In this reply I shall attempt to answer some of the questions raised by South et al., and demonstrate that our current understanding of the climate system and where it is headed is quite sufficient to guide the creation of good public policy.

A planet with no atmosphere orbiting the sun at the same distance as the Earth would have an average surface temperature of -18°C. The effect of all the so-called greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide and various halocarbons) acting together is to provide 32°C of warming, maintaining global average temperature at about +14°C. Carbon dioxide plays a crucial role in that process, a fact that's been understood since the first half of the 19th century, and the pioneering work of Fourier and Tyndall1. Work on past climate shows that during the ice ages that have dominated the planet's climate over the last four million years, CO₂ levels bottomed out at 180 ppm, while during the relatively brief warm interglacial periods it reached 280 to 300 ppm. 125,000 years ago during the last (Eemian) interglacial, CO₂ levels peaked at 300 ppm, global temperatures were a degree or two warmer than at present, sea level was up to 3 metres higher, and there were hippos and crocodiles in the Thames. A recent paper2 suggests that the last time the planet experienced atmospheric CO₂ has reached 387 ppm and is increasing at roughly 2 ppm per year. No hippos have been sighted off Westminster. Yet.

This much is basic knowledge, presumably not disputed by South et al., but I include it to demonstrate that our understanding of climate and where it may be headed is not solely based on computer modelling. The radiative behaviour of CO₂ is understood in great detail, supported by theory down to the quantum level, and can be calculated with great accuracy. These calculations, in a slightly simplified form, are incorporated in all current global climate models. The study of previous climates - paleoclimatology - provides a wealth of information about the way the climate system has behaved, and how it might react to the sudden injection of 40% more CO₂ than would be normal for an interglacial. The 100 ppm difference between ice age and interglacial CO₂ levels is associated with a change in global average temperatures of about 5°C. In the last 150 years, human actions have added nearly as much again, and we observe the planet warming.

Global climate models (GCMs) are complex beasts. They are our best attempt to build a physical model of the way that the atmosphere, oceans, land and biosphere interact to create the climates we experience. GCMs are closely related to the numerical models used by weather forecasters - some include the same atmospheric models - but climate models are not concerned with predicting individual weather events. Climate can be thought of as what weather averages out to over time, and that's what climate models are intended to project - the statistics of climate for a given set of circumstances. These can be scenarios of future changes in greenhouse gas levels, or simulations of past climates, but the key point is that they allow scientists to explore the workings of a complex system in ways that are not possible through observation alone. We are limited to one planet, and one set of data. The models allow us to pose the “what if?” questions that are essential to understanding the climate system and thereby inform policy making.

South et al begin their blizzard of questions by asking if climate models have been “verified” and “validated”. In essence, they are asking if the models accurately represent the real world, and have made testable predictions. They then present a series of examples that might suggest major problems with the way models work. I shall deal with some of those points in due course, but it’s worth noting here that no model of a system as complex as the ocean/land/atmosphere/biosphere is ever going to be “perfect”. Most current models are built on a 300 km grid covering the surface of the earth, with up to 20 slices of atmosphere above the surface and ocean representations of varying complexity. They calculate new data for each grid point with a time step of an hour. A long - 100 year - model run therefore represents a huge computing task, and even with recent rapid advances in available computing power GCM runs can take weeks.

Climate models produce a good “broad brush” picture of the ocean/atmosphere system. Major features of the general circulation of the atmosphere emerge from the model physics. For example, GCMs are not explicitly programmed to have strong westerly winds around Antarctica, but those wind belts can be seen in model outputs - a sign that models are getting the basics of ocean/atmosphere/geography interaction right.

GCMs are also tested by running them with known forcing factors - greenhouse gas levels, solar radiation, volcanic dust and aerosols - to see if they can reproduce what was observed. Model “hindcasts” of the last 100 years produce a good representation of the global temperature changes that were observed. Early GCM projections have also had some success, the most notable being those presented to US Congressional hearings in 1988 by James Hansen. He presented projections made by the then state-of-the-art NASA GISS model for a variety of scenarios, and for the greenhouse gas changes that occurred they have proved to be pretty good3.

