Environment Canada / Environnement Canada

CO_2 / CLIMATE REPORT

A Periodical Newsletter Devoted to the Review of Climate Change Research

This issue of the CO_2/Climate Report is devoted to three brief assessments of a number of recently published scientific reports and articles that have attracted considerable attention within the climate change science and policy communities.

The first article provides an assessment of two reports on the science and policy options with respect to carbon sinks. These reports have considerable relevance to the current international discussion of the use of forest and agricultural soil management as a means of sequestering additional atmospheric carbon dioxide within the terrestrial biosphere, thus potentially contributing a partial offset to anthropogenic emissions of greenhouse gases. While these reports do not address all of the related scientific questions involved (particularly some of those that arose during the negotiations at the CoP6 meeting in the Hague), they do provide a good perspective of how complex the issue is.

The second assessment presents a synthesis of the new future 'business-as-usual' emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for use in international discussions about the risks of climate change. These scenarios have replaced earlier scenarios that have been the basis for many climate model projections of future climate change. Thus it is important to understand how the use of the new scenarios might affect such projections.

Finally, the third assessment examines the scientific arguments used by a team of experts at the NASA Goddard Institute for Space Studies last summer when they released an assessment of the relative roles of various greenhouse gases and aerosol emissions in past and future climate change, and related implications for mitigative policies. The assessment looks both at how these arguments have been misinterpreted by some media reports, and at how they compare with the perspectives presented in the broader international scientific literature.

Winter 2001 Issue

Inside....

Carbon Sinks - Counting the Molecules Sequestered into Trees and Soils

The Kyoto Protocol commits Annex I countries, including Canada, to reducing greenhouse gas emissions by an average of approximately 5% below 1990 emissions levels by years 2008 to 2012. However, the Kyoto agreement also commits countries to include within their national greenhouse gas inventories those sources (that is, emissions into the atmosphere) and sinks (removals from the atmosphere) associated with afforestation, reforestation, deforestation and any other land use change activities agreed upon by the Parties to the Protocol.

While the inclusion of forest and other biological sinks in meeting emission reduction commitments may provide some countries with important options for reducing the costs of meeting Kyoto commitments, there are a number of important hurdles to be addressed before the methodologies for quantifying and reporting such sinks can be accepted and properly implemented. Several recent reports have provided insights into what these hurdles are and how they might be addressed.

The IPCC Special Report on Land Use, Land Use Change, and Forestry (LULUCF). This IPCC report provides an in depth analysis of the science relevant to the discussion of sources and sinks of carbon from forest and soil management within the context of the Kyoto

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Protocol. It notes that land use change over the past several centuries has already contributed significantly to a change in atmospheric concentrations of carbon dioxide. While fossil fuel combustion since 1850 has collectively emitted an estimated 270 billion tonnes of carbon (GtC) into the atmosphere as carbon dioxide, deforestation activities have added another 50% or so. Since, over the same period of time, the atmosphere has only increased its net carbon pool by an estimated 176 GtC, about 2/3 of the accumulated emissions must have been removed by oceans and the terrestrial biosphere. During the most recent decade, annual emissions from human activities have increased to an estimated 7.9 GtC/year, while atmospheric concentrations have been rising at 3.3 GtC/year. Hence, currently about 58% of the excess carbon released into the atmosphere by humans is being removed again by ocean and terrestrial systems. Oceanographers estimate that the ocean sink is in the order of 2 GtC/year, implying a land sink of the same order of magnitude. These results demonstrate that land use change activities are already an important factor in the release (through deforestation) and removal (through forest regrowth) of atmospheric carbon dioxide.

Deliberate human policies to increase this land sink can make an important contribution to slowing down the rate of growth in atmospheric CO_2 concentrations. The LULUCF report estimates, for example, that a concerted global effort at increasing carbon stocks on some 12 billion ha of land could potentially remove in the order of an additional 1 GtC/year from the atmosphere by 2010. Of this, less than 0.3 GtC would be attributable to Annex I countries.

The report also examines some of the major hurdles to be addressed in order to ensure that accounting procedures adopted by the international community for land use and land use change activities under the Kyoto Protocol will be transparent, verifiable and an accurate representation of the real changes they generate in the atmospheric concentrations of carbon dioxide and other greenhouse gases.

