Earth Science and climate change: member Q&A

The topics of climate change and anthropogenic global warming have been very prominent in both the global community and Australia over the last year. These are clearly the most significant geoscience-related issues that the world is currently dealing with. In this context, and informed by discussions with Society members, industry representatives, and policy advisors, it seemed to the GSA Executive that the Australian geological community was being left behind in this debate. We debated what, if anything, to do about it and finally concluded, motivated by the clear relevance of geology to the issue and increasing approaches from the media and policy advisors for comment, that it would be useful for the GSA to have a formal position.

Recognising the scepticism over the IPCC report that exists within some segments of the Australian geological community, but also the mounting scientific evidence for anthropogenic influence on Earth's climate systems (encompassing the oceans, atmosphere, biosphere, and lithosphere), we wanted to position the GSA as an effective voice for Earth Sciences in the scientific and public arena. In particular, it was our objective to ensure that a sound, geoscience-based perspective was not marginalised in the current policy debates.

Our first inclination was to conduct a bottom up analysis of the IPCC report and claims of prominent skeptics, but we quickly realised that this was unrealistic. So we moved toward a position aimed at supporting the role of geological sciences in the debate. Members who read the Position Statement, rather than media reports, will see that it clearly and intentionally does not support the IPCC report specifically. Rather it takes the stance that a prudent and objective reading of the science does raise concern. Clearly many factors remain to be clarified, and Earth Scientists are well equipped to participate at a variety of levels from research through to education and policy advice.

The primary purpose of the Climate Change Position Statement (*TAG* 152, p 31) was to support the Australian geological community rather than to make specific pronouncements on climate change *per se*. We looked in some detail at the positions adopted by other European, American, and Australian scientific societies, and considered several of the key scientific issues in what would fairly be called a robust debate that echoed many of the often divergent views within the GSA. At all times our discussions were mindful and respectful of the diversity of views that exist within the membership, and we can assure members that this process was not driven by any external political agenda.

Although not everyone was completely happy with every word, in the end we did reach a consensus that the Statement was a fair and concise reflection of current knowledge and useful to the Society. We urge the membership to continue raising their voices on this matter of broad public interest and to pursue their science to advance a better understanding of the Earth and demonstrate the relevance of geologists in the service of society as a whole.

To this end, *TAG* is pleased to present a series of responses to questions outlining some of the key issues in the climate debate and the role of Earth Sciences in resolving some of these issues. Responding to the questions are Bob Carter, Adjunct Professorial Research Fellow, Marine Geophysical Laboratory at James Cook University; David Denham, past President of the GSA and current Secretary of the Australian Society of Exploration Geophysicists; GSA, American Association of Petroleum Geologists and Petroleum Exploration Society of Australia member John Geary, whose background is in petroleum exploration in Australia and Canada; and Mike Sandiford, Professor of Geology and Director of the Melbourne Energy Institute, University of Melbourne.

The views expressed are the contributors' own and do not represent the views of the organisations listed above.

GSA EXECUTIVE

Q1. What is the role of Earth Sciences in clarifying the climate change debate? Where can it contribute and what are its limitations?

BOB CARTER: It is widely, and wrongly, believed by the public that the study of climate change is the exclusive province of meteorologists and climatologists. In reality, scientists who study climate change come from a very wide range of disciplines that can be grouped into three main categories.

The first group comprises scientists who are expert in meteorology, atmospheric physics, atmospheric chemistry and computer modelling, who mostly study change over short periods of time, and are primarily concerned with weather (and, by extension, climate) processes.

A second group comprises geologists and other Earth Scientists, who hold the key to delineating *climate history* and the inference of ancient climate processes.

The third category comprises those persons who study enabling disciplines like mathematics, statistics and (perhaps) engineering. Logically, computer modellers belong in this group, but in applying supposedly independent technical skills to the complexities of climate science, deterministic modelling has become entwined with the dangerous and pragmatic art of simplification through parameterisation; hence the listing of GCM modelling also in the first grouping of scientists above, for it is indeed both fish and fowl.

Geoscientists, here taking sediment cores at a lake in Tasmania, "hold the key to delineating climate history and the inference of ancient climate processes" (Bob Carter) and hence contribute to an understanding of our climate future. Image courtesy ANSTO.

In this wide context, all competent scientists accept: 1) that global climate has always changed, and always will; 2), that human activities (not just CO_2 emissions) definitely affect local climate (sometimes warming, and sometimes cooling), and therefore have the potential, summed, to measurably affect global climate; and 3) that CO_2 is a mild greenhouse gas. The true scientific debate, then, is about none of these issues, but rather about the sign and magnitude of any net, global human effect, and its likely significance when considered in the context of natural climate change and variability.

