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Understanding the Climate System, and the Consequences of Climate Change for the Exploitation and Management of Natural Resources: The View from Banff

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Résumé de l'article

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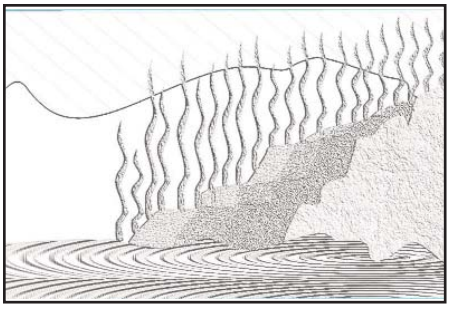
SERIES



The Geoscience of Climate and Energy 1. Understanding the Climate System, and the Consequences of Climate Change for the Exploitation and Management of Natural Resources: The View from Banff

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SUMMARY
A commonly expressed opinion within the earth-science community is that the work of the Intergovernmental Panel on Climate Change (IPCC) has largely ignored paleoclimate data and the methods of research utilized by earth scientists. It can be demonstrated that this is not the case, and one of the objectives of the Gussow–Nuna conference was to present current research in this area.

Whereas earth scientists might seem ideally placed to address issues of climate change and energy, many of the beliefs that inform public opinion about global warming and climate change are based on misrepresentations or over-simplifications. Six examples are discussed here, including misperceptions about the melting and retreat of glaciers, the true causes of concern about the future fate of polar bears, and myths about petroleum pricing and availability.

There is ample space for the earth-science community to add its informed voice to debates about energy and climate change, but, to date, this voice appears to be have been largely ineffective.

RÉSUMÉ
Dans le milieu des sciences de la Terre on a souvent l'opinion que les travaux du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) ont largement ignoré les données et les méthodes de recherche paléoclimatiques employées par les géoscientiques. On peut prouver que ce n'est pas le cas, et que c'était un des objectifs de la Conférence Gussow–Nuna que de présenter les recherches actuelles en la matière.

Bien qu'il semble que les géoscientifiques soient les mieux placés pour traiter de questions de changement climatique et d'énergie, de nombreuses croyances qui modèlent l'opinion publique sur le réchauffement global et le changement climatique reposent sur des informations trompeuses ou des simplifications excessives. Six exemples seront discutées ci-dessous, dont les perceptions erronées sur la fonte et le retrait des glaciers, les véritables motifs d'inquiétude sur le sort des ours blancs, et la saga des prix et de la disponibilité du pétrole.

Nombreux sont les forums où les géoscientifiques peuvent faire entendre leur voix compétentes dans les débats sur l'énergie et le changement climatique, mais il semble que cela ait été sans grand effet jusqu'à maintenant.

INTRODUCTION
The modern world is facing several significant and interrelated problems: A global climate system that is evidently undergoing rapid change, and a growing world economy that will soon have to deal with the rapid depletion of its most important energy source: readily available and inexpensive oil and gas. Concurrently, as the degradation of the environment has emerged as a major global concern, attention has focused on the role of *anthropogenic* or human influences such as the burning of fossil fuels, on global environmental problems of ozone depletion, toxic gas emissions, and global warming. In their discussion of these pressing issues, scientists who work with the rock record have repeatedly voiced the following three concerns about scientific investigations of climate change:

1) that throughout the First, Second and Third assessments by the Intergovernmental Panel on Climate Change (IPCC), there was no specific focus on paleoclimates, leaving the impression that this rich geological database and the role of natural processes in climate change have been ignored. The other two concerns arise from this:
2) that there is no complete, unanimous scientific consensus that

anthropogenic processes are driving recent climate change; and 3) that Earth's climate has constantly changed over time, so why focus on this issue now?

These and other concerns were explored in a survey of Canadian earth scientists in 2007, which was supported by the Geological Association of Canada (GAC) and the Canadian Society of Petroleum Geologists (CSPG) (Miall and Miall 2008). Discussions among executive members of GAC and CSPG and the Canadian Federation of Earth Scientists led, in the summer of 2007, to the decision to hold the Gussow–Nuna conference on the Geoscience of Climate Change. To situate the purposes of the conference and this series in *Geoscience Canada*, this introductory article presents an overview of these issues and attempts to correct some common misperceptions.