The first hurdle is that of definitions. Countries around the world use a broad range of definitions of a forest, some based on land use criteria, others on canopy cover or carbon density thresholds, and still others based on cultural or other legal or institutional definitions. Inappropriate definitions for the purposes of the Kyoto Protocol could result in considerable carbon leakage, where reported carbon sinks may be well in excess of that actually realized or, conversely, may significantly under-estimate the actual sinks. Likewise, various definitions are possible for what the terms deforestation, reforestation and afforestation mean. Broad definitions of such activities would result in confusion between what is natural and what is human, while narrow definitions can provide significant accounting challenges to avoid double counting or other concerns. Likewise, the term ‘carbon pool’ can be defined as above ground biomass only, or as combinations of carbon content in above ground, below ground, soils, litter and other components of a forest ecosystem.

A second major hurdle is the development of an accounting protocol that would be both accurate and sufficiently simple to implement. There are two fundamental approaches to accounting. One is a land based method which measures the net change in carbon stock in applicable carbon pools between two reporting periods on lands where Kyoto related land use change activities are undertaken. However, it would be difficult under this method to determine what part of the change in carbon stock is directly attributable to the land use change activities versus that due to natural processes or due to indirect effects of human activities such as CO_2 fertilization and climate change. The other approach is an activity based method, which considers only the direct effect of each activity on the carbon stock for all the land areas where that activity is undertaken, and sums up all the changes activity by activity. The concern here may be that land areas where multiple activities occur would be counted more than once, and the effects of such activities may not be additive. In both cases, changes in sources and sinks of other non-CO_2 greenhouse gases caused by these activities would also need to be included in the accounting. Furthermore, considerations would need to be made to avoid accounting leakage (where the activities included in the accounting method generate other offsetting activities elsewhere). The accounting methods would also need to address the issue of the permanence of the carbon stock change. For example, some types of activities such as minimum till to enhance soil carbon sequestration would need to be maintained indefinitely to retain the stored carbon. Likewise, natural disturbances such as wild fire and insect infestations could reverse the accumulation of carbon stocks in forests achieved by the Kyoto-related land use activities.

Proper design of the measurement and monitoring protocols for accounting is also a challenge. These will need to combine the use of direct measurements with indirect estimations based on remote sensing and models. Accuracy and verifiability of the reported changes in carbon stock will need to be traded off against the cost of achieving such measurements. Spatial resolution will be an important factor. For example, coarse resolution measurements may lose much of the small scale change in stock due to small patches of land clearing in the averaging process, while high resolution monitoring and measurement can be excessively costly.

Sinks Table Options Report: The second document that is particularly relevant to the question of Kyoto related land use and land use change activities in Canada is the 1999 report of the Sinks Table, established under the country’s National Post-Kyoto Climate Change Implementation Process. The Sinks Table recognized that there were still many questions remaining about how sinks will be defined under the Kyoto Protocol and the modalities, rules and guidelines that will be adopted for reporting such sinks. However, it undertook a thorough assessment of the scientific and policy issues involved, partly to ensure that Canada would have adequate expertise on the subject to participate effectively in future international negotiations to develop such definitions and guidelines. Following are some of the key conclusions that emerged out of that assessment:

- There is a large potential for **afforestation** in Canada, both as block plantations on private land and as shelter belts in the Prairies. Most trees, however, accumulate very little carbon during their first decade of growth. Hence much of the benefit of afforestation programs initiated within the next decade in terms of carbon sinks would be realized beyond the first Kyoto reporting period of 2008-2012. The greatest potential in the near term would be for fast growing species. For example, a concerted effort to plant fast growing tree species on 50,000 ha of unforested land between 2001-2005 could generate a sink of about 1.3 Mt of atmospheric CO_2 by 2010. By comparison, similar plantations of some 800,000 ha of native species between 2001 and 2015 would accumulate only 0.8 Mt CO_2 by 2010 However, for long term sinks to 2050, the native species would accumulate an average of about 4 Mt of CO_2 per year, while the short lived fast growing species would quickly mature and slow down as a sink.