1 See Weart S, The History of Global Warming, American Institute of Physics, 2008, available as a web site here: http://www.aip.org/history/climate/
2 Tripati et al, Coupling of CO2 and ice sheet stability over major climate transitions of the last 20 million years, Science DOI: 10.1126/science.1178296 Published Online October 8, 2009
South et al. make much of the presence of a tropical tropospheric “hot zone” in model output, and claim that there are no papers that report its observation in the real world. In fact, Santer et al. (2008) show that observations from radiosondes and satellites are consistent with model outputs for this region of the atmosphere. However, the “hot zone” is not itself a “signature” of warming caused by greenhouse gas accumulation in the atmosphere. For instance, it would also be present if warming was being caused by increased solar output. On the other hand, climate models have long projected that if warming is caused by greenhouse gas accumulation in the atmosphere, the troposphere - the layer of atmosphere immediately above the stratosphere - the layer of atmosphere immediately above the troposphere, would cool. This has been observed.

South et al.’s Fig 2 shows recent annual global average temperatures plotted on to a graph showing IPCC multi-model mean projections over the near term, and they suggest that current temperatures are outside the “range of uncertainty” for those projections. In this instance, South et al. appear to misunderstand what “multi-model mean” projections consist of. Single runs of a climate model contain a lot of “variability” in annual mean temperatures, just as the annual mean temperatures out here in the real world go up and down a lot. There’s a lot of “noise” in the data, and single runs of a climate model are similarly noisy. Averaging over a number of model runs effectively removes the noise to show the underlying trend, but the effect is that those means can not be taken as projections or forecasts for actual temperatures.

South et al. then move on to consider other features of the “accuracy” of climate model predictions and state:

Some claim it is more difficult to predict weather three months into the future than it is to predict the climate 100 years into the future. We question this belief system.

This is not a matter of belief, it is a reflection of the differing nature of the predictions being made. The accuracy of a weather forecast is dependent on the accuracy of the data fed into it from observations. As the forecast model runs forward in time, errors in those “initial conditions” tend to multiply, and forecast skill declines. For forecasts of a week or longer, meteorologists can use multiple model runs with minor changes in initial conditions to see if a consistent pattern emerges, but even with this approach forecasts of up to about 14 days seem to be the practical limit.

Climate models are not making long term forecasts of weather. They are projecting the future statistics of weather for a multi-decadal period in the future, given a set of assumptions about the climate forcings (the factors that tend to change climate, such as greenhouse gases) at that time. GCMs are not subject to uncertainties about initial conditions, but they are dependant on a good understanding of the “boundary conditions” - the climate forcings. Beyond the model uncertainties, climate projections are extremely vulnerable to the assumptions they are fed about future emissions trajectories, but that is not the model’s fault.

In their discussion of cloud feedbacks, South et al. suggest, based on one paper, that cloud feedbacks could be negative, that is, would tend to damp down future warming by reflecting more heat away from the planet or by trapping less heat near the surface. While accepting that there’s considerable uncertainty about the way that cloud feedbacks will operate as the world warms, most scientists working in this field do not consider that they will be negative. One reason for this is that if there were strong negative
feedbacks in the climate system the planet would find it hard to warm up out of ice ages - after an initial warming “kick” from orbital changes, a negative feedback would act to slow down warming. The record suggests that warming out of ice ages is instead rather fast, a 5°C increase in global average temperature over roughly 5,000 years, while the return to cold conditions is slower.

South et al. also refer here (and elsewhere) to suggestions by Svensmark\(^8\) that cosmic rays could influence cloud formation, and that changes in the cosmic ray flux could therefore influence the current warming. This theory, while intriguing, has not found significant support amongst atmospheric physicists and chemists, and analysis of cosmic ray flux and the global temperature history finds little correlation between the two\(^9\).

South et al.’s 5th section asks “Can we estimate how much of the +0.76°C temperature departure recorded in February 1998 (Figure 4) can be attributed to El Niño and how much can be attributed to the CO\(_2\) that originates from burning of fossil fuels?” They provide no discussion of this but include an extensive quote given by noted climatologist Steven Schneider in 1988, in which he emphasises the uncertainties associated with climate modelling. The question they ask is however ill-posed. The 1998 El Niño was one of the most intense El Niño Southern Oscillation (ENSO) events of the last century, and it has been known for many years that ENSO cycles have a marked influence on global temperature\(^10\). The influence of CO\(_2\) only emerges from the noise in the global temperature series when looking at periods of decades. An El Niño of similar intensity occurring in the near future would be likely to exceed the positive anomaly seen in 1998, probably by around 0.2°C, that being the current underlying decadal warming trend.

South et al.’s next two sections (6 & 7) are concerned with the ways in which models are used to attribute recent climate change to human action. In referring to the IPCC’s finding that “Anthropogenic change has been detected in surface temperature with very high significance levels (less than 1% error probability)” they say:

“We assume that virtual worlds were sampled to determine the 1% probability. We claim that the 1% probability was applied to output from climate models and not to replications made from the real world.