EARTH SCIENTISTS AND THE CLIMATE-CHANGE DEBATE

In terms of issue 1) (above), it is important to note that while earlier IPCC assessments did not specifically address paleoclimate science, geological datasets have always constituted an important component of climate science. The Fourth Assessment of Working Group 1 (Solomon et al. 2007) contains a lengthy and detailed chapter on paleoclimatology, focusing primarily on the climate of the post-glacial period. For example, this chapter describes research on:

- The overriding importance of orbital forcing (the Milankovitch mechanism) in governing glacial to interglacial changes on a 10^5-year timescale (Ruddiman 2007, and this issue).
- The Heinrich ice-rafting events in the North Atlantic Ocean, and the insights they have provided into thermohaline circulation during ice-house conditions (e.g. Alley 2007).
- Raised beaches and coral terraces and the information they have provided about continental ice cover, ocean-water temperatures and sea-level change (e.g. Peltier and Fairbanks 2006).
- The discovery and documentation of a millennial-scale climatic oscillation in ice cores (Dansgaard–Oeschger cycles) and deep-sea sedimentary records (Bond cycles), and the important questions they have raised about climatic forcing and solar influences on climate at the millennial scale (Alley 2007).

Despite this attention to paleoclimate research, the impression has remained among earth scientists that past climate changes of natural origin have not been a major focus of the work of IPCC, nor the basis for many of its conclusions about climate change. As the paper by W. R. Peltier will show (later in this series), this impression is quite incorrect. *"The [modelling] community has in fact invested enormous resources in testing these models by confronting them with geological constraints on past climate regimes."* (Quoted from the abstract of Peltier's Gussow–Nuna paper).

In terms of issue 2), the debate concerning whether or not there is a scientific consensus on the role of anthropogenic processes in climate change has become highly politicized, with many science groups and non-scientists weighing in with a number of arguments. Some of the relevant debates appearing in the public and scientific media include;

- The controversy about the 'Hockey-Stick' graph (Mann et al. 1998).
- The funding by Exxon Corporation of groups opposing the concept of anthropogenic global warming, the controversy surrounding this activity, and the attempt by the Royal Society of London to suggest that this funding be terminated.
- Congressional hearings in Washington organized by Oklahoma Senator James Inhofe.
- Many foundation and specialized websites, including those of Climate Audit, Friends of Science, Real Climate, The Science and Public Policy Institute, Pembina Institute, etc.
- The movie '*An Inconvenient Truth*' by former US Vice-President Al Gore, and the discussions this movie has generated.
- The 'Joint Academies' statements prepared for the 2005 G-8 meeting in the UK and the 2008 meeting in Japan.
- Extensive writing by non-specialists in the news media and the blogosphere.

A commonly expressed opinion in the blogosphere, in the traditional media, and elsewhere, is that the scientific consensus supports the prevailing IPCC model of anthropogenic climate change. Further, a well known, oft-cited, but controversial paper by Oreskes (2004) has purported to demonstrate the weight of scientific opinion behind this model by reviewing the content of 928 papers published in scientific journals between 1993 and 2003. There is now solid evidence of a near-global consensus amongst scientists that the climate is currently being modified rapidly by the anthropogenic addition of greenhouse gases to the atmosphere. Notably, in the Canada-wide survey of earth scientists conducted in 2007 (Miall and Miall 2008), a majority of respondents [57%] strongly or somewhat agreed that climate change within the last few decades has been driven primarily by anthropogenic influences. However, a much larger majority [82%] agreed, to some extent, that both natural *and* anthropogenic causes are at work.

One of the scientific concerns that has been expressed (e.g. McIntyre and McKitrick 2003, 2005) is that the well-known climate cycles of recent history, the Medieval Warm Period and the Little Ice Age, have been discounted as primarily 'Eurocentric' in origin in the 'Hockey-Stick' graph developed by Mann et al. (1998) (see remarks by Mann in *Eos*, 8th July, 2003), which featured prominently in the IPCC Third Assessment Report. The US Congress subsequently commissioned the *"Wegman Report"* from the National Research Council (Wegman 2006), and the National Academy of Sciences followed up with a *'Report in Brief'* (North et al. 2006) which largely answered the criticisms. In a subsequent major review article, Mann (2007) substantially enlarged the data base, incorporated additional sources of temperature variation, including solar and volcanic influences, and modified the statistical methods. The climatic fluctuations of the last millennium, which had been obscured in the earlier work, now appear more clearly, and the sharp rise in global temperature through the

twentieth century appears just as prominent in the revised graphical summary.

A number of respected scientists have raised legitimate concerns about the anthropogenic model of climate change, particularly about its inattention to the role of the sun, and the apparent discounting of the importance of the climate cycles of the last few millennia. Veizer (2005), for example, has argued that celestial influences have not been adequately taken into account in climate models. His work has itself been discussed by Benestad (2005), who reaches different conclusions. Recent concise summaries of solar influences on climate have been provided by Foukal et al. (2004) and Lean (2005), whose Gussow paper will appear subsequently as part of this series; further discussion of this area of science is available at [www.RealClimate.org]. The European Organization for Nuclear Research (CERN) is preparing experiments to examine one of the concepts discussed by Veizer (2005): the influence of cosmic rays in generating clouds, and the possible modulating influence of the solar wind on this process (Kirkby 2007).