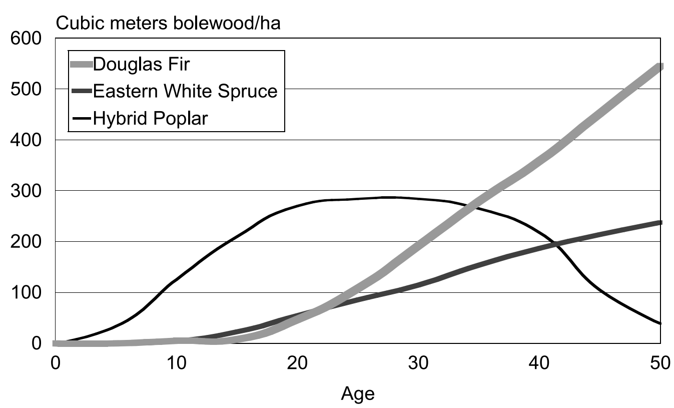

Figure 1: *Growth curves for several Canadian tree species. Fast growing hybrid poplars can accumulate significant amounts of carbon within the first decade of growth, but growth rates peak after 30 years and then begin to decline rapidly. By comparison, douglas firs and white spruce trees grow slowly in the first few decades but can later become large carbon sinks.*

- Currently, 50% of Canada's harvested forest lands are allowed to **reforest** naturally, 5% are restored through seeding and the remaining 45% is replanted. Replanted forest stands generally reach maturity at least a decade sooner than those naturally regenerated. Species selection and density management can also enhance carbon storage. However, the extent to which such actions can be included in national greenhouse gas inventories will depend on the final definitions and accounting practices adopted under the Kyoto agreement.
- Other **forest management practices** such as thinning, fertilization, fire suppression and pest protection can also contribute to enhanced carbon storage in Canadian forests. However, accumulated sinks would be difficult to calculate and verify, since the impact of such practices would vary with the location and species of trees involved. It is unlikely that such activities will be considered individually under the Kyoto Protocol. On the other hand, the concept of a managed forest approach involving full accounting of changes in carbon stock within the managed area is consistent with the FCCC objective of protection and enhancement of carbon sinks and reservoirs and hence may have future possibilities within the Kyoto context.
- A variety of activities contribute to the conversion of Canadian forest lands to other uses, and hence to **deforestation**. For example, between 10,000 to 30,000 ha of land are converted to agricultural lands each year, another estimated 10,000 ha/year are lost to flooding for electricity generation, in excess of 20,000 ha/year to forestry harvesting activities, and additional thousands due to expanding urban centers, transportation corridors, mining activities, etc. The estimated total loss of forest lands per year is estimated at between 55 and 80 thousand hectares. The related carbon loss from the above ground biomass alone, if converted entirely to carbon dioxide, would release about 9-14 Mt of CO_2 annually into the atmosphere. Emissions due to deforestation are already included in the Kyoto Protocol, although definitions and methodologies for calculating the emissions still need to be negotiated.
- Canadian agricultural soils represent a large carbon reservoir that can be substantially enhanced through cropland conservation practices, improved pasture management and conversion of marginal croplands to grasslands. Current trends towards improvement of soil management is already expected to change the flux of carbon from Canadian agricultural lands from a net source estimated at 1.6 million tonnes (Mt) per year in 1996 to a net sink of 1.6 Mt per year by 2010. Through an enhanced management program, this can potentially increase to about 24 Mt per year. However, because of lack of confidence in reporting methods and doubt about the ability to verify changes in soil carbon, this has not as yet been included within the Kyoto agreement on sinks.
- In general, Canadian wetlands are an important sink for CO_2 and a source of methane. Hence changes in wetland conditions due to direct human interference will also affect net flux of greenhouse gases between them and the atmosphere. Although wetlands are not directly included in the Kyoto Protocol, many wetlands are an inherent part of agricultural and boreal forest landscapes, and hence any activities seeking to enhance sinks in agricultural soils and in forests must also

consider the related effects on greenhouse gas fluxes from the wetlands within and adjacent to the areas impacted.

- Finally, to ensure that reporting on net impacts of activities pursued under the Kyoto Protocol is credible and verifiable, and that effective sinks activities that are not as yet included in the provisions of the Protocol can be properly considered in the future, Canada will need to invest significantly into enhanced research and information gathering.

IPCC Special Report on Emissions Scenarios (SRES)

Emissions scenarios are an important component of climate change assessments as climate models require future emissions as a basic input. Scenarios are images of the future, or alternative futures. Thus, emissions scenarios provide projections for a plausible range of future greenhouse gas emissions. To develop scenarios of possible futures, many assumptions are made on future world conditions, especially the three main driving forces: population, economic development and structural or technological change (for example, energy efficiency).