DAVID DENHAM: The Earth Sciences have a huge role to play in obtaining and interpreting palaeoclimatic data, particularly in the last ~500 000 years. Without geoscience input we would know very little about past climates. Two examples from Quaternary data sets: 1) variations in sea level over this period have been determined by dating fossil coral reef terraces and oxygen isotope records from Quaternary sediment cores; 2) data from Antarctic and Greenland ice cores, which have produced a consistent set of estimates for temperature and CO_2 in the same period.

Geoscience will continue to contribute to understanding past climates, particularly in the Quaternary, where techniques to identify annual changes in sedimentary history can be applied. This period is also important because changes in climate due to the movements of the continents/plates can be ignored to a first approximation.

Two examples of key limitations: 1) the geological data do not provide information on the strength of the Sun's radiation in the past. So we do not know the input flux on Earth, and modelling past climates is very difficult; 2) the accuracy of geological data in estimating past climates declines as we investigate older periods.

However, the geological record is all we've got, so we have to make the best of it!

JOHN GEARY: Earth scientists have done most of what can be done to clarify the science. Major past climate change events clearly unrelated to human activity have been demonstrated and with input from allied disciplines likely causes have been identified. This knowledge should have stopped the debate before it began. It hasn't. Unlike other professions we have a low public profile and seem to want to keep it that way. The public is aware of us as finders of minerals, petroleum or whatever and don't appreciate that we have a role to play in the climate change debate. This is largely our own fault; we have in general abandoned the high ground to the astrologers in the IPCC.

The most significant contribution we can now make is a vigorous reversal of this position and to demonstrate that people such as Ian Plimer and Bob Carter are not lone voices in the profession advocating weird and off-beat hypotheses. In this regard, North American scientists have been much more active than Australian scientists. In my letter in the March issue of *TAG* (*TAG* 154, p 40), I referred to the US Senate Minority Report in which over 700 distinguished scientists in many fields from more than 40 countries expressed a sceptic's view of anthropogenic global warming (AGW). Included in the report were the qualifications and affiliations of each and a short summary of their views. The list included Nobel Laureates and also 50 Australian scientists. It is interesting that among the Australian contributors were five former CSIRO scientists expressing fundamentally contrary opinions to the official position of that organisation. It appears that they had to leave the organisation before they had the freedom to make their own views known and in this government-funded body being politically correct takes precedence over being scientifically correct.

It is a sad probability that the views of these 50 Australian scientists are much better known among US politicians than our own. Could we make a similar initiative here or at least forward copies of the US report to each of our Federal members?

MIKE SANDIFORD: As one of the key Earth Sciences, atmospheric science is clearly central to an informed climate change debate. Just as we charge our geologists with, amongst other things, finding new resources and estimating natural hazards vulnerabilities, we charge our atmospheric scientists with monitoring climate change and estimating climate sensitivity to various forcings. Only by precise measurement can we know how the climate system is changing, and only through understanding climate dynamics can we more confidently predict its future. Atmospheric scientists have the added, daunting responsibility of determining the targets that we need to set to be confident of achieving specific climate outcomes.

Of more relevance to the readership of *TAG* is the role of the geological sciences in the debate. In providing a record of past change, the geological archive provides an important reference frame for assessing the scale of contemporary changes. Geology warns us that the present atmospheric greenhouse gas concentration is already outside the range experienced during the evolution of our species, and that the rate of change is

unprecedented in terms of anything our civilisation has experienced. It also tells us that climate responses to various forcing factors can be markedly non-linear. In short, it tells us we are embarking on an unprecedented atmospheric geo-engineering experiment.

Q2. It has long been known that the Sun is the dominant influence of the temperature on Earth. Do you agree with this statement, and if so, what is the role of atmospheric gases, particularly greenhouses gases in comparison with this dominant influence? Do you agree that greenhouse gases are required to explain the continuous presence of liquid water on the surface of the Earth since the early Archaean despite solar evolution models which suggest a 25% cooler young Sun? Is there any level of CO_2 in the atmosphere that would be an issue for climate and if so what is it?

BOB CARTER: Whether individual scientists "agree" with these statements is not really the point; rather, the issue is what empirical evidence supports them.

The evidence supports: 1) the Sun being a dominant influence on climate; 2) greenhouse gases playing a significant role in the redistribution of heat and in warming the atmosphere; and 3) that, from the human perspective, the "optimal" level of atmospheric CO_2 for assuring world food supply at a time of rising population, and for biodiversity to flourish, is significantly higher than the current 380 ppm, as has been the case throughout most of Phanerozoic history – for we currently live at a time of planetary CO_2 starvation.

DAVID DENHAM: I agree that the Sun is the dominant influence on the Earth's climate. The energy supplied by solar radiation is at least two orders of magnitude larger than any other energy source affecting the Earth's climate.

