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Global warming: key facts, key solutions

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[The associated PowerPoint presentation slides for this briefing are clearly indicated]

Slide 1. Thank you for the opportunity to come and talk to you today about my new passion for the last few years – climate change. I, in a former life, was predominantly a conservation biologist working on PVA, did some research with Bob Lacy and Phil Miller but at some point I realised that if we didn't do something about climate change then all the other important things that we were doing in conservation biology were going to be swept away by this problem because it's not just another bolt on issue that we could deal with in conjunction with all the other threats facing biodiversity. It's such a profound issue that if we get it wrong, then no matter how well we do in these other areas it's not going to matter. Now you may think that climate change is an important issue but not that important yet, well, let me in the next 40 minutes or so try and persuade you otherwise.

Slide 2. Of course this is ultimately a major problem that we have a large number of people on the planet. It's a growing problem and our destructive use of resources, and the way in which we deposit our waste materials on the planet is growing exponentially. It's growing disproportionately in some areas, we've had large scale development in North America, in Europe, in parts of Asia and yet in areas such as sub-Saharan Africa there's huge population growth occurring now, so we're always going to be faced with this challenge of the nexus between human population needs and those of species.

Slide 3. Climate change represents one of those areas where that nexus becomes profound and ultimately could be a feed back whereby our impacts on the environment most heavily come back to haunt us. Because of course were having impacts not just in terms of habitat destruction and direct exploitation of species but also more pervasively depleting soils and dumping garbage, releasing large amounts of carbon into the atmosphere. All of these have an impact and they have a synergy so they interact with each other to make each of those individual problems worse. Maybe we could get away with one or two of those, but when we have this nexus of all of them together that provides a profound set of consequences.

Slide 4. We're in an age of rising everything, peak everything: population size of people, water use or damming of rivers, paper consumption, transport mode vehicles, MacDonalds restaurants… Really, it doesn't matter what you look at - up it goes! And it's been in the last 50 years our impact has been profound. So, humans have certainly had a large impact for many hundreds of years but in the last 50 years we have used more of Earth's resources than we have for the entire history of humanity before that point so it's a new phase of human development and one that anyone who studies exponential growth of populations would understand can't go on for much longer.

Slide 5. And, of course, one of the ones I am going to dwell on today is the graph over here, which is the incredible rise in the atmospheric concentration of the three of the most important long lived greenhouse gases carbon dioxide, methane and nitrous oxide, as well as many other trace gases.

This is a figure from the developmental panel on climate change fourth assessment report, which is a review conducted every six years by a panel set up by the U.N. first set up in 1990. It attempts to assess all of the published peer reviewed scientific literature on climate change so it doesn't do primary research itself, it's a review body – a very comprehensive one that covers multiple volumes, thousands of pages and thousands of references. Here is one example of a figure that comes out of their synthesis report it's a measure of global temperature change over the last 150 years, since we've had a thermometer record. So the black dots are the year to year variation we have a smooth five year running average and there are some trend lines there so the red line there, the long trend line over the 150 year period, then we see a blue line for a hundred years, orange for 50, yellow for 25. You'll notice that the slopes of those trend lines are increasingly steep as we get to the present. In other words, the warming effect is clearly there and it's also clearly increasing. We also have some maps of warming at the surface and the lower atmosphere and I'll talk more about those in a moment.

A key concept to try and wrap your head around here though is that what this measure represents is not the temperature in this room, or the weather outside. Because it's a global average temperature over a year it's actually an abstract index of the climate system in the planet. We have this entire planet, the Earth, and we have quite different climates in the tropics or in temperate areas or over the poles. We average it over all that we get an annual average figure of about 14.5 degrees, but this doesn't actually mean something in terms of weather it means that is the state of Earth right now and if you shift that back a few degrees you get an ice house planet where you have large ice sheets over North America and Europe. You shift it forward a few degrees and you have a super greenhouse world, like the Cretaceous. So small changes in that measure of global temperature actually have a profound influence. So when we're talking about a change of half of one degree we're already seeing large changes in terms of its impact on biodiversity and when you start to ratchet it up to 2, 3, 4 degrees it's very hard for us to comprehend the magnitude of that impact on the climate system.

Slide 6. Here's another way of looking at temperature change. This time broken down into the Northern and Southern hemispheres. There's more warming in the North than in the South because it takes a lot more energy to heat water and the South is mostly water.