The IS92 scenarios were developed by the IPCC in the early 1990s to illustrate a plausible range of future greenhouse gas emissions. At the high end of the range is IS92e which combines moderate population growth, high economic growth, high fossil fuel availability and eventual phase-out of nuclear power. At the low end is IS92c, with CO_2 emissions in 2100 below those in 1990 due to declining population growth, low economic growth and severe constraints on fossil fuel supplies. In the middle of the pack is IS92a combining moderate population and economic growth, with high availability of fossil fuels balanced by reduced solar energy costs. IS92a has been widely used in climate modelling experiments as the standard "business as usual" scenario. Some recent transient models also use a 1%/year CO_2 emission increase, which is similar to the IS92a scenario. Despite their widespread use, the IS92 scenarios have limitations. Although many studies use the IS92a scenario as an intermediate or reference scenario, it is not necessarily the most likely scenario. In addition, IS92a is only central for certain characteristics, but is lacking in other areas, especially with regard to regional emissions. Other weaknesses of the IS92 suite include: a limited range of CO_2 emissions per unit of energy; the absence of any scenario with significant closure in the income gap between developed and developing countries; and a lack of recognition of future legislation limiting sulphur emissions due to air quality concerns.

The Special Report on Emissions Scenarios (SRES) was undertaken by the IPCC after a 1995 evaluation recommended that significant changes (since the IS92 series were developed) in the understanding of driving forces of emissions and methodologies be addressed. The SRES scenarios reflect the most recent trends in driving forces of emissions: population projections, economic development, and structural and technological change. The process began with a literature review and the development of a database of over 400 global and regional scenarios; 190 of these extend from 1900 to 2100 and thus fed into the development of the narrative scenarios and storylines. The SRES scenarios cover most of the range of global energy related greenhouse gas emissions from the literature, from the 95th percentile at the high end of the distribution down to low emissions just above the 5th percentile. Thus, only the most extreme emissions scenarios found in the literature were excluded. Based on the literature review, the writing team developed a set of four alternative scenario "families", having a total of 40 emission scenarios. Each scenario family includes a narrative storyline which describes a demographic, social, economic, technological, environmental and policy future. The writing team agreed that there could be no "best guess" scenario and thus 4 scenario families were chosen in order to avoid the impression that there is a central or most likely case. See Figure 2 for a schematic representation of the SRES scenarios and their driving forces.

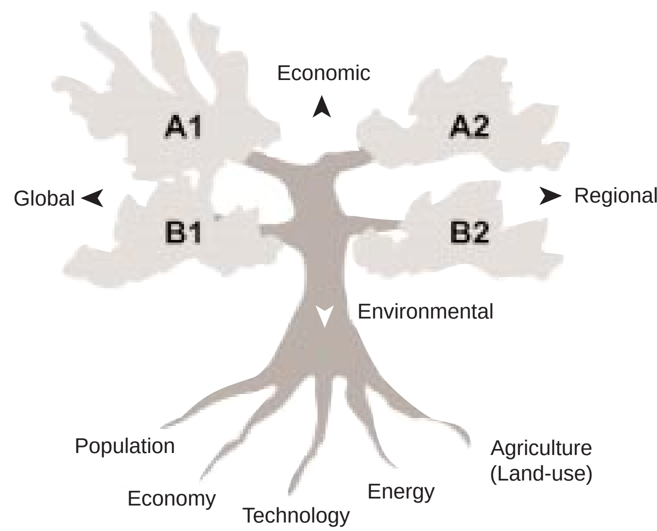

Figure 2: *Schematic illustration of SRES scenarios. (Source: Adapted from The IPCC Special Report on Emissions Scenarios).*

The Scenarios: The Special Report on Emissions Scenarios concluded that, within the four scenario families, there are 6 scenario groups (A1F1, A1T, A1B, A2, B1, B2) that should be considered equally sound, spanning a wide range of uncertainty. Four of these are designated as marker scenarios, characteristic of the 4 scenario families. Two more illustrative scenarios were selected from the A1 family. Together, they capture most of the emissions and driving forces spanned by the full set of scenarios. The six scenarios have the following characteristics:

- The A1 family is based on very rapid economic growth, low population growth and the rapid introduction of new and more efficient technologies. A1B is balanced in the sense that it does not rely too heavily on a single energy source. A1F1 assumes fossil-intensive technologies, while A1T assumes a non-fossil future.
- The A2 scenario describes a very heterogeneous world with high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are fragmented and slow.
- The B1 scenario describes a convergent world. It has the same low population growth as A1 with a rapid change in economic structures toward a service and information economy. Other characteristics include a reduction in material intensity, clean and efficient technologies and improved equity.
- The B2 scenario emphasizes local solutions to economic, social and environmental sustainability. There is moderate population growth and intermediate levels of economic development. Technological change is less rapid and more diverse than in A1 and B1 scenarios.

Comparison between IS92 and SRES: A comparison of the new SRES scenarios with the IS92 scenarios shows that despite some differences, the new scenarios are not radically different. The SRES scenarios cover a wider range of energy structures than the IS92 scenarios, to reflect uncertainties about future fossil resources and technological change. The range of CO_2 emissions for both sets of scenarios is similar (see Figure 1). The full 40 SRES scenarios extend the upper limit of cumulative emissions from IS92 but not towards lower emissions. This is especially evident in 2050, although by 2100 the high end of both series are similar. There are a few differences in the driving forces in SRES compared to IS92:

- global population projections are generally lower;
- all scenarios describe a more affluent society (gross world product is 10-26 times higher than today); and
- SRES scenarios cover a wider range of energy structures – from high fossil fuel to high non-fossil fuels.

Both methane and nitrous oxide emissions span wider ranges by 2100, 250-1000 $MtCH_4$/yr and 5-20 MtN/yr, respectively. Factors other than climate change, such as regional and local air quality, intervene to limit future emissions of sulphur in all SRES scenarios. Scenarios published since IS92 generally assume various degrees of sulphur controls to be implemented in the future, and therefore have projections substantially lower than previous ones. Even the highest range of sulphur emissions in the SRES scenarios (range of 20-60 MtS) is substantially lower than in the IS92a scenario (~170 MtS).

The implication of lower sulphur emissions is that the historically important, albeit uncertain, negative radiative forcing of sulphate aerosols may decline in the long run. In terms of radiative forcing, the combined effect of lower CO_2 emissions in the median scenario and lower sulphur emissions may be quite similar to current model projections using IS92a scenarios.

A comparison of the marker scenarios with IS92 scenarios (see Figure 2) shows that the median and average of the SRES scenarios lead to about a threefold emissions increase over 1990 levels or to about 16GtC/year by 2100. This is lower than the median of the IS92 set and is also lower than the IS92a scenario.

A number of current climate modelling efforts have chosen the A2 and B2 scenarios for initial experiments. CO_2 emissions in the A2 scenario are higher than IS92a, while CO_2 emissions in B2 are lower.

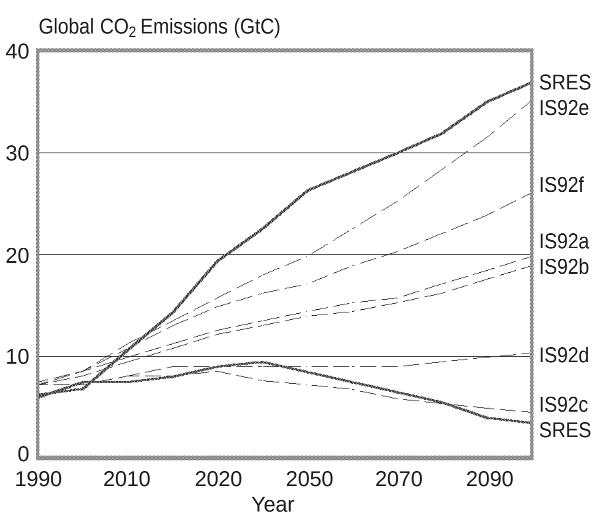

Figure 3: A comparison of the IS92 scenarios with respect to the full range of new SRES scenarios. Note: IS92a has been most commonly used in climate model experiments.