Unfortunately we only have one planet to experiment with, so replications are a little difficult to organise. Model runs to demonstrate what might have happened to global temperature had CO\(_2\) not risen provide a baseline for comparison with the instrumental record.

In this section the authors also assert that the global temperature record is biased upwards by “heat islands” and improperly located thermometers, and refer to a controversial paper\(^11\) still in press (at the time of writing). This is not a generally accepted view in the climate science community. All global temperature datasets are corrected for urban heat island effects.

South et al.’s section 8 discusses the suggestion in one recent paper that taken over the globe, the warming effects of increased CO\(_2\) emitted by deforestation would be offset by increased albedo (reflecting more of the incoming solar radiation back to space), and asks “why are albedo credits not included in Climate Trading Schemes”. The paper in question, Bala et al. (2007) is a great deal more nuanced than this might suggest, and explicitly cautions against using their results to justify deforestation:

Therefore, the cooling that could potentially arise from deforestation outside the tropics should not necessarily be viewed as a strategy for mitigating climate change because, apart from their potential climatic role, forests are valuable in many aspects. They provide natural habitat to plants and animals, preserve the biodiversity of natural ecosystems, produce economically valuable timber and firewood, protect watersheds through prevention of soil erosion, and indirectly prevent ocean acidification by reducing atmospheric CO\(_2\).

However, suggestions have been made that albedo management in the built environment could be used to reduce warming. It has been estimated\(^12\) that increasing the solar reflectance of urban roofs and pavements worldwide would create a one time offset of 44 billion tonnes of CO\(_2\) - equivalent to taking the world’s approximately 600 million cars off the road for 18 years. California already has “cool roof” legislation in place, and this approach could be applied elsewhere with more acceptable results than widespread deforestation.

Section 9 of South et al.’s paper examines predicted changes in the occurrence of hot and cool days, and quotes from the IPCC’s Fourth Report:

Solomon and others (IPCC 2007a) say that “linking a particular extreme event to a single, specific cause is

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\(^{7}\) This is fast in climate terms, but slow in comparison with the current rate of change, which is around 2 K per century

\(^{8}\) Their reference: Svensmark and Calder 2007

\(^{9}\) See this short discussion by Rasmus Benestad, at RealClimate http://www.realclimate.org/index.php/archives/2004/12/recent-warming-but-no-trend-in-galactic-cosmic-rays/

\(^{10}\) Jones, P.D., (1989), The influence of ENSO on global temperatures, Climate Monitor, 17, 80-89

\(^{11}\) South et al’s reference, Klotzbach et al 2009 does not support their claim - discussed in detail here: http://initforthegold.blogspot.com/2009/08/my-final-word-on-klotzbach.html

problematic” and we concur. However, the authors go on to say that “An increase in the frequency of one extreme (e.g., the number of hot days) will often be accompanied by a decline in the opposite extreme (in this case the number of cold days such as frosts).” We do not know of a reference to support this claim.

If South et al. were to take a look at Chapter 3 of the Working Group One report13 (instead of limiting themselves to the Frequently Asked Questions and Selected Technical Summary Boxes section), in particular section 3.8: Changes in extreme events, they would have found an extensively referenced discussion of that point. Indeed, there is a rich literature on the subject, and for South et al. to make statements such as “Other than simply guessing, we fail to see how a scientist could estimate an anthropogenic contribution to an increase in frequency of record cold/high temperatures” either betrays their ignorance of that literature, or a desire to persuade others that it doesn’t exist. In fact, as WG1, Chapter 3 makes clear, evidence of significant changes in the frequency of extreme events is well-documented.

South et al.’s Figure 5 is a schematic from the FAQ they reference designed to illustrate the sort of changes expected, and is not a “hypothesis that assumes no change in kurtosis or skewness”. Indeed the text which accompanies the figure (and which immediately follows their quote above) acknowledges this fact: “Changes in the variability or shape of the distribution can complicate this simple picture.” Those sorts of changes are discussed in detail in WG1, for example in section 3.8.2.1, and illustrated in Fig 3.38 (p300/301).

South et al.’s question 10 states: Solar irradiance that reaches the Earth’s surface has declined since 1950. How much of reduction in irradiance is due to an increase in clouds and how much is due to an increase in pollution (i.e. soot and aerosols)?

