(Press Release from the Danish Center for Earth System Science)

Avoiding the Hothouse and the Icehouse

From an Earth history perspective, we are living in cold times. The greatest climate challenge mankind has faced has been surviving ice ages that have dominated climate during the past million years. Therefore it is not surprising that back in the relatively cold 1970's prominent scientists like Soviet Union climatologist Mikhail Budyko greeted man-made global warming from CO_2 emissions as a way to keep us out of future ice ages. And there are still those around who feel that continued high fossil fuel emissions are good for this reason. But is the extreme global warming that would result from this a reasonable, and indeed necessary, price to pay to keep ice ages at bay? In a paper published on-line on February 11 in the scientific journal **Geophysical Research Letters** ('Long time management of fossil fuels to limit global warming and avoid ice age onsets'), Professor Gary Shaffer of the Niels Bohr Institute, University of Copenhagen, and also leader of the research team at the Danish Center for Earth System Science (DCESS), outlines a way to keep the Earth out of both Hot- and Icehouses for a half a million years into the future.

Ice ages start when conditions at high northern latitudes allow winter snowfall to persist over the summer for enough years to accumulate and build ice sheets. Such conditions depend mainly on summer solar radiation there and atmospheric CO_2 concentration. This radiation is modulated on time scales of 20000, 40000 and 100000 years by changes in the Earth's orbit and orientation. Critical summer solar radiation for initiating ice sheet growth can be significantly lower for higher atmospheric CO_2 with its greenhouse warming effect.

Professor Shaffer made long projections over the next 500,000 years with the DCESS Earth System Model (www.dcess.dk) to calculate the evolution of atmospheric CO_2 for different fossil fuel emission strategies. He also used results of a coupled climate-ice sheet model for the dependency on atmospheric CO_2 of critical summer solar radiation at high northern latitudes for an ice age onset. In the projections, the start of the next ice age was posited to occur when critical summer solar radiation first coincides (with leeway for internal climate-carbon cycle variability) with summer solar radiation there, as calculated from well-known future changes in the Earth's orbit and orientation.

Professor Shaffer's results show global warming of almost 5 degrees Celsius above present for a "business as usual" scenario whereby all 5000 billion tons of fossil fuel carbon in accessible reserves are burned within the next few centuries. In this scenario the onset of next ice age was postponed to about 170,000 years from now. However, for a management scenario whereby fossil fuel use was reduced globally by 20% in 2020 and 60% in 2050 (compared to 1990 levels), maximum global warming was less than one degree Celsius above present. Similar reductions in fossil fuel use have been proposed by various countries. In this scenario, combustion pulses of large remaining fossil fuel reserves were then tailored to raise atmospheric CO_2 content high and long enough to parry forcing of ice age onsets by summer radiation minima as long as possible. In this way our present equable interglacial climate was extended for about 500,000 years, three times as long as in the "business as usual" case.

Professor Shaffer notes that "It appears to be well established that the strong ice ages the Earth has experienced over the past million years were ushered in by declining levels of atmospheric CO_2. Our present atmospheric CO_2 level of about 385 parts per million is already higher than before the transition to these ice ages" and that "The Earth's orbit is

nearly circular at present meaning that the present minimum in summer radiation at high northern latitudes is not very deep. We have already increased atmospheric CO_2 enough to keep us out of the next ice age for at least the next 55,000 years for this orbital setup". He concludes that "Fossil fuel reserves may be too valuable for regulating climate far into the future to allow the reserves to be consumed within the next few centuries. The price of extreme global warming to avoid ice ages is a high and indeed unnecessary price to pay."

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