Slide 7. So, if you look at what we should have expected to see in terms of the amount of extra energy trapped by the increase in greenhouse gases about 90% of it has gone into heating water, the oceans, about 7% into melting ice, the remaining little bit (about 3%) has gone into changing air temperatures. So you can notice that when you look at the hemispheric difference or you can notice it when you look at difference between land and oceans. There's clearly more warming over land because it's easier to heat that area but there is a huge thermal inertia in the oceans which means they gain heat in a long term commitment

Slide 8. The next slide I'm going to show you is another way of looking at the temperature record, this time on the basis of a world map where the blue areas represent those that are cooler on average than a baseline period set between 1951 and 1980. Yellow and red are warmer, so you can see back in 1884 most of the Earth was cooler than that reference period but there were regional anomalies: warm over Alaska, for instance, part of Australia. [Let's start the animation running] And you'll find on a year to year basis you see natural fluctuations. In the late 19th century & early 20th century there wasn't much trend in overall in temperature you can see the climate system varies on a year to year basis. Then we start to see the warming picking up and then it's ameliorated from about the 1950s through the 1970s as a result of mostly sulphate pollution from industrial activity. But as all the greenhouse gases that have continued to accumulate have a longer term impact we see the moment profound warming and leading up to the last decade as been the hottest decade on record by a long shot.

Slide 9. So that's 2007 that's the same sort of anomaly there for one particular year. It was slightly cooler by the fact we had a cooler East Pacific but overall much hotter.

Slide 10. If we look at the average over the last seven years or so and compare that to that baseline period then you can see those regional abnormalities get averaged out. You can see now why it is called global warming – it's happening across the planet where ever we are monitoring it. There is also an Arctic amplification and some amplification in Antarctica round the Antarctic Peninsula. This is largely due to a retreat of snow and ice as you start to have warming temperatures It is one of the feedbacks in the climate system that makes a warming in those areas of the world much more profound. Somewhere between 2 to 4 degrees extra warming in Polar regions compared to the globe overall. And that's predicted to continue.

Of course, you may have heard discussions in the media or so called debates about climate change on whether we're in a cooling period now or whether we are heading for a new ice age and so forth. I can certainly guarantee you we are not heading for an ice age because we understand the principles that cause that and you'll find the amount of what we call climate forcing caused by long lived greenhouse gases have now so much overwhelmed natural forcing as to make that impossible.

Slide 11. Over on the left is a satellite record of lower atmosphere temperatures since 1979 since we've been monitoring it. That's on a month by month basis so there's lots of variation overall but a clear trend upwards – the red line. But of course we've had periods of cooling 1981 through to about 1986, another one in the late eighties, periods of rapid warming in the early nineties, periods of sub stasis in air temperatures over the last few years. That's inherent natural variability of the climate system upon which we have superimposed a trend. So, you calculate a trend by looking at a long term change. If you do that over 8 years then you get a figure like that. If you do it over 15 years you get a figure like that. And you can see once you've averaged those 15 year periods all of the trend lines continue to be upwards.

Slide 12. You can remove some of that variability from the drivers of the climate system that we have some understanding of, or at least some historical representation of such as the El Niño Southern Oscillation. When you do that you change from the dotted line there to the solid line. You can see a lot of variation in the last few years including that super El Niño of 1998 removed and the only deep variation then left are dips from equatorial volcanoes such as Mount Pinatubo in 1991 which have a short term cooling effect.

Slide 13. This is probably the most fundamentally important figure in terms of understanding climate change because it's a gain in heat content of the ocean where 90% of that energy is gone. So the oceans gain heat they take a long while for that energy to move through to the lowest layers of the ocean. The waters expand at that point and this has been the primary cause of sea level rise to date and that starts to then give up energy into the atmosphere and will continue to do that for many centuries. So that's a long term commitment: that heat gain and it's a huge amount of energy represented there and the transfer of energy from the oceans to the atmosphere is a primary determinant of short term climate fluctuations rather than long term change.

Slide 14. We have various proxies we can use to try and infer temperature change over longer periods. Here's the most recent figure published in PNAS using many different proxies such as tree ring data, geochemical signature in caves, bore hole data, the retreat of glaciers and so on. Different ways of reconstructing temperatures beyond the thermometer record which is shown there at the far end in red. When you do that sort of analysis, you can do it reasonably accurately for the northern hemisphere; you find that the last 50 years are clearly the warmest on record. But of course even if that was unremarkable in that period the commitment of future warming takes us well beyond that millennial scale temperature change.

Slide 15. This is Australia looking at temperature change since 1970 when we've had the most intense warming. Over the century we've had about a degree of warming in Australia compared to about ¾ of a degree Celsius world wide. The warming in Australia has been most intense over the centre of the continent.