As Kuhn (1996) has argued, most science is what he has termed 'normal science', the daily science practised by most scientists in supporting and clarifying an existing concept or paradigm. In this regard, consensus (such as that noted by Oreskes 2004) is to be expected, but the discovery of 'anomalies' is extremely important. These may potentially constitute the 'falsifications' of a hypothesis, to use Popper's (1959) term. It is the search for anomalies that commonly constitutes the most original science, as the history of the overturning of continental 'fixism' in favour of plate tectonics, and many other scientific revolutions have demonstrated. However, a careful search of the literature reveals that there are no longer any well-supported anomalies in the IPCC models, beyond the limitations and reservations expressed in the IPCC documents themselves. Further, there now appears to be little, if any, critical peer-reviewed scientific literature that provides reason to question the kinds of datasets and models that have been developed by Working Group 1 of IPCC.

However, several group letters have been written to national governments and to the United Nations expressing concern about the work of IPCC. Earth scientists, including geologists, oceanographers, and meteorologists are on the lists of signatories. The most recent of these is an *"Open Letter to the Secretary-General of the United Nations"* published online at [www.scienceandpublicpolicy.org] on 13th December 2007. Another is the Senate Minority Report containing extracts of statements by "over 400 prominent scientists [who] disputed man-made global warming claims in 2007", at [http://epw.senate.gov/public/index.cfm?FuseAction=Minority.SenateReport]. These debates have been used to create the impression that there is greater scientific controversy than the published scientific literature might suggest. As Dunlap (2008) has noted, for example:

"Republican spokespersons and conservative commentators have long challenged IPCC reports as reflecting the "scientific consensus" on global warming by highlighting the views of a modest number of "skeptic" or "contrarian" scientists who question the IPCC conclusions. One result is that in their efforts to provide "balanced coverage," U.S. media have given disproportionate attention to the skeptics, creating the impression of less scientific consensus on global warming than exists within the mainstream scientific community. As a consequence, American newspapers' portrayal of global warming as a scientifically controversial issue differs significantly from the image presented by the media in other nations".

Further, it should be noted that much of the content of the dissenting group letters and petitions, referred to above, does not cite hard scientific contributions but rather consists of personal opinions, or complaints from scientists that their views have been discounted or ignored, or arguments based on old science already accommodated by the IPCC evaluations. Such comments do not constitute the anomalies that Kuhn (1996) referred to. On the other hand, detailed scientific discussion of highly technical issues is being carried on at [www.realclimate.org], a website that is updated regularly with discussions of new scientific data, observations and arguments, with links provided to the relevant technical papers. As Kuhn (1996) has noted, most complex science is incomplete, or contains generalizations or assumptions that may be questioned. However, in identifying anomalies, it is important to provide alternate scientific models that better explain and predict future results. Those who support the anthropogenic model of global warming complain that most of the sceptics of their models have not published peer-reviewed science in good journals, preferring to cherrypick or pick holes in climate models without providing alternate explanations. The Gussow–Nuna conference focused on climate science itself, and not opinion, by bringing together many of the key players who have contributed to the climate change debate through their research and peer-reviewed publications in the leading science journals.

Although climate scientists have amassed substantial evidence to support an anthropogenic model of climate change, at the same time many of the beliefs that inform public opinion about global warming and climate change are based on misrepresentations or over-simplifications, several of which were included in the movie, '*An Inconvenient Truth*'. In the next section, six issues that are commonly misrepresented in the general media are summarized.

SIX CONTROVERSIES ABOUT ENERGY AND CLIMATE CHANGE

It should be emphasized that the discussion of the first three of these issues (those concerned with climate change) is not an attempt to highlight problems or flaws in the current model of climate change, but precisely the opposite. The overly simplistic representation of important environmental and energy issues in the general media makes it easier for sceptics to point to flaws in the accepted theories and concepts, and thereby keep doubts alive, and make it more difficult for political leadership to coalesce around necessary policies and solutions.

Global Temperature Tracks Atmospheric CO_2 Content

In public discourse, much is now made of the close parallels between global average temperature and carbon diox-

ide composition of the atmosphere, which apparently demonstrate a close covariance over the last few hundred years, suggesting a cause-and-effect relationship. In the movie, '*An Inconvenient Truth'*, what is not made clear is that immediately after glacial maxima, an increase in atmospheric CO_2 lags the post-glacial increase in temperatures over Antarctica and the Southern Ocean by up to a thousand years. This has been well-known to climate scientists for at least nine years (Fischer et al. 1999; Fig. 1). The Fourth IPCC Assessment (Solomon et al. 2007, p. 444) states,

"High-resolution ice-core records of temperature proxies and CO_2 during deglaciation indicate that Antarctic temperature starts to rise several hundred years before CO_2."