Furthermore, the greenhouse gases, such as CO_2, methane and water vapour play a huge role in determining our climate. CO_2's properties as a greenhouse gas that absorbs infrared radiation have been known for many years and in 1896 Arrhenius even estimated the impact of CO_2 on the climate and concluded that a doubling of its concentration might cause almost 6°C of warming, in the same ball park as current estimates. Therefore the climate is very sensitive to changes in CO_2 and the basic physics is well known.

Most of the published models of past climate indicate that both CO_2 levels and global temperatures were much higher in the Archaean, and have been gradually falling. The distribution of vast coal resources worldwide since the Late Palaeozoic intuitively supports these models. I cannot speculate on the Sun's strength in the Archaean.

JOHN GEARY: Yes, temperature on Earth ultimately depends on the total energy received from the Sun. Lesser climatic shifts (eg Medieval Warming Period) are driven by the sunspot cycle, whereas major shifts, such as the Quaternary Ice Ages and the shift from early Permian glaciation to Cretaceous greenhouse, are related to Milankovitch cycles.

Geoscientists undertaking sediment analysis during fieldwork at Wooloweyah Lagoon on the NSW north coast. Image courtesy ANSTO.

Temperature/pressure conditions have retained liquid water on the planet for the past four billion years. All atmospheric gases have contributed to total atmospheric pressure. Greenhouse gases have a role in temperature control and therefore in the presence of liquid water.

There is a level of atmospheric CO_2 critical to providing an equable climate. It is the lower level which probably should be above the 180 ppm of the last Ice Age. There is a decreasing temperature response to increasing CO_2 levels. It has been estimated that 50% of the greenhouse effect of CO_2 is reached at a level of 20 ppm, so the upper limit is much less critical. A doubling of pre-industrial levels of 280 ppm would probably result in a rise of only 0.5°C, which would be quite tolerable and would benefit global agriculture.

MIKE SANDIFORD: It is clear that the Sun is the primary source of energy that heats our atmosphere since the incoming solar radiation that heats the Earth is some 1000 times the rate heat is lost from the Earth. But the extent of heating is clearly affected by the heat-trapping effects of greenhouse gases. The physics behind the greenhouse effect is not in question and can be found in elementary atmospheric science books. To dispute CO_2 as a significant greenhouse gas it is as anti-scientific as disputing the radioactive properties of uranium. Moreover, without a mechanism such as the greenhouse effect, it is very difficult to

account for many aspects of Earth's history. Examples include the "*faint young Sun paradox*"; the wild climatic gyrations associated with the late Proterozoic glaciations, so wonderfully preserved in our own geological record; and the remarkable synchrony of the ice-age cycle temperature changes and atmospheric CO_2 levels.

This is not to imply the greenhouse effect necessarily provided the 'lead' in any given instance of climate change in the past. It simply implies that a significant greenhouse effect is necessary to explain various manifestations of our past climate history. The intricate patterns of our climate over the last few million years, and the way the climate rhythm changed from a 40 000 year cycle to an ice-age world with a 100 000-year cycle is particularly instructive. It points to a fundamental shift in our climate that cannot readily be attributed simply to the external forcing associated with orbital parameters (ie Milankovitch forcing), just as solar forcing does not explain the measured warming of the last century. Rather, such changes must be due to other dynamics of the climate system, including greenhouse effects.

Q3. The 2007 IPCC report concluded that it was "very likely" that human-generated CO_2 was a driver of climate change. Aspects of the report have recently been criticised (eg the inclusion of a paragraph, now admitted to be wrong, on the melting of glaciers in the Himalayas). Is this document, which states that warming of the globe is "unequivocal", a reliable source upon which to make policy decisions?

BOB CARTER: No. The IPCC reports, and especially the Summaries for Policymakers, are unabashedly political documents.

Most egregiously, in its 3rd and 4th assessment reports the IPCC promulgated a qualitative scale of probability terms that has no rigorous scientific basis. Terms such as "likely" (>66% probable) and "very likely" (>90% probable) have no actual statistical meaning but instead represent considered expert opinions. This practice of allocating meaningless numerical probabilities represents sociology, not science, and is also practiced in the Summary for Policymakers. Such chicanery has no place in what is supposed to be a science-based public policy document.

It has been well known since the mid-1990s, but until very recently ignored by the press, that IPCC processes are scientifically corrupted in this and other ways. The IPCC should be disbanded.

