven or eight billiard balls, the reds all close together, you shoot the white into them and you try to work out using your own brain where all the balls are going to go to. I doubt whether many of you could achieve that; you actually need something like a computer to do it. People talk about "it's only modelling", but actually what it is, it's the encapsulation of all our best scientific theories that we can put our hands on. Don't forget these are the theories that permit heavier than air flying machines which fly through the atmosphere and which you are very happy to travel in. And that's the climate system. Those are all the components of the systems that interact together to create climate. (slides 64 – 74)

About thirty years ago here we could do computer simulations which assumed a flat earth they had precipitation, they had the sun, they had CO_2. Now the computer simulations we do are not far from an almost comprehensive cover of all the things that we can imagine might affect climate and they include us in that and if we look at the output in those models we can run models in different sorts of ways. We can run one where we ignore human effects like production of CO_2 from burning fossil fuel, and we can do one where we incorporate human effects and if we simply use natural effects and look at the hundred years from 1900 to 2000 that's the real change in our temperature in the northern hemisphere over that period of time. This is what we get if we if we only include nature, including volcanic eruptions and we see that it's a pretty good match until about 1960, 1970 and then the two diverge very strongly. If we put in human impacts, particularly the gases that come from burning fossil fuel, then the two match pretty well.. In other words in the last thirty years we are seeing the human impact rise above the level of the natural signal of change and the key of course is what are these emissions going to do in the future? Our presumption is that we are going to have massively increases in demand from China, from the US, in fact all of us are going to increase our demand. If we use scenarios of the future use of fossil fuel and the greenhouse gases that we'll produce and look forward to the future, these are the sorts of forecasts to be created.

These slides are using different scenarios and they are suggesting the extent of global warming – you'll see values of about four degrees Celsius up here values of one degree Celsius down here. So it's quite a wide range of forecast. Don't forget that five degrees Celsius is our ice age interglacial transition, so it's a very big shift. The problem is that if we look at the emissions in the last two or three years – they're plotted here on new data which has became available in the last few months – the actual emissions now are way outside the most pessimistic scenarios that we used in those previous slides which came from the International Panel on Climate Change. What's happened is that the rates of emission of greenhouse gases have doubled since the year 2000. During a period of time when we have all been telling ourselves somehow we're implementing new kinds of technologies and sustainable energy production. It hasn't been happening and things are getting worse and if the impacts, that the models suggest are going to occur then we have to shift our thinking away from trying to ameliorate change by reducing emissions which, of course, we must do, but we've now got to think about impacts how are we going to adapt to things that are very, very likely to happen.

So what's likely to happen? Well, these are model outputs showing the temperature changes we expect through the 21st century giving these really dramatic increases in temperature and you see values of over six, seven, eight degrees in north polar latitudes, which have really very big impacts, you see precipitation too and what you see is the lower latitudes get drier and the higher latitudes get wetter. A warmer earth is a wetter earth because more moisture is evaporated, but a warmer earth is also a more energetic earth; the climate is more energetic, if you like, the winds and the oceans circulate more rapidly and they push precipitation towards the polar regions and away from the mid latitudes. Of course, the mid latitudes of the earth have a greater percent of carbon production, the concentration of population and, of course, the greatest concentration of poverty.

I'll touch on a medical issue. You will all remember the 2003 heat wave in Europe which produced this excess of deaths, particularly in France during the summer time. Well this is a forecast of temperature to 2100 – people shouldn't take this too seriously, it's not a specific forecast – and the variability here is based on the statistic analysis of previous variability. That's the sort of temperature that was reached in the summer of 2003 in Paris and what it suggests as it says here that by the 2040s those temperatures will be normal and by the 2060s those temperatures will actually be rather cool and I leave it to your imagination what the impacts of that might be.

Now it's also worthwhile recognising the fact that from time to time throughout history there have been really dramatic and unpredictable changes and I've just selected one here because it's actually quite photogenic. This stuff has come from a core taken on the western continental shelf west of Shetland and it looks like ice, in fact its methane. Methane goes solid when the temperature is quite cold, not very cold, but quite cold and pressures are high and under many of the earth's continental shelves there is this solid methane, simple methane hibernate, which is frozen and is locked into the sediments of continental shelves. The volume of it is enormous, it is a vast volume. Here you see the methane burning, it's nice to see a snowball burning, someone holding a burning snowball in their hands; quite a party trick. If that methane hibernate were to be released from the continental shelf because the oceans are getting warmer, what it would do would be to acidify the oceans on quite a big scale and with massive consequences for marine life in the oceans and much else besides; also the capacity of the oceans to absorb carbon dioxide from the atmosphere. Well we have evidence that it's happened. This is a core from the Atlantic and there are many more like it. This shows normal deep reed sediment, it's also shown here, which is full of carbonate, tiny fossils I showed you at the beginning made of calcium carbonate. Suddenly the carbonate disappears and the reason is we can infer quite readily from this, it's because the oceans are getting very acidic and what's happening is that all the carbonate in the oceans are being dissolved.