Glacial cycles are driven primarily by orbital forcing. The increased solar radiation that brings a glacial cycle to an end also warms the oceans, leading to degassing of dissolved CO_2, and to other complex processes that are not yet fully understood (Stott et al. 2007). This does not disprove the greenhouse-gas model of global warming, but it does underscore the central importance of understanding the processes of material and energy flux in the oceans and the complexity of the ocean–atmosphere relationship. The current anthropogenic-change model is based on the concept that the natural atmospheric balance is being radically disturbed by anthropogenic emissions at a rate faster than that to which natural systems can adapt. Carbon dioxide is now a principal driver of climate change, whereas under an undisturbed model of natural climate change it is merely part of a number of feedback loops in the carbon cycle.

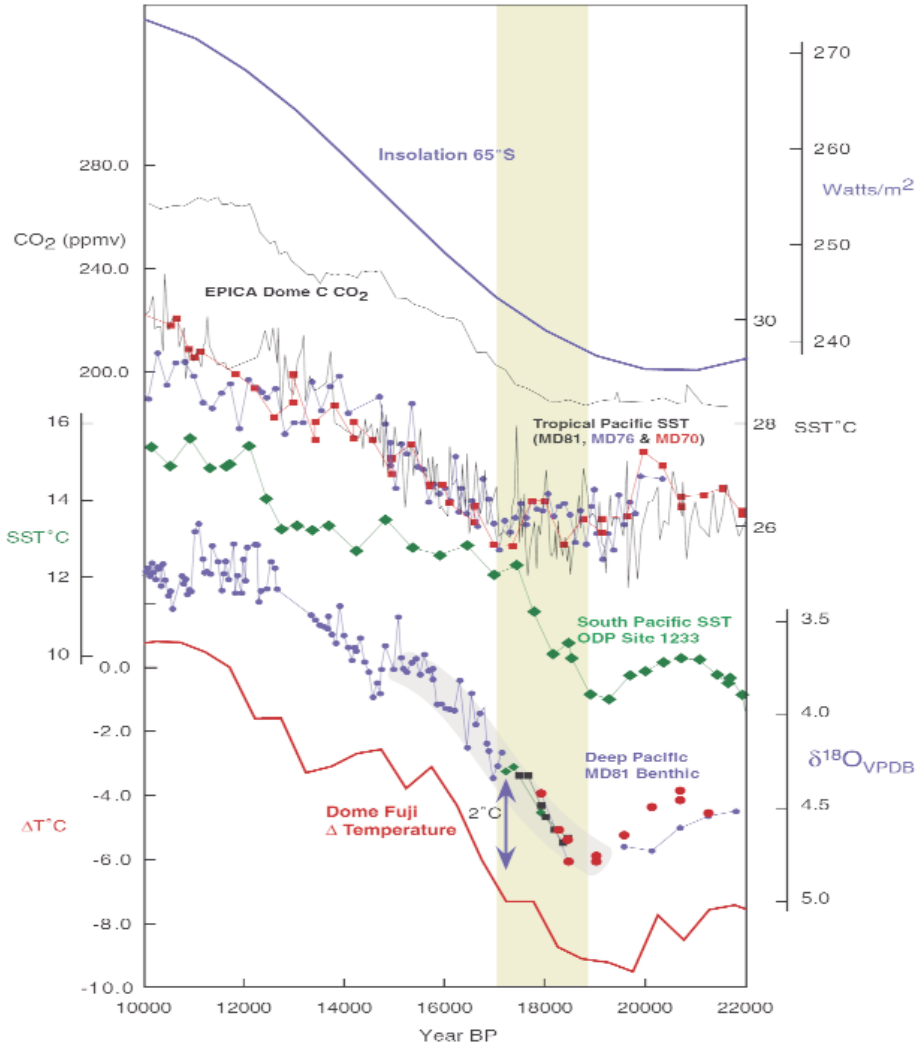

Figure 1. Temporal phasing of the Pacific deep-water and tropical surface water temperatures (SST) during deglaciation, compared with the atmospheric CO_2 record obtained by the European Project for Ice Coring in Antarctica (EPICA). The yellow shading indicates the span of time between the initial post-glacial warming and the beginning of the rise in atmospheric CO_2 content. Warming is indicated by ice dome Fuji temperatures, Pacific deep-sea temperatures, and South Pacific sea surface temperatures (SST). The onset of tropical Pacific SST warming and the beginning of the rapid rise in atmospheric CO_2 commence more than 1000 years after the onset of deglacial warming (from Stott et al. 2007; reproduced with permission).