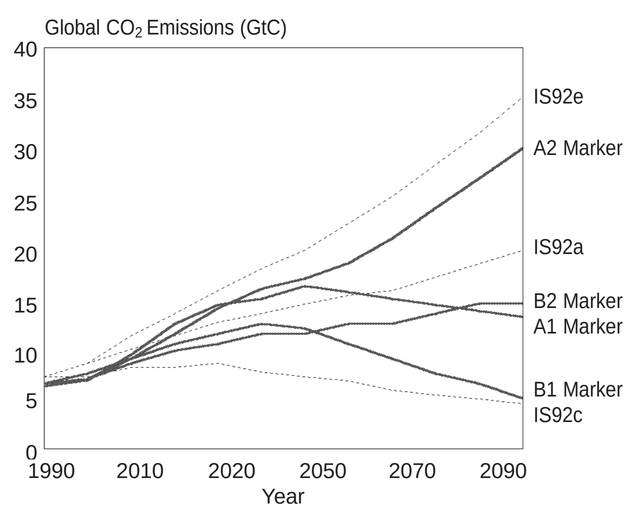

***Figure 4:** A comparison of the IS92 series and the new SRES emission scenarios.*

The new SRES scenarios are an improvement over the IS92 scenarios as they reflect a wider range of future emissions paths and are comprehensive in scope. One main conclusion of the recent scenario modelling effort is that alternative combinations of main scenario driving forces can lead to similar levels of GHG emissions by the end of the 21st century. Scenarios with different underlying assumptions can result in very similar climate change. In addition, technology was found to be at least as important a driving force of GHG emissions as population and economic development. Generally, the SRES scenarios, in comparison with the IS92 scenarios, increase the upper limit of CO_2 emissions and significantly reduce sulphur emissions.

The SRES report is available on the web at: www.ipcc.ch.

Debate About Anthropogenic Radiative Forcing

In mid August 2000, James Hansen and colleagues at the NASA Goddard Institute for Space Studies (GISS) published a paper entitled "Global Warming in the 21st Century: An Alternative Scenario" in the Proceedings of the National Academy of Science. They concurrently placed a similar but less technical note bearing the same title on the GISS website. These papers attracted considerable media attention at the time. However, a number of media articles suggested quite incorrectly that Hansen had recanted his earlier concerns about climate change. Others implied that Hansen no longer considered fossil fuel combustion as a primary concern in international efforts to reduce the risks of climate change over the next few decades, but believed that such risk reduction could be best met through the reduction of non-CO_2 greenhouse gases. Some have even argued that the papers provide further evidence that the ratification and implementation of the Kyoto protocol is inappropriate. Despite various rebuttals that attempted to clarify what Hansen and his colleagues did and did not say, there continues to be confusion and debate about their conclusions. The following analysis provides an assessment of the key points presented by Hansen *et al*. in their papers, how these compare with the general understanding of the international science community, and what the real policy implications are.

Past Anthropogenic Forcing of the Climate System: Hansen *et al.* note that the risk of dangerous climate change is real, and that there is good evidence that past emissions of greenhouse gases have already contributed to global climate change. Thus they clearly did not 'recant' their past concerns about climate change. They note, for example, that there is growing consensus that that the warming during the past few decades is at least in part a consequence of increasing anthropogenic greenhouse gases, and provide supporting evidence from estimates of changes in radiative forcings compared to that from other causes of climate change. They also note that the heat content in the oceans has increased since the mid-1950s by an amount consistent with estimated effects of past increases in radiative forcing due to human activities. Hence, there is abundant empirical evidence that estimates for radiative forcing and model projections appear to be in the right ball park. Finally, they conclude that projections of future climate change due to greenhouse gas and aerosol emissions imply that up to thirty 'Kyotos' may be needed to reduce warming to an acceptable level. These conclusions are generally consistent with interpretation of the evidence by the international expert community.

Hansen *et al*. calculate a total net climate forcing between 1850 and 2000 from all human causes of about 1.6 W/m^2. However, they argue that this is primarily due to increased concentrations of non-CO_2 greenhouse gases. By comparison, they suggest that the net forcing due to fossil fuel combustion is relatively modest, since the forcing caused by CO_2 emissions from this source (about 1.4 W/m^2) is largely offset by an equal but opposite forcing of -1.4 W/m^2 by aerosols emitted by the same combustion processes. They assume that aerosols are primarily generated by the combustion of fossil fuels.