Slide 16. Now there are various drivers of climate that climate scientists study on a day to day basis and have fairly good understanding of. Two of the important ones are the changes in solar activity and changes in concentration of long-lived greenhouse gases. So here we have temperature change represented by the red line, the increase in CO_2 (one of the greenhouse gases that's important) shown in blue monitored directly since 1957 and before that inferred from the ice core record, and in changes in total solar radiance. So we have an 11 year sunspot cycle and a running average there of total solar radiance. You can see that there is very little relationship between solar forcing and temperature change over the last 50 years. That's a period at which there has been a strong divergence between what would be anticipated in terms of climate change from solar forcing and what we've observed.

Slide 17. Other examples of evidence that we can fingerprint global warming to increase the greenhouse gases is diagrams such as this which is showing changes in the frequency of cold nights versus cold days and warm nights versus warm days. Now why is that important? Well, you can see the trend to have fewer cold nights and more warm nights is greater than days. You wouldn't expect that to occur if it was the sun that was changing because you would expect hotter days but in fact because its energy being trapped by greenhouse gases that's exactly the sort of signal you would expect: a lessening of the difference between night time and day time temperatures.

Slide 18. Climate science tries to look at all these drivers and measures what is known as the radiative forcing of these different effects on the climate. So we've got the red line here which is the effect of all of the greenhouse gases combined. We have the blue wiggly line down the bottom which is the effect of volcanoes, they have a short term cooling effect, the pink line there the effect of low level pollution (mostly dust and sulphates). There are many drivers of climate and even the solar signal in there which is that wiggly line you can hardly see there. You put all those together and run a climate model and you get stochastic projections such as the one down below where when they are superimposed on the temperature record you can see that when you understand all those historical climate forcing events you can reproduce 20th century temperature change very well. Now that's not some fitting of the climate model to that temperature record, that's a reconstruction of it on the basis of those forcing events. Its another way you can attribute those different climate forcing effects and know with confidence that human effect of increased greenhouse gases is particularly important.

Slide 19. The human effects actually have both positive and negative effects. Some of those are illustrated here. The top figure there shows the concept of radiative forcing which is essentially the extra energy trapped at the Earth's surface measured in Watts per metre squared here shown for non CO2 , CO2 gases in red. If you add those up and it's about 3W/m2 so it's like putting on a 3W light globe on every square metre of the Earth. That's the extra effect that we've had. But then we've also done things to cool the climate such as release sulphate aerosols and dust and also incomplete combustion of carbon has a warming effect. But these have a profoundly different effect to long lived greenhouse gases which go into the atmosphere, mix well and stay resident for decades or centuries, whereas the aerosols get washed out of the atmosphere in days by rain but they are constantly regenerated so they're always there and have overall a net cooling effect. So somewhere between 20 to 80% (best estimate is 47%) of all of the warming we should have seen apart from that which is in the pipeline due to ocean warming has been masked by the aerosols. If you turned off all coal fired power stations today and that warming effect would come back almost immediately and we would have about a doubling of the warming we have seen so far. So, ironically, the most stringent carbon reduction programs that say we could reduce our emissions by 90% in the next 10 years will have much greater planetary warming than business as usual but then that situation starts to turn around, it's a long lived effect as green house gases accumulate.

To give you another example there's been a lot of coal fired power stations being built in China in the last ten years they've had a net cooling effect on the climate that will take 7 to 10 years for the long lived green house gases released by a coal fired power station to overcome the short term sulphate effects. So, it's a complex story and you need to understand the positive and negative feedbacks. Now you whip out those aerosols and you get a commitment to global warming that looks something like that, which is actually between 1½ and 3 degrees of warming if we didn't release a single molecule of extra anthropogenic CO2 today. So we have a major challenge to face even beyond that of reducing carbon emissions in the first place and that strongly argues for me we're likely to have to intervene in the climate system to cool it at some point.

Slide 20. If you look at the really long term record of climate change, illustrated here from the ice core record, it's a very strong relationship between temperature as we can measure it from oxygen isotopes (shown in the red) and the forcing effect of all the greenhouse gases added together In the case of the ice ages and inter-glacials the trigger for ending the ice age was solar forcing. Changes in the Earth's orbit know as Milankovitch cycles and it was a feedback effect then as temperatures started to warm snow and ice retreated greater amounts of CO2 were released from the oceans and the frozen biosphere, such as the permafrost and that feedback effect then amplified the warming so CO2 can be a driver of climate change if we release fossil CO2 directly into the atmosphere that has been sequestered for millions of years or it can be a feedback effect if the warming is triggered by something else. Now what this tight relationship tells us is that if you zoom in on the last 100 years and look at the forcing effect then the green line just goes off the chart. In other words the concentration of all those greenhouse gases is about 50% higher than what we can measure at any point in that ice core record and that suggests another reason why the commitment to warming is many degrees even if we can shut everything off now. So most of what we should expect to see we haven't yet realised