Ice-calving of Glaciers Indicates Rapid Global Warming

Video clips of these occurrences are shown virtually every time there is a televised discussion of climate change. They appear in '*An Inconvenient Truth*'. The problem is, of course, that ice will always fall off the front of a glacier, whether the glacier is advancing at a time of global cooling or retreating during global warming. The melting 'snout' of a glacier is at a point determined by the dynamic balance between the forward movement of the ice mass under gravity, and the rate at which it melts in the mild temperatures that prevail at sea level. Falling ice means absolutely nothing.

Glacial Retreat in General as an Indication of Global Warming

'An Inconvenient Truth', and many other articles and books contain photographs showing a glacier in modern times and an image showing the same scene several or many decades ago. The recent retreat of the glacier is dramatically indicated by such comparisons. Again, there is a lack of context. The complete story of glacial retreat is much more complex.

Many of the glaciers that are now in retreat did not exist until the Little Ice Age, which climaxed in the mid to late seventeenth century. During the preceding Medieval Warm Period, which peaked at about 1000 AD, Alpine ice cover in the northern hemisphere was substantially less than at present, and over much of the Canadian Cordillera there may have been no glaciers at all during the Holocene

Figure 2. Tree stumps more than 3000 years old in the outwash river below the Saskatchewan Glacier, Columbia Icefields (from Eyles and Miall 2007). These trees have been exposed by the recent retreat of the glacier, but they attest to the variable climates that have existed in the Rocky Mountains. There was little or no alpine glacial cover 8000 to 6500 years ago. The modern glaciers formed during the Peyto Glaciation, about 3000 years ago, and began their current retreat in the late eighteenth century (see Rutter et al. 2006).

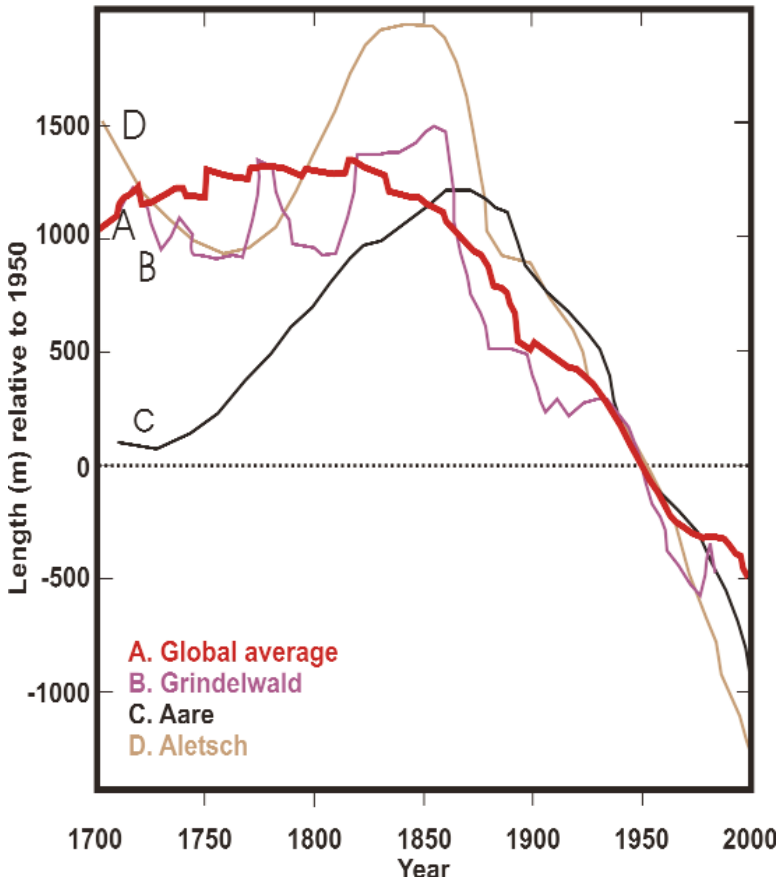

Figure 3. Changes in the length of glaciers relative to their length in 1950. Global average from Oerlemans (2005), and Swiss glaciers from Steiner (2005).

Maximum or Hypsithermal (about 8-6.5 ka), a period during which climates were considerably warmer than at present (an effect of orbital forcing). These Holocene climate changes are discussed by Solomon et al. (2007, p. 460) and by Rutter et al. (2006, p. 68-69).