Latest estimates from other international studies published in various peer reviewed journal articles (and summarized in the IPCC Third Assessment Report) suggest historical radiative forcing of similar magnitude to those estimated by Hansen for carbon dioxide (at 1.46 W/m^2) and for aerosols (estimated at between almost zero and -3 W/m^2 , with a mid range estimate of about -1.4 W/m^2), but lower than Hansen for non-CO_2 greenhouse gases (1.2 W/m^2). These studies also suggest that about 50% of the aerosol forcing is caused by aerosols produced from non-fossil fuel combustion (i.e., biomass burning and mineral dust). Hence, the mid range estimate for sulphate aerosol effects from fossil fuel combustion would be closer to about -0.7 W/m^2, resulting in a combined forcing from fossil fuel emissions (CO_2 + sulphate aerosols) of about 0.7 W/m^2. That for non-fossil fuel combustion processes, which includes the other half of the aerosol effect, would only be about 0.5 W/m^2. Thus other experts do not agree that fossil fuel combustion played a secondary role in past radiative forcing changes.

Hansen *et al.* further note that the rate in growth of atmospheric CO_2 concentrations has slowed down in recent decades, despite continued growth in emissions. This, they suggest, implies that future growth rates may be weaker than some business as usual concentration scenarios suggest. If so, efforts to control CO_2 growth would be easier that many assume. The slower growth appears to be due to larger uptake of emitted CO_2 into the oceans and terrestrial biosphere, not due to lower than expected human emissions. However, they acknowledge that this enhanced sink may be temporary (recent

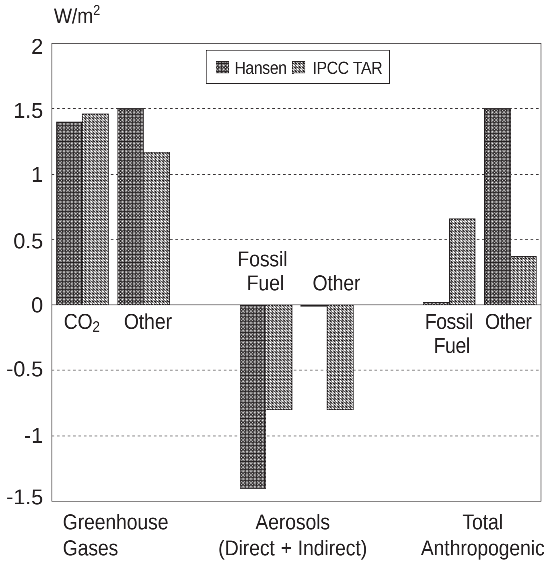

Figure 5: *Comparison of estimates of past anthropogenic radiative forcing from fossil fuel combustion and other sources as presented by Hansen et al. and the IPCC in its Third Assessment Report. Aerosol forcing includes an estimate for indirect effects assumed to be proportional to the direct effects regardless of source. The magnitudes of estimates for total forcing by greenhouse gas only and aerosols only are very similar. The large differences for net forcing are related primarily to the assumption by Hansen et al. that aerosol effects are primarily related to fossil fuel combustion only. By comparison, IPCC estimates that one-half of the direct aerosol effects come from other sources.*

growth rates have, in fact, been increasing again) and that, in order to maintain a continued slow growth rate for CO_2 concentrations, a growth rate of fossil fuel emissions lower than that projected for business as usual would almost certainly be required. By comparison, other recent studies that have included many of the complex and variable feedbacks that affect the global rate of CO_2 uptake from the atmosphere (for example, the effects of El Niños, and volcanoes, ocean circulation changes, CO_2 and nitrogen fertilization effects and temperature changes) in carbon budget models continue to project a range of business as usual CO_2 concentrations by 2100 of between almost a doubling of pre-industrial CO_2 levels, and a possible tripling. Thus, while the business as usual (BAU) CO_2 growth scenario proposed by Hansen *et al.* is within the range of the new SRES estimates proposed by IPCC experts, it is in the lower end of that range and appears to be overly optimistic. A significantly more pessimistic scenario may be equally probable.

Estimated Current and Future BAU Radiative Forcing: Hansen *et al.* argue that current and future combustion of fossil fuels (the primary source of CO_2 emissions) under business as usual scenarios do not and will not have the same offsetting aerosol emissions that they have had in the past. This is primarily because local air pollution concerns have and will continue to generate controls on emissions of aerosols from fossil fuel combustion. Hence the influence of fossil fuel emissions relative to other greenhouse gases is greater now than during the past, and will be even larger in future decades.