Slide 21. Now with climate models you can start to do thought experiments. It's a bit like a sensitivity analysis in a PVA where we say what if we can turn certain things off? So the black line there is the observed temperature record the peak line there is the result of many runs of global climate models and they show a strong match to the observed record that I showed you earlier. But you can also do experiments. Now ideally you'd have multiple planet Earths. You'd have industrial societies in some and not others but like most things in ecology conservation biology there is no perfect experiment like that in climate science so we do model based experiments. Here is the result of one where we turn off the anthropogenic effect and you find that we should have had similar warming to what we'd seen up to about the 1940s and in a slight cooling of the planet another fingerprint of human impact on the climate system.

Slide 22. The projection of these models depends on a number of uncertainties (inherent model-based uncertainties) in terms of how well we attach the sensitivity of the climate system to greenhouse gas forcing that's shown by the different error bars at the side but then the coloured lines represent the different emissions scenario so these are choices that humanity is going to make this century in terms of energy supply and relate to green house gases and then there's possible scenario summarised there They're actually better than reality they're not accounting for aerosol changes that I talked about earlier, so even if we can shut things off early we're probably committed to quite a bit more than 2 to 2.8 degrees warming.

Slide 23. That's what projections look like at the "business as usual" end of things in 2050, 2100. That's what the world would look like with a temperature anomaly map of 2.3 degrees of warming on average and 5.7. You can see the polar amplification continues there where we have up to 28 degrees warming in the Arctic for about a 5 degree global temperature change. At that point if anyone can convince yourself you would have an intact Greenland ice sheet then I think you are kidding yourself. So that's obviously somewhere that we can't go but it's moving into a Cretaceous super greenhouse world in a century whereas it's taken about 80 million years to get out of that. So, the Earth has been there before, but in terms of adaptive rates and evolution its not going to be possible and in terms of movement of species to cope with these sort of changes that's also not going to be possible because there are 6 and a half billion heading to 9 billion people sequestering most of the planetary resources already.

Slide 24. You can look at uncertainties like this as well. This is a CSIRO projection for Australia where we have sensitivity of the climate model represented by the tenth, fiftieth and ninetieth percentile of the outputs and in different emission scenarios here so if we are looking at adaptation of climate change we also need to account for the fact that we can't have a perfect vision of the future both in terms of human decisions and climate sensitivity so we need to manage for that range of variability.

Slide 25. This is a diagram which illustrates why the concept of climate change is important for humanity and species at current in that yes we have had the climate changing in the past quite profoundly we haven't had a climate that we are heading towards, that's as warm as we are heading towards, for millions of years. Climate changed rapidly in the past but then experienced relative stasis as we seen in the Holocene where human civilisation has developed and that's the point at which all of our adaptation potential has been realised and if we're moving rapidly out of that realm that presents a huge challenge to humanity as well as to other species.

Slide 26. Another way to understand why small changes in average temperature are important - we think of temperature as a distribution, like this bell shaped curve, a small change in the average means a huge change in the extremes because of the shape of that distribution. So you might go from heat waves being 5% of occurrences in summer through to 25% with just a small change in the average.

Or to look at it another way you have year to year variability in climate and you have this comfort zone essentially that species might adapt to and you have vulnerable years, both hotter and cooler than average, and you impose a trend upon that and you find that progressively more and more years are what would have historically been considered extreme years until eventually every year is an extreme year.

Slide 27. Another way to look at that is through heat waves. Here we have the European summer of 2003 – an extreme event in that it was about 2 degrees hotter than any other heat wave on record and about 5 degrees hotter than an average summer in Europe. We had one in Adelaide in March this year where we had six previous events where the heat wave had gone on for 8 days at above 35 degrees C and then in March this year we had one that went on for 15 days and you do a return time analysis on that and you find that should have happened about once every 3 thousand years if the climate wasn't changing but with a changing climate these events become much more frequent.

Slide 28. So to go back to that European heat wave – here we have European summer temperatures in the black line there and smoothed average, some model runs based on the Hadley climate model, the black point up there is the European heat wave. I've drawn a line across there to indicate how extreme an event it was but all you have to do is to project business as usual models on this and you find that that extreme year becomes an average year by 2040 and a cold year by 2060. So that 1 in 10,000 year event which was claimed for the 2003 European heat wave becomes a cold summer just in the next 40 years.