Modern glacial retreat in the Columbia Icefields of Jasper National Park has exposed large tree stumps dating from about 3 ka, indicating the former extent of substantial high-altitude forests in that area (Fig. 2; cf. Rutter et al. 2006, Fig. 85). Although the modern trend of rapid retreat commenced on most glaciers around the world in the first half of the nineteenth century (Oerlemans 2005), a few records from Norway and New Zealand indicate that retreats commenced ca. 1750, before the modern industrial era, whereas some Swiss glaciers actually underwent significant expansion between about 1750 and 1850 (Fig. 3; Steiner 2005). Anthropogenic global warming may not have become a significant process until at least the early nineteenth century – the beginning of the modern Industrial Era – although some work suggests a modest anthropogenic influence going back to the beginning of agriculture (see Ruddiman 2003), and clearly there were local or regional processes occurring in the European Alps that have yet to be fully resolved. Changes in Alpine glacial cover since 12 ka have now been documented in detail in the Paleoclimates chapter of the IPCC Fourth Assessment (Solomon et al. 2007, Box 6.3, Fig. 1, p. 461).

High Gas Prices Equal Corporate Rip-off

As predictably as night follows day, a spike in gasoline prices at the pump is usually followed by television news clips of upset consumers complaining while they fill their tanks. Accusations of 'gouging' are heard, and commonly, provincial or federal politicians will initiate an inquiry into pricing practices. Predictably, nothing comes of the inquiry. The fact is, retail gas prices are the subject of intense local competition, and profit margins are small. Retail prices are ultimately a reflection of supply and demand on wholesale markets, which, in turn, reflect the responses of traders and speculators to

geopolitical events, such as crises in the Middle East, and damage to the infrastructure of production platforms and refineries by hurricanes. It is an unfortunate commentary on human nature that we all believe in the value of the 'free market' until free-market forces lead to price increases, and then we start to look for somebody to blame. These media stunts detract attention from the real problem of rising demand at a time of decreasing supply.

'Energy Independence' and 'Reducing Dependence on Foreign Oil'

These are political mantras of US origins, and can be guaranteed to rouse patriotic sentiments, particularly at times of elections. Serious petroleum industry representatives do not support this approach to the issue of energy supply. Scott Tinker, Director, Texas Bureau of Economic Geology and current President of the American Association of Petroleum Geologists, said, in the President's Column of the *AAPG Explorer*, the AAPG house news magazine, in November 2008:

"…we must get away from the notion of energy independence. The world is interdependent, and recent trends toward nationalism in certain countries, although predictable, are shortsighted and ultimately nonproductive. Energy independence is being confused with energy security."

The US now depends on foreign imports for 60% of its daily consumption (up from 50% in 1997), according to the Energy Information Agency (EIA 2007), a proportion that would be affected only temporarily, if at all, by allowing drilling in offshore areas currently under moratorium, or by opening up the Arctic National Wildlife Refuge (ANWR) to exploration. Offshore (and Canadian) imports only became important in the US because of depletion of domestic reserves. Given that the US is the most thoroughly explored country on Earth, the likelihood of major new supplies being located is very remote. Estimates of possible reserves in the ANWR (USGS, [www.anwr.org]) range from 3 to more than 40 billion barrels (depending on the source of the estimate; the size of recoverable reserves also depends on the assumed future price at which the oil could be sold). A 'technically-recoverable' reserve of 10 billion barrels is claimed by [www.anwr.org]. At 20 million barrels/day, which is current US consumption, this represents a supply lasting 17 months: a drop in the bucket.

"Drill, baby, drill!" the Republican slogan for encouraging the opening of the US continental shelf for exploration, is likewise misleading hype. According to the US Minerals Management Service, the total estimated undiscovered recoverable reserves under the US outer continental shelf amount to 73 billion barrels of oil (10 yr US supply), and 330 tcf gas (14 yr US supply), hardly enough to justify going back to the old ways of wasteful use. Even the much vaunted Canadian oil sands are not going to make much of a difference. At a projected 3.6 million barrels per day by 2030 (EIA 2007), this would only amount to about 3% of anticipated world demand.

Further facts and figures on these and other energy-related issues will be provided in an upcoming paper in this series by D. Hughes.

According to Scott Tinker (in a presentation to the American Association of Petroleum Geologists in 2006), some 65% of the world's remaining petroleum reserves are under the control of national oil companies and not open to western development. Most of these countries have monopolistic oil development practices and have terrible track records of exploration and production. In many cases, they do not reinvest in facility upgrading or in hydrocarbon exploration to the extent practised by the major international companies, but divert earnings to domestic needs. Another 16% of global reserves are controlled by Russia, which is using petroleum as a strategic lever in international affairs.

Real political leadership would address these issues head-on by emphasizing the seriousness of the energy situation, for example by discussing the Peak Oil problem. How imminent is 'the Peak'? If the rest of the world's sedimentary basins were explored and developed as thoroughly and efficiently as those in the US, would we be talking about oil prices today? Will oil nationalization in the third world actually preserve oil for the future by virtue of incompetent management? Or will poor production practices damage the remaining potential?