DAVID DENHAM: Yes, the IPCC 2007 report is reliable. It is unfortunate that the 2035 date for the complete melting of Himalayan glaciers was included, but one has to look at the complete set of reports that the IPCC produced in 2007 to appreciate the depth and scope of the work it accomplished. The IPCC's summary, stating that: "*There is unequivocal observation of accelerating warming of the global surface atmosphere and oceans. This is leading to widespread melting of snow and ice, and sea level rising by over 3 mm per year. It is considered very likely – with more than 90% certainty – that the main cause of this climatic change over the last 50 years is the increasing global atmospheric concentration of carbon dioxide, methane and nitrous oxide as a result of human burning of fossil fuels and usages of vegetated land*," is consistent with the observational evidence and still stands. In fact, because the IPCC only used publications up to 2006, some of the more recent work, such as the melting of Greenland and Antarctic ice sheets and the recently published sea level changes, were not included. These more recent results strengthen the IPCC's conclusions.

JOHN GEARY: The name "Intergovernmental Panel on Climate Change" is appropriate. The key word is "Intergovernmental" meaning that their report is a political, not a scientific document, produced under the auspices of a political body, the United Nations. The document was flawed from day one. It purported to represent the overwhelming consensus view of 2500 scientists but the final "Summary for Policy Makers" was written by just 52 scientists and had to be signed off by UN political leaders. The contributions of participating scientists who expressed contrary views were ignored or doctored. At least one threatened legal action to get his name off the document.

In concluding that global warming is almost certainly due to human action the IPCC ignores the following:

1) of the amount of free CO_2 present on the planet, 93% is held in the oceans, 5% in the soils and only 2% in the atmosphere;

2) approximately 82% of the greenhouse effect is due to water vapour, 10% to CO_2 and 8% to other gases. Of CO_2 emissions into the atmosphere, 97% are from natural sources and 3% from human activity. The total greenhouse input by humans is therefore 0.3%;

3) variations in the amount of solar energy reaching the Earth due either to the sunspot or Milankovitch cycles are the principal drivers of climate change, not atmospheric CO_2 levels. It is global warming that drives increasing levels of CO_2 not vice versa. As the oceans warm they disgorge CO_2 into the atmosphere. At present atmospheric temperatures are falling while CO_2 levels continue to rise;

4) NASA space probes have shown evidence of global warming and diminution in the size of polar ice caps on the planet Mars. Anthropogenic? I don't think so. It couldn't be the Sun, could it?

The IPCC claims that the debate on climate change is over and that there is consensus among scientists. Neither claim is true; there never was a debate, just a politically pre-determined position. The US Senate report referred to under Q1 demonstrates an absolute absence of consensus among the scientific community. Such consensus as does exist is among politicians, whose capacity to inflict human misery through unnecessary wars, flawed economic policy and bad legislation is well documented and limitless.

MIKE SANDIFORD: Measurement is what sets science apart from other forms of knowing. It is a matter of measurement – and it is unequivocal – that the last century has seen warming. It is scientific lunacy to deny it, just as it is to pretend the Earth is biblical in age.

As scientists, we all hope that important policy decisions (such as how we best provide reliable, affordable and environmentally-benign energy systems) are informed by the best available science. What constitutes best science? Consensus is not necessarily correct, but it does provide a good starting point and I am impressed by the level of consensus within the climate science community and which is well articulated by the IPCC. Indeed, the level of consensus amongst climate scientists has grown as more evidence has accumulated over the last few decades.

There is of course some dispute, both within and outside the climate science community. Before geologists start to cast stones at climate scientists for a lack of complete consensus, or the odd maverick who raises concerns, we would be advised to look at ourselves. Look no further than to the references to 'the expanding Earth' in previous issues of *TAG* to realise how far we may have to reach to achieve a consensus on plate tectonics. Yet today, plate movements are simply a matter of measurement and within our own community there is undoubtedly a consensus view on plate tectonics. Most of us would be profoundly dismayed if important relevant policy was informed by 'expanding Earthers', rather than 'plate tectonicists'. Recognising that there is always a fringe element comprising contrarians, nutters, etc, I find the level of consensus amongst my climate scientists colleagues extremely impressive and well-reflected in the IPCC reports.

Q4. Climate has varied greatly over geological time, seas have risen and receded, temperatures have fluctuated with Milankovitch cycles and local (or global) influences such as volcanic eruptions. How does the climate of the last hundred years fit within this cycle of change?

BOB CARTER: Climate change over the last 100 years — both in its magnitudes of warming and cooling, and in its rates — falls well within the Earth's geologically recent envelope of climate change. There is no convincing evidence that the phase of mild warming that occurred during the late 20th century was in any way unusual. Indeed, it fits well with known multi-decadal temperature oscillation patterns, which means that the cooling that has occurred since 1998 was not unexpected.

DAVID DENHAM: In the last hundred years there have been more rapid changes in the Earth's climate than at any time in the last 2000 years. The global temperatures are higher now than at any time since at least the last interglacial; sea level is rising faster (~3 mm/yr) than ever in the last 2000 years, glaciers are melting faster throughout the globe, and the Greenland and Antarctic ice sheets are losing mass at a total rate of more than 500 Gt/yr.

