Forecasts of possible future climate changes are driven by forecasts from three kinds of models: greenhouse gas emissions models, atmospheric composition models, and climate models. A great deal of attention has been paid recently to the former and latter kind of model, but models of atmospheric processes have received relatively little attention of late. Danny Harvey has written a paper, Managing Atmospheric CO₂, which dramatically demonstrates the importance of models of atmospheric processes, and in particular models of the carbon cycle.

Carbon cycle models describe the circulation of carbon throughout the Earth system, with particular emphasis on the disposition of atmospheric CO₂. While human-kind currently releases CO₂ into the atmosphere at the rate of between 6 and 9 PgC yr⁻¹ through fossil fuel use and deforestation, observed atmospheric accumulation is approximately 3 PgC yr⁻¹. Between half and two-thirds of the net release of carbon to the atmosphere by human-kind is not staying there. Clearly something big is going on. In fact, the net accumulation of 3 PgC yr⁻¹ in the atmospheric burden of carbon represents a relatively small, though steady, annual differential to a system with massive annual flows both into and out of the atmosphere. Current estimates of the annual fluxes between oceans and atmosphere and between the terrestrial system and the atmosphere each amount to approximately 10² PgC yr⁻¹. These compare to an atmospheric burden of approximately 750 PgC.

While both oceanic and terrestrial systems absorb from and respire to the atmosphere massive quantities of carbon, the carbon cycle has demonstrated remarkable stability, with the historic ratio of atmospheric increase of carbon to fossil fuel CO₂ emissions remaining at or near the value 0.58 over the post World War II period. This stability has been observed during a period when emissions grew at a relatively stable rate. The question is, how stable will this ratio remain as underlying circumstances change. Previous work, see for example Trabalka et al. (1985), showed that a careful analysis of the processes which govern those flows of carbon between the oceans, terrestrial systems, and the atmosphere raised the possibility of substantially higher airborne fraction values if emissions rates continued to grow over the course of the next century.

The Villach Conferences of 1985 and 1987 raised concerns about the continued growth of greenhouse gas emissions, while the Toronto climate conference of 1988 called for a reduction of CO₂ emissions by 20% from its 1988 level. Should CO₂ emissions decline consistently over time, the carbon cycle would experience a regime for which there is no comparable analog in the past century and a half and certainly in the post 1958 period when continuous atmospheric CO₂ observations began at Mauna Loa in Hawaii. What effect would declining, but positive, anthropogenic emissions have on the future atmospheric concentration of CO₂? Would the simple constant airborne fraction model serve as usefully to predict the future as it does to summarize the past, or would an entirely different relationship be engendered?

Danny Harvey has addressed precisely this question in his paper. His answer is that a future with declining emissions will not be like the past. Significantly, it would be characterized by a substantially lower airborne fraction. This is at odds with other recent

analysis of atmospheric stabilization, such as Lashof and Tirpak (1989). The latter analysis concludes that atmospheric stabilization would require emissions reductions of approximately 80 percent from current levels to stabilize the atmospheric concentration of CO₂. Harvey concludes that total emissions (fossil fuel + land use-induced) need initially fall to only about half their present value in order to stabilize atmospheric CO₂.

The main question that must be asked after reading Harvey’s paper is, why are these results so different from the results obtained by researchers whose papers have gone before? More pointedly, where is the carbon going in the Harvey model that it is not going in other models? There are three major sinks in the Harvey model: oceans, biota, and miscellaneous. The ocean model is calibrated to mimic the oceanic uptake of CO₂ obtained by Maier-Reimer and Hasselmann (1987). The biotic uptake is represented by a 6-box globally aggregated model, Harvey (in press). The terrestrial biospheric sink is positively related to both temperature and the atmospheric CO₂ concentration. A third miscellaneous CO₂ sink is included. The miscellaneous sink is calibrated to remove 1.8 PgC yr⁻¹ in 1980. The rate at which the miscellaneous sink removes CO₂ from the atmosphere is related positively to the atmospheric CO₂ concentration.

Harvey’s model obtains some clearly controversial conclusions. The biosphere, for example, becomes a net sink for CO₂ between 1960 and 1980. In some of the emissions control cases about half of the total sink is due to the miscellaneous sink term and enhanced growth of the undisturbed biosphere. The ocean remains a strong absorber of CO₂ even after fossil fuel emissions decline.

If Harvey has accurately modeled the carbon cycle there are important implications for the rate and timing of climate change under a variety of emissions scenarios. I do not intend to comment on the correctness of these results. I do not have the appropriate information set available to make such an assessment. But such an assessment must be made. Policy analysis needs a clear picture of the carbon cycle. Does, for example, Harvey’s reduced form ocean chemistry model mimic real ocean chemistry, or more detailed ocean chemistry models in the range of CO₂ emissions explored in this paper? If it does not match more detailed model results, why? What is the relative importance of the biotic and miscellaneous sink terms over the range of possible future CO₂ emissions? How accurate are the CO₂ and temperature feedbacks hypothesized? Tony King at the Oak Ridge National Laboratory is organizing a carbon cycle model comparison workshop to attempt to reconcile the apparent differences between carbon cycle models. More such work needs to be done. But understanding the differences among competing carbon cycle models is only the beginning. The underlying information bases are not yet in place to reconcile once and for all the important issues of the carbon cycle. Record keeping for the Earth’s oceans pales in comparison to record keeping for the Earth’s atmosphere. Whereas three dimensional climate models are standard fare in greenhouse analysis, three dimensional ocean models are just beginning to become available. Clearly, a quantification of the CO₂ fertilization effect is necessary to understand whether or not the terrestrial biosphere is in fact a net source or sink of CO₂. There have been only two experiments to quantify the influence of atmospheric CO₂ concentrations on unmanaged ecosystems and neither of these have included a forest. More such work needs to be supported. Finally, the importance of the miscellaneous sink in Harvey’s work reminds us of the troubling fact, that after decades of research, scientists still cannot close the carbon cycle.