Slide 29. There are clear geophysical signals in both biological and geological measurements to show the climate change that we've already experienced has already had a major impact. A lot of energy's going into melting ice – that's one of the key signatures – here's the distribution of summer sea ice in the Arctic. This chart shows what was monitored by ship based measurements and satellites and we've seen a gradual decline over the last 50 years and that's suddenly steepened quite a bit. The little insert map here shows the distribution of old verses new ice where one year old ice is in red and old six plus year old ice in purple. In just over the last 5 years we've lost almost all of that old thick ice. About 50% of the volume of the Arctic sea ice has been lost in the last 50 years. These are IPCC projections of sea ice coverage over the next century and the black line is what's actually happened over the last few years.

Slide 30. So we've seen this massive retreat in summer sea ice. It seems it's a non-linier event – there's a feedback effect where as you start to loose you further warm the oceans because their much darker and therefore more absorptive and so progressively year by year that rate of loss becomes more rapid. So from 2005 record through to 2007 there was a 22% extra decline. For 2008 there was a cooler winter, due to natural climate variability, but we're still almost at that 2007 record again.

Slide 31. Once you start to loose Arctic sea ice it doesn't have a direct effect on sea level but it leaves larger land based ice sheets such as on Greenland much more vulnerable. The ocean continues to heat and there's far more energy being absorbed in the Arctic and we're seeing sea melt in Greenland and West Antarctica a rapid melting. As is illustrated here there the penetration of melt inland lowering the elevation of the Greenland Ice Sheet as it melts, retreat of the large discharge glaciers, these huge lakes forming in the centre in summer which absorb a lot of energy and then these unusual structures called moulins which are bore holes in the ice where the melt water can drain directly to the bedrock, lubricate the bedrock then allow the whole ice sheet to start to slip towards the ocean. Right now this is a very minor contribution towards sea level but if you look at long term changes in sea level ice sheet has been the predominate driver.

Slide 32. So what we're looking at is a change moving from what's essentially been a very cool period in Earth's history to where we've had ice ages and warm interglacial's but nevertheless, still those warm interglacial's were 5 degrees C cooler than the temperatures we experienced 40 – 50 million years ago and we're looking to return to that period in the blink of a geological eye.

Slide 33. We have evidence of the relationship between CO2 and temperature change going back over millions of years now. This is a recent paper which looks at various proxies to reconstruct atmospheric CO2 using such measures as the chemical composition of paleosols and a number of stomata in fossil liverwort leaves there's various ways you can do this. You can look at deep ocean temperature as inferred from isotopes of deep sea organisms and you find when you do that the best fit to the long term temperature record and CO2 is the point at which Antarctica fully de-glaciates at around 425ppm CO2. So that's the point at which an ice sheet started to form in Antarctica 35 million years ago and that relationship holds strongly through to the present. So what does that tell us? It says that somewhere between 350 and 450ppm CO_2 we have an ice free planet. Now right now we're at 383ppm CO_2 and increasing at about 2ppm per year so we're already at a point where we're committed to a transformed planet unless we can do something about it very rapidly.

Slide 34. We're already seeing the first signals of sea level change but most of it will happen in the future. Here we've got sea level change from the last Glacial Maximum through to the present. The maximum rate of change then was about a metre every 20 years and that was sustained for about 400 years it was called melt water pulse – a huge amount of sea level change over a rapid period. We look at the current rate of change it pales in comparison but it is much steeper than the sea level change we can monitor in the Holocene illustrated there, so we're sort of halfway between the post glacial-rebound changes and smaller changes during the Holocene. Current sea level observations are running well ahead of projections. The projections are for about 1.8mm a year and we're been tracking at about 3.2 for the last decade.

Slide 35. We can look back to the Palaeo record to find out the relationship between sea level and global temperature in the past. About 125,000 years ago previous interglacial temperatures were globally about a degree warmer than at present due to different changes in orbital forcing, and as a result the Greenland ice sheet was considerably smaller (illustrated there) and sea levels were about 6m higher than the current level.

Slide 36. So just a degree in temperature level and we know how much more vulnerable Greenland is. A metre sea level change, though, is enough to have a major impact in terms of land area, the number of people affected, the GDP affected just one metre, which is what we should expect to experience just on the basis of thermal expansion of the oceans alone is enough to create large losses of low lying land, and huge displacement in terms of human population infrastructure

Slide 37. If you want to take a really long-term palaeo perspective of temperature on sea level rise, then you find there is actually a strong linear relationship once these forces have come into equilibrium. So, about 20,000 years ago temperatures were about 5 degrees cooler than at present, sea level was about 130m below the current level. If you look back about 2 to 3 million years ago it's a slightly warmer world, about 2 degrees warmer, sea levels were about 30m higher than the current level and you need to go back to about the Eocene period for the last time the planet was completely ice free, sea levels were about 80m higher than the current level, at that point. Temperatures were about 4 or 5 degrees warmer than at present.