At the same time the concentration of greenhouse gases in the atmosphere has increased dramatically and is continuing to rise. CO_2 levels are now higher than at any time in the last 400 000 years and have risen by more than 35% in the last 200 years. This rise is not surprising because we are now adding 3.5 Gt/yr of carbon (mainly from CO_2) to the atmosphere every year — and it effectively stays there for at least 100 years.

The Milankovitch cycles have a period of about 100 000 years — they do not play a major role. The effects of volcanic eruptions in the 20th Century are visible in the climate record and have only minor effects.

JOHN GEARY: Seven cyclical ice age events have been recognised in the past 700 000 years. These are characterised by a steady decline in temperature over a period of around 90 000 years and a relatively rapid rise in temperature during the interglacial phase of approximately 10 000 years. These appear to be related to the 100 000-year Milankovitch cycle. We are currently at least 10 000 years into the latest interglacial. If this cycle is continued we are about due to enter a new Ice Age. In the last 1100 years, there has been a transition from a very cold period to the Medieval Warming Period (900–1300 AD), then to the Little Ice Age (1300–1850 AD) and finally to the modern warming period. During this latter period we have not reached the maximum temperatures of the Medieval Warming Period, even though atmospheric CO_2 levels are higher. In the Medieval Warming Period agriculture flourished in Greenland and vines were grown in Britain. The temperature range from the high of this period to the depth of the Little Ice Age was 4°C without any significant change in atmospheric CO_2.

During the last 100 years temperatures rose from a high in the mid 1930s to a low around 1970 with a difference of 1.6°C. Around this time there was a cooling scare advanced by some of the same people or bodies that are now the protagonists of warming (maybe they were right then but 40 years before their time). Throughout these fluctuations CO_2 levels continued to rise. The total temperature rise from the beginning to the end of the 20th Century was 0.7°C.

MIKE SANDIFORD: Change is undoubtedly happening. There has been warming over the last century. The key thing is how we project what will happen over the next few centuries. How do we best make the projections and predictions? We must look at the past trends and understand the physical causes. The fingerprints of our current warming are particularly instructive — greater night rather than day warming, more winter as opposed to summer warming and, most importantly, warming in the lower atmosphere but cooling in the upper atmosphere. All are diagnostic of a greenhouse forcing by enhanced heat trapping, and not with an enhanced input of heat from the Sun.

Moreover, the warming is entirely consistent with the greenhouse forcing due to post-industrial rise in CO_2 levels. The science is just as compelling as the case for plate tectonics! We must use this physics to predict what might happen next. But, just as with modern market economies, non-linearity with complex feedback, thresholds and lags, mean predictions always carry uncertainties. Whether the future is better or bleaker than the model predictions, it is sure to be different!

Q5. What do you think are the key uncertainties within the climate modelling? Is there science that is being ignored while the focus has shifted to policy decisions etc?

BOB CARTER: Pass; this is a question for expert modellers to answer. But to scientists outside that research community, it is self-evident that the current generation of GCMs are completely inadequate to be used as policy tools. First, the models have not been validated. Second, they fail empirical tests using elapsed temperature data since 1990. And, third, as the IPCC itself has observed: "*In climate research and modelling, we should recognise that we are dealing with a coupled non-linear chaotic system, and therefore that long-term prediction of future climate states is not possible*" (IPCC *Third Assessment Report*, p 774).

DAVID DENHAM: Forecasting when the major perturbations in the climate, such as El Niño, are going to happen needs to be improved. Understanding better the regional variations in sea level changes with respect to tectonic events and glacial rebound is another area where a better understanding is required. However, it seems to me that the science of climate change is sufficiently well understood that we should focus on the policy issues that will lead to a more sustainable society, which relies less and less on fossil fuels — and how we do this is hard.

JOHN GEARY: Garbage in, garbage out is one of the maxims of computer language. Computer modelling cannot replicate nature, particularly when the input parameters are inconsequential or incomplete. Models are revised as earlier predictions fail to materialise. The present fall in atmospheric temperatures was not predicted. These flawed models, in the case of the UK and Australian governments, have then been passed on to the economists Stern and Garnaut who produce more models showing even more alarmist projections. They then write voluminous reports which become manuals for government action. These gentlemen, who in their own field of expertise failed to predict the Global Financial Crisis, make wild predictions in a field where they have absolutely no knowledge. Governments apparently accept their recommendations and predictions. The mind boggles. Prognostications as to which specific level of atmospheric CO_2 will limit temperature rise to 2°C as against a level which will result in a 3°C rise are ludicrous, as is the concept of tipping points.