“Global dimming” as it is known is an area of active research, and major efforts are being made to understand the complex interactions between natural and anthropogenic aerosols, clouds and climate. One thing is however clear: the overall impact of aerosols is cooling - they limit the warming caused by increased greenhouse gases, and by a considerable amount. At the time of writing, the total greenhouse gas load in the atmosphere is equivalent to approximately 438 ppm of CO₂-e, but the net impact is equivalent to roughly 385 ppm CO₂-e thanks to the cooling effects of aerosols. For a discussion on this, and the policy implications of aerosol reductions, I recommend On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead, by Ramanathan & Feng (2008)14.

South et al.’s 11th question concerns the downscaling processes used to build a picture of climate changes on smaller scales than the large grid used by global models. This is obviously necessary, given that a small country such as New Zealand might only appear in perhaps four GCM grid cells. There are two main techniques: statistical downscaling and dynamic downscaling. The statistical approach is widely used, but is increasingly being supplemented by the use of regional climate models (RCMs). The RCMs are run in tandem with a GCM, with the GCM providing the global context. The RCM (in NIWA’s case, operating with a 50 km grid) can then build up a much more detailed picture of how, for instance, topography will interact with changing weather patterns to affect the incidence and severity of severe weather events.

South et al.’s principal point, that using limited model runs and scenarios can appear to give too much precision to downscaled projections is reasonable enough, but is hardly an argument for not using downscaling, or for mistrusting model results.

In section 12 South et al. ask if New Zealand’s average temperature has “changed much since 1860”. In their Table 2, they rely on figures produced by Gray for temperatures prior to 1867 in several locations. 1867 is generally taken to be the start of the reliable instrument record in NZ, because that’s when measurements were standardised13, so neither Gray nor South et al. are comparing like with like. A better way to answer the question about changes in NZ’s temperatures over the last 150 years is provided by Fig 2, NIWA’s annual average temperature series where care has been taken to ensure a consistent record.

It’s perfectly clear that New Zealand has warmed significantly over the last 150 years, and projections for the next 90 years based on IPCC scenarios suggest warming will continue.

South et al. refer to a number of model projections of NZ’s future climate, and ask:

When compared to 1987, will NZ be cooler in the winter of 2028 than most other locations in the world (Revkin 1988) or will it be about 2 °C warmer (e.g. miroc32 hires)?

In the absence of a time machine, the question amounts to little more than a rhetorical flourish, so here is one more. Why is a 20 year-old model projection drawn from a magazine article being compared with more modern work? If it is to imply that there is uncertainty about the direction of change, then it is an attempt to mislead the reader.

NZ’s climate is notably variable, as can be seen from the “wiggles” in the historical temperature data. A large part of this variability derives from NZ’s position between

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13 The full report and all supplementary documents can be downloaded here: http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

15 J Salinger, pers comm
the large (and cool) southern ocean and the warm tropics. Ocean/atmosphere interactions such as the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) will continue to cause variability in NZ’s year-to-year temperatures, but this will be overlaid on the underlying warming trend.

In section 12, South et al. ask: Do outputs from climate models allow some researchers to selectively ignore real-world observations? The answer is simple enough: No. The relationship between model and observation is a two-way process. Climate modellers are constantly checking their models against observations, looking to improve their model’s representation of the real world. Observations act as a constraint on model design and performance. However, if a set of observations from a new instrument (on a satellite, for instance) differ markedly from that expected in theory and therefore represented in a model, then there will certainly be an effort to resolve the difference. In the case of the global temperature record as measured by satellite for instance, multiple corrections for orbital changes and other factors have been made to improve the final data quality.

South et al.’s question 14 asks if foresters rely on timber price predictions based on combining three different complex computer models. That is not a question I can answer, but it is certainly true that the direct impacts of climate change, and the policies implemented by governments to effect emissions reductions, will have a major effect on the forestry business. In this respect I would suggest that uncertainty about the nature and consistency of future government action and the performance of the national and global economy are more important sources of risk than the detail of climate model predictions. I leave consideration of the long term accuracy of economic models as an exercise for the reader…

Thus far I have concentrated on providing answers to some of the more cogent questions posed by South et al., but I now want to move on to consider how climate modelling feeds into the policy-making process.

Well-understood atmospheric physics, paleoclimate studies and current observations are sufficient to establish that increasing the atmospheric load of greenhouse gases is causing a major warming of the climate system. The principal uncertainty is not the direction of change (warming), but the extent of warming and the impact on global and regional climate. Once again, climate models are not our only source of information. Studies of the transitions into and out of ice ages provide a means to estimate the climate system’s response to increased GHG levels, and suggest that the “climate sensitivity”, defined as the increase in global temperature for a doubling of CO₂ in the atmosphere, is about 3°C. The models provide supporting evidence.

