LONG-TERM CONSEQUENCES OF CONTINUED CARBON DIOXIDE EMISSION TO THE ATMOSPHERE

K. Caldeira

Department of Global Ecology, Carnegie Institution of Washington, 260 Panama Street, Stanford, CA 94305 USA; kcaldeira@globalecology.stanford.edu

ABSTRACT

Continued emissions of carbon dioxide to the atmosphere will affect climate and ocean chemistry. These consequences can be anticipated by consideration of basic physical principles, past climates, and calculations. Emission of 5,000 PgC (= amount of carbon in conventional fossil-fuel resources) over a few centuries could produce radiative forcing of climate of about 10 W m^{-2} which could be expected to produce global mean warming of ~4 to 12 °C. Warming in this range would have large biological and human consequences. It could threaten the ice sheets and lead to a long-term sea-level rise of 70 m. Ocean *p*H could decrease by 0.7 units, making the oceans more corrosive to carbonate minerals than they have been for many millions of years. From the perspective of geology and biological evolution, these changes would occur rapidly, overwhelming most natural processes that would buffer CO_2 changes occurring over longer time intervals, and thus may produce changes at a rate and of a magnitude that exceed the adaptive capacity of at least some biological systems. To find comparable events in Earth history, we need to look back tens of millions of years to rare catastrophic events.

FOSSIL-FUEL RESOURCES AND ATMOSPHERIC CO_2

Damage from continued emission of fossil-fuel CO_2 to the atmosphere will increase with the amount of CO_2 emitted. Conventional fossil-fuel resources are estimated to be about 5,000 PgC, but methane hydrates on continental shelves might contain more than twice as much carbon [*IPCC*, 2001]. The store of reduced carbon in sediments is thought to be about 1,000,000 PgC; ultimately, it may be economically feasible to extract 40,000 PgC or more (Jae Edmond, pers. comm., 2005). Each PgC of CO_2 added to the atmosphere increases the atmospheric CO_2 concentration by nearly 0.5 ppm; 5,000 PgC added to the atmosphere would be roughly ten times the CO_2 concentration at the start of the industrial era. The land biosphere and the ocean might take up half of this carbon on the time scale on which it is emitted, producing an atmosphere that has roughly five times the CO_2 as it would have otherwise had. Use of unconventional resources could produce much higher atmospheric CO_2 concentrations.

ATMOSPHERIC CO_2 AND CLIMATE CHANGE

The CO_2 greenhouse effect is a fact needed to explain Earth's natural warmth; with no CO_2 greenhouse effect, Earth would be frozen. A variety of physical principles involving snow and ice and latent heat of evaporation suggest that warming at high latitudes would be amplified over the global mean warming, perhaps by a factor of two to three. There is little doubt that continued emission of CO_2 will produce substantial climate change, especially at high latitudes, despite uncertainty in cloud-climate feedbacks.

CLIMATE CHANGE AND THE RESPONSE OF THE LAND BIOSPHERE

Continued CO_2 emission will not lead to simple poleward march of climate bands; nevertheless, if warming were to occur at a rate of only 2 °C per century, this would equate to a poleward march of temperature bands of more than 10 meters per day. For an oak tree to replace itself in the same climate band 50 years later, its acorn would need to sprout over 200 km poleward of the parent tree, exceeding normal rates of ecological adaptation.

CARBON DIOXIDE AND THE RESPONSE OF THE MARINE BIOSPHERE

CO_2 emissions threaten coral reefs and other marine biota not only though climate effects but also through direct chemical effects. Carbon dioxide dissolves in water to form carbonic acid. Carbonic acid is corrosive to the shells and skeletal material of many marine organisms. Furthermore, oxygen and carbon dioxide transport in marine animals is largely controlled by the *p*H of body fluids. It is not known to what extent ocean chemistry changes might affect these animals, or how ecosystems will respond to the extinction of key species, or what the role of micro-evolutionary adaptation might be. We are engaging in an irreversible experiment on the resilience of the marine biosphere to chemical changes of a magnitude and at a rate that has not been experienced except during catastrophic events in Earth's geologic history [*Caldeira and Wickett*, 2003; *Zachos et al.*, 2005].

CLIMATE CHANGE AND SEA-LEVEL RISE

Continued release of fossil fuel CO_2 to the atmosphere might produce a warming that would threaten the long-term stability of Earth's major ice sheets. The Antarctic ice sheet began to form around 34 million years ago when the Earth was around 4°C warmer than today; the Antarctic ice sheets became permanent around 15 million years ago when the Earth was probably less than 3°C warmer than today [*Barrett*, 2003]. Thus, continued CO_2 emission risks a 70 m rise in sea level (perhaps at a rate averaging 1 cm per year over the next 7,000 years).

CONCLUSIONS

Basic physics and chemistry strongly suggest, and observations of ongoing changes in weather, analysis of Earth history, and sophisticated climate models provide further support, that CO_2 emissions will produce major changes in Earth's climate and ocean chemistry, and that these changes will occur at a rate that might challenge the survival of many species. To find examples of rapid changes of such magnitude, one needs to go back tens of millions of years to catastrophic events earlier in Earth's history. If nothing is done, humans are likely to suffer. It is possible that some positive feedback, like the destabilization of methane on continental shelves, could paint a more disturbing picture than that described here. Or we might be lucky, and negative stabilizing feedbacks may be stronger than they now appear to be. What we do this decade and this century will have major implications for our planet for many thousands of years and longer.

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