MIKE SANDIFORD: The positive feedbacks and thresholds are the worry, just as they should have been worrying the subprime lenders well before the International Monetary Fund (IMF) warned, in late 2008, that the world financial system was teetering on the "brink of systemic meltdown". As history now tells, the rather-belated IMF warning came long after the warning bells were sounding. This makes the tame IPCC conclusions ("*warming of the climate system is unequivocal*" and "*most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations...*") seem all the more timely. The question is, do we have the policy frameworks and the appropriate will to do anything about it, or will we risk waiting for a "systematic meltdown" before we do so?

Q6. What is missing in the climate change debate, and what is it that we need to 'bring to the table' from a geological perspective? In other words, what additional data and what geological information do you want to see included in assessing climate change?

BOB CARTER: What is missing are:

- *scientific balance*: the debate is overwhelmingly influenced by the speculative results of unvalidated computer modelling, and pays too little regard to our knowledge of Earth's climatic history;
- *dispassionate assessment*: the public debate is dominated by irrational emotionalism, which is fuelled by self-interested organisations such as environmental NGOs and commercial interests, especially those of the alternative energy (including nuclear) and financial business communities;
- *balanced media coverage*: alarmist environmental stories sell media advertising space, good-news stories do not;
- *an adequate education system*: pupils and students at all levels today receive an unbalanced education in environmental science. Despite the good intentions of the great majority of teachers, many parents throughout Australia are concerned with what they see as the indoctrination of their children about global warming and other environmental issues;
- *impartial science agencies*: the insistence of governments on spending taxpayers' money on "useful" (for garnering votes) or "focused" research has inflicted crippling damage on the enabling sciences, and resulted in: 1) the creation of many research groups whose survival depends upon the continuation of the perceived problem that they were created to tackle (eg to "save" the Great Barrier Reef); and 2) the degradation of science agencies to the point that many now act largely as government environmental consultancies whose main ambition has become to maximise the research income that they earn, from the public purse or otherwise;
- *political wisdom*: politicians by and large lack an understanding of scientific method, and MPs of nearly all the main parties believe that to disagree with the conventional alarmist wisdom on global warming is a political "poison pill". Thereby, and under acute pressure from well-funded and globally co-ordinated environmental activists, governments throughout the world now exhibit a disastrous incapacity to make sensible, as opposed to politically pragmatic, decisions on major environmental issues, and especially so for global warming;
- *risk management*: there is an almost complete lack of proper risk assessment and cost benefit analysis, as typified by the hopelessly inadequate Stern and Garnaut reports. All such alarmist policy documents (and myriads have been prepared within government departments the world over) are woven from a common IPCC cloth; they fail to consider properly the benefits of human-caused warming, *should it ever eventuate*, and do not consider at all the risks of the natural warmings and coolings *that are certain to occur in future*.

DAVID DENHAM: Obviously there needs to be better monitoring of parameters like the Sun's radiation, sea and land temperatures,

greenhouse gas levels, sea levels and so on. The longer any data set is available, the better we can use it to understand the climate. So funding for organisations like the Bureau of Meteorology, CSIRO and our Universities must be maintained.

I think there is enough information in the public domain to make policy decisions, but these are going to be difficult because the media commentators and some of the large fossil-fuel companies have been better equipped at presenting a denier's case. Scientists are usually better at science than they are at communicating it. The media are good at communicating but not so good at understanding the science. We must do a better job at communicating.

It also seems that the scientists who are arguing against both global warming and anthropomorphic influences are mostly not specialists in those fields. For example, how many atmospheric physicists, geologists working on coral reefs, glaciologists and meteorologists are there who would disagree with the main IPCC 2007 conclusions? There may be one or two, but I don't know where they are.

JOHN GEARY: Rationality is what is missing from the climate change debate. Good science has been thrown out the window and agenda-driven science has taken over. The issues previously referred to and the palaeoclimatological history of the planet need to be 'brought to the table'; at present they are locked in the cupboard. One avenue of geological investigation that could be pursued is the extent of heat transference from the Earth's mantle through constant volcanic activity along the mid ocean ridges. Is there sufficient heat input to create significant warming of the oceans and how would this effect global climate?

MIKE SANDIFORD: I am often surprised by the lack of knowledge of basic Earth history, including within the climate change debate. The extent and rates of past change are poorly appreciated even amongst many geologists. That sea levels were rising by 2–4 m/century as recently as 13 000 years ago, as the northern ice melted, is something we should all know. Would we, should we, risk returning to a world of such change by tempting a new round of ice melting, especially in a world of nearly seven billion people? And yet we know that CO_2 levels are now rising at a rate some 200 times faster than 13 000 years ago and that the ice is beginning to melt. That said the problem for geologists with climate change is that the timescale is so short and the rates are so fast. We are talking on the timescales of civilisations, of centuries and millennia, whereas the geological perspective is mostly relevant to much longer timescales. We are now dealing with rates of change that are quite possibly outside of the bounds of geological 'experience', and we geologists need to acknowledge the limitations of our perspective.