The Drowning/Stranded Polar Bear

Photographs of polar bears swimming between ice floes, or perched, apparently forlornly, on a melting iceberg, are often used to make a point about global warming in the Arctic. We are led to think that the bears could not survive a warm, ice-free Arctic. They could even drown – ignoring the fact that polar bears are superb swimmers. Polar bears evolved as a variant of the brown bear about 200 000 years ago ([http://www.geol.umd.edu/~candela/pbevol.html]). They presumably survived the last major interglacial, some 120 000 years ago, and the Holocene Hypsithermal, when the Arctic may have been ice free. Habitat reduction resulting from warming climate and reduction of ice cover in the Arctic is now threatening bear populations (Stirling and Parkinson 2006), but it is competition with the human inhabitants for resources, killing of bears because they injure humans, and health threats related to pollution, that constitute the more immediate threat to the bear population (Ian Stirling, Canadian Wildlife Service, personal communication 2007).

As these six examples illustrate, simplifications can help opinion leaders to make a point. But there are hazards to this approach, as well as benefits. Pointing out the complexities may take spokespersons 'off message' when trying to argue a simple point, but not doing so insults the intelligence of the general public, whose ability and willingness to understand important scientific arguments is all too easily underestimated.

The lack of public understanding of the geological limits to oil and gas potential was summed up by this headline in the Business Section of the Globe and Mail on 5th September, 2008, after the beginning of the current economic crisis sent the world oil price into a tailspin: "Is 10 weeks long enough to solve the energy crisis?" An authoritative source was said to blame the price collapse on 'oversupply'. The rest of the article was all about the 'business cycle', with not a word about

King Hubbert, about the age and potential depletion of Middle East supergiant fields (Simmons 2002), or about the world running out of new places to look for hydrocarbons.

OBJECTIVES OF THIS SERIES

Climate Change

Given the issues outlined earlier in this paper, it became clear to the Gussow–Nuna organizing committee that the most valuable contribution that this conference and series could make would be to focus on the climate science itself, and not opinion, by bringing together many of the key players who have contributed to the climate change debate through their research and peer-reviewed publications in leading science journals. Although there has been a great deal of scientific research on natural and anthropogenic causes of recent climate change, much of this research is poorly known outside the climate-science community; hence, one of the aims of this series is to close this knowledge gap.

Furthermore, given the concerns expressed by earth scientists about the omission of paleoclimate data from models of climate change, the key question that we hoped to address is: *"What natural processes have been influencing climate change over the recent (post-glacial) past, and how much of the currently ongoing climate change do they explain?"* The study of past climates is the domain of the earth sciences, and therefore entirely within the sphere of influence that the CSPG and GAC envisioned in establishing the Gussow and Nuna conferences, respectively. At this point, the most convincing simple indication of anthropogenic influence is the rate of change; indications are that global average temperature is increasing at a rate faster than that documented at any previous period in earth history, with higher CO_2 atmospheric content than at any time over the last 800 000 years.

Implications for Natural Resources

Hydrocarbons are heavily implicated in the greenhouse gas phenomenon. There are also increasing concerns about depletion (Simmons 2002; Hughes 2004; Deffayes 2005), the likely impending end of cheap oil and gas, and an increasing need to rely on coal and oil sands, which, by their nature, are associated with significantly greater atmospheric and other forms of pollution. These concerns were brought into sharp focus recently by the rapid rise in the price of gasoline at the pump.

Some might argue that the twin problems of global warming and hydrocarbon depletion should be left alone because eventually the outcome of one will solve the other. Specifically,

- civilization will be so disrupted by global warming that the developed world will go into industrial decline and energy consumption will collapse; or,
- catastrophic collapse of the energy market due to shortages, rising prices, and competition for remaining supplies will lead to a decline in the industrial world and a sharp reduction in the output of greenhouse gases.

In addition to the problem of energy sustainability, there are some serious environmental issues that must be addressed, notably the problem of water supply and pollution associated with oil sands extraction, and the atmospheric pollution associated with the use of coal. These issues will be discussed in later contributions to this series. Alternative sources of energy that do not directly involve the earth sciences, were not addressed at the Gussow– Nuna conference, and will not be discussed in this series (see Monbiot 2006; Jaccard 2006). These sources, and some of the contentious issues associated with them, include:

- Nuclear power (power-plant design, safety, and waste disposal). Although there are technically feasible solutions to the waste disposal issue, this is a problem of societal acceptance, including the well-known NIMBY response.
- Hydroelectricity (watershed disruption and First Nations land issues).
- Wind and solar power (engineering and technology, societal issues regarding the placement of wind farms, and the scale problem – it requires hundreds of wind turbines to provide the energy yielded by one nuclear or coal-fired power plant).
- Biofuels (the true life-cycle costs and greenhouse gas emissions associated with biofuel production; competition with food producers over land and resources).