Climate models can provide information about the probable course of future warming, and therefore the nature and extent of likely future damage, but they are not themselves the principal source of uncertainty about the future. As a couple of climate scientists wrote in a reply to an article critical of an earlier study on future hurricanes, “If we had observations of the future, we obviously would trust them more than models, but unfortunately observations of the future are not available at this time.”

Climate projections are far more vulnerable to uncertainties about human actions and the impacts of geophysical events such as major volcanic eruptions. Modelling attempts to answer “what if” questions about the future course of climate change, but those answers can only ever be as good as the assumptions fed in. The key parameter in any model run is the change in atmospheric GHG loading over time, and that is not determined by the model itself (except in the case of models where carbon cycle feedbacks add to scenario projections) but by scenarios developed to allow scientists to ask meaningful questions about the climate change that may result from different emissions pathways and varying GHG concentrations in the atmosphere.

16 Thomas Knutson and Robert Tuleva, Journal of Climate Dec 2005, DOI: 10.1175/JCLI3593.1
All of the scenarios for greenhouse gas emissions used in modelling for the IPCC’s Fourth Report explicitly assumed that there would be no action to reduce GHG emissions, beyond an assumption in the lowest emissions scenarios that low-carbon technologies would be widely used. Today, with debate about the reality of climate change long over at government and international level, and a growing appreciation of the urgent need to reduce emissions, climate modelling is therefore being used to provide guidance on policy objectives.

In this context, the de facto internationally-accepted target is to limit warming to a rise of 2ºC above pre-industrial\(^{17}\) levels. The 2ºC “guardrail”, it is hoped, will limit the damages of climate change to acceptable levels. Climate models are therefore being used to examine the chances of keeping within that guardrail under various emissions scenarios. One promising approach derives a total “carbon budget” which gives a good chance of keeping under 2ºC of warming, and then looks at what this implies for emissions reductions\(^{18}\). Policy makers can then translate those numbers into international and national targets for emissions - the process at the heart of the Kyoto Protocol and the follow-up international frameworks currently being worked on. It remains to be seen whether this message - that steep cuts are essential - will survive the real politik of international diplomacy and negotiation, but if it doesn’t, it won’t be because of any shortcomings in the models themselves. As NASA modeller Gavin Schmidt points out in a recent article in Physics World\(^{19}\):

> All climate models are wrong, but some of them are useful, and by working more closely to answer the questions that are actually being posed by policymakers, we can make them more useful still.

Finally, South et al. conclude …it now seems a number of researchers and foresters have accepted the hypothesis that CO\(_2\) is the primary driver of a changing climate. Some ignore factors such as changes in cloud cover, changes in surface albedo (Gibbard et al. 2005), changes in cosmic rays, increases in soot (in air and on ice), and the Pacific Decadal Oscillation. Ignoring these factors appears to be driven by the idea that the Earth’s complex climate system is relatively easy to control by planting more trees on temperate and boreal grasslands.

As I hope I have shown, the role of CO\(_2\) and greenhouse gases in general in the heat budget of the planet is extremely well understood. That other factors have significant impacts is also well understood, even if we do not have perfect knowledge of the details of all the interactions that take place. But the big picture is clear enough, and the likely future damage from warming large enough to make action to restrain emissions an urgent necessity. However, despite South et al.’s assertion, there are very few people who think that the climate system is “relatively easy to control”, and still fewer who think that tree planting alone is all that will be required. Stabilising atmospheric greenhouse gas concentrations at levels which will prevent dangerous climate change is a formidable challenge that will bring substantial changes to energy and transport infrastructures. From the perspective of foresters, however, a carbon-constrained economy where timber is valued for its role in removing carbon from the atmosphere should bring a considerable boost to the industry both in New Zealand and globally.

In choosing to focus on climate models and implying that their output is little better than soothsaying, South et al. have not advanced any “debate” about climate change or the policies required to address it. Their misunderstandings and misapprehensions about climate modelling and what it can tell us amount to a small sideshow, a distraction from the debate that needs to be conducted on forestry’s role in a future where the impacts of climate change and climate policy will shape all our lives.

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\(^{17}\) ie mid-nineteenth century  
\(^{19}\) G. Schmidt, Wrong but useful, PhysicsWorld.com http://physicsworld.com/cws/article/print/40528