Q7. What do we need to do to address climate issues as we move further into the 21st century?

BOB CARTER: To focus on the chimera of dangerous human-caused greenhouse warming while ignoring the real threats posed by the natural variability of the climate system itself is self-delusory. Instead, the realities that global climate is currently cooling, that it will both warm and cool again in the future, and that unpredictable, unpreventable and damaging "weather" events will continue to recur quite irrespective of human activity, need to be recognised.

It is long past time to move away from the stale and repetitive "he-says–she-says" arguments about whether human CO_2 emissions are causing dangerous warming, and on to designing effective policies of hazard management for all climate change, based on adaptation responses that are tailored for individual countries or regions.

The key issue on which all scientists agree is that natural climate change is real, and every year brings new examples that exemplify the substantial human and environmental damage that it can cause. By their very nature, strategies that can cope with the dangers and vagaries of natural climate change will readily cope too with human-caused change, should it ever become manifest.

Even were generous funding to be provided for the implementation of national hazard warning and disaster relief schemes, the overall costs would be orders of magnitude less than those caused by the introduction of unnecessary and ineffectual emissions trading schemes and other futile "anti-carbon dioxide" measures. To boot, contingent damage to the world economy, the standard of living and the world food supply would be avoided.

DAVID DENHAM: I believe we should enter more into the policy debate. We are shirking our responsibilities if we say to the politicians: "The Earth is warming because we are burning too much fossil fuel and we will all be doomed unless we cut our carbon footprint."

Geoscientists are probably more capable than politicians at developing sensible policies. So we should provide more policy input. Do we really want economists to continue to control our future?

JOHN GEARY: Certainly we should not continue to waste trillions of dollars in an attempt to change something which is beyond our capacity to change. The current "Carbon Pollution Reduction Scheme" before the Australian Parliament is a prime example of such waste. The very name is the ultimate inanity. Carbon dioxide a pollutant? It is a natural constituent of the atmosphere and without it there would be no life on the planet.

The positive initiatives we can take to address climate change issues are in the areas of prediction, preparation and adaptation. We do know that climate changes are cyclical and what the principal drivers are even if we do not fully appreciate the inter-reaction between them. With this knowledge we should be able to predict broad trends. Given that the main climate drivers are extraterrestrial this would be a task for the astronomers, astrophysicists and allied disciplines. We could then look to the engineers, agricultural scientists and economists to advise on the best way to cope with predicted changes. While a continuation of the modern warming trend to at least the level of the Medieval Warming Period would be the best outcome for the majority of humans, the evidence suggests that climate may go in the opposite direction.