Much imaginative research is underway to explore the feasibility of bioengineering of biofuels, new materials and equipment for solar power, energy from ocean waves and tidal power, geothermal energy, etc. (Krupp and Horn 2008) and these may ultimately reduce our dependence on fossil fuels.

HOW CAN WE MAKE PROGRESS?

Generally, the North American public is ahead of its governments in urging the adoption of solutions to energy and climate-change issues. There is substantial popular support for measures such as the Kyoto Protocol to reduce greenhouse gas emissions, yet this support is generic rather than specific, as witnessed by the outrage that greets a rise in the retail price of gasoline, proposals to impose tolls on public roads to help pay for transit improvements, or plans for a carbon tax. Governments acknowledge the evidence for climate change, yet continue to provide tax support for the oil industry, and have been extremely slow to make the necessary investments in urban transit and other infrastructure. Metrolinx (the Greater Toronto Transportation Authority, or GTTA) is the public authority that manages transportation planning (including public transit) in the Toronto–Hamilton region. In September 2008, it announced an ambitious $50 billion regional transportation plan, but shied away from making any suggestions about where the funds were to come from. Seven months later, on 1st April 2009, the Government of Ontario, announced a preliminary funding plan of $9.1 billion.

Many suggestions for energy sustainability and for changing society's uses of energy have been made (Jaccard 2006; Monbiot 2006; Simpson et al. 2007). A carbon tax is one suggestion that has received much attention. The introduction of a carbon tax in the Spring 2008 budget of the British Columbia government was intended as a first step towards potential practical solutions to the twin problems of energy depletion and greenhouse gas

emissions. As part of its platform for the 2008 federal election, Canada's federal Liberal Party proposed what it termed a 'Green Shift' plan that contained similar measures. Other government jurisdictions, notably California in the US, are trying to develop solutions but all of these initiatives have generated controversy. The poor performance of the Liberal Party and the Green Party during the recent federal election in Canada suggests that environmental issues are not of leading importance in the minds of Canadian voters (this election took place before the stock market collapse, and the lack of prominence of the environment as an election issue cannot entirely be blamed on this factor).

Some forward-thinking energy companies are leading the way in introducing new 'green' ideas. For example:

- an open letter was sent to the Government of Alberta by several large energy corporations in February 2008 suggesting a moratorium on further land sales until some major environmental issues have been addressed [www.cbc.ca/canada/calgary/story/2008/02/25/oilsands-moratorium.html]; and
- a change in strategy by some oil companies to a 'beyond-petroleum' perspective is underway, and investments are being made in R&D that focuses on alternative energy sources. Some petroleum companies are redefining themselves as 'energy' companies, and diversifying their investments in energy sources.

The problems of depleting reserves, rising oil and gas prices, and environmental pollution are issues that the earth sciences are centrally placed to help resolve. Who knows best not only where the remaining oil and gas reserves are to be found but where to store the CO_2 that results from their use? Who knows the most about groundwater resources and the consequences of aquifer pollution? Who knows the most about nuclear fuel resources and where to safely store nuclear waste? Earth scientists have the most comprehensive scientific expertise and skill sets to understand the nature and extent of Earth's natural fossil fuel resources, the unintended consequences of their use, and the best practices for disposal of the resulting waste products.

A call for action and involvement by the earth-science community was made in an earlier review of climate change in this journal (Piper 2006) but, as Miall and Miall (2008) have documented, this community has not, in fact, been very active in adding its voice to the debate. A plea for earth scientists to embrace Earth System Science and take a greater degree of 'ownership' of global change issues (Piper 2006, p. 54) has likewise been largely ignored. An attempt by the senior author to raise the issue at the University of Toronto (Miall 2006) must be classed as a dismal failure.

It should be noted that many of the widely respected individuals who speak authoritatively on climate change and environmental remediation are not, in fact, climate scientists and have published no relevant peer-reviewed articles on climate science (the irony of which seems lost on those who berate the 'sceptics' for their lack of peer-reviewed publications in the field). These include Nicholas Stern, an economist, Al Gore, a politician, Sir David King, a chemist, Sir Crispin Tickell, a former diplomat trained as an historian, and, in Canada, David Suzuki, a journalist who was once a geneticist, Stéphane Dion, a political scientist, and Elizabeth May, a lawyer, who is now also a politician. There is still room for our collective voice!

CONCLUSIONS

The Gussow–Nuna conference and this series in *Geoscience Canada* were organized in the hope that, through the dissemination of the best science, and the discussions that flow from it, earth scientists would be better situated to provide the kind of specialized knowledge and informed judgment needed to address the social problems facing us today.

We conclude with some big questions:

- Will the economy always trump the environment?
- Can we avoid a global conflict over oil?
- Can we design an economy that is not based on the automobile?
- Can we convince the consumer, developers, and our political leadership to design better cities to make more efficient use of natural resources?

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