Slide 38. The other impacts of warming include effects on water storage in mountain glaciers. So the Himalayas are a source of a huge number of river systems in Asia that are important to people and biodiversity that are melting at a rapid rate which is expected to be largely depleted by about 2050 which mean that the summer flow of rivers such as the Ganges, Indus, Brahmaputra and the Mekong will dry up. These will be dry rivers in the height of summer and that will have implications on hundreds of millions of people and, of course, all the diversity of those rivers.

Slide 39. We are also seeing direct effects of climate change in terms of water balance on the planet. Overall a more energetic climate system results in a more energetic hydrological cycle. More water in the atmosphere which is a feedback on long lived greenhouse gases, more rainfall, but occurring in more intense periods and a lot of it occurring over the poles and the oceans. Less on land especially in the mid latitudes. We have seen that in terms of the trending of severe drought over the last 100 years or so. This is the Palmer drought severity index which represent those areas of the planet which are under sustained and deep drought. So, overall there's been a gain in rainfall in the 20th century but more areas have been under drought more often. We've seen that in Australia over the last 30 years.

Slide 40. Climate models predict that under a mid range emissions scenario, there, that the most intensive drying will be over the mid latitude areas. So most of Australia, South Africa, Mediterranean Europe and a lot of the Southern United States. That's the result from a projection of the Earth simulated model shown down there. And that's a multi model average of about 13 different climate models.

Slide 41. You can look to something like Australia and find that there are clear regional changes that are occurring as predicted in the models or ahead of the models. Here's mean sea level pressure - this is what it looks like in a decade/ 50 years before hand.

Slide 42 That's what it looks like today. This is for autumn and…

Slide 43. similar for winter we had a high pressure system concentrated over the continent there.

Slide 44. 50 years on its intensified and expanded. This has an effect directly on rainfall and is another signature effect that is predicted by climate models to occur.

Slide 45. For somewhere like South Australia we have this clear latitudinal change in rainfall so the isoheights become increasingly intense as we move southwards.

Slide 46. That's what it looks like today, the average rainfall, and most of our cropping systems are based below that dotted line.

Slide 47 – 48. Climate models predict that in the next 50 years we'll have a 10 - 30% decline in rainfall. So you can just get through the changes that result from that and a 30% change in rainfall means those isoheights change dramatically and the runoff to places like the Mount Lofty ranges declines by 70-90%, so in terms of water availability and that synergy with things such as fire frequency and drying of vegetation will be hugely important and that interacts with temperature change which also makes the drying more intense and fire frequency increase. You can get an idea of the synergies I was taking about.

Slide 49. And of course this does not happen in a world otherwise untouched by humanity. So we have all of these other impacts to consider that are dramatically important for biodiversity. But in terms of understanding climate change I guess the point is you need to understand it in the context of these drivers. So you can't just look at climate change in isolation and you can no longer look at habitat destruction or over-exploitation in isolation either, because the synergies will be extremely important.

Slide 50. Now we know habitat loss has been *the* primary driver of biodiversity loss in the last few hundred years and continues dramatically in areas such as South East Asia where I've done a lot of work. But you look at the extent of deforestation in mainland South East Asia or that projected on the islands and it's grim. You're losing most of the forested area of Sumatra in the next few years Borneo will be reduced to the rainforest just in the centre of the island. Huge losses predicted for New Guinea.

On that basis alone you can use species area curve to project 15-40% of species committed to extinction in that area by the end of the century on the basis of habitat loss alone and then you superimpose climate change and you have a greater problem.

Slide 51. Because when you lose habitat, if you imagine an idealised carrying capacity up there, you lose half of it. It doesn't look like that semicircle there it looks more like that slide C. In other words, it's fragmented as well as lost which allows greater penetration of fire; of drying that has an affect on local rainfall in terms of evapo-transpiration; it allows penetration of hunters and loggers. You start to see the idea that it's all of these synergies.

Slide 52. So, rather than just having habitat loss or climate change as individual issues that stack on top of each other they are synergistic and once the synergy's sufficient to drag populations into that realm of the extinction vortex its curtains for them.