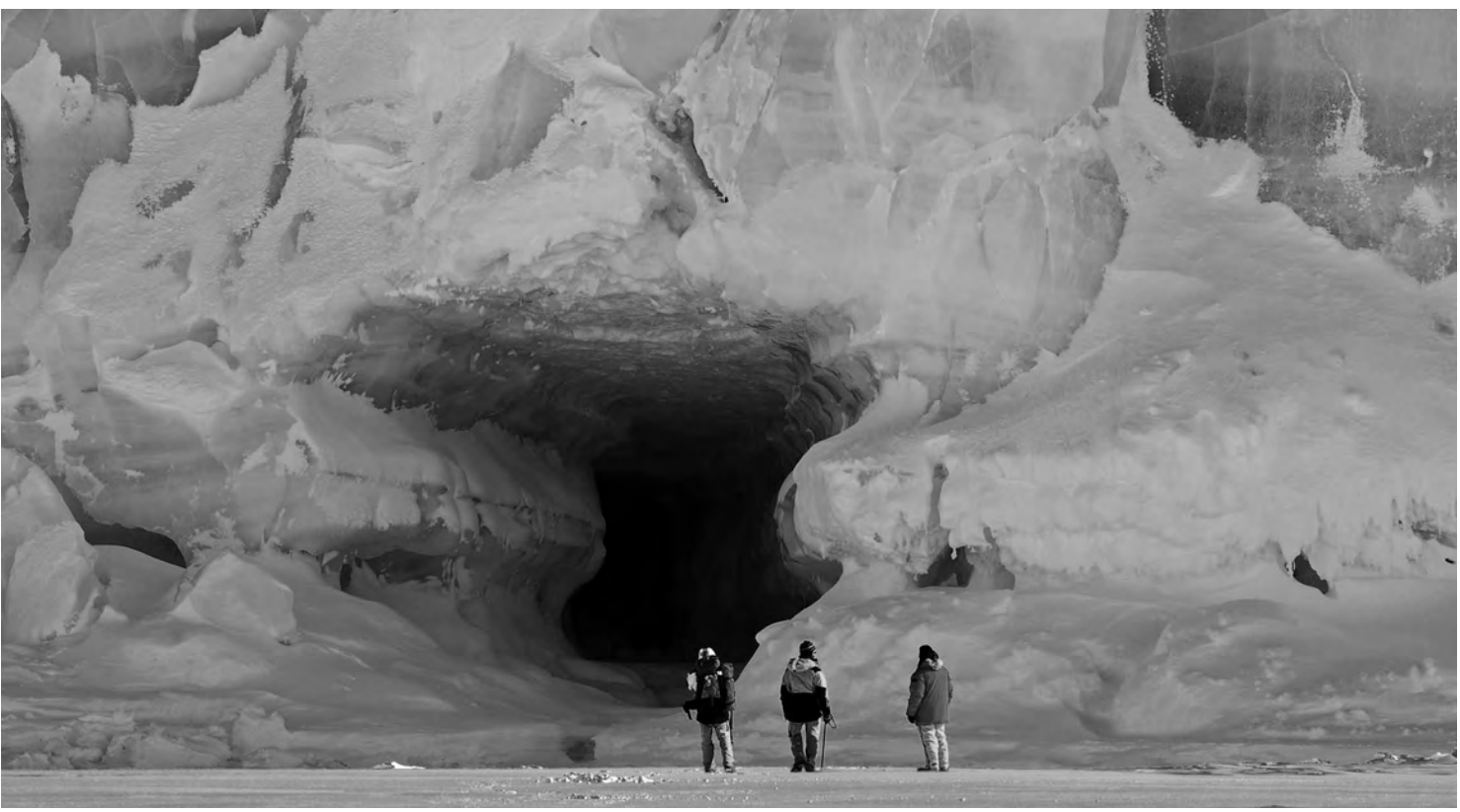
Adaptation to climate change will be challenging particularly in view of the rapidly expanding human population but changes are likely to be slow and we should have time to adapt gradually. How for instance could we cope with a return to the Little Ice Age in a few hundred years? It would be difficult but doable and we would just have to learn to roll with Nature's punches. Much more challenging would be a return to the conditions of a full Ice Age in say 90 000 years. How would millions of inhabitants of Canada, northern Europe and Asia cope with living on a 1000 metre ice cap? Could they migrate? If so where? Where could wheat still be grown? Not to worry, global warming is the greatest moral challenge of our time, or so someone said.

MIKE SANDIFORD: Climate change raises many issues that focus our attention on how we come to terms with living on a finite planet. Independent of whether peak oil (or peak anything else) is reached in this decade or a few decades from now, it is clear that many of the resources that underpin our contemporary lifestyle are finite, and will be significantly depleted as raw commodities in this century. To continue to serve humanity well, we will have to learn to use our natural resources in a more sustainable fashion and to find alternatives. In part, we will address this with new technologies that will give extra life to our exhaustible resources, and care for their waste products. But climate change and related issues should also make us rethink our natural resources in terms of the services they provide.

An example relevant to the climate change debate is the role of climate in maintaining the balance between the amount of ice and water on the planet. It is only since sea level has stabilised in the Holocene that our civilisation has flourished. We risk this fundamental service that climate provides in keeping sea level stable at considerable cost to future generations, and the scientific consensus is that we are risking it by raising atmospheric CO_2 levels at an unprecedented rate.

In-the-ground coal also provides such a service. As a geological bank of carbon long sequestered from the atmosphere, it has set the level of greenhouse forcing of our pre-industrial atmosphere. What value do we place on this service provided by coal-in-the-ground? Any cost we put on carbon pollution will be an implicit measure of the value of the service coal-in-the-ground provides.

Looking forward, I believe the geoscience community would benefit from articulating a shared view of 'Earth services', analogous to the way ecologists have articulated the benefit of 'ecological services'. The notion of 'Earth services' I have in mind is part metaphor, part rallying cry and part road map, helping to align Earth Science with policy that informs how best to utilise our natural bounty for the benefit of both *present and future* generations, including *rich and poor* alike, and for the benefit of *human society and the environment*. Those are the bedrock issues that underpin the sustainability agenda, and the understanding that the Earth Sciences can (and must) provide will be key to informing any real prospect for achieving meaningful sustainability. On a world headed for population of nine billion, most of whom will aspire to dramatically increase their access to energy services in particular, sustainability provides the big challenge we must all face.



Standing on sea ice, Antarctic researchers peer into a cave in an iceberg off Peterson Island. This report, Mike Sandiford writes that climate change raises many issues that focus our attention on how we come to terms with living on a finite planet. Image courtesy Todor Iolovski.