Other studies within the international scientific community have recently estimated that, under SRES scenarios B2 and A2 (at the lower and upper end of the range of the new SRES emission scenarios), CO_2 forcing will increase by about 1.4 and 3 W/m^2, respectively, beyond current levels by 2050, and by about 2.6 and 4.4 W/m^2, respectively, by 2100. By comparison, by 2100, forcing by non-CO_2 greenhouse gases is projected to increase by only 0.6 W/m^2 and 1.2 W/m^2, respectively, while that for sulphate aerosols is expected to decrease slightly from current levels. Thus these studies suggest that the role of fossil fuels, which already dominates the radiative forcing today, will increase dramatically relative to other greenhouse gases under future BAU scenarios, and that long term aerosol offsets will be negligible.

Hansen's Alternative Mitigation Scenario: The alternative mitigation scenario proposed by Hansen *et al*. promotes concentrated efforts to reduce emissions of non-CO_2 greenhouse gases (including pre-cursors of tropospheric ozone) and soot. They note that these efforts would have large co-benefits, including reduction in harmful health effects of substances such as ozone and aerosols. The reductions in non-CO_2 emissions, they suggest, would probably allow forcing due to CO_2 emissions to increase a further 1 W/m^2 by 2050 without compromising efforts to avoid dangerous climate change. While this would continue to require considerable effort to reduce CO_2 emissions as well, they argue this can be achieved with considerable less economic disruption than if all efforts were focused on CO_2 emission reductions only. In fact, during the next 25 years, cost effective energy efficiency and fuel switching programs would be sufficient to accomplish this objective, although economic and social barriers to achieve such improvements would need to be addressed. Beyond 2025, more emphasis would be needed to reduce CO_2 emissions through the increased use of renewable energy, which will require R&D investments in the interim.

Estimates based on the IPCC SRES scenarios noted above suggest that, in order to decrease radiative forcing due to CO_2 to 1 W/m^2 by 2050 (as required in the Hansen *et al*. proposal) CO_2 emissions must be reduced from BAU projections by as much as 40% for the B2 scenario, and more than 100% for the A2 case. Hence even Hansen *et al.'s* optimistic scenario would require a reduction of fossil fuel CO_2 emissions far beyond that committed to under Kyoto. Furthermore, with the exception of ozone and aerosols, the other greenhouse gases discussed in the Hansen *et al*. scenario are already included under the Kyoto Protocol.

The Kyoto Protocol agreement did not include ozone and soot because of the difficulty in relating the effect of measures to reduce emissions to real changes in local concentrations of these short-lived and hence inhomogenous substances. Furthermore, the contribution of these substances to future forcing is not large. The measures for ozone and soot reduction proposed by Hansen *et al.*, for example, are estimated to only reduce global warming by 0.1 W/m^2 and 0.5 W/m^2, respectively, by 2050. Furthermore, these estimates appear to be optimistic, given that all global soot emissions would need to be entirely eliminated to achieve the reductions noted. By comparison, the estimated range of enhanced radiative forcing for the full complement of SRES scenarios is between 1.6 and 2.5 W/m^2 by 2050.

In summary, the Hansen *et al.* emphasis on a climate change mitigation option that focuses on all greenhouse gases is consistent with IPCC recommendations for, and Kyoto Protocol acceptance of, national mitigation portfolios that include a basket of six greenhouse gases and that are unique to each country's social and economic circumstances. A key feature of the Hansen approach is a focus on air pollution, especially tropospheric ozone precursors (NO_x and VOCs) and aerosols. Independent of whether one accepts Hansen's scientific raionale, this approach, if pursued in an integrated fashion, is broadly consistent with government plans for climate change mitigation and for clean air in most Annex I countries, including those in Canada. Furthermore, despite the use of an optimistic Business as Usual scenario, the approach proposed by Hansen *et al.* requires substantial efforts to reduce CO_2 emissions during the next 50 years that go far beyond the Kyoto requirements, and necessitate much more drastic reductions beyond 2050.

The above assessments were prepared by Patti Edwards and Henry Hengeveld, both with the Science Assessment and Integration Branch of the Meteorological Service of Canada.