Slide 53. Now we know over the long term over many millions of years its actually strong relationship between global temperature change and the extinction rate - and here we're talking about big extinctions, including the big five mass extinction event that wiped out between 50 and 95% of all species. There's a strong correlation there, this is based on a paper published Proceedings B (last year). The heavy circles there are big five mass extinction events. The extinction rate on the Y axis and temperature change on the X axis – you can see there's a good correlation there. Now something like the Permian extinction event seems to be strongly related to climate in terms of a large out-gassing of volcanic events and perhaps a large release of methane from the oceans and that was the most profound extinction event of course that, as I say, wiped out about 90% of all species. But of course, to wipe out a species you have to wipe out every single individual of that species – every population, every individual. So to wipe out 95% of those is about 99.999% of all individuals on Earth were eradicated by that event. So we're heading to another mass extinction event and we're talking about an incredible loss of biodiversity and individuals.

Slide 54. You can go to an IPCC report - this is from a recent report published in Australia which was called the Garnaut Review, looking at impact of climate change on different natural systems, and impacts are broken down into different degrees of temperature change and linked to emission scenarios. But the bottom line is that at about 1 or 2 degrees of temperature change the impacts are already dramatic so if we are thinking about climate change it is not some issue that is only going to come into play with 5 or 6 degrees of temperature change. By the time we've got 5 or 6 degrees of temperature change it doesn't matter what else you're doing - it's all over. What really matters is understanding the impacts of what we've already experienced and perhaps the next 1/2 to 1 degree because beyond that it will only be climate change that actually matters in terms of species persistence.

Slide 55. In Australia there's many areas which we know are susceptible to climate change that we've committed to already and so these are obviously areas that we have to focus on as conservation organisations most profoundly because they are the ones that are going to be most heavily impacted. I'm afraid, I have to admit, areas like the Great Barrier Reef are not recoverable and they will be lost in the next 50 or so years because there's a synergy of warming ocean temperatures and ocean acidification which means there is essentially nothing we can do to recover those systems.

Slide 56. Now, right now if you look at the relationship between green house gas concentrations at stabilised level and temperature increases, these are the projections from climate models and different mitigation scenarios indicated in different colours. Over on that far left hand side the arrow points to what we're at right now, so we're committed to conditions that haven't existed for perhaps 3 million years but of course when you take in the aerosol effect it's much more than that. We want to get back to conditions of about 300ppm CO_2. Business as usual is taking us to around 750ppm – 1200 ppm CO_2 which takes us back to an ice free planet and all of the consequences that will entail.

Slide 57. And all of that is before we start to consider these sorts of things, which are tipping points in the climate system that once we cross can take a problem out of our hands. Now imagine as an analogy that you're riding a bicycle along a flat piece of road and you see there is a danger ahead so you take your foot off the pedals or you can hit the brake and you gradually slow down. That's fine, that's what would happen if we didn't [pedal]. If that was the climate system we would gradually grind to a halt and stop further temperature change, but if we go over the crest of the hill it doesn't matter if we stop pedalling, we continue to accelerate down into the abyss.

Well, that's what these tipping points are like because once you cross those, and they include a major reorganisation of ocean currents, a large scale loss of large ice sheets such as East Antarctica (which means the albedo effect on the planet is huge) or more pervasively a loss, the gradual melting of the permafrost in Siberia and Canada, that releases a huge amount of biogenic and geological carbon, which reinforces the human effects so that you can take away the human effect then and its already a climate changed into a new state.

Now we don't know, we have very low uncertainty about what the tipping point of many of those are. For Arctic sea ice we almost certainly crossed it about 15-20 years ago we're near the end of it now. I suspect Greenland and West Antarctica have already tipped over and we just haven't see it all yet. Bearing in mind that the permafrost is less of a tipping point because there's not a non linear change it will continue to accumulate and get worse.

Slide 58. All of it is driven by a demand for energy and I don't think that demand for energy is going to go away so what we have to do is rather than have some future that is predicated on the continued exploitation of fossil fuels it has to be predicated on solutions that involve renewable energy.

Slide 59. If you look at what was expected in terms of carbon emissions and what we've observed you come up with figures such as this. It's a little complicated, this graph, but what it represents is on the Y axis is change in energy, on the X axis change in carbon intensity for generated dollar GDP. So if we move down there you become less efficient in terms of the amount of energy used to generate a dollar and if you move that way you use more carbon to do it. So in an ideal world we'd be in the bottom left hand quadrant where we would be using less energy and less carbon to generate a dollar but observations suggest we're using more energy and more carbon than in the last 5 years. Mostly due to the incredible growth in emissions in the developing world such as India and China which far outweigh the predictions of the IPCC 10 years ago [shown in that chart, there] so we're well above the high scenarios that takes us to 6 degrees of warming. We're heading for 8 to 11 degrees of warming on our current pathway. It's a bitter irony that almost all of the global warming we've seen in the system so far has been driven by emissions from the developed world, yet the future almost entirely depends on emissions from the developing world, so we truly have this global conundrum to deal with.