You can see that's a straight line, it's a very sharp line, but we think that's about 700 years and the total duration of this epoch when the oceans were acidified was about a million and a half years. It happened here, about 50 million years ago, which is nothing really in geological time. It happened at a point when we have this extreme warming of temperature and it looks as if what happened was that the ocean margins warmed up, the methane hydrates were released went into the atmosphere warmed the atmosphere and at the same time produced this dramatic consequence in the oceans. Could it happen again? Yes. Our people researching it… Yes, very, very, serious indeed. Do I think it's likely? No I don't; it's just an example of the sorts of catastrophes that have happened in the past.

Now, if one thinks towards our present mindset which is, you know, global warming and super computers and all that… I'm sure there were moderately intelligent descendants of dinosaurs here. I mean what were they thinking? It's getting a bit warmer, that's all and then suddenly 'the Bang' happens. In other words, in our history that accidents do happen quite regularly and the consequences are very serious.

Just let me very briefly wind up. First to say that I find it really quite, I was going to say distasteful, not quite that, but I find it quite difficult to stand up in front of an audience like this and somehow give you what one could quite readily interpret as a scare story and am I right? Yes I am. I do think these issues are extremely serious. Could I be wrong and the majority of scientists who are involved in climate research be wrong? Yes, of course, they could. There may be processes in the earth which will inhibit this, but the question is what sort of probability are you prepared to accept as not worthy of attention. Is it five per cent, is it fifty per cent or is it ninety per cent? If you say that it's only fifty per cent probability we won't do anything. Well, if I told you that there was a fifty per cent probability that there's a hungry, man-eating lion outside the door, I'm pretty sure none of you would go out of it and, of course, in our individual cases we are all use to coping with uncertainty. One of the difficulties, of course, is that politicians tend to say well come on you're scientists, tell us about the certainty. What they don't understand is that science is not about certainty, it never has been about certainty; it's about uncertainty primarily. Most of our theories are wrong, it's just that we don't actually yet know how they're wrong. One could say well these sorts of things happened before, Malthus you might remember about a hundred years ago and drawing attention to a dawning population problem which never materialised in a way he thought of it. It may be materialising now, we just don't know.

Thirty years ago the Club of Rome producing a book called 'Limits to Growth' in which it argued we would run out of resources. One might contra that mind set with the mind set of typical economists, classic economist who will say to you that the availability of resources is dependent simply on market demand. Well actually if things do run out and the question for us is are they? Can we cope with these problems if they are substantial, as they might be? I'd say no we can't. Some of the trends that might be in the process of working themselves through could be changed within the next decade. We are already seeing dramatic impacts in the arctic, there are whole Inuit communities that are moving location because their lifestyle is not sustainable any more.

Within the next decade we may see, even here in Scotland, changes that are really quite difficult to cope with and processes the government can't cope with. Clearly the energy issue is a vital one because we must somehow try and hold back emissions. Can we cope with it? It's not clear that we can, we certainly haven't made any progress in the last seven years. Maybe this is a rather indelicate thing to say in Scotland, but maybe the nation state is just the wrong political body to cope with these things. The fact that our mindsets are encapsulated within the boundaries and the histories which will enforce those boundaries and actually the idea somehow that we might be able to work together, is very, very difficult to achieve. One of the problems, of course, is the cheating. We'd like to think that everyone will do their bit, when actually it doesn't really matter if we don't because Scotland's emissions are insignificant. And it reminds me of the problem of the MMR vaccine where essentially there is a small but finite risk to your child if you take that vaccine. And if you take the view that I'm not going to have my child subject to that risk, you're essentially cheating because what you're also depending upon is that the herd immunity which will be achieved by large scale vaccination will be achieved because other people have their children vaccinated. And somehow how we get rid of the problem of cheating, the problem of the global commons and how we act together in order to be able to ensure that some of the consequences that this angry planet might visit us with in the way that it has in the past, are somehow set to change.

The title of this talk almost implied that I had some answers for you, but I'm afraid I don't. Thank you

[Applause]

Duncan Booker
Thank you Professor Boulton for a wonderful and thought provoking talk and I took down, I think your first statement about "don't poke an angry beast with a stick". There something to reflect on.

It's traditional to offer our speaker a wee token of our appreciation for coming along and sharing his thoughts with us this evening. I know you will all agree that was a wonderful, thought provoking, engaging presentation and a series of responses to your questions can we therefore collectively offer our gratitude in the usual manner to Professor Boulton.

[Applause]