Slide 60. To give you an example for China look at total carbon emissions there 1.7 billion tons in 2006 the growth anticipated for China between 2007 and 2010 will be the equivalent to the total emissions of Japan, Germany, Canada, the UK and Australia. So because of the huge population base and an 11% growth per year, that's what determines 21st century climate.

Slide 61. And of course as each year you release CO2 into the atmosphere it's a long term commitment because of how long it takes to play out in terms of removing that carbon from the atmosphere – you get rid of about 1/3 of it in 100 years, it takes about 1000 years to get rid of a fifth of it and 100,000 years to get rid of 98% of it so it's a long term commitment.

Slide 62. Now we are seeing signs, and the global financial crisis is one of those, that we are having a peaking of some fossil fuel supplies. An energy crisis coming even in the absence of climate policies. That's a supply of oil from 20 OPEC nations. However, in the last 5 years or so we've had 88 million barrels a day, it seems that's as much as we can extract right now and that's going to start going down. And even the spot price of things such as thermal coal and liquefied natural gas has increased dramatically over the last few years. We've had this conversion climate energy crisis to deal with anyway.

Slide 63. Obviously this is not the place to talk a lot about renewable energy but just a few words I want to say to give you hope otherwise it's been a bit grim is that these have huge potential to change our energy supply. Simply to give us enough energy to re-manage the climate system we already conducted this great experiment and we'll probably have to conduct another one to change it round.

Slide 64. If we look at the price drop in renewable energy for a range of technologies going from wind, solar-thermal, geo-thermal, biomass, they're dropping exponentially. About 7% per year on average for solar-thermal, which means the cross over price in terms of coal fired power stations is coming up within the next 10 – 15 years where it will be more economically sensible to build a solar thermal power plant in the desert than coal fired power. Most of that drop is coming from scalability issues, volume production, as well as technological development.

Slide 65. What a carbon price does, and in Australia we're talking about putting a carbon price in terms of emissions trading scheme. Similar discussions are now going on and both US presidential candidates agreeing in principle to implementing an emissions reduction scheme. What they do is essentially fast track these technologies. So imagine if you've got a declining price of a technology such as solar-thermal power and you put a carbon price on there, then the price of coal fired power goes up there, it means the time it becomes economically sensible to invest in that technology moves from time A to time B. So instead of waiting 10 years before any venture capitalist invests in this technology they do it today instead because it makes more sense.

Slide 66. That's all the carbon price does and if you look at a range of these technologies, their cost in terms of dollars per mega watt hour generated, a lot of those technologies at current development are cost-competitive with coal with carbon capture and storage (which is 10 to 15 years off at best), with gas with carbon capture and storage, or coal with a 40 dollar a ton carbon price. The key difference is that all of these are reducing in price and the cost of coal's going up. So again it's an economic argument that seems like a no brainer to me.

Slide 67. And if you don't believe it can be done, if you just think about all the other technologies that have been developed, it has been a switch from an initial technological push through to a market pull. Then computer storage devices needing cranes to load on storage devised in the 50s, by the 1980s we had Apple Macs with floppy disc drives, today we've got something which is infinitely cheaper and can store millions of times more data.

It's similar with communications technologies, the mobile phone – you needed a back pack to wear one in the 1980s. I was very happy with my micro-portable device in the early 1990s. Today we have a Captain Kirk style communicator and they're only that big because that's about as small as you can comfortably fit into your hand. So in other words a huge drive from innovation once we really decide to make a change and there's money in it. That gives me confidence that we can transform the world's energy system, which is really the first fundamental step to turning around the climate change problem.

Slide 68. So to summarise my talk, I know I've covered a lot of material, we've got to consider two things in the conservation realm. One of those is managing the unavoidable which is the adaptation realm and it's a large adaptation challenge. Don't kid yourselves that its just another issue. Build it into everything you're doing now because it's a huge adaptation challenge already.

But if we don't do something urgently about emissions everything we do is not going to matter anyway because it's going to take us to the point at which no planetary system that we can imagine is going to be able to cope with that sort of level of change. So you should be strong advocates for mitigation and you should be prepared, in all that you do, to building climate change adaptation into your management regimes.

Slide 69. I've set up a website where I put most of my slides and talks and so forth, so you are welcome to log onto there and download those and I have some forum discussions and a bit of a blog as well. It can be found at http://bravenewclimate.com So thanks very much for having me here at the meeting, I look forward to participating in your workshops throughout the next few days. Thanks very much.